

Table of Radionuclides (Vol. 1 - $A = 1$ to 150)

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Preface

This monograph is one of several published in a series by the Bureau International des Poids et Mesures (BIPM) on behalf of the *Comité Consultatif des Rayonnements Ionisants* (CCRI), previously known as the *Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants* (CCEMRI). The aim of this series of publications is to review topics that are of importance for the measurement of ionizing radiation and especially of radioactivity, in particular those techniques normally used by participants in international comparisons. It is hoped that these publications will prove to be useful reference volumes both for those who are already engaged in this field and for those who are approaching such measurements for the first time.

The purpose of this monograph, number 5 in the series, is to present the recommended values of nuclear and decay data for a set of sixty-eight radionuclides. Activity measurements for thirty-two of these radionuclides have already been the subject of comparisons under the auspices of Section II of the CCRI. The material for this monograph will be covered in two volumes. Volume 1 contains the primary recommended data relating to half-lives, decay modes, x-rays, gamma-rays, electron emissions; alpha- and beta-particle transitions and emissions, and their uncertainties for radionuclides with mass number up to and including 150; Volume 2 contains the equivalent data for radionuclides with mass number over 150. The data have been collated and evaluated by an international working group (Decay Data Evaluation Project) led by the BNM-LNHB. The evaluators have agreed on the methodologies to be used and the CD-ROM included with this monograph contains the evaluators' comments for each radionuclide in addition to the data tables included in the monograph.

The work involved in evaluating nuclear data is on-going and the recommended values are updated on the LNHB website at http://www.nucleide.org/DDEP_WG/DDEPdata.htm. The publication of further volumes of Monographie 5 is envisaged as and when necessary to add new radionuclide data or re-evaluations in a more permanent format that can be referenced easily.

Although other data sets may still be used when evaluating radionuclide activity, use of this common, recommended data set should help to reduce the uncertainties in activity evaluations and lead to more coherent results for comparisons.

G. Moscati
President of the CCRI

A.J. Wallard
Director of the BIPM

Note: Following Resolution 10 of the 22nd CGPM in 2003, a decimal point has been used as the decimal marker in the English text but in the data tables, which were edited in French, a decimal comma has been used. There should be no ambiguity in use.

Errata to printed version of volumes 1 and 2

(corrections have been applied in CD-Rom files)

⁸⁵Sr

Main production modes

Sr-84 (n, γ) Sr-85m

⁸⁹Sr

Sr-89 disintegrates by beta minus emission mainly to the Y-89 fundamental level.

Caution:

¹²⁵Sb

Updating of the data is on-going (October 2004).

New issue will be available on the web pages :

http://www.nucleide.org/DDEP_WG/DDEPdata.htm

Monographie BIPM-5 - Table of Radionuclides (Vol. 1 - A = 1 to 150)

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“TABLE DE RADIONUCLÉIDES”

Sommaire - Ce volume regroupe l'évaluation des radionucléides suivants :

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^{\text{m}}$, ^{99}Mo , $^{99}\text{Tc}^{\text{m}}$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^{\text{m}}$, ^{123}I , $^{123}\text{Te}^{\text{m}}$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^{\text{m}}$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^{\text{m}}$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

Les valeurs recommandées et les incertitudes associées comprennent : la période radioactive, les modes de décroissance, les émissions α , β , γ , X et électroniques ainsi que les caractéristiques des transitions correspondantes.

“TABLE OF RADIONUCLIDES”

Summary - This volume includes the evaluation of the following radionuclides :

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^{\text{m}}$, ^{99}Mo , $^{99}\text{Tc}^{\text{m}}$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^{\text{m}}$, ^{123}I , $^{123}\text{Te}^{\text{m}}$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^{\text{m}}$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^{\text{m}}$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

Primary recommended data comprise half-lives, decay modes, X-rays, gamma-rays, electron emissions, alpha- and beta-particle transitions and emissions, and their uncertainties.

“TABELLE DER RADIONUKLIDE”

Zusammenfassung

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^{\text{m}}$, ^{99}Mo , $^{99}\text{Tc}^{\text{m}}$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^{\text{m}}$, ^{123}I , $^{123}\text{Te}^{\text{m}}$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^{\text{m}}$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^{\text{m}}$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

In diesem Bericht sind evaluierte Werte der Halbwertszeiten, Übergangswahrscheinlichkeiten und Übergangsenergien von α , β^- , β^+ , EC- und Gammaübergängen, Konversionskoeffizienten von Gammaübergängen, Emissionswahrscheinlichkeiten von Röntgen- und Gammaquanten, Auger- und Konversions-elektronen.

“TABLA DE RADIONUCLEIDOS”

Prólogo – Este volumen agrupa la evaluación de los radionucleidos siguientes :

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^m$, ^{99}Mo , $^{99}\text{Tc}^m$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^m$, ^{123}I , $^{123}\text{Te}^m$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^m$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^m$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

Los valores recomendados y las incertidumbres asociadas comprenden : el período radioactivo, los modos de desintegración, las emisiones α , β , γ , X y electrónicas incluyendo las características de las transiciones correspondientes.

TABLE DE RADIONUCLÉIDES
TABLE OF RADIONUCLIDES
TABELLE DER RADIONUKLIDE
ТАБЛИЦА РАДИОНУКЛИДОВ
TABLA DE RADIONUCLEIDOS

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TABLE DE RADIONUCLÉIDES

INTRODUCTION

Le Laboratoire National Henri Becquerel (LNHB) a commencé l'étude des données nucléaires et atomiques qui caractérisent la décroissance des radionucléides en 1974. Ces évaluations ont fait l'objet de la publication des quatre volumes de la Table de Radionucléides [87Ta, 99Be]. Ce nouveau volume s'inscrit dans la continuation du travail précédent.

D'autre part, pour des raisons évidentes, telles la facilité de mise à jour des données ou la commodité de consultation pour les utilisateurs, le LNHB a créé une base de données informatisée. Le logiciel NUCLEIDE est la forme informatisée de cette table, il permet un accès aisé aux différentes informations à l'aide de menus déroulants atteints par un simple « clic » sur un « bouton ».

Le propos de la Table est d'étudier un nombre limité de radionucléides utiles dans le domaine de la métrologie ou dans des domaines variés d'applications (médecine nucléaire, environnement, cycle du combustible, etc.) et d'en présenter une étude complète.

Les données recommandées comprennent : la période radioactive, les modes de décroissance, les émissions α , β , γ , X et électroniques ainsi que les caractéristiques des transitions associées.

Dans le but de mettre à jour et d'ajouter de nouvelles évaluations plus rapidement le Laboratoire National Henri Becquerel (LNHB, France) et le Physikalisch - Technische Bundesanstalt (PTB, Allemagne) ont établi un accord de coopération. Ils ont ensuite été rejoints par Idaho National Engineering and Environmental Laboratory (INEEL, États-Unis), Lawrence Berkeley National Laboratory (LBNL, États-Unis) et Khlopin Radium Institute (KRI, Russie). Le premier travail de cette collaboration internationale a été d'établir une méthode et des règles communes d'évaluation. Les évaluations proposent des valeurs recommandées et leurs incertitudes. Ces valeurs ont été évaluées à partir des données expérimentales disponibles. A défaut, elles sont issues de calculs théoriques. Toutes les références utilisées pour l'évaluation d'un radionucléide sont listées à la fin de chaque chapitre.

VALEURS RECOMMANDÉES ET INCERTITUDES

Les principales étapes pour l'évaluation des données et leurs incertitudes sont :

- une analyse critique de toutes les publications disponibles afin de retenir ou non une valeur et son incertitude, ramenée à l'incertitude-type composée ;
- la détermination d'une valeur recommandée qui est, selon les cas, une moyenne simple ou pondérée des valeurs issues des publications, ceci est décidé après examen du chi carré réduit. Dans le cas d'une moyenne pondérée, le poids relatif de chaque valeur est limité à 50 %. L'incertitude, notée uc , est la plus grande des valeurs des incertitudes interne ou externe ; dans le cas de valeurs incompatibles elle peut être étendue pour recouvrir la valeur la plus précise.

Pour certaines applications il est nécessaire de définir une incertitude élargie, notée U , telle que :

$$U(y) = k \cdot uc(y) \quad \text{où } k \text{ est le facteur d'élargissement.}$$

La valeur de k retenue pour cette publication est : $k = 1$.

Les valeurs d'incertitude indiquées portent sur les derniers chiffres significatifs, ainsi :

9,230 (11) signifie $9,230 \pm 0,011$ et

9,2 (11) $9,2 \pm 1,1$

Si une valeur est donnée sans incertitude, cela signifie qu'elle est considérée comme douteuse. Elle est indiquée à titre indicatif et souvent a été estimée en fonction du schéma de désintégration comme étant « de l'ordre de ».

Des précisions concernant les techniques d'évaluation peuvent être obtenues dans les références [85Zi], [96He], [99In] (voir rubrique Références) ou directement auprès des auteurs.

La description physique des données évaluées est disponible dans la référence [99In].

NUMÉROTAGE

Les niveaux d'un noyau sont numérotés, arbitrairement, de 0 pour le niveau fondamental à n pour le n ème niveau excité. Les diverses transitions sont ainsi repérées par leur niveau de départ et leur niveau d'arrivée.

Dans le cas de transition de faible probabilité qu'il n'est pas possible de situer sur le schéma de désintégration, les niveaux de départ et d'arrivée sont notés $(-1, n)$.

Dans le cas de l'émission gamma de 511 keV qui suit une désintégration bêta plus, la notation adoptée est : $(-1, -1)$.

UNITÉS

Les valeurs recommandées sont exprimées :

- pour les périodes

	Symbole
. en secondes pour $T_{1/2} \leq 60$ secondes	s
. en minutes pour $T_{1/2} > 60$ secondes	min
. en heures pour $T_{1/2} > 60$ minutes	h
. en jours pour $T_{1/2} > 24$ heures	d
. en années pour $T_{1/2} > 365$ jours	a

1 année = 365,242 198 jours = 31 556 926 secondes ;

- pour les probabilités de transition et nombre de particules émises, les valeurs sont données pour 100 désintégrations ;

- les énergies sont exprimées en keV.

AVERTISSEMENT

Ce document a été imprimé en 2004, pour toutes les nouvelles évaluations et mises à jour ultérieures le lecteur se référera aux documents accessibles sur :

<http://www.nucleide.org/NucData.htm>

TABLE OF RADIONUCLIDES

INTRODUCTION

The evaluation of decay data for the "Table de Radionucléides" by BNM – LNHB/CEA began in 1974, continued to 1987 and four volumes were published [87Ta] and then, in 1999, the fifth volume was published containing the revised evaluations for 30 selected radionuclides [99Be].

Moreover, LNHB developed a software (NUCLEIDE) with the objectives of making it easier to update and add data and, obviously, to offer easy access to the nuclear and atomic decay data to the user by "click on the button" facilities.

The aim of this Table is to provide recommended data for nuclides of special interest for metrology or practical applications like nuclear medicine, monitoring and reactor shielding, etc.

Primary recommended data comprise half-lives, decay modes, X-rays, gamma-rays, electron emissions, alpha- and beta-particle transitions and emissions, and their uncertainties. All the references used for the evaluations are given.

In order to update the data of the nuclides already present and to add new evaluations, the Laboratoire National Henri Becquerel (LNHB, France) and the Physikalisch-Technische Bundesanstalt (PTB, Germany) established a cooperative agreement ; they were then joined by the Idaho National Engineering and Environmental Laboratory (INEEL, USA), the Lawrence Berkeley National Laboratory (LBNL, USA) and the Khlopin Radium Institute (KRI, Russia). This international collaboration is based on an informal agreement, the initial work of this group was to discuss and to agree on a methodology to be used in these evaluations. The data and associated uncertainties were evaluated from all available experiments and taking into account theoretical considerations.

RECOMMENDED VALUES AND UNCERTAINTIES

The main steps for the evaluation of the data and their uncertainties are :

- a critical analysis of all available original publications in order to accept or not each value and its uncertainty reduced to the combined standard uncertainty ;
- the determination of the best value which is either the weighted or the unweighted average of the retained values, this is decided after examination of the reduced χ^2 value. With a weighted average, each weight is limited to 50 %. The uncertainty, designated uc , is the greatest of the internal or external uncertainty values. For a discrepant set of data, it may be expanded to cover the most precise input value.

For some applications it may be necessary to define an expanded uncertainty, designated U , as :

$$U(y) = k.uc(y) \quad \text{where } k \text{ is the coverage factor.}$$

For this publication the expanded uncertainty is computed with $k = 1$.

The value of the uncertainty, in parentheses, referred to the corresponding last digits, i.e. :

$$9.230 (11) \text{ means } 9.230 \pm 0.011 \text{ and}$$

$$9.2 (11) \quad 9.2 \pm 1.1$$

If a value is given without an uncertainty, this means that this value is considered as questionable. It is provided for information and was often estimated from the decay scheme as to be "in the order of".

Information about evaluation procedures can be obtained from references [85Zi, 96He, 99In] or directly from the authors.

Information about meaning of physical data can be obtained from reference [99In].

NUMBERING

The nuclear levels are arbitrarily numbered from 0 for the ground state level to n for the n th excited level. All the transitions are designated by their initial and final level.

For transitions with weak probabilities which are not shown by an arrow in the decay scheme, the initial and final levels are noted $(-1, n)$.

For the 511 keV gamma emission which follows the beta plus disintegration, the adopted numbering is $(-1, -1)$.

UNITS

The recommended values are expressed :

- for half-lives :

	Symbol
. in seconds for $T_{1/2} \leq 60$ seconds	s
. in minutes for $T_{1/2} > 60$ seconds	min
. in hours for $T_{1/2} > 60$ minutes	h
. in days for $T_{1/2} > 24$ hours	d
. in years for $T_{1/2} > 365$ days	a

1 year = 365.242 198 days = 31 556 926 seconds

- for transition probabilities and number of emitted particles, the values are given for 100 disintegrations ;

- for energies the values are expressed in keV.

CAUTION

This report was printed in 2004, new evaluations and updated issues will be available on :

<http://www.nucleide.org/NucData.htm>

TABELLE DER RADIONUKLIDE

EINLEITUNG

Die Evaluation der Zerfallsdaten für die Table de Radionucléides durch das BNM-LNHB/CEA begann im Jahre 1974, diese Arbeit wurde bis 1987 fortgesetzt, und es wurden vier Bände veröffentlicht [87Ta, 99Be]. Dieser neue Bericht kommt hinzu dem vorhergehend Arbeit.

Übrigens wurde ein Computerform der Table de Radionucléides im LNHB entwickelt. Diese Software erleichtert die Aktualisierung und die Einbeziehung weiterer Daten und ermöglicht den Zugang zu den Kern- und Atomdaten für den Anwender auf „Tastendruck“.

Der Zweck dieser Tabelle ist es, empfohlene Daten einer begrenzten Anzahl von Radionukliden für metrologische und praktische Anwendungen wie etwa in der Nuklearmedizin, der Umgebungsüberwachung, der Reaktorabschirmung usw. zur Verfügung zu stellen.

Die Datenbank umfaßt empfohlene Daten und ihre Unsicherheiten, die aus den verfügbaren Daten oder theoretischen Berechnungen gewonnen worden sind. Alle für die Evaluation benutzten Referenzen werden angegeben.

Um die schon vorliegenden Daten zu aktualisieren und neue Evaluationen schneller einbeziehen zu können, vereinbarten das Laboratoire National Henri Becquerel (LNHB, Frankreich) und die Physikalisch-Technische Bundesanstalt (PTB, Deutschland) einen Vertrag zur Zusammenarbeit. Es schlossen sich das Idaho National Engineering and Environmental Laboratory (INEEL, USA), das Lawrence Berkeley National Laboratory (LBNL, USA) und das Khlopin Radium Institut (KRI, Rußland) an. Eine der ersten Arbeiten dieser Gruppe war es, die in diesen Evaluationen benutzte Methodologie zu diskutieren und festzulegen.

EMPFOHLENE WERTE UND UNSICHERHEITEN

Die Hauptschritte für die Evaluation der Daten und Unsicherheiten sind:

- Eine kritische Analyse aller verfügbaren Veröffentlichungen, um einen Wert und seine Unsicherheit
- auf die kombinierte Standardunsicherheit zurückgeführt - zu berücksichtigen.
- Die Bestimmung eines empfohlenen Wertes, der entweder das gewichtete oder das ungewichtete Mittel der veröffentlichten Werte ist. Die Entscheidung wird nach der Prüfung des reduzierten Chi-Quadrat-Werts getroffen. Im Falle des gewichteten Mittels wird ein Gewicht, das größer ist als 50 %, auf 50 % reduziert. Die Unsicherheit, als *uc* bezeichnet, ist der größere Wert der inneren oder äußeren Unsicherheit. Für einen diskrepanten Datensatz ist sie so zu vergrößern, daß der genaueste Einzelwert in der Unsicherheit mit eingeschlossen ist.

Für einige Anwendungen ist es notwendig, eine vergrößerte Unsicherheit, als *U* bezeichnet, wie folgt zu definieren:

$$U(y) = k \cdot uc(y) \quad \text{wo } k \text{ der Erweiterungsfaktor ist.}$$

Für die vorliegende Veröffentlichung ist die erweiterte Unsicherheit mit $k = 1$ berechnet.

Die Werte der Unsicherheit beziehen sich auf die letzten Stellen, d. h.:

9,230(11) bedeutet $9,230 \pm 0,011$ und

9,2(11) bedeutet $9,2 \pm 1,1$

Wenn ein Wert ohne Unsicherheit angegeben ist, bedeutet das, daß dieser Wert als fragwürdig zu betrachten ist. Er wird zur Information mitgeteilt und ist oft abgeschätzt aus dem Zerfallsschema im Sinne „in der Größenordnung von“.

Informationen über die Evaluationsprozedur können aus den Referenzen [85Zi, 96He, 99In] oder direkt von den Autoren bezogen werden.

NUMERIERUNG

Die Kernniveaus werden willkürlich numeriert von 0 für den Grundzustand bis zu n für das n -te angeregte Niveau. Alle Übergänge werden durch ihr Ausgangs- und Endniveau gekennzeichnet. Für Übergänge mit geringen Wahrscheinlichkeiten, die nicht durch einen Pfeil im Zerfallsschema gezeigt sind, werden das Ausgangs- und Endniveau notiert. $(-1, n)$

Für die 511 keV-Gamma-Emission, die dem Beta Plus-Zerfall folgt, ist die angenommene Numerierung $(-1, -1)$.

EINHEITEN

Die empfohlenen Werte sind ausgedrückt:

- für Halbwertszeiten:

	Symbol
. in Sekunden für $T_{1/2} \leq 60$ Sekunden	s
. in Minuten für $T_{1/2} > 60$ Sekunden	min
. in Stunden für $T_{1/2} > 60$ Minuten	h
. in Tagen für $T_{1/2} > 24$ Stunden	d
. in Jahren für $T_{1/2} > 365$ Tage	a

$$1 \text{ a} = 365,242 \text{ 198 d} = 31 \text{ 556 926 s}$$

- für Übergangswahrscheinlichkeiten und die Anzahl der emittierten Teilchen werden Werte angegeben, die sich auf 100 Zerfälle beziehen.

- die Werte der Energien sind in keV ausgedrückt.

HINWEIS

Dieses Dokument wurde im Jahre 2004 erstellt. Alle späteren Fassungen oder neueren Evaluationen können vom Leser unter <http://www.nucleide.org/NucData.htm> abgerufen werden.

ТАБЛИЦА РАДИОНУКЛИДОВ

ВВЕДЕНИЕ

Оценка данных распада для Table de Radionucléides, BNM – LNHB/CEA была начата в 1974 г. и продолжалась до 1987 г. К тому времени были опубликованы четыре тома [87Ta] и затем, в 1999 г., был опубликован пятый том, содержащий ревизованные оценки для 30 выбранных радионуклидов [99Be]. Новое издание находится в русле предыдущей работы.

В дополнение в LNHB была разработана компьютерная форма Table de Radionucléides (программа NUCLEIDE) с тем, чтобы обеспечить более простое обновление и дополнение данных и, очевидно, также с целью предложить пользователю более легкий доступ к ядерным и атомным данным распада путем "нажатия кнопки".

Цель настоящего издания - дать рекомендованные данные для нуклидов, представляющих специфический интерес для метрологии или практических приложений, таких как ядерная медицина, мониторинг, реакторная защита и др.

Первичные рекомендованные данные включают периоды полураспада, виды распада, характеристики X- и гамма-излучений, электронных излучений, альфа- и бета-переходов и излучений и погрешности величин этих характеристик. В книге дан полный список литературы, использованной для оценок.

Для того чтобы обновить данные по нуклидам, уже имеющимся в Table de Radionucléides, и добавить новые оценки, Национальная лаборатория им. Анри Беккереля (LNHB, Франция) и Физико-Технический Институт (PTB, Германия) заключили кооперативное соглашение. К ним затем присоединились Национальная лаборатория прикладных и экологических исследований Айдахо (INEEL, США), Лоуренсовская Национальная Лаборатория Беркли (LBNL, США) и Радиевый институт им. В.Г. Хлопина (KRI, Россия). Это международное сотрудничество основано на неформальном соглашении. Первоначальная работа состояла в обсуждении и принятии согласованной методологии, которая должна быть использована в этих оценках. Данные и связанные с ними погрешности были оценены с использованием всех имеющихся в распоряжении результатов экспериментов и с учетом теоретических рассуждений.

РЕКОМЕНДОВАННЫЕ ЗНАЧЕНИЯ И ПОГРЕШНОСТИ

Основные шаги для оценки данных и их погрешностей следующие:

- критический анализ всех имеющихся оригинальных публикаций, чтобы принять или отвергнуть данное значение и его погрешность, приведенную к комбинированному стандартному отклонению;
- определение лучшего значения, которое является взвешенным или невзвешенным средним сохраненных величин; выбор взвешенного или невзвешенного среднего определяется анализом величины χ^2 . В случае среднего взвешенного вес каждого оригинального результата ограничивается 50 %. В качестве итоговой погрешности (uc) принимается большая из двух погрешностей среднего взвешенного: внутренней и внешней. Для расходящегося набора данных она может быть расширена, чтобы перекрыть самое точное входное значение.

Для некоторых применений может оказаться необходимым расширенная погрешность (U), выраженная как: $U(y)=k.uc(y)$, где k - коэффициент перекрытия. Для этой публикации принято $k=1$.

Значение погрешности, в скобках, приводится в единицах последней значащей цифры, т.е.:

9,230(11) означает $9,230 \pm 0,011$ и
9,2(11) $9,2 \pm 1,1$

Если значение величины дается без погрешности, она считается сомнительной и приводится для информации. Такие величины часто оценивались из схемы распада под рубрикой "порядка".

Информацию о процедурах оценки можно получить из публикаций [85Zi, 96He, 99In] или непосредственно от авторов.

Информация о смысле физических величин может быть получена из [99In].

НУМЕРАЦИЯ

Ядерные уровни произвольно пронумерованы от 0 для основного состояния до n для n -ого возбужденного уровня. Все переходы обозначаются по их начальному и конечному уровням.

Для слабых переходов, не показанных стрелкой в схеме распада, начальный и конечный уровни обозначаются как $(-1, n)$.

Для гамма-излучения с энергией 511 кэВ, которое следует за бета-плюс распадом, принято обозначение $(-1, -1)$.

ЕДИНИЦЫ

Рекомендованные значения выражены:

- для периодов полураспада:
- в секундах для $T_{1/2} \leq 60$ секунд s
- в минутах для $T_{1/2} > 60$ секунд min
- в часах для $T_{1/2} > 60$ минут h
- в сутках для $T_{1/2} > 24$ часов d
- в годах для $T_{1/2} > 365$ суток a

1 год = 365,242 198 суток = 31 556 926 секунд

- для вероятностей переходов и числа испускаемых частиц значения даны на 100 распадов;
- для энергий значения выражены в килоэлектронвольтах (keV).

ПРИМЕЧАНИЕ

Этот отчет подготовлен в 2004 г. Новые оценки и обновленные результаты можно найти на сайте:

<http://www.nucleide.org/NucData.htm>

TABLA DE RADIONUCLEIDOS

INTRODUCCION

El Laboratoire National Henri Becquerel (LNHB) comenzó el estudio de datos nucleares y atómicos que caracterizan la desintegración de radionucleidos en 1974. Esas evaluaciones han permitido la publicación de cuatro volúmenes de la Tabla de radionucleidos [⁸⁷Ta, ⁹⁹Be]. Este nuevo volumen es el siguiente en la continuación del estudio precedente.

Con la idea de facilitar, la corrección de nuevos datos y la comodidad de consulta para los usuarios, el LNHB a creado una base de datos en computadora. El programa NUCLEIDE es el contenido de la Tabla en computadora, que permite el fácil acceso a diferentes informaciones, con la ayuda de menues en cascada accesibles con un simple « clic » sobre una « tecla ».

El objetivo de la Tabla es estudiar un número limitado de radionucleidos útiles en el campo de la metrología u otros campos de aplicación (medicina nuclear, medio ambiente, ciclo del combustible, etc.) y presentar un estudio completo.

Los datos recomendados comprenden : el período radioactivo, los modos de desintegración, las emisiones α , β , γ , X y electrónicas con las características de transiciones asociadas.

Con el propósito de actualizar y agregar nuevas evaluaciones rapidamente el *Laboratoire National Henri Becquerel* (LNHB, Francia) y el *Physikalisch-Technische Bundesanstalt* (PTB , Alemania) establecieron un acuerdo de colaboración. Luego se unieron a este acuerdo el *Idaho National Engineering and Environmental Laboratory* (INEEL, USA), *Lawrence Berkeley National Laboratory* LBNL, USA) y *Khlopin Radium Institute* (KRI, Rusia). El primer trabajo de esta colaboración internacional ha sido de establecer un método y reglas comunes de evaluación. Las evaluaciones proponen valores recomendados e incertidumbres asociadas. Esos valores han sido evaluados a partir de datos experimentales disponibles. En ausencia de éstos últimos, esos valores han sido obtenidos por cálculos teóricos. Todas las referencias utilizadas para la evaluación de un radionucleido son listadas al final de cada capítulo.

VALORES RECOMENDADOS E INCERTIDUMBRES

Las principales etapas para evaluar datos con sus incertidumbres son :

- Un análisis crítico de todas las publicaciones disponibles con el fin de obtener o no un valor con su incertidumbre, considerada como incertidumbre tipo compuesta.
- La determinación de un valor recomendado que es, según el caso, una media simple o ponderada de valores obtenidos de publicaciones, ésto es decidido luego de examinar el chi al cuadrado reducido. En el caso de una media ponderada, el peso relativo de cada valor es limitado a 50 %. La incertidumbre, llamada uc , es el mayor de los valores de incertidumbres interna o externa ; en el caso de valores incompatibles, este valor puede ser extendido con el fin de recubrir el valor más preciso.

Par ciertas aplicaciones, es necesario definir una incertidumbre extendida, llamada U , la cual es :

$$U(y) = k \cdot uc(y) \quad \text{donde } k \text{ es el factor de extensión.}$$

El valor de k retenido en esta publicación es : $k = 1$.

Los valores de incertidumbres indicados entre paréntesis corresponden a las últimas cifras significativas, por ejemplo :

9,230 (11)	significa	$9,230 \pm 0,011$	y
9,2 (11)	significa	$9,2 \pm 1,1$	

Si un valor es dado sin incertidumbre, significa que ésta es considerada dudosa (es indicada aproximativamente y ha sido estimada a partir del esquema de desintegración).

NUMERACION

Los niveles de un núcleo son numerados de manera arbitraria, de 0 para el nivel fundamental, a n para el n -ésimo nivel excitado. Las diversas transiciones son así señaladas desde el nivel de partida al nivel de llegada.

En el caso de una transición de probabilidad pequeña que es imposible de indicar en el esquema de desintegración, los niveles de partida y de llegada son notificados : $(-1, n)$.

En el caso de una emisión γ de 511 keV que sigue a una desintegración β^+ , la notación adoptada es : $(-1, -1)$.

UNIDADES

Los valores recomendados son expresados :

- para los períodos :

	Símbolo
. en segundos para $T_{1/2} \leq 60$ segundos	s
. en minutos para $T_{1/2} > 60$ segundos	min
. en horas para $T_{1/2} > 60$ minutos	h
. en días para $T_{1/2} > 24$ horas	d
. en años para $T_{1/2} > 365$ días	a

1 año = 365,242 198 días = 31 556 926 segundos ;

- para las probabilidades de transición y número de partículas emitidas, los valores son dados por 100 desintegraciones ;

- para las energías los valores son expresados en keV.

ADVERTENCIA

Este documento ha sido imprimido en 2004, para obtener todas las nuevas evaluaciones actualizadas ulteriormente, el lector deberá referirse a los documentos disponibles en :

<http://www.nucleide.org/NucData.htm>

RÉFÉRENCES
REFERENCES
REFERENZEN
REFERENCIAS

- [87Ta] Table de Radionucléides, F. Lagoutine, N. Coursol, J. Legrand. ISBN 2 7272 0078 1 (LMRI, 1982-1987).
- [85Zi] W.L. Zijp, Netherland Energy Research Foundation, ECN, Petten, The Netherlands, Rep. ECN-179.
- [96He] R.G. Helmer, Proceedings of the Int. Symp. "Advances in alpha-, beta- and gamma-ray Spectrometry", St. Petersburg, September 1996, p. 71.
- [96Be] M.-M. Bé, B. Duchemin and J. Lamé. Nucl. Instrum. Methods A369 (1996) 523 and Bulletin du Bureau National de Métrologie 110 (1998).
- [99In] Table de Radionucléides. Introduction, nouvelle version. Introduction, revised version. Einleitung, überarbeitete Fassung. ISBN 2 7272 0201 6, BNM-CEA/LNHB BP 52, 91191 Gif-sur-Yvette Cedex, France.
- [99Be] M.-M. Bé, E. Browne, V. Chechev, R.G. Helmer, E. Schönfeld. Table de Radionucléides, ISBN 2 7272 0200 8 and ISBN 2 7272 0211 3 (LHNB, 1988-1999).

**AUTEURS POUR CORRESPONDANCE
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ADRESSEN DER AUTOREN
AUTORES PARA CORRESPONDENCIA**

Toutes demandes de renseignements concernant les données recommandées et la façon dont elles ont été établies doivent être adressées directement aux auteurs des évaluations.

Information on the data and the evaluation procedures is available from the authors listed below.

Informationen über die Daten und Evaluationsprozeduren können bei den im folgenden zusammengestellten Autoren angefordert werden.

Todos los pedidos de información relativos a datos recomendados y la manera de establecerlos deben dirigirse directamente a los autores de las evaluaciones.

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1 Decay Scheme

Be-7 disintegrates by electron capture either directly to the ground state of Li-7 (89.56%) or via the 477 keV of Li-7 (10.44%). Recent experiments have shown that the half-life of Be-7 increases as much as 0.7% by embedding this radionuclide in different matrices. The recommended value presented in this evaluation should be adequate for Be and BeO sample.

Le Be-7 se désintègre par capture électronique soit directement vers le niveau fondamental de Li-7, soit via le niveau excité de 477 keV. Des expériences récentes ont montré que la valeur de la période pouvait être affectée jusqu'à 0,7% par une modification de l'environnement extérieur, par exemple la composition chimique. La valeur retenue pour cette évaluation s'applique plutôt à des échantillons de Be ou BeO.

2 Nuclear Data

$$T_{1/2}({}^7\text{Be}) : 53,22 \quad (6) \quad \text{d}$$

$$Q^+({}^7\text{Be}) : 861,815 \quad (18) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg ft	P_K	P_L
$\epsilon_{0,1}$	384,194 (18)	10,44 (4)	Allowed	3,56	0,908 (12)	0,092 (12)
$\epsilon_{0,0}$	861,815 (18)	89,56 (4)	Allowed	3,32	0,908 (12)	0,092 (12)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_T
$\gamma_{1,0}(\text{Li})$	477,621 (2)	10,44 (4)	M1+4%E2	0,00000073 (11)

3 Atomic Data

3.1 Li

$$\omega_K : 0,00029 \quad (15)$$

3.1.1 X Radiations

	Energy keV	Relative probability
X_K	$K\alpha$ 0,0543	

4 Photon Emissions

4.1 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Li})$	477,6035 (20)	10,44 (4)

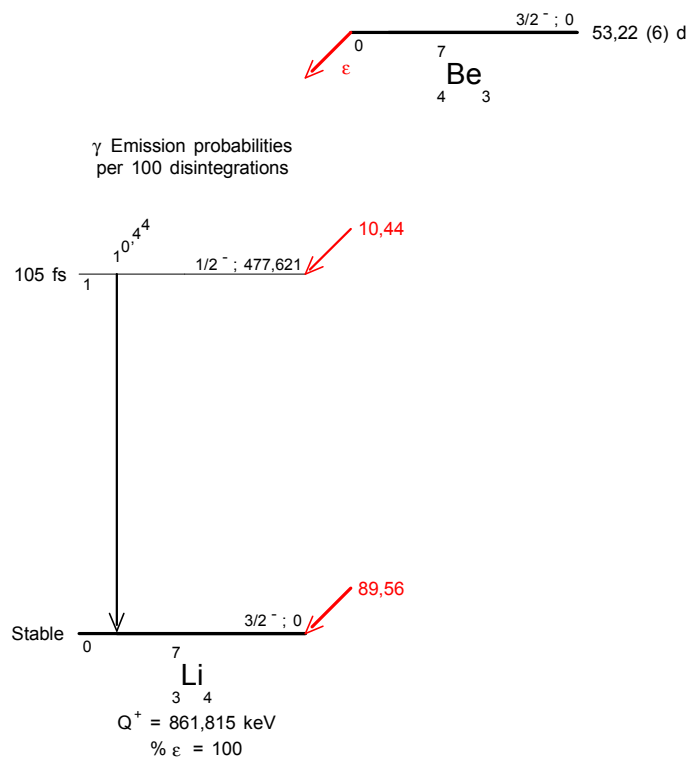
5 Main Production Modes

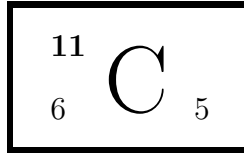
- { Li – 6(d,n)Be – 7
- { Possible impurities : Li – 7
- { B – 10(p, α)Be – 7
- { Possible impurities : C – 9,C – 11
- { C – 12(He – 3, 2α)Be – 7
- { Possible impurities : C – 11,N – 13

6 References

- E.SEGRE, C.E.WIEGAND. Phys Rev. 75 (1949) 39
(Half-life chem. eff.)
- J.J.KRAUSHAAR, E.D.WILSON, K.T.BAINBRIDGE. Phys. Rev. 90 (1953) 610
(Half-life chem. eff.)
- P.BOUCHEZ, J.TOBAILEM, J.ROBERT, R.MUXART, R.MELLETT, P.DAUDEL. J. Phys. Radium 17 (1956) 363
(Half-life chem. eff.)
- H.W.WRIGHT, E.I.WYATT, S.A.REYNOLDS, W.S.LYON, T.H.HANDLEY. Nuclear Sci. Eng. 2 (1957) 427
(Half-life)
- A.KRIESTER. Kernenergie 7 (1964) 748
(ICC)
- J.B.A.ENGLAND. Nucl. Phys. 72 (1965) 449
(Half-life)
- W.POENITZ. J. Nucl. Energy 20 (1966) 825
(Elec. Capt. Probabilities)
- J.G.V.TAYLOR. Report AECL-3512 (1969) 29
(Elec. Capt. Probabilities)
- M.MUTTERER. Neutr.Stand. 452, Flux Normalization 452, AEC Symp.Series 23 (1970)
(Elec. Capt. Probabilities)
- H.W.JOHLIGE, D.C.AUMANN, H.J.BORN. Phys. Rev. C2 (1970) 1616
(Half-life chem. eff.)
- F.YIOU, G.M.RAISBECK. Phys. Rev. Lett. 29 (1972) 372
(Half-life)
- M.MUTTERER. Phys. Rev. C8 (1973) 2089
(Elec. Capt. Probabilities)
- W.P.POENITZ, A.DEVOLPI. Int. J. Appl. Radiat. Isotop. 24 (1973) 471
(Gamma emission probabilities, Elec. Capt. Probabilities)
- P.J.CRESSY JR.. Nucl. Sci. Eng. 55 (1974) 450
(Half-life)
- I.W.GOODIER, J.L.MAKEPEACE, A.WILLIAMS. Int. J. Appl. Radiat. Isotop. 25 (1974) 373
(Gamma emission probabilities, Elec. Capt. Probabilities)
- F.LAGOUTINE, J.LEGRAND, C.BAC. Int. J. Appl. Radiat. Isotop. 26 (1975) 131
(Half-life)
- M.H.CHEN, B.CRASEMANN. Phys. Rev. Lett. 40 (1978) 1423
(PL/PK)
- H.SANJEEVIAH, B.SANJEEVIAH. Phys. Rev. C18 (1978) 974
(Gamma emission probabilities)
- R.G.HELMER, P.H.M.VAN ASSCHE, C.VAN DER LEUN. At.Data.Nuc.Data.Tables 24 (1979) 39
(EGamma)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. Report AECL-6692 (1980) 2
(Half-life, Gamma emission probabilities)
- P.CHRISTMAS. Report NBS-SP-626 (1982) 100
(Half-life)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. Report NBS-SP-626 (1982) 5
(Half-life)
- G.J.MATHEWS, R.C.HAIGHT, R.G.LANIER, R.M.WHITE. Phys. Rev. C28 (1983) 879
(Gamma emission probabilities, Elec. Capt. Probabilities)
- C.N.DAVIDS, A.J.ELWYN, B.W.FILIPPONE, S.B.KAUFMAN, K.E.REHM, J.P.SCHIFFER. Phys. Rev. C28 (1983) 885
(Gamma emission probabilities, Elec. Capt. Probabilities)
- S.A.FISHER, R.L.HERSHBERGER. Bull. Am. Phys. Soc. 28 (1983) 713
(Gamma emission probabilities, Elec. Capt. Probabilities)
- H.KUMAHORA, H.INOUE, Y.YOSHIZAWA. Nucl.Instr.and Meth. 206 (1983) 489
(Gamma energy)
- S.A.FISHER, R.I.HERSHBERGER. Nucl. Phys. A423 (1984) 121
(Gamma emission probabilities, Elec. Capt. Probabilities)
- R.T.SKELTON, R.W.KAVANAGH. Nucl. Phys. A414 (1984) 141
(Gamma emission probabilities, Elec. Capt. Probabilities)

- F.AJZENBERG-SELOVE. Nucl. Phys. A490 (1988) 1
(Levels, Elec. Capt. Probabilities)
- G.AUDI, A.H.WAPSTRA. Nucl. Phys. A565 (1993) 1
(Q)
- T.CHANG, S.WANG, H.WANG. Nucl. Instr. Meth. A325 (1993) 196
(Gamma energy)
- J.H.HUBBELL, P.N.TREHAN, NIRMAL SINGH, B.CHAND, D.MEHTA, M.L.GARG, R.R.GARG, SURINDER SINGH, S.PURI. J.Phys.Chem.Ref.Data 23 (1994) 339
(L fluorescence yield)
- C.-A. HUH, L.-G.LIU. J. Radioanal. Nucl. Chem. 246 (2000) 229
(Half-life)
- R.G.HELMER, C.VAN DER LEUN. Nucl. Instr. Meth. A450 (2000) 35
(Gamma energy)
- L.-G.LIU, C.-A. HUH. Earth and Planetary Science Letters 180 (2000) 163
(Half-life)





1 Decay Scheme

Le carbone 11 se désintègre à 99,750(13)% par émission bêta-plus, et 0,250(13)% par capture électronique vers le niveau fondamental de bore 11.

C-11 disintegrates by 99.750(13) % beta-plus, and 0.250(13)% by electron capture to the ground state of the stable nuclide B-11.

2 Nuclear Data

$$T_{1/2}(^{11}\text{C}) : 20,370 \quad (29) \quad \text{min}$$

$$Q^+(^{11}\text{C}) : 1982,5 \quad (9) \quad \text{keV}$$

2.1 β^+ Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,0}^+$	960,5 (9)	99,750 (13)	Allowed	3,592

2.2 Electron Capture Transitions

	Energy keV	Probability $\times 100$	Nature	P _K	P _L
$\epsilon_{0,0}$	1982,5 (9)	0,250 (13)	Allowed	0,9174 (91)	0,0826 (91)

3 Electron Emissions

	Energy keV	Electrons per 100 disint.
$\beta_{0,0}^+$	max: 960,5 (9)	99,750 (13)
$\beta_{0,0}^+$	avg: 385,7 (4)	

4 Photon Emissions

4.1 Gamma Emissions

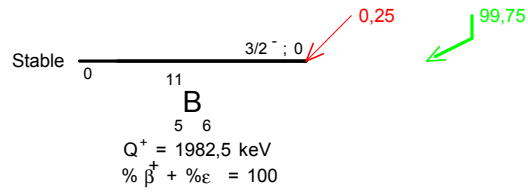
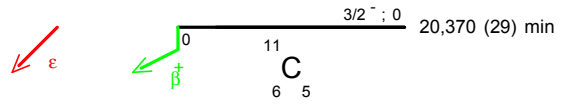
	Energy keV	Photons per 100 disint.
γ^\pm	511	199,500 (26)

5 Main Production Modes

$\text{C} - 12(\gamma, n)\text{C} - 11$
 $\text{C} - 12(d, t)\text{C} - 11$
 $\text{Li} - 6(\text{Li} - 6, n)\text{C} - 11$
 $\text{Li} - 7(\text{Li} - 6, 2n)\text{C} - 11$
 $\text{B} - 11(p, n)\text{C} - 11$
 $\text{B} - 10(d, n)\text{C} - 11$
 $\text{N} - 14(d, n\alpha)\text{C} - 11$
 $\text{B} - 10(\alpha, t)\text{C} - 11$
 $\text{Be} - 9(\alpha, 2n)\text{C} - 11$
 $\text{B} - 10(p, \gamma)\text{C} - 11$
 $\text{B} - 11(d, 2n)\text{C} - 11$
 $\text{C} - 12(p, pn)\text{C} - 11$
 $\text{C} - 12(\text{He} - 3, \alpha)\text{C} - 11$
 $\text{Be} - 9(\text{He} - 3, n)\text{C} - 11$
 $\text{C} - 13(p, p2n)\text{C} - 11$
 $\text{B} - 10(\text{He} - 3, d)\text{C} - 11$
 $\text{C} - 12(\pi^+, p)\text{C} - 11$

6 References

- J. H. C. SMITH, D. B. COWIE. J. Appl. Phys. 12 (1941) 78
(Half-life.)
- A. K. SOLOMON. Phys. Rev. 60 (1941) 279
(Half-life.)
- J. M. DICKSON, T. C. RANDLE. Proc. Phys. Soc. (London) 64A (1951) 902
(Half-life.)
- D. N. KUNDU, T. W. DONAVEN, M. L. POOL, J. K. LONG. Phys. Rev. 89 (1953) 1200
(Half-life.)
- W. C. BARBER, W. D. GEORGE, D. D. REAGAN. Phys. Rev. 98 (1955) 73
(Half-life.)
- I. D. PROKOSHKIN, A. A. TIAPKIN. Soviet. Phys. JETP 5 (1957) 148
(Half-life.)
- J. SCOBIE, G. M. LEWIS. Phys. Mag. 2 (1957) 1089
(K/ β^+ ratio.)
- S. E. ARNELL, J. DUBOIS, O. ALMEN. Nucl. Phys. 6 (1958) 196
(Half-life.)
- V. J. JANECKE. Z. Naturforsch. 15A (1960) 593
(Half-life.)
- T. M. KAVANAGH, J. K. P. LEE, W. T. LINK. Can. J. Phys. 42 (1964) 1429
(Half-life.)
- J. R. PATTERSON, J. M. POATE, E. W. TUTTERTON, B. A. ROBSON. Proc. Phys. Soc. (London) 86 (1965) 1297
(Half-life.)
- J. L. CAMPBELL, W. LEIPER, K. W. LEDINGHAM, R. W. P. DREVER. Nucl. Phys. A 96 (1967) 279
(K/ β^+ ratio, end-point energy.)
- E. VATAI. Proc. Conf. Electron Capture and Higher order processes in Nuclear Decay 2 (1968) 71
(K/ β^+ ratio)
- M. AWSCHALOM, F. L. LARSEN, W. SCHIMMERLING. Nucl. Inst. Meth. 75 (1969) 93
(Half-life.)
- J. SINGH. Proc. Nucl. Phys. and Solid State Phys. Symp. 15B (1972) 1
(Half-life.)
- K. R. HOGSTROM, B. W. MAYES, L. Y. LEE, J. C. ALLRED, C. GOODMAN, G. S. MUTCHLER, C. R. FLETCHER, G. C. PHILLIPS. Nucl. Phys. A 215 (1973) 598
(Half-life.)
- M. L. FITZPATRICK, K. W. D. LEDINGHAM, J. Y. GOURLAY, J. G. LYNCH. J. Phys. A 6 (1973) 713
(K/ β^+ ratio, end-point energy.)
- G. AZUELOS, J. E. KITCHING. Phys. Rev. C 12 (1975) 563
(Half-life, end-point energy.)
- F. AJZENBERG-SELOVE. Nucl. Phys. A 248 (1975) 1
(Half-life, end point energy, Q, log ft.)
- H. BEHRENS, M. KOBELT, L. SZYBISZ, W. G. THIES. Nucl. Phys. A 246 (1975) 317
(Half-life, end-point energy.)
- W. BAMBYNEK, H. BEHRENS, M. H. CHEN, B. CRASEMANN, M. L. FITZPATRICK, K. W. D. LEDINGHAM, H. GENZ, M. MUTTERE, R. L. INTEMANN. Rev. Mod. Phys. 49 (1977) 77
(Electron Capture.)
- S. RAMAN, C. A. HOUSER, T. A. WALKIEWICZ, I. S. TOWNER. Atomic Data and Nucl. Data Tables 21 (1978) 567
(Half-life, Q, End point energy.)
- W. BAMBYNEK. Proc. X-Ray and Inner Shell Processes (1984)
(Atomic Data.)
- F. AJZENBERG-SELOVE. Nucl. Phys. A 506 (1990) 1
(Half-life, end point energy, Q, log ft.)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 595 (1995) 409
(Q.)





1 Decay Scheme

N-13 disintegrates by 99.8 % beta-plus transition to the ground state of the stable nuclide C-13.
l'azote 13 se désintègre à 99,8% par émission bêta-plus vers le niveau fondamental de carbone 13.

2 Nuclear Data

$T_{1/2}(^{13}\text{N})$: 9,9670 (37) min
 $Q^+(^{13}\text{N})$: 2220,45 (27) keV

2.1 β^+ Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,0}^+$	1198,45 (27)	99,818 (13)	Allowed	3,654

2.2 Electron Capture Transitions

	Energy keV	Probability $\times 100$	Nature	P _K	P _L
$\epsilon_{0,0}$	2220,45 (27)	0,182 (12)	Allowed	0,923 (7)	0,078 (7)

3 Atomic Data

3.1 C

$$\omega_K : 0,0026 \quad (3)$$

4 Photon Emissions

4.1 Gamma Emissions

	Energy keV	Photons per 100 disint.
γ^\pm	511	199,636 (26)

5 Electron Emissions

	Energy keV	Electrons per 100 disint.
$\beta_{0,0}^+$	max: 1198,45 (27)	99,818 (13)
$\beta_{0,0}^+$	avg: 493,0 (2)	

6 Main Production Modes

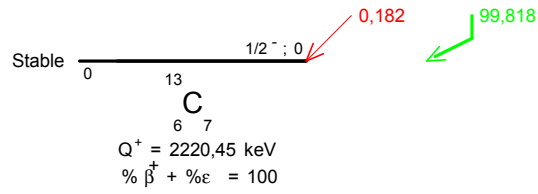
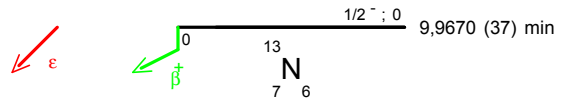
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 C – ${}^{13}(\text{p},\text{n})\text{N} - 13$
 O – ${}^{16}(\text{p},\alpha)\text{N} - 13$
 O – ${}^{16}(\text{d},\text{n}\alpha)\text{N} - 13$
 N – ${}^{14}(\text{p},\text{d})\text{N} - 13$
 N – ${}^{14}(\text{n},2\text{n})\text{N} - 13$
 N – ${}^{14}(\gamma,\text{n})\text{N} - 13$
 N – ${}^{14}(\text{p},\text{pn})\text{N} - 13$
 C – ${}^{12}(\text{p},\gamma)\text{N} - 13$
 Be – ${}^9(\text{Li} - 6,2\text{n})\text{N} - 13$
 B – ${}^{11}(\alpha,2\text{n})\text{N} - 13$

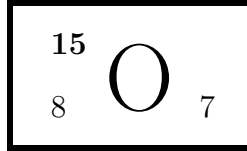
7 References

- W. WARD. Proc. Cambridge Phil. Soc. 35 (1939) 523
(Half-life)
- S. SIEGBAHN. Arkiv F. Art. Mat. Fys. 32A (1945) 9
(Half-life)

- C. S. COOK, L. M. LANGER, C. PRICE JR., M. B. SAMPSON. Phys. Rev. 74 (1948) 502
(Half-life.)
- F. AJZENBERG. Rev. Mod. Phys. 24 (1952) 321
(Half-life, end-point energy, log ft)
- J. L. W. CHURCHILL, W. M. JONES, S. E. HUNT. Nature 172 (1953) 460
(Half-life.)
- D. H. WILKINSON. Phys. Rev. 100 (1955) 32
(Half-life.)
- F. AJZENBERG. Rev. Mod. Phys. 27 (1955) 27
(Half-life, end-point energy, log ft)
- E. NORBECK JR., C. S. LITTLEJOHN. Phys. Rev. 108 (1957) 754
(Half-life.)
- S. DEINEKO, A. IA. TARANOV, A. K. VAL'TER. Sov. Physics - JETP 5 (1957) 201
(Half-life.)
- V. H. DANIEL, U. SCHMIDT-ROHR. Z. Naturforsch. 12A (1957) 750
(Half-life.)
- S. E. ARNELL, J. DUBOIS, O. ALMEN. Nucl. Phys. 6 (1958) 196
(Half-life.)
- D. STROMINGER, J. M. HOLLANDER, G. T. SEABORG. Rev. Mod. Phys. 30 (1958) 585
(Half-life, End-point energy, Q.)
- J. D. KING, R. N. H. HASLAM, R. W. PARSONS. Can. J. Phys. 38 (1960) 231
(Half-life.)
- V. J. JANECKE. Z. Naturforsch. 15A (1960) 593
(Half-life.)
- J. L. SNIDER, M. POSNER, A. M. BERNSTEIN, D. R. HAMILTON. Bull. Am. Phys. Soc. 6 (1961) 22
(Spin.)
- K. W. D. LEDINGHAM, J. A. PAYNE, R. W. P. DREVER. Proc. Int. Conf. Role of Atomic Electrons in Nuclear Transformations Vol. 2 (1963) 359
(K/ β^+ ratio.)
- A.M. BERNSTEIN, R. A. HABERSTROH, D. R. HAMILTON, M. POSNER, J. L. SNIDER. Phys. Rev. 136 (1964) B27
(Spin, magnetic moment.)
- T. G. EBREY, P. R. GRAY. Nucl. Phys. 61 (1965) 479
(Half-life.)
- M. BORMANN, E. FRETWURST, P. SCHEHKA, G. WREGE. Nucl. Phys. 63 (1965) 438
(Half-life.)
- E. D. COMMINS. Ann. Rev. Nucl. Sci. 17 (1967) 33
(Half-life, magnetic moment.)
- A.I. M. RITCHIE. Nucl. Inst. Meth. 64 (1968) 181
(Half-life.)
- H. DANIEL. Rev. Mod. Phys. 40 (1968) 659
(log ft, End-point energy.)
- E. VATAI. Proc. Conf. Electron Capture and Higher order processes in Nuclear Decay 2 (1968) 71
(K/ β^+ ratio.)
- J. SINGH. Proc. Nucl. Phys. and Solid State Phys. Symp. 15B (1972) 1
(Half-life.)
- M. L. FITZPATRICK, K. W. D. LEDINGHAM, J. Y. GOURLAY, J. G. LYNCH. J. Phys. A6 (1973) 713
(K/ β^+ ratio.)
- F. AJZENBERG-SELOVE. Nucl. Phys. A268 (1976) 1
(Half-life, end point energy, Q, log ft.)
- G. AZUELOS, J. E. KITCHING, K. RAMAVATARAM. Phys. Rev. C15 (1977) 1847
(Half-life.)
- W. BAMBYNEK, H. BEHRENS, M. H. CHEN, B. CRASEMANN, M. L. FITZPATRICK, K. W. D. LEDINGHAM, H. GENZ, M. MUTTERE, R. L. INTEMANN. Revs. Modern Phys. 49 (1977) 77
(Electron Capture.)
- S. RAMAN, C. A. HOUSER, T. A. WALKIEWICZ, I. S. TOWNER. At. Data and Nucl. Data Tables 21 (1978) 567
(Half-life, Q, End point energy.)
- F. AJZENBERG-SELOVE. Nucl. Phys. A360 (1981) 1
(Half-life, end point energy, Q, log ft.)
- W. BAMBYNEK. Proc. X-Ray and Inner Shell Processes (1984)
(Atomic Data.)

- F. AJZENBERG-SELOVE. Nucl. Phys. A449 (1986) 1
(Half-life, end point energy, Q, log ft.)
- T. KATOH, K. KAWADE, H. YAMAMOTO. JAERI-M-089-083 (1989)
(Half-life.)
- F. AJZENBERG-SELOVE. Nucl. Phys. A523 (1991) 1
(Half-life, end point energy, Q, log ft.)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q.)





1 Decay Scheme

O-15 disintegrates by 99,9% beta-plus transition to the ground state of the stable nuclide N-15.
L'oxygène 15 se désintègre pour 99,9% par émission bêta plus vers le niveau fondamental de l'azote 15.

2 Nuclear Data

$$T_{1/2}(^{15}\text{O}) : 2,041 \quad (6) \quad \text{min}$$

$$Q^+(^{15}\text{O}) : 2757,0 \quad (13) \quad \text{keV}$$

2.1 β^+ Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,0}^+$	1735,0 (13)	99,885 (6)	Allowed	3,6

2.2 Electron Capture Transitions

	Energy keV	Probability $\times 100$	Nature	P _K	P _L
$\epsilon_{0,0}$	2757,0 (13)	0,115 (6)	Allowed	0,926 (6)	0,074 (6)

3 Atomic Data

3.1 N

$$\omega_K : 0,0044 \quad (4)$$

4 Electron Emissions

	Energy keV	Electrons per 100 disint.
$\beta_{0,0}^+$	max: 1735,0 (13)	99,885 (6)
$\beta_{0,0}^+$	avg: 736,7 (6)	

5 Photon Emissions

5.1 Gamma Emissions

	Energy keV	Photons per 100 disint.
γ^\pm	511	199,770 (12)

6 Main Production Modes

N – 14(p, γ)O – 15

N – 14(d,n)O – 15

C – 12(α ,n)O – 15

N – 15(p,n)O – 15

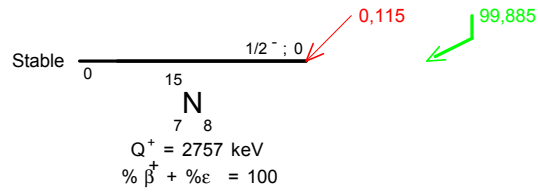
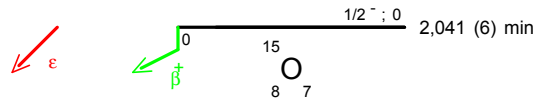
O – 16(He – 3, $\alpha\gamma$)O – 15

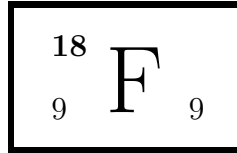
{ Ne – 20(γ ,n α)O – 15
Possible impurities : C – 11, Ne – 19

7 References

- E. McMILLAN, M. S. LIVINGSTON. Phys. Rev. 47 (1935) 452
(Half-life.)
- W. A. FOWLER, L. A. DELSASSO, C. C. LAURITSEN. Phys. Rev. 49 (1936) 561
(End-point energy.)
- W. E. STEPHENS, K. DJANAB, T. W. BONNER. Phys. Rev. 52 (1937) 1079

- (End-point energy.)
- V. PEREZ-MENDEZ, H. BROWN. Phys. Rev. 76 (1949) 689
(End-point energy, ft value.)
 - H. BROWN, V. P. MENDEZ. Phys. Rev. 78 (1950) 649
(Half-life, end point energy.)
 - R. M. KLINE, D. J. ZAFFARANO. Phys. Rev. 96 (1954) 1620
(Half-life.)
 - S. BASHKIN, R. R. CARLSON, E. B. NELSON. Phys. Rev. 99 (1955) 107
(Half-life.)
 - J. D. KINGTON, J. K. BAIR, H. O. COHN, H. B. WILLARD. Phys. Rev. 99 (1955) 1393
(end-point energy.)
 - J. R. PENNING, F. H. SCHMIDT. Phys. Rev. 105 (1957) 647
(Half-life.)
 - O. C. KISTNER, A. SCHAWARZSCHILD, B. M. RUSTAD. Phys. Rev. 105 (1957) 1339
(Half-life, log ft, end-point energy.)
 - O. C. KISTNER, B. M. RUSTAD. Phys. Rev. 114 (1959) 1329
(Half-life, end-point energy.)
 - F. AJZENBERG-SELOVE, T. LAURITSEN. Nucl. Phys. 11 (1959) 1
(Half-life, end point energy, Q, log ft.)
 - V. J. JANECKE. Z. Naturf. 15A (1960) 593
(Half-life.)
 - J. W. NELSON, E. B. CARTER, G. E. MITCHEL, R. H. DAVIS. Phys. Rev. 129 (1963) 1723
(Half-life.)
 - S. S. VASIL'EV, L. YA. SHAVTVALOV. Bull. Acad. Sci. USSR 27 (1963) 1239
(Half-life.)
 - J. CSIKAI, G. PETO. Phys. Lett. 4 (1963) 252
(Half-life.)
 - F. AJZENBERG-SELOVE. Nucl. Phys. A 152 (1970) 1
(Half-life, end point energy, Q, log ft.)
 - W. LEIPER, R. W. P. DREVER. Phys. Rev. C 6 (1972) 1132
(K/ β^+ ratio.)
 - M. L. FITZPATRICK, K. W. D. LEDINGHAM, J. Y. GOURLAY, J. G. LYNCH. J. Phys. A 6 (1973) 713
(K/ β^+ ratio.)
 - F. AJZENBERG-SELOVE. Nucl. Phys. A 268 (1976) 1
(Half-life, end point energy, Q, log ft.)
 - G. AZUELOS, J. E. KITCHING, K. RAMAVATARAM. Phys. Rev. C 15 (1977) 1847
(Half-life.)
 - W. BAMBYNEK, H. BEHRENS, M. H. CHEN, B. CRASEMANN, M. L. FITZPATRICK, K. W. D. LEDINGHAM, H. GENZ, M. MUTTERE, R. L. INTEMANN. Rev. Modern Phys. 49 (1977) 77
(Electron Capture.)
 - S. RAMAN, C. A. HOUSER, T. A. WALKIEWICZ, I. S. TOWNER. Atomic Data and Nucl. Data Tables 21 (1978) 567
(Half-life, Q, End point energy.)
 - F. AJZENBERG-SELOVE. Nucl. Phys. A 360 (1981) 1
(Half-life, end point energy, Q, log ft.)
 - W. BAMBYNEK. Proc. X-Ray and Inner-Shell Processes in Atoms, Molecules and Solids (1984)
(Atomic Data)
 - F. AJZENBERG-SELOVE. Nucl. Phys. A 449 (1986) 1
(Half-life, end point energy, Q, log ft.)
 - F. AJZENBERG-SELOVE. Nucl. Phys. A 523 (1991) 1
(Half-life, end point energy, Q, log ft.)
 - G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 595 (1995) 409
(Q.)
 - CODATA GROUP. Revs. Modern Phys. 72 (2000) 351
(m_0c^2 energy)





1 Decay Scheme

Le fluor 18 se désintègre à 96,86(16) % par émission bêta plus, et 3,14(16) % par capture électronique vers le niveau fondamental de l'oxygène 18.

F-18 disintegrates 96.86(16) % by beta plus, and 3.14(16) % by electron capture to the ground state of the stable nuclide O-18

2 Nuclear Data

$$T_{1/2}(^{18}\text{F}) : 1,8288 \quad (3) \quad \text{h}$$

$$Q^+(^{18}\text{F}) : 1655,5 \quad (6) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	P _K	P _L
ε _{0,0}	1655,5 (6)	3,14 (16)	Allowed	3,57	0,9267 (48)	0,0733 (48)

2.2 β⁺ Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
β _{0,0} ⁺	633,5 (6)	96,86 (16)	Allowed	3,57

3 Atomic Data

3.1 O

$$\omega_K : 0,0069 \quad (5)$$

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e_{AK}	(O)			2,91 (15)
	KLL	0,456 - 0,502	}	
$\beta_{0,0}^+$	max:	633,5	(6)	96,86 (19)
$\beta_{0,0}^+$	avg:	249,3	(3)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.
$XK\alpha_2$	(O)	0,53	0,017 (3)	}
				$K\alpha$

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
γ^\pm	511	193,72 (27)

6 Main Production Modes

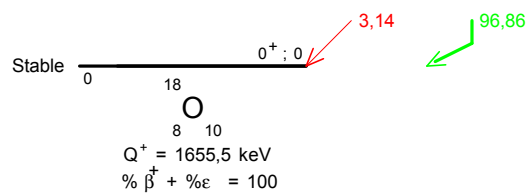
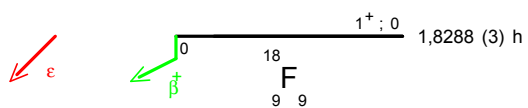
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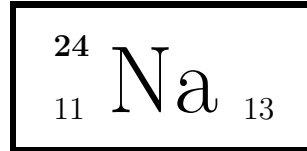
$\text{O} - 16(\text{t},\text{n})\text{F} - 18$
 $\text{F} - 19(\text{p},\text{d})\text{F} - 18$
 $\text{O} - 17(\text{He} - 3,\text{d})\text{F} - 18$

7 References

- J. P. BLASER, F. BOEHM, P. MARMIER. Phys. Rev. 75 (1949) 1953
(Half-life)
- H. T. RICHARDS, R. V. SMITH, C. P. BROWNE. Phys. Rev. 80 (1950) 524
(Q.)
- L. RUBY, J. R. RICHARDSON. Phys. Rev. 83 (1951) 698
(End-point energy.)
- N. JARMIE. Phys. Rev. 98 (1955) 41
(Half-life.)
- R. W. P. DREVER, A. MOLJK, J. SCOBIE. Phil. Mag. 1 (1956) 942
(K/beta+ ratio.)
- W. L. BENDEL, J. MCELHINNEY, R. A. TOBIN. Phys. Rev. 111 (1958) 1297
(Half-life.)
- J. KONIJN, B. VAN NOOIJEN, H. L. HAGEDOORN, A. H. WAPSTRA. Nucl. Phys. 9 (1958) 296
(End-point energy, K/beta+ ratio.)
- C. H. CARLSON, L. SINGER, D. H. SERVICE, W. D. ARMSTRONG. Int. J. Appl. Rad. Isotopes 4 (1959) 210
(Half-life.)
- F. AJZENBERG-SELOVE. Nucl. Phys. 11 (1959) 1
(Half-life, end point energy, Q, log ft.)
- H. P. YULE, A. TURKEVICH. Phys. Rev. 118 (1960) 1591
(Half-life.)
- L. A. RAYBURN. Phys. Rev. 122 (1961) 168
(Half-life.)
- J. D. MAHONY, S. S. MARKOWITZ. Report UCRL 10624 (1963)
(Half-life.)
- K. BEG, F. BROWN. Int. J. Appl. Rad. Isotopes 14 (1963) 137
(Half-life.)
- I. HOFMANN. Acta Physica Austriaca 18 (1964) 309
(Half-life, end-point energy.)
- J. D. MAHONY, S. S. MARKOWITZ. J. Inorg. Nucl. Chem. 26 (1964) 907
(Half-life.)
- T. G. EBREY, P. R. GRAY. Nucl. Phys. 61 (1965) 479
(Half-life.)
- M. BORMANN, E. FRETWURST, P. SCHEHKA, G. WERGE, H. BUTTNER, A. LINDNER, H. MELDNER. Nucl. Phys. 63 (1965) 438
(Half-life.)
- R. W. KAVANAGH. Nucl. Phys. A 129 (1969) 172
(Half-life.)
- F. AJZENBERG-SELOVE. Nucl. Phys. A 190 (1972) 1
(Half-life, end point energy, Q, log ft.)
- M. L. FITZPATRICK, K. W. D. LEDINGHAM, J. Y. GOURLAY, J. G. LYNCH. J. Phys. A 6 (1973) 713
(K/b+ ratio, end-point energy.)
- W. BAMBYNEK, H. BEHRENS, M. H. CHEN, B. CRASEMANN, M. L. FITZPATRICK, K. W. D. LEDINGHAM, H. GENZ, M. MUTTERE, R. L. INTEMANN. Rev. Modern Phys. 49 (1977) 77
(Electron Capture.)
- F. AJZENBERG-SELOVE. Nucl. Phys. A 300 (1978) 1
(Half-life, end point energy, Q, log ft.)

- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. Report AECL 6692 (1980) 2
(Half-life.)
- W. BAMBYNEK. Proc. X-Ray and Inner Shell Processes (1984)
(Atomic Data.)
- F. AJZENBERG-SELOVE. Nucl. Phys. A 475 (1987) 1
(Half-life, end point energy, Q, log ft.)
- T. KATOH, K. KAWADE, H. YAMAMOTO. Report JAERI-M 089-083 (1989)
(Half-life.)
- G. AUDI, A. H. WASPTRA. Nucl. Phys. A 595 (1995) 409
(Q)
- H. SCHRADER. Appl. Rad. Isotopes 60 (2004) 317
(Half-life)





1 Decay Scheme

Na-24 disintegrates by emission of beta- particles (100%). The main transition (99.939%) has a maximum energy of 1393 keV and populates the 4123 keV level of Mg-24. This process is followed by two gamma rays in a cascade (2754 and 1393 keV) which leads through the 1368 keV level to the ground state of Mg-24. Due to the high transition energies internal pair formation takes place.

Le Na-24 se désintègre par émission bêta moins (100%). La transition principale a une énergie maximale de 1393 keV et peuple le niveau d'énergie 4123 keV du Mg-24. Cette désintégration est suivie par deux émissions gamma en cascade vers le niveau fondamental de Mg-24. Les énergies élevées de ces transitions permettent la création de paires électron-positon.

2 Nuclear Data

$$T_{1/2}(^{24}\text{Na}) : 14,9574 \quad (20) \quad \text{h}$$

$$Q^-(^{24}\text{Na}) : 5515,78 \quad (16) \quad \text{keV}$$

2.1 β^- Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,4}^-$	279,3 (6)	0,057 (7)	Allowed	6,74
$\beta_{0,3}^-$	1277,5 (11)	0,001 (1)	2nd forbidden	10,6
$\beta_{0,2}^-$	1392,94 (16)	99,939 (8)	Allowed	6,12
$\beta_{0,1}^-$	4147,11 (16)	0,003 (2)	2nd forbidden	12,7

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K (10^{-5})	α_L (10^{-6})	α_T (10^{-5})	α_π (10^{-5})
$\gamma_{4,3}$ (Mg)	996,09 (6)	0,00123 (27)	M1+18,1%E2	1,6 (5)	1	1,7 (5)	
$\gamma_{1,0}$ (Mg)	1368,669 (5)	99,9990 (3)	E2	0,98	0,6	1,04	4,5 (4)
$\gamma_{2,1}$ (Mg)	2754,177 (11)	99,940 (7)	E2	0,26	0,17	0,28	68 (4)
$\gamma_{3,1}$ (Mg)	2869,69 (6)	0,00024 (3)	M1+99,8%E2	0,25	0,16	0,26	
$\gamma_{4,1}$ (Mg)	3866,48 (10)	0,056 (7)	E2	0,14	0,1	0,15	
$\gamma_{3,0}$ (Mg)	4238,37 (6)	0,00084 (10)	E2	0,15	0,1	0,16	

3 Atomic Data

3.1 Mg

ω_K	:	0,0291	(9)
$\bar{\omega}_L$	:	0,00030	(12)
n_{KL}	:	1,938	(6)

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	1,254	
	$K\alpha_1$	1,254	
	$K\beta_1$	1,302	}
	$K\beta_5''$		}
			2,6
X_L	$L\ell$	0,039	
	$L\eta$	0,049	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	1,10 – 1,18	

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AK}	(Mg)			0,00145 (11)
	KLL	1,10 - 1,18	}	
ec _{1,0} α	(Mg)	346,62	(1)	0,0045 (4)
ec _{1,0} K	(Mg)	1367,321	(5)	0,00028 (3)
ec _{2,1} α	(Mg)	1732,177	(11)	0,068 (4)
ec _{2,1} K	(Mg)	2752,72		0,00026 (3)
β _{0,4} ⁻	max:	279,3	(6)	0,057 (7)
β _{0,4} ⁻	avg:	89,56	(19)	
β _{0,3} ⁻	max:	1277,5	(11)	0,001 (1)
β _{0,3} ⁻	avg:	502,7	(5)	
β _{0,2} ⁻	max:	1392,94	(16)	99,939 (8)
β _{0,2} ⁻	avg:	555,15	(8)	
β _{0,1} ⁻	max:	4147,11	(16)	0,003 (2)
β _{0,1} ⁻	avg:	1866,79	(8)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.
XL	(Mg)	0,039 — 0,049		0,00000071 (29)
XKα ₂	(Mg)	1,254		0,0000119 (5) } Kα
XKα ₁	(Mg)	1,254		0,0000236 (10) }

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
γ [±]	511	0,145 (11)
γ _{4,3} (Mg)	996,09 (6)	0,00123 (27)
γ _{1,0} (Mg)	1368,626 (5)	99,9935 (5)
γ _{2,1} (Mg)	2754,007 (11)	99,872 (8)
γ _{3,1} (Mg)	2869,50 (6)	0,00024 (3)
γ _{4,1} (Mg)	3866,14 (10)	0,056 (7)
γ _{3,0} (Mg)	4237,96 (6)	0,00084 (10)

6 Main Production Modes

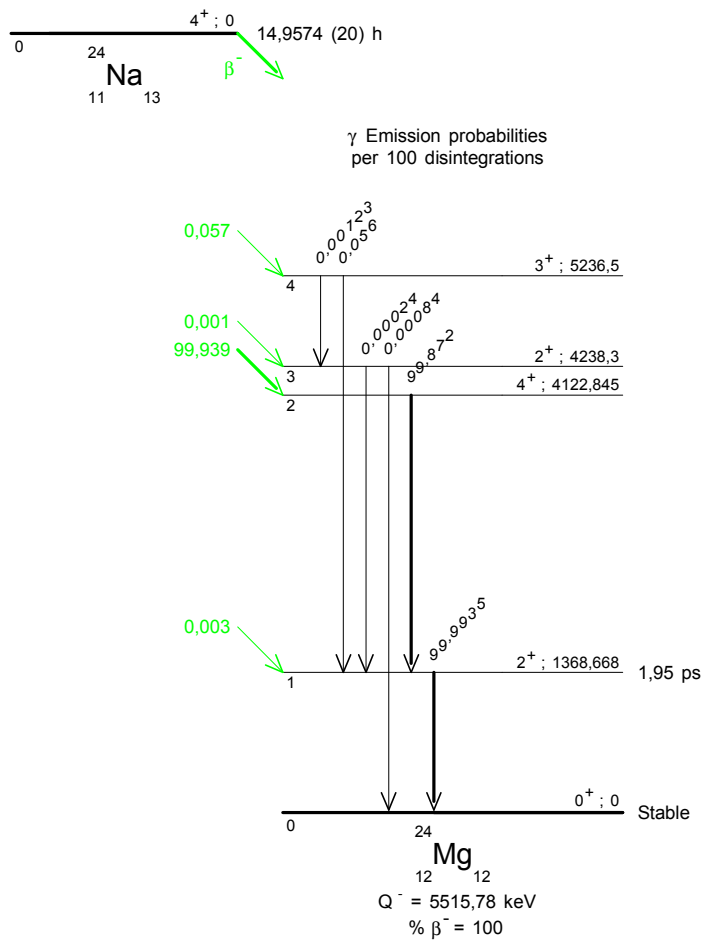
Na – 23(n,γ)Na – 24

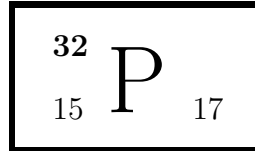
7 References

- E. R. RAE. Phil. Mag. 40 (1949) 1155
(Internal pair creation coefficient)
- R. WILSON, G. R. BISHOP. Proc. Phys. Soc. (London) 62 (1949) 457
(Half-life)
- J. W. COBBLE, R. W. ATTEBERRY. Phys. Rev. 80 (1950) 917
(Half-life)
- P. GRANT. Proc. Phys. Soc. (London) 63 (1950) 1298
(Transition Probability - beta- transition)
- W. MIMS, H. HALBAN, R. WILSON. Nature 166 (1950) 1571
(Internal pair creation coefficient)
- M. R. CLELAND, J. TOWNSEND, A. L. HUGHES. Phys. Rev. 84 (1951) 298
(Internal pair creation coefficient)
- J. F. TURNER, P. E. CAVANAGH. Phil. Mag. 42 (1951) 636
(Transition Probability - beta- transition)
- H. SLÄTIS, K. SIEGBAHN. Arkiv f. Fysik 4 (1952) 485
(Internal pair creation coefficient)
- S. D. BLOOM. Phys. Rev. 88 (1952) 312
(Internal pair creation coefficient)
- E. E. LOCKETT, R. H. THOMAS. Nucleonics 11 (1953) 14
(Half-life)
- J. TOBAILEM. J. Phys. Radium 16 (1955) 48
(Half-life)
- F. T. PORTER, F. WAGNER JR., M. S. FREEDMAN. Phys. Rev. 107 (1957) 135
(Beta- particle maximum energy)
- P. J. CAMPION, J. S. MERRITT. Can. J. Phys. 36 (1958) 983
(Half-life)
- H. DANIEL. Nucl. Phys. 8 (1958) 191
(Beta- particle maximum energy)
- R. BATCHLOR, A. J. FERGUSON, H. E. GOVE, A. E. LITHERLAND. Nucl. Phys. 16 (1960) 38
(Mixing of different multipolarities)
- G. WOLF. Nukleonik 2 (1960) 255
(Half-life)
- P. DEPOMMIER, M. CHABRC. J. Phys. Radium 22 (1961) 656 ,
(Beta- particle maximum energy)
- K. P. ARTAMONOVA, L. V. GUSTOVA, Y. N. PODKAPAEV, O. V. CHUBINSKII. Soviet Phys. JETP 12 (1961) 1109
(Gamma ray emission probability)
- E. I. WYATT, S. A. REYNOLDS, T. H. HANDLICY, W. S. LYON, H. A. PARKER. Nucl. Sci. Eng. 11 (1961) 74
(Half-life)
- J. E. MONAHAN, S. RABOY, C. C. TRAIL. Nucl. Phys. 33 (1962) 633
(Gamma ray emission probability)
- J. E. MONAHAN, S. RABOY, C. C. TRAIL. Nucl. Instrum. Meth. 17 (1962) 225
(Half-life)
- C. BROUDE, H. E. GOVE. Ann. Phys. (New York) 23 (1963) 71
(Mixing of different multipolarities)
- H. PAUL, F. P. VIEHBÖCK, P. SKAREK, H. BAICR, I. HOFFMANN, H. WOTKE. Acta Phys. Austr. 16 (1963) 278
(Beta- particle maximum energy)
- J. LEHMANN. J. Phys. 25 (1964) 326
(Beta- particle maximum energy)
- G. MURRAY, R. L. GRAHAM, J. S. GEIGER. Nucl. Phys. 63 (1965) 353
(Gamma ray energy)
- J. J. REIDY, M. L. WIEDENBECK. Bull. Am. Phys. Soc. (abstract SP2) 10 (1965) 1131
(Gamma ray energy)

- H. BEEKHUIS, H. DE WAARD. Nucl. Phys. 74 (1965) 459
(Beta- particle maximum energy)
- E. SPRING. Phys. Lett. 18 (1965) 132
(Total internal conversion coefficient)
- P. M. ENDT, C. VAN DER LEUN. Nucl. Phys. A105 (1967) 1
(Gamma ray emission probability)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-Ray energies)
- F. LAGOUTINE, Y. LE GALLIC, J. LCGRAND. Int. J. Appl. Rad. Isot. 19 (1968) 475
(Half-life)
- J. VAN KLINKEN, F. PLEITER, H. T. DIJKSTRA. Nucl. Phys. A112 (1968) 372
(Gamma ray emission probability)
- P. KEMENY. Radiochem. Radioanal. Letters 2 (1969) 119
(Half-life)
- H. M. W. BOOIJ, E. A. VAN HOEK., J. BLOK. Nucl. Instrum. Meth. 72 (1969) 40
(Beta- particle maximum energy)
- J. LEBOWITZ, A. R. SAYRES, C. C. TRAIL, B. WEBER, P. L. ZIRKIND. Nuovo Cim. 65A (1970) 675
(Gamma ray energy, Gamma ray emission probability)
- M. A. MEYER, J. P. L. REINECKE, D. REITMANN. Nucl. Phys. A196 (1972) 635
(Gamma ray energy, Gamma ray emission probability)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
(Half-life)
- F. RAHN, H. CAMARDA, G. HACKEN, W. W. HAVENS JR., H. LIOU, J. RAINWATER, M. SLAGOWITZ, S. WYNCHANK. Nucl. Sci. Eng. 47 (1972) 372
(Gamma ray energy)
- S. RAMAN, N. B. GOVE, J. K. DICKEN, T. A. WALKIEWICZ. Phys. Lett. 40B (1972) 89
(Gamma ray energy, Gamma ray emission probability)
- H. J. GILS, D. FLOTHMANN, R. LÖHKEN, W. WIESNER. Nucl. Instrum. Meth. 105 (1972) 179
(Beta- particle maximum energy)
- M. A. MEYER, J. P. L. REINECKE, D. REITMANN. Nucl. Phys. A185 (1972) 625
(Gamma ray energy, Gamma ray emission probability)
- D. BRANFORD. Austral. J. Phys. 26 (1973) 1995
(Transition Probability - beta- transition)
- F. LECCIA, M. M. ALCONARD, D. CASTERA, P. HUBERT, P. MENNRATH. J. Phys. 34 (1973) 147
(Gamma ray emission probability, Multipolarities)
- S. RAMAN, N.B.GOVE. Phys. Rev. C7 (1973) 1995
(Transition Probability - beta- transition)
- S. CHAKRABORTY. Radiochem. Radioanal. Lett. 17 (1974) 61
(Half-life)
- S. G. BOYDELL, D. G. SARGOOD. Austral. J. Phys. 28 (1975) 369
(Gamma ray emission probability)
- H. GENZ, J. REISBERG, A. RICHTER, B. M. SCHMITZ, G. SCHRIEDER, K. WERNER, H. BEHRENS. Nucl. Instrum. Methods 134 (1976) 309
(Half-life, Beta particle maximum energy)
- I. M. BAND, M. B. TRZHASKOVSKAYA, M. A. LISTENGARTEN. At. Data Nucl. Data Tables 18 (1976) 433
(Total internal conversion coefficient)
- F. P. LARKINS. At. Data Nucl. Data Tables 20 (1977) 311
(Energy, Auger electrons)
- M. C. DAVIS, W. C. BOWMAN, J. C. ROBERTSON. Int. J. Appl. Radiat. Isotop. 29 (1978) 331
(Half-life)
- R. C. GREENWOOD, R. G. HELMER, R. J. GEHRKE. Nucl. Instrum. Methods 159 (1979) 465
(Gamma ray energy)
- P. SCHLÜTER, G. SOFF. At. Data Nucl. Data Tables 24 (1979) 509
(Gamma ray emission probability)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- W. MUCKENHEIM, P. RULLHUSEN, F. SMEND, M. SCHUMACHER. Nucl. Instrum. Meth. 173 (1980) 403
(Half-life)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. Report AECL 6692 (1980)
(Half-life)

- E. K. WARBURTON, C. J. LISTER, D. E. ALBURGER, J. W. OLNES. Phys. Rev. C23 (1981) 1242
(Gamma ray emission probability)
- D. D. HOPPE, J. M. R. HUTCHINSON, F. J. SCHIMA, M. P. UNTERWEGER. Report NBS-SP 626 (1982) 85
(Half-life)
- F. LAGOUTINE, J. LEGRAND. Int. J. Appl. Radiat. Isotop. 33 (1982) 711
(Half-life)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. Report NBS-SP 626 (1982) 5
(Half-life)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- W. L. ZIJP. Report ECN FYS/RASA 85/19 (1985)
(averages)
- A. ABZOUZI, M. S. ANTONY, V. B. NDOCKO NDONGUC. J. Radioanal. Nucl. Chem. 135 (1989) 1
(Half-life)
- P. M. ENDT ET AL.. Nucl. Phys. A510 (1990) 209
(Gamma ray emission probability)
- P. M. ENDT. Nucl. Phys. A521 (1990) 209
(Spin and parity)
- P. BODE, M. J. J. AMMERLAAN, M. KOESE. Appl. Radiat. Isot. 42 (1991) 692
(Half-life)
- P. M. ENDT. Nucl. Phys. A529 (1991) 763
(Spin and parity)
- M. U. RAJPUT, T. D. MACMAHON. Nucl. Instrum. Methods 312 (1992) 289
(Half-life)
- M. P. UNTERWEGER, D. D. HOPPE, F. J. SCHIMA. Nucl. Instrum. Methods 312 (1992) 349
(Half-life)
- P.M.ENDT. Nucl. Phys. A564 (1993) 609
(Spin and parity)
- J. H. HUBBELL, P. N. TREHAN, NIRMAL SINGH, B. CHAND, D. MEHTA, M. L. GARG, R. R. GARG, SURINDER SINGH, S. PURI. J. Phys. Chem. Ref. Data 23 (1994) 33
(Mean L-shell fluorescence yield)
- E. P. MIGNONSIN. Appl. Radiat. Isot. 45 (1994) 17
(Half-life)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Total available energy of beta- disintegration)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma emission energies)





1 Decay Scheme

P-32 decays by beta minus emission to the S-32 fundamental level.

Le phosphore 32 se désintègre par émission bêta moins vers le niveau fondamental de soufre 32.

2 Nuclear Data

$$T_{1/2}({}^{32}\text{P}) : 14,284 \quad (36) \quad \text{d}$$

$$Q^{-}({}^{32}\text{P}) : 1710,66 \quad (21) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,0}^{-}$	1710,66 (21)	100	Allowed	7,9

3 Atomic Data

3.1 S

$$\omega_K : 0,0642 \quad (16)$$

$$n_{KL} : 1,856 \quad (7)$$

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
$\beta_{0,0}^-$	max:	1710,66 (21)	100
$\beta_{0,0}^-$	avg:	695,5 (3)	

5 Main Production Modes

{ P – 31(n, γ)P – 32 σ : 0,172 (6) barns
 { Possible impurities : None

{ S – 32(n,p)P – 32
 { Possible impurities : P – 33, S – 35

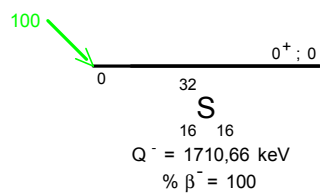
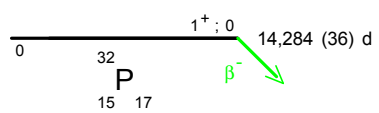
{ S – 34(d, α)P – 32
 { Possible impurities : None

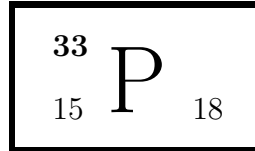
6 References

- J. AMBROSEN. Z. Phys. 91 (1934) 43
(Half-life.)
- P. PREISWERK, H. VON HALBAN. Compt. Rend. 201 (1935) 722
(Half-life.)
- G. J. SIZOO, C. P. KOENE. Physica 3 (1936) 1053
(Half-life.)
- E. M. LYMAN. Phys. Rev. 51 (1937) 1
(End-point energy.)
- H. W. NEWSON. Phys. Rev. 51 (1937) 624
(Half-life , End-point energy.)
- P. C. CAPRON. Physica 5 (1938) 882
(Half-life , End-point energy.)
- N. B. CACCIAPUOTI. Nuovo Cimento 15 (1938) 213
(Half-life.)
- D. MULDER, G. W. HOEKSEMA , G. J. SIZOO. Physica 7 (1940) 849
(Half-life.)
- K. SIEGBAHN. Phys. Rev. 70 (1946) 127
(End-point energy.)
- E. D. KLEMA, A. O. HANSON. Phys. Rev. 73 (1948) 106
(Half-life.)
- L. M. LANGER, H. C. PRICE JR.. Phys. Rev. 76 (1949) 641
(End-point energy.)
- H. M. AGNEW. Phys. Rev. 77 (1950) 655
(End-point energy.)
- S. D. MARSHAW, J. J. L. CHEN , G. L. APPLETON. Phys. Rev. 80 (1950) 288
(End-point energy.)
- W. K. SINCLAIR, A. F. HOLLOWAY. Nature 167 (1951) 365
(Half-life.)
- E. N. JENSEN, R. T. NICHOLS , J. CLEMENT , A. POHM. Phys. Rev. 85 (1952) 112
(End-point energy.)

- E. E. LOCKETT, R. H. THOMAS. *Nucleonics* 11 (1953) 14
(Half-life.)
- H. M. ANTONEVA. *Izv. Akad. Nauk. (Ser. Fiz.)* 18 (1954) 93
(End-point energy.)
- J. G. BAYLY. *Can. J. Research* 28A (1956) 520
(Half-life.)
- A. V. POHM, R. C. WADDELL , E. N. JENSEN. *Phys. Rev.* 101 (1956) 1315
(End-point energy.)
- O. U. ANDERS, W. W. WAYNE MEINKE. *Nucleonics* 15 (1957) 68
(Half-life.)
- R. A. RICCI. *Physica* 23 (1957) 693
(End-point energy.)
- O. E. JOHNSON, R. G. JOHNSON , L. M. LANGER. *Phys. Rev.* 112 (1958) 2004
(End-point energy.)
- H. DANIEL. *Nucl. Phys.* 8 (1958) 191
(Half-life , End-point energy.)
- J. ROBERT. *Annales de Physique* 4 (1959) 89
(Half-life.)
- D. FEHRENTZ, H. DANIEL. *Nucl. Instr. Meth.* 10 (1961) 185
(End-point energy.)
- R. T. NICHOLS, R. E. MCADAMS , E. N. JENSEN. *Phys. Rev.* 122 (1961) 172
(End-point energy.)
- P. G. MARAIS, J. DEIST. *South African J. Agricultural Science* 4 (1961) 627
(Half-life.)
- H. E. BOSCH, T. URSTEIN. *Nucl. Instr. Meth.* 24 (1963) 109
(End-point energy.)
- M. J. CANTY, W. F. DAVIDSON , R. D. CONNOR. *Nucl. Phys.* 85 (1966) 317
(End-point energy.)
- I. W. GOODIER, D. H. PRITCHARD. *Int. J. Appl. Rad. Isotopes* 17 (1966) 121
(Half-life.)
- P. M. ENDT, C. VAN DER LEUN. *Nucl. Phys. A* 105 (1967) 1
(Half-life, end-point energy, Q, lg ft.)
- H. J. FISCHBECK. *Phys. Rev.* 173 (1968) 1078
(End-point energy.)
- F. LAGOUTINE, J. LEGRAND , Y. LE GALLIC. *Int. J. Appl. Rad. Isotopes* 20 (1969) 868
(Half-life.)
- D. FLOTHMANN, W. WIESNER , R. LOHKEN , H. REBEL. *Z. Phys.* 225 (1969) 164
(End-point energy.)
- D. W. PERNAA. *Int. J. Appl. Rad. Isotopes* 20 (1969) 613
(Half-life.)
- H. M. W. BOOIJ, E. A. VAN HOEK , H. VAN DER MOLEN , W. F. SLOT , J. BLOK. *Nucl. Phys. A* 160 (1971) 337
(End-point energy.)
- B. I. PERSSON, I. PLESSER. *Nucl. Phys. A.* 167 (1971) 470
(End-point energy.)
- P. M. ENDT, C. VAN DER LEUN. *Nucl. Phys. A* 214 (1973) 1
(Half-life, end-point energy, Q, lg ft.)
- R. B. MOORE, S. I. HAYAKAWA , D. M. REHFELD. *Nucl. Instr. Meth.* 133 (1976) 457
(End-point energy.)
- T. S. MUDHOLE. *Indian J. Pure and Appl. Phys.* 15 (1977) 284
(Half-life.)
- B. N. BELYAEV, S. S. VASILENKO , A. I. EGOROV , A. I. PAUTOV. *Izv. Akad. Nauk. (Ser. Fiz.)* 41 (1977) 66
(Half-life.)
- P. M. ENDT, C. VAN DER LEUN. *Nucl. Phys. A* 310 (1978) 1
(Half-life, end-point energy, Q, lg ft.)
- J. PRECKER, K. BLANSDORF. *Atomkernenergie* 34 (1979) 136
(Half-life , End-point energy)
- A. H. WAPSTRA. *Nucl. Phys. A* 432 (1985) 1
(End-point energy.)
- P. M. ENDT. *Nucl. Phys. A* 521 (1990) 1
(Half-life, end-point energy, Q, lg ft.)

- R. C. GREENWOOD, M. H. PUTNAM. Nucl. Instr. Meth. Phys. Res. A 337 (1993) 106
(End-point energy.)
- B. M. COURSEY, J. M. CALHOUN , J. CESSNA , D. B. GOLAS , F. J. SCHIMA , M. P. UNTERWEGER. Nucl. Instr. Meth. Phys. Res. A 339 (1994) 26
(Half-life.)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 595 (1995) 409
(Q.)
- E. SCHONFELD, H. JANSSEN. Nucl. Phys. Instr. Meth. Phys. Res. A 369 (1996) 527
(Atomic data.)
- Y. KOJIMA, M. SHIBATA , H. UNO , K. KAWADE , A. TANIGUCHI , Y. KAWASE , K. SHIZUMA. Nucl. Instr. Meth. Phys. Res. A 458 (2001) 656
(End-point energy.)





1 Decay Scheme

Le phosphore 33 se désintègre par émission bêta moins vers le niveau fondamental de soufre 33.
P-33 decays by beta minus emission to the S-33 fundamental level.

2 Nuclear Data

$$T_{1/2}({}^{33}\text{P}) : 25,383 \quad (40) \quad \text{d}$$

$$Q^{-}({}^{33}\text{P}) : 248,5 \quad (11) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,0}^{-}$	248,5 (11)	100	Allowed	5

3 Atomic Data

3.1

$$\omega_K : 0,0642 \quad (16)$$

$$n_{KL} : 1,856 \quad (7)$$

4 Electron Emissions

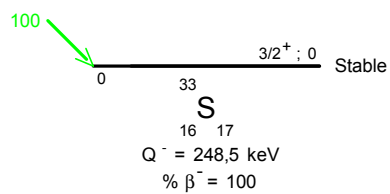
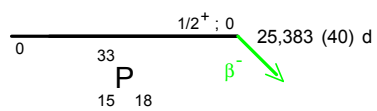
	Energy keV	Electrons per 100 disint.
$\beta_{0,0}^{-}$	max: 248,5 (11)	100
$\beta_{0,0}^{-}$	avg: 76,4 (5)	

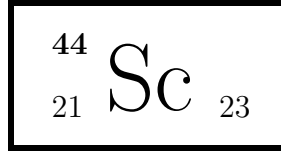
5 Main Production Modes

S – $^{33}(\text{n,p})\text{P} - 33$
 P – $^{32}(\text{n},\gamma)\text{P} - 33$
 S – $^{34}(\gamma,\text{n})\text{P} - 33$

6 References

- P. K. SHELINE, R. B. HOLTZMAN, C. Y. FAN. Phys. Rev. 83 (1951) 919
(Half-life, End-point energy, scheme.)
- P. K. SHELINE, R. B. HOLTZMAN, C. Y. FAN. Phys. Rev. 83 (1951) 215
(Half-life, End-point energy.)
- E. N. JENSEN, R. T. NICHOLS. Phys. Rev. 83 (1951) 215
(Half-life, End-point energy.)
- E. N. JENSEN, R. T. NICHOLS, J. CLEMENT, A. POHM. Phys. Rev. 85 (1952) 112
(End-point energy.)
- T. WESTERMARK. Phys. Rev. 88 (1952) 573
(Half-life, End-point energy.)
- R. T. NICHOLS, E. N. JENSEN. Phys. Rev. 94 (1954) 369
(Half-life, End-point energy.)
- B. ELBEK, K. O. NIELSEN, O. B. NIELSEN. Phys. Rev. 95 (1954) 96
(End-point energy.)
- T. WESTERMARK. Arkiv Fysik 7 (1954) 87
(Half-life, End-point energy.)
- J. E. RUSSELL. Bull. Am. Phys. Soc. 3 (1958) 61
(Half-life, End-point energy.)
- I. FOGELSTROM-FINEMAN, T. WESTERMARK. Acta Chem. Scan. 14 (1960) 2046
(Half-life.)
- P. M. ENDT, C. VAN DER LEUN. Nucl. Phys. A 105 (1967) 1
(Half-life, End-point energy, lg ft, Q.)
- S. A. REYNOLDS, J. F. EMERY, E. I. WYATT. Nucl. Sci. Eng. 32 (1968) 46
(Half-life.)
- F. LAGOUTINE, J. LEGRAND, C. PERROT, J. P. BRETHON, J. MOREL. Int. J. Appl. Radiat. Isotopes 23 (1972) 219
(Half-life.)
- P. M. ENDT, C. VAN DER LEUN. Nucl. Phys. A 214 (1973) 1
(Half-life, End-point energy, lg ft, Q.)
- P. M. ENDT, C. VAN DER LEUN. Nucl. Phys. A 310 (1978) 1
(Half-life, End-point energy, lg ft, Q.)
- P. POLAK, L. LINDNER. Radiochimica Acta 35 (1984) 23
(End-point energy.)
- A. H. WAPSTRA, G. AUDI. Nucl. Phys. A 432 (1985) 1
(End-point energy.)
- P. M. ENDT. Nucl. Phys. A 521 (1990) 1
(Half-life, End-point energy, lg ft, Q.)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 565 (1993) 1
(Q.)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 595 (1995) 409
(Q.)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic data.)
- P. M. ENDT. Nucl. Phys. A 633 (1998) 1
(Half-life, End-point energy, lg ft, Q.)





1 Decay Scheme

Sc-44 disintegrates by beta plus emission mainly (94.27(5) %) and by electron capture (5.73(5)%) to excited levels in Ca-44. No transition to the ground state has been observed.

Le scandium 44 se désintègre principalement par émission bêta plus (94,27(5) %) et par capture électronique (5,73(5) %) vers des niveaux excités du calcium 44. Aucune transition vers le niveau fondamental n'a été observée.

2 Nuclear Data

$$T_{1/2}({}^{44}\text{Sc}) : 3,97 \quad (4) \quad \text{h}$$

$$Q^+({}^{44}\text{Sc}) : 3653,3 \quad (19) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	<i>P_K</i>	<i>P_L</i>	<i>P_{M+}</i>
$\epsilon_{0,3}$	351,8 (19)	0,00440 (11)	Allowed	6,6	0,8954 (20)	0,0911 (16)	0,0135 (7)
$\epsilon_{0,2}$	996,8 (19)	1,02 (2)	Super Allowed Or Allowed	5,2	0,8966 (19)	0,0900 (16)	0,0134 (7)
$\epsilon_{0,1}$	2496,3 (19)	4,70 (5)	Allowed	5,3	0,8970 (19)	0,0897 (16)	0,0133 (7)

2.2 β^+ Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,1}^+$	1474,3 (19)	94,27 (5)	Allowed	

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K (10^{-5})	α_L (10^{-5})	α_M (10^{-5})	α_T (10^{-5})	α_π (10^{-5})
$\gamma_{1,0}$ (Ca)	1157,023 (15)	99,882 (3)	E2	5,90 (18)	0,499 (15)	0,081 (2)	6,48 (19)	
$\gamma_{2,1}$ (Ca)	1499,463 (20)	0,908 (15)	M1+1,8%E2	2,9 (1)	0,243 (7)	0,047 (2)	3,19 (10)	
$\gamma_{3,1}$ (Ca)	2144,42 (8)	0,0036 (7)	[M1+E2+E0]					35 (4)
$\gamma_{2,0}$ (Ca)	2656,444 (24)	0,112 (3)	[E2]					60 (6)
$\gamma_{3,0}$ (Ca)	3301,33 (6)	0,0017 (2)	[E2]					78 (8)

3 Atomic Data

3.1 Ca

$$\omega_K : 0,169 \quad (4)$$

$$\bar{\omega}_L : 0,0022 \quad (5)$$

$$n_{KL} : 1,621 \quad (6)$$

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	K α_2	3,68813	
	K α_1	3,69172	
	K β_1	4,0128	}
	K β_5''	4,0325	
			19,52
X _L	L ℓ	0,350	
	L γ	- 0,412	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K	KLL	3,123 – 3,307
	KLX	3,543 – 3,666
	KXY	3,951 – 3,987
Auger L	0,044 – 0,387	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Ca)	0,044 - 0,387	8,71 (5)
e _{AK}	(Ca)		4,21 (3)
	KLL	3,123 - 3,307	}
	KLX	3,543 - 3,666	}
	KXY	3,951 - 3,987	}
$\beta_{0,1}^+$	max:	1474,3 (19)	94,27 (5)
$\beta_{0,1}^+$	avg:	632,0 (9)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Ca)	0,350 — 0,412	0,019 (4)	
XK α_2	(Ca)	3,68813	0,255 (7)	} K α
XK α_1	(Ca)	3,69172	0,504 (13)	}
XK β_1	(Ca)	4,0128	} 0,098 (3)	K' β_1
XK β_5''	(Ca)	4,0325	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
γ^\pm	511	188 (3)
$\gamma_{1,0}(\text{Ca})$	1157,020 (15)	99,875 (3)
$\gamma_{2,1}(\text{Ca})$	1499,46 (2)	0,908 (15)
$\gamma_{3,1}(\text{Ca})$	2144,33 (10)	0,0036 (7)
$\gamma_{2,0}(\text{Ca})$	2656,48 (7)	0,112 (3)
$\gamma_{3,0}(\text{Ca})$	3301,35 (6)	0,0017 (2)

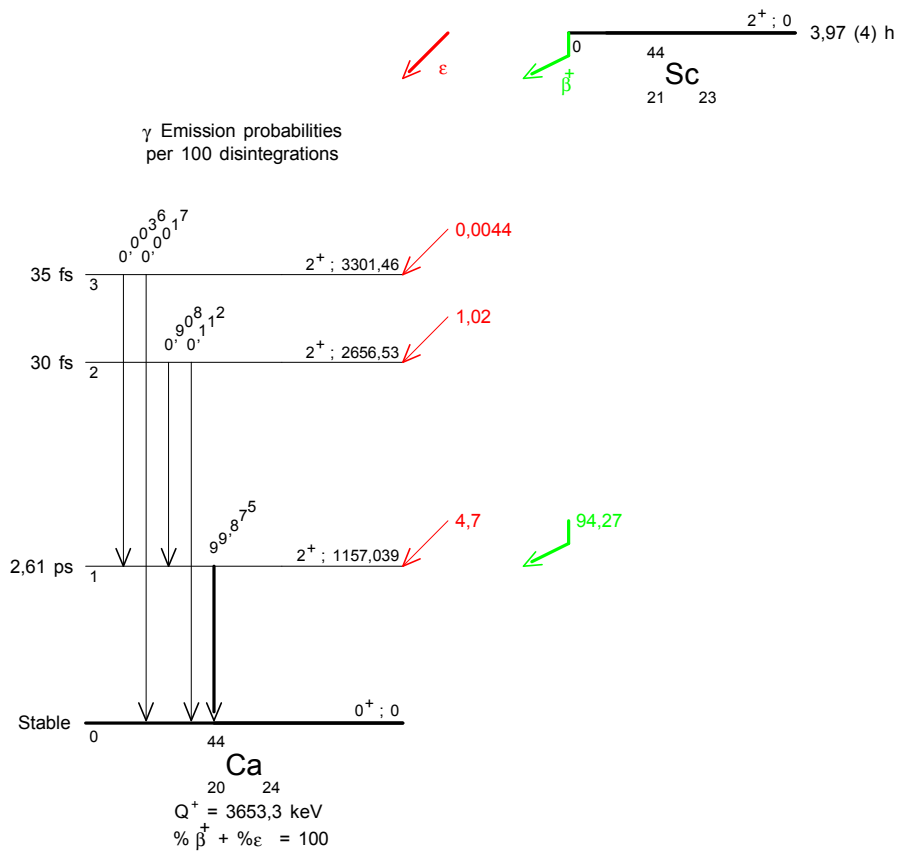
6 Main Production Modes

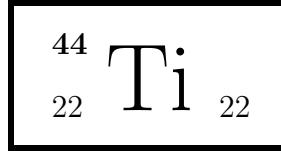
K – 41(α ,n)Sc – 44
 Sc – 45(γ ,n)Sc – 44
 Daughter of Ti – 44
 Daughter of Sc – 44 (2,4d)

7 References

- J. W. BLUE, E. BLEUER. Phys. Rev. 100 (1955) 1324
(ICC)
- P. F. ZWEIFEL. Phys. Rev. 107 (1957) 329
(Theoretical EC/B+ ratios)
- L. A. RAYBURN. Phys. Rev. 122 (1961) 168
(Half-life)
- C. S. KHURANA, H. S. HANS. Nucl. Phys. 28 (1961) 560
(Half-life)
- L. T. DILLMAN, J. D. McCULLEN. Nucl. Phys. 42 (1963) 383
(Half-life)
- J. TATARCZUK. Phys. Rev. 143 (1966) 818
(Half-life)
- H. K. WALTER, A. WEITSCH, H. J. WELKE. Z. Physik 213 (1968) 323
(Gamma-ray multipolarities, mixing ratios)
- H. RAVN. J. Inorg. Nucl. Chem. 31 (1969) 1883
(Half-life)
- D. R. SACHDEV, L. YAFFE. Can. J. Chem. 47 (1969) 1667
(Half-life)
- J. J. SIMPSON. Nucl. Phys. A203 (1973) 221
(Gamma ray energies, Gamma-ray emission probabilities)
- R. L. HEATH. Report ANCR-1000-2 (1974)
(Gamma ray energies, Gamma-ray emission probabilities)
- H. STOCKER, A. P. BAERG. Can. J. Phys. 54 (1976) 2396
(Electron Capture/Beta plus ratio)
- I.M.BAND ET AL.. At. Data Nucl. Data Tables 18 (1976) 433
(Theoretical ICC)
- G. COLEMAN, R. A. MEYER. Phys. Rev. C13 (1976) 847
(Gamma ray energies, Gamma-ray emission probabilities)
- P. SCHLUTER, G. SOFF. At. Data Nucl. Data Tables 24 (1979) 509
(Internal Pair Conversion Coefficients)
- A. P. BAERG. Can. J. Phys. 61 (1983) 1222
(Electron Capture/Beta plus ratio)
- GUANJUN YUAN ET AL.. Nucl. Sci. Eng. 84 (1983) 320
(Gamma ray energies, Gamma-ray emission probabilities)
- E. BROWNE, R. B. FIRESTONE. Table of Radioactive Isotopes, John Wiley and Sons, New York (1986) (1986)
(Positron annihilation in flight)
- M. J. WOODS, A. S. MUNSTER. Report NPL RS(EXT) 95 (1988)
(Limitation of Relative Statistical Weight)
- U. SCHÖTZIG. Nucl. Instrum. Methods A286 (1990) 523
(Positron annihilation radiation, Gamma-ray emission probabilities)
- R. A. MEYER. Fizika 22 (1990) 153
(Gamma ray energies, Gamma-ray emission probabilities)
- P. M. ENDT. Nucl. Phys. A521 (1990) 1
(Levels half-life)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q(EC))
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(X-ray, K-fluorescence yields.)

- B. SINGH, J. L. RODRIGUEZ, S. S. WONG, J. K. TULI. Nucl. Data Sheets 84 (1998) 487
(Log ft systematics)
- H. JANSSEN, E. SCHÖNFELD. EMISSION program (1998)
(X-ray and Auger-electron probabilities)
- E. SCHÖNFELD. Appl. Rad. Isotopes 49 (1998) 1353
(Elec. Capt. probability sub-shell ratios)
- E. SCHÖNFELD, F. Y. CHU, E. BROWNE. EC-CAPTURE program (1998)
(Elec. Capt. probability sub-shell ratios)





1 Decay Scheme

Ti-44 disintegrate 100% by electron capture to excited levels in Sc-44 ($T_{1/2} = 3.93$ h), which subsequently decays by EC and beta plus to Ca-44.

Le titane 44 se désintègre à 100% par capture électronique vers des niveaux excités du scandium 44; lequel décroît ($T_{1/2} = 3,93$ h) par capture électronique et émission bêta plus vers le calcium 44.

2 Nuclear Data

$T_{1/2}({}^{44}\text{Ti})$	:	60,0	(11)	a
$T_{1/2}({}^{44}\text{Sc})$	:	3,97	(4)	h
$Q^+({}^{44}\text{Ti})$	:	267,5	(19)	keV

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg ft	P_K	P_L	P_{M+}
$\epsilon_{0,2}$	121,3 (19)	99,6 (11)	1 st Forbidden	6,5	0,8891 (20)	0,0960 (16)	0,0149 (7)
$\epsilon_{0,1}$	199,6 (19)	0,4 (11)	1 st Forbidden	9,3	0,8917 (19)	0,0938 (16)	0,0145 (7)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{1,0}(\text{Sc})$	67,8680 (14)	100,9 (15)	E1	0,0766 (23)	0,00665	0,00125	0,0845 (25)
$\gamma_{2,1}(\text{Sc})$	78,36 (3)	99,5 (11)	M1	0,0273 (8)	0,00244	0,00046	0,032 (1)
$\gamma_{2,0}(\text{Sc})$	146,22 (3)	0,096 (3)	[M2]	0,0414 (12)	0,00385	0,00075	0,046 (1)

3 Atomic Data

3.1 Sc

ω_K	:	0,196	(5)
$\bar{\omega}_L$	:	0,0027	(6)
n_{KL}	:	1,594	(5)

3.1.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	4,0862	50,69
$K\alpha_1$	4,0906	100
$K\beta_1$	4,4604	}
$K\beta_5''$	4,4866	
		20,13
X_L		
$L\ell$	0,348	
$L\gamma$	- 0,468	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	3,45 – 3,65	100
KLX	3,93 – 4,08	26,4
KXY	4,38 – 4,48	1,74
Auger L	0,3 – 0,5	270

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Sc)	0,3 - 0,5	167,5 (24)
e _{AK}	(Sc)		79,5 (21)
	KLL	3,45 - 3,65	}
	KLX	3,93 - 4,08	}
	KXY	4,38 - 4,48	}
ec _{1,0} K	(Sc)	63,375 (2)	7,12 (24)
ec _{1,0} L	(Sc)	67,37 - 67,47	0,621 (21)
ec _{1,0} M	(Sc)	67,81 - 67,86	0,116 (4)
ec _{2,1} K	(Sc)	73,83 (3)	2,63 (8)
ec _{2,1} L	(Sc)	77,82 - 77,92	0,235 (8)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Sc)	0,348 — 0,468	0,45 (9)	
XK α_2	(Sc)	4,0862	5,76 (18)	} K α
XK α_1	(Sc)	4,0906	11,4 (4)	}
XK β_1	(Sc)	4,4604	}	2,26 (8) K' β_1
XK β_5''	(Sc)	4,4866	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Sc)	67,8679 (14)	93,0 (15)
$\gamma_{2,1}$ (Sc)	78,36 (3)	96,4 (11)
$\gamma_{2,0}$ (Sc)	146,22 (3)	0,092 (3)

6 Main Production Modes

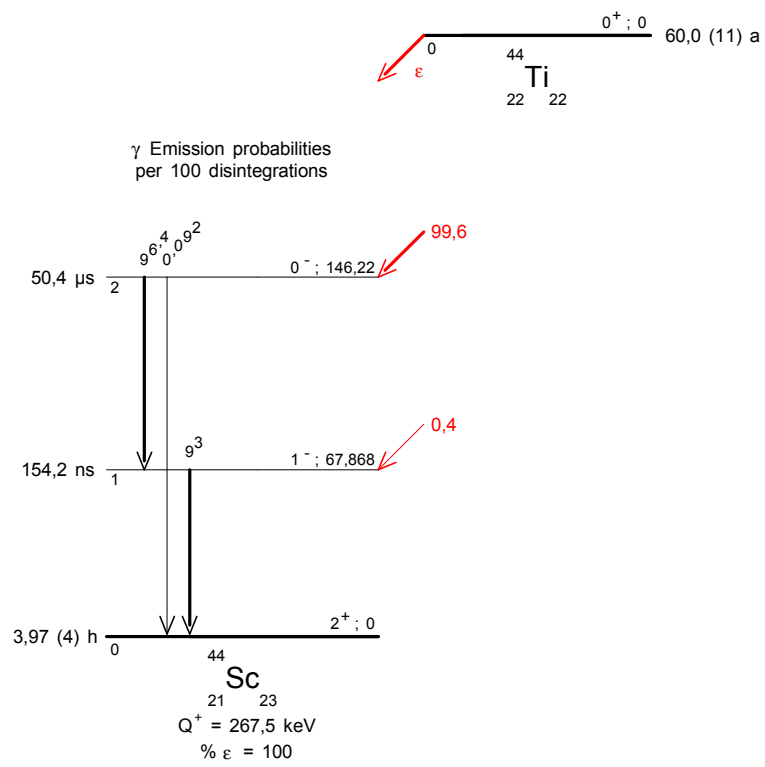
Sc – 45(p,2n)Ti – 44

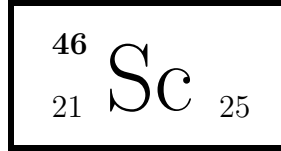
Sc – 45(d,3n)Ti – 44

7 References

- E.W. CYBULSKA, L. MARQUEZ. Nuovo Cim. 14 (1959) 479
(Half-life (level))
- P. THIEBERGER. Ark. Fysik 22 (1962) 127
(Half-life (level))
- J.K KLIWER, *et al.* Nucl. Phys. 49 (1963) 328
(Gamma ray energies)
- K. BANDI, *et al.* Nucl. Phys. 59 (1964) 33
(Half-life(level))
- P.E. MORELAND, D. HEYMANN. J. Inorg. Nucl. Chem. 27 (1965) 493
(Half-life)
- J. WING, *et al.* J. Inorg. Nucl. Chem. 27 (1965) 487
(Half-life)
- R.A. RISTINEN, A.W. SUNYAR. Phys. Rev. 153 (1967) 1209
(Gamma ray energies, Gamma-ray emission probabilities)
- V.P. GUPTA, D.K. GUPTA. Indian J. Pure Appl. Phys. 13 (1975) 334
(Half-life(level))
- I.M.BAND, *et al.* At. Data. Nucl. Data Tables 18 (1976) 433
(ICC (Theoretical))
- D.E. FREKERS, *et al.* Phys. Rev. C28 (1983) 1756
(Half-life)
- T.W. BURROWS. The Program RADLST, report BNL-NCS-52142 (1988)
()
- D.E. ALBURGER, E.K. WARBURTON. Phys. Rev. C38 (1988) 1843
(Gamma-ray emission probabilities)
- M.J.WOODS. (1988)
(Limitation of Relative Statistical Weights)
- D.E. ALBURGER, G. HARBOTTLE. Phys. Rev. C41 (1990) 2320
(Half-life)
- U. SCHOTZIG. Nucl. Instrum. Methods A286 (1990) 523
(Gamma-ray emission probabilities)
- C. WESSELBORG, D.E. ALBURGER. Nucl. Instrum. Methods A302 (1991) 89
(Gamma ray energies)
- A.F. LYUDIN, *et al.* Astrn. Astrophys. 284 (1994) L1
(Gamma-ray emission probabilities, Gamma ray energies)
- J. MEISSNER, *et al.* Nuclei in the Cosmos III, edited by Maurizio Busso and Claudia M. Raiteri, AIP Conf. Proc. No. 327 (AIP, New York) 327 (1995) 303
(Half-life)
- G. AUDI, A.H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q-value)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(X rays. Atomic fluorescence yields.)
- J. MEISSNER. (1996)
(Half-life)
- R.B. FIRESTONE. (1996)
(⁴⁴Sc EC+B+ decay, Gamma ray energies, Gamma-ray emission probabilities)
- E.B. NORMAN, *et al.* Nucl. Phys. A621 (1997) 92c
(Half-life)
- S. WOOSLEY, R. DIEHL. Physics World 11 (1998) 22
(Half-life)

- B. SINGH, J.L RODRIGUEZ, S.S. WONG, J.K. TULI. Nucl. Data Sheets 84 (1998) 487
(Log ft systematics)
- E. YAKUSEV, N. COURSOLO. (1998)
(ICC calculations)
- E. SCHÖNFELD. Appl. Rad. Isotopes 49 (1998) 1353
(Elec. Capt. probability sub-shell ratios)
- E.B. NORMAN, *et al.* Phys. Rev. C57 (1998) 2010
(Half-life)
- J. GORRES, *et al.* Phys. Rev. Lett. 80 (1998) 2554
(Half-life)
- I. AHAMD, *et al.* Phys. Rev. Lett. 80 (1998) 2550
(Half-life)
- E. SCHÖNFELD, F. CHU, E. BROWNE. EC-Capture, a computer program (1998)
(Elec. Capt. probability sub-shell ratios)
- F.E. WIETFELDT, *et al.* Phys. Rev. C59 (1999) 528
(Half-life)





1 Decay Scheme

Sc-46 disintegrates by 100% beta minus emission to excited levels in Ti-46. The main path (99.99%) leads to 2009.8 keV level of Ti-46. The ground state of Ti-46 is reached via a gamma cascade of 1120.5 and 889.3 keV.

Le scandium 46 se désintègre à 100% par émission bêta moins vers les niveaux excités du titane 46, dont 99,99% vers le niveau de 2009,8 keV. Le niveau fondamental du titane 46 est atteint par une cascade gamma de 1120,5 et 889,3 keV.

2 Nuclear Data

$$T_{1/2}(^{46}\text{Sc}) : 83,788 \quad (22) \quad \text{d}$$

$$Q^-(^{46}\text{Sc}) : 2366,7 \quad (7) \quad \text{keV}$$

2.1 β^- Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,2}^-$	356,9 (7)	99,98 (2)	Allowed	6,2
$\beta_{0,1}^-$	1477,4 (7)	0,02 (2)	2nd forbidden	≥ 11,9

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K (10 ⁻⁶)	α_L (10 ⁻⁷)	α_T (10 ⁻⁶)	α_π (10 ⁻⁷)
$\gamma_{1,0}(\text{Ti})$	889,280 (2)	99,9999 (7)	E2	149 (4)	134 (4)	167 (5)	
$\gamma_{2,1}(\text{Ti})$	1120,552 (3)	99,986 (36)	E2	85 (3)	76,1 (19)	95 (3)	22 (4)
$\gamma_{2,0}(\text{Ti})$	2009,832 (4)	0,000013 (10)	[E4]	63,8 (2)	57,5 (17)	71,4 (21)	

3 Atomic Data

3.1 Ti

ω_K	:	0,226	(5)
$\bar{\omega}_L$	:	0,0032	(7)
n_{KL}	:	1,566	(5)

3.1.1 X Radiations

		Energy keV	Relative probability
X _K	K α_2	4,505	50,8
	K α_1	4,511	100
X _L	L ℓ	0,40	
	L γ	- 0,46	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	3,796 – 4,014	100
KLX	4,328 – 4,507	26,5
KXY	4,846 – 4,959	1,76

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AK}	(Ti)		0,0181 (4)
	KLL	3,796 - 4,014	}
	KLX	4,328 - 4,507	}
	KXY	4,846 - 4,959	}
ec _{1,0} K	(Ti)	884,314 (2)	0,0149 (4)
ec _{1,0} L	(Ti)	888,72 - 888,83	0,00134 (4)
ec _{2,1} K	(Ti)	1115,586 (3)	0,0085 (3)
ec _{2,1} L	(Ti)	1119,99 - 1120,10	0,00076 (2)
$\beta_{0,2}^-$	max:	356,9 (7)	99,98 (2)
$\beta_{0,2}^-$	avg:	111,8 (3)	
$\beta_{0,1}^-$	max:	1477,4 (7)	0,02 (2)
$\beta_{0,1}^-$	avg:	580,8 (4)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Ti)	0,40 — 0,46	0,00013 (3)
XK α_2	(Ti)	4,505	0,00157 (5) } K α
XK α_1	(Ti)	4,511	0,0031 (1) }

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Ti)	889,271 (2)	99,9833 (5)
$\gamma_{2,1}$ (Ti)	1120,537 (3)	99,986 (36)
$\gamma_{2,0}$ (Ti)	2009,785 (4)	0,000013 (10)

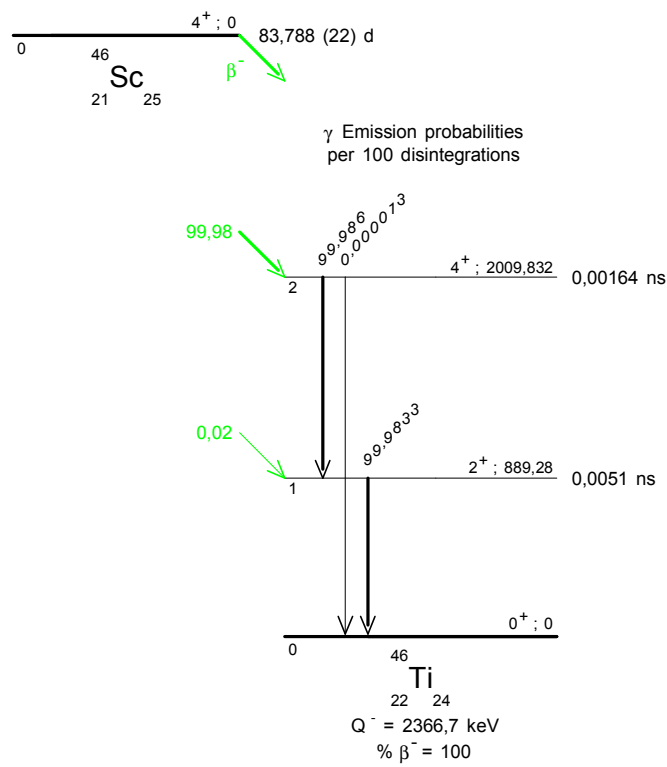
6 Main Production Modes

Sc – 46(I.T.)
 Ca – 43(α ,p γ)Sc – 46
 Ca – 44(He – 3,p)Sc – 46
 Sc – 45(n, γ)Sc – 46
 Sc – 45(d,p)Sc – 46
 Sc – 45(d,p γ)Sc – 46
 Sc – 45(t,d)Sc – 46
 Ca – 46(He – 3,t)Sc – 46
 Ti – 46(t,He – 3)Sc – 46
 Ti – 47(d,He – 3)Sc – 46
 Ti – 48(p,He – 3)Sc – 46
 Ti – 48(d, α)Sc – 46

7 References

- H.WALKE. Phys. Rev. 57 (1940) 163
(Half-life)
- M.L.MOON, M.A.WAGGONER, A.ROBERTS. Phys.Rev. 79 (1950) 905
(Beta emission intensities)
- B.N.SORENSEN, B.M.DALE, J.D.KURBATOV. Phys.Rev. 79 (1950) 1007
(Beta emission intensities)
- G.L.KEISTER, F.H.SCHMIDT. Phys.Rev. 93 (1954) 140
(Beta emission intensities)
- R.P.SCHUMAN, M.E.JONES, A.C.MCWHERTER. J. Inorg. Nucl. Chem 3 (1956) 160
(Half-life)
- J.L.WOLFSON. Can.J.Phys. 34 (1956) 256
(Beta emission intensities)
- H.W.WRIGHT, E.I.WYATT, S.A.REYNOLDS, W.S.LYON, T.H.HANDLEY. Nucl. Sci. Eng. 2 (1957) 427
(Half-life)
- K.W.GEIGER. Phys.Rev. 105 (1957) 1539
(Half-life)
- S.C.ANSPACH, L.M.CAVALLO, S.B.GARFINKEL, J.M.R.HUTCHINSON, C.N.SMITH. Report NP 15663 (1965)
(Half-life)
- P.J.CRESSY JR. Nucl. Sci. Eng. 55 (1974) 450
(Half-life)
- I.M.BAND, M.B.TRZHASKOVSKAYA, M.A.LISTENGARTEN. At. Data. Nucl. Data Tables 18 (1976) 433
(ICC)
- J.S.MERRITT, F.H.GIBSON. Report AECL 5696 (1977) 40
(Half-life)
- P.SCHLUTER, G.SOFF. At.Data Nucl.Data Tables 24 (1979) 509
(IPFC)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. Report AECL 6692 (1980)
(Half-life)
- J.B.OLOMO, T.D.MACMAHON. J.Phys. (London) G6 (1980) 367
(Half-life)
- M.FUJISHIRO, Y.SATOH, K.OKAMOTO, T.TSUJIMOTO. Can.J.Phys. 58 (1980) 1712
(Gamma ray emission probability)
- H.HOUTERMANS, O.MILOSEVIC, F.REICHEL. Int.J.Appl.Radiat.Isotop. 31 (1980) 153
(Half-life)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. Report NBS-SP 626 (1982) 5
(Half-life)
- D.D.HOPPE, J.M.R.HUTCHINSON, F.J.SCHIMA, M.P.UNTERWEGER. Report NBS-SP 626 (1982) 85
(Half-life)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. Nucl.Instrum.Methods 206 (1983) 211
(Half-life)

- K.F.WALZ, K.DEBERTIN, H.SCHRADER. Int.J.Appl.Radiat.Isotop. 34 (1983) 1191
(Half-life)
- W.L.ZIJP. Report ECN (Petten) 179 (1985)
(analysis methodology)
- D.E.ALBURGER. Nucl. Data Sheets 49 (1986) 237
(evaluation)
- M.U.RAJPUT, T.D.MACMAHON. Nucl. Instrum. Methods A312 (1992) 289
(analysis methodology)
- M.P.UNTERWEGER, D.D.HOPPE, F.J.SCHIMA. Nucl. Instrum. Methods A312 (1992) 349
(Half-life)
- G.AUDI, A.H.WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic data)
- B.SINGH, J.L.RODRIGUES, S.S M.WONG, J.K.TULI. Nucl. Data Sheets 84 (1998) 487
(log ft systematics)
- R.G.HELMEER, C.VAN DER LEUN. Nucl. Instrum. Methods A 450 (2000) 35
(Gamma ray energy)
- S.-C.WU. Nucl.Data Sheets 91 (2000) 1
(J, multipolarities)





1 Decay Scheme

Cr-51 disintegrates by electron capture either to the ground state of V-51 (90.11%) or via the 320 keV level of V-51 (9.89%).

Le Cr-51 se désintègre par capture électronique vers l'état fondamental (90,11%) ou vers le niveau à 320 keV (9,89%) du V-51.

2 Nuclear Data

$$T_{1/2}({}^{51}\text{Cr}) : 27,703 \quad (3) \quad \text{d}$$

$$Q^+({}^{51}\text{Cr}) : 752,73 \quad (24) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	P_K	P_L	P_{M+}
$\epsilon_{0,1}$	432,65 (24)	9,89 (5)	Allowed	5,86	0,8910 (17)	0,0941 (14)	0,0145 (6)
$\epsilon_{0,0}$	752,73 (24)	90,11 (5)	Allowed	5,39	0,8919 (17)	0,0934 (14)	0,0144 (6)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K (10 ⁻³)	α_L (10 ⁻⁴)	α_M (10 ⁻⁵)	α_T (10 ⁻³)
$\gamma_{1,0}(V)$	320,0835 (4)	9,89 (5)	M1+12,6%E2	1,54 (3)	1,36 (8)	2,7 (4)	1,69 (5)

3 Atomic Data

3.1 V

ω_K	:	0,256	(5)
$\bar{\omega}_L$	:	0,0038	(8)
n_{KL}	:	1,539	(5)

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	K α_2	4,9447	50,83
	K α_1	4,95224	100
	K β_3	5,42735	}
	K β_1	5,42735	
	K β_5''	5,46296	
			20,12
X _L	L ℓ	0,446	
	L γ	- 0,585	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	4,16 – 4,38	100
KLX	4,76 – 4,90	26,7
KXY	5,32 – 5,46	1,78
Auger L	0,45 – 0,59	282,4

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(V)	0,45 - 0,59	147,6 (1)
e _{AK}	(V)		66,4 (6)
	KLL	4,16 - 4,38	}
	KLX	4,76 - 4,90	}
	KXY	5,32 - 5,46	}
ec _{1,0 K}	(V)	314,618 (4)	0,0152 (3)
ec _{1,0 L}	(V)	319,45 - 319,57	0,00134 (8)
ec _{1,0 M}	(V)	320,02 - 320,08	0,00027 (4)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(V)	0,446 — 0,585	0,56 (11)
XK α_2	(V)	4,9447	6,79 (14) } K α
XK α_1	(V)	4,95224	13,36 (27) }
XK β_3	(V)	5,42735 }	
XK β_1	(V)	5,42735 }	2,69 (7) K' β_1
XK β_5''	(V)	5,46296 }	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0(V)}$	320,0835 (4)	9,87 (5)

6 Main Production Modes

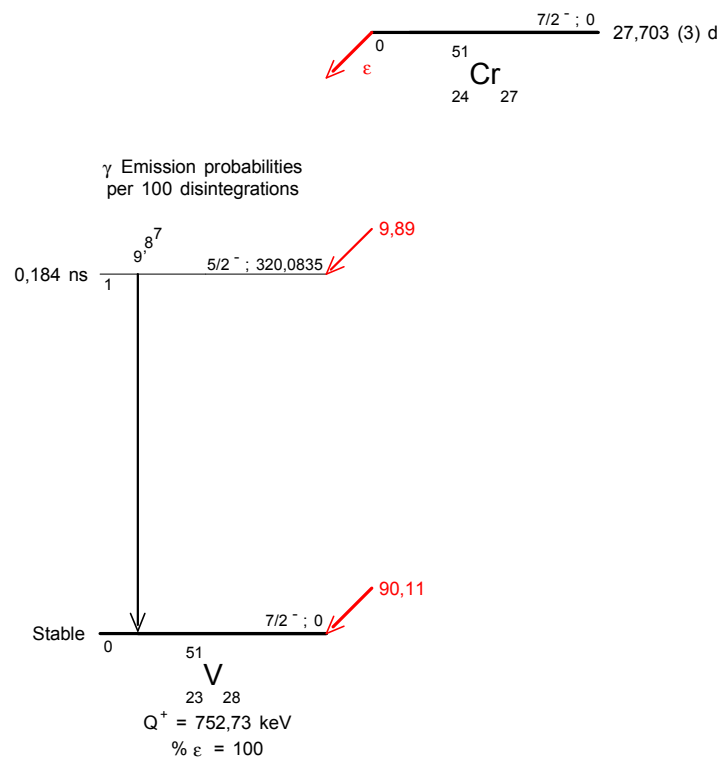
- Cr – 50(n,γ)Cr – 51 σ : 15,9 (2) barns
- Possible impurities : K – 42
- V – 51(p,n)Cr – 51 σ : 0,52 barns
- Ti – 48(α,n)Cr – 51
- Cr – 50(d,p)Cr – 51
- Fe – 54(n,α)Cr – 51
- Cr – 52(n,2n)Cr – 51
- Cr – 50(d,n)Mn – 51

7 References

- H.WALKE, F.C.THOMPSON, J.HOLT. Phys. Rev. 57 (1940) 171
(Half-Life)
- H.BRADT, P.C.GUGELOT, O.HUBER, H.MEDICUS, P.PREISWERK, P.SCHERRER. Helv.Phys. Acta 18 (1945) 252
(Gamma emission probabilities)
- H.H.HOPKINS JR., B.B.CUNNINGHAM. Phys.Rev. 73 (1948) 1406
(Half-life)
- D.R.MILLER, R.C.THOMPSON, B.B.CUNNINGHAM. Phys.Rev. 74 (1948) 347
(Half-life)
- W.S.LYON. Phys.Rev. 87 (1952) 1126
(Half-life)
- D.MAEDER, P.PREISWERK, A.STEINEMANN. Helv. Phys. Acta 25 (1952) 46
(Gamma emission probabilities, K-shell internal conversion coefficient)
- I.V.ESTULIN, E.M.MOISEEVA. Sov. Phys. JETP 1 (1955) 463
(ICC, K-shell internal coefficient)
- Z.O'FRIEL, A.H.HUBER. Phys. Rev. 99 (1955) 659
(K-shell internal conversion coefficient)
- A.BISI, E.GERMAGNOLI, L.ZAPPA. Nuovo cimento 2 (1955) 1052
(Gamma emission probabilities)
- M.E.BUNKER, J.W.STARNER. Phys. Rev. 99 (1955) 1906
(Gamma emission probabilities, ICC, mixing of different multipolarities)
- S.G.COHEN, S.OFER. Phys. Rev. 100 (1955) 856
(Bremsstrahlung)
- M.E.BUNKER, J.W.STARNER. Phys. Rev. 97 (1955) 1272
(Gamma emission probabilities, alpha, mixing of different multipolarities)
- P.KAFALAS, J.W.IRVINE JR.. Phys.Rev. 104 (1956) 703
(Half-life)
- Z.O'FRIEL, A.H.HUBER. Phys. Rev. 101 (1956) 1076
(ICC)
- R.P.SCHUMANN, M.E.JONES, A.C.MEWHERTER. J. Inorg. Chem. 3 (1956) 160
(Half-life)
- S.OFER, R.WIENER. Phys. Rev. 107 (1957) 1639
(Gamma emission probabilities)
- G.M.KARAVAEV, S.A.RUSINOVA. Trudy Vsesoyuz.Nauch.- Issledovatel. Inst. Metrol. 30 (1957) 132
(Half-life)
- H.W.WRIGHT, E.I.WYATT, S.A.REYNOLDS, W.S.LYON, T.H.HANDLEY. Nucl. Sci. Eng. 2 (1957) 427
(Half-life)
- U.FASOLI, C.MANDUCHI, G.ZANNONI. Nuovo cimento 23 (1962) 1126
(Elec. Capt. probability sub-shell ratios)
- U.C.GUPTA, M.G.SHANANI, P.K.SRIVASTAVA. J.Sci.Industr. Res. 21B (1962) 1
(ICC)
- S.HONTZEAS, L.YAFFE. Can.J.Chem. 41 (1963) 2194
(Half-life)
- I.Y.KRAUSE. Phys.Rev. 129 (1963) 1330
(Gamma mixing ratio)

- J.S.MERRITT, J.G.V.TAYLOR. Report AECL 1778 (1963) 31
(Gamma emission probabilities)
- P.J.MARAIS, F.J.HAASBROEK, J.H.M.KARSTEN. S. Afr. J. Agr. Sci. 7 (1964) 881
(Half-life)
- K.C.DHINGRA, U.C.GUPTA, N.P.S.SIDHU. Current Sci. (India) 34 (1965) 504
(Gamma emission probabilities)
- J.LEGRAND. Report CEA-R 2813 (1965)
(Gamma emission probabilities)
- S.R.SALISBURY, R.A.CHALMERS. Phys.Rev. 140 (1965) B305
(Half-life)
- F.LAGOUTINE, Y.LE GALLIC, J.LEGRAND. Proc.Symp.Standardization of Radionuclides. Vienna. Austria (1966)
(Half-life)
- W.HEUER. Z. Physik 194 (1966) 224
(PK, PL)
- F.LAGOUTINE, Y.LE GALLIC, J.LEGRAND. Intern.At.Energy Agency.Vienna CONF-661012 (1967) 603
(Half-life)
- M.BORMANN, A.BEHREND, I.RIEHLE, O.VOGEL. Nucl.Phys. A115 (1968) 309
(Half-life)
- C.RIBORDY, J.KERN, L.SCHELLENBERG, O.HUBER. Helv. Phys. Acta 41 (1968) 429
(K-shell internal conversion coefficient)
- O.DRAGON, C.RIBORDY, O.HUBER. Nucl.Phys. A124 (1969) 337
(ICC)
- J.W.KANE JR. Thesis University of Alabama (1969)
(K-shell internal conversion coefficient)
- J.B.WILLET. Thesis Indiana University (1969)
(K-shell internal conversion coefficient)
- J.S.MERRITT, J.G.V.TAYLOR. Report AECL 3512 (1969) 30
(Half-life)
- H.C.CARTER, J.H.HAMILTON. Z. Phys. 235 (1970) 383
(K-shell internal conversion coefficient)
- R.N.HOROSHKO, D.CLIN, P.M.S.LESSER. Nucl.Phys. A149 (1970) 562
(Gamma mixing ratio)
- C.RIBORDY, O.HUBER. Helv. Phys. Acta 43 (1970) 345
(Gamma energy, K-shell internal conversion)
- U.SCHÖTZIG, H.M.WEISS, K.F.WALZ. Wissenschaftliche Abhandlungen der Phys.-Techn. Bundesanstalt 22 (1970) 76
(Gamma emission probabilities)
- K.F.WALZ, U.SCHÖTZIG. Wissenschaftliche Abhandlungen der Phys.-Techn. Bundesanstalt 22 (1970) 76
(Half-life)
- J.F.EMERY, S.A.REYNOLDS, E.I.WYATT, G.I.GLEASON. Nucl.Sci.Eng. 48 (1972) 319
(Half-life)
- F.LAGOUTINE. to be published as quoted in 1973De60 (1973)
(Half-life)
- J.B.WILLET, G.T.EMERY. Ann. Phys. (New York) 78 (1973) 496
(K-shell internal conversion coefficient)
- J.ARAMINOWICZ, J.DRESLER. Report INR 1464 (1973) 14
(Half-life)
- C.J.VISSER, J.H.M.KARSTEN, F.J.HAASBROEK, P.G.MARAIS. Agrochemophysica 5 (1973) 15
(Half-life)
- E.DE ROOST, F.LAGOUTINE. At. Energy Rev. 11 (1973) 642
(alpha, mixing of different multipolarities, half-life)
- C.W.TSE, J.N.MUNDY, W.D.MCFALL. Phys. Rev. C10 (1974) 838
(Half-life)
- G.L.BORCHERT, W.SCHECK, K.P.WIEDER. Z.Naturforsch. 30a (1975) 274
(Gamma energy)
- F.LAGOUTINE, J.LEGRAND, C.BAC. Intern. J. Appl. Radiat. Isotop. 26 (1975) 131
(Half-life)
- I.M.BAND, M.B.TRZHASKOVSKAYA., M.A.LISTENGARTEN. Atomic Data Nucl. Data Tables 18 (1976) 433
(K-shell and L-shell internal conversion coefficients)

- T.MORII. Nucl.Instrum.Methods 151 (1978) 489
(Gamma energy)
- K.S.KRANE. At. Data. Nucl. Data Tables 22 (1978) 269
(mixing of different multipolarities)
- U.SCHÖTZIG, K.DEBERTIN, K.F.WALZ. Nucl. Instrum. Methods 169 (1980) 43
(Gamma energy, Gamma ray emission probability)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. Report AECL 6692 (1980)
(Half-life)
- H.HOUTERMANS, O.MILOSEVIC, F.REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- P.CHRISTMAS. Report NBS-SP 6262 (1982) 100
(Half-life)
- K.DEBERTIN, U.SCHOTZIG, K.F.WALZ. Report NBS-SP 626 (1982) 101
(Half-life)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. Report NBS-SP 626 (1982) 5
(Half-life)
- K.F.WALZ, K.DEBERTIN, H.SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life.)
- A.FISHER, R.I.HERSHBERGER. Nucl. Phys. A423 (1984) 121
(Gamma ray emission probability, EC transition prob)
- W.L.ZIJP. Report ECN (Petten) 179 (1985)
(analysis methodology)
- H.H.HANSEN. European Appl. Res. Rept. Nucl. Sci. Technol. EUR 9478 EN 6,44 (1985) 777
(ICC, K-shell ICC)
- T.BARTA, L.SZÜCS, A.ZSINKA. Appl. Rad. Isotopes 42 (1991) 490
(Gamma ray emission probability)
- M.P.UNTERWEGER, D.D.HOPPE, F.J.SCHIMA. Nucl. Instrum. Methods A312 (1992) 349
(Half-life)
- M.U.RAJPUT, T.D.MACMAHON. Nucl. Instrum. Methods A312 (1992) 289
(Analysis methodology)
- G.AUDI, A.H.WAPSTRA. Nucl. Phys. A595 (1995) 409
(Total available energy of ec transformation)
- E.SCHÖNFELD. Report PTB 6.33-95-2 (1995)
(EC emission probability)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic Data)
- R.G.HELMER, C.VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma ray energy)





1 Decay Scheme

Mn-54 disintegrates by electron capture via the 835 keV level of Cr-54. An electron capture and a beta plus transition to the ground state of Cr-54 have not been observed but upper limits have been determined. *Le Mn-54 se désintègre par capture électronique vers le niveau à 835 keV du Cr-54. Une capture électronique et une émission bêta plus vers l'état fondamental n'ont jamais été mesurées, mais des limites supérieures ont été déterminées.*

2 Nuclear Data

$T_{1/2}({}^{54}\text{Mn})$	:	312,13	(3)	d
$Q^+({}^{54}\text{Mn})$	:	1377,1	(10)	keV
$Q^-({}^{54}\text{Mn})$	:	697,1	(11)	keV

2.1 β^+ Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,1}^+$	355,1 (10)	0,00000057	Unique 2nd forbidden	13,8

2.2 Electron Capture Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft	P_K	P_L	P_{M+}
$\epsilon_{0,1}$	542,3 (10)	99,9997 (3)	Allowed	6,17	0,8895 (17)	0,0950 (15)	0,0150 (16)
$\epsilon_{0,0}$	1377,1 (10)	0,0003 (3)	Unique 2nd forbidden	< 13,9	0,8198 (17)	0,0858 (15)	0,0149 (16)

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K (10^{-4})	α_L (10^{-5})	α_T (10^{-4})
$\gamma_{1,0}(\text{Cr})$	834,845 (5)	99,9997 (3)	E2	2,24 (11)	2,20 (13)	2,51 (11)

3 Atomic Data

3.1 Cr

ω_K	:	0,289	(5)
$\bar{\omega}_L$	:	0,0045	(9)
n_{KL}	:	1,508	(5)

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	5,405	
	$K\alpha_1$	5,415	
	$K\beta_3$	5,947	}
	$K\beta_1$	5,947	
	$K\beta_5''$		20,31
X_L	$L\ell$	0,50	
	$L\gamma$	- 0,65	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	4,554 – 4,794	100
KLX	5,206 – 5,412	26,92
KXY	5,841 – 5,985	1,913
Auger L	0,4 – 0,7	2,91

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Cr)	0,4 - 0,7	143,0 (6)
e _{AK}	(Cr)		63,3 (5)
	KLL	4,554 - 4,794	}
	KLX	5,206 - 5,412	}
	KXY	5,841 - 5,985	}
ec _{1,0 K}	(Cr)	828,849 (5)	0,0224 (11)
ec _{1,0 L}	(Cr)	834,143 - 834,264	0,00220 (13)
$\beta_{0,1}^+$	max:	355,1 (10)	0,00000057
$\beta_{0,1}^+$	avg:	182	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Cr)	0,50 — 0,65	0,65 (13)
XK α_2	(Cr)	5,405	7,66 (13) } K α
XK α_1	(Cr)	5,415	15,0 (3) }
XK β_3	(Cr)	5,947	}
XK β_1	(Cr)	5,947	} 3,05 (6) K' β_1

5.2 Gamma Emissions

		Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Cr})$		834,838 (5)	99,9746 (11)

6 Main Production Modes

$$\left\{ \begin{array}{l} \text{Fe} - 54(n,p)\text{Mn} - 54 \\ \text{Possible impurities : Cr} - 51, \text{Fe} - 55, \text{Fe} - 57 \end{array} \right.$$

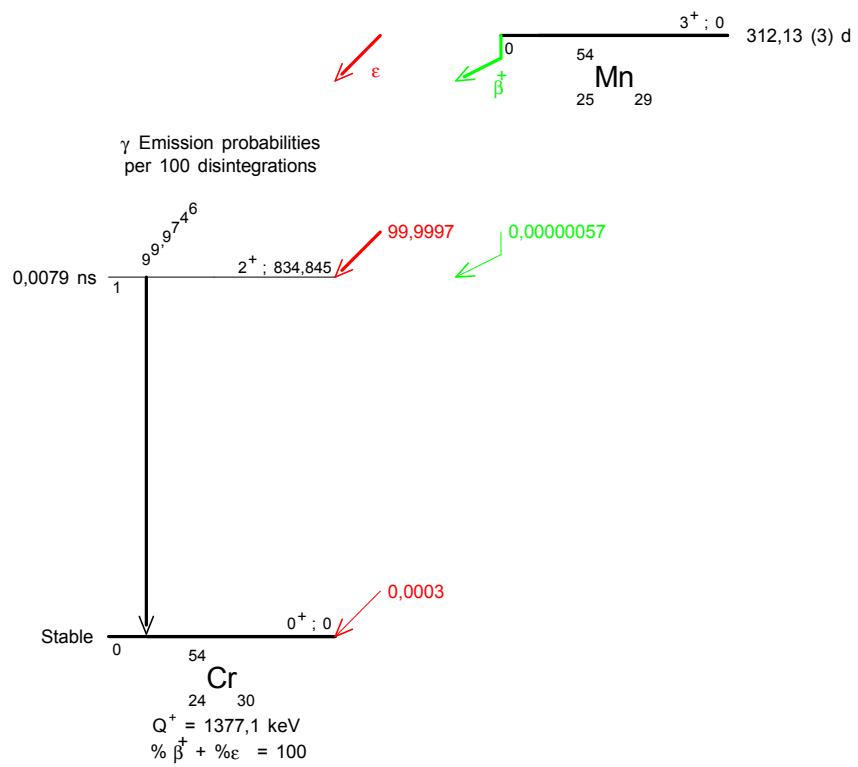
$$\left\{ \begin{array}{l} \text{Cr} - 53(d,n)\text{Mn} - 54 \\ \text{Possible impurities : V} - 48, \text{Mn} - 52 \end{array} \right.$$

V – 51(α ,n)Mn – 54
 Cr – 52(t,n)Mn – 54
 Cr – 52(α ,d)Mn – 54
 Cr – 53(d,n)Mn – 54
 Cr – 54(p,n)Mn – 54
 Cr – 54(t,He – 3)Mn – 54
 Fe – 54(n,p)Mn – 54

7 References

- E.W.BACKOFEN, R.H.HERBER. Phys. Rev. 97 (1955) 743
(Half-life)
- P.KAFALAS, J.W.IRVINE JR.. Phys. Rev. 104 (1956) 703
(Half-life)
- R.P.SCHUMAN, M.E.JONES, A.C.MCWHERTER. J. Inorg. Nucl. Chem. 3 (1956) 160
(Half-life)
- E.I.WYATT, S.A.REYNOLDS, T.H.HANDLEY, W.S.LYONS, H.A.PARKER. Nucl. Sci. and Eng. 11 (1961) 74
(Half-life)
- J.G.V.TAYLOR, J.S.MERRITT. Proc. Intern. Conf. Role of Atomic Electrons in Nuclear Transformations - Warsaw III (1963) 465
(X-ray emission probabilities)
- G.BEN-DAVID. Nucl. Sci. and Eng. 20 (1964) 281
(Half-life)
- W.H.MARIN, D.M.CLARE. Nucl. Sci. and Eng. 19 (1964) 465
(Half-life)
- J.G.V.TAYLOR, J.S.MERRITT. report AECL 2501 (1965) 26
(Half-life)
- K.F.LEISTNER. Atomkerenergie 10 (1965) 311
(X-ray emission probabilities)
- S.C.ANSPACH, L.M.CAVALLO, S.B.GARFINKEL, J.M.R.HUTCHINSON, C.N.SMITH. Report NP 15663 (1965)
(Half-life)
- S.R.SALISBURY, R.A.CHALMERS. Phys. Rev. 140 (1965) B305
(Half-life)
- J.H.HAMILTON, S.R.AMTEY, B.VAN NOOIJEN, A.V.RAMAYYA, J.J.PINAJIAN. Phys. Letters 19 (1966) 682
(ICC)
- M.PETEL, H.HOUTERMANS. Standardization of Radionuclides - IAEA (Vienna) (1967) 301
(X-ray emission probabilities)
- W.BAMBYNEK. Z. Phys. 206 (1967) 66
(X-ray emission probabilities)
- D.BERENYI, D.VARGA, B.VASVARI, E.BRUCHER. Nucl. Phys. A106 (1968) 248
(β^+ emission intensity)
- J.W.HAMMER. Z. Phys. 216 (1968) 355
(X-ray emission probabilities)
- F.LAGOUTINE, Y.LE GALLIC, J.LEGRAND. Intern. J. Appl. Radiat. Isot. 19 (1968) 475
(Half-life)
- W.H.ZIMMER, R.E.DAHL. Nucl. Sci. and Eng. 32 (1968) 132
(Half-life)
- P.BOCK. Report KFK 1116 10/14/71 (1969)
(Half-life)

- C.J.VISSER, J.H.M.KARSTEN, F.J.HAASBROEK, P.G.MARIAS. *Agrochemophysica* 5 (1973) 15
(Half-life)
- P.J.CRESSY JR.. *Nucl. Sci. and Eng.* 55 (1974) 450
(Half-life)
- J.S.MERRITT, J.G.V.TAYLOR. Report AECL 4657 (1974) 30
(Half-life)
- I.M.BAND, M.B.TRZHASKOVSKAYA, M.A.LISTENGARTEN. *Atomic Data and Nuclear Data Tables* 18 (1976) 433
(K and L-shell internal conversion coefficients)
- P.MAGNIER, J.BOUCARD, M.BLONDEL, J.LEGRAND, J.-P.PEROLAT, R.VATIN. *Z. Phys.* A284 (1978) 383, 3
(Fluorescence yield, K X-ray emission intensity)
- J.S.MERRITT, A.R.RUTLEDGE, L.V.SMITH, F.H.GIBSON. Report NEANDC-CAN 51/L (1979) 12
(Half-life)
- D.D.COHEN. *Nucl. Instr. Meth.* 178 (1980) 481
(X-ray emission probabilities)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. Report AECL 6692 (1980)
(Half-life)
- D.D.HOPPE, J.M.R.HUTCHINSON, F.J.SCHIMA, M.P.UNTERWEGER. Report NBS-SP 626 (1982) 85
(Half-life)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. Report NBS-SP 6262 (1982) 5
(Half-life)
- A.RYTZ. Report NBS-SP- 6262 (1982) 32
(Half-life)
- W.L.ZIJP. Report ECN (Petten) 179 (1985)
(Analysis methodology)
- H.H.HANSEN, EUROPEAN APP.RES.REPERS. *Nucl. Sci. and Technol. EUR 9478 EN 6,4* (1985) 777
(ICC)
- B.SUR, K.R.VOGEL, E.B.NORMAN, K.T.LESKO, R.-M.LARIMER, E.BROWNE. *Phys. Rev.* C39 (1989) 1511
(Half-life)
- M.P.UNTERWEGER, D.D.HOPPE, F.J.SCHIMA. *Nucl. Instr. and Meth.* A312 (1992) 349
(Half-life)
- M.U.RAJPUT, T.D.MAC MAHON. *Nucl. Instr. Meth. A* 312 (1992) 289
(Analysis methodology)
- M.T.F.DA CRUZ, Y.CHAN, A.GARCIA, M.M.HINDI, G.KENCHIAN, R.-M.LARIMER, K.T.LESKO, E.B.NORMAN, R.G.STOKSTAD, F.E.WIETFELDT, I.ZLIMEN. *Phys. Rev.* C48 (1993) 31110
(transition by EC, β^+ decay)
- J.HUO, H.SUN, W.ZHAO, Q.ZHOU. *Nucl. Data Sheets* 68 (1993) 887
(Half-life)
- G.AUDI, A.H.WAPSTRA. *Nucl. Phys.* A 595 (1995) 409
(Q)
- M.A.DUVERNOIS. *Phys. Rev.* C54 (1996) A2134
(Half-life)
- R.H.MARTIN, K.I.W.BURNS, J.V.G.TAYLOR. *Nucl. Instr. and Meth.* A390 (1997) 267
(Half-life)
- B.SINGH, J.L.RODRIGUEZ, S.S.M.WONG, J.K.TULI. *Nucl. Data Sheets* 84 (1998) 487
(log ft systematics)
- R.G.HELMER, C.VAN DER LEUN. *Nucl. Instr. Meth.* A450 (2000) 35
(Gamma ray energy)





1 Decay Scheme

Mn-56 decays by beta minus emission to excited levels of Fe-56.

Le manganèse 56 se désintègre par émission bêta moins vers les niveaux excités du fer 56.

2 Nuclear Data

$$T_{1/2}({}^{56}\text{Mn}) : 2,57878 \quad (46) \quad \text{h}$$

$$Q^{-}({}^{56}\text{Mn}) : 3695,5 \quad (3) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,7}^{-}$	250,2 (3)	0,020 (2)	Allowed	6,57
$\beta_{0,6}^{-}$	325,7 (3)	1,20 (3)	Allowed	5,17
$\beta_{0,5}^{-}$	572,6 (3)	0,040 (4)	Allowed	7,5
$\beta_{0,4}^{-}$	735,6 (3)	14,5 (3)	Allowed	5,34
$\beta_{0,3}^{-}$	1037,9 (3)	27,5 (4)	Allowed	5,621
$\beta_{0,2}^{-}$	1610,4 (3)	0,057 (6)	Allowed	9,06
$\beta_{0,1}^{-}$	2848,7 (3)	56,6 (7)	Allowed	7,101

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{1,0}(\text{Fe})$	846,776 (5)	98,88 (3)	E2	0,000270 (8)	0,0000250 (8)	0,0000037 (1)	0,000300 (9)
$\gamma_{5,2}(\text{Fe})$	1037,85 (2)	0,040 (4)	M1+0.04%E2	0,000130 (4)	0,0000120 (4)	0,0000060 (2)	0,0001500 (45)
$\gamma_{2,1}(\text{Fe})$	1238,300 (12)	0,097 (2)	E2	0,000110 (3)	0,0000100 (3)	0,00000200 (6)	0,000120 (4)
$\gamma_{3,1}(\text{Fe})$	1810,786 (15)	26,9 (4)	M1+3%E2	0,0000460 (14)	0,00000430 (13)	0,00000063 (2)	0,0000510 (15)
$\gamma_{4,1}(\text{Fe})$	2113,15 (1)	14,2 (3)	M1+4%E2				

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{6,1}(\text{Fe})$	2523,06 (5)	1,02 (2)	M1+E2				
$\gamma_{7,1}(\text{Fe})$	2598,53 (2)	0,020 (2)	M1+E2				
$\gamma_{3,0}(\text{Fe})$	2657,56 (1)	0,645 (7)	E2				
$\gamma_{4,0}(\text{Fe})$	2959,92 (1)	0,307 (5)	E2				
$\gamma_{6,0}(\text{Fe})$	3369,84 (4)	0,17 (1)	E2				

3 Atomic Data

3.1 Fe

ω_K	:	0,355	(4)
$\bar{\omega}_L$	:	0,0060	(6)
n_{KL}	:	1,447	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	6,39091	51
	$K\alpha_1$	6,40391	100
	$K\beta_1$	7,05804	}
	$K\beta_5''$	7,1083	
			20,6

3.1.2 Auger Electrons

	Energy keV	Relative probability	
Auger K	KLL	5,370 – 5,645	100
	KLX	6,158 – 6,400	27,4
	KXY	6,926 – 7,105	1,87
	Auger L	0,510 – 0,594	307

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Fe)	0,510 - 0,594	0,0428 (3)
e _{AK}	(Fe)		0,0180 (1)
	KLL	5,370 - 5,645	}
	KLX	6,158 - 6,400	}
	KXY	6,926 - 7,105	}
$\beta_{0,7}^-$	max:	250,2 (3)	0,020 (2)
$\beta_{0,7}^-$	avg:	73,5 (1)	
$\beta_{0,6}^-$	max:	325,7 (3)	1,20 (3)
$\beta_{0,6}^-$	avg:	99,1 (1)	
$\beta_{0,5}^-$	max:	572,6 (3)	0,040 (4)
$\beta_{0,5}^-$	avg:	190,4 (2)	
$\beta_{0,4}^-$	max:	735,6 (3)	14,5 (3)
$\beta_{0,4}^-$	avg:	255,2 (2)	
$\beta_{0,3}^-$	max:	1037,9 (3)	27,5 (4)
$\beta_{0,3}^-$	avg:	381,9 (2)	
$\beta_{0,2}^-$	max:	1610,4 (3)	0,057 (6)
$\beta_{0,2}^-$	avg:	636,3 (2)	
$\beta_{0,1}^-$	max:	2848,7 (3)	56,6 (7)
$\beta_{0,1}^-$	avg:	1216,8 (2)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XK α_2	(Fe)	6,39091	0,00295 (4) } K α
XK α_1	(Fe)	6,40391	0,00578 (7) }
XK β_1	(Fe)	7,05804 }	0,00119 (2) K' β_1
XK β_5''	(Fe)	7,1083 }	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Fe})$	846,7638 (19)	98,85 (3)
$\gamma_{5,2}(\text{Fe})$	1037,8333 (24)	0,040 (4)
$\gamma_{2,1}(\text{Fe})$	1238,2736 (22)	0,097 (2)
$\gamma_{3,1}(\text{Fe})$	1810,726 (4)	26,9 (4)
$\gamma_{4,1}(\text{Fe})$	2113,092 (6)	14,2 (3)
$\gamma_{6,1}(\text{Fe})$	2523,06 (5)	1,02 (2)
$\gamma_{7,1}(\text{Fe})$	2598,438 (4)	0,020 (2)
$\gamma_{3,0}(\text{Fe})$	2657,56 (1)	0,645 (7)
$\gamma_{4,0}(\text{Fe})$	2959,92 (1)	0,307 (5)
$\gamma_{6,0}(\text{Fe})$	3369,84 (4)	0,17 (1)

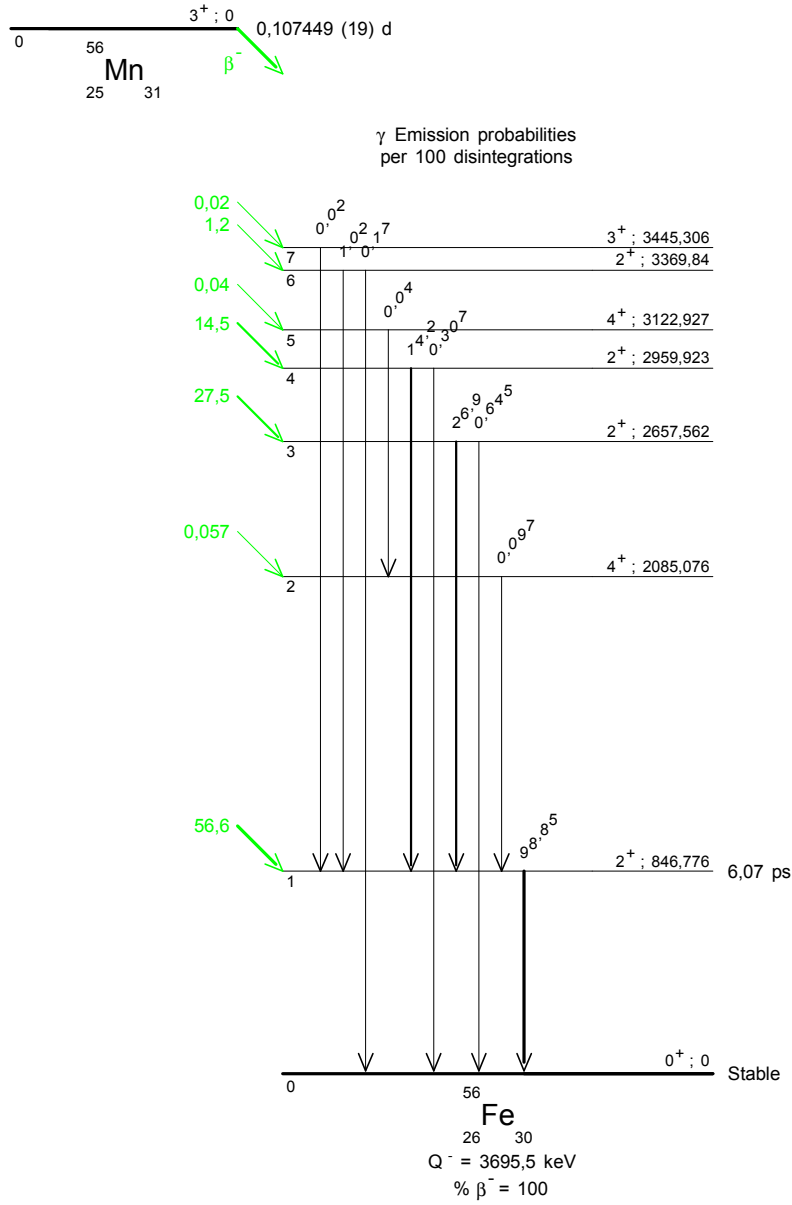
6 Main Production Modes

Cr – $56(\beta^-)\text{Mn} - 56$
Mn – $55(\text{n},\gamma)\text{Mn} - 56$
Mn – $55(\text{d},\text{p})\text{Mn} - 56$
Fe – $58(\text{d},\alpha)\text{Mn} - 56$

7 References

- R. L. AUBLE, W. C. MCHARRIS, W. H. KELLY. Nucl. Phys. A91 (1967) 225
(Gamma-ray emission probabilities)
- A. H. SHER, B. D. PATE. Nucl. Phys. A112 (1968) 85
(Half-life, Gamma-ray emission probabilities)
- I. W. GOODIER, M. J. WOODS, A. WILLIAMS. Proc. Int. Conf. Chemical Nucl. Data, Canterbury, Editor: M. L. Hurrell (1971) 175
(Half-life)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
(Half-life)
- F. LAGOUTINE, J. LEGRAND. Nucl. Instrum. Methods 112 (1973) 323
(Half-life)
- G. ARDISSON, C. MARSOL. Nucl. Phys. A212 (1973) 424
(Gamma-ray emission probabilities)
- S. HOFFMANN. Z. Phys. 270 (1974) 133
(Gamma-ray emission probabilities)
- K. G. TIRSELL, L. G. MULTHAUF, S. RAMAN. Phys. Rev. C10 (1974) 785
(Gamma-ray emission probabilities)
- I. M. BAND, M. B. TRZHASKOVSKAYA, M. A. LISTENGARTEN. At. Data Nucl. Data Tables 18 (1976) 433
(Internal conversion coefficients)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. Report AECL-6692 (1980)
(Half-life)
- S. P. COLLINS, S. A. EID, S. A. HAMADA, W. D. HAMILTON, F. HOYLER. J. Phys. G: Nucl. Part. Phys. 15 (1989) 321
(Multipolarity)
- M. S. ANTONY, D. OSTER, A. HACHEM. J. Radioanal. Nucl. Chem. Letts 164 (1992) 303
(Half-life)

- T. YASSINE, I. OTHMAN. Appl. Rad. Isotopes 45 (1994) 271
(Half-life)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q value)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(K x-ray, L x-ray, Auger electrons)
- B. SINGH, J. L. RODRIGUEZ, S. S. M. WONG, J. K. TULI. Nucl. Data Sheets 84 (1998) 487
(log ft)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 (1998)
(Auger electrons)
- HUO JUNDE. Nucl. Data Sheets 86 (1999) 315
(Nuclear structure, energies)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-1999-1 (1999)
(K x-ray)
- R.G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
(Gamma-ray energies)
- T.D. MACMAHON, A. PEARCE, P. HARRIS. Appl. Rad. Isotopes 60 (2004) 275
(Statistical analyses)
- M.J. WOODS. IAEA TECDOC (2004)
(Half-life evaluation)
- H. MIYAHARA, Y. OGATA, K. FUJIKI, K. KATOH, N. MARNADA. Appl. Rad. Isotopes 60 (2004) 295
(Gamma-ray emission probabilities)





1 Decay Scheme

Co-57 disintegrates by 100% electron capture to the excited levels of 706.42 keV (0.18%), and 136.47 keV (99.82%) in Fe-57.

Le cobalt 57 se désintègre à 100 % par capture électronique principalement vers les niveaux excités de 706 et 136 keV du fer 57.

2 Nuclear Data

$$T_{1/2}({}^{57}\text{Co}) : 271,80 \quad (5) \quad \text{d}$$

$$Q^+({}^{57}\text{Co}) : 836,0 \quad (4) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg ft	P_K	P_L	P_M
$\epsilon_{0,4}$	129,6 (4)	0,183 (7)	Allowed	7,69	0,8789 (17)	0,1035 (14)	0,0168 (6)
$\epsilon_{0,3}$	469,2 (4)	< 0,002	2nd forbidden	> 10,8			
$\epsilon_{0,2}$	699,5 (4)	99,82 (20)	Allowed	6,45	0,8875 (16)	0,0963 (13)	0,0154 (5)
$\epsilon_{0,1}$	821,6 (4)	< 0,003	2nd forbidden	> 11,1			
$\epsilon_{0,0}$	836,0 (4)	< 0,00035	2nd forbidden unique	> 12,9			

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M (10^{-3})	α_T
$\gamma_{1,0}(\text{Fe})$	14,41295 (31)	87,69 (7)	M1+0,0005%E2	7,69 (16)	0,782 (16)	113 (3)	8,58 (18)
$\gamma_{2,1}(\text{Fe})$	122,06079 (12)	87,53 (8)	M1+1,4%E2	0,0212 (5)	0,00208 (5)	0,303 (7)	0,0236 (5)
$\gamma_{2,0}(\text{Fe})$	136,47374 (29)	12,30 (18)	E2	0,133 (3)	0,0136 (3)	1,96 (4)	0,148 (3)
$\gamma_{3,2}(\text{Fe})$	230,27 (3)	0,0004 (4)	M1+0,04%E2	0,00374 (8)	0,000356 (8)	0,0524 (11)	0,00415 (9)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M (10^{-3})	α_T
$\gamma_{4,3}$ (Fe)	339,67 (3)	0,0039 (4)	M1+0,7%E2	0,00149 (3)	0,000142 (3)	0,0208 (5)	0,00165 (4)
$\gamma_{3,1}$ (Fe)	352,34 (2)	0,0032 (4)	M1+0,06%E2	0,00135 (3)	0,000129 (3)	0,0188 (4)	0,00150 (3)
$\gamma_{3,0}$ (Fe)	366,74 (3)	0,0013 (4)	M1+17%E2	0,00160 (5)	0,000153 (5)	0,0223 (7)	0,00178 (6)
$\gamma_{4,2}$ (Fe)	569,94 (4)	0,015 (2)	M1+0,94%E2	0,000458 (10)	0,0000434 (9)	0,00631 (14)	0,000508 (12)
$\gamma_{4,1}$ (Fe)	692,01 (2)	0,159 (6)	M1+17,8%E2	0,000328 (10)	0,000031 (1)	0,00452 (14)	0,000364 (12)
$\gamma_{4,0}$ (Fe)	706,42 (2)	0,0050 (5)	(E2)				

3 Atomic Data

3.1 Fe

ω_K	:	0,352	(4)
$\bar{\omega}_L$	:	0,0061	(5)
n_{KL}	:	1,456	(12)

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	6,39084	
	$K\alpha_1$	6,40384	
	$K\beta_3$	7,05798	}
	$K\beta_5''$	7,1081	
			21,4
X_L	$L\ell$	0,61	
	$L\beta$	- 0,79	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K	KLL	5,37 – 5,64
	KLX	6,16 – 6,40
	KXY	6,91 – 7,10
Auger L	0,6 – 0,7	302

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Fe)	0,6	- 0,7	252 (3)
e _{AK}	(Fe)			105,2 (13)
	KLL	5,37	- 5,64	}
	KLX	6,16	- 6,40	}
	KXY	6,91	- 7,10	}
ec _{1,0} K	(Fe)	7,3009	(3)	70,4 (20)
ec _{1,0} L	(Fe)	13,567	- 13,705	7,16 (20)
ec _{1,0} M	(Fe)	14,312	- 14,409	1,03 (3)
ec _{2,1} K	(Fe)	114,9486	(1)	1,81 (4)
ec _{2,1} L	(Fe)	121,215	- 121,353	0,178 (4)
ec _{2,1} M	(Fe)	121,968	- 122,057	0,0259 (6)
ec _{2,0} K	(Fe)	129,3616	(3)	1,42 (4)
ec _{2,0} L	(Fe)	135,628	- 135,766	0,146 (4)
ec _{2,0} M	(Fe)	136,381	- 136,470	0,0210 (5)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.
XL	(Fe)	0,61	— 0,79	1,55 (13)
XK α_2	(Fe)	6,39084		16,8 (3) } K α
XK α_1	(Fe)	6,40384		33,2 (5) }
XK β_3	(Fe)	7,05798	}	
XK β_1	(Fe)		}	7,1 (2) K' β_1
XK β_5''	(Fe)	7,1081	}	
XK β_4	(Fe)		}	K' β_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Fe)	14,41295 (31)	9,15 (17)
$\gamma_{2,1}$ (Fe)	122,06065 (12)	85,51 (6)
$\gamma_{2,0}$ (Fe)	136,47356 (29)	10,71 (15)

	Energy keV	Photons per 100 disint.
$\gamma_{3,2}(\text{Fe})$	230,27 (3)	0,0004 (4)
$\gamma_{4,3}(\text{Fe})$	339,67 (3)	0,0038 (4)
$\gamma_{3,1}(\text{Fe})$	352,34 (2)	0,0032 (4)
$\gamma_{3,0}(\text{Fe})$	366,74 (3)	0,0013 (4)
$\gamma_{4,2}(\text{Fe})$	569,94 (4)	0,015 (2)
$\gamma_{4,1}(\text{Fe})$	692,01 (2)	0,159 (6)
$\gamma_{4,0}(\text{Fe})$	706,42 (2)	0,0050 (5)

6 Main Production Modes

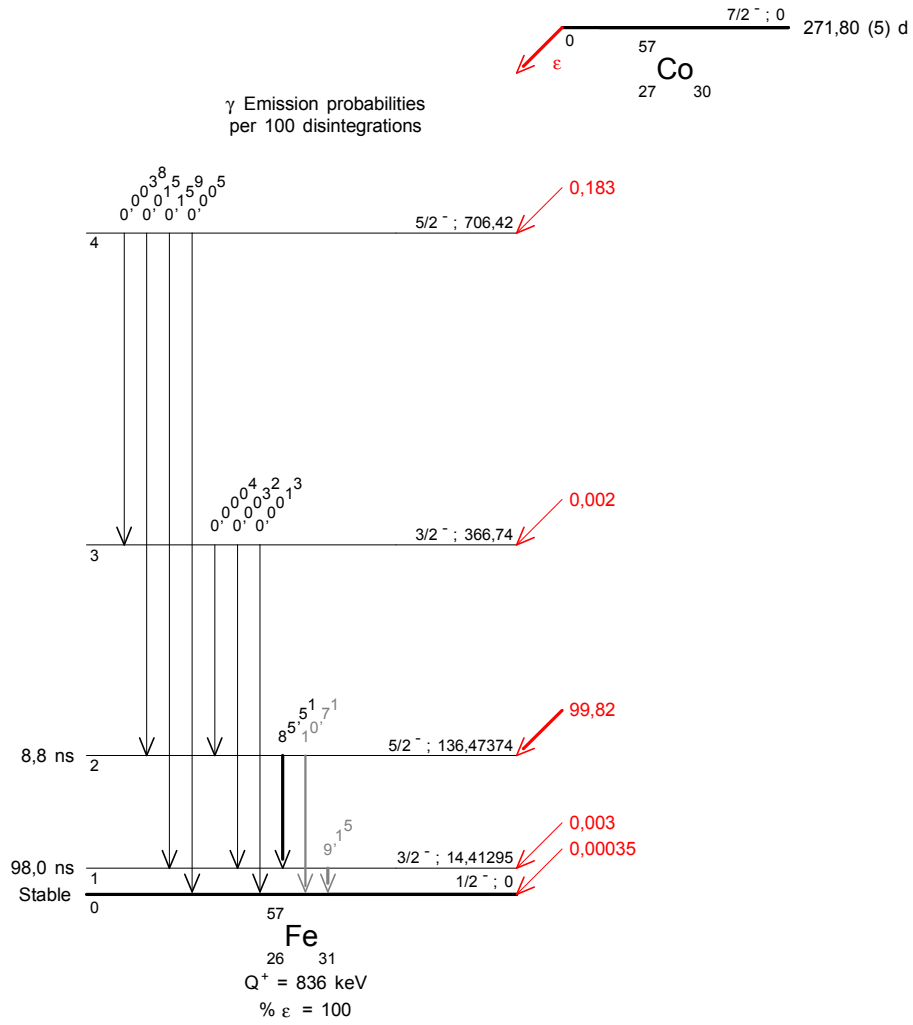
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Possible impurities : Co – 56, Co – 58
- { Ni – 58(p,2p)Co – 57
Possible impurities : Co – 56, Co – 58
- { Fe – 56(d,n)Co – 57
Possible impurities : Co – 56, Co – 58

7 References

- J. M. CORK, M. K. BRICE, L. C. SCHMID. Phys. Rev. 99 (1955) 703
(Relative conversion electron intensities)
- O. C. KISTNER, A. W. SUNYAR. Phys. Rev. 139 (1965) B295
(Experimental ICC, gamma ray energies and relative emission probabilities)
- J. M. MATHIESEN, J. P. HURLEY. Nucl. Phys. 72 (1965) 475
(Relative gamma ray emission probabilities)
- G. MOREAU, G. AMBROSINO. Comptes Rend. Ac. Sci. (Paris) 261 (1965) 5438
(Experimental ICC)
- S. C. ANSPACH, L. M. CAVALLO, S. B. GARFINKEL, J. M. R. HUTCHINSON, C. N. SMITH. Report NP- 15663 (1965)
(Half-life)
- E. H. SPEJEWSKI. Nucl. Phys. 82 (1966) 481
(Experimental ICC and gamma ray energies)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- D. C. HALL, R. G. ALBRIDGE. Nucl. Phys. A91 (1967) 495
(Experimental ICC)
- W. RUBINSON, K. P. GOPINATHAN. Phys. Rev. 170 (1968) 969
(Experimental ICC, PK and P XK values)
- H. E. BOSCH, M. A. FARIOLLI, N. MARTIN, M. C. SIMON. Nucl. Instrum. Methods 73 (1969) 323
(Experimental PK values)
- D. P. JOHNSON. Phys. Rev. B1 (1970) 3551
(Experimental ICC)
- R. C. GREENWOOD, R. G. HELMER, R. J. GEHRKE. Nucl. Instrum. Methods 77 (1970) 141
(Gamma ray energies)
- F. T. PORTER, M. S. FREEDMAN. Phys. Rev. C3 (1971) 2285
(Relative conversion electron intensities)

- J. KONIJN, E. W. A. LINGEMAN. Nucl. Instrum. Methods 94 (1971) 389
(Gamma ray energies and emission probabilities)
- R. A. FOX, W. D. HAMILTON, M. J. HOLMES. Phys. Rev. C5 (1972) 853
(Mixing ratios E2/M1 for gamma transitions)
- U. HEIM, O. W. B. SCHULT. Z. Naturforsch 27a (1972) 1861
(14,4 keV gamma ray energy)
- K. S. KRANE, W. A. STEYERT. Phys. Rev. C6 (1972) 2268
(Mixing ratios E2/M1 for gamma transitions)
- F. LAGOUTINE, J. LEGRAND, C. PERROT, J. P. BRETHON, J. MOREL. Int. J. Appl. Radiat. Isotop. 23 (1972) 219
(Half-life)
- A. MUKERJI, LEE CHIN. Proc. of the Intern. Conf. on Inner-Shell Ioniz. Phenom. and Future Appl. Apr.17-22, 1972 (1973)
(Experimental PK and P_K values)
- E. SCHOETERS, R. E. SILVERANS, L. VANNESTE. Z. Physik 260 (1973) 337
(Mixing ratios E2/M1 for gamma transitions)
- R. L. HEATH. Report ANCR-1000-2 (1974)
(Relative gamma ray emission probabilities)
- K. G. TIRSELL, L. G. MULTHAUF, S. RAMAN. Phys. Rev. C10 (1974) 785
(Gamma ray energies)
- E. J. COHEN, A. J. BECKER, N. K. CHEUNG, H. E. HENRIKSON. Hyperfine Interact. 1 (1975) 193
(Mixing ratios E2/M1 for gamma transitions)
- G. I. BORCHERT. Z. Naturforsch 31a (1976) 387
(Gamma ray energies)
- I. M. BAND, M. B. TRZHASKOVSKAYA, M. A. LISTENGARTEN. At. Data Nuc. Data Tables 18 (1976) 433
(Theoretical ICC)
- F. P. LARKINS. At. Data Nuc. Data Tables 20 (1977) 311
(Auger electron emission)
- C. VYLOV. Preprint JINR R6-10416, Dubna, 1977 (1978)
(Experimental P_K and P(g_{14,4 keV}) values)
- K. S. KRANE. At. Data Nuc. Data Tables 22 (1978) 269
(Mixing ratios E2/M1 for gamma transitions)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- U. SCHÖTZIG, K. DEBERTIN, K. F. WALZ. Nucl. Instrum. Methods 169 (1980) 43
(Relative gamma ray emission probabilities)
- R. VENNINK, J. KOPECKY, P. M. ENDT, P. W. M. GLAUDEMANS. Nucl. Phys. A344 (1980) 421
(Gamma ray energies)
- R. VANINBROUKX, G. GROSSE, W. ZEHNER. Int. J. Appl. Radiat. Isotop. 32 (1981) 589
(Half-life)
- A. GRUTTER. Int. J. Appl. Radiat. Isotop. 33 (1982) 533
(Relative gamma ray emission probabilities)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- H. H. HANSEN. European App. Res. Rept. Nucl. Sci. Technol. 6,4 (1985) 777
(Compilation of experimental ICC)
- K. DEBERTIN, U. SCHÖTZIG. informal IAEA CRP paper GS/55 (1989)
(quoted in IAEA-TecDoc-619 (1991), exp. KX and g_{1,0} (14,4 keV) abs. emis.prob.)
- A. L. NICHOLS. Nucl. Instrum. Methods A286 (1990) 467
(Half-life)
- K. SINGH, T. S. GILL, K. SINGH. Appl. Rad. Isotopes 41 (1990) 333
(Experimental PK values)
- U. SCHÖTZIG, H. SCHRADER, K. DEBERTIN. Proc. Int. Conf. Nucl. Data for Sci. and Techn., Julich, Germany (1992) 562
(Experimental P_g(14,4 keV) value)
- D. ARNOLD, G. ULM. Nucl. Instrum. Methods A339 (1994) 43
(Experimental K_a absolute emission probability)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q value)

- R. YA. METSKHVARISHVILI, Z. N. MIMINOSHVILI, M. A. ELIZBARASHVILI, L. V. NEKRASOVA, I. R. METSKHVARISHVILI, N. G. KHAZARADZE, N. M. MARCHILASHVILI, I. V. ZHORZHOLIANI. Phys. Atomic Nuclei 59 (1996) 737
(Relative conversion electron intensities and experimental ICC)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic data)
- M.-C. LÉPY, M.-M. BÉ, J. PLAGNARD. CAARI'96 Conference proceedings AIP Press (1997) 1067
(Experimental Kb/Ka.)
- R. H. MARTIN, K. I. W. BURNS, J. G. V. TAYLOR. Nucl. Instrum. Methods A390 (1997) 267
(Half-life)
- A. KOVALIK, M. RYSAVY, V. M. GOROZHANKIN, Ts. VYLOV, D. V. FILOSOFOV, M. A. MAHMOUD, A. MINKOVA, N. COURSOL, P. CASSETTE, CH. BRIANCON. Proc. 47th Ann. Conf. on Nucl. Spectr. Struct. At. Nuclei, Obninsk (1997) 277
(Relative low energy electron emission probabilities)
- M.- M. BÉ, M.-C. LÉPY, J. PLAGNARD, B. DUCHEMIN. Appl. Rad. Isotopes 49 (1998) 1367
(Experimental Kb/Ka)
- M. R. BHAT. Nucl. Data Sheets 85 (1998) 415
(Mixing ratios E2/M1 for gamma transitions)
- E. SCHÖNFELD. Appl. Rad. Isot. 49 (1998) 1353
(Fractional electron capture probabilities PK, PL, PM)
- R. G. HELMER, C.VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma ray energies)
- V. P. CHECHEV, A. G. EGOROV. Appl. Rad. Isotopes 52 (2000) 601
(Evaluation technique)





1 Decay Scheme

Ni-57 disintegrates by electron capture (56.6 %) and positron emission (43.4 %) to excited levels in Co-57. The transition to the ground state has not been observed.

Le nickel 57 se désintègre par capture électronique (56,6%) et émission de positrons (43,4%) vers des niveaux excités de cobalt 57. La transition vers le niveau fondamental n'a pas été observée.

2 Nuclear Data

$T_{1/2}({}^{57}\text{Ni})$	:	35,9	(3)	h
$T_{1/2}({}^{57}\text{Co})$	:	271,80	(5)	d
$Q^+({}^{57}\text{Ni})$	:	3264,2	(26)	keV

2.1 β^+ Transitions

	Energy keV	Probability $\times 100$	Nature
$\beta_{0,6}^+$	320,6 (3)	0,45 (3)	Allowed
$\beta_{0,4}^+$	482,6 (3)	0,85 (6)	Allowed
$\beta_{0,3}^+$	735,4 (3)	6,8 (3)	Allowed
$\beta_{0,2}^+$	862,6 (3)	35,3 (5)	Allowed

2.2 Electron Capture Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft	P_K	P_L	P_M
$\epsilon_{0,11}$	87 (3)	0,025 (5)	Allowed	6	0,8706 (19)	0,1103 (15)	0,0181 (6)
$\epsilon_{0,10}$	156 (3)	0,063 (4)	Allowed	6,1	0,8790 (17)	0,1033 (14)	0,0168 (5)
$\epsilon_{0,9}$	460 (3)	0,308 (23)	Allowed	6,4	0,8853 (16)	0,0980 (13)	0,0158 (5)
$\epsilon_{0,8}$	533 (3)	0,020 (3)	Allowed	7,7	0,8857 (16)	0,0977 (13)	0,0158 (5)

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	P_K	P_L	P_M
$\epsilon_{0,7}$	1131 (3)	0,039 (5)	Allowed	8,1	0,8871 (16)	0,0965 (13)	0,0156 (5)
$\epsilon_{0,6}$	1345 (3)	12,1 (6)	Allowed	5,7	0,8873 (16)	0,0964 (13)	0,0155 (5)
$\epsilon_{0,4}$	1507 (3)	5,2 (3)	Allowed	6,2	0,8874 (16)	0,0963 (13)	0,0155 (5)
$\epsilon_{0,3}$	1759 (3)	9,6 (4)	Allowed	6,1	0,8875 (16)	0,0962 (13)	0,0155 (5)
$\epsilon_{0,2}$	1887 (3)	29,3 (5)	Allowed	5,6	0,8876 (16)	0,0961 (13)	0,0155 (5)

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_T
$\gamma_{3,2}(\text{Co})$	127,164 (3)	16,4 (5)	M1+0,0064%E2	0,0193 (6)	0,00191 (6)	0,0215 (6)
$\gamma_{6,4}(\text{Co})$	161,86 (3)	0,0204 (24)	M1	0,0104 (3)	0,00102 (3)	0,0115 (3)
$\gamma_{10,9}(\text{Co})$	304,1 (1)	0,0020 (6)				
$\gamma_{4,2}(\text{Co})$	379,941 (20)	0,072 (6)	[M1]	0,00129 (4)	0,000124 (4)	0,00143 (4)
$\gamma_{6,2}(\text{Co})$	541,9 (1)	0,0036 (5)	[E2]	0,00105 (3)	0,000102 (3)	0,00116 (3)
$\gamma_{5,1}(\text{Co})$	673,44 (4)	0,0483 (15)	M1+0,04%E2	0,00036 (1)	0,000034 (1)	0,00040 (1)
$\gamma_{6,1}(\text{Co})$	696,0 (4)	0,0009 (6)	[E2]	0,00050 (2)	0,000048 (1)	0,00056 (2)
$\gamma_{7,2}(\text{Co})$	755,31 (10)	0,0054 (6)	M1+10,9%E2	0,000295 (9)	0,0000282 (8)	0,00033 (1)
$\gamma_{9,5}(\text{Co})$	906,99 (5)	0,075 (14)				
$\gamma_{9,4}(\text{Co})$	1046,55 (14)	0,132 (3)				
$\gamma_{1,0}(\text{Co})$	1223,8 (3)	0,076 (13)	M1+6,3%E2	0,000108 (3)	0,0000103 (3)	0,000120 (4)
$\gamma_{11,5}(\text{Co})$	1280,01 (6)	0,0096 (7)				
$\gamma_{10,4}(\text{Co})$	1350,54 (6)	0,002 (1)				
$\gamma_{2,0}(\text{Co})$	1377,64 (4)	81,2 (6)	E2	0,000095 (3)	0,0000091 (3)	0,000105 (3)
$\gamma_{10,3}(\text{Co})$	1603,30 (6)	0,0039 (6)				
$\gamma_{10,2}(\text{Co})$	1730,48 (6)	0,055 (3)				
$\gamma_{4,0}(\text{Co})$	1757,58 (3)	6,1 (4)	E2			
$\gamma_{5,0}(\text{Co})$	1897,0 (5)	0,0252 (25)	M1+0,16%E2			
$\gamma_{6,0}(\text{Co})$	1919,65 (14)	12,5 (5)	M1+5,0%E2			
$\gamma_{7,0}(\text{Co})$	2133,08 (5)	0,033 (5)	M1			
$\gamma_{8,0}(\text{Co})$	2730,83 (14)	0,020 (3)				
$\gamma_{9,0}(\text{Co})$	2804,15 (15)	0,102 (17)	E2			
$\gamma_{11,0}(\text{Co})$	3177,37 (5)	0,015 (4)				

3 Atomic Data

3.1 Co

ω_K	:	0,388	(4)
$\bar{\omega}_L$	:	0,0072	(5)
n_{KL}	:	1,418	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	K α_2	6,9153	51,16
	K α_1	6,93032	100
	K β_1	7,6495	}
	K β_5''	7,706	
			20,74
X _L	L ℓ	0,678	
	L γ	- 0,87	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	5,81 – 6,10	100
KLX	6,67 – 6,86	27,3
KXY	7,50 – 7,58	1,88
Auger L	0,564 – 0,653	319

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Co)	0,564 - 0,653	76,7 (12)
e _{AK}	(Co)		31,0 (6)
	KLL	5,81 - 6,10	}
	KLX	6,67 - 6,86	}
	KXY	7,50 - 7,58	}
ec _{3,2} K	(Co)	119,46 (3)	0,310 (14)
ec _{6,4} K	(Co)	154,15 (3)	0,00021 (3)
$\beta_{0,6}^+$	max:	320,6 (3)	0,45 (3)
$\beta_{0,6}^+$	avg:	138,6	
$\beta_{0,4}^+$	max:	482,6 (3)	0,85 (6)
$\beta_{0,4}^+$	avg:	206,1	
$\beta_{0,3}^+$	max:	735,4 (3)	6,8 (3)
$\beta_{0,3}^+$	avg:	313,4	
$\beta_{0,2}^+$	max:	862,6 (3)	35,3 (5)
$\beta_{0,2}^+$	avg:	368,3	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Co)	0,678 — 0,870	0,56 (4)
XK α_2	(Co)	6,9153	5,84 (12) } K α
XK α_1	(Co)	6,93032	11,42 (23) }
XK β_1	(Co)	7,6495	} 2,37 (6) K' β_1
XK β_5''	(Co)	7,706	}

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{3,2}(\text{Co})$	127,164 (3)	16,0 (5)
$\gamma_{6,4}(\text{Co})$	161,86 (3)	0,0202 (24)
$\gamma_{10,9}(\text{Co})$	304,1 (1)	0,0020 (6)
$\gamma_{4,2}(\text{Co})$	379,94 (2)	0,072 (6)
γ^{\pm}	511	86,8 (12)
$\gamma_{6,2}(\text{Co})$	541,9 (1)	0,0036 (5)
$\gamma_{5,1}(\text{Co})$	673,44 (4)	0,0483 (15)
$\gamma_{6,1}(\text{Co})$	696,0 (4)	0,0009 (6)
$\gamma_{7,2}(\text{Co})$	755,3 (1)	0,0054 (6)
$\gamma_{9,5}(\text{Co})$	906,98 (5)	0,075 (14)
$\gamma_{9,4}(\text{Co})$	1046,68 (14)	0,132 (3)
$\gamma_{1,0}(\text{Co})$	1223,8 (3)	0,076 (13)
$\gamma_{11,5}(\text{Co})$	1279,99 (6)	0,0096 (7)
$\gamma_{10,4}(\text{Co})$	1350,52 (6)	0,002 (1)
$\gamma_{2,0}(\text{Co})$	1377,62 (4)	81,2 (6)
$\gamma_{10,3}(\text{Co})$	1603,28 (6)	0,0039 (6)
$\gamma_{10,2}(\text{Co})$	1730,45 (6)	0,055 (3)
$\gamma_{4,0}(\text{Co})$	1757,55 (3)	6,1 (4)
$\gamma_{5,0}(\text{Co})$	1897,0 (5)	0,0252 (25)
$\gamma_{6,0}(\text{Co})$	1919,62 (14)	12,5 (5)
$\gamma_{7,0}(\text{Co})$	2133,04 (5)	0,033 (5)
$\gamma_{8,0}(\text{Co})$	2730,76 (14)	0,020 (3)
$\gamma_{9,0}(\text{Co})$	2804,08 (15)	0,102 (17)
$\gamma_{11,0}(\text{Co})$	3177,27 (5)	0,015 (4)

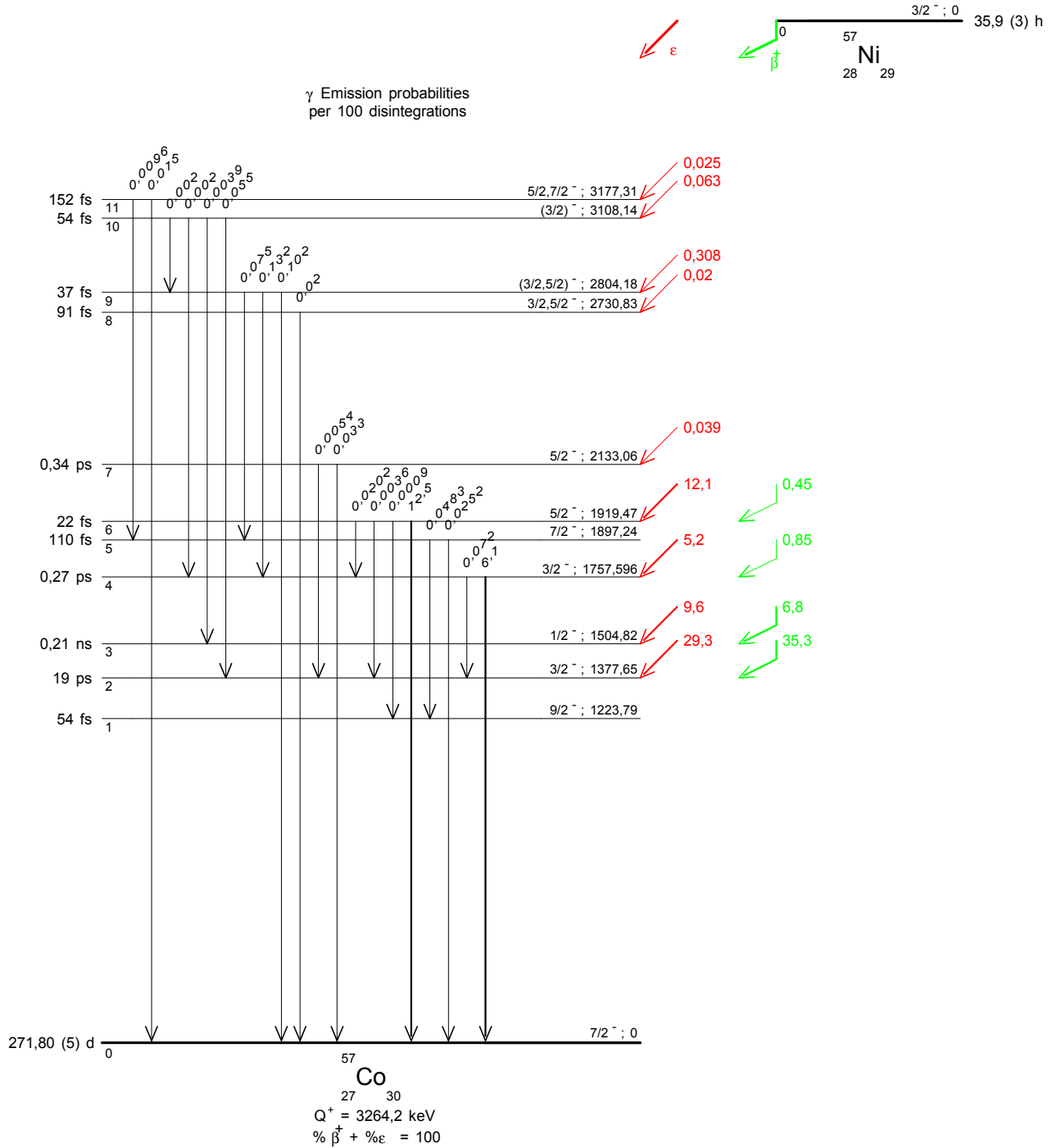
6 Main Production Modes

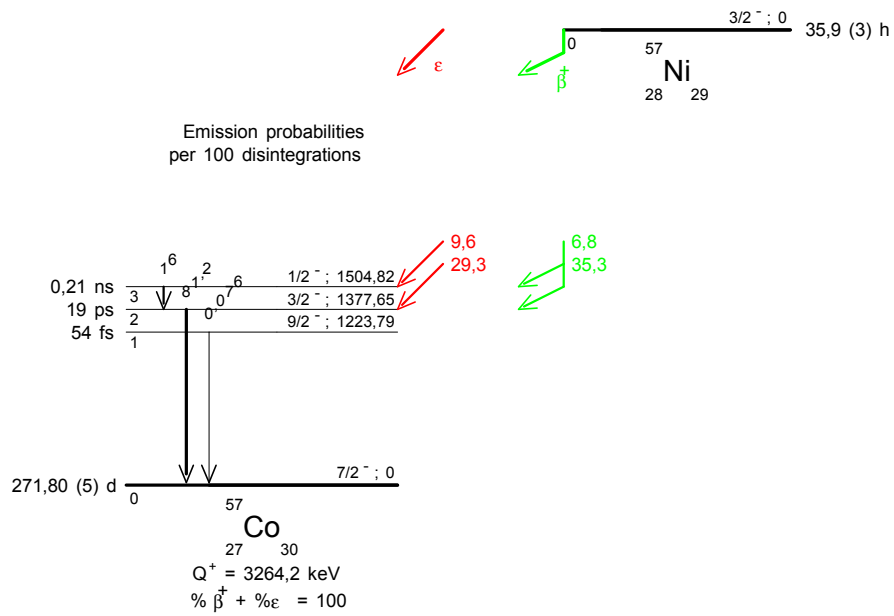
Ni – 58(γ, n)Ni – 57
 Ni – 58($n, 2n$)Ni – 57
 Ni – 58(d, dn)Ni – 57
 Fe – 56(p, γ)Ni – 57
 Fe – 56(d, n)Ni – 57
 Mn – 55($\alpha, 2n$)Ni – 57

7 References

- F. MAIENSCHIN, J.L. MEEM JR. Phys. Rev. 76 (1949) 899
(Half-life)
- G. FRIEDLANDER, M.L. PERLMAN, D. ALBURGER, A. W. SUNYAR. Phys. Rev. 80 (1950) 30
(Half-life)
- P.F. ZWEIFEL. Phys. Rev. 96 (1954) 1572
(Electron Capture/Beta plus ratio)
- G. RUDSTAM. Thesis, University of Uppsala (1956)
(Half-life)

- P.F. ZWEIFEL. Phys. Rev. 107 (1957) 329
(Electron Capture/Beta plus ratio)
- J. KONIJN, H. L. HAGEDOORN, B. VAN NOOIJEN. Physica 24 (1958) 129
(Electron Capture/Beta plus ratio)
- L.A. RAYBURN. Phys. Rev. 122 (1961) 168
(Half-life)
- G. CHILOSI, S. MONARO, R. A. RICCI. Nuovo Cim. 26 (1962) 440
(Electron Capture/Beta plus ratio)
- G. RUDSTAM. Nucl. Phys. 56 (1964) 593
(Half-life, Electron Capture/Beta plus ratio)
- T.G. EBREY, P.R. GRAY. Nucl. Phys. 61 (1965) 479
(Half-life)
- C.J. PILUSO, D.O. WELLS, D.K. MCDANIELS. Nucl. Phys. 77 (1966) 193
(Gamma ray energies)
- E.W.A. LINGEMAN, J. KONIJN, F. DIEDERIX, B. J. MEIJER. Nucl. Phys. A100 (1967) 136
(Gamma ray energies, Electron Capture/Beta plus ratio)
- C. GATROUSIS, R.A. MEYER, L.G. MANN, J.B. MCGRORY. Phys. Rev. 180 (1969) 1052
(Gamma ray energies)
- S.J. ROTHMAN, N.L. PETERSON, W.K. CHEN, J.J. HINES, R. BASTAR, L.C. ROBINSON, L.J. NOWICKI, J.B. ANDERSON. Phys. Rev. C9 (1974) 2272
(Half-life)
- I.M. BAND, M.B. TRZHASKOVSKAYA, M. A. LISTENGARTEN. At. Data. Nucl. Data Tables 18 (1976) 433
(ICC)
- W. BAMBYNEK, H. BEHRENS, M.H. CHEN, B. CRASEMANN, M.L. FITZPATRICK, K.W.D. LEDINGHAM, H. GENZ, M. MUTTERER, R.L. INTEMANN. Rev. Mod. Phys. 49 (1977) 77
(Electron Capture/Beta plus ratio)
- A. GRUTTER. Int. J. Appl. Radiat. Isotop. 33 (1982) 533
(Half-life)
- J.K. DICKENS. J. Radioanal. Nucl. Chem. 103 (1986) 273
(Half-life)
- A.M.S. SCARDINO, O. HELENE, P. R. PASCHOLATI, V. R. VANIN. Z. Physik A336 (1990) 313
(Gamma ray energies, Gamma-ray emission probabilities)
- M.R. BHAT. Nucl. Data Sheets 67 (1992) 195
(Gamma-ray emission probabilities)
- NNDC. The Program LOGFT (1993)
(lg ft)
- G.AUDI, A.H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(Atomic Data)
- H.JANSSEN, E.SCHÖNFELD. PTB (1997)
(EMISSION, a computer program to calculate X-ray and Auger electron emission probabilities.)
- E.SCHÖNFELD, F.CHU, E.BROWNE. PTB, LBNL (1997)
(EC-Capture, a computer program to calculate electron-capture probabilities for allowed and first-forbidden non-unique transitions)







1 Decay Scheme

Le fer 59 se désintègre par émission bêta moins principalement vers des niveaux excités de 1099 et 1291 keV de cobalt 59.

Fe-59 decays to the 1099 and 1291 keV excited levels of Co-59 mainly.

2 Nuclear Data

$$T_{1/2}({}^{59}\text{Fe}) : 44,495 \text{ (8) d}$$

$$Q^{-}({}^{59}\text{Fe}) : 1565,2 \text{ (6) keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,4}^{-}$	83,6 (6)	0,082 (4)	Allowed	6,9
$\beta_{0,3}^{-}$	130,9 (6)	1,25 (2)	Allowed	6,5
$\beta_{0,2}^{-}$	273,6 (6)	45,21 (25)	Allowed	5,9
$\beta_{0,1}^{-}$	465,9 (6)	53,33 (23)	Allowed	6,7
$\beta_{0,0}^{-}$	1565,2 (6)	0,25 (15)	2nd Forbidden	11

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{3,2}(\text{Co})$	142,652 (2)	0,988 (15)	M1+0,0064%E2	0,01433 (43)	0,001428 (43)	0,000199 (6)	0,0160 (1)
$\gamma_{2,1}(\text{Co})$	192,349 (5)	2,944 (29)	M1+4,22%E2	0,00807 (24)	0,000804 (24)	0,0001119 (34)	0,00899 (15)
$\gamma_{3,1}(\text{Co})$	335,00 (1)	0,265 (7)	M1+1,42%E2	0,00179 (5)	0,000175 (5)	0,0000244 (7)	0,00199 (6)
$\gamma_{4,1}(\text{Co})$	382,32 (20)	0,0215 (16)	M1+E2				
$\gamma_{1,0}(\text{Co})$	1099,262 (5)	56,60 (21)	E2	0,0001572 (47)	0,00001516 (45)	0,00000211 (6)	0,000175 (5)
$\gamma_{2,0}(\text{Co})$	1291,611 (6)	43,22 (25)	E2	0,00011 (3)	0,0000106 (30)	0,0000015 (5)	0,000122 (4)
$\gamma_{4,0}(\text{Co})$	1481,58 (20)	0,0603 (37)	M1+E2				

3 Atomic Data

3.1 Co

ω_K	:	0,388	(4)
$\bar{\omega}_L$	:	0,0072	(5)
n_{KL}	:	1,418	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	K α_2	6,9154	51,16
	K α_1	6,9304	100
	K β_1	7,6495	}
	K β_5''		
			21,11

4 Electron Emissions

	Energy keV	Electrons per 100 disint.
$\beta_{0,4}^-$	max: 83,6 (6)	0,082 (4)
$\beta_{0,4}^-$	avg: 22,0 (6)	
$\beta_{0,3}^-$	max: 130,9 (6)	1,25 (2)
$\beta_{0,3}^-$	avg: 35,8 (8)	
$\beta_{0,2}^-$	max: 273,6 (6)	45,21 (25)
$\beta_{0,2}^-$	avg: 81 (1)	
$\beta_{0,1}^-$	max: 465,9 (6)	53,33 (23)
$\beta_{0,1}^-$	avg: 149,5 (10)	
$\beta_{0,0}^-$	max: 1565,2 (6)	0,25 (15)
$\beta_{0,0}^-$	avg: 522 (2)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XK α_2	(Co)	6,9154	0,00596 (13)	} K α
XK α_1	(Co)	6,9304	0,01170 (28)	
XK β_1	(Co)	7,6495	} 0,00243 (7)	K' β_1

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{3,2}$ (Co)	142,651 (2)	0,972 (15)
$\gamma_{2,1}$ (Co)	192,349 (5)	2,918 (29)
$\gamma_{3,1}$ (Co)	334,8 (2)	0,264 (7)
$\gamma_{4,1}$ (Co)	382,0 (4)	0,0215 (16)
$\gamma_{1,0}$ (Co)	1099,245 (3)	56,59 (21)
$\gamma_{2,0}$ (Co)	1291,590 (6)	43,21 (25)
$\gamma_{4,0}$ (Co)	1481,7 (2)	0,0603 (37)

6 Main Production Modes

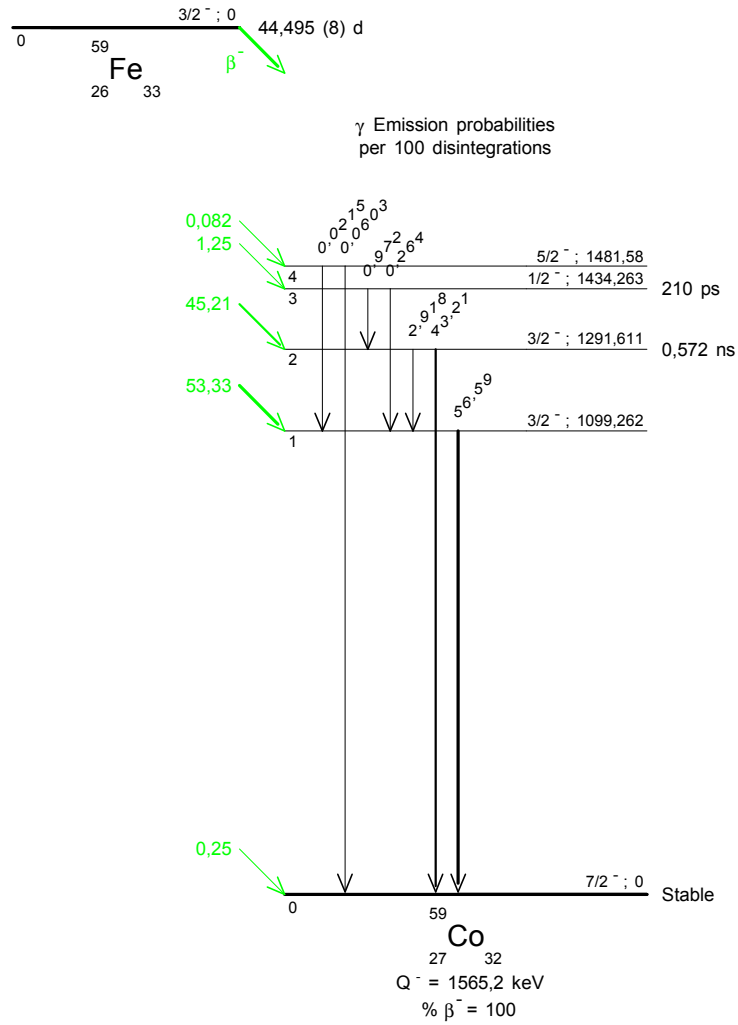
$$\left\{ \begin{array}{l} \text{Fe} - 58(n,\gamma)\text{Fe} - 59 \quad \sigma : 1,15 (2) \text{ barns} \\ \text{Possible impurities : Fe} - 55, \text{Cr} - 51 \end{array} \right.$$

$$\left\{ \begin{array}{l} \text{Co} - 59(n,p)\text{Fe} - 59 \\ \text{Possible impurities : Fe} - 55, \text{Co} - 60 \end{array} \right.$$

7 References

- F. R. METZGER. Phys. Rev. 88 (1952) 1360
(T ICC, Half-life)
- G. HINMAN, D. BROWER, R. LEAMER. Phys. Rev. 90 (1953) 370A
(T ICC)
- J. P. KEENE, L. A. MACKENZIE, C. W. GILBERT. Phys. in Med. Biol. 2 (1958) 360
(Half-life)
- J. M. FERGUSON. Nucl. Phys. 12 (1959) 579
(Gamma-ray emission probabilities)
- A. PIERROUX, G. GUÉBEN, J. GOVAERTS. Bull. Soc. Royale Sci. Liège 28, 7-8 (1959) 180
(Half-life)

- E. FUSCHINI *et al.* Nuovo Cim. XVI,5 (1960) 1910
(Half-life)
- R. L. HEATH, C. W. REICH, D. G. PROCTOR. Phys. Rev. 118,4 (1960) 1082
(Half-life)
- B. N. SUBBA RAO. Proceeding of the Indian Acad. of Sciences 3A (1960) 130
(Half-life)
- D. E. WORTMAN, L. M. LANGER. Phys. Rev. 131,1 (1963) 325
(Half-life)
- W. COLLIN *et al.* Z. Physik 180 (1964) 143
(Gamma-ray emission probabilities, mixing ratio)
- Y. K. AGARWAL, C. V. K. BABA, S. K. BHATTACHERJEE. Nucl. Phys. A99 (1967) 457
(1291 keV level half-life)
- R. BÉRAUD *et al.* Comp. Rend. Acad. Sci. (Paris) 265-B (1967) 1354
(Gamma-ray emission probabilities)
- N. P. S. SIDHU, U. C. GUPTA. Nucl. Phys. A91 (1967) 557
(1291 keV level half-life)
- J. LEGRAND, J. MOREL, C. CLEMENT. Nucl. Phys. A142 (1970) 63
(Gamma-ray emission probabilities)
- I. ARENS, H. J. KORNER. Z. Phys. 242 (1971) 138
(Mixing Ratio, Half-life)
- M. I. GREEN, P. F. KENEALY, G. B. BEARD. Nucl. Instrum. Methods 99 (1972) 445
(1291 keV level half-life)
- R. K. GARG *et al.* Z. Physik 257 (1972) 124
(1291 keV level half-life)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT. Nucl. Sci. Eng. 48 (1972) 319
(Half-life)
- S. C. PANCHOLI, J. J. PINAJIAN, N. R. JOHNSON, A. KUMAR, S. K. SONI, M. M. BAJAJ, S. L. GUPTA, N. L. SAHA. Phys. Rev. C8 (1973) 2277
(Gamma-ray emission probabilities, Spin and Parity, Mixing Ratio)
- C. J. VISSER *et al.* Agrochimica 5 (1973) 15
(Half-life)
- L. ERIKSSON, L. GIDEFELDT. Physica Scripta 7 (1973) 169
(Mixing ratio)
- A. MUKERJI, D. PALAZZO, J. D. ULLMAN. Phys. Rev. C10,2 (1974) 949
(Gamma-ray emission probabilities)
- M. M. BAJAJ, A. KUMAR, S. K. SONI, S. C. PANCHOLI, S. L. GUPTA, N. K. SAHA. Proceeding of the nuclear physics and solid state physics symposium 14B,2 (1974) 375
(Mixing ratio)
- S. RAMAN *et al.* Phys. Rev. C9,6 (1974) 2463
(Beta emission probabilities and energies)
- J. ALSTAD, I. R. HALDORSEN, A. C. PAPPAS, M. SKARESTAD. J. Inorg. Nucl. Chem. 37 (1975) 873
(Half-life)
- K. S. KRANE, S. S. ROSEMBLUM, W. A. STEYERT. Phys. Rev. C 14,2 (1976) 653
(1291 keV Mixing ratio)
- K. S. KRANE. At. Data Nucl. Data Tables 19 (1977) 363
(142 keV Mixing ratio)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- K. F. WALZ, H. M. WEISS, K. DEBERTIN. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- H. MIYAHARA *et al.* Appl. Rad. Isotopes 40,4 (1989) 343
(Gamma-ray emission probabilities)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- R. H. MARTIN, K. I. W. BURNS, J. G. V. TAYLOR. Nucl. Instrum. Methods A390 (1997) 267
(Half-life)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma ray energies)





1 Decay Scheme

Cu-64 disintegrates by beta minus emission to the Zn-64 ground state (39%) and by electron capture to the excited level and the ground state of Ni-64.

Le Cu-64 se désintègre par émission bêta moins (39%) vers le niveau fondamental de Zn-64 et par capture électronique vers le niveau excité et le fondamental de Ni-64.

2 Nuclear Data

$T_{1/2}({}^{64}\text{Cu})$	:	12,701	(2)	h
$Q^{-}({}^{64}\text{Cu})$	:	578,7	(9)	keV
$Q^{+}({}^{64}\text{Cu})$	:	1675,1	(2)	keV

2.1 β^{-} Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,0}^{-}$	578,7 (9)	39,0 (3)	allowed	5,29

2.2 β^{+} Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,0}^{+}$	653,1 (2)	17,86 (14)	Allowed	4,97

2.3 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	<i>P_K</i>	<i>P_L</i>	<i>P_M</i>
ε _{0,1}	329,33 (26)	0,475 (10)	Allowed	5,51	0,884 (3)	0,099 (2)	0,0162 (5)
ε _{0,0}	1675,1 (2)	42,6 (5)	Allowed	4,97	0,888 (3)	0,095 (2)	0,0155 (5)

2.4 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	<i>P_{γ+ce}</i> × 100	Multipolarity	<i>α_K</i> (10 ⁻⁴)	<i>α_L</i> (10 ⁻⁴)	<i>α_T</i> (10 ⁻⁴)	<i>α_π</i> (10 ⁻⁵)
γ _{1,0} (Ni)	1345,79 (16)	0,475 (10)	E2	1,12 (3)	0,108 (3)	1,26 (4)	3,4

3 Atomic Data

3.1 Ni

<i>ω_K</i>	:	0,421	(4)
<i>ω_L</i>	:	0,0084	(4)
<i>n_{KL}</i>	:	1,388	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	Kα ₂	7,46093	
	Kα ₁	7,47819	
	Kβ ₃	8,2647	}
	Kβ ₅ ''	8,3287	
			13,78
X _L	Lℓ	0,74	
	Lγ	- 0,94	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	6,262 – 6,567	100
KLX	7,196 – 7,475	27,6
KXY	8,109 – 8,326	1,9
Auger L	0,6 – 0,9	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Ni)	0,6 - 0,9	52,7 (6)
e _{AK}	(Ni)		22,1 (3)
	KLL	6,262 - 6,567	}
	KLX	7,196 - 7,475	}
	KXY	8,109 - 8,326	}
ec _{1,0 K}	(Ni)	1337,46 (16)	0,0000532 (18)
β _{0,0} ⁺	max:	653,1 (2)	17,86 (14)
β _{0,0} ⁺	avg:	278,21 (9)	
β _{0,0} ⁻	max:	578,7 (9)	39,0 (3)
β _{0,0} ⁻	avg:	190,4 (4)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Ni)	0,74 — 0,94	0,448 (9)
XKα ₂	(Ni)	7,46093	4,79 (8) } Kα
XKα ₁	(Ni)	7,47819	9,36 (15) }
XKβ ₃	(Ni)	8,2647	}
XKβ ₁	(Ni)		} 1,95 (4) K'β ₁
XKβ ₅ ^{''}	(Ni)	8,3287	}

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
γ^\pm	511	35,36 (28)
$\gamma_{1,0}(\text{Ni})$	1345,77 (16)	0,475 (10)

6 Main Production Modes

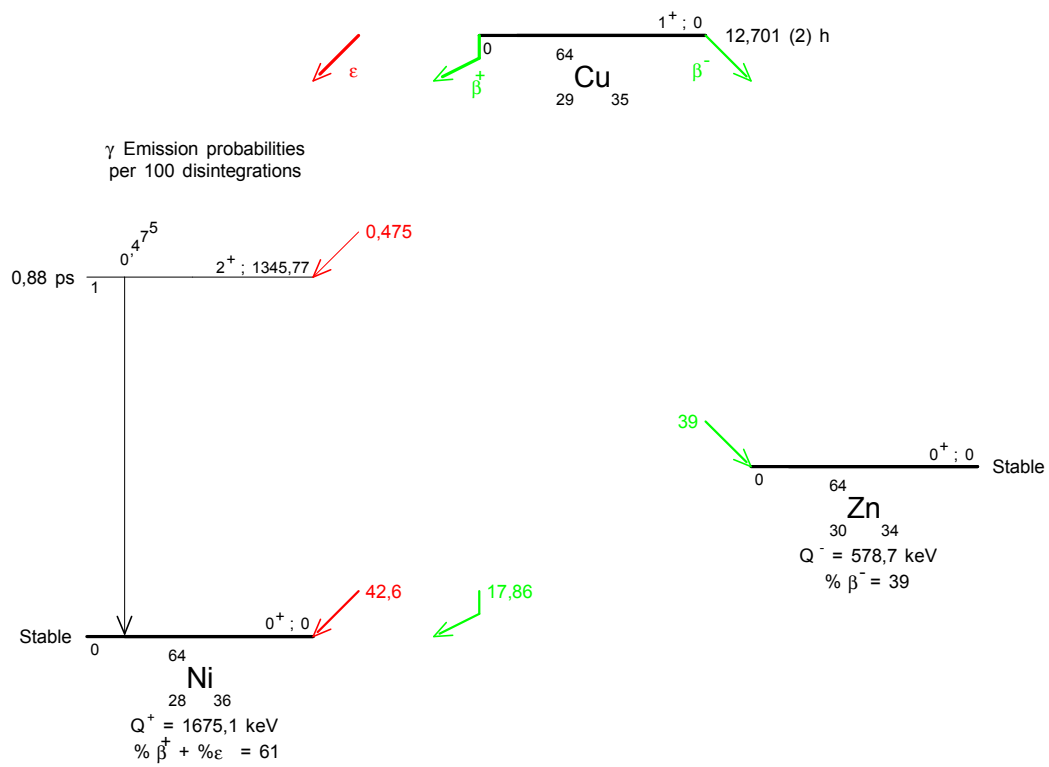
- { Cu – 63(n, γ)Cu – 64 σ : 4,50 (2) barns
Possible impurities : Cu – 67
- { Cu – 65(n,2n)Cu – 64
Possible impurities : Ni – 65
- { Zn – 64(n,p)Cu – 64
Possible impurities : Cu – 67, Zn – 63, Ni – 65
- { Zn – 64(d,2p)Cu – 64
Possible impurities : Cu – 67

7 References

- E. AMALDI, O. D'AGOSTINO, E. FERMI, B. PONTECORVO, F. RASETTI, E. SEGRE. Proc. Roy. Soc.(London) 149A (1935) 522
(Half-life.)
- S. N. VAN VOORHIS. Phys. Rev. 50 (1936) 895
(Half-life.)
- F. A. HEYN. Physica 4 (1937) 1224
(Half-life.)
- N. RIDENOUR. Phys. Rev. 53 (1938) 770
(Half-life.)
- R. SAGANE. Phys. Rev. 55 (1939) 31
(Half-life.)
- O. HUBER, O. LIENHARD, H. WAFFLER. Helv. Phys. Acta 16 (1943) 226
(Half-life.)
- O. HUBER, O. LIENHARD, H. WAFFLER. Helv. Phys. Acta 17 (1944) 195
(Half-life.)
- D. R. MILLER, R. C. THOMPSON, B. B. CUNNINGHAM. Phys. Rev. 74 (1948) 347
(Half-life.)
- H. H. HOPKINS. Phys. Rev. 77 (1950) 717
(Half-life.)
- E. RABINOWICZ. Proc. Phys. Soc. (London) 63A (1950) 1040
(Half-life.)
- R. P. SCHUMAN, A. CAMILLI. Phys. Rev. 84 (1951) 158
(Half-life.)
- M. SILVER. Can. J. Phys. 29 (1951) 59
(Half-life.)
- J. TOBAILEM. J. Phys. Radium 16 (1955) 48
(Half-life.)

- H. W. WRIGHT, E. I. WYATT, S. A. REYNOLDS, W. S. LYON, T. H. HANDLEY. Nuclear Sci. and Eng. 2 (1957) 427
(Half-life.)
- A. POULARIKAS, R. W. FINK. Phys. Rev. 115 (1959) 989
(Half-life.)
- HE-SUNG, N. S. MALTSEVA, V. N. MEKHEDOV, V. N. RYBAKOV. Soviet J. Nucl. Phys. 1 (1965) 132
(Half-life.)
- V. A. PAULSEN, H. LISKIEN. Nukleonik 7 (1965) 117
(Half-life.)
- K. FUJIWARA, O. SUEKA. J. Phys. Soc. Japan 21 (1966) 1947
(Half-life.)
- H. LISKIEN, A. PAULSEN. Proc. Intern. Conf. Radiat. Meas. Nucl. Power, Berkeley, Engl., D. J. Littler, Ch., Editorial Panel, Inst. Ph 2 (1966) 352
(Half-life.)
- G. P. VINITSKAYA, V. N. LEVKOVSKY, V. V. SOKOLSKY, I. V. KAZACHEVSKY. Sov. J. Nucl. Phys. 5 (1967) 839
(Half-life.)
- F. HEINRICH, G. PHILIPPIN. Helv. Phys. Acta 41 (1968) 431
(Half-life.)
- P. KEMÉNY. Rev. Roumaine Phys. 13 (1968) 901
(Half-life.)
- M. BORMANN, B. LAMMERS. Nucl. Phys. A130 (1969) 195
(Half-life.)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
(Half-life.)
- E. I. WYATT. Report ORNL-4749 (1972) 61
(Half-life.)
- AURIC, J. I. VARGAS. Chem. Phys. Lett. 15 (1972) 366
(Half-life.)
- D. F. CRISLER, H. B. ELDRIDGE, R. KUNSELMAN, C. S. ZAIDINS. Phys. Rev. C5 (1972) 419
(Half-life.)
- J. S. MERRITT, J. G. V. TAYLOR. Report AECL-4257 (1972) 25
(Half-life.)
- J. ARAMINOWICZ, J. DRESLER. Report INR-1464 (1973) 14
(Half-life.)
- I. DEMA, G. HARBOTTLE. Radiochem. Radioanal. Lett. 15 (1973) 261
(Half-life.)
- G. HARBOTTLE, C. KOEHLER, R. WITHNELL. Rev. Sci. Instr. 44 (1973) 55
(Half-life.)
- D. A. NEWTON, S. SARKAR, L. YAFFE, R. B. MOORE. J. Inorg. Nucl. Chem. 35 (1973) 361
(Half-life.)
- B. JENSCHKE. German Phys. Soc., Spring Conf. (1974)
(Half-life.)
- R. L. HEATH. Report ANCR-1000-2 (1974)
(Gamma ray energies.)
- T. B. RYVES, K. J. ZIEBA. J. Phys. (London) A7 (1974) 2318
(Half-life.)
- J. A. JOHNSON, I. DEMA, G. HARBOTTLE. Radiochim. Acta 21 (1974) 196
(Half-life.)
- I. M. BAND, M. B. TRZHASKOVSKAYA, M. A. LISTENGARTEN. At. Data. Nucl. Data Tables 18 (1976) 433
(ICC.)
- H. -P. HAHN, H. -J. BORN, J. I. KIM. Radiochim. Acta 23 (1976) 23
(Half-life.)
- P. SCHLUTER, G. SOFF. At. Data Nucl. Data Tables 24 (1979) 509
(IPFC.)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. Report AECL-6692 (1980)
(Half-life.)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. Report NBS-SP-626 (1982) 5
(Half-life.)
- P. CHRISTMAS, S. M. JUDGE, T. B. RYVES, D. SMITH, G. WINKLER. Nucl. Instr. Meth. 215 (1983) 397
(Beta emission probabilities, Gamma-ray emission probabilities, Elec. Capt. Probabilities.)

- KAWADA. Intern. J. Appl. Radiat. Isot. 37 (1986) 7
(Beta emission probabilities, Gamma-ray emission probabilities, Elec. Capt. Probabilities.)
- AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q.)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instr. Meth. A369 (1996) 527
(Fluorescence yields.)
- B. SINGH. Nucl. Data Sheets 78 (1996) 395
(Multipolarities, Spin and Parity.)
- G. WERMANN, D. ALBER, W. PRITZKOW, G. RIEBE, J. VOGL, W. GÖRNER. Appl. Rad. Isotopes 56, 1-2 (2002) 145
(Beta branching ratio.)





1 Decay Scheme

Ga-66 disintegrates 56 (4)% by beta plus and 44 (4)% by electron capture to Zn-66. Ga-66 emits gamma-rays up to 4800 keV and their emission probabilities are useful for the efficiency calibration of Ge detectors. *Le gallium 66 se désintègre vers le zinc 66, par émission bêta plus (56 (4)%) et capture électronique (44 (4)%). Les émissions gamma du gallium 66 (jusqu' à 4800 keV) sont utiles pour l'étalonnage de détecteurs au germanium.*

2 Nuclear Data

$$T_{1/2}({}^{66}\text{Ga}) : 9,49 \quad (7) \quad \text{h}$$

$$Q^+({}^{66}\text{Ga}) : 5175 \quad (3) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	<i>P_K</i>	<i>P_L</i>	<i>P_M</i>
ε _{0,32}	169 (3)	0,00122 (15)		7,47	0,8742 (16)	0,1067 (13)	0,0178 (5)
ε _{0,31}	217 (3)	0,0020 (5)		7,48	0,8768 (16)	0,1046 (13)	0,0174 (5)
ε _{0,30}	309 (3)	0,047 (6)		6,42	0,8794 (15)	0,1024 (13)	0,0170 (5)
ε _{0,29}	325 (3)	0,033 (4)		6,62	0,8797 (15)	0,1021 (13)	0,0170 (5)
ε _{0,28}	369 (3)	2,27 (19)	Allowed	4,9	0,8804 (15)	0,1016 (13)	0,0169 (4)
ε _{0,27}	499 (3)	0,0015 (5)		8,35	0,8817 (15)	0,1005 (12)	0,0166 (4)
ε _{0,26}	537 (3)	0,0042 (10)		7,96	0,8820 (15)	0,1003 (12)	0,0166 (4)
ε _{0,25}	714 (3)	1,96 (17)	Allowed	5,54	0,8828 (15)	0,0996 (12)	0,0165 (4)
ε _{0,24}	880 (3)	6,2 (5)	Allowed	5,23	0,8833 (15)	0,0992 (12)	0,0164 (4)
ε _{0,23}	1089 (3)	1,67 (14)		5,99	0,8837 (15)	0,0988 (12)	0,0163 (4)
ε _{0,22}	1293 (3)	0,0014 (9)		9,2	0,8840 (15)	0,0986 (12)	0,0163 (4)
ε _{0,21}	1350 (3)	0,0030 (6)		8,92	0,8840 (15)	0,0986 (12)	0,0163 (4)
ε _{0,20}	1384 (3)	26,0 (21)	Allowed	5	0,8841 (15)	0,0985 (12)	0,0163 (4)
ε _{0,18}	1437 (3)	0,015 (6)		8,27	0,8841 (15)	0,0985 (12)	0,0163 (4)
ε _{0,13}	1743 (3)	0,39 (4)	1st forbidden	7,03	0,8843 (15)	0,0983 (12)	0,0162 (4)
ε _{0,12}	1748 (3)	0,0047 (11)	1st forbidden	8,95	0,8843 (15)	0,0983 (12)	0,0162 (4)
ε _{0,11}	1794 (3)	1,31 (11)	1st forbidden	6,53	0,8843 (15)	0,0983 (12)	0,0162 (4)
ε _{0,9}	1946 (3)	3,7 (3)	Allowed	6,14	0,8844 (15)	0,0982 (12)	0,0162 (4)

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	<i>P_K</i>	<i>P_L</i>	<i>P_M</i>
ε _{0,5}	2348 (3)	0,0017 (3)		9,66	0,8846 (15)	0,0981 (12)	0,0162 (4)
ε _{0,3}	2803 (3)	0,038 (3)	Allowed	8,46	0,8847 (15)	0,0980 (12)	0,0162 (4)
ε _{0,0}	5175 (3)	0,47 (4)	Allowed	7,88	0,8850 (15)	0,0978 (12)	0,0161 (4)

2.2 β⁺ Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
β _{0,20} ⁺	362 (3)	0,94 (8)	Allowed	5
β _{0,18} ⁺	415 (3)	0,0009 (3)		8,3
β _{0,13} ⁺	721 (3)	0,16 (2)	1st forbidden	7,03
β _{0,12} ⁺	726 (3)	0,0020 (5)	1st forbidden	8,9
β _{0,11} ⁺	772 (3)	0,70 (6)	1st forbidden	6,53
β _{0,9} ⁺	924 (3)	3,7 (3)	Allowed	6,14
β _{0,5} ⁺	1326 (3)	0,0053 (8)	1st forbidden	9,7
β _{0,3} ⁺	1781 (3)	0,30 (3)	Allowed	8,46
β _{0,0} ⁺	4153 (3)	50 (4)	Allowed	7,88

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	<i>P_{γ+ce}</i> × 100	Multipolarity
γ _(-1,1) (Zn)			
γ _{20,14} (Zn)	283,87 (3)	0,0036 (8)	
γ _{9,6} (Zn)	290,812 (6)	0,049 (4)	
γ _{23,18} (Zn)	347,775 (25)	0,0018 (6)	
γ _{25,23} (Zn)	375,388 (9)	0,0021 (6)	
γ _{20,11} (Zn)	410,179 (7)	0,065 (6)	
γ _{24,22} (Zn)	412,915 (14)	0,0034 (6)	
γ _{11,6} (Zn)	442,870 (7)	0,01554 (16)	
γ _{9,4} (Zn)	448,728 (10)	0,107 (9)	M1+E2
γ _{20,10} (Zn)	459,681 (9)	0,088 (8)	
γ _{13,6} (Zn)	494,334 (7)	0,0056 (9)	
γ _{3,2} (Zn)	499,590 (6)	0,0048 (12)	E2+M3
γ _{10,4} (Zn)	551,284 (13)	0,0070 (8)	
γ _{23,15} (Zn)	554,291 (18)	0,0045 (6)	
γ _{24,18} (Zn)	557,13 (5)	0,0061 (8)	M1+E2
γ _{20,9} (Zn)	562,237 (6)	0,0066 (8)	
γ _{20,8} (Zn)	578,541 (11)	0,059 (6)	
γ _{11,4} (Zn)	600,786 (11)	0,0135 (14)	
γ _{23,13} (Zn)	653,576 (8)	0,0013 (5)	
γ _{23,12} (Zn)	658,578 (22)	0,0075 (10)	

	Energy keV	P _{γ+ce} × 100	Multipolarity
γ _{25,20} (Zn)	670,249 (8)	0,0041 (7)	
γ _{14,5} (Zn)	680,56 (10)	0,0015 (4)	
γ _{20,7} (Zn)	686,083 (7)	0,252 (22)	
γ _{23,11} (Zn)	705,040 (8)	0,0038 (5)	
γ _{25,19} (Zn)	708,36 (5)	0,0087 (10)	
γ _{24,16} (Zn)	718,97 (5)	0,0099 (10)	
γ _{25,18} (Zn)	723,163 (26)	0,0034 (6)	
γ _{16,5} (Zn)	749,68 (7)	0,0014 (4)	
γ _{24,15} (Zn)	763,646 (15)	0,0089 (10)	
γ _{16,4} (Zn)	796,212 (29)	0,0029 (7)	
γ _{18,6} (Zn)	800,135 (24)	0,0010 (5)	
γ _{2,1} (Zn)	833,5365 (45)	5,9 (5)	M1+E2
γ _{20,6} (Zn)	853,049 (6)	0,076 (6)	M1+E2
γ _{9,3} (Zn)	856,532 (7)	0,111 (11)	
γ _{23,9} (Zn)	857,098 (7)	0,015 (5)	
γ _{24,13} (Zn)	862,931 (8)	0,0152 (14)	
γ _{24,12} (Zn)	867,933 (22)	0,0043 (6)	
γ _{23,8} (Zn)	873,402 (12)	0,0170 (18)	
γ _{25,16} (Zn)	885,002 (27)	0,0019 (5)	
γ _{4,2} (Zn)	907,393 (9)	0,0218 (23)	M1+E2
γ _{24,11} (Zn)	914,395 (8)	0,027 (3)	
γ _{25,15} (Zn)	929,679 (19)	0,0046 (7)	
γ _{5,2} (Zn)	953,93 (9)	0,00100 (13)	
γ _{25,14} (Zn)	954,123 (28)	0,0045 (7)	
γ _{24,10} (Zn)	963,897 (10)	0,0144 (16)	
γ _{23,7} (Zn)	980,944 (8)	0,048 (19)	
γ _{11,3} (Zn)	1008,590 (8)	0,059 (9)	
γ _{20,4} (Zn)	1010,965 (10)	0,027 (3)	
γ _{28,20} (Zn)	1015,076 (8)	0,012 (3)	
γ _{1,0} (Zn)	1039,2268 (20)	37 (3)	E2
γ _{13,3} (Zn)	1060,054 (8)	0,0155 (17)	
γ _{6,2} (Zn)	1065,309 (5)	0,0023 (5)	
γ _{24,9} (Zn)	1066,453 (7)	0,0024 (5)	
γ _{24,8} (Zn)	1082,757 (12)	0,0133 (13)	
γ _{26,15} (Zn)	1106,53 (24)	0,0012 (4)	
γ _{25,10} (Zn)	1129,930 (11)	0,0136 (13)	
γ _{28,17} (Zn)	1135,48 (6)	0,0047 (6)	
γ _{23,6} (Zn)	1147,910 (7)	0,078 (9)	M1+E2
γ _{24,7} (Zn)	1190,299 (8)	0,128 (13)	
γ _{30,17} (Zn)	1195,33 (9)	0,0009 (3)	
γ _{7,2} (Zn)	1232,275 (6)	0,50 (4)	
γ _{25,9} (Zn)	1232,486 (8)	0,056 (19)	
γ _{25,8} (Zn)	1248,790 (13)	0,0010 (3)	
γ _{28,15} (Zn)	1274,506 (19)	0,0070 (8)	
γ _{28,14} (Zn)	1298,950 (28)	0,0038 (5)	
γ _{23,4} (Zn)	1305,826 (11)	0,0040 (5)	
γ _{3,1} (Zn)	1333,125 (6)	1,17 (9)	E2
γ _{9,2} (Zn)	1356,121 (5)	0,36 (5)	
γ _{25,7} (Zn)	1356,332 (9)	0,122 (21)	
γ _{24,6} (Zn)	1357,265 (7)	0,16 (5)	M1+E2
γ _{26,9} (Zn)	1409,36 (14)	0,0016 (7)	
γ _{20,3} (Zn)	1418,769 (7)	0,61 (5)	
γ _{28,11} (Zn)	1425,255 (9)	0,0060 (7)	
γ _{30,13} (Zn)	1433,648 (20)	0,0018 (4)	
γ _{10,2} (Zn)	1458,680 (8)	0,096 (23)	M1+E2
γ _{29,11} (Zn)	1468,99 (3)	0,0014 (4)	
γ _{11,2} (Zn)	1508,179 (6)	0,55 (4)	
γ _{24,4} (Zn)	1515,181 (11)	0,0062 (7)	
γ _{25,6} (Zn)	1523,298 (8)	0,0055 (7)	

	Energy keV	P _{γ+ce} × 100	Multipolarity
γ _{30,10} (Zn)	1534,614 (22)	0,0057 (16)	
γ _{12,2} (Zn)	1554,64 (2)	0,0183 (18)	
γ _{13,2} (Zn)	1559,643 (6)	0,0219 (23)	
γ _{28,9} (Zn)	1577,313 (8)	0,0040 (7)	
γ _{14,2} (Zn)	1634,48 (3)	0,0035 (6)	
γ _{16,2} (Zn)	1703,61 (2)	0,0054 (19)	
γ _{23,3} (Zn)	1713,630 (8)	0,0243 (23)	
γ _{4,1} (Zn)	1740,930 (9)	0,029 (4)	M1+E2
γ _{5,1} (Zn)	1787,46 (5)	0,0089 (10)	(E1)
γ _{17,2} (Zn)	1797,96 (5)	0,0019 (5)	
γ _{28,6} (Zn)	1868,125 (8)	0,0027 (6)	
γ _{2,0} (Zn)	1872,740 (6)	0,0229 (24)	[E2]
γ _{6,1} (Zn)	1898,850 (5)	0,39 (3)	(M1+E2)
γ _{20,2} (Zn)	1918,358 (5)	1,99 (16)	M1+E2
γ _{30,6} (Zn)	1927,98 (2)	0,0022 (8)	
γ _{22,2} (Zn)	2009,659 (12)	0,0031 (7)	
γ _{28,4} (Zn)	2026,041 (12)	0,0026 (6)	
γ _{7,1} (Zn)	2065,811 (6)	0,031 (3)	
γ _{30,4} (Zn)	2085,898 (23)	0,0021 (15)	
γ _{25,3} (Zn)	2089,018 (9)	0,011 (3)	
γ _{8,1} (Zn)	2173,353 (10)	0,084 (8)	
γ _{9,1} (Zn)	2189,657 (5)	5,3 (4)	M1+E2
γ _{23,2} (Zn)	2213,219 (6)	0,131 (12)	M1+E2
γ _{26,3} (Zn)	2265,89 (14)	0,0014 (5)	
γ _{10,1} (Zn)	2292,213 (8)	0,0170 (18)	
γ _{11,1} (Zn)	2341,715 (6)	0,0032 (7)	
γ _{13,1} (Zn)	2393,179 (6)	0,23 (2)	E1
γ _{24,2} (Zn)	2422,574 (6)	1,88 (15)	M1+E2
γ _{28,3} (Zn)	2433,845 (9)	0,0074 (9)	
γ _{14,1} (Zn)	2468,02 (3)	0,0084 (10)	
γ _{15,1} (Zn)	2492,46 (2)	0,0222 (23)	
γ _{16,1} (Zn)	2537,14 (2)	0,0051 (12)	
γ _{25,2} (Zn)	2588,607 (7)	0,0263 (26)	M1+E2
γ _{17,1} (Zn)	2631,49 (5)	0,0029 (11)	
γ _{18,1} (Zn)	2698,98 (2)	0,0037 (7)	
γ _{19,1} (Zn)	2713,78 (4)	0,0062 (19)	
γ _{20,1} (Zn)	2751,894 (5)	22,7 (18)	(M1+E2)
γ _{4,0} (Zn)	2780,156 (16)	0,123 (10)	E2
γ _{21,1} (Zn)	2785,8 (3)	0,0030 (6)	
γ _{27,2} (Zn)	2802,8 (5)	0,0015 (4)	
γ _{22,1} (Zn)	2843,190 (12)	0,0017 (4)	
γ _{28,2} (Zn)	2933,434 (7)	0,213 (17)	M1+E2
γ _{29,2} (Zn)	2977,17 (3)	0,023 (3)	
γ _{30,2} (Zn)	2993,29 (2)	0,031 (4)	
γ _{23,1} (Zn)	3046,755 (6)	0,057 (5)	M1+E2
γ _{31,2} (Zn)	3085,4 (4)	0,0020 (5)	
γ _{8,0} (Zn)	3212,499 (19)	0,0019 (4)	
γ _{9,0} (Zn)	3228,884 (3)	1,51 (12)	M1+E2
γ _{24,1} (Zn)	3256,110 (6)	0,094 (8)	M1+E2
γ _{10,0} (Zn)	3331,440 (14)	0,0023 (30)	
γ _{11,0} (Zn)	3380,940 (6)	1,46 (12)	
γ _{25,1} (Zn)	3422,140 (7)	0,86 (7)	M1+E2
γ _{13,0} (Zn)	3432,406 (7)	0,288 (24)	
γ _(-1,4) (Zn)	3724,8 (10)	0,0024 (4)	
γ _{18,0} (Zn)	3738,21 (5)	0,0138 (13)	E0
γ _{28,1} (Zn)	3766,970 (7)	0,149 (13)	M1+E2
γ _{20,0} (Zn)	3791,121 (8)	1,09 (9)	M1+E2
γ _(-1,3) (Zn)	3806,3 (10)	0,0024 (4)	
γ _{29,1} (Zn)	3810,70 (3)	0,0092 (11)	

	Energy keV	P _{γ+ce} × 100	Multipolarity
γ _(-1,2) (Zn)	3827,5 (8)	0,0069 (10)	M1+E2
γ _{23,0} (Zn)	4085,982 (9)	1,27 (10)	
γ _{24,0} (Zn)	4295,337 (10)	3,8 (3)	
γ _{25,0} (Zn)	4461,370 (9)	0,84 (7)	
γ _{28,0} (Zn)	4806,197 (9)	1,86 (15)	
γ _{30,0} (Zn)	4866,05 (4)	0,0028 (3)	
γ _{32,0} (Zn)	5005,8 (3)	0,00124 (18)	

3 Atomic Data

3.1 Zn

ω_K	:	0,486	(4)
$\bar{\omega}_L$	:	0,0108	(4)
n_{KL}	:	1,326	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	Kα ₂	8,61587	51,42
	Kα ₁	8,63896	100
	Kβ ₁	9,5721	}
	Kβ ₅ ''	9,6499	
			21,35
X _L	Lℓ	0,884	
	Lβ	- 1,035	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	7,21 – 7,55	100
KLX	8,31 – 8,63	28,3
KXY	9,39 – 9,65	2,01
Auger L	0,732 – 0,997	361,7

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Zn)	0,732 - 0,997	57,2 (16)
e _{AK}	(Zn)		20,6 (10)
	KLL	7,21 - 7,55	}
	KLX	8,31 - 8,63	}
	KXY	9,39 - 9,65	}
$\beta_{0,0}^+$	max:	4153 (3)	50 (4)
$\beta_{0,0}^+$	avg:	1904,1 (15)	
$\beta_{0,3}^+$	max:	1781 (3)	0,30 (3)
$\beta_{0,3}^+$	avg:	781,6 (14)	
$\beta_{0,5}^+$	max:	1326 (3)	0,0053 (8)
$\beta_{0,5}^+$	avg:	575,3 (14)	
$\beta_{0,9}^+$	max:	924 (3)	3,7 (3)
$\beta_{0,9}^+$	avg:	397,1 (14)	
$\beta_{0,11}^+$	max:	772 (3)	0,70 (6)
$\beta_{0,11}^+$	avg:	331,1 (13)	
$\beta_{0,12}^+$	max:	726 (3)	0,0020 (5)
$\beta_{0,12}^+$	avg:	311,1 (13)	
$\beta_{0,13}^+$	max:	721 (3)	0,16 (2)
$\beta_{0,13}^+$	avg:	308,9 (13)	
$\beta_{0,18}^+$	max:	415 (3)	0,0009 (3)
$\beta_{0,18}^+$	avg:	179,2 (13)	
$\beta_{0,20}^+$	max:	362 (3)	0,94 (8)
$\beta_{0,20}^+$	avg:	157,0 (13)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Zn)	0,884 — 1,035	0,597 (19)
XK α_2	(Zn)	8,61587	5,8 (3) } K α
XK α_1	(Zn)	8,63896	11,3 (6) }
XK β_1	(Zn)	9,5721	} 2,42 (12) K' β_1

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{(-1,1)}(\text{Zn})$	171,9 (2)	0,0104 (9)
$\gamma_{20,14}(\text{Zn})$	283,87 (3)	0,0036 (8)
$\gamma_{9,6}(\text{Zn})$	290,8105 (11)	0,049 (4)
$\gamma_{23,18}(\text{Zn})$	347,77 (5)	0,0018 (6)
$\gamma_{25,23}(\text{Zn})$	375,398 (17)	0,0021 (6)
$\gamma_{20,11}(\text{Zn})$	410,178 (12)	0,065 (6)
$\gamma_{24,22}(\text{Zn})$	412,916 (16)	0,0034 (6)
$\gamma_{11,6}(\text{Zn})$	442,873 (14)	0,01554 (16)
$\gamma_{9,4}(\text{Zn})$	448,73 (2)	0,107 (9)
$\gamma_{20,10}(\text{Zn})$	459,683 (14)	0,088 (8)
$\gamma_{13,6}(\text{Zn})$	494,336 (13)	0,0056 (9)
$\gamma_{3,2}(\text{Zn})$	499,590 (6)	0,0048 (12)
$\gamma_{10,4}(\text{Zn})$	551,284 (22)	0,0070 (8)
$\gamma_{23,15}(\text{Zn})$	554,28 (3)	0,0045 (6)
$\gamma_{24,18}(\text{Zn})$	557,13 (5)	0,0061 (8)
$\gamma_{20,9}(\text{Zn})$	562,241 (10)	0,0066 (8)
$\gamma_{20,8}(\text{Zn})$	578,540 (19)	0,059 (6)
$\gamma_{11,4}(\text{Zn})$	600,788 (21)	0,0135 (14)
$\gamma_{23,13}(\text{Zn})$	653,568 (14)	0,0013 (5)
$\gamma_{23,12}(\text{Zn})$	658,57 (3)	0,0075 (10)
$\gamma_{25,20}(\text{Zn})$	670,251 (14)	0,0041 (7)
$\gamma_{14,5}(\text{Zn})$	680,56 (10)	0,0015 (4)
$\gamma_{20,7}(\text{Zn})$	686,080 (6)	0,252 (22)
$\gamma_{23,11}(\text{Zn})$	705,031 (15)	0,0038 (5)
$\gamma_{25,19}(\text{Zn})$	708,36 (5)	0,0087 (10)
$\gamma_{24,16}(\text{Zn})$	718,97 (5)	0,0099 (10)
$\gamma_{25,18}(\text{Zn})$	723,17 (5)	0,0034 (6)
$\gamma_{16,5}(\text{Zn})$	749,68 (10)	0,0014 (4)
$\gamma_{24,15}(\text{Zn})$	763,64 (3)	0,0089 (10)
$\gamma_{16,4}(\text{Zn})$	796,21 (5)	0,0029 (7)
$\gamma_{18,6}(\text{Zn})$	800,13 (5)	0,0010 (5)
$\gamma_{2,1}(\text{Zn})$	833,5324 (21)	5,9 (5)
$\gamma_{20,6}(\text{Zn})$	853,038 (8)	0,076 (6)
$\gamma_{9,3}(\text{Zn})$	856,527 (10)	0,111 (11)
$\gamma_{23,9}(\text{Zn})$	857,093 (9)	0,015 (5)
$\gamma_{24,13}(\text{Zn})$	862,926 (13)	0,0152 (14)
$\gamma_{24,12}(\text{Zn})$	867,93 (3)	0,0043 (6)
$\gamma_{23,8}(\text{Zn})$	873,392 (21)	0,0170 (18)
$\gamma_{25,16}(\text{Zn})$	885,00 (5)	0,0019 (5)
$\gamma_{4,2}(\text{Zn})$	907,390 (19)	0,0218 (23)
$\gamma_{24,11}(\text{Zn})$	914,388 (14)	0,027 (3)
$\gamma_{25,15}(\text{Zn})$	929,68 (3)	0,0046 (7)
$\gamma_{5,2}(\text{Zn})$	953,93 (9)	0,00100 (13)
$\gamma_{25,14}(\text{Zn})$	954,12 (7)	0,0045 (7)
$\gamma_{24,10}(\text{Zn})$	963,892 (15)	0,0144 (16)

	Energy keV	Photons per 100 disint.
$\gamma_{23,7}(\text{Zn})$	980,934 (13)	0,048 (19)
$\gamma_{11,3}(\text{Zn})$	1008,588 (12)	0,059 (9)
$\gamma_{20,4}(\text{Zn})$	1010,957 (19)	0,027 (3)
$\gamma_{28,20}(\text{Zn})$	1015,081 (18)	0,012 (3)
$\gamma_{1,0}(\text{Zn})$	1039,220 (3)	37 (3)
$\gamma_{13,3}(\text{Zn})$	1060,051 (11)	0,0155 (17)
$\gamma_{6,2}(\text{Zn})$	1065,305 (9)	0,0023 (5)
$\gamma_{24,9}(\text{Zn})$	1066,450 (12)	0,0024 (5)
$\gamma_{24,8}(\text{Zn})$	1082,75 (2)	0,0133 (13)
$\gamma_{26,15}(\text{Zn})$	1106,53 (24)	0,0012 (4)
$\gamma_{25,10}(\text{Zn})$	1129,923 (18)	0,0136 (13)
$\gamma_{28,17}(\text{Zn})$	1135,47 (9)	0,0047 (6)
$\gamma_{23,6}(\text{Zn})$	1147,896 (10)	0,078 (9)
$\gamma_{24,7}(\text{Zn})$	1190,287 (7)	0,128 (13)
$\gamma_{30,17}(\text{Zn})$	1195,32 (9)	0,0009 (3)
$\gamma_{7,2}(\text{Zn})$	1232,264 (8)	0,50 (4)
$\gamma_{25,9}(\text{Zn})$	1232,480 (15)	0,056 (19)
$\gamma_{25,8}(\text{Zn})$	1248,779 (22)	0,0010 (3)
$\gamma_{28,15}(\text{Zn})$	1274,50 (3)	0,0070 (8)
$\gamma_{28,14}(\text{Zn})$	1298,95 (7)	0,0038 (5)
$\gamma_{23,4}(\text{Zn})$	1305,807 (21)	0,0040 (5)
$\gamma_{3,1}(\text{Zn})$	1333,112 (5)	1,17 (9)
$\gamma_{9,2}(\text{Zn})$	1356,104 (9)	0,36 (5)
$\gamma_{25,7}(\text{Zn})$	1356,320 (15)	0,122 (21)
$\gamma_{24,6}(\text{Zn})$	1357,250 (12)	0,16 (5)
$\gamma_{26,9}(\text{Zn})$	1409,35 (24)	0,0016 (7)
$\gamma_{20,3}(\text{Zn})$	1418,754 (5)	0,61 (5)
$\gamma_{28,11}(\text{Zn})$	1425,25 (2)	0,0060 (7)
$\gamma_{30,13}(\text{Zn})$	1433,63 (4)	0,0018 (4)
$\gamma_{10,2}(\text{Zn})$	1458,662 (12)	0,096 (23)
$\gamma_{29,11}(\text{Zn})$	1468,97 (5)	0,0014 (4)
$\gamma_{11,2}(\text{Zn})$	1508,158 (7)	0,55 (4)
$\gamma_{24,4}(\text{Zn})$	1515,162 (20)	0,0062 (7)
$\gamma_{25,6}(\text{Zn})$	1523,279 (15)	0,0055 (7)
$\gamma_{30,10}(\text{Zn})$	1534,60 (4)	0,0057 (16)
$\gamma_{12,2}(\text{Zn})$	1554,62 (3)	0,0183 (18)
$\gamma_{13,2}(\text{Zn})$	1559,627 (10)	0,0219 (23)
$\gamma_{28,9}(\text{Zn})$	1577,308 (20)	0,0040 (7)
$\gamma_{14,2}(\text{Zn})$	1634,46 (7)	0,0035 (6)
$\gamma_{16,2}(\text{Zn})$	1703,59 (5)	0,0054 (19)
$\gamma_{23,3}(\text{Zn})$	1713,602 (12)	0,0243 (23)
$\gamma_{4,1}(\text{Zn})$	1740,904 (16)	0,029 (4)
$\gamma_{5,1}(\text{Zn})$	1787,44 (9)	0,0089 (10)
$\gamma_{17,2}(\text{Zn})$	1797,94 (9)	0,0019 (5)
$\gamma_{28,6}(\text{Zn})$	1868,105 (20)	0,0027 (6)
$\gamma_{2,0}(\text{Zn})$	1872,740 (6)	0,0229 (24)
$\gamma_{6,1}(\text{Zn})$	1898,823 (8)	0,39 (3)

	Energy keV	Photons per 100 disint.
$\gamma_{20,2}(\text{Zn})$	1918,329 (5)	1,99 (16)
$\gamma_{30,6}(\text{Zn})$	1927,96 (4)	0,0022 (8)
$\gamma_{22,2}(\text{Zn})$	2009,628 (16)	0,0031 (7)
$\gamma_{28,4}(\text{Zn})$	2026,016 (25)	0,0026 (6)
$\gamma_{7,1}(\text{Zn})$	2065,778 (7)	0,031 (3)
$\gamma_{30,4}(\text{Zn})$	2085,86 (4)	0,0021 (15)
$\gamma_{25,3}(\text{Zn})$	2088,985 (13)	0,011 (3)
$\gamma_{8,1}(\text{Zn})$	2173,319 (15)	0,084 (8)
$\gamma_{9,1}(\text{Zn})$	2189,616 (6)	5,3 (4)
$\gamma_{23,2}(\text{Zn})$	2213,181 (9)	0,131 (12)
$\gamma_{26,3}(\text{Zn})$	2265,84 (24)	0,0014 (5)
$\gamma_{10,1}(\text{Zn})$	2292,171 (13)	0,0170 (18)
$\gamma_{11,1}(\text{Zn})$	2341,673 (11)	0,0032 (7)
$\gamma_{13,1}(\text{Zn})$	2393,129 (7)	0,23 (2)
$\gamma_{24,2}(\text{Zn})$	2422,525 (7)	1,88 (15)
$\gamma_{28,3}(\text{Zn})$	2433,807 (18)	0,0074 (9)
$\gamma_{14,1}(\text{Zn})$	2467,97 (7)	0,0084 (10)
$\gamma_{15,1}(\text{Zn})$	2492,42 (3)	0,0222 (23)
$\gamma_{16,1}(\text{Zn})$	2537,09 (5)	0,0051 (12)
$\gamma_{25,2}(\text{Zn})$	2588,553 (13)	0,0263 (26)
$\gamma_{17,1}(\text{Zn})$	2631,44 (9)	0,0029 (11)
$\gamma_{18,1}(\text{Zn})$	2698,92 (5)	0,0037 (7)
$\gamma_{19,1}(\text{Zn})$	2713,73 (5)	0,0062 (19)
$\gamma_{20,1}(\text{Zn})$	2751,835 (5)	22,7 (18)
$\gamma_{4,0}(\text{Zn})$	2780,095 (16)	0,123 (10)
$\gamma_{21,1}(\text{Zn})$	2785,7 (3)	0,0030 (6)
$\gamma_{27,2}(\text{Zn})$	2802,8 (5)	0,0015 (4)
$\gamma_{22,1}(\text{Zn})$	2843,130 (16)	0,0017 (4)
$\gamma_{28,2}(\text{Zn})$	2933,358 (9)	0,213 (17)
$\gamma_{29,2}(\text{Zn})$	2977,08 (4)	0,023 (3)
$\gamma_{30,2}(\text{Zn})$	2993,21 (3)	0,031 (4)
$\gamma_{23,1}(\text{Zn})$	3046,684 (9)	0,057 (5)
$\gamma_{31,2}(\text{Zn})$	3085,4 (4)	0,0020 (5)
$\gamma_{8,0}(\text{Zn})$	3212,499 (19)	0,0019 (4)
$\gamma_{9,0}(\text{Zn})$	3228,800 (6)	1,51 (12)
$\gamma_{24,1}(\text{Zn})$	3256,021 (9)	0,094 (8)
$\gamma_{10,0}(\text{Zn})$	3331,351 (14)	0,0023 (30)
$\gamma_{11,0}(\text{Zn})$	3380,850 (6)	1,46 (12)
$\gamma_{25,1}(\text{Zn})$	3422,040 (8)	0,86 (7)
$\gamma_{13,0}(\text{Zn})$	3432,309 (7)	0,288 (24)
$\gamma_{(-1,4)}(\text{Zn})$	3724,8 (10)	0,0024 (4)
$\gamma_{18,0}(\text{Zn})$	3738,10 (5)	0,0138 (13)
$\gamma_{28,1}(\text{Zn})$	3766,850 (9)	0,149 (13)
$\gamma_{20,0}(\text{Zn})$	3791,004 (8)	1,09 (9)
$\gamma_{(-1,3)}(\text{Zn})$	3806,3 (10)	0,0024 (4)
$\gamma_{29,1}(\text{Zn})$	3810,59 (5)	0,0092 (11)
$\gamma_{(-1,2)}(\text{Zn})$	3827,5 (8)	0,0069 (10)

	Energy keV	Photons per 100 disint.
$\gamma_{23,0}(\text{Zn})$	4085,853 (9)	1,27 (10)
$\gamma_{24,0}(\text{Zn})$	4295,187 (10)	3,8 (3)
$\gamma_{25,0}(\text{Zn})$	4461,202 (9)	0,84 (7)
$\gamma_{28,0}(\text{Zn})$	4806,007 (9)	1,86 (15)
$\gamma_{30,0}(\text{Zn})$	4865,87 (4)	0,0028 (3)
$\gamma_{32,0}(\text{Zn})$	5005,6 (3)	0,00124 (18)

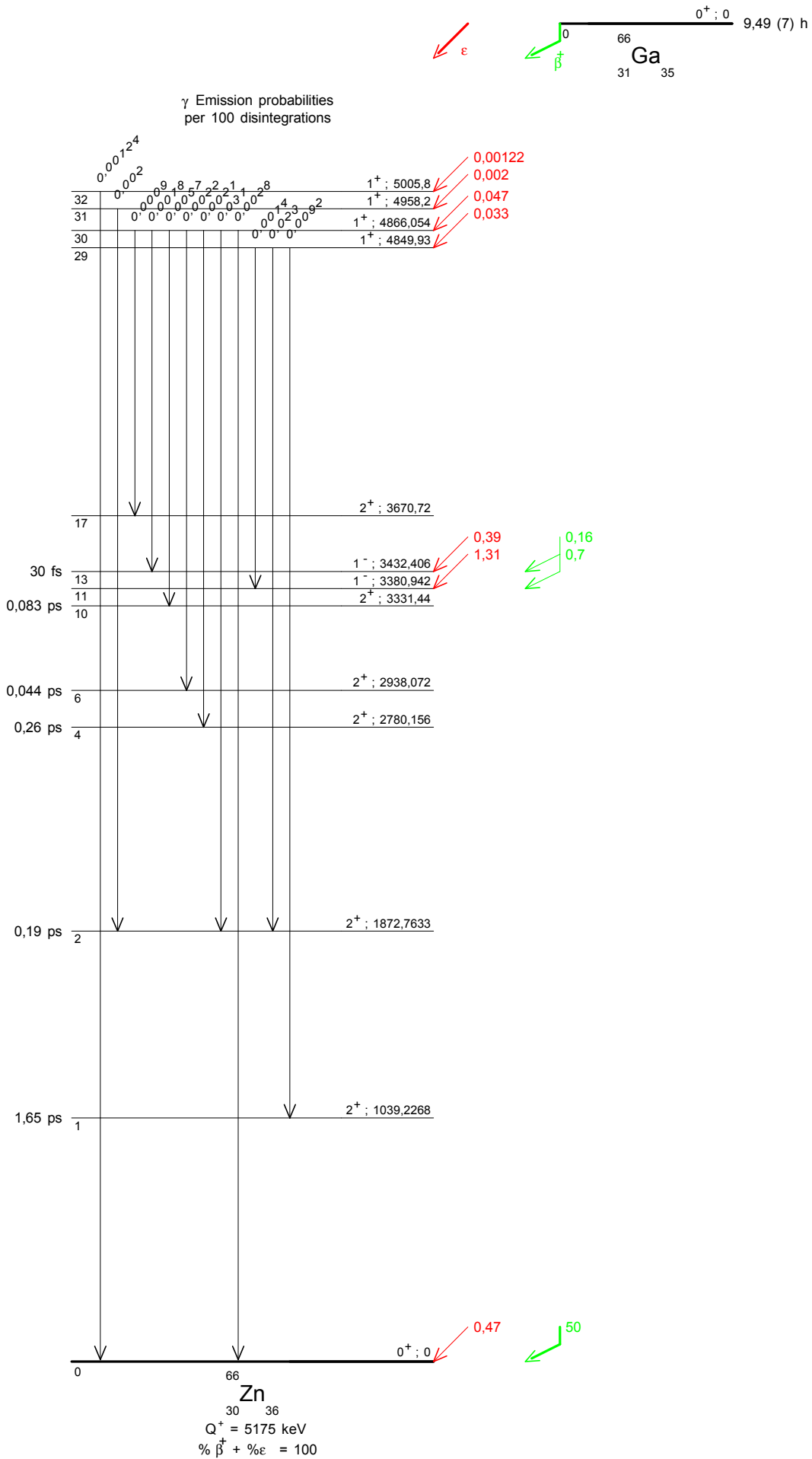
6 Main Production Modes

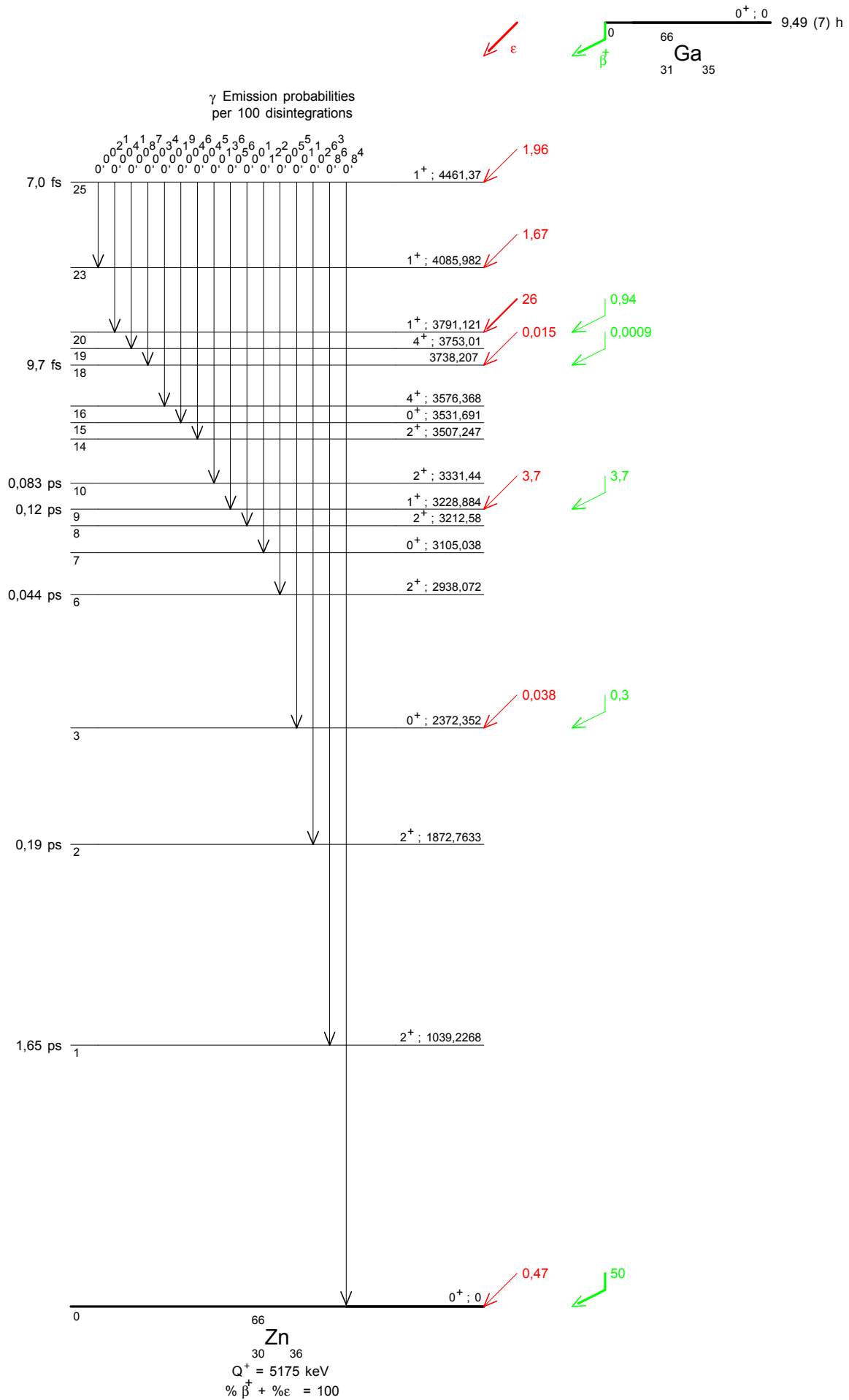
$$\left\{ \begin{array}{l} \text{Zn} - 66(\text{p,n})\text{Ga} - 66 \\ \text{Possible impurities : Ga} - 68 \text{ (68min) and Ga} - 67 \text{ (3,3d)} \\ \text{Cu} - 63(\alpha,\text{n})\text{Ga} - 66 \end{array} \right.$$

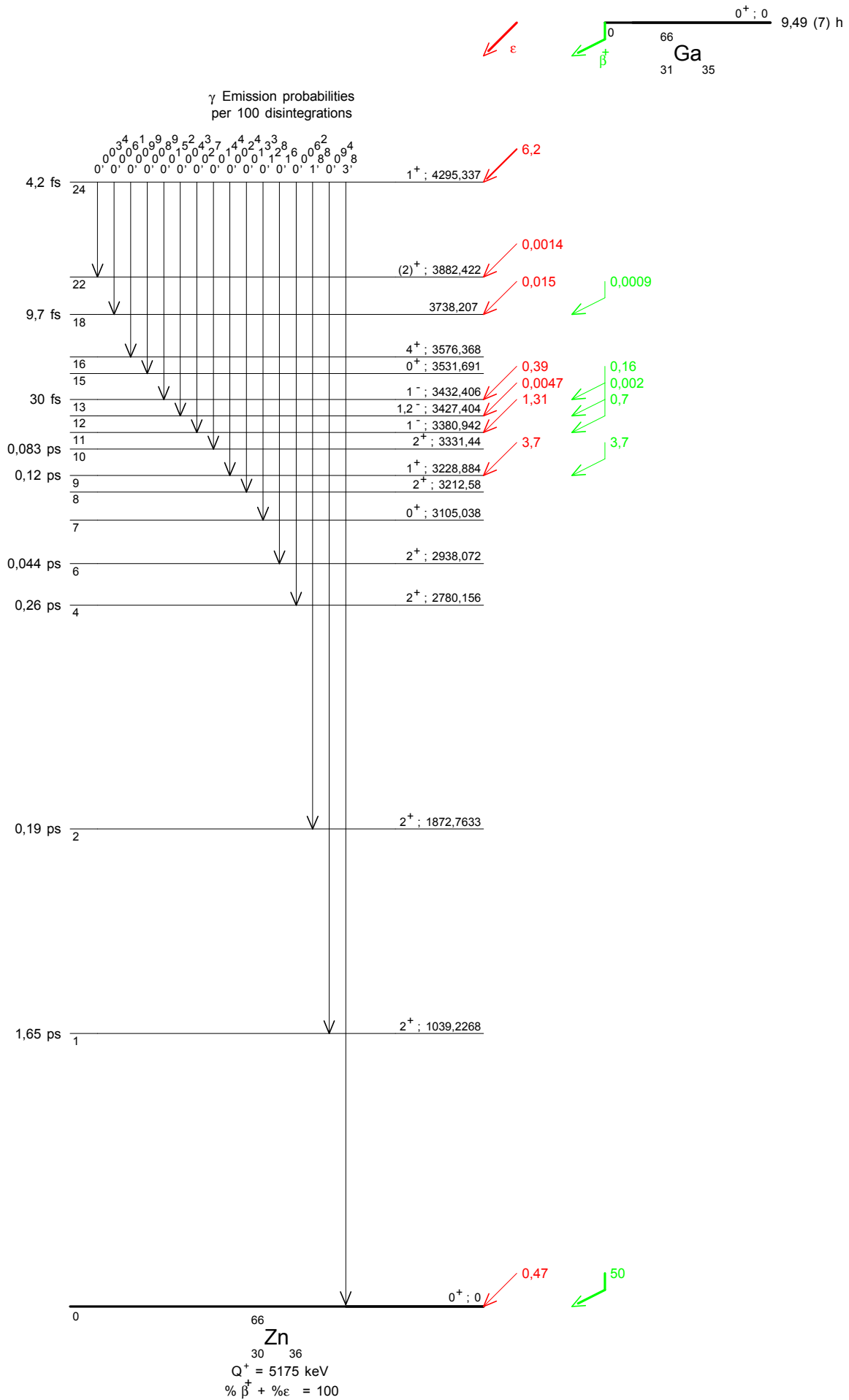
7 References

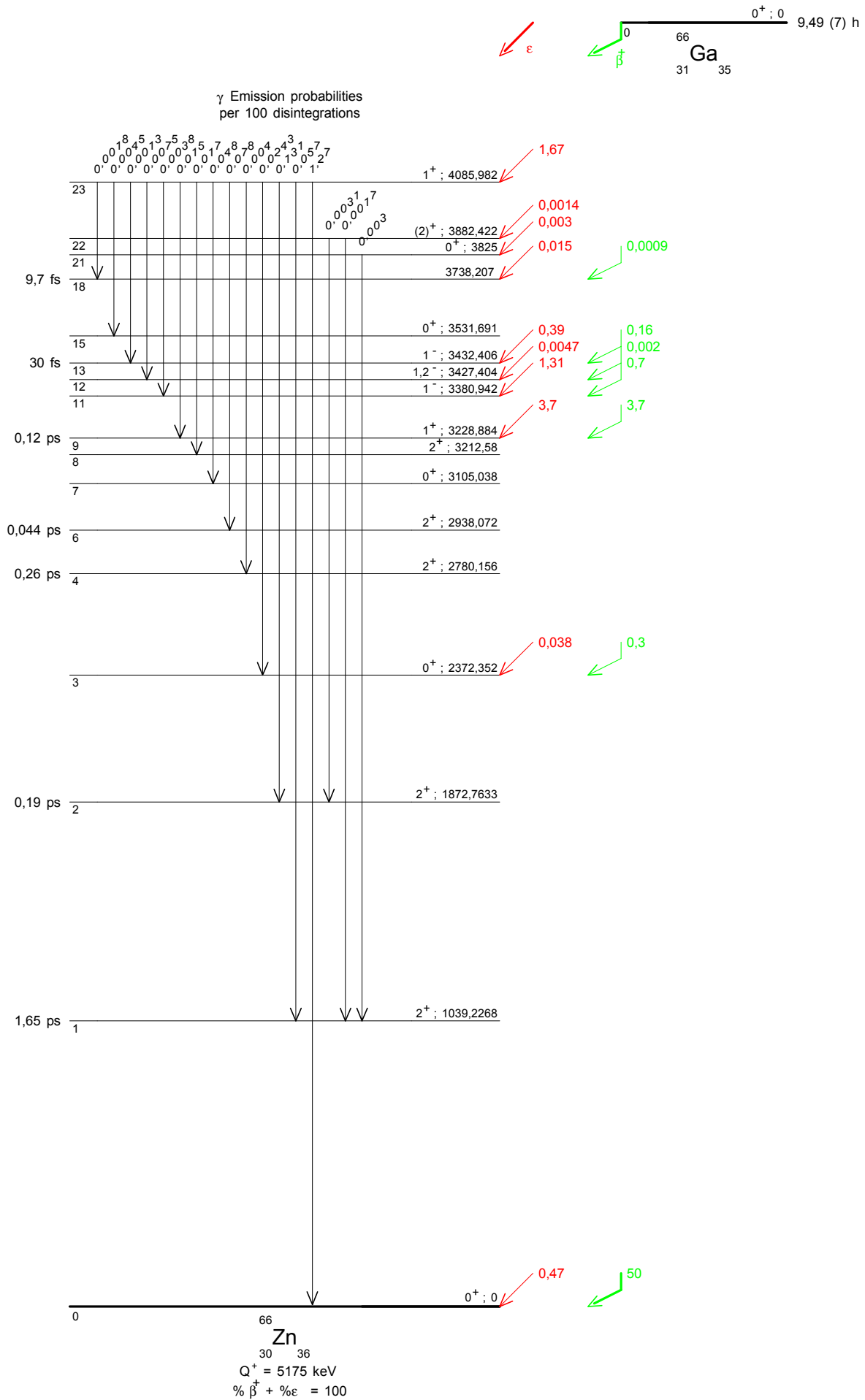
- G. RUDSTAM. Thesis, University of Uppsala (1956)
(Half-life)
- A. SCHARZSCHILD, L. GRODZINS. Phys. Rev. 119 (1960) 276
($I_{\gamma}(1039)/I_{b^+}(gs)$)
- M. E. PHELPS, D. G. SARANTITES, W. G. WINN. Nucl. Phys. A149 (1970) 647
(Relative gamma-ray emission probabilities.)
- D. C. CAMP, G. L. MEREDITH. Nucl. Phys. A166 (1971) 349
(Relative gamma-ray emission probabilities.)
- G. J. MACCALLUM, G. E. COOTE. Nucl. Instrum. Methods 124 (1975) 309
(Relative gamma-ray emission probabilities.)
- F. RÖSEL, H. M. FRIESS, K. ALDER, H. C. PAULI. At. Data Nucl. Data Tables 21 (1978) 92
(Theoretical conversion coefficients.)
- W. L. ZIJP. Report ECN FYS/RASA-8519 (1985)
(Discrepant data. Limited Relative Statistical Weight Method.)
- E. R. COHEN, B. N. TAYLOR. Rev. Mod. Phys. 59 (1987) 1121
(The 1986 Adjustment of the Fundamental Physical Constants)
- C. ALDERLIESTEN, J. A. VAN NIE, A. P. SLOCK, P. M. ENDT. Nucl. Instrum. Methods A335 (1993) 219
(Gamma-ray energies.)
- P. M. ENDT, C. ALDERLIESTEN. Nucl. Phys. A575 (1994) 297
(Gamma-ray energies and relative emission probabilities.)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(Atomic data, X-rays, Auger electrons.)
- E. SCHÖNFELD, F. CHU, E. BROWNE. (1997)
(The Program EC-CAPTURE)
- M. R. BHAT. Nucl. Data Sheets 83 (1998) 789
(⁶⁶Ga decay scheme.)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 (1998)
(Table of the energies of K-Auger electrons for elements with atomic numbers in the range from Z=11 to Z=100.)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-1999-1 (1999)
(Energies and relative emission probabilities of K X-rays for elements with atomic numbers in the range from Z=5)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
(Precise evaluated gamma-ray energies.)

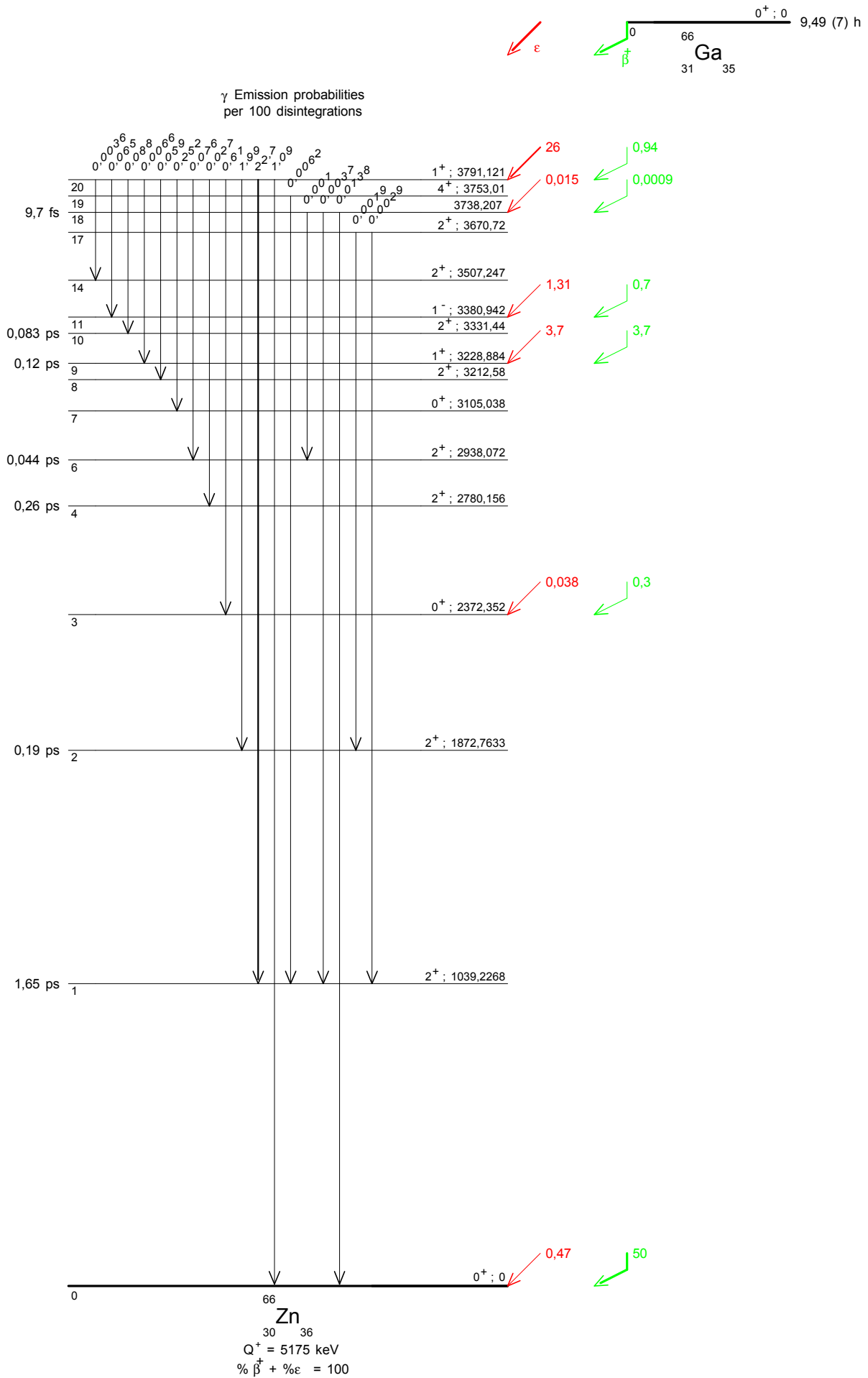
- S. RAMAN, C. YONEZAWA, H. MATSUE, H. IMURA, N. SHINOHARA. Nucl. Instrum. Methods Phys. Res. A454 (2000) 389
(Precise relative gamma-ray emission probabilities.)
- C. M. BAGLIN, E. BROWNE, E. B. NORMAN, G. L. MOLNAR, T. BELGYA, ZS. REVAY, F. SZEIECSENYI. Nucl. Instrum. Methods Phys. Res. A481 (2002) 365
(Precise relative gamma-ray emission probabilities.)
- A. GADE, H. KLEIN, N. PIETRALLA, P. VON BRENTANO. Phys. Rev. C65 (2002) 054311
(Levels half-life in ⁶⁶Zn.)
- E. SCHÖNFELD, H. JANSSEN. (2002)
(The Program EMISSION (version 3.04 (2002)))

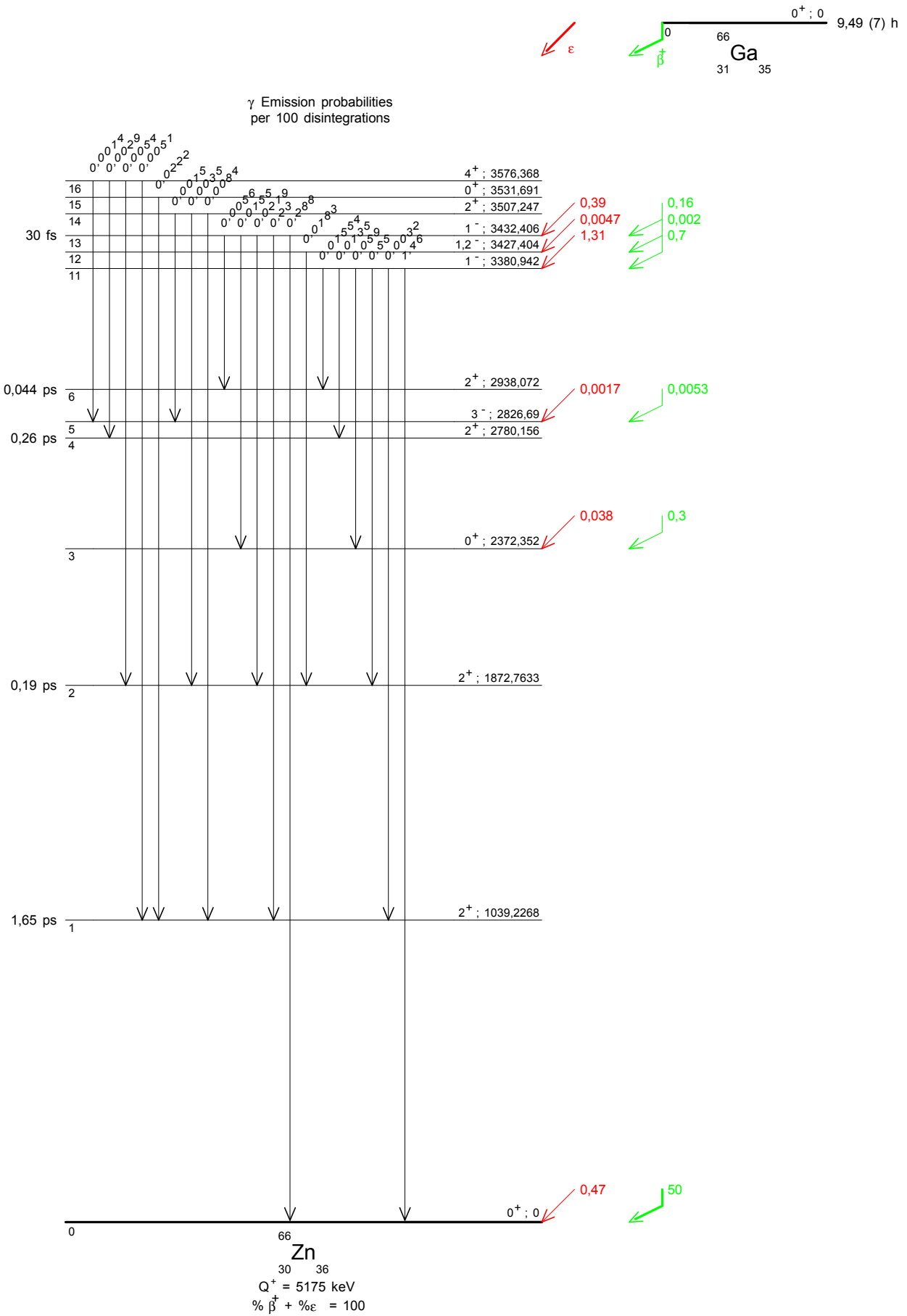


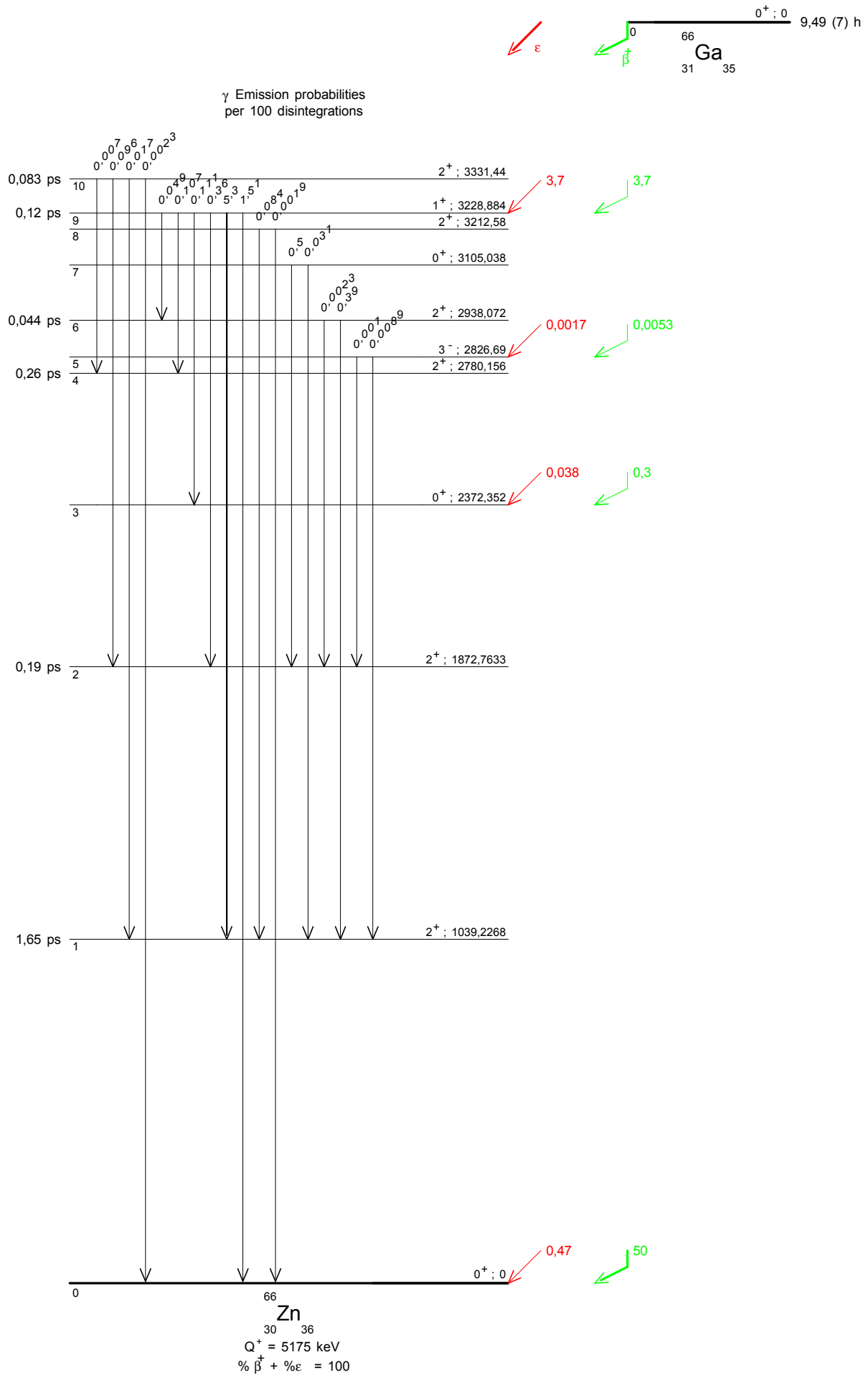


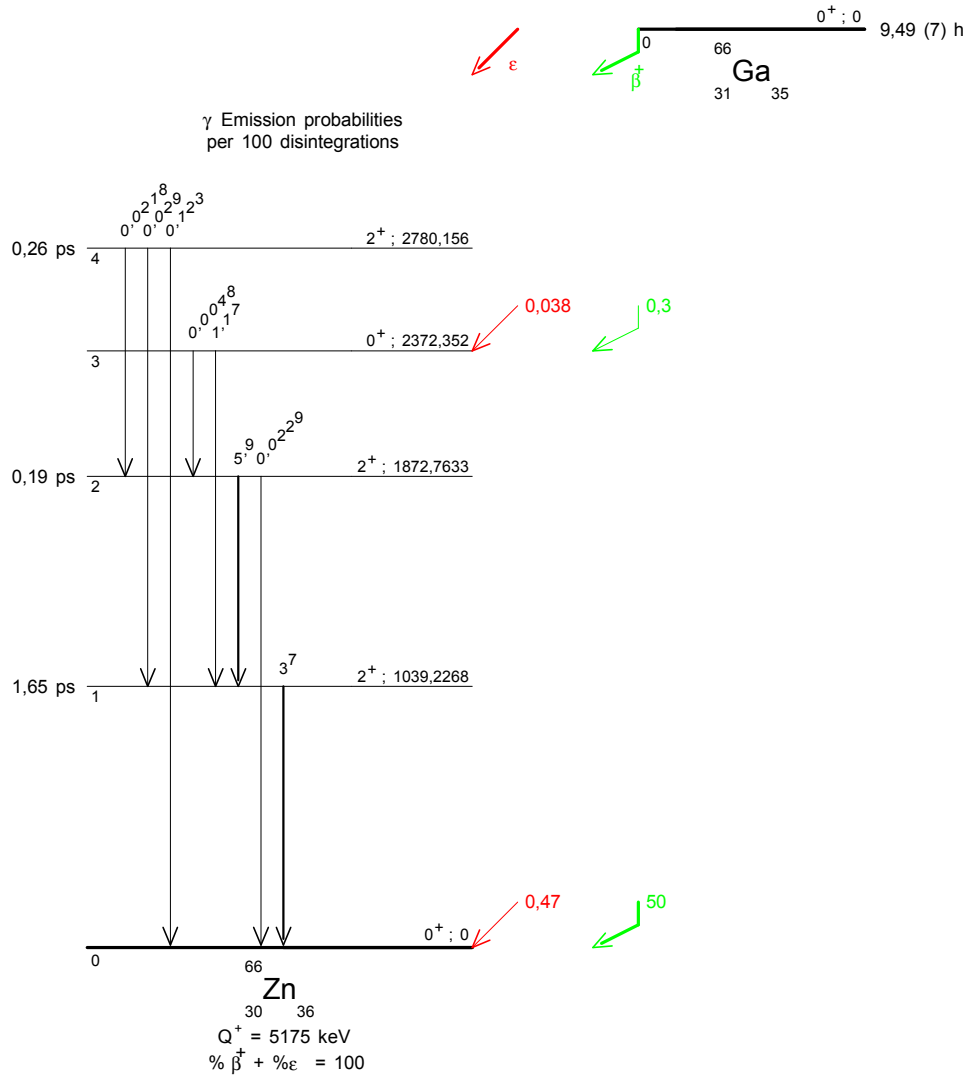














1 Decay Scheme

Ga-67 disintegrates by 100 % electron capture to the excited levels of 887.7 keV, 393.5 keV, 184.6 keV, 93.3 keV and ground state of the stable Zn-67.

Le gallium 67 se désintègre à 100 % par capture électronique vers les niveaux excités (887,7; 393,5; 184,6; et 93,3 keV) et le niveau fondamental de zinc 67.

2 Nuclear Data

$$T_{1/2}({}^{67}\text{Ga}) : 3,2613 \quad (5) \quad \text{d}$$

$$Q^+({}^{67}\text{Ga}) : 1000,5 \quad (13) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg ft	P_K	P_L	P_M
$\epsilon_{0,4}$	112,8 (13)	0,279 (6)	Allowed	5,647	0,8680 (17)	0,1119 (14)	0,0188 (5)
$\epsilon_{0,3}$	607,0 (13)	23,8 (6)	Allowed	5,234	0,8824 (15)	0,0999 (12)	0,0165 (4)
$\epsilon_{0,2}$	815,9 (13)	22,2 (7)	Allowed	5,525	0,8832 (15)	0,0993 (12)	0,0164 (4)
$\epsilon_{0,1}$	907,6 (13)	50,1 (18)	Allowed	5,264	0,8834 (15)	0,0991 (12)	0,0164 (4)
$\epsilon_{0,0}$	1000,5 (13)	3,6 (20)	Allowed, 1st forbidden	6,49	0,8836 (15)	0,0989 (12)	0,0164 (4)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K (10^{-4})	α_L (10^{-4})	α_M (10^{-4})	α_T (10^{-4})
$\gamma_{2,1}(\text{Zn})$	91,265 (5)	3,32 (12)	M1+0,4(4)%E2	735 (15)	78,1 (16)	11,7 (3)	827 (17)
$\gamma_{1,0}(\text{Zn})$	93,310 (5)	70,3 (17)	E2	7510 (15)	939 (19)	138 (3)	8590 (17)
$\gamma_{2,0}(\text{Zn})$	184,576 (10)	21,3 (7)	M1+11(2)%E2	158 (6)	16,7 (7)	2,5 (1)	178 (7)
$\gamma_{3,2}(\text{Zn})$	208,95 (1)	2,39 (8)	M1+0,1%E2	81,1 (17)	8,4 (2)	1,25 (3)	90,9 (18)
$\gamma_{3,1}(\text{Zn})$	300,217 (10)	16,9 (6)	M1+3,1(2)%E2	35,6 (15)	3,64 (16)	0,54 (3)	39,8 (18)
$\gamma_{3,0}(\text{Zn})$	393,527 (10)	4,67 (16)	M1+0,18(6)%E2	17,4 (4)	1,77 (4)	0,264 (6)	19,5 (4)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K (10^{-4})	α_L (10^{-4})	α_M (10^{-4})	α_T (10^{-4})
$\gamma_{4,3}(\text{Zn})$	494,166 (15)	0,0686 (27)	M1+1,9(6)%E2	10,4 (3)	1,05 (3)	0,157 (5)	11,7 (4)
$\gamma_{4,2}(\text{Zn})$	703,110 (15)	0,0111 (6)	(M1+E2)				
$\gamma_{4,1}(\text{Zn})$	794,386 (15)	0,0520 (24)	E2+0,16%M3	4,76 (10)	0,481 (10)	0,072 (2)	5,31 (11)
$\gamma_{4,0}(\text{Zn})$	887,694 (15)	0,147 (5)	M1+48(4)%E2	3,2 (3)	0,32 (3)	0,047 (5)	3,6 (4)

3 Atomic Data

3.1 Zn

ω_K	:	0,486	(4)
$\bar{\omega}_L$	:	0,0108	(4)
n_{KL}	:	1,326	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	8,61587	
	$K\alpha_1$	8,63896	
	$K\beta_3$	9,5728	}
	$K\beta_5''$	9,6499	}
			21,46
	$K\beta_2$	9,65806	}

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	7,21 – 7,55	100
KLX	8,31 – 8,63	28,3
KXY	9,39 – 9,65	2,01
Auger L		
	0,732 – 0,997	361,7

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Zn)	0,732 - 0,997	167,1 (22)
e _{AK}	(Zn)		60,2 (10)
	KLL	7,21 - 7,55	}
	KLX	8,31 - 8,63	}
	KXY	9,39 - 9,65	}
ec _{2,1} K	(Zn)	81,606 (5)	0,230 (9)
ec _{1,0} K	(Zn)	83,651 (5)	28,4 (7)
ec _{1,0} L	(Zn)	92,116 - 93,290	3,55 (9)
ec _{1,0} M	(Zn)	93,174 - 93,302	0,522 (13)
ec _{2,0} K	(Zn)	174,917 (10)	0,332 (17)
ec _{3,1} K	(Zn)	290,558 (10)	0,060 (3)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Zn)	0,884 — 1,107	1,82 (12)	
XK α_2	(Zn)	8,61587	17,0 (6)	} K α
XK α_1	(Zn)	8,63896	33,0 (11)	}
XK β_3	(Zn)	9,5728	}	
XK β_1	(Zn)		}	
XK β_5''	(Zn)	9,6499	}	K' β_1
XK β_2	(Zn)	9,65806	}	
XK β_4	(Zn)		}	K' β_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{2,1}$ (Zn)	91,265 (5)	3,07 (11)
$\gamma_{1,0}$ (Zn)	93,310 (5)	37,8 (9)
$\gamma_{2,0}$ (Zn)	184,576 (10)	20,9 (7)

	Energy keV	Photons per 100 disint.
$\gamma_{3,2}(\text{Zn})$	208,95 (1)	2,37 (8)
$\gamma_{3,1}(\text{Zn})$	300,217 (11)	16,8 (6)
$\gamma_{3,0}(\text{Zn})$	393,527 (10)	4,66 (16)
$\gamma_{4,3}(\text{Zn})$	494,166 (15)	0,0685 (27)
$\gamma_{4,2}(\text{Zn})$	703,106 (15)	0,0111 (6)
$\gamma_{4,1}(\text{Zn})$	794,381 (15)	0,0520 (24)
$\gamma_{4,0}(\text{Zn})$	887,688 (15)	0,147 (5)

6 Main Production Modes

{ Zn – 67(p,n)Ga – 67
Possible impurities : Ga – 66

{ Zn – 67(d,n)Ga – 67
Possible impurities : Ga – 66

{ Zn – 67(p,n)Ga – 67
Possible impurities : Ga – 66

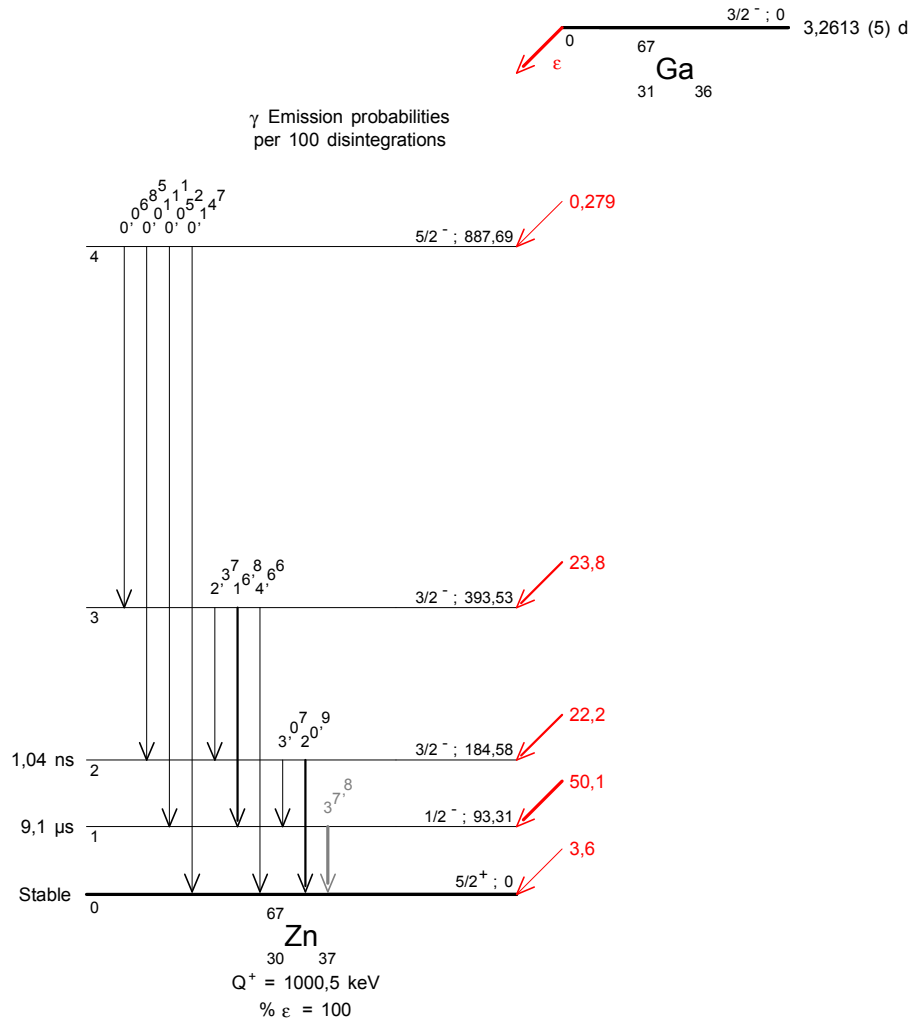
{ Zn – 66(d,n)Ga – 67
Possible impurities : Ga – 66

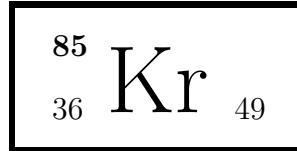
7 References

- W. B. MANN. Phys. Rev. 54 (1938) 649
(Half-life)
- H. HOPKINS, B. CUNNINGHAM. Phys. Rev. 73 (1948) 1406
(Half-life)
- D. A. MCCOWN *et al.* Phys. Rev. 74 (1948) 1311
(Half-life)
- H. H. HOPKINS. Phys. Rev. 77 (1950) 717
(Half-life)
- J. TOBAILEM. Ann. Phys. (Paris) 10 (1955) 783
(Half-life)
- E. L. CHUPP *et al.* Phys. Rev. 109 (1958) 2036
(Gamma-ray energies)
- R. C. RITTER *et al.* Phys. Rev. 128 (1962) 2320
(mixing ratio (E2/M1) for gamma-transitions)
- G. RUDSTAM. Nucl. Phys. 56 (1964) 593
(Half-life)
- D. C. ALKHAZOV *et al.* Bull. Ac. Sc URSS, Phys. Ser. 28 (1965) 1575
(mixing ratio (E2/M1) for gamma-transitions)
- M. S. FREEDMAN *et al.* Phys. Rev. 151 (1967) 886
(mixing(E2/M1), ICC, EG,IG)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- J. VRZAL *et al.* Bull. Ac. Sc. URSS, Phys. Ser. 31 (1968) 1687
(Gamma-ray emission probabilities)

- S. RAMAN, J. J. PINAJIAN. Nucl. Phys. A131 (1969) 393
(gamma-ray energies)
- A. LI-SCHOLZ, H. BAKHRU. Phys. Rev. 177 (1969) 1629
(Gamma-ray emission probabilities, gamma-mixing, ICC)
- W. BAMBYNEK *et al.* Rev. Mod. Phys. 44 (1972) 716
(K X-Ray Fluorescence Yield)
- D. F. L. CRISLER *et al.* Phys. Rev. C. 5 (1972) 419
(Half-life)
- V. E. LEWIS *et al.* I. J. A. R. I. 23 (1972) 279
(Half-life)
- C. BARGHOLTZ *et al.* Z. Phys. 263 (1973) 89
(mixing ratio (E2/M1) for gamma-transitions)
- A. NILSSON, Z. P. SAWA. Phys. Scripta 9 (1974) 83
(mixing ratio (E2/M1) for gamma-transitions)
- R. L. HEATH. Report ANCR-1000-2 (1974)
(Gamma-ray energies and emission probabilities)
- P. O. ARONSSON *et al.* J. Inorg. Nucl. Chem. 36 (1974) 2397
(Gamma-ray energies)
- S. A. WENDER, J. A. CAMERON. Nucl. Phys. A241 (1975) 332
(Mixing ratio (E2/M1) for gamma-transitions, gamma-ray emission probabilities)
- M. J. THROOP *et al.* Nucl. Phys. A239 (1975) 333
(mixing ratio (E2/M1) for gamma-transitions, gamma-ray emission probabilities)
- F. P. LARKINS. At. Data Nuc. Data. Tables 20 (1977) 313
(Auger electron energies)
- R. DUFFAIT *et al.* Phys. Rev. C17 (1978) 2031
(Gamma-ray energies)
- F. LAGOUTINE *et al.* Int. J. Appl. Radiat. Isotop. 29 (1978) 269
(Half-life)
- P. R. G. LORNIE *et al.* J. Phys. (London) G4 (1978) 923
(mixing ratio (E2/M1) for gamma-transitions)
- R. A. MEYER *et al.* Phys. Rev. C17 (1978) 1822
(Half-life, gamma-ray energies and emission probabilities)
- F. RÖSEL *et al.* At. Data Nuc. Data. Tables 21 (1978) 91
(ICC)
- K. DEBERTIN *et al.* Int. J. Appl. Radiat. Isotop. 30 (1979) 551
(Half-life and X- and gamma-ray emission probabilities)
- H. HOUTERMANS *et al.* Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- D. D. HOPPE *et al.* NBS-SP-626 (1982) 85
(Half-life)
- F. LAGOUTINE *et al.* Table de Radionucléides, CEA-LMRI ISBN 2-7272-0078-1 (1987)
(Auger electron energies)
- R. B. BEGZHANOV *et al.* Bull. Ac. Sc. URSS, Phys. Ser. 52(11) (1988) 88
(Experimental PK values)
- R. A. MEYER. Fizika (Zagreb) 22 (1990) 153
(Gamma-ray energies and emission probabilities)
- M. R. BHAT. Nucl. Data Sheets 64 (1991) 875
(Decay scheme)
- A. T. HIRSHFELD *et al.* Priv. Comm., 1991HiZZ (1991)
(Gamma-ray emission probabilities)
- M. P. UNTERWEGER *et al.* Nucl. Instrum. Methods A312 (1992) 349
(Half-life)
- S. I. KAFALA *et al.* Nucl. Instrum. Methods A339 (1994) 151
(Evaluation technique)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q value)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic data)
- M. R. P. ATTIE *et al.* Appl. Rad. Isotopes 49 (1998) 1175
(Internal conversion electron intensities)

- E. SCHÖNFELD. Appl. Rad. Isotopes 49 (1998) 1353
(Fractional electron capture probabilities)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma ray energy)
- B. R. S. SIMPSON, T. NTSOANE. Appl.Rad.Isot. 52 (2000) 551
(ICC intensities, electron capture branching ratio to the ground state)
- M. P. UNTERWEGER. Appl. Rad. Isotopes 56 (2002) 125
(Half-life)
- H. SCHRADER. Appl. Rad. Isotopes 60 (2004) 317
(Half-life)
- M. A. L. DA SILVA, M. C. M. DE ALMEIDA, C. J. DA SILVA, J. U. DELGADO. Appl. Rad. Isotopes 60 (2004) 301
(Half-life)





1 Decay Scheme

The Kr-85 disintegrates by beta minus emission mainly to the Rb-85 ground state level.

Le krypton 85 se désintègre par émission bêta moins principalement vers le niveau fondamental de rubidium 85.

2 Nuclear Data

$$T_{1/2}({}^{85}\text{Kr}) : 10,752 \quad (23) \quad \text{a}$$

$$Q^{-}({}^{85}\text{Kr}) : 687,1 \quad (19) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability $\times 100$	Nature	$\lg ft$
$\beta_{0,2}^{-}$	173,1 (19)	0,438 (10)	Allowed	9,5
$\beta_{0,0}^{-}$	687,1 (19)	99,562 (10)	1st Forbidden Unique	8,4

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_T
$\gamma_{1,0}(\text{Rb})$	151,18 (3)	0,0000023 (14)	M1 + 0,52(4)% E2	0,0430 (13)	0,00485 (14)	0,0488 (14)
$\gamma_{2,1}(\text{Rb})$	362,81 (3)	0,00000225 (45)	(E3)	0,0292 (9)	0,00400 (12)	0,034 (1)
$\gamma_{2,0}(\text{Rb})$	513,998 (5)	0,438 (10)	M2	0,00635 (19)	0,00072 (2)	0,00721 (22)

3 Atomic Data

3.1 Rb

ω_K	:	0,674	(4)
$\bar{\omega}_L$	:	0,0237	(6)
n_{KL}	:	1,125	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	13,3359	51,95	
	K α_1	13,3955	100	
	K β_3	14,9519	}	
	K β_1	14,9614		
	K β_5''	15,085	}	24,34
	K β_2	15,1856		
	K β_4	15,205	}	2,82

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	10,987 – 11,503	100
KLX	12,782 – 13,381	35,8
KXY	14,556 – 15,172	3,2
Auger L	1,1 – 2,0	

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Rb)	1,1	- 2,0	0,00336 (6)
e _{AK}	(Rb)			0,000901 (24)
	KLL	10,987	- 11,503	}
	KLX	12,782	- 13,381	}
	KXY	14,556	- 15,172	}
$\beta_{0,2}^-$	max:	173,1	(19)	0,438 (10)
$\beta_{0,2}^-$	avg:	47,5	(6)	
$\beta_{0,0}^-$	max:	687,1	(19)	99,562 (10)
$\beta_{0,0}^-$	avg:	251,4	(8)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.
XK α_2	(Rb)	13,3359		0,000540 (14) } K α
XK α_1	(Rb)	13,3955		0,001040 (25) }
XK β_3	(Rb)	14,9519	}	
XK β_1	(Rb)	14,9614	}	0,000253 (7) K' β_1
XK β_5''	(Rb)	15,085	}	
XK β_2	(Rb)	15,1856	}	
XK β_4	(Rb)	15,205	}	0,0000294 (13) K' β_2

5.2 Gamma Emissions

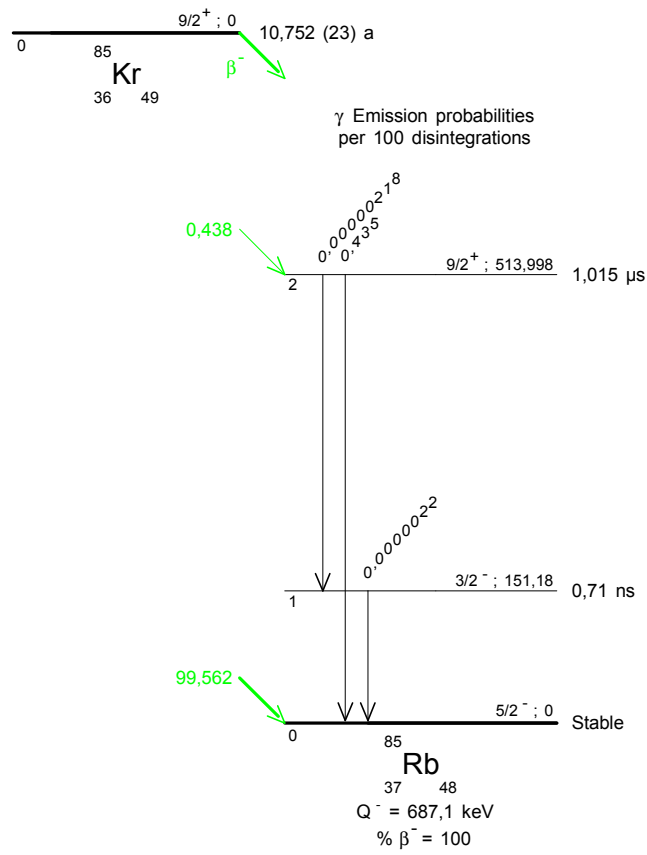
	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Rb)	151,18 (3)	0,0000022 (13)
$\gamma_{2,1}$ (Rb)	362,81 (4)	0,00000218 (44)
$\gamma_{2,0}$ (Rb)	513,997 (5)	0,435 (10)

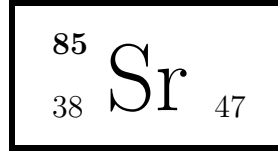
6 Main Production Modes

- Kr – 84(n,γ)Kr – 85 σ : 0,042 (4) barns
- Kr – 84(n,γ)Kr – 85m σ : 0,090 (13) barns
- { Kr – 85m(I.T.)Kr – 85
- { Possible impurities : Half – life(Kr – 85m) = 4,48h
- { Fission products
- { Possible impurities : None

7 References

- H. G. THODE. Nucleonics 3 (1948) 14
(Half-life)
- R. K. WANLESS, H. G. THODE. Can. J. Phys. 31 (1953) 517
(Half-life)
- J. F. TURNER. AERE - N/R 1254 (1953)
(Half-life)
- K. W. GEIGER, J. S. MERRITT, J. G. V. TAYLOR. Nucleonics 19 (1961) 97
(Gamma Branching ratio)
- J. LERNER. J. Inorg. Nucl. Chem. 25 (1963) 749
(Half-life)
- T. A. EASTWOOD, F. BROWN, R. D. WERNER. Can. J. Phys. 42 (1964) 218
(Gamma Branching ratio)
- S. C. ANSPACH, L. M. CAVALLO, S. B. GARFINKEL, J. M. R. HUTCHINSON, C. N. SMITH. Report NP - 15663 (1965)
(Half-life)
- B. DENECKE, E. DE ROOST, A. SPERNOL, R. VANINBROUKX. Nucl. Sci. Eng. 28 (1967) 305
(Gamma Branching ratio)
- J. W. JOHNSTON. Report BNWL - B -369 (1974)
(Half-life)
- R. A. MEYER, J. E. FONTANILLA, N. L. SMITH, C. F. SMITH, R. C. RAGAINI. Phys. Rev. C21 (1980) 2590
(Energy and emission probability)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- H. SIEVERS. Nucl. Data Sheets 62 (1991) 271
(Multipolarities, mixing ratio, half-life)
- M. P. UNTERWEGER, D. D. HOPPES, F. J. SCHIMA. Nucl. Instrum. Methods Phys. Res. A312 (1992) 349
(Half-life)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A565 (1993) 1
(Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Research A369 (1996) 527
(Atomic Data)
- L. ERBESZKORN, A. SZORÉNYI, J. VAGVOLGYI. Nucl. Instrum. Methods Phys. Res. A363 (1996) 463
(Half-life)
- M. P. UNTERWEGER. Appl. Rad. Isotopes 56 (2002) 125
(Half-life)
- H. SCHRADER. Appl. Rad. Isotopes 60, 2-3 (2004) 317
(Half-life)





1 Decay Scheme

The Sr-85 disintegrates by electron capture to the Rb-85 excited levels, mainly to the 514 keV level.
Le strontium 85 se désintègre par capture électronique vers les niveaux excités de rubidium 85, principalement vers celui de 514 keV.

2 Nuclear Data

$$T_{1/2}({}^{85}\text{Sr}) : 64,850 \quad (7) \quad \text{d}$$

$$Q^+({}^{85}\text{Sr}) : 1065 \quad (3) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	<i>P_K</i>	<i>P_L</i>	<i>P_M</i>
ε _{0,4}	196 (3)	0,0129 (4)	1st Forbidden	9,1	0,8610 (16)	0,1146 (13)	0,0214 (4)
ε _{0,3}	551 (3)	99,2 (4)	Allowed	6,2	0,8718 (15)	0,1059 (12)	0,0195 (4)
ε _{0,2}	784 (3)	0,0005	Unique 3rd Forbidden	11,8			
ε _{0,1}	914 (3)	0,0005	3rd Forbidden	11,5			
ε _{0,0}	1065 (3)	0,8 (4)	Unique 1st Forbidden	9,3	0,85 (3)	0,12 (3)	0,03 (1)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	<i>P_{γ+ce}</i> × 100	Multipolarity	<i>α_K</i>	<i>α_L</i> (10 ⁻³)	<i>α_M</i> (10 ⁻³)	<i>α_T</i>
γ _{2,1} (Rb)	129,826 (10)	0,0005	(M1)	0,0635 (19)	7,17 (21)	1,208 (36)	0,0721 (22)
γ _{1,0} (Rb)	151,160 (6)	0,0012 (9)	M1+E2	0,0430 (13)	4,85 (15)	0,817 (25)	0,0488 (15)
γ _{4,3} (Rb)	354,97 (5)	0,0005 (2)	(E1)	0,00225 (7)	0,242 (7)	0,0405 (12)	0,00253 (8)
γ _{3,1} (Rb)	362,847 (6)	0,0014 (3)	(E3)	0,0292 (9)	3,97 (12)	0,67 (2)	0,0339 (10)
γ _{3,0} (Rb)	514,007 (3)	99,2 (4)	M2	0,00635 (19)	0,722 (22)	0,1219 (37)	0,00721 (22)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L (10^{-3})	α_M (10^{-3})	α_T
$\gamma_{4,1}$ (Rb)	717,81 (5)	0,00032 (3)	(E2)	0,00109 (3)	0,120 (4)	0,0202 (6)	0,00124 (4)
$\gamma_{4,0}$ (Rb)	868,98 (5)	0,0121 (4)	M1+E2	0,00065 (2)	0,070 (2)	0,01176 (35)	0,00073 (3)

3 Atomic Data

3.1 Rb

ω_K	:	0,674	(4)
$\bar{\omega}_L$	:	0,0237	(6)
n_{KL}	:	1,125	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	13,3359	51,95	
	K α_1	13,3955	100	
	K β_3	14,9519	}	
	K β_1	14,9614		
	K β_5''	15,085	}	24,34
	K β_2	15,1856		
	K β_4	15,205	}	2,82
	X _L	L ℓ		1,48
L γ		- 2,05		

3.1.2 Auger Electrons

	Energy keV	Relative probability	
Auger K	KLL	10,987 – 11,503	100
	KLX	12,782 – 13,381	35,8
	KXY	14,556 – 15,172	3,2
Auger L	1,1 – 2,0		

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Rb)	1,1 - 2,0	96,5 (4)
e _{AK}	(Rb)		28,6 (4)
	KLL	10,987 - 11,503	}
	KLX	12,782 - 13,381	}
	KXY	14,556 - 15,172	}
ec _{3,0 K}	(Rb)	498,811 (12)	0,630 (19)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Rb)	1,48 — 2,05	2,30 (5)	
XK α_2	(Rb)	13,3359	17,16 (17)	} K α
XK α_1	(Rb)	13,3955	33,04 (29)	}
XK β_3	(Rb)	14,9519	}	
XK β_1	(Rb)	14,9614	}	K' β_1
XK β_5''	(Rb)	15,085	}	
XK β_2	(Rb)	15,1856	}	
XK β_4	(Rb)	15,205	}	K' β_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{2,1}$ (Rb)	129,826 (10)	0,0005
$\gamma_{1,0}$ (Rb)	151,160 (6)	0,0012 (9)
$\gamma_{4,3}$ (Rb)	354,97 (5)	0,0005 (2)
$\gamma_{3,1}$ (Rb)	362,847 (6)	0,0014 (3)
$\gamma_{3,0}$ (Rb)	514,0048 (22)	98,5 (4)
$\gamma_{4,1}$ (Rb)	717,81 (5)	0,00032 (3)
$\gamma_{4,0}$ (Rb)	868,98 (5)	0,0121 (4)

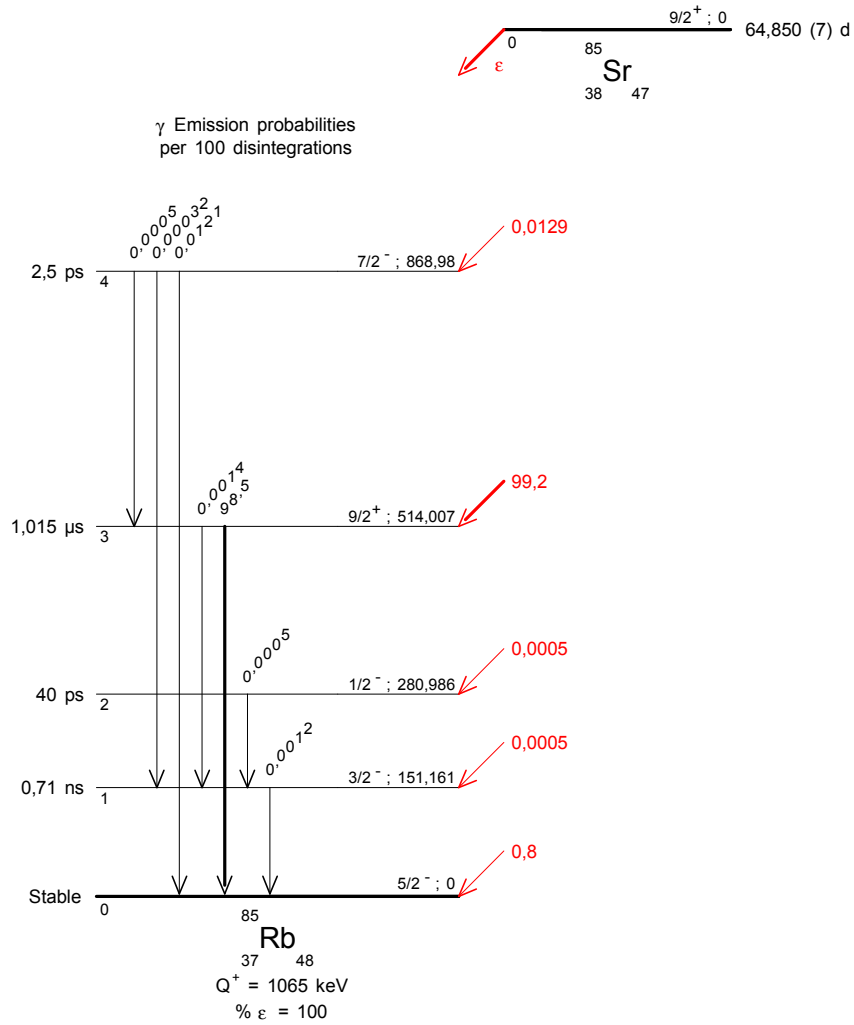
6 Main Production Modes

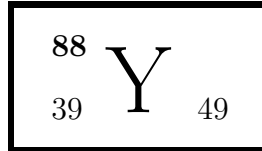
- { Sr – 84(n,γ)Sr – 85 σ : 0,35 (7) barns
Possible impurities : Sr – 89, Rb – 84
- { Sr – 84(n,γ)Sr – 85m σ : 0,60 (6) barns
Possible impurities : Sr – 89, Rb – 84
- { Sr – 85m(I.T.)Sr – 85
Possible impurities : Sr – 85m, half – life : 68 min

7 References

- L.A.DUBRIDGE, J.MARSHALL. Phys. Rev. 58 (1940) 7
(Half-life)
- A.W.SUNYAR, J. W. MIHELICH, G. SCHARFF-GOLDHABER, M. GOLDHABER, N.S. WALL, M. DEUTSCH. Phys. Rev. 86 (1952) 1023
(Conv. Elec. emission probabilities)
- G.HERRMANN, F.STRASSMANN. Z. Naturforsch. 11a (1956) 946
(Half-life)
- J.G.SIEKMAN. Nucl. Phys. 2 (1956) 254
(Half-life, 514 keV level)
- H.W.WRIGHT, E.L. WYATT, S.A REYNOLDS, W.S.LYON, T.H. HANDLEY. Nucl. Sci. Eng. 2 (1957) 427
(Half-life)
- M.K.RAMASWAMY, B.A.BISHARA, P.S.JASTRAM. Bull. Am .Phys. Soc. 7,4 (1962) 341
(Beta emission probabilities)
- A.R.SATTLER. Phys. Rev. 127 (1962) 854
(Half-life, Gamma-ray emission probabilities)
- K.E.G.LÖBNER. Nucl. Phys. 58 (1964) 49
(Half-life, 514 keV level)
- S.C.ANSPACH, L.M CAVALLO, S.B GARFINKEL, J.M.R HUTCHINSON, C.N.SMITH. NBS Misc. Publ. 260-9 (1965)
(Half-life)
- N.A.VARTANOV, P.S.SAMOILOV, Y.S.TSATUROV. Sov. J. Nucl. Phys. 3 (1966) 436
(Gamma-ray emission probabilities)
- J.A.BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- J.LEGRAND, J.P.BOULANGER, J.P.BRETHON. Nucl. Phys. A107 (1968) 177
(Gamma-ray energies)
- H.H.GROTHER, J.W. HAMMER, K.W. HOFFMANN. Z. Physik 225 (1969) 293
(K x-ray emission probabilities, Half-life, K fluorescence yield)
- M.MCDONNELL, M.K.RAMASWAMY. Nucl. Phys. A127 (1969) 531
(Q(EC))
- W.BAMBYNEK, D. REHER. Z. Physik 238 (1970) 49
(K x-ray emission probabilities, K fluorescence yield)
- I.F.BUBB, S.I.H.NAGUI, J.L.WOLFSON. Nucl. Phys. A167 (1971) 252
(Gamma-ray emission probabilities)
- N.B GOVE, M.J. MARTIN. At. Data Nucl. Data Tables 10 (1971) 205
(lg ft)
- G.H.MILLER, P.DILLARD, M.ECKHAUSE, R.E.WELSH. Nucl. Instrum. Methods 104 (1972) 11
(Half-life)
- J.F.EMERY, S.A REYNOLDS, E.I. WYATT, G.I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
(Half-life)
- F.LAGOUTINE, J. LEGRAND, C.PERROT, J.P. BRETHON, J. MOREL. Int. J. Appl. Radiat. Isotop. 23 (1972) 219
(Half-life)
- R.C.RAGAINI, C.F.SMITH, R.A MEYER. Bull. Am .Phys. Soc. 17 (1972) 444
(level energies)

- R.P.TORTI *et al.* Phys. Rev. 6C (1972) 1686
(Gamma-ray energies)
- J.ARAMINOWICZ, R.DRESLER. Report INR 1464 (1973) 14
(Half-life)
- E.BARNARD *et al.* Z. Physik 260 (1973) 197
(Spin and Parity)
- P.D.BOND, G.J.KUMBARTZKI. Nucl. Phys. A205 (1973) 239
(Spin and Parity, Gamma-ray emission probabilities)
- E.VATAI *et al.* Nucl. Phys. A219 (1974) 595
(Gamma-ray energies)
- J.S.MERRIT, F.H.GIBSON. Report AECL 5315 (1976) 37
(Half-life)
- W.W.PRATT. J. Inorg. Nucl. Chem. 39 (1977) 919
(Gamma-ray emission probabilities)
- F.P.LARKINS. At. Data Nucl. Data Tables 20 (1977) 311
(Auger electron energies)
- Y.YOSHIZAWA. report Jaeri-M 7567 (1978)
(Gamma-ray emission probabilities, Half-life, lg ft)
- F.RÖSEL, H.M.FRIES, K.ALDER, H.C.PAULI. At. Data Nucl. Data Tables 21 (1978) 110
(Conv. Elec. emission probabilities)
- D.J.THOMAS. Z. Physik A289 (1978) 51
(Half-life)
- R.G.HELMER, R.G.GREENWOOD, R.J.GEHRKE. Nucl. Instrum. Methods 155 (1978) 189
(Gamma-ray energies)
- S.K.BASU *et al.* J. Phys. G: Nucl. Phys. 5 (1979) 585
(Half-life, level energies)
- Y.YOSHIZAWA, H.INOUE, M.HOSHI, K.SHIZUMA, Y. IWATA, Y. IWATA. report Jaeri-M 8811 (1980)
(Half-life, Gamma-ray emission probabilities)
- H.HOUTERMANS, O.MILESEVIC, F.REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRIT. Report AECL-6692 (1980) 3
(Half-life)
- R.A.MEYER, J.E.FONTANILLA, N.L.SMITH. Phys. Rev. C21 (1980) 2590
(Gamma-ray energies)
- D.D.HOPES, J.M.R. HUTCHINSON, F.J. SCHIMA, M.P.UNTERWEGGER. NBS Special Publication 626 (1982)
85
(Half-life)
- H.KUMAHORA, H.INOUE, Y. YOSHIZAWA. Nucl. Instrum. Methods 206 (1983) 489
(Gamma ray energies, Gamma-ray emission probabilities)
- K.F. WALZ, K. DEBERTIN, H.SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- G.SCHUPP, H.J.NAGY. Phys. Rev. C29 (1984) 1414
(double K shell ionization)
- G.JERBIC-ZORK, K.ILAKOVAC, Z.KRECAK, V.HORVAT. Fizika 22 (1990) 413
(level energies, Gamma-ray emission probabilities)
- Y.YOSHIZAWA, H.INOUE. IAEA-Tecdoc 619 (1991) 73
(Gamma ray energies)
- H.SIEVERS. Nucl. Data Sheets 62 (1991) 271
(Gamma ray energies, main production modes, Half-life of excited levels)
- M.P. UNTERWEGGER, D.D.HOPES, F.J.SCHIMA. Nucl. Instrum. Methods Phys. Res. A312 (1992) 349
(Half-life)
- T.CHANG, S.WANG, H.WANG. Nucl. Instrum. Methods Phys. Res. A325 (1993) 196
(Gamma ray energies)
- G.AUDI, A.H.WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(K X-ray emission probabilities, KL vacancy numbers)
- E.SCHÖNFELD. Appl. Rad. Isotopes 9-11 (1998) 1353
(PK, PL, PM)
- R.G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
(Gamma ray energies)





1 Decay Scheme

Le Y-88 se désintègre par capture électronique et émission bêta plus vers des niveaux excités de Sr-88. Aucune transition vers le niveau fondamental de Sr-88 n'a été mise en évidence.

Y-88 decays by electron capture and beta plus emission towards excited levels of Sr-88. None transition towards the fundamental level of Sr-88 was shown.

2 Nuclear Data

$$T_{1/2}({}^{88}\text{Y}) : 106,626 \quad (21) \quad \text{d}$$

$$Q^+({}^{88}\text{Y}) : 3622,6 \quad (15) \quad \text{keV}$$

2.1 β^+ Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,1}^+$	764,5 (15)	0,204 (11)	Unique 1st Forbidden	9,7

2.2 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	P _K	P _L	P _{M+}
$\epsilon_{0,4}$	37,6 (15)	0,048 (18)	Allowed	6,9	0,72 (4)	0,23 (4)	0,047 (9)
$\epsilon_{0,3}$	404,0 (15)	0,023 (4)	Unique 1st Forbidden	9,4			
$\epsilon_{0,2}$	888,5 (15)	94,50 (23)	Allowed	7	0,8725 (15)	0,1050 (14)	0,0195 (5)
$\epsilon_{0,1}$	1776,5 (15)	5,23 (23)	Unique 1st Forbidden	9,8	0,65 (15)	0,20 (5)	

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K (10^{-4})	α_L (10^{-4})	α_T (10^{-4})	α_π (10^{-4})
$\gamma_{3,2}(\text{Sr})$	484,368 (26)	0,0009	E1	10,8	1,17	12,3	
$\gamma_{4,2}(\text{Sr})$	850,647 (24)	0,048 (18)	(M1,E2)	7,4 (7)	0,8 (1)	8,3 (8)	
$\gamma_{2,1}(\text{Sr})$	898,041 (4)	93,93 (23)	E1	2,77 (20)	0,29 (3)	3,15 (23)	
$\gamma_{3,1}(\text{Sr})$	1382,409 (26)	0,016 (3)	M1+0,3%E2	2,6 (3)	0,28 (3)	2,9 (3)	
$\gamma_{1,0}(\text{Sr})$	1836,073 (13)	99,38 (3)	E2	1,35 (14)	0,15 (2)	1,52 (15)	2,3 (2)
$\gamma_{2,0}(\text{Sr})$	2734,132 (15)	0,614 (25)	E3	1,1 (2)	0,2 (1)	1,3 (2)	4,4 (4)
$\gamma_{3,0}(\text{Sr})$	3218,546 (49)	0,007 (2)	E2	0,55	0,1	0,65	

3 Atomic Data

3.1 Sr

ω_K	:	0,696	(4)
$\bar{\omega}_L$	:	0,0262	(7)
n_{KL}	:	1,102	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	14,098	52,05	
	K α_1	14,1652	100	
	K β_3	15,8252	}	
	K β_1	15,8359	}	
	K β_5''	15,969	}	24,69
	K β_2	16,0847	}	
	K β_4	16,104	}	3,21
	X _L	L ℓ	1,6	
L γ		- 2,2		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	11,59 – 12,13	100
KLX	13,50 – 14,14	36,7
KXY	15,39 – 16,07	3,37
Auger L	1,2 – 2,1	

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Sr)	1,2	- 2,1	102,9 (10)
e _{AK}	(Sr)			26,1 (5)
	KLL	11,59	- 12,13	}
	KLX	13,50	- 14,14	}
	KXY	15,39	- 16,07	}
ec _{1,0} ±	(Sr)	814,058	(15)	0,0228 (20)
ec _{2,1} K	(Sr)	881,936	(4)	0,0260 (19)
ec _{2,1} L	(Sr)	895,825	- 896,101	0,00272 (28)
ec _{2,0} ±	(Sr)	1712,080	(18)	0,00027 (4)
ec _{1,0} K	(Sr)	1819,968	(13)	0,0134 (14)
ec _{1,0} L	(Sr)	1833,857	- 1834,133	0,00149 (20)
ec _{2,0} K	(Sr)	2718,027	(15)	0,000068 (13)
ec _{2,0} L	(Sr)	2731,916	- 2732,192	0,000012 (6)
β _{0,1} ⁺	max:	764,5	(15)	0,204 (11)
β _{0,1} ⁺	avg:	359,4	(2)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Sr)	1,6 — 2,2	2,77 (8)	
XK α_2	(Sr)	14,098	17,30 (22)	} K α
XK α_1	(Sr)	14,1652	33,2 (4)	
XK β_3	(Sr)	15,8252	}	K β'_1
XK β_1	(Sr)	15,8359	}	
XK β_5''	(Sr)	15,969	}	
XK β_2	(Sr)	16,0847	}	
XK β_4	(Sr)	16,104	}	K β'_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.	
$\gamma_{3,2}$ (Sr)	484,368 (26)	0,0009	
γ^\pm	511	0,408 (22)	
$\gamma_{4,2}$ (Sr)	850,643 (24)	0,048 (18)	
$\gamma_{2,1}$ (Sr)	898,036 (4)	93,90 (23)	
$\gamma_{3,1}$ (Sr)	1382,397 (26)	0,016 (3)	
$\gamma_{1,0}$ (Sr)	1836,052 (13)	99,32 (3)	
$\gamma_{2,0}$ (Sr)	2734,068 (14)	0,614 (25)	
$\gamma_{3,0}$ (Sr)	3218,419 (22)	0,007 (2)	

6 Main Production Modes

$$\left\{ \begin{array}{l} \text{Sr} - 88(\text{p,n})\text{Y} - 88 \\ \text{Possible impurities : Y} - 84, \text{Y} - 85, \text{Y} - 86, \text{Y} - 87, \text{Rb} - 83, \text{Rb} - 84, \text{Rb} - 86 \end{array} \right.$$

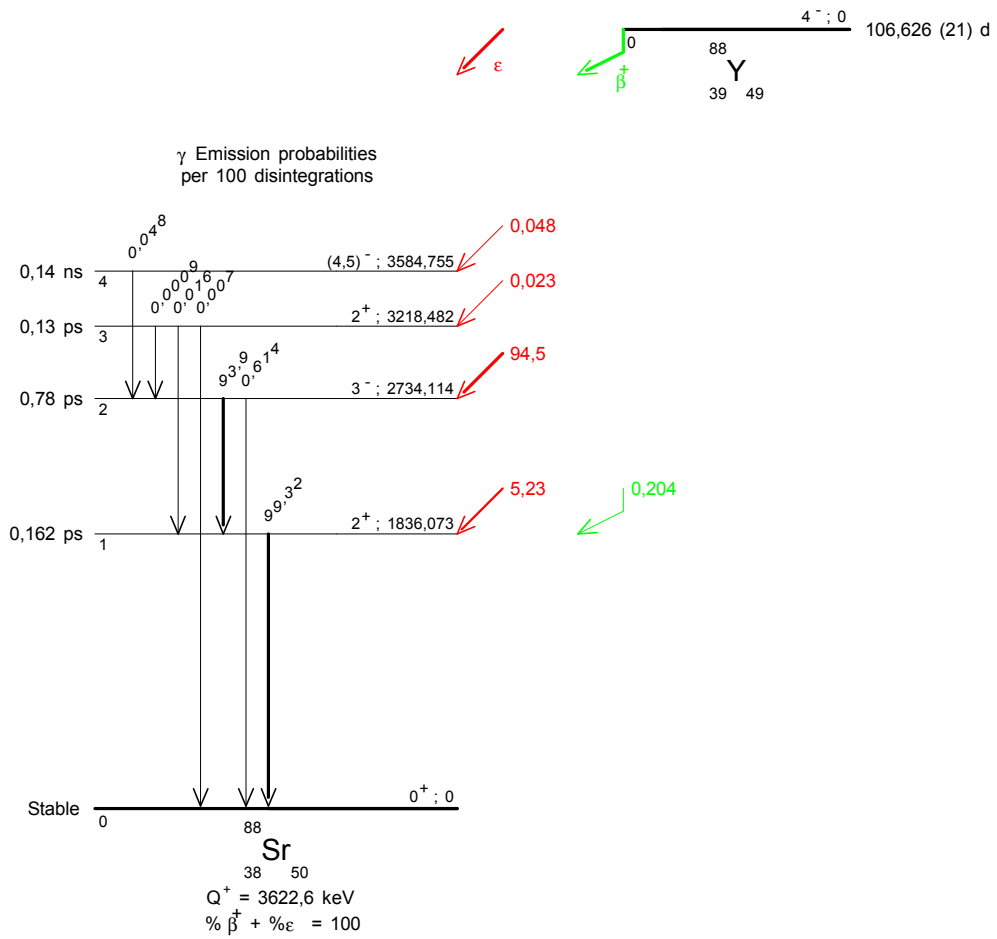
$$\left\{ \begin{array}{l} \text{Sr} - 88(\text{d,2n})\text{Y} - 88 \\ \text{Possible impurities : Y} - 84, \text{Y} - 87, \text{Sr} - 89 \end{array} \right.$$

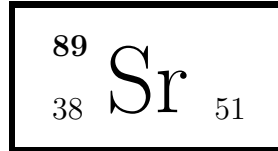
7 References

- L. A. DuBRIDGE, J. MARSHALL. Phys. Rev. 58 (1940) 7
(T1/2)

- W. C. PEACOCK, J. W. JONES. Report AECD 1812 (1948)
(T1/2, Beta emission intensities)
- M. K. RAMASWAMY, P. S. JASTRAM. Nucl. Phys. 19 (1960) 243
(Max. beta plus energy, T1/2)
- R. W. PEELE. Report ORNL 3016 (1960) 110
(Gamma-ray emission intensities)
- J. I. RHODE, O. E. JOHNSON, W. G. SMITH. Phys. Rev. 129 (1963) 815
(Max. beta plus energy, T1/2)
- S. SHASTRY, R. BHATTACHARYYA. Nucl. Phys. 55 (1964) 397
(P gamma)
- R. L. ROBINSON, P. H. STELSON, F. K. MCGOWAN, J. L. C. FORD, JR. , W. T. MILNER. Nucl. Phys. 74 (1964) 281
(Gamma ray energies)
- J. H. HAMILTON ET AL.. Phys. Lett. 19 (1966) 682
(K ICC, T ICC)
- M. SAKAI, T. YAMAZAKI, J. M. HOLLANDER. Nucl. Phys. 84 (1966) 302
(Gamma-ray emission intensities, Elec. Capt. Probabilities)
- A. V. RAMAYYA, J. H. HAMILTON, S. M. BRAHMAVAR , J. J. PINAJIAN. Phys. Lett. 24B (1967) 49
(Gamma ray energies)
- W. W. BLACK, R. L. HEATH. Nucl. Phys. A90 (1967) 650
(Gamma ray energies)
- D. H. WHITE, D. J. GROVES. Nucl. Phys. A91 (1967) 453
(Gamma ray energies)
- A. LUUKKO, P. HOLMBERG. Comm. Phys.-math. 33 (1968) 1
(angular corr., spin and parity of levels)
- S. C. ANSPACH, L. M. CAVALLO, S. B. GARFINKEL, J. M. R. HUTCHINSON, C. N. SMITH. private Mitteilung (1968)
(T1/2)
- J. LEGRAND, J. P. BOULANGER , J. P. BRETHON. Nucl. Phys. A107 (1968) 177
(Gamma ray energies)
- R. GUNNINK, R. A. MEYER, J. B. NIDAY , R. P. ANDERSON. Nucl. Instrum. Methods 65 (1968) 26
(Gamma ray energies)
- H. LYCKLAMA, N. P. ARCHER, T. J. KENNETH. Can. J. Phys. 47 (1969) 393
(Gamma ray energies, Spin and Parity)
- M. G. STRAUSS, F. R. LENKSZUS , J. J. EICHHOLZ. Nucl. Instrum. Methods 76 (1969) 285
(Gamma ray energies)
- H. H. GROTHEER, J. W. HAMMER, K. W. HOFFMANN. Z. Physik 225 (1969) 293
(Beta plus emission probabilities)
- J. KERN. Nucl. Instrum. Methods 79 (1970) 233
(Gamma ray energies)
- C. J. ALLAN. Nucl. Instrum. Methods 91 (1971) 117
(ICC, Internal-pair formation coefficient)
- L. J. JARDINE. Nucl. Instrum. Methods 96 (1971) 259
(Gamma-ray emission intensities)
- N. B. GOVE, M. J. MARTIN. Nuclear Data Tables 10 (1971) 205
(log ft)
- W. BAMBYNEK, D. REHER. Z. Physik 264 (1973) 253
(K fluorescence yield)
- A. HESS, H. SCHNEIDER. Z. Physik 262 (1973) 231
(mixing ratio, angular correlations)
- G. ARDISSON, S. LARIBI, C. MARSOL. Nucl. Phys A223 (1974) 616
(Gamma-ray emission intensities)
- A. V. BARKOW, W. M. WINOGRADOW, A. W. SOLOTAWIN, W. M. MAKAROW, T. M. USYPKO. Program and abstracts of 24th Conference on nuclear spectroscopy and nuclear structure, Kharkov, 29 (1974) 58
(Beta plus emission probabilities, Internal-pair formation coefficient)
- R. L. HEATH. Gamma-ray Spectrum Catalogue. USAEL, Rep. ANCR 1000-2 (1974)
(Gamma ray energies, Gamma-ray emission intensities)
- F. LAGOUTINE, J. LEGRAND, C. BAC. Int. J. Appl. Radiat. Isot. 26 (1975) 131
(T1/2)

- M. BORMANN, H.-K. FEDDERSEN, H.-H. HÖLSCHER, W. SCOBEL, H. WAGNER. Z. Physik A277 (1976) 203 (T1/2)
- N. J. AMINARASCHWILI, V. A. DZHASHI, W. L. TSCHICHLADSE, S. D. SHAWGULIDSE. Conference: 27th Annual conference on nuclear spectroscopy and nuclear structure, Tashkent, USSR, 22-25 (1977) (K ICC)
- W. BAMBYNEK ET AL.. Rev. Mod. Phys. 49 (1977) 77 (K fluorescence yield)
- A. A. KONSTANTINOV, T. E. SAZONOVA, S. W. SEPMAN.. Conference: 27th Annual conference on nuclear spectroscopy and nuclear structure, Tashkent, USSR, 22- (1977) 6 (T1/2)
- N. M. ANTONEVA, V. M. VINDGRADOV, E. P. GRIGOREV, P. P. DMITRIEV, A. V. ZOLOTAVIN, G. S. KATYKHIN, N. KRASNOV, V. N. MAKAROV. Bull. Ac. Sci. USSR, Phys. Ser. 43 (1979) 155 (Beta plus emission probabilities, ICC, Gamma ray energies, Gamma-ray emission intensities)
- R. C. GREENWOOD, R. G. HELMER, R. J. GEHRKE. Nucl. Instrum. Methods 159 (1979) 465 (Gamma ray energies)
- R. G. HELMER, J. W. STARNER, M. E. BUNKER. Nucl. Instrum. Methods 158 (1979) 489 (Gamma ray energies)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153 (T1/2)
- Y. YOSHIZAWA, Y. IWATA, T. KAKU, T. KATOH, J. RUAN, T. KOJIMA, Y. KAWADA. Nucl. Instrum. Methods 174 (1980) 109 (Gamma-ray emission intensities)
- K. DEBERTIN, U. SCHÖTZIG, K. F. WALZ. NBS-SP 626 (1982) 101 (T1/2, Gamma-ray emission intensities)
- D. D. HOPPES, J. M. R. HUTCHINSON, F. J. SCHIMA, M. P. UNTERWEGER. NBS-SP 626 (1982) 85 (T1/2, Gamma-ray emission intensities)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191 (T1/2)
- H.-W. MÜLLER. Nuclear Data Sheets 54 (1988) 1 (lg ft)
- U. SCHÖTZIG. Nucl. Instrum. Methods A286 (1990) 523 (Gamma-ray emission intensities)
- A. A. KONSTANTINOV, T. E. SAZONOVA, S. V. SEPMAN, A. V. ZANEVSKY, N. I. KARMALITSYN. Nucl. Instrum. Methods A339 (1994) 200 ()
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527 (Atomic Data)
- R. H. MARTIN, K. I. W. BURNS, J. G. V. TAYLOR. Nucl. Instrum. Methods A390 (1997) 267 (T1/2)
- M.N. AMIOT, J. BOUCHARD, M.-M. BÉ, J. B. ADAMO. To be published in Appl. Rad. Isotopes (2004) (T1/2)





1 Decay Scheme

Sr-89 disintegrates by beta minus emission mainly to the Y-89 fundamental level. A small fraction 0,0096% populates the isomeric level at 909 keV in Y-89.

Le strontium 89 se désintègre par émission bêta moins principalement vers le niveau fondamental de l'yttrium 89 ainsi que vers le niveau excité de 909 keV avec une intensité de 0,0096 %.

2 Nuclear Data

$$T_{1/2}({}^{89}\text{Sr}) : 50,57 \quad (3) \quad \text{d}$$

$$Q^{-}({}^{89}\text{Sr}) : 1495,1 \quad (22) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,1}^{-}$	586,1 (22)	0,00964 (6)	2nd Forbidden	11,1
$\beta_{0,0}^{-}$	1495,1 (22)	99,99036 (4)	Unique 1st Forbidden	9,4

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_T
$\gamma_{1,0}(Y)$	909,0 (1)	0,00964 (6)	(M4)	0,00746 (23)	0,00091 (3)	0,00850 (26)

3 Atomic Data

3.1 Y

ω_K	:	0,716	(4)
$\bar{\omega}_L$	:	0,0289	(7)
n_{KL}	:	1,081	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	14,8829	52,15	
	K α_1	14,9585	100	
	K β_3	16,7259	}	
	K β_1	16,7381		
	K β_5''	16,88	}	25,11
	K β_2	17,0156		
	K β_4	17,0362	}	3,47

4 Electron Emissions

	Energy keV	Electrons per 100 disint.
$\beta_{0,1}^-$	max: 586,1 (22)	0,00964 (6)
$\beta_{0,1}^-$	avg: 189,1 (9)	
$\beta_{0,0}^-$	max: 1495,1 (22)	99,99036 (4)
$\beta_{0,0}^-$	avg: 584,6 (10)	

5 Photon Emissions

5.1 X-Ray Emissions

	Energy keV	Photons per 100 disint.	
XK α_2 (Y)	14,8829		} K α
XK α_1 (Y)	14,9585	0,086 (7)	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(Y)$	909,0 (1)	0,00956 (6)

6 Main Production Modes

{ Sr – 88(n, γ)Sr – 89 σ : 0,058 (4) barns
Possible impurities : Sr – 85, Sr – 90

{ Fission product
Possible impurities : Sr – 90

Rb – 89(β^-)

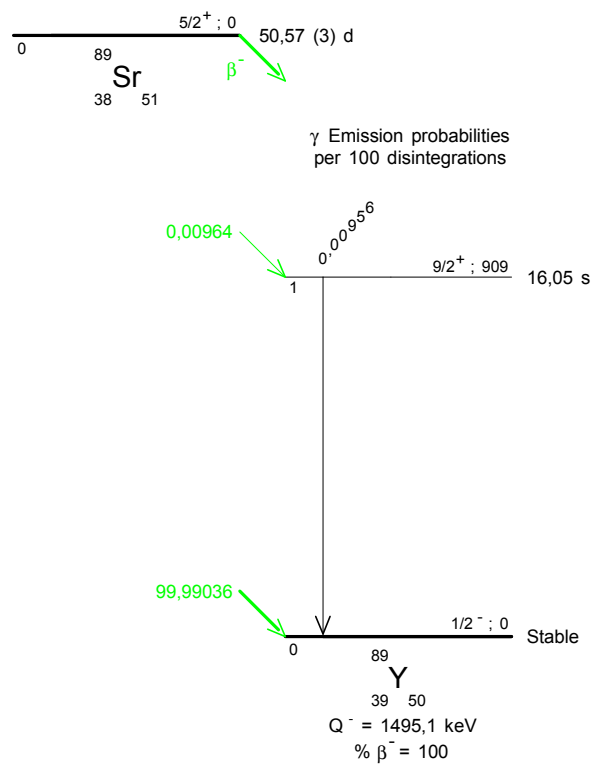
Sr – 87(t,p)Sr – 89

Kr – 86(α ,n γ)Sr – 89

7 References

- G. HERRMANN. Z. f. Elektrochemie 58 (1954) 626
(Half-life)
- W. S. LYON, R. R. RICKARD. Phys. Rev. 100 (1955) 112
(Half-life)
- C. P. SWANN, F. R. METZGER. Phys. Rev. 100 (1955) 1329
(Half-life isomeric level)
- A. BISI, S. TERRANI, L. ZAPPA. Il Nuovo Cimento II (1955) 1297
(Beta emission energies)
- G. HERRMANN, F. STRASSMANN. Z. Naturforsch. 10A (1955) 146
(Half-life)
- A. KJELBERG, A. C. PAPAS. Nucl. Phys. 1 (1956) 322
(Half-life)
- R. G. OSMOND, N. J. OWERS. J. Inorg. Nucl. Chem. 9 (1959) 96
(Half-life)
- A. R. SATTLER. Nucl. Phys. 36 (1962) 648
(Half-life)

- K. F. FLYNN, L. G. GLENDENIN , E. E. STEINBERG. Nucl. Sci. Eng. 22 (1965) 416
(Half-life)
- S. C. ANSPACH, L. M. CAVALLO, S. B. GARFINKEL, J. M. R. HUTCHINSON, C. N. SMITH. Report NP-15663 (1965)
(Half-life)
- D. A. MARSDEN, L. YAFFEE. Can. J. Chem. 43 (1965) 249
(Half-life)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(E(KX))
- E. L. ROBINSON, R. C. HAGENAUER , E. EICHLER. Nucl. Phys. A123 (1969) 471
(Gamma ray energies, Gamma-ray emission intensities)
- F. K. WOHN, W. L. TALBERT JR. Nucl. Phys. A146 (1970) 33
(Beta emission energies)
- S. BABA, H. BABA , H. NATSUME. J. Inorg. Nucl. Chem. 33 (1971) 589
(Half-life)
- F. LAGOUTINE, J. LEGRAND, C. PERROT, J. P. BRETHON , J. MOREL. Int. J. Appl. Radiat. Isotop. 23 (1972) 219
(Half-life)
- H. H. HANSEN, K. PARTHASARADHI. Phys. Rev. C9 (1974) 1143
(X-ray emission intensities)
- F. P. LARKINS. At. Data Nucl. Data Tables 20 (1977) 313
(Auger electron energies)
- F. RÖSEL, H. M. FRIES, K. ALDER, H. C. PAULI. At. Data Nucl. Data Tables 21 (1978) 91
(ICC)
- J. S. MERRITT, K. M. OPHEL, A. R. RUTLEDGE , L. V. SMITH. Report AECL 7102 (1980) 32
(Gamma-ray emission intensities)
- J. S. MERRITT, A. R. RUTLEDGE, L. V. SMITH. Int. J. Appl. Radiat. Isotop. 33 (1982) 77
(Gamma-ray emission intensities, Gamma ray energies)
- T. SAYIBABA, K. NARASIMHA MURTY , C. R. RAO. Il Nuovo Cimento 97A (1987) 365
(Bremsstrahlung)
- B. R. S. BABU, P. VENKATARAMAIAH , H. SANJEEVIAH. Nucl. Instrum. Methods Phys. Res. A255 (1987) 96
(Bremsstrahlung)
- H. SIEVERS. Nuclear Data Sheets 58 (1989) 351
(production modes, spins, parities)
- U. SCHÖTZIG. Nucl. Instrum. Methods Phys. Res. A286 (1990) 523
(Gamma-ray emission intensities)
- M. BASHA, E. I. KHALIL, M. HUSSEIN, H. RAGAB. Indian J. Phys. 65A (1991) 120
(Bremsstrahlung)
- S. DHALIWAL, M. S. POWAR, M. SINGH. J. Phys. G Nucl. Part. Phys. 20 (1994) 135
(Bremsstrahlung)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(Atomic Data)
- F. J. SCHIMA. Appl. Rad. Isotopes 49 (1998) 1359
(Gamma-ray emission intensities)
- M. N. AMIOT, J. BOUCHARD, M.-M. BÉ, J. B. ADAMO. To be published in Appl. Rad. Isotopes (2004)
(Half-life)





1 Decay Scheme

Nb-93m disintegrates by 100 % gamma transition to the ground state of the stable nuclide Nb-93.
Le niobium 93m se désexcite à 100% par transition gamma vers le noyau stable de niobium 93.

2 Nuclear Data

$T_{1/2}(^{93}\text{Nb}^m)$: 16,12 (15) a

2.1 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K (10^5)	α_L (10^5)	α_M (10^5)	α_T (10^5)
$\gamma_{1,0}(\text{Nb})$	30,77 (2)	100	M4	0,262 (8)	1,216 (40)	0,269 (8)	1,79 (5)

3 Atomic Data

3.1 Nb

ω_K : 0,751 (4)
 $\bar{\omega}_L$: 0,0347 (9)
 n_{KL} : 1,045 (4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	Kα ₂	16,5213	52,36	
	Kα ₁	16,6152	100	
	Kβ ₃	18,607	}	
	Kβ ₁	18,623	}	
	Kβ ₅ ^{''}	18,78	}	25,8
	Kβ ₂	18,952	}	
	Kβ ₄	18,982	}	3,86
	X _L			
L ℓ	1,90			
L γ	- 2,66			

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	13,49 – 14,14	100
KLX	15,79 – 16,58	39,1
KXY	18,02 – 18,91	3,81
Auger L	1,4 – 2,6	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Nb)	1,4 - 2,6	80,4 (30)
e _{AK}	(Nb)		3,64 (11)
	KLL	13,49 - 14,14	}
	KLX	15,79 - 16,58	}
	KXY	18,02 - 18,91	}
ec _{1,0 T}	(Nb)	11,78 - 30,74	99,999441 (16)
ec _{1,0 K}	(Nb)	11,78 (2)	14,6 (3)
ec _{1,0 L}	(Nb)	28,07 - 28,40	68 (3)
ec _{1,0 M}	(Nb)	30,30 - 30,56	15,0 (9)
ec _{1,0 N}	(Nb)	30,71 - 30,74	2,4 (1)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Nb)	1,90 — 2,66	2,89 (13)	
XK α_2	(Nb)	16,5213	3,16 (7)	} K α
XK α_1	(Nb)	16,6152	6,04 (12)	}
XK β_3	(Nb)	18,607	}	
XK β_1	(Nb)	18,623	}	K' β_1
XK β_5''	(Nb)	18,78	}	
XK β_2	(Nb)	18,952	}	
XK β_4	(Nb)	18,982	}	K' β_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Nb})$	30,77 (2)	0,000559 (16)

6 Main Production Modes

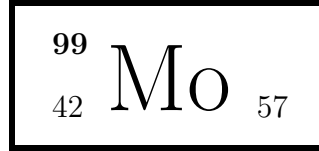
- { Nb – 93(n,n')Nb – 93m
Possible impurities : Nb – 92m, Nb – 94, Nb – 95
- { Mo – 92(n,γ)Mo – 93
Possible impurities : none
- { Separation from Zr – 93 + Nb – 93m (Fission product)
Possible impurities : Nb – 94

7 References

- R. P. SCHUMAN. Phys. Rev. 96 (1954) 121
(Half-life)
- K. HOHMUTH, G. MULLER, J. SCHINTHMEISTER. Nucl. Phys. 52 (1964) 590
(ICC subshell ratios)
- K. F. FLYNN, L. E. GLENDENIN, E. P. STEINBERG. Nucl. Sci. Eng. 22 (1965) 416
(Half-life)
- K. F. FLYNN. Priv. comm. (1972)
(Gamma-ray energies)
- D. C. KOCHER. Nucl. Data Sheets 8 (1972) 527
(multipolarity)
- F. HEGEDUES. Report EUR 5667E 1 (1976) 757
(Half-life)
- M. JURCEVIC, A. LJUBICIC, D. RENDIC. Fizika 8 (1976) 81
(K ICC)
- F. P. LARKINS. At. Data Nuc. Data. Tables 20 (1977) 313
(Auger electron energies)
- R. L. LLORET. Radiochem. Radioanal. Letters 29 (1977) 165
(Half-life)
- J. MOREL, J.-P. PEROLAT, N. COURSOL. Comp. Rend. Acad. Sci. (Paris) B284 (1977) 223
(X-ray and gamma-ray energies and emission probabilities, K ICC)
- F. RÖSEL ET AL.. At. Data Nuc. Data. Tables 21 (1978) 92
(ICC)
- W. BAMBYNEK, D. REHER, R. VANINBROUKX. Proc. Int. Conf., Harwell, September 1978, OECD Nuclear Energy Agency, Paris (1978) 778
(KX-ray emission probabilities)
- R. VANINBROUKX. Liquid Scintillation Counting, Academic Press, New York 1 (1980) 43
(KX-ray emission probability)
- R. LLORET. Radiochem. Radioanal. Letters 50 (1981) 113
(Half-life)
- W. G. ALBERTS, R. HOLLNAGEL, K. KNAUF, W. PESSARA. NUREG/CP-0029, Gaithersburg 1 (1982) 433
(KX-ray emission probabilities)
- D. REHER. Int. J. Appl. Radiat. Isotop. 33 (1982) 537
(ICC subshell ratios, multipolarity)
- R. VANINBROUKX. Int. J. Appl. Radiat. Isotop. 34 (1983) 1211
(Half-life, KX-ray emission probability)
- R. J. GEHRKE, J. W. ROGERS, J. D. BAKER. Proc. 5th ASTM-EURATOM Symp. on React. Dos., Geesthacht, FRG, 24-28 September 1984, Dordrecht 1 (1985) 319
(KX-ray emission probability)
- F. LAGOUTINE, N. COURSOL, J. LEGRAND. Table de Radionucléides, ISBN-2-7272-0078-1. LMRI, 1982-1987 (1987)
(ICC, multipolarity)
- B. M. COURSEY. Nucl. Instrum. Methods A290 (1990) 537
(KX-ray emission probability)
- W. BAMBYNEK, T. BARTA, R. JEDLOVSZKY, P. CHRISTMAS, N. COURSOL, K. DEBERTIN, R. G. HELMER, A. L. NICHOLS, F. J. SCHIMA, Y. YOSHIZAWA. Report TECDOC-619, IAEA (1991)
(KX-ray emission probabilities)

- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic data)
- E. BAGLIN. Nucl. Data Sheets 80 (1997) 1
(Decay scheme)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6 11-1999-1 (1999)
(Atomic data)
- V. A. ZHELTONOZHISKY, A. G. ZELINSKY, YU. M. SHEVCHENKO, E. G. SHEMCHUK. Proc. 49th Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, Dubna (1999) 100
(Electron, X-ray and gamma-ray emission probabilities, K ICC)
- N. COURSOL, V. M. GOROZHANKIN, E. A. YAKUSHEV, C. BRIANCON, Ts. VYLOV. Appl. Rad. Isot. 52 (2000) 557
(ICC)





1 Decay Scheme

Mo-99 disintegrates to the Tc-99 excited levels by beta minus emissions.

The 142 keV excited level (Tc-99m) has a half-life of 6,0082 h. At the equilibrium ($t > 60$ h), the Tc-99m activity in relation to those of Mo-99 is:

Le Mo-99 se désintègre par émission bêta moins vers les niveaux excités de Tc-99.

Une proportion $p = 87,6$ (19)% de désintégrations conduit au niveau excité de 142 keV (Tc-99m) de 6,0082 heures de période. Ce niveau excité est alimenté directement par émission bêta moins (82,1 (15)) % et aussi par des transitions gamma.

A l'équilibre ($t > 60$ heures) l'activité de Tc-99m par rapport à celle de Mo-99 s'écrit :

$$A(\text{Tc-99m}) / A(\text{Mo-99}) = p \times T_{1/2}(\text{Mo-99}) / [T_{1/2}(\text{Mo-99}) - T_{1/2}(\text{Tc-99m})] = 0,963(21)$$

$$T_{1/2}(\text{Mo-99}) / [T_{1/2}(\text{Mo-99}) - T_{1/2}(\text{Tc-99m})] = 1,1005 \quad (8)$$

with $p = 0,876(19)$

For this evaluation Mo-99 and Tc-99m are considered in equilibrium

Pour cette évaluation Mo-99 et Tc-99m sont considérés à l'équilibre.

2 Nuclear Data

$T_{1/2}({}^{99}\text{Mo})$	:	2,7479	(5)	d
$T_{1/2}({}^{99}\text{Tc})$	:	214	(8)	10^3 a
$Q^{-}({}^{99}\text{Mo})$	:	1357,2	(10)	keV

2.1 β^{-} Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,15}^{-}$	158,3 (10)	0,0021 (3)	Allowed	8,65
$\beta_{0,14}^{-}$	185,2 (10)	0,0016 (4)	Allowed	8,91
$\beta_{0,13}^{-}$	215,3 (10)	0,111 (3)	Allowed	7,39
$\beta_{0,12}^{-}$	228,1 (10)	0,011 (1)	1st Forbidden	8,5
$\beta_{0,11}^{-}$	285 (1)	0,0027 (7)	2nd Forbidden	

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,10}^-$	353,1 (10)	0,134 (5)	1st Forbidden	7,97
$\beta_{0,9}^-$	436,6 (10)	16,45 (30)	Allowed	6,21
$\beta_{0,6}^-$	685,7 (10)	0,052 (5)	1st Forbidden	9,46
$\beta_{0,5}^-$	822,8 (10)	0,0010 (2)		
$\beta_{0,4}^-$	848,1 (10)	1,18 (3)	1st Forbidden	8,38
$\beta_{0,2}^-$	1214,5 (10)	82,1 (15)	1st Forbidden	7,1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{2,1}(\text{Tc})$	2,1726 (4)	86,8 (19)	E3			119 (3).10 ⁸	135 (4).10 ⁸
$\gamma_{3,1}(\text{Tc})$	40,5833 (2)	5,30 (19)	M1+1,4(2)%E2	3,50 (8)	0,560 (13)	0,104 (3)	4,19 (10)
$\gamma_{1,0}(\text{Tc})$	140,511 (1)	92,1 (19)	M1+3,2(3)%E2	0,104 (3)	0,0129 (4)	0,00236 (7)	0,119 (3)
$\gamma_{2,0}(\text{Tc})$	142,683 (1)	0,88 (6)	M4	29,3 (6)	9,35 (20)	1,86 (6)	40,9 (8)
$\gamma_{9,7}(\text{Tc})$	158,782 (15)	0,0145 (9)					
$\gamma_{6,4}(\text{Tc})$	162,370 (15)	0,0114 (6)					
$\gamma_{3,0}(\text{Tc})$	181,094 (2)	6,91 (13)	E2	0,125 (3)	0,0191 (4)	0,00353 (7)	0,149 (3)
$\gamma_{10,7}(\text{Tc})$	242,29 (8)	0,0014 (3)	(E1)	0,0093 (2)	0,00106 (2)	0,000193 (6)	0,0106 (2)
$\gamma_{9,6}(\text{Tc})$	249,03 (3)	0,0035 (4)					
$\gamma_{4,2}(\text{Tc})$	366,422 (15)	1,21 (3)	M1	0,00802 (16)	0,00093 (2)	0,000170 (4)	0,00915 (18)
$\gamma_{13,7}(\text{Tc})$	380,13 (8)	0,0092 (6)	M1+63(22)%E2	0,0091 (7)	0,00113 (8)	0,00021 (2)	0,0105 (8)
$\gamma_{5,2}(\text{Tc})$	391,7 (4)	0,0025 (6)					
$\gamma_{14,7}(\text{Tc})$	410,27 (10)	0,0016 (4)	M1+20%E2	0,0065 (6)	0,00076 (7)	0,00014 (1)	0,0074 (7)
$\gamma_{9,4}(\text{Tc})$	411,492 (15)	0,0162 (15)	E1	0,00226 (6)	0,000256 (5)	0,0000467 (9)	0,00257 (5)
$\gamma_{12,6}(\text{Tc})$	457,60 (3)	0,0075 (6)	M1+72%E2	0,0054 (4)	0,00066 (5)	0,00012 (1)	0,0063 (7)
$\gamma_{13,6}(\text{Tc})$	469,63 (7)	0,0027 (5)					
$\gamma_{6,2}(\text{Tc})$	528,790 (15)	0,0543 (21)	M1	0,00331 (7)	0,000379 (8)	0,00006930 (14)	0,00378 (8)
$\gamma_{11,5}(\text{Tc})$	537,79 (15)	0,0015 (5)					
$\gamma_{7,3}(\text{Tc})$	580,51 (5)	0,0036 (4)					
$\gamma_{8,3}(\text{Tc})$	581,30 (12)	0,00010 (5)					
$\gamma_{12,4}(\text{Tc})$	620,03 (5)	0,0024 (6)					
$\gamma_{8,1}(\text{Tc})$	621,773 (24)	0,0263 (10)	M1(+E2)	0,00227 (7)	0,000259 (8)	0,0000473 (14)	0,00258 (8)
$\gamma_{15,4}(\text{Tc})$	689,6 (9)	0,00042 (20)					
$\gamma_{9,3}(\text{Tc})$	739,503 (17)	12,14 (15)	E2+7,6%M1	0,00151 (3)	0,000178 (5)	0,000032 (1)	0,00173 (4)
$\gamma_{7,0}(\text{Tc})$	761,77 (8)	0,0023 (13)					
$\gamma_{9,2}(\text{Tc})$	777,924 (20)	4,28 (8)	E1	0,000518 (10)	0,0000580 (12)	0,00001057 (2)	0,000589 (12)
$\gamma_{10,3}(\text{Tc})$	822,976 (15)	0,1322 (30)	E1	0,000461 (9)	0,000052 (1)	0,0000094 (2)	0,000524 (11)
$\gamma_{10,2}(\text{Tc})$	861,2 (9)	0,0007 (2)					
$\gamma_{13,3}(\text{Tc})$	960,759 (20)	0,095 (3)	(M1)				0,0010 (1)
$\gamma_{12,2}(\text{Tc})$	986,45 (4)	0,0014 (1)					
$\gamma_{13,1}(\text{Tc})$	1001,348 (18)	0,0043 (4)	(E2)				0,0008 (1)
$\gamma_{15,3}(\text{Tc})$	1017,0 (5)	0,0007 (2)					
$\gamma_{15,2}(\text{Tc})$	1056,20 (5)	0,00103 (9)					
$\gamma_{11,0}(\text{Tc})$	1072,2 (4)	0,0012 (5)					

3 Atomic Data

3.1 Tc

ω_K	:	0,782	(4)
$\bar{\omega}_L$	:	0,0415	(10)
$\bar{\omega}_M$	:	0,0010	(1)
n_{KL}	:	1,014	(4)

3.1.1 X Radiations

		Energy keV		Relative probability
X _K	K α_2	18,251		52,59
	K α_1	18,3672		100
	K β_3	20,599	}	
	K β_1	20,619	}	
	K β_5''	20,789	}	26,58
	K β_2	21,005	}	
	K β_4	21,042	}	4,2
	X _L	L α	2,424 –	
	L β	2,537 –		

3.1.2 Auger Electrons

		Energy keV	Relative probability
Auger K	KLL	14,858 – 15,582	100
	KLX	17,418 – 18,365	40,3
	KXY	19,956 – 21,040	4,07
	Auger L	1,60 – 3,04	736

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Tc)	1,60	- 3,04	15,87 (26)
e _{AK}	(Tc)			3,1 (1)
	KLL	14,858	- 15,582	}
	KLX	17,418	- 18,365	}
	KXY	19,956	- 21,040	}
ec _{2,1} M	(Tc)	1,6286	- 1,9197	83 (2)
ec _{2,1} N	(Tc)	2,1046	- 2,1706	10,0 (4)
ec _{3,1} K	(Tc)	19,540	(3)	3,58 (12)
ec _{3,1} L	(Tc)	37,542	- 37,907	0,57 (2)
ec _{3,1} M	(Tc)	40,040	- 40,331	0,106 (4)
ec _{1,0} K	(Tc)	119,467	(1)	9,2 (3)
ec _{2,0} K	(Tc)	121,631	(25)	0,62 (5)
ec _{1,0} L	(Tc)	137,4685	- 137,8341	1,18 (4)
ec _{2,0} L	(Tc)	139,6325	- 139,9981	0,198 (17)
ec _{1,0} M	(Tc)	139,9670	- 140,2581	0,231 (7)
ec _{3,0} K	(Tc)	160,024	(8)	0,756 (28)
ec _{3,0} L	(Tc)	178,0255	- 178,3911	0,115 (4)
$\beta_{0,15}^-$	max:	158,3	(10)	0,0021 (3)
$\beta_{0,15}^-$	avg:	43,3	(4)	
$\beta_{0,14}^-$	max:	185,2	(10)	0,0016 (4)
$\beta_{0,14}^-$	avg:	51,0	(4)	
$\beta_{0,13}^-$	max:	215,3	(10)	0,111 (3)
$\beta_{0,13}^-$	avg:	59,8	(3)	
$\beta_{0,12}^-$	max:	228,1	(10)	0,011 (1)
$\beta_{0,12}^-$	avg:	69,3	(3)	
$\beta_{0,11}^-$	max:	285	(1)	0,0027 (7)
$\beta_{0,11}^-$	avg:	82	(1)	
$\beta_{0,10}^-$	max:	353,1	(10)	0,134 (5)
$\beta_{0,10}^-$	avg:	104,3	(3)	
$\beta_{0,9}^-$	max:	436,6	(10)	16,45 (30)
$\beta_{0,9}^-$	avg:	133,0	(3)	
$\beta_{0,6}^-$	max:	685,7	(10)	0,052 (5)
$\beta_{0,6}^-$	avg:	225,4	(4)	
$\beta_{0,5}^-$	max:	822,8	(10)	0,0010 (2)
$\beta_{0,5}^-$	avg:	279	(2)	
$\beta_{0,4}^-$	max:	848,1	(10)	1,18 (3)
$\beta_{0,4}^-$	avg:	289,7	(3)	
$\beta_{0,2}^-$	max:	1214,5	(10)	82,1 (15)
$\beta_{0,2}^-$	avg:	442,7	(3)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Tc)	2,424 — 2,537	0,697 (17)	
XK α_2	(Tc)	18,251	3,19 (9)	} K α
XK α_1	(Tc)	18,3672	6,06 (16)	
XK β_3	(Tc)	20,599	}	K β'_1
XK β_1	(Tc)	20,619	}	
XK β''_5	(Tc)	20,789	}	
XK β_2	(Tc)	21,005	}	K β'_2
XK β_4	(Tc)	21,042	} 0,254 (11)	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{2,1}$ (Tc)	2,1726 (4)	$7 \cdot 10^{-9}$
$\gamma_{3,1}$ (Tc)	40,58323 (17)	1,022 (27)
$\gamma_{1,0}$ (Tc)	140,511 (1)	89,6 (17)
$\gamma_{2,0}$ (Tc)	142,675 (25)	0,0211 (17)
$\gamma_{9,7}$ (Tc)	158,782 (15)	0,0145 (9)
$\gamma_{6,4}$ (Tc)	162,370 (15)	0,0114 (6)
$\gamma_{3,0}$ (Tc)	181,068 (8)	6,01 (11)
$\gamma_{10,7}$ (Tc)	242,29 (8)	0,0014 (3)
$\gamma_{9,6}$ (Tc)	249,03 (3)	0,0035 (4)
$\gamma_{4,2}$ (Tc)	366,421 (15)	1,194 (23)
$\gamma_{13,7}$ (Tc)	380,13 (8)	0,0091 (5)
$\gamma_{5,2}$ (Tc)	391,7 (4)	0,0025 (6)
$\gamma_{14,7}$ (Tc)	410,27 (10)	0,0016 (4)
$\gamma_{9,4}$ (Tc)	411,491 (15)	0,0161 (12)
$\gamma_{12,6}$ (Tc)	457,60 (3)	0,0074 (6)
$\gamma_{13,6}$ (Tc)	469,63 (7)	0,0027 (5)
$\gamma_{6,2}$ (Tc)	528,788 (15)	0,0541 (19)
$\gamma_{11,5}$ (Tc)	537,79 (15)	0,0015 (5)
$\gamma_{7,3}$ (Tc)	580,51 (5)	0,0036 (4)
$\gamma_{8,3}$ (Tc)	581,30 (12)	0,00010 (5)
$\gamma_{12,4}$ (Tc)	620,03 (5)	0,0024 (6)
$\gamma_{8,1}$ (Tc)	621,773 (24)	0,0262 (10)
$\gamma_{15,4}$ (Tc)	689,6 (9)	0,00042 (18)
$\gamma_{9,3}$ (Tc)	739,500 (17)	12,12 (15)
$\gamma_{7,0}$ (Tc)	761,77 (8)	0,0023 (13)

	Energy keV	Photons per 100 disint.
$\gamma_{9,2}(\text{Tc})$	777,921 (20)	4,28 (8)
$\gamma_{10,3}(\text{Tc})$	822,972 (15)	0,1321 (29)
$\gamma_{10,2}(\text{Tc})$	861,2 (9)	0,0007 (2)
$\gamma_{13,3}(\text{Tc})$	960,754 (20)	0,095 (3)
$\gamma_{12,2}(\text{Tc})$	986,44 (4)	0,0014 (1)
$\gamma_{13,1}(\text{Tc})$	1001,343 (18)	0,0043 (4)
$\gamma_{15,3}(\text{Tc})$	1017,0 (5)	0,0007 (2)
$\gamma_{15,2}(\text{Tc})$	1056,20 (5)	0,00103 (9)
$\gamma_{11,0}(\text{Tc})$	1072,2 (4)	0,0012 (5)

6 Main Production Modes

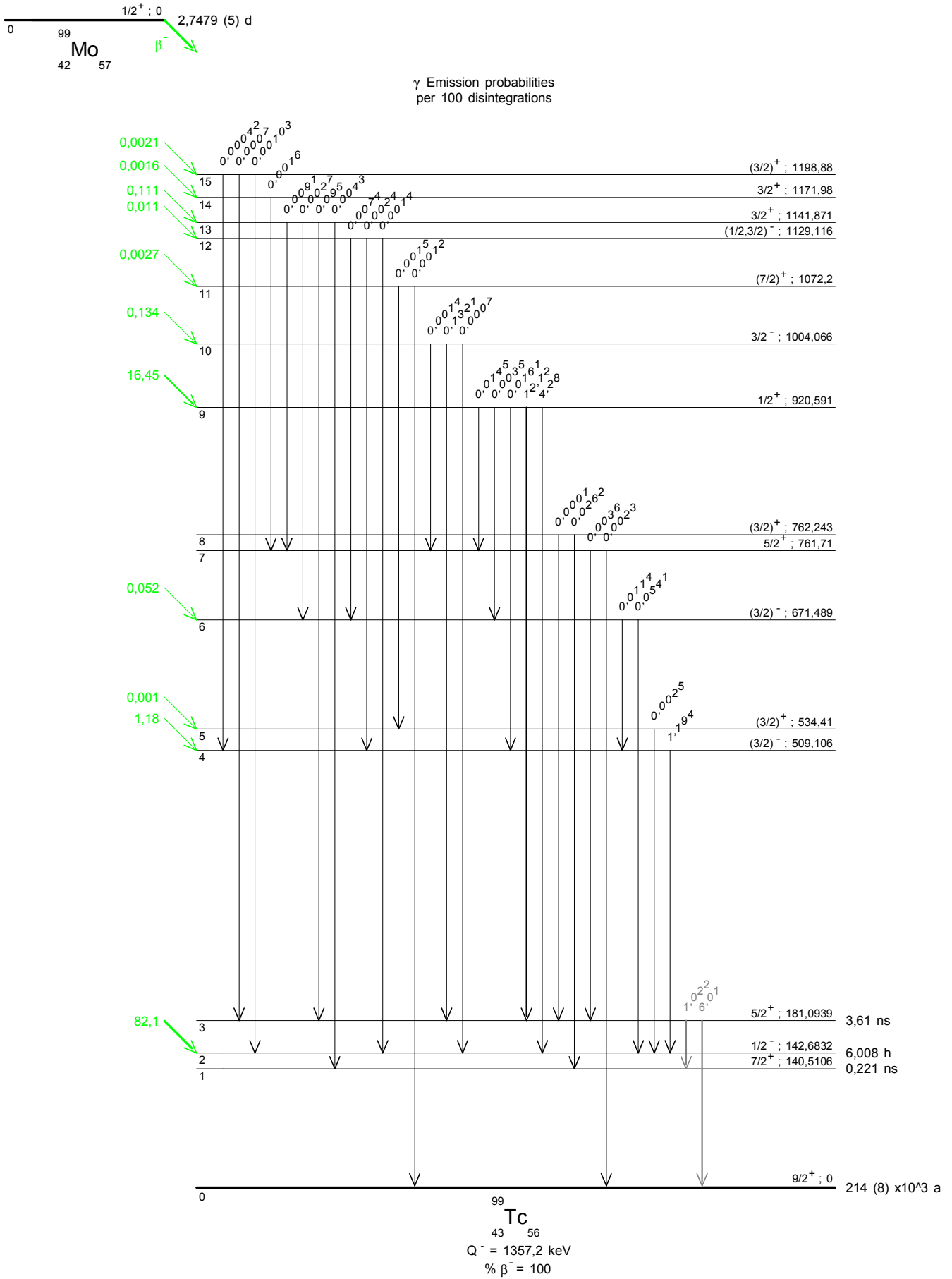
- { Mo – $98(n,\gamma)\text{Mo} - 99$ σ : 0,130 (6) barns
- { Possible impurities : Nb – 92m
- { Fission product
- { Possible impurities : None

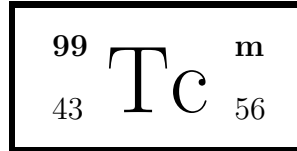
7 References

- J. A. SEILER. Report ANL-4000 (1947) 119
(Half-life)
- S. R. GUNN, H. G. HICKS, H. B. LEVY, P. C. STEVENSON. Phys. Rev. 107 (1957) 1642
(Half-life)
- H. W. WRIGHT, E. I. WYATT, S. A. REYNOLDS, W. S. LYON, T. H. HANDLEY. Nucl. Sci. Eng. 2 (1957) 427
(Half-life)
- A. N. PROTOPOPOV, G. M. TOLMACHEV ET AL.. J. Nucl. Energy 10A (1959) 80
(Half-life)
- J. RAVIER, P. MARGUIN, A. MOUSSA. J. Phys. Radium 22 (1961) 249
(K/L)
- R. D. NEWMAN. Priv. Comm. (1961)
(Half-life)
- P. CROWTHER. Nucl. Phys. 66 (1965) 472
(Half-life, Gamma emission probabilities, T ICC, K ICC)
- S. R. AMTEY, J. H. HAMILTON, M. J. ZENDER. Phys. Lett. 23-10 (1966) 581
(K ICC, L ICC, M ICC)
- J. A. BEARDEN. Rev. Mod. Phys. 39,1 (1967) 78
(X-Rays energies)
- M. N. BALDWIN. Nucl. Sci. Eng. 30 (1967) 144
(Half-life)
- C. W. E. VAN EIJK, B. VAN NOOIJNEN, F. SCHUTTE. Nucl. Phys. A121 (1968) 440
(Gamma-ray energies, K-Conv. Elec. , Gamma-ray emission probabilities)
- J. S. GEIGER. AECL-3166 PR-P- 79 (1968) 29
(Gamma-ray energies, K-Conv. Elec. , Gamma emission probabilities)
- S. M. BRAHMAVAR, J. H. HAMILTON, J. J. PINAJIAN. Quoted in Nucl. Phys. A121 (1968) 440
(ICC)
- S. A. REYNOLDS, J. F. EMERY, E. I. WYATT. Nucl. Sci. Eng. 32 (1968) 46
(Half-life)

- N. RANAKUMAR, R. W. FINK, P. V. RAO. Nucl. Phys. A217 (1969) 683
(K ICC)
- W. B. COOK, L. SCHELLENBERG, M. W. JOHNS. Nucl. Phys. A139 (1969) 277
(Gamma-ray energies, Gamma-ray emission probabilities)
- E. BASHANDY. Z. Naturforsch 24A (1969) 1893
(K ICC)
- V. A. AGEEV ET AL.. Bull. Ac. Sc. USSR, Phys. Ser. 33 (1969) 1183
(Conv. Elec. emission probabilities)
- A. VUORINEN. Ann. Acad. Sci. Fenn. Ser. A VI. (1969) 311
(T ICC)
- E. BASHANDY, N. IBRAHIEM. Z. Phys. 219 (1969) 337
(K ICC K/L)
- P. STEINER, E. GERDAU, W. HAUTSCH, D. STREENKEN. Z. Physik 221 (1969) 281
(Level half-life)
- N. A. VOINOVA ET AL.. Bull. Ac. Sc. URSS, Phys. Ser. 35 (1971) 794
(K ICC)
- J. Mc DONALD, A. BACKLIN, S. G. MALMSKOG. Nucl. Phys. A 162 (1971) 365
(Mean half-life, Multipolarity mixing ratio)
- T. NAGARAJAN, M. RAVINDRANATH, K. V. REDDY. Phys. Rev. C3 (1971) 247
(Beta emission energies)
- W. M. LACASSE, J. H. HAMILTON. Nucl. Phys. A171 (1971) 641
(Gamma ray energies)
- S. BABA, H. BABA, H. NATSUME. J. Inorg. Nucl. Chem. 33 (1971) 589
(Half-life)
- P. L. GARDULSKI, M. L. WIEDENBECK. Nucl. Instrum. Methods 105 (1972) 169
(Gamma-ray energies)
- N. A. VOINOVA, A. I. EGOROV, Y. V. KALINICHEV, A. G. SERGEEV. Bull. Ac. Sc. URSS, Phys. Ser. 35 (1972) 794
(K ICC)
- J. F. EMERY, S. A. REYNOLDS, E. Y. WYATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
(Half-life)
- G. K. SHENOY, G. ABSTREITER, G. M. KALVIUS, K. SCHWOCHAU, K. H. LINSE. J.Phys. A (London) 6 (1973) L144
(Level half-life)
- J. LEGRAND ET AL.. Report CEA-R-4427 (1973)
(Gamma-ray emission probabilities, Conv. Elec. emission probabilities)
- R. J. GEHRKE, L. D. MAC ISSAC, R. L. HEATH. Report ANCR-1129 (1973) 23
(Gamma-ray energies, Gamma-ray emission probabilities)
- P. L. GARDULSKI, M. L. WIEDENBECK. Phys. Rev. C9 (1974) 262.
(Spin and Parity, Mixing Ratio)
- R. L. HEATH. Report ANCR-1002 (1974)
(Gamma-ray energies, Gamma-ray emission probabilities)
- R. A. MEYER. Report UCRL-76207 (1974)
(Spin and Parity)
- F. P. LARKINS. At. Data Nucl. Data Tables 20,4 (1977) 338
(Auger Electrons)
- J. MOREL, J. P. PEROLAT. Report CEA-N-2043 (1978)
(Gamma-ray emission probabilities)
- J. K. DICKENS, T. A. LOVE. Radiochem. Radioanal. Letters 39 (1979) 107
(Gamma-ray emission probabilities)
- H. HOUTERMANS, D. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- J. K. DICKENS, T. A. LOVE. Nucl. Instrum. Methods 175 (1980) 535
(Gamma-ray emission probabilities)
- YANG CHUNXIANG ET AL.. Chin. J. Nucl. Phys. 2 (1980) 41
(Gamma-ray emission probabilities)
- R. G. HELMER, A. J. CAFFREY, R. J. GEHRKE, R. C. GREENWOOD. Nucl. Instrum. Methods 188 (1981) 671
(Gamma-ray energies)

- K. YOSHIHARA, A. HIBINO, I. YAMOTO, H. KAJI. Radiochem. Radioanal. Lett. 48 (1981) 303
(KX-ray intensities)
- A. SIMONITS. J. Radioanal. Nucl. Chem. 67 (1981)
(Gamma-ray emission probabilities)
- V. N. GERASIMOV ET AL.. Yadern. Fiz. 34 (1981) 3
(Gamma ray energies)
- K.SINGH, H. S. SAHOTA. J. Phys. Soc. Jap. 51,12 (1982) 153
(Multipole mixing ratio)
- D. D. HOPPE, J. M. R. HUTCHINSON, F. J. SCHIMA, M. P. UNTERWEGER. NBS-SP-626 (1982) 85
(Half-life)
- Y. V. KHOLNOV. Handbook, Energoizdat, Moscou (1982)
(Beta emission probabilities)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Appl. Rad. Isot. 34 (1983) 1191
(Half-life)
- W. BAMBYNEK. X-84 Proc. X-Ray and Inner-Shell Processes in Atoms, Molecules and Solids, A. Meisel Ed., Leipzig Aug. 20-23 (1984)
(K fluorescence yield)
- CHEN DA, ZHANG QIAOLIAN, CHANG YONGFU. IEEE-Transactions on Nuclear Science Vol.32- n°1 (1985) 153
(Gamma-ray emission probabilities)
- R. A. MEYER. Fizika 22 (1990) 153
(Gamma-ray energies, Gamma-ray emission probabilities)
- J. GOSWAMY, B. CHAND, D. MEHTA, N. SINGH, P. N. TREHAN. Appl. Rad. Isot. 43 (1992) 1467
(Gamma-ray emission probabilities)
- I. ALFTER, E. BODENSTEDT, B. HAMER, W. KNICHEL, R. MÜSSELER, R. SAJOK, T. SCHAEFER, J. SCHÜTH, R. VIANDEN. Z. Physik A347 (1993) 1
(Level half-life)
- L. K. PEKER. Nucl. Data Sheets 73,1 (1994) 1
(Spin and Parity)
- J. H. HUBBELL, P. N. TREHAN, NIRMAL SINGH, B. CHAND, D. MEHTA, M. L. GARG, R. R. GARG, SURINDER SINGH, S. J. PURI. Phys. Chem. Ref. Data 23-2 (1994) 339
(M fluorescence yield)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(L fluorescence yield)
- V. S. BUTSEV, G. L. BUTSEVA, D. CHULTEM, P. I. GOLUBEV, D. KISS, E. J. LANGROCK, R. A. ZULKARNEV. Heavy Ion Physics 8 (1998) 227
(Half-life)
- M.-M. BÉ, E. BROWNE, V. CHECHEV, R. HELMER, E. SCHÖNFELD. Table de Radionucléides, ISBN 2 7272 0200 8, CEA, F-91191 Gif sur Yvette (1999)
(T ICC (Cs-137))
- R. G. HELMER, C.VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma ray energies)
- H. SCHRADER. to be published in Int. J. Appl. Isotopes (2004)
(Half-life.)





1 Decay Scheme

Tc-99m mainly disintegrates to Tc-99. Weak beta minus transitions have been observed to Ru-99 nuclear levels. Depending on the chemical environment, some changes can modify the value of the half-life.

Le technétium 99m se désexcite vers le niveau fondamental du technétium 99. Des changements dans la valeur de la période peuvent être obtenus par une modification de l'environnement extérieur, composition chimique par exemple qui influence la conversion interne de la transition de 2,17 keV dans les couches externes. Des transitions bêta moins de très faible intensité vers le niveau fondamental et les deux niveaux excités de ruthénium 99 ont été mises en évidence.

2 Nuclear Data

$T_{1/2}(^{99}\text{Tc}^m)$	:	6,0067	(10)	h
$T_{1/2}(^{99}\text{Tc})$	:	214	(8)	10^3 a
$Q^-(^{99}\text{Tc}^m)$	:	436,2	(2)	keV

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,2}^-$	113,9 (2)	0,000106 (6)	1st Forbidden	8,5
$\beta_{0,1}^-$	346,7 (2)	0,0026 (5)	1st Forbidden	8,7
$\beta_{0,0}^-$	436,3 (2)	0,0010 (3)	Unique 1st Forbidden	9,4

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{2,1}(\text{Tc})$	2,1726 (4)	99,0 (4)	E3			$119 (3) 10^8$	$135 (4) 10^8$
$\gamma_{1,0}(\text{Ru})$	89,6 (3)	0,00259 (20)	29%M1+E2	1,17 (4)	0,27 (1)		1,49 (5)
$\gamma_{1,0}(\text{Tc})$	140,511 (1)	99,0 (4)	M1+3,3%E2	0,104 (3)	0,01290 (39)	0,00236 (7)	0,119 (3)
$\gamma_{2,0}(\text{Tc})$	142,675 (25)	1,0 (1)	M4	29,3 (6)	9,35 (20)	1,86 (6)	40,9 (8)
$\gamma_{2,1}(\text{Ru})$	232,7 (2)	0,0000088 (15)		0,0412 (15)			0,048 (2)
$\gamma_{2,0}(\text{Ru})$	322,4 (1)	0,000098 (6)		0,0152 (5)			0,0175 (5)

3 Atomic Data

3.1 Tc

ω_K	:	0,782	(4)
$\bar{\omega}_L$	:	0,0415	(10)
$\bar{\omega}_M$	:	0,0010	(1)
n_{KL}	:	1,014	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X_K	$K\alpha_2$	18,251	52,59	
	$K\alpha_1$	18,3672	100	
	$K\beta_3$	20,599	}	
	$K\beta_1$	20,619	}	
	$K\beta_5''$	20,789	}	26,58
	$K\beta_2$	21,005	}	
	$K\beta_4$	21,042	}	4,2
	X_L	$L\ell$	2,134	
$L\alpha$		2,42 – 2,425		
$L\eta$		2,25		
$L\beta$		2,456 – 2,788		
$L\gamma$		2,726 – 3,002		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	14,86 – 15,58	100
KLX	17,43 – 18,33	40,3
KXY	19,93 – 21,00	4,1
Auger L	1,6 – 2,9	736

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Tc)	1,6 - 2,9		10,89 (9)
e _{AK}	(Tc)			2,15 (8)
	KLL	14,86 - 15,58	}	
	KLX	17,43 - 18,33	}	
	KXY	19,93 - 21,00	}	
ec _{2,1} T	(Tc)	1,628 - 2,170		99,9 (27)
ec _{2,1} M	(Tc)	1,628 - 1,919		88,0 (24)
ec _{2,1} N	(Tc)	2,104 - 2,170		11,7 (3)
ec _{1,0} T	(Tc)	119,467 - 140,510		10,53 (27)
ec _{1,0} K	(Tc)	119,467 (1)		9,20 (27)
ec _{2,0} K	(Tc)	121,631 (25)		0,67 (6)
ec _{1,0} L	(Tc)	137,468 - 137,834		1,142 (35)
ec _{2,0} L	(Tc)	139,632 - 139,998		0,215 (20)
ec _{1,0} M	(Tc)	139,967 - 140,258		0,209 (6)
$\beta_{0,2}^-$	max:	113,9 (2)		0,000106 (6)
$\beta_{0,2}^-$	avg:	37,8 (6)		
$\beta_{0,1}^-$	max:	346,7 (2)		0,0026 (5)
$\beta_{0,1}^-$	avg:	102,1 (5)		
$\beta_{0,0}^-$	max:	436,3 (2)		0,0010 (3)
$\beta_{0,0}^-$	avg:	152,3 (5)		

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Tc)	2,134 — 3,002	0,482 (12)	
XK α_2	(Tc)	18,251	2,22 (7)	} K α
XK α_1	(Tc)	18,3672	4,21 (12)	
XK β_3	(Tc)	20,599	}	K' β_1
XK β_1	(Tc)	20,619	}	
XK β_5''	(Tc)	20,789	}	
XK β_2	(Tc)	21,005	}	K' β_2
XK β_4	(Tc)	21,042	} 0,177 (8)	

5.2 Gamma Emissions

		Energy keV	Photons per 100 disint.
$\gamma_{2,1}$ (Tc)		2,1726 (4)	0,0000000074 (2)
$\gamma_{1,0}$ (Ru)		89,6 (3)	0,00104 (20)
$\gamma_{1,0}$ (Tc)		140,511 (1)	88,5 (2)
$\gamma_{2,0}$ (Tc)		142,683 (1)	0,023 (2)
$\gamma_{2,1}$ (Ru)		232,7 (2)	0,0000084 (15)
$\gamma_{2,0}$ (Ru)		322,4 (1)	0,000096 (6)

6 Main Production Modes

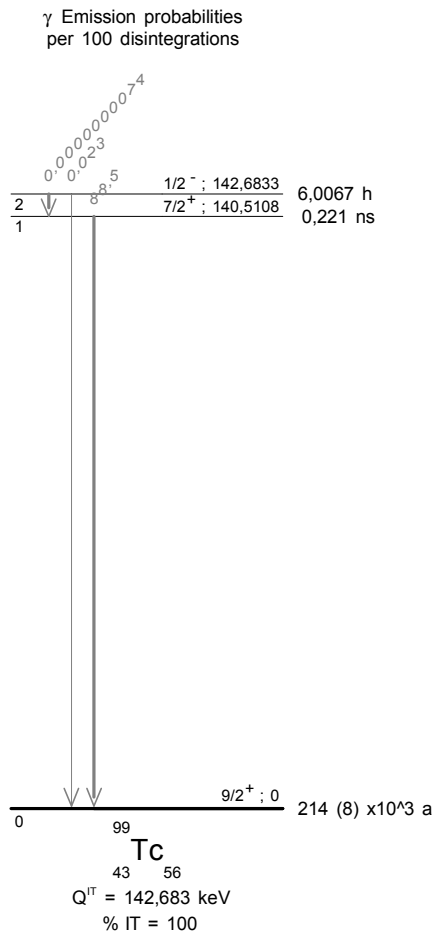
Mo-99 Separation from Mo-99 + Tc-99m

7 References

- K. T. BAINBRIGE, M. GOLDHABER, E. WILSON. Phys. Rev. 90 (1953) 430
(Half-life)
- J. RAVIER, P. MARGUIN, A. MOUSSA. J. Phys. Radium 22 (1961) 249
(K/L)
- P. CROWTHER, J. S. ELDRIDGE. Nucl. Phys. 66 (1965) 472
(Half-life)
- S. R. AMTEY. Phys. Lett. 23-10 (1966) 581
(M ICC, multipolarity)
- I. W. GOODIER, A. WILLIAMS. Nature 210 (1966) 614
(Half-life)

- C. W. E. VAN EIJK, B. VAN NOOIJNEN, F. SCHUTTE. Nucl. Phys. A121 (1968) 440
(Gamma-ray energies, Conv. Elec. emission probabilities)
- S. M. BRAHMAVAR, J. H. HAMILTON, J. J. PINAJIAN. Quoted in Nucl. Phys. A121 (1968) 440
(ICC)
- J. S. GEIGER. AECL-3166 PR-P-79 (1968) 29
(Gamma-ray energies, K-Conv. Elec. emission probabilities)
- P. STEINER, E. GERDAU, W. HAUTSCH, D. STEENKEN. Z. Phys. 221 (1969) 281
(Half-life)
- W. B. COOK, L. SCHELLENBERG, M. W. JOHNS. Nucl. Phys. A139 (1969) 277
(Multipole mixing ratio)
- P. STEINER. Z.Phys. 221 (1969) 281
(Half-life)
- E.BASHANDY, N. IBRAHIEM. Z. Phys. 219 (1969) 337
(K/L ratio)
- V. A. AGEEV ET AL.. Izv. Akad. Nauk SSSR, Ser. Fiz. 33 (1969) 1279
(Conv. Elec. emission probabilities)
- A. VUORINEN. Ann. Acad. Sci. Fenn. Ser. A VI (1969) 311
(ICC, half-life)
- E. BASHANDY. Z. Naturforsch 24A (1969) 1893
(K ICC, Multipolarity)
- J. LEGRAND, F. LAGOUTINE, J. P. BRETHON. Int. J. Appl. Rad. Isot. 21 (1970) 139
(Half-life)
- J. D. JONES, H. C. GRIFFIN. Radiochem. Radioanal. Letters 4-6 (1970) 381
(Beta emission probabilities, Gamma-ray energies)
- J. Mc DONALD, A. BÄCKLIN, S. G. MALMSKOG. Nucl. Phys. A162 (1971) 365
(Multipolarity, Half-life, Gamma-ray emission probabilities)
- D. C. SANTRY, G. C. BOWES. Health Physics A (1971) 673
(Half-life)
- W. M. LACASSE, J. H. HALMILTON. Nucl. Phys. A171 (1971) 641
(M ICC/N ICC, Gamma-ray energies)
- N. A. VOINOVA, A. I. EGOROV, Yu. V. KALINICHEV, A. G. SERGEEV. Bull. Ac.Sc URSS, Phys. Ser. 35 (1972) 794
(K ICC, K/L, Multipolarity)
- J. F. EMERY. Nucl. Sci. Eng. 48-3 (1972) 319
(Half-life)
- M. DECOMBAZ, J. J. GOSTELY, P. LERCH. Radiochem. Radioanal. Letters 10 (1972) 119
(Gamma emission probabilities)
- G. K. SHENOY. J. Phys. (London) A6 (1973) L144
(Half-life)
- J. LEGRAND, M. BLONDEL, P. MAGNIER, C. PERROT, J. P. BRETHON. Report CEA-R-4427 (1973)
(Gamma-ray emission probabilities, Conv. Elec. emission probabilities)
- R. A. MEYER. Report UCRL-76207 (1974)
(Half-life)
- P. L. GARDULSKI, M. L. WIEDENBECK. Phys. Rev. C9,1 (1974) 262
(Multipole mixing ratio)
- I. M. BAND, M. B. TRZHASKOVSKAYA, M. A. LISTENGARTEN. Atomic Data and Nuclear Data Tables 18 (1976) 433
(K and L-shell internal conversion coefficients)
- O. C. KISTNER, A. H. LUMPKIN. Phys. Rev. C13 (1976) 1132
(Multipolarities)
- H. HOUTERMANS, D. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- D. E. ALBURGER, P. RICHARDS, T. H. KU. Phys. Rev. C21 (1980) 705
(Beta emission probabilities, Beta emission energies)
- H. MAZAKI, S. KAKIUCHI, T. MUKOYAMA, M. MATSUI. Phys. Rev. C21 (1980) 344
(Half-life)
- J. K. DICKENS, T. A. LOVE. Nucl. Inst. Meth. 175 (1980) 535
(Gamma-ray emission probabilities, X-ray emission probabilities, K ICC, T ICC)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRIT. Report AECL-6692 (1980)
(Half-life)

- R. G. HELMER, A. J. CAFFREY, R. J. GEHRKE, R. C. GREENWOOD. Nucl. Instrum. Methods 188 (1981) 151
(Gamma-ray energies)
- V. N. GERASIMOV, A. G. ZELENKOV, V. M. KULAKOV, V. A. PCHELIN, A. A. SOLDATOV. Sov. J. Nucl. Phys. 34-1 (1981) 1
(Multipolarity, Gamma ray energies)
- A. SIMONITS, L. MOENS, F. DE CORTE, A. DE WISPELAERE, J. HOSTE. J. Radioanal. Chem. 67 (1981) 61
(Gamma-ray emission probabilities)
- K. SINGH, H. S. SAHOTA. J. Phys. Soc. Jap. 51-12 (1982) 3766
(Multipole mixing ratio)
- R. L. AYRES, A. T. HIRSCHFELD. Int. J. Appl. Rad. Isot. 33-10 (1982) 835
(Half-life)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Rad. Isot. 34-8 (1983) 1191
(Half-life)
- CHEN DA. IEEE-Transactions on Nuclear Science 32-1 (1985) 71
(Gamma-ray emission probabilities)
- D. C. SANTRY, G. C. BOWES. Health Physics 57-4 (1989) 673
(Half-life)
- I. ALFTER. Z. Phys. A347 (1993) 1
(Nuclear levels half-life)
- L. K. PEKER. Nucl. Data Sheets 73,1 (1994) 1
(Level energies, Spin and Parity)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 595 (1995) 409
(Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Fluorescence yields)
- B. SINGH, J. L. RODRIGUEZ, S. S. M. WONG, J. K. TULI. Nucl. Data Sheets 84,3 (1998)
(lg ft)
- V. KOLTSOV, L. G. MASHIROV, D. N. SUGLOBOV. Bull. Acad. Sci. USSR, Phys. Ser. 62,5 (1998) 789
(Half-life)
- M.-M. BÉ, E. BROWNE, V. CHECHEV, R. HELMER, E. SCHÖNFELD. Table de Radionucléides, ISBN 2 7272 0200 8, CEA, F-91191 Gif sur Yvette (1999)
(T ICC (Cs-137))
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
(Gamma ray energies)
- H. SCHRADER. Appl. Rad. Isotopes 60, 2-3 (2004) 317
(Half-life)
- M. A. L. DA SILVA, M. C. M. DE ALMEIDA, J. U. DELGADO. Appl. Rad. Isotopes 60, 2-3 (2004) 301
(Half-life)





1 Decay Scheme

Cd-109 decays by electron capture to the isomeric state (88 keV) of Ag-109.

Le cadmium 109 se désintègre uniquement par capture électronique vers l'état isomérique de l'argent 109 (88 keV).

2 Nuclear Data

$$T_{1/2}({}^{109}\text{Cd}) : 461,4 \quad (12) \quad \text{d}$$

$$Q^+({}^{109}\text{Cd}) : 213,8 \quad (27) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	<i>P_K</i>	<i>P_L</i>	<i>P_M</i>
ε _{0,1}	125,8 (27)	100	Allowed	5,1	0,8118 (23)	0,1497 (23)	0,0321 (8)
ε _{0,0}	213,8 (27)	< 0,005	2nd Forbidden	11			

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	<i>P_{γ+ce}</i> × 100	Multipolarity	α _{<i>K</i>}	α _{<i>L</i>}	α _{<i>M</i>}	α _{<i>T</i>}
γ _{1,0} (Ag)	88,0337 (1)	100	E3	11,28 (12)	12,34 (13)	2,70 (3)	26,58 (20)

3 Atomic Data

3.1 Ag

ω_K	:	0,831	(4)
$\bar{\omega}_L$	:	0,0583	(14)
n_{KL}	:	0,964	(4)

3.1.1 X Radiations

		Energy keV		Relative probability
X _K	K α_2	21,9906		53,05
	K α_1	22,16317		100
	K β_3	24,9118	}	
	K β_1	24,9427	}	
	K β_5''	25,146	}	27,7
	K β_2	25,4567	}	
	K β_4	25,512	}	4,82
	X _L			
	L ℓ	2,63		
	L γ	– 3,75		

3.1.2 Auger Electrons

		Energy keV	Relative probability
Auger K			
	KLL	17,79 – 18,69	100
	KLX	20,945 – 22,160	42,5
	KXY	24,079 – 25,507	4,51
Auger L			
		1,8 – 3,8	1194

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Ag)	1,8 - 3,8	167 (10)
e _{AK}	(Ag)		20,6 (5)
	KLL	17,79 - 18,69	}
	KLX	20,945 - 22,160	}
	KXY	24,079 - 25,507	}
ec _{1,0 K}	(Ag)	62,520 (2)	40,8 (5)
ec _{1,0 L}	(Ag)	84,228 - 84,683	44,8 (5)
ec _{1,0 M}	(Ag)	87,316 - 88,030	9,28 (29)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Ag)	2,63 — 3,75	10,34 (26)	
XK α_2	(Ag)	21,9906	29,00 (25)	} K α
XK α_1	(Ag)	22,16317	54,7 (4)	}
XK β_3	(Ag)	24,9118	}	
XK β_1	(Ag)	24,9427	}	K' β_1
XK β_5''	(Ag)	25,146	}	
XK β_2	(Ag)	25,4567	}	
XK β_4	(Ag)	25,512	}	K' β_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Ag})$	88,0336 (1)	3,626 (26)

6 Main Production Modes

- $$\left\{ \begin{array}{l} \text{Cd} - 108(n,\gamma)\text{Cd} - 109 \quad \sigma : 1,1 \text{ (3) barns} \\ \text{Possible impurities : Ag} - 110\text{m} \end{array} \right.$$
- $$\left\{ \begin{array}{l} \text{Ag} - 109(p,n)\text{Cd} - 109 \\ \text{Possible impurities : None} \end{array} \right.$$

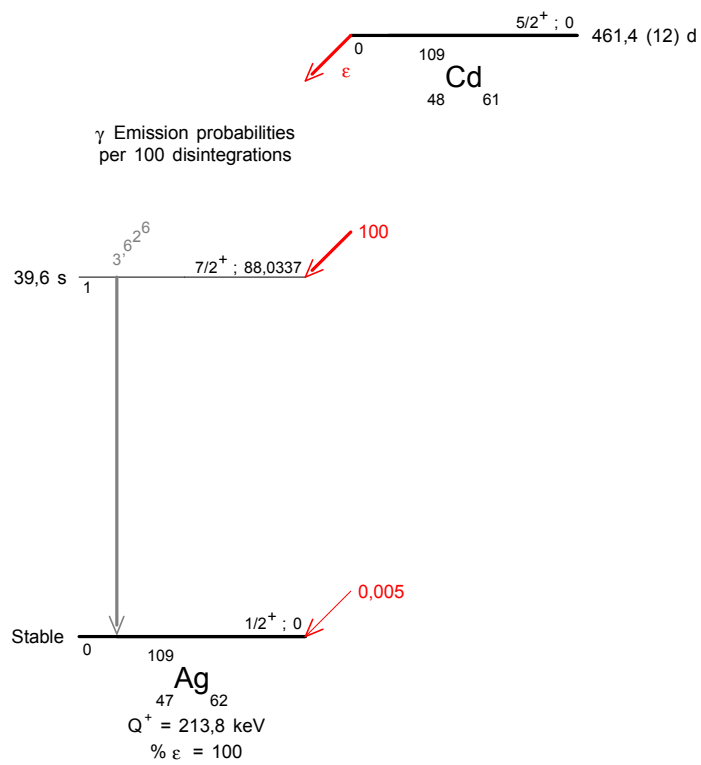
7 References

- J.R.GUM, M.L.POOL. Phys. Rev. 80 (1950) 315
(Half-life)
- J.BRUNNER, O.HUBER, R.JOLY, D.MAEDER. Helv. Phys. Acta 26 (1953) 588
(Conv. Elec. emission probabilities)
- E.DERMATEOSIAN. Phys. Rev. 92 (1953) 938
(X-ray emission probabilities)
- G.BERTOLINI, A.BISI, E.LAZZARINI, L.ZAPPA. Nuovo Cimento 11 (1954) 539
(X-ray emission probabilities)
- A.H.WAPSTRA, W.VANDERELJK. Nucl. Phys. 4 (1957) 325
(X-ray emission probabilities)
- H.W.BOYD, J.H.HAMILTON, A.R.SATTLER, P.F.A.GOUDSMIT. Physica 30 (1964) 124
(Conv. Elec. emission probabilities)
- R.B.MOLER, R.W.FINK. Phys. Rev. 2B (1965) B282
(X-ray emission probabilities)
- H.LEUTZ, K.SCHNECKENBERGER, H.WENNINGER. Nucl. Phys. 63 (1965) 263
(X-ray emission probabilities, Conv. Elec. emission probabilities, Half-life, Q(EC))
- S.K.SEN, I.O.DUROSINMI-ETTI. Phys. Lett. 18 (1965) 144
(Conv. Elec. emission probabilities)
- J.W.F.JANSEN, A.H.WAPSTRA. Internal Conversion Processes, ed. J. H. Hamilton, Academic Press, New York (1966) p.237
(K X-ray emission probabilities, Gamma-ray emission probabilities)
- M.S.FREEDMAN, F.T.PORTER, F.WAGNER. Phys. Rev. 151 (1966) 886
(K X-ray emission probabilities, Gamma-ray emission probabilities)
- I.O.DUROSINMI-ETTI, D.R.BRUNDRIT, S.K.SEN. International Conversion Processes, Ed. Hamilton, Acad. Press, New York (1966) 201
(K X-ray emission probabilities, X-ray emission probabilities)
- F.J.SCHIMA, J.M.R.HUTCHINSON. Nucl. Phys. A102 (1967) 667
(Gamma ray energies)
- J.LIBERT. Nucl. Phys. A102 (1967) 477
(Gamma ray energies)
- J.A.BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- W.R.PIERSON, R.H.MARSH. Nucl. Phys. A104 (1967) 511
(Gamma ray energies)
- K.P.GOPINATHAN, W.RUBINSON. Bull. Am. Phys. Soc. 13, 11 (1968) 1452
(Q(EC))
- T.FURUTA, J.R.RHODES. Int. J. Appl. Radiat. Isotop. 19 (1968) 483
(Gamma ray energies)
- K.C.FOIN, A.GIZON, J.OMS. Nucl. Phys. A113 (1968) 241
(Gamma-ray emission probabilities, X-ray emission probabilities, Gamma ray energies, Conv. Elec. emission probabilities, K fluorescence yield)
- S.A.REYNOLDS, J.F.EMERY, E.I.WYATT. Nucl. Sci. Eng. 32 (1968) 46
(Half-life)
- L.V.EAST, H.M.MURPHY, JR.. Nucl. Phys. A107 (1968) 382
(Half-life)
- W.GOEDBLOED, PROC.CONF.ELECTRONCAPTURE, HIGHERORDERPROCESSES IN NUCL.DECAYS, DEBRECEN, HUNGARY, D.BER
Eötvös Lorand Phys.Soc., Budapest, vol. 1 (1968) 92
(Q(EC), X-ray emission probabilities)

- B.PLANSKOY. Nucl. Instrum. Methods 73 (1969) 205
(Conv. Elec. emission probabilities)
- R.L.HEATH. Proc. Int. Conf. On Radioactivity, Nucl.Spectroscopy, Nashville, USA (1969)
(Gamma ray energies)
- R.W.FINK. Phys. Rev. 180 (1969) 1220
(X-ray emission probabilities)
- E.VATAI. Acta Physica Hungarica 28 (1970) 103
(X-ray emission probabilities)
- E.BASHANDY. Z. Phys. 236 (1970) 130
(Conv. Elec. emission probabilities)
- R.C.GREENWOOD, R.G.HELMER, R.J.GEHRKE. Nucl. Instrum. Methods 77 (1970) 141
(Gamma ray energies)
- D.E.RAESIDE. Nucl. Instrum. Methods 87 (1970) 7
(Gamma ray energies)
- W.GOEDBLOED, S.C.GOVERSE, C.P.GERNER, A.BRINKMAN, J.BLOK. Nucl. Instrum. Methods 88 (1970) 197
(X-ray emission probabilities, Q(EC))
- D.S.BRENNER, M.L.PERLMAN. Nucl. Phys. A181 (1972) 207
(K X-ray energies, K X-ray emission probabilities, Conv. Elec. emission probabilities)
- J.L.CAMPBELL, L.A.McNELLES. Nucl. Instrum. Methods 98 (1972) 433
(Gamma-ray emission probabilities, K X-ray emission probabilities)
- ZS.NEMETH, A.VERES. Phys. Rev. C35 (1973)
(Conv. Elec. emission probabilities)
- J.LEGRAND, M.BLONDEL, P.MAGNIER. Nucl. Instrum. Methods 112 (1973) 101
(Conv. Elec. emission probabilities)
- S.RAMAN, T.A.WALKIEWICZ, R.GUNNINK, B.MARTIN. Phys. Rev. C7 (1973) 2531
(Conv. Elec. emission probabilities)
- J.H.SCOFIELD. Phys. Rev. A9 (1974) 1041
(X-ray energies)
- B.MARTIN, D.MERKERT, J.L.CAMPBELL. Z.Physik A274 (1975) 15
(K X-ray emission probabilities, K X-ray energies)
- H.J.NAGY, G.SCHUPP, R.R.HURST. Phys. Rev. C11 (1975) 205
(K X-ray emission probabilities)
- O.DRAGON, V.BRABEC, M.RYSAVY, J.PLCH, J.ZDERADICKA. Physik A279 (1976) 107
(Conv. Elec. emission probabilities, K X-ray emission probabilities, Gamma-ray emission probabilities)
- C.W.E.VANELJK, J.WIJNHORST. Phys. Rev. C15 (1977) 1068
(K ICC)
- F.P.LARKINS. At. Data. Nucl. Data Tables 20 (1977) 312
(Auger electron energies)
- I.PROCHAZKA, T.I.KRACIKOVA, V.JAHELKOVA, Z.HONS, M.FRISER, J.JURSIK. Czech. J. Phys. B28 (1978) 134
(Conv. Elec. emission probabilities)
- F.RÖSEL, H.M.FRIES, K.ALDER, H.C.PAULI. At. Data. Nucl. Data Tables 21 (1978) 91
(Conv. Elec. emission probabilities)
- R.G.HELMER, R.C.GREENWOOD, R.J.GEHRKE. Nucl. Instrum. Methods 155 (1978) 189
(Gamma ray energies)
- T.MORII. Nucl. Instrum. Methods 151 (1978) 489
(Half-life)
- G.A.SHEVELEV, A.G.TROITSKAYA, V.M.KARTASHOV. Izv. Akad. Nauk SSSR, Ser. Fiz. 42 (1978) 211
(ICC ratios)
- J.PLCH, P.DRYAK, J.ZDERADICKA, E.SCHÖNFELD, A.SZÖRENYI. Czech. J. Phys. B29 (1979) 1071
(K fluorescence yield, K X-ray emission probabilities, Conv. Elec. emission probabilities, Gamma-ray emission probabilities)
- C.W.E.VANELJK, J.WIJNHORST, M.A.POPELIER. Phys. Rev. C19 (1979) 1047
(K ICC)
- R.I.DAVIDONIS, R.K.ZHIRGULYAVICHYUS, R.A.KALINAUSKAS, V.I.KERSKULIS, K.V.MAKARYUNAS. Izv. Akad. Nauk. SSSR, Ser. Fiz. 44 (1980) 1060
(ICC ratios)
- H.H.HANSEN, G.GROSSE, D.MOUCHEL, R.VANINBROUKX. Annual Progress Report CBNM, Geel (1980) 44
(Half-life)
- R.VANINBROUKX, G.GROSSE, W.ZEHNER. Int. J. Appl. Radiat. Isot. 32 (1981) 589
(Half-life)

- D.D.HOPPES, J.M.R.HUTCHINSON, F.J.SCHIMAAND, M.P.UNTERWEGER. NBS-Special Publ. 626 (1982) 85;90
(Half-life, K X-ray emission probabilities, Gamma-ray emission probabilities)
- F.LAGOUTINE, J.LEGRAND. Int. J. Appl. Radiat. Isotop. 33 (1982) 711
(Half-life)
- K.V.MAKARYUNAS, E.K.MAKARYUNENE. Izv. Akad. Nauk. SSSR,Ser. Fiz. 48 (1984) 23-27
(Half-life)
- J.BLACHOT. Nucl. Data Sheets 41,2 (1984) p.157
(Half-life)
- H.HORVATH, K.ILAKOVAC. Phys. Rev. A31 (1985) 1543
(Double K capture probability)
- H.H.HANSEN. Europ. Appl. Res. Report-Nucl. Sci. Technol. 6 (1985) 777
(ICC)
- R.L.INTEMAN. Phys. Rev. C31 (1985) 1961
(K X-ray energies)
- E.FUNCK, U.SCHÖTZIG. PTB Annual Report (1985)
(Gamma-ray emission probabilities)
- H.KAWAKAMI, K.NISIMURA, T.OHSHIMA. Inst. For Nuclear Study, Tokyo Univ., Report INS-613, (1986)
(KLL Auger electron)
- B.CHAUVENET. Report BIPM-88/4 (1988)
(Gamma-ray emission probabilities)
- A.SZÖRENYI, A.ZSINKA, M.CSIKOS, GY.HORVATH., Report BIPM-88/4 (1988)
(Gamma-ray emission probabilities)
- J.PLCH, J.SURAN. Institute for Research, Production and Application of Radioisotopes, UVVVR, Prague, Czechoslovakia, Report tBIP (1988)
(Gamma-ray emission probabilities)
- R.H.MARTIN. AECL, Chalk River, Canada, Report BIPM-88/4 (1988)
(Gamma-ray emission probabilities)
- J.J.GOSTELY. Institut d'Electrochimie et Radiochimie, Lausanne, Switzerland, in Report BIPM-88/4 (1988)
(Gamma-ray emission probabilities)
- C.BALLAUX, B.M.COURSEY, D.D.HOPPES. Appl. Radiat. Isot. 39 (1988) 1131
(Gamma-ray emission probabilities, Conv. Elec. emission probabilities)
- N.K.KUZMENKO, V.G.NEDOVESOV, V.P.CHECHEV. Nuclear Spectroscopy Accuracy Problems, 1988, Proc. Seminar. Vilnius1988, Institute of Physics of Academy 156-161 (1988)
(Gamma-ray emission probabilities,)
- A.M.GEIDELMAN, Y.S.EGOROV, N.K.KUZMENKO, V.G.NEDOVESOV, V.P.CHECHEV, G.E.SHYUKIN. Proc. Int. Conf. Nucl. Data for Science and Technology, S. Igarasi, Ed., May30-June3, 1988, Mito, Japan (1988) 909
(K X-ray emission probabilities, K X-ray energies, Gamma-ray emission probabilities)
- R.JU.DAVIDONIS ET AL.. Proc.7th. Seminary on Precise Measurements in Nuclear Spectroscopy, Vilnius (1988) 24
(K X-ray energies, K X-ray emission probabilities)
- D.H.WOODS, D.SMITH. National Physical Laboratory, NPL, Teddington, UK, in Report BIPM-88/4 (1988)
(Gamma-ray emission probabilities)
- K.ILAKOVAC, G.JERBIC-ZORC, M.BOZIN, R.POSIC, W.HORVAT. Fizika (Zagreb) 20 (1988) 91
(Gamma-ray emission probabilities)
- TAE SOON PARK, PILJAE OH, SUN-TAE HWANG. Korea Standards Research Institute, KSRI, Taejon, Korea, in Report BIPM-88/4 (1988)
(Gamma-ray emission probabilities)
- K.DEBERTIN, U.SCHÖTZIG. PTB Annual Report (1989)
(Gamma-ray emission probabilities)
- Y.HINO, Y.KAWADA. Appl. Radiat. Isot. 40 (1989) 79
(Gamma-ray emission probabilities)
- A.G.YEGOROV, Y.S.YEGOROV, V.G.NEDOVESOV, G.E.SHCHUKIN, K.P.YAKOVLEV. 39th Conf. On Nucl. Spectroscopy and Atomic Nucleus Structure, Tashkent, USSR 18-21 April 1989, Lo.Nauka, Leningrad (1989) 505
(Gamma-ray emission probabilities, K X-ray emission probabilities)
- ZS.NEMETH, A.VERES. Nucl. Instrum. Methods A286 (1990) 601
(Conv. Elec. emission probabilities)
- U.SCHÖTZIG, H.SCHRADER, K.DEBERTIN. Proc. Int. Conf. Nuclear Data for Science and Technology, Jülich (1991) 562
(Gamma-ray emission probabilities)
- R.L.KOZUB, M.M.HINDI. Research Nuclear Physics: Progress Report, June1,1993-July31,1994, Tennessee Technological Univ., Cookevill (1993)
(Q(EC), inner bremsstr. Endpoint energy)

- I.M.BAND, M.B.TRZHASKOVSKAYA. At. Data. Nucl. Data Tables 55 (1993) 43
(Conv. Elec. emission probabilities)
- G.RATEL. Nucl. Instrum. Methods A345 (1994) 289
(Conv. Elec. emission probabilities, Gamma-ray emission probabilities)
- G.AUDI, A.H.WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q(EC))
- E.SCHÖNFELD. Report PTB-6.33-95-2 1995, Tables for the Calculation of Electron Capture probabilities (1995)
(X-ray emission probabilities)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(K X-ray emission probabilities)
- R.H.MARTIN, K.I.W. BURNS, J.G.V.TAYLOR. Nucl. Instrum. Methods A390 (1997) 267
(Half-life)
- R.G.HELMER, C.VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma ray energies)





1 Decay Scheme

Ag-110 decays by beta minus emission to the Cd-110 fundamental level (99.70 (6)%) and by electron capture to the Pd-110 fundamental level (0.30 (6)%).

L'argent 110 se désintègre à 99,70(6)% par émission bêta moins principalement vers le niveau fondamental de cadmium 110 et à 0,30(6)% par capture électronique vers le niveau fondamental du palladium 110.

2 Nuclear Data

$T_{1/2}({}^{110}\text{Ag})$	:	24,56	(11)	s
$Q^{-}({}^{110}\text{Ag})$	:	2892,2	(16)	keV
$Q^{+}({}^{110}\text{Ag})$	:	892	(11)	keV

2.1 β^{-} Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,10}^{-}$	230,2 (17)	0,0063 (8)	Allowed	4,83
$\beta_{0,9}^{-}$	560,4 (17)	0,0072 (5)	Allowed	6,05
$\beta_{0,8}^{-}$	604,8 (17)	0,0022 (5)	Allowed	6,68
$\beta_{0,7}^{-}$	813,3 (17)	0,0022 (5)	Unique 1st forb.	7,54
$\beta_{0,6}^{-}$	813,6 (17)	0,0076 (14)	Allowed	6,6
$\beta_{0,5}^{-}$	1108,8 (17)	0,0121 (17)	Allowed	6,89
$\beta_{0,4}^{-}$	1160,7 (17)	0,0009 (5)	Allowed	8,1
$\beta_{0,3}^{-}$	1416,5 (16)	0,0099 (10)	Allowed	7,39
$\beta_{0,2}^{-}$	1419,2 (17)	0,038 (3)	Allowed	6,81
$\beta_{0,1}^{-}$	2234,4 (16)	4,4 (4)	Allowed	5,53
$\beta_{0,0}^{-}$	2892,2 (16)	95,2 (4)	Allowed	4,66

2.2 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	<i>P_K</i>	<i>P_L</i>	<i>P_{M+}</i>
ε _{0,0}	892 (11)	0,30 (6)	Allowed	4,1	0,862	0,111	0,027

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	<i>P_{γ+ce}</i> × 100	Multipolarity	<i>α_K</i> (10 ⁻³)	<i>α_L</i> (10 ⁻⁴)	<i>α_M</i> (10 ⁻⁴)	<i>α_T</i> (10 ⁻³)
γ _{6,5} (Cd)	295,3 (2)	0,0078 (16)	(E1)	7,03 (21)	8,3 (3)	1,6 (1)	8,05 (24)
γ _{1,0} (Cd)	657,7600 (11)	4,6 (4)	E2	2,72 (8)	0,34 (1)		3,18 (9)
γ _{2,1} (Cd)	815,50 (2)	0,039 (4)	E2	1,59 (5)	1,9 (1)		1,85 (6)
γ _{3,1} (Cd)	818,0277 (18)	0,0092 (9)	M1+E2	1,67 (5)	0,20 (1)		1,94 (6)
γ _{4,1} (Cd)	1074,0 (2)	0,0009 (5)	E2	8,5 (3)	1,0 (1)		9,8 (3)
γ _{5,1} (Cd)	1125,705 (20)	0,0156 (14)	M1+E2	0,89 (3)	1,0 (1)		1,05 (3)
γ _{10,3} (Cd)	1186,3 (2)	0,0028 (5)	[E2]	6,9 (2)	0,9 (1)		7,9 (2)
γ _{7,1} (Cd)	1421,5 (2)	0,0023 (5)		2,3 (1)	0,3 (1)		2,6 (1)
γ _{3,0} (Cd)	1475,7898 (23)	0,0037 (6)	E2	4,4 (1)	0,7		5,1 (2)
γ _{8,1} (Cd)	1629,9 (2)	0,0023 (5)	E2(+M1)				
γ _{9,1} (Cd)	1674,3 (2)	0,007 (1)					
γ _{5,0} (Cd)	1783,48 (3)	0,0046 (8)	E2				
γ _{10,1} (Cd)	2004,40 (2)	0,0037 (6)	E2				

3 Atomic Data

3.1 Pd

<i>ω_K</i>	:	0,820	(2)
<i>ω_L</i>	:	0,0536	(13)
<i>n_{KL}</i>	:	0,975	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	Kα ₂	21,0203	52,93	
	Kα ₁	21,1774	100	
	Kβ ₃	23,7914	}	
	Kβ ₁	23,819		
	Kβ ₅ ''	24,013	}	27,43
	Kβ ₂	24,2994		
	Kβ ₄	24,344	}	4,67

3.2 Cd

ω_K	:	0,842	(4)
$\bar{\omega}_L$	:	0,0632	(16)
n_{KL}	:	0,953	(4)

3.2.1 X Radiations

	Energy keV	Relative probability	
X _K	K α_2	22,9843	53,17
	K α_1	23,1738	100
	K β_3	26,0615	}
	K β_1	26,0958	}
	K β_5''		}
	K β_5'	26,304	}
	K β_2	26,644	}
	K β_4	26,702	}
			32,95

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
ec _{6,5} K	(Cd)	268,59	(20)	0,000055 (11)
ec _{1,0} K	(Cd)	631,049	(1)	0,0125 (12)
ec _{1,0} L	(Cd)	653,74 - 654,22		0,00156 (16)
$\beta_{0,10}^-$	max:	230,1	(16)	0,0063 (8)
$\beta_{0,10}^-$	avg:	64,2	(5)	
$\beta_{0,9}^-$	max:	560,4	(17)	0,0072 (5)
$\beta_{0,9}^-$	avg:	176,4	(6)	
$\beta_{0,8}^-$	max:	604,8	(17)	0,0022 (5)
$\beta_{0,8}^-$	avg:	192,8	(6)	
$\beta_{0,7}^-$	max:	813,3	(17)	0,0022 (5)
$\beta_{0,7}^-$	avg:	290,7	(7)	
$\beta_{0,6}^-$	max:	813,6	(17)	0,0076 (14)
$\beta_{0,6}^-$	avg:	273,3	(7)	
$\beta_{0,5}^-$	max:	1108,8	(17)	0,0121 (17)
$\beta_{0,5}^-$	avg:	394,1	(7)	

		Energy keV		Electrons per 100 disint.
$\beta_{0,4}^-$	max:	1160,7	(17)	0,0009 (5)
$\beta_{0,4}^-$	avg:	415,9	(7)	
$\beta_{0,3}^-$	max:	1416,5	(16)	0,0099 (10)
$\beta_{0,3}^-$	avg:	526,0	(7)	
$\beta_{0,2}^-$	max:	1419,2	(17)	0,038 (3)
$\beta_{0,2}^-$	avg:	527,1	(7)	
$\beta_{0,1}^-$	max:	2234,4	(16)	4,4 (4)
$\beta_{0,1}^-$	avg:	893,8	(8)	
$\beta_{0,0}^-$	max:	2892,2	(16)	95,2 (4)
$\beta_{0,0}^-$	avg:	1199,0	(8)	

5 Photon Emissions

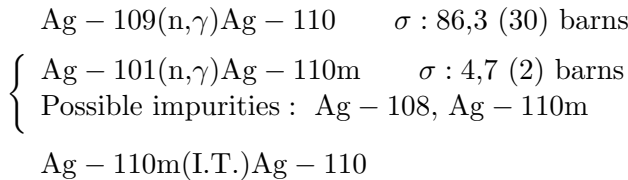
5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XK α_2	(Pd)	21,0203		0,060 (12)	} K α
XK α_1	(Pd)	21,1774		0,114 (23)	
XK β_3	(Pd)	23,7914	}	0,032 (7)	K' β_1
XK β_1	(Pd)	23,819	}		
XK β_5''	(Pd)	24,013	}		
XK β_2	(Pd)	24,2994	}		
XK β_4	(Pd)	24,344	}		
XK α_2	(Cd)	22,9843		0,0032 (3)	} K α
XK α_1	(Cd)	23,1738		0,0061 (6)	
XK β_3	(Cd)	26,0615	}	0,00169 (15)	K' β_1
XK β_1	(Cd)	26,0958	}		
XK β_5'	(Cd)	26,304	}		
XK β_2	(Cd)	26,644	}		
XK β_4	(Cd)	26,702	}		
				0,00031 (3)	K' β_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{6,5}(\text{Cd})$	295,3 (2)	0,0078 (16)
$\gamma_{1,0}(\text{Cd})$	657,7600 (11)	4,6 (4)
$\gamma_{2,1}(\text{Cd})$	815,50 (2)	0,039 (4)
$\gamma_{3,1}(\text{Cd})$	818,0244 (18)	0,0092 (9)
$\gamma_{4,1}(\text{Cd})$	1074,0 (2)	0,0009 (5)
$\gamma_{5,1}(\text{Cd})$	1125,699 (20)	0,0156 (14)
$\gamma_{10,3}(\text{Cd})$	1186,3 (2)	0,0028 (5)
$\gamma_{7,1}(\text{Cd})$	1421,5 (2)	0,0023 (5)
$\gamma_{3,0}(\text{Cd})$	1475,7792 (23)	0,0037 (6)
$\gamma_{8,1}(\text{Cd})$	1629,9 (2)	0,0023 (5)
$\gamma_{9,1}(\text{Cd})$	1674,3 (2)	0,007 (1)
$\gamma_{5,0}(\text{Cd})$	1783,46 (3)	0,0046 (8)
$\gamma_{10,1}(\text{Cd})$	2004,40 (2)	0,0037 (6)

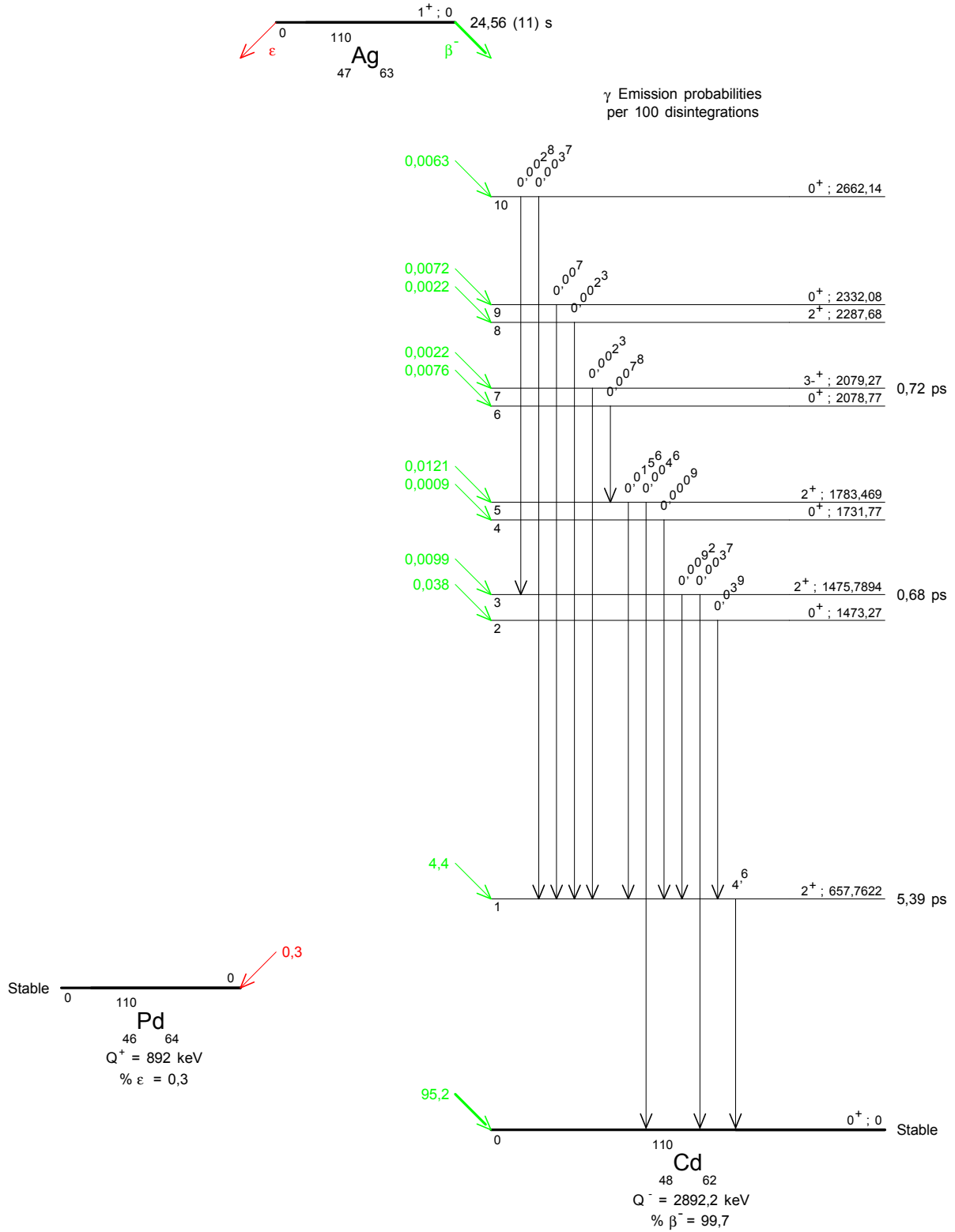
6 Main Production Modes

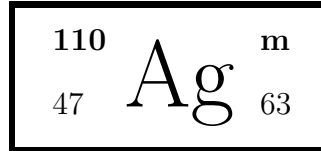


7 References

- E. AMALDI, O. D'AGOSTINO, E. FERMI, B. PONTECORVO, R. RASETT, E. SEGRÈ. Proc Roy. Soc. (London) 149A (1935) 522
(Half-life)
- M. L. POOL. Phys. Rev. 53 (1938) 116
(Half-life)
- H. REDDEMANN. Naturwiss. 26 (1938) 124
(Half-life)
- A. FLAMMERSFELD. Naturwiss. 32 (1944) 36
(Half-life)
- B. O. HIRZEL, H. WÄFFLER. Helv. Phys. Acta 19 (1946) 214
(Half-life)
- F. I. BOLEY. Phys. Rev. 94 (1954) 1078
(Half-life)
- M. L. SEGHAL. Indian J. Phys. 31 (1957) 630
(Half-life)
- T. KATOH, Y. YOSHIZAWA. Nucl. Phys. 32 (1962) 5
(Energy and Intensity beta, Mult, α_k)
- S. MALMSKOG, J. KONIJN. Nucl. Phys. 38 (1962) 196
(Half-life)
- H. DANIEL, O. MEHLING, D. SCHOTTE. Z. Physik 172 (1963) 202
(Energy and probability beta)

- L.FREVERT, P. H. HECKMANN, A. FLAMMERSFELD. Z. Physik 175 (1963) 221
(Energy and probability beta)
- T. SUTER, P. REYES-SUTER, W. SCHEUER. Nucl. Phys. 47 (1963) 251
(Gamma energy, Electron capture intensity)
- W. B. NEWBOLT, J. H. HAMILTON. Nucl. Phys. 53 (1964) 353
(Gamma energy, Electron Capture intensity, α_k)
- L. FREVERT, R. SCHÖNEBERG, A. FLAMMERSFELD. Z. Physik 182 (1965) 439
(Intensity)
- H. P. YULE. Nucl. Phys. A 94 (1967) 442
(Half-life)
- J. A. MORAGUES, P. REYES-SUTER, T. SUTER. Nucl. Phys. A 99 (1967) 652
(Energy and intensity beta)
- J. R. VAN HISE, M. C. KELLEY, R. G. LANIER, N. R. JOHNSON. Phys. Rev. C1 (1970) 8161
(Half-life, Energy and intensity gamma)
- S. P. SUD, P. C. MANGAL, P. N. TREHAN. Aust. J. Phys. 23 (1970) 87
(Mixing ratio)
- K. S. KRANE, R. M. STEFFEN. Phys. Rev. C 2 (1970) 724
(Mixing ratio)
- Y. KAWASE, K. OKANO, S. UEHARA, T. HAYASHI. Nucl. Phys. A 193 (1972) 204
(Energy and intensity gamma)
- P. D. JOHNSTON, N. J. STONE. Nucl. Phys. A 206 (1973) 273
(Mixing ratio)
- P. L. GARDULSKI, M. L. WIEDENBECK. Phys. Rev. C 7 (1973) 2080
(Mixing ratio)
- G. W. WANG, A. J. BECKER, L. M. CHIROVSKY, J. L. GROVES, C. S. WU. Phys. Rev. C 18 (1978) 476
(Mixing ratio)
- P. SCHLÜTER, G. SOFF. Atomic Data Nuclear Data Tables 24 (1979) 509
(α_{pi})
- H. R. VERMA, A. K. SHARMA, R. KAUR, K. K. SURI, P. N. TREHAN. J. Phys. Soc. Japan 47 (1979) 16
(Energy and intensity gamma, mixing ratio)
- W. L. ZIJP. Report ECN FYS/RASA 85/19 (1985)
(averages)
- M. U. RAJPUT, T. D. MACMAHON. Nucl. Instr. and Meth. A 312 (1992) 289
(averages)
- V. M. KARTASHOV, A. I. OBOROVSKY, A. G. TROITSKAYA. Bull. Russ. Acad. Sci. 57 (1993) 1554
(Electron capture intensity)
- L. L. KIANG, P. K. TENG, G. C. KIANG, W. S. CHANG, P. J. TU. J. Phys. Soc. Japan 62 (1993) 888
(Energy and intensity gamma, mixing ratio)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 595 (1995) 409
(Q)
- D. DEFRENNE, E. JACOBS. Nucl. Data Sheets 89 (2000) 481
(J, multipolarity, mixing ratio)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instr. Meth. A 450 (2000) 35
(Energy gamma)





1 Decay Scheme

Ag-110m decays by beta minus emissions to Cd-110 excited levels for 98.64 (8) % and, with two gamma in cascade, to Ag-110 for 1.36 (8) %.

L'argent 110 métastable se désintègre pour 98,64 (8) %, par émission bêta moins, vers des niveaux excités de cadmium 110 et se désexcite dans une proportion de 1,36 (6) % vers le niveau fondamental d'argent 110 selon 2 transitions gamma en cascade.

2 Nuclear Data

$T_{1/2}(^{110}\text{Ag}^m)$	:	249,78	(2)	d
$T_{1/2}(^{110}\text{Ag})$	:	24,56	(11)	s
$Q^-(^{110}\text{Ag}^m)$	:	3009,8	(16)	keV

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,22}^-$	83,1 (16)	67,5 (6)	Allowed	5,36
$\beta_{0,21}^-$	133,0 (16)	0,392 (18)	Allowed	8,2
$\beta_{0,20}^-$	167,3 (16)	0,0252 (10)	1st forbidden	9,7
$\beta_{0,15}^-$	349,9 (16)	0,031 (4)	1st forbidden	10,7
$\beta_{0,13}^-$	470,1 (16)	0,060 (4)	1st forbidden	10,8
$\beta_{0,12}^-$	529,9 (16)	30,8 (3)	Allowed	8,28
$\beta_{0,8}^-$	759,3 (16)	0,06 (5)	2nd forbidden	11,5

2.2 Gamma Transitions and Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K (10^{-1})	α_L (10^{-2})	α_M	α_T	α_π (10^{-4})
$\gamma_{1,0}$ (Ag)	1,113		E1					
$\gamma_{2,1}$ (Ag)	116,48 (5)	1,3520 (3)	M4	1050 (30)	5010 (150)	11	168 (5)	
$\gamma_{15,13}$ (Cd)	120,23 (3)	0,0218 (18)	M1(+E2)	2,5 (6)	3,2 (18)	0,006 (4)	0,29 (8)	
$\gamma_{22,19}$ (Cd)	133,333 (7)	0,0736 (16)						
$\gamma_{22,18}$ (Cd)	219,348 (8)	0,072 (5)						
$\gamma_{22,17}$ (Cd)	221,079 (10)	0,068 (10)						
$\gamma_{12,8}$ (Cd)	229,423 (23)	0,0119 (14)						
$\gamma_{22,15}$ (Cd)	266,913 (12)	0,041 (4)						
$\gamma_{14,7}$ (Cd)	341,3 (2)	0,0022 (5)						
$\gamma_{19,11}$ (Cd)	360,23 (8)	0,008 (5)						
$\gamma_{22,14}$ (Cd)	365,448 (10)	0,092 (5)						
$\gamma_{22,13}$ (Cd)	387,073 (9)	0,0518 (9)						
$\gamma_{21,12}$ (Cd)	396,895 (23)	0,037 (4)						
$\gamma_{15,8}$ (Cd)	409,4 (5)	0,0063	E1(+M2)	0,0303 (9)	0,036 (1)		0,00346 (10)	
$\gamma_{20,11}$ (Cd)	409,4 (5)	0,0063	E1(+M2)	0,0303 (9)	0,036 (1)		0,00346 (10)	
$\gamma_{22,12}$ (Cd)	446,812 (3)	3,68 (5)	M1+E2	0,0772 (23)	0,094 (3)	0,00018 (1)	0,0089 (3)	
$\gamma_{8,4}$ (Cd)	467,03 (4)	0,0251 (19)	(E2)	0,0699 (21)	0,092 (3)	0,00018 (1)	0,00813 (24)	
$\gamma_{22,11}$ (Cd)	493,43 (10)	0,0095 (11)						
$\gamma_{18,6}$ (Cd)	544,55 (5)	0,018 (3)	M1+E2	0,0464 (19)	0,057 (2)		0,0054 (2)	
$\gamma_{19,7}$ (Cd)	572,8 (2)	0,0173 (13)						
$\gamma_{5,2}$ (Cd)	603,08 (10)	0,011 (8)	E1	0,0121 (4)	0,014 (10)		0,00139 (40)	
$\gamma_{6,3}$ (Cd)	620,3572 (17)	2,73 (8)	M1+E2	0,0342 (10)	0,041 (1)		0,00397 (12)	
$\gamma_{21,8}$ (Cd)	626,26 (1)	0,215 (17)	E2	0,0309 (9)	0,039 (1)		0,00361 (11)	
$\gamma_{19,6}$ (Cd)	630,62 (6)	0,033 (5)						
$\gamma_{1,0}$ (Cd)	657,7600 (11)	94,68 (8)	E2	0,0272 (8)	0,034 (1)		0,00318 (9)	
$\gamma_{7,3}$ (Cd)	677,6239 (12)	10,59 (6)	M1+E2	0,0280 (8)	0,033 (1)		0,00324 (10)	
$\gamma_{6,2}$ (Cd)	687,0114 (18)	6,47 (3)	M1+E2	0,0251 (8)	0,031 (1)		0,00292 (9)	
$\gamma_{22,7}$ (Cd)	706,6780 (15)	16,53 (8)	M1+E2	0,0237 (7)	0,029 (1)		0,00275 (8)	
$\gamma_{8,3}$ (Cd)	708,13 (2)	0,23 (5)	M1+E2	0,0255 (8)	0,030 (1)		0,00295 (9)	
$\gamma_{19,5}$ (Cd)	714,9 (1)	0,0092 (24)						
$\gamma_{7,2}$ (Cd)	744,2782 (18)	4,72 (3)	E2(+M3)	0,0199 (6)	0,025 (1)		0,00232 (7)	
$\gamma_{22,6}$ (Cd)	763,9452 (17)	22,36 (9)	E2+M3	0,0198 (10)	0,024 (2)		0,00230 (9)	
$\gamma_{8,2}$ (Cd)	774,7 (1)	0,006 (3)	(E2)	0,0180 (5)	0,022 (1)		0,00210 (6)	
$\gamma_{2,1}$ (Cd)	818,0277 (18)	7,34 (4)	M1+E2	0,0167 (5)	0,020 (1)		0,00194 (6)	
$\gamma_{3,1}$ (Cd)	884,6819 (13)	74,1 (12)	E2	0,0131 (4)	0,016 (1)		0,00152 (5)	
$\gamma_{12,3}$ (Cd)	937,485 (3)	34,56 (27)	E2(+M3)	0,0115 (3)	0,014 (1)		0,00133 (4)	
$\gamma_{11,2}$ (Cd)	957,35 (10)	0,0093 (19)	M1+E2	0,0120 (9)	0,014 (1)		0,00139 (10)	
$\gamma_{13,3}$ (Cd)	997,248 (15)	0,128 (4)	E1(+M2)				0,0007 (9)	
$\gamma_{14,3}$ (Cd)	1018,96 (8)	0,0141 (7)	M1+E2					
$\gamma_{14,2}$ (Cd)	1085,453 (14)	0,072 (4)	E2	0,0083 (3)	0,010 (1)		0,00096 (3)	
$\gamma_{15,3}$ (Cd)	1117,47 (3)	0,0488 (9)	E1(+M2)	0,0034 (1)			0,00040 (1)	
$\gamma_{4,1}$ (Cd)	1125,705 (20)	0,0304 (14)	M1+E2	0,0089 (30)	0,010 (1)		0,00103 (3)	
$\gamma_{17,3}$ (Cd)	1163,15 (8)	0,074 (24)	M1+E2	0,0084 (3)	0,0098 (3)		0,00097 (3)	
$\gamma_{18,3}$ (Cd)	1164,95 (9)	0,043 (3)	M1+E2	0,0077 (7)			0,00090 (3)	
$\gamma_{16,2}$ (Cd)	1186,7 (1)	0,00160 (5)						
$\gamma_{19,3}$ (Cd)	1251,05 (4)	0,026 (3)						0,1
$\gamma_{20,3}$ (Cd)	1300,06 (10)	0,0189 (7)	E1(+M2)	0,0026 (1)			0,00030 (1)	0,19
$\gamma_{21,3}$ (Cd)	1334,335 (17)	0,141 (5)	E2	0,0054 (2)			0,00062 (2)	0,29
$\gamma_{22,3}$ (Cd)	1384,3025 (20)	24,7 (5)	M1+E2	0,0056 (2)			0,00065 (2)	0,39
$\gamma_{5,1}$ (Cd)	1420,08 (5)	0,026 (4)	E1	0,0023 (1)			0,00026 (1)	1,7
$\gamma_{2,0}$ (Cd)	1475,7898 (23)	4,03 (5)	E2	0,0044 (1)			0,00051 (2)	0,67
$\gamma_{6,1}$ (Cd)	1505,039 (2)	13,16 (16)	M1+E2	0,0045 (1)			0,00045 (1)	0,76
$\gamma_{7,1}$ (Cd)	1562,2940 (18)	1,21 (3)	E2(+M3)					1,1
$\gamma_{8,1}$ (Cd)	1592,80 (15)	0,0207 (8)	(E2)					1,2
$\gamma_{9,1}$ (Cd)	1629,76 (15)	0,0040 (5)	M1+E2					1,3
$\gamma_{10,1}$ (Cd)	1698,8 (2)	0,0017 (3)						1,4
$\gamma_{11,1}$ (Cd)	1775,43 (4)	0,0065 (3)	M1+E2					2
$\gamma_{4,0}$ (Cd)	1783,48 (3)	0,0101 (5)	E2					2

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K (10^{-1})	α_L (10^{-2})	α_M	α_T	α_π (10^{-4})
$\gamma_{14,1}$ (Cd)	1903,54 (4)	0,0159 (7)						
$\gamma_{16,1}$ (Cd)	2004,67 (10)	0,0012 (4)						3

3 Atomic Data

3.1 Cd

ω_K	:	0,842	(4)
$\bar{\omega}_L$	:	0,0632	(16)
n_{KL}	:	0,953	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	22,9843	53,17	
	K α_1	23,1738	100	
	K β_3	26,0615	}	
	K β_1	26,0958		
	K β_5''	26,304	}	27,88
	K β_2	26,644		
	K β_4	26,702	}	5,07

3.2 Ag

ω_K	:	0,831	(4)
$\bar{\omega}_L$	:	0,0583	(14)
n_{KL}	:	0,964	(4)

3.2.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	21,9906	53,05	
	K α_1	22,1632	100	
	K β_3	24,9118	}	
	K β_1	24,9427		
	K β_5''	25,146	}	27,7
	K β_2	25,4567		
	K β_4	25,512	}	4,82

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
ec _{22,12} K	(Cd)	420,101	(3)	0,0282 (9)
ec _{1,0} K	(Cd)	631,0490	(11)	0,257 (8)
ec _{7,3} K	(Cd)	650,9130	(12)	0,0296 (9)
ec _{1,0} L	(Cd)	653,742 - 654,222		0,0321 (9)
ec _{22,7} K	(Cd)	679,9670	(15)	0,0391 (12)
ec _{22,6} K	(Cd)	737,2340	(17)	0,0442 (22)
ec _{3,1} K	(Cd)	857,9710	(13)	0,097 (3)
ec _{3,1} L	(Cd)	880,664 - 881,144		0,0118 (8)
ec _{12,3} K	(Cd)	910,774	(3)	0,0397 (11)
$\beta_{0,22}^-$	max:	83,1	(16)	67,5 (6)
$\beta_{0,22}^-$	avg:	21,6	(5)	
$\beta_{0,21}^-$	max:	133,0	(16)	0,392 (18)
$\beta_{0,21}^-$	avg:	35,5	(5)	
$\beta_{0,20}^-$	max:	167,3	(16)	0,0252 (10)
$\beta_{0,20}^-$	avg:	45,4	(5)	
$\beta_{0,15}^-$	max:	349,9	(16)	0,031 (4)
$\beta_{0,15}^-$	avg:	102,6	(6)	
$\beta_{0,13}^-$	max:	470,1	(16)	0,060 (4)
$\beta_{0,13}^-$	avg:	143,9	(6)	
$\beta_{0,12}^-$	max:	529,9	(16)	30,8 (3)
$\beta_{0,12}^-$	avg:	165,3	(6)	
$\beta_{0,8}^-$	max:	759,3	(16)	0,06 (5)
$\beta_{0,8}^-$	avg:	251,9	(7)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XK α_2	(Cd)	22,9843	0,153 (9)	} K α
XK α_1	(Cd)	23,1738	0,288 (16)	}
XK β_3	(Cd)	26,0615	}	
XK β_1	(Cd)	26,0958	0,080 (5)	K' β_1
XK β_5''	(Cd)	26,304	}	
XK β_2	(Cd)	26,644	}	
XK β_4	(Cd)	26,702	0,0146 (9)	K' β_2

	Energy keV	Photons per 100 disint.	
XK α_2 (Ag)	21,9906	0,198 (12)	} K α
XK α_1 (Ag)	22,1632	0,372 (22)	
XK β_3 (Ag)	24,9118	0,103 (7)	} K' β_1
XK β_1 (Ag)	24,9427		
XK β_5'' (Ag)	25,146		
XK β_2 (Ag)	25,4567	0,0179 (12)	} K' β_2
XK β_4 (Ag)	25,512		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{2,1}$ (Ag)	116,48 (5)	0,0080 (3)
$\gamma_{15,13}$ (Cd)	120,23 (3)	0,0169 (9)
$\gamma_{22,19}$ (Cd)	133,333 (7)	0,0736 (16)
$\gamma_{22,18}$ (Cd)	219,348 (8)	0,072 (5)
$\gamma_{22,17}$ (Cd)	221,079 (10)	0,068 (10)
$\gamma_{12,8}$ (Cd)	229,423 (23)	0,0119 (14)
$\gamma_{(-1,1)}$ (Cd)	264,25 (6)	0,0060 (6)
$\gamma_{22,15}$ (Cd)	266,913 (12)	0,041 (4)
$\gamma_{14,7}$ (Cd)	341,3 (2)	0,0022 (5)
$\gamma_{(-1,2)}$ (Cd)	356,43 (10)	0,00425 (30)
$\gamma_{19,11}$ (Cd)	360,23 (8)	0,008 (5)
$\gamma_{22,14}$ (Cd)	365,448 (10)	0,092 (5)
$\gamma_{22,13}$ (Cd)	387,073 (9)	0,0518 (9)
$\gamma_{21,12}$ (Cd)	396,895 (23)	0,037 (4)
$\gamma_{20,11}$ (Cd)	409,4 (5)	0,0063
$\gamma_{15,8}$ (Cd)	409,4 (5)	0,0063
$\gamma_{22,12}$ (Cd)	446,812 (3)	3,65 (5)
$\gamma_{8,4}$ (Cd)	467,03 (4)	0,0249 (19)
$\gamma_{22,11}$ (Cd)	493,43 (10)	0,0095 (11)
$\gamma_{18,6}$ (Cd)	544,55 (5)	0,018 (3)
$\gamma_{19,7}$ (Cd)	572,8 (2)	0,0173 (13)
$\gamma_{5,2}$ (Cd)	603,08 (10)	0,011 (8)
$\gamma_{6,3}$ (Cd)	620,3553 (17)	2,72 (8)
$\gamma_{21,8}$ (Cd)	626,258 (10)	0,214 (17)
$\gamma_{19,6}$ (Cd)	630,62 (6)	0,033 (5)
$\gamma_{(-1,3)}$ (Cd)	647,8 (4)	0,0175 (50)
$\gamma_{1,0}$ (Cd)	657,7600 (11)	94,38 (8)
$\gamma_{(-1,4)}$ (Cd)	666,6 (5)	0,028 (14)
$\gamma_{(-1,5)}$ (Cd)	676,58 (10)	0,14 (1)
$\gamma_{7,3}$ (Cd)	677,6217 (12)	10,56 (6)

	Energy keV	Photons per 100 disint.
$\gamma_{6,2}(\text{Cd})$	687,0091 (18)	6,45 (3)
$\gamma_{22,7}(\text{Cd})$	706,6760 (15)	16,48 (8)
$\gamma_{8,3}(\text{Cd})$	708,128 (20)	0,23 (5)
$\gamma_{19,5}(\text{Cd})$	714,9 (1)	0,0092 (24)
$\gamma_{7,2}(\text{Cd})$	744,2755 (18)	4,71 (3)
$\gamma_{22,6}(\text{Cd})$	763,9424 (17)	22,31 (9)
$\gamma_{8,2}(\text{Cd})$	774,7 (1)	0,006 (3)
$\gamma_{2,1}(\text{Cd})$	818,0244 (18)	7,33 (4)
$\gamma_{3,1}(\text{Cd})$	884,6781 (13)	74,0 (12)
$\gamma_{12,3}(\text{Cd})$	937,485 (3)	34,51 (27)
$\gamma_{11,2}(\text{Cd})$	957,35 (10)	0,0093 (19)
$\gamma_{13,3}(\text{Cd})$	997,243 (15)	0,128 (4)
$\gamma_{14,3}(\text{Cd})$	1018,95 (8)	0,0141 (7)
$\gamma_{(-1,8)}(\text{Cd})$	1050,5 (5)	0,0076 (10)
$\gamma_{14,2}(\text{Cd})$	1085,447 (14)	0,072 (4)
$\gamma_{15,3}(\text{Cd})$	1117,46 (3)	0,0488 (9)
$\gamma_{4,1}(\text{Cd})$	1125,699 (20)	0,0304 (14)
$\gamma_{17,3}(\text{Cd})$	1163,14 (8)	0,074 (24)
$\gamma_{18,3}(\text{Cd})$	1164,94 (9)	0,043 (3)
$\gamma_{16,2}(\text{Cd})$	1186,7 (1)	0,00160 (5)
$\gamma_{19,3}(\text{Cd})$	1251,04 (4)	0,026 (3)
$\gamma_{20,3}(\text{Cd})$	1300,05 (10)	0,0189 (7)
$\gamma_{21,3}(\text{Cd})$	1334,326 (17)	0,141 (5)
$\gamma_{22,3}(\text{Cd})$	1384,2931 (20)	24,7 (5)
$\gamma_{5,1}(\text{Cd})$	1420,07 (5)	0,026 (4)
$\gamma_{(-1,9)}(\text{Cd})$	1465,6 (1)	0,0018 (2)
$\gamma_{2,0}(\text{Cd})$	1475,7792 (23)	4,03 (5)
$\gamma_{6,1}(\text{Cd})$	1505,028 (2)	13,16 (16)
$\gamma_{7,1}(\text{Cd})$	1562,2940 (18)	1,21 (3)
$\gamma_{(-1,10)}(\text{Cd})$	1572,4 (2)	0,0011 (3)
$\gamma_{8,1}(\text{Cd})$	1592,80 (15)	0,0207 (8)
$\gamma_{9,1}(\text{Cd})$	1629,75 (15)	0,0040 (5)
$\gamma_{10,1}(\text{Cd})$	1698,8 (2)	0,0017 (3)
$\gamma_{11,1}(\text{Cd})$	1775,41 (4)	0,0065 (3)
$\gamma_{4,0}(\text{Cd})$	1783,46 (3)	0,0101 (5)
$\gamma_{14,1}(\text{Cd})$	1903,52 (4)	0,0159 (7)
$\gamma_{16,1}(\text{Cd})$	2004,65 (10)	0,0012 (4)

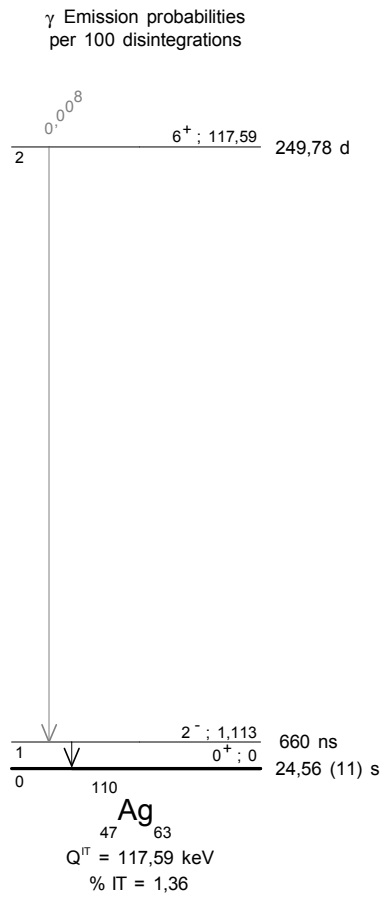
6 Main Production Modes

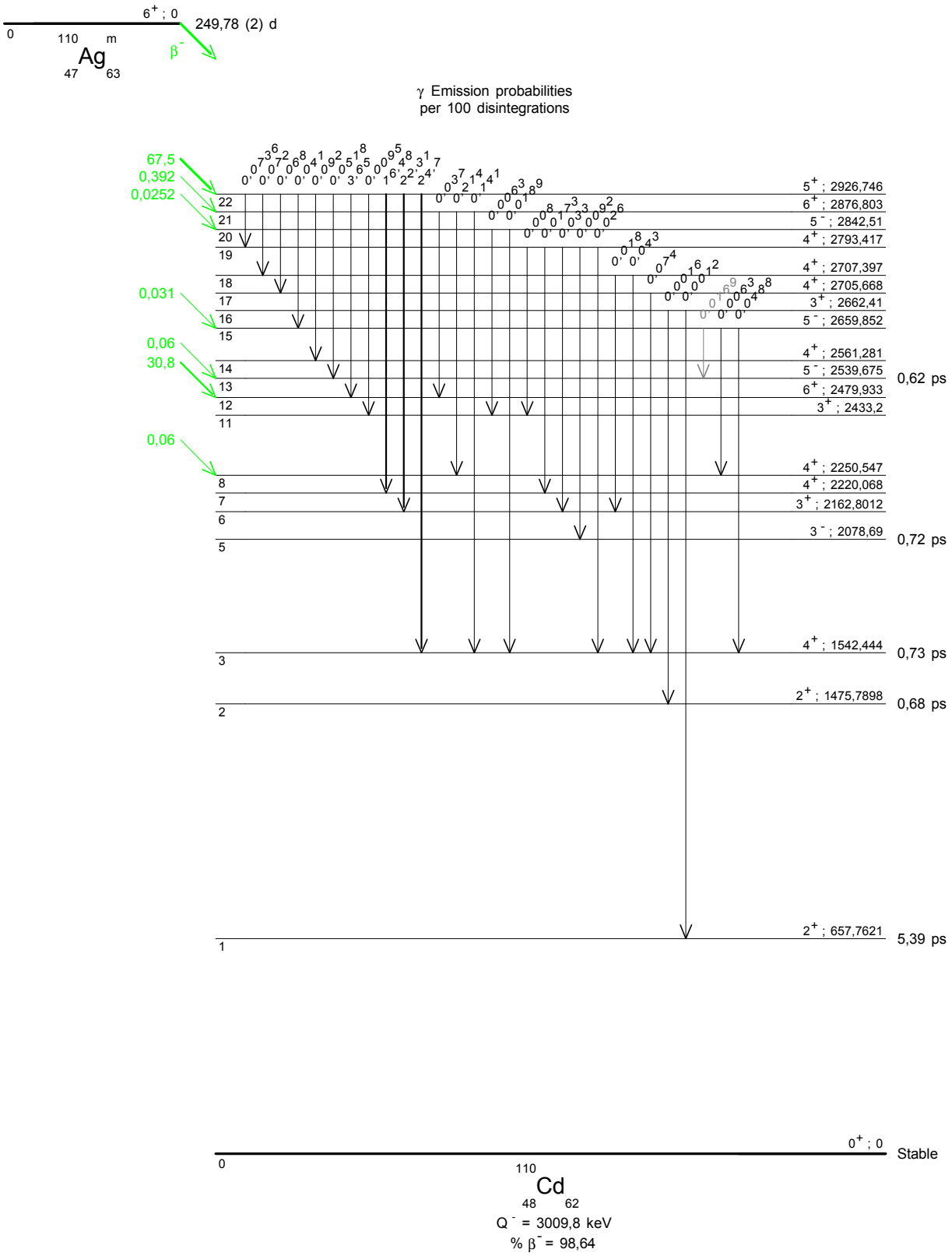
$$\left\{ \begin{array}{l} \text{Ag} - 109(n,\gamma)\text{Ag} - 110\text{m} \quad \sigma : 4,7 (2) \text{ barns} \\ \text{Possible impurities : Ag} - 108\text{m}, \text{Ag} - 110 \end{array} \right.$$

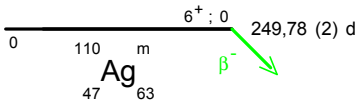
7 References

- J. J. LIVINGOOD, G. T. SEABORG. Phys. Rev. 54 (1938) 88
(Half-life)
- J. R. GUM, M. L. POOL. Phys. Rev. 80 (1950) 315
(Half-life)
- T. SUTER, P. REYES-SUTER, W. SCHEUER. Nucl. Phys. 47 (1963) 251
(Energy gamma, Electron capture intensity)
- J. SCHINTLMEISTER, L. WERNER. Nucl. Phys. 51 (1964) 383
(Energy and intensity beta, electron capture intens)
- W. B. NEWBOLT, J. H. HAMILTON. Nucl. Phys. 53 (1964) 353
(Energy gamma, electron capture intensity, α_k)
- S. M. BRAHMAVAR, J. H. HAMILTON, A. V. RAMAYYA, E. F. ZGANJAR, C. E. BEMIS JR.. Nucl. Phys. A 125 (1969) 217
(Energy and intensity gamma)
- K. S. KRANE, R. M. STEFFEN. Phys. Rev. C 2 (1970) 724
(Mixing ratio)
- S. P. SUD, P. C. MANGAL, P. N. TREHAN. Aust. J. Phys. 23 (1970) 87
(Mixing ratio)
- G. B. PHILIPS, S. M. BRAHMAVAR, J. H. HAMILTON, T. KRACIKOVA. Nucl. Phys. A 182 (1972) 606
(Energy and intensity gamma)
- P. D. JOHNSTON, N. J. STONE. Nucl. Phys. A 206 (1973) 273
(Mixing ratio)
- P. L. GARDULSKI, M. L. WIEDENBECK. Phys. Rev. C 7 (1973) 2080
(Mixing ratio)
- W. W. PRATT. J. Inorg. Nucl. Chem. 36 (1974) 1199
(Energy and intensity gamma)
- K. F. WALZ, H. M. WEISS, K. DEBERTIN. Priv. Comm. (1976)
(Half-life)
- K. DEBERTIN, U. SCHÖTZIG, K. F. WALZ, H. M. WEISS. Proc. ERDA Symposium on X- and Gamma-ray Sources and Applications - Ann. Arbor. (1976) 59
(Intensity gamma)
- R. J. GEHRKE, R. G. HELMER, R. C. GREENWOOD. Nucl. Instr. Meth. 147 (1977) 405
(Intensity gamma)
- J. KERN, S. SCHWITZ. Nucl. Instr. Meth. 151 (1978) 549
(Energy gamma)
- G. W. WANG, A. J. BECKER, L. M. CHIROVSKY, J. L. GROVES, C. S. WU. Phys. Rev. C 18 (1978) 476
(Mixing ratio)
- H. R. VERMA, A. K. SHARMA, P. KAUR, K. K. SURI, P. N. TREHAN. J. Phys. Soc. Japan 47 (1979) 16
(Energy and intensity gamma, mixing ratio)
- E. J. COHEN, H. R. ANDREWS, T. F. KNOTT, F. M. PIPKIN, D. C. SANTRY. Phys. Rev. C 20 (1979) 847
(Mixing ratio)
- P. SCHLÜTER, G. SOFF. Atomic Data Nuclear Data Tables 24 (1979) 509
(α_{pi})
- V. V. BABENKO, I. N. VISHNEVSKII, V. A. ZHELTONOZHSHKII, V. P. SVYATO, V. V. TRISHIN. Bull. Acad. Sci. (USSR) - Phys. Ser. 44, 5 (1980) 132
(Angular correlation, mixing ratio)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. Intern. J. Appl. Radiat. Isot. 31 (1980) 153
(Half-life)
- Y. YOSHIZAWA, Y. IWATA, T. KATU, T. KATOH, J.-Z. RUAN, T. KOJIMA, Y. KAWADA. Nucl. Instr. Meth. 174 (1980) 109
(Intensity gamma)
- W. M. RONEY JR., W. A. SEALE. Nucl. Instr. Meth. 171 (1980) 389
(Intensity gamma)
- W. D. RUHTER, D. C. CAMP. Nucl. Instr. Meth. 173 (1980) 489
(Mixing ratio)
- G. MALLET. J. Phys. Soc. Japan 50 (1981) 384
(Energy and intensity gamma)
- G. MALLET, J. DALMASSO, H. MARIA, G. ARDISSON. J. Phys. G - Nucl. Phys. 7 (1981) 1259
(scheme)

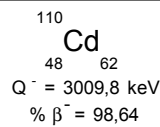
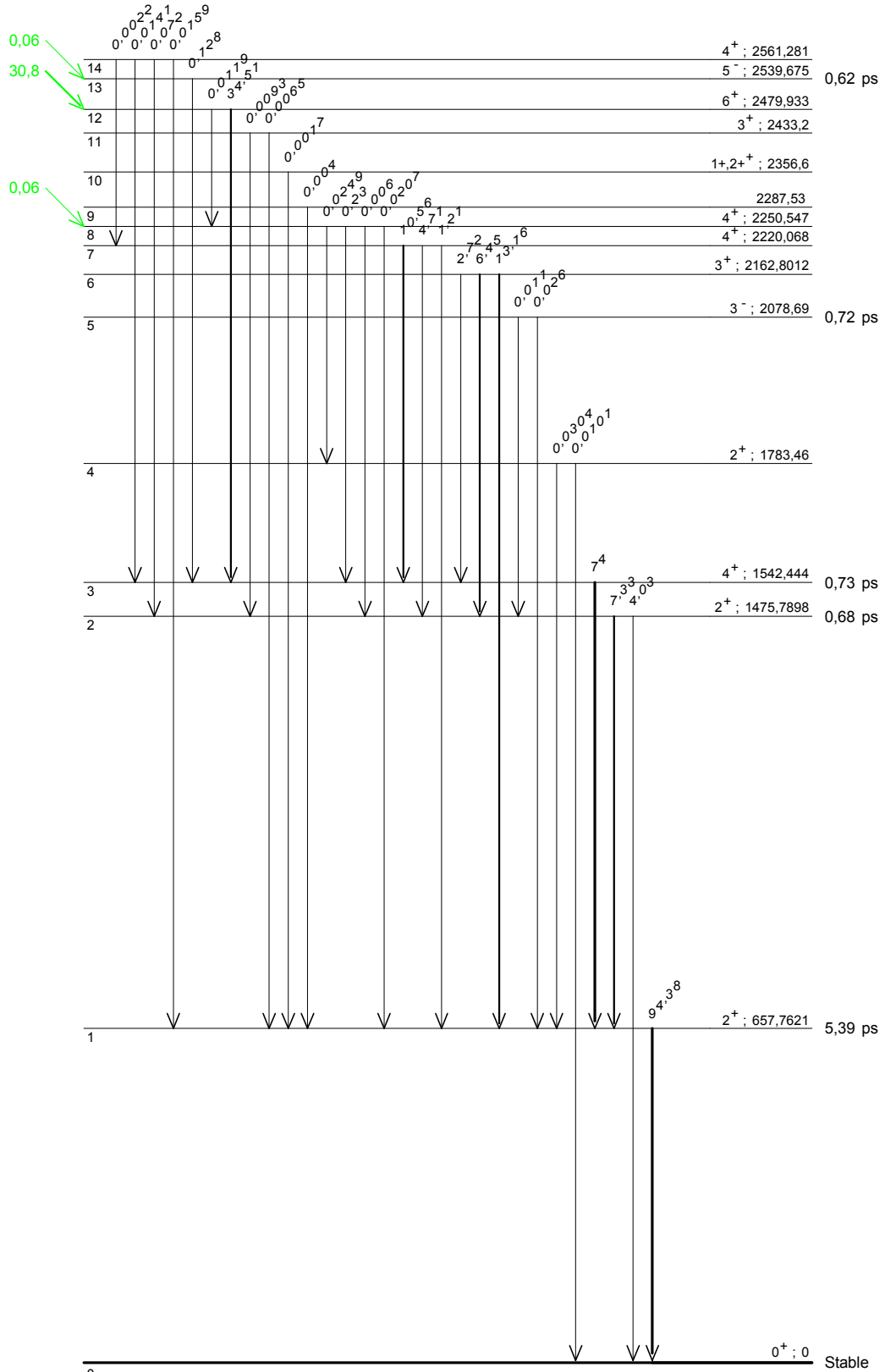
- R. A. MEYER, T. N. MASSEY. Intern. J. Appl. Radiat. Isot. 34 (1983) 1073
(Energy gamma)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Inter. J. Appl. Radiat. Isot. 34 (1983) 1191
(Half-life)
- W. L. ZIJP. Report ECN FYS - RASA 85/19 (1985)
(Averages)
- K. S. KRANE, N. S. SCHULZ. Phys. Rev. C 37 (1988) 747
(Mixing ratio)
- R. A. MEYER. Fizika 22 (1990) 153
(Energy and intensity gamma)
- I. M. BAND, M. B. TRZHASKOVSKAYA. Bull. Acad. Sci. (USSR) - Phys. Ser. 55, 11 (1991) 39
(α)
- M. U. RAJPUT, T. D. MACMAHON. Nucl. Instr. Meth. A 312 (1992) 289
(Averages)
- R. C. GREENWOOD, R. G. HELMER, M. A. LEE, M. H. PUTNAN, M. A. OATES, D. A. STRITTMANN, K. D. WATTS. Nucl. Instr. Meth. A 314 (1992) 514
(Intensity beta)
- L. L. KIANG, P. K. TENG, G. C. KIANG, W. S. CHANG, P. J. TU. J. Phys. Soc. Japan 62 (1993) 888
(Energy and intensity gamma, mixing ratio)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 595 (1995) 409
(Q)
- B. SINGH, J. L. RODRIGUEZ, S. S. M. WONG, J. K. TULI. Nucl. Data Sheets 84 (1998) 487
(Logft systematics)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instr. Meth. A 450 (2000) 35
(Energy gamma)
- D. DEFRENNE, E. JACOBS. Nucl. Data Sheets 89 (2000) 481
(Jp, multipolarities, mixing ratio)

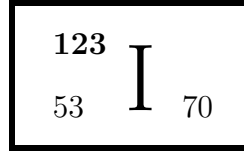






γ Emission probabilities per 100 disintegrations





1 Decay Scheme

I-123 disintegrates by electron capture mainly via the 159 keV level of Te-123 (97%).

L'iodo123 se désintègre par capture électronique principalement vers le niveau excité de 159 keV du tellure 123, avec une probabilité de 97%.

2 Nuclear Data

$T_{1/2}(^{123}\text{I})$	:	13,2234	(37)	h
$T_{1/2}(^{123}\text{Te})$	:	12		10^{12} a
$Q^+(^{123}\text{I})$	:	1234	(3)	keV

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	P_K	P_L	P_M
$\epsilon_{0,13}$	165,8 (30)	0,0079 (4)	Allowed	7,59	0,8082 (21)	0,1503 (15)	0,0336 (7)
$\epsilon_{0,12}$	197,4 (30)	0,0025 (9)	Allowed	8,27	0,8182 (18)	0,1427 (13)	0,0316 (6)
$\epsilon_{0,11}$	237,9 (30)	0,0035 (3)	1st Forbidden	8,31	0,8266 (16)	0,1363 (12)	0,0300 (6)
$\epsilon_{0,10}$	339,3 (30)	0,0744 (13)	Allowed	7,32	0,8377 (15)	0,1283 (11)	0,0278 (5)
$\epsilon_{0,9}$	450,4 (30)	0,1461 (20)	Allowed	7,29	0,8436 (14)	0,1237 (10)	0,0267 (5)
$\epsilon_{0,8}$	464,7 (30)	0,0037 (6)	Allowed	8,92	0,8441 (14)	0,1233 (10)	0,0266 (5)
$\epsilon_{0,7}$	536,5 (30)	0,419 (13)	Allowed	6,98	0,8464 (14)	0,1216 (10)	0,0262 (5)
$\epsilon_{0,6}$	546 (3)	1,40 (12)	Allowed	6,49	0,8466 (14)	0,1214 (10)	0,0261 (5)
$\epsilon_{0,4}$	728,7 (30)	0,349 (42)	Allowed	7,35	0,8501 (14)	0,1187 (10)	0,0254 (5)
$\epsilon_{0,3}$	744,3 (30)	0,0025 (10)	Allowed	9,52	0,8503 (14)	0,1186 (10)	0,0254 (5)
$\epsilon_{0,2}$	794 (3)	0,419 (5)	Allowed	7,35	0,8510 (14)	0,1181 (10)	0,0253 (5)
$\epsilon_{0,1}$	1075 (3)	97,18 (32)	Allowed	5,26	0,8533 (14)	0,1163 (10)	0,0248 (5)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_T
$\gamma_{1,0}(\text{Te})$	158,99 (5)	99,22 (30)	M1 + 1,22%E2	0,1648 (16)	0,02160 (22)	0,1918 (19)
$\gamma_{13,10}(\text{Te})$	174,2 (3)	0,00099 (30)	M1 + 50% E2	0,159 (32)	0,029 (12)	0,195 (47)
$\gamma_{6,4}(\text{Te})$	182,61 (8)	0,021 (6)	M1 + 50% E2	0,138 (24)	0,024 (10)	0,168 (38)
$\gamma_{7,4}(\text{Te})$	192,18 (9)	0,0227 (10)	M1 + 50% E2	0,118 (20)	0,020 (8)	0,143 (30)
$\gamma_{10,7}(\text{Te})$	197,22 (11)	0,00037 (19)	M1 + 50% E2	0,109 (18)	0,018 (7)	0,132 (26)
$\gamma_{6,3}(\text{Te})$	198,25 (12)	0,0040 (8)	M1 + 50% E2	0,107 (17)	0,018 (7)	0,130 (26)
$\gamma_{10,6}(\text{Te})$	206,79 (10)	0,0037 (9)	M1 + 50% E2	0,094 (14)	0,016 (5)	0,114 (21)
$\gamma_{7,3}(\text{Te})$	207,82 (13)	0,00125 (36)	M1 + 50% E2	0,093 (14)	0,015 (5)	0,119 (20)
$\gamma_{6,2}(\text{Te})$	247,96 (8)	0,0743 (25)	M1 + 50% E2	0,054 (5)	0,0084 (21)	0,065 (8)
$\gamma_{7,2}(\text{Te})$	257,52 (9)	0,0017 (2)	E2	0,0526 (16)	0,00917 (27)	0,0640 (19)
$\gamma_{9,4}(\text{Te})$	278,26 (8)	0,0024 (4)	M1 + 50% E2	0,0387 (22)	0,0058 (11)	0,0459 (36)
$\gamma_{2,1}(\text{Te})$	281,03 (7)	0,0822 (10)	M1 + 13,2% E2	0,0362 (20)	0,0048 (11)	0,0422 (33)
$\gamma_{10,5}(\text{Te})$	295,17 (21)	0,001582 (4)				
$\gamma_{8,2}(\text{Te})$	329,38 (18)	0,0026 (6)				
$\gamma_{3,1}(\text{Te})$	330,71 (11)	0,01197 (34)	E2	0,0237 (7)	0,00376 (11)	0,0284 (9)
$\gamma_{9,2}(\text{Te})$	343,73 (8)	0,0044 (3)				
$\gamma_{4,1}(\text{Te})$	346,35 (7)	0,1287 (9)	M1 + 0,49% E2	0,02080 (14)	0,00262 (29)	0,02407 (23)
$\gamma_{10,3}(\text{Te})$	405,04 (14)	0,00298 (23)				
$\gamma_{12,5}(\text{Te})$	437,5 (3)	0,0007 (7)				
$\gamma_{2,0}(\text{Te})$	440,02 (5)	0,4280 (44)	M1 + 81,5% E2	0,0103 (7)	0,001452 (18)	0,0121 (7)
$\gamma_{10,2}(\text{Te})$	454,76 (15)	0,00412 (22)				
$\gamma_{4,0}(\text{Te})$	505,34 (6)	0,268 (42)	M1 + 1% E2	0,0081 (7)	0,001063 (27)	0,0093 (7)
$\gamma_{6,1}(\text{Te})$	528,96 (7)	1,28 (12)				
$\gamma_{7,1}(\text{Te})$	538,54 (8)	0,393 (13)	E2 + 50% M3	0,032 (26)	0,0049 (41)	0,038 (31)
$\gamma_{11,2}(\text{Te})$	556,06 (16)	0,0029 (3)				
$\gamma_{13,4}(\text{Te})$	562,84 (12)	0,00115 (7)				
$\gamma_{13,3}(\text{Te})$	578,48 (20)	0,00126 (8)				
$\gamma_{5,0}(\text{Te})$	599,69 (16)	0,00266 (17)				
$\gamma_{8,1}(\text{Te})$	610,27 (23)	0,0011 (3)				
$\gamma_{9,1}(\text{Te})$	624,61 (7)	0,0802 (20)	M1 + 62,8% E2	0,0042 (5)	0,000549 (40)	0,0049 (6)
$\gamma_{13,2}(\text{Te})$	628,26 (22)	0,00164 (14)				
$\gamma_{6,0}(\text{Te})$	687,95 (10)	0,0269 (6)				
$\gamma_{10,1}(\text{Te})$	735,78 (9)	0,0616 (8)				
$\gamma_{9,0}(\text{Te})$	783,62 (6)	0,0591 (11)				
$\gamma_{11,1}(\text{Te})$	837,1 (2)	0,000582 (8)				
$\gamma_{12,1}(\text{Te})$	877,65 (17)	0,00083 (7)				
$\gamma_{10,0}(\text{Te})$	894,8 (2)	0,00101 (7)				
$\gamma_{13,1}(\text{Te})$	909,19 (12)	0,00141 (8)				
$\gamma_{12,0}(\text{Te})$	1036,64 (17)	0,00097 (7)				
$\gamma_{13,0}(\text{Te})$	1068,18 (15)	0,00142 (7)				

3 Atomic Data

3.1 Te

ω_K	:	0,875	(4)
$\bar{\omega}_L$	:	0,0862	(35)
n_{KL}	:	0,917	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	Kα ₂	27,202	53,7	
	Kα ₁	27,4726	100	
	Kβ ₃	30,9446	}	
	Kβ ₁	30,996	}	
	Kβ ₅ ^{''}	31,236	}	28,6
	Kβ ₅ [']	31,241	}	
	Kβ ₂	31,7008	}	
	Kβ ₄	31,774	}	6,2
	KO _{2,3}	31,812	}	
	X _L	Lℓ	3,336	
Lα		3,76 – 3,77		
Lη		3,606		
Lβ		4,02 – 4,37		
Lγ		4,44 – 4,82		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	21,804 – 22,989	100
KLX	25,814 – 27,470	45,3
KXY	29,80 – 31,81	5,13
Auger L	2,3 – 4,8	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Te)	2,3 - 4,8	95,3 (6)
e _{AK}	(Te)		12,4 (4)
	KLL	21,804 - 22,989	}
	KLX	25,814 - 27,470	}
	KXY	29,80 - 31,81	}
ec _{1,0 K}	(Te)	127,176 (5)	13,72 (14)
ec _{1,0 L}	(Te)	154,051 - 154,649	1,798 (19)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Te)	3,336 — 4,82	9,0 (4)	
XK α_2	(Te)	27,202	24,69 (20)	} K α
XK α_1	(Te)	27,4726	45,98 (29)	}
XK β_3	(Te)	30,9446	}	
XK β_1	(Te)	30,996	}	
XK β_5''	(Te)	31,236	}	
XK β_5'	(Te)	31,241	}	
XK β_2	(Te)	31,7008	}	
XK β_4	(Te)	31,774	}	
XKO _{2,3}	(Te)	31,812	}	
			2,86 (8)	K' β_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Te})$	158,97 (5)	83,25 (21)
$\gamma_{13,10}(\text{Te})$	174,2 (3)	0,00083 (25)

	Energy keV	Photons per 100 disint.
$\gamma_{6,4}(\text{Te})$	182,61 (6)	0,018 (5)
$\gamma_{7,4}(\text{Te})$	192,17 (7)	0,0199 (7)
$\gamma_{10,7}(\text{Te})$	197,22	0,00033 (17)
$\gamma_{6,3}(\text{Te})$	198,23	0,0035 (7)
$\gamma_{10,6}(\text{Te})$	206,79	0,0033 (8)
$\gamma_{7,3}(\text{Te})$	207,8	0,00112 (32)
$\gamma_{6,2}(\text{Te})$	247,96 (5)	0,0698 (23)
$\gamma_{7,2}(\text{Te})$	257,51 (15)	0,0016 (2)
$\gamma_{9,4}(\text{Te})$	278,36 (12)	0,0023 (4)
$\gamma_{2,1}(\text{Te})$	281,03 (5)	0,0789 (9)
$\gamma_{10,5}(\text{Te})$	295,17	0,001582 (4)
$\gamma_{8,2}(\text{Te})$	329,38 (17)	0,0026 (6)
$\gamma_{3,1}(\text{Te})$	330,70 (8)	0,01164 (33)
$\gamma_{9,2}(\text{Te})$	343,73 (14)	0,0044 (3)
$\gamma_{4,1}(\text{Te})$	346,35 (5)	0,1257 (9)
$\gamma_{10,3}(\text{Te})$	405,02 (13)	0,00298 (23)
$\gamma_{12,5}(\text{Te})$	437,5 (3)	0,0007 (7)
$\gamma_{2,0}(\text{Te})$	440,02 (5)	0,4229 (43)
$\gamma_{10,2}(\text{Te})$	454,76 (15)	0,00412 (22)
$\gamma_{4,0}(\text{Te})$	505,33 (5)	0,266 (42)
$\gamma_{6,1}(\text{Te})$	528,96 (5)	1,28 (12)
$\gamma_{7,1}(\text{Te})$	538,54 (5)	0,3788 (43)
$\gamma_{11,2}(\text{Te})$	556,05 (13)	0,0029 (3)
$\gamma_{13,4}(\text{Te})$	562,79 (12)	0,00115 (7)
$\gamma_{13,3}(\text{Te})$	578,26 (20)	0,00126 (8)
$\gamma_{5,0}(\text{Te})$	599,69 (16)	0,00266 (17)
$\gamma_{8,1}(\text{Te})$	610,05 (23)	0,0011 (3)
$\gamma_{9,1}(\text{Te})$	624,57 (5)	0,0798 (20)
$\gamma_{13,2}(\text{Te})$	628,26 (22)	0,00164 (14)
$\gamma_{6,0}(\text{Te})$	687,95 (10)	0,0269 (6)
$\gamma_{10,1}(\text{Te})$	735,78 (7)	0,0616 (8)
$\gamma_{9,0}(\text{Te})$	783,59 (6)	0,0591 (11)
$\gamma_{11,1}(\text{Te})$	837,1 (2)	0,000582 (8)
$\gamma_{12,1}(\text{Te})$	877,52 (17)	0,00083 (7)
$\gamma_{10,0}(\text{Te})$	894,8 (2)	0,00101 (7)
$\gamma_{13,1}(\text{Te})$	909,12 (12)	0,00141 (8)
$\gamma_{12,0}(\text{Te})$	1036,63 (17)	0,00097 (7)
$\gamma_{13,0}(\text{Te})$	1068,12 (15)	0,00142 (7)

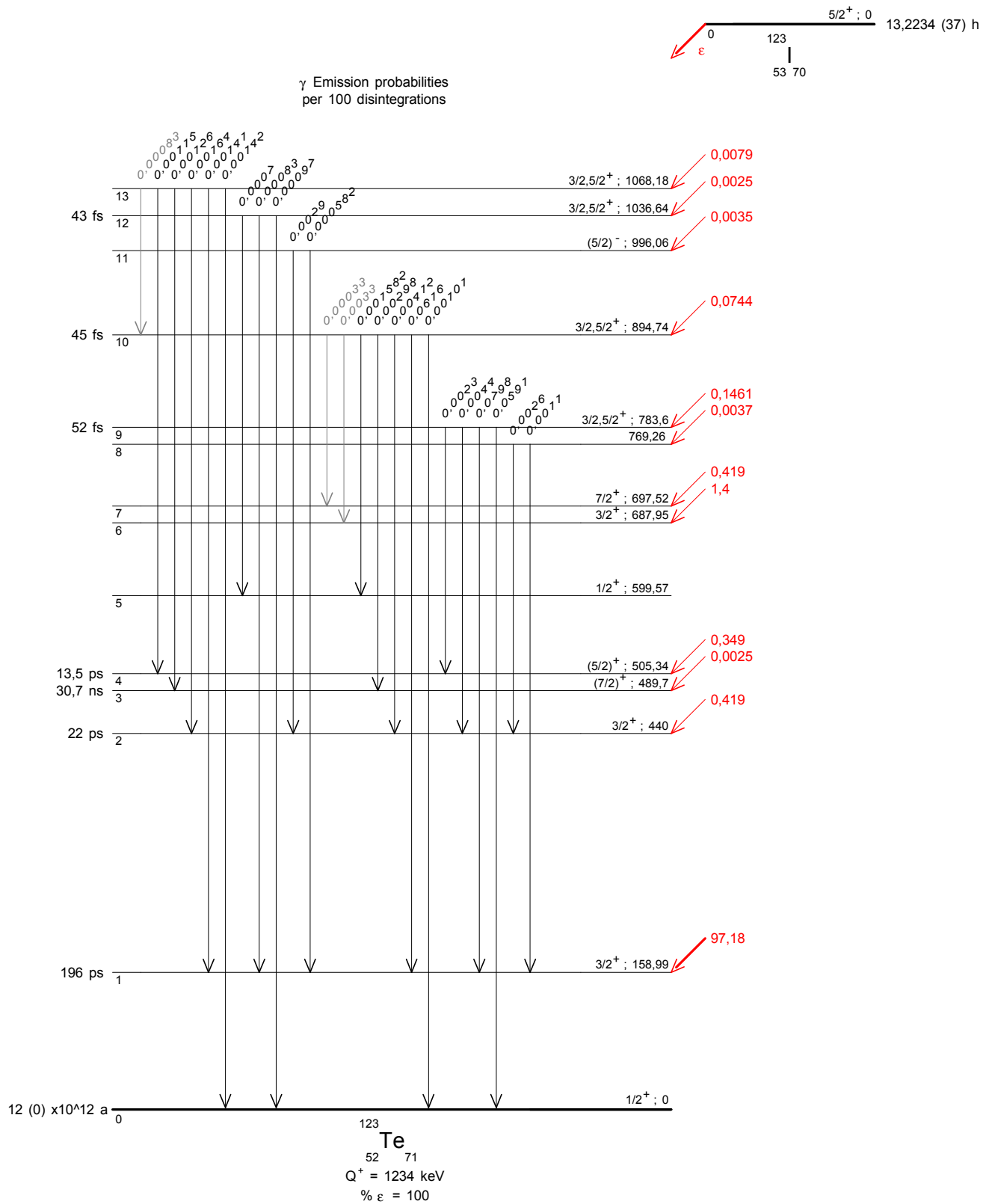
6 Main Production Modes

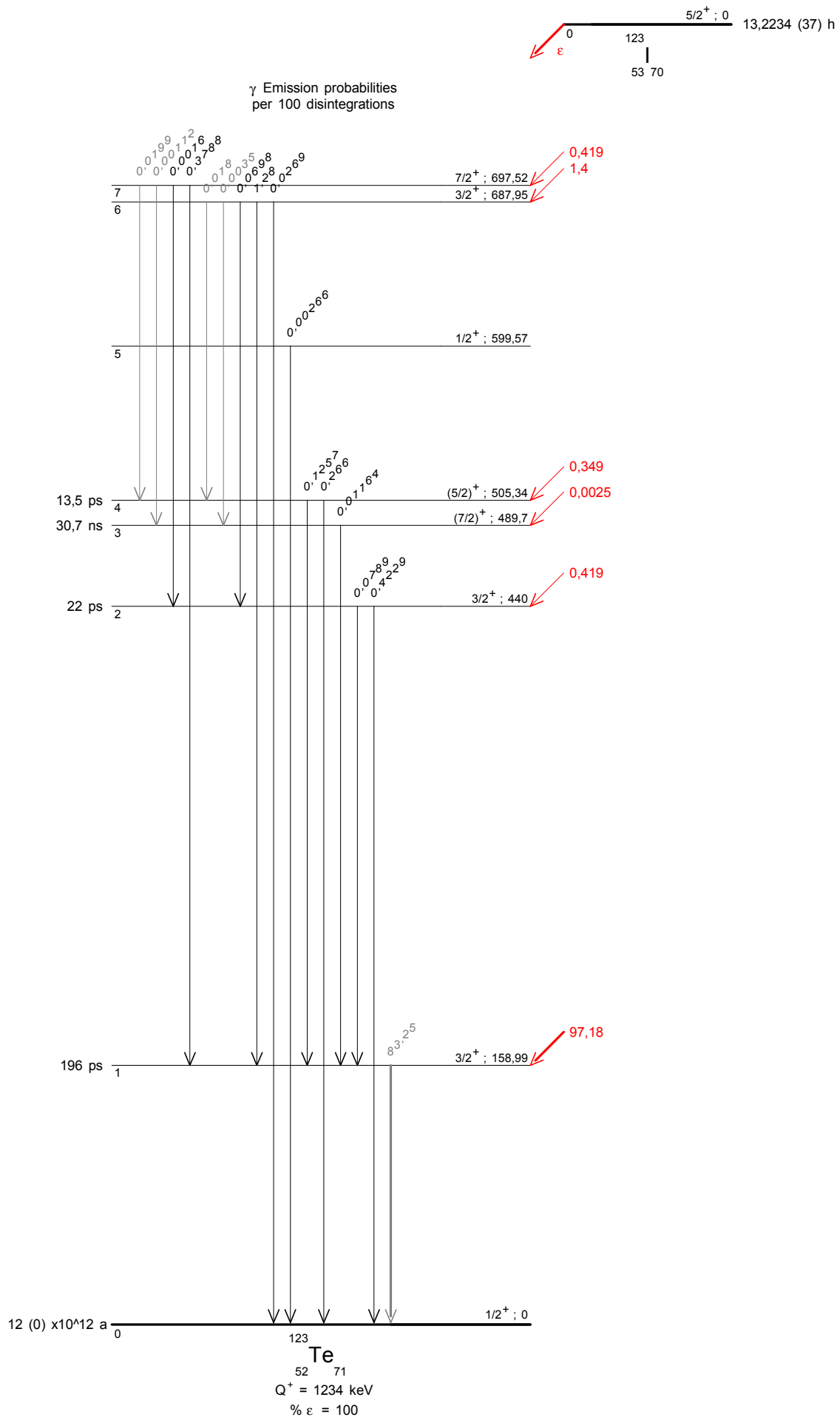
- { Sb – 121($\alpha,2n$)I – 123
Possible impurities : I – 121, I – 124, I – 125, I – 126
- { I – 127(p,5n)Xe – 123
Te – 124(p,2n)I – 123
Possible impurities : I – 124, I – 126, I – 125
- { Te – 123(p,n)I – 123
Possible impurities : I – 124, I – 126, I – 130, I – 125
- { Te – 122($\alpha,3n$)Xe – 123
Possible impurities : I – 125
- { Te – 123(He – 3,3n)Xe – 123
Possible impurities : I – 125
- { Te – 124(He – 3,4n)Xe – 123
Possible impurities : I – 125
- { Te – 122(d,n)I – 123
Possible impurities : I – 124, I – 126, I – 131, I – 125

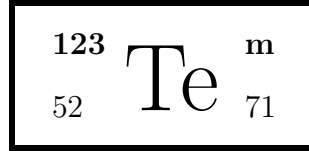
7 References

- R. K. GUPTA. Nucl. Phys. 14 (1960) 606
(Gamma-ray Emission, emission probabilities)
- G. ANDERSON, G. RUDSTAM, G. SORENSEN. Ark. Fys. 28 (1964) 3
(Half-life)
- Y. Y. CHU, O. C. KISTNER, A. C. LI, S. MONARO, M. L. PERLMAN. Phys. Rev. 133 (1964) B1316
(E2/M1 ratios)
- Y. Y. CHU, M. L. PERLMAN. Phys. Rev. 135 (1964) B319
(internal conversion coefficients)
- E. N. HATCH, G. W. EAKINS, G. C. NELSON, R. E. MCADAMS. Proc. Inter. Conf. : Internal Conversion Process (1965)
(Internal Conversion Coefficient)
- H. SERGOLE, G. ALBOUY, J. BOULOUME, J. M. LAGRANGE, L. MARCUS, M. PAUTRAT. J. Phys. (Paris) 28 (1967) 383
(Gamma-ray Emissions)
- G. G. JONSSON, B. FORKMAN. Nucl. Phys. A 107 (1968) 52
(Half-life)
- H. B. HUPF, J. S. ELDRIDGE, J. E. BREAVER. Int. J. Appl. Radiat. Isotop. 19 (1968) 345
(Half-Life)
- R. C. RAGAINI, W. B. WALTERS, G. E. GORDON, P. A. BAEDECKER. Nucl. Phys. A 115 (1968) 611
(Gamma-ray Emissions)
- B. V. NARASIMHA RAO, SWANI JNANANANDA. Phys. Rev. 165 (1968) 1296
(E2 transitions)
- H. SERGOLE, G. ALBOUY, M. JOURDAIN, J. M. LAGRANGE, N. POFPE, M. PAUTRAT. J. Phys. (Paris) C1 (1968) 187
(Gamma-ray Emissions)
- H. SERGOLE, J. VANHORENBEECK. Nucl. Phys. A 139 (1969) 554
(Gamma-ray emissions, angular correlations)
- E. H. SPEJEWSKI, P. K. HOPKE, F. W. LOESER JR. Nucl. Phys. A 146 (1970) 182
(Gamma ray energy and intensity)
- H. SCHRADER, R. STIPPLER, F. MUNICH. Nucl. Phys. A 151 (1970) 331
(Gamma-ray emission, emission probabilities)

- A. HOGLEEND, S. G. MALMSTOG, F. MUNICH, H. SCHRADER. Nucl. Phys. A 165 (1971) 513
(M1 and E2 transitions)
- R. STIPPLER, D. CODE, H. SCHRADER, F. MUNICH. Z. Phys. 242 (1971) 121
(Gamma-ray emission, K-shell conversion coefficient)
- H. C. CHEUNG, S. K. MARK. Nucl. Phys. A 176 (1971) 489
(Half-life)
- S. RAMAN. Nucl. Instrum. Methods 103 (1972) 407
(Internal Conversion Coefficient)
- H. M. A. KARIM. Radiochim. Acta 19 (1973) 1
(Half-life)
- V. J. SODD, J. W. BLUE, K. L. SCHOLZ, M. C. OSELKA. Int. J. Appl. Radiat. Isotop. 24 (1973) 171
(Gamma ray energy and intensity)
- W. N. RONEY, D. W. GEBBIE, R. R. BORCHERS. Nucl. Phys. A236 (1974) 165
(Mixing of different multipolarities)
- W. B. WALTERS, R. A. MEYER. Phys. Rev. C14 (1976) 1925
(Gamma-ray energy and intensity)
- D. B. FOSSAN, *et al.* Phys. Rev. C15 (1977) 1732
(Gamma-ray transitions, spin and parity)
- U. HAGEMANN, H.-J. KELLER, H.-F. BRINCKMAN. Nucl. Phys. A289 (1977) 292
(Gamma-ray energy and intensity)
- K. S. KRANE. At. Data. Nucl. Data Tables 19 (1977) 363
(E2, M1 multipole mixing ratios)
- E. SCHOETERS, J. GEENEN, C. NUYTEN, L. VANNESTE. Nucl. Phys. A323 (1979) 1
(J, mixing of different multipolarities)
- R. E. SHROY, *et al.* Phys. Rev. C26 (1982) 1089
(Gamma-ray emission probabilities)
- F. LAGOUTINE, J. LEGRAND. Int. J. Appl. Radiat. Isotop. 33 (1982) 711
(Half-life)
- R. JACQUEMIN. Int. J. Appl. Radiat. Isotop. 38 (1987) 1087
(Half-life)
- M. P. UNTERWEGER, D. D. HOPPES, F. J. SCHIMA. Nucl. Instrum. Methods A312 (1992) 349
(Half-life)
- S. OHYA, T. TAMURA. Nucl. Data Sheets 70 (1993) 531
(Spin, Parity)
- R. GOSWANI, B. SETHI, P. BARNERJEE, P. K. CHATTOPADHYAY. Phys. Rev. C47 (1993) 1013
(Gamma-ray energy)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic data)
- M. A. L. DA SILVA, M. C. M. DE ALMEIDA, C. J. DA SILVA, J. U. DELGADO. Appl. Rad. Isotopes 60 (2004) 301
(Half-life)
- H. SCHRADER. Appl. Rad. Isotopes 60 (2004) 317
(Half-life)







1 Decay Scheme

Te-123m decays via two successive gamma transitions.

A gamma transition with a small probability and an energy of 247 keV has been observed.

Te-123m se désintègre via deux transitions gamma en cascade. Une transition de 247 keV et de faible probabilité a été observée.

2 Nuclear Data

$$T_{1/2}(^{123}\text{Te}^m) : 119,3 \quad (1) \quad \text{d}$$

$$T_{1/2}(^{123}\text{Te}) : 12 \quad 10^{12} \quad \text{a}$$

2.1 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{2,1}(\text{Te})$	88,46 (7)	100,0 (1)	M4	463 (14)	493 (15)	118,0 (35)	1099 (33)
$\gamma_{1,0}(\text{Te})$	158,99 (5)	100,0 (1)	M1+1,22%E2	0,1648 (16)	0,02160 (22)	0,00433 (13)	0,1918 (19)
$\gamma_{2,0}(\text{Te})$	247,4 (2)	0,0030 (3)	E5	3,0 (1)	3,75 (21)	0,84 (3)	7,75 (30)

3 Atomic Data

3.1 Te

$$\omega_K : 0,875 \quad (4)$$

$$\bar{\omega}_L : 0,0862 \quad (35)$$

$$n_{KL} : 0,917 \quad (4)$$

3.1.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	27,202	53,7
$K\alpha_1$	27,4726	100
$K\beta_3$	30,9446	}
$K\beta_1$	30,996	}
$K\beta_5''$	31,236	}
$K\beta_5'$	31,241	}
$K\beta_2$	31,7008	}
$K\beta_4$	31,774	}
$KO_{2,3}$	31,812	}
X_L		
$L\ell$	3,336	
$L\alpha$	3,76 – 3,77	
$L\eta$	3,606	
$L\beta$	4,02 – 4,37	
$L\gamma$	4,44 – 4,82	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	21,804 – 22,989	100
KLX	25,814 – 27,470	45,3
KXY	29,80 – 31,81	5,13
Auger L	2,3 – 4,8	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Te)	2,3 - 4,8	89,7 (7)
e _{AK}	(Te)		7,0 (4)
	KLL	21,804 - 22,989	}
	KLX	25,814 - 27,470	}
	KXY	29,80 - 31,81	}
ec _{2,1} K	(Te)	56,65 (7)	42,1 (18)
ec _{2,1} L	(Te)	83,52 - 84,12	44,8 (19)
ec _{2,1} M	(Te)	87,45 - 87,89	10,73 (45)
ec _{2,1} N	(Te)	88,29 - 88,42	2,07 (9)
ec _{1,0} K	(Te)	127,18 (5)	13,84 (14)
ec _{1,0} L	(Te)	154,05 - 154,69	1,81 (2)
ec _{1,0} M	(Te)	157,98 - 158,42	0,364 (11)
ec _{1,0} N	(Te)	158,82 - 158,95	0,0769 (23)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Te)	3,336 — 4,82	8,25 (21)	
XK α_2	(Te)	27,202	13,9 (5)	} K α
XK α_1	(Te)	27,4726	26,0 (9)	}
XK β_3	(Te)	30,9446	}	
XK β_1	(Te)	30,996	}	K' β_1
XK β_5''	(Te)	31,236	}	
XK β_5'	(Te)	31,241	}	
XK β_2	(Te)	31,7008	}	
XK β_4	(Te)	31,774	}	K' β_2
XK $O_{2,3}$	(Te)	31,812	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{2,1}(\text{Te})$	88,46 (7)	0,0909 (27)
$\gamma_{1,0}(\text{Te})$	158,97 (5)	83,99 (8)
$\gamma_{2,0}(\text{Te})$	247,4 (2)	0,000344 (34)

6 Main Production Modes

- { Te – 122(n, γ)Te – 123m σ : 3,4 (5) barns
- { Possible impurities : Te – 121, Te – 125m, Te – 129m

- { Sb – 123(p,n)Te – 123m
- { Possible impurities : Te – 121, Te – 121m

- { Sb – 123(d,2n)Te – 123m
- { Possible impurities : Te – 121, Te – 121m

7 References

- L.W.FAGG, E.A. WOLIKI, R.O. BONDELID, K.L. DUNNING, S. SNYDER. Phys. Rev. 100 (1955) 1299
(Mixing ratio)
- N.GOLDBERG, S.FRANKEL. Phys. Rev. 100 (1955) 1350
(Mixing ratio)
- Y.Y.CHU, M.L.PERLMAN. Phys. Rev. 135,2B (1964) 319
(ICC)
- Y.Y.CHU, O.C.KRISTNER, A.C.LI, S.MONARO, M.L.PERLMAN. Phys. Rev. 133,6B (1964) 1361
(ICC, Gamma-ray intensities)
- D.G.ALKHAZOV, V.D. VASILEV, G.M. GUSINSKII, I.K. LEMBERG, V.A. NABICHVRISHVILI. Bull. Acad. Sci. USSR Phys. Serv. 28 (1964) 1575
(Mixing ratio)
- E.N.HATCH, G.W.EAKINS, G.C.NELSON, R.E.MC ADAMS. Proc. Intern. Conf. Intern. Conversion Processes, Nashville, Tenn. (1965), Ed. J.H.Hamilton (1966) 183
(Gamma-ray emission probabilities, ICC)
- R.K.GUPTA, M.M. BAJAJ, N.K. SAHA. Nucl. Phys. 80 (1966) 471
(Mixing ratio)
- S.TÖRNKVIST, S.STROM, L.HASSELGREN. Nucl. Phys. A130 (1969) 604
(Mixing ratio)
- R.A.KALINAUSKAS, K.V.MAKARYUNAS, K.MAKATYUNENE, R.I.DAVIDONIS. Bull. Acad. Sci. USSR Phys. Serv. 32 (1969) 187
(T ICC)
- J.F.EMERY, S.A.REYNOLDS, E.I.WAYTT. report ORNL-4466 (1970) 75
(Half-life)
- S.RAMAN. Nucl. Instrum. Methods 103 (1972) 407
(Gamma-ray emission intensities)
- S.RAMAN, R.L.AUBLE, W.T.MILNER, T.A.WALKIEWICZ, R.GUNNINK, B.MARTINE. Report ORNL-4937 (1973) 144
(ICC)

- S.RAMAN, R.L.AUBLE, W.T.MILNER. Phys. Lett. 47B (1973) 19
(Conv. Elec. emission probabilities, Gamma-ray emission probabilities, Multipolarity)
- K.S.KRANE. At. Data. Nucl. Data Tables 19 (1977) 19
(Mixing ratio)
- W.BAMBYNEK. X-84 Proc. X-Ray and Inner-Shell Processes in Atoms, Molecules and Solids, A. Meisel Ed., Leipzig Aug. 20-23 (1984)
(K fluorescence yield)
- U.SCHÖTZIG, H.SCHRADER, K.DEBERTIN. Proc. Int. Conf. Nuclear Data Sci. Techn., Jülich, 13-17 May (1991)
(Gamma-ray emission probabilities)
- B.M.COURSEY, D.B.GOLAS, D.H.GRAY, D.D.HOPPES, F.J.SCHIMA. Nucl. Instrum. Methods A312 (1992) 121
(Gamma-ray emission probability, Half-life)
- H.JANSSEN, E.SCHÖNFELD, R.KLEIN. Int. J. Appl. Radiat. Isotop. 43,11 (1992) 1309
(T ICC (1,0), Gamma-ray emission probability)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic Data)
- I.M.BAND, M.B.TRZHASKOVSKAYA. At. Data. Nucl. Data Tables 88,1 (2002)
(Theoretical ICC)
- V.M.GOROZHANKIN, N.COURSOL, E.A.YAKUSHEV, Ts.VYLOV, C.BRIANÇON. Appl. Rad. Isotopes 56 (2002) 189
(M4 transition)



1 Decay Scheme

Sb-125 decays by beta minus emission to levels in Te-125. The percentage of disintegrations to the Te-125m ($T_{1/2}$: 57 d) is $p = (23.9 (9))\%$.

L'antimoine 125 se désintègre par émissions bêta moins vers des niveaux excités de tellure 125. Le pourcentage de désintégrations conduisant à l'isomère de Te-125 de 57 jours de période est $p = (23,9 (9))\%$. Le rapport au temps t des activités Te-125m / Sb-125 dans le Sb-125 initialement pur est :

$$p \times T1 / (T1 - T2) \times (1 - \exp^{-\lg 2 \times t \times (T1 - T2) / (T1 T2)})$$

T1 et T2 étant respectivement les périodes de Sb-125 et Te-125m.

Pour $t > 1,6$ a, ce qui correspond à dix fois la période de Te-125m, ce rapport est égal à :

$$p \times T1 / (T1 - T2) = 0,253(10)$$

avec $p = 0,239 (9)$.

2 Nuclear Data

$$T_{1/2} (^{125}\text{Sb}) : 2,75855 (25) \text{ a}$$

$$Q^- (^{125}\text{Sb}) : 766,7 (21) \text{ keV}$$

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,12}^-$	95,3 (21)	13,42 (15)	Allowed	6,93
$\beta_{0,10}^-$	124,5 (21)	5,75 (6)	Allowed	7,66
$\beta_{0,9}^-$	130,6 (21)	17,95 (22)	Allowed	7,23
$\beta_{0,7}^-$	241,5 (21)	1,585 (24)	1st forbidden	9,12
$\beta_{0,6}^-$	303,3 (21)	39,8 (4)	Allowed	8,04
$\beta_{0,5}^-$	323,1 (21)	0,087 (10)	2nd forbidden	11,06
$\beta_{0,3}^-$	444,0 (21)	7,1 (1)	1st forbidden	934
$\beta_{0,2}^-$	621,0 (21)	15,2 (9)	Unique 1st forbidden	9,77

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{6,5}(\text{Te})$	19,80 (6)	0,2448 (5)	[M1]		9,1 (3)	1,82 (5)	11,3 (3)
$\gamma_{1,0}(\text{Te})$	35,489 (5)	89,4 (26)	M1+E2	12,1 (4)	1,64 (5)	0,329 (10)	14,3 (4)
$\gamma_{2,1}(\text{Te})$	109,276 (15)	24,6375 (14)	M4	186 (5)	138 (4)	32,3 (9)	364 (11)
$\gamma_{9,7}(\text{Te})$	110,895 (12)	0,00124 (9)	[E1]	0,127 (4)	0,0165 (5)	0,00328 (11)	0,147 (4)
$\gamma_{10,7}(\text{Te})$	116,955 (11)	0,293 (4)	E1	0,109 (3)	0,0141 (4)	0,00281 (8)	0,127 (4)
$\gamma_{9,6}(\text{Te})$	172,719 (8)	0,219 (9)	M1	0,129 (4)	0,0168 (5)	0,00337 (11)	0,151 (5)
$\gamma_{3,2}(\text{Te})$	176,314 (2)	7,87 (8)	M1+E2	0,139 (4)	0,0221 (7)	0,00449 (13)	0,167 (5)
$\gamma_{10,6}(\text{Te})$	178,842 (5)	0,0400 (15)	M1+E2	0,147 (26)	0,026 (11)	0,0054 (21)	0,18 (4)
$\gamma_{10,5}(\text{Te})$	198,654 (11)	0,0151 (7)	[E2]	0,123 (4)	0,0245 (8)	0,00504 (15)	0,154 (5)
$\gamma_{7,3}(\text{Te})$	204,138 (10)	0,350 (15)	M1+E2	0,104 (3)	0,0189 (6)	0,00386 (11)	0,128 (4)
$\gamma_{12,6}(\text{Te})$	208,077 (5)	0,265 (8)	M1+E2	0,0791 (24)	0,0102 (3)	0,00205 (6)	0,092 (3)
$\gamma_{12,5}(\text{Te})$	227,891 (10)	0,140 (3)	M1+E2	0,070 (11)	0,011 (4)	0,0023 (6)	0,084 (13)
$\gamma_{9,3}(\text{Te})$	314,95 (11)	0,0042 (3)	(E1)	0,00726 (22)	0,00089 (3)		0,00839 (30)
$\gamma_{10,3}(\text{Te})$	321,040 (4)	0,414 (5)	E1	0,00691 (21)	0,000856 (30)		0,00798 (24)
$\gamma_{7,2}(\text{Te})$	380,452 (8)	1,5295 (15)	E2	0,0154 (5)	0,00233 (7)	0,000473 (15)	0,0183 (5)
$\gamma_{5,1}(\text{Te})$	408,065 (10)	0,1829 (24)	M1+E2	0,01290 (4)	0,00181 (5)	0,00036 (1)	0,0152 (5)
$\gamma_{6,1}(\text{Te})$	427,874 (4)	29,6 (3)	M1+E2	0,0119 (4)	0,00154 (5)	0,00031 (1)	0,0138 (4)
$\gamma_{5,0}(\text{Te})$	443,555 (9)	0,306 (4)	M1+E2	0,0100 (3)	0,00142 (4)	0,00029 (1)	0,0118 (4)
$\gamma_{6,0}(\text{Te})$	463,365 (4)	10,47 (10)	E2	0,0086 (3)	0,00124 (4)	0,00025 (1)	0,0102 (3)
$\gamma_{10,2}(\text{Te})$	497,37 (12)	0,0033 (3)	[M2]	0,0271 (8)	0,00373 (11)	0,00075 (2)	0,0318 (10)
$\gamma_{9,1}(\text{Te})$	600,599 (2)	17,64 (21)	E2	0,00421 (13)	0,00058 (2)		0,00498 (15)
$\gamma_{10,1}(\text{Te})$	606,715 (3)	4,98 (5)	E2	0,00415 (13)	0,00056 (2)		0,00485 (15)
$\gamma_{12,1}(\text{Te})$	635,950 (3)	11,25 (12)	M1+E2	0,00455 (14)	0,00057 (2)		0,00526 (16)
$\gamma_{12,0}(\text{Te})$	671,443 (6)	1,770 (19)	E2	0,00319 (10)	0,00043 (1)		0,00373 (11)

3 Atomic Data

3.1 Te

ω_K	:	0,875	(4)
$\bar{\omega}_L$	:	0,0862	(35)
n_{KL}	:	0,917	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	K α_2	27,202	
	K α_1	27,473	
	K β_3	30,945	}
	K β_1	30,996	}
	K β_5''	31,236	}
			28,6
	K β_2	31,701	}
	K β_4	31,774	}
			6,2

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	21,804 – 22,989	100
KLX	25,814 – 27,470	45,5
KXY	29,80 – 31,81	5,1

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AK}	(Te)			0,098 (5)
	KLL	21,804 - 22,989	}	
	KLX	25,814 - 27,470	}	
	KXY	29,80 - 31,81	}	
ec _{1,0} T	(Te)	3,675 - 35,379		84 (3)
ec _{1,0} K	(Te)	3,675 (5)		71 (3)
ec _{6,5} L	(Te)	14,86 - 15,46		0,180 (7)
ec _{1,0} L	(Te)	30,550 - 31,148		9,6 (4)
ec _{1,0} M	(Te)	34,483 - 34,670		1,93 (9)
ec _{1,0} N	(Te)	35,321 - 35,379		0,406 (16)
ec _{2,1} K	(Te)	77,462 (15)		12,6 (5)
ec _{2,1} T	(Te)	77,462 - 109,166		24,6 (9)
ec _{2,1} L	(Te)	104,337 - 104,935		9,3 (5)
ec _{2,1} M	(Te)	108,270 - 108,457		2,18 (8)
ec _{2,1} N	(Te)	109,108 - 109,166		0,451 (18)
ec _{3,2} K	(Te)	144,500 (2)		0,94 (4)
ec _{3,2} L	(Te)	171,375 - 171,973		0,149 (6)
ec _{6,1} K	(Te)	396,060 (4)		0,347 (14)
ec _{6,0} K	(Te)	431,551 (4)		0,090 (4)
ec _{9,1} K	(Te)	568,783 (2)		0,074 (3)
ec _{12,1} K	(Te)	604,136 (3)		0,051 (2)
$\beta_{0,12}^-$	max:	95,3 (21)		13,42 (15)
$\beta_{0,12}^-$	avg:	24,9 (6)		
$\beta_{0,10}^-$	max:	124,5 (21)		5,75 (6)
$\beta_{0,10}^-$	avg:	33,0 (6)		
$\beta_{0,9}^-$	max:	130,6 (21)		17,95 (22)
$\beta_{0,9}^-$	avg:	34,7 (6)		
$\beta_{0,7}^-$	max:	241,5 (21)		1,585 (24)
$\beta_{0,7}^-$	avg:	67,5 (7)		
$\beta_{0,6}^-$	max:	303,3 (21)		39,8 (4)

		Energy keV	Electrons per 100 disint.
$\beta_{0,6}^-$	avg:	86,9 (7)	
$\beta_{0,5}^-$	max:	323,1 (21)	0,087 (10)
$\beta_{0,5}^-$	avg:	93,3 (7)	
$\beta_{0,3}^-$	max:	444,0 (21)	7,1 (1)
$\beta_{0,3}^-$	avg:	134,5 (8)	
$\beta_{0,2}^-$	max:	621,0 (21)	15,2 (9)
$\beta_{0,2}^-$	avg:	215,5 (8)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XK α_2	(Te)	27,202	19,5 (6)	} K α
XK α_1	(Te)	27,473	36,3 (11)	
XK β_3	(Te)	30,945	} 10,4 (4)	K' β_1
XK β_1	(Te)	30,996		
XK β_5''	(Te)	31,236		
XK β_2	(Te)	31,701	} 2,26 (9)	K' β_2
XK β_4	(Te)	31,774		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{6,5}(\text{Te})$	19,80 (6)	0,0199 (5)
$\gamma_{1,0}(\text{Te})$	35,489 (5)	5,84 (8)
$\gamma_{2,1}(\text{Te})$	109,276 (15)	0,0675 (14)
$\gamma_{9,7}(\text{Te})$	110,895 (12)	0,00108 (9)
$\gamma_{10,7}(\text{Te})$	116,955 (11)	0,260 (4)
$\gamma_{9,6}(\text{Te})$	172,719 (8)	0,190 (9)
$\gamma_{3,2}(\text{Te})$	176,314 (2)	6,74 (8)
$\gamma_{10,6}(\text{Te})$	178,842 (5)	0,0339 (15)
$\gamma_{10,5}(\text{Te})$	198,654 (11)	0,0131 (7)
$\gamma_{7,3}(\text{Te})$	204,138 (10)	0,310 (15)
$\gamma_{12,6}(\text{Te})$	208,077 (5)	0,243 (8)

	Energy keV	Photons per 100 disint.
$\gamma_{12,5}(\text{Te})$	227,891 (10)	0,129 (3)
$\gamma_{9,3}(\text{Te})$	314,95 (11)	0,0042 (3)
$\gamma_{10,3}(\text{Te})$	321,040 (4)	0,411 (5)
$\gamma_{7,2}(\text{Te})$	380,452 (8)	1,5020 (15)
$\gamma_{5,1}(\text{Te})$	408,065 (10)	0,1802 (24)
$\gamma_{6,1}(\text{Te})$	427,874 (4)	29,2 (3)
$\gamma_{5,0}(\text{Te})$	443,555 (9)	0,302 (4)
$\gamma_{6,0}(\text{Te})$	463,365 (4)	10,36 (10)
$\gamma_{10,2}(\text{Te})$	497,37 (12)	0,0032 (3)
$\gamma_{9,1}(\text{Te})$	600,597 (2)	17,55 (21)
$\gamma_{10,1}(\text{Te})$	606,713 (3)	4,96 (5)
$\gamma_{12,1}(\text{Te})$	635,950 (3)	11,19 (12)
$\gamma_{12,0}(\text{Te})$	671,441 (6)	1,763 (19)

6 Main Production Modes

$\text{Sn} - 124(n,\gamma)\text{Sn} - 125\text{m}$ $\sigma : 0,130$ (5) barns

{ $\text{Sn} - 125\text{m}(\beta^-)\text{Sb} - 125$
Possible impurities : Half – life = 9,7 min

{ $\text{Sn} - 124(n,\gamma)\text{Sn} - 125$ $\sigma : 0,004$ (2) barns
Possible impurities : Half – life = 9,5 d

{ $\text{Sn} - 125(\beta^-)\text{Sb} - 125$
Possible impurities : $\text{Sn} - 113$, $\text{Sn} - 117\text{m}$, $\text{Sn} - 119\text{m}$, $\text{Sn} - 121\text{m}$, $\text{Sn} - 123\text{m}$, $\text{Sn} - 125$

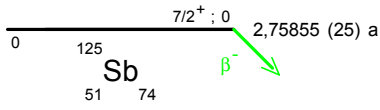
{ Fission product
Possible impurities : $\text{Sb} - 121\text{m}$, $\text{Sn} - 125$

7 References

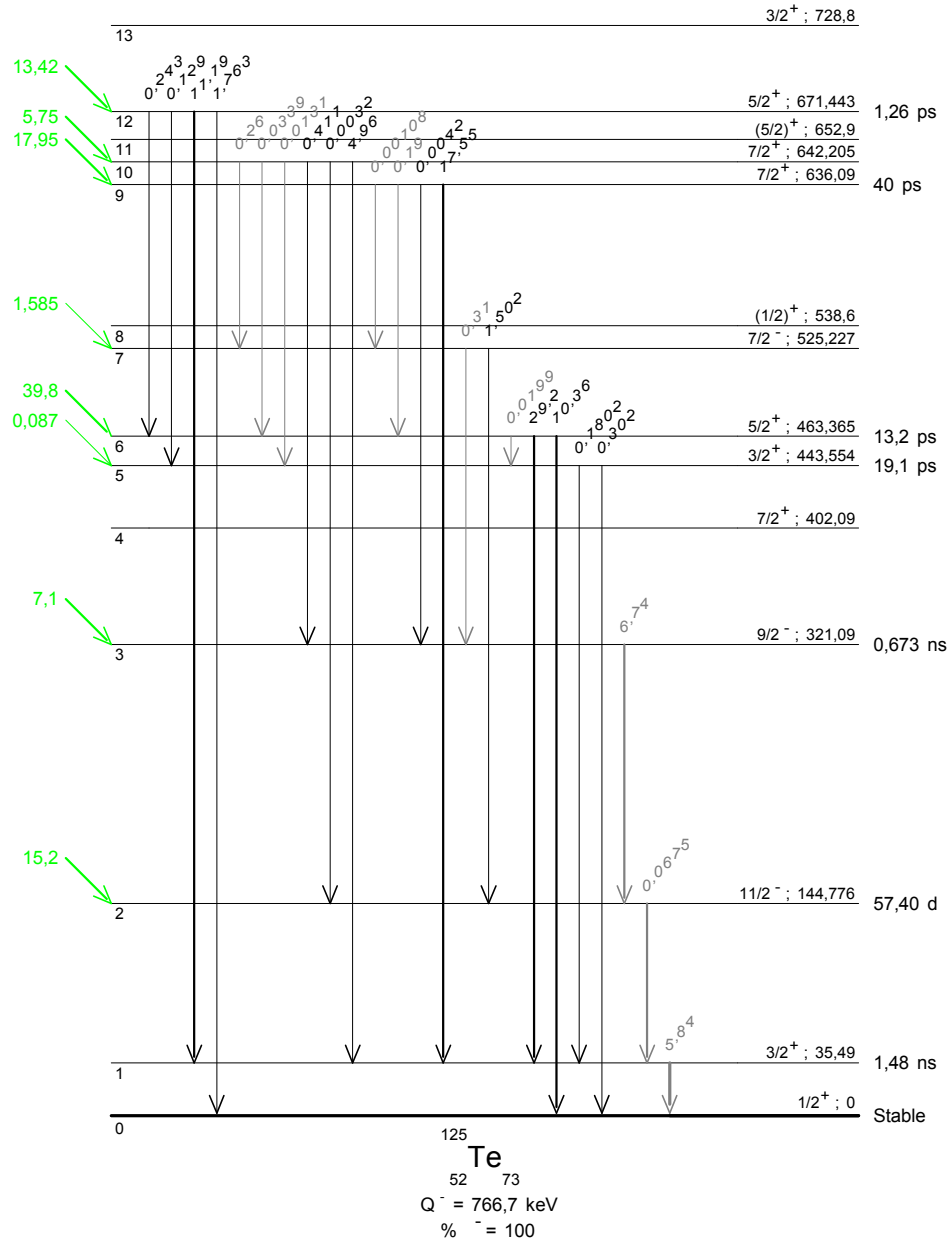
- G. R. LEADER, W. H. SULLIVAN. NNES 9 (1950) 934
(Half-life)
- R. S. NARCISI. Thesis, Harvard University, AECU 4336 (1959)
(Beta emission probabilities)
- E. H. KLEHR, A. F. VOIGT. J. Inorg. Nuclear Chem. 16 (1960) 8
(Half-life)
- E. I. WYATT, S. A. REYNOLDS, T. H. HANDLEY, W. S. LYON, H. A. PARKER. Nucl. Sci. Eng. 11 (1961) 74
(Half-life)
- G. ANDERSSON, G. RUDSTAM, G. SORENSEN. Ark. Fys. 28 (1965) 37
(Half-life level)
- K. F. FLYNN, L. E. GLENDENIN, E. P. STEINBERG. Nucl. Sci. Eng. 22 (1965) 416
(Half-life)
- T. INAMURA, T. IWASHITA, S. KAGEYAMA. J. Phys. Soc. Japan 21 (1966) 2425
(Half-life level)

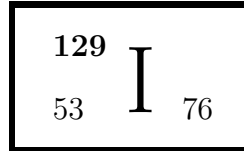
- F. O. LAWRENCE, W. R. DANIELS, D. C. HOFFMAN. J. Inorg. Nucl. Chem. 28 (1966) 2477
(Half-life)
- C. HOHENEMSER, R. ROSNER. Nucl. Phys. A109 (1968) 364
(Half-life level)
- H. SERGOLLE. Compt. Rend. 267B (1968) 1042
(Gamma emission probabilities)
- J. KOWNACKI, J. LUDZIEJEWSKI, M. MOSZYNSKI. Nucl. Phys. A113 (1968) 561
(Half-life level)
- P. R. CHRISTENSEN, A. BERINDE, I. NEAMU, N. SCINTEI. Nucl. Phys. A129 (1969) 337
(Gamma energy and probability)
- R. R. HOSANGDI, P. N. TANDON, S. H. DEVARE. Indian J. Pure Appl. Phys. 7 (1969) 604
(Half-life level)
- D. S. ANDREEV, V. K. BONDAREV, L. N. LAPERIN, A. Z. ILYASOV, I. K. LEMBERG. Bull. Acad. Sci. USSR, Phys. Ser. 32 (1969) 225
(Gamma emission probabilities, multipolarity)
- M. M. BAJAJ, S. L. GUPTA, N. K. SAHA. Proc. Natl. Inst. Sci. India 36A (1970) 176
(Half-life level)
- B. BENGSTON, M. MOSZYNSKI. Nucl. Instrum. Methods 85 (1970) 133
(Half-life level)
- A. MARELIUS, J. LINDSKOG, Z. AWWAD, K. G. VALIVAARA, S. E. HAGGLUND, J. PIHL. Nucl. Phys. A148 (1970) 433
(Half-life level)
- L. D. WYLY, J. B. SALZBERG, E. T. PATRONIS, JR., N. S. KENDRICK, C. H. BRADEN. Phys. Rev. C1 (1970) 2062
(Multipolarity)
- T. S. NAGPAL, R. E. GAUCHER. Can. J. Phys. 48 (1970) 2978
(Gamma energy and probability, multipolarity)
- K. S. KRANE, J.R. SITES, W. A. SEYERT. Phys. Rev. C4 (1971) 565
(Multipolarity)
- M. ROTS, R. SILVERANS, R. COUSSEMENT. Nucl. Phys. A170 (1971) 240
(Multipolarity)
- G. SATYANARAYANA, V. LAKSHMINARAYANA. Curr. Sci. (India) 40 (1971) 458
(Multipolarity)
- E. E. BERLOVICH, V. V. LUKASHEVICH, A. V. POPOV, V. M. ROMANOV. Sov. J. Nucl. Phys. 12 (1971) 117
(Half-life level)
- T. BADICA, S. DIMA, A. GELBERG, I. POPESCU. Z. Phys. 249 (1972) 321
(Multipolarity)
- B. BENGSTON, M. MOSZYNSKI. Nucl. Instrum. Methods 100 (1972) 293
(Half-life level)
- D. S. BRENNER, M. L. PERLMAN. Nucl. Phys. A181 (1972) 207
(Multipolarity)
- G. SATYANARAYANA, V. LAKSHMINARAYANA, D. S. MURTY. Can. J. Phys. 50 (1972) 600
(Half-life level)
- G. SATYANARAYANA, V. V. RAMAMURTY, V. LAKSHMINARAYANA. J. Phys. (London) A5 (1972) 1243
(Half-life level)
- J. B. GUPTA, N. C. SINGHAL, J. H. HAMILTON. Z. Phys. 261 (1973) 137
(Gamma energy and probability)
- P. ILA, K. SUDHAKAR, K. L. NARASIMHAM, V. LAKSHMINARAYANA. Curr. Sci. (India) 43 (1974) 176
(Gamma probability)
- B. MARTIN, D. MERKERT, J.L. CAMPBELL. Z. Phys. A274 (1975) 15
(Multipolarity)
- I. M. BAND, M. B. TRZHASKOVSKAYA, M. A. LISTENGARTEN. Atomic Data Nucl. Data Tables 18 (1976) 433
(Internal Conversion Coefficient)
- W.B. WALTERS, R.A. MEYER. Phys. Rev. C14 (1976) 1925
(Gamma energy and probability)
- G. ARDISSON, K. ABDMEZIEM. Radiochem. Radioanal. Lett. 29 (1977) 1
(Gamma probability)
- R.J. GEHRKE, R.G. HELMER, R.C. GREENWOOG. Nucl. Instrum. Methods 147 (1977) 405
(Gamma probability)

- F. LAGOUTINE, J. LEGRAND, C. BAC. *Int. J. Appl. Radiat. Isotop.* 29 (1978) 269
(Half-life level)
- F. RÖSEL, H. M. FRIES, K. ALDER, H. C. PAULI. *Atomic Data Nucl. Data Tables* 21 (1978) 92
(Internal Conversion Coefficients)
- R. PRASAD. *Czech. J. Phys.* B29 (1979) 737
(Gamma probability)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. *Int. J. Appl. Radiat. Isotop.* 31 (1980) 153
(Half-life)
- W. M. RONEY, JR., W. A. SEALE. *Nucl. Instrum. Methods* 171 (1980) 389
(Gamma probability)
- P. MUKHERJEE, S. BHATTACHARYA, S. SARKAR, I. MUKHERJEE, B. K. DASMAHAPATRA. *Phys. Rev.* C25 (1982) 2120
(Multipolarity)
- K. SINGH, H. S. SAHOTA. *Indian J. Phys.* 56A (1982) 291
(Multipolarity)
- K. SINGH, H. S. SAHOTA. *Indian J. Pure Appl. Phys.* 21 (1983) 19
(Gamma probability)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. *Int. J. Appl. Radiat. Isotop.* 34 (1983) 1191
(Half-life)
- WANG XINLIN, LI XIAODI, DU HONGSHAN. *Chin. J. Nucl. Phys.* 8 (1986) 371
(Gamma probability)
- A. M. GEIDELMAN, YU. S. EGOROV, N. K. KUZMENKO, V. G. NEDOVESOV, V. P. CHECHEV, G. E. SHUKIN. *Proc. Intern. Conf. Nuclear Data for Science and Technology, Mito, Japan* (1988) 909
(Half-life level)
- R. G. HELMER. *Appl. Radiat. Isot.* 41 (1990) 75
(Gamma energy and probability)
- L. LONGORIA-GANDARA, M. U. RAJPUT, T. D. MAC MAHON. *Nucl. Instrum. Methods Phys. Res.* A286 (1990) 529
(Gamma probability evaluation)
- C. C. DEY, B. K. SINHA, R. BHATTACHARYA. *Nuovo Cim.* 105A (1992) 523
(Half-life level)
- N. I. FAWWAZ, N. M. STEWART. *J. Phys. (London)* G19 (1993) 113
(Gamma probability)
- E. SCHÖNFELD, H. JANSSEN. *Nucl. Instrum. Methods Phys. Res.* A369 (1996) 527
(Atomic data)
- C. C. DEY, B. K. SINHA, R. BHATTACHARYA. *Can. J. Phys.* 75 (1997) 591
(Multipolarity)
- M. ROTETA, E. GARCIA-TORANO. *Appl. Radiat. Isot.* 49 (1998) 1349
(Multipolarity)
- A. GRAU CARLES, L. RODRIGUEZ BARQUERO, A. JIMENEZ DE MINGO. *Appl. Radiat. Isot.* 49 (1998) 1377
(Beta probability)
- M. SAINATH, K. VENKATARAMANIAN, P. C. SOOD. *Phys. Rev.* C58 (1998) 3730
(Gamma energy and probability, multipolarity)
- M. SAINATH, K. VENKATARAMANIAN. *Nuovo Cim.* 111A (1998) 223
(Multipolarity)
- B. SINGH, J. L. RODRIGUEZ, S. S. M. WONG, J. K. TULLI. *Nucl. Data Sheets* 84 (1998) 487
(log ft sys.)
- J. KATAKURA. *Nucl. Data Sheets* 86 (1999) 955
(Evaluation)
- M. SAINATH, K. VENKATARAMANIAN, P. C. SOOD. *Pramana* 53 (1999) 289
(Multipolarity)
- R. G. HELMER, C. VAN DER LEUN. *Nucl. Instrum. Methods Phys. Res.* A450 (2000) 35
(Gamma energy)
- M. P. UNTERWEGER. *Appl. Radiat. Isot.* 56 (2002) 125
(Half-life)
- G. AUDI, A. H. WAPSTRA, C. THIBAUT. *Nucl. Phys.* A729 (2003) 337
(Q)
- M. J. WOODS, S. M. COLLINS. *Appl. Radiat. Isot.* 60 (2004) 257
(Half-life evaluation)



γ Emission probabilities
per 100 disintegrations





1 Decay Scheme

I-129 disintegrates by 100 % beta minus decay to the excited level of 39.58 keV in Xe-129. The transition to the Xe-129 ground state was not observed.

L'iode 129 se désintègre par émission bêta moins vers le niveau excité de 39,58 keV du xenon 129. La transition vers le niveau fondamental du xenon 129 n'a pas été observée expérimentalement.

2 Nuclear Data

$$T_{1/2}(^{129}\text{I}) : 16,1 \quad (7) \quad 10^6 \text{ a}$$

$$Q^-(^{129}\text{I}) : 190,8 \quad (11) \quad \text{keV}$$

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,1}^-$	151,2 (11)	99,5 (5)	2nd Forbidden	13,49
$\beta_{0,0}^-$	190,8 (11)	0,5 (5)	2nd Unique Forbidden	>14,9

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(\text{Xe})$	39,578 (4)	99,5 (5)	M1+0,07%E2	10,59 (11)	1,45 (5)	0,296 (10)	12,41 (13)

3 Atomic Data

3.1 Xe

ω_K	:	0,888	(5)
$\bar{\omega}_L$	:	0,097	(5)
n_{KL}	:	0,905	(4)

3.1.1 X Radiations

		Energy keV		Relative probability	
X _K	K α_2	29,459		53,98	
	K α_1	29,779		100	
	K β_3	33,562	}		
	K β_1	33,625	}		
	K β_5''	33,881	}	27,7	
	K β_2	34,415	}		
	K β_4	34,496	}	6,2	
	KO _{2,3}	34,552	}		
	X _L	L ℓ	3,6		
		L γ	- 5,4		

3.1.2 Auger Electrons

		Energy keV	Relative probability
Auger K			
KLL	23,512 – 24,842		100
KLX	27,897 – 29,770		46,5
KXY	32,27 – 34,54		5,41
Auger L			
	2,4 – 5,4		

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Xe)	2,4 - 5,4	73,9 (12)
e _{AK}	(Xe)		8,8 (4)
	KLL	23,512 - 24,842	}
	KLX	27,897 - 29,770	}
	KXY	32,27 - 34,54	}
ec _{1,0 K}	(Xe)	5,017 (4)	78,6 (12)
ec _{1,0 L}	(Xe)	34,126 - 34,796	10,8 (4)
ec _{1,0 M}	(Xe)	38,43 - 38,90	2,20 (8)
ec _{1,0 N}	(Xe)	39,37 - 39,56	0,55 (1)
$\beta_{0,1}^-$	max:	151,2 (11)	99,5 (5)
$\beta_{0,1}^-$	avg:	37 (1)	
$\beta_{0,0}^-$	max:	190,8 (11)	0,5 (5)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Xe)	3,6 — 5,4	7,9 (4)
XK α_2	(Xe)	29,459	20,1 (3) } K α
XK α_1	(Xe)	29,779	37,2 (6) }
XK β_3	(Xe)	33,562	}
XK β_1	(Xe)	33,625	}
XK β_5''	(Xe)	33,881	}
XK β_2	(Xe)	34,415	}
XK β_4	(Xe)	34,496	}
XK $\beta_{2,3}$	(Xe)	34,552	}
			2,30 (13) } K' β_2
			10,3 (4) } K' β_1

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Xe})$	39,578 (4)	7,42 (8)

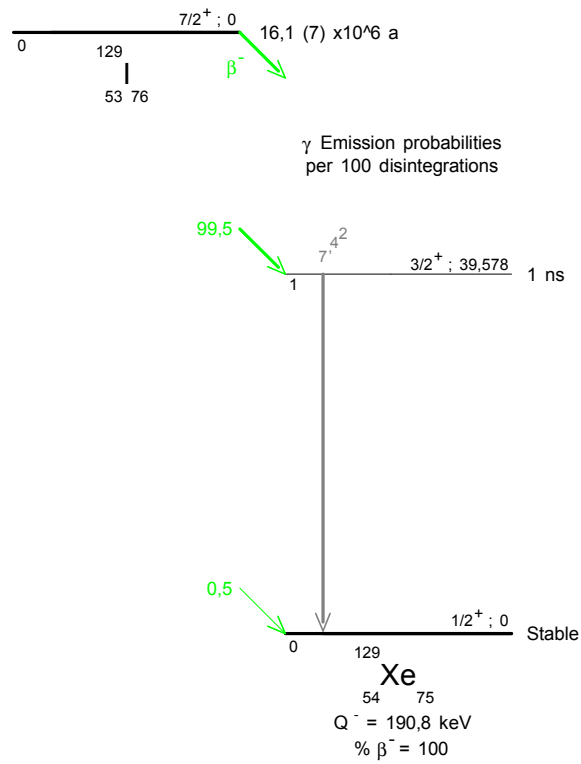
6 Main Production Modes

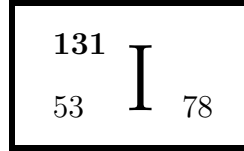
- { Fission product
- { Possible impurities : I – 131, I – 132, I – 133, I – 135

7 References

- S. KATCOFF, O. A. SCHAEFFER, J. M. HASTINGS. Phys. Rev. 82 (1951) 688
(Half-life)
- DER E. MATEOSIAN, C. S. WU. Phys. Rev. 91 (1953) 497A
(beta spectrum shape factor)
- DER E. MATEOSIAN, C. S. WU. Phys. Rev. 95 (1954) 458
(Gamma ray energy)
- H. T. RUSSELL. Report ORNL - 2293 (1957)
(Half-life)
- J. S. GEIGER, R. L. GRAHAM, I. BERGSTROM, F. BROWN. Nucl. Phys. 68 (1965) 352
(Gamma ray energy, multipolarity)
- I. REZANKA, A. SPALEK, J. FRANA, A. MASTALKA. Nucl. Phys. 89 (1966) 609
(Gamma ray energy)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- G. GRAEFFE, W. B. WALTERS. Phys. Rev. 153 (1967) 1321
(Gamma ray energy, K ICC)
- R. S. HAGER, E. C. SELTZER. Nucl. Data Tables A4 (1968) 1
(Theoretical ICC)
- S. A. REYNOLDS, J. F. EMERY. Report ORNL-4343 (1968) (1968) 78
(K ICC)
- R. S. HAGER, E. C. SELTZER. Nucl. Data Tables A6 (1969) 1
(Theoretical ICC)
- F. N. GYGAX, R. F. JENEFSKY, H. J. LEISI. Phys. Lett. 32B (1970) 359
(K ICC)
- K. S. R. SASTRY, R. E. WOOD, J. M. PALMS, P. V. RAO. Bull. Am .Phys. Soc. JE12 (1970) 623
(K ICC)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
(Half-life)
- H. W. TAYLOR, B. SINGH. J. Phys. Soc. Jap. 32 (1972) 1472
(Gamma ray energy)
- J. G. KUHRy, G. BONTEMS. Radiochem. Radioanal. Letters 15 (1973) 29
(Half-life)
- K. VENKATA RAMANIAH, T. SESHU REDDY, K. VENKATA REDDY. Current Sci. (India) 43 (1974) 406
(Multipolarity, K ICC)
- G. MAREST, R. HAROUTUNIAN, I. BERKES, M. MEYER, M. ROTS, J. DE RAEDT VAN DE VOORDE, VAN DE H. OONIS, R. COUSSEMENT. Phys. Rev. 10 (1974) 402
(Multipolarity)

- R. A. MEYER, F. F. MOMYER, J. H. LANDRUM, E. A. HENRY, R. P. YAFFE, W. B. WALTERS. Phys.Rev. C14 (1976) 1152
(Gamma ray energy)
- T. K. RAGIMOV, D. F. RAU, V. I. TIMOSHIN. Izv. Akad. Nauk. SSSR 41 (1977) 1222
(K ICC)
- N. F. COURSOL. Thesis, Univ de Paris (1979) (1979)
(K ICC, M ICC, beta- emission energy)
- G. BARCI-FUNEL, M. C. KOUASSI, G. ARDISSON. Nucl. Instrum. Methods 241 (1985) 252
(K ICC, gamma ray energy, gamma ray and KX-ray emission probabilities)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q value)
- E. SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic data)
- Y. TENDOW. Nucl. Data Sheets 77 (1996) 631
(Level energies)
- E. SCHÖNFELD, G. RODLOFF. report PTB-6,11-98-1 (1998)
(Energies of Auger electrons)
- B. SINGH, J. L. RODRIGUEZ, S. S. M. WONG, J. K. TULI. Nucl. Data Sheets 84 (1998) 487
(Systematics of log ft values)
- E. SCHÖNFELD, G. RODLOFF. report PTB-6.11-1999-1999-1 (1999)
(KX ray energies and relative emission probabilities)
- M. M. BÉ. INDC(NDS)-422, IAEA, Vienna (2001) 112
(Average beta- energy)





1 Decay Scheme

L'I-131 se désintègre par émission beta moins vers les niveaux excités de Xe-131, incluant l'isomère Xe-131M de 11,930(16) jours de période. L'état d'équilibre idéal, c'est à dire l'activité de I-131 étant égale à l'activité de Xe-131m, est obtenu après 13,994(1) jours.

I-131 disintegrates through beta minus emission to the excited levels of Xe-131, the isomeric state Xe-131m (half-life = 11.930(16) d) included. The radioactive equilibrium, i.e. the activity of I-131 is equal to the activity of Xe-131m, is obtained after 13.994(1) days.

Pour cette évaluation, l'intensité de la raie gamma de 163,9 keV est donnée pour I-131 et Xe-131m étant à l'équilibre.

For this evaluation, the intensity of the 163.9 keV gamma ray is given for I-131 and Xe-131 to be in radioactive equilibrium.

2 Nuclear Data

$$T_{1/2}(^{131}\text{I}) : 8,0233 \quad (19) \quad \text{d}$$

$$Q^-(^{131}\text{I}) : 970,8 \quad (6) \quad \text{keV}$$

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,8}^-$	247,9 (6)	2,114 (20)	Allowed	6,98
$\beta_{0,7}^-$	303,9 (6)	0,643 (27)	1st Forbidden	7,79
$\beta_{0,6}^-$	333,8 (6)	7,36 (8)	Allowed	6,86
$\beta_{0,4}^-$	606,3 (6)	89,4 (8)	Allowed	6,64
$\beta_{0,3}^-$	629,7 (6)	0,053 (29)	1st Forbidden	9,8
$\beta_{0,2}^-$	806,9 (6)	0,396 (14)	1st Forbidden Unique	10,03

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(\text{Xe})$	80,1853 (19)	6,72 (14)	M1[+E2]	1,353 (41)	0,180 (5)	0,0367 (11)	1,579 (47)
$\gamma_{8,6}(\text{Xe})$	85,918 (8)	0,00029 (16)	[M1, E2]	1,508 (31)	0,558 (15)		2,21 (5)
$\gamma_{2,0}(\text{Xe})$	163,930 (8)	1,086 (7)	M4	30,8 (9)	14,66 (44)	3,38 (10)	49,6 (15)
$\gamma_{3,2}(\text{Xe})$	177,214 (17)	0,3294 (44)	M1+94,87%E2	0,187 (6)	0,0427 (13)	0,00901 (27)	0,241 (7)
$\gamma_{6,5}(\text{Xe})$	232,175 (8)	0,00282 (42)	[E2]	0,0782 (23)	0,01534 (46)		0,0976 (29)
$\gamma_{6,4}(\text{Xe})$	272,501 (8)	0,0603 (10)	M1+12,62%E2	0,04613 (36)	0,0063 (13)		0,054 (2)
$\gamma_{4,1}(\text{Xe})$	284,305 (5)	6,36 (6)	E2	0,0409 (12)	0,00725 (22)		0,0500 (15)
$\gamma_{6,3}(\text{Xe})$	295,848 (13)	0,00084 (27)	[E1]	0,00937 (28)	0,001185 (36)		0,01086 (33)
$\gamma_{7,4}(\text{Xe})$	302,444 (13)	0,0046 (5)	[E1]	0,00885 (27)	0,001118 (34)		0,01025 (31)
$\gamma_{8,5}(\text{Xe})$	318,093 (8)	0,0824 (16)	M1+1,19%E2	0,0307 (9)	0,00397 (12)	0,000808 (24)	0,0357 (11)
$\gamma_{5,1}(\text{Xe})$	324,651 (6)	0,0225 (27)	M1+39,02%E2	0,0283 (8)	0,00406 (12)	0,000832 (25)	0,0334 (10)
$\gamma_{7,3}(\text{Xe})$	325,791 (18)	0,276 (27)	M1+5,02%E2	0,0288 (9)	0,00376 (11)	0,000765 (23)	0,0335 (10)
$\gamma_{8,4}(\text{Xe})$	358,419 (8)	0,0100 (23)	[M1, E2]	0,02130 (45)	0,00307 (7)		0,0252 (5)
$\gamma_{4,0}(\text{Xe})$	364,490 (4)	83,1 (8)	M1+95,35%E2	0,0191 (6)	0,00304 (9)	0,000628 (19)	0,0229 (7)
$\gamma_{5,0}(\text{Xe})$	404,816 (4)	0,0561 (13)	M1+50%E2	0,0153 (14)	0,002140 (18)		0,0179 (13)
$\gamma_{7,2}(\text{Xe})$	503,005 (17)	0,3621 (43)	E2	0,00751 (23)	0,001096 (33)	0,000225 (7)	0,00889 (27)
$\gamma_{6,0}(\text{Xe})$	636,991 (4)	7,29 (8)	E2	0,00404 (12)	0,000558 (17)	0,0001141 (34)	0,00474 (14)
$\gamma_{8,1}(\text{Xe})$	642,724 (6)	0,2203 (28)	[E2]	0,00395 (12)	0,000545 (16)		0,00463 (14)
$\gamma_{8,0}(\text{Xe})$	722,909 (4)	1,804 (20)	M1+4,11%E2	0,00399 (12)	0,000500 (15)	0,0001014 (30)	0,00461 (14)

3 Atomic Data

3.1 Xe

ω_K	:	0,888 (5)
$\bar{\omega}_L$	:	0,097 (5)
n_{KL}	:	0,902 (4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	29,459		
	K α_1	29,779	53,98	
	K β_3	33,562	}	
	K β_1	33,625		
	K β_5''	33,881		28,99
	K β_2	34,415	}	
	K β_4	34,496		6,84
	KO _{2,3}	34,552		
X _L	L ℓ	3,64		
	L γ	- 5,30		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	23,512 – 24,842	100
KLX	27,897 – 29,770	46,5
KXY	32,27 – 34,54	5,41
Auger L	0,140 – 5,316	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Xe)	0,140 - 5,316	5,91 (4)
e _{AK}	(Xe)		0,68 (4)
	KLL	23,512 - 24,842	}
	KLX	27,897 - 29,770	}
	KXY	32,27 - 34,54	}
ec _{1,0} K	(Xe)	45,621 (2)	3,53 (11)
ec _{1,0} L	(Xe)	74,732 - 75,403	0,469 (14)
ec _{1,0} M	(Xe)	79,036 - 79,508	0,0957 (30)
ec _{1,0} N	(Xe)	79,972 - 80,118	0,0210 (7)
ec _{2,0} K	(Xe)	129,366 (8)	0,662 (29)
ec _{2,0} L	(Xe)	158,477 - 159,148	0,315 (14)
ec _{2,0} M	(Xe)	162,781 - 163,253	0,0727 (32)
ec _{4,0} K	(Xe)	329,926 (4)	1,55 (5)
ec _{4,0} L	(Xe)	359,037 - 359,708	0,247 (8)
ec _{4,0} M	(Xe)	363,341 - 363,813	0,0510 (16)
$\beta_{0,8}^-$	max:	247,9 (6)	2,114 (20)
$\beta_{0,8}^-$	avg:	69,35 (19)	
$\beta_{0,7}^-$	max:	303,9 (6)	0,643 (27)
$\beta_{0,7}^-$	avg:	86,94 (19)	
$\beta_{0,6}^-$	max:	333,8 (6)	7,36 (8)
$\beta_{0,6}^-$	avg:	96,61 (19)	
$\beta_{0,4}^-$	max:	606,3 (6)	89,4 (8)
$\beta_{0,4}^-$	avg:	191,59 (22)	
$\beta_{0,3}^-$	max:	629,7 (6)	0,053 (29)
$\beta_{0,3}^-$	avg:	200,23 (22)	
$\beta_{0,2}^-$	max:	806,9 (6)	0,396 (14)
$\beta_{0,2}^-$	avg:	267,91 (23)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Xe)	3,64 — 5,30	0,635 (13)	
XK α_2	(Xe)	29,459	1,54 (4)	} K α
XK α_1	(Xe)	29,779	2,85 (7)	
XK β_3	(Xe)	33,562	}	} K' β_1
XK β_1	(Xe)	33,625	}	
XK β_5''	(Xe)	33,881	}	
XK β_2	(Xe)	34,415	}	
XK β_4	(Xe)	34,496	}	} K' β_2
XKO $_{2,3}$	(Xe)	34,552	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Xe)	80,1850 (19)	2,607 (27)
$\gamma_{8,6}$ (Xe)	85,9 (2)	0,000089 (49)
$\gamma_{2,0}$ (Xe)	163,930 (8)	0,0215 (7)
$\gamma_{3,2}$ (Xe)	177,214 (2)	0,2654 (32)
$\gamma_{6,5}$ (Xe)	232,18 (15)	0,00257 (38)
$\gamma_{6,4}$ (Xe)	272,498 (17)	0,0572 (9)
$\gamma_{4,1}$ (Xe)	284,305 (5)	6,06 (6)
$\gamma_{6,3}$ (Xe)	295,8 (2)	0,00083 (27)
$\gamma_{7,4}$ (Xe)	302,4 (2)	0,00455 (49)
$\gamma_{8,5}$ (Xe)	318,088 (16)	0,0796 (15)
$\gamma_{5,1}$ (Xe)	324,651 (25)	0,0218 (26)
$\gamma_{7,3}$ (Xe)	325,789 (4)	0,267 (26)
$\gamma_{8,4}$ (Xe)	358,4 (2)	0,0098 (22)
$\gamma_{4,0}$ (Xe)	364,489 (5)	81,2 (8)
$\gamma_{5,0}$ (Xe)	404,814 (4)	0,0551 (13)
$\gamma_{7,2}$ (Xe)	503,004 (4)	0,3589 (43)
$\gamma_{6,0}$ (Xe)	636,989 (4)	7,26 (8)
$\gamma_{8,1}$ (Xe)	642,719 (5)	0,2193 (28)
$\gamma_{8,0}$ (Xe)	722,911 (5)	1,796 (20)

6 Main Production Modes

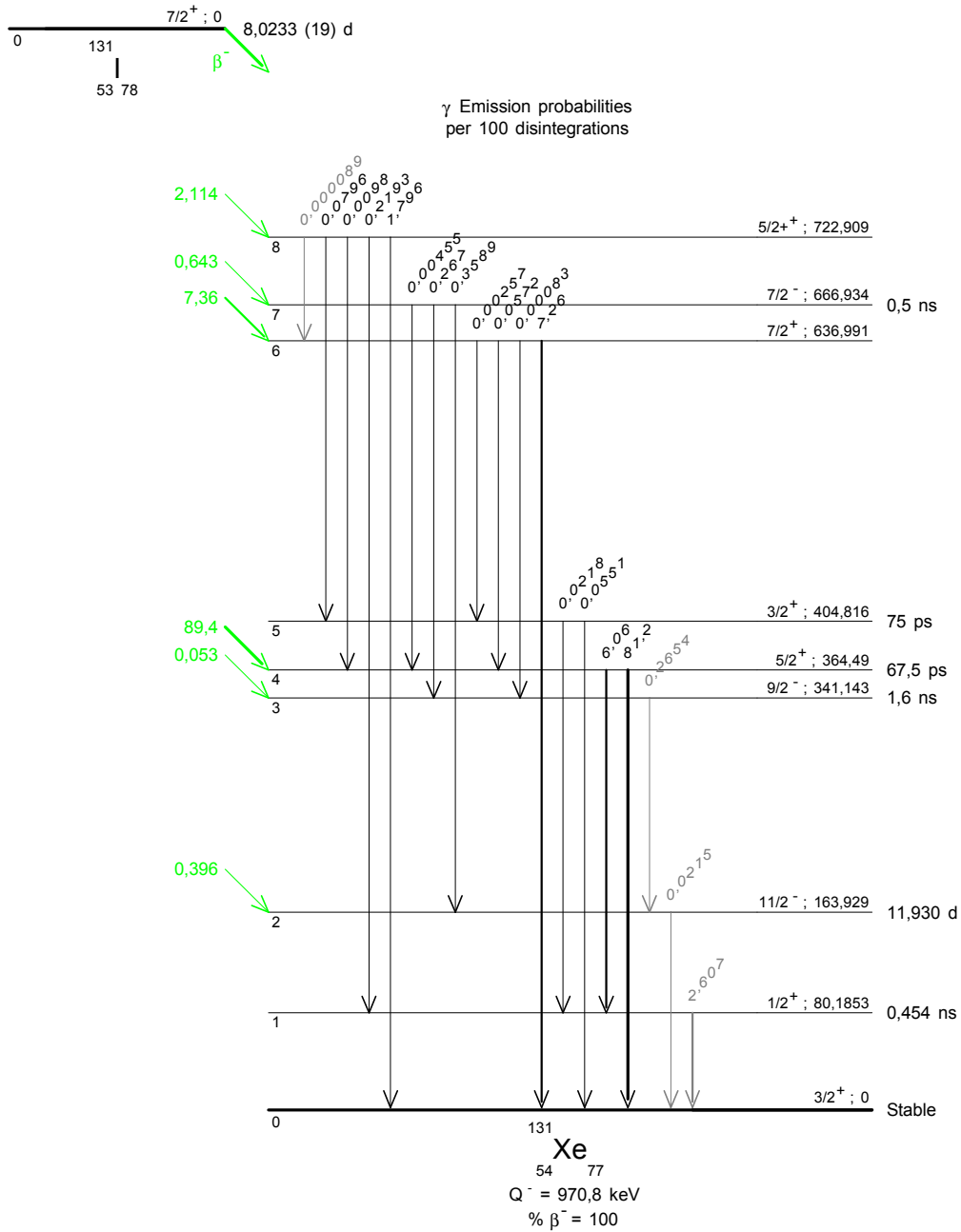
- { Fission product
Possible impurities : None
- { Te – 130(n,γ)Te – 131m
Possible impurities : $T_{1/2}(\text{Te} - 131\text{m}) = 30 \text{ h}$
- { Te – 131m(β^-)I – 131 $\sigma : 0,02 \text{ (1) barns}$
Possible impurities : Te – 121m, Te – 121, Te – 123m, Te – 125m, Te – 127, Te – 129m
- { Te – 130(n,γ)Te – 131
Possible impurities : $T_{1/2}(\text{Te} - 131) = 25\text{min}$
- { Te – 131(β^-)I – 131 $\sigma : 0,27 \text{ (6) barns}$
Possible impurities : Te – 121m, Te – 121, Te – 123m, Te – 125m, Te – 127, Te – 129m

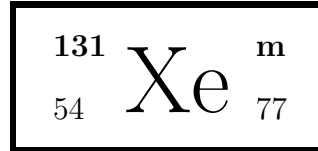
7 References

- J. J. LIVINGOOD, G. T. SEABORG. Phys. Rev. 54 (1938) 775
(Half-life)
- N. F. VERSTER, G. J. NIJGH, R. VAN LIESHOUT, C. J. BAKKER. Physica 17 (1951) 637
(K conversion coefficients)
- J. H. SREB. Phys. Rev. 81 (1951) 643
(Half-life)
- W. K. SINCLAIR, A. F. HOLLOWAY. Nature (London) 167 (1951) 365
(Half-life)
- D. ROSE, G. HINMAN, L. G. LANG. Phys. Rev. 86 (1952) 863
(K conversion coefficients)
- J. L. WOLFSON. Can. J. Phys. 30 (1952) 715
(K conversion coefficients)
- J. R. HASKINS, J. D. KURBATOV. Phys. Rev. 88 (1952) 884
(K, L conversion coefficients)
- R. E. BELL, R. L. GRAHAM. Phys. Rev. 86 (1952) 212
(Gamma ray intensities, K-internal coefficients)
- R. M. BARTHOLOMEW, F. BROWN, R. C. HAWKINGS, W. F. MERRITT, L. YAFFE. Can. J. Chem. 31 (1953) 120
(Half-life)
- E. E. LOCKETT, R. H. THOMAS. Nucleonics 11 (1953) 14
(Half-life)
- H. H. SELIGER, L. CAVALLO, S. V. CULPEPPER. Phys. Rev. 90 (1953) 443
(Half-life)
- J. P. KEENE, L. A. MACKENZIE, C. W. GILBERT. Philos. Mag. 2 (1958) 360
(Half-life)
- L. BURKINSHAW. Phys. in. Med. Biol. 2 (1958) 255
(Half-life)
- J. L. WOLFSON, J. J. H. PARK, L. YAFFE. Nucl. Phys. 39 (1962) 613
(Internal Conversion)
- C. K. HARGROVE, K. W. GEIGER, A. CHATTERJEE. Nucl. Phys. 40 (1963) 566
(Gamma ray intensities, Multipolarity)
- H. JUNGCLAUSSEN, J. S. SCHINTLMEISTER, H. SODAN. Nucl. Phys. 43 (1963) 650
(Gamma ray intensities)
- H. DANIEL, O. MEHLING, P. SCHMIDLIN, D. SCHOTTE, E. THUMMERNICHT. Z. Phys. 179 (1964) 62
(Gamma ray intensities, L,M-internal coefficients)
- G. A. MOSS, D. O. WELLS, D. K. MCDANIELS. Nucl. Phys. 82 (1966) 289
(Gamma ray energies and intensities)
- C. YTHIER, G. ARDISSON. Comp. Rend. Acad. Sci. (Paris) 264C (1967) 944
(Gamma ray intensities)

- G. GRAEFFE, W. B. WALTERS. Phys. Rev. 153 (1967) 1321
(Gamma ray intensities, K, L conversion coefficients)
- P. KEMENY. Rev. Roumaine Phys. 13 (1968) 485
(Half-life)
- R. S. HAGER, E. C. SELTZER. Nucl. Data A4 (1968) 1
(K,L and M conversion coefficients)
- CHR. BARGHOLTZ, S. BEHAI, L. GIDEFELDT. Nucl. Phys. A270 (1970) 189
(Mixing Ratio)
- M. BERMAN, G. B. BEARD. Phys. Rev. C2 (1970) 1506
(Total conversion coefficients)
- G. I. GLEASON. Report - ORNL-TM 2876 (1970)
(Half-life)
- W. H. ZOLLER, P. K. HOPKE, J. L. FASCHING, E. S. MACIAS, W. B. WALTERS. Phys. Rev. C3 (1971) 1699
(Half-life)
- H. GFIRTNER, W. KREISEL. Z. Phys. 244 (1971) 332
(K conversion coefficients)
- K. S. KRANE, C. E. OLSEN, W. A. STEYERT. Phys. Rev. C5 (1972) 1671
(Mixing Ratios)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Science and Eng. 48 (1972) 319
(Half-life)
- N. SINGH, S. S. BHATI, R. L. DHINGRA, P. N. TRETHAN. Nucl. Phys. and Solid State Phys. Symp. - Chandigarh (Indie) (1972) 435
(Gamma ray intensities)
- R. A. MEYER, F. MOMYER, W. B. WALTERS. Z. Phys. 268 (1974) 387
(Gamma ray energies and intensities, Total Branching)
- B. K. S. KOENE, H. POSTMA. Nucl. Phys. A219 (1974) 563
(Mixing ratios)
- J. H. M. KARSTEN, P. G. MARAIS, F. J. HAASBROEK, C. J. VISSER. Agrochemophysica 6 (1974) 25
(Half-life)
- B. K. S. KOENE, H. POSTMA, H. LIGTHART. Nucl. Phys. A250 (1975) 38
(Mixing ratio)
- K. S. KRANE. At. Data. Nucl. Data Tables 19 (1977) 363
(Mixing Ratio)
- F. LAGOUTINE, J. LEGRAND, C. BAC. Int. J. Appl. Radiat. Isotop. 29 (1978) 269
(Half-life)
- A. D. IRVING, P. D. FORSYTH, I. HALL, D. G. E. MARTIN. J. Phys. (London) G5 (1979) 1595
(Mixing Ratio)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- D. D. HOPPES. Report NBS-SP 626 (1982) 93
(Half-life)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- B. CHAND, J. GOSWAMY, D. MEHTA, N. SINGH, P. N. TRETHAN. Nucl. Instrum. Methods A284 (1989) 393
(Gamma ray intensities)
- O. NAVILIAT-CUNCIC, M. LOISELET, J. VERVIER. Nucl. Phys. A514 (1990) 145
(Mixing Ratio.)
- R. A. MEYER. Fisika (Zagreb) 22 (1990) 153
(Gamma rays intensities.)
- M. P. UNTERWEGER. Nucl. Instrum. Methods A312 (1992) 349
(Half-life.)
- YU. V. SERGEENKOV, YU. L. KHAZOV, T. W. BURROWS, M. R. BHAT. Nucl. Data Sheets 72 (1994) 487
(Gamma ray energies, Spin, Parity, Gamma intensities)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic Data)
- V.M.GOROZHANKIN, N.COURSOL, E.A.YAKUSHEV, Ts.VYLOV, C.BRIANÇON. Appl. Rad. Isotopes 56 (2002) 189
(M4 transition)

- H. SCHRADER. Appl. Rad. Isotopes 60 (2004) 317
(Half-life)
- M. A. L. DA SILVA, M. C. M. DE ALMEIDA, C. J. DA SILVA, J. U. DELGADO. Appl. Rad. Isotopes 60 (2004) 301
(Half-life)





1 Decay Scheme

Le xenon 131m se désexcite par une transition gamma (163,930 keV) fortement convertie.
Xe-131m decays by a strongly converted gamma transition.

2 Nuclear Data

$T_{1/2}(^{131}\text{Xe}^m)$: 11,930 (16) d

2.1 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(\text{Xe})$	163,930 (8)	100	M4	30,8 (9)	14,66 (44)	3,38 (10)	49,6 (15)

3 Atomic Data

3.1 Xe

ω_K : 0,888 (5)
 $\bar{\omega}_L$: 0,097 (5)
 n_{KL} : 0,902 (4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X_K	$K\alpha_2$	29,459	53,98	
	$K\alpha_1$	29,779	100	
	$K\beta_3$	33,562	}	
	$K\beta_1$	33,625	}	
	$K\beta_5''$	33,881	}	28,99
	$K\beta_2$	34,415	}	
	$K\beta_4$	34,496	}	6,84
	$KO_{2,3}$	34,552	}	
	X_L	$L\ell$	3,64	
		$L\alpha$	4,1 – 4,11	
$L\eta$		3,96		
$L\beta$		4,42 – 4,78		
$L\gamma$		4,89 – 5,30		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	23,512 – 24,842	100
KLX	27,897 – 29,770	46,5
KXY	32,27 – 34,54	5,41
Auger L	0,14 – 5,30	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Xe)	0,14 - 5,30	75,9 (8)
e _{AK}	(Xe)		6,8 (5)
	KLL	23,512 - 24,842	}
	KLX	27,897 - 29,770	}
	KXY	32,27 - 34,54	}
ec _{1,0 T}	(Xe)	129,3656 - 163,9179	98,02 (6)
ec _{1,0 K}	(Xe)	129,366 (8)	61,0 (26)
ec _{1,0 L}	(Xe)	158,477 - 159,148	29,0 (12)
ec _{1,0 M}	(Xe)	162,781 - 163,253	6,69 (28)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Xe)	3,64 — 5,30	8,13 (21)
XK α_2	(Xe)	29,459	15,4 (7) } K α
XK α_1	(Xe)	29,779	28,5 (13) }
XK β_3	(Xe)	33,562	}
XK β_1	(Xe)	33,625	}
XK β_5''	(Xe)	33,881	}
XK β_2	(Xe)	34,415	}
XK β_4	(Xe)	34,496	1,95 (10) } K' β_1
XK $\beta_{2,3}$	(Xe)	34,552	}

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Xe})$	163,930 (8)	1,98 (6)

6 Main Production Modes

{ Fission products
Possible impurities : Xe – 127, Xe – 129m, Xe – 133, Xe – 133m, Xe – 135

I – 129(n,γ)I – 130 σ : 9 (1) barns
{ I – 130(β⁻)Xe – 130
Possible impurities : T_{1/2} = 12,3 h

I – 129(n,γ)I – 130m
{ I – 130m(β⁻)Xe – 130 σ : 18 (2) barns
Possible impurities : T_{1/2} = 9,2 min

{ I – 130m(I.T.)I – 130
Possible impurities : T_{1/2} = 9,2 min

{ Xe – 130(n,γ)Xe – 131m σ : 0,45 (10) barns
Possible impurities : Xe – 129m

7 References

- J. S. GEIGER, R. L. GRAHAM, F. BROWN. Can. J. Phys. 40 (1962) 1258
(K conversion coefficient)
- G. ANDERSSON. Ark. Fysik 28 (1964) 37
(Half-life)
- K. KNAUF, H. SOMMER, H. KLEWE-NEBENIUS. Z. Phys. 197 (1966) 101
(Half-life, K conversion coefficient)
- K. FRANSSON, P. ERMAN. Ark. Fysik 39 (1968) 7
(Multipolarity)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Science and Eng. 48 (1972) 319
(Half-life)
- P. A. BENSON, H. Y. GEE, M. W. NATHANS. J. Inorg. Nucl. Chem. 35 (1973) 2614
(Branching Ratio)
- R. A. MEYER, F. MOMYER, W. B. WALTERS. Z. Phys. 268 (1974) 387
(Total branching, Half-life)
- J. L. CAMPBELL, B. MARTIN. Z. Phys. A274 (1975) 9
(K conversion coefficient)
- D. C. HOFFMAN, J. W. BARNES, B. J. DROPEK, F. O. LAWRENCE, G. M. KELLEY, M. A. OTT. J. Inorg. Nucl. Chem. 37 (1975) 2336
(Half-life)
- R. L. AUBE, H. R. HIDDLESTON, C. P. BROWNE. Nucl. Data Sheets 17 (1976) 573
(Spin, Parity, Energy Levels)
- N. C. TAM, A. VERES, I. PAVLICSEK, L. LAKOSI. J. Phys. G 16 (1990) 1215
(Half-life)
- M. P. UNTERWEGER. Nucl. Instrum. Methods A312 (1992) 349
(Half-life)
- YU. V. SERGEENKOV, YU. L. KHAZOV, T. W. BURROWS, M. R. BHAT. Nucl. Data Sheets 72 (1994) 487
(Spin, Parity, Level Energy, Gamma Transition Energy)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic Data)
- V.M.GOROZHANKIN, N.COURSOL, E.A.YAKUSHEV, T.S.VYLOV, C.BRIANÇON. Appl. Rad. Isotopes 56 (2002) 189
(M4 transition)





1 Decay Scheme

Ba-133 disintegrates by electron capture to Cs-133 via the excited states of 437 keV (86.1%) and of 383 keV (13.9%).

Le baryum 133 se désintègre par capture électronique vers des niveaux excités de 437 et 383 keV du césium 133.

2 Nuclear Data

$$T_{1/2}({}^{133}\text{Ba}) : 10,540 \quad (6) \quad \text{a}$$

$$Q^+({}^{133}\text{Ba}) : 517,4 \quad (10) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	<i>P_K</i>	<i>P_L</i>	<i>P_M</i>
ε _{0,4}	80,4 (10)	86,2 (5)	Allowed	6,68	0,672 (5)	0,252 (4)	0,0612 (13)
ε _{0,3}	133,6 (10)	13,7 (4)	Allowed	8,07	0,7734 (21)	0,1761 (15)	0,0408 (8)
ε _{0,2}	356,8 (10)	< 0,3	2nd Forbidden	> 10,6	0,79 (3)		
ε _{0,1}	436,4 (10)	< 0,7	2nd Forbidden	> 10,6	0,88 (4)		
ε _{0,0}	517,4 (10)	< 0,0005	Uniq. 2ndForbidden	> 13,9			

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	<i>P_{γ+ce}</i> × 100	Multipolarity	<i>α_K</i>	<i>α_L</i>	<i>α_{MNO}</i>	<i>α_T</i>
γ _{4,3} (Cs)	53,1622 (6)	15,0 (4)	M1+2,2(13)%E2	4,93 (10)	0,86 (3)	0,226 (8)	6,02 (18)
γ _{2,1} (Cs)	79,6142 (12)	7,34 (17)	M1+0,09(9)%E2	1,515 (30)	0,204 (5)	0,0530 (11)	1,77 (4)
γ _{1,0} (Cs)	80,9979 (11)	90,1 (16)	M1+2,23(4)%E2	1,46 (3)	0,220 (5)	0,0570 (14)	1,74 (4)
γ _{2,0} (Cs)	160,6121 (16)	0,84 (3)	M1+62(12)%E2	0,24 (3)	0,054 (7)	0,014 (3)	0,31 (4)

	Energy keV	P _{γ+ce} × 100	Multipolarity	α _K	α _L	α _{MNO}	α _T
γ _{3,2} (Cs)	223,2370 (13)	0,498 (6)	M1+1,3(2)%E2	0,0853 (20)	0,0113 (3)	0,00292 (6)	0,0995 (30)
γ _{4,2} (Cs)	276,3992 (12)	7,57 (5)	E2	0,0461 (9)	0,00855 (17)	0,00225 (5)	0,0569 (12)
γ _{3,1} (Cs)	302,8512 (5)	19,15 (14)	M1+0,05(6)%E2	0,0381 (8)	0,00496 (10)	0,00128 (3)	0,0443 (9)
γ _{4,1} (Cs)	356,0134 (7)	63,64 (20)	E2	0,0211 (4)	0,00351 (7)	0,00092 (30)	0,0256 (5)
γ _{3,0} (Cs)	383,8491 (12)	9,12 (6)	E2	0,0169 (3)	0,00273 (5)	0,00071 (2)	0,0203 (4)

3 Atomic Data

3.1 Cs

ω _K	:	0,894	(4)
ω̄ _L	:	0,104	(5)
n _{KL}	:	0,895	(4)

3.1.1 X Radiations

	Energy keV	Relative probability
X _K		
Kα ₂	30,625	54,13
Kα ₁	30,973	100
Kβ ₃	34,92	}
Kβ ₁	34,987	}
Kβ ₅ ''	35,245	}
Kβ ₅ '	35,259	}
Kβ ₂	35,818	}
Kβ ₄	35,907	}
KO _{2,3}	35,972	}
X _L		
Lℓ	3,8	
Lγ	– 5,7	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	24,41 – 25,80	100
KLX	29,00 – 30,96	47,2
KXY	33,51 – 35,95	5,56
Auger L	2,5 – 5,6	

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Cs)	2,5	- 5,6	138,0 (15)
e _{AK}	(Cs)			14,2 (6)
	KLL	24,41	- 25,80	}
	KLX	29,00	- 30,96	}
	KXY	33,51	- 35,95	}
ec _{4,3} K	(Cs)	17,1776	(6)	10,6 (3)
ec _{2,1} K	(Cs)	43,6296	(12)	4,01 (9)
ec _{1,0} K	(Cs)	45,0133	(11)	48,1 (11)
ec _{4,3} L	(Cs)	47,45	- 48,15	1,84 (7)
ec _{4,3} MNO	(Cs)	51,94	- 53,08	0,484 (18)
ec _{2,1} L	(Cs)	73,9	- 74,6	0,541 (17)
ec _{1,0} L	(Cs)	75,29	- 75,79	7,25 (18)
ec _{2,1} MNO	(Cs)	78,40	- 79,53	0,140 (5)
ec _{1,0} MNO	(Cs)	79,78	- 80,92	1,88 (5)
ec _{2,0} K	(Cs)	124,6274	(16)	0,15 (2)
ec _{4,2} K	(Cs)	240,4143	(12)	0,330 (7)
ec _{3,1} K	(Cs)	266,8862	(5)	0,70 (2)
ec _{4,2} L	(Cs)	270,69	- 271,39	0,0612 (13)
ec _{3,1} L	(Cs)	297,14	- 297,85	0,091 (2)
ec _{4,1} K	(Cs)	320,0283	(7)	1,31 (3)
ec _{3,0} K	(Cs)	347,8639	(12)	0,151 (3)
ec _{4,1} L	(Cs)	350,30	- 351,01	0,218 (4)
ec _{4,1} MNO	(Cs)	354,80	- 355,93	0,57 (1)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.
XL	(Cs)	3,8	— 5,7	16,0 (8)
XK α_2	(Cs)	30,625		34,0 (4)
XK α_1	(Cs)	30,973		62,8 (7)
XK β_3	(Cs)	34,92	}	
XK β_1	(Cs)	34,987	}	18,2 (2)
XK β_5''	(Cs)	35,245	}	
XK β_5'	(Cs)	35,259	}	

		Energy keV	Photons per 100 disint.		
XK β_2	(Cs)	35,818	}	4,6 (1)	K' β_2
XK β_4	(Cs)	35,907	}		
XKO $_{2,3}$	(Cs)	35,972	}		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{4,3}$ (Cs)	53,1622 (6)	2,14 (3)
$\gamma_{2,1}$ (Cs)	79,6142 (12)	2,65 (5)
$\gamma_{1,0}$ (Cs)	80,9979 (11)	32,9 (3)
$\gamma_{2,0}$ (Cs)	160,6121 (16)	0,638 (4)
$\gamma_{3,2}$ (Cs)	223,2368 (13)	0,453 (3)
$\gamma_{4,2}$ (Cs)	276,3989 (12)	7,16 (5)
$\gamma_{3,1}$ (Cs)	302,8508 (5)	18,34 (13)
$\gamma_{4,1}$ (Cs)	356,0129 (7)	62,05 (19)
$\gamma_{3,0}$ (Cs)	383,8485 (12)	8,94 (6)

6 Main Production Modes

{ Ba – 132(n, γ)Ba – 133 σ : 6,5 (8) barns
Possible impurities : Ba – 131, Ba – 140

{ Ba – 132(n, γ)Ba – 133m σ : 0,5 barns
Possible impurities : Ba – 131, Ba – 140

{ Cs – 133(p,n)Ba – 133
Possible impurities : Cs – 132

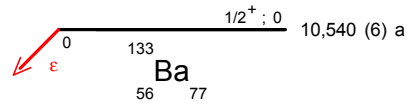
7 References

- E. I. WYATT, S. A. REYNOLDS, T. H. HANDLEY, W. S. LYON, H. A. PARKER. Nucl. Sci. Eng. 11 (1961) 74 (Half-life)
- P. BLASI, M. BOCCIOLINI, P. R. MAURENZIG, P. SONA, N. TACCETTI. Nuovo Cim. 50B (1967) 298 (Gamma-ray emission intensities)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78 (X-ray energies)
- F. LAGOUTINE, Y. LE.GALLIC, J. LEGRAND. Int. J. Appl. Radiat. Isotop. 19 (1968) 475 (Half-life)
- A. NOTEA, Y. GURFINKEL. Nucl. Phys. A107 (1968) 193 (Gamma-ray emission intensities)

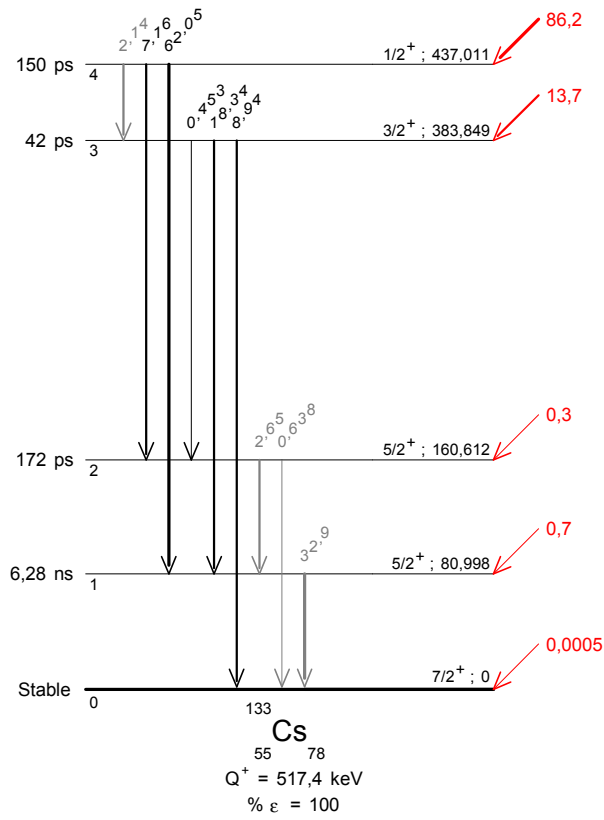
- S. A. REYNOLDS, J. F. EMERY, E. I. WYATT. Nucl. Sci. Eng. 32 (1968) 46
(Half-life)
- P. ALEXANDER, J. P. LAU. Nucl. Phys. A121 (1968) 612
(Gamma-ray emission intensities)
- H. E. BOSCH, A. J. HAVERFIELD, E. SZICHMAN, S. M. ABECASIS. Nucl. Phys. A108 (1968) 209
(Gamma-ray emission intensities)
- D. P. DONNELLY, J. J. REIDY, M. L. WIEDENBECK. Phys.Rev. 173 (1968) 1192
(Gamma-ray emission intensities)
- V. NARAND, H. HOUTERMANS. Phys. Soc., Budapest (1968) 97
(L/K-capture ratio)
- R. GUNNINK, J. B. NIDAY, R. P. ANDERSON, R. A. MEYER. Priv. Comm. UCID-15439 (1969)
(Gamma-ray emission intensities)
- K. F. WALZ, J. L. CAMPBELL. Z. Naturforsch. 25a (1970) 921
(Half-life)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
([Half-life])
- W.-D. SCHMIDT-OTT, R. M. FINK. Z. Phys. 249 (1972) 286
(K-capture probability, absolute XKemission probability, g-ray emission])
- H. INOUE, Y. YOSHIZAWA, T. MORII. J. Phys. Soc. Jap. 34 (1973) 1437
(Gamma-ray emission intensities)
- L. A. MCNELLES, J. L. CAMPBELL. Nucl. Instrum. Methods 109 (1973) 241
(Gamma-ray emission intensities)
- R. D. LLOYD, C. W. MAYS. Int. J. Appl. Radiat. Isotop. 24 (1973) 189
(Half-life)
- J. LEGRAND, K. DEBERTIN, K. F. WALZ. Nucl. Instrum. Methods 112 (1973) 229
(Gamma-ray emission intensities)
- DAS. B. K. MAHAPATRA, P. MUKHERJEE. J. Phys. (London) A7 (1974) 388
(K-capture probabilities)
- W. F. NICAISE, A. W. WALTNER. Nucl. Instrum. Methods 131 (1975) 477
(K-capture probability)
- U. SCHÖTZIG, K. DEBERTIN, K. F. WALZ. Int. J. Appl. Radiat. Isotop. 28 (1977) 503
(XK-ray and g-ray emission probabilities)
- R. J. GEHRKE, R. G. HELMER, R. C. GREENWOOD. Nucl. Instrum. Methods 147 (1977) 405
(K-capture probability)
- K. S. KRANE. At. Data Nucl. Data Tables 19 (1977) 363
(E2/M1 mixing ratio)
- F. P. LARKINS. At. Data Nucl. Data Tables 20 (1977) 313
(Auger electron energies)
- F. RÖSEL, H. M. FRIESS, K. ALDER, H. C. PAULI. At. Data Nuc. Data Tables 21 (1978) 92
(Internal conversion coefficients)
- R. G. HELMER, R. C. GREENWOOD, R. J. GEHRKE. Nucl. Instrum. Methods 155 (1978) 189
(Gamma-ray emission intensities)
- C. VYLOV, B. P. OSIPENKO, V. G. CHUMIN. Particles and Nuclei 6 (1978) 1350
(Gamma-ray emission intensities)
- H. H. HANSEN, J. MOREL, J. LEGRAND. Report NEANDC v.3 (1979) 28
(Half-life)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153
(Half-life)
- W. M. RONEY JR., W. A. SEALE. Nucl. Instrum. Meth. 171 (1980) 389
(Gamma-ray emission intensities)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. Report AECL 6692 (1980)
(Half-life)
- K. S. KRANE. At. Data Nuc. Data Tables 25 (1980) 29
(E2/M1 mixing ratio)
- B. CHAUVENET, J. MOREL, J. LEGRAND. Report ICRM-S-6 (1980)
(Absolut gamma-ray emission intensities)
- D. D. HOPPE, J. M. R. HUTCHINSON, F. J. SCHIMA, M. P. UNTERWEGER. Report NBS-SP 626 (1982) 85
(half-life)
- J. KITS, F. LATAL, M. CHOC. Int. J. Appl. Radiat. Isotop. 34 (1983) 935
(Half-life)

- K. SINGH, H. S. SAHOTA. J. Phys. (London) G9 (1983) 1565
(K-capture probabilities)
- K. SINGH, H. S. SAHOTA. J. Phys. Soc. Jap. 52 (1983) 2336
(K-capture probability)
- B. CHAUVENET, J. MOREL, J. LEGRAND. Int. J. Appl. Radiat. Isotop. 34 (1983) 479
(Absolute g-ray emission probabilities)
- K. F. WALZ, K. DEBERTIN H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- Y. YOSHIKAWA, Y. IWATA, T. KATOH, J.-Z. RUAN, Y. KAWADA. Nucl. Instrum. Methods 212 (1983) 249
(Gamma-ray emission intensities)
- LAKSHN, S. B. REDDY, K. B. REDDY. Curr. Sci. V.50 (1987) 407
(Gamma-ray emission intensities)
- R. B. BEGZHANOV, SH. K. AZIMOV, R. D. MAGRUPOV, SH. A. MIRAKHMEDOV, A. MUKHAMMADIEV, M. NARZIKULOV, S. KH. SALIMOV. Proc. 38th Ann. Conf. Spectros. Struct. At. Nuclei, Baku (1988) 93
(K-capture probabilities)
- V. N. DANILENKO, A. A. KONSTANTINOV, N. V. KURENKOV, L. N. KURCHATOVA, A. B. MALININ, A. V. MAMELIN, S. V. MATVEEV, T. E. SAZONOVA, E. K. STEPANOV, S. V. SERMAN, YU. G. TOPOROV. Appl. Rad. Isotopes 40 (1989) 707
(Gamma-ray emission intensities)
- M. C. MARTINS, M. I. MARQUES, F. PARENTE, J. G. FERREIRA. J. Phys. (London) B.22 (1989) 3167
(KB²/K¹B¹ ratio)
- A. G. EGOROV, YU. S. EGOROV, V. G. NEDOVESOV, G. E. SHCHUKIN, K. P. YAKOVLEV. Proc. 39th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Leningrad (1989) 505
(K X-ray emission intensities)
- R. A. MEYER. Fizika (Zagreb) 22 (1990) 153
(Gamma-ray emission intensities)
- B. DASMAHAPATRA, S. BHATTACHARYA, S. SEN, M. SAHA, A. GOSWAMI. J. Phys. (London) G.67 (1990) 1227
(K-capture probability)
- R. B. FIRESTONE. Nucl. Instrum. Methods A286 (1990) 584
(Decay scheme)
- K. RAO, BHASKARA, S. S. RAO, V. S. RAO, H. C. PADHI. Nuovo Cim. 103A (1990) 683
(K-capture probability)
- C. WESSELBORG, D. E. ALBURGER. Nucl. Instrum. Methods A302 (1991) 89
(Gamma ray energies)
- F. E. CHUKREEV. Yadern. Konstanti v.2 (1992) 92
(Decay scheme)
- G. PS. SAHOTA, H. SINGH, H. S. BINARH, B. S. PALLAN, H. S. SAHOTA. J. Phys. Soc. Jap. 61 (1992) 3518
(K-capture probability)
- M. P. UNTERWERGER, D. D. HOPPES, F. J. SCHIMA. Nucl. Instrum. Methods A312 (1992) 349
(Half-life)
- A. L. NICHOLS. AEA Technology Report AEA-RS 5449 (1993)
(Decay Scheme)
- S. RAB. Nucl. Data Sheets 75 (1995) 491
(Decay Scheme)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 595 (1995) 409
(Q-value)
- H. MIYAHARA, K. USAMI, C. MORI. Nucl. Instrum. Methods A374 (1996) 193
(gamma-ray emission probabilities)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic Data)
- R. H. MARTIN, K. I. W. BURNS, J. G. V. TAYLOR. Nucl. Instrum. Methods A390 (1997) 267
(Half-life)
- H. Y. HWANG, C. B. LEE, T. S. PARK. Appl. Rad. Isotopes 49 (1998) 1201
(gamma-ray emission probabilities)
- E. SCHÖNFELD. Appl. Rad. Isotopes 49 (1998) 1353
(Pk, Pl, Pm electron capture probabilities)
- B. SINGH, J. L. RODRIGUEZ, S. S. WONG, J. K. TULI. Nucl. Data Sheets 84 (1998) 487
(lg ft)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Meth. Phys. Res. A450 (2000) 35
(Gamma-ray energies)

- V. P. CHECHEV, A. G. EGOROV. Appl. Rad. Isotopes 52 (2000) 601
(Evaluation technique)
- M. P. UNTERWERGER. Appl. Rad. Isotopes 56 (2002) 125
(Half-life)
- H. SCHRADER. Appl. Rad. Isotopes 60 (2004) 317
(Half-life)



γ Emission probabilities per 100 disintegrations





1 Decay Scheme

Le baryum 140 se désintègre par émissions bêta moins vers des niveaux excités de lanthane 140.

Le rapport au temps t des activités La-140/Ba-140 dans le Ba-140 initialement pur s'écrit :

$$T1/(T1 - T2)(1 - e^{t \times (-\ln 2(T1-T2)/T1 \times T2)})$$

T1 et T2 étant respectivement les périodes de Ba-140 et de La-140

A l'équilibre (t ≥ 19 jours), ce rapport est égal à : T1/(T1-T2) = 1,1516 ± 0,0007.

The Ba-140 disintegrates by beta minus emissions to La-140 excited levels.

At equilibrium (t ≥ 19 d), with T1 : Ba-140 half-life and, T2 : La-140 half-Life, the activity ratio is :

$$T1/(T1-T2) = 1.1516 \pm 0.0007.$$

2 Nuclear Data

$T_{1/2}(^{140}\text{Ba})$	:	12,753	(4)	d
$T_{1/2}(^{140}\text{La})$	:	1,67850	(17)	d
$Q^-(^{140}\text{Ba})$	:	1047	(8)	keV

2.1 β^- Transitions

	Energy keV	Probability × 100	Nature	lg ft
$\beta_{0,6}^-$	469 (8)	24,73 (23)	1st forbidden	7,05
$\beta_{0,5}^-$	582 (8)	9,63 (10)	1st forbidden	7,78
$\beta_{0,4}^-$	887 (8)	3,9000 (11)	Unique 1st forbidden	9,2
$\beta_{0,3}^-$	987 (8)	<0,00000001	Unique 3rd forbidden	>18
$\beta_{0,2}^-$	1006 (8)	39 (4)	1st forbidden	8
$\beta_{0,1}^-$	1020 (8)	23 (4)	Unique 1st forbidden	8,8
$\beta_{0,0}^-$	1050 (8)	≤0,00001	3rd forbidden	≥15

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{2,1}(\text{La})$	13,849 (4)	66,24 (3)	M1+E2		44,7 (9)	9,7 (20)	56,6 (11)
$\gamma_{1,0}(\text{La})$	29,9656 (15)	93,80 (25)	M1+E2		4,4 (9)	0,9 (2)	5,55 (11)
$\gamma_{3,0}(\text{La})$	63,184 (13)	0,000232 (15)	[M1,E2]	4,0 (2)	3 (2)		7 (3)
$\gamma_{4,3}(\text{La})$	99,479 (13)	0,000061 (12)	[E2]	1,230 (25)	0,635 (13)	0,17 (2)	2,04 (4)
$\gamma_{6,5}(\text{La})$	113,582 (7)	0,0303 (7)	E0	0,658 (13)	0,0893 (18)	0,027 (3)	0,771 (15)
$\gamma_{4,2}(\text{La})$	118,849 (4)	0,1015 (18)	M1	0,587 (18)	0,0785 (18)	0,024 (2)	0,678 (14)
$\gamma_{4,1}(\text{La})$	132,6972 (25)	0,301 (4)	M1	0,424 (8)	0,0575 (11)	0,017 (2)	0,497 (10)
$\gamma_{4,0}(\text{La})$	162,6628 (24)	8,03 (9)	M1(+E2)	0,241 (5)	0,0325 (7)	0,0082 (8)	0,282 (6)
$\gamma_{5,4}(\text{La})$	304,872 (4)	4,52 (4)	M1(+E2)	0,0444 (9)	0,00589 (12)	0,0016 (2)	0,0519 (10)
$\gamma_{5,2}(\text{La})$	423,721 (4)	3,18 (3)	M1	0,0190 (4)	0,0027 (2)		0,0222 (4)
$\gamma_{5,1}(\text{La})$	437,569 (3)	1,967 (19)	M1	0,0176 (4)	0,00230 (5)	0,0007 (1)	0,0205 (4)
$\gamma_{6,2}(\text{La})$	537,304 (6)	24,69 (22)	M1	0,0105 (2)	0,00137 (3)		0,0122 (2)
$\gamma_{6,1}(\text{La})$	551,153 (8)	0,0049 (20)	[E2]	0,00671 (13)	0,00101 (2)		0,00799 (16)

3 Atomic Data

3.1 La

ω_K	:	0,905	(4)
$\bar{\omega}_L$	:	0,117	(5)
n_{KL}	:	0,888	(4)
\bar{n}_{LM}	:	1,574	

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	33,0344	
	$K\alpha_1$	33,4421	
	$K\beta_3$	37,7206	}
	$K\beta_1$	37,8015	}
	$K\beta_5''$	38,075	}
	$K\beta_5'$	39,095	}
	$K\beta_2$	38,7303	}
	$K\beta_4$	38,828	}
	$KO_{2,3}$	39,91	}
			54,44
		100	
		29,8	
		7,5	

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
ec _{2,1} L	(La)	7,560	- 8,363	51,4 (13)
ec _{2,1} M	(La)	12,485	- 12,743	11,2 (23)
ec _{2,1} N	(La)	13,576	- 13,655	2,9 (5)
ec _{1,0} L	(La)	23,702	- 24,485	63 (13)
ec _{1,0} M	(La)	28,606	- 28,844	13 (3)
ec _{1,0} N	(La)	29,697	- 29,776	3,2 (7)
ec _{6,5} K	(La)	74,657	(7)	0,0113 (5)
ec _{4,2} K	(La)	79,922	(4)	0,0355 (14)
ec _{4,1} K	(La)	93,767	(5)	0,0852 (23)
ec _{6,5} L	(La)	107,316	- 108,099	0,00153 (7)
ec _{6,5} M	(La)	112,221	- 112,459	0,00046 (2)
ec _{4,0} K	(La)	123,735	(2)	1,51 (4)
ec _{4,0} L	(La)	156,394	- 157,177	0,203 (5)
ec _{4,0} M	(La)	161,299	- 161,537	0,051 (5)
ec _{5,4} K	(La)	265,950	(4)	0,191 (19)
ec _{5,4} L	(La)	298,609	- 299,392	0,025 (3)
ec _{5,4} M	(La)	303,514	- 303,752	0,007 (1)
ec _{5,2} K	(La)	384,7979	(23)	0,0591 (14)
ec _{5,1} K	(La)	398,643	(4)	0,0339 (7)
ec _{5,2} L	(La)	417,456	- 418,239	0,0084 (8)
ec _{5,1} L	(La)	431,501	- 432,084	0,0044 (1)
ec _{6,2} K	(La)	498,379	(7)	0,256 (6)
ec _{6,2} L	(La)	531,038	- 531,821	0,0334 (7)
$\beta_{0,6}^-$	max:	469	(8)	24,73 (23)
$\beta_{0,6}^-$	avg:	136	(4)	
$\beta_{0,5}^-$	max:	582	(8)	9,63 (10)
$\beta_{0,5}^-$	avg:	176	(4)	
$\beta_{0,4}^-$	max:	887	(8)	3,9000 (11)
$\beta_{0,4}^-$	avg:	305	(4)	
$\beta_{0,3}^-$	max:	987	(8)	<0,00000001
$\beta_{0,3}^-$	avg:			
$\beta_{0,2}^-$	max:	1006	(8)	39 (4)
$\beta_{0,2}^-$	avg:	339	(4)	
$\beta_{0,1}^-$	max:	1020	(8)	23 (4)
$\beta_{0,1}^-$	avg:	357	(4)	
$\beta_{0,0}^-$	max:	1050	(8)	≤0,00001
$\beta_{0,0}^-$	avg:			

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XK α_2	(La)	33,0344	0,535 (11)	} K α
XK α_1	(La)	33,4421	0,982 (20)	
XK β_3	(La)	37,7206	}	} K' β_1
XK β_1	(La)	37,8015	} 0,292 (7)	
XK β_5''	(La)	38,075	}	
XK β_5'	(La)	39,095	}	
XK β_2	(La)	38,7303	}	
XK β_4	(La)	38,828	} 0,074 (2)	} K' β_2
XKO _{2,3}	(La)	39,91	}	

5.2 Gamma Emissions

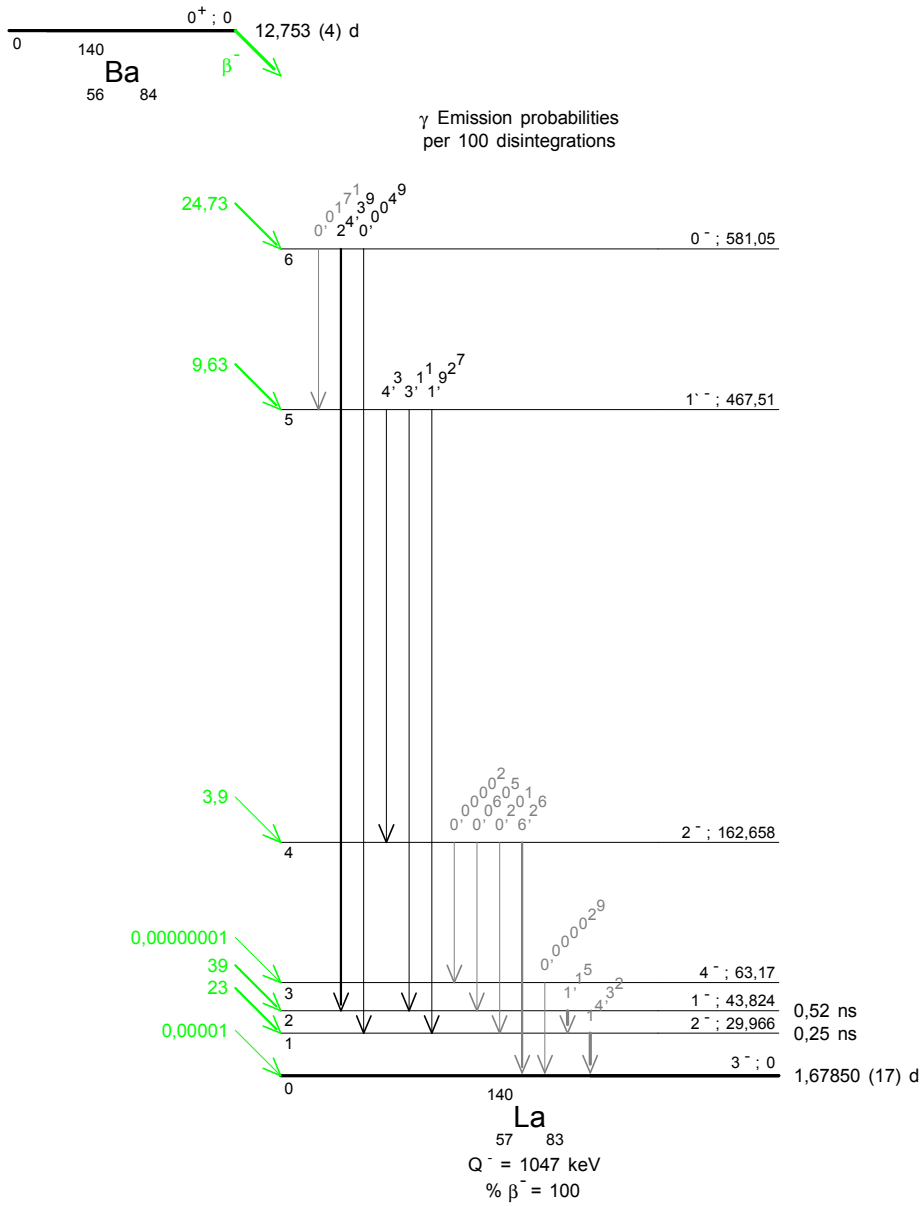
	Energy keV	Photons per 100 disint.
$\gamma_{2,1}$ (La)	13,849 (4)	1,15 (3)
$\gamma_{1,0}$ (La)	29,9656 (15)	14,32 (25)
$\gamma_{3,0}$ (La)	63,184 (13)	0,000029 (15)
$\gamma_{4,3}$ (La)	99,479 (13)	0,000020 (12)
$\gamma_{6,5}$ (La)	113,582 (7)	0,0171 (7)
$\gamma_{4,2}$ (La)	118,849 (4)	0,0605 (18)
$\gamma_{4,1}$ (La)	132,6972 (25)	0,201 (4)
$\gamma_{4,0}$ (La)	162,6628 (24)	6,26 (9)
$\gamma_{5,4}$ (La)	304,872 (4)	4,30 (4)
$\gamma_{5,2}$ (La)	423,721 (4)	3,11 (3)
$\gamma_{5,1}$ (La)	437,569 (3)	1,927 (19)
$\gamma_{6,2}$ (La)	537,303 (6)	24,39 (22)
$\gamma_{6,1}$ (La)	551,152 (8)	0,0049 (20)

6 Main Production Modes

{ Fission product
 { Possible impurities : None

7 References

- J. S. GEIGER, R. L. GRAHAM, G. T. EWAN. Bull. Am. Phys. Soc. 6 (1961) 71
(Gamma ray energies)
- P. SIMONET, G. BOILE, G. SIMONET. Report CEA-R-2461 (1965)
(Half-life)
- G. A. MOSS, D. K. MCDANIELS. Nucl. Phys. 85 (1966) 513
(Gamma ray energies)
- V. G. KALINNIKOV, H. L. RAVN. Bull. Acad. Sci. USSR, Phys. Ser. 33 (1970) 1283
(Gamma ray energies, Gamma-ray emission intensities)
- E. T. JURNEY, R. K. SHELINE, E. B. SHERA, H. R. KOCH, B. P. K. MAIER, U. GRUBER, H. BAADER, D. BREITIG, O.W. B. SCHULT, J. KERN, G. L. STRUBLE. Phys. Rev. C 2 (1970) 2323
(Gamma ray energies)
- J. KERN, G. MAURON. Helv. Phys. Acta 43 (1970) 272
(Gamma ray energies, Gamma-ray emission intensities)
- S. BABA, H. BABA, H. NATSUME. J. Inorg. Nucl. Chem. 33 (1971) 589
(Half-life)
- J. T. HARVEY, J. L. MEASON, J. C. HOGAN, H. L. WRIGHT. Nucl. Sci. Eng. 58, (1975) 431
(Gamma-ray emission intensities)
- C.-C. LIN. J. Inorg. Nucl. Chem. 38 (1976) 1409
(Gamma-ray emission intensities)
- K. DEBERTIN, U. SCHÖTZIG, K. F. WALZ. Nucl. Sci. Eng. 64 (1977) 784
(Gamma-ray emission intensities)
- R. J. GEHRKE, R. G. HELMER, R. C. GREENWOOD. Nucl. Instrum. Methods 147 (1977) 405
(Gamma-ray emission intensities)
- H. G. BÖRNER, W. F. DAVISON, J. ALMEUDA, J. BLACHOT, J. A. PINSTON, P. H. M. VAN ASSCHE. Nucl. Instrum. Methods 164 (1979) 579
(Gamma ray energies)
- I. ADAM, N. M. ANTONEVA, V. B. BRUDANIN, M. BUDZYNSKI, Ts. VYLOV, V. A. DZHASHI, A. ZHUMAMURATOV, A. I. IVANOV, V. G. KALINNIKOV, A. KUGLER, V. V. KUZNETSOV, LI ZON SIK, T. M. MUMINOV, A. F. NOVGORODOV, YU. . Izv. Akad. Nauk. SSSR, Ser. Fiz. 46 (1982) 2
(Gamma ray energies, Gamma-ray emission intensities)
- K. DEBERTIN, U. SCHÖTZIG, K. F. WALZ. Report NBS-SP-626 (1982) 101
(Half-life)
- D. D. HOPPE, J. M. R. HUTCHINSON, F. J. SCHIMA, M. P. UNTERWEGER. Report NBS-SP-626 (1982) 85
(Half-life)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- W. L. ZIJP. Report ECN FYS/FYSRASA-85/19 (1985)
(Averages)
- R. A. MEYER, K. V. MARSH, H. SEYFARTH, S. BRANT, M. BOGDANOVIC, V. PAAR. Phys. Rev. C 41 (1990) 1172
(Gamma ray energies, Gamma-ray emission intensities)
- B. CHAND, J. GOSWAMY, D. MEHTA, N. SINGH, P. N. TREHAN. Can. J. Phys. 69 (1991) 90
(Gamma-ray emission intensities)
- M. U. RAJPUT, T. D. MACMAHON. Nucl. Instrum. Methods Phys. Res. A312 (1992) 289
(Averages)
- M. P. UNTERWEGER, D. D. HOPPE, F. J. SCHIMA. Nucl. Instrum. Methods Phys. Res. A312 (1992) 349
(Half-life)
- L. K. PEKER. Nucl. Data Sheets 73 (1994) 261
(Multipolarities, Spin and Parity)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(Atomic data)
- B. SINGH, J. L. RODRIGUEZ, S. S. M WONG, J. K. TULI. Nucl. Data Sheets 84 (1998) 487
(log ft systematics)
- E. SCHÖNFELD, H. JANSSEN. Report PTB-6.11-1999-1 (1999)
(Px)
- M. P. UNTERWEGER. Appl. Rad. Isotopes 56 (2002) 125
(Half-life)





1 Decay Scheme

La-140 decays by beta minus emission to the Ce-140 excited levels.

Le lanthane 140 se désintègre par émission bêta moins vers des niveaux excités de cerium 140. La transition bêta moins vers le niveau fondamental n' a pas été mise en évidence d'une manière significative (0,0008 %).

2 Nuclear Data

$$T_{1/2}(^{140}\text{La}) : 1,67850 \quad (17) \quad \text{d}$$

$$Q^-(^{140}\text{La}) : 3761,9 \quad (19) \quad \text{keV}$$

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,19}^-$	241,1 (19)	0,0102 (13)	1st forbidden	8,66
$\beta_{0,18}^-$	288,3 (19)	0,051 (4)	Allowed	8,21
$\beta_{0,17}^-$	367,1 (10)	0,019 (3)	Allowed	8,98
$\beta_{0,16}^-$	442,3 (20)	0,00392 (19)	1st forbidden	9,94
$\beta_{0,15}^-$	643,4 (19)	0,0256 (5)	1st forbidden	9,68
$\beta_{0,14}^-$	761,0 (19)	0,084 (6)	1st forbidden	9,42
$\beta_{0,13}^-$	862,2 (19)	0,111 (4)	1st forbidden	9,49
$\beta_{0,12}^-$	1214,7 (19)	0,635 (5)	Unique 1st forbidden	9,96
$\beta_{0,11}^-$	1240,5 (19)	11,12 (6)	1st forbidden	8,07
$\beta_{0,10}^-$	1246,2 (19)	5,79 (3)	1st forbidden	8,36
$\beta_{0,9}^-$	1281,0 (19)	1,15 (3)	1st forbidden	9,11
$\beta_{0,8}^-$	1297,8 (19)	5,59 (3)	Allowed	8,44
$\beta_{0,7}^-$	1349,9 (19)	44,9 (4)	1st forbidden	7,6
$\beta_{0,6}^-$	1412,1 (19)	0,25 (3)	Unique 1st forbidden	10,72
$\beta_{0,5}^-$	1414,0 (19)	5,03 (4)	1st forbidden	8,63
$\beta_{0,3}^-$	1678,7 (19)	20,7 (20)	1st forbidden	8,3
$\beta_{0,1}^-$	2165,7 (19)	4,5 (20)	1st forbidden	9,4

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T	α_π (10^{-4})
$\gamma_{4,3}$ (Ce)	24,595 (4)	0,52 (3)	E2		560 (18)	114 (4)	712 (21)	
$\gamma_{7,5}$ (Ce)	64,129 (4)	0,0746 (17)	M1	3,72 (11)	0,514 (16)	0,11	4,37 (13)	
$\gamma_{9,7}$ (Ce)	68,923 (5)	0,3499 (18)	M1	3,02 (9)	0,417 (13)	0,08	3,55 (11)	
$\gamma_{11,7}$ (Ce)	109,417 (4)	0,421 (6)	M1	0,799 (24)	0,110 (3)	0,03	0,939 (28)	
$\gamma_{9,6}$ (Ce)	131,121 (4)	0,734 (14)	M1+E2	0,480 (14)	0,068 (2)	0,004	0,566 (18)	
$\gamma_{11,5}$ (Ce)	173,546 (5)	0,159 (5)	M1	0,220 (7)	0,0299 (9)	0,008	0,258 (8)	
$\gamma_{6,4}$ (Ce)	241,959 (6)	0,481 (10)	M1+E2	0,0892 (27)	0,0120 (4)	0,003	0,104 (3)	
$\gamma_{6,3}$ (Ce)	266,554 (5)	0,527 (9)	M1+E2	0,0564 (17)	0,0118 (4)	0,0033	0,0715 (22)	
$\gamma_{2,1}$ (Ce)	307,08 (4)	0,023 (3)	E2	0,0365 (11)	0,0071 (2)	0,002	0,0456 (14)	
$\gamma_{7,3}$ (Ce)	328,761 (4)	21,8 (3)	M1+E2	0,0396 (12)	0,0053 (2)	0,0015	0,0464 (14)	
$\gamma_{9,3}$ (Ce)	397,674 (6)	0,0764 (24)	E2	0,0170 (5)	0,0029 (1)	0,0009	0,0208 (6)	
$\gamma_{10,3}$ (Ce)	432,513 (8)	3,059 (16)	M1+E2	0,0182 (5)	0,0025 (1)	0,0007	0,0214 (7)	
$\gamma_{11,3}$ (Ce)	438,178 (6)	0,017 (10)	M1	0,0129 (4)	0,00214 (6)	0,0006	0,0156 (5)	
$\gamma_{5,2}$ (Ce)	444,57 (4)	0,0033 (7)	[E2]	0,0124 (4)	0,00205 (6)	0,0006	0,0150 (5)	
$\gamma_{3,1}$ (Ce)	487,022 (6)	46,6 (4)	E2	0,00970 (29)	0,00155 (5)	0,0004	0,0117 (4)	
$\gamma_{11,2}$ (Ce)	618,12 (4)	0,041 (3)	[E2]	0,00524 (16)	0,00078 (2)	0,00021	0,00623 (19)	
$\gamma_{5,1}$ (Ce)	751,655 (7)	4,417 (24)	M1+E2	0,00484 (15)	0,00063 (2)	0,00017 (1)	0,00564 (17)	
$\gamma_{7,1}$ (Ce)	815,784 (6)	23,83 (12)	M1+E2	0,00415 (12)	0,00054 (2)	0,00013	0,00482 (14)	
$\gamma_{8,1}$ (Ce)	867,842 (16)	5,59 (3)	E1+M2	0,00098 (3)	0,00012	0,00004	0,00114 (4)	
$\gamma_{10,1}$ (Ce)	919,536 (10)	2,801 (23)	M1+E2	0,00211 (8)	0,00030 (1)	0,00008	0,02590 (9)	
$\gamma_{11,1}$ (Ce)	925,201 (7)	7,07 (4)	M1+E2	0,00307 (9)	0,00040 (1)	0,0001	0,00357 (11)	
$\gamma_{12,1}$ (Ce)	950,991 (20)	0,532 (5)	[M1,E2]	0,0024 (5)	0,00032 (6)	0,0001	0,0028 (6)	
$\gamma_{18,9}$ (Ce)	992,64 (18)	0,0100 (25)	[E1]	0,000744 (22)	0,000093 (3)	0,000024	0,000861 (25)	
$\gamma_{17,6}$ (Ce)	1045,02 (9)	0,020 (3)	[E1]	0,000676 (20)	0,000084 (2)	0,000022	0,000782 (23)	
$\gamma_{14,2}$ (Ce)	1097,58 (9)	0,023 (5)	[E2]	0,00143 (3)	0,00019 (1)	0,00005	0,00167 (5)	
$\gamma_{13,1}$ (Ce)	1303,35 (7)	0,045 (4)	[M1,E2,E0]	0,0012 (2)	0,00016 (1)		0,00140 (23)	
$\gamma_{14,1}$ (Ce)	1404,67 (9)	0,062 (5)	M1,E2	0,00108 (3)	0,00017 (1)		0,00125 (4)	
$\gamma_{1,0}$ (Ce)	1596,213 (13)	95,49 (8)	E2	0,00068 (2)	0,00009	0,00002	0,00079 (2)	1,06 (1)
$\gamma_{18,1}$ (Ce)	1877,34 (18)	0,041 (3)	[E1]	0,000247 (8)	0,000038 (1)		0,000285 (8)	
$\gamma_{2,0}$ (Ce)	1903,29 (4)	0,0146 (15)	E0					
$\gamma_{19,1}$ (Ce)	1924,5 (2)	0,011 (3)	[E2]	0,00481 (15)	0,000072 (2)		0,000553 (16)	
$\gamma_{3,0}$ (Ce)	2083,236 (14)	0,036 (7)	E4	0,00117 (4)	0,00020 (1)		0,00137 (4)	
$\gamma_{5,0}$ (Ce)	2347,868 (14)	0,845 (7)	E2	0,000335 (10)	0,000050 (2)		0,000385 (11)	
$\gamma_{8,0}$ (Ce)	2464,054 (20)	0,0097 (13)	[E3]	0,00044	0,00007		0,00051	
$\gamma_{11,0}$ (Ce)	2521,410 (14)	3,413 (24)	E2	0,000295 (9)	0,000042 (1)		0,000337 (10)	
$\gamma_{12,0}$ (Ce)	2547,200 (23)	0,1017 (12)	M1	0,000327 (10)	0,000052 (2)		0,000379 (11)	
$\gamma_{13,0}$ (Ce)	2899,56 (7)	0,0660 (6)	E2	0,000232 (7)	0,000032 (1)		0,000264 (80)	
$\gamma_{15,0}$ (Ce)	3118,53 (10)	0,0256 (5)	(E2)	0,000205 (6)	0,000026 (1)		0,000231 (7)	
$\gamma_{16,0}$ (Ce)	3319,56 (24)	0,00392 (18)	(E2)	0,000184 (5)	0,000024 (1)		0,000208 (6)	

3 Atomic Data

3.1 Ce

ω_K	:	0,910	(4)
$\bar{\omega}_L$	:	0,125	(5)
n_{KL}	:	0,876	(4)
\bar{n}_{LM}	:	1,57	(3)

3.1.1 X Radiations

	Energy keV	Relative probability		
X_K	$K\alpha_2$	34,2793	54,6	
	$K\alpha_1$	34,72	100	
	$K\beta_3$	39,1705	}	
	$K\beta_1$	39,2578	}	
	$K\beta_5''$	39,549	}	30,31
	$K\beta_2$	40,233	}	
	$K\beta_4$	40,337	}	9,8

4 Electron Emissions

	Energy keV	Electrons per 100 disint.
$ec_{4,3} L$	(Ce) 18,046 - 18,872	0,39 (2)
$ec_{4,3} M$	(Ce) 23,16 - 23,41	0,081 (5)
$ec_{7,5} K$	(Ce) 23,686 (4)	0,052 (6)
$ec_{9,7} K$	(Ce) 28,480 (5)	0,232 (9)
$ec_{11,7} K$	(Ce) 68,974 (4)	0,173 (7)
$ec_{9,6} K$	(Ce) 90,678 (4)	0,225 (9)
$ec_{7,3} K$	(Ce) 288,318 (4)	0,80 (3)
$ec_{7,3} L$	(Ce) 322,212 - 322,597	0,100 (4)
$ec_{10,3} K$	(Ce) 392,070 (8)	0,055 (3)
$ec_{3,1} K$	(Ce) 446,579 (6)	0,447 (14)
$ec_{3,1} L$	(Ce) 480,473 - 481,299	0,071 (2)
$ec_{7,1} K$	(Ce) 775,341 (6)	0,100 (3)
$ec_{1,0} K$	(Ce) 1555,760 (13)	0,065 (2)
$\beta_{0,19}^-$	max: 241,1 (19)	0,0102 (13)
$\beta_{0,19}^-$	avg: 67,1 (6)	
$\beta_{0,18}^-$	max: 288,3 (19)	0,051 (4)
$\beta_{0,18}^-$	avg: 81,7 (8)	
$\beta_{0,17}^-$	max: 367,1 (10)	0,019 (3)
$\beta_{0,17}^-$	avg: 107,1 (7)	
$\beta_{0,16}^-$	max: 442,3 (20)	0,00392 (19)
$\beta_{0,16}^-$	avg: 132,4 (7)	
$\beta_{0,15}^-$	max: 643,4 (19)	0,0256 (5)
$\beta_{0,15}^-$	avg: 204,1 (7)	

		Energy keV		Electrons per 100 disint.
$\beta_{0,14}^-$	max:	761,0	(19)	0,084 (6)
$\beta_{0,14}^-$	avg:	248,4	(8)	
$\beta_{0,13}^-$	max:	862,2	(19)	0,111 (4)
$\beta_{0,13}^-$	avg:	287,8	(8)	
$\beta_{0,12}^-$	max:	1214,7	(19)	0,635 (5)
$\beta_{0,12}^-$	avg:	438,9	(8)	
$\beta_{0,11}^-$	max:	1240,5	(19)	11,12 (6)
$\beta_{0,11}^-$	avg:	441,9	(8)	
$\beta_{0,10}^-$	max:	1246,2	(19)	5,79 (3)
$\beta_{0,10}^-$	avg:	444,3	(8)	
$\beta_{0,9}^-$	max:	1281,0	(19)	1,15 (3)
$\beta_{0,9}^-$	avg:	458,9	(8)	
$\beta_{0,8}^-$	max:	1297,8	(19)	5,59 (3)
$\beta_{0,8}^-$	avg:	466,1	(8)	
$\beta_{0,7}^-$	max:	1349,9	(19)	44,9 (4)
$\beta_{0,7}^-$	avg:	488,1	(8)	
$\beta_{0,6}^-$	max:	1412,1	(19)	0,25 (3)
$\beta_{0,6}^-$	avg:	519,3	(8)	
$\beta_{0,5}^-$	max:	1414,0	(19)	5,03 (4)
$\beta_{0,5}^-$	avg:	515,5	(9)	
$\beta_{0,3}^-$	max:	1678,7	(19)	20,7 (20)
$\beta_{0,3}^-$	avg:	630,2	(9)	
$\beta_{0,1}^-$	max:	2165,7	(19)	4,5 (20)
$\beta_{0,1}^-$	avg:	846,9	(9)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XK α_2	(Ce)	34,2793		0,60 (1)	} K α
XK α_1	(Ce)	34,72		1,11 (2)	
XK β_3	(Ce)	39,1705	}	0,301 (13)	K' β_1
XK β_1	(Ce)	39,2578	}		
XK β_5''	(Ce)	39,549	}		
XK β_2	(Ce)	40,233	}	0,098 (2)	K' β_2
XK β_4	(Ce)	40,337	}		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{4,3}(\text{Ce})$	24,595 (4)	0,001
$\gamma_{7,5}(\text{Ce})$	64,129 (4)	0,0139 (17)
$\gamma_{9,7}(\text{Ce})$	68,923 (5)	0,0769 (18)
$\gamma_{11,7}(\text{Ce})$	109,417 (4)	0,217 (6)
$\gamma_{9,6}(\text{Ce})$	131,121 (4)	0,469 (14)
$\gamma_{11,5}(\text{Ce})$	173,546 (5)	0,126 (5)
$\gamma_{6,4}(\text{Ce})$	241,959 (6)	0,436 (10)
$\gamma_{6,3}(\text{Ce})$	266,554 (5)	0,492 (9)
$\gamma_{2,1}(\text{Ce})$	307,08 (4)	0,022 (3)
$\gamma_{7,3}(\text{Ce})$	328,761 (4)	20,8 (3)
$\gamma_{9,3}(\text{Ce})$	397,674 (6)	0,0748 (24)
$\gamma_{10,3}(\text{Ce})$	432,513 (8)	2,995 (16)
$\gamma_{11,3}(\text{Ce})$	438,178 (6)	0,017 (10)
$\gamma_{5,2}(\text{Ce})$	444,57 (4)	0,0033 (7)
$\gamma_{3,1}(\text{Ce})$	487,022 (6)	46,1 (4)
$\gamma_{11,2}(\text{Ce})$	618,12 (4)	0,041 (3)
$\gamma_{5,1}(\text{Ce})$	751,653 (7)	4,392 (24)
$\gamma_{7,1}(\text{Ce})$	815,781 (6)	23,72 (12)
$\gamma_{8,1}(\text{Ce})$	867,839 (16)	5,58 (3)
$\gamma_{10,1}(\text{Ce})$	919,533 (10)	2,730 (23)
$\gamma_{11,1}(\text{Ce})$	925,198 (7)	7,04 (4)
$\gamma_{12,1}(\text{Ce})$	950,988 (20)	0,531 (5)
$\gamma_{18,9}(\text{Ce})$	992,64 (18)	0,0100 (25)
$\gamma_{17,6}(\text{Ce})$	1045,02 (9)	0,020 (3)
$\gamma_{14,2}(\text{Ce})$	1097,58 (9)	0,023 (5)
$\gamma_{13,1}(\text{Ce})$	1303,34 (7)	0,045 (4)
$\gamma_{14,1}(\text{Ce})$	1404,66 (9)	0,062 (5)
$\gamma_{1,0}(\text{Ce})$	1596,203 (13)	95,40 (8)
$\gamma_{18,1}(\text{Ce})$	1877,33 (18)	0,041 (3)
$\gamma_{19,1}(\text{Ce})$	1924,5 (2)	0,011 (3)
$\gamma_{3,0}(\text{Ce})$	2083,219 (14)	0,036 (7)
$\gamma_{5,0}(\text{Ce})$	2347,847 (14)	0,845 (7)
$\gamma_{8,0}(\text{Ce})$	2464,031 (20)	0,0097 (13)
$\gamma_{11,0}(\text{Ce})$	2521,390 (14)	3,412 (24)
$\gamma_{12,0}(\text{Ce})$	2547,180 (23)	0,1017 (12)
$\gamma_{13,0}(\text{Ce})$	2899,53 (7)	0,0660 (6)
$\gamma_{15,0}(\text{Ce})$	3118,49 (10)	0,0256 (5)
$\gamma_{16,0}(\text{Ce})$	3319,52 (24)	0,00392 (18)

6 Main Production Modes

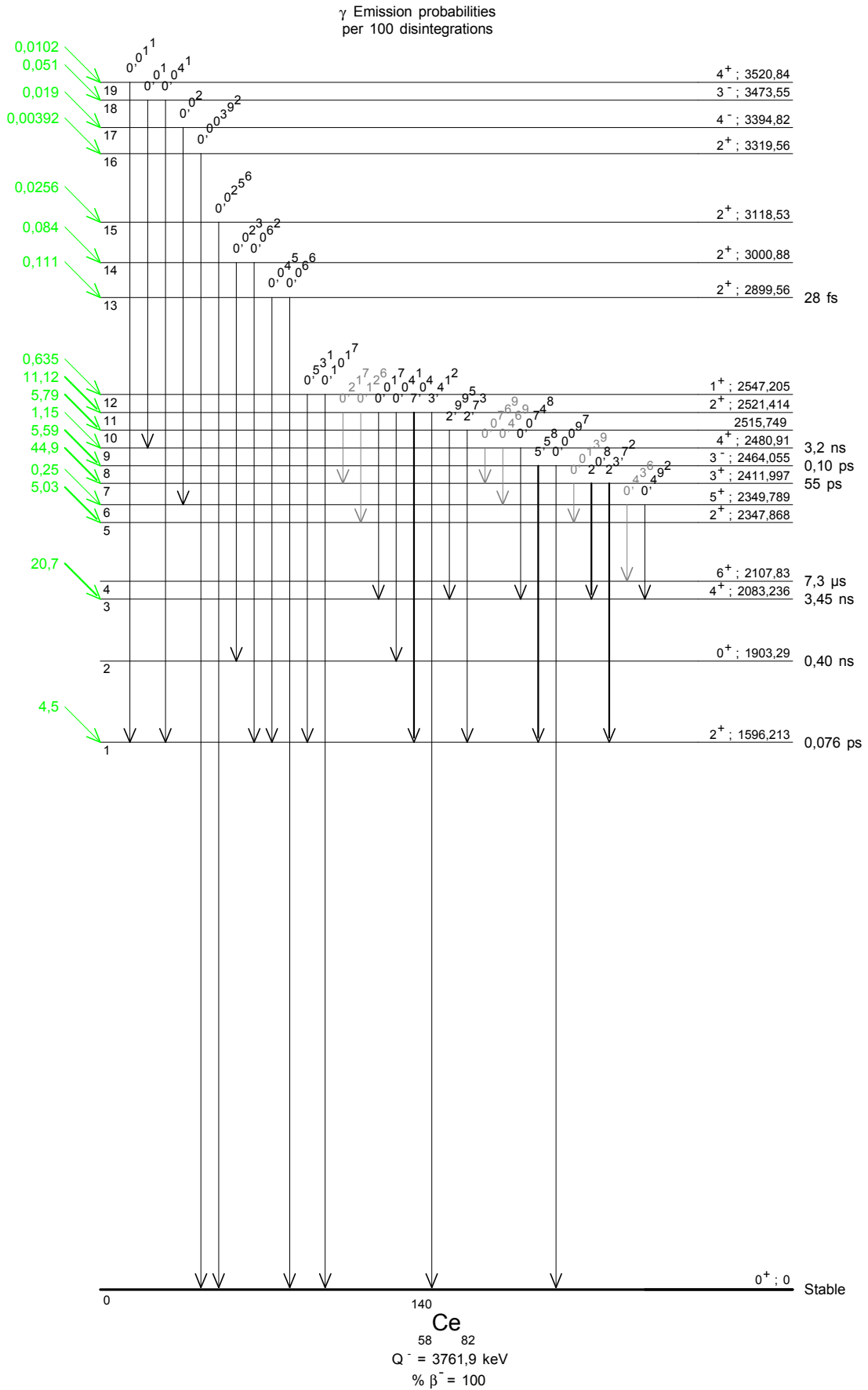
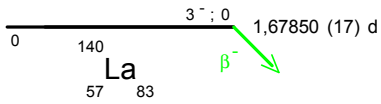
- { Separate from Ba – 140 + La – 140
- { Possible impurities : Ba – 140

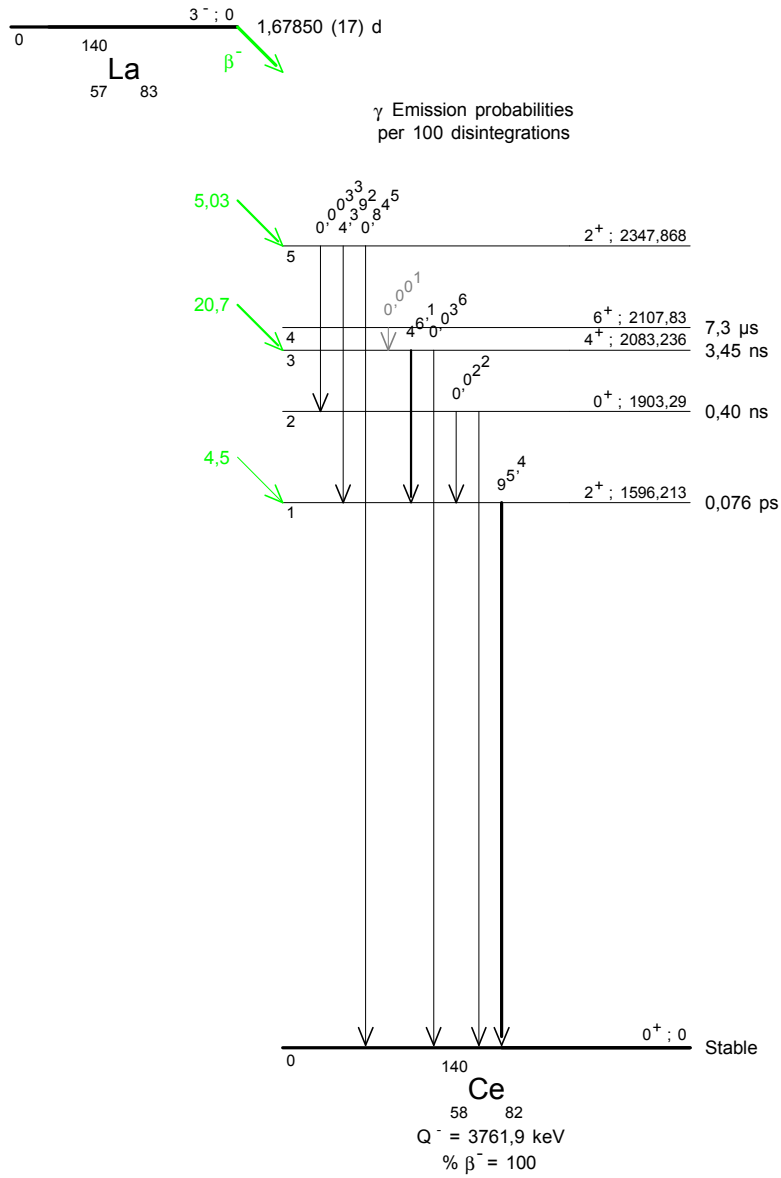
- { La – 139(n, γ)La – 140 σ : 8,93 (4) barns
- { Possible impurities : La – 141

7 References

- H. W. KIRBY, M. L. SALUTSKY. Phys. Rev. 93 (1954) 1051
(Half-life)
- L. YAFFE, H. G. THODE, W. F. MERRITT, R. C. HAWKINGS, F. BROWN, R. M. BARTHOLOMEW. Can. J. Chem. 32 (1954) 1017
(Half-life)
- D. F. PEPPARD, G. W. MASON, S. W. MOLINE. J. Inorg. Nuclear Chem. 5 (1957) 141
(Half-life)
- S. F. ANTONOVA, S. S. VASILENKO, M. G. KAGANSKII, D. L. KAMINSKII. Soviet Phys. JETP 11 (1960) 554
(Gamma-ray emission intensities)
- R. G. WILLE, R. W. FINK. Phys. Rev. 118 (1960) 242
(Half-life)
- P. G. HANSEN, K. WILSKY. Nucl. Phys. 30 (1962) 405
(Gamma-ray emission intensities)
- J. J. REIDY. report TID-21826 (1964)
(Gamma ray energies)
- P. SIMONET, G. BOILE, G. SIMONET. Report CEA-R-2461 (1965)
(Half-life)
- G. I. HARRIS, D. V. BREITENBECHER. Phys. Rev. 145 (1966) 866
(Gamma-ray emission intensities)
- H. W. BAER, J. J. REIDY, M. L. WIEDENBECK. Nucl. Phys. 86 (1966) 332
(Gamma ray energies)
- S.-E. KARLSSON, B. SVAHN, H. PETTERSSON, G. MALMSTEN, E. Y. DE AISENBERG. Nucl. Phys. A100 (1967) 113
(Gamma-ray energies and emission intensities)
- B. S. DZELEPOV, N. N. ZHUKOVSKII, A. G. MALOYAN, V. P. PRIKHODTSEVA. Bull. Acad. Sci. USSR, Phys. Ser. 30 (1967) 410
(Gamma-ray emission intensities)
- A. REYNOLDS, J. F. EMERY, E. I. WYATT. Nucl. Sci. Eng. 32 (1968) 46
(Half-life)
- W. BAER, J. J. REIDY, M. L. WIEDENBECK. Nucl. Phys. A113 (1968) 33
(Gamma-ray energies and emission intensities)
- R. GUNNINK, R. A. MEYER, J. B. NIDAY, R. P. ANDERSON. Nucl. Instr. Methods 65 (1968) 26
(Gamma ray energies)
- N. BELYAEV, S. S. VASILENKO, V. S. GVOZDEV. Soviet J. Nucl. Phys. 8 (1969) 135
(Internal-pair formation coefficient)
- R. GUNNINK, J. B. NIDAY, R. P. ANDERSON, R. A. MEYER. Report UCID-15439 (1969)
(Gamma-ray emission intensities)
- J. KERN. Nucl. Instr. Methods 79 (1970) 233
(Gamma ray energies)
- G. KALINNIKOV, H. L. RAVN, H. G. HANSEN, N. A. LEBEDEV. Bull. Acad. Sci. USSR, Phys. Ser. 34 (1971) 815
(Gamma-ray energies and emission intensities)
- R. J. GEHRKE. Report ANCR-1088 (1972) 392
(Gamma energy)
- R. L. HEATH. Report ANCR-1000-2 (1974)
(Gamma-ray emission intensities)
- J. T. HARVEY, J. L. MEASON, J. C. HOGAN, H. L. WRIGHT. Nucl. Sci. Eng. 58 (1975) 431
(Gamma-ray emission intensities)

- I. M. BAND, M. B. TRZHASKOVSKAYA, M. A. LISTENGARTEN. Atomic Data Nucl. Data Tables 18 (1976) 433 (ICC)
- C.-C. LIN. J. Inorg. Nucl. Chem. 38 (1976) 1409 (Gamma-ray emission intensities)
- K. DEBERTIN, U. SCHÖTZIG, K. F. WALZ. Nucl. Sci. Eng. 64 (1977) 784 (Gamma-ray emission intensities)
- K. DEBERTIN, U. SCHÖTZIG AND K. F. WALZ. INDC Ger-10/L+Special (1977) 83 (Half-life)
- R. J. GEHRKE, R. G. HELMER, R. C. GREENWOOD. Nucl. Instrum. Methods 147 (1977) 405 (Gamma-ray emission intensities)
- G. ARDISSON. Nucl. Instr. Methods 151 (1978) 505 (Gamma-ray energies and emission intensities)
- M. C. DAVIS, W. C. BOWMAN, J. C. ROBERTSON. Int. J. Appl. Radiat. Isotop. 29 (1978) 331 (Half-life)
- F. RÖSEL, H. M. FRIES, K. ALDER, H. C. PAULI. Atomic Data Nucl. Data Tables 21 (1978) 269 (ICC)
- H. G. BÖRNER, W. F. DAVIDSON, J. ALMEIDA, J. BLACHOT, J. A. PINSTON, P. H. M. VAN ASSCHE. Nucl. Instr. Methods 164 (1979) 579 (Gamma ray energies)
- P. SCHLÜTER, G. SOFF. Atomic Data Nucl. Data Tables 24 (1979) 509 (Internal-pair formation coefficient)
- R. KAUR, A. K. SHARMA, S. S. SOOCH, P. N. TREHAN. J. Phys. Soc. Japan. 49 (1980) 2122 (Gamma-ray energies and emission intensities)
- J. B. OLOMO, T. D. MACMAHON. J. Phys. London G6 (1980) 367 (Half-life)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153 (Half-life)
- I. ADAM, N. M. ANTONEVA, V. B. BRUDANIN, M. BUDZYNSKI, TS. VYLOV, V. A. DZHASHI, A. ZHUMAMURATOV, A. I. IVANOV, V. G. KALINNIKOV, A. KUGLER, V. V. KUZNETSOV, LI ZON SIK, T. M. MUMINOV, A. F. NOVGORODOV, YU. N. Izv. Akad. Nauk SSSR, Ser. Fiz. 46 (1982) 2 (Gamma energy and probability)
- D. D. HOPPE, J. M. R. HUTCHINSON, F. J. SCHIMA, M. P. UNTERWEGER. Report NBS-SP-626 (1982) 85 (Half-life)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191 (Half-life)
- A. ABZOUZI, M. S. ANTONY, V. B. NDOCKO NDONGUE. J. Radioanal. Nucl. Chem. 137 (1989) 381 (Half-life)
- B. CHAND, J. GOSWAMY, D. MEHTA, N. SINGH, P. N. TREHAN. Can. J. Phys. 69 (1991) 90 (Gamma probability)
- M. P. UNTERWEGER, D. D. HOPPE, F. J. SCHIMA. Nucl. Instr. Methods Phys. Res. A312 (1992) 349 (Half-life)
- L. K. PEKER. Nucl. Data Sheets 73 (1994) 261 (Multipolarities, Spin and Parity)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409 (Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instr. Methods Phys. Res. A 369 (1996) 527 (Fluorescence yields)
- B. SINGH, J. L. RODRIGUEZ, S. S. M. WONG, J. K. TULI. Nucl. Data Sheets 84 (1998) 565 (log ft systematics)
- E. SCHÖNFELD, H. JANSSEN. Report PTB-6.11 1999-1 (1999) (PX)





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Table of Radionuclides (Vol. 2 - $A = 151$ to 242)

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Preface

This monograph is one of several published in a series by the Bureau International des Poids et Mesures (BIPM) on behalf of the *Comité Consultatif des Rayonnements Ionisants* (CCRI), previously known as the *Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants* (CCEMRI). The aim of this series of publications is to review topics that are of importance for the measurement of ionizing radiation and especially of radioactivity, in particular those techniques normally used by participants in international comparisons. It is hoped that these publications will prove to be useful reference volumes both for those who are already engaged in this field and for those who are approaching such measurements for the first time.

The purpose of this monograph, number 5 in the series, is to present the recommended values of nuclear and decay data for a set of sixty-eight radionuclides. Activity measurements for thirty-two of these radionuclides have already been the subject of comparisons under the auspices of Section II of the CCRI. The material for this monograph will be covered in two volumes. Volume 1 contains the primary recommended data relating to half-lives, decay modes, x-rays, gamma-rays, electron emissions; alpha- and beta-particle transitions and emissions, and their uncertainties for radionuclides with mass number up to and including 150; Volume 2 contains the equivalent data for radionuclides with mass number over 150. The data have been collated and evaluated by an international working group (Decay Data Evaluation Project) led by the BNM-LNHB. The evaluators have agreed on the methodologies to be used and the CD-ROM included with this monograph contains the evaluators' comments for each radionuclide in addition to the data tables included in the monograph.

The work involved in evaluating nuclear data is on-going and the recommended values are updated on the LNHB website at http://www.nucleide.org/DDEP_WG/DDEPdata.htm. The publication of further volumes of Monographie 5 is envisaged as and when necessary to add new radionuclide data or re-evaluations in a more permanent format that can be referenced easily.

Although other data sets may still be used when evaluating radionuclide activity, use of this common, recommended data set should help to reduce the uncertainties in activity evaluations and lead to more coherent results for comparisons.

G. Moscati
President of the CCRI

A.J. Wallard
Director of the BIPM

Note: Following Resolution 10 of the 22nd CGPM in 2003, a decimal point has been used as the decimal marker in the English text but in the data tables, which were edited in French, a decimal comma has been used. There should be no ambiguity in use.

Monographie BIPM-5 - Table of Radionuclides, Vol. 2 (A = 151 to 242)

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“TABLE DE RADIONUCLÉIDES”

Sommaire - Ce volume regroupe l'évaluation des radionucléides suivants :

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^{\text{m}}$, ^{99}Mo , $^{99}\text{Tc}^{\text{m}}$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^{\text{m}}$, ^{123}I , $^{123}\text{Te}^{\text{m}}$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^{\text{m}}$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^{\text{m}}$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

Les valeurs recommandées et les incertitudes associées comprennent : la période radioactive, les modes de décroissance, les émissions α , β , γ , X et électroniques ainsi que les caractéristiques des transitions correspondantes.

“TABLE OF RADIONUCLIDES”

Summary - This volume includes the evaluation of the following radionuclides :

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^{\text{m}}$, ^{99}Mo , $^{99}\text{Tc}^{\text{m}}$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^{\text{m}}$, ^{123}I , $^{123}\text{Te}^{\text{m}}$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^{\text{m}}$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^{\text{m}}$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

Primary recommended data comprise half-lives, decay modes, X-rays, gamma-rays, electron emissions, alpha- and beta-particle transitions and emissions, and their uncertainties.

“TABELLE DER RADIONUKLIDE”

Zusammenfassung

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^{\text{m}}$, ^{99}Mo , $^{99}\text{Tc}^{\text{m}}$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^{\text{m}}$, ^{123}I , $^{123}\text{Te}^{\text{m}}$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^{\text{m}}$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^{\text{m}}$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

In diesem Bericht sind evaluierte Werte der Halbwertszeiten, Übergangswahrscheinlichkeiten und Übergangsenergien von α , β^- , β^+ , EC- und Gammaübergängen, Konversionskoeffizienten von Gammaübergängen, Emissionswahrscheinlichkeiten von Röntgen- und Gammaquanten, Auger- und Konversions-elektronen.

“TABLA DE RADIONUCLEIDOS”

Prólogo – Este volumen agrupa la evaluación de los radionucleidos siguientes :

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^m$, ^{99}Mo , $^{99}\text{Tc}^m$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^m$, ^{123}I , $^{123}\text{Te}^m$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^m$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^m$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

Los valores recomendados y las incertidumbres asociadas comprenden : el período radioactivo, los modos de desintegración, las emisiones α , β , γ , X y electrónicas incluyendo las características de las transiciones correspondientes.

TABLE DE RADIONUCLÉIDES
TABLE OF RADIONUCLIDES
TABELLE DER RADIONUKLIDE
ТАБЛИЦА РАДИОНУКЛИДОВ
TABLA DE RADIONUCLEIDOS

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TABLE DE RADIONUCLÉIDES

INTRODUCTION

Le Laboratoire National Henri Becquerel (LNHB) a commencé l'étude des données nucléaires et atomiques qui caractérisent la décroissance des radionucléides en 1974. Ces évaluations ont fait l'objet de la publication des quatre volumes de la Table de Radionucléides [87Ta, 99Be]. Ce nouveau volume s'inscrit dans la continuation du travail précédent.

D'autre part, pour des raisons évidentes, telles la facilité de mise à jour des données ou la commodité de consultation pour les utilisateurs, le LNHB a créé une base de données informatisée. Le logiciel NUCLEIDE est la forme informatisée de cette table, il permet un accès aisé aux différentes informations à l'aide de menus déroulants atteints par un simple « clic » sur un « bouton ».

Le propos de la Table est d'étudier un nombre limité de radionucléides utiles dans le domaine de la métrologie ou dans des domaines variés d'applications (médecine nucléaire, environnement, cycle du combustible, etc.) et d'en présenter une étude complète.

Les données recommandées comprennent : la période radioactive, les modes de décroissance, les émissions α , β , γ , X et électroniques ainsi que les caractéristiques des transitions associées.

Dans le but de mettre à jour et d'ajouter de nouvelles évaluations plus rapidement le Laboratoire National Henri Becquerel (LNHB, France) et le Physikalisch - Technische Bundesanstalt (PTB, Allemagne) ont établi un accord de coopération. Ils ont ensuite été rejoints par Idaho National Engineering and Environmental Laboratory (INEEL, États-Unis), Lawrence Berkeley National Laboratory (LBNL, États-Unis) et Khlopin Radium Institute (KRI, Russie). Le premier travail de cette collaboration internationale a été d'établir une méthode et des règles communes d'évaluation. Les évaluations proposent des valeurs recommandées et leurs incertitudes. Ces valeurs ont été évaluées à partir des données expérimentales disponibles. A défaut, elles sont issues de calculs théoriques. Toutes les références utilisées pour l'évaluation d'un radionucléide sont listées à la fin de chaque chapitre.

VALEURS RECOMMANDÉES ET INCERTITUDES

Les principales étapes pour l'évaluation des données et leurs incertitudes sont :

- une analyse critique de toutes les publications disponibles afin de retenir ou non une valeur et son incertitude, ramenée à l'incertitude-type composée ;
- la détermination d'une valeur recommandée qui est, selon les cas, une moyenne simple ou pondérée des valeurs issues des publications, ceci est décidé après examen du chi carré réduit. Dans le cas d'une moyenne pondérée, le poids relatif de chaque valeur est limité à 50 %. L'incertitude, notée uc , est la plus grande des valeurs des incertitudes interne ou externe ; dans le cas de valeurs incompatibles elle peut être étendue pour recouvrir la valeur la plus précise.

Pour certaines applications il est nécessaire de définir une incertitude élargie, notée U , telle que :

$$U(y) = k \cdot uc(y) \quad \text{où } k \text{ est le facteur d'élargissement.}$$

La valeur de k retenue pour cette publication est : $k = 1$.

Les valeurs d'incertitude indiquées portent sur les derniers chiffres significatifs, ainsi :

$$\begin{array}{ll} 9,230 (11) \text{ signifie} & 9,230 \pm 0,011 \text{ et} \\ 9,2 (11) & 9,2 \pm 1,1 \end{array}$$

Si une valeur est donnée sans incertitude, cela signifie qu'elle est considérée comme douteuse. Elle est indiquée à titre indicatif et souvent a été estimée en fonction du schéma de désintégration comme étant « de l'ordre de ».

Des précisions concernant les techniques d'évaluation peuvent être obtenues dans les références [85Zi], [96He], [99In] (voir rubrique Références) ou directement auprès des auteurs.

La description physique des données évaluées est disponible dans la référence [99In].

NUMÉROTAGE

Les niveaux d'un noyau sont numérotés, arbitrairement, de 0 pour le niveau fondamental à n pour le n ème niveau excité. Les diverses transitions sont ainsi repérées par leur niveau de départ et leur niveau d'arrivée.

Dans le cas de transition de faible probabilité qu'il n'est pas possible de situer sur le schéma de désintégration, les niveaux de départ et d'arrivée sont notés $(-1, n)$.

Dans le cas de l'émission gamma de 511 keV qui suit une désintégration bêta plus, la notation adoptée est : $(-1, -1)$.

UNITÉS

Les valeurs recommandées sont exprimées :

- pour les périodes

	Symbole
. en secondes pour $T_{1/2} \leq 60$ secondes	s
. en minutes pour $T_{1/2} > 60$ secondes	min
. en heures pour $T_{1/2} > 60$ minutes	h
. en jours pour $T_{1/2} > 24$ heures	d
. en années pour $T_{1/2} > 365$ jours	a

1 année = 365,242 198 jours = 31 556 926 secondes ;

- pour les probabilités de transition et nombre de particules émises, les valeurs sont données pour 100 désintégrations ;

- les énergies sont exprimées en keV.

AVERTISSEMENT

Ce document a été imprimé en 2004, pour toutes les nouvelles évaluations et mises à jour ultérieures le lecteur se référera aux documents accessibles sur :

<http://www.nucleide.org/NucData.htm>

TABLE OF RADIONUCLIDES

INTRODUCTION

The evaluation of decay data for the "Table de Radionucléides" by BNM – LNHB/CEA began in 1974, continued to 1987 and four volumes were published [87Ta] and then, in 1999, the fifth volume was published containing the revised evaluations for 30 selected radionuclides [99Be].

Moreover, LNHB developed a software (NUCLEIDE) with the objectives of making it easier to update and add data and, obviously, to offer easy access to the nuclear and atomic decay data to the user by "click on the button" facilities.

The aim of this Table is to provide recommended data for nuclides of special interest for metrology or practical applications like nuclear medicine, monitoring and reactor shielding, etc.

Primary recommended data comprise half-lives, decay modes, X-rays, gamma-rays, electron emissions, alpha- and beta-particle transitions and emissions, and their uncertainties. All the references used for the evaluations are given.

In order to update the data of the nuclides already present and to add new evaluations, the Laboratoire National Henri Becquerel (LNHB, France) and the Physikalisch-Technische Bundesanstalt (PTB, Germany) established a cooperative agreement ; they were then joined by the Idaho National Engineering and Environmental Laboratory (INEEL, USA), the Lawrence Berkeley National Laboratory (LBNL, USA) and the Khlopin Radium Institute (KRI, Russia). This international collaboration is based on an informal agreement, the initial work of this group was to discuss and to agree on a methodology to be used in these evaluations. The data and associated uncertainties were evaluated from all available experiments and taking into account theoretical considerations.

RECOMMENDED VALUES AND UNCERTAINTIES

The main steps for the evaluation of the data and their uncertainties are :

- a critical analysis of all available original publications in order to accept or not each value and its uncertainty reduced to the combined standard uncertainty ;
- the determination of the best value which is either the weighted or the unweighted average of the retained values, this is decided after examination of the reduced χ^2 value. With a weighted average, each weight is limited to 50 %. The uncertainty, designated uc , is the greatest of the internal or external uncertainty values. For a discrepant set of data, it may be expanded to cover the most precise input value.

For some applications it may be necessary to define an expanded uncertainty, designated U , as :

$$U(y) = k.uc(y) \quad \text{where } k \text{ is the coverage factor.}$$

For this publication the expanded uncertainty is computed with $k = 1$.

The value of the uncertainty, in parentheses, referred to the corresponding last digits, i.e. :

$$9.230 (11) \text{ means } 9.230 \pm 0.011 \text{ and}$$

$$9.2 (11) \quad 9.2 \pm 1.1$$

If a value is given without an uncertainty, this means that this value is considered as questionable. It is provided for information and was often estimated from the decay scheme as to be "in the order of".

Information about evaluation procedures can be obtained from references [85Zi, 96He, 99In] or directly from the authors.

Information about meaning of physical data can be obtained from reference [99In].

NUMBERING

The nuclear levels are arbitrarily numbered from 0 for the ground state level to n for the n th excited level. All the transitions are designated by their initial and final level.

For transitions with weak probabilities which are not shown by an arrow in the decay scheme, the initial and final levels are noted $(-1, n)$.

For the 511 keV gamma emission which follows the beta plus disintegration, the adopted numbering is $(-1, -1)$.

UNITS

The recommended values are expressed :

- for half-lives :

	Symbol
. in seconds for $T_{1/2} \leq 60$ seconds	s
. in minutes for $T_{1/2} > 60$ seconds	min
. in hours for $T_{1/2} > 60$ minutes	h
. in days for $T_{1/2} > 24$ hours	d
. in years for $T_{1/2} > 365$ days	a

1 year = 365.242 198 days = 31 556 926 seconds

- for transition probabilities and number of emitted particles, the values are given for 100 disintegrations ;

- for energies the values are expressed in keV.

CAUTION

This report was printed in 2004, new evaluations and updated issues will be available on :

<http://www.nucleide.org/NucData.htm>

TABELLE DER RADIONUKLIDE

EINLEITUNG

Die Evaluation der Zerfallsdaten für die Table de Radionucléides durch das BNM-LNHB/CEA begann im Jahre 1974, diese Arbeit wurde bis 1987 fortgesetzt, und es wurden vier Bände veröffentlicht [87Ta, 99Be]. Dieser neue Bericht kommt hinzu dem vorhergehend Arbeit.

Übrigens wurde ein Computerform der Table de Radionucléides im LNHB entwickelt. Diese Software erleichtert die Aktualisierung und die Einbeziehung weiterer Daten und ermöglicht den Zugang zu den Kern- und Atomdaten für den Anwender auf „Tastendruck“.

Der Zweck dieser Tabelle ist es, empfohlene Daten einer begrenzten Anzahl von Radionukliden für metrologische und praktische Anwendungen wie etwa in der Nuklearmedizin, der Umgebungsüberwachung, der Reaktorabschirmung usw. zur Verfügung zu stellen.

Die Datenbank umfaßt empfohlene Daten und ihre Unsicherheiten, die aus den verfügbaren Daten oder theoretischen Berechnungen gewonnen worden sind. Alle für die Evaluation benutzten Referenzen werden angegeben.

Um die schon vorliegenden Daten zu aktualisieren und neue Evaluationen schneller einbeziehen zu können, vereinbarten das Laboratoire National Henri Becquerel (LNHB, Frankreich) und die Physikalisch-Technische Bundesanstalt (PTB, Deutschland) einen Vertrag zur Zusammenarbeit. Es schlossen sich das Idaho National Engineering and Environmental Laboratory (INEEL, USA), das Lawrence Berkeley National Laboratory (LBNL, USA) und das Khlopin Radium Institut (KRI, Rußland) an. Eine der ersten Arbeiten dieser Gruppe war es, die in diesen Evaluationen benutzte Methodologie zu diskutieren und festzulegen.

EMPFOHLENE WERTE UND UNSICHERHEITEN

Die Hauptschritte für die Evaluation der Daten und Unsicherheiten sind:

- Eine kritische Analyse aller verfügbaren Veröffentlichungen, um einen Wert und seine Unsicherheit
- auf die kombinierte Standardunsicherheit zurückgeführt - zu berücksichtigen.
- Die Bestimmung eines empfohlenen Wertes, der entweder das gewichtete oder das ungewichtete Mittel der veröffentlichten Werte ist. Die Entscheidung wird nach der Prüfung des reduzierten Chi-Quadrat-Werts getroffen. Im Falle des gewichteten Mittels wird ein Gewicht, das größer ist als 50 %, auf 50 % reduziert. Die Unsicherheit, als *uc* bezeichnet, ist der größere Wert der inneren oder äußeren Unsicherheit. Für einen diskrepanten Datensatz ist sie so zu vergrößern, daß der genaueste Einzelwert in der Unsicherheit mit eingeschlossen ist.

Für einige Anwendungen ist es notwendig, eine vergrößerte Unsicherheit, als *U* bezeichnet, wie folgt zu definieren:

$$U(y) = k \cdot uc(y) \quad \text{wo } k \text{ der Erweiterungsfaktor ist.}$$

Für die vorliegende Veröffentlichung ist die erweiterte Unsicherheit mit $k = 1$ berechnet.

Die Werte der Unsicherheit beziehen sich auf die letzten Stellen, d. h.:

9,230(11) bedeutet $9,230 \pm 0,011$ und

9,2(11) bedeutet $9,2 \pm 1,1$

Wenn ein Wert ohne Unsicherheit angegeben ist, bedeutet das, daß dieser Wert als fragwürdig zu betrachten ist. Er wird zur Information mitgeteilt und ist oft abgeschätzt aus dem Zerfallsschema im Sinne „in der Größenordnung von“.

Informationen über die Evaluationsprozedur können aus den Referenzen [85Zi, 96He, 99In] oder direkt von den Autoren bezogen werden.

NUMERIERUNG

Die Kernniveaus werden willkürlich numeriert von 0 für den Grundzustand bis zu n für das n -te angeregte Niveau. Alle Übergänge werden durch ihr Ausgangs- und Endniveau gekennzeichnet. Für Übergänge mit geringen Wahrscheinlichkeiten, die nicht durch einen Pfeil im Zerfallsschema gezeigt sind, werden das Ausgangs- und Endniveau notiert. $(-1, n)$

Für die 511 keV-Gamma-Emission, die dem Beta Plus-Zerfall folgt, ist die angenommene Numerierung $(-1, -1)$.

EINHEITEN

Die empfohlenen Werte sind ausgedrückt:

- für Halbwertszeiten:

	Symbol
. in Sekunden für $T_{1/2} \leq 60$ Sekunden	s
. in Minuten für $T_{1/2} > 60$ Sekunden	min
. in Stunden für $T_{1/2} > 60$ Minuten	h
. in Tagen für $T_{1/2} > 24$ Stunden	d
. in Jahren für $T_{1/2} > 365$ Tage	a

$$1 \text{ a} = 365,242 \text{ 198 d} = 31 \text{ 556 926 s}$$

- für Übergangswahrscheinlichkeiten und die Anzahl der emittierten Teilchen werden Werte angegeben, die sich auf 100 Zerfälle beziehen.

- die Werte der Energien sind in keV ausgedrückt.

HINWEIS

Dieses Dokument wurde im Jahre 2004 erstellt. Alle späteren Fassungen oder neueren Evaluationen können vom Leser unter <http://www.nucleide.org/NucData.htm> abgerufen werden.

ТАБЛИЦА РАДИОНУКЛИДОВ

ВВЕДЕНИЕ

Оценка данных распада для Table de Radionucléides, BNM – LNHB/CEA была начата в 1974 г. и продолжалась до 1987 г. К тому времени были опубликованы четыре тома [87Ta] и затем, в 1999 г., был опубликован пятый том, содержащий ревизованные оценки для 30 выбранных радионуклидов [99Be]. Новое издание находится в русле предыдущей работы.

В дополнение в LNHB была разработана компьютерная форма Table de Radionucléides (программа NUCLEIDE) с тем, чтобы обеспечить более простое обновление и дополнение данных и, очевидно, также с целью предложить пользователю более легкий доступ к ядерным и атомным данным распада путем "нажатия кнопки".

Цель настоящего издания - дать рекомендованные данные для нуклидов, представляющих специфический интерес для метрологии или практических приложений, таких как ядерная медицина, мониторинг, реакторная защита и др.

Первичные рекомендованные данные включают периоды полураспада, виды распада, характеристики X- и гамма-излучений, электронных излучений, альфа- и бета-переходов и излучений и погрешности величин этих характеристик. В книге дан полный список литературы, использованной для оценок.

Для того чтобы обновить данные по нуклидам, уже имеющимся в Table de Radionucléides, и добавить новые оценки, Национальная лаборатория им. Анри Беккереля (LNHB, Франция) и Физико-Технический Институт (PTB, Германия) заключили кооперативное соглашение. К ним затем присоединились Национальная лаборатория прикладных и экологических исследований Айдахо (INEEL, США), Лоуренсовская Национальная Лаборатория Беркли (LBNL, США) и Радиевый институт им. В.Г. Хлопина (KRI, Россия). Это международное сотрудничество основано на неформальном соглашении. Первоначальная работа состояла в обсуждении и принятии согласованной методологии, которая должна быть использована в этих оценках. Данные и связанные с ними погрешности были оценены с использованием всех имеющихся в распоряжении результатов экспериментов и с учетом теоретических рассуждений.

РЕКОМЕНДОВАННЫЕ ЗНАЧЕНИЯ И ПОГРЕШНОСТИ

Основные шаги для оценки данных и их погрешностей следующие:

- критический анализ всех имеющихся оригинальных публикаций, чтобы принять или отвергнуть данное значение и его погрешность, приведенную к комбинированному стандартному отклонению;
- определение лучшего значения, которое является взвешенным или невзвешенным средним сохраненных величин; выбор взвешенного или невзвешенного среднего определяется анализом величины χ^2 . В случае среднего взвешенного вес каждого оригинального результата ограничивается 50 %. В качестве итоговой погрешности (uc) принимается большая из двух погрешностей среднего взвешенного: внутренней и внешней. Для расходящегося набора данных она может быть расширена, чтобы перекрыть самое точное входное значение.

Для некоторых применений может оказаться необходимым расширенная погрешность (U), выраженная как: $U(y)=k.uc(y)$, где k - коэффициент перекрытия. Для этой публикации принято $k=1$.

Значение погрешности, в скобках, приводится в единицах последней значащей цифры, т.е.:

9,230(11) означает $9,230 \pm 0,011$ и
9,2(11) $9,2 \pm 1,1$

Если значение величины дается без погрешности, она считается сомнительной и приводится для информации. Такие величины часто оценивались из схемы распада под рубрикой "порядка".

Информацию о процедурах оценки можно получить из публикаций [85Zi, 96He, 99In] или непосредственно от авторов.

Информация о смысле физических величин может быть получена из [99In].

НУМЕРАЦИЯ

Ядерные уровни произвольно пронумерованы от 0 для основного состояния до n для n -ого возбужденного уровня. Все переходы обозначаются по их начальному и конечному уровням.

Для слабых переходов, не показанных стрелкой в схеме распада, начальный и конечный уровни обозначаются как $(-1, n)$.

Для гамма-излучения с энергией 511 кэВ, которое следует за бета-плюс распадом, принято обозначение $(-1, -1)$.

ЕДИНИЦЫ

Рекомендованные значения выражены:

- для периодов полураспада:
- в секундах для $T_{1/2} \leq 60$ секунд s
- в минутах для $T_{1/2} > 60$ секунд min
- в часах для $T_{1/2} > 60$ минут h
- в сутках для $T_{1/2} > 24$ часов d
- в годах для $T_{1/2} > 365$ суток a

1 год = 365,242 198 суток = 31 556 926 секунд

- для вероятностей переходов и числа испускаемых частиц значения даны на 100 распадов;
- для энергий значения выражены в килоэлектронвольтах (keV).

ПРИМЕЧАНИЕ

Этот отчет подготовлен в 2004 г. Новые оценки и обновленные результаты можно найти на сайте:

<http://www.nucleide.org/NucData.htm>

TABLA DE RADIONUCLEIDOS

INTRODUCCION

El Laboratoire National Henri Becquerel (LNHB) comenzó el estudio de datos nucleares y atómicos que caracterizan la desintegración de radionucleidos en 1974. Esas evaluaciones han permitido la publicación de cuatro volúmenes de la Tabla de radionucleidos [⁸⁷Ta, ⁹⁹Be]. Este nuevo volumen es el siguiente en la continuación del estudio precedente.

Con la idea de facilitar, la corrección de nuevos datos y la comodidad de consulta para los usuarios, el LNHB a creado una base de datos en computadora. El programa NUCLEIDE es el contenido de la Tabla en computadora, que permite el fácil acceso a diferentes informaciones, con la ayuda de menues en cascada accesibles con un simple « clic » sobre una « tecla ».

El objetivo de la Tabla es estudiar un número limitado de radionucleidos útiles en el campo de la metrología u otros campos de aplicación (medicina nuclear, medio ambiente, ciclo del combustible, etc.) y presentar un estudio completo.

Los datos recomendados comprenden : el período radioactivo, los modos de desintegración, las emisiones α , β , γ , X y electrónicas con las características de transiciones asociadas.

Con el propósito de actualizar y agregar nuevas evaluaciones rapidamente el *Laboratoire National Henri Becquerel* (LNHB, Francia) y el *Physikalisch-Technische Bundesanstalt* (PTB , Alemania) establecieron un acuerdo de colaboración. Luego se unieron a este acuerdo el *Idaho National Engineering and Environmental Laboratory* (INEEL, USA), *Lawrence Berkeley National Laboratory* LBNL, USA) y *Khlopin Radium Institute* (KRI, Rusia). El primer trabajo de esta colaboración internacional ha sido de establecer un método y reglas comunes de evaluación. Las evaluaciones proponen valores recomendados e incertidumbres asociadas. Esos valores han sido evaluados a partir de datos experimentales disponibles. En ausencia de éstos últimos, esos valores han sido obtenidos por cálculos teóricos. Todas las referencias utilizadas para la evaluación de un radionucleido son listadas al final de cada capítulo.

VALORES RECOMENDADOS E INCERTIDUMBRES

Las principales etapas para evaluar datos con sus incertidumbres son :

- Un análisis crítico de todas las publicaciones disponibles con el fin de obtener o no un valor con su incertidumbre, considerada como incertidumbre tipo compuesta.
- La determinación de un valor recomendado que es, según el caso, una media simple o ponderada de valores obtenidos de publicaciones, ésto es decidido luego de examinar el chi al cuadrado reducido. En el caso de una media ponderada, el peso relativo de cada valor es limitado a 50 %. La incertidumbre, llamada uc , es el mayor de los valores de incertidumbres interna o externa ; en el caso de valores incompatibles, este valor puede ser extendido con el fin de recubrir el valor más preciso.

Par ciertas aplicaciones, es necesario definir una incertidumbre extendida, llamada U , la cual es :

$$U(y) = k \cdot uc(y) \quad \text{donde } k \text{ es el factor de extensión.}$$

El valor de k retenido en esta publicación es : $k = 1$.

Los valores de incertidumbres indicados entre paréntesis corresponden a las últimas cifras significativas, por ejemplo :

9,230 (11) significa $9,230 \pm 0,011$ y
9,2 (11) significa $9,2 \pm 1,1$

Si un valor es dado sin incertidumbre, significa que ésta es considerada dudosa (es indicada aproximativamente y ha sido estimada a partir del esquema de desintegración).

NUMERACION

Los niveles de un núcleo son numerados de manera arbitraria, de 0 para el nivel fundamental, a n para el n -ésimo nivel excitado. Las diversas transiciones son así señaladas desde el nivel de partida al nivel de llegada.

En el caso de una transición de probabilidad pequeña que es imposible de indicar en el esquema de desintegración, los niveles de partida y de llegada son notificados : $(-1, n)$.

En el caso de una emisión γ de 511 keV que sigue a una desintegración β^+ , la notación adoptada es : $(-1, -1)$.

UNIDADES

Los valores recomendados son expresados :

- para los períodos :

	Símbolo
. en segundos para $T_{1/2} \leq 60$ segundos	s
. en minutos para $T_{1/2} > 60$ segundos	min
. en horas para $T_{1/2} > 60$ minutos	h
. en días para $T_{1/2} > 24$ horas	d
. en años para $T_{1/2} > 365$ días	a

1 año = 365,242 198 días = 31 556 926 segundos ;

- para las probabilidades de transición y número de partículas emitidas, los valores son dados por 100 desintegraciones ;

- para las energías los valores son expresados en keV.

ADVERTENCIA

Este documento ha sido imprimido en 2004, para obtener todas las nuevas evaluaciones actualizadas ulteriormente, el lector deberá referirse a los documentos disponibles en :

<http://www.nucleide.org/NucData.htm>

RÉFÉRENCES
REFERENCES
REFERENZEN
REFERENCIAS

- [87Ta] Table de Radionucléides, F. Lagoutine, N. Coursol, J. Legrand. ISBN 2 7272 0078 1 (LMRI, 1982-1987).
- [85Zi] W.L. Zijp, Netherland Energy Research Foundation, ECN, Petten, The Netherlands, Rep. ECN-179.
- [96He] R.G. Helmer, Proceedings of the Int. Symp. "Advances in alpha-, beta- and gamma-ray Spectrometry", St. Petersburg, September 1996, p. 71.
- [96Be] M.-M. Bé, B. Duchemin and J. Lamé. Nucl. Instrum. Methods A369 (1996) 523 and Bulletin du Bureau National de Métrologie 110 (1998).
- [99In] Table de Radionucléides. Introduction, nouvelle version. Introduction, revised version. Einleitung, überarbeitete Fassung. ISBN 2 7272 0201 6, BNM-CEA/LNHB BP 52, 91191 Gif-sur-Yvette Cedex, France.
- [99Be] M.-M. Bé, E. Browne, V. Chechev, R.G. Helmer, E. Schönfeld. Table de Radionucléides, ISBN 2 7272 0200 8 and ISBN 2 7272 0211 3 (LHNB, 1988-1999).

**AUTEURS POUR CORRESPONDANCE
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Toutes demandes de renseignements concernant les données recommandées et la façon dont elles ont été établies doivent être adressées directement aux auteurs des évaluations.

Information on the data and the evaluation procedures is available from the authors listed below.

Informationen über die Daten und Evaluationsprozeduren können bei den im folgenden zusammengestellten Autoren angefordert werden.

Todos los pedidos de información relativos a datos recomendados y la manera de establecerlos deben dirigirse directamente a los autores de las evaluaciones.

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1 Decay Scheme

Eu-152 disintegrates 72.1% by electron-capture and about 0.027% by emission of positrons to Sm-152 and by beta minus emission (27.9%) to Gd-152.

L'euporium 152 se désintègre par capture électronique (72,1%) et par émission de positron (environ 0,027%) vers le samarium 152 et par émission bêta moins (27,9%) vers le gadolinium 152.

2 Nuclear Data

$T_{1/2}({}^{152}\text{Eu})$	:	13,522	(16)	a
$Q^{-}({}^{152}\text{Eu})$	:	1818,8	(11)	keV
$Q^{+}({}^{152}\text{Eu})$	:	1874,3	(7)	keV

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg ft	P_K	P_L	P_M
$\epsilon_{0,19}$	105,2 (7)	0,068 (5)	1st Forbidden	10,3	0,6586 (33)	0,2591 (24)	0,0657 (12)
$\epsilon_{0,18}$	117,1 (7)	0,041 (3)	1st Forbidden	10,7	0,6903 (28)	0,2358 (20)	0,0591 (11)
$\epsilon_{0,17}$	144,1 (7)	0,0422 (12)	(Allowed)	10,9	0,7339 (23)	0,2036 (16)	0,0499 (9)
$\epsilon_{0,16}$	224,4 (7)	0,889 (14)	Allowed	10,1	0,7859 (19)	0,1651 (13)	0,0392 (7)
$\epsilon_{0,15}$	261,4 (7)	0,0208 (14)		11,9	0,7966 (18)	0,1571 (13)	0,0370 (7)
$\epsilon_{0,14}$	294,9 (7)	2,068 (12)	Allowed	10	0,8036 (17)	0,1519 (12)	0,0356 (7)
$\epsilon_{0,13}$	344,5 (7)	24,72 (11)	Allowed	9,1	0,8109 (17)	0,1465 (12)	0,0341 (7)
$\epsilon_{0,12}$	502,6 (7)	0,869 (24)	1st Forbidden	10,9	0,8236 (16)	0,1370 (11)	0,0316 (6)
$\epsilon_{0,11}$	581,5 (7)	0,644 (10)	(1st Forbidden)	11,2	0,8271 (16)	0,1344 (11)	0,0309 (6)
$\epsilon_{0,10}$	640,4 (7)	17,16 (8)	1st Forbidden	9,8	0,8291 (16)	0,1329 (11)	0,0305 (6)
$\epsilon_{0,9}$	788,5 (7)	21,35 (11)	1st Forbidden	9,9	0,8327 (15)	0,1302 (11)	0,0297 (6)
$\epsilon_{0,8}$	833,2 (7)	0,086 (7)	Allowed	12,4	0,8335 (15)	0,1296 (11)	0,0296 (6)
$\epsilon_{0,7}$	851,3 (7)	0,238 (5)	1st Forbidden	11,9	0,8338 (15)	0,1294 (11)	0,0295 (6)
$\epsilon_{0,5}$	1063,9 (7)	1,28 (3)	1st Forbidden	11,4	0,8366 (15)	0,1273 (11)	0,0290 (6)
$\epsilon_{0,2}$	1507,8 (7)	0,77 (5)	1st Forbidden	12	0,8398 (15)	0,1249 (11)	0,0283 (5)
$\epsilon_{0,1}$	1752,5 (7)	1,7 (10)	1st Forbidden	11,8	0,8408 (15)	0,1241 (10)	0,0281 (5)

2.2 β^+ Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,2}^+$	485,8 (7)	0,0024 (2)	1st Forbidden	
$\beta_{0,1}^+$	730,5 (7)	0,025 (15)	1st Forbidden	

2.3 β^- Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,15}^-$	126,4 (11)	0,0203 (11)	1st Forbidden	11,1
$\beta_{0,14}^-$	175,4 (11)	1,826 (21)	Allowed	9,6
$\beta_{0,13}^-$	213,5 (11)	0,101 (3)	1st Forbidden	11,1
$\beta_{0,12}^-$	268,6 (11)	0,0536 (18)	1st Forbidden	11,7
$\beta_{0,11}^-$	384,8 (11)	2,44 (3)	1st Forbidden	10,5
$\beta_{0,10}^-$	500,3 (11)	0,0267 (17)	1st Forbidden	12,9
$\beta_{0,9}^-$	504,1 (11)	0,0048 (7)	2nd Forbidden	13,6
$\beta_{0,8}^-$	536,5 (11)	0,037 (8)	1st Forbidden	12,8
$\beta_{0,7}^-$	695,6 (11)	13,80 (15)	Allowed	10,6
$\beta_{0,6}^-$	709,7 (11)	0,245 (8)	1st Forbidden	12,4
$\beta_{0,4}^-$	888,2 (11)	0,303 (7)	1st Forbidden	12,7
$\beta_{0,3}^-$	1063,4 (11)	0,904 (14)	1st Forbidden	12,5
$\beta_{0,1}^-$	1474,5 (11)	8,17 (11)	1st Forbidden	12,1

2.4 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L (10^{-3})	α_M (10^{-3})	α_T
$\gamma_{1,0}$ (Sm)	121,7818 (3)	61,5 (10)	E2	0,676 (20)	378 (11)	87,5 (26)	1,165 (35)
$\gamma_{5,3}$ (Sm)	125,69 (13)	0,038 (13)	(E2)	0,616 (18)	329 (10)	76,0 (23)	1,042 (31)
$\gamma_{10,9}$ (Sm)	148,010 (17)	0,055 (8)	(M1+50%E2)	0,430 (13)	115,0 (34)	26,0 (8)	0,578 (17)
$\gamma_{7,4}$ (Gd)	192,6 (4)	0,00714 (22)	(E1)	0,0426 (13)	6,09 (18)	1,32 (4)	0,0504 (15)
$\gamma_{14,12}$ (Sm)	207,6 (3)	0,0062 (4)	(E1)	0,0327 (10)	4,55 (14)	0,975 (29)	0,0385 (12)
$\gamma_{14,11}$ (Gd)	209,41 (13)	0,0058 (5)	(E1)	0,0342 (10)	4,86 (15)	1,050 (32)	0,0404 (12)
$\gamma_{7,5}$ (Sm)	212,568 (15)	0,0229 (8)	E2	0,1244 (37)	36,4 (11)	8,25 (25)	0,171 (5)
$\gamma_{(-1,0)}$ (Sm)	237,3 (1)	0,0026 (9)	(E1)	0,0231 (7)	3,18 (10)	0,681 (20)	0,0272 (8)
$\gamma_{19,13}$ (Sm)	239,42 (17)	0,008 (3)	(E1)	0,0225 (7)	3,11 (9)	0,665 (20)	0,0265 (8)
$\gamma_{2,1}$ (Sm)	244,6976 (8)	8,37 (5)	E2	0,0809 (24)	21,1 (6)	4,75 (14)	0,1080 (32)
$\gamma_{11,8}$ (Sm)	251,633 (7)	0,0687 (15)	(E1)	0,0198 (6)	2,72 (8)	0,583 (17)	0,0233 (7)
$\gamma_{11,7}$ (Sm)	269,86 (6)	0,006 (3)	(E2)	0,0602 (18)	14,60 (44)	3,27 (10)	0,0789 (24)
$\gamma_{2,1}$ (Gd)	271,131 (8)	0,084 (3)	E2	0,0621 (19)	16,20 (49)	3,70 (11)	0,0831 (25)
$\gamma_{9,5}$ (Sm)	275,449 (15)	0,0357 (19)	(M1)	0,0887 (27)	12,30 (37)	2,65 (8)	0,1044 (31)
$\gamma_{12,9}$ (Sm)	285,98 (3)	0,0107 (7)	(E2)	0,0506 (15)	11,80 (35)	2,63 (8)	0,0657 (20)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L (10^{-3})	α_M (10^{-3})	α_T
$\gamma_{13,10}$ (Sm)	295,9390 (17)	0,449 (3)	E1	0,01310 (39)	1,78 (5)	0,381 (11)	0,01530 (46)
$\gamma_{4,2}$ (Gd)	315,174 (17)	0,052 (2)	(E2)	0,0400 (12)	9,38 (28)	2,12 (6)	0,0521 (16)
$\gamma_{7,4}$ (Sm)	316,2 (2)	0,0032 (10)	(E2)	0,0376 (11)	8,19 (25)	1,83 (5)	0,0481 (14)
$\gamma_{(-1,1)}$ (Sm)	320,03 (15)	0,0017 (6)					
$\gamma_{11,6}$ (Gd)	324,83 (3)	0,0785 (16)	M1+50%E2	0,0521 (16)	8,97 (27)	1,99 (6)	0,0636 (19)
$\gamma_{11,6}$ (Sm)	329,425 (21)	0,131 (6)	(E1)	0,0100 (3)	1,360 (41)	0,290 (9)	0,01170 (35)
$\gamma_{12,8}$ (Sm)	330,54 (10)	0,0061 (17)	(E1)	0,0099 (3)	1,34 (4)	0,288 (9)	0,01160 (35)
$\gamma_{4,2}$ (Sm)	340,40 (14)	0,033 (3)	E2	0,0304 (9)	6,32 (19)	1,410 (42)	0,0385 (12)
$\gamma_{1,0}$ (Gd)	344,2789 (12)	27,65 (13)	E2	0,0311 (9)	6,87 (21)	1,550 (46)	0,0399 (12)
$\gamma_{8,4}$ (Gd)	351,66 (4)	0,0145 (24)	E2	0,0293 (9)	6,39 (19)	1,440 (43)	0,0375 (11)
$\gamma_{16,11}$ (Sm)	357,26 (5)	0,0041 (5)	(E1)	0,00820 (25)	1,110 (33)	0,237 (7)	0,00960 (29)
$\gamma_{7,3}$ (Gd)	367,7896 (20)	0,870 (5)	E1	0,00830 (25)	1,130 (34)	0,245 (7)	0,00970 (29)
$\gamma_{(-1,2)}$ (Sm)	379,37 (6)	0,00083 (21)					
$\gamma_{18,12}$ (Sm)	385,69 (20)	0,0052 (7)	(M1+50%E2)	0,0290 (9)	4,59 (14)	0,999 (30)	0,0348 (10)
$\gamma_{10,4}$ (Gd)	387,90 (8)	0,00429 (45)	(M1+E2+E0)	0,38 (9)			0,45 (11)
$\gamma_{(-1,3)}$ (Sm)	391,32 (14)	0,00125 (22)					
$\gamma_{(-1,4)}$ (Sm)	406,74 (15)	0,00083 (21)					
$\gamma_{3,1}$ (Gd)	411,1171 (12)	2,292 (11)	E2	0,0190 (6)	3,79 (11)	0,849 (25)	0,0239 (7)
$\gamma_{16,10}$ (Sm)	416,049 (8)	0,1097 (17)	(E1)	0,00570 (17)	0,762 (23)	0,1630 (49)	0,0067 (2)
$\gamma_{10,5}$ (Sm)	423,45 (4)	0,0033 (5)	(M1+50%E2)	0,0226 (7)	3,5 (1)	0,761 (23)	0,0271 (8)
$\gamma_{12,6}$ (Gd)	440,86 (10)	0,0136 (11)	(E2)	0,01580 (47)	3,03 (9)	0,677 (20)	0,0197 (6)
$\gamma_{5,2}$ (Sm)	443,966 (3)	0,325 (18)	(E2)	0,01450 (44)	2,63 (8)	0,579 (17)	0,0178 (5)
$\gamma_{13,9}$ (Sm)	443,966 (3)	2,821 (22)	E1(+M2)	0,00520 (16)	0,635 (19)	0,1390 (42)	0,00600 (18)
$\gamma_{13,7}$ (Gd)	482,31 (3)	0,0014 (6)	(E1)	0,00440 (13)	0,594 (18)	0,1280 (38)	0,00510 (15)
$\gamma_{11,5}$ (Sm)	482,31 (3)	0,0285 (16)	(M1+50%E2)	0,01610 (48)	2,43 (7)	0,526 (16)	0,0192 (6)
$\gamma_{13,8}$ (Sm)	488,680 (2)	0,4197 (24)	M1+E2	0,01150 (34)	1,96 (6)	0,429 (13)	0,01400 (42)
$\gamma_{14,9}$ (Sm)	493,508 (20)	0,028 (3)	(E1)	0,00380 (11)	0,509 (15)	0,1090 (33)	0,00450 (14)
$\gamma_{6,2}$ (Gd)	493,509 (20)	0,0093 (21)	(E2)	0,01180 (35)	2,14 (6)	0,476 (14)	0,01450 (44)
$\gamma_{13,6}$ (Gd)	496,39 (3)	0,00461 (44)	M1+E2+E0	0,082 (9)			0,097 (11)
$\gamma_{17,10}$ (Sm)	496,39 (3)	0,0049 (8)	(E1)	0,00380 (11)	0,502 (15)	0,1070 (32)	0,00440 (13)
$\gamma_{11,4}$ (Gd)	503,475 (5)	0,1554 (18)	(E2)	0,01120 (34)	2,02 (6)	0,448 (13)	0,01380 (41)
$\gamma_{14,7}$ (Gd)	520,228 (5)	0,0545 (12)	(M1+50%E2)	0,01520 (46)	2,30 (7)	0,504 (15)	0,0181 (5)
$\gamma_{18,10}$ (Sm)	523,13 (5)	0,0114 (21)	(M1+50%E2)	0,01310 (39)	1,94 (6)	0,421 (13)	0,01560 (47)
$\gamma_{8,3}$ (Gd)	526,882 (20)	0,0141 (7)	M1+E2+E0	0,084 (9)			0,094 (8)
$\gamma_{14,6}$ (Gd)	534,246 (7)	0,0369 (19)	(E1)	0,0035 (1)	0,470 (14)	0,101 (3)	0,00410 (12)
$\gamma_{(-1,5)}$ (Sm)	535,4 (4)	0,0060 (16)	(M1+50%E2)	0,01240 (37)	1,83 (5)	0,395 (12)	0,01470 (44)
$\gamma_{14,8}$ (Sm)	538,29 (6)	0,0042 (6)	(M1+50%E2)	0,01220 (37)	1,80 (5)	0,389 (12)	0,01450 (44)
$\gamma_{14,7}$ (Sm)	556,56 (3)	0,0178 (11)	(E1)	0,00290 (9)	0,387 (12)	0,0826 (25)	0,0034 (1)
$\gamma_{13,5}$ (Gd)	557,91 (17)	0,0044 (7)	(E2)	0,00870 (26)	1,490 (45)	0,331 (10)	0,01060 (32)
$\gamma_{12,5}$ (Sm)	561,2 (5)	0,00109 (21)	(E2)	0,00790 (24)	1,300 (39)	0,285 (9)	0,00960 (29)
$\gamma_{3,1}$ (Sm)	562,93 (2)	0,038 (13)	E2	0,00780 (23)	1,290 (39)	0,282 (8)	0,00950 (28)
$\gamma_{16,9}$ (Sm)	563,991 (7)	0,458 (14)	E1	0,00280 (8)	0,376 (11)	0,0802 (24)	0,0033 (1)
$\gamma_{13,6}$ (Sm)	566,442 (5)	0,133 (4)	M1+35,4%E2	0,01170 (35)	1,66 (5)	0,357 (11)	0,01380 (41)
$\gamma_{15,8}$ (Sm)	571,83 (8)	0,0048 (8)					
$\gamma_{4,1}$ (Gd)	586,266 (3)	0,4732 (41)	E2+4%M1+E0	0,0202 (16)			0,0243 (9)
$\gamma_{(-1,6)}$ (Sm)	595,61 (1)	0,0031 (17)					
$\gamma_{14,6}$ (Sm)	616,05 (3)	0,0092 (6)	(E2)	0,00630 (19)	1,00 (3)	0,219 (7)	0,00760 (23)
$\gamma_{17,9}$ (Sm)	644,37 (5)	0,0063 (6)	(E1)	0,00210 (6)	0,280 (8)	0,0598 (18)	0,00250 (8)
$\gamma_{7,2}$ (Sm)	656,490 (5)	0,1519 (19)	E2+18%M1+E0	0,0497 (16)			0,0568 (20)
$\gamma_{12,4}$ (Sm)	664,78 (5)	0,010 (3)	(E2)	0,00520 (16)	0,818 (25)	0,178 (5)	0,00630 (19)
$\gamma_{18,9}$ (Sm)	671,157 (17)	0,0196 (13)	M1+1,9%E2	0,00900 (27)	1,220 (37)	0,260 (8)	0,01050 (32)
$\gamma_{13,4}$ (Gd)	674,677 (7)	0,0172 (18)	E2+17%M1	0,00630 (19)	0,980 (29)	0,215 (6)	0,00760 (23)
$\gamma_{8,2}$ (Sm)	674,677 (3)	0,170 (4)	E1	0,00190 (6)	0,254 (8)	0,0542 (16)	0,00230 (7)
$\gamma_{11,3}$ (Gd)	678,625 (5)	0,473 (4)	E2+6%M1	0,00570 (17)	0,900 (27)	0,198 (6)	0,00690 (21)
$\gamma_{(-1,7)}$ (Sm)	683,32 (11)	0,0031 (8)					
$\gamma_{16,6}$ (Sm)	686,61 (5)	0,0201 (17)	(M1+50%E2)	0,0067 (2)	0,954 (29)	0,205 (6)	0,00790 (24)
$\gamma_{5,1}$ (Sm)	688,672 (5)	0,877 (6)	E2+M1+E0	0,0359 (13)			0,0434 (13)
$\gamma_{(-1,8)}$ (Sm)	696,87 (19)	0,0029 (10)					
$\gamma_{5,1}$ (Gd)	703,25 (6)	0,0018 (9)	(E2)	0,00500 (15)	0,796 (24)	0,175 (5)	0,00600 (18)

	Energy keV	P _{γ+ce} × 100	Multipolarity	α _K	α _L (10 ⁻³)	α _M (10 ⁻³)	α _T
γ _{10,2} (Gd)	703,25 (6)	0,0035 (9)	(E2)	0,00500 (15)	0,796 (24)	0,175 (5)	0,00600 (18)
γ _{14,4} (Gd)	712,845 (6)	0,0963 (19)	(E1)	0,00190 (6)	0,251 (8)	0,0541 (16)	0,00220 (7)
γ _{13,5} (Sm)	719,351 (4)	0,059 (7)	(E1)	0,00170 (5)	0,222 (7)	0,0473 (14)	0,00200 (6)
γ _{9,2} (Sm)	719,351 (4)	0,270 (13)	(E2)	0,00440 (13)	0,666 (20)	0,1440 (43)	0,00520 (16)
γ _{19,8} (Sm)	727,99 (14)	0,0106 (13)	(E1)	0,00166 (5)	0,216 (6)	0,0461 (14)	0,00193 (6)
γ _(-1,9) (Sm)	735,4 (1)	0,0058 (10)					
γ _(-1,10) (Sm)	756,12 (9)	0,0054 (8)					
γ _{6,1} (Gd)	764,902 (9)	0,191 (4)	E2+6,5%M1	0,00440 (13)	0,669 (20)	0,1460 (44)	0,00520 (16)
γ _{14,5} (Sm)	768,946 (9)	0,089 (3)	(E1)	0,001500 (45)	0,193 (6)	0,0412 (12)	0,00170 (5)
γ _{7,1} (Gd)	778,9066 (24)	12,99 (6)	E1	0,001600 (48)	0,209 (6)	0,0450 (14)	0,00190 (6)
γ _{12,3} (Gd)	794,81 (3)	0,0265 (11)	M1(+13,8%E2)	0,0065 (2)	0,905 (27)	0,196 (6)	0,00770 (23)
γ _{19,6} (Sm)	805,70 (7)	0,0125 (8)	(E1)	0,001400 (42)	0,176 (5)	0,0374 (11)	0,001600 (48)
γ _{5,0} (Sm)	810,453 (5)	0,318 (3)	(E2)	0,0033 (1)	0,493 (15)	0,1070 (32)	0,00400 (12)
γ _{16,5} (Sm)	839,36 (4)	0,0161 (8)	(E1)	0,001200 (36)	0,1620 (49)	0,0345 (10)	0,001500 (45)
γ _{6,1} (Sm)	841,576 (5)	0,163 (2)	E1	0,001200 (36)	0,1610 (48)	0,0343 (10)	0,001500 (45)
γ _{10,2} (Sm)	867,383 (3)	4,258 (23)	E2+2%M1	0,00290 (9)	0,423 (13)	0,0913 (27)	0,0035 (1)
γ _(-1,11) (Sm)	896,58 (9)	0,0669 (21)					
γ _{7,1} (Sm)	901,184 (11)	0,084 (3)	E2	0,00260 (8)	0,382 (11)	0,0824 (25)	0,00310 (9)
γ _{15,4} (Sm)	906,01 (6)	0,016 (1)					
γ _{8,1} (Sm)	919,340 (4)	0,430 (4)	E1	0,00100 (3)	0,135 (4)	0,0288 (9)	0,001200 (36)
γ _{11,2} (Sm)	926,320 (15)	0,274 (4)	(E2)	0,00250 (8)	0,358 (11)	0,0772 (23)	0,00290 (9)
γ _{4,0} (Gd)	930,58 (15)	0,0731 (19)	(E2)	0,00270 (8)	0,400 (12)	0,0872 (26)	0,0032 (1)
γ _{15,3} (Gd)	937,053 (15)	0,0027 (6)	(M1+50%E2)	0,00370 (11)	0,516 (15)	0,1120 (34)	0,00430 (13)
γ _{19,5} (Sm)	958,63 (5)	0,0211 (19)	(M1+E2)	0,00310 (9)			0,00360 (11)
γ _{6,0} (Sm)	963,393 (12)	0,1342 (20)	E1	0,00100 (3)	0,1230 (37)	0,0263 (8)	0,001100 (33)
γ _{9,1} (Sm)	964,082 (18)	14,54 (7)	E2(+M1)	0,00230 (7)	0,327 (10)	0,0703 (21)	0,00270 (8)
γ _{10,1} (Gd)	974,09 (4)	0,0139 (8)	M1+50%E2+E0	0,0048 (5)			0,0056 (6)
γ _{13,2} (Gd)	990,19 (3)	0,0315 (13)	(E2)	0,00240 (7)	0,347 (10)	0,0755 (23)	0,00300 (9)
γ _(-1,12) (Sm)	1001,1 (3)	0,0046 (10)					
γ _{12,2} (Sm)	1005,276 (17)	0,667 (23)		0,00220 (7)	0,311 (9)	0,0669 (20)	0,00260 (8)
γ _(-1,15) (Sm)	1084 (1)	0,244 (8)					
γ _{9,0} (Sm)	1085,841 (10)	10,15 (6)	E2	0,00180 (5)	0,250 (8)	0,0536 (16)	0,00210 (6)
γ _{11,1} (Gd)	1089,741 (5)	1,735 (10)	(M1)+E2	0,00200 (6)			0,00230 (7)
γ _{6,0} (Gd)	1109,178 (12)	0,186 (4)	E2	0,00190 (6)	0,269 (8)	0,0584 (18)	0,00220 (7)
γ _{10,1} (Sm)	1112,080 (3)	13,44 (6)	E2(+1%M1)	0,00170 (5)	0,238 (7)	0,0511 (15)	0,00200 (6)
γ _(-1,13) (Sm)	1139 (1)	0,0013 (3)					
γ _{11,1} (Sm)	1170,93 (11)	0,0366 (13)	(M1+50%E2)	0,00200 (6)	0,265 (8)	0,0567 (17)	0,00230 (7)
γ _{12,1} (Gd)	1206,11 (15)	0,0138 (8)	(E2)	0,001600 (48)	0,225 (7)	0,0487 (15)	0,00190 (6)
γ _{14,2} (Sm)	1212,953 (11)	1,417 (9)	E1	0,000600 (18)	0,0802 (24)	0,0170 (5)	0,000700 (21)
γ _{12,1} (Sm)	1249,944 (13)	0,187 (3)	E2	0,001400 (42)	0,184 (6)	0,0395 (12)	0,001600 (48)
γ _{13,1} (Gd)	1261,349 (23)	0,0337 (11)	M1	0,00230 (7)	0,313 (9)	0,0676 (20)	0,00270 (8)
γ _{11,0} (Sm)	1292,784 (19)	0,104 (3)	(E2)	0,001300 (39)	0,172 (5)	0,0368 (11)	0,001500 (45)
γ _{14,1} (Gd)	1299,148 (8)	1,634 (9)	E1(+0,2%M2)	0,000600 (18)	0,0803 (24)	0,0172 (5)	0,000700 (21)
γ _{9,0} (Gd)	1314,7 (2)	0,0048 (6)	E1	0,000600 (18)	0,0773 (23)	0,0166 (5)	0,000700 (21)
γ _{15,1} (Gd)	1348,10 (7)	0,0175 (8)	E2+(0,6%M1)	0,001300 (39)	0,179 (5)	0,0387 (12)	0,001600 (48)
γ _{17,2} (Sm)	1363,77 (5)	0,0257 (8)	M1(+E2)	0,00170 (5)	0,222 (7)	0,0474 (14)	0,00200 (6)
γ _{18,2} (Sm)	1390,36 (16)	0,0048 (6)	(M1+50%E2)	0,001400 (42)	0,180 (5)	0,0385 (12)	0,001600 (48)
γ _{13,1} (Sm)	1408,013 (3)	20,86 (9)	E1(+M2)	0,000500 (15)	0,0615 (18)	0,01310 (39)	0,000600 (18)
γ _{14,1} (Sm)	1457,651 (11)	0,498 (4)	E1	0,000500 (15)	0,0580 (17)	0,01230 (37)	0,000500 (15)
γ _{16,1} (Sm)	1528,111 (18)	0,281 (5)	E1	0,000400 (12)			0,000500 (15)
γ _{13,0} (Gd)	1605,61 (7)	0,0081 (4)	(E2)	0,000900 (27)			0,000900 (27)
γ _{17,1} (Sm)	1608,36 (8)	0,0053 (3)	(E1)	0,000400 (12)			0,000400 (12)
γ _{18,1} (Sm)	1635,2 (5)	0,00015 (5)	(M1+50%E2)	0,00100 (3)			0,00100 (3)
γ _{14,0} (Gd)	1643,6 (1)	0,0015 (4)	(M2)	0,00280 (8)			0,0032 (1)
γ _{19,1} (Sm)	1647,41 (14)	0,0064 (4)	(E2)	0,000800 (24)			0,000800 (24)
γ _(-1,14) (Sm)	1674,30 (6)	0,0060 (8)					
γ _{19,0} (Sm)	1769,09 (5)	0,0092 (3)	(E2)	0,000700 (21)			0,000700 (21)

3 Atomic Data

3.1 Sm

ω_K	:	0,926	(4)
$\bar{\omega}_L$	:	0,158	(6)
n_{KL}	:	0,857	(4)

3.1.1 X Radiations

		Energy keV		Relative probability	
X_K	$K\alpha_2$	39,5229		55,25	
	$K\alpha_1$	40,1186		100	
	$K\beta_3$	45,289	}		
	$K\beta_1$	45,413	}		
	$K\beta_5''$	45,731	}	31,23	
	$K\beta_2$	46,575	}		
	$K\beta_4$	46,705	}	8,06	
	$KO_{2,3}$	46,813	}		
	X_L	$L\alpha$	5,61 – 5,64		
		$L\gamma$	– 7,18		

3.1.2 Auger Electrons

		Energy keV	Relative probability
Auger K	KLL	31,190 – 33,218	100
	KLX	37,302 – 40,097	50,7
	KXY	43,39 – 46,79	6,42
	Auger L	0,08 – 7,69	1815

3.2 Gd

ω_K	:	0,932	(4)
$\bar{\omega}_L$	:	0,176	(6)
n_{KL}	:	0,850	(4)

3.2.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	42,3093	55,59
$K\alpha_1$	42,9967	100
$K\beta_3$	48,556	}
$K\beta_1$	48,697	}
$K\beta_5''$	49,053	}
		31,6
$K\beta_2$	49,961	}
$K\beta_4$	50,099	}
$KO_{2,3}$	50,219	}
		8,31
X_L		
$L\alpha$	6,025 – 6,057	
$L\gamma$	– 7,78	

3.2.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	33,310 – 35,562	100
KLX	39,907 – 42,976	51,3
KXY	46,48 – 50,20	6,58
Auger L	0,07 – 8,33	

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Sm)	0,08	- 7,69	67,7 (7)
e _{AK}	(Sm)			5,9 (4)
	KLL	31,190	- 33,218	}
	KLX	37,302	- 40,097	}
	KXY	43,39	- 46,79	}
e _{AL}	(Gd)	0,07	- 8,33	0,800 (14)
e _{AK}	(Gd)			0,062 (4)
	KLL	33,310	- 35,562	}
	KLX	39,907	- 42,976	}
	KXY	46,48	- 50,20	}
ec _{1,0} K	(Sm)	74,9475	(20)	19,2 (6)
ec _{1,0} L	(Sm)	114,045	- 115,066	10,7 (3)
ec _{1,0} M	(Sm)	120,059	- 120,702	2,48 (7)
ec _{1,0} N	(Sm)	121,436	- 121,776	0,57 (2)
ec _{2,1} K	(Sm)	197,8632	(20)	0,611 (19)
ec _{2,1} L	(Sm)	236,961	- 237,981	0,159 (5)
ec _{1,0} K	(Gd)	294,0394	(20)	0,86 (3)
ec _{1,0} L	(Gd)	335,903	- 337,036	0,190 (6)
$\beta_{0,1}^+$	max:	730,5	(7)	0,025 (15)
$\beta_{0,1}^+$	avg:	338,1	(3)	
$\beta_{0,2}^+$	max:	485,8	(7)	0,0024 (2)
$\beta_{0,2}^+$	avg:	230,7	(3)	
$\beta_{0,15}^-$	max:	126,4	(11)	0,0203 (11)
$\beta_{0,15}^-$	avg:	33,4	(3)	
$\beta_{0,14}^-$	max:	175,4	(11)	1,826 (21)
$\beta_{0,14}^-$	avg:	47,4	(4)	
$\beta_{0,13}^-$	max:	213,5	(11)	0,101 (3)
$\beta_{0,13}^-$	avg:	58,6	(4)	
$\beta_{0,12}^-$	max:	268,6	(11)	0,0536 (18)
$\beta_{0,12}^-$	avg:	75,2	(4)	
$\beta_{0,11}^-$	max:	384,8	(11)	2,44 (3)
$\beta_{0,11}^-$	avg:	112,3	(4)	
$\beta_{0,10}^-$	max:	500,3	(11)	0,0267 (17)
$\beta_{0,10}^-$	avg:	151,4	(4)	
$\beta_{0,9}^-$	max:	504,1	(11)	0,0048 (7)
$\beta_{0,9}^-$	avg:	152,7	(4)	
$\beta_{0,8}^-$	max:	536,5	(11)	0,037 (8)
$\beta_{0,8}^-$	avg:	164,1	(4)	

		Energy keV	Electrons per 100 disint.
$\beta_{0,7}^-$	max:	695,6 (11)	13,80 (15)
$\beta_{0,7}^-$	avg:	221,7 (4)	
$\beta_{0,6}^-$	max:	709,7 (11)	0,245 (8)
$\beta_{0,6}^-$	avg:	226,9 (5)	
$\beta_{0,4}^-$	max:	888,2 (11)	0,303 (7)
$\beta_{0,4}^-$	avg:	295,1 (5)	
$\beta_{0,3}^-$	max:	1063,4 (11)	0,904 (14)
$\beta_{0,3}^-$	avg:	364,6 (5)	
$\beta_{0,1}^-$	max:	1474,5 (11)	8,17 (11)
$\beta_{0,1}^-$	avg:	535,4 (5)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Sm)	5,61 — 7,18	13,0 (4)
XK α_2	(Sm)	39,5229	20,8 (3) } K α
XK α_1	(Sm)	40,1186	37,7 (5) }
XK β_3	(Sm)	45,289 }	11,78 (19) K' β_1
XK β_1	(Sm)	45,413 }	
XK β_5''	(Sm)	45,731 }	
XK β_2	(Sm)	46,575 }	
XK β_4	(Sm)	46,705 }	
XK $O_{2,3}$	(Sm)	46,813 }	3,04 (8) K' β_2
XL	(Gd)	6,025 — 7,78	0,177 (5)
XK α_2	(Gd)	42,3093	0,243 (7) } K α
XK α_1	(Gd)	42,9967	0,437 (12) }
XK β_3	(Gd)	48,556 }	0,138 (4) K' β_1
XK β_1	(Gd)	48,697 }	
XK β_5''	(Gd)	49,053 }	
XK β_2	(Gd)	49,961 }	
XK β_4	(Gd)	50,099 }	
XK $O_{2,3}$	(Gd)	50,219 }	0,0363 (13) K' β_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Sm})$	121,7817 (3)	28,41 (13)
$\gamma_{5,3}(\text{Sm})$	125,69 (13)	0,019 (6)
$\gamma_{10,9}(\text{Sm})$	148,010 (17)	0,035 (5)
$\gamma_{7,4}(\text{Gd})$	192,6 (4)	0,0068 (2)
$\gamma_{14,12}(\text{Sm})$	207,6 (3)	0,0059 (4)
$\gamma_{14,11}(\text{Gd})$	209,41 (13)	0,0055 (5)
$\gamma_{7,5}(\text{Sm})$	212,568 (15)	0,0196 (6)
$\gamma_{(-1,0)}(\text{Sm})$	237,31 (5)	0,0025 (8)
$\gamma_{19,13}(\text{Sm})$	239,42 (17)	0,008 (3)
$\gamma_{2,1}(\text{Sm})$	244,6974 (8)	7,55 (4)
$\gamma_{11,8}(\text{Sm})$	251,633 (10)	0,0671 (15)
$\gamma_{11,7}(\text{Sm})$	269,86 (6)	0,0060 (24)
$\gamma_{2,1}(\text{Gd})$	271,131 (8)	0,078 (3)
$\gamma_{9,5}(\text{Sm})$	275,449 (15)	0,0323 (17)
$\gamma_{12,9}(\text{Sm})$	285,98 (3)	0,0100 (6)
$\gamma_{13,10}(\text{Sm})$	295,9387 (17)	0,442 (3)
$\gamma_{4,2}(\text{Gd})$	315,174 (17)	0,0496 (17)
$\gamma_{7,4}(\text{Sm})$	316,2 (2)	0,0031 (10)
$\gamma_{(-1,1)}(\text{Sm})$	320,03 (15)	0,0017 (6)
$\gamma_{11,6}(\text{Gd})$	324,83 (3)	0,0738 (15)
$\gamma_{11,6}(\text{Sm})$	329,425 (21)	0,129 (6)
$\gamma_{12,8}(\text{Sm})$	330,54 (10)	0,0060 (17)
$\gamma_{4,2}(\text{Sm})$	340,40 (14)	0,031 (3)
$\gamma_{1,0}(\text{Gd})$	344,2785 (12)	26,59 (12)
$\gamma_{8,4}(\text{Gd})$	351,66 (4)	0,0140 (22)
$\gamma_{16,11}(\text{Sm})$	357,26 (5)	0,0040 (5)
$\gamma_{7,3}(\text{Gd})$	367,7891 (20)	0,862 (5)
$\gamma_{(-1,2)}(\text{Sm})$	379,37 (6)	0,00083 (21)
$\gamma_{18,12}(\text{Sm})$	385,69 (20)	0,0050 (6)
$\gamma_{10,4}(\text{Gd})$	387,90 (8)	0,00296 (21)
$\gamma_{(-1,3)}(\text{Sm})$	391,32 (14)	0,00125 (21)
$\gamma_{(-1,4)}(\text{Sm})$	406,74 (15)	0,00083 (21)
$\gamma_{3,1}(\text{Gd})$	411,1165 (12)	2,238 (10)
$\gamma_{16,10}(\text{Sm})$	416,048 (8)	0,1090 (17)
$\gamma_{10,5}(\text{Sm})$	423,45 (4)	0,0032 (5)
$\gamma_{12,6}(\text{Gd})$	440,86 (10)	0,0133 (10)
$\gamma_{5,2}(\text{Sm})$	443,965 (3)	0,32 (2)
$\gamma_{13,9}(\text{Sm})$	443,965 (3)	2,80 (2)
$\gamma_{13,7}(\text{Gd})$	482,31 (3)	0,00139 (6)
$\gamma_{11,5}(\text{Sm})$	482,31 (3)	0,0279 (16)
$\gamma_{13,8}(\text{Sm})$	488,6792 (20)	0,4139 (24)
$\gamma_{6,2}(\text{Gd})$	493,508 (20)	0,009 (2)
$\gamma_{14,9}(\text{Sm})$	493,508 (20)	0,0278 (30)
$\gamma_{13,6}(\text{Gd})$	496,39 (3)	0,0042 (4)
$\gamma_{17,10}(\text{Sm})$	496,39 (3)	0,0049 (5)

	Energy keV	Photons per 100 disint.
$\gamma_{11,4}(\text{Gd})$	503,474 (5)	0,1533 (18)
γ^{\pm}	511	0,054 (30)
$\gamma_{14,7}(\text{Gd})$	520,227 (5)	0,0536 (13)
$\gamma_{18,10}(\text{Sm})$	523,13 (5)	0,0113 (21)
$\gamma_{8,3}(\text{Gd})$	526,881 (20)	0,0129 (6)
$\gamma_{14,6}(\text{Gd})$	534,245 (7)	0,0368 (19)
$\gamma_{(-1,5)}(\text{Sm})$	535,4 (4)	0,0060 (16)
$\gamma_{14,8}(\text{Sm})$	538,29 (6)	0,0042 (6)
$\gamma_{14,7}(\text{Sm})$	556,56 (3)	0,0177 (11)
$\gamma_{13,5}(\text{Gd})$	557,91 (17)	0,0044 (7)
$\gamma_{12,5}(\text{Sm})$	561,2 (5)	0,00108 (21)
$\gamma_{3,1}(\text{Sm})$	562,93 (2)	0,038 (13)
$\gamma_{16,9}(\text{Sm})$	563,990 (7)	0,457 (13)
$\gamma_{13,6}(\text{Sm})$	566,442 (5)	0,131 (4)
$\gamma_{15,8}(\text{Sm})$	571,83 (8)	0,0048 (8)
$\gamma_{4,1}(\text{Gd})$	586,265 (3)	0,462 (4)
$\gamma_{(-1,6)}(\text{Sm})$	595,61 (1)	0,0031 (17)
$\gamma_{14,6}(\text{Sm})$	616,05 (3)	0,0092 (6)
$\gamma_{17,9}(\text{Sm})$	644,37 (5)	0,0063 (6)
$\gamma_{7,2}(\text{Sm})$	656,489 (5)	0,1437 (18)
$\gamma_{12,4}(\text{Sm})$	664,78 (5)	0,010 (3)
$\gamma_{18,9}(\text{Sm})$	671,155 (17)	0,0194 (13)
$\gamma_{8,2}(\text{Sm})$	674,675 (3)	0,170 (4)
$\gamma_{13,4}(\text{Gd})$	674,677 (3)	0,0171 (18)
$\gamma_{11,3}(\text{Gd})$	678,623 (5)	0,470 (4)
$\gamma_{(-1,7)}(\text{Sm})$	683,32 (11)	0,0031 (8)
$\gamma_{16,6}(\text{Sm})$	686,61 (5)	0,0200 (17)
$\gamma_{5,1}(\text{Sm})$	688,670 (5)	0,841 (6)
$\gamma_{(-1,8)}(\text{Sm})$	696,87 (19)	0,0029 (10)
$\gamma_{10,2}(\text{Gd})$	703,25 (6)	0,0035 (9)
$\gamma_{5,1}(\text{Gd})$	703,25 (6)	0,0018 (9)
$\gamma_{14,4}(\text{Gd})$	712,843 (6)	0,0961 (19)
$\gamma_{13,5}(\text{Sm})$	719,349 (4)	0,059 (7)
$\gamma_{9,2}(\text{Sm})$	719,349 (4)	0,268 (13)
$\gamma_{19,8}(\text{Sm})$	727,99 (14)	0,0106 (13)
$\gamma_{(-1,9)}(\text{Sm})$	735,4 (1)	0,0058 (10)
$\gamma_{(-1,10)}(\text{Sm})$	756,12 (9)	0,0054 (8)
$\gamma_{6,1}(\text{Gd})$	764,900 (9)	0,190 (4)
$\gamma_{14,5}(\text{Sm})$	768,944 (9)	0,088 (3)
$\gamma_{7,1}(\text{Gd})$	778,9045 (24)	12,97 (6)
$\gamma_{12,3}(\text{Gd})$	794,81 (3)	0,0263 (10)
$\gamma_{19,6}(\text{Sm})$	805,70 (7)	0,0125 (8)
$\gamma_{5,0}(\text{Sm})$	810,451 (5)	0,317 (3)
$\gamma_{16,5}(\text{Sm})$	839,36 (4)	0,0160 (8)
$\gamma_{6,1}(\text{Sm})$	841,574 (5)	0,163 (2)
$\gamma_{10,2}(\text{Sm})$	867,380 (3)	4,243 (23)
$\gamma_{(-1,11)}(\text{Sm})$	896,58 (9)	0,0669 (21)

	Energy keV	Photons per 100 disint.
$\gamma_{7,1}(\text{Sm})$	901,181 (11)	0,084 (3)
$\gamma_{15,4}(\text{Sm})$	906,01 (6)	0,016 (1)
$\gamma_{8,1}(\text{Sm})$	919,337 (4)	0,429 (5)
$\gamma_{11,2}(\text{Sm})$	926,317 (15)	0,273 (4)
$\gamma_{4,0}(\text{Gd})$	930,58 (15)	0,0729 (19)
$\gamma_{15,3}(\text{Gd})$	937,050 (15)	0,0027 (6)
$\gamma_{19,5}(\text{Sm})$	958,63 (5)	0,0210 (19)
$\gamma_{6,0}(\text{Sm})$	963,390 (12)	0,1341 (20)
$\gamma_{9,1}(\text{Sm})$	964,079 (18)	14,50 (6)
$\gamma_{10,1}(\text{Gd})$	974,09 (4)	0,0138 (8)
$\gamma_{13,2}(\text{Gd})$	990,19 (3)	0,0315 (13)
$\gamma_{(-1,12)}(\text{Sm})$	1001,1 (3)	0,0046 (10)
$\gamma_{12,2}(\text{Sm})$	1005,272 (17)	0,665 (23)
$\gamma_{(-1,15)}(\text{Sm})$	1084 (1)	0,244 (8)
$\gamma_{9,0}(\text{Sm})$	1085,837 (10)	10,13 (6)
$\gamma_{11,1}(\text{Gd})$	1089,737 (5)	1,73 (1)
$\gamma_{6,0}(\text{Gd})$	1109,174 (12)	0,186 (4)
$\gamma_{10,1}(\text{Sm})$	1112,076 (3)	13,41 (6)
$\gamma_{(-1,13)}(\text{Sm})$	1139 (1)	0,0013 (3)
$\gamma_{11,1}(\text{Sm})$	1170,93 (11)	0,0365 (13)
$\gamma_{12,1}(\text{Gd})$	1206,11 (15)	0,0135 (8)
$\gamma_{14,2}(\text{Sm})$	1212,948 (11)	1,416 (9)
$\gamma_{12,1}(\text{Sm})$	1249,938 (13)	0,186 (3)
$\gamma_{13,1}(\text{Gd})$	1261,343 (23)	0,0336 (11)
$\gamma_{11,0}(\text{Sm})$	1292,778 (19)	0,104 (3)
$\gamma_{14,1}(\text{Gd})$	1299,142 (8)	1,633 (9)
$\gamma_{9,0}(\text{Gd})$	1314,7 (2)	0,0048 (6)
$\gamma_{15,1}(\text{Gd})$	1348,10 (7)	0,0175 (8)
$\gamma_{17,2}(\text{Sm})$	1363,77 (5)	0,0256 (8)
$\gamma_{18,2}(\text{Sm})$	1390,36 (16)	0,0048 (6)
$\gamma_{13,1}(\text{Sm})$	1408,013 (3)	20,85 (8)
$\gamma_{14,1}(\text{Sm})$	1457,643 (11)	0,498 (4)
$\gamma_{16,1}(\text{Sm})$	1528,103 (18)	0,281 (5)
$\gamma_{13,0}(\text{Gd})$	1605,61 (7)	0,0081 (4)
$\gamma_{17,1}(\text{Sm})$	1608,36 (8)	0,0053 (3)
$\gamma_{18,1}(\text{Sm})$	1635,2 (5)	0,00015 (5)
$\gamma_{14,0}(\text{Gd})$	1643,6 (1)	0,0015 (4)
$\gamma_{19,1}(\text{Sm})$	1647,41 (14)	0,0064 (4)
$\gamma_{(-1,14)}(\text{Sm})$	1674,30 (6)	0,0060 (8)
$\gamma_{19,0}(\text{Sm})$	1769,09 (5)	0,0092 (3)

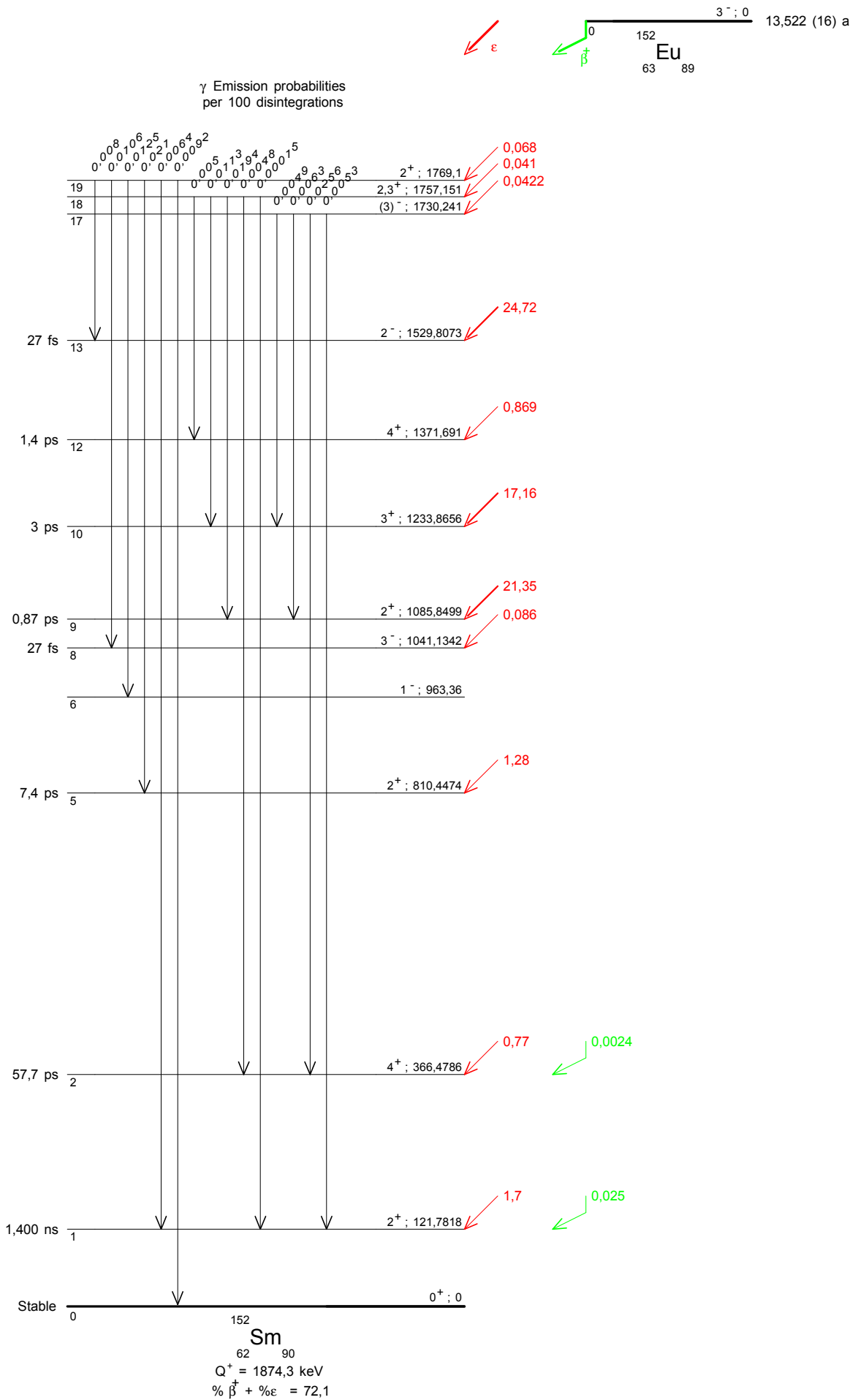
6 Main Production Modes

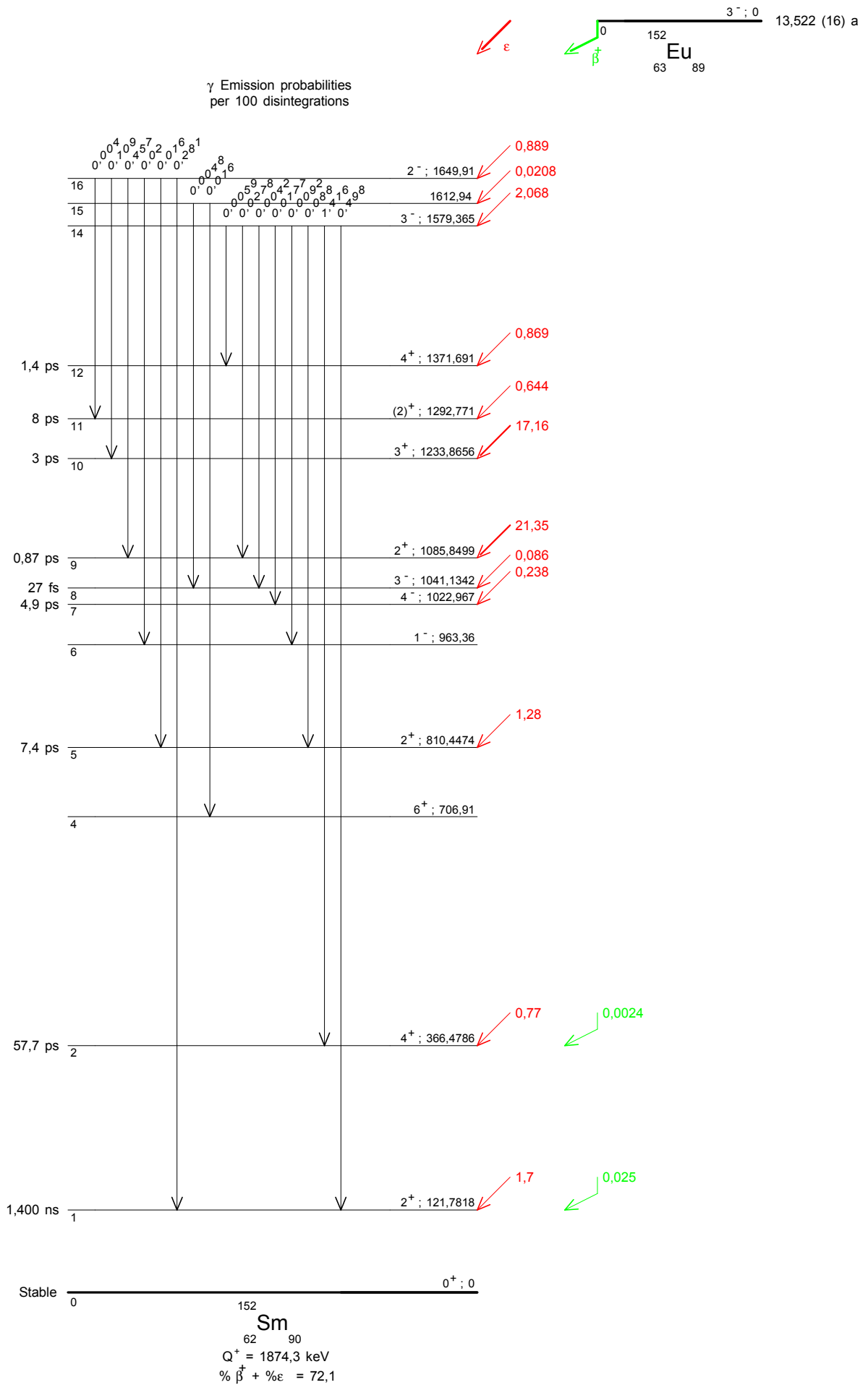
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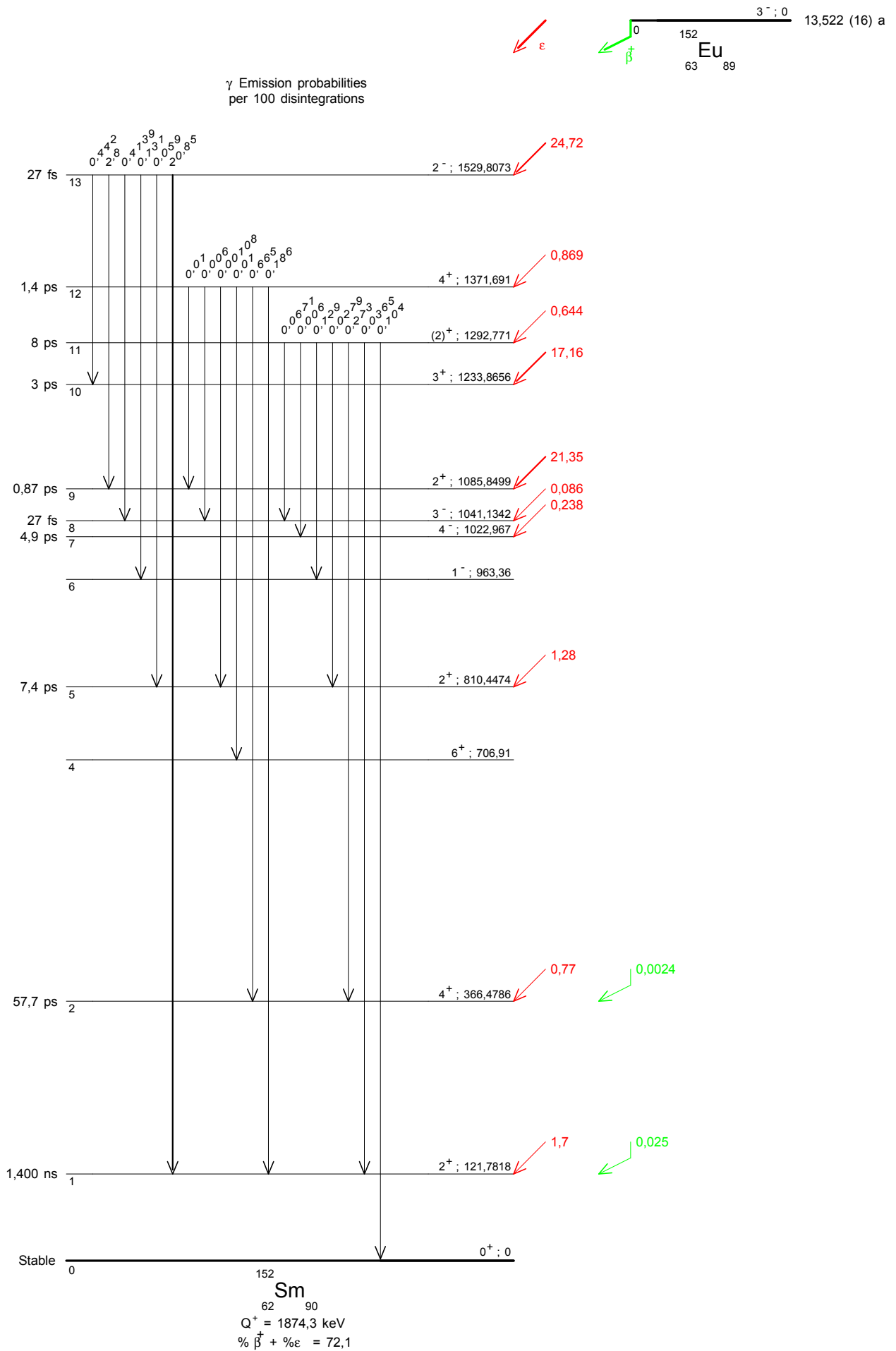
7 References

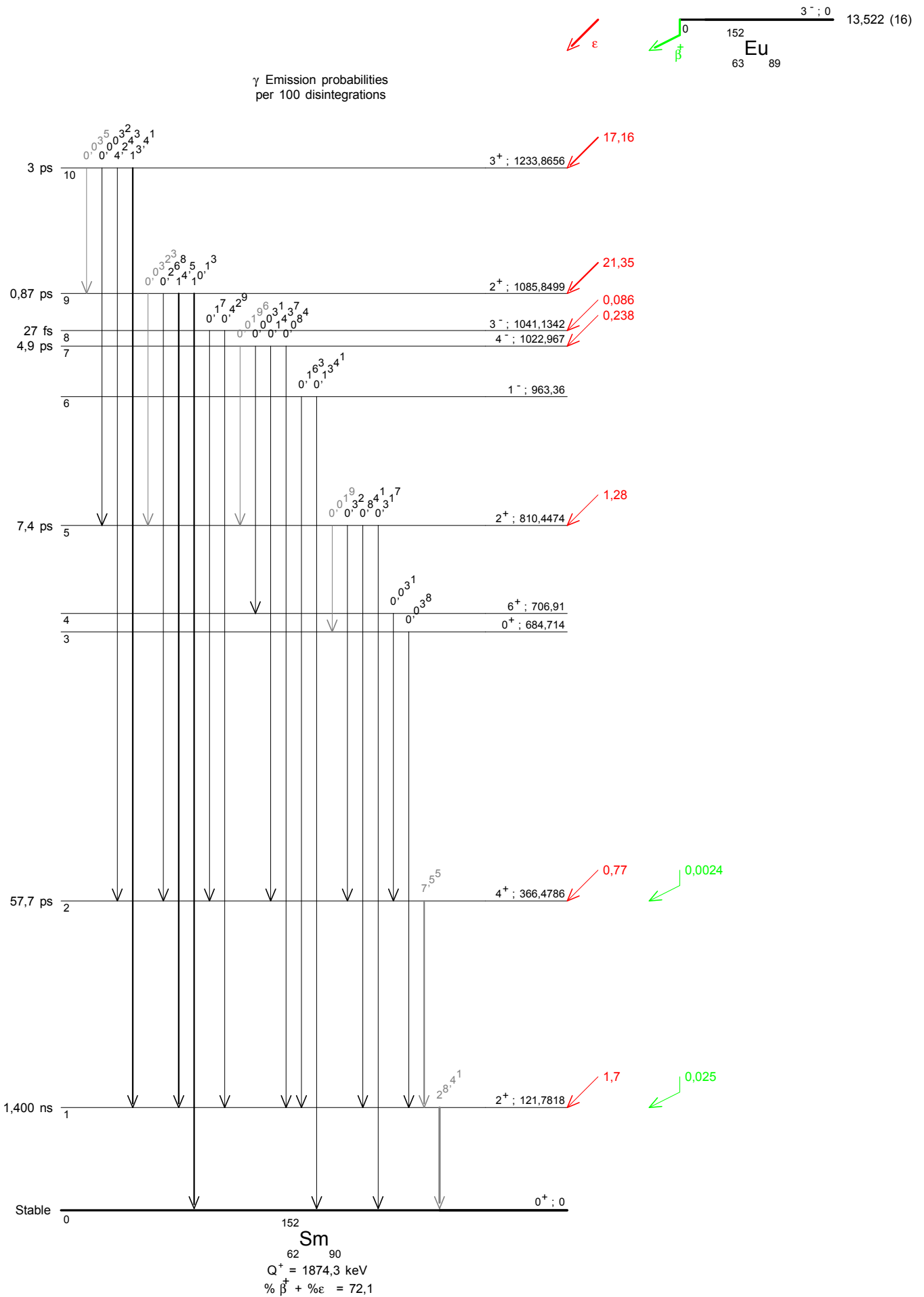
- P. F. ZWEIFEL. Phys. Rev. 107 (1957) 329
(Electron Capture/Beta plus ratio)
- A. NOTEA, E. ELIAS. Nucl. Instrum. Methods 86 (1970) 269
(Gamma-ray emission probabilities)
- L. L. RIEDINGER, N. R. JOHNSON, J. H. HAMILTON. Phys. Rev. C2 (1970) 2358
(Gamma-ray emission probabilities)
- J. BARRETTE, M. BARRETTE, A. BOUTARD, G. LAMOUREUX, S. MONARO, S. MARKIZA. Can. J. Phys. 49 (1971) 2462
(Gamma-ray emission probabilities)
- K. R. BAKER, J. H. HAMILTON, A. V. RAMAYYA. Z. Physik 256 (1972) 387
(Gamma-ray emission probabilities)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
(Half-life)
- F. B. LARKINS. At. Data Nucl. Data Tables 20 (1977) 313
(Atomic Electron Binding Energies.)
- R. J. GHERKE, R. G. HELMER, R. C. GREENWOOD. Nucl. Instrum. Methods 147 (1977) 405
(Gamma-ray emission probabilities)
- F. LAGOUTINE, J. LEGRAND, C. BAC. Int. J. Appl. Radiat. Isotop. 29 (1978) 269
(Half-life)
- F. RÖSEL, H. M. FRIESS, K. ALDER, H. C. PAULI. At. Data Nucl. Data Tables 21 (1978) 92
(Theoretical ICC)
- K. DEBERTIN. Report PTB-Ra-7 (1978)
(Gamma-ray emission probabilities)
- K. DEBERTIN. Nucl. Instrum. Methods 158 (1979) 479
(Gamma-ray emission probabilities)
- A. K. SHARMA, R. KAUR, H. R. VERMA, P. N. TREAHAN. J. Phys. Soc. Jpn 48 (1980) 1407
(Gamma-ray emission probabilities)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. NBS Special Publication 626 (1982) 5
(Half-life)
- S. BABA, K. ICHIKAWA, K. GUNJI, T. SEKINE, H. BABA, T. KOMORI. Int. J. Appl. Radiat. Isotop. 34 (1983) 891
(Half-life)
- K. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- Y. IWATA, M. YASUHARA, K. MAEDA, Y. YOSHIZAWA. Nucl. Instrum. Methods 219 (1984) 123
(Gamma-ray emission probabilities)
- W. L. ZIJP. Report FYS/RASA-85 19 (1985)
(Limitation of Relative Statistical Weights)
- D. MEHTA, M. L. GARG, J. SINGH, N. SINGH, T. S. CHEEMA, P. N. TREHAN. Nucl. Instrum. Methods A219 (1986) 447
(Gamma-ray emission probabilities)
- M. J. WOODS, S. E. M. LUCAS. Int. J. Appl. Radiat. Isotop. 37 (1986) 1157
(Half-life)
- E. R. COHEN, B. N. TAYLOR. Rev. Mod. Phys. 59 (1987) 1121
(Fundamental Constants)
- T. W. BURROWS. Report BNL-NCS-52142 (1988)
(The program RADLST.)
- V. N. DANILENKO, N. P. GROMOVA, A. A. KONSTANTINOV, N. V. KURENKOV, A. B. MALININ, S. V. MATVEEV, T. E. SAZONOVA, E. K. STEPANOV, S. V. SEPMAN, I. N. TRONOVA. Appl. Rad. Isotopes 40 (1989) 711
(Gamma-ray emission probabilities)
- N. M. STEWART, E. EID, M. S. S. EL-DAGHMAH, J. K. JABBER. Z. Physik A335 (1990) 13
(Gamma-ray emission probabilities)

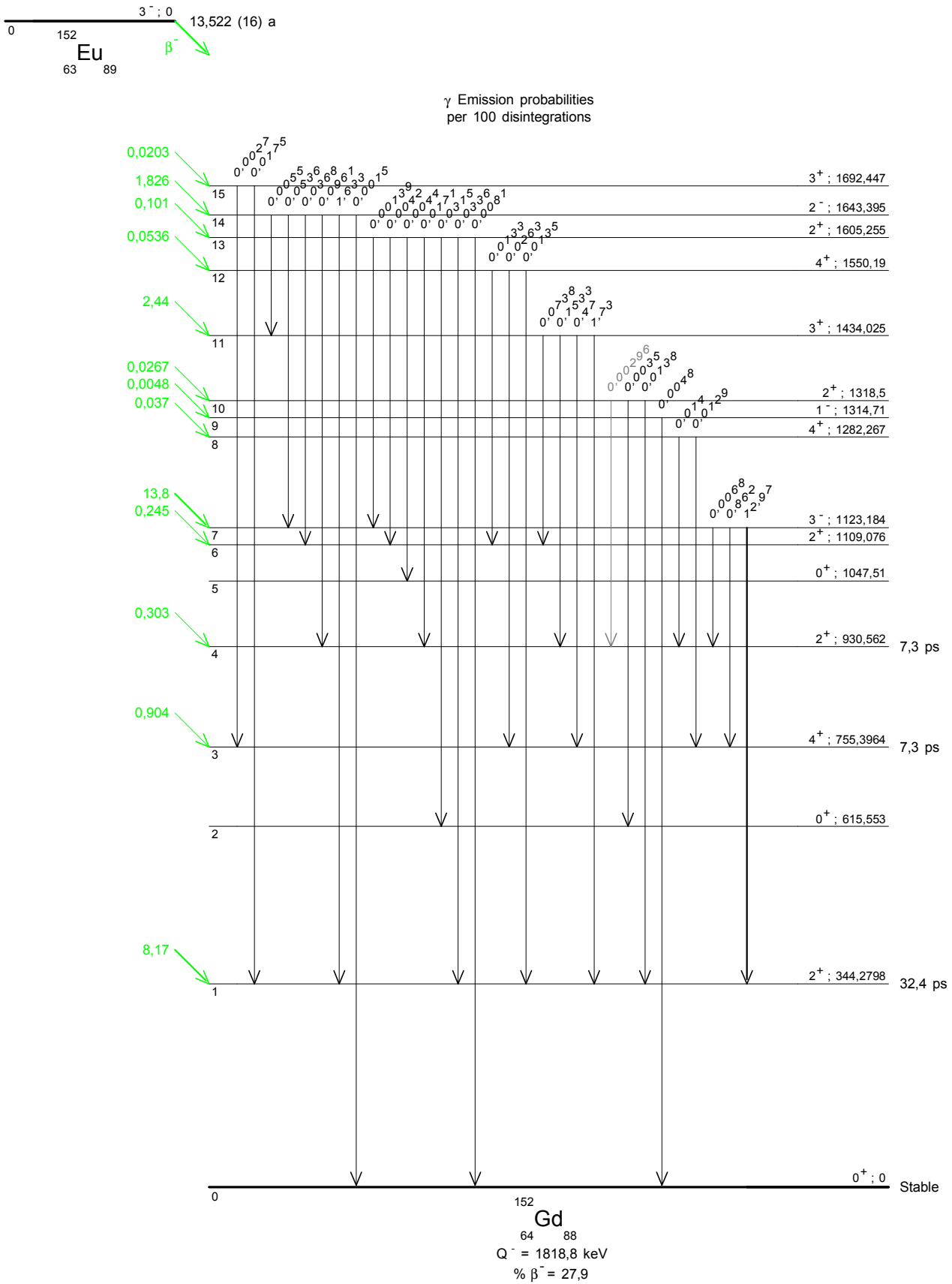
- R. A. MEYER. Fizika 22 (1990) 153
(Gamma-ray emission probabilities)
- W. BAMBYNEK, T. BARTA, R. JEDLOVSKY, P. CHRISTMAS, N. COURSOL, K. DEBERTIN, R. G. HELMER, A. L. NICHOLS, F. J. SCHIMA, Y. YOSHIZAWA. Report IAEA-TECDOC 619 (1991)
(Gamma-ray emission probabilities)
- M. P. UNTERWEGER, D. D. HOPPE, F. J. SCHIMA. Nucl. Instrum. Methods A312 (1992) 349
(Half-life)
- Y. YAN, H. SUN, D. HU, J. HUO, Y. LIU. Z. Physik A344 (1992) 25
(Gamma-ray emission probabilities)
- M. U. RAJPUT, T. D. MAC MAHON. Nucl. Instrum. Methods A312 (1992) 289
(Limitation of Relative Statistical Weights)
- KAWALDEEP, V. KUMAR, K. S. DHILLON, K. SINGH. J. Phys. Soc. Jpn 62 (1993) 901
(Gamma-ray emission probabilities)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- A. ARTNA-COHEN. Nucl. Data Sheets 79 (1996) 1
(Gamma ray energies, Gamma-ray emission probabilities, Multipolarities)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(K fluorescence yield)
- R. H. MARTIN, K. I. W. BURNS, J. G. V. TAYLOR. Nucl. Instrum. Methods A390 (1997) 267
(Half-life)
- H. Y. HWANG, T. S. PARK, J. M. LEE. Appl. Rad. Isotopes 49 (1998) 1201
(Gamma-ray emission probabilities)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 (1998)
(K X-ray emission probabilities, K fluorescence yield.)
- E. YAKUSEV, N. COURSOL. Note CEA/LPRI 98/002 (1998)
(ICC, a computer program to interpolate theoretical conversion coefficients.)
- H. JANSSEN, E. SCHÖNFELD. (1998)
(EMISSION, a computer program to calculate X-ray and Auger-electron emission probabilities.)
- E. SCHÖNFELD, F. Y. CHU, E. BROWNE. (1998)
(EC-CAPTURE, a computer program to calculate EC probabilities to atomic sub-shells.)
- E. SCHÖNFELD. Appl. Rad. Isotopes 49 (1998) 1353
(PK,PL,PM)
- H. SIEGERT, H. SCHRADER, U. SCHÖTZIG. Appl. Rad. Isotopes 49 (1998) 1397
(Half-life)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-1999-1 (1999)
(K X-ray energies, K Auger electron energies)
- R.G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma ray energies)
- H.SCHRADER. Appl. Rad. Isotopes 60,2-3 (2004) 317
(Half-life)

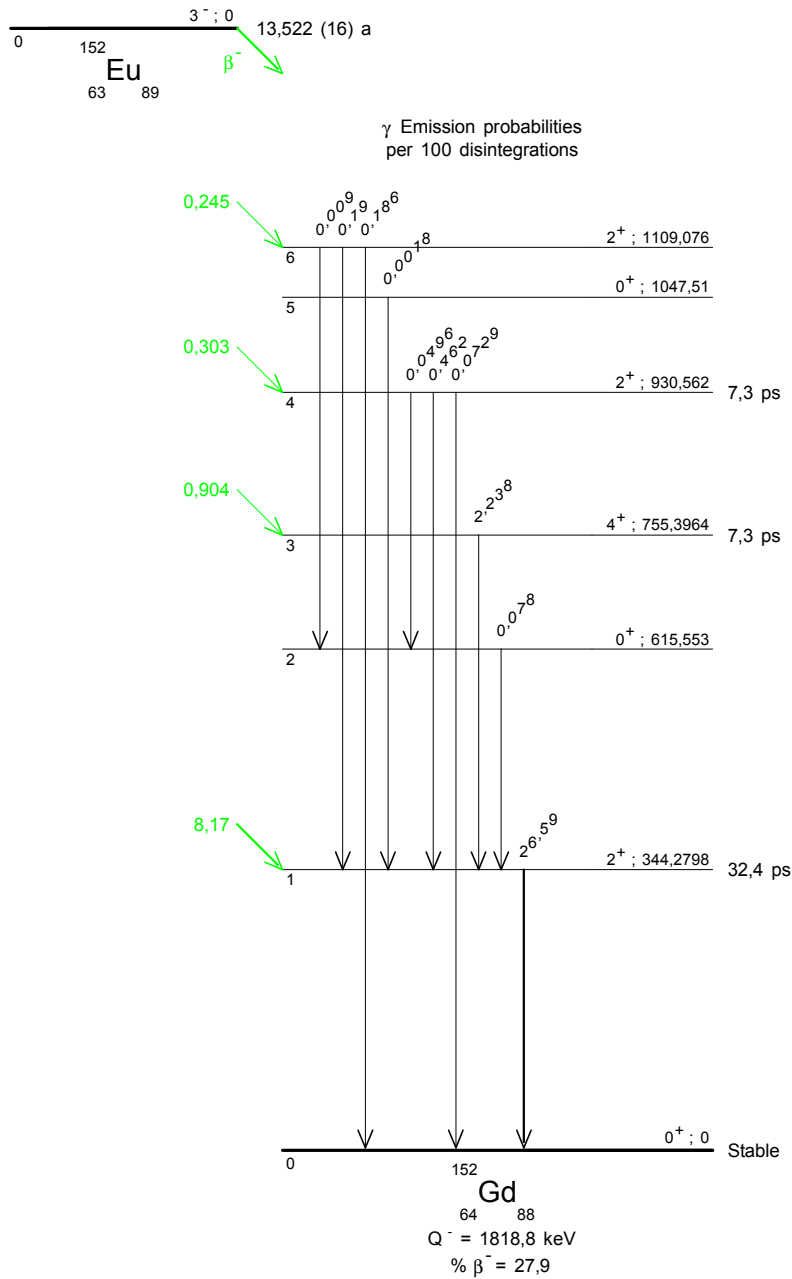














1 Decay Scheme

Gd-153 disintegrates by 100% electron capture to levels in Eu-153.

Le gadolinium 153 se désintègre à 100% par capture électronique vers des niveaux excités de l'euporium 153.

2 Nuclear Data

$$T_{1/2}({}^{153}\text{Gd}) : 240,4 \text{ (10) d}$$

$$Q^+({}^{153}\text{Gd}) : 484,4 \text{ (11) keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	P_K	P_L	P_M
$\epsilon_{0,4}$	311,5 (11)	15,9 (6)	1st forbidden	7,9	0,8019 (19)	0,1519 (4)	0,0359 (9)
$\epsilon_{0,3}$	381,2 (11)	42,4 (18)	1st forbidden	7,7	0,8111 (18)	0,1452 (16)	0,0341 (8)
$\epsilon_{0,2}$	387,0 (11)	38,0 (11)	Allowed	7,7	0,8116 (18)	0,1448 (16)	0,034 (8)
$\epsilon_{0,1}$	401,0 (11)	0,08 (7)	1st forbidden				
$\epsilon_{0,0}$	484,4 (11)	4 (3)	1st forbidden	8,9	0,8192 (17)	0,1392 (15)	0,0324 (8)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{2,1}(\text{Eu})$	14,06383 (20)	0,244 (61)	E1		8,70 (26)	1,92 (6)	11,2 (3)
$\gamma_{3,1}(\text{Eu})$	19,81296 (19)	0,39 (1)	E2		2523 (76)	579 (17)	3290 (99)
$\gamma_{4,3}(\text{Eu})$	69,67302 (13)	2,42 (7)	M1+1,8%E2	4,48 (14)	0,730 (23)	0,204 (6)	5,41 (16)
$\gamma_{4,2}(\text{Eu})$	75,42215 (21)	0,138 (3)	E1+0,3%M2	0,63 (5)	0,113 (15)	0,032 (4)	0,77 (7)
$\gamma_{1,0}(\text{Eu})$	83,36719 (17)	0,950 (7)	M1+65,6%E2	2,37 (7)	1,13 (5)	0,329 (12)	3,82 (12)
$\gamma_{4,1}(\text{Eu})$	89,48598 (21)	0,252 (5)	M1+6,2%E2	2,15 (6)	0,39 (7)	0,110 (17)	2,65 (6)
$\gamma_{2,0}(\text{Eu})$	97,43103 (17)	37,9 (8)	E1	0,258 (8)	0,0384 (12)	0,0105 (3)	0,307 (9)
$\gamma_{3,0}(\text{Eu})$	103,18016 (13)	57,4 (6)	M1+1,4%E2	1,45 (5)	0,216 (7)	0,0603 (18)	1,72 (5)
$\gamma_{4,0}(\text{Eu})$	172,85317 (13)	0,050 (2)	M1+65,6%E2	0,300 (5)	0,064 (2)	0,0184	0,382 (6)

3 Atomic Data

3.1 Eu

ω_K	:	0,929	(4)
$\bar{\omega}_L$	:	0,168	(7)
n_{KL}	:	0,853	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	40,9024	55,42	
	K α_1	41,5427	100	
	K β_3	46,9004	}	
	K β_1	47,0384	}	
	K β_5''	47,373	}	31,5
	K β_2	48,2566	}	
	K β_4	48,386	}	8,1
	KO _{2,3}	48,4979	}	
	X _L	L α	5,85 –	
		L γ	– 8,03	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	32,25 – 34,38	100
KLX	38,59 – 41,27	51
KXY	44,9 – 48,2	6,5
Auger L	3,4 – 7,8	18,9

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Eu)	3,4 - 7,8	111,5 (25)
e _{AK}	(Eu)		9,3 (6)
	KLL	32,25 - 34,38	}
	KLX	38,59 - 41,27	}
	KXY	44,9 - 48,2	}
ec _{2,1} L	(Eu)	6,012 - 7,097	0,174 (24)
ec _{3,1} L	(Eu)	11,761 - 12,836	0,30 (8)
ec _{4,3} K	(Eu)	21,1540 (5)	10,8 (5)
ec _{1,0} K	(Eu)	34,8482 (5)	0,47 (2)
ec _{2,0} K	(Eu)	48,9120 (5)	7,5 (3)
ec _{3,0} K	(Eu)	54,6611 (5)	30,6 (11)
ec _{4,3} L	(Eu)	61,621 - 62,896	1,77 (8)
ec _{4,3} M	(Eu)	67,873 - 68,742	0,49 (2)
ec _{1,0} L	(Eu)	75,315 - 76,390	0,22 (2)
ec _{2,0} L	(Eu)	89,379 - 90,454	1,10 (5)
ec _{3,0} L	(Eu)	95,128 - 96,203	4,6 (2)
ec _{2,0} M	(Eu)	95,631 - 96,300	0,30 (1)
ec _{3,0} M	(Eu)	101,38 - 102,10	1,30 (5)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Eu)	5,85 — 8,03	22,5 (11)
XK α_2	(Eu)	40,9024	34,5 (9)
XK α_1	(Eu)	41,5427	62,2 (15)
XK β_3	(Eu)	46,9004	}
XK β_1	(Eu)	47,0384	}
XK β_5''	(Eu)	47,373	}
XK β_2	(Eu)	48,2566	}
XK β_4	(Eu)	48,386	}
XKO _{2,3}	(Eu)	48,4979	}
			19,6 (6)
			5,05 (17)

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{2,1}(\text{Eu})$	14,06383 (20)	0,020 (5)
$\gamma_{3,1}(\text{Eu})$	19,81296 (19)	0,00012
$\gamma_{4,3}(\text{Eu})$	69,67302 (13)	2,42 (7)
$\gamma_{4,2}(\text{Eu})$	75,42213 (23)	0,078 (3)
$\gamma_{1,0}(\text{Eu})$	83,36717 (21)	0,197 (7)
$\gamma_{4,1}(\text{Eu})$	89,48595 (22)	0,069 (5)
$\gamma_{2,0}(\text{Eu})$	97,43100 (21)	29,0 (8)
$\gamma_{3,0}(\text{Eu})$	103,18012 (17)	21,1 (6)
$\gamma_{4,0}(\text{Eu})$	172,85307 (21)	0,036 (2)

6 Main Production Modes

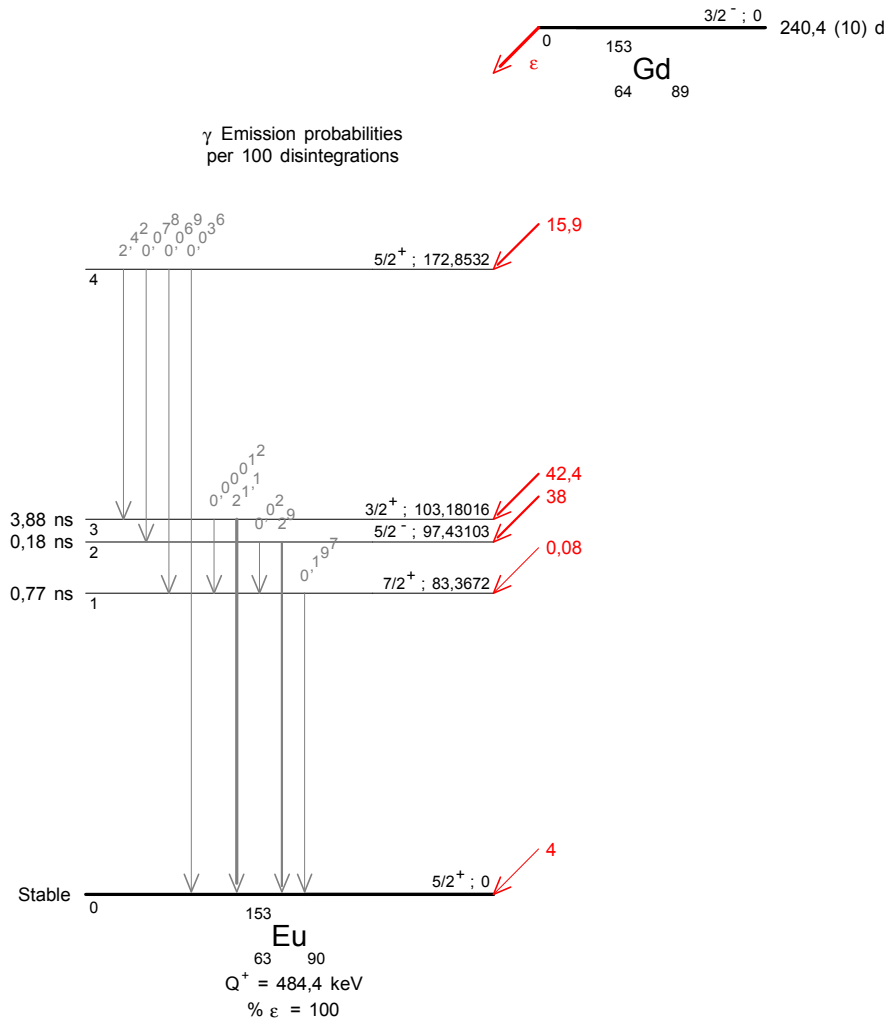
Gd – $^{152}(\text{n},\gamma)\text{Gd} - 153$

Eu – $^{153}(\text{d},2\text{n})\text{Gd} - 153$

7 References

- R.E.HEIN, A.F.VOIGT. Phys.Rev. 79 (1950) 783
(Half-life)
- D.C.HOFFMAN. J. Inorg. Nucl. Chem. 25 (1963) 1196
(Half-life)
- K.MÜHLBAUER. Z.Phys. 230 (1970) 18
(Gamma-ray energies)
- J.F.EMERY, S.A.REYNOLDS, E.I.WYATT, K.I. GLEASON. Nucl.Sci.Eng. 48 (1972) 319
(Half-life)
- V.A.SERGIENKO, V.M.LEBEDEV. Bull. Ac.Sc. URSS Phys.Ser.38 4 (1974) 122
(Gamma-ray emission probabilities)
- K.SINGH, H.S.SAHOTA. Indian J. Phys. 59A (1985) 95
(Gamma-ray emission probabilities)
- E.BROWNE, R.B.FIRESTONE. Table of Radioactive Isotopes, Appendix C, Table 7a (John Wiley and Sons, New York) C (1986) 7a
(P Xrel)
- B.M.COURSEY, D.D.HOPPE, F.J.SHIMA, M.P.UNTERWEGER. Appl. Rad. Isotopes 38 (1987) 31
(Gamma-ray emission probabilities)
- S.SUBRAHMANYESWARA RAO, K.BHASKARA RAO, V.SESHAGIRI RAO, H.C.PADHI. J.Phys.G.Nucl.Phys 14 (1988) 1259
(Gamma-ray emission probabilities)
- N.VENKATESWARA RAO, G.S.SRI KRISHNA, S. BHULOKA REDDY, C.V.RAGHAVAIAH, G.SATYANARAYANA, D.L.SASTRY. Nuovo Cim. 99A (1988) 303
(Gamma-ray emission probabilities)
- YU.S.POPOV, N.YU.NEZGOVOROV, G.A.TIMOFEEV. Sov. J. Radiochem. 31 (1989) 1
(Half-life)
- B.CHAND, J.GOSWAMY, D.METHA, N.SINGH, P.N.TREHAN. Appl. Rad. Isotopes 43 (1992) 997
(Gamma-ray emission probabilities)
- V.P.CHECHEV, A.G.EGOROV. Nucl. Instrum. Methods Phys. Res. A 312 (1992) 378
(Gamma-ray emission probabilities)

- M.P.UNTERWEGER, D.D.HOPPES, F.J.SHIMA. Nucl. Instrum. Methods Phys. Res. A 312 (1992) 349
(Half-life)
- A.G.EGOROV, V.P.CHECHEV, G.E.SHCHUKIN. Bull. Acad. Sci. URSS, Phys. 57 5 (1993) 911
(Gamma-ray emission probabilities)
- E. SCHÖNFELD. Report PTB 6.33-95-2 (1995)
(Elec. capt. probabilities in atomic shells)
- V.KUMAR, KAWALDEEP, K.SINGH. J.Radioanal.Nucl.Chem. 189 (1995) 3
(Gamma-ray emission probabilities)
- G. AUDI, A.H.WAPSTRA. Nucl.Phys. A595 (1995) 409
(Q)
- E. SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods Phys. Res. A 369 (1996) 572
(Atomic Data)
- R.G.HELMER. Nuclear Data Sheets 83 (1998) 285
(Multipolarities)
- R.G.HELMER, C.VAN DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
(Gamma-ray energies)





1 Decay Scheme

Sm-153 disintegrates via 3 main branches and at least 10 others very weak branches by 100% beta-emission to levels in Eu-153.

Le samarium 153 se désintègre vers 3 branches principales et vers au moins 10 autres branches plus faibles de l'euporium 153 par émission bêta moins.

2 Nuclear Data

$$T_{1/2}({}^{153}\text{Sm}) : 1,92849 \quad (11) \quad \text{d}$$

$$Q^{-}({}^{153}\text{Sm}) : 808,2 \quad (8) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,18}^{-}$	44,4 (8)	0,000025 (25)		8,9
$\beta_{0,17}^{-}$	47,8 (8)	0,00063 (7)		7,9
$\beta_{0,16}^{-}$	89,5 (8)	0,00134 (15)	Allowed	8,4
$\beta_{0,15}^{-}$	95,1 (8)	0,0135 (8)		7,4
$\beta_{0,14}^{-}$	101,6 (8)	0,0237 (8)	Allowed	7,3
$\beta_{0,13}^{-}$	106,7 (8)	0,00076 (15)		8,8
$\beta_{0,12}^{-}$	114,0 (8)	0,0242 (10)	Allowed	7,4
$\beta_{0,11}^{-}$	126,3 (8)	0,0102 (4)	1st forbidden	7,9
$\beta_{0,10}^{-}$	150,5 (8)	0,0005 (5)		9,3
$\beta_{0,9}^{-}$	171,7 (8)	0,0665 (13)	1st forbidden	7,5
$\beta_{0,8}^{-}$	173,5 (8)	0,0568 (11)	Allowed	7,6
$\beta_{0,7}^{-}$	223,2 (8)	0,00228 (6)		9,4
$\beta_{0,6}^{-}$	538,4 (8)	0,0012 (12)	2nd forbidden	11
$\beta_{0,5}^{-}$	635,3 (8)	31,1 (10)	Allowed	6,7
$\beta_{0,4}^{-}$	656,6 (8)	0,034 (12)	Unique 1st forbidden	10
$\beta_{0,3}^{-}$	705,0 (8)	49,6 (19)	Allowed	6,7

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,2}^-$	710,8 (8)	0,59 (6)	1st forbidden	8,6
$\beta_{0,0}^-$	808,2 (8)	18,4 (18)	Allowed	7,3

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{2,1}$ (Eu)	14,06383 (24)		E1		8,7 (3)	1,92 (6)	11,2 (4)
$\gamma_{3,1}$ (Eu)	19,81296 (21)	0,28	E2		2523 (76)	579 (18)	3290 (99)
$\gamma_{4,2}$ (Eu)	54,1936 (12)	0,0304 (4)	M1+E2	7,9 (15)	5 (4)	1,5 (8)	15 (5)
$\gamma_{4,1}$ (Eu)	68,2557 (12)	0,0023 (4)	E1	0,664 (20)	0,105 (3)	0,0285 (9)	0,797 (24)
$\gamma_{5,3}$ (Eu)	69,67300 (13)	30,32 (3)	M1+1,82%E2	4,48 (13)	0,731 (23)	0,204 (6)	5,41 (16)
$\gamma_{5,2}$ (Eu)	75,42213 (21)	0,342 (26)	E1+0,3%M2	0,63 (5)	0,113 (14)	0,032 (4)	0,77 (7)
$\gamma_{1,0}$ (Eu)	83,36717 (17)	0,927 (7)	M1+40%E2	2,37 (8)	1,13 (6)	0,329 (12)	3,83 (12)
$\gamma_{5,1}$ (Eu)	89,48595 (21)	0,577 (55)	M1+5,8%E2	2,15 (7)	0,39 (7)	0,111 (17)	2,65 (10)
$\gamma_{6,5}$ (Eu)	96,8825 (7)	0,024	M1+E2	1,52 (23)	0,7 (5)	0,16 (9)	2,4 (4)
$\gamma_{2,0}$ (Eu)	97,43100 (21)	1,009 (18)	E1	0,258 (8)	0,0384 (12)	0,0105 (3)	0,307 (9)
$\gamma_{3,0}$ (Eu)	103,18012 (17)	79,7 (3)	M1+1,4%E2	1,45 (4)	0,216 (6)	0,061 (2)	1,72 (5)
$\gamma_{6,4}$ (Eu)	118,1105 (10)	0,00027 (6)	[E1]	0,153 (5)	0,0223 (7)	0,0061 (2)	0,181 (5)
$\gamma_{4,0}$ (Eu)	151,6245 (12)	0,0116 (4)	E1	0,0782 (23)	0,0111 (3)	0,00315 (9)	0,092 (3)
$\gamma_{6,3}$ (Eu)	166,5548 (15)	0,00086 (6)	[E2]	0,268 (9)	0,104 (3)	0,0304 (9)	0,403 (12)
$\gamma_{6,2}$ (Eu)	172,3035 (13)	0,0004	[E1]	0,0555 (16)	0,0078 (2)	0,00214 (6)	0,0655 (20)
$\gamma_{5,0}$ (Eu)	172,85307 (21)	0,1019 (20)	M1+40%E2	0,301 (10)	0,064 (3)	0,0184 (8)	0,382 (11)
$\gamma_{7,5}$ (Eu)	412,17 (10)	0,00192 (5)					
$\gamma_{12,6}$ (Eu)	424,45 (11)	0,00189 (5)					
$\gamma_{14,6}$ (Eu)	436,89 (9)	0,00170 (15)					
$\gamma_{15,6}$ (Eu)	443,38 (20)	0,000088 (15)					
$\gamma_{8,5}$ (Eu)	461,81 (12)	0,00158 (26)					
$\gamma_{9,5}$ (Eu)	463,62 (10)	0,0136 (6)					
$\gamma_{10,5}$ (Eu)	484,82 (14)	0,00038 (3)					
$\gamma_{7,2}$ (Eu)	487,59 (15)	0,00036					
$\gamma_{11,5}$ (Eu)	509,06 (10)	0,00199 (18)					
$\gamma_{12,5}$ (Eu)	521,34 (11)	0,0069 (3)					
$\gamma_{8,3}$ (Eu)	531,47 (12)	0,0547 (9)					
$\gamma_{9,3}$ (Eu)	533,29 (10)	0,0299 (6)					
$\gamma_{9,2}$ (Eu)	539,04 (10)	0,0211 (6)					
$\gamma_{12,4}$ (Eu)	542,56 (11)	0,0032 (9)					
$\gamma_{16,5}$ (Eu)	545,84 (14)	0,00076 (3)					
$\gamma_{14,4}$ (Eu)	555,01 (9)	0,00474 (9)					
$\gamma_{10,1}$ (Eu)	574,31 (14)	0,00016 (5)					
$\gamma_{11,3}$ (Eu)	578,73 (10)	0,00328 (9)					
$\gamma_{11,2}$ (Eu)	584,48 (10)	0,00106 (3)					
$\gamma_{17,5}$ (Eu)	587,54 (17)	0,00050 (5)					
$\gamma_{12,3}$ (Eu)	591,01 (11)	0,00118 (5)					
$\gamma_{12,2}$ (Eu)	596,76 (11)	0,0109 (3)					
$\gamma_{13,3}$ (Eu)	598,28 (24)	0,0018 (3)					
$\gamma_{11,1}$ (Eu)	598,54 (10)	0,0018 (3)					
$\gamma_{14,3}$ (Eu)	603,45 (9)	0,00448 (12)					
$\gamma_{13,2}$ (Eu)	604,03 (24)	0,00448 (12)					
$\gamma_{14,2}$ (Eu)	609,20 (9)	0,0128 (7)					
$\gamma_{15,3}$ (Eu)	609,95 (20)	0,0128 (7)					
$\gamma_{16,3}$ (Eu)	615,51 (14)	0,00056 (15)					
$\gamma_{15,2}$ (Eu)	615,69 (20)	0,00056 (15)					
$\gamma_{13,1}$ (Eu)	618,09 (24)	0,00073 (15)					

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{15,1}(\text{Eu})$	629,75 (20)	0,000099 (15)					
$\gamma_{8,0}(\text{Eu})$	634,66 (12)	0,00052 (6)					
$\gamma_{9,0}(\text{Eu})$	636,47 (10)	0,00193 (12)					
$\gamma_{17,3}(\text{Eu})$	657,21 (7)	0,00040 (2)					
$\gamma_{10,0}(\text{Eu})$	657,67 (25)	0,00040 (2)					
$\gamma_{17,2}(\text{Eu})$	662,96 (17)	0,00005 (4)					
$\gamma_{17,1}(\text{Eu})$	677,02 (17)	0,000044 (15)					
$\gamma_{11,0}(\text{Eu})$	681,91 (10)	0,00015 (12)					
$\gamma_{12,0}(\text{Eu})$	694,19 (11)	0,000020 (6)					
$\gamma_{13,0}(\text{Eu})$	701,46 (24)	0,000029 (6)					
$\gamma_{14,0}(\text{Eu})$	706,63 (9)	0,000023 (12)					
$\gamma_{15,0}(\text{Eu})$	713,12	0,000231 (20)					
$\gamma_{16,0}(\text{Eu})$	718,69 (14)	0,000025 (5)					
$\gamma_{17,0}(\text{Eu})$	760,39 (17)	0,000032 (5)					
$\gamma_{18,0}(\text{Eu})$	763,8 (8)	0,000044 (12)					

3 Atomic Data

3.1 Eu

ω_K	:	0,929	(4)
$\bar{\omega}_L$	:	0,168	(7)
n_{KL}	:	0,853	(4)

3.1.1 X Radiations

	Energy keV	Relative probability
X _K		
$K\alpha_2$	40,9024	55,42
$K\alpha_1$	41,5427	100
$K\beta_3$	46,904	}
$K\beta_1$	47,0384	}
$K\beta_5''$	47,373	}
		31,5
$K\beta_2$	48,266	}
$K\beta_4$	48,386	}
$KO_{2,3}$	48,499	}
		8,13
X _L		
$L\alpha$	5,18 – 8,03	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	32,24 – 34,38	100
KLX	38,59 – 41,52	51
KXY	44,9 – 48,5	6,5
Auger L	3,4 – 7,8	1870

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Eu)	3,4 - 7,8		56,1 (16)
e _{AK}	(Eu)			4,7 (3)
	KLL	32,24 - 34,38	}	
	KLX	38,59 - 41,52	}	
	KXY	44,9 - 48,5	}	
ec _{3,1} L	(Eu)	11,760 - 12,836		0,214
ec _{5,3} T	(Eu)	21,154 - 68,542		25,6 (11)
ec _{5,3} K	(Eu)	21,1541 (5)		21 (1)
ec _{5,2} K	(Eu)	26,9031 (5)		0,122 (17)
ec _{1,0} K	(Eu)	34,8482 (5)		0,46 (3)
ec _{5,1} K	(Eu)	40,9669 (5)		0,34 (3)
ec _{2,0} K	(Eu)	48,9121 (5)		0,199 (6)
ec _{3,0} T	(Eu)	54,661 - 102,049		50,3 (15)
ec _{3,0} K	(Eu)	54,6611 (5)		42,4 (13)
ec _{5,3} L	(Eu)	61,621 - 62,696		3,46 (17)
ec _{5,3} M	(Eu)	67,873 - 68,542		0,96 (5)
ec _{1,0} L	(Eu)	75,315 - 76,390		0,22 (1)
ec _{5,1} L	(Eu)	81,434 - 82,509		0,062 (6)
ec _{1,0} M	(Eu)	81,567 - 82,236		0,063 (3)
ec _{3,0} L	(Eu)	95,128 - 96,203		6,3 (2)
ec _{3,0} M	(Eu)	101,380 - 102,049		1,78 (6)
$\beta_{0,18}^-$	max:	44,4	(8)	0,000025 (25)
$\beta_{0,18}^-$	avg:	11,3	(3)	
$\beta_{0,17}^-$	max:	47,8	(8)	0,00063 (7)
$\beta_{0,17}^-$	avg:	12,19	(22)	
$\beta_{0,16}^-$	max:	89,5	(8)	0,00134 (15)
$\beta_{0,16}^-$	avg:	23,29	(22)	

		Energy keV		Electrons per 100 disint.
$\beta_{0,15}^-$	max:	95,1	(8)	0,0135 (8)
$\beta_{0,15}^-$	avg:	24,80	(23)	
$\beta_{0,14}^-$	max:	101,6	(8)	0,0237 (8)
$\beta_{0,14}^-$	avg:	26,57	(22)	
$\beta_{0,13}^-$	max:	106,7	(8)	0,00076 (15)
$\beta_{0,13}^-$	avg:	27,99	(25)	
$\beta_{0,12}^-$	max:	114,0	(8)	0,0242 (10)
$\beta_{0,12}^-$	avg:	29,99	(23)	
$\beta_{0,11}^-$	max:	126,3	(8)	0,0102 (4)
$\beta_{0,11}^-$	avg:	33,41	(23)	
$\beta_{0,10}^-$	max:	150,5	(8)	0,0005 (5)
$\beta_{0,10}^-$	avg:	40,24	(24)	
$\beta_{0,9}^-$	max:	171,7	(8)	0,0665 (13)
$\beta_{0,9}^-$	avg:	46,32	(24)	
$\beta_{0,8}^-$	max:	173,5	(8)	0,0568 (11)
$\beta_{0,8}^-$	avg:	46,84	(24)	
$\beta_{0,7}^-$	max:	223,2	(8)	0,00228 (6)
$\beta_{0,7}^-$	avg:	61,5	(3)	
$\beta_{0,6}^-$	max:	538,4	(8)	0,0012 (12)
$\beta_{0,6}^-$	avg:	164,9	(3)	
$\beta_{0,5}^-$	max:	635,3	(8)	31,1 (10)
$\beta_{0,5}^-$	avg:	199,7	(3)	
$\beta_{0,4}^-$	max:	656,6	(8)	0,034 (12)
$\beta_{0,4}^-$	avg:	221,2	(3)	
$\beta_{0,3}^-$	max:	705,0	(8)	49,6 (19)
$\beta_{0,3}^-$	avg:	225,3	(3)	
$\beta_{0,2}^-$	max:	710,8	(8)	0,59 (6)
$\beta_{0,2}^-$	avg:	227,6	(3)	
$\beta_{0,0}^-$	max:	808,2	(8)	18,4 (18)
$\beta_{0,0}^-$	avg:	264,5	(3)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Eu)	5,18 — 8,03	10,04 (15)	
XK α_2	(Eu)	40,9024	16,3 (3)	} K α
XK α_1	(Eu)	41,5427	29,3 (4)	

		Energy keV	Photons per 100 disint.		
XK β_3	(Eu)	46,904	}	9,20 (14)	K' β_1
XK β_1	(Eu)	47,0384	}		
XK β_5''	(Eu)	47,373	}		
XK β_2	(Eu)	48,266	}	2,36 (11)	K' β_2
XK β_4	(Eu)	48,386	}		
XKO _{2,3}	(Eu)	48,499	}		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{3,1}$ (Eu)	19,81296 (21)	0,000085
$\gamma_{4,2}$ (Eu)	54,1936 (12)	0,0019 (4)
$\gamma_{4,1}$ (Eu)	68,2574 (12)	0,0013 (4)
$\gamma_{5,3}$ (Eu)	69,67300 (13)	4,73 (3)
$\gamma_{5,2}$ (Eu)	75,42213 (23)	0,193 (26)
$\gamma_{1,0}$ (Eu)	83,36717 (21)	0,192 (7)
$\gamma_{5,1}$ (Eu)	89,48595 (22)	0,158 (15)
$\gamma_{6,5}$ (Eu)	96,8824 (7)	0,007
$\gamma_{2,0}$ (Eu)	97,43100 (21)	0,772 (18)
$\gamma_{3,0}$ (Eu)	103,18012 (17)	29,26 (32)
$\gamma_{6,4}$ (Eu)	118,1105 (10)	0,00023 (6)
$\gamma_{4,0}$ (Eu)	151,6244 (12)	0,0106 (4)
$\gamma_{6,3}$ (Eu)	166,5546 (15)	0,00061 (6)
$\gamma_{6,2}$ (Eu)	172,3032 (13)	0,0004
$\gamma_{5,0}$ (Eu)	172,85307 (21)	0,0737 (20)
$\gamma_{7,5}$ (Eu)	412,05 (20)	0,00192 (5)
$\gamma_{12,6}$ (Eu)	424,4 (3)	0,00189 (5)
$\gamma_{14,6}$ (Eu)	436,9 (3)	0,00170 (15)
$\gamma_{15,6}$ (Eu)	443,2 (5)	0,000088 (15)
$\gamma_{8,5}$ (Eu)	462,0 (3)	0,00158 (26)
$\gamma_{9,5}$ (Eu)	463,6 (2)	0,0136 (6)
$\gamma_{10,5}$ (Eu)	485,0 (2)	0,00038 (3)
$\gamma_{7,2}$ (Eu)	487,75 (23)	0,00036
$\gamma_{11,5}$ (Eu)	509,15 (20)	0,00199 (18)
$\gamma_{12,5}$ (Eu)	521,30 (25)	0,0069 (3)
$\gamma_{8,3}$ (Eu)	531,40 (15)	0,0547 (9)
$\gamma_{9,3}$ (Eu)	533,2 (2)	0,0299 (6)
$\gamma_{9,2}$ (Eu)	539,1 (2)	0,0211 (6)
$\gamma_{12,4}$ (Eu)	542,7 (2)	0,0032 (9)
$\gamma_{16,5}$ (Eu)	545,75 (15)	0,00076 (3)
$\gamma_{14,4}$ (Eu)	554,94 (10)	0,00474 (9)
$\gamma_{10,1}$ (Eu)	574,1 (3)	0,00016 (5)
$\gamma_{11,3}$ (Eu)	578,75 (20)	0,00328 (9)

	Energy keV	Photons per 100 disint.
$\gamma_{11,2}(\text{Eu})$	584,55 (20)	0,00106 (3)
$\gamma_{17,5}(\text{Eu})$	587,60 (25)	0,00050 (5)
$\gamma_{12,3}(\text{Eu})$	590,96 (20)	0,00118 (5)
$\gamma_{12,2}(\text{Eu})$	596,7 (2)	0,0109 (3)
$\gamma_{13,3}(\text{Eu})$	598,3 (3)	0,0018 (3)
$\gamma_{11,1}(\text{Eu})$	598,54 (10)	0,0018 (3)
$\gamma_{14,3}(\text{Eu})$	603,6 (4)	0,00448 (12)
$\gamma_{13,2}(\text{Eu})$	604,03 (24)	0,00448 (12)
$\gamma_{14,2}(\text{Eu})$	609,5 (3)	0,0128 (7)
$\gamma_{15,3}(\text{Eu})$	609,95 (20)	0,0128 (7)
$\gamma_{16,3}(\text{Eu})$	615,51 (14)	0,00056 (15)
$\gamma_{15,2}(\text{Eu})$	615,8 (4)	0,00056 (15)
$\gamma_{13,1}(\text{Eu})$	617,9 (3)	0,00073 (15)
$\gamma_{15,1}(\text{Eu})$	630,5 (4)	0,000099 (15)
$\gamma_{8,0}(\text{Eu})$	634,8 (3)	0,00052 (6)
$\gamma_{9,0}(\text{Eu})$	636,5 (2)	0,00193 (12)
$\gamma_{17,3}(\text{Eu})$	657,21 (7)	0,00040 (2)
$\gamma_{10,0}(\text{Eu})$	657,55 (25)	0,00040 (2)
$\gamma_{17,2}(\text{Eu})$	662,4 (6)	0,00005 (4)
$\gamma_{17,1}(\text{Eu})$	677,0 (3)	0,000044 (15)
$\gamma_{11,0}(\text{Eu})$	682,0 (6)	0,00015 (12)
$\gamma_{12,0}(\text{Eu})$	694,1 (3)	0,000020 (6)
$\gamma_{13,0}(\text{Eu})$	701,8 (4)	0,000029 (6)
$\gamma_{14,0}(\text{Eu})$	706,8 (5)	0,000023 (12)
$\gamma_{15,0}(\text{Eu})$	713,9 (3)	0,000231 (20)
$\gamma_{16,0}(\text{Eu})$	719,0 (4)	0,000025 (5)
$\gamma_{17,0}(\text{Eu})$	760,5 (4)	0,000032 (5)
$\gamma_{18,0}(\text{Eu})$	763,8 (6)	0,000044 (12)

6 Main Production Modes

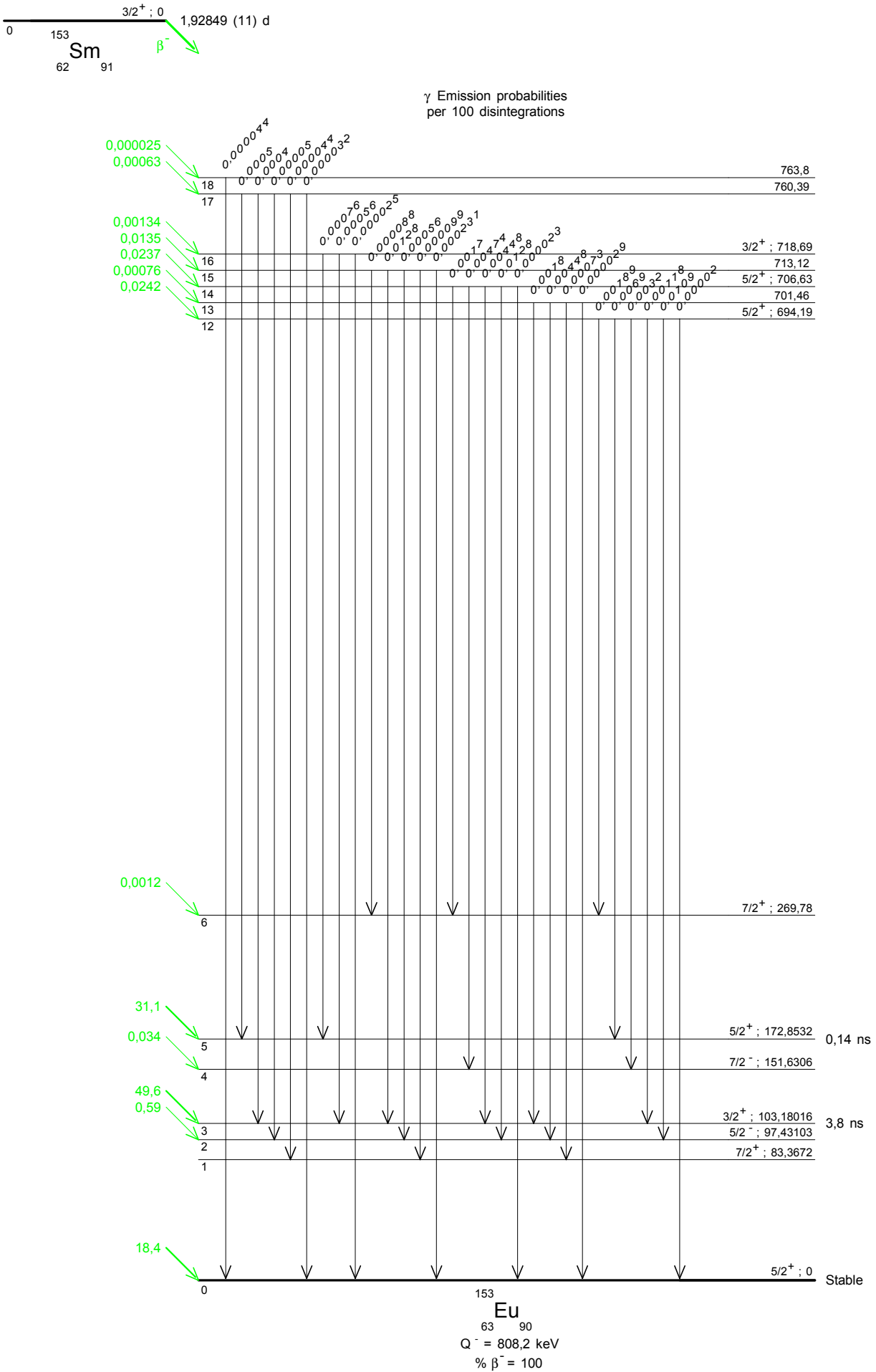
Sm – 152(n, γ)Sm – 153

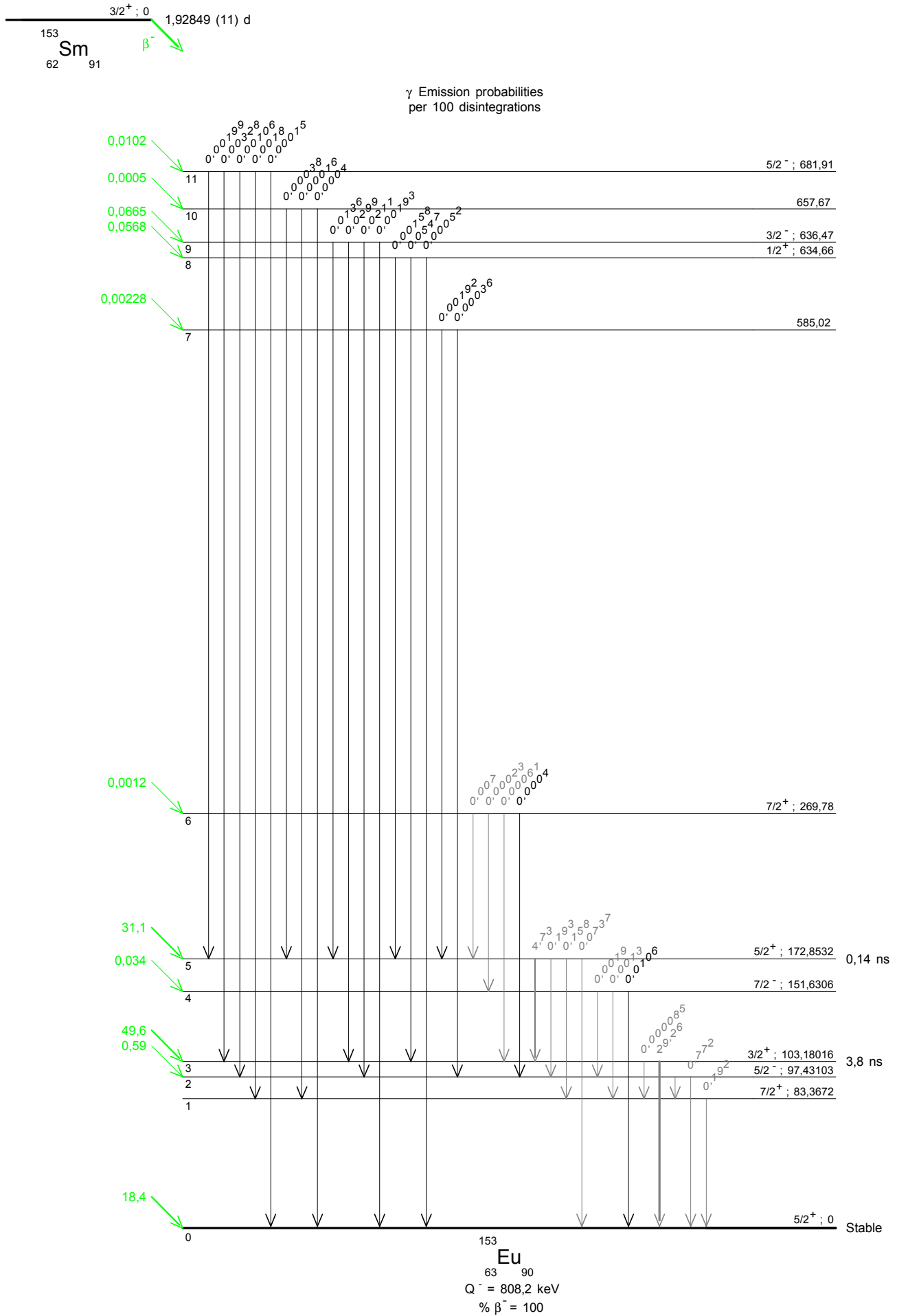
Nd – 150(α ,n)Sm – 153

7 References

- M. E. LEE, R. KATZ. Phys. Rev. 93 (1954) 155
(Half-life)
- J. M. CORK, M. K. BRICE, R. G. HELMER, R. M. WOODS. Phys. Rev. 110 (1958) 526
(Half-life)
- E. MONNAND, A. MOUSSA. Nucl. Phys. 25 (1961) 292
(L1/L2/L3, eA, KXY/KLX/KLL, E2/M1 for 70/83, Conv. Elec.)
- R. E. GREEN, W. H. WALKER. Can. J. Phys. 39 (1961) 1216
(Half-life)
- E. I. WYATT, S. A. REYNOLDS, T. H. HANDLEY, W. S. LYON, H. A. PARKER. Nucl. Sci. Eng. 11 (1961) 74
(Half-life)

- M. J. CABELL. J. Inorg. Nucl. Chem. 24 (1961) 749
(Half-life)
- T. SUTER, P. REYES-SUTER, S. GUSTAFSON, I. MARKLUND. Nucl. Phys. 29 (1962) 33
(Gamma emission probabilities, mixing ratios, Gamma ray energies, Conv. Elec. emission energies, Conv. Elec. emission probabilities, K ICC)
- D. C. HOFFMAN. J. Inorg. Nucl. Chem. 25 (1963) 1196
(Half-life)
- P. ALEXANDER. Phys. Rev. 134 (1964) B499
(Gamma emission probabilities)
- P. H. BLICHERT-TOFT, E. G. FUNK, J. W. MIHELICH. Nucl. Phys. 79 (1966) 12
(Gamma emission probabilities)
- R. SMITHER, E. BIEBER, T. VON EGIDY, W. KAISER, K. WIEN. Phys. Rev. 187 (1969) 1632
(Gamma emission probabilities)
- J. UNGRIN, M. W. JOHNS. Nucl. Phys. A127 (1969) 353
(Gamma emission probabilities, Gamma ray energies)
- Y. PATIN. Compt. Rend. 268B (1969) 574
(Gamma emission probabilities, Gamma ray energies)
- K. MUHLBAUER. Z. Phys. 230 (1970) 18
(Gamma ray energies)
- Y. Y. CHU, E. M. FRANZ, G. FRIEDLANDER. Phys. Rev. C1 (1970) 1826
(Half-life)
- S. BABA, H. BABA, H. NATSUME. J. Inorg. Nucl. Chem. 33 (1971) 589
(Half-life)
- S. ABDEL-MALAK, S. M. DARWISH, M. ABOU-LEILA, N. WALLEY EL-DIN, A. M. HASSAN. Z. Phys. A322 (1985) 163
(Gamma emission probabilities and energies)
- E. BROWNE, R. B. FIRESTONE. Table of Radioact. Isot., Ann. C, Table 7a (John Wiley & Sons, New York) (1986)
(PX)
- B. M. COURSEY, D. D. HOPPE, F. J. SCHIMA, M. P. UNTERWEGER. Appl. Rad. Isotopes 38 (1987) 31
(Gamma emission probabilities)
- R. G. HELMER. Nucl. Data Sheets 83 (1988) 285
(Multipolarities)
- M. P. UNTERWEGER, D. D. HOPPE, F. J. SCHIMA. Nucl. Instrum. Methods Phys. Res. A312 (1992) 349
(Half-life)
- B. CHAND, J. GOSWAMY, D. MEHTA, N. SING, P. N. TREHAN. Appl. Rad. Isotopes 43 (1992) 997
(Gamma emission probabilities)
- B. M. COURSEY, J. M. CALHOUN, J. CESSNA, D. B. GOLAS, F. J. SCHIMA, M. P. UNTERWEGER. Nucl. Instrum. Methods Phys. Res. A339 (1994) 26
(Half-life)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 572
(P(KBeta)/P(KAlpha), P(KLX)/P(KLL), P(KXY)P(KLL), n)
- N. E. BOWLES, S. A. WOODS, D. H. WOODS, S. M. JEROME, M. J. WOODS, P. DE LAVISON, S. LINEHAM, J. KEIGHTLEY, J. POUPAKI. Appl. J. Rad. Isotopes (1997)
(Half-life)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
(Gamma ray energies)







1 Decay Scheme

Eu-154 disintegrates by 99.982 % beta decay via excited levels of Gd-154 and by 0.018 % electron capture via excited levels of Sm-154. Transitions to the ground states of Gd-154 and Sm-154 have not been observed. *L'euporium 154 se désintègre par émission bêta vers les niveaux excités de gadolinium 154 (99,982%) et par capture électronique vers les niveaux excités de samarium 154 (0,02%). Des transitions vers les niveaux fondamentaux du gadolinium 154 et du samarium 154 n'ont pas été observées.*

2 Nuclear Data

$T_{1/2}({}^{154}\text{Eu})$	:	8,601	(4)	a
$Q^+({}^{154}\text{Eu})$	:	717,3	(11)	keV
$Q^-({}^{154}\text{Eu})$	:	1968,4	(11)	keV

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg ft	P_K	P_L	P_M
$\epsilon_{0,2}$	450,6 (11)	0,0047 (8)	1st forbidden	12,9	0,8205 (16)	0,1393 (11)	0,0322 (6)
$\epsilon_{0,1}$	635,3 (11)	0,013 (13)	1st forbidden	12,7	0,8289 (16)	0,1330 (11)	0,0305 (6)

2.2 β^- Transitions

	Energy keV	Probability × 100	Nature	lg ft
$\beta_{0,33}^-$	73,7 (11)	0,0035 (6)	1 st forbidden	10,92
$\beta_{0,32}^-$	89,4 (11)	0,0042 (3)		
$\beta_{0,31}^-$	107,2 (11)	0,034 (3)	allowed	10,44
$\beta_{0,30}^-$	130,1 (12)	0,017 (5)	1 st forbidden	10,99
$\beta_{0,29}^-$	171,7 (12)	0,060 (6)	allowed	10,8

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,28}^-$	178,1 (11)	0,022 (1)	1 st forbidden	11,31
$\beta_{0,27}^-$	197,9 (11)	0,0022 (4)	1 st forbidden	12,46
$\beta_{0,26}^-$	248,8 (11)	28,32 (22)	allowed	8,66
$\beta_{0,25}^-$	270,2 (11)	0,0100 (4)	(1 st forbidden)	12,33
$\beta_{0,24}^-$	307,5 (11)	0,849 (9)	1 st forbidden	10,48
$\beta_{0,23}^-$	322,6 (11)	0,148 (4)	1 st forbidden	11,31
$\beta_{0,22}^-$	351,3 (11)	1,78 (3)	allowed	10,34
$\beta_{0,21}^-$	408,8 (12)	0,100 (4)	allowed	11,81
$\beta_{0,20}^-$	437,1 (11)	0,330 (13)	1 st forbidden	11,39
$\beta_{0,19}^-$	458,3 (11)	0,021 (2)	(2nd forbidden)	12,66
$\beta_{0,18}^-$	550,0 (11)	0,075 (2)	1 st forbidden	12,23
$\beta_{0,16}^-$	570,9 (11)	36,06 (35)	allowed	9,74
$\beta_{0,13}^-$	704,6 (11)	0,707 (7)	1 st forbidden	11,76
$\beta_{0,12}^-$	716,8 (11)	0,289 (6)	allowed	12,18
$\beta_{0,8}^-$	840,6 (11)	17,33 (18)	1 st forbidden	10,64
$\beta_{0,7}^-$	920,8 (11)	0,108 (18)	1 st forbidden	13
$\beta_{0,6}^-$	972,1 (11)	2,82 (18)	1 st forbidden	11,66
$\beta_{0,5}^-$	1152,9 (11)	0,33 (3)	1 st forbidden	12,8
$\beta_{0,2}^-$	1597,4 (11)	0,31 (7)	1 st forbidden	13,43
$\beta_{0,1}^-$	1845,3 (11)	10,3 (5)	1 st forbidden	12,4

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{26,24}(\text{Gd})$	58,4	0,0087 (9)	(E1)				1,23 (3)
$\gamma_{8,7}(\text{Gd})$	80,4	0,016 (13)	(M1,E2)				4,8 (10)
$\gamma_{1,0}(\text{Sm})$	81,99 (2)	0,018 (13)	E2	1,98 (4)	2,28 (5)	0,532 (11)	4,93 (10)
$\gamma_{1,0}(\text{Gd})$	123,0707 (9)	88,8 (13)	E2	0,653 (13)	0,418 (9)	0,096 (2)	1,197 (19)
$\gamma_{18,15}(\text{Gd})$	125,39 (5)	0,007 (2)					
$\gamma_{24,20}(\text{Gd})$	129,5	0,028 (4)	(M1,E2)				0,99 (3)
$\gamma_{8,6}(\text{Gd})$	131,58 (5)	0,0216 (11)	M1+E2				0,95 (4)
$\gamma_{5,3}(\text{Gd})$	134,84	0,0134 (8)	E2				0,868 (18)
$\gamma_{16,12}(\text{Gd})$	146,05 (5)	0,044 (2)	(M1,E2)				0,68 (2)
$\gamma_{16,11}(\text{Gd})$	156,2	0,0152 (6)	(M1,E2)				0,55 (3)
$\gamma_{(-1,1)}(\text{Gd})$	159,9	0,0010 (5)					
$\gamma_{21,16}(\text{Gd})$	162,09 (5)	0,0016 (6)	(E2)				0,457 (9)
$\gamma_{15,8}(\text{Gd})$	165,90 (21)	0,0025 (5)					
$\gamma_{6,5}(\text{Gd})$	180,7	0,0054 (7)	(M1,E2)				0,35 (4)
$\gamma_{2,1}(\text{Sm})$	184,72	0,0047 (8)	E2	0,193 (4)	0,0642 (13)	0,0146 (3)	0,275 (6)
$\gamma_{26,20}(\text{Gd})$	188,24 (2)	0,252 (6)	E1	0,0453 (90)	0,0065 (2)		0,0536 (11)
$\gamma_{(-1,2)}(\text{Gd})$	195,5 (5)	0,002 (1)					
$\gamma_{(-1,3)}(\text{Gd})$	197	0,0016 (2)					
$\gamma_{22,17}(\text{Gd})$	202,50 (16)	0,03 (1)					
$\gamma_{26,19}(\text{Gd})$	209,4 (4)	0,0025 (6)					

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{22,16}$ (Gd)	219,4	0,0028 (6)	(M1,E2)				0,20 (4)
$\gamma_{14,7}$ (Gd)	229,01 (13)	0,0024 (8)					
$\gamma_{7,5}$ (Gd)	232,01 (5)	0,0270 (11)	E2				0,137 (3)
$\gamma_{20,15}$ (Gd)	237	0,006 (3)					0,018 (7)
$\gamma_{2,1}$ (Gd)	247,9290 (7)	7,65 (8)	E2	0,0810 (16)	0,0228 (5)		0,110 (2)
$\gamma_{16,9}$ (Gd)	260,9	0,0022 (7)					
$\gamma_{20,13}$ (Gd)	267,44	0,0148 (8)	(E2)				0,087 (2)
$\gamma_{(-1,4)}$ (Gd)	269,8	0,0071 (11)	(E1)				0,0209 (4)
$\gamma_{(-1,5)}$ (Gd)	274,0 (5)	0,0039 (2)					
$\gamma_{20,12}$ (Gd)	279,9	0,0030 (2)	(E1)				0,0190 (4)
$\gamma_{20,11}$ (Gd)	290	0,0033 (2)	(E1)				0,0174 (3)
$\gamma_{21,13}$ (Gd)	295,7	0,0024 (2)	(E1)				0,0166 (3)
$\gamma_{16,8}$ (Gd)	296 (1)	0,0014 (9)	(E1)				0,0166 (3)
$\gamma_{26,18}$ (Gd)	301,25	0,0102 (4)	(E2)				0,0158 (3)
$\gamma_{26,17}$ (Gd)	305,1	0,0187 (8)	(M1,E2)				0,075 (18)
$\gamma_{(-1,6)}$ (Gd)	308,2	0,0024 (6)					
$\gamma_{8,5}$ (Gd)	312,3	0,019 (2)	(M1,E2)				0,07 (2)
$\gamma_{6,3}$ (Gd)	315,4	0,007 (2)	(E2)				0,052 (1)
$\gamma_{(-1,7)}$ (Gd)	320 (1)	0,0010 (7)					
$\gamma_{26,16}$ (Gd)	322,02 (5)	0,070 (3)	(M1,E2)				0,065 (17)
$\gamma_{7,4}$ (Gd)	329,9 (7)	0,0095 (5)	E2				0,0454 (9)
$\gamma_{4,2}$ (Gd)	346,72 (5)	0,030 (1)	E2				0,0391 (8)
$\gamma_{23,14}$ (Gd)	368,21	0,0030 (2)					
$\gamma_{18,7}$ (Gd)	370,71	0,0058 (14)	E2				0,0321 (7)
$\gamma_{22,11}$ (Gd)	375,2 (5)	0,0021 (8)	(E2)				0,0310 (6)
$\gamma_{23,13}$ (Gd)	382,00 (5)	0,0100 (4)	(E2,M1)				0,034 (11)
$\gamma_{24,13}$ (Gd)	397,1	0,030 (1)	(M1,E2)				0,036 (10)
$\gamma_{16,6}$ (Gd)	401,260 (14)	0,202 (4)	(E1,M2,E3)				0,07 (2)
$\gamma_{20,8}$ (Gd)	403,55 (5)	0,027 (1)	(M1,E2)				0,035 (10)
$\gamma_{(-1,8)}$ (Gd)	414,3	0,0049 (6)					
$\gamma_{24,11}$ (Gd)	419,4	0,0039 (23)	M2				0,140 (3)
$\gamma_{(-1,9)}$ (Gd)	422,1	0,0022 (9)					
$\gamma_{(-1,10)}$ (Gd)	435,9	0,0038 (10)					
$\gamma_{5,2}$ (Gd)	444,4931 (19)	0,570 (6)	E2	0,0154 (3)	0,00295 (6)		0,0192 (4)
$\gamma_{32,17}$ (Gd)	463,9	0,0042 (3)					
$\gamma_{26,12}$ (Gd)	467,84 (5)	0,0618 (24)	(M1,E2)				0,024 (7)
$\gamma_{26,11}$ (Gd)	478,27 (5)	0,230 (2)	M1	0,0245 (5)	0,00341 (7)		0,0287 (6)
$\gamma_{22,9}$ (Gd)	480,61	0,0048 (3)					
$\gamma_{20,7}$ (Gd)	483,74	0,0051 (3)	(E2)				0,0153 (3)
$\gamma_{(-1,11)}$ (Gd)	484,64	0,0039 (2)					
$\gamma_{22,8}$ (Gd)	488,26	0,007 (3)	(E1)				0,00498 (10)
$\gamma_{27,13}$ (Gd)	506,4	0,0064 (14)	E2				0,0136 (3)
$\gamma_{(-1,12)}$ (Gd)	510	0,059 (7)					
$\gamma_{(-1,13)}$ (Gd)	512	0,032 (7)					
$\gamma_{23,8}$ (Gd)	518,00 (5)	0,047 (2)	(E2,M1)				0,013 (1)
$\gamma_{24,8}$ (Gd)	533,1	0,007 (2)					
$\gamma_{29,13}$ (Gd)	533,1	0,004 (3)	E1				0,00412 (8)
$\gamma_{13,4}$ (Gd)	545,6	0,014 (2)	(E2)				0,0112 (2)
$\gamma_{3,1}$ (Gd)	557,58 (5)	0,270 (5)	E2	0,0087 (2)	0,0015 (3)		0,0106 (2)
$\gamma_{21,6}$ (Gd)	563,4	0,0030 (7)	(M2)				0,058 (1)
$\gamma_{22,7}$ (Gd)	569,23	0,0100 (8)	(E1)				0,0036 (1)
$\gamma_{16,5}$ (Gd)	582,01 (5)	0,889 (11)	E1	0,00288 (6)	0,000385 (8)		0,00339 (7)
$\gamma_{26,8}$ (Gd)	591,755 (3)	4,97 (5)	E1+(M2)	0,0028 (6)	0,000374 (8)		0,00329 (10)
$\gamma_{31,13}$ (Gd)	597,5	0,0055 (3)	(E1)				0,00321 (7)
$\gamma_{23,7}$ (Gd)	598,3	0,0062 (7)	M1+2,8%E2				0,014 (1)
$\gamma_{17,5}$ (Gd)	600,0 (5)	0,006 (4)	(E1)				0,00318 (7)
$\gamma_{18,5}$ (Gd)	602,81 (5)	0,0035 (2)	E0+M1+E2				0,048 (6)
$\gamma_{24,7}$ (Gd)	613,26 (5)	0,094 (4)	(E2,M1)				0,012 (4)
$\gamma_{22,6}$ (Gd)	620,52	0,091 (5)	(E1)				0,00296 (6)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{6,2}$ (Gd)	625,2570 (24)	0,319 (5)	E2	0,00658 (13)	0,00109 (2)		0,00797 (16)
$\gamma_{27,8}$ (Gd)	642,4	0,0044 (17)	(M1,E2)				0,011 (4)
$\gamma_{23,6}$ (Gd)	649,44 (5)	0,079 (3)	E2				0,0073 (2)
$\gamma_{25,7}$ (Gd)	650,6	0,0100 (4)	(E0,M1,E2)				0,026 (8)
$\gamma_{24,6}$ (Gd)	664,68 (5)	0,029 (1)	(M1,E2)				0,010 (3)
$\gamma_{29,8}$ (Gd)	668,9	0,013 (2)	E1				0,00253 (5)
$\gamma_{7,2}$ (Gd)	676,598 (12)	0,166 (11)	E0+M1+E2	0,049 (5)	0,0080 (8)		0,059 (6)
$\gamma_{3,0}$ (Gd)	680,72 (10)	0,0052 (7)	E0				
$\gamma_{5,1}$ (Gd)	692,4222 (18)	1,88 (3)	E0+M1+E2	0,040 (4)	0,0070 (7)		0,049 (6)
$\gamma_{20,5}$ (Gd)	715,77 (3)	0,19 (1)	(E0,M1,E2)				0,013 (4)
$\gamma_{26,6}$ (Gd)	723,3032 (22)	20,09 (21)	E1+0,05%M2	0,00184 (4)	0,000244 (5)		0,00215 (5)
$\gamma_{(-1,14)}$ (Gd)	737,6	0,0063 (24)					
$\gamma_{8,2}$ (Gd)	756,8040 (23)	4,55 (5)	E1+2,8%M2	0,00431 (9)	0,00067 (2)		0,0051 (12)
$\gamma_{27,6}$ (Gd)	774,4	0,008 (4)	(M3)				0,053 (2)
$\gamma_{30,7}$ (Gd)	790,2	0,010 (3)	(E2)				0,00462 (9)
$\gamma_{29,6}$ (Gd)	800,2	0,032 (5)	E1				0,00175 (4)
$\gamma_{22,5}$ (Gd)	801,21 (4)	0,012 (3)	(E1)				0,00175 (4)
$\gamma_{5,0}$ (Gd)	815,53 (5)	0,514 (7)	E2	0,00360 (7)	0,000548 (11)		0,00430 (9)
$\gamma_{(-1,15)}$ (Gd)	830,3	0,008 (3)					
$\gamma_{24,5}$ (Gd)	845,418 (7)	0,588 (9)	E2	0,00333 (7)	0,000502 (10)		0,00397 (8)
$\gamma_{20,3}$ (Gd)	850,64 (3)	0,242 (4)	E2				0,00392 (8)
$\gamma_{6,1}$ (Gd)	873,1860 (23)	12,22 (12)	E2+1,55%M1+E0	0,00313 (6)	0,00047 (1)		0,00373 (8)
$\gamma_{12,2}$ (Gd)	880,60 (3)	0,081 (4)	E1+0,05%M2				0,00153 (8)
$\gamma_{13,2}$ (Gd)	892,778 (6)	0,516 (7)	E0+E2+M1				0,00369 (8)
$\gamma_{33,6}$ (Gd)	898,36	0,0020 (5)	(M1,E2)				0,0048 (13)
$\gamma_{26,5}$ (Gd)	904,067 (3)	0,891 (11)	E1(+M2)	0,00118 (4)	0,000156 (3)		0,00138 (3)
$\gamma_{14,2}$ (Gd)	906,1	0,0118 (6)					
$\gamma_{(-1,16)}$ (Gd)	919,24	0,012 (1)					
$\gamma_{7,1}$ (Gd)	924,63 (5)	0,062 (2)	E2				0,00327 (7)
$\gamma_{(-1,17)}$ (Gd)	928,4	0,0045 (21)					
$\gamma_{29,5}$ (Gd)	981,3 (5)	0,0084 (17)	(E1)				0,00118 (3)
$\gamma_{(-1,18)}$ (Gd)	984,5	0,0094 (21)					
$\gamma_{6,0}$ (Gd)	996,25 (5)	10,53 (10)	E2	0,00236 (5)	0,000342 (7)		0,00279 (6)
$\gamma_{8,1}$ (Gd)	1004,722 (7)	17,91 (18)	E1+1,35%M2	0,00232 (5)	0,000336 (7)		0,00276 (6)
$\gamma_{9,1}$ (Gd)	1012,8 (2)	0,003 (1)					
$\gamma_{30,5}$ (Gd)	1023 (1)	0,0066 (25)	(M1,E2)				
$\gamma_{(-1,19)}$ (Gd)	1033,4	0,0117 (8)					
$\gamma_{18,2}$ (Gd)	1047,4 (1)	0,049 (3)	E2				0,00251 (5)
$\gamma_{(-1,20)}$ (Gd)	1049,4 (1)	0,0172 (8)					
$\gamma_{(-1,21)}$ (Gd)	1072,2	0,0035 (14)					
$\gamma_{10,1}$ (Gd)	1110	0,003 (2)					
$\gamma_{11,1}$ (Gd)	1118,53 (6)	0,108 (14)	E1	0,000798 (16)	0,000103 (20)		0,00093 (2)
$\gamma_{(-1,22)}$ (Gd)	1124,2	0,0069 (10)					
$\gamma_{12,1}$ (Gd)	1128,556 (7)	0,317 (5)	E1	0,000785 (16)	0,000101 (2)		0,000915 (18)
$\gamma_{9,0}$ (Gd)	1136,1	0,007 (1)					
$\gamma_{13,1}$ (Gd)	1140,707 (6)	0,235 (4)	E2				0,00211 (4)
$\gamma_{(-1,23)}$ (Gd)	1153,1 (5)	0,011 (4)					
$\gamma_{20,2}$ (Gd)	1160,37 (8)	0,0437 (21)	(E2)				0,00204 (4)
$\gamma_{15,1}$ (Gd)	1170,7 (5)	0,0036 (10)					
$\gamma_{21,2}$ (Gd)	1188,35 (17)	0,093 (7)	(E1)				0,00083 (2)
$\gamma_{(-1,25)}$ (Gd)	1216,8	0,0035 (10)					
$\gamma_{(-1,24)}$ (Gd)	1232,1 (5)	0,008 (5)					
$\gamma_{11,0}$ (Gd)	1241,44 (10)	0,133 (6)	E1+(M2)	0,000662 (13)			0,000771 (15)
$\gamma_{22,2}$ (Gd)	1246,126 (4)	0,863 (11)	E1	0,000658 (13)			0,000766 (15)
$\gamma_{16,1}$ (Gd)	1274,435 (4)	34,9 (3)	E1+0,1%M2	0,000632 (13)			0,000737 (15)
$\gamma_{24,2}$ (Gd)	1290,51 (10)	0,025 (3)	(M1,E2)				0,0021 (5)
$\gamma_{17,1}$ (Gd)	1292,0 (2)	0,0127 (5)	E1				0,00072 (2)
$\gamma_{18,1}$ (Gd)	1295,5 (2)	0,0091 (10)					
$\gamma_{(-1,26)}$ (Gd)	1316,4 (3)	0,017 (4)					

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{19,1}$ (Gd)	1387,0 (5)	0,019 (2)	(E1)				0,00063 (2)
$\gamma_{27,2}$ (Gd)	1397,35 (5)	0,0031 (8)	(M1,E2)				0,0018 (4)
$\gamma_{20,1}$ (Gd)	1408,5 (2)	0,023 (3)	(E0,M1,E2)				0,0037 (14)
$\gamma_{17,0}$ (Gd)	1415,0 (5)	0,040 (2)	E1				0,00061 (1)
$\gamma_{18,0}$ (Gd)	1418,6 (2)	0,011 (2)	E2				0,00138 (3)
$\gamma_{28,2}$ (Gd)	1419,0 (2)	0,0020 (1)	(M1,E2)				0,0017 (4)
$\gamma_{29,2}$ (Gd)	1425,9 (5)	0,0012 (7)	(E1)				0,00060 (1)
$\gamma_{31,2}$ (Gd)	1489,6 (2)	0,0029 (4)	(E1)				0,00056 (1)
$\gamma_{22,1}$ (Gd)	1494,056 (4)	0,699 (9)	E1	0,000481 (10)			0,00056 (1)
$\gamma_{19,0}$ (Gd)	1510,0 (5)	0,0048 (10)	(E1)				0,00047 (1)
$\gamma_{33,2}$ (Gd)	1522 (1)	0,0006 (3)	(E2)				0,00102 (2)
$\gamma_{20,0}$ (Gd)	1531,5 (2)	0,0060 (4)	(E2)				0,00101 (2)
$\gamma_{24,1}$ (Gd)	1537,82 (4)	0,053 (2)	(M1,E2)				0,0012 (3)
$\gamma_{(-1,27)}$ (Gd)	1554	0,0011 (5)					
$\gamma_{26,1}$ (Gd)	1596,4892 (28)	1,784 (17)	E1(+M2)	0,000430 (9)			0,00049 (1)
$\gamma_{28,1}$ (Gd)	1667,3 (2)	0,0019 (3)	(E2)				
$\gamma_{29,1}$ (Gd)	1674,0 (5)	0,0017 (4)	(E1)				
$\gamma_{30,1}$ (Gd)	1716,9 (5)	0,0006 (3)	(M1,E2)				
$\gamma_{33,1}$ (Gd)	1773 (1)	0,00035 (21)	(M1,E2)				
$\gamma_{30,0}$ (Gd)	1838,0 (5)	0,0008 (2)	(E2)				
$\gamma_{33,0}$ (Gd)	1895 (1)	0,0006 (2)	(E2)				

3 Atomic Data

3.1 Sm

ω_K	:	0,926	(4)
$\bar{\omega}_L$	:	0,158	(6)
n_{KL}	:	0,857	(4)

3.1.1 X Radiations

	Energy keV	Relative probability		
X_K	$K\alpha_2$	39,5229	55,25	
	$K\alpha_1$	40,1186	100	
	$K\beta_3$	45,289	}	
	$K\beta_1$	45,413		
	$K\beta_5''$	45,731		31,26
	$K\beta_2$	46,575	}	
	$K\beta_4$	46,705		8,06
	$KO_{2,3}$	46,813		
	X_L	$L\ell$	4,99	
$L\gamma$		- 7,49		

3.1.2 Auger Electrons

	Energy keV	Relative probability
KLL	31,19 – 33,22	100
KLX	37,30 – 40,18	50,7
KXY	45,30 – 46,23	6,42
Auger L	3,2 – 7,6	2277

3.2 Gd

$$\begin{aligned} \omega_K &: 0,932 \quad (4) \\ \bar{\omega}_L &: 0,176 \quad (6) \\ n_{KL} &: 0,850 \quad (4) \end{aligned}$$

3.2.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	42,3093	55,59	
	K α_1	42,9967	100	
	K β_3	48,556	}	
	K β_1	48,697	}	
	K β_5''	49,053	}	31,66
	K β_2	49,961	}	
	K β_4	50,099	}	8,32
	KO _{2,3}	50,219	}	
	X _L	L ℓ	5,36	
		L γ	– 8,1	

3.2.2 Auger Electrons

	Energy keV	Relative probability
KLL	33,32 – 35,58	100
KLX	39,98 – 42,86	51,3
KXY	47,98 – 48,91	6,58
Auger L	3,4 – 8,3	2814

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Sm)	3,2	- 7,6	0,023 (13)
e _{AK}	(Sm)			0,0016 (13)
	KLL	31,19	- 33,22	}
	KLX	37,30	- 40,18	}
	KXY	45,30	- 46,23	}
e _{AL}	(Gd)	3,4	- 8,3	33,2 (6)
e _{AK}	(Gd)			1,86 (12)
	KLL	33,32	- 35,58	}
	KLX	39,98	- 42,86	}
	KXY	47,98	- 48,91	}
ec _{1,0} K	(Gd)	72,832	(1)	26,4 (4)
ec _{1,0} L	(Gd)	114,70	- 115,83	16,9 (4)
ec _{1,0} M	(Gd)	121,19	- 121,89	3,88 (9)
ec _{2,1} K	(Gd)	197,6898	(7)	0,558 (12)
ec _{2,1} L	(Gd)	239,56	- 240,69	0,157 (4)
ec _{5,1} K	(Gd)	642,180	(2)	0,072 (7)
$\beta_{0,33}^-$	max:	73,7	(11)	0,0035 (6)
$\beta_{0,33}^-$	avg:	19,0	(3)	
$\beta_{0,32}^-$	max:	89,4	(11)	0,0042 (3)
$\beta_{0,32}^-$	avg:	23,3	(3)	
$\beta_{0,31}^-$	max:	107,2	(11)	0,034 (3)
$\beta_{0,31}^-$	avg:	28,1	(3)	
$\beta_{0,30}^-$	max:	130,1	(12)	0,017 (5)
$\beta_{0,30}^-$	avg:	34,5	(3)	
$\beta_{0,29}^-$	max:	171,7	(12)	0,060 (6)
$\beta_{0,29}^-$	avg:	46,3	(3)	
$\beta_{0,28}^-$	max:	178,1	(11)	0,022 (1)
$\beta_{0,28}^-$	avg:	48,1	(3)	
$\beta_{0,27}^-$	max:	197,9	(11)	0,0022 (4)
$\beta_{0,27}^-$	avg:	53,9	(3)	
$\beta_{0,26}^-$	max:	248,8	(11)	28,32 (22)
$\beta_{0,26}^-$	avg:	69,2	(3)	
$\beta_{0,25}^-$	max:	270,2	(11)	0,0100 (4)
$\beta_{0,25}^-$	avg:	75,7	(3)	
$\beta_{0,24}^-$	max:	307,5	(11)	0,849 (9)
$\beta_{0,24}^-$	avg:	87,4	(3)	
$\beta_{0,23}^-$	max:	322,6	(11)	0,148 (4)
$\beta_{0,23}^-$	avg:	92,2	(4)	

		Energy keV		Electrons per 100 disint.
$\beta_{0,22}^-$	max:	351,3	(11)	1,78 (3)
$\beta_{0,22}^-$	avg:	101,4	(4)	
$\beta_{0,21}^-$	max:	408,8	(12)	0,100 (4)
$\beta_{0,21}^-$	avg:	120,3	(4)	
$\beta_{0,20}^-$	max:	437,1	(11)	0,330 (13)
$\beta_{0,20}^-$	avg:	129,8	(4)	
$\beta_{0,19}^-$	max:	458,3	(11)	0,021 (2)
$\beta_{0,19}^-$	avg:	136,9	(4)	
$\beta_{0,18}^-$	max:	550,0	(11)	0,075 (2)
$\beta_{0,18}^-$	avg:	168,8	(4)	
$\beta_{0,16}^-$	max:	570,9	(11)	36,06 (35)
$\beta_{0,16}^-$	avg:	176,2	(4)	
$\beta_{0,13}^-$	max:	704,6	(11)	0,707 (7)
$\beta_{0,13}^-$	avg:	225,0	(4)	
$\beta_{0,12}^-$	max:	716,8	(11)	0,289 (6)
$\beta_{0,12}^-$	avg:	229,5	(4)	
$\beta_{0,8}^-$	max:	840,6	(11)	17,33 (18)
$\beta_{0,8}^-$	avg:	276,6	(4)	
$\beta_{0,7}^-$	max:	920,8	(11)	0,108 (18)
$\beta_{0,7}^-$	avg:	307,8	(4)	
$\beta_{0,6}^-$	max:	972,1	(11)	2,82 (18)
$\beta_{0,6}^-$	avg:	328,1	(4)	
$\beta_{0,5}^-$	max:	1152,9	(11)	0,33 (3)
$\beta_{0,5}^-$	avg:	401,0	(5)	
$\beta_{0,2}^-$	max:	1597,4	(11)	0,31 (7)
$\beta_{0,2}^-$	avg:	588,0	(5)	
$\beta_{0,1}^-$	max:	1845,3	(11)	10,3 (5)
$\beta_{0,1}^-$	avg:	695,6	(5)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Sm)	4,99 — 7,49	0,0044 (20)	
XK α_2	(Sm)	39,5229	0,006 (4)	} K α
XK α_1	(Sm)	40,1186	0,010 (8)	
XK β_3	(Sm)	45,289	}	} K' β_1
XK β_1	(Sm)	45,413	}	
XK β_5''	(Sm)	45,731	}	
XK β_2	(Sm)	46,575	}	} K' β_2
XK β_4	(Sm)	46,705	}	
XKO _{2,3}	(Sm)	46,813	}	
XL	(Gd)	5,36 — 8,1	7,1 (3)	
XK α_2	(Gd)	42,3093	7,2 (2)	} K α
XK α_1	(Gd)	42,9967	13,0 (3)	
XK β_3	(Gd)	48,556	}	} K' β_1
XK β_1	(Gd)	48,697	}	
XK β_5''	(Gd)	49,053	}	
XK β_2	(Gd)	49,961	}	} K' β_2
XK β_4	(Gd)	50,099	}	
XKO _{2,3}	(Gd)	50,219	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{26,24}$ (Gd)	58,4	0,0039 (4)
$\gamma_{8,7}$ (Gd)	80,4	0,0028 (14)
$\gamma_{1,0}$ (Sm)	81,99 (2)	0,0031 (21)
$\gamma_{1,0}$ (Gd)	123,0706 (9)	40,4 (5)
$\gamma_{18,15}$ (Gd)	125,39 (5)	0,007 (2)
$\gamma_{24,20}$ (Gd)	129,5	0,014 (2)
$\gamma_{8,6}$ (Gd)	131,58 (5)	0,0111 (5)
$\gamma_{5,3}$ (Gd)	134,84	0,0072 (4)
$\gamma_{16,12}$ (Gd)	146,05 (5)	0,026 (1)
$\gamma_{16,11}$ (Gd)	156,2	0,0098 (4)
$\gamma_{(-1,1)}$ (Gd)	159,9	0,0010 (5)

	Energy keV	Photons per 100 disint.
$\gamma_{21,16}$ (Gd)	162,09 (5)	0,0011 (4)
$\gamma_{15,8}$ (Gd)	165,90 (21)	0,0025 (5)
$\gamma_{6,5}$ (Gd)	180,7	0,0040 (5)
$\gamma_{2,1}$ (Sm)	184,72	0,0037 (7)
$\gamma_{26,20}$ (Gd)	188,24 (2)	0,239 (6)
$\gamma_{(-1,2)}$ (Gd)	195,5 (5)	0,002 (1)
$\gamma_{(-1,3)}$ (Gd)	197	0,0016 (2)
$\gamma_{22,17}$ (Gd)	202,50 (16)	0,03 (1)
$\gamma_{26,19}$ (Gd)	209,4 (4)	0,0025 (6)
$\gamma_{22,16}$ (Gd)	219,4	0,0023 (5)
$\gamma_{14,7}$ (Gd)	229,01 (13)	0,0024 (8)
$\gamma_{7,5}$ (Gd)	232,01 (5)	0,024 (1)
$\gamma_{20,15}$ (Gd)	237	0,006 (3)
$\gamma_{2,1}$ (Gd)	247,9288 (7)	6,89 (7)
$\gamma_{16,9}$ (Gd)	260,9	0,0022 (7)
$\gamma_{20,13}$ (Gd)	267,44	0,0136 (7)
$\gamma_{(-1,4)}$ (Gd)	269,8	0,0070 (11)
$\gamma_{(-1,5)}$ (Gd)	274,0 (5)	0,0039 (2)
$\gamma_{20,12}$ (Gd)	279,9	0,0030 (2)
$\gamma_{20,11}$ (Gd)	290	0,0033 (2)
$\gamma_{21,13}$ (Gd)	295,7	0,0024 (2)
$\gamma_{16,8}$ (Gd)	296 (1)	0,0014 (9)
$\gamma_{26,18}$ (Gd)	301,25	0,0102 (4)
$\gamma_{26,17}$ (Gd)	305,1	0,0174 (7)
$\gamma_{(-1,6)}$ (Gd)	308,2	0,0024 (6)
$\gamma_{8,5}$ (Gd)	312,3	0,018 (2)
$\gamma_{6,3}$ (Gd)	315,4	0,007 (2)
$\gamma_{(-1,7)}$ (Gd)	320 (1)	0,0010 (7)
$\gamma_{26,16}$ (Gd)	322,02 (5)	0,066 (3)
$\gamma_{7,4}$ (Gd)	329,9 (7)	0,0091 (5)
$\gamma_{4,2}$ (Gd)	346,72 (5)	0,029 (1)
$\gamma_{23,14}$ (Gd)	368,21	0,0030 (2)
$\gamma_{18,7}$ (Gd)	370,71	0,0056 (14)
$\gamma_{22,11}$ (Gd)	375,2 (5)	0,0020 (8)
$\gamma_{23,13}$ (Gd)	382,00 (5)	0,0099 (4)
$\gamma_{24,13}$ (Gd)	397,1	0,029 (1)
$\gamma_{16,6}$ (Gd)	401,259 (14)	0,189 (3)
$\gamma_{20,8}$ (Gd)	403,55 (5)	0,026 (1)
$\gamma_{(-1,8)}$ (Gd)	414,3	0,0049 (6)
$\gamma_{24,11}$ (Gd)	419,4	0,0034 (20)
$\gamma_{(-1,9)}$ (Gd)	422,1	0,0022 (9)
$\gamma_{(-1,10)}$ (Gd)	435,9	0,0038 (10)
$\gamma_{5,2}$ (Gd)	444,4924 (19)	0,560 (8)
$\gamma_{32,17}$ (Gd)	463,9	0,0042 (3)
$\gamma_{26,12}$ (Gd)	467,84 (5)	0,0604 (24)
$\gamma_{26,11}$ (Gd)	478,27 (5)	0,224 (3)
$\gamma_{22,9}$ (Gd)	480,61	0,0048 (3)

	Energy keV	Photons per 100 disint.
$\gamma_{20,7}$ (Gd)	483,74	0,0050 (3)
$\gamma_{(-1,11)}$ (Gd)	484,64	0,0039 (2)
$\gamma_{22,8}$ (Gd)	488,26	0,007 (3)
$\gamma_{27,13}$ (Gd)	506,4	0,0063 (14)
$\gamma_{(-1,12)}$ (Gd)	510	0,059 (7)
γ^{\pm}	511	
$\gamma_{(-1,13)}$ (Gd)	512	0,032 (7)
$\gamma_{23,8}$ (Gd)	518,00 (5)	0,047 (2)
$\gamma_{24,8}$ (Gd)	533,1	0,007 (2)
$\gamma_{29,13}$ (Gd)	533,1	0,004 (3)
$\gamma_{13,4}$ (Gd)	545,6	0,014 (2)
$\gamma_{3,1}$ (Gd)	557,58 (5)	0,267 (5)
$\gamma_{21,6}$ (Gd)	563,4	0,0028 (7)
$\gamma_{22,7}$ (Gd)	569,23	0,0100 (8)
$\gamma_{16,5}$ (Gd)	582,01 (5)	0,886 (11)
$\gamma_{26,8}$ (Gd)	591,755 (3)	4,95 (5)
$\gamma_{31,13}$ (Gd)	597,5	0,0055 (3)
$\gamma_{23,7}$ (Gd)	598,3	0,0062 (7)
$\gamma_{17,5}$ (Gd)	600	0,006 (4)
$\gamma_{18,5}$ (Gd)	602,81 (5)	0,0033 (2)
$\gamma_{24,7}$ (Gd)	613,26 (5)	0,093 (4)
$\gamma_{22,6}$ (Gd)	620,52	0,091 (5)
$\gamma_{6,2}$ (Gd)	625,2556 (24)	0,317 (5)
$\gamma_{27,8}$ (Gd)	642,4	0,0044 (17)
$\gamma_{23,6}$ (Gd)	649,44 (5)	0,078 (3)
$\gamma_{25,7}$ (Gd)	650,6	0,0098 (4)
$\gamma_{24,6}$ (Gd)	664,68 (5)	0,029 (1)
$\gamma_{29,8}$ (Gd)	668,9	0,013 (2)
$\gamma_{7,2}$ (Gd)	676,596 (12)	0,157 (11)
$\gamma_{5,1}$ (Gd)	692,4205 (18)	1,79 (3)
$\gamma_{20,5}$ (Gd)	715,77 (3)	0,19 (1)
$\gamma_{26,6}$ (Gd)	723,3014 (22)	20,05 (21)
$\gamma_{(-1,14)}$ (Gd)	737,6	0,0063 (24)
$\gamma_{8,2}$ (Gd)	756,8020 (23)	4,53 (5)
$\gamma_{27,6}$ (Gd)	774,4	0,008 (4)
$\gamma_{30,7}$ (Gd)	790,2	0,010 (3)
$\gamma_{29,6}$ (Gd)	800,2	0,032 (5)
$\gamma_{22,5}$ (Gd)	801,21 (4)	0,012 (3)
$\gamma_{5,0}$ (Gd)	815,53 (5)	0,512 (7)
$\gamma_{(-1,15)}$ (Gd)	830,3	0,008 (3)
$\gamma_{24,5}$ (Gd)	845,416 (7)	0,586 (9)
$\gamma_{20,3}$ (Gd)	850,64 (3)	0,241 (4)
$\gamma_{6,1}$ (Gd)	873,1834 (23)	12,17 (12)
$\gamma_{12,2}$ (Gd)	880,60 (3)	0,081 (4)
$\gamma_{13,2}$ (Gd)	892,775 (6)	0,514 (7)
$\gamma_{33,6}$ (Gd)	898,36	0,0020 (5)
$\gamma_{26,5}$ (Gd)	904,064 (3)	0,890 (11)

	Energy keV	Photons per 100 disint.
$\gamma_{14,2}$ (Gd)	906,1	0,0118 (6)
$\gamma_{(-1,16)}$ (Gd)	919,24	0,012 (1)
$\gamma_{7,1}$ (Gd)	924,63 (5)	0,062 (2)
$\gamma_{(-1,17)}$ (Gd)	928,4	0,0045 (21)
$\gamma_{29,5}$ (Gd)	981,3 (5)	0,0084 (17)
$\gamma_{(-1,18)}$ (Gd)	984,5	0,0094 (21)
$\gamma_{6,0}$ (Gd)	996,25 (5)	10,5 (1)
$\gamma_{8,1}$ (Gd)	1004,718 (7)	17,86 (18)
$\gamma_{9,1}$ (Gd)	1012,8 (2)	0,003 (1)
$\gamma_{30,5}$ (Gd)	1023 (1)	0,0066 (25)
$\gamma_{(-1,19)}$ (Gd)	1033,4	0,0119 (7)
$\gamma_{18,2}$ (Gd)	1047,4 (1)	0,049 (3)
$\gamma_{(-1,20)}$ (Gd)	1049,4 (1)	0,0172 (8)
$\gamma_{(-1,21)}$ (Gd)	1072,2	0,0035 (14)
$\gamma_{10,1}$ (Gd)	1110	0,003 (2)
$\gamma_{11,1}$ (Gd)	1118,52 (6)	0,108 (14)
$\gamma_{(-1,22)}$ (Gd)	1124,2	0,0069 (10)
$\gamma_{12,1}$ (Gd)	1128,552 (7)	0,317 (5)
$\gamma_{9,0}$ (Gd)	1136,1	0,007 (1)
$\gamma_{13,1}$ (Gd)	1140,702 (6)	0,235 (4)
$\gamma_{(-1,23)}$ (Gd)	1153,1 (5)	0,011 (4)
$\gamma_{20,2}$ (Gd)	1160,36 (8)	0,0436 (21)
$\gamma_{15,1}$ (Gd)	1170,7 (5)	0,0036 (10)
$\gamma_{21,2}$ (Gd)	1188,34 (17)	0,093 (7)
$\gamma_{(-1,25)}$ (Gd)	1216,8	0,0033 (10)
$\gamma_{(-1,24)}$ (Gd)	1232,1 (5)	0,008 (5)
$\gamma_{11,0}$ (Gd)	1241,43 (10)	0,133 (6)
$\gamma_{22,2}$ (Gd)	1246,121 (4)	0,862 (11)
$\gamma_{16,1}$ (Gd)	1274,429 (4)	34,9 (3)
$\gamma_{24,2}$ (Gd)	1290,5 (1)	0,025 (3)
$\gamma_{17,1}$ (Gd)	1292,0 (2)	0,0127 (5)
$\gamma_{18,1}$ (Gd)	1295,5 (2)	0,0091 (10)
$\gamma_{(-1,26)}$ (Gd)	1316,4 (3)	0,017 (4)
$\gamma_{19,1}$ (Gd)	1387,0 (5)	0,019 (2)
$\gamma_{27,2}$ (Gd)	1397,34 (5)	0,0031 (8)
$\gamma_{20,1}$ (Gd)	1408,5 (2)	0,023 (3)
$\gamma_{17,0}$ (Gd)	1415,0 (5)	0,040 (2)
$\gamma_{18,0}$ (Gd)	1418,6 (2)	0,011 (2)
$\gamma_{28,2}$ (Gd)	1419,0 (2)	0,0020 (1)
$\gamma_{29,2}$ (Gd)	1425,9 (5)	0,0012 (7)
$\gamma_{31,2}$ (Gd)	1489,6 (2)	0,0029 (4)
$\gamma_{22,1}$ (Gd)	1494,048 (4)	0,698 (9)
$\gamma_{19,0}$ (Gd)	1510,0 (5)	0,0048 (10)
$\gamma_{33,2}$ (Gd)	1522 (1)	0,0006 (3)
$\gamma_{20,0}$ (Gd)	1531,4 (2)	0,0060 (4)
$\gamma_{24,1}$ (Gd)	1537,81 (4)	0,053 (2)
$\gamma_{(-1,27)}$ (Gd)	1554	0,0011 (5)

	Energy keV	Photons per 100 disint.
$\gamma_{26,1}$ (Gd)	1596,4804 (28)	1,783 (17)
$\gamma_{28,1}$ (Gd)	1667,3 (2)	0,0019 (3)
$\gamma_{29,1}$ (Gd)	1674,0 (5)	0,0017 (4)
$\gamma_{30,1}$ (Gd)	1716,9 (5)	0,0006 (3)
$\gamma_{33,1}$ (Gd)	1773 (1)	0,00035 (21)
$\gamma_{30,0}$ (Gd)	1838,0 (5)	0,0008 (2)
$\gamma_{33,0}$ (Gd)	1895 (1)	0,0006 (2)

6 Main Production Modes

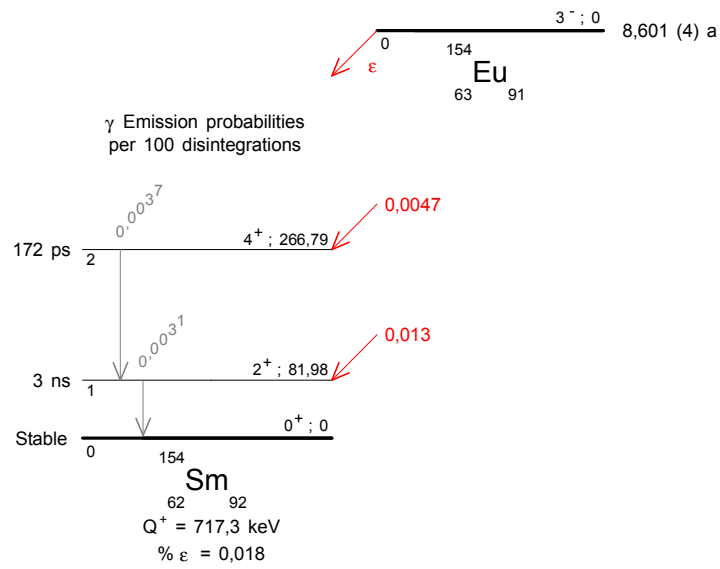
$$\left\{ \begin{array}{l} \text{Eu} - 153(n,\gamma)\text{Eu} - 154 \\ \text{Possible impurities : Eu} - 152, \text{Eu} - 155 \end{array} \right.$$

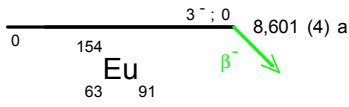
7 References

- R. J. HAYDEN, J. H. REYNOLDS, M. G. INGRAM. Phys. Rev. 75 (1949) 1500
(Half-life.)
- D. G. KARRAKER, R. J. HAYDEN, M. G. INGRAM. Phys. Rev. 87 (1952) 901
(Half-life.)
- V. M. KELMAN, V. A. ROMANOV, R. Y. METSKHVARISHVILI, V. A. KOLYUNOV. Nucl. Phys. 2 (1957) 395
(Gamma Multipolarities.)
- E. L. CHUPP, J. W. M. DUMOND, F. J. GORDON, R. C. JOPSON, H. MARK. Phys. Rev. 112 (1958) 518
(Gamma-ray energies.)
- D. S. LU, R. S. DINGUS. Phys. Lett. 3 (1962) 44
(Gamma-ray energies, experimental internal conversion electrons.)
- P. C. HANSEN, H. L. NIELSEN, K. WILSKY. Nucl. Phys. 89 (1966) 571
(Beta transition probabilities.)
- J. S. W. JANSEN, J. H. HAMILTON, E. F. ZGANJAR. Proc. Intern. Conf. Internal Conversion Process, Nashville (1966) 257
(Experimental ICC, gamma multipolarities.)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies.)
- R. A. MEYER. Phys. Rev. 174 (1968) 1478
(Gamma-ray energies, relative emission probabilities.)
- L. K. NG, K. S. MANN, T. G. WALTON. Nucl. Phys. A116 (1968) 433
(Beta transition probabilities.)
- G. I. ANDERSON, G. T. EVANS. Nucl. Phys. A123 (1969) 609
(Gamma multipolarities.)
- L. VARNELL, J. D. BOWMAN, J. TRISCHUK. Nucl. Phys. A127 (1969) 270
(Gamma-ray emission probabilities.)
- L. L. RIEDINGER, E. EICHLER, J. FUGLSANG. Proc. Intern. Conf. Nucl. Reactors Induced By Heavy ions, Heidelberg (1970) 442
(Gamma-ray relative emission probabilities.)
- L. L. RIEDINGER, N. R. JOHNSON, J. H. HAMILTON. Phys. Rev. C2 (1970) 2358
(Gamma-ray energies)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
(Half-life.)
- T. S. NAGPAL, R. E. CAUCHER. Can. J. Phys. 50 (1972) 2688
(Gamma multipolarities.)
- R. L. HEATH. Gamma-ray Spectrum Catalogue In.: ANCR 1000 2 (1974)
(Gamma-ray energies.)

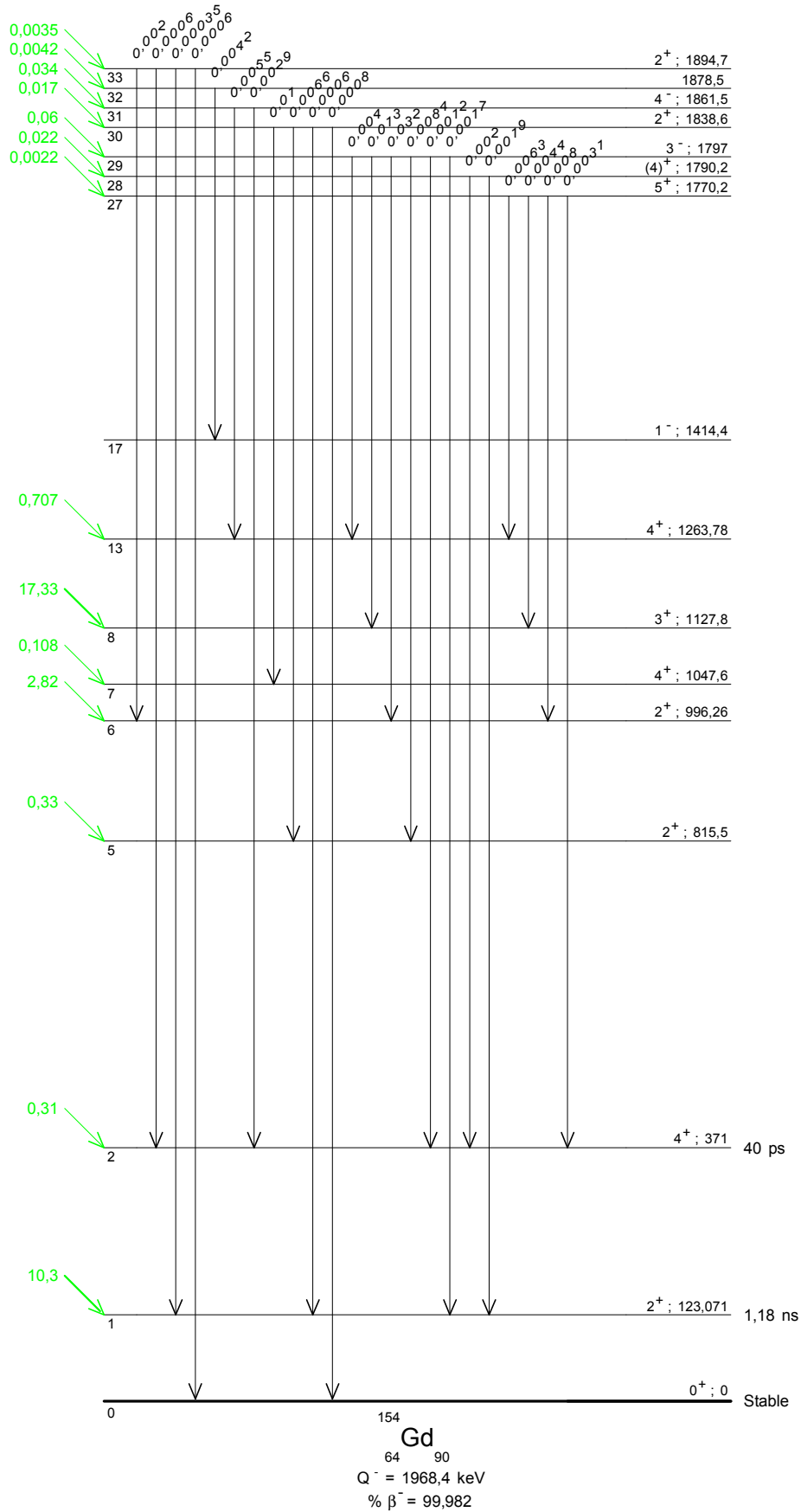
- F. P. LARKINS. At. Data Nucl. Data Tables 20 (1977) 313
(Auger electrons energies.)
- H. YAMADA, H. KAWAKAMI, M. KOIKE, K. KOMURA. J. Phys. Soc. Jpn 42 (1977) 1448
(Gamma multipolarities.)
- F. ROSEL, H. M. FRIESS, K. ALDER, H. C. PAULI. At. Data Nucl. Data Tables 21 (1978) 92
(Theoretical ICC.)
- W. N. RONEY JR, W. A. SEALE. Nucl. Instrum. Methods 171 (1980) 389
(Gamma-ray relative emission probabilities.)
- A. K. SHARMA, R. KAUR, H. R. VERMA, P. N. TREHAN. J. Phys. Soc. Jpn 48 (1980) 1407
(Gamma-ray relative emission probabilities.)
- D. D. HOPES, J. M. R. HUTCHINSON, F. J. SCHIMA, M. P. UNTERWEGER. NBS-SP 626 (1982) 85
(Half-life.)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life.)
- J. IWATA, M. YASUHARA, K. MAEDA, Y. YOSHIKAWA. Nucl. Instrum. Methods 219 (1984) 123
(Gamma-ray relative emission probabilities.)
- W. XINLIN, L. XIAODI, D. HONGSHAN. Chin. J. Nucl. Phys. 8 (1986) 371
(Gamma-ray relative emission probabilities.)
- M. J. WOODS, S. F. M. LUCAS. Int. J. Appl. Radiat. Isotop. 37 (1986) 1157
(Half-life.)
- F. LAGOUTINE, N. COURSOL, J. LEGRAND. Table de Radionucléides, ISBN 2-7272-0078-1 (1987)
(Energy of Auger electrons.)
- M. U. RAJPUT, T. D. MACMAHON. ZFK - 732 (1988) 313
(Half-life.)
- L. L. KIANG, G. C. KIANG, P. K. TENG ET AL.. Z. Physik A333 (1989) 19
(Gamma-ray relative emission probabilities.)
- F. J. SCHIMA. IAEA-CPR informal report GS/59 IAEA-TECDOC-619 (1989)
(Gamma-ray relative emission probabilities.)
- R. A. MEYER. Fizika (Zagreb) 22 (1990) 153
(Gamma-ray energies and relative emission probabilities.)
- R. C. HELMER. Appl. Rad. Isotopes Phys. Rev. 41 (1990) 75
(Gamma-ray relative emission probabilities.)
- A. V. ZANEVSKY, G. A. ISAAKYAN, N. V. KURENKOV ET AL.. Proc. 41st. Ann. Conf. Nucl. Spectr. At Nuclei (1991) 477
(123-keV gamma-ray absolute emission probability.)
- S. U. EL-KAMEESY, M. S. ABDEL-WAHAB, L. AL-HOUTY, H. ABOU-LEILA. Act. Phys. Acad. Sci. Hung. 71 (1992) 161
(Gamma-ray relative emission probabilities.)
- M. A. HAMMED, I. M. LOWIES, T. D. MACMAHON. Nucl. Instrum. Methods Phys. Res. A312 (1992) 308
(Gamma-ray relative emission probabilities and 1274-keV gamma-ray absolute emission probability.)
- T. E. SAZONOVA, G. A. ISAAKYAN, N. I. KARMALITSYN, S. V. SEPMAN, A. V. ZANEVSKY. Nucl. Instrum. Methods Phys. Res. A312 (1992) 372
(Gamma-ray relative emission probabilities.)
- U. SCHOTZIG, H. SCHRADER, K. DEBERTIN. Proc. Intern. Conf. Nucl. Data for Science and Techn. (1992) 562
(Half-life.)
- D. SMITH, D. H. WOODS, S. A. WOODS ET AL.. Nucl. Instrum. Methods Phys. Res. A312 (1992) 353
(Gamma-ray energies and emission probabilities.)
- M. P. UNTERWEGER, D. D. HOPES, F. J. SCHIMA. Nucl. Instrum. Methods Phys. Res. A312 (1992) 349
(Half-life.)
- J. L. THOMPSON, A. R. CARTWRIGHT. Appl. Rad. Isotopes 44 (1993) 707
(Half-life.)
- B. M. COURSEY, J. M. CALHOUN, J. CESSNA, D. B. GOLAS, F. J. SCHIMA, M. P. UNTERWEGER. Nucl. Instrum. Methods Phys. Res. A339 (1994) 26
(1274-keV gamma-ray absolute emission probability.)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q-value)
- N. MACH, B. FOGERBERG. Phys. Rev. C51 (1995) 509
(Experimental internal conversion electrons.)
- I. ALFTER, E. BODENSTEDT, W. KNICHEL, J. SCHUTH. Z. Physik A355 (1996) 277
(Experimental gamma multipolarities.)

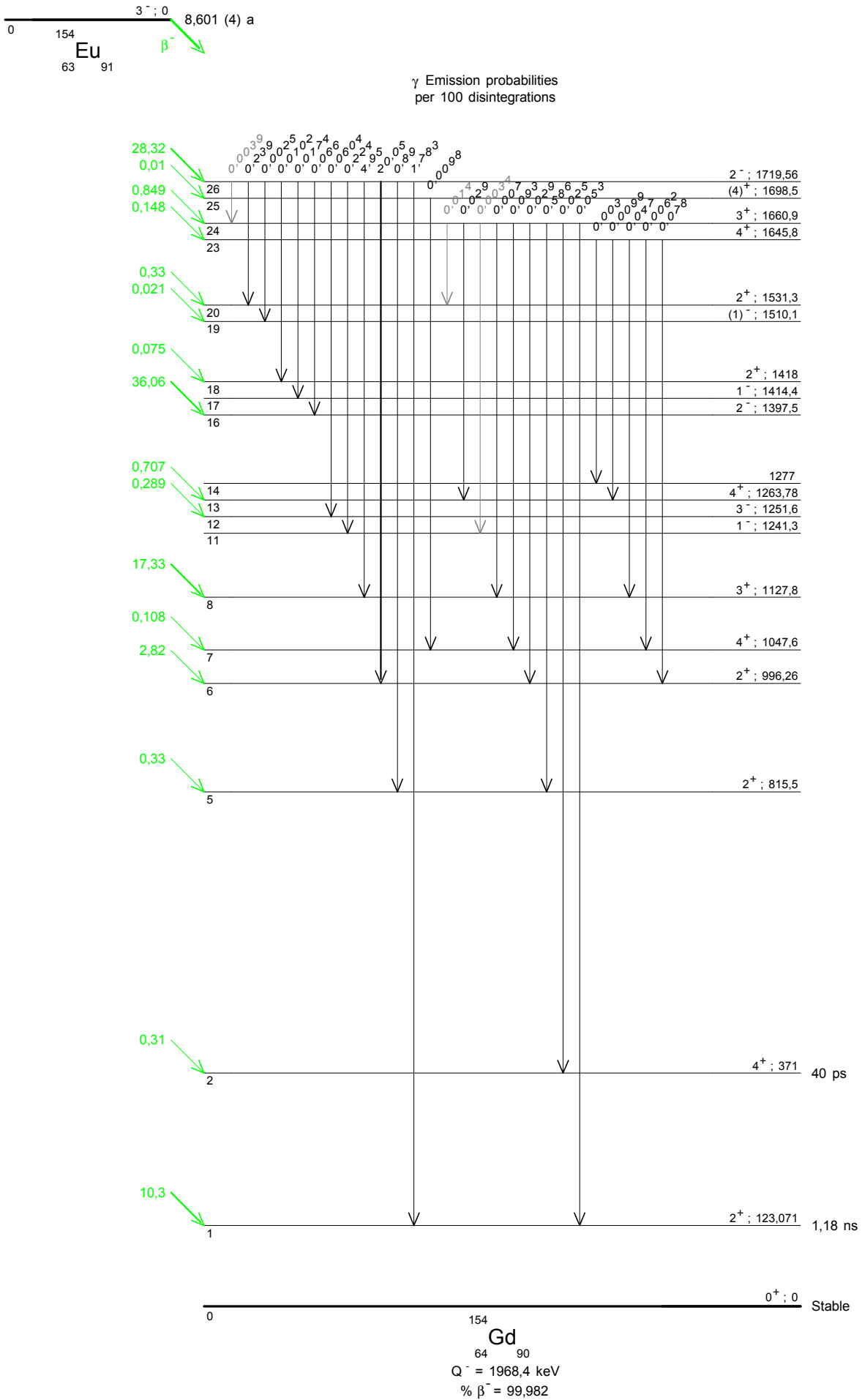
- E. SCHONFELD, H. JANSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(Atomic Data.)
- S. I. KAFALA, T. D. MACMAHON, S. V. BORZAKOV. J. Radioanal. Nucl. Chem. 215 (1997) 193
(248 and 996-keV gamma-ray absolute emission probabilities.)
- H. SIEGERT, H. SCHRADER, U. SCHOTZIG. Appl. Rad. Isotopes 49 (1998) 1397
(Half-life.)
- E. SCHONFELD. Appl. Rad. Isotopes 49 (1998) 1353
(Fractional electron capture probabilities Pk, Pl, Pm.)
- C. W. REICH, R. G. HELMER. Nucl. Data Sheets 85 (1998) 171
(Level scheme, multipolarities, total ICC.)
- E. SCHONFELD, G. RODLOFF. PTB- 6.11-1999-1999-1 (1999)
(KX-ray energies and relative emission probabilities.)
- V. P. CHECHEV, A. G. EGOROV. Appl. Rad. Isotopes 52 (2000) 601
(Evaluation technique.)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
(Gamma-ray energies.)
- M. P. UNTERWEGER. Appl. Rad. Isotopes 56 (2002) 125
(Half-life.)

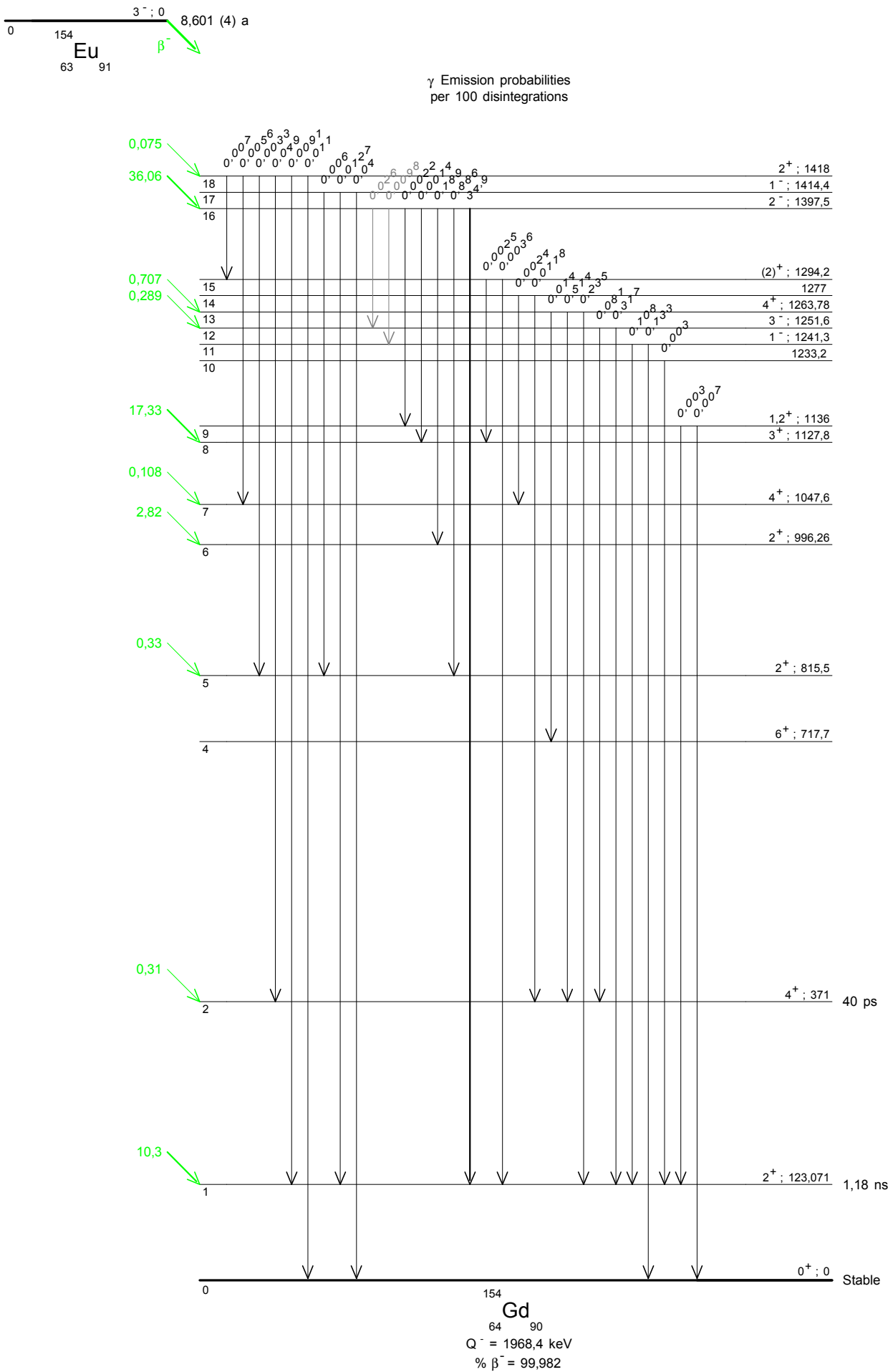


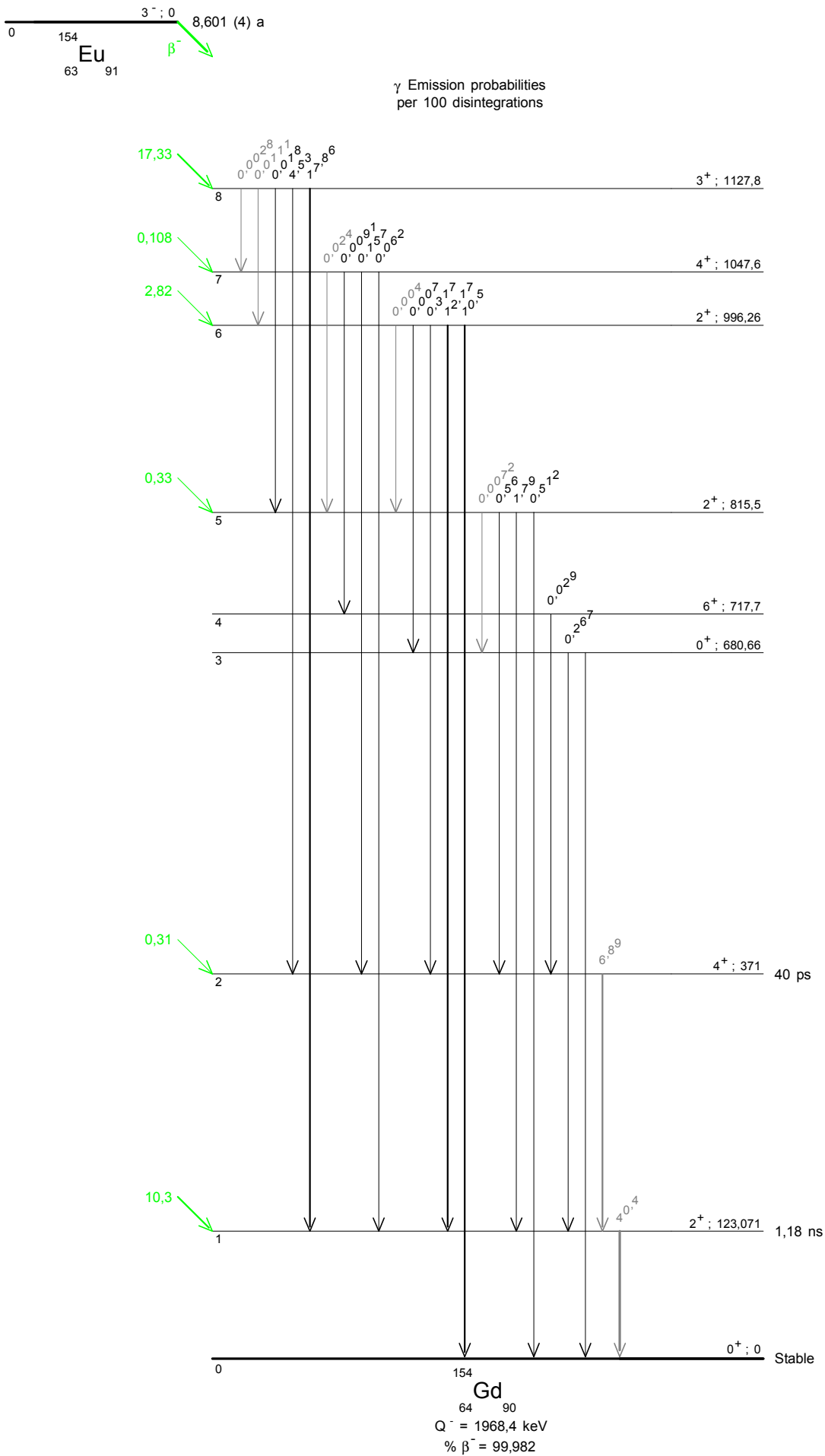


γ Emission probabilities
per 100 disintegrations











1 Decay Scheme

Eu-155 disintegrates 100 % via beta minus disintegration to excited levels and to the ground state in Gd-155.

L'euporium 155 se désintègre par émission bêta moins vers des niveaux excités et le niveau fondamental de gadolinium 155.

2 Nuclear Data

$$T_{1/2}(^{155}\text{Eu}) : 4,753 \quad (14) \quad \text{a}$$

$$Q^-(^{155}\text{Eu}) : 252,1 \quad (11) \quad \text{keV}$$

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,6}^-$	106,1 (11)	0,73 (7)	1st Forbidden	8,83
$\beta_{0,5}^-$	134,2 (11)	1,85 (23)	Allowed	8,75
$\beta_{0,4}^-$	144,6 (11)	<0,01	2nd Forbidden	>11,1
$\beta_{0,3}^-$	146,9 (11)	46,1 (29)	Allowed	7,47
$\beta_{0,2}^-$	165,7 (11)	25,5 (29)	Allowed	7,89
$\beta_{0,1}^-$	192,2 (11)	9,2 (4)	1st Forbidden	8,54
$\beta_{0,0}^-$	252,2 (11)	16,6 (11)	Allowed	8,65

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{5,4}(\text{Gd})$	10,4183 (13)	1,2 (1)	M1+0,11%E2		265 (22)	59 (5)	340 (23)
$\gamma_{3,2}(\text{Gd})$	18,763 (2)	17,7 (28)	M1+7,1%E2		284 (22)	65,9 (30)	367 (22)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{4,2}$ (Gd)	21,035 (4)	1,2 (1)	E2		2013 (60)	471 (14)	2600 (70)
$\gamma_{2,1}$ (Gd)	26,531 (21)	0,94 (7)	E1		1,55 (5)	0,342 (11)	1,98 (6)
$\gamma_{5,2}$ (Gd)	31,444 (7)	0,50 (15)	M1+17%E2		53 (13)	12,5 (30)	69 (14)
$\gamma_{3,1}$ (Gd)	45,299 (1)	1,89 (7)	E1		0,347 (10)	0,0758 (23)	0,443 (11)
$\gamma_{5,1}$ (Gd)	57,989 (1)	0,150 (14)	E1	1,021 (10)	0,173 (5)	0,0377 (11)	1,243 (11)
$\gamma_{1,0}$ (Gd)	60,0086 (10)	12,8 (6)	M1+4,1%E2	7,48 (9)	1,55 (6)	0,347 (14)	9,48 (11)
$\gamma_{6,1}$ (Gd)	86,0591 (10)	0,65 (7)	M1+3,0%E2	2,66 (3)	0,443 (17)	0,098 (4)	3,23 (4)
$\gamma_{2,0}$ (Gd)	86,5479 (10)	44,0 (5)	E1	0,360 (4)	0,0561 (17)	0,0122 (4)	0,432 (7)
$\gamma_{3,0}$ (Gd)	105,3083 (10)	26,5 (8)	E1	0,214 (2)	0,0323 (10)	0,00701 (21)	0,255 (3)
$\gamma_{6,0}$ (Gd)	146,071 (1)	0,084 (7)	E2	0,397 (4)	0,198 (6)	0,0462 (14)	0,653 (8)

3 Atomic Data

3.1 Gd

ω_K	:	0,932	(4)
$\bar{\omega}_L$	:	0,176	(6)
n_{KL}	:	0,850	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	42,3093	
	$K\alpha_1$	42,9967	
	$K\beta_3$	48,556	}
	$K\beta_1$	48,697	}
	$K\beta_5''$	49,053	}
	$K\beta_2$	49,961	}
	$K\beta_4$	50,099	}
	$KO_{2,3}$	50,219	}
	X_L	$L\ell$	5,36
		$L\gamma$	- 8,35

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	33,49 – 35,75	100
KLX	39,98 – 42,86	51,3
KXY	47,98 – 48,95	6,58
Auger L	3,4 – 8,3	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Gd)	3,4 - 8,3	35,1 (20)
e _{AK}	(Gd)		1,71 (11)
	KLL	33,49 - 35,75	}
	KLX	39,98 - 42,86	}
	KXY	47,98 - 48,95	}
ec _{5,4} L	(Gd)	2,043 - 3,175	0,93 (13)
ec _{5,1} K	(Gd)	7,75 (3)	0,068 (7)
ec _{5,4} M	(Gd)	8,538 - 9,233	0,21 (3)
ec _{1,0} K	(Gd)	9,770 (3)	9,1 (4)
ec _{3,2} L	(Gd)	10,387 - 11,520	13,6 (23)
ec _{4,2} L	(Gd)	12,659 - 13,792	0,93 (18)
ec _{3,2} M	(Gd)	16,882 - 17,578	3,2 (5)
ec _{2,1} L	(Gd)	18,155 - 19,288	0,49 (4)
ec _{4,2} M	(Gd)	19,154 - 19,850	0,22 (4)
ec _{5,2} L	(Gd)	23,068 - 24,201	0,38 (4)
ec _{2,1} M	(Gd)	24,650 - 25,346	0,108 (8)
ec _{5,2} M	(Gd)	29,563 - 30,259	0,09 (3)
ec _{6,1} K	(Gd)	35,820 (3)	0,41 (5)
ec _{2,0} K	(Gd)	36,309 (3)	11,05 (16)
ec _{3,1} L	(Gd)	36,923 - 38,056	0,45 (2)
ec _{3,1} M	(Gd)	43,418 - 44,114	0,100 (5)
ec _{5,1} L	(Gd)	49,613 - 50,746	0,012 (1)
ec _{1,0} L	(Gd)	51,633 - 52,766	1,89 (11)
ec _{3,0} K	(Gd)	55,069 (3)	4,52 (14)
ec _{5,1} M	(Gd)	56,108 - 56,804	0,0030 (3)
ec _{1,0} M	(Gd)	58,128 - 58,823	0,42 (3)
ec _{6,1} L	(Gd)	77,683 - 78,816	0,068 (8)
ec _{2,0} L	(Gd)	78,172 - 79,305	1,72 (5)
ec _{6,1} M	(Gd)	84,178 - 84,874	0,015 (2)
ec _{2,0} M	(Gd)	84,667 - 85,363	0,375 (13)

		Energy keV	Electrons per 100 disint.
ec _{6,0} K	(Gd)	95,832 (3)	0,0202 (16)
ec _{3,0} L	(Gd)	96,933 - 98,066	0,68 (3)
ec _{3,0} M	(Gd)	103,428 - 104,123	0,148 (8)
ec _{6,0} L	(Gd)	137,696 - 138,829	0,0101 (8)
ec _{6,0} M	(Gd)	144,190 - 144,886	0,0024 (2)
$\beta_{0,6}^-$	max:	106,1 (11)	0,73 (7)
$\beta_{0,6}^-$	avg:	27,8 (3)	
$\beta_{0,5}^-$	max:	134,2 (11)	1,85 (23)
$\beta_{0,5}^-$	avg:	35,6 (3)	
$\beta_{0,4}^-$	max:	144,6 (11)	0,01
$\beta_{0,4}^-$	avg:		
$\beta_{0,3}^-$	max:	146,9 (11)	46,1 (29)
$\beta_{0,3}^-$	avg:	39,2 (3)	
$\beta_{0,2}^-$	max:	165,7 (11)	25,5 (29)
$\beta_{0,2}^-$	avg:	44,6 (3)	
$\beta_{0,1}^-$	max:	192,2 (11)	9,2 (4)
$\beta_{0,1}^-$	avg:	52,3 (3)	
$\beta_{0,0}^-$	max:	252,2 (11)	16,6 (11)
$\beta_{0,0}^-$	avg:	70,2 (3)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Gd)	5,36 — 8,35	7,5 (5)
XK α_2	(Gd)	42,3093	6,70 (13)
XK α_1	(Gd)	42,9967	12,05 (23)
XK β_3	(Gd)	48,556 }	
XK β_1	(Gd)	48,697 }	3,84 (11)
XK β_5''	(Gd)	49,053 }	
XK β_2	(Gd)	49,961 }	
XK β_4	(Gd)	50,099 }	0,977 (26)
XKO _{2,3}	(Gd)	50,219 }	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{5,4}(\text{Gd})$	10,4183 (13)	0,0035 (4)
$\gamma_{3,2}(\text{Gd})$	18,763 (2)	0,048 (7)
$\gamma_{4,2}(\text{Gd})$	21,035 (4)	0,00046 (3)
$\gamma_{2,1}(\text{Gd})$	26,531 (21)	0,316 (22)
$\gamma_{5,2}(\text{Gd})$	31,444 (7)	0,0071 (15)
$\gamma_{3,1}(\text{Gd})$	45,299 (1)	1,31 (5)
$\gamma_{5,1}(\text{Gd})$	57,989 (1)	0,067 (6)
$\gamma_{1,0}(\text{Gd})$	60,0086 (10)	1,22 (5)
$\gamma_{6,1}(\text{Gd})$	86,0591 (10)	0,154 (17)
$\gamma_{2,0}(\text{Gd})$	86,5479 (10)	30,7 (3)
$\gamma_{3,0}(\text{Gd})$	105,3083 (10)	21,1 (6)
$\gamma_{6,0}(\text{Gd})$	146,071 (1)	0,051 (4)

6 Main Production Modes

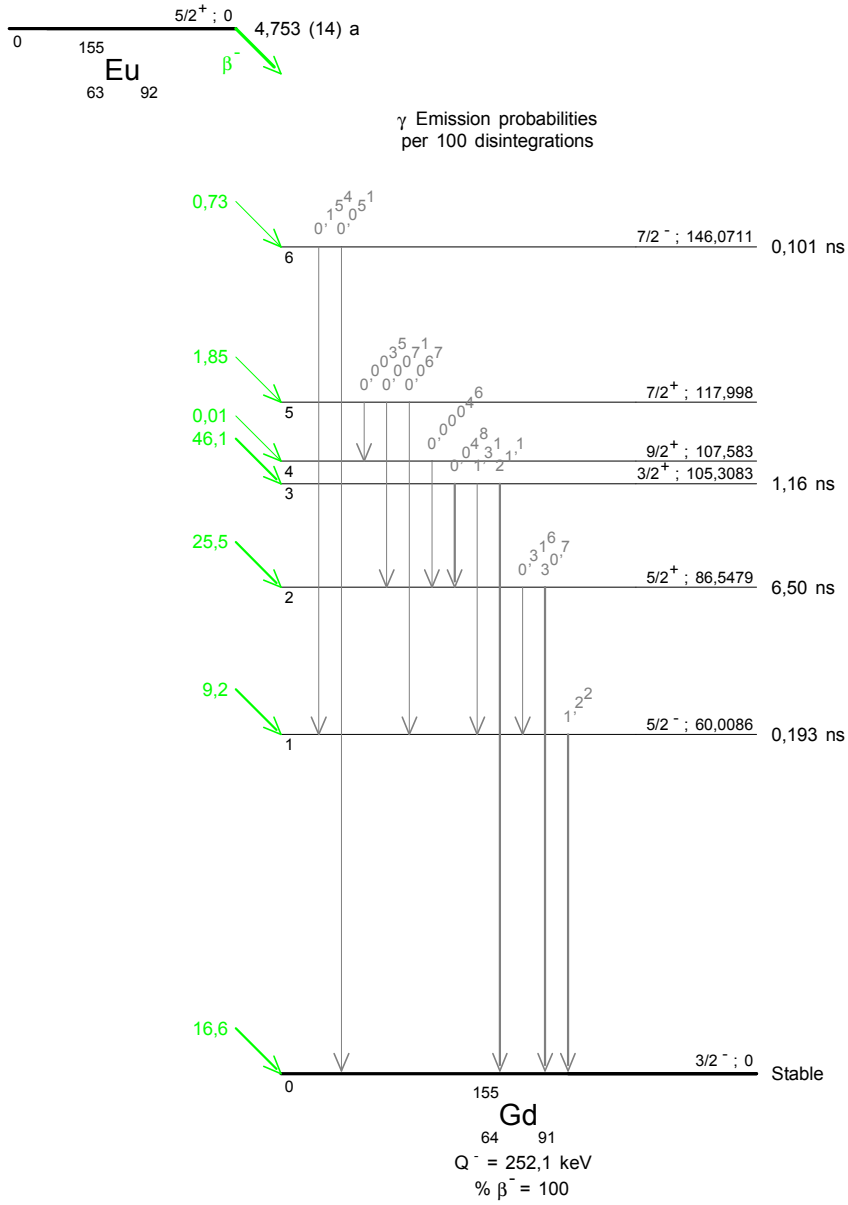
$$\left\{ \begin{array}{l} \text{Sm} - 154(n,\gamma)\text{Sm} - 155 \\ \text{Possible impurities : Eu} - 152, \text{Eu} - 154 \end{array} \right.$$

7 References

- J.A.MARINSKY, L.E.GLENDENIN, F.METZGER. MIT-LNS Progr Report NP-1272 (1949) 67
(Beta emission energies and probabilities)
- M.R.LEE, R.KATZ. Phys.Rev. 93 (1954) 155
(Beta emission energies and probabilities)
- V.S.DUBEY, C.E.MANDEVILLE, M.A.ROTHMAN. Phys.Rev. 103 (1956) 1430
(Beta emission energies and probabilities)
- M.C. JOSHI, B.V.THOSAR. Proc. Indian Acad. Sci. 50A (1959) 342
(Beta emission energies and probabilities)
- J. DE BOER, M.MARTIN, P.MARMIER. Helv. Phys. Acta 32 (1959) 658
(Multipolarity mixing ratios)
- E.N.HATCH, F.BOEHM. Z. Physik 155 (1959) 609
(Gamma ray energies and relative emission probabilities)
- B.N. SUBBA RAO. Nuovo Cim. 16 (1960) 283
(Beta emission energies and probabilities)
- B.N. SUBBA RAO. Nucl.Phys. 28 (1961) 503
(Multipolarity mixing ratios)
- B. HARMATZ, T.H. HANDLEY, J.W. MIHELICH. Phys.Rev. 128 (1962) 1176
(Multipolarity mixing ratios)
- D.ASHERY, A.E.BLAUGRUND, R.KALISH. Nucl.Phys. 76 (1966) 336
(Multipolarity mixing ratios)
- C.FOIN, J.OMS, J-L.BARAT. J.Phys.(Paris) 28 (1967) 861
(G-energies, P(KX), Pce, multipolarity mixing ratios)
- J.KORMICKI, H.NIEWODNICZANSKI, Z.STACHURA, K.ZUBER, A.BUDZIAK. Nucl.Phys. A102 (1967) 253
(Multipolarity mixing ratios)

- P.H.BLICHERT-TOFT, E.G.FUNK, J.W.MIHELICH., Nucl.Phys. A96 (1967) 190
(KX-ray emission probabilities)
- R.E.BERG, J.L.SNELGROVE, E.KASHY. Phys.Rev. 153 (1967) 1165
(Gamma ray relative emission probabilities)
- R.S.HAGER, E.C.SELTZER. Nucl. Data Tables A4 (1968) 1
(Theoretical ICC)
- J.OMS, C.FOIN, A.BAUDRY. Comp. Rend. Acad. Sci. (Paris) 266B (1968) 1292
(KX ray emission probabilities)
- P.ALEXANDER. Nucl.Phys. A108 (1968) 145
(Gamma ray relative emission probabilities)
- R.A.MEYER, J.W.T.MEADOWS. Nucl.Phys. A132 (1969) 177
(Gamma and KX ray energies and emission probabilities)
- R.S MOWATT. Can J.Phys. 48 (1970) 1933
(Half-life)
- D.E.RAESIDE. Nucl. Instrum. Methods 87 (1970) 7
(Gamma ray energies)
- J.D.REIERSON, G.C.NELSON, E.N.HATCH. Nucl.Phys. A153 (1970) 109
(Gamma ray energies and relative emission probabilities)
- R.J.GEHRKE, R.A.LOKKEN. Nucl. Instrum. Methods 97 (1971) 219
(Gamma ray relative emission probabilities)
- J.F.EMERY, S.A.REYNOLDS, E.I.WYATT, G.I.GLEASON. Nucl.Sci.Eng. 48 (1972) 319
(Half-life)
- B.N. SUBBA RAO. Current Sci. (India) 41 (1972) 692
(Half-life)
- S.I.SALEM, S.L.PANOSSIAN, R.A.KRAUSE. At.Data.Nuc.Data.Tables 14 (1974) 91
(KX ray relative emission probabilities)
- W.R.DANIELS, D.W BARR, G.F.GRISHAM, F.O.LAWRENCE. J. Inorg. Nucl. Chem. 36 (1974) 3874
(Half-life)
- R.L.HEATH. Report Ancr 1000-2 (1974)
(Gamma ray relative emission probabilities)
- P.CHRISTMAS, P.CROSS. J.Phys.(London) G1 (1975) 113
(Gamma ray energies, multipolarity mixing ratios)
- H. J. KRELL, S. HOFMANN. Z. Physik A272 (1975) 257
(Egamma, P'gamma, multipolarity mixing ratios)
- R.A.MEYER, R.GUNNINK, C.M.LEDERER, E.BROWNE. Phys.Rev. C13 (1976) 2466
(Gamma ray energies)
- F.P.LARKINS. At.Data.Nuc.Data.Tables 20 (1977) 313
(Auger electron energies)
- I.M.BAND, M.B.TRZHASKOVSKAYA. Special report of Leningrad nuclear physics institute (1978)
(Theoretical ICC)
- F.RÖSEL, H.M.FRIESS, K.ALDER, H.C.PAULI. At.Data.Nuc.Data.Tables 21 (1978) 92
(Theoretical ICC)
- B.M.COURSEY, D.D.HOPPES, F.J. SCHIMA. Nucl. Instrum. Methods 193 (1982) 1
(Gamma ray relative emission probabilities)
- K.F.WALZ, K.DEBERTIN, H.SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- H.H.SCHMIDT, W.STOFFL, T.EGIDY, P.HUNGERFORD, H.J. SCHEERER, K. SCHRECKENBACH, H.G.BORNER, D.D.WARNER, R.E.CHRIEN, R.C.GREENWOOD, C.W. REICH. J.Phys.(London) G12 (1986) 411
(Gamma ray and level energies, multipolarity mixing ratios)
- F. LAGOUTINE, COURSOL N., LEGRAND J. Table de Radionucleides, ISBN-2-7272-0078-1. (LMRI, 1982-1987)
(1987)
(Energy of Auger electrons)
- R.A.MEYER. Fizika (Zagreb) 22 (1990) 153
(Gamma ray energies and relative emission probabilities)
- V.M. GOROZHANKIN, A.KOVALIK, L.E.IR, M.A. MAKHMUD, YA.NOVAK, A.F. NOVGORODOV. Program and Thesis, Proc 40th Ann Conf Nucl Spectrosc Struct At Nuclei, Leningrad (1990) 97
(Gamma ray energies, multipolarity mixing ratios)
- T.E.SAZONOVA, G.A.ISAAKYAN, N.I.KARMALITSYN, S.V. SEPMAN, A.V. ZANEVSKY. Nucl. Instrum. Methods Phys. Res. A312 (1992) 372
(105,31 keV gamma ray absolute emission probability)

- M.P.UNTERWEGER, D.D.HOPPES, F.J.SCHIMA. Nucl. Instrum. Methods Phys. Res. A312 (1992) 349
(Half-life)
- I.M.BAND, M.B.TRZHASKOVSKAYA. At.Data.Nuc.Data.Tables 55 (1993) 43
(Theoretical ICC)
- J.L.THOMPSON, AND A.R.CARTWRIGHT. Appl. Rad. Isotopes 44 (1993) 707
(Half-life)
- B.M.COURSEY, J.M.CALHOUN, J.CESSNA, D.B.GOLAS, F.J.SCHIMA, M.P. UNTERWEGER. Nucl. Inst. Meth. Phys. Res. A339 (1994) 26
(86,55 keV gamma ray absolute emission probability)
- A.G.EGOROV, V.P.CHECHEV. Nucl. Instrum. Methods Phys. Res. A339 (1994) 248
(Gamma and KX ray absolute emission probabilities)
- C.W.REICH. Nucl.Data Sheets 71 (1994) 709
(Decay scheme and level energies)
- G. AUDI, A.H WAPSTRA. Nucl.Phys. A595 (1995) 409
(Q value)
- V.P.CHECHEV, A.G.EGOROV, G.E.SHCHUKIN. Appl. Rad. Isotopes 47 (1996) 329
(Gamma ray relative emission probabilities)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(Atomic data)
- H.SIEGERT, H.SCHRADER, U.SCHOTZIG. Appl. Rad. Isotopes 49 (1998) 1397
(Half-life)
- E.SCHÖNFELD, G.RODLOFF. Report PTB-6.11, Braunschweig 1999-1 (1999)
(KX ray energies and relative emission probabilities)
- V.P.CHECHEV, A.G.EGOROV. Appl. Rad. Isotopes 52 (2000) 601
(Evaluation of half-life)
- M.P.UNTERWEGER. Appl. Rad. Isotopes 56 (2002) 125
(Half-life)





1 Decay Scheme

Ho-166 decays by beta minus emission to excited states of Er-166.

L'holmium 166 se désintègre uniquement par émission bêta moins vers les états excités d'erbium 166.

2 Nuclear Data

$$T_{1/2}({}^{166}\text{Ho}) : 26,795 \quad (29) \quad \text{h}$$

$$Q^{-}({}^{166}\text{Ho}) : 1854,5 \quad (9) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,8}^{-}$	24,1 (9)	0,0353 (11)		5
$\beta_{0,7}^{-}$	41,7 (9)	0,00010 (3)	1st forbidden	12,1
$\beta_{0,6}^{-}$	192,0 (9)	0,304 (7)	Allowed	6,9
$\beta_{0,5}^{-}$	326,2 (9)	0,00276 (22)	Unique 1st forbidden	9,5
$\beta_{0,4}^{-}$	394,5 (9)	0,955 (16)	1st forbidden	7,4
$\beta_{0,3}^{-}$	1068,6 (9)	0,0072 (21)	Unique 1st forbidden	11,6
$\beta_{0,1}^{-}$	1773,9 (9)	50,5 (15)	Unique 1st forbidden	9
$\beta_{0,0}^{-}$	1854,5 (9)	48,2 (15)	1st forbidden	8,1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L (10^{-2})	α_M (10^{-2})	α_T
$\gamma_{1,0}(\text{Er})$	80,5725 (13)	51,7 (11)	E2	1,65 (5)	401 (8)	97,8 (20)	6,90 (14)
$\gamma_{2,1}(\text{Er})$	184,4107 (21)	0,0020 (9)	E2	0,205 (6)	9,84 (30)	2,36 (7)	0,333 (10)
$\gamma_{3,2}(\text{Er})$	520,80 (7)	0,00036 (2)	E2	0,01192 (36)	0,234 (7)	0,0535 (16)	0,0149 (5)
$\gamma_{4,3}(\text{Er})$	674,25 (7)	0,0200 (17)	E2	0,00653 (20)	0,1138 (34)	0,0257 (8)	0,00799 (24)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L (10^{-2})	α_M (10^{-2})	α_T
$\gamma_{3,1}$ (Er)	705,21 (7)	0,0147 (12)	E2+M1	0,00591 (18)	0,1012 (30)	0,0228 (7)	0,00721 (22)
$\gamma_{3,0}$ (Er)	785,78 (7)	0,0121 (3)	E2	0,00467 (14)	0,0769 (23)	0,0173 (5)	0,00566 (17)
$\gamma_{5,2}$ (Er)	1263,25 (15)	0,0155 (9)	E2(+M3)	0,0018 (2)	0,03 (1)	0,0058 (2)	0,0021 (2)
$\gamma_{4,1}$ (Er)	1379,452 (10)	0,935 (35)	E2	0,00151 (5)	0,022 (1)	0,0048 (2)	0,00179 (5)
$\gamma_{5,1}$ (Er)	1447,66 (15)	0,00105 (10)	E2(+E0)	0,00138 (4)	0,0198 (6)	0,0044 (2)	0,00163 (5)
$\gamma_{4,0}$ (Er)	1460,025 (10)	0,0003	E0	0,3			
$\gamma_{5,0}$ (Er)	1528,23 (15)	0,00014 (5)	E2	0,00125 (4)	0,0178 (5)		0,00147 (4)
$\gamma_{6,1}$ (Er)	1581,860 (15)	0,186 (4)	E1+(M2)	0,0006 (1)			
$\gamma_{6,0}$ (Er)	1662,433 (15)	0,118 (5)	E1	0,000484 (15)			
$\gamma_{7,1}$ (Er)	1732,2 (5)	0,000046 (20)	M1(+E2)	0,0015 (2)			
$\gamma_{8,1}$ (Er)	1749,846 (24)	0,0272 (10)	E1(+M2)	0,0005 (2)			
$\gamma_{7,0}$ (Er)	1812,8 (5)	0,000056 (19)	E1(+M2)	0,0004 (2)			
$\gamma_{8,0}$ (Er)	1830,419 (24)	0,0081 (2)	E1	0,000413 (12)			

3 Atomic Data

3.1 Er

ω_K	:	0,942	(4)
$\bar{\omega}_L$	:	0,216	(9)
n_{KL}	:	0,838	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	48,2215	
	$K\alpha_1$	49,1282	
	$K\beta_3$	55,495	}
	$K\beta_1$	55,682	}
	$K\beta_5''$	56,04	}
			32,5
	$K\beta_2$	57,21	}
	$K\beta_4$	57,313	}
	$KO_{2,3}$	57,456	}
			8,45
X_L	$L\ell$	6,14	
	$L\alpha$	6,9 – 6,95	
	$L\eta$	7,05	
	$L\beta$	7,75 – 8,34	
	$L\gamma$	8,81 – 9,43	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	37,78 – 40,55	100
KLX	45,52 – 49,10	52,4
KXY	53,07 – 57,84	6,86
Auger L		
	3,9 – 7,6	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Er)	3,9 - 7,6	28,0 (6)
e _{AK}	(Er)		0,63 (5)
	KLL	37,78 - 40,55	}
	KLX	45,52 - 49,10	}
	KXY	53,07 - 57,84	}
ec _{1,0} T	(Er)	23,09 - 80,54	45,2 (15)
ec _{1,0} K	(Er)	23,090 (2)	10,81 (35)
ec _{1,0} L	(Er)	70,82 - 72,22	26,3 (8)
ec _{1,0} M	(Er)	78,37 - 79,16	6,41 (21)
ec _{1,0} N	(Er)	80,12 - 80,57	1,493 (49)
$\beta_{0,8}^-$	max:	24,1 (9)	0,0353 (11)
$\beta_{0,8}^-$	avg:	7,1 (10)	
$\beta_{0,7}^-$	max:	41,7 (9)	0,00010 (3)
$\beta_{0,7}^-$	avg:	13 (2)	
$\beta_{0,6}^-$	max:	192,0 (9)	0,304 (7)
$\beta_{0,6}^-$	avg:	52 (1)	
$\beta_{0,5}^-$	max:	326,2 (9)	0,00276 (22)
$\beta_{0,5}^-$	avg:	93 (3)	
$\beta_{0,4}^-$	max:	394,5 (9)	0,955 (16)
$\beta_{0,4}^-$	avg:	115 (3)	
$\beta_{0,3}^-$	max:	1068,6 (9)	0,0072 (21)
$\beta_{0,3}^-$	avg:	356 (9)	
$\beta_{0,1}^-$	max:	1773,9 (9)	50,5 (15)
$\beta_{0,1}^-$	avg:	651,1 (6)	
$\beta_{0,0}^-$	max:	1854,5 (9)	48,2 (15)
$\beta_{0,0}^-$	avg:	693,8 (6)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Er)	6,14 — 9,43	7,91 (18)	
XK α_2	(Er)	48,2215	2,91 (10)	} K α
XK α_1	(Er)	49,1282	5,16 (17)	
XK β_3	(Er)	55,495	} 1,68 (6)	K' β_1
XK β_1	(Er)	55,682		
XK β_5''	(Er)	56,04		
XK β_2	(Er)	57,21	} 0,436 (18)	K' β_2
XK β_4	(Er)	57,313		
XKO _{2,3}	(Er)	57,456		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Er)	80,5725 (13)	6,55 (8)
$\gamma_{2,1}$ (Er)	184,4107 (11)	0,0015 (7)
$\gamma_{3,2}$ (Er)	520,80 (7)	0,00035 (2)
$\gamma_{4,3}$ (Er)	674,24 (7)	0,0198 (17)
$\gamma_{3,1}$ (Er)	705,21 (7)	0,0146 (12)
$\gamma_{3,0}$ (Er)	785,78 (7)	0,0120 (3)
$\gamma_{5,2}$ (Er)	1263,24 (15)	0,0155 (9)
$\gamma_{4,1}$ (Er)	1379,446 (10)	0,933 (35)
$\gamma_{5,1}$ (Er)	1447,66 (15)	0,00105 (10)
$\gamma_{4,0}$ (Er)	1460,018 (10)	0,0002
$\gamma_{5,0}$ (Er)	1528,23 (15)	0,00014 (5)
$\gamma_{6,1}$ (Er)	1581,852 (15)	0,186 (4)
$\gamma_{6,0}$ (Er)	1662,424 (15)	0,118 (5)
$\gamma_{7,1}$ (Er)	1732,2 (5)	0,000046 (20)
$\gamma_{8,1}$ (Er)	1749,837 (14)	0,0272 (10)
$\gamma_{7,0}$ (Er)	1812,8 (5)	0,000056 (19)
$\gamma_{8,0}$ (Er)	1830,408 (24)	0,0081 (2)

6 Main Production Modes

Ho – 165 (E = thermal)(n, γ)Ho – 166

Ho – 165(d,p)Ho – 166

Ho – 165(d,pg)Ho – 166

Er – 167(t)Ho – 166

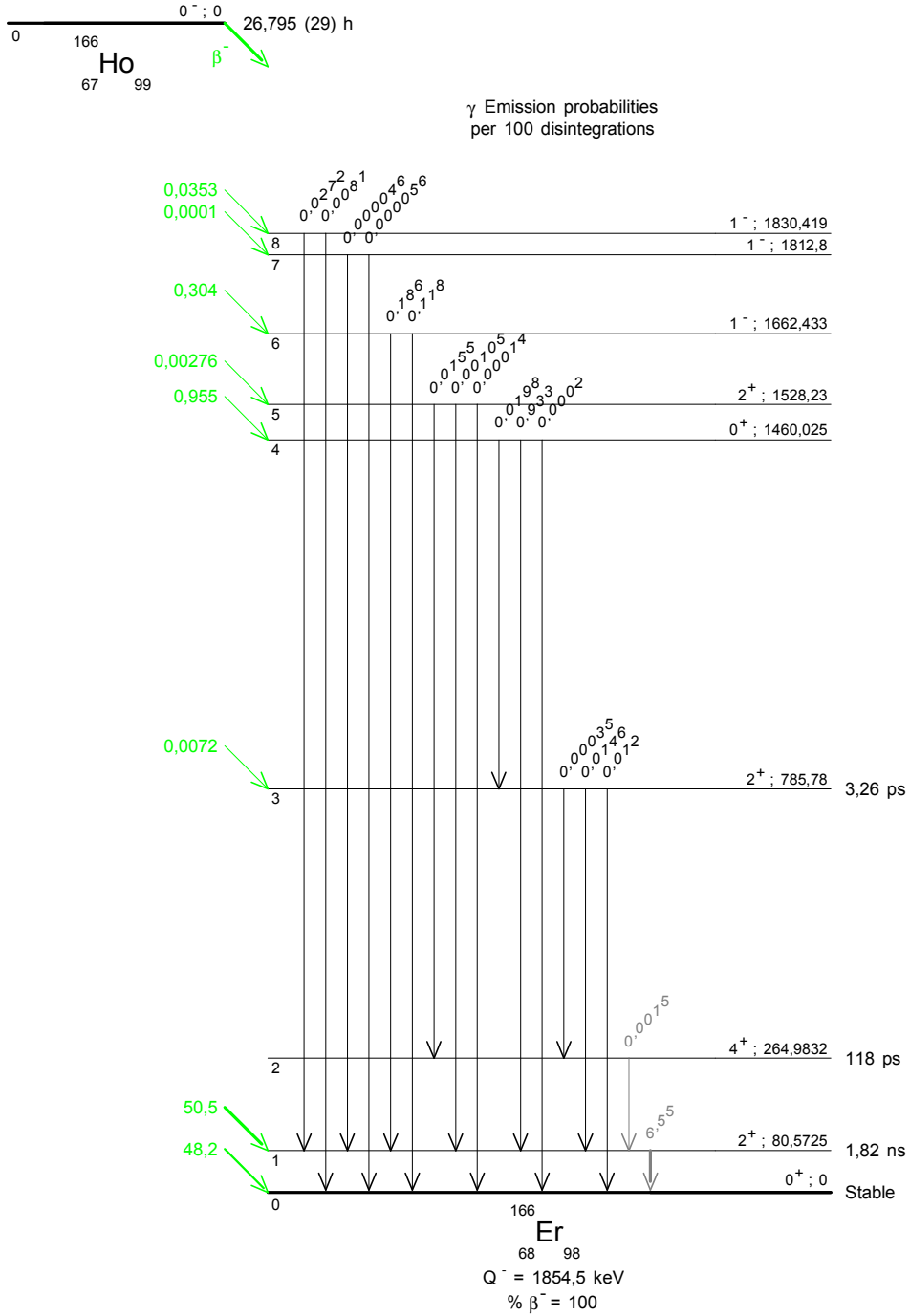
Dy – 166 decay, $T_{1/2} = 81,6$ h

7 References

- M.G.INGHRAM, R.J.HAYDEN. Phys. Rev. 71 (1947) 130
(Half-life)
- P.J.GRANT, J.M.HILL. Nature 163 (1949) 524
(Half-life)
- M.ANTONEVA, A.A.BASHILOV, B.S.DZHELEPOV. Izv. Acad. Nauk. SSSR 14 (1950) 299
(Half-life)
- A.SUNYAR. Phys. Rev. 93 (1954) 1345
(Beta transitions)
- R.L.GRAHAM, J.L.WOLFSON, M.A.CLARK. Phys. Rev. 98 (1955) 1173a
(Beta emission probabilities)
- J.M.CORK, M.K.BRICE, R.G.HELMEYER, R.M.WOODS JR. Phys. Rev. 110 (1958) 526
(Half-life, Beta plus transitions)
- J.E CLINE, E.C.YATES, E.H.TURK. Nucl. Phys. 30 (1962) 154
(Beta transitions)
- D.C.HOFFMAN. J. Inorg. Nucl. Chem. 25 (1963) 1196
(Half-life)
- M.K.RAMASWAMY, S.M.BRAHMAVAR. Curr. Sci. India 32 (1963) 451
(Conv. Elec. emission probabilities)
- L.FUNKE, K.HOHMUT, H.JUNGCLAUSEN, K.KANN, G.MUELLER, H.SODAN, L.WERNER. Kernenergie 6 (1963) 152
(Beta emission energies)
- W.GELLETLY, J.S.GEIGER, R.L.GRAHAM. Bull. Amer. Phys. Soc. 11 (1966) 352
(K X-ray emission probabilities, K X-ray energies)
- H.A.NEUMANN. Z. Naturforsch. 21a (1966) 1328
(Gamma-ray emission probabilities)
- P.ERMAN, G.T.EMERY, M.L.PERLMAN. Phys. Rev. 147 (1966) 858
(K X-ray emission probabilities, K X-ray energies)
- W.H.BRANTLEY, A.R.POLDERMAN, W.H.G.LEWIN. Bull. Amer. Phys. Soc. 11 (1966) 824
(Conv. Elec. emission probabilities)
- H.DANIEL, G.TH.KASCHL. Nucl. Phys. 76 (1966) 97-117
(Half-life, Beta emission probabilities, Conv. Elec. emission probabilities)
- J.ZYLICZ, M.H.JORGENSEN, O.B.NIELSEN, O.SKILBREID. Nucl. Phys. 81 (1966) 88
(Conv. Elec. emission probabilities)
- S.E.KARLSSON, I.ANDERSSON, O.NILSSON, G.MALMSTEN, C.NORDLING, K.SIEGBAHN. Nucl. Phys. 89 (1966) 513
(K X-ray emission probabilities, K X-ray energies)
- J.A.BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(K X-ray energies)
- C.GUNTHER, L.D.PARSIGNAULT. Phys. Rev. 153 (1967) 1297
(Gamma-ray emission probabilities)
- S.B.BURSON. Phys. Rev. 158 (1967) 1161
(Gamma-ray emission probabilities)
- W.GELLETLY, J.S.GEIGER, R.L.GRAHAM. Phys. Rev. 157 (1967) 1043
(L X-ray ratio)
- M.ARNOUX, A.GIZON. Compt. Rend. Acad. Sci. Paris 264 (1967) 1518
(L/M ratio)
- S.HOEGBERG, J.E.BERGMARK, G.MALMSTEN, O.NILSSON. Nucl. Phys. A120 (1968) 569
(K X-ray emission probabilities, K X-ray energies)
- M.BOGDANOVIC, M.MLADJENOVIC, R.STEPIC. Nucl. Phys. A106 (1968) 209
(Conv. Elec. emission probabilities)
- O.NILSSON, I.THOREN, G.MALMSTEN, S.HOEGBERG. Nucl. Phys. A120 (1968) 561
(K/L ratio)

- E.FALKSTROEM, S.NILSSON, S.BOREVING. Arkiv Pysik 39 (1968) 1
(Conv. Elec. emission energies)
- M.BOGDANOVIC, M.MLADJENOVIC, R.STEPIC. Z. Physik 216 (1968) 267
(K/L ratio)
- G.C.NELSON, E.N.HATCH. Nucl. Phys. A127 (1969) 560
(Conv. Elec. emission energies)
- O.NILSSON, I.THOREIN, G.MALMSTEN, S.HOGBERG. Nucl. Phys. A139 (1969) 712
(ICC)
- C.W.REICH, J.E.CLIN. Phys. Rev. A159 (1970) 181-201
(Gamma ray energies, Gamma-ray emission probabilities)
- J.L.CAMPBELL, H.J.SMITH, I.K.MAC KENZIE. Nucl. Instrum. Methods 92 (1971) 237
(Conv. Elec. emission energies)
- O.DRAGON, B.MARTIN, D.MERKERT, M.VINDUSKA. Nucl. Phys. A183 (1972) 390
(K X-ray emission probabilities, K X-ray energies)
- J.L.CAMPBELL, R.J.GOBLE, J.J.SMITH, J.H.AMILTON, J.C.MANTHURUTHIL. Radioactivity in Nuc. Spec. (1972) 1387
(Conv. Elec. emission energies)
- E.P.GREGORIEV, A.V.ZOLOTAVIN, S.V.KAMYNOV. Bull. Acad. Sci. USSR, Fyz. Ser. 38 (1974) 30
(Beta emission probabilities)
- E.P.GREGORIEV, A.V.ZOLOTAVIN, S.V.KAMYNOV. Izv. Akad. Nauk. SSSR, Ser. Fiz. 38 (1974) 2499
(Beta emission probabilities)
- K.VENKATARAMANIAH, V.LAKSHMINARAYANA, K.VENKATAREDDY. Curr. Science (India) 45 (1976) 473
(Beta emission probabilities, Gamma-ray emission probabilities)
- F.P.LARKINS. At. Data. Nucl. Data Tables 20 (1977) 313
(Auger electron energies)
- M.ALLAB, F.AZGUI, G.ARDISSON. Radiochem. Radioanal. Letters 30 (1977) 253
(Gamma-ray emission probabilities, Gamma ray energies)
- V.M.KARTASHOV, A.G.TROIZKAYA, G.A.SHEVILEV. Probl. Yad. Fiz. Kosm. Luchei 7 (1977) 3
(Conv. Elec. emission probabilities)
- F.RÖSEL, W.M.FRIES, K.ADLER, H.C.PAULI. At. Data. Nucl. Data Tables 21 (1978) 92
(Conv. Elec. emission probabilities)
- SRINIVASA RAO, S.LAKSHMINARAYANA, V.SESHAGIRI RAO, D.L.SASTRY. Current Science 48 (1979) 811
(angular corr.)
- V.V.BULGAKOV, V.I.GAVRILYUK, A.A.KLYUCHNIKOV, A.P.LASKO, P.N.MUZALEV, N.V.STRELCHUK, A.I.FEOKISTOV, Y.E.FRANTSEV. Summaries of the 30th Conf. Nucl. Spectr. and Struct. Samarkand (1981) 293
(L/M/N)
- T.SEKINE, H.BABA. J. Inorg. Nucl. Chem. 43 (1981) 1107
(Gamma-ray emission probabilities)
- M.SRINIVASA RAO, S.LAKSHMINARAYANA, D.G.S.NAGARAYANA, L.RAGHAVENDRA RAO, V.SESHAGIRI RAO, D.L.SASTRY. Indian J. of Pure and Applied Physics 22 (1984) 10
(Gamma ray energies)
- A.E.IGNATOCHKIN, E.N.SHURSHIKOV, YU.F.JABOROV. Nucl. Data Sheets 52 (1987) 365
(Spin and Parity, Half-life, excited levels, Gamma ray energies)
- B.CHAND, J.GOSWAMY, D.MEHTA, N.SINGH, P.N.TREHAN. Proc. Phys. Soc. (1988)
(X-ray emission probabilities)
- M.K.BALODIS, A.V.AFANASEV, P.T.PROKOFEV, YU.JA.TAMBERG. Izvestiya Akademii Nauk. SSSR, Seriya Fizicheskaya 52 (1988) 2117
(level scheme)
- A.ABZOUZI, M.S.ANTONY, V.B.NDOCKO NDONGUE. J. Radioanal. Nucl. Chem. 135 (1989) 1
(Half-life)
- B.CHAND, J. GOSWAMY, D. MEHTA, N.SINGH, P.N TREHAN. Nucl. Instrum. Methods Phys. Res. A284 (1989) 393
(Gamma-ray emission probabilities)
- J.M.CALHOUN, J.T.CESSNA, B.M.COURSEY, D.D.HOPPES, F.J.SCHIMA, M.P.UNTERWEGER. Radioactivity and Radiochemistry 2 (1991) 38-45
(Half-life, Gamma-ray emission probabilities)
- C.ARDISSON, V.BARCI, J.DALMASSO, A.HACHEM, G.ARDISSON. Il Nuovo Cimento 105A (1992) 215-232
(Gamma ray energies, Gamma-ray emission probabilities)
- M.P.UNTERWEGER, D.D.HOPPES, F.J.SCHIMA. Nucl. Instrum. Methods Phys. Res. A312 (1992) 349-352
(Half-life)

- J.M.DOMINGOS, G.D.SYMOW, A.C.DOUGLAS. Nucl. Phys. A180 (1992) 600
(mixing ratios)
- B.M.COURSEY, J.M.CALHOUN, J.CESSNA, D.B.GOLAS, F.J.SCHIMA, M.P.UNTERWEGER. Nucl. Instrum. Methods Phys. Res. A339 (1994) 26-30
(Gamma-ray emission probabilities)
- G.AUDI, A.H.WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(K fluorescence yield, L vacancies)
- R.B.FIRESTONE, V.S.SHIRLEY. Table of Isotopes, Wiley NewYork (1996)
(Production modes)
- R.G.HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
(Gamma ray energies)





1 Decay Scheme

Ho-166m disintegrates by β^- emission mainly to the 1827 keV and to the 1786 keV levels of Er-166.
L'holmium 166 métastable se désintègre par émission bêta moins, principalement vers les deux niveaux de 1827 keV et 1786 keV de l'erbium 166.

2 Nuclear Data

$$T_{1/2}(^{166}\text{Ho}^m) : 1200 \quad (180) \quad \text{a}$$

$$Q^-(^{166}\text{Ho}^m) : 1860,5 \quad (9) \quad \text{keV}$$

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,17}^-$	32,9 (9)	17,2 (4)	Allowed	8,4
$\beta_{0,16}^-$	73,5 (9)	74,8 (12)	Allowed	8,8
$\beta_{0,11}^-$	304,6 (9)	0,394 (5)	1st forbidden	12,9
$\beta_{0,10}^-$	484,5 (9)	0,81 (26)	1st forbidden	13
$\beta_{0,9}^-$	644,5 (9)	2,31 (29)	1st forbidden	13,4
$\beta_{0,6}^-$	949,3 (9)	1,12 (6)	1st forbidden	14,2
$\beta_{0,3}^-$	1315,1 (9)	3,4 (6)	1st forbidden	14,3

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{5,4}$ (Er)	73,62 (7)	0,212 (14)	M1+E2	5,98 (18)	0,902 (27)	0,201 (6)	7,14 (21)
$\gamma_{1,0}$ (Er)	80,580 (3)	99,981 (4)	E2	1,65 (3)	4,01 (8)	0,978 (29)	6,90 (14)
$\gamma_{16,15}$ (Er)	94,675 (14)	0,650 (23)	M1+E2	2,89 (9)	0,435 (13)	0,0967 (29)	3,45 (10)
$\gamma_{8,7}$ (Er)	119,033 (9)	0,452 (11)	E2+M1	0,888 (27)	0,556 (17)	0,1339 (40)	1,614 (48)
$\gamma_{16,14}$ (Er)	121,176 (31)	0,593 (20)	E2	0,663 (20)	0,610 (18)	0,1480 (44)	1,460 (44)
$\gamma_{17,15}$ (Er)	135,260 (14)	0,194 (4)	E2	0,493 (15)	0,373 (11)	0,0904 (27)	0,981 (29)
$\gamma_{9,8}$ (Er)	140,703 (7)	0,0829 (44)	M1+E2	0,604 (18)	0,256 (8)	0,0611 (18)	0,938 (28)
$\gamma_{10,9}$ (Er)	160,039 (7)	0,157 (8)	M1+E2	0,417 (13)	0,1530 (46)	0,0363 (11)	0,616 (18)
$\gamma_{17,14}$ (Er)	161,76 (3)	0,166 (6)	E2 (+M1)	0,299 (9)	0,171 (5)	0,0412 (12)	0,522 (16)
$\gamma_{2,1}$ (Er)	184,4107 (11)	96,7 (7)	E2	0,205 (6)	0,0984 (30)	0,0236 (7)	0,334 (7)
$\gamma_{16,13}$ (Er)	190,86 (7)	0,279 (7)	E2	0,186 (6)	0,0853 (26)	0,0204 (6)	0,297 (9)
$\gamma_{16,12}$ (Er)	214,75 (6)	0,534 (13)	E2	0,1318 (40)	0,0526 (16)	0,01254 (38)	0,200 (4)
$\gamma_{8,5}$ (Er)	215,869 (8)	3,18 (20)	E2	0,1299 (26)	0,0516 (10)	0,01229 (37)	0,197 (4)
$\gamma_{17,13}$ (Er)	231,45 (7)	0,253 (7)	E2	0,1062 (21)	0,0391 (8)	0,00928 (28)	0,157 (3)
$\gamma_{9,7}$ (Er)	259,736 (9)	1,195 (11)	E2	0,0762 (15)	0,0249 (5)	0,00589 (18)	0,1087 (22)
$\gamma_{3,2}$ (Er)	280,4630 (34)	32,07 (28)	E2	0,0613 (12)	0,0187 (4)	0,00439 (13)	0,0855 (17)
$\gamma_{10,8}$ (Er)	300,742 (7)	3,99 (4)	E2	0,0503 (10)	0,0144 (3)	0,00338 (10)	0,0691 (14)
$\gamma_{9,6}$ (Er)	304,758 (9)	0,0195 (13)	E2	0,0485 (10)	0,0137 (3)	0,00322 (10)	0,0662 (13)
$\gamma_{11,9}$ (Er)	339,75 (5)	0,1694 (24)	E2	0,0359 (7)	0,00930 (19)	0,00217 (7)	0,048 (1)
$\gamma_{6,3}$ (Er)	365,768 (8)	2,56 (4)	E2	0,0294 (6)	0,00721 (15)	0,00167 (5)	0,0388 (8)
$\gamma_{16,10}$ (Er)	410,955 (9)	11,45 (18)	E1(+M2)	0,00743 (22)	0,001055 (32)	0,000233 (7)	0,00878 (26)
$\gamma_{17,10}$ (Er)	451,540 (9)	2,936 (14)	E1(+M2)	0,00599 (18)	0,000846 (25)	0,000187 (6)	0,00707 (21)
$\gamma_{10,6}$ (Er)	464,797 (9)	1,28 (4)	M1+E2	0,01579 (47)	0,0033 (1)	0,000758 (23)	0,0201 (6)
$\gamma_{15,9}$ (Er)	476,319 (13)	0,0365 (13)	E1	0,00531 (16)	0,000748 (22)	0,000165 (5)	0,00627 (19)
$\gamma_{12,8}$ (Er)	496,95 (6)	0,126 (3)	E1(+M2)	0,00483 (15)	0,000679 (20)	0,0001497 (45)	0,00571 (17)
$\gamma_{4,2}$ (Er)	520,80 (7)	0,155 (6)	E2	0,01192 (36)	0,00234 (7)	0,000535 (16)	0,0149 (3)
$\gamma_{8,3}$ (Er)	529,823 (6)	9,5 (4)	M1+E2	0,01145 (26)	0,00223 (5)	0,000508 (15)	0,0144 (3)
$\gamma_{16,9}$ (Er)	570,994 (9)	5,45 (20)	E1(+M2)	0,00358 (11)	0,000498 (15)	0,0001097 (33)	0,00421 (13)
$\gamma_{5,2}$ (Er)	594,417 (6)	0,59 (6)	E2+M1	0,00881 (26)	0,001613 (48)	0,000366 (11)	0,01089 (33)
$\gamma_{17,9}$ (Er)	611,579 (9)	1,31 (21)	E1(+M2)	0,00309 (9)	0,000429 (13)	0,0000944 (28)	0,00364 (11)
$\gamma_{12,7}$ (Er)	615,98 (6)	0,100 (31)	E4	0,0444 (13)	0,0185 (6)	0,00449 (13)	0,0687 (21)
$\gamma_{13,7}$ (Er)	639,86 (7)	0,0946 (7)	E1	0,00282 (8)	0,000389 (12)	0,0000857 (26)	0,00331 (10)
$\gamma_{11,6}$ (Er)	644,51 (5)	0,145 (4)	E2+M1	0,00810 (24)	0,001384 (42)	0,000312 (9)	0,00989 (30)
$\gamma_{9,3}$ (Er)	670,526 (6)	5,38 (21)	E2+M1	0,00666 (20)	0,001161 (35)	0,000262 (8)	0,00816 (24)
$\gamma_{7,2}$ (Er)	691,253 (8)	1,33 (7)	E2+M1	0,00620 (19)	0,001069 (32)	0,000241 (7)	0,00758 (23)
$\gamma_{4,1}$ (Er)	705,21 (7)	0,014 (7)	E2(+M1)	0,00591 (18)	0,001012 (30)	0,000228 (7)	0,00721 (22)
$\gamma_{16,8}$ (Er)	711,697 (9)	55,0 (9)	E1(+M2)	0,00227 (7)	0,000311 (9)	0,0000685 (21)	0,00266 (8)
$\gamma_{13,5}$ (Er)	736,70 (7)	0,374 (6)	E1	0,00211 (6)	0,000290 (9)	0,0000637 (19)	0,00249 (7)
$\gamma_{17,8}$ (Er)	752,282 (9)	12,2 (3)	E1(+M2)	0,00203 (6)	0,000278 (8)	0,0000611 (18)	0,00238 (7)
$\gamma_{5,1}$ (Er)	778,828 (6)	3,03 (8)	E2+M1	0,00477 (14)	0,000788 (24)	0,000177 (5)	0,00579 (17)
$\gamma_{4,0}$ (Er)	785,78 (7)	0,019 (4)	E2	0,00467 (14)	0,000769 (23)	0,000173 (5)	0,00566 (17)
$\gamma_{8,2}$ (Er)	810,286 (5)	57,6 (11)	E2+M1	0,00438 (9)	0,00071 (2)	0,0001603 (48)	0,0053 (1)
$\gamma_{10,3}$ (Er)	830,565 (6)	9,77 (18)	E2+M1	0,00416 (12)	0,000673 (20)	0,0001509 (45)	0,00503 (15)
$\gamma_{7,1}$ (Er)	875,664 (8)	0,724 (9)	E2	0,00371 (11)	0,000592 (18)	0,0001324 (40)	0,00447 (13)
$\gamma_{9,2}$ (Er)	950,989 (5)	2,754 (19)	E2	0,00313 (9)	0,000488 (15)	0,0001089 (33)	0,00376 (11)
$\gamma_{11,3}$ (Er)	1010,27 (5)	0,0797 (16)	E2	0,00277 (8)	0,000425 (13)	0,0000947 (28)	0,00332 (10)
$\gamma_{14,3}$ (Er)	1120,344 (30)	0,199 (4)	E1	0,000956 (29)	0,0001283 (38)	0,0000281 (8)	0,001121 (34)
$\gamma_{15,3}$ (Er)	1146,845 (12)	0,2061 (26)	E1	0,000918 (28)	0,0001230 (37)	0,0000270 (8)	0,001075 (32)
$\gamma_{16,3}$ (Er)	1241,520 (8)	0,85 (3)	E1(+M2)	0,000796 (24)	0,0001063 (32)	0,0000233 (7)	0,000932 (28)
$\gamma_{17,3}$ (Er)	1282,105 (8)	0,183 (7)	E1(+M2)	0,000752 (23)	0,0001004 (30)	0,0000220 (7)	0,000881 (26)
$\gamma_{12,2}$ (Er)	1307,24 (6)	0,0055 (11)	E1	0,000727 (22)	0,0000970 (29)	0,0000213 (6)	0,000852 (26)
$\gamma_{13,2}$ (Er)	1331,12 (7)	0,0043 (12)	E1	0,000705 (21)	0,0000939 (28)	0,0000206 (6)	0,000825 (25)
$\gamma_{14,2}$ (Er)	1400,79 (2)	0,508 (6)	E1	0,000645 (19)	0,0000859 (26)	0,0000188 (6)	0,000755 (23)
$\gamma_{15,2}$ (Er)	1427,24 (2)	0,498 (6)	E1	0,000625 (19)	0,0000831 (25)	0,0000182 (5)	0,000732 (22)

3 Atomic Data

3.1 Er

ω_K	:	0,942	(4)
$\bar{\omega}_L$	:	0,216	(9)
n_{KL}	:	0,836	(4)

3.1.1 X Radiations

		Energy keV		Relative probability	
X_K	$K\alpha_2$	48,2211		56,4	
	$K\alpha_1$	49,1277		100	
	$K\beta_3$	55,494	}		
	$K\beta_1$	55,681	}		
	$K\beta_5''$	56,04	}	31,9	
	$K\beta_2$	57,21	}		
	$K\beta_4$	57,313	}	8,8	
	$KO_{2,3}$	57,45	}		
	X_L	$L\ell$	6,14		
		$L\alpha$	6,9 – 6,95		
$L\eta$		7,05			
$L\beta$		7,75 – 8,34			
$L\gamma$		8,81 – 9,43			

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	37,78 – 40,55	100
KLX	45,52 – 49,10	52,2
KXY	53,07 – 56,84	7,84
Auger L		
	3,9 – 7,6	

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Er)	3,9	- 7,6	72,0 (7)
e _{AK}	(Er)			2,33 (17)
	KLL	37,78	- 40,55	}
	KLX	45,52	- 49,10	}
	KXY	53,07	- 56,84	}
ec _{5,4} K	(Er)	16,13	(7)	0,15 (10)
ec _{1,0} T	(Er)	23,095	- 80,550	87,4 (31)
ec _{1,0} K	(Er)	23,095	(3)	20,9 (7)
ec _{16,15} K	(Er)	37,189	(14)	0,422 (18)
ec _{8,7} K	(Er)	61,548	(9)	0,154 (5)
ec _{16,14} K	(Er)	63,69	(3)	0,160 (7)
ec _{1,0} L	(Er)	70,828	- 72,222	50,8 (18)
ec _{1,0} M	(Er)	78,374	- 79,171	12,38 (43)
ec _{1,0} N	(Er)	80,131	- 80,576	2,89 (10)
ec _{16,15} L	(Er)	84,924	- 86,317	0,0635 (26)
ec _{10,9} K	(Er)	102,554	(7)	0,0524 (31)
ec _{8,7} L	(Er)	109,282	- 110,675	0,0962 (34)
ec _{16,14} L	(Er)	111,424	- 112,818	0,147 (6)
ec _{2,1} T	(Er)	126,925	- 184,381	24,1 (7)
ec _{2,1} K	(Er)	126,925	(1)	14,86 (44)
ec _{16,12} K	(Er)	157,26	(6)	0,0587 (23)
ec _{8,5} K	(Er)	158,384	(8)	0,346 (24)
ec _{2,1} L	(Er)	174,659	- 176,053	7,13 (22)
ec _{2,1} M	(Er)	182,204	- 183,001	1,71 (5)
ec _{2,1} N	(Er)	183,962	- 184,406	0,402 (12)
ec _{9,7} K	(Er)	202,251	(9)	0,0821 (26)
ec _{8,5} L	(Er)	206,118	- 207,511	0,137 (10)
ec _{3,2} T	(Er)	222,978	- 280,433	2,5 (16)
ec _{3,2} K	(Er)	222,978	(4)	1,8 (12)
ec _{10,8} K	(Er)	243,257	(7)	0,188 (6)
ec _{3,2} L	(Er)	270,711	- 272,105	0,55 (36)
ec _{3,2} M	(Er)	278,256	- 279,053	0,13 (8)
ec _{10,8} L	(Er)	290,991	- 292,384	0,0537 (17)
ec _{6,3} K	(Er)	308,282	(8)	0,0723 (25)
ec _{16,10} K	(Er)	353,469	(9)	0,0843 (28)
ec _{8,3} K	(Er)	472,338	(6)	0,108 (6)
ec _{16,8} K	(Er)	654,211	(9)	0,1246 (47)
ec _{8,2} K	(Er)	752,80	(5)	0,251 (9)
$\beta_{0,17}^-$	max:	32,9	(9)	17,2 (4)
$\beta_{0,17}^-$	avg:	8,2	(2)	
$\beta_{0,16}^-$	max:	73,5	(9)	74,8 (12)
$\beta_{0,16}^-$	avg:	18,6	(4)	

		Energy keV		Electrons per 100 disint.
$\beta_{0,11}^-$	max:	304,6	(9)	0,394 (5)
$\beta_{0,11}^-$	avg:			
$\beta_{0,10}^-$	max:	484,5	(9)	0,81 (26)
$\beta_{0,10}^-$	avg:			
$\beta_{0,9}^-$	max:	644,5	(9)	2,31 (29)
$\beta_{0,9}^-$	avg:	201,2	(9)	
$\beta_{0,6}^-$	max:	949,3	(9)	1,12 (6)
$\beta_{0,6}^-$	avg:	294,3	(9)	
$\beta_{0,3}^-$	max:	1315,1	(9)	3,4 (6)
$\beta_{0,3}^-$	avg:	674,6	(9)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XL	(Er)	6,14 — 9,43		20,8 (4)	
XK α_2	(Er)	48,2211		10,81 (21)	} K α
XK α_1	(Er)	49,1277		19,2 (4)	}
XK β_3	(Er)	55,494	}		
XK β_1	(Er)	55,681	}	6,24 (14)	K' β_1
XK β_5''	(Er)	56,04	}		
XK β_2	(Er)	57,21	}		
XK β_4	(Er)	57,313	}	1,62 (5)	K' β_2
XKO _{2,3}	(Er)	57,45	}		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{5,4}(\text{Er})$	73,62 (7)	0,0260 (16)
$\gamma_{1,0}(\text{Er})$	80,5725 (13)	12,66 (23)
$\gamma_{16,15}(\text{Er})$	94,675 (14)	0,146 (4)
$\gamma_{8,7}(\text{Er})$	119,033 (10)	0,173 (3)
$\gamma_{16,14}(\text{Er})$	121,175 (10)	0,241 (7)
$\gamma_{17,15}(\text{Er})$	135,260 (14)	0,0979 (19)
$\gamma_{9,8}(\text{Er})$	140,703 (7)	0,0428 (22)
$\gamma_{10,9}(\text{Er})$	160,039 (7)	0,097 (5)

	Energy keV	Photons per 100 disint.
$\gamma_{17,14}(\text{Er})$	161,76 (3)	0,109 (4)
$\gamma_{2,1}(\text{Er})$	184,4107 (11)	72,5 (3)
$\gamma_{16,13}(\text{Er})$	190,86 (7)	0,215 (5)
$\gamma_{16,12}(\text{Er})$	214,79 (3)	0,445 (11)
$\gamma_{8,5}(\text{Er})$	215,871 (7)	2,66 (17)
$\gamma_{17,13}(\text{Er})$	231,45 (7)	0,219 (6)
$\gamma_{9,7}(\text{Er})$	259,736 (10)	1,078 (10)
$\gamma_{3,2}(\text{Er})$	280,4630 (23)	29,54 (25)
$\gamma_{10,8}(\text{Er})$	300,741 (3)	3,73 (3)
$\gamma_{9,6}(\text{Er})$	304,758 (9)	0,0183 (12)
$\gamma_{11,9}(\text{Er})$	339,75 (5)	0,1616 (23)
$\gamma_{6,3}(\text{Er})$	365,768 (6)	2,46 (4)
$\gamma_{16,10}(\text{Er})$	410,956 (3)	11,35 (17)
$\gamma_{17,10}(\text{Er})$	451,540 (4)	2,915 (14)
$\gamma_{10,6}(\text{Er})$	464,798 (6)	1,25 (4)
$\gamma_{15,9}(\text{Er})$	476,25 (4)	0,0363 (13)
$\gamma_{12,8}(\text{Er})$	496,90 (6)	0,125 (3)
$\gamma_{4,2}(\text{Er})$	520,80 (7)	0,153 (6)
$\gamma_{8,3}(\text{Er})$	529,825 (4)	9,4 (4)
$\gamma_{16,9}(\text{Er})$	570,995 (5)	5,43 (20)
$\gamma_{5,2}(\text{Er})$	594,417 (6)	0,58 (6)
$\gamma_{17,9}(\text{Er})$	611,579 (6)	1,31 (21)
$\gamma_{12,7}(\text{Er})$	615,93 (6)	0,094 (29)
$\gamma_{13,7}(\text{Er})$	639,86 (6)	0,0943 (7)
$\gamma_{11,6}(\text{Er})$	644,51 (7)	0,144 (4)
$\gamma_{9,3}(\text{Er})$	670,526 (4)	5,34 (21)
$\gamma_{7,2}(\text{Er})$	691,253 (7)	1,32 (7)
$\gamma_{4,1}(\text{Er})$	705,21 (7)	0,014 (7)
$\gamma_{16,8}(\text{Er})$	711,697 (3)	54,9 (9)
$\gamma_{13,5}(\text{Er})$	736,70 (7)	0,373 (6)
$\gamma_{17,8}(\text{Er})$	752,280 (4)	12,2 (3)
$\gamma_{5,1}(\text{Er})$	778,827 (6)	3,01 (8)
$\gamma_{4,0}(\text{Er})$	785,78 (7)	0,019 (4)
$\gamma_{8,2}(\text{Er})$	810,286 (4)	57,3 (11)
$\gamma_{10,3}(\text{Er})$	830,565 (4)	9,72 (18)
$\gamma_{7,1}(\text{Er})$	875,663 (7)	0,721 (9)
$\gamma_{9,2}(\text{Er})$	950,988 (4)	2,744 (19)
$\gamma_{11,3}(\text{Er})$	1010,27 (6)	0,0794 (16)
$\gamma_{14,3}(\text{Er})$	1120,32 (3)	0,199 (4)
$\gamma_{15,3}(\text{Er})$	1146,77 (3)	0,2059 (26)
$\gamma_{16,3}(\text{Er})$	1241,519 (4)	0,85 (3)
$\gamma_{17,3}(\text{Er})$	1282,102 (5)	0,183 (7)
$\gamma_{12,2}(\text{Er})$	1307,19 (6)	0,0055 (11)
$\gamma_{13,2}(\text{Er})$	1331,12 (7)	0,0043 (12)
$\gamma_{14,2}(\text{Er})$	1400,79 (2)	0,508 (6)
$\gamma_{15,2}(\text{Er})$	1427,24 (2)	0,498 (6)

6 Main Production Modes

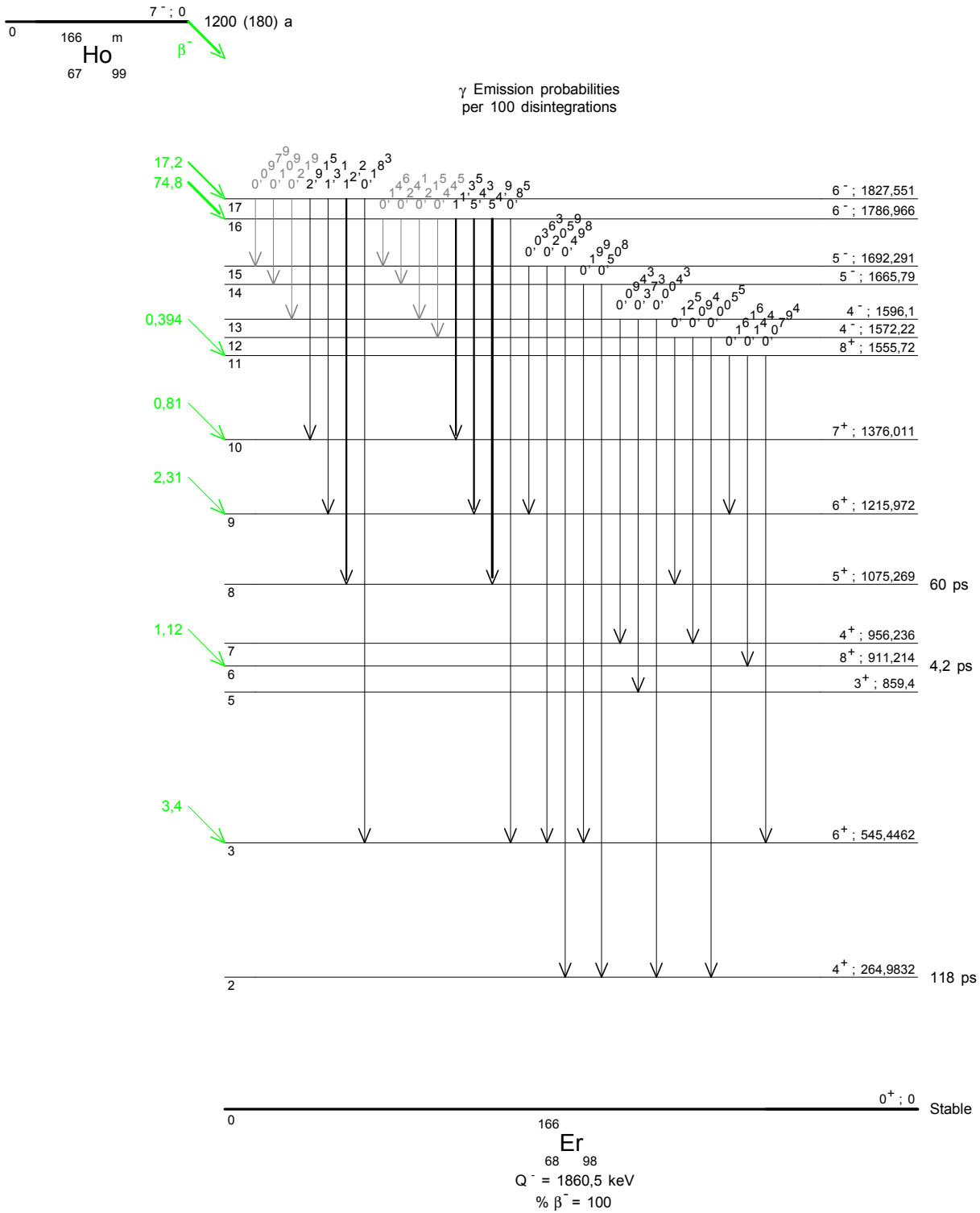
$$\left\{ \begin{array}{l} \text{Ho} - 165(n,\gamma)\text{Ho} - 166\text{m} \quad \sigma : 1 \text{ barns} \\ \text{Possible impurities : Ho} - 166 \end{array} \right.$$

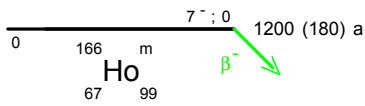
7 References

- I.MARKLUND, B.V.VANNOOIJEN, Z.GRABOWSKI. Nucl. Phys. 15 (1960) 533
(Conv. Elec. emission probabilities)
- R.HARDELL, S.NILSSON. Nucl. Phys. 39 (1962) 286
(Gamma ray energies)
- E.GERDAU, W.KRULL, L.MAYER, J.BRAUNSFURTH, J.HEISENBERG, P.STEINER, E.BODENSTEDT. Z. Phys. 174 (1963) 389
(angular correlation)
- C.W.REICH, J.E.CLIN. Phys. Rev. 137 (1965) B1424
(Gamma-ray emission probabilities, Delta)
- K.T.FALER, J.INORG.. Nucl. Chem. 27 (1965) 25
(Half-life)
- S.B.BURSON, P.F.A.GOUDSMIT, J.KONIJN. Phys. Rev. 158 (1967) 1161
(levels)
- C.GUNTHER, D.W.PARSIGNAULT. Phys. Rev. 153 (1967) 1297
(Gamma rays)
- J.A.BEARDEN. Rev. Mod. Phys. (1967) 78
(x-ray energie)
- E.C.NELSON, E.N.HATCH. Nucl. Phys. A127 (1969) 560
(Conv. Elec. emission probabilities)
- C.W.REICH, J.E.CLIN. Nucl. Phys. A159 (1970) 181
(Normalization factor)
- J.L.CAMPBELL, H.J.SMITH, I.K.MACKENZIE. Nucl. Instrum. Methods 92 (1971) 237
(Conv. Elec. emission probabilities)
- T.MIYOKAWA, I.KATAYAMA, S.MORINOBU, H.IKEGAMI. Int. Conf. Nucl. Moments and Nucl. Structure, Osaka, Japan 34 (1972) 247
(Delta)
- J.M.DOMINGOS, G.D.SYMONS, A.C.DOUGLAS. Nucl. Phys. A180 (1972) 600
(Normalization factor, Delta)
- N.LAVI. Nucl. Instrum. Methods 109 (1973) 265
(Gamma rays)
- E.W.A.LINGEMAN, F.W.N.DEBOER, B.J.MEIJER. Nucl. Instrum. Methods 118 (1974) 609
(Gamma rays)
- K.R.BAKER, J.H.HAMILTON, J.LANGE, A.V.RAMAYYA, L.VARNELL, V.MARUN-REZWANI, T. MORI, H.IONUE, Y.YOSUZAWA. J. Phys. Soc. Jap. 38 (1975) 611,14
(Gamma ray energies)
- J.J.PINAJIN, J.A.MARUHN. Phys. Lett. 57B (1975) 441
(mixing ratios)
- K.R.BAKER, J.H.HAMILTON, J.LANGE, A.V.RAMAYYA, L.VARNELL, V.MARUHN-REZWANI, J.J.PINAJIAN, J.A.MARUHN. Phys. Lett. 57B (1975) 441
(Delta)
- TSUNEO MORII, HIKARUINOUE, YASUKAZUYOSHIKAWA. J. Phys. Soc. Japan 38 (1975) 611
(Gamma ray energies)
- J.H.HAMILTON. Bull. Akad. Sci. USSR, Phys. Ser. 40 (1976) 14
(mixing ratios)
- J.H. HAMILTON. Bull. Acad. Sci. URSS 40 (1976) 14
(Mixing ratio)
- R.L.WEST, E.G.FUNK, A.VISVANATHAN, J.P.ADAMS, J.W.MIHELICH. Nucl. Phys. A270 (1976) 300
(mixing ratios, Delta)
- R.J.GEHRKE, R.G.HELMER, R.C.GREENWOOD. Nucl. Instrum. Methods 147 (1977) 405
(Gamma rays)

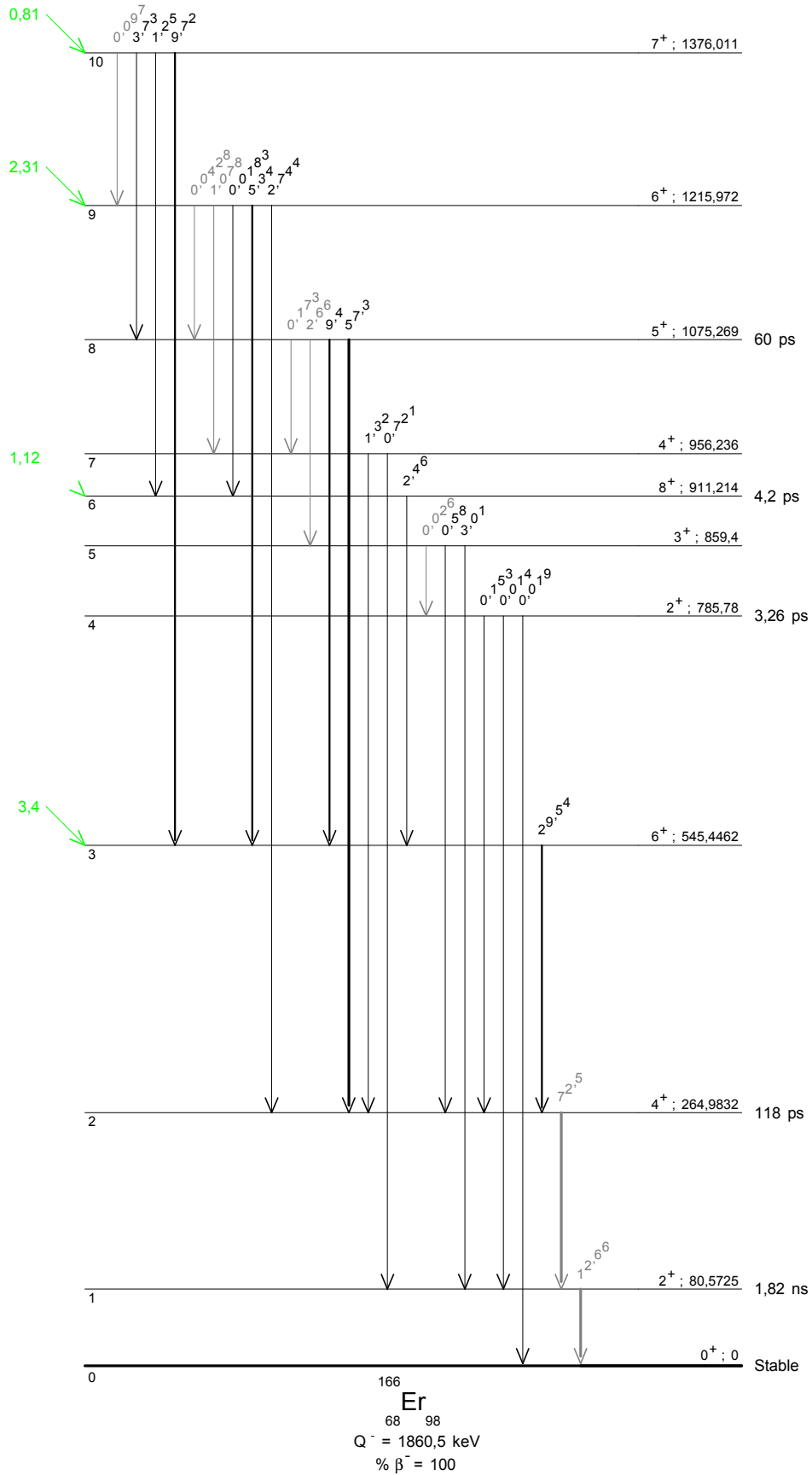
- F.,H.M.FRIES, K.ALDER, H.C.PAULI. At. Data. Nucl. Data Tables 21 (1978) 92
(Conv. Elec. emission probabilities)
- F.K.MCGOWAN, W.T.MILNER, R.L.ROBINSON, P.H.STELSON, Z.W.GRABOWSKI. Nucl. Phys. (1978) 51
(Delta)
- T.E.SAMPSON. Nucl. Instrum. Methods 150 (1978)
(Gamma rays)
- F.K.MCGOWAN, W.T.MILNER, R.L.ROBINSON, P.H.STELSON, Z.W.GRABOWSKI. Nucl. Phys. A297 (1978) 51
(Gamma rays, Delta)
- J.ADAM, J.FRANA, E.P.GRIGORIEV, K.YA.GROMOV, M.HONUŠEK, T.A.ISLAMOV, V.O.SERGEEV. Czech. J. Phys. B29 (1979) 997
(Gamma ray energies)
- J.LANGE, K.R.BAKER, J.H.HAMILTON, A.V.RAMAYYA, L.VARNELL, J.J.PINAJIAN, V.MARUHN-REZWANI. Z. Phys. A303 (1981) 321
(mixing ratios, Delta)
- K.S.KRANE, J.D.MOSES. Phys. Rev. C24 (1981) 654
(mixing ratios, Delta)
- J.LANGE, K.R.BAKER, J.H.HAMILTON, A.V.RAMAYYA, L.VARNELL, J.J.PINAJIAN, V.MARUHN REZWANI. Z. Phys. A303 (1981) 321
(mixing ratios, delta)
- A.RYTZ. NBS-SP-626 (1982) 140
(Gamma-ray emission probabilities)
- S.S.SOOCH, RAVINDER KAUR, NIRMAL SINGH, P.N.TREHAN. Nucl. Instrum. Methods 203 (1982) 339
(Gamma ray energies, Gamma-ray emission probabilities)
- N.BLAGOJEVIC, N.R.WOOD. Int. J. Appl. Radiat. Isotop. 33 (1982) 153
(Gamma rays)
- A.ALZNER, E.BODENSTEDT, B.GEMÜNDEN, J.VAN DEN HOFF, H.REIF. Z. Phys. A322 (1985) 467
(mixing ratios, Delta)
- T.OGANDAGA, J.DALMASSO, G.ARDISSON. J. Radioanal. Nucl. Chem. 107 (1986) 59
(Gamma ray energies)
- P.O.LIPAS, P.TOIVONEN, E.HAMMAREN. Nucl. Phys. A469 (1987) 348
(mixing ratios)
- J.ADAM, W.WAGNER, W.ZWOLSKA, J.ZWOLSKI, B.KRACIK, M.FISCHER. Izvestiya Akademii Nauk SSSR, Seriya Fizicheskaya 52 (1988) 18
(Gamma ray energies, Gamma-ray emission probabilities)
- B.CHAND, J.GOSWAMY, D.MEHTA, S.SINGH, M.L.GARG, N.SINGH, P.N.TREHAN. Nucl. Instrum. Methods A273 (1988) 310
(K X-ray emission probabilities, Gamma-ray emission probabilities, K X-ray energies)
- J.ADAM, M.FISER, B.KRACIK, V.WAGNER, V.ZVOLSKA, J.ZVOLSKY. UJF02/88 (1988)
(Gamma rays)
- V.N.DANILENKO, N.P.GROMOVA, A.A.KONSTANTINOV, N.V.KURENKOV, A.B.MALININ, A.V.MAMELIN, S.V.MATVEEV, T.E.SAZONOVA, E.K.STEPANOV, S.V.SEPMAN, YU.G.TOPOROV, I.N.TRONOVA. Appl. Rad. Isotopes 40 (1989) 789
()
- V.VAGNER. 41th Int. Conf. Nucl. Structure, Minsk (1991) 97
(Gamma-ray emission probabilities)
- C.ARDISSON, V.BARCI, J.DALMASSO, A.HACHEM, G.ARDISSON. Il Nuovo Cimento 105 (1992) 215
(Gamma ray energies, Gamma-ray emission probabilities)
- C.WESSELBORG, D.E.ALBURGER. Verh. Der Deutschen Phys. Gesellschaft 27 (1992) 136
(Gamma ray energies)
- W.WAGNER. Bull. Russ. Acad. Sci. 56 (1992) 675
(Gamma-ray emission probabilities, mixing ratios, Delta)
- WANG XIN LIN, YANG JING XIA. Nucl. Instrum. Methods A312 (1992) 385
(Gamma-ray emission probabilities)
- E.N.SHURSIKOW, N.V.TIMOFEEVA. Nucl. Data Sheets 67 (1992) 45-152
(Half-life, excited levels, Gamma ray energies, Gamma-ray emission probabilities)
- HIROSHI MIYAHARA, HIROKI MATUMOTO, CHIZUO MORI, NORIOTAKEUCHI, TSUGUO GENKA. Nucl. Instrum. Methods A339 (1994) 203
(Gamma-ray emission probabilities)
- J.MOREL, M.ETCHEVERRY, J.PLAGNARD. Appl. Radiat. Isot. 47 (1996) 529
(Gamma-ray emission probabilities)

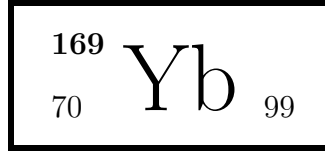
- R.B.FIRESTONE, V.S.SHIRLEY. Table of Isotopes, Wiley, New York (1996)
(Production modes)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 572
(K X-ray emission probabilities)
- Y.HINO, S.MATUI, T.YAMADA, N.TAKEUCHI, K.ONOMA, S.IWAMOTO, H.KOGURE. Appl. Rad. Isotopes 52 (2000) 545
(Gamma-ray emission probabilities)
- R.G.HELMER, C.VAN DER LEUN. Nucl. Instrum. Meth. A450 (2000) 35
(Gamma ray energies)





γ Emission probabilities per 100 disintegrations





1 Decay Scheme

The Yb-169 disintegrates 100 % by electron capture to excited levels of Tm-169.

L'ytterbium 169 se désintègre à 100 % par capture électronique vers des niveaux excités du thulium 169.

2 Nuclear Data

$$T_{1/2}({}^{169}\text{Yb}) : 32,018 \quad (5) \quad \text{d}$$

$$Q^+({}^{169}\text{Yb}) : 909 \quad (5) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	<i>P_K</i>	<i>P_L</i>	<i>P_M</i>
$\epsilon_{0,19}$	31 (5)	0,000004 (1)	Allowed	10,8			
$\epsilon_{0,18}$	77 (5)	0,0000175 (5)	Allowed	11,2			
$\epsilon_{0,17}$	127 (5)	0,0045 (3)	Allowed	10,5	0,623 (15)	0,280 (11)	0,0743 (32)
$\epsilon_{0,16}$	190 (5)	0,0037 (2)	Allowed	10,3	0,725 (5)	0,2073 (35)	0,0526 (13)
$\epsilon_{0,15}$	262 (5)	0,00013 (7)	1st forbidden	12			
$\epsilon_{0,14}$	276 (5)	0,0109 (4)	Allowed	10,3	0,7692 (25)	0,1750 (18)	0,0432 (9)
$\epsilon_{0,13}$	338 (5)	0,00030 (6)	(2nd Forbidden)	12			
$\epsilon_{0,12}$	434 (5)	0,000344 (7)	Unique 1st forbidden	12			
$\epsilon_{0,11}$	436 (5)	12,6 (3)	1st forbidden	7,6	0,7980 (19)	0,1540 (13)	0,0372 (7)
$\epsilon_{0,10}$	474 (5)	0,121 (14)	Allowed	9,9	0,8017 (18)	0,1513 (13)	0,0365 (7)
$\epsilon_{0,9}$	479 (5)	0,0044 (1)	1st forbidden	11,2	0,8020 (18)	0,1511 (13)	0,0364 (7)
$\epsilon_{0,8}$	530 (5)	82,2 (18)	1st forbidden	7	0,8057 (18)	0,1484 (12)	0,0356 (7)
$\epsilon_{0,6}$	564 (5)	0,0138 (13)	1st forbidden	11	0,8078 (18)	0,1469 (12)	0,0352 (7)
$\epsilon_{0,5}$	577 (5)	0,0142 (16)	Allowed	10,9	0,8085 (18)	0,1463 (12)	0,0350 (7)
$\epsilon_{0,4}$	593 (5)	5,1 (19)	Allowed	8,33	0,8093 (17)	0,1457 (12)	0,0349 (7)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}$ (Tm)	8,41016 (15)	95,1 (8)	M1+0,108%E2			218 (11)	273 (13)
$\gamma_{3,2}$ (Tm)	20,74370 (21)	11,2 (4)	M1+0,085%E2		44,5 (13)	10,0 (3)	57,3 (17)
$\gamma_{7,4}$ (Tm)	51,51 (40)	0,1686 (1)	E2		37,1 (15)	9,1 (4)	48,6 (22)
$\gamma_{8,4}$ (Tm)	63,12044 (4)	92,9 (18)	E1+0,01%M2	0,899 (27)	0,163 (6)	0,0366 (12)	1,11 (4)
$\gamma_{11,8}$ (Tm)	93,61450 (8)	12,6 (3)	M1+3,25%E2	3,18 (10)	0,55 (2)	0,124 (4)	3,89 (12)
$\gamma_{11,7}$ (Tm)	105,19 (10)	0,0034 (10)	[E1]	0,24 (1)	0,039 (3)		0,293 (15)
$\gamma_{2,1}$ (Tm)	109,77928 (4)	59,9 (7)	M1+2,17%E2	2,03 (3)	0,327 (5)	0,0730 (11)	2,45 (4)
$\gamma_{10,4}$ (Tm)	117,377 (18)	0,121 (14)	(M1+E2)	1,70 (17)	0,257 (26)	0,057 (6)	2,03 (20)
$\gamma_{2,0}$ (Tm)	118,18944 (14)	4,97 (9)	E2	0,697 (21)	0,734 (22)	0,179 (6)	1,66 (5)
$\gamma_{3,1}$ (Tm)	130,52293 (6)	24,5 (5)	E2	0,538 (17)	0,470 (15)	0,115 (4)	1,15 (4)
$\gamma_{11,4}$ (Tm)	156,73495 (9)	0,0109 (3)	(E1)	0,0853 (26)	0,0132 (4)	0,0029 (1)	0,102 (3)
$\gamma_{4,3}$ (Tm)	177,21317 (6)	35,49 (26)	M1+15,8%E2	0,484 (7)	0,0868 (13)	0,0197 (3)	0,590 (9)
$\gamma_{5,3}$ (Tm)	193,15 (5)	0,0111 (16)	M1+1,1%E2	0,42 (2)	0,063 (5)		0,50 (3)
$\gamma_{4,2}$ (Tm)	197,95687 (7)	52,03 (31)	M1+9%E2	0,370 (6)	0,0603 (9)	0,0136 (2)	0,448 (7)
$\gamma_{6,3}$ (Tm)	205,99 (6)	0,0036 (8)	(E1)	0,042 (2)	0,0020 (2)		0,050 (2)
$\gamma_{5,2}$ (Tm)	213,936 (17)	0,0035 (3)	E2	0,135 (7)	0,072 (6)		0,21 (1)
$\gamma_{6,2}$ (Tm)	226,3 (7)	0,00025 (18)					
$\gamma_{8,3}$ (Tm)	240,33362 (12)	0,120 (6)	E1+0,9%M2	0,037 (4)	0,0065 (7)	0,0009 (1)	0,045 (5)
$\gamma_{8,2}$ (Tm)	261,07734 (9)	1,735 (9)	E1+0,1%M2	0,0237 (7)	0,00355 (11)	0,00079 (3)	0,0283 (9)
$\gamma_{9,3}$ (Tm)	291,1909	0,0044 (1)	[E1]	0,018 (1)	0,0026 (2)		0,021 (2)
$\gamma_{10,3}$ (Tm)	294,54 (11)	0,0011 (5)					
$\gamma_{4,1}$ (Tm)	307,73616 (9)	10,72 (5)	E2	0,0482 (15)	0,0141 (4)	0,00333 (10)	0,0666 (20)
$\gamma_{4,0}$ (Tm)	316,1463	0,0033 (3)	M3+E4				
$\gamma_{(-1,20)}$ (Tm)	328 (2)	0,00672 (43)					
$\gamma_{11,3}$ (Tm)	333,94777 (27)	0,00174 (9)	E1	0,0126 (13)	0,00182 (19)	0,00040 (4)	0,0149 (15)
$\gamma_{6,1}$ (Tm)	336,621 (3)	0,0099 (9)	(E1)	0,0123 (13)	0,00179 (18)	0,00040 (4)	0,0146 (15)
$\gamma_{12,2}$ (Tm)	356,74 (5)	0,000141 (6)					
$\gamma_{8,1}$ (Tm)	370,85660 (29)	0,00111 (15)	[M2]	0,249 (8)	0,0460 (14)	0,0106 (3)	0,308 (9)
$\gamma_{8,0}$ (Tm)	379,26676 (25)	0,00034 (14)	[E3]	0,0757 (23)	0,0401 (12)	0,0098 (3)	0,128 (4)
$\gamma_{16,5}$ (Tm)	386,673 (13)	0,00038 (4)	[M1,E2]				
$\gamma_{10,1}$ (Tm)	425,1138	0,00162 (29)					
$\gamma_{13,2}$ (Tm)	452,62 (8)	0,000035 (19)	(M1+E2)				
$\gamma_{17,4}$ (Tm)	465,657 (6)	0,000231 (24)					
$\gamma_{12,0}$ (Tm)	474,973 (9)	0,000203 (9)					
$\gamma_{14,3}$ (Tm)	494,360 (8)	0,00157 (12)					
$\gamma_{18,5}$ (Tm)	500,35 (10)	0,0000088 (8)					
$\gamma_{15,3}$ (Tm)	507,8 (3)	0,0000015 (8)					
$\gamma_{14,2}$ (Tm)	515,108 (6)	0,00437 (16)	(M1)	0,0306 (30)	0,0045 (5)	0,00099 (10)	0,036 (4)
$\gamma_{15,2}$ (Tm)	528,573 (10)	0,00013 (6)					
$\gamma_{19,5}$ (Tm)	546,16 (22)	0,0000015 (4)					
$\gamma_{13,1}$ (Tm)	562,414 (12)	0,00014 (4)	(M1+E2)				
$\gamma_{13,0}$ (Tm)	570,89 (3)	0,000127 (26)	(M1+E2)				
$\gamma_{16,3}$ (Tm)	579,855 (5)	0,00210 (17)	(M1)	0,023 (1)	0,0033 (3)		0,027 (2)
$\gamma_{16,2}$ (Tm)	600,608 (8)	0,00114 (7)	(M1)				
$\gamma_{(-1,33)}$ (Tm)	614,1 (5)	0,000097 (14)					
$\gamma_{14,1}$ (Tm)	624,887 (4)	0,00495 (27)	(M1)	0,0187 (19)	0,0027 (3)	0,00060 (6)	0,0222 (22)
$\gamma_{14,0}$ (Tm)	633,32 (10)	0,0000070 (5)					
$\gamma_{17,3}$ (Tm)	642,878 (9)	0,000081 (5)					
$\gamma_{17,2}$ (Tm)	663,604 (7)	0,00203 (15)					
$\gamma_{18,3}$ (Tm)	693,46 (8)	0,0000087 (4)					
$\gamma_{16,1}$ (Tm)	710,360 (15)	0,0000313 (22)					
$\gamma_{19,3}$ (Tm)	739,42 (11)	0,00000183 (22)					
$\gamma_{19,2}$ (Tm)	760,24 (24)	0,00000083 (22)					
$\gamma_{17,1}$ (Tm)	773,390 (14)	0,00219 (11)					
$\gamma_{17,0}$ (Tm)	781,64 (8)	0,0000030 (3)					

3 Atomic Data

3.1 Tm

ω_K	:	0,945	(4)
$\bar{\omega}_L$	:	0,227	(9)
n_{KL}	:	0,835	(4)

3.1.1 X Radiations

		Energy keV		Relative probability	
X_K	$K\alpha_2$	49,7731		56,64	
	$K\alpha_1$	50,7417		100	
	$K\beta_3$	57,304	}		
	$K\beta_1$	57,516	}		
	$K\beta_5''$	57,925	}	32,7	
	$K\beta_2$	59,1	}		
	$K\beta_4$	59,21	}	8,5	
	$KO_{2,3}$	59,357	}		
	X_L	$L\ell$	6,34		
		$L\alpha$	7,13 – 7,18		
$L\eta$		7,31			
$L\beta$		8,18 – 8,64			
$L\gamma$		9,15 – 9,78			

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	38,96 – 41,88	100
KLX	46,88 – 50,71	52,6
KXY	54,78 – 59,32	6,92
Auger L	3,85 – 7,18	2450

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Tm)	3,85	- 7,18	168,2 (18)
e _{AK}	(Tm)			10,8 (8)
	KLL	38,96	- 41,88	}
	KLX	46,88	- 50,71	}
	KXY	54,78	- 59,32	}
ec _{8,4} T	(Tm)	3,7308	- 63,0881	48,9 (18)
ec _{8,4} K	(Tm)	3,7308	(4)	39,6 (12)
ec _{1,0} T	(Tm)	6,10	- 8,38	95 (6)
ec _{1,0} M	(Tm)	6,103	- 6,942	76 (5)
ec _{3,2} T	(Tm)	10,628	- 20,711	11,0 (4)
ec _{3,2} L	(Tm)	10,628	- 12,096	8,6 (3)
ec _{3,2} M	(Tm)	18,437	- 19,276	1,93 (7)
ec _{11,8} K	(Tm)	34,2249	(8)	8,18 (27)
ec _{11,8} T	(Tm)	34,225	- 93,582	10,0 (3)
ec _{2,1} K	(Tm)	50,3897	(4)	35,2 (6)
ec _{2,1} T	(Tm)	50,3897	- 109,7470	42,5 (7)
ec _{8,4} L	(Tm)	53,0047	- 54,4720	7,18 (27)
ec _{10,4} K	(Tm)	57,987	(18)	0,068 (9)
ec _{2,0} T	(Tm)	58,79	- 118,16	3,1 (1)
ec _{2,0} K	(Tm)	58,7998	(2)	1,30 (4)
ec _{8,4} M	(Tm)	60,8136	- 61,6527	1,61 (5)
ec _{3,1} T	(Tm)	71,133	- 130,491	13,1 (5)
ec _{3,1} K	(Tm)	71,1333	(1)	6,1 (2)
ec _{11,8} L	(Tm)	83,499	- 84,967	1,4 (5)
ec _{11,8} M	(Tm)	91,308	- 92,147	0,32 (1)
ec _{2,1} L	(Tm)	99,6636	- 101,1310	5,68 (9)
ec _{2,1} M	(Tm)	107,4725	- 108,3116	1,267 (20)
ec _{2,0} L	(Tm)	108,074	- 109,541	1,37 (4)
ec _{2,0} M	(Tm)	115,883	- 116,723	0,33 (1)
ec _{4,3} T	(Tm)	117,823	- 177,181	13,2 (2)
ec _{4,3} K	(Tm)	117,8235	(1)	10,8 (2)
ec _{3,1} L	(Tm)	120,407	- 121,875	5,3 (2)
ec _{3,1} M	(Tm)	128,216	- 129,055	1,31 (5)
ec _{4,2} T	(Tm)	138,567	- 197,924	16,1 (3)
ec _{4,2} K	(Tm)	138,5671	(1)	13,29 (22)
ec _{4,3} L	(Tm)	167,097	- 168,565	1,94 (3)
ec _{4,3} M	(Tm)	174,906	- 175,745	0,44 (1)
ec _{4,2} L	(Tm)	187,841	- 189,308	2,17 (3)
ec _{4,2} M	(Tm)	195,649	- 196,489	0,49 (1)
ec _{4,1} K	(Tm)	248,3479	(1)	0,484 (15)
ec _{4,1} L	(Tm)	297,621	- 299,089	0,142 (4)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Tm)	6,34 — 9,78	49,4 (8)	
XK α_2	(Tm)	49,7731	52,9 (8)	} K α
XK α_1	(Tm)	50,7417	93,5 (13)	}
XK β_3	(Tm)	57,304	}	
XK β_1	(Tm)	57,516	}	K β'_1
XK β''_5	(Tm)	57,925	}	
XK β_2	(Tm)	59,1	}	
XK β_4	(Tm)	59,21	}	K β'_2
XKO _{2,3}	(Tm)	59,357	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Tm)	8,41016 (15)	0,347 (17)
$\gamma_{3,2}$ (Tm)	20,74370 (21)	0,1925 (43)
$\gamma_{7,4}$ (Tm)	51,51 (40)	0,0034 (1)
$\gamma_{8,4}$ (Tm)	63,12044 (4)	44,05 (24)
$\gamma_{11,8}$ (Tm)	93,61447 (8)	2,571 (17)
$\gamma_{11,7}$ (Tm)	105,19 (10)	0,0026 (8)
$\gamma_{2,1}$ (Tm)	109,77924 (4)	17,36 (9)
$\gamma_{10,4}$ (Tm)	117,377 (18)	0,0398 (36)
$\gamma_{2,0}$ (Tm)	118,18940 (14)	1,87 (1)
$\gamma_{3,1}$ (Tm)	130,52293 (6)	11,38 (5)
$\gamma_{11,4}$ (Tm)	156,73487 (9)	0,00990 (25)
$\gamma_{4,3}$ (Tm)	177,21307 (6)	22,32 (10)
$\gamma_{5,3}$ (Tm)	193,15 (5)	0,0074 (10)
$\gamma_{4,2}$ (Tm)	197,95675 (7)	35,93 (12)
$\gamma_{6,3}$ (Tm)	205,99 (6)	0,0034 (8)
$\gamma_{5,2}$ (Tm)	213,936 (17)	0,00291 (22)
$\gamma_{6,2}$ (Tm)	226,3 (7)	0,00025 (18)
$\gamma_{8,3}$ (Tm)	240,33344 (12)	0,115 (5)
$\gamma_{8,2}$ (Tm)	261,07712 (9)	1,687 (8)
$\gamma_{9,3}$ (Tm)	291,190 (11)	0,00431 (14)
$\gamma_{10,3}$ (Tm)	294,54 (11)	0,0011 (5)
$\gamma_{4,1}$ (Tm)	307,73757 (9)	10,046 (45)
$\gamma_{4,0}$ (Tm)	316,2 (7)	0,0033 (3)

	Energy keV	Photons per 100 disint.
$\gamma_{(-1,20)}(\text{Tm})$	328 (2)	0,00672 (43)
$\gamma_{11,3}(\text{Tm})$	333,94777 (27)	0,00171 (9)
$\gamma_{6,1}(\text{Tm})$	336,621 (3)	0,0098 (9)
$\gamma_{12,2}(\text{Tm})$	356,74 (5)	0,000141 (6)
$\gamma_{8,1}(\text{Tm})$	370,85616 (29)	0,00085 (11)
$\gamma_{8,0}(\text{Tm})$	379,26630 (25)	0,00030 (12)
$\gamma_{16,5}(\text{Tm})$	386,673 (13)	0,00038 (4)
$\gamma_{10,1}(\text{Tm})$	425,0 (2)	0,00162 (29)
$\gamma_{13,2}(\text{Tm})$	452,62 (8)	0,000035 (19)
$\gamma_{17,4}(\text{Tm})$	465,657 (6)	0,000231 (24)
$\gamma_{12,0}(\text{Tm})$	474,973 (9)	0,000203 (9)
$\gamma_{14,3}(\text{Tm})$	494,360 (8)	0,00157 (12)
$\gamma_{18,5}(\text{Tm})$	500,35 (10)	0,0000088 (8)
$\gamma_{15,3}(\text{Tm})$	507,8 (3)	0,0000015 (8)
$\gamma_{14,2}(\text{Tm})$	515,107 (6)	0,00422 (16)
$\gamma_{15,2}(\text{Tm})$	528,572 (10)	0,00013 (6)
$\gamma_{19,5}(\text{Tm})$	546,16 (22)	0,0000015 (4)
$\gamma_{13,1}(\text{Tm})$	562,413 (12)	0,00014 (4)
$\gamma_{13,0}(\text{Tm})$	570,89 (3)	0,000127 (26)
$\gamma_{16,3}(\text{Tm})$	579,854 (5)	0,00204 (16)
$\gamma_{16,2}(\text{Tm})$	600,607 (8)	0,00114 (7)
$\gamma_{(-1,33)}(\text{Tm})$	614,1 (5)	0,000097 (14)
$\gamma_{14,1}(\text{Tm})$	624,886 (4)	0,00484 (27)
$\gamma_{14,0}(\text{Tm})$	633,32 (10)	0,0000070 (5)
$\gamma_{17,3}(\text{Tm})$	642,877 (9)	0,000081 (5)
$\gamma_{17,2}(\text{Tm})$	663,603 (7)	0,00203 (15)
$\gamma_{18,3}(\text{Tm})$	693,46 (8)	0,0000087 (4)
$\gamma_{16,1}(\text{Tm})$	710,358 (15)	0,0000313 (22)
$\gamma_{19,3}(\text{Tm})$	739,42 (11)	0,00000183 (22)
$\gamma_{19,2}(\text{Tm})$	760,24 (24)	0,00000083 (22)
$\gamma_{17,1}(\text{Tm})$	773,390 (14)	0,00219 (11)
$\gamma_{17,0}(\text{Tm})$	781,64 (8)	0,0000030 (3)

6 Main Production Modes

$$\left\{ \begin{array}{l} \text{Yb} - 169\text{m(I.T.)Yb} - 169 \\ T_{1/2} = 46 \text{ s} \end{array} \right.$$

$$\left\{ \begin{array}{l} \text{Lu} - 169\text{(E.C.)Yb} - 169 \\ T_{1/2} = 34,06 \text{ h} \end{array} \right.$$

Er – 167($\alpha, 2n\gamma$)Yb – 169

Yb – 168(n, γ)Yb – 169

Yb – 168(d,p)Yb – 169

Yb – 170(d,t)Yb – 169

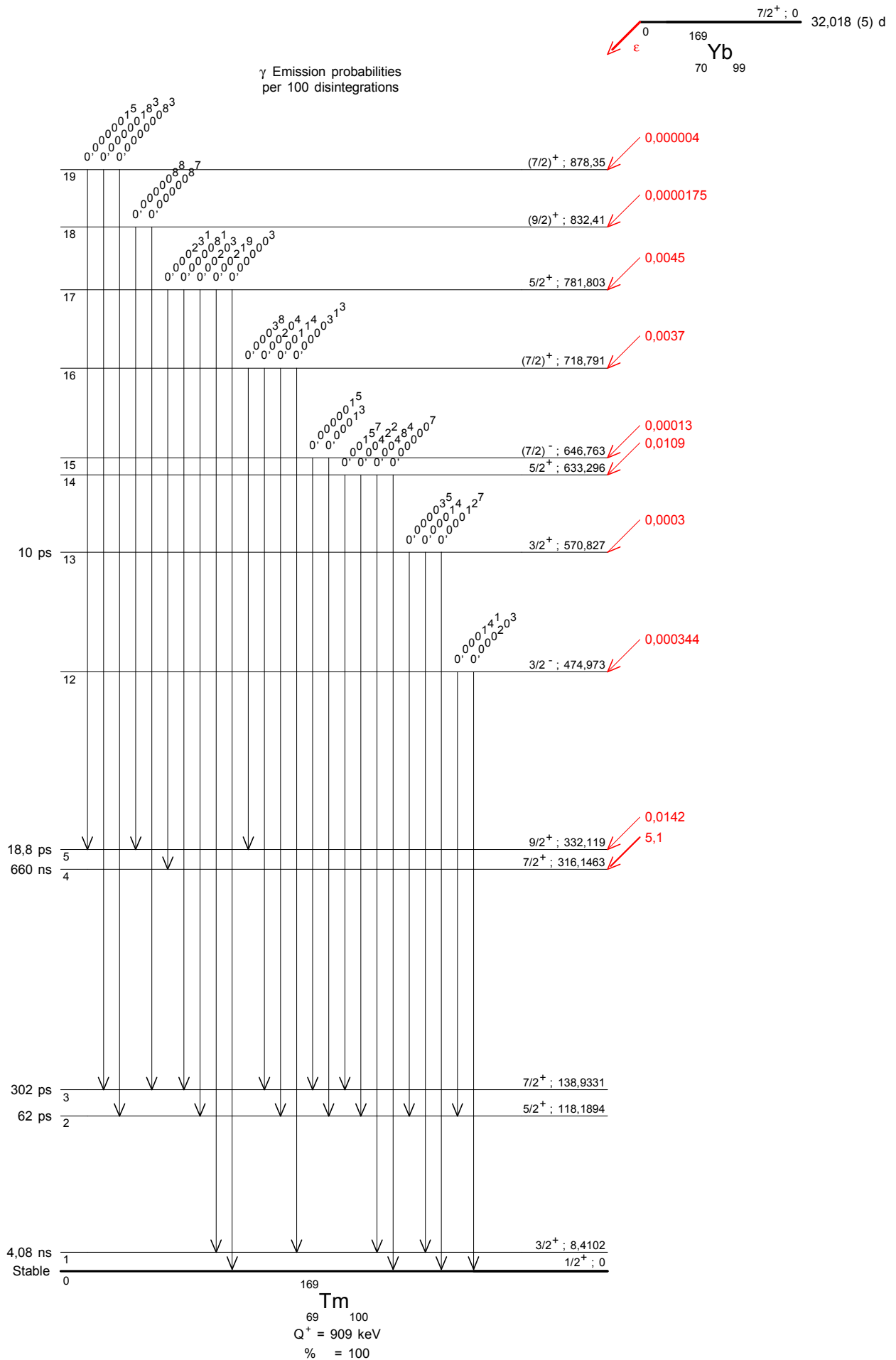
Yb – 171(p,t)Yb – 169

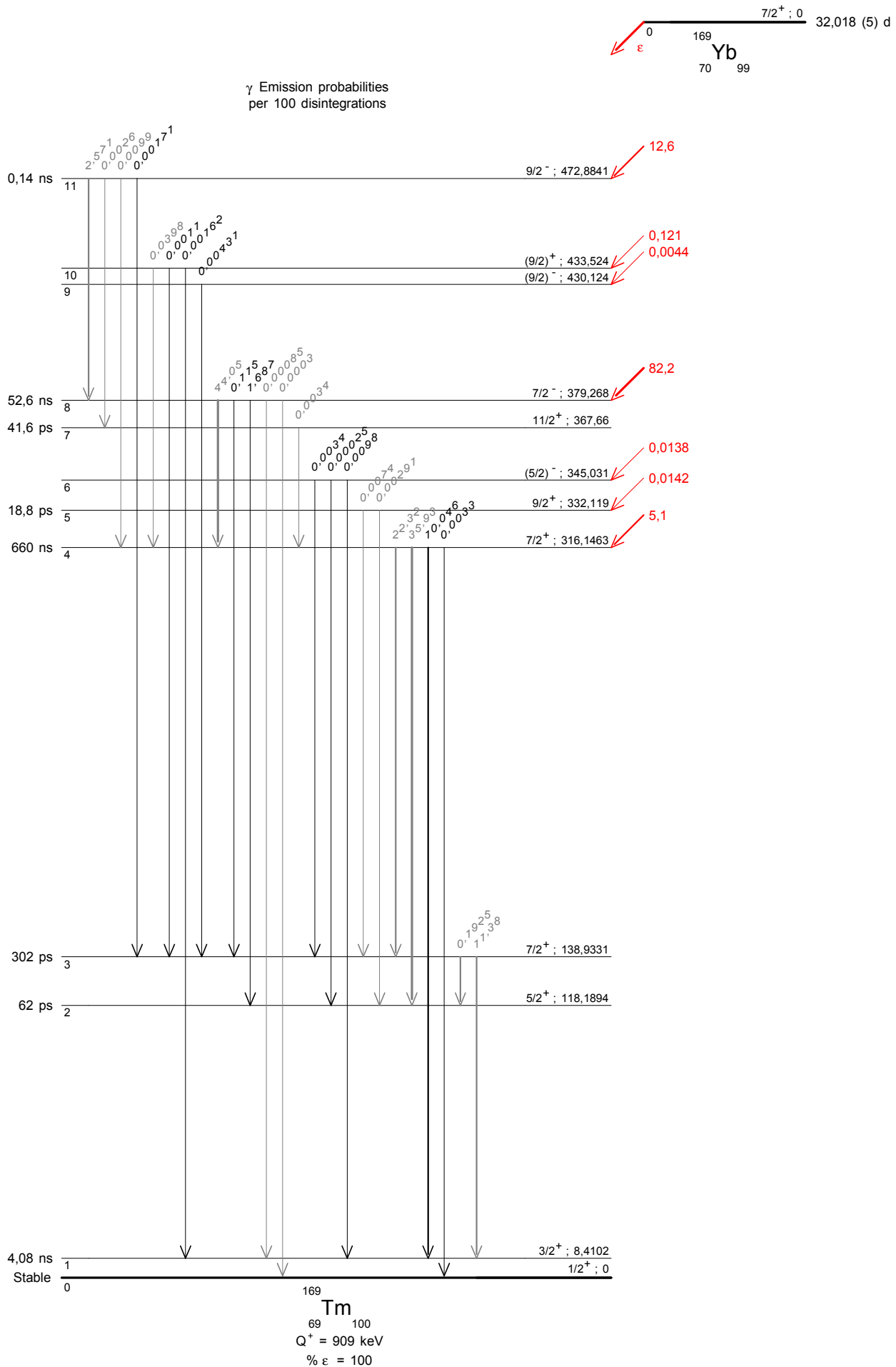
7 References

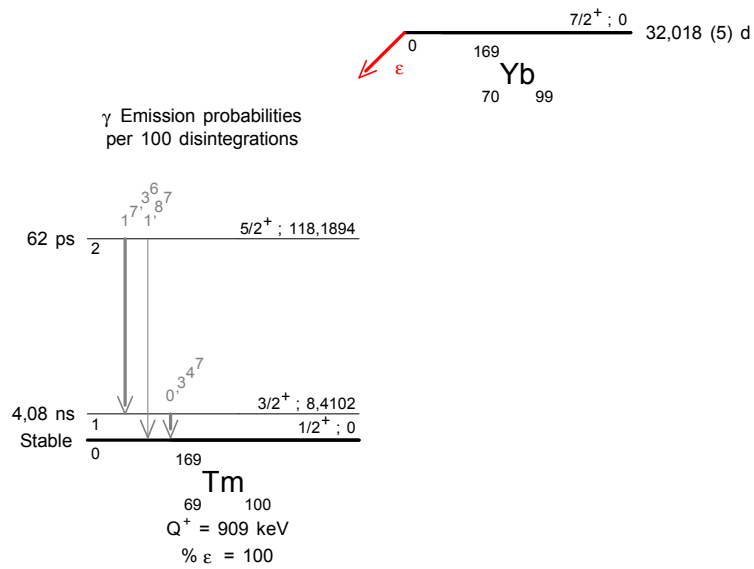
- D. WALKER. Proc. Phys. Soc., London 62A (1949) 799
(Half-life)
- G. CHARPAK, F. SUZOR. J. Phys. Radium 20 (1959) 513
(ICC)
- Z. GRABOWSKI, J. E. THUN, B. LINDSTRÖM. Z. Physik 169 (1962) 303
(ICC)
- P. ALEXANDER, F. BOEHM. Nucl. Phys. 46 (1963) 108
(Gamma-ray emission probabilities)
- J. E. BROWN, E. N. HATCH. Nucl. Instrum. Methods 47 (1967) 185
(Gamma-ray emission probabilities)
- T. A. CARLSON, P. ERMAN, F. FRANSON. Nucl. Phys. A111 (1968) 371
(ICC)
- C. GÜNTHER, H. HÜBEL, A. KLUGE, K. KRIEN, H. TOSCHINSKI. Nucl. Phys. A123 (1969) 386
(Multipolarity)
- V. S. ALEKSANDROV, V. A. BALALAEV, B. S. DZHELEPOV, V. E. TER-NERSESYANTS. Bull. Acad. Sci. URSS, Phys. Ser. 34 (1970) 42
(Gamma-ray emission probabilities)
- N. B. GOVE, M. J. MARTIN. Nuclear Data Tables 10 (1971) 206
(lg ft)
- S. K. SEN, D. L. SALIE, E. TOMCHUK. Can. J. Phys. 50 (1972) 2348
(Gamma-ray emission probabilities)
- V. A. BALALAEV, B. S. DZHELEPOV. Izv. Akad. Nauk SSSR, Ser.Fiz. 36,10 (1972) 2089
(Gamma-ray emission probabilities)
- V. R. POTNIS, G. P. AGIN, C. E. MANDEVILLE, R. ROGOW. Bull. Amer. Phys. Soc. 17 (1972) 28
(Gamma-ray emission probabilities)
- K. S. KRANE, C. E. OLSEN, W. A. STEYERT. Nucl. Phys. A197 (1972) 352
(Multipolarity. Erratum Nucl.Phys. A224 (1974) 596)
- A. P. AGNIHOTRY, K. P. GOPINATHAN, H. C. JAIN, C. V. K. BABA. Phys. Rev. C 6,1 (1972) 321
(Gamma-ray emission probabilities, ICC, multipolarity)
- V. S. ALEKSANDROV, TS. VYLOV, T. M. MUMINOV, B. OSIPENKO. Joint Nuclear Research Institute, Dubna, Preprint P6-7308 (1973)
(Gamma-ray emission probabilities)
- N. LAVI. Nucl. Instrum. Methods 107 (1973) 197
(Gamma-ray emission probabilities)
- F. LAGOUTINE, J. LEGRAND, C. BAC. Int. J. Appl. Rad. Isot. 26 (1975) 131
(Half-life)
- G. L.B ORCHERT, W. SCHECK, K. P. WIEDER. Z. Naturforsch. 30a (1975) 274
(Gamma-ray energies)
- K. P. ARTOMONOVA, A. A. VORONKOV, E. P. GRIGORIEV, A. V. ZOLOTAVIN, V. O. SERGEEV. Bull. Acad. Sci. USSR, Phys. Ser. 40, 1 (1976) 30
(Gamma-ray emission probabilities and Internal Conversion Coefficients)
- H. R. VERMA, A. K. SHARMA, N. SINGH, P. TREHAN. J. Phys. Soc. Japan 45 (1976) 374
(Gamma-ray emission probabilities)
- M. K. GEORGIEVA, G. CH. TUMBEV. Comp. Rend. de l'Academia Bulgare des Sciences 29 (1976) 639
(Gamma-ray emission probabilities)
- R. J. GEHRKE, R. G. HELMER, R. C. GREENWOOD. Nucl. Instrum. Methods 147 (1977) 405
(Gamma-ray emission probabilities)
- F. RÖSEL, H. M. FRIES, K. ALDER, H. C. PAULI. At. Data. Nucl. Data Tables 21 (1978) 292
(Theoretical Internal Conversion Coefficients)
- E. G. KESSLER JR, L. JACOBS, W. SCHWITZ, R. D. DESLATTES. Nucl. Instrum. Methods 160 (1979) 435
(Gamma-ray energies)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. Report AECL 6692 (1980)
(Half-life)
- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. Int. J. Appl. Rad. Isot. 31 (1980) 153
(Half-life)
- E. FUNCK, U. SCHÖTZIG, K. F. WALZ. Int. J. Appl. Radiat. Isotop. 34,8 (1983) 1215
(Gamma-ray emission probabilities)

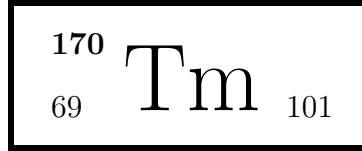
- K. M. AKHMETOV, W. I. BALASCHOW, B. V. BOBYKIN. 35 Conf. on nuclear spectroscopy and nuclear structure. Summaries of reports. *Yadernoj Fiziki* (1985) 127
(Multipolarity)
- E. GARCIA TORANO, A. GRAU MALONDA. *Comp. Phys. Commun.* 36 (1985) 307
(Gamma-ray emission probabilities)
- V. V. BULGAKOV, V. I. GAVRILYUK, A. P. LASHKO, N. V. STRIL'CHUK, A. I. FEOKTISTOV, YU. E. FRANTSEV, V. B. KHARLANOV. *Izv. Akad. Nauk SSSR, Ser. Fiz* 49, 11 (1985) 2107
(Gamma-ray emission probabilities)
- I. ADAM, W. WAGNER, M. GONUSEK, B. KRAZIK. 35 Conf. on nuclear spectroscopy and nuclear structure. Summaries of reports. *Yadernoj Fiziki* (1985) 126
(Gamma-ray emission probabilities)
- I. ADAM, W. WAGNER, M. GONUSEK, B. KRACIK. *Izv. Akad. Nauk SSSR, Ser. Fiz.* 50,5 (1986) 855
(Gamma-ray energy and emission probabilities)
- D. MEHTA, M. L. GARG, J. SINGH, N. SINGH, T. S. CHEEMA, P. N. TREHAN. *Nucl. Instrum. Methods* A245 (1986) 447
(Gamma-ray emission probabilities)
- S. DAVAA, T. I. KRACIKOVA, M. FINGER, V. M. TSUPKO-SITNIKOV, V. N. PAVLOV. *Sov. J. Nucl. Phys.* 45 ,3 (1987) 397
(Multipolarity)
- T. I. KRACIKOVA, S. DAVAA, M. FINGER, V. N. PAVLOV, V. M. TSUPKO-SITNIKOV. *Hyperfine Interactions* 34 (1987) 127
(Multipolarity)
- H. S. SAHOTA, T. IWASHITA, B. S. GREWAL. *J. Phys. Soc. Japan* 56, 11 (1987) 3881
(Elec. Capt. Probabilities)
- J. KITS, M. CHOC, F. LATAL. *Jaderna energie* 34 (1988) 231
(Half-life)
- W. WAGNER, I. ADAM, S. BATSEV, B. KRATSIK, M. FISHER, D. SRNKA. *Izv. Akad. Nauk SSSR, Ser. Fiz.* 54, 9 (1990) 1811
(Gamma-ray emission probabilities)
- J. L. PARKER. *Nucl. Instrum. Methods* A286 (1990) 502
(Half-life)
- I. ADAM, S. BAZEVA, W. WAGNER, B. KRAZIK, M. FISCHER. *Nuclear Spectroscopy and Nuclear Structure. Nuclear Spectroscopy and Nuclear Shape. Summaries of repo AN SSSR* (1990) 106
(Gamma-ray energy and emission probabilities)
- V. S. SHIRLEY. *Nuclear Data Sheets* 64 (1991) 505
(Level energies, spin and parity)
- W. A. VOLKERT, W. F. GOECKELER, G. J. EHRHARDT, A. R. KETRING. *J. Nucl. Med.* 32 (1991) 174
(Gamma-ray emission probabilities)
- M. P. UNTERWEGER, D. O. HOPPE, F. J. SCHIMA. *Nucl. Instrum. Methods Phys. Res.* A312 (1992) 349
(Half-life)
- I. M. BAND, M. B. TRZHASKOVSKAYA. *At. Data. Nucl. Data Tables* 55,1 (1993) 43
(Theoretical ICC)
- M. A. BARATOVA, T. A. ISLAMOV, A. X. KHOLMATOV, M. S. HHODZAEV, YU. ZAINUTDINOV, R. A. NIYAZOV. *Ann. Conf. Nucl. Spectrosc. At. Nuclei, Dubna* (1993) 98
(ICC)
- B. M. COURSEY, J. M. CALHOUN, J. CESSNA, D. B. GOLAS, F. J. SCHIMA. *Nucl. Instrum. Methods Phys. Res.* A339 (1994) 26
(Half-life)
- V. A. ZHEZLTONOZHISKY, N. V. STRILCHUK, V. P. KHOMENKOV. *Bull. Acad. Sci. URSS* 59,1 (1995) 15
(ICC)
- G. AUDI, A. H. WAPSTRA. *Nucl. Phys.* A595 (1995) 409
(Q)
- S. BHATTACHARYA, D. BANDYOPADHYAY, S. K. SAHA, S. K. BASU. *Nucl. Instrum. Methods Phys. Res.* A378 (1996) 515
(Gamma-ray emission probabilities)
- E. SCHÖNFELD, H. JANSSEN. *Nucl. Instrum. Methods* A369 (1996) 527
(Atomic Data)
- R. B. FIRESTONE, V. S. SHIRLEY. *Table of Isotopes*, Wiley, New York, (1996)
(Production modes)
- C. C. DEY, B. K. SINHA, K. S. BASU. *Phys. Rev.* C55 ,3 (1997) 1197
(Multipolarity)

- E. SCHÖNFELD. Appl. Rad. Isotopes 49,9 (1998) 1353
(Elec. Capt. Probabilities)
- H. MIYAHARA, H. NAGATA, T. FURUSAWA, N. MURAKAMI, C. MORI, N. TAKEUCHI, T. GENKA. Nucl. Instrum. Methods Phys. Res. A420 (1999) 155
(Gamma-ray emission probabilities)
- E. SCHÖNFELD, U. SCHÖTZIG, R. KLEIN. Appl. Rad. Isotopes 50 (1999) 753
(Gamma-ray emission probabilities)
- J. MOREL, M. ETCHEVERRY, J. PLAGNARD *et al.* Euromet 410 - Report CEA N-2842 (1999)
(Gamma-ray emission probabilities)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
(Gamma ray energies)
- A. IWAHARA, J. U. DELGADO, R. POLEDNA, C. J. DA SILVA, R. T. LOPES. Nucl. Instrum. Methods Phys. Res. A455 (2000) 607
(Half-life)
- J. MOREL, M. ETCHEVERRY, J. PLAGNARD. Appl. Rad. Isotopes 52 (2000) 455
(Gamma-ray emission probabilities)
- T. E. SAZONOVA, S. V. SEPMAN *et al.* Appl. Rad. Isotopes 52 (2000) 455
(Gamma-ray emission probabilities)









1 Decay Scheme

Tm-170 disintegrates by both beta minus decay and electron capture, respectively, to the first excited level of 84.25 keV (18.3 %) and the ground state (81 %) in Yb-170, and to the first excited level of 78.6 keV (0.03 %) and the ground state (0.12 %) in Er-170.

Le thulium 170 se désintègre par émission bêta moins et par capture électronique vers le premier niveau à 84,25 keV (18,3%), le niveau fondamental (81,6 %) de l'ytterbium 170, et le premier niveau à 78,6 keV (0,03 %) et le niveau fondamental (0,12 %) de l'erbium 170.

2 Nuclear Data

$T_{1/2}(^{170}\text{Tm})$	:	127,8	(6)	d
$Q^-(^{170}\text{Tm})$	:	968,0	(8)	keV
$Q^+(^{170}\text{Tm})$	:	314,4	(18)	keV

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,1}^-$	883,7 (8)	18,3 (7)	1st forbidden	8,924
$\beta_{0,0}^-$	968,0 (8)	81,6 (7)	1st forbidden	9,432

2.2 Electron Capture Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft	P_K	P_L	P_M
$\epsilon_{0,1}$	235,8 (18)	0,029 (3)	1st forbidden	10,21	0,7595 (22)	0,1822 (15)	0,0451 (9)
$\epsilon_{0,0}$	314,4 (18)	0,118 (7)	1st forbidden	9,906	0,7838 (19)	0,1645 (13)	0,0401 (8)

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{(-1,0)}(\text{Er})$							
$\gamma_{1,0}(\text{Er})$	78,59 (2)	0,029 (3)	E2	1,72 (11)	4,51 (30)	1,10 (7)	7,62 (50)
$\gamma_{1,0}(\text{Yb})$	84,25474 (8)	18,3 (7)	E2	1,39 (2)	3,81 (6)	0,94 (1)	6,39 (10)

3 Atomic Data

3.1 Er

ω_K	:	0,942	(4)
$\bar{\omega}_L$	:	0,216	(9)
n_{KL}	:	0,838	(4)

3.1.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	48,2212	56,34
$K\alpha_1$	49,1276	100
$K\beta_3$	55,4797	}
$K\beta_1$	55,6737	}
$K\beta_5''$	56,0322	}
$K\beta_5'$	56,0762	}
$K\beta_2$	57,142	}
$K\beta_4$	57,313	}
$KO_{2,3}$	57,456	}
X_L		
$L\ell$	6,15	
$L\gamma$	- 9,43	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	37,79 – 40,56	100
KLX	45,47 – 49,10	52,4
KXY	53,02 – 57,43	6,9

3.2 Yb

$$\begin{aligned}\omega_K &: 0,947 \quad (4) \\ \bar{\omega}_L &: 0,238 \quad (10) \\ n_{KL} &: 0,833 \quad (4)\end{aligned}$$

3.2.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	51,3541	56,73
$K\alpha_1$	52,3887	100
$K\beta_3$	59,1593	}
$K\beta_1$	59,3825	}
$K\beta_5''$	59,756	}
$K\beta_5'$	59,8045	}
$K\beta_2$	60,962	}
$K\beta_4$	61,141	}
$KO_{2,3}$	61,309	}
X_L		
$L\ell$	6,548	
$L\alpha$	7,369 – 7,416	
$L\eta$	7,583	
$L\beta$	8,026 – 8,756	
$L\gamma$	9,736 – 10,142	

3.2.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	40,16 – 43,23	100
KLX	48,36 – 52,36	52,8
KXY	56,48 – 61,29	7

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e_{AK}	(Er)		0,0072 (6)
	KLL	37,79 - 40,56	}
	KLX	45,47 - 49,10	}
	KXY	53,02 - 57,43	}
e_{AK}	(Yb)		0,182 (14)
	KLL	40,16 - 43,23	}
	KLX	48,36 - 52,36	}
	KXY	56,48 - 61,29	}
$ec_{1,0}$ K	(Er)	21,10 (2)	0,0058 (5)
$ec_{1,0}$ K	(Yb)	22,9224 (1)	3,45 (13)
$ec_{1,0}$ L	(Er)	68,84 - 70,23	0,015 (1)
$ec_{1,0}$ L	(Yb)	73,77 - 75,31	9,4 (4)
$ec_{1,0}$ M	(Er)	76,38 - 77,18	0,0037 (3)
$ec_{1,0}$ M	(Yb)	81,86 - 82,73	2,3 (1)
$\beta_{0,1}^-$	max:	883,7 (8)	18,3 (7)
$\beta_{0,1}^-$	avg:	290,5 (3)	
$\beta_{0,0}^-$	max:	968,0 (8)	81,6 (7)
$\beta_{0,0}^-$	avg:	323,1 (3)	

5 Photon Emissions

5.1 X-Ray Emissions

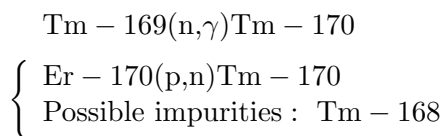
		Energy keV	Photons per 100 disint.
XL	(Er)	6,15 — 9,43	0,0306 (19)
$XK\alpha_2$	(Er)	48,2212	0,332 (16)
$XK\alpha_1$	(Er)	49,1276	0,0590 (24)
$XK\beta_3$	(Er)	55,4797	}
$XK\beta_1$	(Er)	55,6737	}
$XK\beta_5''$	(Er)	56,0322	}
$XK\beta_5'$	(Er)	56,0762	}
$XK\beta_2$	(Er)	57,142	}
$XK\beta_4$	(Er)	57,313	}
$XKO_{2,3}$	(Er)	57,456	}

		Energy keV	Photons per 100 disint.	
XL	(Yb)	6,548 — 10,142	3,22 (13)	
XK α_2	(Yb)	51,3541	0,95 (4)	} K α
XK α_1	(Yb)	52,3887	1,67 (7)	
XK β_3	(Yb)	59,1593	}	K' β_1
XK β_1	(Yb)	59,3825	}	
XK β_5''	(Yb)	59,756	}	
XK β_5'	(Yb)	59,8045	}	
XK β_2	(Yb)	60,962	}	
XK β_4	(Yb)	61,141	}	K' β_2
XKO $_{2,3}$	(Yb)	61,309	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Er})$	78,59 (2)	0,0034 (3)
$\gamma_{1,0}(\text{Yb})$	84,25474 (8)	2,48 (9)

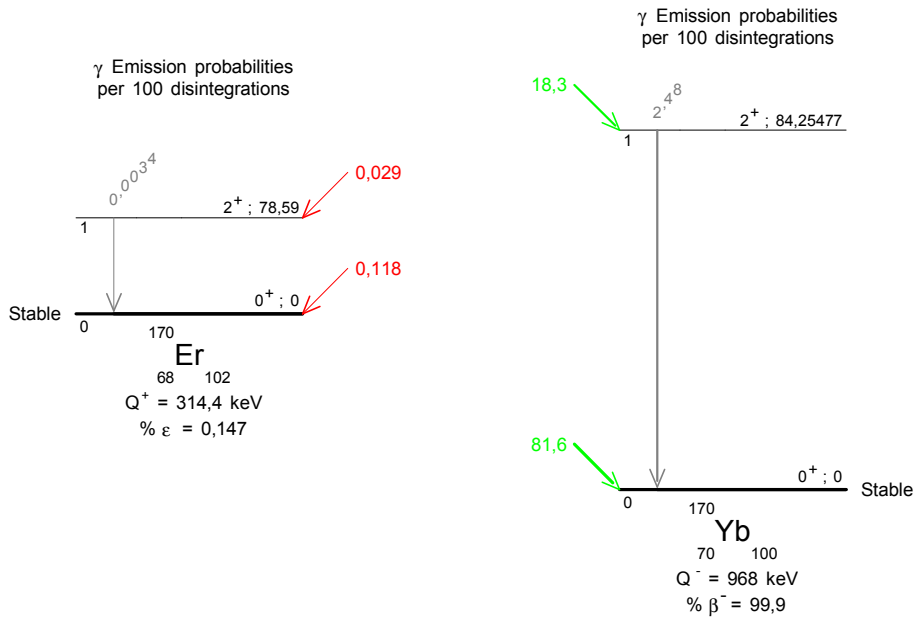
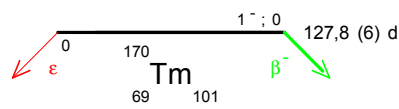
6 Main Production Modes

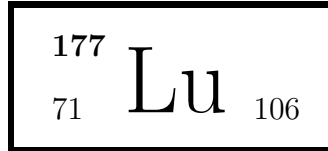


7 References

- E. L. CHUPP *et al.* Phys. Rev. 112 (1958) 518
(gamma ray energy)
- BONNER *et al.* Phys. Rev. 127 (1962) 217
(Half-life)
- K. F. FLYNN *et al.* Nucl. Sci. Eng. 22 (1965) 416
(Half-life)
- R. S. DINGUS *et al.* Nucl. Phys. 83 (1966) 545
(ICC K, g-84)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- W. I. KERRIGAN. J. Inorg. Nucl. Chem. 29 (1967) 2657
(Half-life)

- O. NILSSON *et al.* Nucl. Phys. A120 (1968) 561
(ICC M / ICC NO)
- S. A. REYNOLDS, *et al.* Nucl. Sci. Eng. 32 (1968) 46
(Half-life)
- H. H. HANSEN, S. HELLSTROM. Z. Phys. 223 (1969) 139
(Energy of g-79)
- F. LAGOUTINE *et al.* Int. J. Appl. Radiat. Isotop. 20 (1969) 868
(Half-life)
- G. C. NELSON, E. N. HATCH. Nucl. Phys. A127 (1969) 560
(ICC K, g-84)
- S. MOHAN. Phys. Rev. C1 (1970) 254
(ICC K(g84), energy and relative probability of g-79)
- J. L. CAMPBELL. Nucl. Instrum. Methods 92 (1971) 237
(ICC K(g84))
- J. PLCH *et al.* Czech. J. Phys. 23 (1973) 1181
(ICC K(g84), absolute g-84 emission probability)
- F. P. LARKINS. At. Data Nuc. Data Tables 20 (1977) 313
(Auger electron energies)
- F. RÖSEL *et al.* At. Data Nuc. Data Tables 21 (1978) 293
(Internal conversion coefficients)
- D. MEHTA *et al.* Nucl. Instrum. Methods A242 (1985) 149
(ICC K(g84), PX/Pg(84), Pg(79)/Pg(84))
- RAO N. VENKATESWARA, *et al.* J. Phys. (London) G12 (1986) 45
(ICC K(g84), Pg(79)/Pg(84))
- RAO N. VENKATESWARA, *et al.* Indian J. Phys. 60A (1986) 162
(PX/Pg(84))
- A.M. GEIDELMAN *et al.* Conf. on Nucl. Spectr. and Atomic Nucl. Structure, Yurmala, 14-17 April, LO Nauka, Leningrad, 1987 (1987) 133
(Absolute g(84) emission probability)
- N.K. KUZMENKO *et al.* Izmeritelnay Tekhnika N9 (1988) 47
(1988 decay data evaluation, absolute g(84) emission probability)
- A.M. GEIDELMAN *et al.* Proc. Intern. Conf. Nuclear data for Science and Technology, Mito, Japan, 1988 (1988) 909
(Absolute g(84) emission probability)
- A.G. EGOROV *et al.* Program. and Thesis, Proc.39th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Leningrad, 1989 (1989) 505
(Yb XK-ray emission probabilities)
- T. KEMPISTY *et al.* Nucl. Instrum. Methods A286 (1990) 535
(Absolute g(84) emission probability, ICC K(g84))
- A.G. EGOROV *et al.* Program and Thesis, Proc. 40th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Leningrad, 1990 (1990) 486
(Er XK-ray emission probabilities)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q values)
- C. M. BAGLIN. Nucl. Data Sheets 77 (1996) 125
(Decay scheme)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic data)
- B. SINGH *et al.* Nucl. Data Sheets 84 (1998) 487
(lg ft)
- E. SCHÖNFELD. Appl. Rad. Isotopes 49 (1998) 1353
(gamma-ray energies)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(gamma-ray energies)
- R.D. DESLATTES, *et al.* Rev. Mod. Phys. 75 (2003) 35
(L X-ray energies)





1 Decay Scheme

The Lu-177 ground state (JPI=7/2+) disintegrates by beta- emission (PB=100%) to the ground state (JPI=7/2-) and to three excited levels (JPI=9/2-,11/2- and 9/2+) of Hf-177.

Le lutécium 177 se désintègre par émission bêta moins vers le niveau fondamental d' hafnium 177 via trois niveaux excités.

2 Nuclear Data

$$T_{1/2}(^{177}\text{Lu}) : 6,647 \quad (4) \quad \text{d}$$

$$Q^-(^{177}\text{Lu}) : 498,3 \quad (8) \quad \text{keV}$$

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,3}^-$	177,0 (8)	11,64 (10)	Allowed	6,1
$\beta_{0,2}^-$	248,6 (8)	0,012 (8)	1st forbidden Unique	9,2
$\beta_{0,1}^-$	385,4 (8)	9,1 (5)	1st Forbidden	7,3
$\beta_{0,0}^-$	498,3 (8)	79,3 (5)	1st Forbidden	6,7

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{3,2}(\text{Hf})$	71,6418 (6)	0,327 (6)	E1+M2	0,715 (14)	0,138 (6)	0,0317 (14)	0,894 (22)
$\gamma_{1,0}(\text{Hf})$	112,9498 (4)	20,29 (7)	M1+95,1%E2	0,817 (12)	1,104 (6)	0,2755 (14)	2,272 (5)
$\gamma_{2,1}(\text{Hf})$	136,7245 (5)	0,1014 (7)	M1+90%E2	0,559 (21)	0,456 (7)	0,1129 (21)	1,158 (18)
$\gamma_{3,1}(\text{Hf})$	208,3662 (4)	11,09 (7)	E1+0,54%M2	0,055 (4)	0,0094 (10)	0,00216 (24)	0,068 (5)
$\gamma_{2,0}(\text{Hf})$	249,6742 (6)	0,2296 (21)	E2	0,091	0,038	0,009	0,141
$\gamma_{3,0}(\text{Hf})$	321,3159 (6)	0,233 (8)	E1+M2	0,06 (5)	0,012 (10)	0,0028 (22)	0,08 (6)

3 Atomic Data

3.1 Hf

ω_K	:	0,951	(4)
$\bar{\omega}_L$	:	0,26	(1)
n_{KL}	:	0,829	(4)

3.1.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	54,612	57,2
$K\alpha_1$	55,7909	100
$K\beta_3$	62,985	}
$K\beta_1$	63,234	}
$K\beta_5''$	63,662	}
		33
$K\beta_2$	64,942	}
$K\beta_4$	65,132	}
$KO_{2,3}$	65,316	}
		8,8
X_L		
$L\ell$	6,96	
$L\alpha$	7,844 – 7,899	
$L\eta$	8,139	
$L\beta$	8,905 – 9,342	
$L\gamma$	10,516 – 10,89	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	42,601 – 46,007	100
KLX	51,391 – 55,784	53,4
KXY	60,15 – 65,34	7,08
Auger L	4,3 – 11,2	

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Hf)	4,3	- 11,2	8,75 (20)
e _{AK}	(Hf)			0,283 (90)
	KLL	42,601	- 46,007	}
	KLX	51,391	- 55,784	}
	KXY	60,15	- 65,34	}
ec _{3,2} K	(Hf)	6,2910	(9)	0,123 (5)
ec _{1,0} K	(Hf)	47,5990	(8)	5,07 (18)
ec _{1,0} L	(Hf)	101,678	- 101,679	6,84 (23)
ec _{1,0} M	(Hf)	110,348	- 110,349	1,71 (6)
ec _{3,1} K	(Hf)	143,0154	(8)	0,57 (5)
ec _{3,1} L	(Hf)	197,094	- 197,096	0,098 (11)
$\beta_{0,3}^-$	max:	177,0	(8)	11,64 (10)
$\beta_{0,3}^-$	avg:	47,66	(23)	
$\beta_{0,2}^-$	max:	248,6	(8)	0,012 (8)
$\beta_{0,2}^-$	avg:	78,6	(3)	
$\beta_{0,1}^-$	max:	385,4	(8)	9,1 (5)
$\beta_{0,1}^-$	avg:	111,7	(3)	
$\beta_{0,0}^-$	max:	498,3	(8)	79,3 (5)
$\beta_{0,0}^-$	avg:	149,4	(3)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.
XL	(Hf)	6,96	— 10,89	3,18 (6)
XK α_2	(Hf)	54,612		1,59 (3) } K α
XK α_1	(Hf)	55,7909		2,78 (6) }
XK β_3	(Hf)	62,985	}	
XK β_1	(Hf)	63,234	}	0,917 (23) K' β_1
XK β_5''	(Hf)	63,662	}	
XK β_2	(Hf)	64,942	}	
XK β_4	(Hf)	65,132	}	0,245 (8) K' β_2
XKO _{2,3}	(Hf)	65,316	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{3,2}(\text{Hf})$	71,6418 (6)	0,1726 (23)
$\gamma_{1,0}(\text{Hf})$	112,9498 (4)	6,20 (7)
$\gamma_{2,1}(\text{Hf})$	136,7245 (5)	0,0470 (7)
$\gamma_{3,1}(\text{Hf})$	208,3662 (4)	10,38 (7)
$\gamma_{2,0}(\text{Hf})$	249,6742 (6)	0,2012 (21)
$\gamma_{3,0}(\text{Hf})$	321,3159 (6)	0,216 (8)

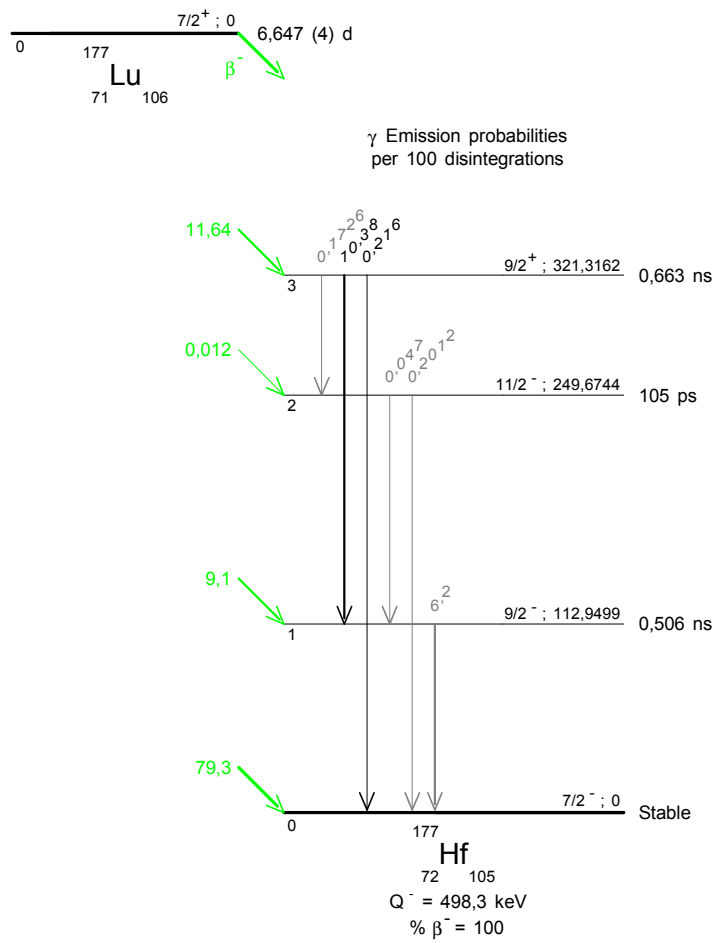
6 Main Production Modes

Lu – 176(n, γ)Lu – 177 σ : 1778 (75) barns

7 References

- D. G. DOUGLAS. Phys. Rev. 75 (1949) 1960
(Beta minus emission probability)
- P. MARMIER, F. BOEHM. Phys. Rev. 97 (1955) 103
(Beta minus emission probability, Gamma ray energies, Gamma-ray emission probabilities)
- T. WIEDLING. Thesis, Univ. of Stockholm (1956)
(Beta minus emission probability)
- R. H. BETTS, O. F. DAHLINGER, D. M. MUNRO. Can. J. Phys. 36 (1958) 73
(Half-life)
- L. C. SCHMID, W. P. STINSON. Nucl. Sci. Eng. 7 (1960) 477
(Half-life)
- H. I. WEST JR, L. G. MANN, R. J. NAGLE. Phys. Rev. 124 (1961) 527
(Gamma ray energies, Gamma-ray emission probabilities, Mixing ratio, K ICC, L ICC)
- M. S. EL-NESR, E. BASHANDY. Nucl. Phys. 31 (1962) 128
(Beta minus emission probability)
- P. ALEXANDER, F. BOEHM, E. KANKELEIT. Phys. Rev. 133 (1964) B284
(Beta minus emission probability, Gamma ray energies, Gamma-ray emission probabilities)
- D. F. CROUCH, L. D. MCISAAC. Report IDO-16932 (1964) 26
(Gamma-ray emission probabilities)
- B. P. MAIER. Z. Physik 184 (1965) 153
(Gamma ray energies)
- A. J. HAVERFIELD, F. M. BERNTHAL, J. M. HOLLANDER. Nucl. Phys. A94 (1967) 337
(Beta minus emission probability, Gamma ray energies, Gamma-ray emission probabilities)
- B. HRASTNIK, I. BASAR, M. DIKSIC, K. ILAKOVAC, V. KOS, A. LJUBCIC. Z. Physik 239 (1970) 25
(Mixing ratio)
- J. F. EMERY, S. A. REYNOLDS, E. I. WATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319
(Half-life)
- S. HOGBERG, R. JADRNY, S.-E. KARLSSON, G. MALMSTEN, O. NILSSON. Z. Physik 254 (1972) 89
(Mixing ratio)
- L. HOLMBERG, V. STEFANSSON, J. BECKER, C. BARGHOLTZ, L. GIDEFELDT. Phys. Scr. 6 (1972) 177
(Mixing ratio)
- V. N. GRIGORIEV, D. M. KAMINKER, Y. V. SERGEENKOV. Bull. Acad. Sci. URSS 36 (1973) 762
(K ICC, L ICC)
- B. D. JELTEMA, F. M. BERNTHAL. Phys. Rev. C10 (1974) 778
(K ICC, L ICC)

- K. S.KRANE, C. E. OLSEN, W. A. STEYERT. Phys. Rev. C10 (1974) 825
(Mixing ratio)
- A. P. AGNIHOTRY, K. P. GOPINATHAN, H. C. JAIN. Phys. Rev. C9 (1974) 336
(Gamma-ray emission probabilities, Mixing ratio, K ICC, L ICC)
- H. E. KEUS, W. J. HUISKAMP. Physica 85B (1977) 137
(Mixing ratio)
- F. RÖSEL, H. M. FRIES, K. ALDER, H. C. PAULI. At. Data Nucl. Data Tables 21 (1978) 92
(Theoretical ICC)
- V. HNATOWICZ. Czech. J. Phys. B31 (1981) 260
(Gamma ray energies, Gamma-ray emission probabilities)
- F. LAGOUTINE, J. LEGRAND. Int. J. Appl. Radiat. Isotop. 33 (1982) 711
(Half-life)
- D. MEHTA, B. CHAND, S. SINGH, M. L. GARG, N. SINGH, T. S. CHEEMA, T. N. TREHAN. Nucl. Instrum. Methods Phys. Res. A260 (1987) 157
(Gamma-ray emission probabilities)
- S. MATSUI, H. INOUE, Y. YOSHIZAWA. Nucl. Instrum. Methods Phys. Res. A281 (1989) 568
(Gamma-ray energy)
- A. ABZOUZI, M. S. ANTONY, A. HACHEM, V. B. NDOCKO NDONGUE. J. Radioanal. Nucl. Chem. 144 (1990) 359
(Half-life)
- C. C. DEY, B. K. SINHA, R. BHATTACHARYA. Nuovo Cim. 105A (1992) 1307
(Mixing ratio)
- E. BROWNE. Nucl. Data Sheets 68 (1993) 747
(Nuclear Data)
- G. AUDI, A. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(Atomic Data)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 (1998)
(X-ray energies)
- B. E. ZIMMERMAN, M. P. UNTERWEGER, J. W. BRODACK. Appl. Rad. Isotopes 54 (2001) 623
(Half-life)
- E. SCHÖNFELD, U. SCHÖTZIG. Appl. Rad. Isotopes 54 (2001) 785
(X-ray emission probabilities)
- U. SCHÖTZIG, H. SCHRADER, E. SCHÖNFELD, E. GUNTHER, R. KLEIN. Appl. Rad. Isotopes 55 (2001) 89
(Beta minus emission probability, Half-life, Gamma-ray emission probabilities)





1 Decay Scheme

Re-186 decays by beta minus emissions mainly to the fundamental and the 137 keV excited levels of Os-186 and by electron capture to the W-186.

Le rhénium 186 se désintègre par émission bêta moins principalement vers le niveau fondamental et le niveau excité de 137 keV de l'osmium 186 ; et par capture électronique vers le niveau fondamental et vers le niveau excité de 122 keV du tungstène 186.

2 Nuclear Data

$T_{1/2}(^{186}\text{Re})$	:	3,7186	(17)	d
$Q^-(^{186}\text{Re})$	:	1069,5	(9)	keV
$Q^+(^{186}\text{Re})$	:	581,6	(17)	keV

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg ft	P_K	P_L	P_M
$\epsilon_{0,1}$	459,3 (17)	1,69 (3)	1st Forbidden	7,8	0,7836 (19)	0,1638 (13)	0,0404 (8)
$\epsilon_{0,0}$	581,6 (17)	5,84 (12)	1st Forbidden	7,5	0,7943 (18)	0,1560 (12)	0,0382 (7)

2.2 β^- Transitions

	Energy keV	Probability × 100	Nature	lg ft
$\beta_{0,4}^-$	159,0 (9)	0,000027 (9)	unique 1st forbidden	10,9
$\beta_{0,3}^-$	302,0 (9)	0,0627 (9)	1st Forbidden	8,9
$\beta_{0,1}^-$	932,3 (9)	21,5 (3)	1st Forbidden	8
$\beta_{0,0}^-$	1069,5 (9)	70,9 (3)	1st Forbidden	7,7

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(W)$	122,33 (10)	1,694 (29)	E2	0,585 (12)	0,927 (19)	0,234 (7)	1,81 (4)
$\gamma_{1,0}(Os)$	137,157 (8)	21,57 (39)	E2	0,433 (13)	0,645 (19)	0,1648 (49)	1,290 (39)
$\gamma_{4,3}(Os)$	143,000 (42)	0,0000021 (7)	M1+E2	1,39 (8)	0,35 (2)	0,0842 (25)	1,85 (11)
$\gamma_{2,1}(Os)$	296,933 (31)	0,000058 (16)	E2	0,0609 (12)	0,0260 (6)	0,00645 (19)	0,095 (2)
$\gamma_{3,2}(Os)$	333,390 (42)	0,000066 (16)	[E2]	0,0454 (14)	0,0170 (5)	0,00418 (13)	0,0678 (20)
$\gamma_{4,2}(Os)$	476,390 (42)	0,0000015 (5)	E2+M1	0,0193 (6)	0,00512 (15)	0,001235 (37)	0,0259 (8)
$\gamma_{3,1}(Os)$	630,323 (31)	0,0297 (6)	M1+E2	0,0105 (6)	0,0023 (2)	0,000538 (16)	0,0134 (1)
$\gamma_{3,0}(Os)$	767,48 (3)	0,0330 (6)	E2	0,00690 (21)	0,001342 (40)	0,000315 (9)	0,00865 (26)
$\gamma_{4,1}(Os)$	773,323 (31)	0,000023 (7)	E2+M1	0,0189 (6)	0,00291 (9)		0,0266 (7)

3 Atomic Data

3.1 W

ω_K	:	0,954	(4)
$\bar{\omega}_L$	:	0,283	(11)
n_{KL}	:	0,825	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	K α_2	57,9823	
	K α_1	59,3189	
	K β_3	66,952	}
	K β_1	67,2451	}
	K β_5''	67,664	}
	K β_2	69,033	}
	K β_4	69,295	}
	KO _{2,3}	69,484	}
X _L	L ℓ	7,38	
	L γ	– 12,07	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	45,109 – 48,882	100
KLX	54,514 – 59,312	53,7
KXY	63,89 – 69,51	7,18
Auger L	4,5 – 12,1	27,6

3.2 Os

$$\begin{aligned}\omega_K &: 0,957 \quad (4) \\ \bar{\omega}_L &: 0,308 \quad (12) \\ n_{KL} &: 0,821 \quad (4)\end{aligned}$$

3.2.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	61,4873	58,03
$K\alpha_1$	63,0011	100
$K\beta_3$	71,078	}
$K\beta_1$	71,414	}
$K\beta_5''$	71,855	}
		33,46
$K\beta_2$	73,319	}
$K\beta_4$	73,615	}
$KO_{2,3}$	73,819	}
		9,37
X_L		
$L\ell$	7,82	
$L\gamma$	– 12,92	

3.2.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	47,710 – 51,892	100
KLX	57,759 – 62,955	54,2
KXY	67,77 – 73,78	7,34
Auger L	4,7 – 12,9	60

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(W)	4,5 - 12,1		4,11 (4)
e _{AK}	(W)			0,291 (26)
	KLL	45,109 - 48,882	}	
	KLX	54,514 - 59,312	}	
	KXY	63,89 - 69,51	}	
e _{AL}	(Os)	4,7 - 12,9		6,43 (8)
e _{AK}	(Os)			0,175 (18)
	KLL	47,710 - 51,892	}	
	KLX	57,759 - 62,955	}	
	KXY	67,77 - 73,78	}	
ec _{1,0} K	(W)	52,8	(1)	0,353 (8)
ec _{1,0} T	(Os)	63,29 - 137,11		12,15 (38)
ec _{1,0} K	(Os)	63,29	(1)	4,08 (13)
ec _{1,0} L	(W)	110,23 - 112,12		0,559 (13)
ec _{1,0} M	(W)	119,51 - 120,52		0,1411 (44)
ec _{1,0} L	(Os)	124,19 - 126,29		6,08 (18)
ec _{1,0} M	(Os)	134,11 - 135,20		1,552 (47)
ec _{1,0} N	(Os)	136,5 - 137,1		0,381 (12)
$\beta_{0,4}^-$	max:	159,0	(9)	0,000027 (9)
$\beta_{0,4}^-$	avg:	42,6	(7)	
$\beta_{0,3}^-$	max:	302,0	(9)	0,0627 (9)
$\beta_{0,3}^-$	avg:	84,7	(7)	
$\beta_{0,1}^-$	max:	932,3	(9)	21,5 (3)
$\beta_{0,1}^-$	avg:	306,7	(7)	
$\beta_{0,0}^-$	max:	1069,5	(9)	70,9 (3)
$\beta_{0,0}^-$	avg:	359,6	(7)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(W)	7,38 — 12,07	1,66 (4)	
XK α_2	(W)	57,9823	1,736 (30)	} K α
XK α_1	(W)	59,3189	3,02 (5)	
XK β_3	(W)	66,952	}	K' β_1
XK β_1	(W)	67,2451	}	
XK β_5''	(W)	67,664	}	
XK β_2	(W)	69,033	}	K' β_2
XK β_4	(W)	69,295	}	
XKO _{2,3}	(W)	69,484	}	
XL	(Os)	7,82 — 12,92	2,99 (7)	
XK α_2	(Os)	61,4873	1,13 (4)	} K α
XK α_1	(Os)	63,0011	1,94 (6)	
XK β_3	(Os)	71,078	}	K' β_1
XK β_1	(Os)	71,414	}	
XK β_5''	(Os)	71,855	}	
XK β_2	(Os)	73,319	}	K' β_2
XK β_4	(Os)	73,615	}	
XKO _{2,3}	(Os)	73,819	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(W)$	122,33 (10)	0,603 (6)
$\gamma_{1,0}(Os)$	137,157 (8)	9,42 (6)
$\gamma_{4,3}(Os)$	143,00 (4)	0,00000074 (25)
$\gamma_{2,1}(Os)$	296,93 (3)	0,000053 (15)
$\gamma_{3,2}(Os)$	333,39 (4)	0,000062 (15)
$\gamma_{4,2}(Os)$	476,39 (4)	0,0000015 (5)
$\gamma_{3,1}(Os)$	630,32 (3)	0,0293 (6)
$\gamma_{3,0}(Os)$	767,478 (30)	0,0327 (6)
$\gamma_{4,1}(Os)$	773,32 (3)	0,000022 (7)

6 Main Production Modes

$$\left\{ \begin{array}{l} \text{Re} - 185(n,\gamma)\text{Re} - 186 \quad \sigma : 112 (3) \text{ barns} \\ \text{Possible impurities : Re} - 186\text{m}, \text{Re} - 188, \text{Re} - 188\text{m} \end{array} \right.$$

7 References

- K.SINMA, H.YAMASAKI. Phys. Rev. 55 (1939) 320
(Half-life)
- K.FAJANS, W.H.SULLIVAN. Phys. Rev. 58 (1940) 276
(Half-life)
- J.M.CORK, R.G.SHREFFER, C.M.FOWLER. Phys. Rev. 74 (1940) 1657
(Half-life)
- H.YAMASAKI, K.SINMA. Sci. Pap. Inst. Phys. Chem. Res. 37 (1940) 10
(Half-life)
- P.J.GRANT, R.RICHMOND. Proc. Phys. Soc. 62A (1945) 573
(Half-life)
- L.J.GOODMAN, M.L.POOL. Phys. Rev. 71 (1947) 288
(Half-life)
- A.T.DYBVIK, M.L.POOL. Phys. Rev. 80 (1950) 126
(Half-life)
- T.C.CHU. Phys. Rev. 79 (1950) 582
(Half-life)
- D.GUSS, L.KILLION, F.T.PORTER. Phys. Rev. 95 (1954) 627
(Gamma ray energies, lg ft)
- F.T.PORTER, M.S.FREEDMAN, T.B.NOVEY, F.WAGNER JR. Phys. Rev. 103 (1956) 921
(Gamma ray energies, Beta emission probabilities)
- T.B.NOVEY, M.S.FREEDMAN, F.T.PORTER, F.WAGNER JR. Phys. Rev. 103 (1956) 942
(Beta emission probabilities, Gamma ray energies, angular correlation)
- M.W.JOHNS, C.C.MACMULLEN, I.R.WILLIAMS, S.V.NABLO. Can. J. Phys. 34 (1956) 69
(Beta emission probabilities)
- E.L.CHUPP, A.F.CLARK, J.W.M.DUMOND, F.J.GORDON, H.MARK. Phys. Rev. 107 (1957) 745
(Gamma ray energies)
- G.GUEBEN, J.GOVAERTS. Monographie Nr.2, Inst. Inter univ. Sciences Nucleaires (1958)
(Half-life)
- G.T.EMERY, W.R.KANE, M.MACKEOWN, M.L.PERLMAN, G.SCHARFF-GOLDHABER. Phys. Rev. 129 (1963) 2597
(Gamma ray energies, Gamma-ray emission probabilities)
- I.MARKLUND, B.LINDSTRÖM. Nucl. Phys. 40 (1963) 329
(Gamma ray energies)
- L.MALY, Z.PLAJNER, J.JURSIK, M.FINGER. Czech. J. Phys. B14 (1964) 240
(Gamma-ray emission probabilities, Gamma ray energies, Beta emission energies, Beta emission probabilities, Conv. Elec. emission probabilities)
- B.HARMATZ, T.H.HANDLEY. Nucl. Phys. 56 (1964) 1
(Gamma ray energies)
- J.D.KURFESS, R.P.SCHARENBERG. Phys. Rev. 161 (1967) 1185
(Half-life, of the 122 keV level)
- J.O.NEWTON, F.S.STEPHENS, R.M.DIAMOND, K.KOTAJIMA, E.MATTHIAS. Nucl. Phys. A95 (1967) 357
(Gamma ray energies)
- J.A.BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(Gamma ray energies)
- K.V.R.RAO, P.JAGAM, A.R., D.L.SASTRY. Nuclear Physics and Solid State Physics Symposium (1969)
(angular correlation, decay scheme)
- S.ANDRE, P.LIAUD. Comp. Rend. Acad. Sci. (Paris) 268 (1969) 270
(Beta emission energies)
- S.ANDRE, P.LIAUD. J. Phys. 31 (1970) 155
(Beta emission energies)

- M.TRUDEL, E.E.HABIB, H.OGATA. Phys. Rev. C1 (1970) 643
(Beta emission energies)
- R.MICHEL, U.HERPERS. Radiochim. Acta 16 (1971) 115
(Half-life)
- K.V.RAMANA RAO, V.LAKSHMINARAYANA. Current Science-Bangalore, India 40 (1971) 1
(K X-ray emission probabilities, K X-ray energies, angular correlation)
- D.W.SEEGMILLER, M.LINDNER, R.A.MEYER. Nucl. Phys. A185 (1972) 94
(Gamma-ray emission probabilities, Conv. Elec. emission probabilities)
- B.FOGELBERG. Nucl. Phys. A197 (1972) 497
(Gamma ray energies, Gamma-ray emission probabilities)
- B.N.SUBBA RAO. Proceedings of the Nuclear Physics and Solid State Symposium, Bombay (1972) 1344
(Conv. Elec. emission probabilities)
- H.KARWOWSKI, S.MAJEWSKI, B.PIETRZYK, L.WENCEL, J.JASTRZEBSKI. J. Phys. 36 (1975) 471
(Half-life, of the 122 keV level)
- D.BOGDAN, TR.CRETU, H.FUIA, G.MACARIE, D.G.POPESCU. Bul. Inst. Politehnic Gheorghe Gheorghiu-Dej Bucuresti Seria Electrotehnika (1977) 18
(Beta decay)
- F.RÖSEL, H.M.FRIES, K.ALDER, H.C.PAULI. At. Data. Nucl. Data Tables 21 (1978) 92
(Conv. Elec. emission probabilities)
- D.OERTEL, W.D.BREWER. Phys. Rev. C23 (1981) 2751
(Beta branches)
- R.B.FIRESTONE. Nucl. Data Sheets 55 (1988) 583
(levels)
- A.ABZOUZI, MS.ANTONY, V.B.NDOCKOÑDONGUE. J. Radioanal. Nucl. Chem. 137 (1989) 381
(Half-life)
- J.GOSWAMI, B.CHAND, D.MEHTA, N.SINGH, P.N.TREHAN. Appl. Rad. Isotopes 42 (1991) 1033
(Gamma-ray emission probabilities)
- B.M.COURSEY, J.CESSNA, E.GARCIA-TORANO, D.B.GOLAS, A.GRAUMALONDA, D.H.GRAY, D.D.HOPPES, J.M.LOSARCOS, M.T.MARTIN-CASALLO, F.J.SCHIMA, M.P.UNTERWEGER. Appl. Rad. Isotopes 42 (1991) 865
(Half-life)
- M.P.UNTERWEGER, D.D.HOPPES, F.J.SCHIMA. Nucl. Instrum. Methods Phys. Res. A312 (1992) 349
(Half-life)
- E.SCHÖNFELD, H.JANSSEN, U.SCHÖTZIG, E.GÜNTHER, H.SCHRADER. Nucl. Instrum. Methods Phys. Res. A339 (1994) 174
(Gamma-ray emission probabilities, Half-life, Conv. Elec. emission probabilities)
- G.AUDI, A.H.WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(K fluorescence yield, K X-ray emission probabilities, L vacancies)
- C.M.BAGLIN. Nucl. Data Sheets 82 (1997) 1
(Spin and Parity, Half-life, excited levels)
- E.SCHÖNFELD. Appl. Rad. Isotopes 49 (1998) 1353
(X-ray emission probabilities)
- H.MIYAHARA, G. WURDIYANTO, H. NAGATA, A. YOSHIDA, K. YANAGIDA, C. MORI. Appl. Rad. Isotopes 52 (2000) 573
(Gamma-ray emission probabilities)
- D.H.WOODS, M. CIOCANEL, L. J. HUSBAND, J. D. KEIGHTLEY, P. DE LAVISON, S. LINEHAM, M. J. WOODS, S. A. WOODS. Appl. Rad. Isotopes 52 (2000) 581
(Gamma-ray emission probabilities)
- H.SCHRADER. Appl. Rad. Isotopes 60, 2-3 (2004) 317
(Half-life)



1 Decay Scheme

The Au-198 disintegrates following three beta minus transitions, the main one is to the 411 keV level of Hg-198.

L'or 198 se désintègre selon trois transitions bêta moins, la principale vers le niveau de 411 keV du mercure 198, les deux autres de plus faible intensité vers le niveau de 1087 keV et le niveau fondamental.

2 Nuclear Data

$$T_{1/2}({}^{198}\text{Au}) : 2,6944 \quad (8) \quad \text{d}$$

$$Q^{-}({}^{198}\text{Au}) : 1372,2 \quad (10) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability $\times 100$	Nature	lg <i>ft</i>
$\beta_{0,2}^{-}$	284,5 (10)	0,989 (8)	1st Forbidden	7,6
$\beta_{0,1}^{-}$	960,4 (10)	98,986 (10)	1st Forbidden	7,36
$\beta_{0,0}^{-}$	1372,2 (10)	0,025 (5)	Unique 1st Forbidden	12,27

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(\text{Hg})$	411,80250 (17)	99,81 (9)	E2	0,0301 (2)	0,01091 (25)	0,0027 (2)	0,0447 (5)
$\gamma_{2,1}(\text{Hg})$	675,8849 (7)	0,827 (7)	M1+56(5)%E2	0,0211 (15)	0,00380 (26)	0,00090 (7)	0,0261 (18)
$\gamma_{2,0}(\text{Hg})$	1087,6874 (7)	0,1598 (30)	E2	0,00419 (13)	0,000761 (23)	0,000179 (5)	0,00519 (16)

3 Atomic Data

3.1 Hg

$$\begin{aligned}\omega_K &: 0,962 \quad (4) \\ \bar{\omega}_L &: 0,355 \quad (14) \\ n_{KL} &: 0,813 \quad (4)\end{aligned}$$

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	68,895	59	
	K α_1	70,819	100	
	K β_3	79,822	}	
	K β_1	80,253	}	
	K β_5''	80,75	}	33,9
	K β_2	82,435	}	
	K β_4	82,776	}	9,94
	KO _{2,3}	83,028	}	
	X _L			
L ℓ	8,721			
L α	9,898 – 9,989			
L η	10,651			
L β	11,358 – 12,56			
L γ	13,41 – 14,474			

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	53,17 – 58,28	100
KLX	64,59 – 70,81	55,2
KXY	75,92 – 83,08	7,62
Auger L	5,1 – 14,8	32

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e _{AL}	(Hg)	5,1	- 14,8	2,170 (24)
e _{AK}	(Hg)			0,110 (12)
	KLL	53,17	- 58,28	}
	KLX	64,59	- 70,81	}
	KXY	75,92	- 83,08	}
ec _{1,0} K	(Hg)	328,7002	(5)	2,876 (19)
ec _{1,0} L	(Hg)	396,963	- 399,519	1,042 (24)
ec _{1,0} M	(Hg)	408,241	- 409,508	0,258 (19)
$\beta_{0,2}^-$	max:	284,5	(10)	0,989 (8)
$\beta_{0,2}^-$	avg:	79,4	(3)	
$\beta_{0,1}^-$	max:	960,4	(10)	98,986 (10)
$\beta_{0,1}^-$	avg:	314,5	(3)	
$\beta_{0,0}^-$	max:	1372,2	(10)	0,025 (5)
$\beta_{0,0}^-$	avg:	466	(1)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.
XL	(Hg)	8,721	— 14,474	1,21 (2)
XK α_2	(Hg)	68,895		0,809 (8)
XK α_1	(Hg)	70,819		1,372 (12)
XK β_3	(Hg)	79,822	}	
XK β_1	(Hg)	80,253	}	0,466 (8)
XK β_5''	(Hg)	80,75	}	
XK β_2	(Hg)	82,435	}	
XK β_4	(Hg)	82,776	}	0,136 (4)
XK $O_{2,3}$	(Hg)	83,028	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Hg})$	411,80205 (17)	95,54 (7)
$\gamma_{2,1}(\text{Hg})$	675,8836 (7)	0,806 (7)
$\gamma_{2,0}(\text{Hg})$	1087,6842 (7)	0,159 (3)

6 Main Production Modes

$$\left\{ \begin{array}{l} \text{Au} - 197(n,\gamma)\text{Au} - 198 \quad \sigma : 98,8 (3) \text{ barns} \\ \text{Possible impurities : Au} - 199 \end{array} \right.$$

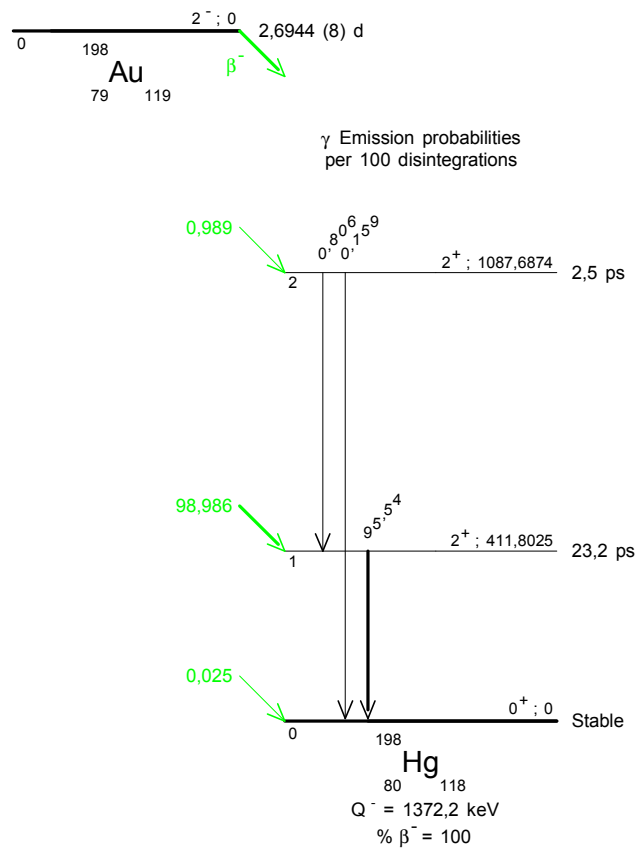
7 References

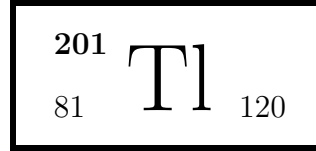
- E.McMILLAN, M.KAMEN, S.RUBEN. Phys. Rev. 52 (1937) 531
(Half-life)
- C.DIEMER, H.GROENDIJK. Physica 11 (1946) 396
(Half-life)
- L.M.SILVER. Phys. Rev. 76 (1949) 589
(Half-life)
- D.SAXON, R.HELLER. Phys. Rev. 75 (1949) 909
(Half-life)
- L.M.SILVER. Can. J. Phys. 29 (1950) 59
(Half-life)
- M.HUBERT. Comp. Rend. Acad. Sci. (Paris) 232 (1951) 2201
(Gamma-ray emission probabilities)
- A.BROSI, B.KETELLE, H.ZELDES, E.FAIRSTEIN. Phys. Rev. 84 (1951) 586
(Gamma-ray emission probabilities)
- W.K.SINCLAIR, A.F.HOLLOWAY. Nature 167 (1951) 365
(Half-life)
- P.E.CAVANAGH, J.F.TURNER, D.V.BOOKER, H.J.DUNSTER. Proc. Phys. Soc. London 64A (1951) 13
(Half-life, Gamma-ray emission probabilities)
- D.SCHIFF, F.R.METZGER. Phys. Rev. 90 (1953) 849
(Multipolarities 676 keV)
- E.E.LOCKETT, R.H.THOMAS. Nucleonics 11 (1953) 14
(Half-life)
- C.D.SCHRADER, E.B.NELSON, J.A.JACOBS. Phys. Rev. 90 (1953) 159
(Multipolarities 676 keV)
- R.E.BELL, L.YAFFE. Can. J. Phys. 32 (1954) 416
(Half-life)
- L.G.ELLIOTT, M.A.PRESTON, J.L.WOLFSON. Can. J. Phys. 32 (1954) 153
(Beta emission probabilities, Conv. Elec. emission probabilities)
- D.MAEDER, R.MUELLER, V.WINTERSTEIGER. Helv. Phys. Acta 27 (1954) 3
(Gamma-ray emission probabilities)
- J.TOBAILEM. J. Phys. Rad. 16 (1955) 48
(Half-life)
- B.S.DZHELEPOV, N.N.ZHUKOVSKI, V.P.PRIKHODTSEVA, I.U.V.KHOLNOV. Bull. Acad. Sci. USSR 19 (1955) 247
(Gamma-ray emission probabilities)

- C.SASTRE, G.PRICE. Nucl. Sci. Eng. 1 (1956) 325
(Half-life)
- K.-E.JOHANSSON. Arkiv Fysik 10 (1956) 247
(Half-life)
- F.T.PORTER, M.S.FRIEDMAN, T.B.NOVEY, F.WAGNER JR.. Phys. Rev. 103 (1956) 921
(Beta emission probabilities)
- J.VOLPE, G.HINMANN. Phys. Rev. 104 (1956) 753
(Multipolarities 676 keV)
- J.P.KEENE, L.A.MACKENZIE, C.W.GILBERT. Phys. Med. Biol. 2 (1958) 360
(Half-life)
- V.M.KELMAN, R.YA.METSKHVARISHVILI. Soviet. Phys. JETP 36 (1959) 486
(Conv. Coeff. Ratios K/L/M)
- J.ROBERT. J. Phys. Rad. 21 (1960) 808
(Half-life)
- P.DEPOMMIER, M.CHABRE. Comp. Rend. Acad. Sci. (Paris) 252 (1961) 1587
(Beta emission probabilities)
- P.DEPOMMIER, M.CHABRE. J. Phys. Rad. 22 (1961) 674
(Beta emission probabilities)
- R.L.GRAHAM. Privat. Comm. quoted by Depommier and Chabre (1961)
(Beta emission probabilities)
- R.P.SHARMA, S.H.DEVARE, B.SARAF. Phys. Rev. 125 (1962) 2071
(Beta emission probability)
- J.H.HAMILTON ET AL.. Nucl. Phys. 36 (1962) 567
(Beta emission probability)
- T.J.KUREY JR., P.R.ROY. Nucl. Phys. 44 (1963) 670
(Conv. Coeff. Ratios K/LM)
- V.STARODUBTSEV ET AL.. Izv. Akad. Nauk. USSR, Ser. Fiz.- Mat. Nauk. 2 (1963) 44
(Half-life)
- W.H.G.LEWIN, B.VANNOOYEN, C.W.E.VANELJK, A.H.WAPSTRA. Nucl. Phys. 48 (1963) 159
(Beta emission probabilities)
- J.LEHMANN. J. Phys. 25 (1964) 326
(Beta emission probabilities)
- C.J.HERRLANDER, R.L.GRAHAM. Nucl. Phys. 58 (1964) 544
(Conv. Coeff. Ratios K/L)
- M.SAKAI, M.NOZAWA, H.I.KEGAMI, T.YAMAZAKI. Nucl. Phys. 53 (1964) 529
(Multipolarities)
- V.STARODUBTSEV ET AL.. Nucl. Sci. Abstr. 18 (1964) 9348
(Half-life)
- H.BEEKHUIS, H.DEWAARD. Nucl. Phys. 74 (1965) 459-46
(Beta emission probabilities)
- K.E.BERGKVIST. Arkiv Fysik 27 (1965) 351
(Conv. Elec. emission probabilities)
- H.PAUL. Nucl. Phys. 72 (1965) 326
(Beta emission probabilities)
- W.J.KEELER, R.D.CONNOR. Nucl. Phys. 61 (1965) 513
(Conv. Elec. emission probabilities, Beta emission probabilities)
- S.C.ANSPACH, L.M.CAVALLO, S.B.GARFINKEL, J.M.R.HUTCHINSON. NBS Misc.Publ. 260-9 (1965) NP-15663
(Half-life)
- W.H.G.LEWIN. thesis, Delft (1965)
(Beta emission probabilities)
- D.PARSIGNAULT. Internal Conversion Processes, J. H. Hamilton, ed. Acad. Press, New York (1966) 173
(Conv. Coeff. Ratios K/L and K/LMN)
- S.A.REYNOLDS, J.F.EMERY, E.I.WYATT. Nucl. Sci. Eng. 32 (1966) 46
(Half-life)
- M.UHL, H.WARHANEK. Oesterr. Akad. Wiss. Sitzber. Math-Nat.Kl., Abt.II 175 (1966) 77
(Multipolarities 676 keV)
- J.KOCH, F.MÜNNICH, U.SCHÖTZIG. Nucl. Phys. A103 (1967) 300
(Multipolarities 676 keV)
- H.E.BOSCH, E.SZICHMAN. Bull. Am. Phys. Soc. 12 (1967) 598
(Conv. Elec. emission probabilities)

- J.A.BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- F.LAGOUTINE, Y.LEGALLIC, J.LEGRAND. Int. J. Appl. Radiat. Isotop. 19 (1968) 475
(Half-life)
- I.W.GOODIER. Int. J. Appl. Radiat. Isotop. 19 (1968) 823
(Half-life)
- S.A.REYNOLDS, J.F.EMERY, E.I.WYATT. Nucl. Sci. Eng. 32 (1968) 46
(Half-life)
- M.BOGDANOVICH, M.MLADJENOVICH, R.STEPICH. Nucl. Phys. A106 (1968) 209
(Conv. Coeff. Ratios K/L)
- R.BERAUD, I.BERKES, J.DANIERE, R.HAROUTUNIAN, M.LEVY, G.MAREST, R.ROUGNY. Phys. Rev. 188 (1969) 1958
(Multipolarities 676 keV)
- A.VUORINEN, E.KALOINEN. Ann. Acad. Sci. Fennicae Ser. Avi 310 (1969)
(Half-life)
- M.J.CABELL, M.WILKINS. J.Inorg.Nucl.Chem. 32 (1970) 1409
(Half-life)
- M.M.COSTAPAIVA, E.MARTINHO. Int. J. Appl. Radiat. Isotop. 21 (1970) 40
(Half-life)
- A.PAKKANEN. Nucl. Phys. A172 (1971) 193
(Multipolarities 676 keV)
- K.DEBERTIN. Atomkernenergie 17 (1971) 97
(Half-life)
- O.DRAGON, B.MARTIN, D.MERKERT, M.VINDUSKA. Nucl. Phys. A183 (1972) 390
(Conv. Elec. emission probabilities)
- K.VENKATA RAMANA RAO, V.LAKSHMINARAYANA. Nuovo Cimento 8A (1972) 298
(Multipolarities 676 keV)
- T.NAGARAJAN, M.RAVINDRANATH, K.VENKATAREDDY. J. Phys. A (Gen.Phys.) 5 (1972) 1395
(Conv. Elec. emission probabilities, Beta emission probabilities)
- M.S.EL-NESR, M.G.MOUSA. Atomkernenergie 21 (1973) 207
(Conv. Elec. emission energies)
- P.NYIKOS, H.B.BIER, P.HUBERIT, H.R.KOBEL, H.LEUENBERGER. Helv. Phys. Acta 46 (1973) 444
(Half-life)
- M.KAWAMURA, T.TOMIYAMA. J. Phys. Soc. Japan 36 (1974) 27
(Multipolarities 676 keV)
- C.N.RAO, B.M.RAO, P.M.RAO, K.V.REDDY. Phys. Rev. 11C (1975) 1735
(Conv. Elec. emission probabilities)
- J.L.CAMPBELL, L.A.McNELLES. Nucl. Instrum. Methods 125 (1975) 205
(X/ γ - ratio)
- T.S.REDDY. thesis Andhra Univ., Waltair, India (1976)
(Conv. Elec. emission probabilities)
- J.S.MERRITT, F.H.GIBSON. Report AECL-5802 (1977) p.43
(Half-life)
- F.RÖSEL, H.M.FRIES, K.ALDER, H.C.PAULI. At. Data. Nucl. Data Tables 21 (1978)
(Conv. Elec. emission probabilities)
- Y.IWATA, Y.YOSHIZAWA. Nucl. Instrum. Methods 175 (1980) 525
(Gamma-ray emission probabilities)
- R.G.DESLATTES, E.G.KESSLER, W.C.SAUDER, A.HENINS. Ann. Phys. 129 (1980) 378
(Gamma ray energies)
- A.R.RUTLEDGE, L.V.SMITH, J.S.MERRITT. report AECL-6692 (1980)
(Half-life)
- D.D.HOPPE, J.M.R.HUTCHINSON, F.J.SCHIMA, M.P.UNTERWEGER. Report NBS-SP 626 (1982) 85
(Half-life)
- H.HANSEN. European Applied Research Reports 6 (1985) 777
(Conv. Elec. emission probabilities)
- R.B.BEGZHANOV, D.A.GLADYSHEV, L.D.MAGRUPOV, SCH.A.MIRACHMEDOV, M.NARSIKULOV, P.A.ABDULCHATOV, S.CH.SALIMOV. 37th All-Union conference on Nuclear Spectroscopy and Nuclear Structure, Yirmala, USSR (1987) p.260
(L X-rays)

- B.CHAND, J.GOSWAMY, D.MEHTA, N.SINGH, P.N.TREHAN. Nucl. Instrum. Methods A284 (1989) 393
(Gamma-ray emission probabilities, X-ray emission probabilities)
- A.ABZOUZI, M.S.ANTONY, A.HACHEM, V.B.NDOCKONDONGUE. J. Radioanal. Nucl. Chem.Lett. 144 (1990) 359
(Half-life)
- M.P.UNTERWEGER, D.D.HOPPES, F.J.SCHIMA. Nucl. Instrum. Methods A312 (1992) 349-35
(Half-life)
- E.P.MIGNONSIN. Appl. Radiat. Isotopes 45 (1994) 17
(Half-life)
- ZHOU CHUNMEI. Nuclear Data Sheets 74 (1995) 259
(Production modes)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(fluorescence yield; KB/KA ratio, Auger electron)
- R.G.HELMER, C.VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma energies)





1 Decay Scheme

Tl-201 decays by electron capture to the Hg-201.

Le thallium 201 se désintègre par capture électronique vers le mercure 201.

2 Nuclear Data

$$T_{1/2}({}^{201}\text{Tl}) : 3,0421 \quad (17) \quad \text{d}$$

$$Q^+({}^{201}\text{Tl}) : 483 \quad (15) \quad \text{keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	P_K	P_L	P_M
$\epsilon_{0,4}$	316 (15)	40,9 (9)	1st Forbidden	6,1	0,724 (7)	0,206 (7)	0,054 (2)
$\epsilon_{0,3}$	451 (15)	13,0 (5)	1st Forbidden	6,9	0,758 (3)	0,181 (3)	0,0461 (12)
$\epsilon_{0,2}$	457 (15)	0,23	Unique 1st Forbidden	8,5			
$\epsilon_{0,1}$	482 (15)	25 (22)	1st Forbidden	6,5	0,763 (3)	0,178 (3)	0,0451 (12)
$\epsilon_{0,0}$	483 (15)	21 (21)	1st Forbidden	6,5	0,763 (3)	0,178 (3)	0,0451 (12)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(\text{Hg})$	1,565 (6)	38 (22)	M1+E2				4,7 (7) 10 ⁴
$\gamma_{3,2}(\text{Hg})$	5,869 (26)	0,52 (14)	[M1+E2]				
$\gamma_{2,0}(\text{Hg})$	26,269 (7)	0,64 (7)	M1(+E2)		58,8 (18)	13,74 (41)	76,9 (23)
$\gamma_{3,1}(\text{Hg})$	30,573 (17)	12,77 (25)	M1+E2		36,9 (4)	8,79 (26)	48,5 (2)
$\gamma_{3,0}(\text{Hg})$	32,138 (16)	11,28 (22)	M1+E2		32,0 (4)	7,62 (23)	41,9 (2)
$\gamma_{4,3}(\text{Hg})$	135,312 (34)	11,59 (28)	M1+E2	2,83 (3)	0,48 (5)	0,1138 (34)	3,45 (10)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{4,2}$ (Hg)	141,18 (4)	< 0,02	[E2]	0,372 (11)	0,774 (23)	0,202 (6)	1,41 (4)
$\gamma_{4,1}$ (Hg)	165,885 (31)	0,420 (13)	M1(+E2)	1,57 (3)	0,270 (5)	0,0634 (19)	1,86 (8)
$\gamma_{4,0}$ (Hg)	167,45 (3)	28,9 (9)	M1+E2	1,55 (3)	0,262 (5)	0,0620 (19)	1,89 (8)

3 Atomic Data

3.1 Hg

ω_K	:	0,962	(4)
$\bar{\omega}_L$	:	0,355	(14)
n_{KL}	:	0,813	(4)

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	K α_2	68,895	
	K α_1	70,82	
	K β_3	79,823	}
	K β_1	80,254	}
	K β_5''	80,762	}
			33,94
	K β_2	82,435	}
	K β_4	82,776	}
	KO _{2,3}	83,028	}
			10
X _L	L ℓ	8,72	
	L α	9,898 – 9,989	
	L η	10,651	
	L β	11,563 – 12,56	
	L γ	13,41 – 14,85	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	53,178 – 58,277	100
KLX	64,594 – 68,430	55,2
KXY	75,98 – 83,09	7,62
Auger L	5,1 – 14,8	34

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Hg)	5,1 - 14,8	57,7 (7)
e _{AK}	(Hg)		3,7 (4)
	KLL	53,178 - 58,277	}
	KLX	64,594 - 68,430	}
	KXY	75,98 - 83,09	}
ec _{2,0} L	(Hg)	11,429 - 13,985	0,48 (5)
ec _{3,1} L	(Hg)	15,734 - 18,289	9,70 (34)
ec _{3,0} L	(Hg)	17,299 - 19,854	8,57 (31)
ec _{2,0} M	(Hg)	22,707 - 23,974	0,113 (13)
ec _{3,1} M	(Hg)	27,011 - 28,278	2,27 (8)
ec _{3,0} M	(Hg)	28,576 - 29,843	2,00 (7)
ec _{3,1} N	(Hg)	29,770 - 30,473	0,583 (21)
ec _{3,0} N	(Hg)	31,334 - 32,038	0,515 (19)
ec _{4,3} K	(Hg)	52,210 (34)	7,45 (24)
ec _{4,1} K	(Hg)	82,783 (31)	0,237 (8)
ec _{4,0} K	(Hg)	84,348 (30)	15,6 (5)
ec _{4,3} L	(Hg)	120,473 - 123,028	1,268 (41)
ec _{4,3} M	(Hg)	131,750 - 133,017	0,296 (9)
ec _{4,3} N	(Hg)	134,509 - 135,212	0,0760 (24)
ec _{4,0} L	(Hg)	152,611 - 155,166	2,65 (8)
ec _{4,0} M	(Hg)	163,888 - 165,155	0,62 (2)
ec _{4,0} N	(Hg)	166,647 - 167,350	0,159 (5)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Hg)	8,72 — 14,85	42,7 (18)	
XK α_2	(Hg)	68,895	27,3 (5)	} K α
XK α_1	(Hg)	70,82	46,4 (7)	
XK β_3	(Hg)	79,823	}	K' β_1
XK β_1	(Hg)	80,254	}	
XK β_5''	(Hg)	80,762	}	
XK β_2	(Hg)	82,435	}	K' β_2
XK β_4	(Hg)	82,776	}	
XKO _{2,3}	(Hg)	83,028	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Hg)	1,565 (6)	0,00081 (47)
$\gamma_{3,2}$ (Hg)	5,869 (26)	0,5
$\gamma_{2,0}$ (Hg)	26,269 (7)	0,0082 (9)
$\gamma_{3,1}$ (Hg)	30,573 (17)	0,258 (5)
$\gamma_{3,0}$ (Hg)	32,138 (16)	0,263 (5)
$\gamma_{4,3}$ (Hg)	135,312 (34)	2,604 (22)
$\gamma_{4,2}$ (Hg)	141,18 (4)	< 0,008
$\gamma_{4,1}$ (Hg)	165,885 (31)	0,147 (2)
$\gamma_{4,0}$ (Hg)	167,45 (3)	10,0 (1)

6 Main Production Modes

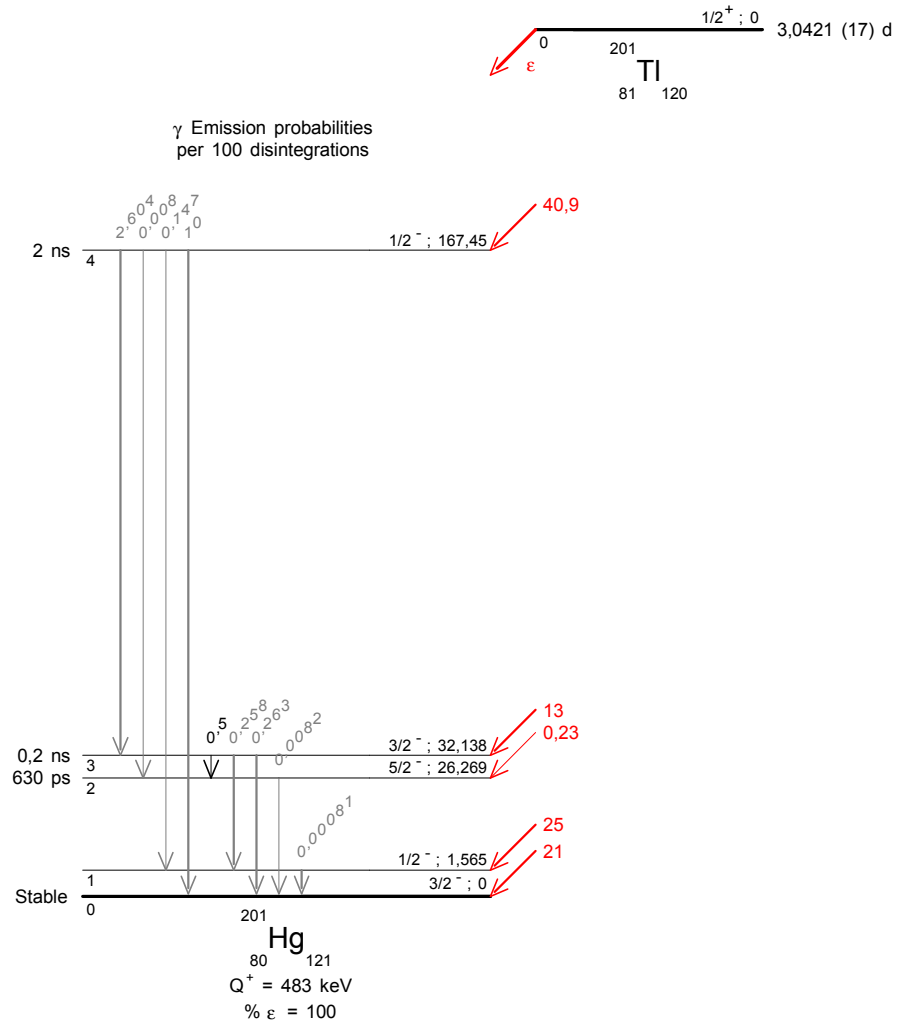
{ Tl – 203(p,3n)Pb – 201
Possible impurities : Pb – 200, Pb – 202m, Pb – 203, Pb – 204m, Tl – 200

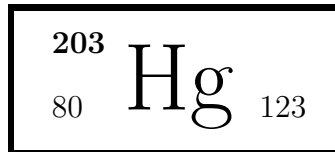
{ Tl – 205(p,5n)Pb – 201
Possible impurities : Pb – 200, Pb – 202m, Pb – 204m, Tl – 200, Tl – 202

{ Tl – 203(d,4n)Pb – 201
Possible impurities : Pb – 200, Pb – 202m, Pb – 203, Pb – 204m, Tl – 200, Tl – 202

7 References

- H.M.NEUMANN, I.PERLMAN. Phys. Rev. 78 (1950) 191
(Half-life)
- R.K.GUPTA. Arkiv Fysik 17 (1960) 337
(Relative emission probabilities of KLL Auger lines)
- C.J.HERRLANDER, R.STOCKENDAL, R.K.GUPTA. Arkiv Fysik 17 (1960) 315
(Gamma ray energies, Conv. Elec. emission probabilities)
- D.REYES-SUTER, T.SUTER. Arkiv Fysik 20 (1961) 415
(Half-life 32 keV level in HG201)
- D.J.HOREN, J.ARVIENX, M.BUENERD, J.COLE, G.PERRIN, P.DE SAINTIGUON. Phys. Rev. C11 (1975) 1247
(Multipolarities)
- S.HOFMANN, D.WALCHER. Z. Physik A272 (1975) 351
(Multipolarities, Spin and Parity)
- H.W.NASS. J. Nucl. Med. 18 (1977) 1047
(Gamma-ray emission probabilities)
- E.F.NOVAK, A.P.ARYA, R.L.MARTZ. Phys. Rev. C18 (1978) 1045
(Multipolarities)
- K.DEBERTIN, W.PESSARA, U.SCHÖTZIG, K.F.WALZ. Int. J. Appl. Radiat. Isotop. 30 (1979) 551
(Half-life)
- F.LAGOUTINE, J.LEGRAND. Int. J. Appl. Radiat. Isotop. 33 (1982) 711
(Half-life)
- P.SCHULER, K.HARDT, C.GUNTHER, K.FREITAG, P.HERZOG, N.NIEDERWESTBERY, H.REIF, E.B.SHERA, M.V.HOEHN. Z. Physik A313 (1983) 305
(Gamma ray energies, Gamma-ray emission probabilities, Multipolarities)
- N.DRAGON, V.BRABEC, M.RYSAVY, A.SPALEK, K.FREITAG. Z. Physik A326 (1987) 279
(Conv. Elec. emission probabilities)
- E.FUNCK. Appl. Rad. Isotopes 38 (1987) 771
(Gamma-ray emission probabilities)
- H.SCHRADER. Appl. Rad. Isotopes 40 (1989) 381
(Half-life)
- J.PLCH, P.KOVAR, P.DRYAK. Appl. Rad. Isotopes 40,513 (1989)
(Gamma-ray emission probabilities)
- YU.S.KALASHNIKOVA, I.M.NARODETSCHIN, V.P.YUROV. Nucl. Phys. A508 (1990) 239c
(Gamma-ray emission probabilities)
- B.M.COURSEY, D.D.HOPPE, A.T.HIRSCHFELD, S.M.JUDGE, D.H.WOODS, M.J.WOODS, E.FUNCK, H.SCHRADER, A.G.TUCK. Appl. Rad. Isotopes 41 (1990) 289
(Gamma-ray emission probabilities)
- Y.KAWADA, Y.HINO, W.GATOT. Nucl. Instrum. Methods Phys. Res. A286 (1990) 539
(Gamma-ray emission probabilities)
- M.P.UNTERWEGER, D.D.HOPPE, F.J.SCHIMA. Nucl. Instrum. Methods Phys. Res. A312 (1992) 349
(Gamma-ray emission probabilities)
- S.RAB. Nucl. Data Sheets 71 (1994) 421
(Level Half-lives, Spin and Parity, Conv. Elec. emission probabilities, Multipolarities)
- B.R.S.SIMPSON, B.R.MEYER. Appl. Rad. Isotopes 45 (1994) 669
(Half-life)
- K.DE SOUZA, *et al.*. Appl. Rad. Isotopes 60, 2-3 (2004) 317
(Half-life)
- H.SCHRADER. Appl. Rad. Isotopes 60, 2-3 (2004) 317
(Half-life)





1 Decay Scheme

The simple and consistent decay scheme is dominated by beta decay to the first excited state of Tl-203, followed by a single gamma transition to the ground state.

Le mercure 203 se désintègre par émission bêta moins vers le niveau excité de 279 keV du thallium 203.

2 Nuclear Data

$$T_{1/2}({}^{203}\text{Hg}) : 46,594 \quad (12) \quad \text{d}$$

$$Q^{-}({}^{203}\text{Hg}) : 491,8 \quad (12) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,1}^{-}$	212,6 (12)	99,99 (1)	Allowed	6,455
$\beta_{0,0}^{-}$	491,8 (12)	0,01 (1)	1st Forbidden Unique	11,6

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(\text{Tl})$	279,1969 (12)	99,99 (1)	M1+75%E2	0,1640 (10)	0,0476 (2)	0,0155 (2)	0,2271 (12)

3 Atomic Data

3.1 Tl

ω_K	:	0,963	(4)
$\bar{\omega}_L$	:	0,367	(15)
n_{KL}	:	0,812	(5)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	70,8325	59,24	
	K α_1	72,8725	100	
	K β_3	82,118	}	
	K β_1	82,577	}	
	K β_5''	83,115	}	34
	K β_2	84,838	}	
	K β_4	85,134	}	10,1
	KO _{2,3}	85,444	}	
	X _L	L ℓ	8,953	
		L α	10,172 – 10,268	
L η		10,994		
L β		11,812 – 12,643		
L γ		14,291 – 14,738		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	54,587 – 59,954	100
KLX	66,37 – 72,86	56
KXY	78,12 – 85,50	7,7
Auger L	5,18 – 10,13	3370

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Tl)	5,18 - 10,13	10,1 (1)
e _{AK}	(Tl)		0,49 (6)
	KLL	54,587 - 59,954	}
	KLX	66,37 - 72,86	}
	KXY	78,12 - 85,50	}
ec _{1,0 T}	(Tl)	193,66 - 279,18	18,5 (1)
ec _{1,0 K}	(Tl)	193,66 (1)	13,37 (6)
ec _{1,0 L}	(Tl)	263,85 - 266,54	3,88 (2)
ec _{1,0 M}	(Tl)	275,49 - 279,18	1,26 (1)
$\beta_{0,1}^-$	max:	212,6 (12)	99,99 (1)
$\beta_{0,1}^-$	avg:	57,8 (4)	
$\beta_{0,0}^-$	max:	491,8 (12)	0,01 (1)
$\beta_{0,0}^-$	avg:	154,4 (4)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Tl)	8,953 — 14,738	5,43 (9)
XK α_2	(Tl)	70,8325	3,75 (4) } K α
XK α_1	(Tl)	72,8725	6,33 (6) }
XK β_3	(Tl)	82,118	}
XK β_1	(Tl)	82,577	} 2,15 (4) K' β_1
XK β_5''	(Tl)	83,115	}
XK β_2	(Tl)	84,838	}
XK β_4	(Tl)	85,134	} 0,639 (16) K' β_2
XK $O_{2,3}$	(Tl)	85,444	}

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(Tl)$	279,1952 (10)	81,48 (8)

6 Main Production Modes

Au – 203(β^-)Hg – 203

Tl – 204(γ,p)Hg – 203

Hg – 202(n, γ)Hg – 203

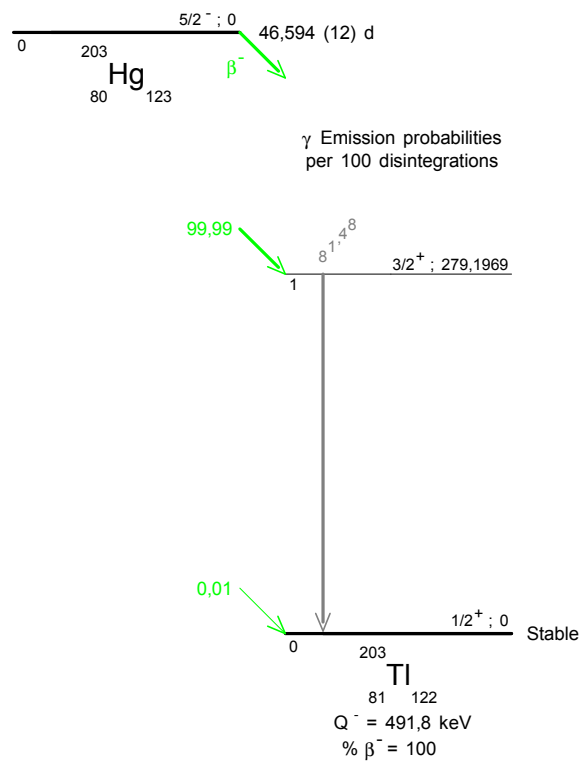
Hg – 202(d,p)Hg – 203

Hg – 204(d,t)Hg – 203

7 References

- N. MARTY. Comp. Rend. Acad. Sci. (Paris) 240B (1955) 291-294
(Beta-particle emission probabilities)
- A. H. WAPSTRA, G. J. NIJGH. Nucl. Phys. 1 (1956) 245-258
(Internal conversion coefficients)
- J. L. WOLFSON. Can. J. Phys. 34 (1956) 256-264
(Beta-particle emission probabilities, transition type)
- G. J. NIJGH, A. H. WAPSTRA, L. TH. M. ORNSTEIN, N. SALOMONS-GROBBEN, J. R. HUIZENGA, O. ALMEN. Nucl. Phys. 9 (1958) 528-537
(Internal conversion coefficients)
- R. W. PEELLE. ORNL Report ORNL-3016 (1960) 116-125
(Internal conversion coefficients)
- Z. SUJKOWSKI. Ark. Fysik 20, No. 16 (1961) 243-267
(Internal conversion coefficients)
- J. G. V. TAYLOR. Can. J. Phys. 40 (1962) 383-392
(Internal conversion coefficients)
- R. BURMEISTER, H. GRABER, J. SCHINTLMESTER, R. WEIBRECHT. Nucl. Phys. 42 (1963) 56-61
(Internal conversion coefficients)
- W. L. CROFT, B. G. PETERSSON, J. H. HAMILTON. Nucl. Phys. 48 (1963) 267-272
(Internal conversion coefficients)
- C. J. HERRLANDER, R. L. GRAHAM. Nucl. Phys. 58 (1964) 544-560
(Internal conversion coefficients)
- F. LAGOUTINE, Y. LE GALLIC, J. LEGRAND. Int. J. Appl. Radiat. Isot. 19 (1968) 475-482
(Half-life)
- J. F. EMERY, S. A. REYNOLDS, E. I. WYATT, G. I. GLEASON. Nucl. Sci. Eng. 48 (1972) 319-323
(Half-life)
- K. F. WALZ, H. M. WEISS, E. FUNCK. PTB Jahresbericht (1972) 150-151
(Internal conversion coefficients)
- H. S. SAHOTA. Indian J. Phys. 46 (1972) 86-92
(Internal conversion coefficients)
- H. H. HANSEN, D. MOUCHEL. Z. Phys. 267 (1974) 371-377
(Internal conversion coefficients)
- F. RÖSEL, H. M. FRIES, K. ALDER, H. C. PAULI. At. Data. Nucl. Data Tables 21 (1978) 291-514
(Internal conversion coefficients)

- H. HOUTERMANS, O. MILOSEVIC, F. REICHEL. *Int. J. Appl. Radiat. Isotop.* 31 (1980) 153
(Half-life)
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRITT. AECL Report AECL-6692 (1980)
(Half-life)
- K. F. WALZ, K. DEBERTIN, H. SCHRADER. *Int. J. Appl. Radiat. Isotop.* 34 (1983) 1191
(Half-life)
- M. R. SCHMORAK. *Nucl. Data Sheets* 46 (1985) 287
(Nuclear structure, energies)
- H. H. HANSEN. *European Appl. Res. Rept. - Nucl. Sci. Technol.* 6, No. 4 (1985) 777-816
(Internal conversion coefficients)
- M. P. UNTERWEGER, D. D. HOPPES, F. J. SCHIMA. *Nucl. Instrum. Methods* A312 (1992) 349-352
(Half-life)
- S. RAB. *Nucl. Data Sheets* 70 (1993) 173
(Nuclear structure, energies)
- G. AUDI, A. H. WAPSTRA. *Nucl. Phys.* A595 (1995) 409
(Q value)
- E. SCHÖNFELD, H. JANSSEN. *Nucl. Instrum. Methods* A369 (1996) 527-533
(K X-ray, L X-ray, Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. PTB Report PTB-6.11-98-1 (1998)
(Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. PTB Report PTB-6.11-1999-1 (1999)
(K X-ray)
- R. G. HELMER, C. VAN DER LEUN. *Nucl. Instrum. Methods* A450 (2000) 35-70
(Gamma-ray energies)
- E. SCHÖNFELD, H. JANSSEN, R. KLEIN. *Appl. Rad. Isotopes* 52 (2000) 955-956
(Internal conversion coefficients)
- M.J. WOODS. IAEA TECDOC (2004)
(Half-life evaluation)





1 Decay Scheme

Le Tl-204 se désintègre par capture électronique (2,92 %) vers le niveau fondamental de Hg-204 et par émission bêta moins (97,08 %) vers le niveau fondamental de Pb-204.

Tl-204 disintegrates 97.08 (13)% by beta minus emission and 2.92 (13)% by electron capture transition to the ground states of Pb-204 and Hg-204, respectively.

2 Nuclear Data

$T_{1/2}(^{204}\text{Tl})$	:	3,788	(15)	a
$Q^-(^{204}\text{Tl})$	:	763,72	(18)	keV
$Q^+(^{204}\text{Tl})$	:	345,0	(13)	keV

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,0}^-$	763,7 (2)	97,08 (13)	Unique 1st Forbidden	10,1

2.2 Electron Capture Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft	P_K	P_L	P_{M+}
$\epsilon_{0,0}$	347,5 (15)	2,92 (13)	Unique 1st Forbidden	9,6	0,5843 (14)	0,3024 (10)	0,1133 (5)

3 Atomic Data

3.1 Hg

ω_K	:	0,962	(4)
$\bar{\omega}_L$	:	0,355	(14)
$\bar{\omega}_M$	:	0,026	(3)
n_{KL}	:	0,815	(4)
\bar{n}_{LM}	:	1,34	(4)

3.1.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	68,895	58,99
$K\alpha_1$	70,82	100
$K\beta_3$	79,823	}
$K\beta_1$	80,254	}
$K\beta_5''$	80,762	}
		34,3
$K\beta_2$	82,435	}
$K\beta_4$	82,776	}
$KO_{2,3}$	83,028	}
		10,04
X_L		
$L\ell$	8,721	
$L\alpha$	9,898 – 9,989	
$L\eta$	10,647	
$L\beta$	11,924 – 11,822	
$L\gamma$	– 14,847	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	53,17 – 58,28	100
KLX	64,59 – 70,81	55,2
KXY	75,92 – 83,08	7,62
Auger L	5,1 – 14,8	

3.2 Pb

$$\begin{aligned}\omega_K &: 0,963 \quad (4) \\ \bar{\omega}_L &: 0,379 \quad (15) \\ n_{KL} &: 0,811 \quad (5)\end{aligned}$$

3.2.1 X Radiations

	Energy keV	Relative probability		
X_K	$K\alpha_2$	72,8049	59,5	
	$K\alpha_1$	74,97	100	
	$K\beta_3$	84,451	}	
	$K\beta_1$	84,937	}	
	$K\beta_5''$	85,47	}	34,2
	$K\beta_2$	87,238	}	
	$K\beta_4$	87,58	}	10,3
	$KO_{2,3}$	87,911	}	

4 Electron Emissions

	Energy keV	Electrons per 100 disint.
e_{AL}	(Hg) 5,1 - 14,8	1,48 (3)
e_{AK}	(Hg)	0,065 (8)
	KLL 53,17 - 58,28	}
	KLX 64,59 - 70,81	}
	KXY 75,92 - 83,08	}
$\beta_{0,0}^-$	max: 763,7 (2)	97,08 (13)
$\beta_{0,0}^-$	avg: 243,9 (1)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Hg)	8,721 — 14,847	0,787 (20)	
XK α_2	(Hg)	68,895	0,474 (20)	} K α
XK α_1	(Hg)	70,82	0,812 (34)	
XK β_3	(Hg)	79,823	}	K' β_1
XK β_1	(Hg)	80,254	}	
XK β_5''	(Hg)	80,762	}	
XK β_2	(Hg)	82,435	}	
XK β_4	(Hg)	82,776	}	
XKO _{2,3}	(Hg)	83,028	}	0,081 (3) K' β_2
XK α_2	(Pb)	72,8049	0,0044 (3)	} K α
XK α_1	(Pb)	74,97	0,0061 (3)	
XK β_3	(Pb)	84,451	}	K' β_1
XK β_1	(Pb)	84,937	}	
XK β_5''	(Pb)	85,47	}	
XK β_2	(Pb)	87,238	}	
XK β_4	(Pb)	87,58	}	
XKO _{2,3}	(Pb)	87,911	}	0,00073 (2) K' β_2

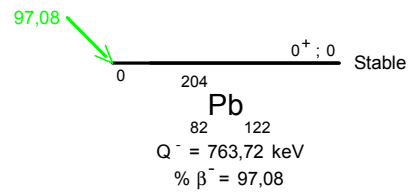
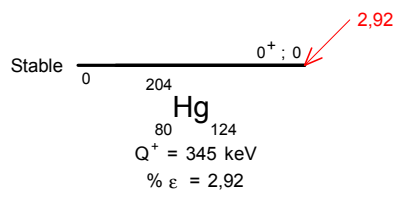
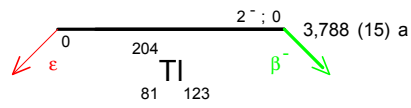
6 Main Production Modes

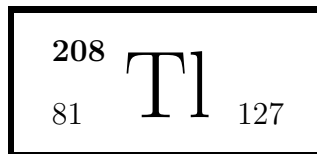
$$\left\{ \begin{array}{l} \text{Tl} - 203(n,\gamma)\text{Tl} - 204 \quad \sigma : 11,0 (5) \text{ barns} \\ \text{Possible impurities : None} \end{array} \right.$$

7 References

- M.H.BIAVATI, S.J.NASSIFF, C.S.WU. Phys. Rev. 125,4 (1961) 1364 (Q)
- B.R.JOSHI. Proc. Phys.Soc. 77 (1961) 1205 (PL/PK ratio)
- H.LEUTZ, K.ZIEGLER. Z. Phys. 166 (1962) 582 (Half-life)
- P.CHRISTMAS. Nucl. Phys. 55 (1964) 577 (Beta emission energies X-ray emission probabilities)
- S.C.ANSPACH, *et al.*. Report NBS 260-9 (1965) (Half-life)
- H.KLEIN, H. LEUTZ. Nucl. Phys. 79 (1966) 27 (Q)
- D.L.HORROCKS. Nucl. Phys. A110 (1968) 238 (Half-life)

- J.J.H.PARK, P.CHRISTMAS. Can. J. Phys. 45 (1968) 2621
(K Auger/B-)
- G.BORTELS. Int. J. Appl. Radiat. Isotop. 20 (1969) 613
(Half-life)
- K.C.JORDAN, J.H BIRDEN, B.C BLANKE. J. Inorg. Nucl. Chem. 31 (1969) 2641
(Half-life)
- G.HARBOTTLE. Radiochim. Acta 13 (1970) 132
(Half-life)
- H.LANCMAN, A.BOND. Phys. Rev. C 7, 6 (1973) 2600
(Q)
- A.ZIDE, H.LANCMAN. Phys. Rev. C19 (1979) 1053
(Q)
- U.SCHÖTZIG. Nucl. Instrum. Methods A286 (1990) 523
(X-ray emission intensities)
- M.R.SCHMORAK. Nucl. Data Sheets 72,3 (1994) 409
(Spin and Parity)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A 595 (1995) 409
(Q)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic Data)
- I.BERGSTRÖM, *et al.* Nucl. Instrum. Methods A487 (2002) 618
(Atomic mass)





1 Decay Scheme

Tl-208 decays by beta minus emission to the Pb-208 excited levels.

Le thallium 208 se désintègre par émission bêta moins vers les niveaux excités du plomb 208.

2 Nuclear Data

$$T_{1/2}({}^{208}\text{Tl}) : 3,060 \quad (8) \quad \text{min}$$

$$Q^{-}({}^{208}\text{Tl}) : 5001 \quad (2) \quad \text{keV}$$

2.1 β^{-} Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,18}^{-}$	521 (2)	0,053 (5)	1st Forbidden	6,67
$\beta_{0,17}^{-}$	618 (2)	0,017 (5)	1st Forbidden	7,4
$\beta_{0,16}^{-}$	643 (2)	0,045 (7)	1st Forbidden	7,05
$\beta_{0,15}^{-}$	678 (2)	0,005 (2)	1st Forbidden	8,1
$\beta_{0,14}^{-}$	690 (2)	0,076 (11)	1st Forbidden	6,93
$\beta_{0,13}^{-}$	705 (2)	0,048 (6)	1st Forbidden	7,16
$\beta_{0,12}^{-}$	718 (2)	0,030 (7)	1st Forbidden	7,4
$\beta_{0,11}^{-}$	739 (2)	0,002 (1)	1st Forbidden	8,6
$\beta_{0,10}^{-}$	821 (2)	0,231 (9)	1st Forbidden	6,71
$\beta_{0,9}^{-}$	876 (2)	0,18 (2)	1st Forbidden	6,91
$\beta_{0,8}^{-}$	1005 (3)	0,007 (3)	1st Forbidden	8,5
$\beta_{0,7}^{-}$	1040 (2)	3,26 (7)	1st Forbidden	5,92
$\beta_{0,6}^{-}$	1055 (2)	0,048 (3)	1st Forbidden	7,77
$\beta_{0,5}^{-}$	1081 (2)	0,64 (6)	1st Forbidden	6,69
$\beta_{0,4}^{-}$	1293 (2)	24,1 (3)	1st Forbidden	5,39
$\beta_{0,3}^{-}$	1526 (2)	22,2 (7)	1st Forbidden	5,69
$\beta_{0,2}^{-}$	1803 (2)	49,0 (9)	1st Forbidden	5,62

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{5,4}$ (Pb)	211,4 (2)	0,39 (2)	[M1+2%E2]	0,952 (29)	0,166 (5)	0,052 (2)	1,17 (4)
$\gamma_{4,3}$ (Pb)	233,3 (1)	0,59 (2)	[M1+2%E2]	0,724 (22)	0,125 (4)	0,039 (1)	0,888 (27)
$\gamma_{7,4}$ (Pb)	252,5 (2)	1,34 (4)	[M1+2%E2]	0,582 (17)	0,100 (3)	0,0310 (9)	0,713 (21)
$\gamma_{3,2}$ (Pb)	277,37 (3)	10,3 (5)	[M1]	0,457 (14)	0,078 (2)	0,0240 (7)	0,559 (17)
$\gamma_{7,3}$ (Pb)	485,8 (1)	0,055 (4)	[M1]	0,101 (3)	0,0170 (5)	0,0050 (2)	0,123 (4)
$\gamma_{4,2}$ (Pb)	510,7 (1)	25,0 (2)	[M1+0,27%E2]	0,089 (3)	0,0156 (5)	0,0040 (1)	0,108 (3)
$\gamma_{2,1}$ (Pb)	583,187 (2)	86,8 (1)	E2	0,0152 (5)	0,0042 (1)	0,00130 (4)	0,0207 (6)
$\gamma_{13,4}$ (Pb)	587,8 (2)	0,060 (21)	[M1]	0,0614 (18)	0,0102 (3)	0,0032 (1)	0,0748 (22)
$\gamma_{9,3}$ (Pb)	650,2 (2)	0,05 (2)	[M1]	0,0472 (14)	0,0078 (2)	0,00250 (8)	0,0575 (17)
$\gamma_{10,3}$ (Pb)	705,3 (2)	0,023 (4)	[M1]	0,0382 (11)	0,0063 (2)	0,00200 (6)	0,0465 (14)
$\gamma_{5,2}$ (Pb)	722,0 (1)	0,25 (4)	[M1+8,8%E2]	0,0337 (10)	0,0056 (2)	0,00180 (5)	0,0411 (10)
$\gamma_{6,2}$ (Pb)	748,7 (2)	0,0480 (31)	[M1]	0,0328 (10)	0,0054 (2)	0,00170 (5)	0,0399 (12)
$\gamma_{7,2}$ (Pb)	763,2 (1)	1,86 (3)	[M1+0,01%E2]	0,0312 (10)	0,0052 (2)	0,00150 (5)	0,0379 (11)
$\gamma_{12,3}$ (Pb)	808,3 (2)	0,030 (7)					
$\gamma_{13,3}$ (Pb)	821,1 (2)	0,042 (4)	[M1]	0,0258 (8)	0,0043 (1)	0,00130 (4)	0,0314 (9)
$\gamma_{14,3}$ (Pb)	835,9 (2)	0,076 (11)					
$\gamma_{3,1}$ (Pb)	860,56 (3)	12,8 (1)	[M1+33,5%E2]	0,0176 (5)	0,0030 (1)	0,00100 (3)	0,0216 (6)
$\gamma_{16,3}$ (Pb)	883,4 (2)	0,032 (3)	[M1]	0,0214 (7)	0,0035 (1)	0,00120 (4)	0,0261 (8)
$\gamma_{9,2}$ (Pb)	927,6 (2)	0,128 (1)	[M1]	0,0189 (6)	0,0031 (1)	0,00100 (3)	0,0230 (7)
$\gamma_{10,2}$ (Pb)	982,7 (2)	0,209 (8)	[M1]	0,0163 (5)	0,00270 (8)	0,00080 (2)	0,0198 (6)
$\gamma_{4,1}$ (Pb)	1093,9 (1)	0,43 (2)	E2	0,00455 (14)	0,00084 (3)	0,000270 (8)	0,00566 (17)
$\gamma_{15,2}$ (Pb)	1125,7 (4)	0,005 (2)					
$\gamma_{16,2}$ (Pb)	1160,8 (2)	0,011 (3)	[M1]	0,0107 (3)	0,00160 (5)	0,00060 (2)	0,0129 (4)
$\gamma_{17,2}$ (Pb)	1185,2 (3)	0,017 (5)	[M1]	0,0101 (3)	0,00160 (5)	0,00060 (2)	0,0123 (4)
$\gamma_{18,2}$ (Pb)	1282,8 (3)	0,053 (5)	[M1]	0,00830 (25)	0,00127 (4)	0,00049 (2)	0,01006 (30)
$\gamma_{8,1}$ (Pb)	1381,1 (5)	0,007 (3)	[E2]	0,00297 (9)	0,00051 (2)	0,000160 (5)	0,00364 (11)
$\gamma_{11,1}$ (Pb)	1647,5 (7)	0,002 (1)					
$\gamma_{16,1}$ (Pb)	1743,9 (2)	0,002 (1)	[M1]	0,00382 (11)	0,00057 (2)	0,000160 (5)	0,00455 (14)
$\gamma_{1,0}$ (Pb)	2614,511 (10)	100,00 (1)	E3	0,00173 (5)	0,000290 (9)	0,000080 (2)	0,00210 (6)

3 Atomic Data

3.1 Pb

ω_K	:	0,963	(4)
$\bar{\omega}_L$	:	0,379	(15)
n_{KL}	:	0,811	(5)

3.1.1 X Radiations

	Energy keV	Relative probability	
X _K	K α_2	72,8049	59,6
	K α_1	74,97	100
	K β_3	84,451	}
	K β_1	84,937	
	K β_5''	85,47	

	Energy keV	Relative probability	
	K β_2	87,238	
	K β_4	87,58	
	KO _{2,3}	87,911	
X _L	L ℓ	9,184	
	L α	10,45 – 10,551	
	L η	11,349	
	L β	12,142 – 13,015	
	L γ	14,765 – 15,216	
			10,3

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	56,03 – 61,67	100
KLX	68,18 – 74,97	56
KXY	80,3 – 88,0	7,8
Auger L	5,26 – 10,40	3020

4 Electron Emissions

	Energy keV	Electrons per 100 disint.
e _{AL}	(Pb) 5,26 - 10,40	5,23 (9)
e _{AK}	(Pb)	0,28 (4)
	KLL	56,03 - 61,67 } }
	KLX	68,18 - 74,97 } }
	KXY	80,3 - 88,0 } }
ec _{3,2} K	(Pb) 189,37 (3)	3,01 (9)
ec _{3,2} L	(Pb) 261,51 - 264,33	0,51 (2)
ec _{3,2} M	(Pb) 273,52 - 277,23	0,16 (1)
ec _{4,2} K	(Pb) 422,7 (1)	2,0 (1)
ec _{4,2} L	(Pb) 494,8 - 497,7	0,3
ec _{2,1} K	(Pb) 495,19 (3)	1,3 (1)
ec _{4,2} M	(Pb) 506,8 - 510,6	0,09
ec _{2,1} L	(Pb) 567,33 - 570,15	0,4
ec _{2,1} M	(Pb) 579,34 - 583,05	0,1

		Energy keV		Electrons per 100 disint.
$\beta_{0,18}^-$	max:	521	(2)	0,053 (5)
$\beta_{0,18}^-$	avg:	155,1	(7)	
$\beta_{0,17}^-$	max:	618	(2)	0,017 (5)
$\beta_{0,17}^-$	avg:	188,6	(7)	
$\beta_{0,16}^-$	max:	643	(2)	0,045 (7)
$\beta_{0,16}^-$	avg:	197,1	(7)	
$\beta_{0,15}^-$	max:	678	(2)	0,005 (2)
$\beta_{0,15}^-$	avg:	209,5	(7)	
$\beta_{0,14}^-$	max:	690	(2)	0,076 (11)
$\beta_{0,14}^-$	avg:	213,9	(7)	
$\beta_{0,13}^-$	max:	705	(2)	0,048 (6)
$\beta_{0,13}^-$	avg:	219,2	(7)	
$\beta_{0,12}^-$	max:	718	(2)	0,030 (7)
$\beta_{0,12}^-$	avg:	223,8	(7)	
$\beta_{0,11}^-$	max:	739	(2)	0,002 (1)
$\beta_{0,11}^-$	avg:	231,4	(8)	
$\beta_{0,10}^-$	max:	821	(2)	0,231 (9)
$\beta_{0,10}^-$	avg:	261,2	(7)	
$\beta_{0,9}^-$	max:	876	(2)	0,18 (2)
$\beta_{0,9}^-$	avg:	281,5	(7)	
$\beta_{0,8}^-$	max:	1005	(3)	0,007 (3)
$\beta_{0,8}^-$	avg:	330,4	(8)	
$\beta_{0,7}^-$	max:	1040	(2)	3,26 (7)
$\beta_{0,7}^-$	avg:	343,6	(8)	
$\beta_{0,6}^-$	max:	1055	(2)	0,048 (3)
$\beta_{0,6}^-$	avg:	349,2	(8)	
$\beta_{0,5}^-$	max:	1081	(2)	0,64 (6)
$\beta_{0,5}^-$	avg:	359,5	(8)	
$\beta_{0,4}^-$	max:	1293	(2)	24,1 (3)
$\beta_{0,4}^-$	avg:	442,3	(8)	
$\beta_{0,3}^-$	max:	1526	(2)	22,2 (7)
$\beta_{0,3}^-$	avg:	536,2	(8)	
$\beta_{0,2}^-$	max:	1803	(2)	49,0 (9)
$\beta_{0,2}^-$	avg:	650,3	(8)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Pb)	9,184 — 15,216	2,89 (6)	
XK α_2	(Pb)	72,8049	2,15 (6)	} K α
XK α_1	(Pb)	74,97	3,61 (9)	
XK β_3	(Pb)	84,451	}	K' β_1
XK β_1	(Pb)	84,937	}	
XK β_5''	(Pb)	85,47	}	
XK β_2	(Pb)	87,238	}	K' β_2
XK β_4	(Pb)	87,58	}	
XK $O_{2,3}$	(Pb)	87,911	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{5,4}$ (Pb)	211,4 (2)	0,18 (1)
$\gamma_{4,3}$ (Pb)	233,3 (1)	0,31 (1)
$\gamma_{7,4}$ (Pb)	252,5 (2)	0,78 (2)
$\gamma_{3,2}$ (Pb)	277,37 (3)	6,6 (3)
$\gamma_{7,3}$ (Pb)	485,8 (1)	0,049 (4)
$\gamma_{4,2}$ (Pb)	510,7 (1)	22,6 (2)
$\gamma_{2,1}$ (Pb)	583,187 (2)	85,0 (3)
$\gamma_{13,4}$ (Pb)	587,8 (2)	0,06 (2)
$\gamma_{9,3}$ (Pb)	650,2 (2)	0,05 (2)
$\gamma_{10,3}$ (Pb)	705,3 (2)	0,022 (4)
$\gamma_{5,2}$ (Pb)	722,0 (1)	0,24 (4)
$\gamma_{6,2}$ (Pb)	748,7 (2)	0,046 (3)
$\gamma_{7,2}$ (Pb)	763,2 (1)	1,79 (3)
$\gamma_{12,3}$ (Pb)	808,3 (2)	0,030 (7)
$\gamma_{13,3}$ (Pb)	821,1 (2)	0,041 (4)
$\gamma_{14,3}$ (Pb)	835,9 (2)	0,076 (11)
$\gamma_{3,1}$ (Pb)	860,56 (3)	12,5 (1)
$\gamma_{16,3}$ (Pb)	883,4 (2)	0,031 (3)
$\gamma_{9,2}$ (Pb)	927,6 (2)	0,125 (1)
$\gamma_{10,2}$ (Pb)	982,7 (2)	0,205 (8)
$\gamma_{4,1}$ (Pb)	1093,9 (1)	0,43 (2)
$\gamma_{15,2}$ (Pb)	1125,7 (4)	0,005 (2)
$\gamma_{16,2}$ (Pb)	1160,8 (2)	0,011 (3)
$\gamma_{17,2}$ (Pb)	1185,2 (3)	0,017 (5)
$\gamma_{18,2}$ (Pb)	1282,8 (3)	0,052 (5)

	Energy keV	Photons per 100 disint.
$\gamma_{8,1}(\text{Pb})$	1381,1 (5)	0,007 (3)
$\gamma_{11,1}(\text{Pb})$	1647,5 (7)	0,002 (1)
$\gamma_{16,1}(\text{Pb})$	1743,9 (2)	0,002 (1)
$\gamma_{1,0}(\text{Pb})$	2614,511 (10)	99,79 (1)

6 Main Production Modes

Bi – 212 α decay

7 References

- D.L. BAULCH, H.A. DAVID, J.F. DUNCAN. Australian J. Chem. 10 (1957) 85
(Half-life)
- G. SCHUPP, H. DANIEL, G.W. EAKINS, E.N. JENSEN. Phys. Rev. 120 (1960) 189
(Beta-ray emission probabilities, gamma-ray emission probabilities)
- G.T. EMERY, W.R. KANE. Phys. Rev. 118 (1960) 755
(Beta-ray emission probabilities, gamma-ray emission probabilities)
- L. SIMONS, M. BRENNER, L. KÄLD, K-E. NYSTEN, E. SPRING. Soc. Sci. Fennica Comm. Phys. Math. 26 (1961) part 6
(Gamma-ray emission probabilities)
- H. OSTERTAG, K.H. LAUTERJUNG. Z. Phys. 199 (1967) 25
(Beta-ray emission probabilities)
- N.O. LASSEN, N. HORNSTRUP. Mat. Fys. Medd. Dan. Vit Selsk 36 (1967) No. 4
(Half-life)
- J.S. LARSEN, B.C. JORGENSEN. Z. Phys. 227 (1969) 65
(Gamma-ray emission probabilities)
- S.M. BRAHMAVAR, J.H. HAMILTON. Nucl. Instrum. Methods 69 (1969) 353
(Gamma-ray energies)
- A. PAKKANEN, J. KANTELE, P. SUOMINEN. Z. Phys. 218 (1969) 273
(Gamma-ray emission probabilities)
- G. AUBIN, J. BARRETTE, G. LAMOUREUX, S. MONARO. Nucl. Instrum. Methods 76 (1969) 85
(Gamma-ray emission probabilities)
- V.H. MUNDSCHEK. Radiochim. Acta 14 (1970) 72
(Half-life)
- R. ACKERHALT, P. ELLERBE, G. HARBOTTLE. Radiochem. Radioanal. Letters 8 (1971) 75
(Half-life)
- J. DALMASSO. FRNC-TH-441 (1972)
(Gamma-ray emission probabilities)
- P. JAGAM, D.S. MURTY. Nucl. Phys. A197 (1972) 540
(Gamma-ray emission probabilities, multipolarity)
- J. DALMASSO, H. MARIA, C. YTHIER. Comp. Rend. Acad. Sci. (Paris) 277B (1973) 467
(Gamma-ray emission probabilities)
- M. KORTELÄHTI, A. PAKKANEN, J. KANTELE. Nucl. Phys. A240 (1975) 87
(Gamma-ray emission probabilities, multipolarity)
- W. KURCEWICZ, E. RUCHOWSKA, N. KAFFRELL, N. TRAUTMANN. Nucl. Instrum. Methods 146 (1977) 613
(Gamma-ray energies)
- R.J. GEHRKE, R.G. HELMER, R.C. GREENWOOD. Nucl. Instrum. Methods 147 (1977) 405
(Gamma-ray emission probabilities)

- F. RÖSEL, H.M. FRIES, K. ALDER, H.C. PAULI. *At. Data. Nucl. Data Tables* 21 (1978) 291
(Internal conversion coefficients)
- F.T. AVIGNONE, A.G. SCHMIDT. *Phys. Rev. C* 17 (1978) 380
(Gamma-ray emission probabilities)
- R.G. HELMER. *Nucl. Instrum. Methods* 164 (1979) 355
(Gamma-ray energies)
- S. SADASIVAN, V.M. RAGHUNATH. *Nucl. Instrum. Methods* 196 (1982) 561
(Gamma-ray emission probabilities)
- U. SCHÖTZIG, K. DEBERTIN. *Int. J. Appl. Radiat. Isot.* 34 (1983) 533
(Gamma-ray emission probabilities)
- R. VANINBROUKX, H.H. HANSEN. *Int. J. Appl. Radiat. Isot.* 34 (1983) 1395
(Gamma-ray emission probabilities)
- R.J. GEHRKE, V.J. NOVICK, J.D. BAKER. *Int. J. Appl. Radiat. Isot.* 35 (1984) 581
(Gamma-ray emission probabilities)
- M.J. MARTIN. *Nucl. Data Sheets* 47 (1986) 797
(Nuclear structure, energies)
- W-J. LIN, G. HARBOTTLE. *J. Radioanal. Nucl. Chem.* 157 (1992) 367
(Gamma-ray emission probabilities)
- O. EL SAMAD, J. DALMASSO, G. BARCI-FUNEL, G. ARDISSON. *Radiochim. Acta* 62 (1993) 65
(Gamma-ray emission probabilities)
- G. AUDI, A.H. WAPSTRA. *Nucl. Phys.* A595 (1995) 409
(Q value)
- E. SCHÖNFELD, H. JANSSSEN. *Nucl. Instrum. Methods* A369 (1996) 527
(K-x ray, L-x ray, Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 (1998)
(Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-1999-1 (1999)
(K-x ray)
- R.G. HELMER, C. VAN DER LEUN. *Nucl. Instrum. Methods* A450 (2000) 35
(Gamma energy)



1 Decay Scheme

Bi-212 undergoes β^- decay to Po-212 (64.07(7)%), and α decay to Tl-208 (35.93(7)%).

Le bismuth 212 se désintègre à 64,07(7)% par émission β^- vers le polonium 212 et à 35,93(7)% par émission α vers le thallium 208.

2 Nuclear Data

$T_{1/2}({}^{212}\text{Bi})$	:	60,54	(6)	min
$T_{1/2}({}^{212}\text{Po})$	:	300	(2)	10^{-9} s
$T_{1/2}({}^{208}\text{Tl})$	:	3,060	(8)	min
$Q^-({}^{212}\text{Bi})$	:	2254	(2)	keV
$Q^\alpha({}^{212}\text{Bi})$	:	6207,14	(4)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,7}$	5400 (1)	0,000039 (4)	20800
$\alpha_{0,6}$	5448 (1)	0,00036 (18)	3810
$\alpha_{0,5}$	5586,7 (3)	0,0050 (7)	1370
$\alpha_{0,4}$	5714,45 (14)	0,43 (4)	66,9
$\alpha_{0,3}$	5733,6 (2)	0,06 (1)	594
$\alpha_{0,2}$	5879,2 (1)	0,63 (3)	269
$\alpha_{0,1}$	6167,28 (4)	25,1 (1)	126
$\alpha_{0,0}$	6207,14 (4)	9,7 (1)	480
* $\alpha_{1,0}$	9681,46 (12)	0,0024 (2)	
* $\alpha_{4,0}$	10633,58 (13)	0,0010 (1)	
* $\alpha_{5,0}$	10755,0 (3)	0,0106 (8)	

* Transitions α of long range.

2.2 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg <i>ft</i>
$\beta_{0,6}^-$	448 (2)	0,68 (5)	1st Forbidden non-unique	6,69
$\beta_{0,5}^-$	453 (2)	0,029 (1)	1st Forbidden non-unique	8,08
$\beta_{0,4}^-$	575 (2)	0,21 (5)	1st Forbidden non-unique	7,56
$\beta_{0,3}^-$	633 (2)	1,90 (4)	1st Forbidden non-unique	6,74
$\beta_{0,2}^-$	741 (2)	1,45 (2)	1st Forbidden non-unique	7,1
$\beta_{0,1}^-$	1527 (2)	4,58 (21)	1st Forbidden non-unique	7,71
$\beta_{0,0}^-$	2254 (2)	55,23 (21)	1st Forbidden non-unique	7,269

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{1,0}$ (Tl)	39,858 (4)	26 (1)	[M1]		18,6 (5)	6,00 (18)	24,6 (7)
$\gamma_{5,3}$ (Po)	180,2 (2)	0,010 (3)	M1	1,79 (5)	0,32 (1)	0,100 (3)	2,21 (7)
$\gamma_{2,1}$ (Tl)	288,08 (6)	0,47 (3)	[M1+E2]	0,378 (11)	0,064 (2)	0,0190 (6)	0,461 (14)
$\gamma_{2,0}$ (Tl)	327,94 (6)	0,160 (4)	[M1]	0,267 (8)	0,0450 (13)	0,0130 (4)	0,325 (10)
$\gamma_{3,1}$ (Tl)	433,7 (2)	0,011 (2)	[M1]	0,126 (4)	0,0210 (6)	0,0060 (2)	0,153 (5)
$\gamma_{4,1}$ (Tl)	452,8 (1)	0,39 (3)	[M1]	0,112 (3)	0,0190 (6)	0,0060 (2)	0,137 (4)
$\gamma_{3,0}$ (Tl)	473,6 (2)	0,049 (3)	[M1]	0,100 (3)	0,0160 (5)	0,00500 (15)	0,121 (4)
$\gamma_{4,0}$ (Tl)	492,7 (1)	0,04 (1)	[M1]	0,090 (3)	0,0150 (5)	0,00400 (12)	0,109 (3)
$\gamma_{5,1}$ (Tl)	580,5 (3)	0,0010 (2)	[E2]	0,0148 (5)	0,0039 (1)	0,00130 (4)	0,0200 (6)
$\gamma_{5,0}$ (Tl)	620,4 (3)	0,0040 (6)	[M1]	0,0492 (15)	0,0081 (2)	0,00250 (8)	0,0598 (18)
$\gamma_{1,0}$ (Po)	727,33 (1)	6,84 (12)	E2	0,0106 (3)	0,00260 (8)	0,00090 (3)	0,0141 (4)
$\gamma_{6,0}$ (Tl)	759 (1)	0,00036 (18)					
$\gamma_{2,1}$ (Po)	785,37 (9)	1,16 (1)	[M1+E2]	0,0338 (10)	0,0057 (2)	0,00180 (5)	0,0413 (12)
$\gamma_{7,0}$ (Tl)	807 (1)	0,000039 (4)					
$\gamma_{3,1}$ (Po)	893,41 (2)	0,39 (1)	[M1+E2]	0,0243 (7)	0,0041 (1)	0,00130 (4)	0,0297 (9)
$\gamma_{4,1}$ (Po)	952,12 (2)	0,14 (4)	[M1+E2]	0,0164 (5)	0,00280 (8)	0,00100 (3)	0,0202 (6)
$\gamma_{5,1}$ (Po)	1073,6 (2)	0,015 (5)	E2	0,00516 (15)	0,00100 (3)	0,00033 (1)	0,00649 (20)
$\gamma_{6,1}$ (Po)	1078,63 (11)	0,56 (2)	[M1+E2]	0,0149 (4)	0,00230 (7)	0,00090 (3)	0,0181 (5)
$\gamma_{2,0}$ (Po)	1512,70 (8)	0,29 (1)	E2	0,00278 (8)	0,00048 (2)	0,000160 (5)	0,00342 (10)
$\gamma_{3,0}$ (Po)	1620,74 (1)	1,52 (3)	[M1+E2]	0,00504 (15)	0,00078 (2)	0,000030 (1)	0,00585 (18)
$\gamma_{4,0}$ (Po)	1679,45 (1)	0,07 (1)	E2	0,00230 (7)	0,00039 (1)	0,000130 (4)	0,00282 (8)
$\gamma_{5,0}$ (Po)	1800,9 (2)	0,004 (2)	E0				
$\gamma_{6,0}$ (Po)	1805,96 (10)	0,12 (3)	E2	0,00202 (6)	0,00034 (1)	0,000110 (3)	0,00247 (7)

3 Atomic Data

3.1 Po

ω_K	:	0,965	(4)
$\bar{\omega}_L$	:	0,403	(16)
n_{KL}	:	0,807	(5)

3.1.1 X Radiations

	Energy keV	Relative probability
X _K		
K α_2	76,864	60,1
K α_1	79,293	100
K β_3	89,256	}
K β_1	89,63	}
K β_5''	90,363	}
		34,4
K β_2	92,45	}
K β_4	92,62	}
K $O_{2,3}$	92,98	}
		10,7
X _L		
L ℓ	9,66	
L α	11,016 – 11,13	
L η	12,085	
L β	12,823 – 13,778	
L γ	15,742 – 16,21	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	58,98 – 65,21	100
KLX	71,90 – 79,29	57
KXY	84,8 – 93,1	8,1
Auger L	5,43 – 10,93	3190

3.2 Tl

$$\begin{aligned}\omega_K &: 0,963 \quad (4) \\ \bar{\omega}_L &: 0,367 \quad (15) \\ n_{KL} &: 0,812 \quad (5)\end{aligned}$$

3.2.1 X Radiations

	Energy keV	Relative probability
X _K		
K α_2	70,833	59
K α_1	72,873	100
K β_3	82,118	}
K β_1	82,43	}
K β_5''	83,115	}
		34
K β_2	84,838	}
K β_4	85,134	}
K $O_{2,3}$	85,444	}
		10,1
X _L		
L ℓ	8,953	
L α	10,172 – 10,268	
L η	10,994	
L β	11,812 – 12,643	
L γ	14,291 – 14,738	

3.2.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	54,59 – 59,95	100
KLX	66,37 – 72,86	55
KXY	78,12 – 85,50	7,6
Auger L	5,18 – 10,13	363000

4 α Emissions

	Energy keV	Probability × 100
$\alpha_{0,7}$	5298 (1)	0,000039 (4)
$\alpha_{0,6}$	5345 (1)	0,00036 (18)
$\alpha_{0,5}$	5481,3 (3)	0,0050 (7)
$\alpha_{0,4}$	5606,63 (14)	0,43 (4)
$\alpha_{0,3}$	5625,4 (2)	0,06 (1)
$\alpha_{0,2}$	5768,27 (10)	0,63 (3)
$\alpha_{0,1}$	6050,92 (4)	25,1 (1)
$\alpha_{0,0}$	6090,02 (4)	9,7 (1)
* $\alpha_{1,0}$	9498,79 (12)	0,0024 (2)
* $\alpha_{4,0}$	10432,95 (13)	0,0010 (1)
* $\alpha_{5,0}$	10552,1 (3)	0,0106 (8)

* α of long range.

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Po)	5,43 - 10,93	0,0958 (16)
e _{AK}	(Po)		0,0050 (6)
	KLL	58,98 - 65,21	}
	KLX	71,90 - 79,29	}
	KXY	84,8 - 93,1	}
e _{AL}	(Tl)	5,18 - 10,13	16,7 (7)
e _{AK}	(Tl)		0,0074 (9)
	KLL	54,59 - 59,95	}
	KLX	66,37 - 72,86	}
	KXY	78,12 - 85,50	}
ec _{1,0} L	(Tl)	24,51 - 27,20	19 (1)
ec _{1,0} M	(Tl)	36,15 - 39,85	6,1 (2)
$\beta_{0,6}^-$	max:	448 (2)	0,68 (5)
$\beta_{0,6}^-$	avg:	130,7 (7)	
$\beta_{0,5}^-$	max:	453 (2)	0,029 (1)
$\beta_{0,5}^-$	avg:	132,3 (7)	
$\beta_{0,4}^-$	max:	575 (2)	0,21 (5)
$\beta_{0,4}^-$	avg:	173,0 (7)	

		Energy keV		Electrons per 100 disint.
$\beta_{0,3}^-$	max:	633	(2)	1,90 (4)
$\beta_{0,3}^-$	avg:	193,3	(7)	
$\beta_{0,2}^-$	max:	741	(2)	1,45 (2)
$\beta_{0,2}^-$	avg:	231,5	(8)	
$\beta_{0,1}^-$	max:	1527	(2)	4,58 (21)
$\beta_{0,1}^-$	avg:	533,9	(8)	
$\beta_{0,0}^-$	max:	2254	(2)	55,23 (21)
$\beta_{0,0}^-$	avg:	835,0	(9)	

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XL	(Po)	9,66 — 16,21		0,0581 (12)	
XK α_2	(Po)	76,864		0,0404 (10)	} K α
XK α_1	(Po)	79,293		0,0672 (17)	
XK β_3	(Po)	89,256	}		} K' β_1
XK β_1	(Po)	89,63	}	0,0231 (7)	
XK β_5''	(Po)	90,363	}		
XK β_2	(Po)	92,45	}		} K' β_2
XK β_4	(Po)	92,62	}	0,00720 (24)	
XKO $_{2,3}$	(Po)	92,98	}		
XL	(Tl)	8,953 — 14,738		6,73 (22)	
XK α_2	(Tl)	70,833		0,0563 (27)	} K α
XK α_1	(Tl)	72,873		0,095 (5)	
XK β_3	(Tl)	82,118	}		} K' β_1
XK β_1	(Tl)	82,43	}	0,0323 (16)	
XK β_5''	(Tl)	83,115	}		
XK β_2	(Tl)	84,838	}		} K' β_2
XK β_4	(Tl)	85,134	}	0,0096 (5)	
XKO $_{2,3}$	(Tl)	85,444	}		

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Tl)	39,858 (4)	1,01 (3)
$\gamma_{5,3}$ (Po)	180,2 (2)	0,003 (1)
$\gamma_{2,1}$ (Tl)	288,08 (6)	0,32 (2)
$\gamma_{2,0}$ (Tl)	327,94 (6)	0,121 (3)
$\gamma_{3,1}$ (Tl)	433,7 (2)	0,0095 (20)
$\gamma_{4,1}$ (Tl)	452,8 (1)	0,34 (3)
$\gamma_{3,0}$ (Tl)	473,6 (2)	0,044 (3)
$\gamma_{4,0}$ (Tl)	492,7 (1)	0,04 (1)
$\gamma_{5,1}$ (Tl)	580,5 (3)	0,0010 (2)
$\gamma_{5,0}$ (Tl)	620,4 (3)	0,0038 (6)
$\gamma_{1,0}$ (Po)	727,33 (1)	6,74 (12)
$\gamma_{6,0}$ (Tl)	759 (1)	0,00036 (18)
$\gamma_{2,1}$ (Po)	785,37 (9)	1,11 (1)
$\gamma_{7,0}$ (Tl)	807 (1)	0,000039 (4)
$\gamma_{3,1}$ (Po)	893,41 (2)	0,38 (1)
$\gamma_{4,1}$ (Po)	952,12 (2)	0,14 (4)
$\gamma_{5,1}$ (Po)	1073,6 (2)	0,015 (5)
$\gamma_{6,1}$ (Po)	1078,63 (11)	0,55 (2)
$\gamma_{2,0}$ (Po)	1512,70 (8)	0,29 (1)
$\gamma_{3,0}$ (Po)	1620,74 (1)	1,51 (3)
$\gamma_{4,0}$ (Po)	1679,45 (1)	0,07 (1)
$\gamma_{5,0}$ (Po)	1800,9 (2)	0,004 (2)
$\gamma_{6,0}$ (Po)	1805,96 (10)	0,12 (3)

7 Main Production Modes

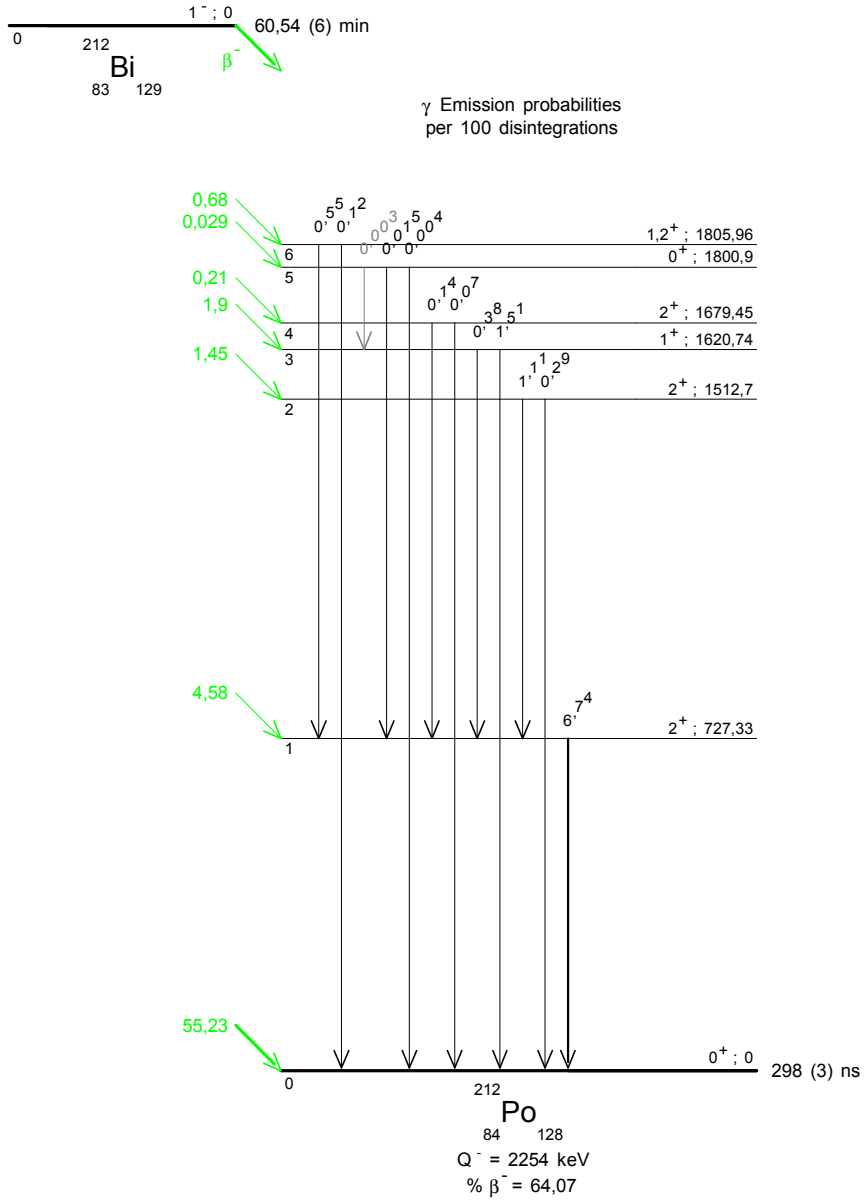
Pb – 212 β^- decay

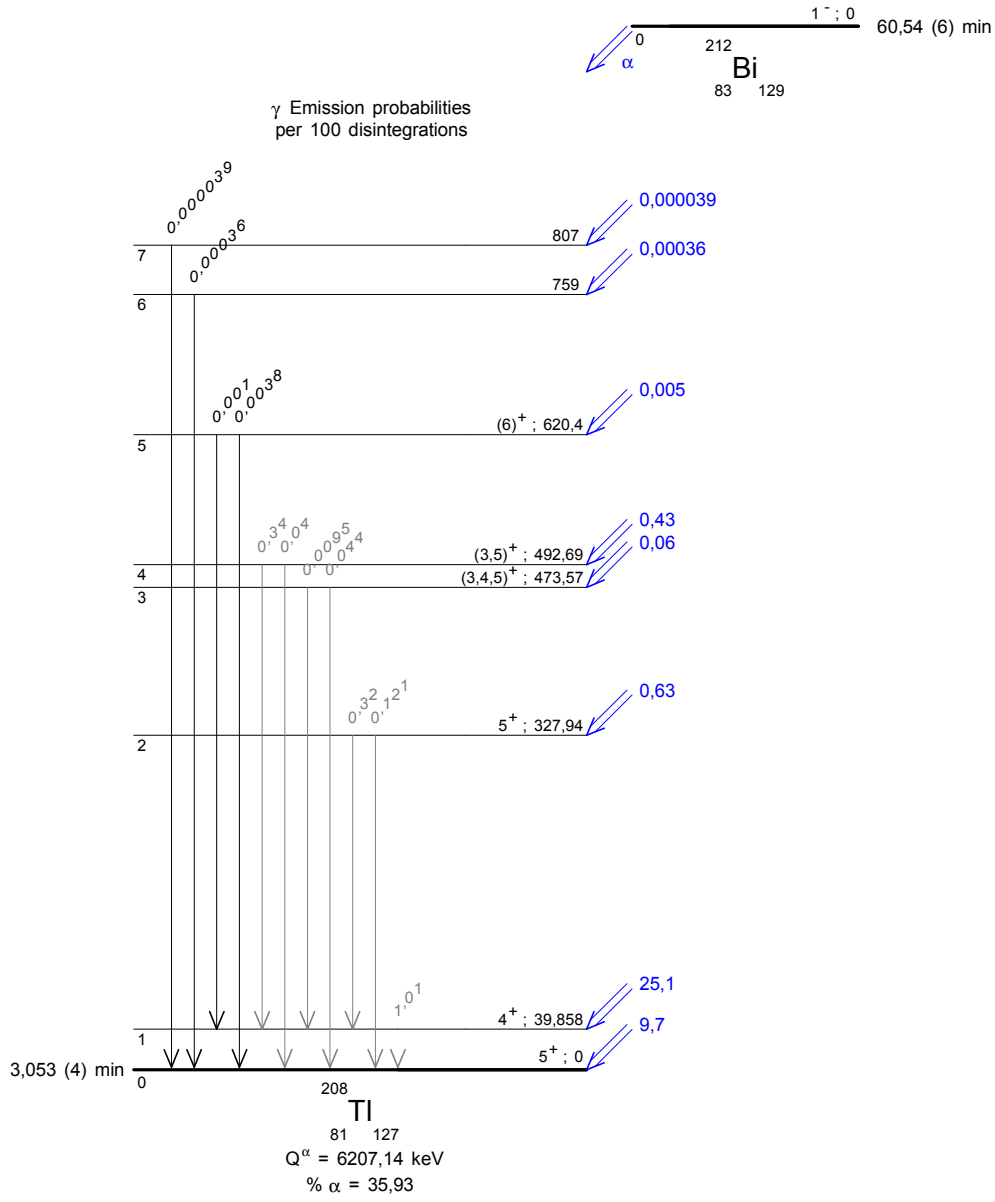
8 References

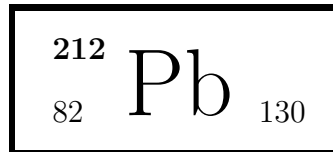
- F.V. LERCH. Sitzber. Akad. Wiss. Wien, Wath-naturw. Kl. Abt. IIa 123 (1914) 699
(Half-life)
- W.B. LEWIS, B.V. BOWDEN. Proc. Roy. Soc. (London) A145 (1934) 235
(Alpha emission energies, Alpha emission probabilities)
- D.E. BUNYAN, A. LUNDBY, W. WALKER. Proc. Phys. Soc. (London) 62A (1949) 253
(Half-life)
- A. RYTZ. Comp. Rend. Acad. Sci. (Paris) 233 (1951) 790
(Alpha emission energies, Alpha emission probabilities)
- K. SIEGBAHN, K. EDVARSON. Nucl. Phys. 1 (1956) 137
(Gamma-ray energies)
- J. BURDE, B. ROZNER. Phys. Rev. 107 (1957) 531
(Beta-ray emission probabilities)
- R.J. WALEN, G. BASTIN-SCOFFIER. Nucl. Phys. 16 (1960) 246
(Alpha emission energies, Alpha emission probabilities)

- G. SCHUPP, H. DANIEL, G.W. EAKINS, E.N. JENSEN. Phys. Rev. 120 (1960) 189
(Gamma-ray emission probabilities)
- G.T. EMERY, W.R. KANE. Phys. Rev. 118 (1960) 755
(Gamma-ray emission probabilities, high-energy alpha)
- K.P. APPLIGATE, E.M. MORIMOTO, M. KAHR, J.D. KNIGHT. J. Inorg. Nucl. Chem. 19 (1961) 375
(Half-life)
- F.C. FLACK, J.E. JOHNSON. Proc. Phys. Soc. 79 (1962) 10
(Gamma-ray emission probabilities, branching fraction)
- G. BERTOLINI, F. CAPELLANI, G. RESTELLI, A. ROTA. Nucl. Phys. 30 (1962) 599
(Alpha emission probabilities)
- G. ASTNER, I. BERGSTROM, L. ERIKSSON, U. FAGERQUIST, G. HOLM, A. PERSSON. Nucl. Phys. 45 (1963) 49
(Half-life)
- H. DANIEL, G. LUHRS. Z. Phys. 176 (1963) 30
(Gamma-ray emission probabilities)
- J.L. WININGER. J. Phys. (Paris) 25 (1964) 897
(Gamma-ray energies)
- J. WALKER, T. SALGIR. Proc. Phys. Soc. 86 (1965) 423
(Branching fraction)
- C.F. LEANG. Comp. Rend. Acad. Sci. (Paris) 260 (1965) 3037
(Alpha emission energies, Alpha emission probabilities)
- S.S. KLEIN. NP-16835 (1965)
(Gamma-ray energies)
- N.O. LASSEN, N. HORNSTRUP. Mat. Fys. Medd. Dan. Vit. Selsk. 36, No.4 (1967)
(Half-life)
- R. BENOIT, G. BERTOLINI, F. CAPELLANI, G. RESTELLI. Nuovo Cim. 49B (1967) 125
(Gamma-ray emission probabilities)
- J. DALMASSO, C. MARSOL. Comp. Rend. Acad. Sci. (Paris) 267B (1968) 1366
(Gamma-ray emission probabilities)
- C. YTHIER, H. FOREST, G. ARDISSON, H. MARIA. Comp. Rend. Acad. Sci. (Paris) 267 (1968) 1362
(Gamma-ray energies, Gamma-ray emission probabilities)
- B. GRENNBERG, A. RYTZ. Comp. Rend. Acad. Sci. (Paris) 269B (1969) 652
(Alpha emission probabilities, Alpha emission energies)
- S.M. BRAHMAVAR, J.H. HAMILTON. Nucl. Instrum. Methods 69 (1969) 353
(Gamma-ray energies)
- R. ACKERHALT, P. ELLERBE, G. HARBOTTLE. Radiochem. Radioanal. Lett. 8 (1971) 75
(Half-life)
- J. DALMASSO. FRNC-TH-441 (1972)
(Gamma-ray emission probabilities)
- J. DALMASSO, H. MARIA, C. YTHIER. Comp. Rend. Acad. Sci. (Paris) 277B (1973) 467
(Gamma-ray emission probabilities)
- A.G.DA SILVA, L.T. AULER, G.L. AULER, G.L.DE ALMEIDA, R.H. TOPKE. INIS Atomindex-mf-1222 (1974)
(Gamma-ray energies, Gamma-ray emission probabilities)
- S. SANYAL, R.K. GARG, S.D. CHAUHAN, S.I. GUPTA, S.C. PANCHOLI. Phys. Rev. C12 (1975) 318
(Half-life)
- F.T. AVIGNONE, A.G. SCHMIDT. Phys. Rev. C17 (1978) 380
(Gamma-ray emission probabilities)
- F. RÖSEL, H.M. FRIES, K. ALDER, H.C. PAULI. At. Data Nucl. Data Tables 21 (1978) 291
(Internal conversion coefficients)
- R.G. HELMER. Nucl. Instrum. Methods 164 (1979) 355
(Gamma-ray energies)
- A. RYTZ. At. Data. Nucl. Data Tables 23 (1979) 507
(Alpha emission energies, Alpha emission probabilities)
- S. SADASIVAN, V.M. RAGHUNATH. Nucl. Instrum. Methods 196 (1982) 561
(Gamma-ray emission probabilities)
- B. BENGTON, H.L. NIELSEN, N. RUD, K. WILSKY. Nucl. Phys. A378 (1982) 1
(Multipolarity)
- R. VANINBROUKX, H.H. HANSEN. Int. J. Appl. Radiat. Isotop. 34 (1983) 1395
(Gamma-ray emission probabilities)

- U. SCHÖTZIG, K. DEBERTIN. Int. J. Appl. Radiat. Isotop. 34 (1983) 533
(Gamma-ray emission probabilities)
- R.J. GEHRKE, V.J. NOVICK, J.D. BAKER. Int. J. Appl. Radiat. Isotop. 35 (1984) 581
(Gamma-ray emission probabilities)
- A.H. WAPSTRA, G. AUDI. Nucl. Phys. A432 (1985) 1
(Q values)
- M.J. MARTIN. Nucl. Data Sheets 47 (1986) 797
(Nuclear structure, energies)
- A. ARTNA-COHEN. Nucl. Data Sheets 66 (1992) 171
(Nuclear structure, energies)
- W.-J. LIN, G. HARBOTTLE. J. Radioanal. Nucl. Chem. 157 (1992) 367
(Gamma-ray emission probabilities)
- G. AUDI, A.H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q values)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(K-x ray, L-x ray, Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 (1998)
(Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-1999-1 (1999)
(K-x ray)







1 Decay Scheme

Pb-212 disintegrates by beta minus emission to excited and fundamental levels of Bi-212.

Le plomb 212 se désintègre par émission bêta moins vers des niveaux excités et fondamental du bismuth 212.

2 Nuclear Data

$T_{1/2}(^{212}\text{Pb})$	:	10,64	(1)	h
$T_{1/2}(^{212}\text{Bi})$	:	60,54	(6)	min
$Q^-(^{212}\text{Pb})$	:	574	(2)	keV

2.1 β^- Transitions

	Energy keV	Probability $\times 100$	Nature	lg ft
$\beta_{0,3}^-$	159 (2)	5,1 (2)	1st Forbidden	5,38
$\beta_{0,2}^-$	335 (2)	84,0 (14)	1st Forbidden	5,19
$\beta_{0,0}^-$	574 (2)	10,9 (14)	1st Forbidden	6,84

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{1,0}(\text{Bi})$	115,183 (5)	5,12 (21)	[M1]	5,87 (18)	1,027 (30)	0,323 (10)	7,22 (22)
$\gamma_{2,1}(\text{Bi})$	123,45 (1)	0,37 (1)	[E2]	0,418 (8)	1,802 (36)	0,630 (13)	2,85 (6)
$\gamma_{3,2}(\text{Bi})$	176,64 (1)	0,16 (2)	[M1]	1,742 (50)	0,303 (10)	0,095 (3)	2,14 (6)
$\gamma_{2,0}(\text{Bi})$	238,632 (2)	83,8 (11)	[M1]	0,753 (23)	0,130 (4)	0,040 (1)	0,923 (30)
$\gamma_{3,1}(\text{Bi})$	300,09 (1)	4,74 (20)	[M1]	0,401 (12)	0,069 (2)	0,0210 (6)	0,491 (15)
$\gamma_{3,0}(\text{Bi})$	415,27 (1)	0,17 (3)	[M1]	0,167 (5)	0,028 (1)	0,0090 (3)	0,204 (6)

3 Atomic Data

3.1 Bi

ω_K	:	0,964	(4)
$\bar{\omega}_L$	:	0,391	(16)
n_{KL}	:	0,809	(5)

3.1.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	74,8157	59,8
$K\alpha_1$	77,1088	100
$K\beta_3$	86,835	}
$K\beta_1$	87,344	}
$K\beta_5''$	87,862	}
		34,2
$K\beta_2$	89,91	}
$K\beta_4$	90,074	}
$KO_{2,3}$	90,421	}
		10,4
X_L		
$L\ell$	9,42	
$L\alpha$	10,731 – 10,839	
$L\eta$	11,712	
$L\beta$	12,48 – 13,393	
$L\gamma$	15,248 – 15,709	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	57,49 – 63,42	100
KLX	70,03 – 77,11	57
KXY	82,53 – 90,52	7,8
Auger L	5,35 – 10,66	3040

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Bi)	5,35 - 10,66	25,2 (5)
e _{AK}	(Bi)		1,37 (16)
	KLL	57,49 - 63,42	}
	KLX	70,03 - 77,11	}
	KXY	82,53 - 90,52	}
ec _{1,0} K	(Bi)	24,657 (5)	3,66 (13)
ec _{1,0} L	(Bi)	98,80 - 101,76	0,64 (2)
ec _{1,0} M	(Bi)	111,18 - 115,03	0,20 (1)
ec _{2,0} K	(Bi)	148,106 (2)	33 (1)
ec _{3,1} K	(Bi)	209,56 (2)	1,27 (4)
ec _{2,0} L	(Bi)	222,24 - 225,21	5,7 (2)
ec _{2,0} M	(Bi)	234,63 - 238,47	1,7 (1)
ec _{3,1} L	(Bi)	283,70 - 286,67	0,22 (1)
ec _{3,1} M	(Bi)	296,09 - 299,93	0,07
$\beta_{0,3}^-$	max:	159 (2)	5,1 (2)
$\beta_{0,3}^-$	avg:	42,3 (6)	
$\beta_{0,2}^-$	max:	335 (2)	84,0 (14)
$\beta_{0,2}^-$	avg:	94,8 (7)	
$\beta_{0,0}^-$	max:	574 (2)	10,9 (14)
$\beta_{0,0}^-$	avg:	173,1 (7)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Bi)	9,42 — 15,709	14,5 (4)
XK α_2	(Bi)	74,8157	10,7 (3) } K α
XK α_1	(Bi)	77,1088	17,9 (5) }
XK β_3	(Bi)	86,835	}
XK β_1	(Bi)	87,344	}
XK β_5''	(Bi)	87,862	}
XK β_2	(Bi)	89,91	}
XK β_4	(Bi)	90,074	}
XKO _{2,3}	(Bi)	90,421	}
			6,12 (20) K' β_1
			1,87 (7) K' β_2

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Bi})$	115,183 (5)	0,623 (22)
$\gamma_{2,1}(\text{Bi})$	123,45 (1)	0,096 (4)
$\gamma_{3,2}(\text{Bi})$	176,64 (1)	0,052 (4)
$\gamma_{2,0}(\text{Bi})$	238,632 (2)	43,6 (3)
$\gamma_{3,1}(\text{Bi})$	300,09 (1)	3,18 (13)
$\gamma_{3,0}(\text{Bi})$	415,27 (1)	0,144 (22)

6 Main Production Modes

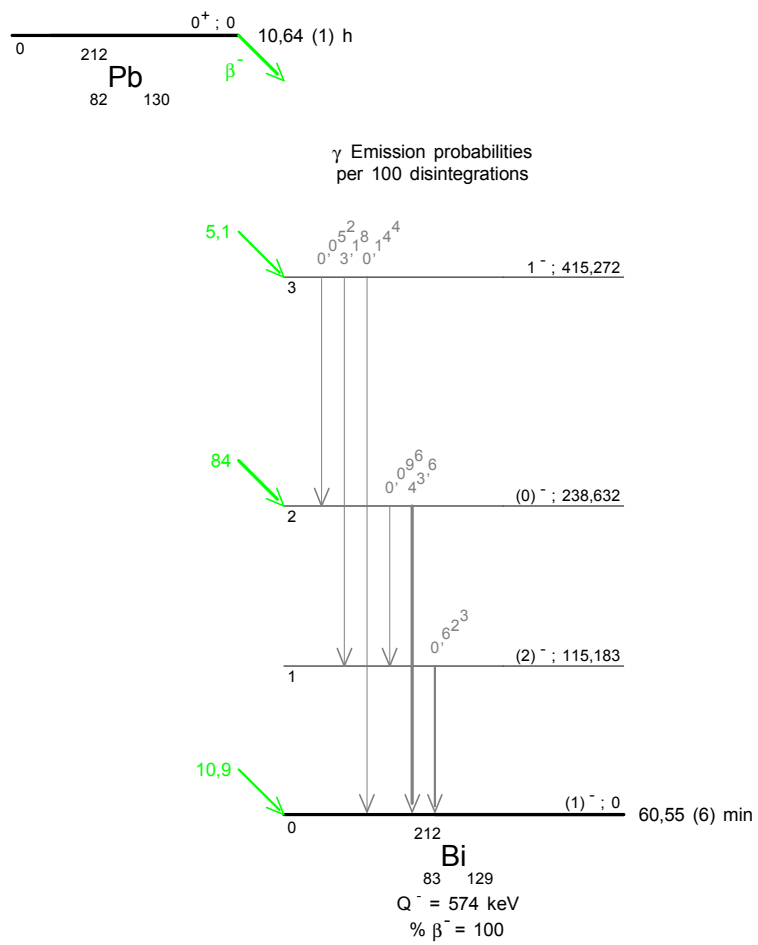
Po – 210(t,p)Pb – 212

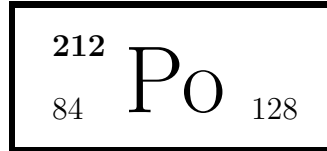
Po – 216 α decay

7 References

- D.G.E. MARTIN, H.O.W. RICHARDSON. Proc. Phys. Soc. 195A (1948) 287
(Beta-ray emission probabilities)
- H.VON BUTTLAR. Naturwissenschaften 39 (1952) 575
(Half-life)
- P. MARIN, G.R. BISHOP, H. HALBAN. Proc. Phys. Soc. (London) 66A (1953) 608
(Half-life)
- J. TOBAILEM, J. ROBERT. J. Phys. Radium 16 (1955) 115
(Half-life)
- E.M. KRISYOUK, A.G. SERVEYEV, G.D. LATYSHEV, V.D. VOROBYOV. Nucl. Phys. 4 (1957) 579
(Conversion-electron emission probabilities, multipolarity)
- K.O. NIELSEN, O.B. NIELSEN, M.A. WAGGONER. Nucl. Phys. 2 (1957) 476
(Conversion-electron emission probabilities, multipolarity)
- A.G. SERGEYEV, V.D. VOROBYEV, A.S. REMENNYI, T.J. KOLCHENSKAYA, G.D. LATYSHEV, Y.S. YEGOROV. Nucl. Phys. 9 (1959) 498
(Mixing Ratio)
- P.G. ROETLING, W.P. GANLEY, G.S. KLAIBER. Nucl. Phys. 20 (1960) 347
(Gamma-ray emission probabilities, multipolarity)
- M. GIANNINI, D. PROSPERI, S. SCIUTI. Nuovo Cim. 21 (1961) 430
(Gamma-ray emission probabilities)
- H. DANIEL, G. LÜHRS. Z. Phys. 176 (1963) 30
(Conversion-electron emission probabilities, multipolarity)
- D. KRPIĆ, R. STEPIC, M. BOGDANOVIC, M. MLADENOVIC. Fizika 1 (1969) 171
(Mixing Ratio)
- J. DALMASSO. Report FRNC-TH-441 (1972)
(Gamma-ray emission probabilities)
- J. DALMASSO, H. MARIA, C. YTHIER. Comp. Rend. Acad. Sci. (Paris) 277B (1973) 467
(Gamma-ray emission probabilities)
- F. RÖSEL, H.M. FRIES, K. ALDER, H.C. PAULI. At. Data. Nucl. Data Tables 21 (1978) 291
(Internal conversion coefficients)
- F.T. AVIGNONE, A.G. SCHMIDT. Phys. Rev. C17 (1978) 380
(Gamma-ray emission probabilities)
- S. SADASIVAN, V.M. RAGHUNATH. Nucl. Instrum. Methods 196 (1982) 561
(Gamma-ray emission probabilities)

- R. VANINBROUKX, H.H. HANSEN. Int. J. Appl. Radiat. Isot. 34 (1983) 1395
(Gamma-ray emission probabilities)
- U. SCHÖTZIG, K. DEBERTIN. Int. J. Appl. Radiat. Isot. 34 (1983) 533
(Gamma-ray emission probabilities)
- R.J. GEHRKE, V.J. NOVICK, J.D. BAKER. Int. J. Appl. Radiat. Isot. 35 (1984) 581
(Gamma-ray emission probabilities)
- A. ARTNA-COHEN. Nucl. Data Sheets 66 (1992) 171
(Nuclear structure, energies)
- W-J. LIN, G. HARBOTTLE. J. Radioanal. Nucl. Chem. 157 (1992) 367
(Gamma-ray emission probabilities)
- G. AUDI, A.H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q value)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(K-x ray, L-x ray, Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 (1998)
(Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-1999-1 (1999)
(K-x ray)





1 Decay Scheme

Po-212 is an extremely short-lived radionuclide populated via the beta decay of Bi-212 and the alpha decay of Rn-216. Alpha decay of Po-212 occurs directly to the ground state of Pb-208.

Le polonium 212 se désintègre par émission alpha vers le niveau fondamental du plomb 208.

2 Nuclear Data

$$T_{1/2}(^{212}\text{Po}) : 300 \quad (2) \quad 10^{-9} \text{ s}$$

$$Q^\alpha(^{212}\text{Po}) : 8954,13 \quad (11) \quad \text{keV}$$

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,0}$	8954,13 (11)	100	1

3 α Emissions

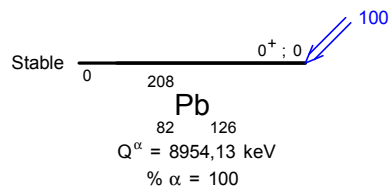
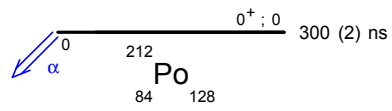
	Energy keV	Probability $\times 100$
$\alpha_{0,0}$	8785,18 (11)	100

4 Main Production Modes

Bi – $212(\beta^-)\text{Po} - 212$
 Rn – $216(\alpha)\text{Po} - 212$
 Bi – $209(\alpha,p)\text{Po} - 212$
 Pb – $210(\alpha,2n\gamma)\text{Po} - 212$

5 References

- D.E. BUNYAN, A. LUNDLY, W. WALKER. Proc. Phys. Soc. (London) 62A (1949) 253
(Half-life)
- F.C. FLACK, J.E. JOHNSON. Proc. Phys. Soc. 79 (1962) 10
(Half-life)
- G. ASTNER, I. BERGSTROM, L. ERIKSSON, U. FAGERGUIST, G. HOLM, A. PERSSON. Nucl. Phys. 45 (1963) 49
(Half-life)
- A. RYTZ, B. GRENNBERG, D.J. GORMAN. Proc. 4th Int. Conf. Atomic Masses and Fund. Constants, Teddington, England, Eds Plenum Press (1971) 1
(Alpha emission energies)
- H. DEL CASTILLO, R. ROOS, A. TEJERA, F. ALBA. Rev. Mex. Fis. 20 (1971) 17
(Alpha emission energies)
- G.W. MCBETH, R.A. WINYARD. Int. J. Appl. Radiat. Isotop. 23 (1972) 527
(Half-life)
- E. HUENGES, H. VONACH, J. LABETZKI. Nucl. Instrum. Methods 121 (1974) 307
(Alpha emission energies)
- S. SANYAL, R.K. GARG, S.D. CHAUHAN, S.L. GUPTA, S.C. PANCHOLI. Phys. Rev. C12 (1975) 318
(Half-life)
- A. RYTZ. At. Data Nucl. Data Tables 23 (1979) 507
(Alpha emission energies)
- G. AUDI, A.H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q value)





1 Decay Scheme

Po-216 decays (100%) by alpha emission to the Pb-212 fundamental level.

Le polonium 216 se désintègre (100%) par émission alpha vers le niveau fondamental de plomb 212.

2 Nuclear Data

$T_{1/2}(^{216}\text{Po})$	:	0,150	(5)	s
$T_{1/2}(^{212}\text{Pb})$	:	10,64	(1)	h
$Q^\alpha(^{216}\text{Po})$	:	6906,52	(51)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,1}$	6101,6 (10)	0,0019 (3)	34,7
$\alpha_{0,0}$	6906,52 (50)	99,9981 (3)	1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	P $_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{1,0}(\text{Pb})$	804,9 (5)	0,0019 (3)	[E2]	0,0081 (2)	0,00180 (4)	0,00050 (1)	0,0104 (2)

3 Atomic Data

3.1 Pb

ω_K	:	0,963	(4)
$\bar{\omega}_L$	:	0,379	(15)
n_{KL}	:	0,811	(5)

3.1.1 X Radiations

	Energy keV	Relative probability		
X_K	$K\alpha_2$	72,8049	59	
	$K\alpha_1$	74,97	100	
	$K\beta_3$	84,451	}	
	$K\beta_1$	84,937	}	
	$K\beta_5''$	85,47	}	34
	$K\beta_2$	87,238	}	
	$K\beta_4$	87,58	}	10,3
	$KO_{2,3}$	87,911	}	
	X_L	$L\ell$	9,184	
$L\alpha$		10,45 – 10,551		
$L\eta$		11,349		
$L\beta$		12,142 – 13,015		
$L\gamma$		14,765 – 15,216		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	56,03 – 61,67	100
KLX	68,18 – 74,97	54
KXY	80,3 – 88,0	7,7
Auger L	5,26 – 10,40	3060

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,1}$	5988,6 (10)	0,0019 (3)
$\alpha_{0,0}$	6778,6 (5)	99,9981 (3)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Pb)	5,26 - 10,40	0,0000107 (10)
e _{AK}	(Pb)		0,00000057 (11)
	KLL	56,03 - 61,67	}
	KLX	68,18 - 74,97	}
	KXY	80,3 - 88,0	}

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Pb)	9,184 — 15,216	0,0000060 (6)	
XK α_2	(Pb)	72,8049	0,0000043 (7)	} K α
XK α_1	(Pb)	74,97	0,0000073 (12)	}
XK β_3	(Pb)	84,451	}	
XK β_1	(Pb)	84,937	}	0,0000025 (4) K' β_1
XK β_5''	(Pb)	85,47	}	
XK β_2	(Pb)	87,238	}	
XK β_4	(Pb)	87,58	}	0,00000075 (13) K' β_2
XK $O_{2,3}$	(Pb)	87,911	}	

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Pb})$	804,9 (5)	0,0019 (3)

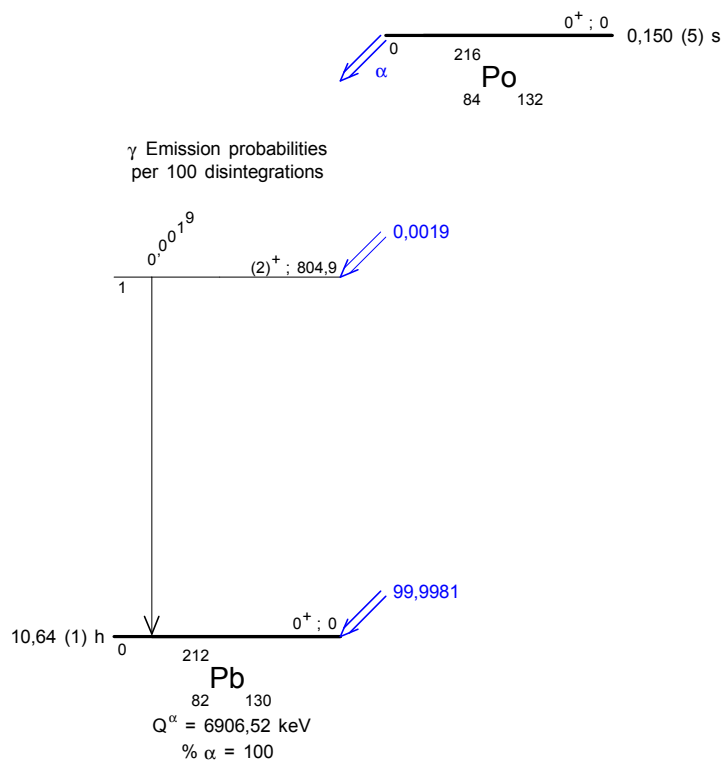
7 Main Production Modes

Bi – 216(β^-)Po – 216

Th – 228 α decays

8 References

- H.G.J. MOSELEY, K. FAJANS. Phil. Mag. 22 (1911) 629
(Half-life)
- A.G. WARD. Proc. Roy. Soc. (London) 181A (1942) 183
(Half-life)
- H.V. BUTTLAR. Naturwissenschaften 39 (1952) 575
(Half-life)
- P. MARIN, G.R. BISHOP, H. HALBAN. Proc. Phys. Soc. (London) 66A (1953) 608
(Half-life)
- J. TOBAILEM, J. ROBERT. J. Phys. Radium 16 (1955) 115
(Half-life)
- R.J. WALEN. Comp. Rend. Acad. Sci. (Paris) 255 (1962) 1604
(Alpha emission energies, Alpha emission probabilities)
- H. DIAMOND, J.E. GINDLER. J. Inorg. Nucl. Chem. 25 (1963) 143
(Half-life)
- W. KURCEWICZ, N. KAFFRELL, N. TRAUTMANN, A. PLOCHOCKI, J. ZYLICZ, M. MATUL, K. STRYCZNIEWICZ. Nucl. Phys. A289 (1977) 1
(Gamma-ray energies, Gamma-ray emission probabilities)
- F. RÖSEL, H.M. FRIES, K. ALDER, H.C. PAULI. At. Data Nucl. Data Tables 21 (1978) 291
(Internal conversion coefficients)
- A. ARTNA-COHEN. Nucl. Data Sheets 66 (1992) 171
(Nuclear structure, energies)
- G. AUDI, A.H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q value)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(K-x ray, L-x ray, Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 (1998)
(Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-1999 (1999)
(K-x ray)





1 Decay Scheme

Rn-220 mainly decays by alpha emission to the Po-216 fundamental level.

Le radon 220 se désintègre par émission alpha principalement vers le niveau fondamental du polonium 216.

2 Nuclear Data

$T_{1/2}(^{220}\text{Rn})$	:	55,8	(3)	s
$T_{1/2}(^{216}\text{Po})$	:	0,150	(5)	s
$Q^\alpha(^{220}\text{Rn})$	:	6404,67	(10)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,1}$	5854,91 (14)	0,118 (15)	3,08
$\alpha_{0,0}$	6404,67 (10)	99,882 (15)	1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{1,0}(\text{Po})$	549,76 (4)	0,118 (15)	E2	0,0184 (6)	0,0057 (2)	0,00190 (6)	0,0260 (8)

3 Atomic Data

3.1 Po

ω_K	:	0,965	(4)
$\bar{\omega}_L$	:	0,403	(16)
n_{KL}	:	0,807	(5)

3.1.1 X Radiations

	Energy keV	Relative probability		
X_K	$K\alpha_2$	76,864	60	
	$K\alpha_1$	79,293	100	
	$K\beta_3$	89,256	}	
	$K\beta_1$	89,807	}	
	$K\beta_5''$	90,363	}	34,43
	$K\beta_2$	92,263	}	
	$K\beta_4$	92,618	}	10,71
	$KO_{2,3}$	92,983	}	
	X_L	$L\ell$	9,658	
		$L\alpha$	11,016 – 11,13	
$L\eta$		12,085		
$L\beta$		12,823 – 13,778		
$L\gamma$		15,742 – 16,213		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	58,98 – 65,21	100
KLX	71,90 – 79,29	55
KXY	84,8 – 93,1	8
Auger L	5,43 – 10,93	3400

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,1}$	5748,46 (14)	0,118 (15)
$\alpha_{0,0}$	6288,22 (10)	99,882 (15)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Po)	5,43 - 10,93	0,00155 (12)
e _{AK}	(Po)		0,000074 (13)
	KLL	58,98 - 65,21	}
	KLX	71,90 - 79,29	}
	KXY	84,8 - 93,1	}

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Po)	9,658 — 16,213	0,00096 (7)	
XK α_2	(Po)	76,864	0,00060 (8)	} K α
XK α_1	(Po)	79,293	0,00100 (14)	}
XK β_3	(Po)	89,256	}	
XK β_1	(Po)	89,807	}	0,00034 (5) K' β_1
XK β_5''	(Po)	90,363	}	
XK β_2	(Po)	92,263	}	
XK β_4	(Po)	92,618	}	0,000107 (15) K' β_2
XK $O_{2,3}$	(Po)	92,983	}	

6.2 Gamma Emissions

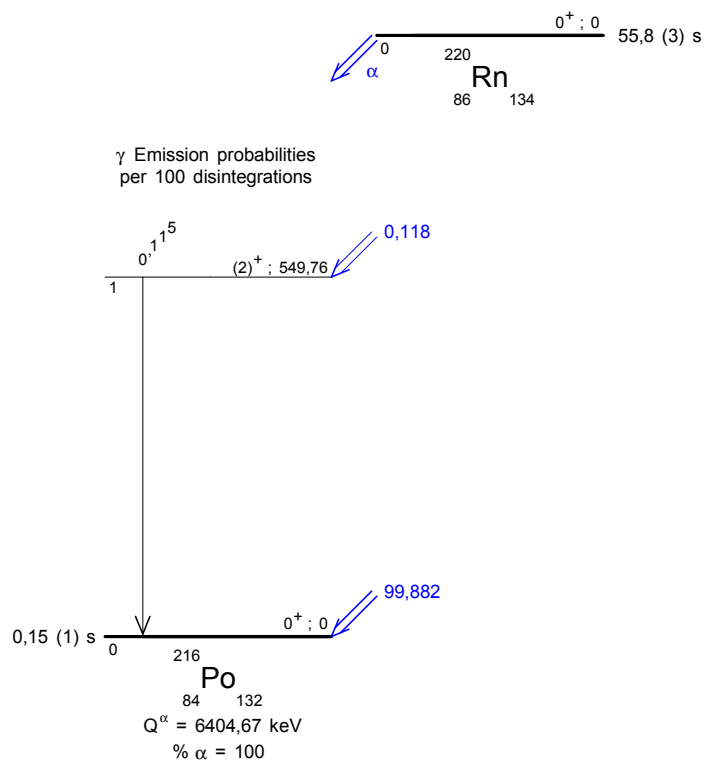
	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Po})$	549,76 (4)	0,115 (15)

7 Main Production Modes

Th – 228 α decays()

8 References

- A.G. WARD. Proc. Roy. Soc. (London) 181A (1942) 183
(Half-life)
- H. SCHMIED, R.W. FINK, B.L. ROBINSON. J. Inorg. Nucl. Chem. 1 (1955) 342
(Half-life)
- L. MADANSKY, F. RASETTI. Phys. Rev. 102 (1956) 464
(Gamma-ray emission probabilities)
- H. RODENBUSCH, G. HERRMANN. Z. Naturforsch. 16a (1961) 577
(Half-life)
- R.J. WALEN. Compt. Rend. Ac. Sci. (Paris) 255 (1962) 1604
(Alpha emission energies, Alpha emission probabilities)
- J.E. GINDLER, D.W. ENGELKEMEIR. Radiochim. Acta 2 (1963) 58
(Half-life)
- H. DIAMOND, J.E. GINDLER. J. Inorg. Nucl. Chem. 25 (1963) 143
(Half-life)
- J.B. HURSH. J. Inorg. Nucl. Chem. 28 (1966) 2771
(Half-life)
- J. DALMASSO. Report FRNC-TH-441 (1972)
(Gamma-ray emission probabilities)
- J. DALMASSO. Comp. Rend. Acad. Sci. (Paris) 277B (1973) 467
(Gamma-ray emission probabilities)
- W. KURCEWICZ, N. KAFFRELL, N. TRAUTMANN, A. PLOCHOCKI, J. ZYLICZ, A. MATUL, K. STRYCZNIEWICZ. Nucl. Phys. A289 (1977) 1
(Gamma-ray emission probabilities)
- F. RÖSEL, H.M. FRIES, K. ALDER, H.C. PAULI. At. Data. Nucl. Data Tables 21 (1978) 291
(Internal conversion coefficients)
- R.J. GEHRKE, V.J. NOVICK, J.D. BAKER. Int. J. Appl. Radiat. Isotop. 35 (1984) 581
(Gamma-ray emission probabilities)
- G. AUDI, A.H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q value)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(K-x ray, L-x ray, Auger electrons)
- A. ARTNA-COHEN. Nucl. Data Sheets 80 (1997) 157
(Nuclear structure, energies)
- E. SCHÖNFELD, G. RODLOFF. PTB Report 6.11-98-1 (1998)
(Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. PTB Report 6.11-1999-1 (1999)
(K-x ray)





1 Decay Scheme

Ra-224 mainly decays by alpha emission to the fundamental and the 241 keV levels of Rn-220.

Le radium 224 se désintègre par émission alpha principalement vers le niveau fondamental et le niveau excité de 241 keV du radon 220.

2 Nuclear Data

$T_{1/2}({}^{224}\text{Ra})$	:	3,627	(7)	d
$T_{1/2}({}^{220}\text{Rn})$	:	55,8	(3)	s
$Q^\alpha({}^{224}\text{Ra})$	:	5788,87	(15)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,4}$	5125,84 (25)	0,0030 (5)	7,42
$\alpha_{0,3}$	5143,43 (24)	0,0076 (14)	3,73
$\alpha_{0,2}$	5255,18 (25)	0,0074 (8)	17,4
$\alpha_{0,1}$	5547,88 (16)	5,26 (7)	1,03
$\alpha_{0,0}$	5788,87 (15)	94,72 (7)	1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{1,0}(\text{Rn})$	240,986 (6)	5,27 (7)	E2	0,111 (2)	0,124 (3)	0,045 (1)	0,280 (6)
$\gamma_{2,1}(\text{Rn})$	292,70 (11)	0,0073 (8)	E2	0,0730 (15)	0,057 (1)	0,0210 (4)	0,151 (3)
$\gamma_{3,1}(\text{Rn})$	404,5 (1)	0,0022 (5)	E1	0,0141 (3)	0,00240 (5)	0,00080 (2)	0,0173 (4)
$\gamma_{4,1}(\text{Rn})$	422,04 (11)	0,0030 (5)	[E1]	0,0129 (3)	0,00220 (4)	0,00070 (1)	0,0158 (3)
$\gamma_{3,0}(\text{Rn})$	645,44 (9)	0,0054 (9)	E1	0,0055 (1)	0,00090 (2)	0,00030 (1)	0,0067 (1)

3 Atomic Data

3.1 Rn

ω_K	:	0,967	(4)
$\bar{\omega}_L$	:	0,428	(17)
n_{KL}	:	0,804	(5)

3.1.1 X Radiations

	Energy keV	Relative probability
X _K		
K α_2	81,07	60,5
K α_1	83,78	100
K β_3	94,247	}
K β_1	94,868	}
K β_5''	95,449	}
		34,68
K β_2	97,48	}
K β_4	97,853	}
K $O_{2,3}$	98,357	}
		11
X _L		
L ℓ	10,137	
L α	11,598 – 11,726	
L η	12,855	
L β	14,565 – 13,52	
L γ	16,77 – 17,28	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	62,02 – 68,89	100
KLX	75,74 – 83,79	56
KXY	89,45 – 98,39	8
Auger L	5,58 – 11,48	5840

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,4}$	5034,31 (25)	0,0030 (5)
$\alpha_{0,3}$	5051,58 (24)	0,0076 (14)
$\alpha_{0,2}$	5161,34 (25)	0,0074 (8)
$\alpha_{0,1}$	5448,81 (16)	5,26 (7)
$\alpha_{0,0}$	5685,50 (15)	94,72 (7)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Rn)	5,58 - 11,48	0,537 (9)
e _{AK}	(Rn)		0,0151 (19)
	KLL	62,02 - 68,89	}
	KLX	75,74 - 83,79	}
	KXY	89,45 - 98,39	}
ec _{1,0} K	(Rn)	142,590 (12)	0,46 (2)
ec _{1,0} L	(Rn)	222,94 - 226,38	0,51 (2)
ec _{1,0} M	(Rn)	236,51 - 240,76	0,18 (1)

6 Photon Emissions**6.1 X-Ray Emissions**

		Energy keV	Photons per 100 disint.	
XL	(Rn)	10,137 — 17,28	0,387 (8)	
XK α_2	(Rn)	81,07	0,130 (4)	} K α
XK α_1	(Rn)	83,78	0,215 (7)	}
XK β_3	(Rn)	94,247	}	
XK β_1	(Rn)	94,868	}	K' β_1
XK β_5''	(Rn)	95,449	}	
XK β_2	(Rn)	97,48	}	
XK β_4	(Rn)	97,853	}	K' β_2
XK $\alpha_{2,3}$	(Rn)	98,357	}	

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(\text{Rn})$	240,986 (6)	4,12 (4)
$\gamma_{2,1}(\text{Rn})$	292,70 (11)	0,0063 (7)
$\gamma_{3,1}(\text{Rn})$	404,5 (1)	0,0022 (5)
$\gamma_{4,1}(\text{Rn})$	422,04 (11)	0,0030 (5)
$\gamma_{3,0}(\text{Rn})$	645,44 (9)	0,0054 (9)

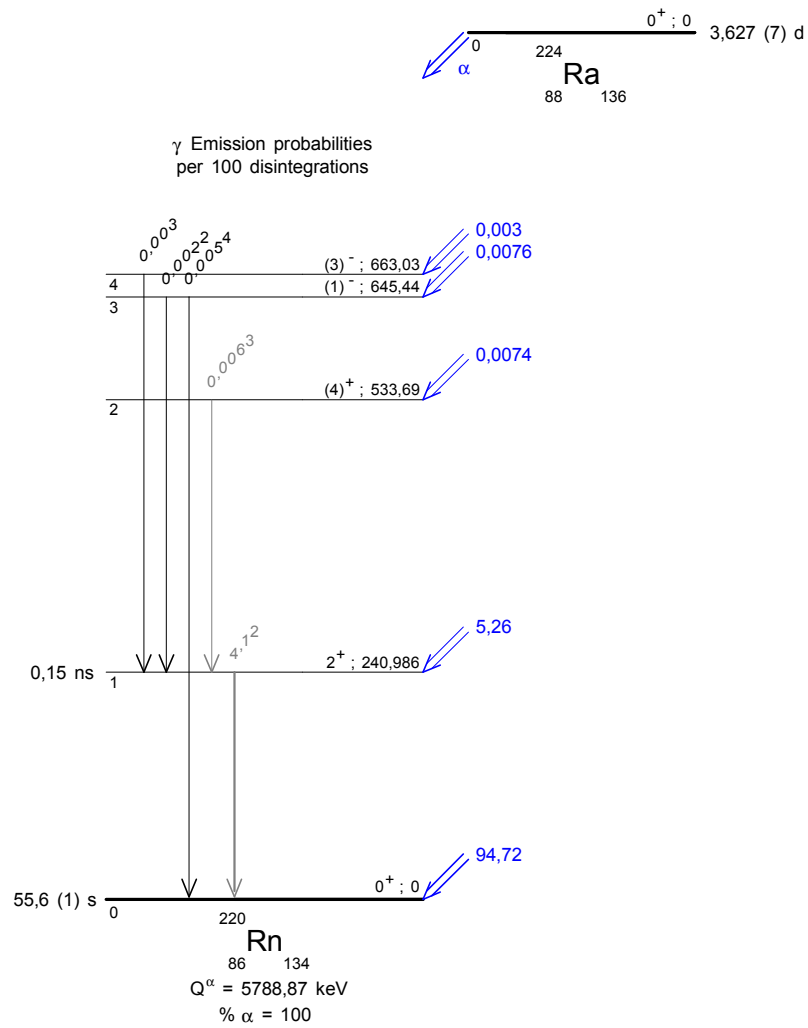
7 Main Production Modes

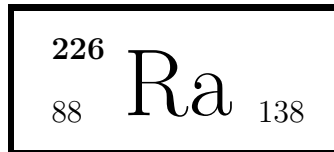
Ra – $^{226}(\text{p,t})\text{Ra} - ^{224}$
 Th – $^{228} \alpha$ decays

8 References

- F. ASARO, F. STEPHENS, I. PERLMAN. Phys. Rev. 92 (1953) 1495
(Alpha-particle emission probabilities)
- R.D. LLOYD, C.W. MAYS, D.R. ATHERTON, D.O. CLARK. Report COO-225 (1962) 88
(Half-life)
- R.J. WALLEN. Comp. Rend. Acad. Sci. (Paris) 255 (1962) 1604
(Alpha emission energies)
- J.B. HURSH. J. Inorg. Nucl. Chem. 28 (1966) 2771
(Half-life)
- A. PEGHAIRE. Nucl. Instrum. Methods 75 (1969) 66
(Gamma-ray emission probabilities)
- J.C. SOARES, J.P. RIBEIRO, A. GONCALVES, F.B. GIL, J.G. FERREIRA. Comp. Rend. Acad. Sci. (Paris) 273B (1971) 985
(Alpha-particle emission probabilities)
- K.C. JORDAN, G.W. OTTO, R.P. RATAY. J. Inorg. Nucl. Chem. 33 (1971) 1215
(Half-life)
- J. DALMASSO. FRNC-TH-441 (1972)
(Gamma-ray emission probabilities)
- J. DALMASSO, H. MARIA, C. YTHIER. Comp. Rend. Acad. Sci. (Paris) 277B (1973) 467
(Gamma-ray emission probabilities)
- W. KURCEWICZ, N. KAFFRELL, N. TRAUTMANN, A. PLOCHOCKI, J. ZYLICZ, M. MATUL, K. STRYCNIEWICZ. Nucl. Phys. A289 (1977) 1
(Gamma-ray energies, Gamma-ray emission probabilities)
- W. KURCEWICZ, E. RUCHOWSKA, N. KAFFRELL, N. TRAUTMANN. Nucl. Instrum. Methods 146 (1977) 613
(Gamma-ray energies)
- F. RÖSEL, H.M. FRIES, K. ALDER, H.C. PAULI. At. Data Nucl. Data Tables 21 (1978) 291
(Internal conversion coefficients)
- S. SADASIVAN, V.M. RAGHUNATH. Nucl. Instrum. Methods 196 (1982) 561
(Gamma-ray emission probabilities)
- R. VANINBROUKX, H.H. HANSEN. Int. J. Appl. Radiat. Isot. 34 (1983) 1395
(Gamma-ray emission probabilities)
- U. SCHÖTZIG, K. DEBERTIN. Int. J. Appl. Radiat. Isot. 34 (1983) 533
(Gamma-ray emission probabilities)

- R.J. GEHRKE, V.J. NOVICK, J.D. BAKER. *Int. J. Appl. Radiat. Isot.* 35 (1984) 581
(Gamma-ray emission probabilities)
- G. BORTELS, D. REHER, R. VANINBROUKX. *Int. J. Appl. Radiat. Isot.* 35 (1984) 305
(Gamma-ray emission probabilities)
- P.B. PRICE, J.D. STEVENSON, S.W. BARWICK, H.L. RAVN. *Phys. Lett.* 54 (1985) 297
(Cluster decay)
- E. HOURANI, L. ROSIER, G. BERRIER-RONSIN, A. ELAYI, A.C. MUELLER, G. RAPPENECKER,
G. ROTBARD, G. RENOU, A. LIEBE, L. STAB, H.L. RAVN. *Phys. Lett. C44* (1991) 1424
(Cluster decay)
- W.-J. LIN, G. HARBOTTLE. *J. Radioanal. Nucl. Chem.* 157 (1992) 367
(Gamma-ray emission probabilities)
- T. BABELIOWSKY, G. BORTELS. *Appl. Rad. Isotopes* 44 (1993) 1349
(Alpha-particle emission probabilities)
- G. AUDI, A.H. WAPSTRA. *Nucl. Phys. A595* (1995) 409
(Q value)
- G. ARDISSON, M. HUSSONNOIS. *Radiochim. Acta* 70/71 (1995) 123
(Cluster decay)
- E. SCHÖNFELD, H. JANSSEN. *Nucl. Instrum. Methods Phys. Res. A369* (1996) 527
(K-x ray, L-x ray, Auger electrons)
- A. ARTNA-COHEN. *Nucl. Data Sheets* 80 (1997) 157
(Nuclear structure, energies)
- S.P. TRETYAKOVA, V.L. MIKHEEV. *Nuovo Cim.* 110 (1997) 1043
(Cluster decay)
- E. SCHÖNFELD, G. RODLOFF. *PTB Report* 6.11-98-1 (1998)
(Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. *PTB Report* 6.11-1999-1 (1999)
(K-x ray)
- H. SCHRADER. *Appl. Rad. Isotopes* 60 (2004) 317
(Half-life)





1 Decay Scheme

Le Ra-226 se désintègre par émission alpha principalement vers le niveau excité de 186 keV et le niveau fondamental de Rn-222.

Ra-226 disintegrates by alpha emission mainly to the 186 keV level and to the ground state level of Rn-222.

2 Nuclear Data

$T_{1/2}({}^{226}\text{Ra})$	:	1600	(7)	a
$T_{1/2}({}^{222}\text{Rn})$	:	3,8235	(4)	d
$Q^\alpha({}^{226}\text{Ra})$	:	4870,63	(25)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,4}$	4235 (2)	0,0002	8,65
$\alpha_{0,3}$	4270 (2)	0,0008	4,5
$\alpha_{0,2}$	4422 (1)	0,0065 (16)	10,4
$\alpha_{0,1}$	4684 (1)	5,96 (8)	0,96
$\alpha_{0,0}$	4870,54 (25)	94,03 (8)	1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	P _{$\gamma+ce$} $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(\text{Rn})$	186,211 (13)	5,97 (8)	E2	0,190 (6)	0,367 (11)	0,0986 (30)	0,689 (21)
$\gamma_{2,1}(\text{Rn})$	262,27 (5)	0,0065 (16)	(E2)				0,212 (2)
$\gamma_{3,1}(\text{Rn})$	414,60 (5)	0,0003	(E1)				0,0165 (3)
$\gamma_{4,1}(\text{Rn})$	449,37 (10)	0,0002	[E1]				
$\gamma_{3,0}(\text{Rn})$	600,66 (5)	0,0005	(E1)				0,0077 (2)

3 Atomic Data

3.1 Rn

ω_K	:	0,967	(4)
$\bar{\omega}_L$	:	0,428	(17)
n_{KL}	:	0,804	(5)

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	81,07	60,62	
	K α_1	83,78	100	
	K β_3	94,247	}	
	K β_1	94,868	}	
	K β_5''	95,449	}	34,68
	K β_2	97,48	}	
	K β_4	97,853	}	11,1
	KO _{2,3}	98,357	}	
	X _L	L ℓ	10,137	
		L α	11,59 – 11,72	
L η		12,855		
L β		14,31 – 14,51		
L γ		16,24 – 17,2		

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,4}$	4160 (2)	0,0002
$\alpha_{0,3}$	4191 (2)	0,0008
$\alpha_{0,2}$	4340 (1)	0,0065 (16)
$\alpha_{0,1}$	4601 (1)	5,96 (8)
$\alpha_{0,0}$	4784,34 (25)	94,03 (8)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
ec _{1,0} T	(Rn)	87,814 - 186,168	2,43 (7)
ec _{1,0} K	(Rn)	87,814 (13)	0,67 (2)
ec _{1,0} L	(Rn)	168,163 - 171,601	1,30 (4)
ec _{1,0} M	(Rn)	181,738 - 183,327	0,35 (1)
ec _{1,0} N	(Rn)	185,121 - 185,989	0,092 (3)

6 Photon Emissions

6.1 X-Ray Emissions

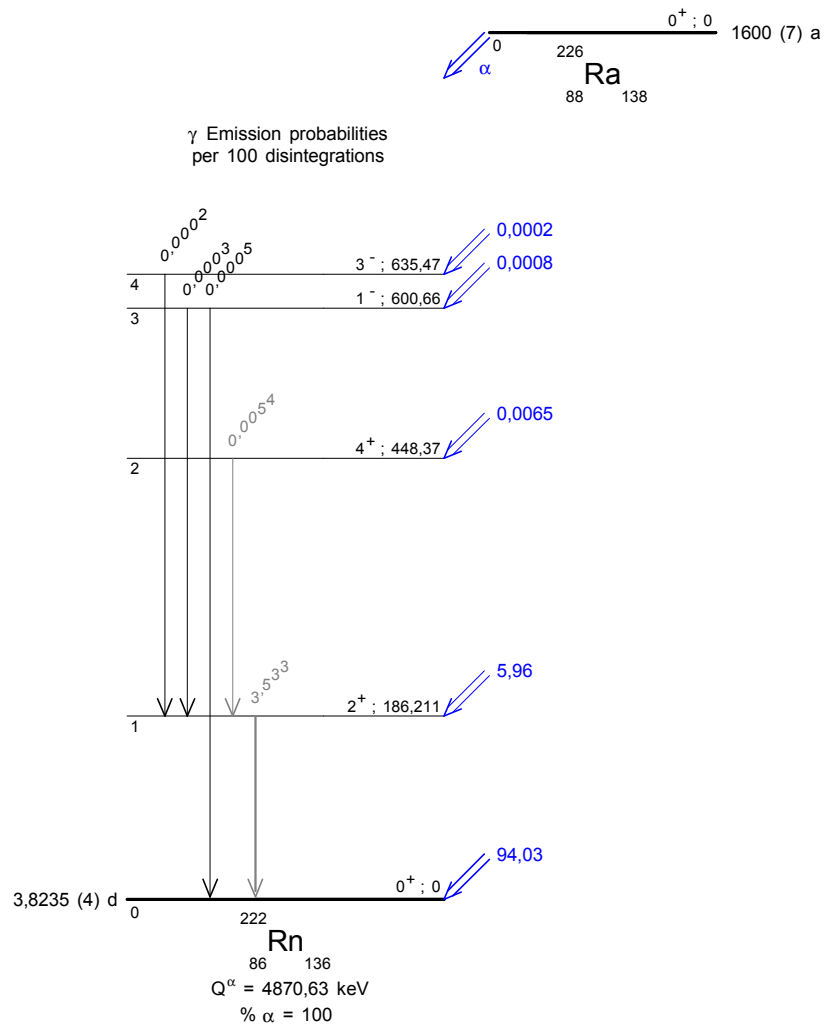
		Energy keV	Photons per 100 disint.	
XL	(Rn)	10,137 — 17,2	0,813 (17)	
XK α_2	(Rn)	81,07	0,191 (7)	} K α
XK α_1	(Rn)	83,78	0,315 (11)	
XK β_3	(Rn)	94,247	} 0,109 (4)	K' β_1
XK β_1	(Rn)	94,868		
XK β_5''	(Rn)	95,449		
XK β_2	(Rn)	97,48		
XK β_4	(Rn)	97,853		
XK $\beta_{2,3}$	(Rn)	98,357		
			0,0349 (14)	K' β_2

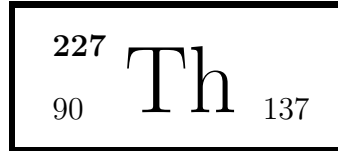
6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (Rn)	186,211 (13)	3,533 (21)
$\gamma_{2,1}$ (Rn)	262,27 (5)	0,0054 (13)
$\gamma_{3,1}$ (Rn)	414,60 (5)	0,0003
$\gamma_{4,1}$ (Rn)	449,37 (10)	0,0002
$\gamma_{3,0}$ (Rn)	600,66 (5)	0,0005

7 References

- T.P.KOHMAN, D.P.AMES, J.SEDLET. NNES 14B (1949) 1675
(Half-life)
- W.SEBAOUN. Ann. Phys. 1 (1956) 680
(Half-life)
- G.R.MARTIN, D.G.TUCK. Int. J. Appl. Radiat. Isotop. 5 (1959) 141
(Half-life)
- G.V.GORSHKOV, ET AL.. Atomnaya Energ., Atomic Energy (USSR) 7 (1959) 912
(Half-life)
- F.S.STEPHENS, F.ASARO, I.PERLMAN. Phys. Rev. 119 (1960) 796
(Gamma-ray emission probabilities)
- G.BASTIN-SCOFFIER, C.F LEANG, R.J WALEN. J. Phys. (Paris) 24 (1963) 854
(Alpha emission energies Alpha emission probabilities)
- H.RAMTHUN. Nucleonics 8 (1966) 244
(Half-life)
- E.W.A.LINGEMAN, J.KONIJN, P.POLAK, A.H.WAPSTRA. Nucl. Phys. A133 (1969) 630
(Gamma-ray emission intensities)
- W.LOURENS, A.H.WAPSTRA. Z. Phys. 247 (1971) 147
(Gamma-ray energies Gamma-ray emission probabilities)
- A.G. DE PINHO, M.WEKSLEK. Z. Naturforsch. 28a (1973) 1635
(X-ray emission intensities)
- A.HACHEM. Comp. Rend. Acad. Sci. (Paris) 281 Serie B (1975) 45
(Gamma-ray emission intensities)
- F.RÖSEL, H.M.FRIESS, K.ALDER, H.C.PAULI. At. Data. Nucl. Data Tables 21 (1978) 92
(Theoretical internal conversion coefficients)
- H.AKÇAY, G.MOUZE, D.MAILLARD, C.YTHIER. Radiochem. Radioanal. Lett. 51 (1982) 1
(Gamma-ray emission intensities)
- D.G.OLSON. Nucl. Instrum. Methods 206 (1983) 313
(Gamma-ray emission intensities)
- U.SCHÖTZIG, K.DEBERTIN. Int. J. Appl. Radiat. Isotop. 34,2 (1983) 533
(Gamma-ray emission intensities, X-ray emission intensities)
- G.MOUZE, C.YTHIER, J.F.COMANDUCCI. Rev. Roumaine Phys. 35 (1990) 337
(Gamma-ray emission intensities)
- W.J.LIN, G.HARBOTTLE. J. Radioanal. Nucl. Chem. Lett. 153 (1991) 137
(Gamma-ray emission intensities)
- A.RYTZ. At. Data. Nucl. Data Tables 47 (1991) 205
(Alpha emission energies Alpha emission probabilities)
- O.DIALLO, G.MOUZE, C.YTHIER, J.F.COMANDUCCI. Nuovo Cim. 106A,10 (1993) 1321
(Gamma-ray emission intensities)
- G.AUDI, A.H.WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q)
- Y.A.AKOVALI. Nucl. Data Sheets 77 (1996) 271
(Spin and Parity)
- J.MOREL, M.ETCHEVERRY, J.L.PICOLO. Appl. Rad. Isotopes 49 (1998) 1387
(Gamma-ray emission intensities)
- D.SARDARI, T.D.MACMAHON. J. Radioanal. Nucl. Chem. 244,2 (2000) 463
(Gamma-ray emission intensities)
- J.U.DELGADO, J.MOREL, M.ETCHEVERRY. Appl. Rad. Isotopes 56 (2002) 137
(Gamma-ray emission intensities, X-ray emission intensities)
- G.L.MOLNAR, ZS.RÉVAY, T.BELGYA. Proc.11th Int. Symp. On Capture gamma-ray Spectroscopy, 2-6 Sep 2002, Pruhonice, Ed. J.Kvasil, P.Cejnar, M.Krticka (2003) 522
(Gamma-ray emission intensities)
- R.G.HELMER. IAEA - CRP Report To be published (2004)
(186-keV gamma ray intensity)





1 Decay Scheme

Th-227 is member of the natural U-235 radioactive decay chain. Th-227 disintegrates entirely by alpha decay to Ra-223.

Le thorium 227 appartient à la chaîne naturelle de l'uranium 235, il se désintègre à 100 % par émission alpha vers le radium 223.

2 Nuclear Data

$T_{1/2}(^{227}\text{Th})$	:	18,718	(5)	d
$T_{1/2}(^{223}\text{Ra})$	:	11,43	(5)	d
$Q^\alpha(^{227}\text{Th})$	:	6146,43	(15)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,56}$	5123,8 (40)	0,00031 (2)	30
$\alpha_{0,53}$	5146,8 (40)	0,00023 (2)	58
$\alpha_{0,52}$	5174,7 (40)	0,000150 (15)	133
$\alpha_{0,51}$	5202,2 (40)	0,00028 (2)	106
$\alpha_{0,50}$	5220,7 (30)	0,00062 (5)	60
$\alpha_{0,49}$	5238,8 (20)	0,00410 (8)	12
$\alpha_{0,46}$	5264 (3)	0,00170 (17)	39
$\alpha_{0,45}$	5273,5 (40)	0,00120 (24)	60
$\alpha_{0,43}$	5286,9 (25)	0,0038 (3)	25
$\alpha_{0,42}$	5303,7 (20)	0,0070 (3)	17
$\alpha_{0,40}$	5323 (2)	0,0098 (3)	16
$\alpha_{0,38}$	5342,4 (20)	0,00320 (16)	61
$\alpha_{0,36}$	5358,7 (20)	0,0026 (2)	94
$\alpha_{0,34}$	5417,3 (40)	0,00024 (10)	2190
$\alpha_{0,33}$	5431,6 (50)	0,0002 (1)	3240
$\alpha_{0,32}$	5461,0 (25)	0,00066 (3)	1410
$\alpha_{0,31}$	5505,7 (30)	0,00044 (7)	3700
$\alpha_{0,30}$	5556,5 (20)	0,00270 (5)	1140
$\alpha_{0,29}$	5578,7 (22)	0,0012 (1)	3400
$\alpha_{0,28}$	5608,7 (20)	0,0166 (3)	362
$\alpha_{0,27}$	5630,9 (18)	0,021 (2)	377

	Energy keV	Probability × 100	F
$\alpha_{0,26}$	5686,1 (16)	0,176 (6)	87
$\alpha_{0,25}$	5701,1 (18)	0,170 (17)	108
$\alpha_{0,23}$	5714,0 (16)	0,216 (8)	99
$\alpha_{0,22}$	5723,0 (17)	0,0070 (4)	3380
$\alpha_{0,21}$	5741,4 (15)	0,0179 (15)	1660
$\alpha_{0,20}$	5770,0 (15)	2,06 (12)	20
$\alpha_{0,19}$	5776,1 (16)	0,057 (4)	791
$\alpha_{0,18}$	5795,0 (16)	1,5 (1)	38
$\alpha_{0,16}$	5803,1 (16)	3,63 (20)	17
$\alpha_{0,15}$	5811,2 (16)	8,3 (3)	8,2
$\alpha_{0,14}$	5815,7 (16)	4,89 (20)	15
$\alpha_{0,13}$	5830,8 (16)	0,0342 (25)	2490
$\alpha_{0,12}$	5860,13 (15)	20,4 (9)	5,9
$\alpha_{0,11}$	5865,7 (15)	0,228 (10)	561
$\alpha_{0,10}$	5899,5 (15)	0,311 (5)	599
$\alpha_{0,9}$	5911,7 (15)	1,27 (2)	169
$\alpha_{0,7}$	5971,8	2,42 (10)	175
$\alpha_{0,6}$	6015,9 (15)	0,174 (8)	4000
$\alpha_{0,5}$	6022,0 (15)	0,775 (30)	963
$\alpha_{0,4}$	6066,6 (15)	3,00 (15)	404
$\alpha_{0,3}$	6084,94 (10)	23,5 (9)	63
$\alpha_{0,2}$	6096,8 (20)	<0,005	835000
$\alpha_{0,1}$	6116,6 (15)	2,90 (15)	717
$\alpha_{0,0}$	6146,32 (15)	24,2 (9)	118

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{6,5}(\text{Ra})$	6,5 (3)	3,7 (11)	[E1]				41,2 (12)
$\gamma_{17,16}(\text{Ra})$	8,15 (20)	0,008 (3)					
$\gamma_{2,1}(\text{Ra})$	20,25 (5)	1,90 (23)	[E1]		2,83 (8)	1,51 (5)	7,2 (2)
$\gamma_{25,22}(\text{Ra})$	20,94 (5)	0,006 (3)					
$\gamma_{(-1,1)}(\text{Ra})$	22,0 (2)	0,009 (9)					
$\gamma_{(-1,2)}(\text{Ra})$	24,13 (5)	0,086 (8)					
$\gamma_{(-1,3)}(\text{Ra})$	27,41 (9)	0,029 (5)					
$\gamma_{4,2}(\text{Ra})$	29,60 (3)	13,0 (7)	[M1+62,8%E2]		1653 (50)	444 (13)	2246 (67)
$\gamma_{1,0}(\text{Ra})$	29,86 (1)	43 (6)	M1+14,4%E2		429 (13)	113 (3)	581 (17)
$\gamma_{3,1}(\text{Ra})$	31,58 (1)	19 (3)	M1+7,3%E2		205 (6)	53,2 (16)	276 (8)
$\gamma_{20,17}(\text{Ra})$	33,39 (8)	0,023 (8)	[E1]		1,57 (5)	0,395 (12)	2,09 (6)
$\gamma_{25,21}(\text{Ra})$	40,20 (3)	0,015 (4)					
$\gamma_{20,15}(\text{Ra})$	41,93 (5)	0,06 (3)	[E1]		0,86 (3)	0,214 (6)	1,14 (3)
$\gamma_{14,12}(\text{Ra})$	43,77 (5)	0,42 (3)	E1		0,767 (23)	0,191 (6)	1,02 (3)
$\gamma_{(-1,4)}(\text{Ra})$	43,8 (5)	0,054 (22)					
$\gamma_{5,4}(\text{Ra})$	44,22 (12)	6,9 (17)	M1+21,3%E2		98 (3)	25,8 (8)	132 (4)
$\gamma_{8,6}(\text{Ra})$	44,40 (5)	0,6 (4)	M1		27,1 (8)	6,55 (20)	35,8 (11)
$\gamma_{15,12}(\text{Ra})$	48,30 (3)	4,4 (16)	E2		232 (7)	63,1 (19)	317 (10)
$\gamma_{4,1}(\text{Ra})$	49,82 (5)	0,72 (16)	E1		0,542 (16)	0,133 (4)	0,72 (2)
$\gamma_{2,0}(\text{Ra})$	50,13 (1)	14,0 (9)	E1		0,533 (16)	0,131 (4)	0,708 (21)
$\gamma_{7,5}(\text{Ra})$	50,85 (5)	0,8 (4)	M1+13,8%E2		40,6 (12)	10,5 (3)	54,7 (16)
$\gamma_{15,11}(\text{Ra})$	54,19 (4)	0,13 (3)	(M1)		15,0 (5)	3,60 (11)	19,9 (6)
$\gamma_{23,20}(\text{Ra})$	56,00 (6)	0,091 (5)	M1		13,6 (4)	3,27 (10)	18,1 (5)
$\gamma_{16,12}(\text{Ra})$	56,42 (7)	0,4 (3)	M1+18,1%E2		30,7 (9)	8,00 (24)	41,5 (12)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{(-1,8)}$ (Ra)	59,6 (5)	0,010 (4)					
$\gamma_{3,0}$ (Ra)	61,44 (2)	8,8 (11)	E2		72,4 (22)	19,7 (6)	99 (3)
$\gamma_{17,11}$ (Ra)	62,45 (5)	4,0 (6)	M1+7,8%E2		14,4 (4)	3,61 (11)	19,2 (6)
$\gamma_{21,17}$ (Ra)	62,68 (3)	0,010 (4)	[E1]		0,294 (9)	0,0719 (22)	0,39 (1)
$\gamma_{18,12}$ (Ra)	64,35 (10)	0,034 (5)	[E1]		0,274 (8)	0,067 (2)	0,363 (11)
$\gamma_{(-1,9)}$ (Ra)	66,2 (5)	0,006 (4)					
$\gamma_{(-1,10)}$ (Ra)	66,4 (5)	0,008 (4)					
$\gamma_{(-1,11)}$ (Ra)	68,7 (1)	0,202 (11)	M1+50%E2		24,9 (7)	6,7 (2)	33,8 (10)
$\gamma_{6,3}$ (Ra)	68,74 (3)	1,07 (20)	M1+16,8%E2		13,3 (4)	3,43 (10)	17,9 (5)
$\gamma_{(-1,12)}$ (Ra)	69,8 (3)	0,010 (4)					
$\gamma_{10,7}$ (Ra)	72,85 (5)	0,024 (19)					
$\gamma_{5,2}$ (Ra)	73,63 (5)	0,59 (22)	E2		30,4 (9)	8,29 (25)	41,5 (12)
$\gamma_{(-1,0)}$ (Ra)	75,01 (5)	0,026 (10)					
$\gamma_{(-1,13)}$ (Ra)	77,4 (4)	0,0101 (5)					
$\gamma_{4,0}$ (Ra)	79,69 (2)	2,30 (13)	E1		0,155 (5)	0,0377 (11)	0,205 (6)
$\gamma_{23,17}$ (Ra)	89,6 (4)	0,0038 (13)					
$\gamma_{5,1}$ (Ra)	93,88 (5)	1,67 (9)	E1		0,100 (3)	0,0243 (7)	0,133 (4)
$\gamma_{7,4}$ (Ra)	94,97 (5)	0,32 (19)	E2		9,1 (3)	2,48 (7)	12,4 (4)
$\gamma_{20,11}$ (Ra)	96,03 (5)	0,077 (15)	(E1)		0,094 (3)	0,0229 (7)	0,125 (4)
$\gamma_{15,9}$ (Ra)	99,58 (10)	0,025 (6)					
$\gamma_{24,17}$ (Ra)	99,6 (2)	0,0126 (6)					
$\gamma_{6,1}$ (Ra)	100,27 (3)	0,87 (17)	E2		7,06 (21)	1,93 (6)	9,6 (3)
$\gamma_{23,14}$ (Ra)	102,5 (1)	0,00113 (5)					
$\gamma_{11,7}$ (Ra)	105,2 (1)	0,0097 (5)					
$\gamma_{16,9}$ (Ra)	107,76 (7)	0,09 (3)	(M1), [E2]	5,6 (2)	3,53 (11)	0,93 (3)	10,4 (3)
$\gamma_{22,1}$ (Ra)	109,2 (4)	0,0052 (15)					
$\gamma_{25,15}$ (Ra)	110,65 (5)	0,023 (15)	E2	0,286 (9)	4,46 (13)	1,22 (4)	6,38 (19)
$\gamma_{(-1,14)}$ (Ra)	112,6 (5)	0,009 (4)					
$\gamma_{8,3}$ (Ra)	113,11 (5)	0,75 (14)	E1	0,279 (8)	0,0613 (18)	0,0148 (4)	0,360 (11)
$\gamma_{7,3}$ (Ra)	113,11	1,3 (6)	E2	0,294 (9)	4,03 (12)	1,10 (3)	5,80 (17)
$\gamma_{10,6}$ (Ra)	117,20 (5)	0,258 (22)	E1	0,256 (8)	0,0558 (17)	0,0135 (4)	0,33 (1)
$\gamma_{(-1,61)}$ (Ra)	117,5 (5)	0,012 (4)					
$\gamma_{10,5}$ (Ra)	123,58 (10)	0,014 (5)					
$\gamma_{21,11}$ (Ra)	124,44 (20)	0,0040 (22)					
$\gamma_{(-1,15)}$ (Ra)	128,02 (2)	0,0032 (5)					
$\gamma_{(-1,19)}$ (Ra)	129,4 (2)	0,0013 (6)					
$\gamma_{19,9}$ (Ra)	134,6 (1)	0,040 (8)	[E1]	0,185 (6)	0,0389 (12)	0,0094 (3)	0,236 (7)
$\gamma_{(-1,23)}$ (Ra)	138,4 (1)	0,014 (3)					
$\gamma_{(-1,24)}$ (Ra)	140,6 (3)	0,021 (3)					
$\gamma_{20,9}$ (Ra)	141,42 (5)	0,140 (28)	E1	0,164 (5)	0,0342 (10)	0,00820 (25)	0,210 (6)
$\gamma_{11,6}$ (Ra)	150,14 (20)	0,011 (3)					
$\gamma_{24,11}$ (Ra)	162,19 (10)	0,008 (3)					
$\gamma_{(-1,25)}$ (Ra)	164,52 (10)	0,014 (3)					
$\gamma_{17,7}$ (Ra)	168,36 (10)	0,014 (3)					
$\gamma_{21,9}$ (Ra)	169,95 (10)	0,0054 (22)					
$\gamma_{(-1,27)}$ (Ra)	171,5 (2)	0,0038 (13)					
$\gamma_{9,3}$ (Ra)	173,45 (3)	0,055 (1)	M1,E2	1,51 (5)	0,553 (17)	0,142 (4)	2,26 (7)
$\gamma_{(-1,30)}$ (Ra)	175,8 (3)	0,020 (5)					
$\gamma_{(-1,33)}$ (Ra)	181,1 (3)	0,0025 (13)					
$\gamma_{(-1,35)}$ (Ra)	182,3 (2)	0,0038 (13)					
$\gamma_{9,2}$ (Ra)	184,65 (5)	0,039 (5)	E1	0,0874 (30)	0,0172 (5)	0,00410 (12)	0,110 (3)
$\gamma_{25,10}$ (Ra)	197,56 (10)	0,013 (4)					
$\gamma_{11,4}$ (Ra)	200,5 (1)	0,013 (9)					
$\gamma_{20,7}$ (Ra)	201,64 (10)	0,048 (6)	M1+71,7%E2	0,636 (20)	0,316 (9)	0,0825 (25)	1,06 (3)
$\gamma_{(-1,37)}$ (Ra)	202,5 (5)	0,006 (3)					
$\gamma_{15,6}$ (Ra)	204,14 (10)	0,340 (47)	E2	0,156 (5)	0,291 (9)	0,0787 (24)	0,552 (17)
$\gamma_{9,1}$ (Ra)	204,98 (10)	0,51 (8)	M1+1,4%E2	1,74 (5)	0,322 (10)	0,0774 (23)	2,17 (7)
$\gamma_{14,5}$ (Ra)	206,08 (5)	0,38 (4)	E2	0,153 (5)	0,280 (8)	0,0756 (23)	0,534 (16)
$\gamma_{15,5}$ (Ra)	210,62 (5)	1,32 (11)	E1	0,0642 (19)	0,0124 (4)	0,00297 (9)	0,0805 (24)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{17,6}(\text{Ra})$	212,70 (4)	0,21 (3)	M1+13,8%E2	1,39 (4)	0,285 (9)	0,0692 (21)	1,77 (5)
$\gamma_{26,10}(\text{Ra})$	212,7 (3)	0,019 (5)					
$\gamma_{(-1,40)}(\text{Ra})$	216,0 (1)	0,00025 (13)					
$\gamma_{11,3}(\text{Ra})$	218,90 (5)	0,30 (3)	M1	1,47 (4)	0,268 (8)	0,0643 (19)	1,82 (5)
$\gamma_{(-1,43)}(\text{Ra})$	219,0 (2)	0,049 (12)					
$\gamma_{(-1,45)}(\text{Ra})$	223,2 (4)	0,0050 (13)					
$\gamma_{26,9}(\text{Ra})$	225,5 (3)	0,009 (3)					
$\gamma_{21,7}(\text{Ra})$	229,9 (5)	0,0038 (13)					
$\gamma_{9,0}(\text{Ra})$	234,76 (10)	1,10 (14)	M1(+0,5%E2)	1,20 (4)	0,220 (7)	0,0528 (16)	1,49 (4)
$\gamma_{12,2}(\text{Ra})$	235,96 (2)	13,4 (6)	E1	0,0493 (15)	0,0093 (3)	0,00224 (7)	0,0617 (19)
$\gamma_{20,6}(\text{Ra})$	246,12 (10)	0,0120 (22)					
$\gamma_{(-1,63)}(\text{Ra})$	248,1 (1)	0,024 (5)					
$\gamma_{22,8}(\text{Ra})$	249,6 (5)	0,0076 (25)					
$\gamma_{11,1}(\text{Ra})$	250,15 (5)	0,020 (4)	M1	1,01 (3)	0,185 (6)	0,0443 (13)	1,26 (4)
$\gamma_{14,4}(\text{Ra})$	250,27 (8)	0,64 (6)	M1+81,5%E2	0,271 (8)	0,136 (4)	0,0355 (11)	0,455 (14)
$\gamma_{20,5}(\text{Ra})$	252,50 (5)	0,24 (4)	M1	0,99 (3)	0,180 (5)	0,0431 (13)	1,22 (4)
$\gamma_{15,4}(\text{Ra})$	254,63 (3)	0,73 (14)	E1	0,041 (1)	0,00776 (23)	0,00186 (6)	0,0517 (16)
$\gamma_{12,1}(\text{Ra})$	256,23 (2)	8,5 (4)	E2	0,099 (3)	0,114 (3)	0,0305 (9)	0,253 (8)
$\gamma_{(-1,47)}(\text{Ra})$	260,6 (2)	0,0051 (13)					
$\gamma_{16,4}(\text{Ra})$	262,87 (5)	0,110 (9)	E1	0,0385 (10)	0,00719 (22)	0,00172 (5)	0,0480 (14)
$\gamma_{(-1,50)}(\text{Ra})$	265,3 (2)	0,0050 (13)					
$\gamma_{27,10}(\text{Ra})$	267,05 (20)	0,010 (3)					
$\gamma_{24,8}(\text{Ra})$	267,86 (20)	0,0069 (25)					
$\gamma_{25,7}(\text{Ra})$	270,56 (20)	0,028 (9)					
$\gamma_{15,3}(\text{Ra})$	272,91 (5)	0,80 (6)	M1+50%E2	0,441 (13)	0,117 (4)	0,0292 (9)	0,597 (18)
$\gamma_{14,2}(\text{Ra})$	279,80 (5)	0,101 (25)	M1+1,4%E2	0,773 (23)	0,135 (4)	0,0323 (10)	0,91 (3)
$\gamma_{21,5}(\text{Ra})$	280,7 (3)	0,0025 (13)					
$\gamma_{17,3}(\text{Ra})$	281,42 (5)	0,304 (25)	M1+21,9%E2	0,588 (18)	0,121 (4)	0,0294 (9)	0,749 (22)
$\gamma_{15,10}(\text{Ra})$	284,24 (10)	0,039 (13)					
$\gamma_{26,7}(\text{Ra})$	285,52 (10)	0,066 (18)	M1+50%E2	0,390 (12)	0,101 (3)	0,0252 (8)	0,526 (16)
$\gamma_{12,0}(\text{Ra})$	286,09 (2)	2,6 (3)	M1+50%E2	0,390 (12)	0,101 (3)	0,0252 (8)	0,526 (16)
$\gamma_{19,4}(\text{Ra})$	289,59 (10)	1,9 (4)					
$\gamma_{28,10}(\text{Ra})$	289,77 (10)	0,019 (4)					
$\gamma_{16,2}(\text{Ra})$	292,41 (5)	0,066 (8)	E1	0,0303 (10)	0,00557 (17)	0,00133 (4)	0,0377 (11)
$\gamma_{20,4}(\text{Ra})$	296,50 (5)	0,76 (8)	M1+1,7%E2	0,624 (19)	0,114 (3)	0,0274 (8)	0,775 (23)
$\gamma_{14,1}(\text{Ra})$	299,98 (3)	2,24 (12)	E1	0,0286 (10)	0,00525 (16)	0,00125 (4)	0,0356 (11)
$\gamma_{18,2}(\text{Ra})$	300,50 (16)	0,0200 (44)	(M1+50%E2)	0,34 (1)	0,086 (3)	0,0214 (6)	0,455 (14)
$\gamma_{15,1}(\text{Ra})$	304,50 (2)	2,4 (3)	M1+6,3%E2(+E0)	0,95 (12)	0,161 (22)	0,024 (8)	1,1 (1)
$\gamma_{(-1,53)}(\text{Ra})$	306,1 (3)	0,010 (4)					
$\gamma_{23,5}(\text{Ra})$	308,40 (3)	0,024 (4)	M1+50%E2	0,318 (10)	0,0792 (24)	0,0197 (6)	0,424 (13)
$\gamma_{16,1}(\text{Ra})$	312,69 (3)	0,83 (8)	M1+2,5%E2	0,535 (16)	0,098 (3)	0,0236 (7)	0,665 (20)
$\gamma_{(-1,55)}(\text{Ra})$	314,75 (10)	0,034 (2)					
$\gamma_{20,3}(\text{Ra})$	314,85 (48)	0,48 (4)	E1 or M1				
$\gamma_{24,5}(\text{Ra})$	318,46 (20)	0,0066 (22)					
$\gamma_{19,2}(\text{Ra})$	319,24 (5)	0,050 (11)	M1+3,1%E2	0,503 (15)	0,093 (3)	0,0222 (7)	0,626 (19)
$\gamma_{21,4}(\text{Ra})$	324,88 (20)	0,014 (4)	M1+50%E2	0,277 (8)	0,0674 (20)	0,0167 (5)	0,367 (11)
$\gamma_{20,2}(\text{Ra})$	325,99 (18)	0,006 (3)					
$\gamma_{14,0}(\text{Ra})$	329,85 (2)	3,0 (2)	(E1)	0,0232 (10)	0,0042 (1)	0,00100 (3)	0,0288 (9)
$\gamma_{(-1,57)}(\text{Ra})$	332,2 (2)	0,0016 (5)					
$\gamma_{15,0}(\text{Ra})$	334,37 (2)	1,60 (13)	M1+27,1%E2	0,348 (10)	0,0714 (21)	0,0174 (5)	0,442 (13)
$\gamma_{27,8}(\text{Ra})$	339,76 (10)	0,0038 (13)					
$\gamma_{16,0}(\text{Ra})$	342,55 (4)	0,43 (11)	M1+62,5%E2	0,194 (6)	0,0523 (16)	0,0131 (4)	0,264 (8)
$\gamma_{20,1}(\text{Ra})$	346,45 (1)	0,0117 (14)					
$\gamma_{(-1,60)}(\text{Ra})$	348,5 (5)	0,0066 (22)					
$\gamma_{18,0}(\text{Ra})$	350,54 (7)	0,110 (19)	E1	0,0204 (10)	0,00366 (11)	0,00090 (3)	0,0252 (8)
$\gamma_{23,4}(\text{Ra})$	352,61 (10)	0,013 (3)	M1+50%E2	0,223 (7)	0,0525 (16)	0,0130 (4)	0,293 (9)
$\gamma_{22,3}(\text{Ra})$	362,63 (10)	0,050 (3)					
$\gamma_{19,0}(\text{Ra})$	369,35 (5)	0,0060 (13)					
$\gamma_{23,3}(\text{Ra})$	370,93 (8)	0,004 (3)					

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{21,1}$ (Ra)	374,8 (2)	0,00151 (7)					
$\gamma_{20,0}$ (Ra)	376,27 (10)	0,0050 (13)					
$\gamma_{(-1,62)}$ (Ra)	379,4 (1)	0,010 (3)					
$\gamma_{23,2}$ (Ra)	382,2 (3)	0,0063 (13)					
$\gamma_{25,3}$ (Ra)	383,51 (4)	0,03 (3)	M1+17,5%E2	0,267 (8)	0,0512 (15)	0,0124 (4)	0,335 (10)
$\gamma_{(-1,64)}$ (Ra)	392,4 (5)	0,0098 (22)					
$\gamma_{26,3}$ (Ra)	398,6 (3)	0,0014 (4)					
$\gamma_{23,1}$ (Ra)	402,2 (3)	0,008 (5)					
$\gamma_{25,1}$ (Ra)	415,11 (10)	0,0014 (6)					
$\gamma_{23,0}$ (Ra)	432,33 (10)	0,0040 (5)					
$\gamma_{(-1,66)}$ (Ra)	442,5 (10)	0,000058 (3)					
$\gamma_{(-1,68)}$ (Ra)	445	0,0005 (5)					
$\gamma_{49,26}$ (Ra)	448,0 (6)	0,000139 (8)					
$\gamma_{36,15}$ (Ra)	452,9 (3)	0,001					
$\gamma_{36,14}$ (Ra)	457,5 (1)	0,000068 (3)					
$\gamma_{(-1,70)}$ (Ra)	462 (1)	0,000048 (2)					
$\gamma_{30,5}$ (Ra)	466,8 (2)	0,0005 (3)					
$\gamma_{(-1,72)}$ (Ra)	469,0 (2)	0,0009 (3)					
$\gamma_{40,17}$ (Ra)	480 (1)	0,00029 (9)					
$\gamma_{43,20}$ (Ra)	482 (1)	0,00014 (4)					
$\gamma_{40,14}$ (Ra)	493,1 (2)	0,00053 (8)					
$\gamma_{42,15}$ (Ra)	507,5 (1)	0,00064 (25)					
$\gamma_{43,16}$ (Ra)	516,6 (3)	0,00028 (10)					
$\gamma_{(-1,74)}$ (Ra)	521,8 (3)	0,00038 (13)					
$\gamma_{43,15}$ (Ra)	524,5 (4)	0,00019 (4)					
$\gamma_{48,19}$ (Ra)	534,6 (4)	0,00010 (3)					
$\gamma_{40,12}$ (Ra)	536,9 (1)	0,00107 (17)					
$\gamma_{(-1,78)}$ (Ra)	540,2 (3)	0,00025 (13)					
$\gamma_{36,9}$ (Ra)	552,4 (5)	0,00023 (5)					
$\gamma_{42,12}$ (Ra)	556,1 (2)	0,00037 (15)					
$\gamma_{(-1,80)}$ (Ra)	565,4 (1)	0,0014 (3)					
$\gamma_{38,9}$ (Ra)	569,1 (3)	0,00058 (9)					
$\gamma_{50,18}$ (Ra)	576,0 (2)	0,00032 (19)					
$\gamma_{43,11}$ (Ra)	579,0 (2)	0,0004 (3)					
$\gamma_{(-1,82)}$ (Ra)	585,8 (1)	0,0009 (3)					
$\gamma_{40,9}$ (Ra)	589,0 (6)	0,000058 (15)					
$\gamma_{50,14}$ (Ra)	596 (1)	0,0000101 (5)					
$\gamma_{(-1,84)}$ (Ra)	598,9 (2)	0,00063 (13)					
$\gamma_{42,9}$ (Ra)	607,7 (3)	0,00018 (4)					
$\gamma_{49,12}$ (Ra)	621,4 (5)	0,000058 (15)					
$\gamma_{53,20}$ (Ra)	623,8 (5)	0,00016 (4)					
$\gamma_{33,4}$ (Ra)	632,3 (7)	0,00014 (3)					
$\gamma_{52,14}$ (Ra)	641,0 (5)	0,000019 (6)					
$\gamma_{45,9}$ (Ra)	644,3 (3)	0,00009 (4)					
$\gamma_{(-1,86)}$ (Ra)	648,5 (5)	0,000019 (6)					
$\gamma_{33,2}$ (Ra)	662,8 (4)	0,000058 (18)					
$\gamma_{50,9}$ (Ra)	692,0 (7)	0,000039 (11)					
$\gamma_{45,8}$ (Ra)	704,3 (5)	0,000078 (16)					
$\gamma_{36,4}$ (Ra)	707,2 (7)	0,000039 (11)					
$\gamma_{42,5}$ (Ra)	718,5 (10)	0,000029 (11)					
$\gamma_{35,3}$ (Ra)	722,1 (6)	0,00037 (12)					
$\gamma_{38,4}$ (Ra)	723,5 (1)	0,00027 (10)					
$\gamma_{35,2}$ (Ra)	734,4 (5)	0,00010 (4)					
$\gamma_{43,5}$ (Ra)	735,4 (2)	0,00016 (5)					
$\gamma_{36,2}$ (Ra)	738,4 (10)	0,000068 (17)					
$\gamma_{41,4}$ (Ra)	746,4 (7)	0,00010 (4)					
$\gamma_{45,6}$ (Ra)	748,8 (4)	0,00040 (12)					
$\gamma_{35,1}$ (Ra)	754,1 (2)	0,00024 (14)					
$\gamma_{36,1}$ (Ra)	756,9 (2)	0,00019 (5)					

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{(-1,88)}$ (Ra)	757,3 (4)	0,00102 (24)					
$\gamma_{42,4}$ (Ra)	762,6 (5)	0,00026 (5)					
$\gamma_{41,3}$ (Ra)	766,3 (5)	0,00029 (6)					
$\gamma_{40,2}$ (Ra)	773,4 (4)	0,00015 (4)					
$\gamma_{41,2}$ (Ra)	775,8 (5)	0,00151 (15)					
$\gamma_{42,3}$ (Ra)	781,0 (5)	0,00032 (6)					
$\gamma_{35,0}$ (Ra)	784,2 (5)	0,000097 (24)					
$\gamma_{36,0}$ (Ra)	787,4 (5)	0,000039 (10)					
$\gamma_{(-1,95)}$ (Ra)	787,6 (5)	0,00011 (3)					
$\gamma_{40,1}$ (Ra)	792,6 (6)	0,000029 (8)					
$\gamma_{37,0}$ (Ra)	792,6 (6)	0,000039 (10)					
$\gamma_{43,3}$ (Ra)	797,3 (5)	0,00090 (12)					
$\gamma_{38,0}$ (Ra)	803,9 (4)	0,00063 (6)					
$\gamma_{43,2}$ (Ra)	808,6 (4)	0,000076 (25)					
$\gamma_{42,1}$ (Ra)	812,6 (4)	0,0017 (3)					
$\gamma_{(-1,92)}$ (Ra)	818 (1)	0,000029 (11)					
$\gamma_{45,3}$ (Ra)	818,1 (2)	0,00017 (8)					
$\gamma_{40,0}$ (Ra)	823,4 (4)	0,0025 (3)					
$\gamma_{41,0}$ (Ra)	826,7 (5)	0,00016 (5)					
$\gamma_{43,1}$ (Ra)	828,5 (5)	0,00019 (5)					
$\gamma_{(-1,94)}$ (Ra)	828,9 (2)	0,00076 (4)					
$\gamma_{44,1}$ (Ra)	837,8 (5)	0,00052 (12)					
$\gamma_{42,0}$ (Ra)	842,5 (3)	0,00087 (13)					
$\gamma_{50,4}$ (Ra)	846,7 (5)	0,00015 (3)					
$\gamma_{45,1}$ (Ra)	848,3 (6)	0,00027 (11)					
$\gamma_{46,1}$ (Ra)	854,3 (5)	0,000068 (14)					
$\gamma_{49,2}$ (Ra)	857,3 (7)	0,000058 (18)					
$\gamma_{43,0}$ (Ra)	858,9 (2)	0,00025 (4)					
$\gamma_{51,4}$ (Ra)	863 (1)	0,000019 (8)					
$\gamma_{44,0}$ (Ra)	867,3 (5)	0,00029 (22)					
$\gamma_{50,2}$ (Ra)	876,3 (4)	0,00023 (8)					
$\gamma_{49,1}$ (Ra)	878,2 (4)	0,00014 (4)					
$\gamma_{47,0}$ (Ra)	891 (1)	0,000019 (6)					
$\gamma_{51,2}$ (Ra)	893 (1)	0,000013 (4)					
$\gamma_{50,1}$ (Ra)	896,1 (5)	0,00011 (3)					
$\gamma_{49,0}$ (Ra)	908,6 (4)	0,0023 (3)					
$\gamma_{52,3}$ (Ra)	910 (1)	0,000015 (6)					
$\gamma_{53,4}$ (Ra)	920,0 (5)	0,000011 (3)					
$\gamma_{50,0}$ (Ra)	927 (1)	0,000006 (3)					
$\gamma_{53,3}$ (Ra)	938,0 (8)	0,000010 (4)					
$\gamma_{52,1}$ (Ra)	941,6 (3)	0,000069 (11)					
$\gamma_{55,3}$ (Ra)	958,7 (3)	0,000061 (13)					
$\gamma_{53,1}$ (Ra)	970,2 (2)	0,00014 (11)					
$\gamma_{52,0}$ (Ra)	971,7 (10)	0,000010 (5)					
$\gamma_{55,1}$ (Ra)	990,0 (7)	0,000034 (9)					
$\gamma_{56,1}$ (Ra)	995 (1)	0,000006 (4)					
$\gamma_{53,0}$ (Ra)	999,8 (5)	0,000029 (8)					
$\gamma_{54,0}$ (Ra)	1015,2 (7)	0,000015 (4)					
$\gamma_{55,0}$ (Ra)	1020 (1)	0,000019 (6)					
$\gamma_{56,0}$ (Ra)	1025 (1)	0,000015 (4)					

3 Atomic Data

3.1 Ra

ω_K	:	0,968	(4)
$\bar{\omega}_L$	:	0,452	(18)
n_{KL}	:	0,801	(5)

3.1.1 X Radiations

		Energy keV	Relative probability
X _K	K α_2	85,43	61,15
	K α_1	88,47	100
	K β_3	99,432	}
	K β_1	100,13	
	K β_5''	100,738	
	K β_2	102,89	}
	K β_4	103,295	
	KO _{2,3}	103,74	
	X _L	L ℓ	10,662
L α		12,196 – 12,339	
L η		13,662	
L β		14,236 – 15,447	
L γ		17,848 – 18,412	

3.1.2 Auger Electrons

		Energy keV	Relative probability
Auger K			
KLL	65,149 – 72,729	100	
KLX	79,721 – 88,466	58,2	
KXY	94,27 – 103,91	8,36	
Auger L			
	5,71 – 12,04		

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,56}$	5033,5 (40)	0,00031 (2)
$\alpha_{0,53}$	5056,1 (40)	0,00023 (2)
$\alpha_{0,52}$	5083,5 (40)	0,000150 (15)

	Energy keV	Probability × 100
$\alpha_{0,51}$	5110,5 (40)	0,00028 (2)
$\alpha_{0,50}$	5128,7 (30)	0,00062 (5)
$\alpha_{0,49}$	5146,5 (20)	0,00410 (8)
$\alpha_{0,46}$	5171 (3)	0,00170 (17)
$\alpha_{0,45}$	5180,6 (40)	0,00120 (24)
$\alpha_{0,43}$	5193,7 (25)	0,0038 (3)
$\alpha_{0,42}$	5210,2 (20)	0,0070 (3)
$\alpha_{0,40}$	5229,2 (20)	0,0098 (3)
$\alpha_{0,38}$	5248,3 (20)	0,00320 (16)
$\alpha_{0,36}$	5264,3 (20)	0,0026 (2)
$\alpha_{0,34}$	5321,8 (40)	0,00024 (10)
$\alpha_{0,33}$	5335,9 (50)	0,0002 (1)
$\alpha_{0,32}$	5365,0 (25)	0,00066 (3)
$\alpha_{0,31}$	5408,7 (30)	0,00044 (7)
$\alpha_{0,30}$	5458,6 (20)	0,00270 (5)
$\alpha_{0,29}$	5480,4 (22)	0,0012 (1)
$\alpha_{0,28}$	5509,9 (20)	0,0166 (3)
$\alpha_{0,27}$	5531,7 (18)	0,021 (2)
$\alpha_{0,26}$	5585,9 (16)	0,176 (6)
$\alpha_{0,25}$	5600,6 (18)	0,170 (17)
$\alpha_{0,23}$	5613,3 (16)	0,216 (8)
$\alpha_{0,22}$	5622,0 (17)	0,0070 (4)
$\alpha_{0,21}$	5640,2 (15)	0,0179 (15)
$\alpha_{0,20}$	5668,0 (15)	2,06 (12)
$\alpha_{0,19}$	5674,3 (16)	0,057 (4)
$\alpha_{0,18}$	5693,0 (16)	1,5 (1)
$\alpha_{0,16}$	5700,8 (16)	3,63 (20)
$\alpha_{0,15}$	5708,8 (16)	8,3 (3)
$\alpha_{0,14}$	5713,2 (16)	4,89 (20)
$\alpha_{0,13}$	5728,1 (16)	0,0342 (25)
$\alpha_{0,12}$	5756,87 (15)	20,4 (9)
$\alpha_{0,11}$	5762,3 (15)	0,228 (10)
$\alpha_{0,10}$	5795,5 (15)	0,311 (5)
$\alpha_{0,9}$	5807,5 (15)	1,27 (2)
$\alpha_{0,7}$	5866,6	2,42 (10)
$\alpha_{0,6}$	5909,9 (15)	0,174 (8)
$\alpha_{0,5}$	5916,0 (15)	0,775 (30)
$\alpha_{0,4}$	5959,7 (15)	3,00 (15)
$\alpha_{0,3}$	5977,72 (10)	23,5 (9)
$\alpha_{0,2}$	5989,4 (20)	<0,005
$\alpha_{0,1}$	6008,8 (15)	2,90 (15)
$\alpha_{0,0}$	6038,01 (15)	24,2 (9)

5 Electron Emissions

	Energy keV	Electrons per 100 disint.
e_{AL}	(Ra) 5,71 - 12,04	55,9 (22)
e_{AK}	(Ra)	0,20 (3)
	KLL 65,149 - 72,729	}
	KLX 79,721 - 88,466	}
	KXY 94,27 - 103,91	}

		Energy keV	Electrons per 100 disint.
ec2,1 L	(Ra)	1,018 - 4,806	0,65 (9)
ec7,3 K	(Ra)	9,195	0,06 (3)
ec4,2 L	(Ra)	10,368 - 14,156	9,6 (9)
ec1,0 L	(Ra)	10,628 - 14,416	32 (5)
ec3,1 L	(Ra)	12,348 - 16,136	13,7 (25)
ec2,1 M	(Ra)	15,428 - 17,145	0,35 (5)
ec2,1 N	(Ra)	19,042 - 19,971	0,66 (9)
ec4,2 M	(Ra)	24,778 - 26,495	2,58 (23)
ec5,4 L	(Ra)	24,988 - 28,776	5,1 (13)
ec1,0 M	(Ra)	25,038 - 26,755	8,5 (14)
ec3,1 M	(Ra)	26,758 - 28,475	3,6 (6)
ec4,2 N	(Ra)	28,392 - 29,321	0,86 (8)
ec1,0 N	(Ra)	28,652 - 29,581	2,9 (5)
ec15,12 L	(Ra)	29,068 - 32,856	3,2 (12)
ec3,1 N	(Ra)	30,372 - 31,301	1,19 (22)
ec2,0 L	(Ra)	30,898 - 34,686	4,4 (4)
ec5,4 M	(Ra)	39,398 - 41,115	1,3 (3)
ec3,0 L	(Ra)	42,208 - 46,000	6,4 (9)
ec5,4 N	(Ra)	43,012 - 43,941	0,44 (11)
ec17,11 L	(Ra)	43,218 - 47,010	2,9 (4)
ec15,12 M	(Ra)	43,478 - 45,195	0,9 (3)
ec2,0 M	(Ra)	45,308 - 47,025	1,10 (11)
ec15,12 N	(Ra)	47,092 - 48,021	0,31 (11)
ec2,0 N	(Ra)	48,922 - 49,851	0,40 (4)
ec6,3 L	(Ra)	49,508 - 53,296	0,76 (15)
ec3,0 M	(Ra)	56,618 - 58,335	1,7 (3)
ec17,11 M	(Ra)	57,628 - 59,345	0,72 (11)
ec3,0 N	(Ra)	60,232 - 61,161	0,60 (9)
ec17,11 N	(Ra)	61,242 - 62,171	0,24 (4)
ec6,3 M	(Ra)	63,918 - 65,635	0,20 (4)
ec6,3 N	(Ra)	67,532 - 68,461	0,067 (13)
ec7,3 L	(Ra)	93,878 - 97,666	0,8 (4)
ec7,3 M	(Ra)	108,288 - 110,005	0,2 (1)
ec7,3 N	(Ra)	111,902 - 112,831	0,07 (3)
ec20,5 K	(Ra)	148,585 (50)	0,107 (16)
ec12,1 K	(Ra)	152,315 (20)	0,673 (45)
ec15,3 K	(Ra)	168,995 (50)	0,220 (15)
ec12,0 K	(Ra)	182,175 (20)	0,66 (7)
ec20,4 K	(Ra)	192,585 (50)	0,268 (26)
ec14,1 K	(Ra)	196,065 (30)	0,0618 (41)
ec15,1 K	(Ra)	200,585 (20)	1,06 (19)
ec16,1 K	(Ra)	208,775 (30)	0,268 (23)
ec14,0 K	(Ra)	225,935 (20)	0,067 (5)
ec15,0 K	(Ra)	230,455 (20)	0,386 (33)
ec12,1 L	(Ra)	236,998 - 240,786	0,78 (5)
ec12,1 M	(Ra)	251,408 - 253,125	0,207 (14)
ec15,3 L	(Ra)	253,678 - 257,466	0,0585 (40)
ec12,0 L	(Ra)	266,858 - 270,646	0,172 (18)
ec15,1 L	(Ra)	285,268 - 289,056	0,180 (33)
ec15,0 L	(Ra)	315,138 - 318,926	0,079 (7)

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Ra)	10,662 — 18,412	41,3 (17)	
XK α_2	(Ra)	85,43	1,81 (6)	} K α
XK α_1	(Ra)	88,47	2,96 (10)	
XK β_3	(Ra)	99,432	}	K' β_1
XK β_1	(Ra)	100,13	}	
XK β_5''	(Ra)	100,738	}	
XK β_2	(Ra)	102,89	}	
XK β_4	(Ra)	103,295	}	
XKO _{2,3}	(Ra)	103,74	}	K' β_2

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{6,5}$ (Ra)	6,5 (3)	0,09 (3)
$\gamma_{17,16}$ (Ra)	8,15 (20)	0,008 (3)
$\gamma_{2,1}$ (Ra)	20,25 (5)	0,23 (3)
$\gamma_{25,22}$ (Ra)	20,94 (5)	0,006 (3)
$\gamma_{(-1,1)}$ (Ra)	22,0 (2)	0,009 (9)
$\gamma_{(-1,2)}$ (Ra)	24,13 (5)	0,086 (8)
$\gamma_{(-1,3)}$ (Ra)	27,41 (9)	0,029 (5)
$\gamma_{4,2}$ (Ra)	29,60 (3)	0,0058 (3)
$\gamma_{1,0}$ (Ra)	29,86 (1)	0,074 (11)
$\gamma_{3,1}$ (Ra)	31,58 (1)	0,067 (11)
$\gamma_{20,17}$ (Ra)	33,39 (8)	0,008 (3)
$\gamma_{25,21}$ (Ra)	40,20 (3)	0,015 (4)
$\gamma_{20,15}$ (Ra)	41,93 (5)	0,028 (13)
$\gamma_{14,12}$ (Ra)	43,77 (5)	0,208 (16)
$\gamma_{(-1,4)}$ (Ra)	43,8 (5)	0,054 (22)
$\gamma_{5,4}$ (Ra)	44,22 (12)	0,052 (13)
$\gamma_{8,6}$ (Ra)	44,40 (5)	0,016 (10)
$\gamma_{15,12}$ (Ra)	48,30 (3)	0,014 (5)
$\gamma_{4,1}$ (Ra)	49,82 (5)	0,42 (9)
$\gamma_{2,0}$ (Ra)	50,13 (1)	8,2 (5)
$\gamma_{7,5}$ (Ra)	50,85 (5)	0,015 (6)
$\gamma_{15,11}$ (Ra)	54,19 (4)	0,0063 (13)
$\gamma_{23,20}$ (Ra)	56,00 (6)	0,0048 (2)
$\gamma_{16,12}$ (Ra)	56,42 (7)	0,009 (8)
$\gamma_{(-1,8)}$ (Ra)	59,6 (5)	0,010 (4)
$\gamma_{3,0}$ (Ra)	61,44 (2)	0,088 (11)
$\gamma_{17,11}$ (Ra)	62,45 (5)	0,20 (3)
$\gamma_{21,17}$ (Ra)	62,68 (3)	0,007 (3)
$\gamma_{18,12}$ (Ra)	64,35 (10)	0,025 (4)
$\gamma_{(-1,9)}$ (Ra)	66,2 (5)	0,006 (4)
$\gamma_{(-1,10)}$ (Ra)	66,4 (5)	0,008 (4)
$\gamma_{(-1,11)}$ (Ra)	68,7 (1)	0,0058 (3)
$\gamma_{6,3}$ (Ra)	68,74 (3)	0,057 (10)
$\gamma_{(-1,12)}$ (Ra)	69,8 (3)	0,010 (4)

	Energy keV	Photons per 100 disint.
$\gamma_{10,7}$ (Ra)	72,85 (5)	0,024 (19)
$\gamma_{5,2}$ (Ra)	73,63 (5)	0,014 (5)
$\gamma_{(-1,0)}$ (Ra)	75,01 (5)	0,026 (10)
$\gamma_{(-1,13)}$ (Ra)	77,4 (4)	0,0101 (5)
$\gamma_{4,0}$ (Ra)	79,69 (2)	1,90 (11)
$\gamma_{23,17}$ (Ra)	89,6 (4)	0,0038 (13)
$\gamma_{5,1}$ (Ra)	93,88 (5)	1,48 (8)
$\gamma_{7,4}$ (Ra)	94,97 (5)	0,024 (14)
$\gamma_{20,11}$ (Ra)	96,03 (5)	0,068 (13)
$\gamma_{15,9}$ (Ra)	99,58 (10)	0,025 (6)
$\gamma_{24,17}$ (Ra)	99,6 (2)	0,013 (1)
$\gamma_{6,1}$ (Ra)	100,27 (3)	0,082 (16)
$\gamma_{23,14}$ (Ra)	102,5 (1)	0,00113 (5)
$\gamma_{11,7}$ (Ra)	105,2 (1)	0,0097 (5)
$\gamma_{16,9}$ (Ra)	107,76 (7)	0,0076 (25)
$\gamma_{22,1}$ (Ra)	109,2 (4)	0,0052 (15)
$\gamma_{25,15}$ (Ra)	110,65 (5)	0,0032 (20)
$\gamma_{(-1,14)}$ (Ra)	112,6 (5)	0,009 (4)
$\gamma_{7,3}$ (Ra)	113,11	0,19 (9)
$\gamma_{8,3}$ (Ra)	113,11 (5)	0,55 (10)
$\gamma_{10,6}$ (Ra)	117,20 (5)	0,194 (17)
$\gamma_{(-1,61)}$ (Ra)	117,5 (5)	0,012 (4)
$\gamma_{10,5}$ (Ra)	123,58 (10)	0,014 (5)
$\gamma_{21,11}$ (Ra)	124,44 (20)	0,0040 (22)
$\gamma_{(-1,15)}$ (Ra)	128,02 (2)	0,0032 (5)
$\gamma_{(-1,19)}$ (Ra)	129,4 (2)	0,0013 (6)
$\gamma_{19,9}$ (Ra)	134,6 (1)	0,033 (7)
$\gamma_{(-1,23)}$ (Ra)	138,4 (1)	0,014 (3)
$\gamma_{(-1,24)}$ (Ra)	140,6 (3)	0,021 (3)
$\gamma_{20,9}$ (Ra)	141,42 (5)	0,116 (23)
$\gamma_{11,6}$ (Ra)	150,14 (20)	0,011 (3)
$\gamma_{24,11}$ (Ra)	162,19 (10)	0,008 (3)
$\gamma_{(-1,25)}$ (Ra)	164,52 (10)	0,014 (3)
$\gamma_{17,7}$ (Ra)	168,36 (10)	0,014 (3)
$\gamma_{21,9}$ (Ra)	169,95 (10)	0,0054 (22)
$\gamma_{(-1,27)}$ (Ra)	171,5 (2)	0,0038 (13)
$\gamma_{9,3}$ (Ra)	173,45 (3)	0,017 (3)
$\gamma_{(-1,30)}$ (Ra)	175,8 (3)	0,020 (5)
$\gamma_{(-1,33)}$ (Ra)	181,1 (3)	0,0025 (13)
$\gamma_{(-1,35)}$ (Ra)	182,3 (2)	0,0038 (13)
$\gamma_{9,2}$ (Ra)	184,65 (5)	0,035 (4)
$\gamma_{25,10}$ (Ra)	197,56 (10)	0,013 (4)
$\gamma_{11,4}$ (Ra)	200,5 (1)	0,013 (9)
$\gamma_{20,7}$ (Ra)	201,64 (10)	0,023 (3)
$\gamma_{(-1,37)}$ (Ra)	202,5 (5)	0,006 (3)
$\gamma_{15,6}$ (Ra)	204,14 (10)	0,22 (3)
$\gamma_{9,1}$ (Ra)	204,98 (10)	0,16 (3)
$\gamma_{14,5}$ (Ra)	206,08 (5)	0,25 (3)
$\gamma_{15,5}$ (Ra)	210,62 (5)	1,22 (11)
$\gamma_{17,6}$ (Ra)	212,70 (4)	0,077 (10)
$\gamma_{26,10}$ (Ra)	212,7 (3)	0,019 (5)
$\gamma_{(-1,40)}$ (Ra)	216,0 (1)	0,00025 (13)
$\gamma_{11,3}$ (Ra)	218,90 (5)	0,107 (11)
$\gamma_{(-1,43)}$ (Ra)	219,0 (2)	0,049 (12)
$\gamma_{(-1,45)}$ (Ra)	223,2 (4)	0,0050 (13)
$\gamma_{26,9}$ (Ra)	225,5 (3)	0,009 (3)
$\gamma_{21,7}$ (Ra)	229,9 (5)	0,0038 (13)
$\gamma_{9,0}$ (Ra)	234,76 (10)	0,44 (5)
$\gamma_{12,2}$ (Ra)	235,96 (2)	12,6 (6)

	Energy keV	Photons per 100 disint.
$\gamma_{20,6}$ (Ra)	246,12 (10)	0,0120 (22)
$\gamma_{(-1,63)}$ (Ra)	248,1 (1)	0,024 (5)
$\gamma_{22,8}$ (Ra)	249,6 (5)	0,0076 (25)
$\gamma_{11,1}$ (Ra)	250,15 (5)	0,0087 (17)
$\gamma_{14,4}$ (Ra)	250,27 (8)	0,44 (4)
$\gamma_{20,5}$ (Ra)	252,50 (5)	0,108 (16)
$\gamma_{15,4}$ (Ra)	254,63 (3)	0,69 (13)
$\gamma_{12,1}$ (Ra)	256,23 (2)	6,8 (4)
$\gamma_{(-1,47)}$ (Ra)	260,6 (2)	0,0051 (13)
$\gamma_{16,4}$ (Ra)	262,87 (5)	0,105 (9)
$\gamma_{(-1,50)}$ (Ra)	265,3 (2)	0,0050 (13)
$\gamma_{27,10}$ (Ra)	267,05 (20)	0,010 (3)
$\gamma_{24,8}$ (Ra)	267,86 (20)	0,0069 (25)
$\gamma_{25,7}$ (Ra)	270,56 (20)	0,028 (9)
$\gamma_{15,3}$ (Ra)	272,91 (5)	0,50 (3)
$\gamma_{14,2}$ (Ra)	279,80 (5)	0,053 (13)
$\gamma_{21,5}$ (Ra)	280,7 (3)	0,0025 (13)
$\gamma_{17,3}$ (Ra)	281,42 (5)	0,174 (14)
$\gamma_{15,10}$ (Ra)	284,24 (10)	0,039 (13)
$\gamma_{26,7}$ (Ra)	285,52 (10)	0,043 (12)
$\gamma_{12,0}$ (Ra)	286,09 (2)	1,70 (17)
$\gamma_{19,4}$ (Ra)	289,59 (10)	1,9 (4)
$\gamma_{28,10}$ (Ra)	289,77 (10)	0,019 (4)
$\gamma_{16,2}$ (Ra)	292,41 (5)	0,064 (8)
$\gamma_{20,4}$ (Ra)	296,50 (5)	0,43 (4)
$\gamma_{14,1}$ (Ra)	299,98 (3)	2,16 (12)
$\gamma_{18,2}$ (Ra)	300,50 (16)	0,014 (3)
$\gamma_{15,1}$ (Ra)	304,50 (2)	1,12 (14)
$\gamma_{(-1,53)}$ (Ra)	306,1 (3)	0,010 (4)
$\gamma_{23,5}$ (Ra)	308,40 (3)	0,017 (3)
$\gamma_{16,1}$ (Ra)	312,69 (3)	0,50 (4)
$\gamma_{(-1,55)}$ (Ra)	314,75 (10)	0,034 (2)
$\gamma_{20,3}$ (Ra)	314,85 (4)	0,48 (4)
$\gamma_{24,5}$ (Ra)	318,46 (20)	0,0066 (22)
$\gamma_{19,2}$ (Ra)	319,24 (5)	0,031 (7)
$\gamma_{21,4}$ (Ra)	324,88 (20)	0,010 (3)
$\gamma_{20,2}$ (Ra)	325,99 (18)	0,0062 (25)
$\gamma_{14,0}$ (Ra)	329,85 (2)	2,9 (2)
$\gamma_{(-1,57)}$ (Ra)	332,2 (2)	0,0016 (5)
$\gamma_{15,0}$ (Ra)	334,37 (2)	1,11 (9)
$\gamma_{27,8}$ (Ra)	339,76 (10)	0,0038 (13)
$\gamma_{16,0}$ (Ra)	342,55 (4)	0,34 (9)
$\gamma_{20,1}$ (Ra)	346,45 (1)	0,0117 (14)
$\gamma_{(-1,60)}$ (Ra)	348,5 (5)	0,0066 (22)
$\gamma_{18,0}$ (Ra)	350,54 (7)	0,107 (18)
$\gamma_{23,4}$ (Ra)	352,61 (10)	0,0098 (22)
$\gamma_{22,3}$ (Ra)	362,63 (10)	0,050 (3)
$\gamma_{19,0}$ (Ra)	369,35 (5)	0,0060 (13)
$\gamma_{23,3}$ (Ra)	370,93 (8)	0,004 (3)
$\gamma_{21,1}$ (Ra)	374,8 (2)	0,00151 (7)
$\gamma_{20,0}$ (Ra)	376,27 (10)	0,0050 (13)
$\gamma_{(-1,62)}$ (Ra)	379,4 (1)	0,010 (3)
$\gamma_{23,2}$ (Ra)	382,2 (3)	0,0063 (13)
$\gamma_{25,3}$ (Ra)	383,51 (4)	0,024 (23)
$\gamma_{(-1,64)}$ (Ra)	392,4 (5)	0,0098 (22)
$\gamma_{26,3}$ (Ra)	398,6 (3)	0,0014 (4)
$\gamma_{23,1}$ (Ra)	402,2 (3)	0,008 (5)
$\gamma_{25,1}$ (Ra)	415,11 (10)	0,0014 (6)
$\gamma_{23,0}$ (Ra)	432,33 (10)	0,0040 (5)

	Energy keV	Photons per 100 disint.
$\gamma_{(-1,66)}(\text{Ra})$	442,5 (10)	0,000058 (3)
$\gamma_{(-1,68)}(\text{Ra})$	445	0,0005 (5)
$\gamma_{49,26}(\text{Ra})$	448,0 (6)	0,000139 (7)
$\gamma_{36,15}(\text{Ra})$	452,9 (3)	0,001
$\gamma_{36,14}(\text{Ra})$	457,5 (1)	0,000068 (3)
$\gamma_{(-1,70)}(\text{Ra})$	462 (1)	0,000048 (2)
$\gamma_{30,5}(\text{Ra})$	466,8 (2)	0,0005 (3)
$\gamma_{(-1,72)}(\text{Ra})$	469,0 (2)	0,0009 (3)
$\gamma_{40,17}(\text{Ra})$	480 (1)	0,00029 (9)
$\gamma_{43,20}(\text{Ra})$	482 (1)	0,00014 (4)
$\gamma_{40,14}(\text{Ra})$	493,1 (2)	0,00053 (8)
$\gamma_{42,15}(\text{Ra})$	507,5 (1)	0,00064 (25)
$\gamma_{43,16}(\text{Ra})$	516,6 (3)	0,00028 (10)
$\gamma_{(-1,74)}(\text{Ra})$	521,8 (3)	0,00038 (13)
$\gamma_{43,15}(\text{Ra})$	524,5 (4)	0,00019 (4)
$\gamma_{48,19}(\text{Ra})$	534,6 (4)	0,00010 (3)
$\gamma_{40,12}(\text{Ra})$	536,9 (1)	0,00107 (17)
$\gamma_{(-1,78)}(\text{Ra})$	540,2 (3)	0,00025 (13)
$\gamma_{36,9}(\text{Ra})$	552,4 (5)	0,00023 (5)
$\gamma_{42,12}(\text{Ra})$	556,1 (2)	0,00037 (15)
$\gamma_{(-1,80)}(\text{Ra})$	565,4 (1)	0,0014 (3)
$\gamma_{38,9}(\text{Ra})$	569,1 (3)	0,00058 (9)
$\gamma_{50,18}(\text{Ra})$	576,0 (2)	0,00032 (19)
$\gamma_{43,11}(\text{Ra})$	579,0 (2)	0,0004 (3)
$\gamma_{(-1,82)}(\text{Ra})$	585,8 (1)	0,0009 (3)
$\gamma_{40,9}(\text{Ra})$	589,0 (6)	0,000058 (15)
$\gamma_{50,14}(\text{Ra})$	596 (1)	0,0000101 (5)
$\gamma_{(-1,84)}(\text{Ra})$	598,9 (2)	0,00063 (13)
$\gamma_{42,9}(\text{Ra})$	607,7 (3)	0,00018 (4)
$\gamma_{49,12}(\text{Ra})$	621,4 (5)	0,000058 (15)
$\gamma_{53,20}(\text{Ra})$	623,8 (5)	0,00016 (4)
$\gamma_{33,4}(\text{Ra})$	632,3 (7)	0,00014 (3)
$\gamma_{52,14}(\text{Ra})$	641,0 (5)	0,000019 (6)
$\gamma_{45,9}(\text{Ra})$	644,3 (3)	0,00009 (4)
$\gamma_{(-1,86)}(\text{Ra})$	648,5 (5)	0,000019 (6)
$\gamma_{33,2}(\text{Ra})$	662,8 (4)	0,000058 (18)
$\gamma_{50,9}(\text{Ra})$	692,0 (7)	0,000039 (11)
$\gamma_{45,8}(\text{Ra})$	704,3 (5)	0,000078 (16)
$\gamma_{36,4}(\text{Ra})$	707,2 (7)	0,000039 (11)
$\gamma_{42,5}(\text{Ra})$	718,5 (10)	0,000029 (11)
$\gamma_{35,3}(\text{Ra})$	722,1 (6)	0,00037 (12)
$\gamma_{38,4}(\text{Ra})$	723,5 (1)	0,00027 (10)
$\gamma_{35,2}(\text{Ra})$	734,4 (5)	0,00010 (4)
$\gamma_{43,5}(\text{Ra})$	735,4 (2)	0,00016 (5)
$\gamma_{36,2}(\text{Ra})$	738,4 (10)	0,000068 (17)
$\gamma_{41,4}(\text{Ra})$	746,4 (7)	0,00010 (4)
$\gamma_{45,6}(\text{Ra})$	748,8 (4)	0,00040 (12)
$\gamma_{35,1}(\text{Ra})$	754,1 (2)	0,00024 (14)
$\gamma_{36,1}(\text{Ra})$	756,9 (2)	0,00019 (5)
$\gamma_{(-1,88)}(\text{Ra})$	757,3 (4)	0,00102 (24)
$\gamma_{42,4}(\text{Ra})$	762,6 (5)	0,00026 (5)
$\gamma_{41,3}(\text{Ra})$	766,3 (5)	0,00029 (6)
$\gamma_{40,2}(\text{Ra})$	773,4 (4)	0,00015 (4)
$\gamma_{41,2}(\text{Ra})$	775,8 (5)	0,00151 (15)
$\gamma_{42,3}(\text{Ra})$	781,0 (5)	0,00032 (6)
$\gamma_{35,0}(\text{Ra})$	784,2 (5)	0,000097 (24)
$\gamma_{36,0}(\text{Ra})$	787,4 (5)	0,000039 (10)
$\gamma_{(-1,95)}(\text{Ra})$	787,6 (5)	0,00011 (3)
$\gamma_{40,1}(\text{Ra})$	792,6 (6)	0,000029 (8)

	Energy keV	Photons per 100 disint.
$\gamma_{37,0}$ (Ra)	792,6 (6)	0,000039 (10)
$\gamma_{43,3}$ (Ra)	797,3 (5)	0,00090 (12)
$\gamma_{38,0}$ (Ra)	803,9 (4)	0,00063 (6)
$\gamma_{43,2}$ (Ra)	808,6 (4)	0,000076 (25)
$\gamma_{42,1}$ (Ra)	812,6 (4)	0,0017 (3)
$\gamma_{(-1,92)}$ (Ra)	818 (1)	0,000029 (11)
$\gamma_{45,3}$ (Ra)	818,1 (2)	0,00017 (8)
$\gamma_{40,0}$ (Ra)	823,4 (4)	0,0025 (3)
$\gamma_{41,0}$ (Ra)	826,7 (5)	0,00016 (5)
$\gamma_{43,1}$ (Ra)	828,5 (5)	0,00019 (5)
$\gamma_{(-1,94)}$ (Ra)	828,9 (2)	0,00076 (4)
$\gamma_{44,1}$ (Ra)	837,8 (5)	0,00052 (12)
$\gamma_{42,0}$ (Ra)	842,5 (3)	0,00087 (13)
$\gamma_{50,4}$ (Ra)	846,7 (5)	0,00015 (3)
$\gamma_{45,1}$ (Ra)	848,3 (6)	0,00027 (11)
$\gamma_{46,1}$ (Ra)	854,3 (5)	0,000068 (14)
$\gamma_{49,2}$ (Ra)	857,3 (7)	0,000058 (18)
$\gamma_{43,0}$ (Ra)	858,9 (2)	0,00025 (4)
$\gamma_{51,4}$ (Ra)	863 (1)	0,000019 (8)
$\gamma_{44,0}$ (Ra)	867,3 (5)	0,00029 (22)
$\gamma_{50,2}$ (Ra)	876,3 (4)	0,00023 (8)
$\gamma_{49,1}$ (Ra)	878,2 (4)	0,00014 (4)
$\gamma_{47,0}$ (Ra)	891 (1)	0,000019 (6)
$\gamma_{51,2}$ (Ra)	893 (1)	0,000013 (4)
$\gamma_{50,1}$ (Ra)	896,1 (5)	0,00011 (3)
$\gamma_{49,0}$ (Ra)	908,6 (4)	0,0023 (3)
$\gamma_{52,3}$ (Ra)	910 (1)	0,000015 (6)
$\gamma_{53,4}$ (Ra)	920,0 (5)	0,000011 (3)
$\gamma_{50,0}$ (Ra)	927 (1)	0,000006 (3)
$\gamma_{53,3}$ (Ra)	938,0 (8)	0,000010 (4)
$\gamma_{52,1}$ (Ra)	941,6 (3)	0,000069 (11)
$\gamma_{55,3}$ (Ra)	958,7 (3)	0,000061 (13)
$\gamma_{53,1}$ (Ra)	970,2 (2)	0,00014 (11)
$\gamma_{52,0}$ (Ra)	971,7 (10)	0,000010 (5)
$\gamma_{55,1}$ (Ra)	990,0 (7)	0,000034 (9)
$\gamma_{56,1}$ (Ra)	995 (1)	0,000006 (4)
$\gamma_{53,0}$ (Ra)	999,8 (5)	0,000029 (8)
$\gamma_{54,0}$ (Ra)	1015,2 (7)	0,000015 (4)
$\gamma_{55,0}$ (Ra)	1020 (1)	0,000019 (6)
$\gamma_{56,0}$ (Ra)	1025 (1)	0,000015 (4)

7 Main Production Modes

Ra – $^{226}(\text{n},\gamma)\text{Ra} - ^{227}$

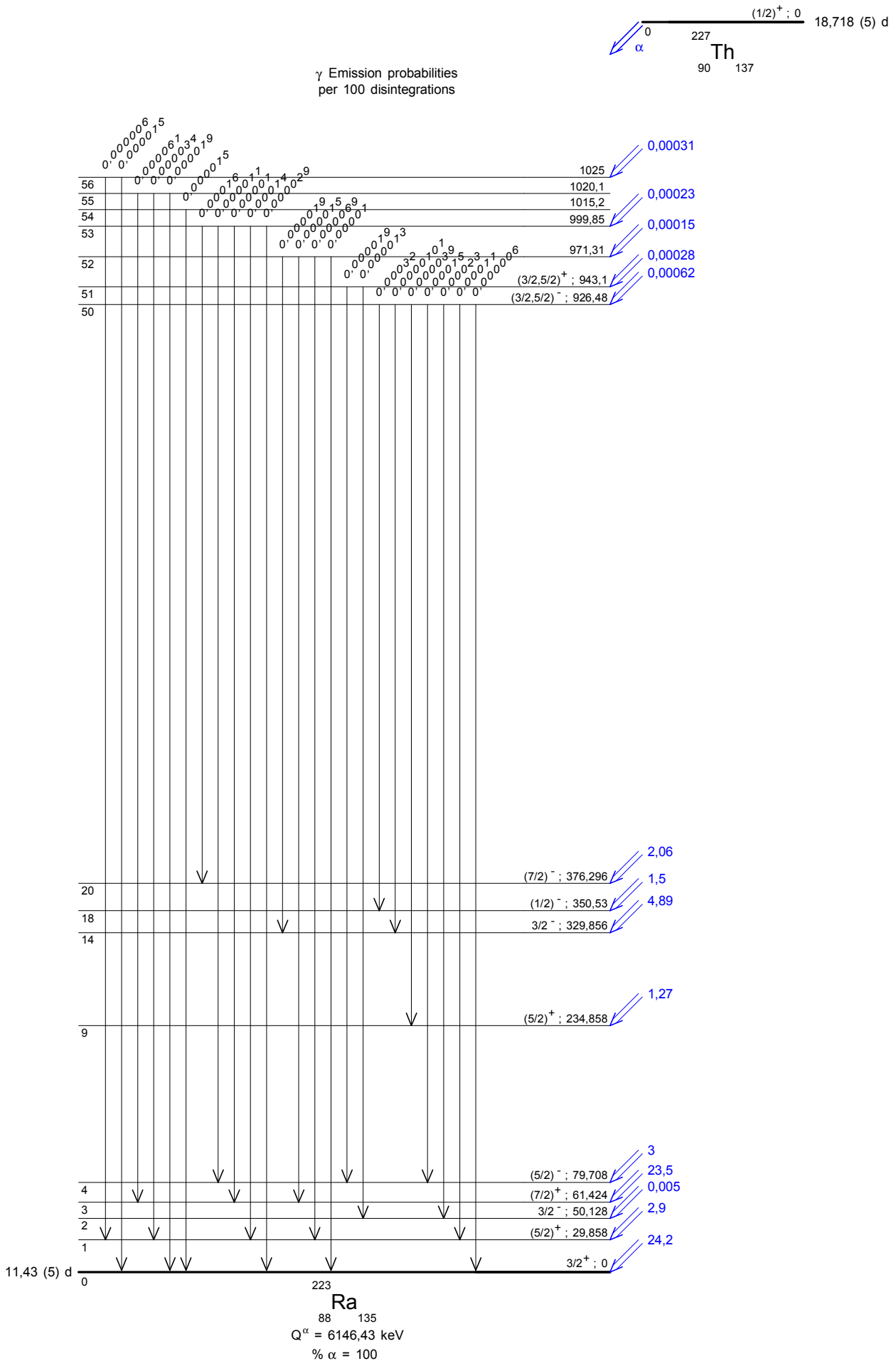
Ra – $^{227}(\beta^-)\text{Ac} - ^{227}$

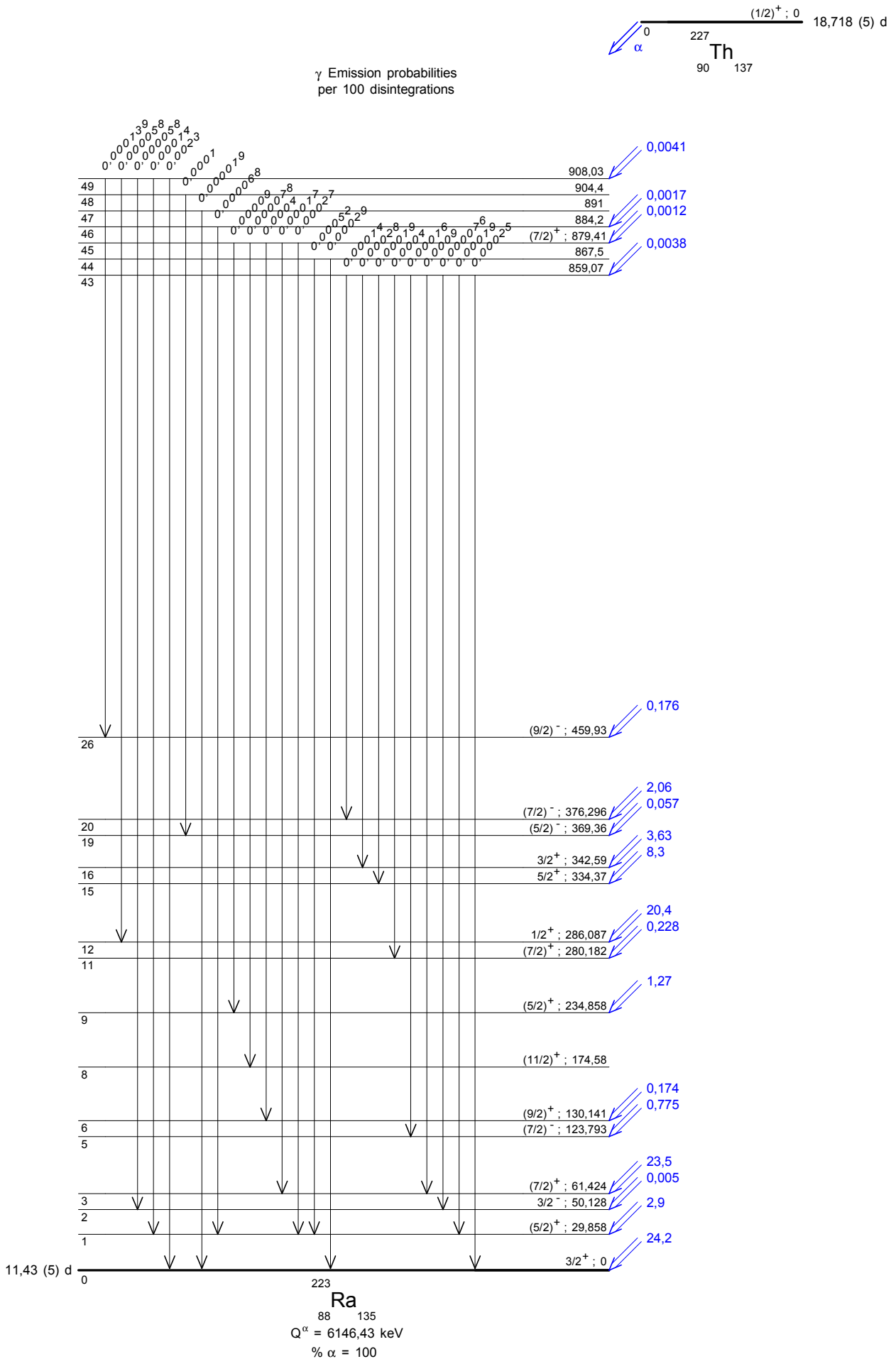
Ac – $^{227}(\beta^-)\text{Th} - ^{227}$

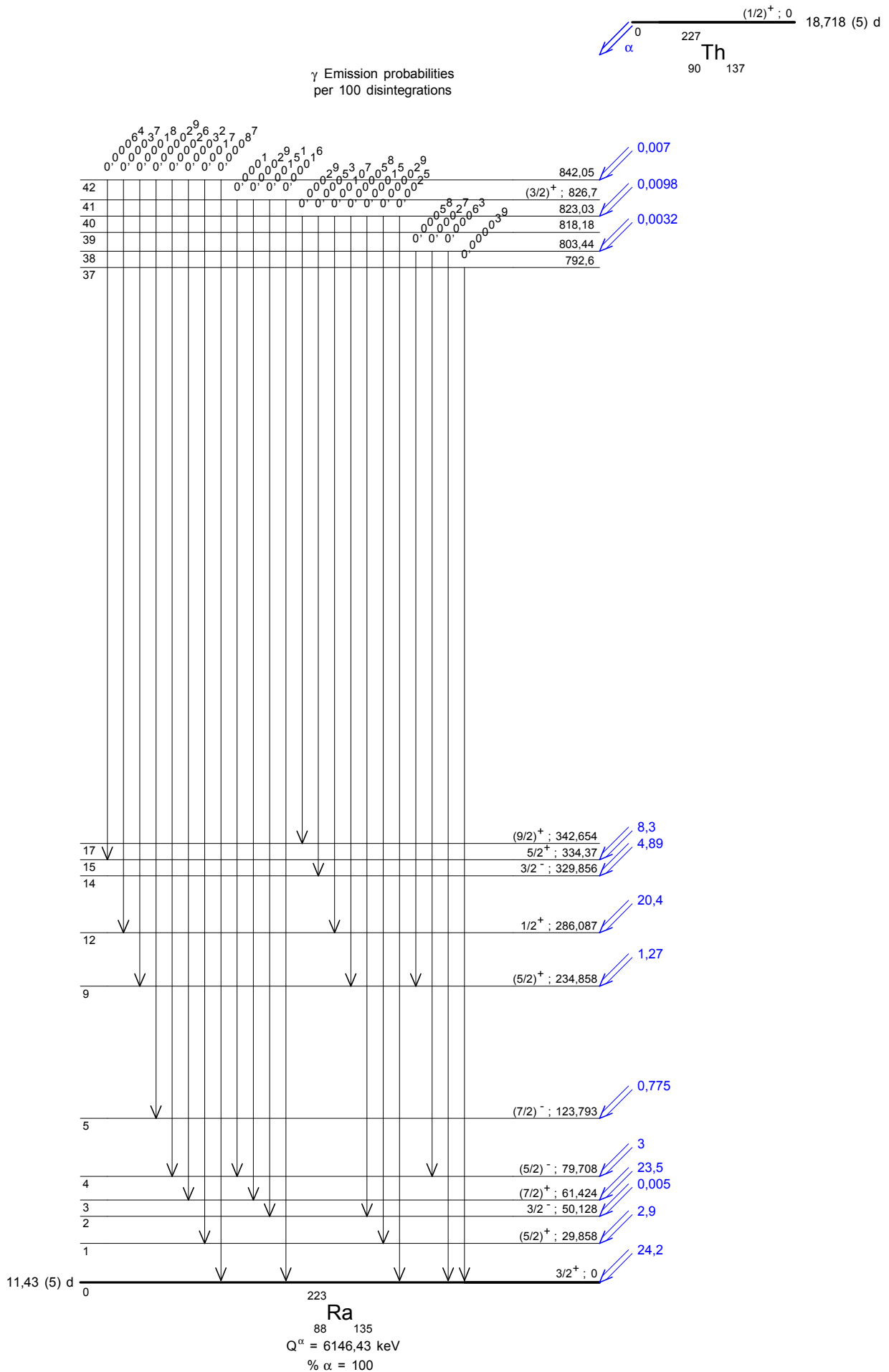
8 References

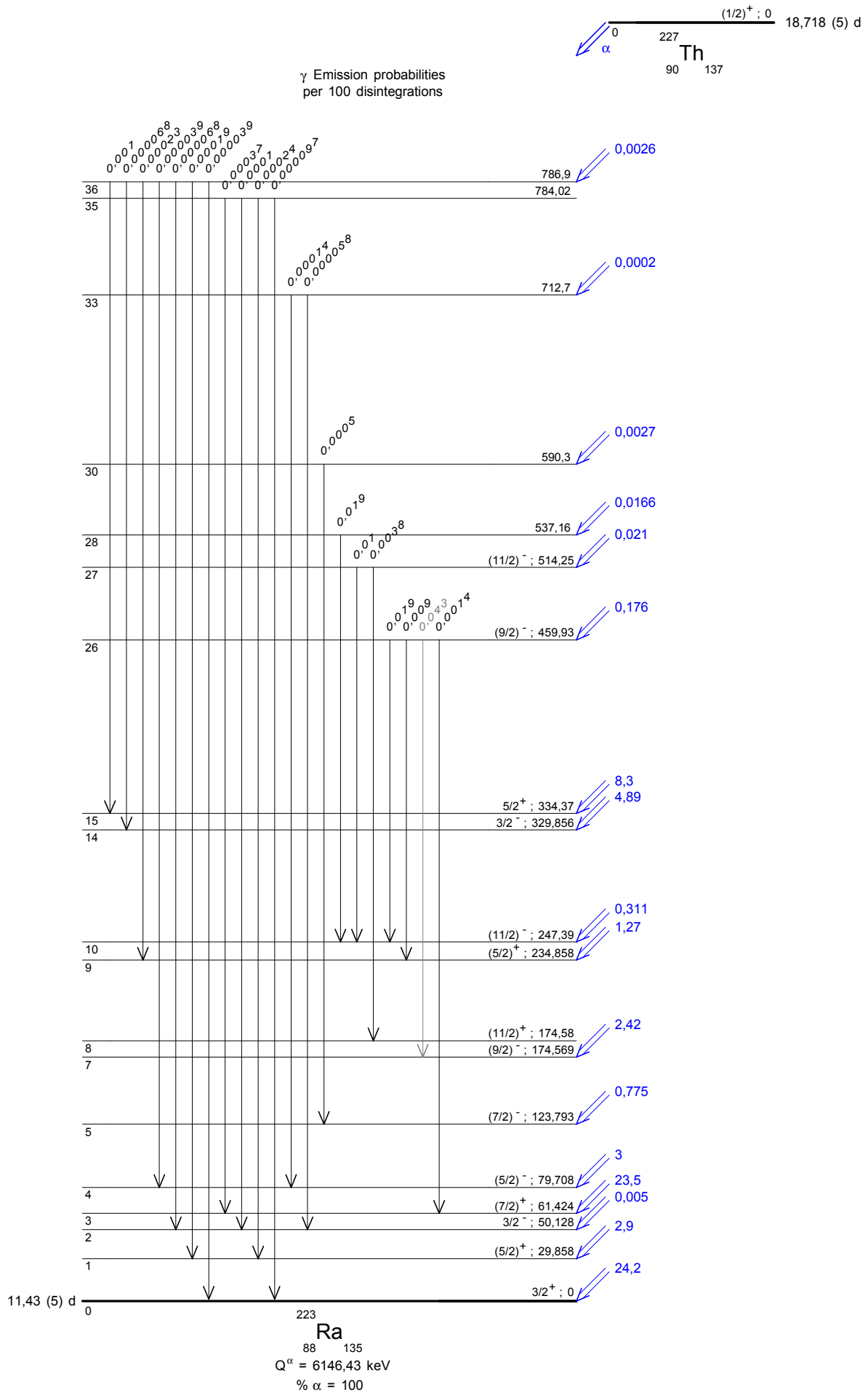
- K. C. JORDAN, B.C.BLANKE. Int. At. Energy (Vienna) (567) 1967
(Half-life)
- G.R.HAGEE, M.L.CURTIS, G.R.GROVE,. Phys. Rev. 96 (1954) 817A
(Half-life)
- J.F.EICHELBERGER, G.R.GROVE, L.V. JONES, E.A.REMBOLD. Report MLM 1155 (1963) 12
(Half-life)
- A.PEGHAIRE. Nucl. Instrum. Methods 75 (1969) 66
(Absolute gamma-ray emission probabilities)

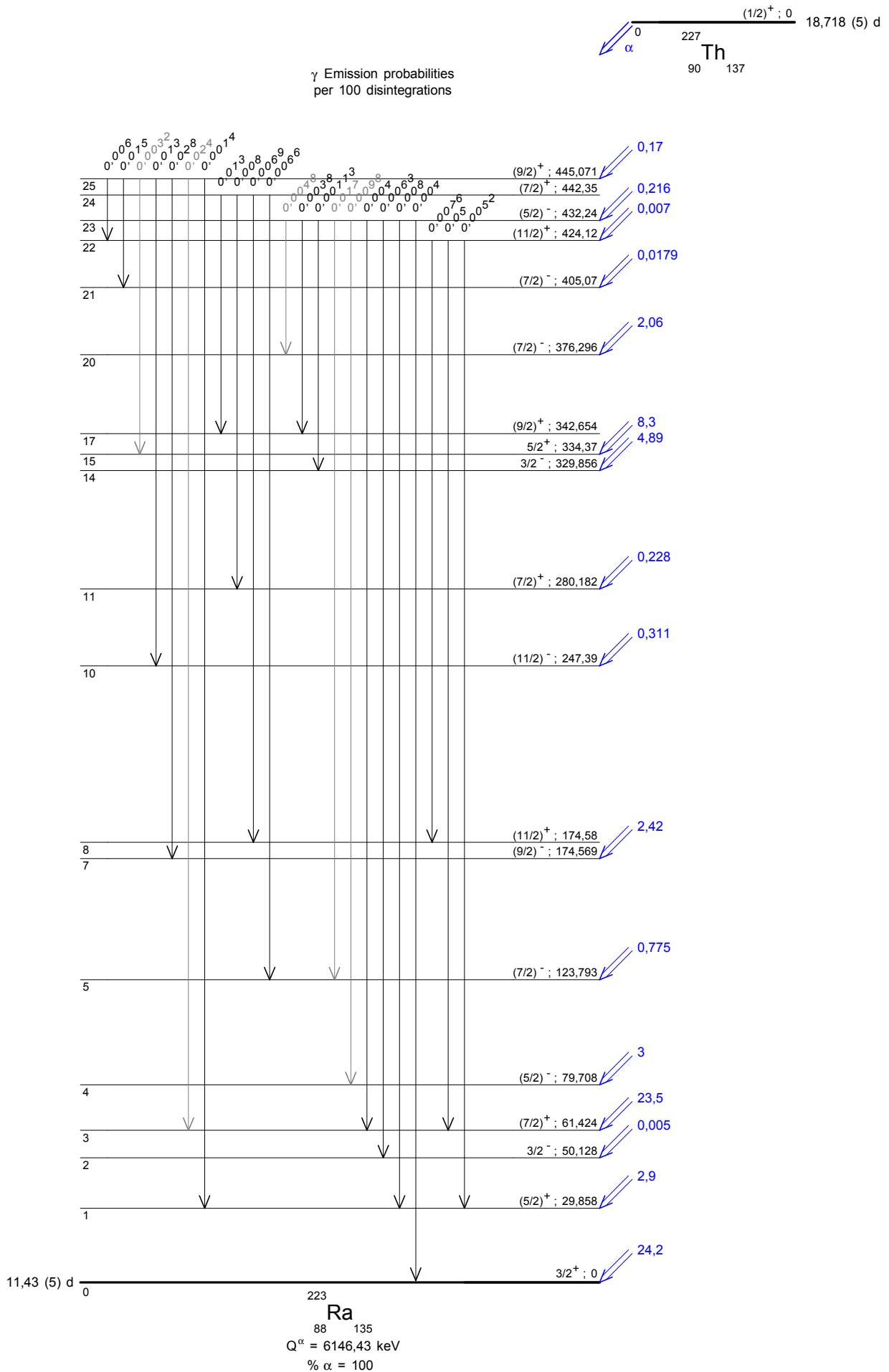
- C.BRIANCON, R.WALEN. J. Phys. (Paris) 30 (1969) 753
(Gamma ray energies,Gamma-ray emission probabilities)
- B.GRENNBERG, A.RYTZ. Metrologia 7 (1971) 65
(Alpha emission energies)
- W.H.A.HESSENLINK, A.H.WAPSTRA, J.G.KROMME, E.J.HAIGHTON, M.VAN KAMPEN, W.HUTJES, K.E.M.DIJKMAN. Nucl. Phys. A191 (1972) 283
(Gamma ray energies,Gamma-ray emission probabilities)
- F.P.LARKINS. At. Data. Nucl. Data Tables 20 (1977) 311
(Atomic electron binding energies)
- F.ROSEL, H.M.FRIES, K.ALDER, H.C.PAULI. At. Data. Nucl. Data Tables 21 (1978) 92
(Theoretical ICC)
- W.L.ZIJP. Report ECN FYS/RASA 85/19 (1985)
(Discrepant data. Limited Relative Statistical Weight method.)
- G.J.MILLER, J.C.MCGEORGE, I.ANTHONY, R.O.OWENS. Phys. Rev. C36 (1987) 420
(Half-life)
- CH.BRIANCON, S.CWIOK, S.A.EID, V.GREE, W.D.HAMILTON, C.F.LIANG, R.J.WALEN. J. Phys. (London) G16 (1990) 1735
(Gamma ray energies)
- K.KOMURA, M.YAMAMOTO, K.UENO. Nucl. Instrum. Methods A295 (1990) 461
(Atomic Data,Auger electron emission probabilities,X-ray emission probabilities)
- A.RYTZ. At. Data. Nucl. Data Tables 47 (1991) 205
(Alpha emission energies)
- A.ABDUL-HADI, V.BARCI, B.WEISS, H.MARIA, G.ARDISSON, M.HUSSONNOIS, O.CONSTANTINESCU. Phys. Rev. C47 (1993) 94
(Gamma ray energies,Gamma-ray emission probabilities)
- G. AUDI, A.H.WAPSTRA. Nucl. Phys. A595 (1995) 409
(The 1995 Update to the Atomic Mass Evaluation. Q-alpha.)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic Data,X-ray emission probabilities,K Auger electron emission probabilities)
- Y.A.AKOVALI. Nucl. Data Sheets 84 (1998) 1
(Alpha decay. Radius parameter of even-even nuclei.)
- E.SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 Braunschweig (1998)
(Auger electron energies)
- E.SCHÖNFELD, H. JANSSEN. Appl. Rad. Isotopes 52 (2000) 595
(X-ray and Auger electron emission probabilities.)
- E.BROWNE. Nucl. Data Sheets 93 (2001) 763
(Evaluated data (ENSDF) for nuclei with A=227. Adjusted alpha-particle energies.)

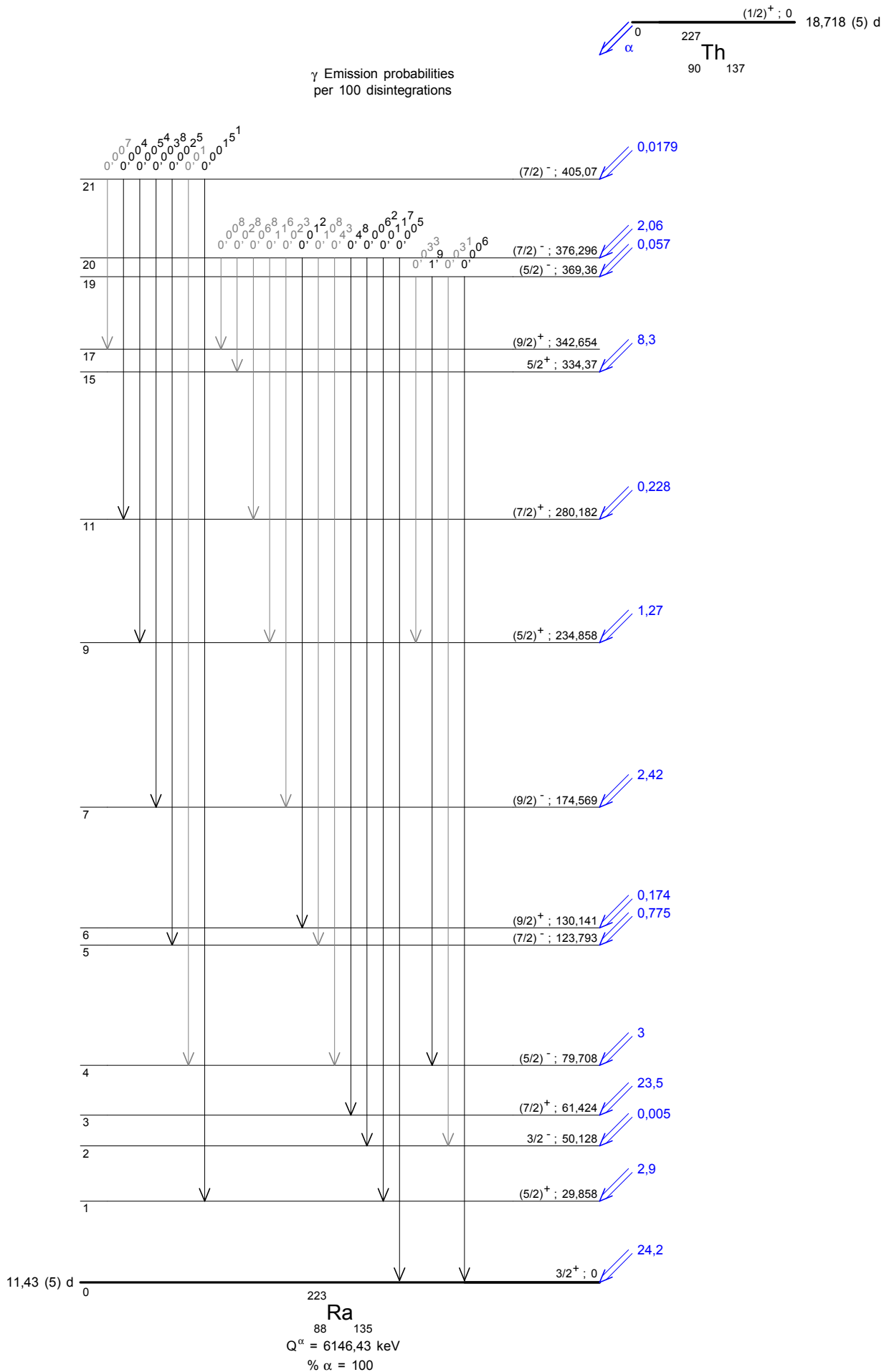


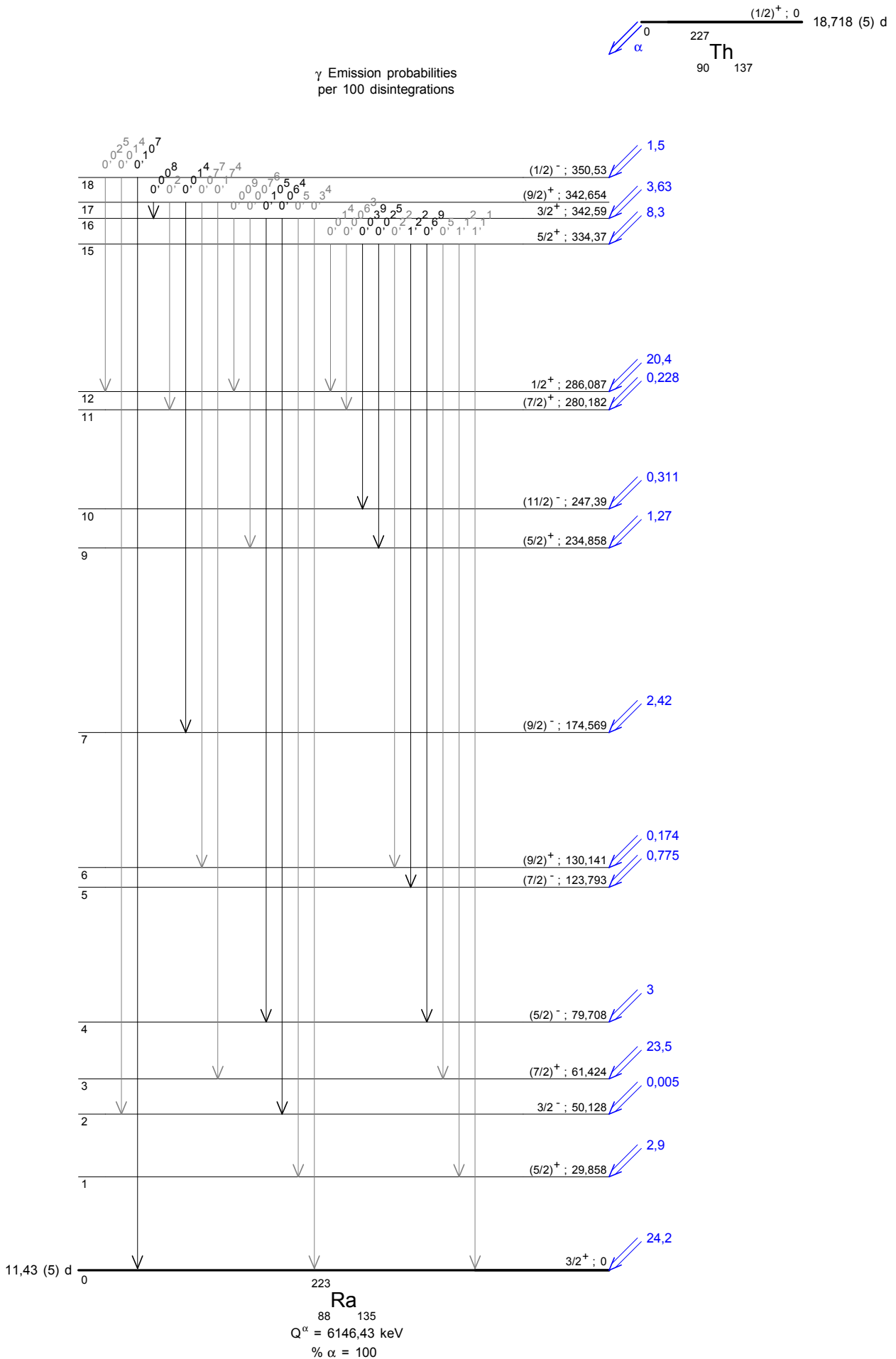


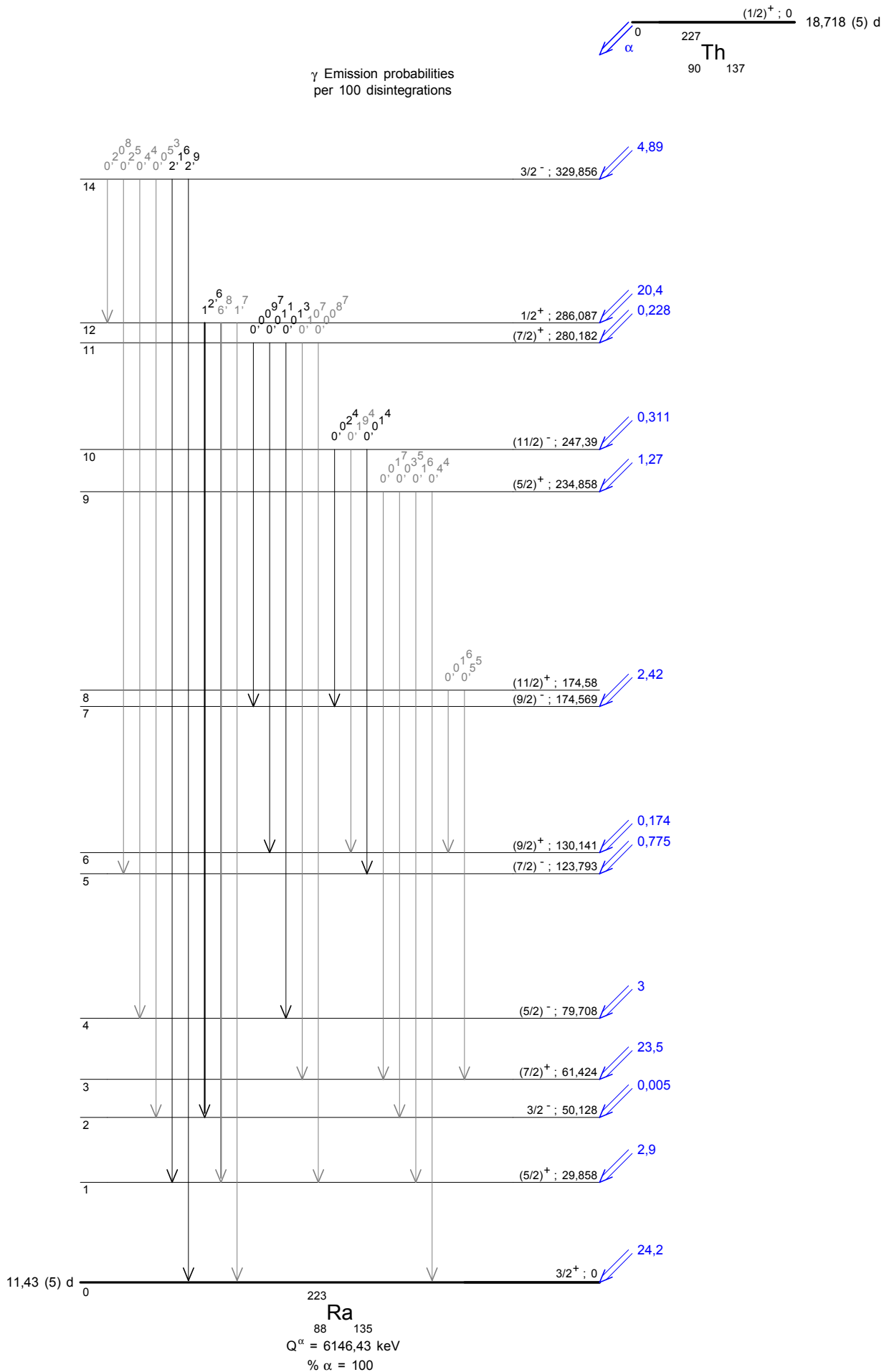


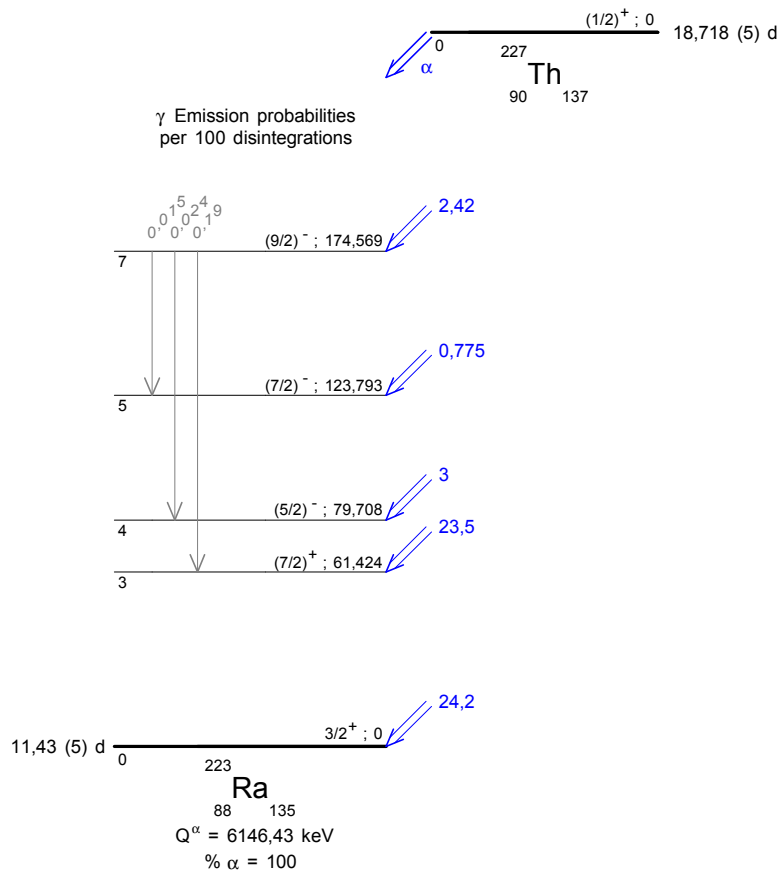


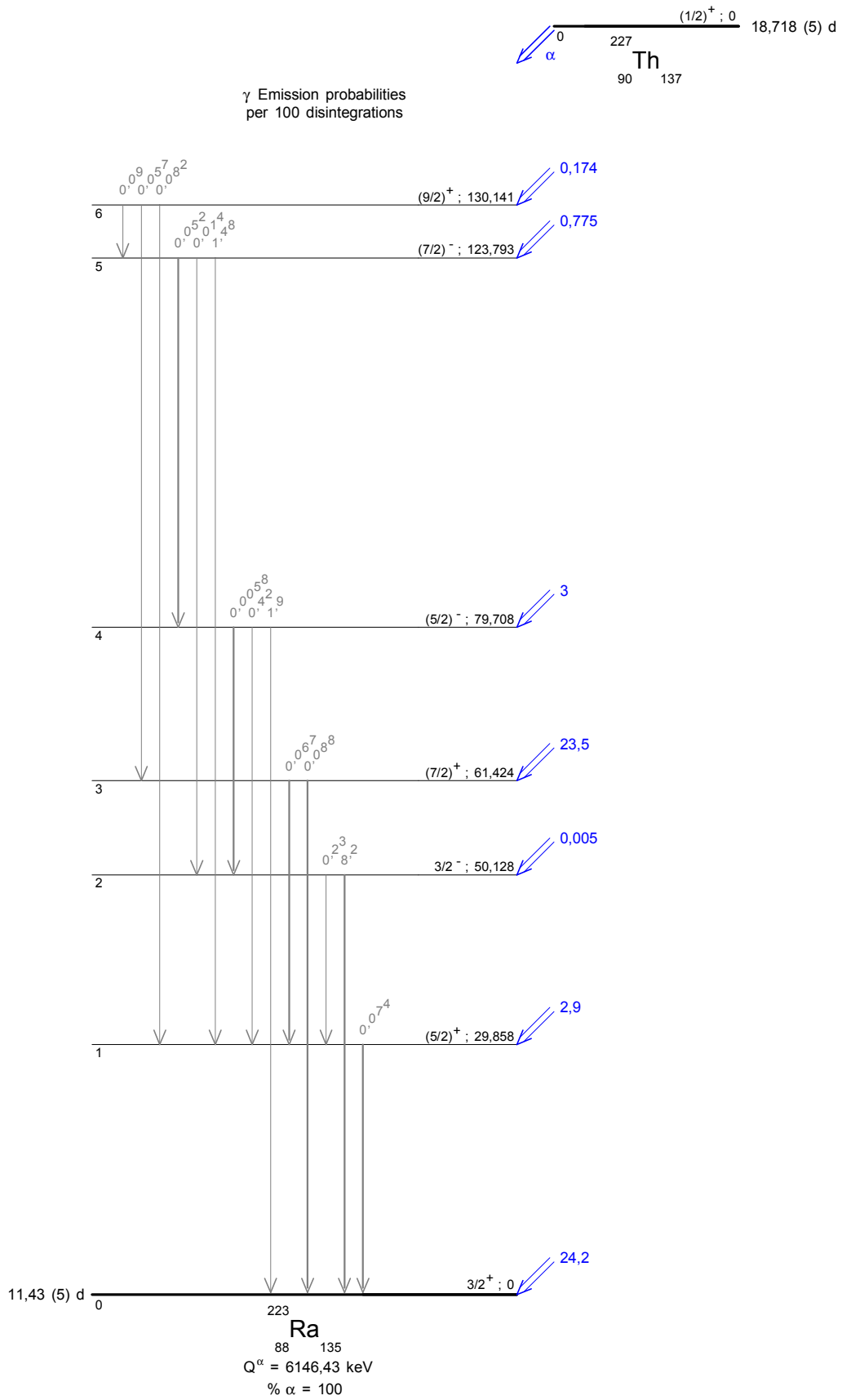














1 Decay Scheme

Th-228 decays 100% by alpha-particle emission to various excited levels and the ground state of Ra-224. *Le thorium 228 se désintègre par émission alpha principalement vers le niveau fondamental et le niveau excité de 84,4 keV de radium 224.*

2 Nuclear Data

$T_{1/2}(^{228}\text{Th})$	: 698,60	(23)	d
$T_{1/2}(^{224}\text{Ra})$	: 3,627	(7)	d
$Q^\alpha(^{228}\text{Th})$	: 5520,12	(22)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,8}$	4527,5 (3)	0,0000044 (12)	7,37
$\alpha_{0,7}$	4603,8 (3)	0,000017 (3)	6,96
$\alpha_{0,6}$	5040,9 (4)	0,000025 (5)	4370
$\alpha_{0,5}$	5087,1 (3)	0,000010 (3)	21300
$\alpha_{0,4}$	5229,76 (26)	0,036 (7)	44,1
$\alpha_{0,3}$	5269,34 (23)	0,20 (2)	13,6
$\alpha_{0,2}$	5304,14 (22)	0,38 (3)	11,5
$\alpha_{0,1}$	5435,75 (22)	26,2 (2)	0,948
$\alpha_{0,0}$	5520,12 (22)	73,2 (2)	1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_{M+}	α_T
$\gamma_{4,2}$ (Ra)	74,4 (1)	0,016 (6)	[E2]		28,9 (8)	7,89 (16)	39,5 (8)
$\gamma_{1,0}$ (Ra)	84,373 (3)	26,6 (14)	E2		15,9 (3)	5,8 (1)	21,7 (4)
$\gamma_{2,1}$ (Ra)	131,612 (4)	0,155 (8)	E1	0,195 (4)	0,041 (1)	0,013 (1)	0,249 (6)
$\gamma_{5,4}$ (Ra)	142,7 (1)	0,0000041 (13)	[E2]	0,280 (6)	1,396 (28)	0,50 (1)	2,18 (4)
$\gamma_{3,1}$ (Ra)	166,410 (4)	0,205 (16)	E2	0,225 (5)	0,704 (14)	0,256 (5)	1,185 (24)
$\gamma_{5,3}$ (Ra)	182,3 (1)	0,0000056 (20)	[E1]	0,090 (2)	0,0178 (3)	0,0060 (1)	0,114 (2)
$\gamma_{4,1}$ (Ra)	205,99 (4)	0,0201 (11)	[E1]	0,0676 (14)	0,0131 (3)	0,0042 (1)	0,0849 (17)
$\gamma_{2,0}$ (Ra)	215,985 (4)	0,243 (22)	E1	0,0605 (12)	0,01160 (25)	0,0038 (1)	0,0759 (15)
$\gamma_{6,3}$ (Ra)	228,4 (2)	0,000025 (5)	[E2]	0,125 (2)	0,182 (4)	0,065 (1)	0,372 (7)
$\gamma_{7,2}$ (Ra)	700,4 (1)	0,0000029 (9)	E1	0,00508 (10)	0,00084 (2)	0,000270 (5)	0,00619 (12)
$\gamma_{8,3}$ (Ra)	741,87 (1)	0,0000014 (4)	[E2]	0,0121 (2)	0,00330 (6)	0,00110 (2)	0,0165 (3)
$\gamma_{7,1}$ (Ra)	832,0 (1)	0,000014 (2)	E2+M3	0,0098 (2)	0,00240 (5)	0,00090 (2)	0,0131 (3)
$\gamma_{8,1}$ (Ra)	908,28 (1)	0,0000016 (5)	[M1+50%E2]	0,0203 (20)	0,0038 (4)	0,0012 (1)	0,0253 (25)
$\gamma_{8,0}$ (Ra)	992,65 (6)	0,0000014 (4)	[E2]	0,00720 (15)	0,00160 (3)	0,00050 (1)	0,0093 (2)

3 Atomic Data

3.1 Ra

ω_K	:	0,968 (4)
$\bar{\omega}_L$	:	0,452 (18)
n_{KL}	:	0,801 (5)

3.1.1 X Radiations

	Energy keV	Relative probability
X _K	K α_2	85,43
	K α_1	88,47
	K β_3	99,432
	K β_1	100,13
	K β_5''	100,738
	K β_2	102,89
	K β_4	103,295
	KO _{2,3}	103,74
X _L	L ℓ	10,622
	L α	12,196 – 12,339
	L η	13,662
	L β	14,236 – 15,447
	L γ	17,848 – 18,412

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	65,15 – 72,73	100
KLX	79,72 – 88,47	58
KXY	94,27 – 103,91	8,4
Auger L		
	5,71 – 12,04	9050

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,8}$	4448,0 (3)	0,0000044 (12)
$\alpha_{0,7}$	4523,0 (3)	0,000017 (3)
$\alpha_{0,6}$	4952,5 (4)	0,000025 (5)
$\alpha_{0,5}$	4997,8 (3)	0,000010 (3)
$\alpha_{0,4}$	5138,01 (26)	0,036 (7)
$\alpha_{0,3}$	5176,89 (23)	0,20 (2)
$\alpha_{0,2}$	5211,08 (22)	0,38 (3)
$\alpha_{0,1}$	5340,38 (22)	26,2 (2)
$\alpha_{0,0}$	5423,28 (22)	73,2 (2)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.	
e _{AL}	(Ra)	5,71 - 12,04	10,5 (4)	
e _{AK}	(Ra)		0,00193 (26)	
	KLL	65,15 - 72,73		}
	KLX	79,72 - 88,47		}
	KXY	94,27 - 103,91		}
ec _{1,0} T	(Ra)	65,14 - 84,09	25,4 (8)	
ec _{1,0} L	(Ra)	65,14 - 68,93	18,6 (6)	
ec _{1,0} M	(Ra)	79,55 - 84,09	6,8 (2)	
ec _{2,0} K	(Ra)	112,067 (5)	0,180 (6)	
ec _{3,1} L	(Ra)	147,17 - 150,97	0,066 (2)	

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Ra)	10,622 — 18,412	8,8 (4)	
XK α_2	(Ra)	85,43	0,0172 (8)	} K α
XK α_1	(Ra)	88,47	0,0281 (12)	
XK β_3	(Ra)	99,432	}	} K' β_1
XK β_1	(Ra)	100,13		
XK β_5''	(Ra)	100,738		
XK β_2	(Ra)	102,89	}	} K' β_2
XK β_4	(Ra)	103,295		
XKO _{2,3}	(Ra)	103,74		

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{4,2}$ (Ra)	74,4 (1)	0,00039 (14)
$\gamma_{1,0}$ (Ra)	84,373 (3)	1,17 (5)
$\gamma_{2,1}$ (Ra)	131,612 (4)	0,124 (6)
$\gamma_{5,4}$ (Ra)	142,7 (1)	0,0000013 (4)
$\gamma_{3,1}$ (Ra)	166,410 (4)	0,094 (7)
$\gamma_{5,3}$ (Ra)	182,3 (1)	0,0000050 (18)
$\gamma_{4,1}$ (Ra)	205,99 (4)	0,0185 (10)
$\gamma_{2,0}$ (Ra)	215,985 (4)	0,226 (20)
$\gamma_{6,3}$ (Ra)	228,4 (2)	0,000018 (4)
$\gamma_{7,2}$ (Ra)	700,4 (1)	0,0000029 (9)
$\gamma_{8,3}$ (Ra)	741,87 (1)	0,0000014 (4)
$\gamma_{7,1}$ (Ra)	832,0 (1)	0,000014 (2)
$\gamma_{8,1}$ (Ra)	908,28 (1)	0,0000016 (5)
$\gamma_{8,0}$ (Ra)	992,65 (6)	0,0000014 (4)

7 Main Production Modes

Th – 230(p,t)Th – 228

Th – 230(α , α 2n γ)Th – 228

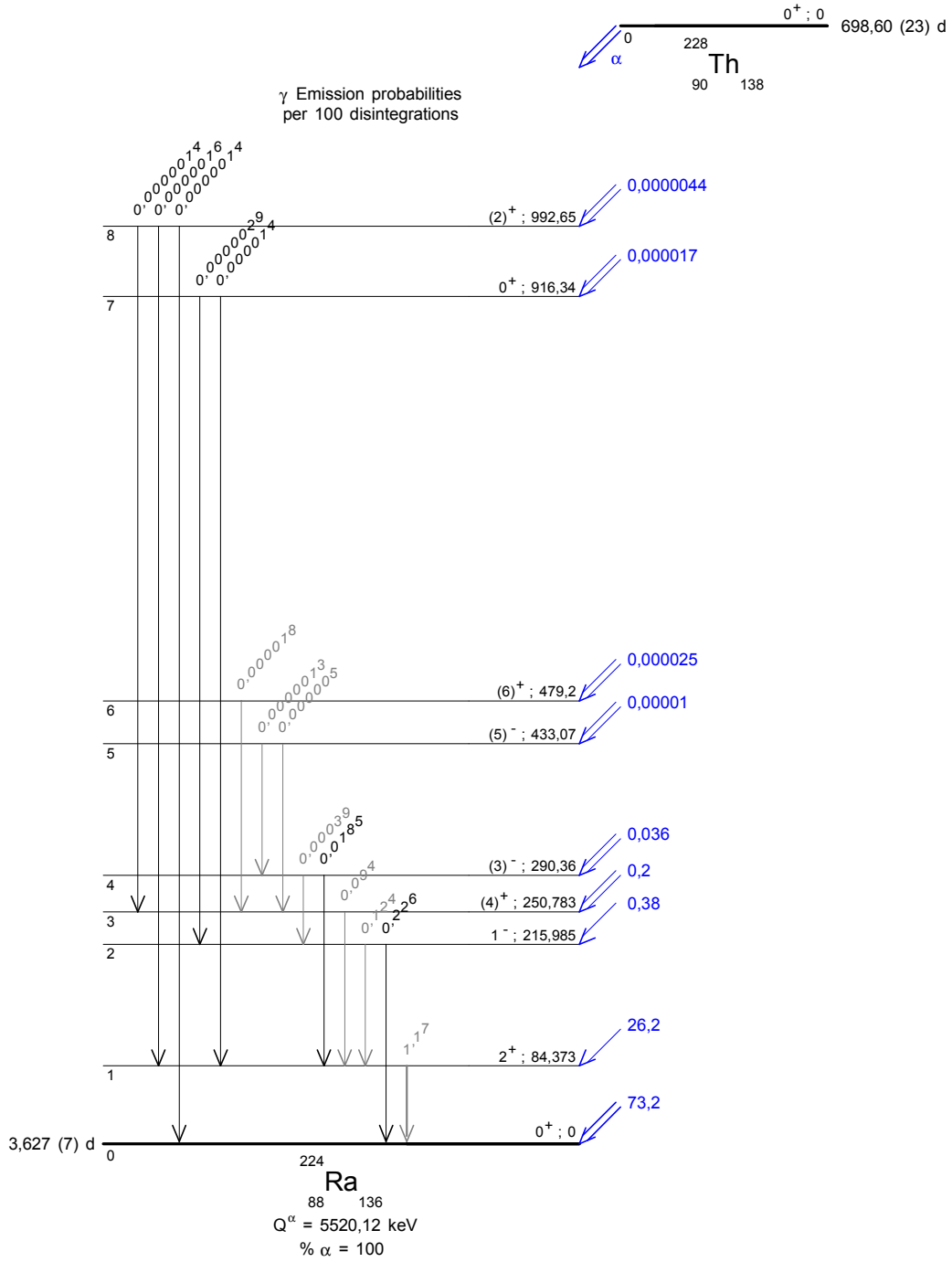
Ra – 226($\alpha, 2n\gamma$)Th – 228

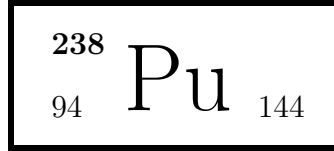
U – 232 alpha decay

8 References

- F. ASARO, F. STEPHENS, I. PERLMAN. Phys. Rev. 92 (1953) 1495
(Alpha-particle emission probabilities, gamma-ray emission probabilities, internal conversion coefficients)
- H.W. KIRBY, G.R. GROVE, D.L. TIMMA. Phys. Rev. 102 (1956) 1140
(Half-life)
- M.O. COSTA, M.R.S. GRADE. Port. Phys. 4 (1966) 267
(Conversion electrons, internal conversion coefficients)
- C.L. DUKE, W.L. TALBERT. Phys. Rev. 173 (1968) 1125
(Internal conversion coefficients)
- A. PEGHAIRE. Nucl. Instrum. Methods 75 (1969) 66
(Gamma-ray emission probabilities)
- S.A. BARANOV, V.M. SHATINSKII, V.M. KULAKOV, Y.F. RODIONOV. Sov. J. Nucl. Phys. 11 (1970) 515
(Gamma-ray emission probabilities)
- K.C. JORDAN, G.W. OTTO, R.P. RATAY. J. Inorg. Nucl. Chem. 33 (1971) 1215
(Half-life)
- J. DALMASSO. Report FRNC-TH-441 (1972)
(Gamma-ray energies)
- R.L. HEATH. Report ANCR-1000-2 (1974)
(Gamma-ray energies)
- S.A. BARANOV, A.G. ZELENKOV, V.M. KULAKOV. IAEA-186 III (1976) 249
(Alpha-particle emission probabilities)
- W. KURCEWICZ, N. KAFFRELL, N. TRAUTMANN, A. PLOCHOCKI, J. ZYLICZ, M. MATUL, K. STRYCZNIEWICZ. Nucl. Phys. A289 (1977) 1
(Gamma-ray energies Gamma-ray emission probabilities)
- W. KURCEWICZ, E. RUCHOWSKA, N. KAFFRELL, N. TRAUTMANN. Nucl. Instrum. Methods 146 (1977) 613
(Gamma-ray energies)
- F. RÖSEL, H.M. FRIES, K. ALDER, H.C. PAULI. At. Data Nucl. Data Tables 21 (1978) 291
(Internal conversion coefficients)
- A. RYTZ. At. Data Nucl. Data Tables 23 (1979) 507
(Alpha emission energies)
- W. KURCEWICZ, E. RUCHOWSKA, N. KAFFRELL, T. BJOERNSTAD, G. NYMAN. Nucl. Phys. A356 (1981) 15
(908.28 keV gamma-ray emission probabilities)
- S. SADASIVAN, V.M. RAGHUNATH. Nucl. Instrum. Methods 196 (1982) 561
(Gamma-ray emission probabilities)
- R.J. GEHRKE, V.J. NOVICK, J.D. BAKER. Int. J. Appl. Radiat. Isotop. 35 (1984) 581
(Gamma-ray emission probabilities)
- M.P. UNTERWEGER, D.D. HOPPES, F.J. SCHIMA. Nucl. Instrum. Methods A312 (1992) 349
(Half-life)
- T. BABELIOWSKY, G. BORTELS. Appl. Rad. Isotopes 44 (1993) 1349
(Alpha-particle emission probabilities)
- G. AUDI, A.H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Q value)
- G. ARDISSON, M. HUSSONNOIS. Radiochim. Acta 70/71 (1995) 123
(Cluster decay)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(K-x ray, L-x ray, Auger electrons)
- A. ARTNA-COHEN. Nucl. Data Sheets 80 (1997) 227
(Nuclear structure, energies)

- S.P. TRETAKOVA, V.L. MIKHEEV. Nuovo Cim. 110 (1997) 1043
(Cluster decay)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-98-1 (1998)
(Auger electrons)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11-1999-1 (1999)
(X-ray emission probabilities)





1 Decay Scheme

Pu-238 decays by alpha transitions to U-234. Most of the alpha decay populates the U-234 ground state (71.04%) and the U-234 first excited level with energy of 43.5 keV (28.85%). Branching of Pu-238 decay by spontaneous fission is $1.85(5) \cdot 10^{-7} \%$.

Le plutonium 238 se désintègre par émission alpha vers le niveau fondamental de l'uranium 234 (71,04%) et vers l'état excité de 43,5 keV. Le nombre de désintégrations par fission spontanée est de $1,85(5) \cdot 10^{-7} \%$.

2 Nuclear Data

$T_{1/2}(^{238}\text{Pu})$	: 87,74	(3)	a
$T_{1/2}(^{234}\text{U})$	: 245,5	(6)	10^3 a
$Q^\alpha(^{238}\text{Pu})$	: 5593,20	(19)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,14}$	4507,90 (24)	$\sim 1,2 \cdot 10^{-6}$	3,5
$\alpha_{0,13}$	4548,67 (20)	$1,17 (7) \cdot 10^{-6}$	7,5
$\alpha_{0,12}$	4569,5 (3)	$\sim 2,0 \cdot 10^{-7}$	64
$\alpha_{0,11}$	4603,75 (20)	$1,52 (16) \cdot 10^{-7}$	152,9
$\alpha_{0,10}$	4645,35 (24)	$1,7 (4) \cdot 10^{-7}$	28
$\alpha_{0,9}$	4666,46 (20)	$1,30 (5) \cdot 10^{-6}$	53
$\alpha_{0,8}$	4741,50 (24)	$8,2 (17) \cdot 10^{-6}$	30,1
$\alpha_{0,7}$	4743,9 (2)	$7,4 (22) \cdot 10^{-8}$	3470
$\alpha_{0,6}$	4783,32 (20)	$1,0 (4) \cdot 10^{-4}$	5
$\alpha_{0,5}$	4806,91 (20)	$8,21 (16) \cdot 10^{-6}$	89,04
$\alpha_{0,4}$	5096,16 (20)	$6,85 (23) \cdot 10^{-6}$	10000
$\alpha_{0,3}$	5297,13 (19)	0,00297 (4)	432
$\alpha_{0,2}$	5449,85 (19)	0,105 (3)	101
$\alpha_{0,1}$	5549,70 (19)	28,85 (6)	1,394
$\alpha_{0,0}$	5593,20 (19)	71,04 (6)	1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{8,6}(U)$	41,82 (11)	$2,7 (14) 10^{-6}$	(E2)		645 (13)	178 (4)	885 (18)
$\gamma_{1,0}(U)$	43,498 (1)	29,1 (8)	E2		532 (11)	147 (3)	731 (15)
$\gamma_{11,9}(U)$	62,70 (1)	$1,6 (3) 10^{-8}$	E1		0,325 (7)	0,0807 (16)	0,434 (9)
$\gamma_{2,1}(U)$	99,852 (3)	0,108 (2)	E2		9,97 (20)	2,78 (6)	13,7 (3)
$\gamma_{11,7}(U)$	140,15 (2)	$2,2 (7) 10^{-8}$	M1 + 63% E2	2,9 (8)	1,8 (5)	0,49 (14)	5,4 (15)
$\gamma_{3,2}(U)$	152,719 (2)	$2,97 (4) 10^{-3}$	E2	0,217 (5)	1,43 (3)	0,397 (8)	2,19 (5)
$\gamma_{13,8}(U)$	192,91 (7)	$1,2 (4) 10^{-9}$	(E2)	0,164 (3)	0,515 (10)	0,142 (3)	0,872 (18)
$\gamma_{4,3}(U)$	200,97 (3)	$6,85 (23) 10^{-6}$	E2	0,150 (3)	0,432 (9)	0,119 (3)	0,748 (15)
$\gamma_{11,5}(U)$	203,12 (3)	$2,2 (5) 10^{-8}$	M1+66% E2	0,88 (17)	0,44 (9)	0,116 (23)	1,56 (30)
$\gamma_{14,8}(U)$	233,6 (2)	$4,1 10^{-7}$	(E0+E2)				
$\gamma_{13,6}(U)$	234,6 (2)	$0,1 10^{-6}$	E0				
$\gamma_{14,7}(U)$	235,9 (3)	$1,0 (5) 10^{-8}$	(E1)	0,0537 (11)	0,0108 (2)	0,00262 (5)	0,0681 (14)
$\gamma_{13,5}(U)$	258,227 (3)	$7,4 (12) 10^{-8}$	(E1)	0,0439 (9)	0,0087 (2)	0,00211 (4)	0,0554 (11)
$\gamma_{14,5}(U)$	299,2 (2)	$4,6 (3) 10^{-8}$	(E1)	0,0318 (7)	0,00616 (13)	0,00149 (3)	0,0400 (8)
$\gamma_{7,2}(U)$	705,9 (3)	$5,0 (13) 10^{-8}$	(E1)	0,00577 (12)	0,00100 (2)	0,000239 (5)	0,00709 (14)
$\gamma_{8,2}(U)$	708,4 (2)	$5,0 (3) 10^{-7}$	(E2)	0,0156 (3)	0,00497 (10)	0,00127 (3)	0,0223 (5)
$\gamma_{12,3}(U)$	727,8 (2)	$2,7 (3) 10^{-9}$	(E2)	0,0149 (3)	0,00462 (9)	0,00118 (3)	0,0211 (4)
$\gamma_{5,1}(U)$	742,814 (5)	$5,13 (13) 10^{-6}$	E1	0,00526 (11)	0,00091 (2)	0,000216 (5)	0,00646 (13)
$\gamma_{6,1}(U)$	766,39 (10)	$2,23 (5) 10^{-5}$	E2	0,0136 (3)	0,00403 (8)	0,00103 (2)	0,0190 (4)
$\gamma_{9,2}(U)$	783,4 (1)	$2,3 (3) 10^{-8}$	(E2)	0,0130 (3)	0,00380 (8)	0,00097 (2)	0,0181 (4)
$\gamma_{5,0}(U)$	786,3 (1)	$3,22 (9) 10^{-6}$	E1	0,00474 (9)	0,000814 (17)	0,000194 (4)	0,00583 (12)
$\gamma_{10,2}(U)$	804,4 (4)	$1,1 (3) 10^{-7}$	E0+E2				0,57
$\gamma_{7,1}(U)$	805,6 (3)	$5,6 (15) 10^{-8}$	(E1)	0,00455 (9)	0,000778 (16)	0,000185 (4)	0,00558 (11)
$\gamma_{8,1}(U)$	808,25 (15)	$4,1 10^{-6}$	E0+17% E2	3,31	0,94		4,3
$\gamma_{6,0}(U)$	809,88 (3)	$7,7 10^{-6}$	E0	>60			
$\gamma_{8,0}(U)$	851,7 (1)	$1,29 (4) 10^{-6}$	(E2)	0,0112 (2)	0,00308 (6)	0,000775 (16)	0,0155 (3)
$\gamma_{12,2}(U)$	880,5 (3)	$> 1,5 (4) 10^{-7}$	(E0+E2)				
$\gamma_{9,1}(U)$	883,23 (10)	$7,3 (4) 10^{-7}$	E2	0,0105 (2)	0,00280 (6)	0,000705 (14)	0,0144 (3)
$\gamma_{10,1}(U)$	904,3 (2)	$6,2 (11) 10^{-8}$	(E2)	0,0102 (2)	0,00264 (5)	0,000664 (13)	0,0137 (3)
$\gamma_{9,0}(U)$	926,72 (15)	$5,65 (25) 10^{-7}$	(E2)	0,00974 (20)	0,00249 (5)	0,000625 (13)	0,0131 (3)
$\gamma_{14,2}(U)$	941,9 (2)	$4,72 (23) 10^{-7}$	(E2)	0,00946 (20)	0,00240 (5)	0,000601 (12)	0,0127 (3)
$\gamma_{11,1}(U)$	946,0 (3)	$9,2 (13) 10^{-8}$	(E1)	0,00342 (7)	0,000579 (12)	0,000137 (3)	0,00419 (9)
$\gamma_{12,1}(U)$	980,3 (1)	$4,2 10^{-8}$	(E2)	0,00882 (18)	0,00218 (5)	0,000544 (11)	0,0117 (3)
$\gamma_{13,1}(U)$	1001,03 (15)	$9,9 (4) 10^{-7}$	E2	0,00850 (17)	0,00207 (4)	0,000517 (11)	0,0113 (3)
$\gamma_{14,1}(U)$	1041,8 (3)	$0,20 (2) 10^{-6}$	(E0+E2)				
$\gamma_{14,0}(U)$	1085,4 (3)	$7,8 (9) 10^{-8}$	(E2)				

3 Atomic Data

3.1 U

ω_K	:	0,970	(4)
$\bar{\omega}_L$	:	0,500	(19)
n_{KL}	:	0,794	(5)

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	94,666	
	$K\alpha_1$	98,44	
	$K\beta_3$	110,421	}
	$K\beta_1$	111,298	}
	$K\beta_5''$	111,964	}
	$K\beta_5'$	111,964	}
	$K\beta_2$	114,46	}
	$K\beta_4$	115,01	}
	$KO_{2,3}$	115,377	}
			62,47
		100	
		36,08	
		12,34	
X_L	$L\ell$	11,62	
	$L\alpha$	13,44 – 13,62	
	$L\eta$	15,4	
	$L\beta$	15,74 – 18,16	
	$L\gamma$	19,5 – 21,75	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	71,78 – 80,95	100
KLX	88,15 – 98,34	59,6
KXY	104,42 – 115,40	8,88
Auger L	5,9 – 21,6	

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,14}$	4432,00 (25)	$\sim 1,2 \cdot 10^{-6}$
$\alpha_{0,13}$	4472,09 (21)	$1,17 (7) \cdot 10^{-6}$
$\alpha_{0,12}$	4492,6 (3)	$\sim 2,0 \cdot 10^{-7}$

	Energy keV	Probability × 100
$\alpha_{0,11}$	4526,24 (21)	1,52 (16) 10 ⁻⁷
$\alpha_{0,10}$	4567,14 (25)	1,7 (4) 10 ⁻⁷
$\alpha_{0,9}$	4587,89 (21)	1,30 (5) 10 ⁻⁶
$\alpha_{0,8}$	4661,67 (23)	8,2 (17) 10 ⁻⁶
$\alpha_{0,7}$	4664,03 (21)	7,4 (22) 10 ⁻⁸
$\alpha_{0,6}$	4702,79 (21)	1,0 (4) 10 ⁻⁴
$\alpha_{0,5}$	4725,98 (21)	8,21 (16) 10 ⁻⁶
$\alpha_{0,4}$	5010,36 (21)	6,85 (23) 10 ⁻⁶
$\alpha_{0,3}$	5207,94 (20)	0,00297 (4)
$\alpha_{0,2}$	5358,09 (20)	0,105 (3)
$\alpha_{0,1}$	5456,26 (20)	28,85 (6)
$\alpha_{0,0}$	5499,03 (20)	71,04 (6)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(U)	5,9 - 21,6	10,6 (9)
e _{AK}	(U)		0,000011 (1)
	KLL	71,78 - 80,95	}
	KLX	88,15 - 98,34	}
	KXY	104,42 - 115,40	}
ec _{1,0} L	(U)	21,74 - 26,33	21,1 (6)
ec _{3,2} K	(U)	37,117 (2)	2,01 (5) 10 ⁻⁴
ec _{1,0} M	(U)	37,950 - 39,948	5,83 (17)
ec _{2,1} L	(U)	78,094 - 82,684	0,0733 (17)
ec _{4,3} K	(U)	85,37 (3)	5,88 (23) 10 ⁻⁷
ec _{2,1} M	(U)	94,304 - 96,302	0,0204 (5)
ec _{3,2} L	(U)	130,960 - 135,551	1,33 (3) 10 ⁻³
ec _{3,2} M	(U)	147,171 - 149,169	3,69 (8) 10 ⁻⁴
ec _{4,3} L	(U)	179,21 - 183,80	1,69 (7) 10 ⁻⁶
ec _{4,3} M	(U)	195,42 - 197,42	4,7 (2) 10 ⁻⁷
ec _{6,1} K	(U)	650,78 (2)	3,0 (1) 10 ⁻⁷
ec _{8,1} K	(U)	692,6 (1)	2,6 10 ⁻⁵
ec _{6,1} L	(U)	744,62 - 749,21	8,8 (3) 10 ⁻⁸
ec _{6,1} M	(U)	760,83 - 762,83	2,26 (7) 10 ⁻⁸
ec _{8,1} L	(U)	786,44 - 791,03	7,0 10 ⁻⁷
ec _{6,0} K	(U)	894,28 (3)	6,0 10 ⁻⁵

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(U)	11,62 — 21,75	10,63 (8)	
XK α_2	(U)	94,666	0,000106 (3)	} K α
XK α_1	(U)	98,44	0,000169 (5)	}
XK β_3	(U)	110,421	}	
XK β_1	(U)	111,298	}	0,0000609 (16) K' β_1
XK β_5''	(U)	111,964	}	
XK β_5	(U)	111,964	}	
XK β_2	(U)	114,46	}	
XK β_4	(U)	115,01	}	0,0000202 (6) K' β_2
XKO $_{2,3}$	(U)	115,377	}	

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{8,6}(\text{U})$	41,82 (11)	3,0 (16) 10^{-9}
$\gamma_{1,0}(\text{U})$	43,498 (1)	3,97 (8) 10^{-2}
$\gamma_{11,9}(\text{U})$	62,70 (1)	1,1 (3) 10^{-8}
$\gamma_{2,1}(\text{U})$	99,852 (3)	7,35 (8) 10^{-3}
$\gamma_{11,7}(\text{U})$	140,15 (2)	3,5 (7) 10^{-8}
$\gamma_{3,2}(\text{U})$	152,719 (2)	9,30 (7) 10^{-4}
$\gamma_{13,8}(\text{U})$	192,91 (7)	6,6 (20) 10^{-10}
$\gamma_{4,3}(\text{U})$	200,97 (3)	3,92 (13) 10^{-6}
$\gamma_{11,5}(\text{U})$	203,12 (3)	8,5 (15) 10^{-9}
$\gamma_{14,7}(\text{U})$	235,9 (3)	9 (5) 10^{-9}
$\gamma_{13,5}(\text{U})$	258,227 (3)	7,0 (11) 10^{-8}
$\gamma_{14,5}(\text{U})$	299,2 (2)	4,4 (3) 10^{-8}
$\gamma_{7,2}(\text{U})$	705,9 (1)	5,0 (13) 10^{-8}
$\gamma_{8,2}(\text{U})$	708,4 (2)	4,9 (3) 10^{-7}
$\gamma_{12,3}(\text{U})$	727,8 (2)	2,7 (3) 10^{-9}
$\gamma_{5,1}(\text{U})$	742,813 (5)	5,10 (13) 10^{-6}
$\gamma_{6,1}(\text{U})$	766,38 (2)	2,19 (5) 10^{-4}
$\gamma_{9,2}(\text{U})$	783,4 (1)	2,2 (3) 10^{-8}
$\gamma_{5,0}(\text{U})$	786,27 (3)	3,20 (9) 10^{-6}
$\gamma_{10,2}(\text{U})$	804,4 (3)	7,1 (17) 10^{-8}
$\gamma_{7,1}(\text{U})$	805,80 (5)	5,6 (15) 10^{-8}
$\gamma_{8,1}(\text{U})$	808,2 (1)	7,67 (25) 10^{-7}

	Energy keV	Photons per 100 disint.
$\gamma_{8,0}(\text{U})$	851,7 (1)	$1,27 (4) 10^{-6}$
$\gamma_{12,2}(\text{U})$	880,5 (1)	$1,5 (4) 10^{-7}$
$\gamma_{9,1}(\text{U})$	883,24 (4)	$7,2 (4) 10^{-7}$
$\gamma_{10,1}(\text{U})$	904,3 (2)	$6,1 (11) 10^{-8}$
$\gamma_{9,0}(\text{U})$	926,74 (5)	$5,58 (25) 10^{-7}$
$\gamma_{14,2}(\text{U})$	941,94 (10)	$4,66 (23) 10^{-7}$
$\gamma_{11,1}(\text{U})$	946,00 (3)	$9,2 (13) 10^{-8}$
$\gamma_{12,1}(\text{U})$	980,3 (1)	$4,2 10^{-8}$
$\gamma_{13,1}(\text{U})$	1001,03 (3)	$9,8 (4) 10^{-7}$
$\gamma_{14,1}(\text{U})$	1041,7 (2)	$1,97 (16) 10^{-7}$
$\gamma_{14,0}(\text{U})$	1085,4 (2)	$7,7 (9) 10^{-8}$

7 Main Production Modes

Np – $238(\beta^-)\text{Pu}$ – 238

Cm – $242(\alpha)\text{Pu}$ – 238

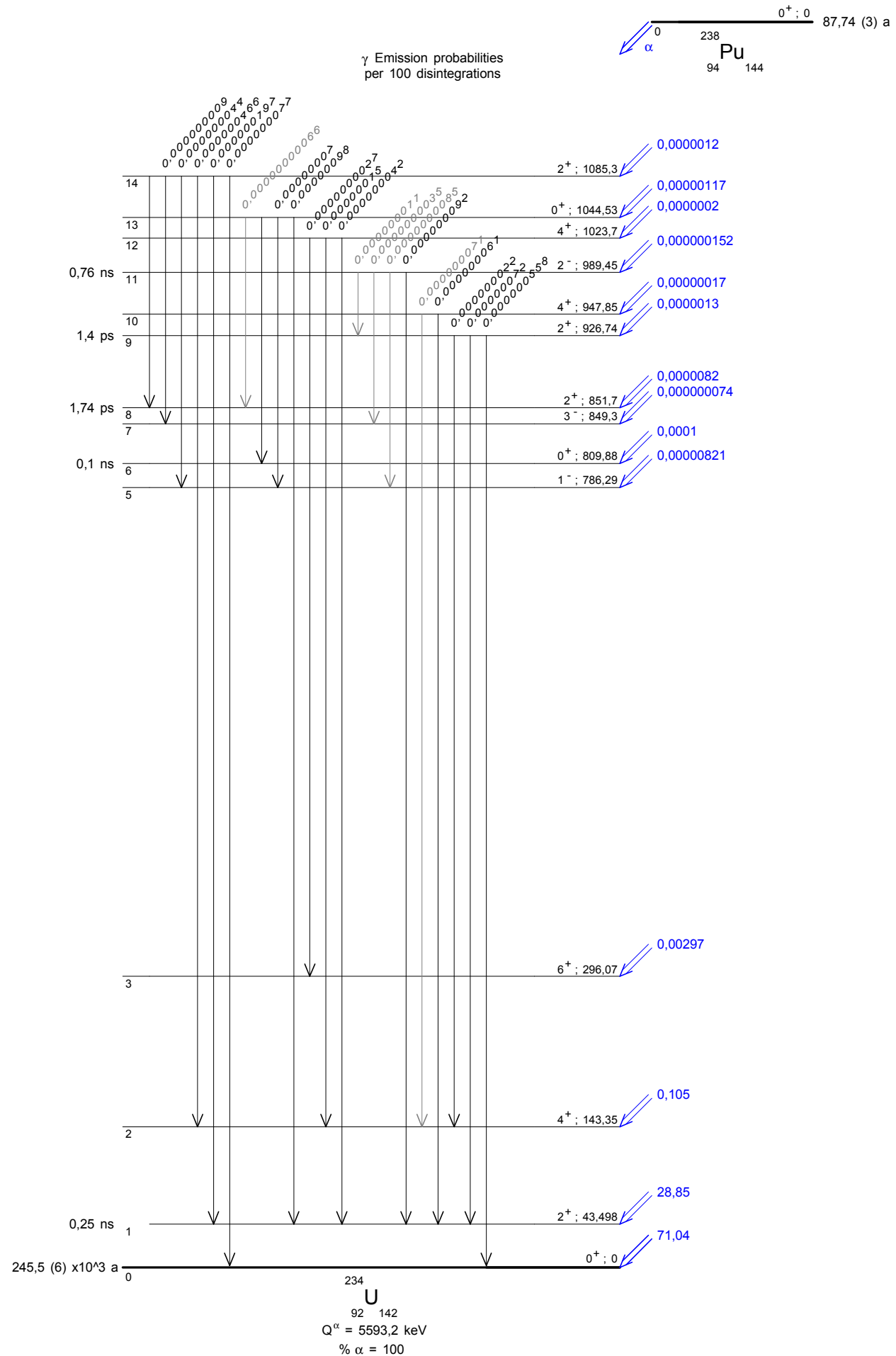
8 References

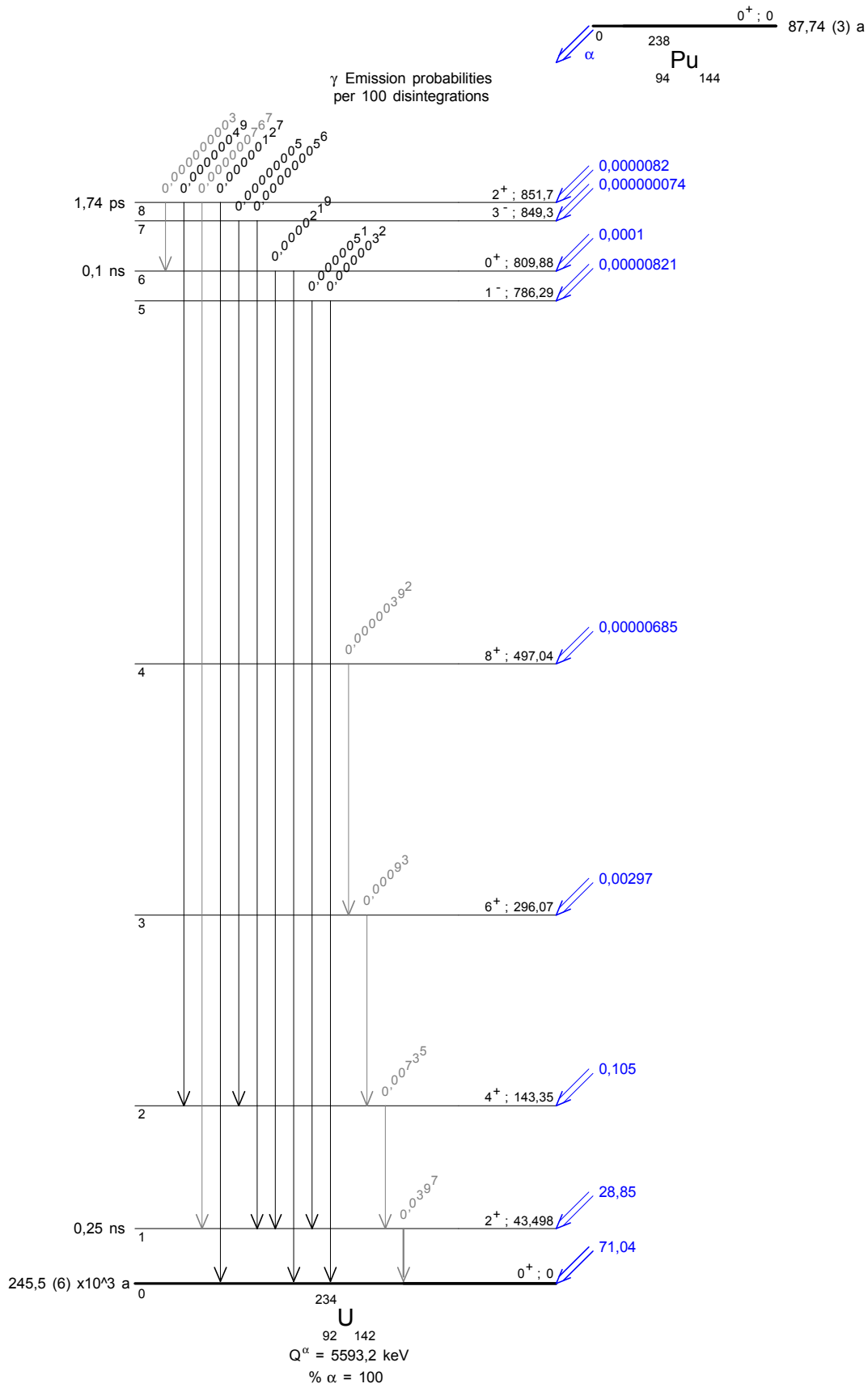
- A. H. JAFFEY, A. HIRSCH. Report ANL-4286 (1949)
(Spontaneous fission half-life)
- A. H. JAFFEY, J. LERNER. Report ANL-4411 (1950)
(Half-life)
- A. H. JAFFEY, L. B. MAGNUSON. Paper No. 14.2. National Nuclear Energy Plutonium Project Record Div. IV .McGraw-Hill, New York. 14B (1951) 978
(Half-life)
- A. H. JAFFEY. Paper No. 2.2. National Nuclear Energy Plutonium Project Record Div. IV. McGraw-Hill, New York. 14B (1951) 89
(Half-life)
- G. T. SEABORG, R. A. JAMES AND A. GIORSO. Paper No. 14.2. National Nuclear Energy Series, Plutonium Project Record, Div. IV. McGraw-Hill, New York. 14B (1951) 978
(Half-life)
- G. T. SEABORG, J.KATZ AND W. M. MANNING. Paper No. 14.2. National Nuclear Energy Series, Plutonium Project Record, Div. IV. McGraw-Hill, New York. 14B (1951) 978
(Half-life)
- E. SEGRE. Phys. Rev. 86 (1952) 21
(Spontaneous fission half-life)
- F. ASARO, I. PERLMAN. Phys. Rev. 94 (1954) 381
(Alpha-particle energies and emission probabilities)
- K. W. JONES, R. A. DOUGLAS, M. T. MCELLISTREM AND H. T. RICHARDS. Phys. Rev. 94 (1954) 947
(Half-life)
- E. L. CHURCH, A. W. SUNYAR. Phys. Rev 98 (1955) 1186A
(Gamma-ray energies)
- J. O. NEWTON, B. ROSE AND J. MILSTED. Phil. Mag. 1 (1956) 981
(Gamma-ray energies)

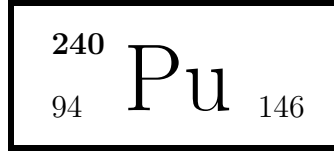
- D. C. HOFFMAN, G. P. FORD AND F. O. LAWRENCE, J. INORG.. Nucl. Chem. 5 (1957) 6
(Half-life)
- L. N. KONDRATEV, G. I. NOVIKOVA, V. B. DEDOV AND L. L. GOLDIN. Izv. Akad. Nauk SSSR, Ser Fiz 21 (1957) 907
(Alpha-particle energies and emission probabilities)
- V. A. DRUIN, V. P. PERELYGIN AND G. I. KHLEBNIKOV. Soviet Phys. JETP 13 (1961) 913; Zhurn. Eksptl. i Teoret. Fiz. 40 (1961)
(Spontaneous fission half-life)
- C. F. LEANG. Compt. Rend. 255 (1962) 3155
(Alpha-particle energies and emission probabilities)
- S. BJORNHOLM, C. M. LEDERER, F. ASARO AND I. PERLMAN. Phys. Rev. 130 (1963) 2000
(Alpha transition probabilities)
- J. W. HALLEY, D. ENGELKEMEIR. Phys. Rev. 134 (1964) A24
(L X-ray emission probabilities)
- F. LES. Acta. Phys. Polon. 26 (1964) 951
(E0+E2 transition probabilities)
- C. M. LEDERER. Priv Comm, quoted by 67Le24, unpublished (1964)
(E0+E2 transition probabilities)
- J. F. EICHELBERGER, G. R. GROVE AND L. V. JONES. MLM-1238 (1965)
(Half-life)
- K. C. JORDAN. Report No. MLM-1443, July-September (1967) 11
(Half-life)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- J. BYRNE, W. GELLETLY, M. A. S. ROSS AND F. SHAIKH. Phys. Rev. 170 (1968) 80
(L X-ray emission probabilities)
- L. SALGUEIRO ET AL.. C. R. Acad. Sci. 267B (1968) 1293
(L X-ray emission probabilities)
- K. L. SWINTH, P. POLISHUK. N.Y. Plenum Press, 1968, (1968) 279
(L X-ray emission probabilities)
- S. A. BARANOV, V. M. KULAKOV AND V. M. SHATINSKII. Nucl. Phys. Yadern. Fiz. 7 (1968) 442, 727.
(Alpha-particle energies and emission probabilities)
- S. R. AMTEY, J. H. HAMILTON, A. V. RAMAYYA. Nucl. Phys. A126 (1969) 201
(Conversion electron relative intensities)
- D. BENSON. Priv. Comm. (1969)
(Half-life)
- C. M. LEDERER, F. ASARO AND I. PERLMAN. UCRL-18667 (1969) 3
(Gamma-ray energies and emission probabilities)
- S. A. BARANOV, V. M. KULAKOV, V. M. SHATINSKII AND Z. S. GLADKIKH. Yad. Fiz. 12 (1970) 1105.
(Alpha-particle energies and emission probabilities)
- J. E. CLINE. IN-1448 Rev. (1971)
(Gamma-ray energies and emission probabilities)
- K. L. SWINTH. IEEE Transactions Nuclear Science, part 1 18 (1971) 125
(L X-ray emission probabilities)
- J. C. SOARES, J. P. RIBEIRO, A. GONCALVES, F. B. GIL AND J. C. FERREIRA. Compt. Rend. 273B (1971) 985
(Alpha-particle energies and emission probabilities)
- A. I. MAKARENKO, L. A. OSTRETISOV AND N. V. FORAFONTOV. Izv. Akad. Nauk SSSR, Ser. Fiz. 35 (1971) 2335; Bull. Acad. Sci. USSR, Phys. Ser. 35 (1972) 2118. ()
(Gamma-ray energies and emission probabilities)
- B. GRENBERG, A. RYTZ. Metrologia. 7 (1971) 65
(Alpha-particle energies)
- S. A. BARANOV, V. M. KULAKOV, V. M. SHATINSKII AND Z. S. GLADKIKH. Soviet J. Nucl. Phys. 12 (1971) 604
(Alpha-particle energies and emission probabilities)
- R. GUNNINK, R. J. MORROW. UCRL-51087 (1971)
(Gamma-ray energies and emission probabilities)
- J. D. HASTINGS, W. W. STROHM. J. Inorg. Nucl. Chem. 34 (1972) 25
(Spontaneous fission half-life)
- M. SCHMORAK, C. E. BEMIS, JR., M. J. ZENDER, N. B. GOVE AND P. F. DITTNER. Nucl. Phys. A178 (1972) 410
(Gamma-ray energies)

- W. W. STROHM, K. C. JORDAN. Nucl. Soc. 18 (1974) 185
(Half-life)
- R. R. GAY, R. SHER. Bull. Am. Phys. Soc. 20(2) (1975) 160,GB13
(Spontaneous fission half-life)
- N. R. GUNNINK, J. E. EVANS AND A. L. PRINDLE. UCRL-52139 (1976)
(Gamma-ray energies and emission probabilities)
- D. G. VASILIK, R. W. MARTIN. Nucl. Instrum. Methods 135 (1976) 405
(L X-ray emission probabilities)
- V. G. POLYUKHOV, G. A. TIMOFEEV, P. A. PRIVALOVA, V. Y. GABESKIRIYA AND A. P. CHETVERIKOV. Soviet. J. At. Energy 40 (1976) 66; At. Energ. 40 (1976) 61 ()
(Half-life)
- H. UMEZAWA, T. SUZUKI AND S. ICHIKAWA. J. Nucl. Sci. Technol. 13 (1976) 327
(Gamma-ray and emission probabilities)
- C. E. BEMIS JR., L. TUBBS. Report ORNL-5297 (1977) 93
(L X-ray emission probabilities)
- H. DIAMOND, W. C. BENTLEY, A. H. JAFFEY AND K. F. FLYNN. Phys. Rev. 15 (1977) 1034
(Half-life)
- F. P. LARKINS. Atomic Data and Nuclear Data Tables 20 (1977) 313
(Auger electron energies)
- F. ROSEL, H. M. FRIESS, K. ALDER AND H. C. PAULI. At. Data Nucl. Data Tables. 21 (1978) 92
(Theoretical ICC)
- R. VANINBROUKX, G. GROSSE AND W. ZEHNER. Report CBNM/RN/45/79 (1979)
(Gamma-ray emission probabilities)
- A. CESANA, G. SANDRELLI, V. SANGIUST AND M. TERRANI. Energia Nucl. (Milan) 26 (1979) 526
(Gamma-ray energies and emission probabilities)
- S. K. AGGARWAL, A. V. JADHAV, S. A. CHITAMBAR, K. RAGHURAMAN, S. N. ACHARYA, A. R. PARAB, C. K. SIVARAMAKRISHNAN AND H. C. JAIN. Radiochem. Radioanal. Lett. 46 (1981) 69
(Half-life)
- V. D. SEVASTYANOV, V. P. JARINA. Voprosi Atomnoi Nauki i Tekhniki, seriya Jadernie Konstanti. 5(44) (1981) 21
(Half-life)
- A. M. GEIDELMAN, YU. S. EGOROV, V. G. NEDOVESOV. Conf. Nucl. Spectrosc. Struct. At. Nuclei, (1982) Kiev (1982) 511
(L X-ray emission probabilities)
- G. BARREAU, H. G. BORNER, T. VON EGIDY, R. W. HOFF. Z. Phys. A308 (1982) 209
(K X-ray energies)
- I. AHMAD, J. HINES, J. E. GINDLER. Phys. Rev. C27 (1983) 2239
(K X-ray energies)
- V. V. OVECHKIN, V. M. CHESALIN AND I. A. SHKABURA. Izv. Akad. Nauk SSSR, Ser. Fiz. 48 (1984) 1029
(Gamma-ray energies and emission probabilities)
- I. AHMAD. Nucl. Instrum. Meth. 223 (1984) 319
(Alpha-particle energies and emission probabilities)
- L. M. BAK, P. DRYAK, V. G. NEDOVESOV, S. A. SIDORENKO, G. E. SHUKIN, K. P. YAKOVLEV. Conf. Nucl. Spectrosc. At. Nuclei, Alma-Ata (1984) 541
(L X-ray emission probabilities)
- G. BORTELS, B. DENECKE, R. VALNINBROUKX. Nucl. Instrum. Meth. 223 (1984) 329
(Alpha-particle, gamma-ray and L X-ray energies and emission probabilities)
- P. DRYAK, YU. S. EGOROV, V. G. NEDOVESOV, I. PLKH, G. E. SHUKIN. Conf. Nucl. Spectrosc. At. Nuclei, Alma-Ata (1984) 540
(L X-ray emission probabilities)
- R. G. HELMER, C. W. REICH. J. Appl. Radiat. Isotop. 35 (1984) 1067
(Gamma-ray energies and emission probabilities)
- P. A. BURNS, P. N. JOHNSTON AND J. R. MORONEY, A. LORENZ. IAEA Tech. Report, Ser. 261 (1986) 147
(Alpha-particle energies and emission probabilities)
- F. LAGOUTINE, N. COURSOL AND J. LEGRAND. ISBN-2-7272-0078-1 (LMRI, 1982-1987)
(Energy of Auger electrons)
- G. BORTELS, P. COLLAERS. Appl. Radiat. Isot. 38 (1987) 831
(Alpha-particle energies and emission probabilities)
- YU. A. SELITSKY, V. B. FUNSHTEIN, V. A. YAKOVLEV. Proc. 38th Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, Baku (1988) 131
(Spontaneous fission half-life)

- I. AHMAD, R. R. BETTS, T. HAPP, D. J. HENDERSON, F. L. H. WOLFS AND A. H. WUOSMAA. Nucl. Instrum. Meth. Phys. Res. A299 (1990) 201
(Alpha-particle energies)
- YU. S. POPOV, I. B. MAKAROV, D. KH. SRUROV, E. A. ERIN. Sov. Radiochem. 32 (1990) 425
(M X-ray emission probability)
- P. N. JOHNSTON, J. R. MORONEY AND P. A. BURNS. Appl. Radiat. Isot. 42 (1991) 245
(Alpha-particle energies)
- A. RYTZ, G. BARCI-FUNEL. At. Data Nucl. Data Tables. 47 (1991) 205
(Alpha-particle energies)
- G. BARCI-FUNEL, J. DALMASSO AND G. ARDISSON. Appl. Radiat. Isot. 43 (1992) 37
(L X-ray emission probabilities)
- M. C. LEPY, B. DUCHEMIN, J. MOREL. Nucl. Instrum. Methods Phys. Res. A339 (1994) 218
(L X-ray energies and emission probabilities)
- M. C. LEPY, B. DUCHEMIN, J. MOREL. Nucl. Instrum. Methods Phys. Res. A353 (1994) 10
(L X-ray energies and emission probabilities)
- S. I. KAFALA, T. D. MACMAHON, P. W. GRAY. Nucl. Instrum. Methods Phys. Res. A339 (1994) 151
(Evaluation technique)
- D. T. BARAN. Appl. Radiat. Isot. 45 (1994) 1177
(Gamma-ray emission probabilities)
- Y. A. AKOVALI. Nuclear Data Sheets 71 (1994) 181
(Level energies and data from Pa-234 and Np-234 decays)
- P. N. JOHNSTON, P. A. BURNS. Nucl. Instrum. Meth. Phys. Res. A361 (1995) 229
(L X-ray energies and emission probabilities)
- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Decay energy)
- E. SCHONFELD, H. JANSSEN. Nucl. Instrum. Meth. Phys. Res. A369 (1996) 527
(Atomic data)
- J. YANG, J. NI. Nucl. Instrum. Meth. Phys. Res. A413 (1998) 239
(Alpha-particle energies and emission probabilities)
- E. SCHÖNFELD, G. RODLOFF. PTB-6.11-1999-1999-1 (1999)
(K X-ray energies and relative emission probabilities)
- E. SCHÖNFELD, H. JANSSEN. Appl. Rad. Isot. 52 (2000) 595
(L X-ray and Auger electron emission probabilities)
- V. P. CHECHEV, A. G. EGOROV. Appl. Rad. Isot. 52 (2000) 601
(Evaluation technique)
- R. G. HELMER, C. VAN DER LEUN. Nucl. Instrum. Meth. Phys. Res. A450 (2000) 35
(Gamma-ray energies)
- N. E. HOLDEN, D. C. HOFFMAN. Pure Appl. Chem. 72 (2000) 1525
(Spontaneous fission half-life)
- Y. NIR-EL. Radiochim. Acta 88 (2000) 83
(Gamma-ray energies)







1 Decay Scheme

Pu-240 decays 100 % by alpha transitions to U-236 and by spontaneous fission with branching fraction of $5.7(2) \cdot 10^{-6}$ %. Most of the alpha decay populates the U-236 ground state (72.7 %) and the U-236 first excited level with energy of 45.24 keV (27.2 %).

Le plutonium 240 décroît à 100 % par émission alpha vers l'uranium 236, et pour une faible proportion par fission spontanée ($5,7 (2) \cdot 10^{-6}$ %). Les branchements alpha principaux se font vers le niveau fondamental (72,7 %) et le niveau excité de 45,24 keV (27,2 %).

2 Nuclear Data

$T_{1/2}(^{240}\text{Pu})$	:	6561	(7)	a
$T_{1/2}(^{236}\text{U})$	:	23,42	(4)	10^6 a
$Q^\alpha(^{240}\text{Pu})$	:	5255,78	(15)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,10}$	4289,15 (18)	$< 1,0 \cdot 10^{-7}$	> 70
$\alpha_{0,9}$	4295,5 (4)	$< 1,3 \cdot 10^{-7}$	> 61
$\alpha_{0,8}$	4297,79 (23)	$< 1,7 \cdot 10^{-7}$	> 49
$\alpha_{0,7}$	4336,57 (23)	$\approx 6,5 \cdot 10^{-7}$	≈ 27
$\alpha_{0,5}$	4568,18 (16)	$1,93 (4) \cdot 10^{-5}$	66
$\alpha_{0,4}$	4733,54 (16)	$4,7 (5) \cdot 10^{-5}$	471
$\alpha_{0,3}$	4946,00 (15)	$1,082 (18) \cdot 10^{-3}$	648
$\alpha_{0,2}$	5106,30 (15)	0,0863 (18)	94,7
$\alpha_{0,1}$	5210,54 (15)	27,16 (11)	1,4
$\alpha_{0,0}$	5255,78 (15)	72,74 (11)	1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(\text{U})$	45,242 (3)	27,2 (8)	E2		439 (9)	121,5 (24)	604 (12)
$\gamma_{6,5}(\text{U})$	56,6 (5)		(E2)		148 (3)	41,1 (8)	204 (4)
$\gamma_{2,1}(\text{U})$	104,234 (6)	0,0874 (18)	E2		8,16 (16)	2,27 (5)	11,24 (22)
$\gamma_{3,2}(\text{U})$	160,307 (3)	$1,129 (17) 10^{-4}$	E2	0,208 (4)	1,154 (23)	0,320 (7)	1,79 (4)
$\gamma_{4,3}(\text{U})$	212,46 (5)	$4,7 (5) 10^{-5}$	E2	0,141 (3)	0,341 (7)	0,0941 (19)	0,610 (12)
$\gamma_{10,6}(\text{U})$	222,4 (1)						
$\gamma_{10,5}(\text{U})$	279,0 (1)		(M1+E2)				
$\gamma_{5,2}(\text{U})$	538,11 (10)	$1,68 (14) 10^{-7}$	E3	0,0631 (13)	0,0599 (12)	0,0164 (4)	0,145 (3)
$\gamma_{6,2}(\text{U})$	594,5 (3)						
$\gamma_{5,1}(\text{U})$	642,35 (9)	$1,45 (4) 10^{-5}$	E1+(M2+E3)	0,112 (10)	0,031 (3)		0,15 (2)
$\gamma_{5,0}(\text{U})$	687,60 (5)	$4,66 (22) 10^{-6}$	E1	0,219 (12)	0,068 (6)		0,31 (2)
$\gamma_{6,1}(\text{U})$	698,1	$< 2,5 10^{-8}$					
$\gamma_{9,2}(\text{U})$	$\approx 810,9$						
$\gamma_{7,1}(\text{U})$	873,92 (15)	$5,9 (6) 10^{-7}$	(E2)	0,01079 (22)	0,00288 (6)	0,000725 (15)	0,0147 (3)
$\gamma_{8,1}(\text{U})$	$\approx 912,7$		(M1)	0,0440 (9)	0,00813 (16)	0,00196 (4)	0,0548 (11)
$\gamma_{9,1}(\text{U})$	915,1 (3)		(M1+E0)				
$\gamma_{7,0}(\text{U})$	918,9 (3)	$\approx 6,0 10^{-8}$	(E0)				
$\gamma_{10,1}(\text{U})$	921,2 (2)		E1	0,00359 (7)	0,000607 (12)	0,000145 (3)	0,00439 (8)
$\gamma_{8,0}(\text{U})$	958,0 (2)	$< 1,0 10^{-7}$					
$\gamma_{9,0}(\text{U})$	$\approx 959,9$	$< 5,0 10^{-8}$					
$\gamma_{10,0}(\text{U})$	966,9 (2)	$< 5,0 10^{-8}$	E1	0,00330 (6)	0,000556 (11)	0,000132 (3)	0,00404 (8)

3 Atomic Data

3.1 U

ω_K	:	0,970 (4)
$\bar{\omega}_L$	:	0,500 (19)
n_{KL}	:	0,794 (5)

3.1.1 X Radiations

	Energy keV	Relative probability	
X_K	$K\alpha_2$	94,666	
	$K\alpha_1$	98,44	
	$K\beta_3$	110,421	}
	$K\beta_1$	111,298	}
	$K\beta_5''$	111,964	}
	$K\beta_2$	114,407	}
	$K\beta_4$	115,012	}
	$KO_{2,3}$	115,377	}
			62,47
			100
			36,06

	Energy keV	Relative probability
X_L		
L ℓ	11,62	
L α	13,44 – 13,62	
L η	15,407	
L β	15,74 – 18,16	
L γ	19,5 – 21,75	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	71,78 – 80,95	100
KLX	88,15 – 98,43	59,6
KXY	104,51 – 115,59	8,88
Auger L	5,9 – 21,6	

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,10}$	4217,62 (18)	$< 1,0 \cdot 10^{-7}$
$\alpha_{0,9}$	4223,8 (4)	$< 1,3 \cdot 10^{-7}$
$\alpha_{0,8}$	4226,12 (23)	$< 1,7 \cdot 10^{-7}$
$\alpha_{0,7}$	4264,25 (23)	$\approx 6,5 \cdot 10^{-7}$
$\alpha_{0,5}$	4492,00 (16)	$1,93 (4) \cdot 10^{-5}$
$\alpha_{0,4}$	4654,60 (16)	$4,7 (5) \cdot 10^{-5}$
$\alpha_{0,3}$	4863,51 (15)	$1,082 (18) \cdot 10^{-3}$
$\alpha_{0,2}$	5021,15 (15)	0,0863 (18)
$\alpha_{0,1}$	5123,64 (15)	27,16 (11)
$\alpha_{0,0}$	5168,13 (15)	72,74 (11)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(U)	5,9 - 21,6	10,3 (8)
e _{AK}	(U)		0,0000027 (4)
	KLL	71,78 - 80,95	}
	KLX	88,15 - 98,43	}
	KXY	104,51 - 115,59	}
ec _{1,0} T	(U)	23,48 - 45,24	27,2 (8)
ec _{1,0} L	(U)	23,484 - 28,074	19,8 (6)
ec _{1,0} M	(U)	39,694 - 41,692	5,47 (15)
ec _{2,1} L	(U)	82,476 - 87,066	0,0583 (13)
ec _{2,1} M	(U)	98,686 - 100,684	0,0162 (4)

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(U)	11,62 — 21,75	10,34 (15)
XK α_2	(U)	94,666	0,0000260 (8) } K α
XK α_1	(U)	98,44	0,0000416 (12) }
XK β_3	(U)	110,421	}
XK β_1	(U)	111,298	}
XK β_5''	(U)	111,964	}
XK β_2	(U)	114,407	}
XK β_4	(U)	115,012	}
XK $\beta_{2,3}$	(U)	115,377	}
			0,0000152 (5) K' β_1
			0,0000049 (2) K' β_2

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$ (U)	45,242 (3)	0,0450 (9)
$\gamma_{6,5}$ (U)	56,6 (5)	
$\gamma_{2,1}$ (U)	104,234 (6)	0,00714 (7)
$\gamma_{3,2}$ (U)	160,307 (3)	4,045 (22) 10^{-4}

	Energy keV	Photons per 100 disint.
$\gamma_{4,3}(\text{U})$	212,46 (5)	$2,9 (3) 10^{-5}$
$\gamma_{10,6}(\text{U})$	222,4 (1)	
$\gamma_{10,5}(\text{U})$	279,0 (1)	
$\gamma_{5,2}(\text{U})$	538,11 (10)	$1,47 (12) 10^{-7}$
$\gamma_{6,2}(\text{U})$	594,5 (3)	
$\gamma_{5,1}(\text{U})$	642,35 (9)	$1,26 (3) 10^{-5}$
$\gamma_{5,0}(\text{U})$	687,60 (5)	$3,56 (16) 10^{-6}$
$\gamma_{6,1}(\text{U})$	698,1	$< 2,5 10^{-8}$
$\gamma_{9,2}(\text{U})$	$\approx 810,9$	
$\gamma_{7,1}(\text{U})$	873,92 (15)	$5,8 (6) 10^{-7}$
$\gamma_{8,1}(\text{U})$	$\approx 912,7$	
$\gamma_{9,1}(\text{U})$	915,1 (3)	
$\gamma_{7,0}(\text{U})$	918,9 (3)	
$\gamma_{10,1}(\text{U})$	921,2 (2)	
$\gamma_{8,0}(\text{U})$	958,0 (2)	$< 1,0 10^{-7}$
$\gamma_{9,0}(\text{U})$	$\approx 959,9$	$< 5,0 10^{-8}$
$\gamma_{10,0}(\text{U})$	966,9 (2)	$< 5,0 10^{-8}$

7 Main Production Modes

- U – $^{238}(\text{n},\gamma)\text{Np} - 240$
- U – $^{238}(\alpha,2\text{n})\text{Pu} - 240$
- U – $^{238}(\alpha,\text{pn})\text{Np} - 240$

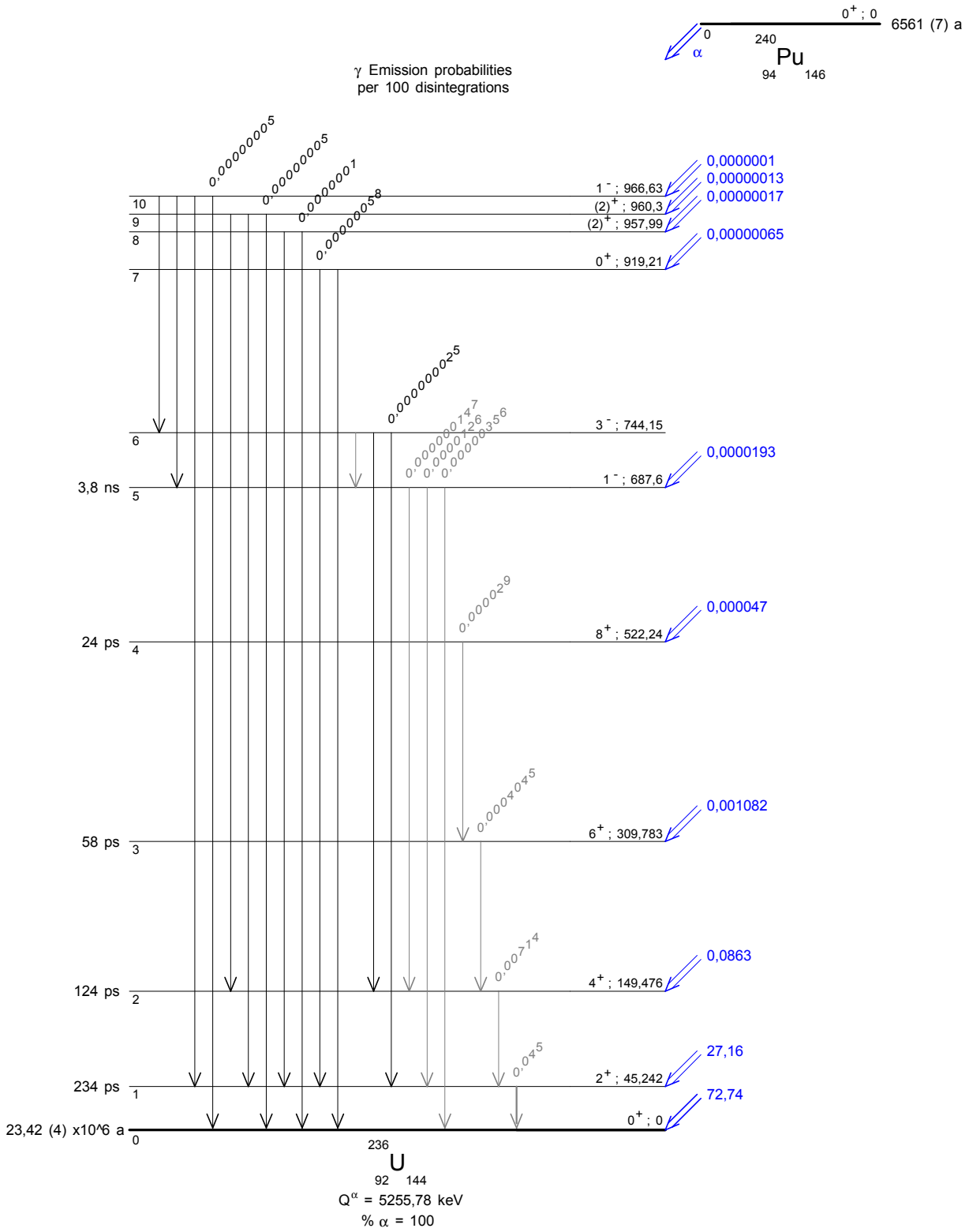
8 References

- M. G. INGRAM, D. C. HESS, P. R. FIELDS, G. L. PYLE. Phys. Rev. 83 (1951) 1250
(Half-life)
- E. F. WESTRUM. Phys. Rev. 83 (1951) 1249
(Half-life)
- F. ASARO, I. PERLMAN. Phys. Rev. 88 (1952) 828
(Alpha emission energies, Alpha emission probabilities)
- E. M. KINDERMAN. Hanford Lab. Report HW 27660 (1953)
(SF Half-life)
- F. R. BARCLAY, W. GALBRAITH, K. M. GLOVER, G. R. HALL, W. J. WHITEHOUSE. Proc. Phys. Soc. (London) 67A (1954) 646
(SF Half-life)
- O. CHAMBERLAIN, G. W. FARWELL, E. SEGRE. Phys. Rev. 94 (1954) 156
(SF Half-life)
- G. FARWELL, J. E. ROBERTS, A. C. WAHL. Phys. Rev. 94 (1954) 363
(Half-life)
- J. P. BUTLER, T. A. EASTWOOD, T. L. COLLINS, M. E. JONES, F. M. ROURKE, R. P. SCHUMAN. Phys. Rev. 103 (1956) 634
(Half-life)
- L. L. GOLDIN, G. I. NOVIKOVA, E. F. TRETAKOV. Phys. Rev. 103 (1956) 1004
(Alpha emission energies, Alpha emission probabilities)
- L. M. KONDRATEV, G. I. NOVIKOVA, Y. P. SOBOLEV, L. L. GOLDIN. Zh. Eksp. Teor. Fiz. 31 (1956) 771
(Alpha emission energies, Alpha emission probabilities)

- F. ASARO, S. G. THOMPSON, F. S. STEPHENS, JR. I. PERLMAN. Priv. Comm. 1957, cited in 1964Hy02 (1957)
(Alpha emission energies, Alpha emission probabilities)
- P. S. SAMOILOV. Atomnaya Energ. 4 (1958) 81
(Gamma ray energies)
- YA. P. DOKUCHAEV. Atomnaya Energ. 6 (1959) 74
(Half-life)
- V. L. MIKHEEV, N. K. SKOBELEV, V. A. DRUIN, G. N. FLEROV. Zhur. Eksptl. i Teoret. Fiz. 37 (1959) 859
(Half-life)
- E. F. TRETIAKOV, L. N. KONDRATEV, G. I. KHLEBNIKOV, L. L. GOLDIN. Zh. Eksp. Teor. Fiz. 36 (1959) 362
(Gamma ray energies)
- D. E. WATT, F. J. BANNISTER, J. B. LAIDLER, F. BROWN. Phys. Rev. 126 (1962) 264
(SF Half-life)
- C. F. LEANG. Compt. Rend. 255 (1962) 3155
(Alpha emission energies)
- L. Z. MALKIN, I. D. ALKHAZOV, A. S. KRIVOKHATSKY, K. A. PETRZHAK. At. Energ. USSR 15 (1963) 158
(SF Half-life)
- E. K. HYDE, I. PERLMAN, G. T. SEABORG. The Nuclear Properties of the Heavy Elements, Vol II. Prentice-Hall, Inc, Englewood Cliffs, N J (1964)
(Alpha emission energies, Alpha emission probabilities)
- J. A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- P. FIELDHOUSE, D. S. MATHER, E. R. CULLIFORD. J. Nucl. Energy 21 (1967) 749
(SF Half-life)
- P. H. WHITE. Priv. Comm., cited in 2000Ho27 (1967)
(SF Half-life)
- F. L. OETTING. Proc. Symp. Thermodyn. Nucl. Mater. With Emphasis on Solution Syst., Vienna, Austria (1967), IAEA, Vienna (1968) 55
(Half-life)
- C. M. LEDERER, J. M. JAKLEVIC, S. G. PRUSSIN. Nucl. Phys. A135 (1969) 36
(Alpha emission energies, Alpha emission probabilities)
- K. L. SWINTH. IEEE Nuclear Science Symp. 4 (1970) 125
(LX-ray emission probabilities)
- R. GUNNINK, R. J. MORROW. UCRL 51087 (1971)
(Gamma ray energies, Gamma-ray emission probabilities)
- M. SCHMORAK, C. E. BEMIS JR, M. J. ZENDER, N. B. GOVE, P. F. DITTNER. Nucl. Phys. A178 (1972) 410
(Gamma ray energies, Gamma-ray emission probabilities)
- J. E. CLINE, R. J. GEHRKE, L. D. MCISAAC. ANCR 1069 (1972)
(Gamma ray energies)
- D. J. GORMAN, A. RYTZ, H. V. MICHEL. Compt. Rend. B275 (1972) 291
(Alpha emission energies)
- R. L. HEATH. Gamma-Ray Spectrum Catalogue. In: ANCR 1000 2 (1974)
(Gamma ray energies)
- T. DRAGNEV, K. SCHARF. Intern. J. Appl. Radiat. Isotop. 26 (1975) 125
(Gamma-ray emission probabilities)
- H. OTTMAR. Proc. Int. Symp. Neutron Capt. G- Ray Spectr. and Related Topics, 2nd, Petten, Netherlands, K. Abrahams et al., Eds., Reactor Centrum (1975) 658
(Gamma-ray energies and emission probabilities)
- R. GUNNINK, J. E. EVANS, A. L. PRINDLE. UCRL-52139 (1976)
(Gamma-ray energies and emission probabilities)
- H. UMEZAWA, T. SUZUKI, S. ICHIKAWA. J. Nucl. Sci. Technol 13 (1976) 327
(Gamma-ray emission probabilities)
- F. P. LARKINS. Atomic Data and Nuclear Data Tables 20 (1977) 313
(Auger electron energies)
- S. A. BARANOV, V. M. SHATINSKII. Yad. Fiz. 26 (1977) 461
(Alpha emission energies, Alpha emission probabilities)
- F. ROSEL, H. M. FRIESS, K. ALDER, H. C. PAULI. At. Data Nucl. Data Tables. 21 (1978) 92
(Theoretical ICC)
- A. H. JAFFEY, H. DIAMOND, W. C. BENTLEY, D. G. GRACZYK, K. P. FLYNN. Phys. Rev. C18 (1978) 969
(Half-life)

- C. BUDTZ-JORGENSEN, H.-H. KNITTER. NEANDC(E) 202U Vol III (1979) p 9
(SF Half-life)
- R. G. HELMER, C. W. REICH. Intern. J. Appl. Radiat. Isotop. 32 (1981) 829
(Gamma-ray energies and emission probabilities)
- J. MOREL. LMRI, Saclay, private communication, 1981 Cited in IAEA, Vienna, Tec. Rep. 261, 1986 (1981)
(Gamma-ray emission probabilities)
- G. BARREAU, H. G. BORNER, T. VON EGIDY, R. W. HOFF. Z. Phys. A308 (1982) 209
(K X-ray energies)
- I. AHMAD, J. HINES, J. E. GINDLER. Phys. Rev. C27 (1983) 2239
(K X-ray energies)
- I. AHMAD. Nucl. Instrum. Methods 223 (1984) 319
(Alpha emission probabilities)
- F. J. STEINKRUGER, G. M. MATLACK, R. J. BECKMAN. Intern. J. Appl. Radiat. Isotop. 35 (1984) 171
(Half-life)
- C. R. RUDY, K. C. JORDAN, R. TSUGAWA. Intern. J. Appl. Radiat. Isotop. 35 (1984) 177
(Half-life)
- S. MIRZADEH, Y. Y. CHU, S. KATCOFF, L. K. PEKER. Phys. Rev. C29 (1984) 985
(Gamma ray energies)
- L. L. LUCAS, J. R. NOYCE. Intern. J. Appl. Radiat. Isotop. 35 (1984) 173
(Half-life)
- G. BORTELS, B. DENECKE, R. VANINBROUXX. Nucl. Instrum. Methods 223 (1984) 329
(L X-ray energies)
- A. A. ANDROSENKO, P. A. ANDROSENKO, YU. V. IVANOV, A. E. KONYAEV, V. F. KOSITSYN, E. M. TSENTER,
V. T. SHCHEBOLEV. At. Energ. 57 (1984) 357
(SF Half-life)
- R. J. BECKMAN, S. F. MARSH, R. M. ABERNATHEY, J. E. REIN. Intern. J. Appl. Radiat. Isotop. 35 (1984) 163
(Half-life)
- IAEA. Decay Data of the Transactinium Nuclides, IAEA, Vienna, Tec. Rep. Ser. 261, 1986. (1986)
(Gamma-ray emission probabilities)
- F. LAGOUTINE, N. COURSOL, J. LEGRAND. ISBN-2-7272-0078-1 (LMRI, 1982-1987) (1987)
(Energy of Auger electrons)
- YU. A. SELITSKY, V. B. FUNSHTEIN, V. A. YAKOVLEV. Program and Theses, Proc. 38th Ann. Conf. Nucl.
Spectrosc. Struct. At. Nuclei, Baku, (1988) 131 (1988)
(SF Half-life)
- N. DYTLEWSKI, M. G. HINES, J. W. BOLDEMAN. Nucl. Sci. Eng. 102 (1989) 423
(SF Half-life)
- S. V. ANICHENKOV, YU. S. POPOV. Radiokhimiya 32 (1990) 109
(Alpha emission probabilities)
- YU. V. IVANOV, A. E. KONYAEV, V. F. KOSITSYN, E. A. KHOLNOVA, V. T. SHCHEBOLEV, M. F. YUDIN. At.
Energ. 70 (1991) 396
(SF Half-life)
- A. RYTZ. At. Data Nucl. Data Tables. 47 (1991) 205
(Alpha-particle energies)
- M. R. SCHMORAK. Nucl. Data Sheets 63 (1991) 139
(Decay scheme, ^{236}U level energies, gamma-ray multipolarities)
- C. J. BLAND, J. TRUFFY. Appl. Radiat. Isot. 43 (1992) 1241
(Alpha emission probabilities)
- G. BARCI-FUNEL, J. DALMASSO, G. ARDISSON. Appl. Rad. Isotopes 43 (1992) 37
(X-ray energies)
- M. SANCHEZ, F. V. TOME, J. D. BEJARANO. Nucl. Instrum. Methods A340 (1994) 509
(Alpha emission probabilities)
- M. C. LÉPY, B. DUCHEMIN, J. MOREL. Nucl. Instrum. Methods A339 (1994) 218
(L X-ray energies and emission probabilities)
- D. T. BARAN. Appl. Radiat. Isot. 45 (1994) 1177
(Alpha emission probabilities)
- W. RAAB, J. L. PARUS. Nucl. Instrum. Methods A339 (1994) 116
(Alpha emission probabilities)
- M. C. LÉPY, B. DUCHEMIN, J. MOREL. Nucl. Instrum. Methods A353 (1994) 10
(L X-ray energies and emission probabilities)

- G. AUDI, A. H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Decay energy)
- P. N. JOHNSTON, P. A. BURNS. Nucl. Instrum. Methods A361 (1995) 229
(L X-ray energies and emission probabilities)
- R. B. FIRESTONE, V. S. SHIRLEY, C. M. BAGLIN, S. Y. F. CHU, J. ZIPKIN. Table of Isotopes, Eighth Edition, Volume II: A=151-272, 2800-2801 (1996)
(Decay scheme, ^{236}U level energies, gamma ray multipolarities)
- L. L. VINTRO, P. I. MITCHELL, O. M. CONDREN, M. MORAN, J. VIVES I BATLLE, J. A. SANCHEZ-CABEZA. Nucl. Instrum. Methods Phys. Res. A369 (1996) 597
(Alpha emission probabilities)
- E. SCHÖNFELD, G. RODLOFF. PTB-6.11-1999-1999-1, Braunschweig, February 1999 (1999)
(K X-ray energies and relative emission probabilities)
- V. P. CHECHEV, A. G. EGOROV. Appl. Rad. Isotopes 52 (2000) 601
(Evaluation technique)
- N. E. HOLDEN, D. C. HOFFMAN. Pure Appl. Chem. 72 (2000) 1525
(Spontaneous fission half-life)
- G. SIBBENS, S. POMMÉ. Appl. Rad. Isotopes 60, 2-3 (2004) 155
(Alpha emission energies, Alpha emission probabilities)





1 Decay Scheme

Am-241 decays 100 % by alpha transitions to Np-237. Most of the decay (84.6 %) populate the excited level of Np-237 with energy of 59.54 keV. Branching of Am-241 decay by spontaneous fission is $4.3(18) \cdot 10^{-10}\%$. *L'américium 241 décroît à 100 % par émission alpha vers le neptunium 237. Le branchement principal (84,6%) se fait vers le niveau excité de 59 keV. Un faible branchement ($4,3(18) \cdot 10^{-10}\%$) par fission spontanée existe.*

2 Nuclear Data

$T_{1/2}(^{241}\text{Am})$	:	432,6	(6)	a
$T_{1/2}(^{237}\text{Np})$	:	2,14	(1)	10^6 a
$Q^\alpha(^{241}\text{Am})$	:	5637,81	(12)	keV

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,36}$	4837,81 (16)	0,00004 (3)	47
$\alpha_{0,34}$	4881,81 (16)	0,000086	44
$\alpha_{0,33}$	4915,86 (13)	0,0007	9,5
$\alpha_{0,32}$	4971,6 (2)		
$\alpha_{0,30}$	5039,8 (3)		
$\alpha_{0,29}$	5044,8 (11)		
$\alpha_{0,28}$	5047,53 (20)		
$\alpha_{0,27}$	5092,22 (20)	0,0001	1000
$\alpha_{0,25}$	5140,79 (14)		
$\alpha_{0,24}$	5151,85 (17)	0,00011	2300
$\alpha_{0,23}$	5178,17 (13)	$\sim 0,0004$	~ 1000
$\alpha_{0,22}$	5185,28 (13)	$\sim 0,0004$	~ 1000
$\alpha_{0,21}$	5193,03 (16)		
$\alpha_{0,20}$	5203,69 (20)	0,0004	1400
$\alpha_{0,19}$	5220 (4)		

	Energy keV	Probability × 100	F
$\alpha_{0,18}$	5242,29 (13)	0,0007	1400
$\alpha_{0,17}$	5266,88 (13)	0,0003	4600
$\alpha_{0,16}$	5269,22 (13)	0,0009	1600
$\alpha_{0,15}$	5278,1 (2)	0,0006	2700
$\alpha_{0,14}$	5305,45 (13)		
$\alpha_{0,13}$	5313,39 (13)	0,0013	2100
$\alpha_{0,12}$	5321,0 (3)		
$\alpha_{0,11}$	5332,75 (13)	0,0022 (3)	1600
$\alpha_{0,9}$	5370,27 (14)	0,0005	12000
$\alpha_{0,8}$	5411,85 (13)	0,014 (3)	770
$\alpha_{0,6}$	5479,32 (13)	1,66 (3)	16,4
$\alpha_{0,5}$	5507,81 (13)	0,01	4000
$\alpha_{0,4}$	5534,85 (12)	13,23 (10)	4,3
$\alpha_{0,3}$	5561,91 (12)	0,04	2000
$\alpha_{0,2}$	5578,27 (12)	84,45 (10)	1,3
$\alpha_{0,1}$	5604,61 (12)	0,23 (1)	600
$\alpha_{0,0}$	5637,81 (12)	0,38 (1)	6100

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{10,9}(\text{Np})$	13,81 (2)						
$\gamma_{2,1}(\text{Np})$	26,3446 (2)	22,56 (70)	E1		6,12 (20)	1,6 (2)	8,4 (3)
$\gamma_{4,3}(\text{Np})$	27,06						
$\gamma_{27,26}(\text{Np})$	31,4						
$\gamma_{(-1,1)}(\text{Np})$	32,183						
$\gamma_{1,0}(\text{Np})$	33,1963 (3)	23,3 (6)	M1+1,7%E2		143 (5)	35 (5)	192 (5)
$\gamma_{(-1,2)}(\text{Np})$	38,54 (3)						
$\gamma_{3,1}(\text{Np})$	42,704 (5)	2,2 (5)	(M1+42%E2)		296 (30)	81 (8)	400 (4)
$\gamma_{4,2}(\text{Np})$	43,420 (3)	12,9 (10)	M1+17%E2		136 (4)	36,5 (12)	186 (5)
$\gamma_{14,10}(\text{Np})$	51,01 (3)	0,000046 (12)	(E1)		0,573 (12)	0,144 (3)	0,77 (2)
$\gamma_{5,3}(\text{Np})$	54,1						
$\gamma_{6,4}(\text{Np})$	55,55 (2)	1,2 (2)	M1+17%E2		49 (4)	13,1 (12)	67 (6)
$\gamma_{13,9}(\text{Np})$	56,8						
$\gamma_{(-1,3)}(\text{Np})$	57,85 (5)						
$\gamma_{2,0}(\text{Np})$	59,5409 (1)	78,0 (11)	E1+0,01%M2		0,875 (18)	0,226 (7)	1,18 (3)
$\gamma_{7,5}(\text{Np})$	61,44						
$\gamma_{14,9}(\text{Np})$	64,83 (2)	0,00020 (3)	E1		0,305 (6)	0,076 (2)	0,41 (1)
$\gamma_{8,6}(\text{Np})$	67,46 (5)	0,013 (4)	M1+17%E2		23 (5)	6,0 (13)	31 (8)
$\gamma_{4,1}(\text{Np})$	69,76 (3)	0,0039 (5)	E1		0,252 (5)	0,0625 (13)	0,336 (7)
$\gamma_{3,0}(\text{Np})$	75,8 (2)	0,0335	E2		39,6 (8)	11,1 (2)	54,8 (11)
$\gamma_{36,33}(\text{Np})$	78,1						
$\gamma_{11,8}(\text{Np})$	79,1						
$\gamma_{15,9}(\text{Np})$	92,1						
$\gamma_{5,1}(\text{Np})$	96,7 (2)	0,00099 (4)	E2		13,7 (3)	3,82 (4)	18,8 (4)
$\gamma_{6,2}(\text{Np})$	98,95 (1)	0,337 (10)	E2		11,3 (3)	3,16 (7)	15,6 (3)
$\gamma_{4,0}(\text{Np})$	102,97 (1)	0,0219 (5)	E1		0,091 (2)	0,0224 (5)	0,121 (3)

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{(-1,4)}(\text{Np})$	106,42 (5)						
$\gamma_{20,13}(\text{Np})$	109,70 (7)	0,0000524	if E2				9,7
$\gamma_{7,3}(\text{Np})$	115,54						
$\gamma_{21,13}(\text{Np})$	120,36 (8)						
$\gamma_{8,4}(\text{Np})$	123,02 (2)	0,0069 (2)	E2	0,187 (4)	4,13 (8)	1,15 (2)	5,90 (12)
$\gamma_{6,1}(\text{Np})$	125,29 (1)	0,0054 (3)	(E1)	0,239 (5)	0,0546 (11)	0,0134 (3)	0,306 (6)
$\gamma_{(-1,5)}(\text{Np})$	128,05						
$\gamma_{20,11}(\text{Np})$	129,2						
$\gamma_{22,13}(\text{Np})$	135,3						
$\gamma_{(-1,6)}(\text{Np})$	136,7						
$\gamma_{30,23}(\text{Np})$	138,5						
$\gamma_{29,22}(\text{Np})$	139,46 (8)	0,000023 (5)	if E2				3,4
$\gamma_{11,6}(\text{Np})$	146,57 (1)	0,00175 (4)	E2	0,210 (4)	1,87 (4)	0,522 (11)	2,80 (6)
$\gamma_{8,3}(\text{Np})$	150,08 (3)	0,000088 (5)	(E1)	0,153 (3)	0,0344 (7)	0,0084 (2)	0,199 (4)
$\gamma_{26,15}(\text{Np})$	154,27 (20)	0,0000042	if M1				7,5
$\gamma_{(-1,7)}(\text{Np})$	156,4 (3)						
$\gamma_{29,20}(\text{Np})$	159,16 (20)	0,0000016 (5)	if E1				0,17
$\gamma_{24,13}(\text{Np})$	161,54 (10)	0,0000114	if M1				6,6
$\gamma_{9,4}(\text{Np})$	164,59 (1)	0,000180 (8)	E2	0,195 (4)	1,12 (2)	0,311 (6)	1,73 (4)
$\gamma_{13,6}(\text{Np})$	165,91 (4)						
$\gamma_{18,8}(\text{Np})$	169,55 (2)	0,00043 (3)		0,190 (4)	0,98 (2)	0,273 (6)	1,55 (3)
$\gamma_{11,5}(\text{Np})$	175,08 (3)	0,000042 (3)	(E2)	0,183 (4)	0,85 (2)	0,237 (5)	1,36 (3)
$\gamma_{(-1,8)}(\text{Np})$	190,4						
$\gamma_{25,11}(\text{Np})$	191,90 (1)	0,0000419 (20)	E2	0,163 (4)	0,57 (1)	0,159 (4)	0,95 (2)
$\gamma_{29,18}(\text{Np})$	197,0 (2)	0,00000054	if E1				0,1
$\gamma_{(-1,9)}(\text{Np})$	201,70 (14)						
$\gamma_{18,7}(\text{Np})$	204,06 (6)						
$\gamma_{9,2}(\text{Np})$	208,00 (2)	0,00329 (10)	M1+2,4%E2	2,56 (6)	0,507 (11)	0,124 (3)	3,19 (7)
$\gamma_{13,4}(\text{Np})$	221,45 (3)						
$\gamma_{26,10}(\text{Np})$	232,81 (5)						
$\gamma_{9,1}(\text{Np})$	234,33	0,0000084	if M2				8,6
$\gamma_{26,9}(\text{Np})$	246,7 (1)						
$\gamma_{13,3}(\text{Np})$	248,58 (8)	0,00000155 (8)	if E1				0,061
$\gamma_{21,7}(\text{Np})$	260,9 (1)						
$\gamma_{13,2}(\text{Np})$	264,87 (5)						
$\gamma_{9,0}(\text{Np})$	267,54 (3)	0,000036 (2)	E1+5,4%M2	0,25 (1)	0,076 (3)	0,20 (1)	0,35 (3)
$\gamma_{(-1,10)}(\text{Np})$	270,63						
$\gamma_{(-1,51)}(\text{Np})$	271,54						
$\gamma_{20,6}(\text{Np})$	275,73 (8)						
$\gamma_{27,9}(\text{Np})$	278,18	0,0000032	if M1				1,4
$\gamma_{13,1}(\text{Np})$	291,26 (20)						
$\gamma_{16,3}(\text{Np})$	292,78 (4)	0,000017 (1)	E2	0,080 (2)	0,101 (2)	0,0276 (6)	0,219 (5)
$\gamma_{15,2}(\text{Np})$	300,13 (6)						
$\gamma_{20,5}(\text{Np})$	304,2 (2)	0,00000093 (2)					
$\gamma_{16,2}(\text{Np})$	309,1 (3)	0,000002	if E1				0,038
$\gamma_{12,0}(\text{Np})$	316,8 (2)						
$\gamma_{21,5}(\text{Np})$	322,53 (3)	0,000264 (8)	(M1+26,5%E2)	0,59 (9)	0,13 (2)	0,032 (5)	0,75 (12)
$\gamma_{(-1,52)}(\text{Np})$	324,69	0,0000018 (3)					
$\gamma_{(-1,53)}(\text{Np})$	329,69	0,0000011 (2)					
$\gamma_{14,0}(\text{Np})$	332,36 (2)	0,0001720 (8)	E2	0,0638 (13)	0,062 (13)	0,0169 (4)	0,150 (3)
$\gamma_{16,1}(\text{Np})$	335,40 (3)	0,00084 (4)	M1+17,3%E2	0,59 (8)	0,12 (2)	0,030 (4)	0,75 (12)
$\gamma_{17,1}(\text{Np})$	337,7 (2)	0,00000488 (7)					
$\gamma_{(-1,11)}(\text{Np})$	350,71	0,00000139 (5)					
$\gamma_{20,3}(\text{Np})$	358,3 (2)	0,00000129 (5)					
$\gamma_{16,0}(\text{Np})$	368,63 (3)	0,00036 (2)	M1	0,538 (11)	0,103 (2)	0,0251 (5)	0,667 (14)
$\gamma_{17,0}(\text{Np})$	370,94 (3)	0,000082 (6)	M1+16%E2	0,45 (5)	0,092 (9)	0,023 (2)	0,57 (6)
$\gamma_{(-1,54)}(\text{Np})$	374,83	0,00000313 (5)					
$\gamma_{21,3}(\text{Np})$	376,66 (3)	0,000225 (9)	M1	0,507 (11)	0,098 (2)	0,0237 (5)	0,629 (13)
$\gamma_{22,3}(\text{Np})$	383,80 (3)	0,000045	if M1				0,6

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{(-1,12)}$ (Np)	389,0 (3)	0,0000005					
$\gamma_{(-1,13)}$ (Np)	390,61 (5)	0,00000573 (8)					
$\gamma_{32,9}$ (Np)	398,6 (2)						
$\gamma_{29,7}$ (Np)	401,68	0,00000018 (4)	M1+E2				0,31 (22)
$\gamma_{30,7}$ (Np)	406,4 (2)	0,0000021	if M1				0,51
$\gamma_{(-1,14)}$ (Np)	411,27	0,00000018 (4)					
$\gamma_{21,1}$ (Np)	419,32 (4)	0,000036 (7)	M1+E2				0,27 (20)
$\gamma_{22,1}$ (Np)	426,47 (4)	0,000031 (6)	M1+E2				0,27 (18)
$\gamma_{(-1,15)}$ (Np)	429,9 (1)	0,00000109 (5)					
$\gamma_{(-1,55)}$ (Np)	440,63	0,00000056 (3)					
$\gamma_{(-1,16)}$ (Np)	442,81 (7)	0,00000331 (7)					
$\gamma_{35,13}$ (Np)	446,68	0,00000011 (2)					
$\gamma_{21,0}$ (Np)	452,5 (3)	0,0000025	if E2				0,063
$\gamma_{26,2}$ (Np)	454,66 (8)	0,0000131 (4)	M1+E2				0,376
$\gamma_{22,0}$ (Np)	459,68 (10)	0,0000043 (8)	M1+E2				0,21 (15)
$\gamma_{29,5}$ (Np)	463,22 (20)	0,000001	if E2				0,059
$\gamma_{30,5}$ (Np)	468,06 (15)	0,0000035 (2)	if M1				0,31
$\gamma_{(-1,17)}$ (Np)	486,05	0,00000105 (6)					
$\gamma_{28,4}$ (Np)	487,64	0,00000081 (7)	if M1				0,31
$\gamma_{(-1,56)}$ (Np)	494,39	0,00000010 (2)					
$\gamma_{(-1,57)}$ (Np)	501,39	0,00000014 (2)					
$\gamma_{27,1}$ (Np)	512,4 (3)	0,0000021	if E1				0,013
$\gamma_{26,0}$ (Np)	514,2 (2)	0,0000039 (2)	if E1				0,013
$\gamma_{30,3}$ (Np)	522,11	0,00000125	if M1				0,26
$\gamma_{(-1,58)}$ (Np)	525,14	0,00000016 (3)					
$\gamma_{38,13}$ (Np)	528,87	0,00000072 (5)	if E2				0,043
$\gamma_{(-1,59)}$ (Np)	532,44	0,00000008 (2)					
$\gamma_{27,0}$ (Np)	545,7	0,00000025 (3)	if E1				0,011
$\gamma_{(-1,60)}$ (Np)	548,15	0,00000005 (2)					
$\gamma_{(-1,61)}$ (Np)	555,25	0,00000009 (2)					
$\gamma_{33,6}$ (Np)	563,48	0,00000046 (2)	if E2				0,038
$\gamma_{36,8}$ (Np)	573,94 (20)	0,00000154 (8)	if M1				0,2
$\gamma_{(-1,18)}$ (Np)	582,89	0,00000101 (6)					
$\gamma_{31,2}$ (Np)	586,5 (2)	0,00000148 (6)	if M1				0,19
$\gamma_{28,0}$ (Np)	590,28 (15)	0,00000333 (6)	if M1				0,19
$\gamma_{34,6}$ (Np)	597,44 (8)	0,00000086 (2)	if M1				0,18
$\gamma_{(-1,62)}$ (Np)	600,26	0,00000022 (3)					
$\gamma_{33,4}$ (Np)	619,01 (2)	0,0000070 (3)	if M1				0,16
$\gamma_{38,8}$ (Np)	627,2 (2)	0,00000059 (3)	if M1				0,16
$\gamma_{32,1}$ (Np)	632,93 (15)	0,00000124 (5)					
$\gamma_{(-1,63)}$ (Np)	636,9	0,00000021 (3)					
$\gamma_{36,6}$ (Np)	641,46 (5)	0,0000081 (1)	if M1				0,15
$\gamma_{34,4}$ (Np)	652,98 (4)	0,000043 (1)	if M1				0,14
$\gamma_{33,2}$ (Np)	662,41 (2)	0,00045 (10)	E0+M1+E2	0,18 (4)			0,23 (5)
$\gamma_{32,0}$ (Np)	666,2 (3)	0,00000095 (7)					
$\gamma_{36,5}$ (Np)	669,9 (2)	0,00000051 (7)	if E1				0,008
$\gamma_{37,5}$ (Np)	675,8 (3)	0,00000085 (5)					
$\gamma_{34,3}$ (Np)	680,1 (1)	0,00000334 (7)	if E1				0,0078
$\gamma_{33,1}$ (Np)	688,76 (4)	0,0000325 (5)	if E1				0,0076
$\gamma_{(-1,19)}$ (Np)	693,46	0,00000354 (7)					
$\gamma_{34,2}$ (Np)	696,48	0,0000058 (2)	if M1				0,12
$\gamma_{(-1,20)}$ (Np)	709,42 (5)	0,00000641 (18)					
$\gamma_{(-1,64)}$ (Np)	712,5	0,00000020 (3)					
$\gamma_{33,0}$ (Np)	721,98 (3)	0,000196 (4)	if E1				0,007
$\gamma_{37,3}$ (Np)	729,52 (15)	0,00000137 (5)					
$\gamma_{(-1,21)}$ (Np)	731,44	0,00000046 (4)					
$\gamma_{(-1,65)}$ (Np)	736,68	0,00000128 (5)					
$\gamma_{35,1}$ (Np)	737,34 (5)	0,00000794 (8)					
$\gamma_{(-1,66)}$ (Np)	740,51	0,00000019 (3)					

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{(-1,22)}$ (Np)	742,9 (3)	0,00000035					
$\gamma_{(-1,67)}$ (Np)	745,02	0,00000009 (2)					
$\gamma_{(-1,85)}$ (Np)	750,39	0,00000006 (2)					
$\gamma_{34,0}$ (Np)	755,91 (5)	0,0000079 (1)	if E1				0,0064
$\gamma_{(-1,23)}$ (Np)	759,5 (1)	0,00000181 (5)					
$\gamma_{(-1,24)}$ (Np)	763,31	0,00000023 (2)					
$\gamma_{36,1}$ (Np)	767,0 (1)	0,00000502 (3)	if E1				0,0063
$\gamma_{35,0}$ (Np)	770,6 (1)	0,00000481 (5)					
$\gamma_{37,1}$ (Np)	772,17	0,00000305 (6)	if M1				0,092
$\gamma_{(-1,69)}$ (Np)	774,67	0,00000011 (2)					
$\gamma_{(-1,25)}$ (Np)	777,39	0,00000015 (2)					
$\gamma_{(-1,26)}$ (Np)	780,53	0,00000031 (2)					
$\gamma_{(-1,27)}$ (Np)	782,2 (5)	0,00000015					
$\gamma_{39,3}$ (Np)	786,00 (15)	0,00000062					
$\gamma_{(-1,28)}$ (Np)	789,0 (3)	0,00000042 (6)					
$\gamma_{(-1,70)}$ (Np)	792,6	0,00000003 (1)					
$\gamma_{(-1,29)}$ (Np)	794,92 (20)	0,00000094					
$\gamma_{39,2}$ (Np)	801,94 (20)	0,00000123 (7)					
$\gamma_{(-1,71)}$ (Np)	803,19	0,00000016 (3)					
$\gamma_{37,0}$ (Np)	806,26 (30)	0,00000031					
$\gamma_{(-1,30)}$ (Np)	811,9 (3)	0,00000063 (6)					
$\gamma_{(-1,31)}$ (Np)	819,33	0,00000043 (6)					
$\gamma_{(-1,32)}$ (Np)	822,21	0,00000024 (6)					
$\gamma_{39,1}$ (Np)	828,54	0,00000021 (4)					
$\gamma_{(-1,33)}$ (Np)	835,21	0,00000003					
$\gamma_{(-1,72)}$ (Np)	838,88	0,00000004 (1)					
$\gamma_{(-1,34)}$ (Np)	841,14	0,00000010 (3)					
$\gamma_{(-1,73)}$ (Np)	843,7	0,00000097 (8)					
$\gamma_{(-1,74)}$ (Np)	846,86	0,00000016 (3)					
$\gamma_{(-1,35)}$ (Np)	847,4 (5)	0,00000003					
$\gamma_{(-1,36)}$ (Np)	851,6 (10)	0,00000041 (6)					
$\gamma_{(-1,37)}$ (Np)	854,95	0,00000023 (4)					
$\gamma_{(-1,75)}$ (Np)	856,26	0,00000010 (3)					
$\gamma_{40,2}$ (Np)	860,7	0,00000008					
$\gamma_{39,0}$ (Np)	862,7 (5)	0,00000061 (6)					
$\gamma_{(-1,38)}$ (Np)	870,63	0,00000150 (3)					
$\gamma_{(-1,76)}$ (Np)	882	0,00000004 (1)					
$\gamma_{(-1,77)}$ (Np)	886,53	0,00000015 (3)					
$\gamma_{40,1}$ (Np)	887,73	0,00000033 (6)					
$\gamma_{(-1,78)}$ (Np)	890,38	0,00000032 (5)					
$\gamma_{(-1,79)}$ (Np)	894,47	0,00000003 (1)					
$\gamma_{(-1,39)}$ (Np)	898,17	0,00000006 (2)					
$\gamma_{(-1,40)}$ (Np)	902,61	0,00000033 (3)					
$\gamma_{(-1,80)}$ (Np)	909,95	0,00000005 (1)					
$\gamma_{(-1,41)}$ (Np)	912,4	0,00000028 (3)					
$\gamma_{40,0}$ (Np)	922,19	0,00000019 (3)					
$\gamma_{(-1,42)}$ (Np)	928,95	0,00000009 (2)					
$\gamma_{(-1,81)}$ (Np)	939,2	0,00000005 (1)					
$\gamma_{41,0}$ (Np)	946,06	0,00000010 (3)					
$\gamma_{(-1,82)}$ (Np)	952,72	0,00000003 (1)					
$\gamma_{(-1,44)}$ (Np)	955,91	0,00000060 (5)					
$\gamma_{42,0}$ (Np)	962,19	0,00000004 (1)					
$\gamma_{(-1,83)}$ (Np)	969,09	0,00000003 (1)					
$\gamma_{(-1,84)}$ (Np)	980,84	0,00000003 (1)					
$\gamma_{43,0}$ (Np)	1014,33	0,00000010 (2)					

3 Atomic Data

3.1 Np

ω_K	:	0,971	(4)
$\bar{\omega}_L$	:	0,511	(20)
$\bar{\omega}_M$	:	0,0528	
n_{KL}	:	0,791	(5)
\bar{n}_{LM}	:	1,163	

3.1.1 X Radiations

	Energy keV	Relative probability		
X _K	K α_2	97,069	62,82	
	K α_1	101,059	100	
	K β_3	113,303	}	
	K β_1	114,234		
	K β_5''	114,912		36,21
	K β_2	117,463	}	
	K β_4	117,876		
	KO _{2,3}	118,429		12,47
	X _L	L ℓ	11,89	
		L α	13,76 – 13,944	
L η		15,876		
L β		16,13 – 17,99		
L γ		20,12 – 22,2		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	73,50 – 83,13	100
KLX	90,36 – 97,28	60,2
KXY	107,10 – 114,58	9,06
Auger L	6,04 – 13,52	55000000

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,36}$	4757,41 (16)	0,00004 (3)
$\alpha_{0,34}$	4800,68 (16)	0,000086
$\alpha_{0,33}$	4834,16 (13)	0,0007
$\alpha_{0,32}$	4889,0 (2)	
$\alpha_{0,30}$	4956,1 (3)	
$\alpha_{0,29}$	4961,7 (11)	
$\alpha_{0,28}$	4963,64 (20)	
$\alpha_{0,27}$	5007,59 (20)	0,0001
$\alpha_{0,25}$	5055,35 (14)	
$\alpha_{0,24}$	5066,23 (17)	0,00011
$\alpha_{0,23}$	5092,06 (13)	0,0004
$\alpha_{0,22}$	5099,10 (13)	0,0004
$\alpha_{0,21}$	5106,72 (16)	
$\alpha_{0,20}$	5117,21 (20)	0,0004
$\alpha_{0,19}$	5133 (4)	
$\alpha_{0,18}$	5155,16 (13)	0,0007
$\alpha_{0,17}$	5179,35 (13)	0,0003
$\alpha_{0,16}$	5181,65 (13)	0,0009
$\alpha_{0,15}$	5190,4 (2)	0,0006
$\alpha_{0,14}$	5217,28 (13)	
$\alpha_{0,13}$	5225,08 (13)	0,0013
$\alpha_{0,12}$	5232,6 (3)	
$\alpha_{0,11}$	5244,12 (13)	0,0022 (3)
$\alpha_{0,9}$	5281,02 (14)	0,0005
$\alpha_{0,8}$	5321,91 (13)	0,014 (3)
$\alpha_{0,6}$	5388,26 (13)	1,66 (3)
$\alpha_{0,5}$	5416,27 (13)	0,01
$\alpha_{0,4}$	5442,86 (12)	13,23 (10)
$\alpha_{0,3}$	5469,47 (12)	0,04
$\alpha_{0,2}$	5485,56 (12)	84,45 (10)
$\alpha_{0,1}$	5511,47 (12)	0,23 (1)
$\alpha_{0,0}$	5544,11 (12)	0,38 (1)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Np)	6,04 - 13,52	36,0 (14)
e _{AK}	(Np)		0,000115 (16)
	KLL	73,50 - 83,13	}
	KLX	90,36 - 97,28	}
	KXY	107,10 - 114,58	}
ec _{2,1} L	(Np)	3,92 - 8,73	14,7 (5)
ec _{1,0} L	(Np)	10,77 - 15,58	17,3 (3)
ec _{3,1} L	(Np)	20,31 - 25,12	1,6 (4)
ec _{2,1} M	(Np)	20,61 - 22,67	3,8 (5)
ec _{4,2} L	(Np)	20,99 - 25,81	8,6 (9)
ec _{1,0} M	(Np)	27,47 - 29,53	4,3 (6)
ec _{6,4} L	(Np)	33,13 - 37,94	0,89 (12)
ec _{3,1} M	(Np)	37,01 - 39,07	0,5 (1)
ec _{2,0} L	(Np)	37,11 - 37,93	31,3 (5)
ec _{4,2} M	(Np)	37,70 - 39,75	2,3 (4)
ec _{6,4} M	(Np)	49,83 - 51,89	0,24 (3)
ec _{2,0} M	(Np)	53,80 - 55,88	8,09 (25)
ec _{6,2} L	(Np)	76,52 - 81,34	0,229 (8)
ec _{6,2} M	(Np)	93,21 - 95,29	0,064 (2)

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.
XL	(Np)	11,89 — 22,2	37,6 (3)
XK α_2	(Np)	97,069	0,00116 (2) } K α
XK α_1	(Np)	101,059	0,00185 (4) }
XK β_3	(Np)	113,303	}
XK β_1	(Np)	114,234	}
XK β_5''	(Np)	114,912	}
XK β_2	(Np)	117,463	}
XK β_4	(Np)	117,876	}
XK $O_{2,3}$	(Np)	118,429	}
			0,000670 (14) K' β_1
			0,000231 (5) K' β_2

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{2,1}(\text{Np})$	26,3446 (2)	2,40 (3)
$\gamma_{1,0}(\text{Np})$	33,1963 (3)	0,121 (3)
$\gamma_{3,1}(\text{Np})$	42,704 (5)	0,0055 (11)
$\gamma_{4,2}(\text{Np})$	43,420 (3)	0,069 (5)
$\gamma_{14,10}(\text{Np})$	51,01 (3)	0,000026 (12)
$\gamma_{6,4}(\text{Np})$	55,55 (2)	0,0181 (18)
$\gamma_{(-1,3)}(\text{Np})$	57,85 (5)	0,0052 (15)
$\gamma_{2,0}(\text{Np})$	59,5409 (1)	35,78 (9)
$\gamma_{14,9}(\text{Np})$	64,83 (2)	0,00014 (3)
$\gamma_{8,6}(\text{Np})$	67,46 (5)	0,00042 (10)
$\gamma_{4,1}(\text{Np})$	69,76 (3)	0,0029 (4)
$\gamma_{3,0}(\text{Np})$	75,8 (2)	0,0006
$\gamma_{5,1}(\text{Np})$	96,7 (2)	0,00005 (2)
$\gamma_{6,2}(\text{Np})$	98,95 (1)	0,0203 (4)
$\gamma_{4,0}(\text{Np})$	102,97 (1)	0,0195 (4)
$\gamma_{(-1,4)}(\text{Np})$	106,42 (5)	0,000015
$\gamma_{20,13}(\text{Np})$	109,70 (7)	0,0000049
$\gamma_{21,13}(\text{Np})$	120,36 (8)	0,0000045
$\gamma_{8,4}(\text{Np})$	123,02 (2)	0,00100 (4)
$\gamma_{6,1}(\text{Np})$	125,29 (1)	0,0041 (2)
$\gamma_{29,22}(\text{Np})$	139,46 (8)	0,0000053 (11)
$\gamma_{11,6}(\text{Np})$	146,57 (1)	0,00046 (1)
$\gamma_{8,3}(\text{Np})$	150,08 (3)	0,000073 (5)
$\gamma_{26,15}(\text{Np})$	154,27 (20)	0,0000005
$\gamma_{29,20}(\text{Np})$	159,16 (20)	0,0000014 (5)
$\gamma_{24,13}(\text{Np})$	161,54 (10)	0,0000015
$\gamma_{9,4}(\text{Np})$	164,59 (1)	0,000066 (3)
$\gamma_{13,6}(\text{Np})$	165,91 (4)	0,000023 (1)
$\gamma_{18,8}(\text{Np})$	169,55 (2)	0,00017 (1)
$\gamma_{11,5}(\text{Np})$	175,08 (3)	0,000018 (3)
$\gamma_{(-1,8)}(\text{Np})$	190,4	0,0000022 (5)
$\gamma_{25,11}(\text{Np})$	191,90 (1)	0,0000215 (10)
$\gamma_{29,18}(\text{Np})$	197,0 (2)	0,00000049
$\gamma_{(-1,9)}(\text{Np})$	201,70 (14)	0,0000008
$\gamma_{18,7}(\text{Np})$	204,06 (6)	0,0000206 (5)
$\gamma_{9,2}(\text{Np})$	208,00 (2)	0,000786 (5)
$\gamma_{13,4}(\text{Np})$	221,45 (3)	0,0000434 (6)
$\gamma_{26,10}(\text{Np})$	232,81 (5)	0,00000482 (8)
$\gamma_{9,1}(\text{Np})$	234,33	0,00000087 (7)
$\gamma_{26,9}(\text{Np})$	246,7 (1)	0,00000244 (6)
$\gamma_{13,3}(\text{Np})$	248,58 (8)	0,00000146 (3)
$\gamma_{21,7}(\text{Np})$	260,9 (1)	0,00000129 (6)
$\gamma_{13,2}(\text{Np})$	264,87 (5)	0,00000943 (7)
$\gamma_{9,0}(\text{Np})$	267,54 (3)	0,0000268 (5)
$\gamma_{(-1,10)}(\text{Np})$	270,63 (15)	0,0000005 (2)

	Energy keV	Photons per 100 disint.
$\gamma_{(-1,51)}(\text{Np})$	271,54	0,00000144 (5)
$\gamma_{20,6}(\text{Np})$	275,73 (8)	0,00000632 (8)
$\gamma_{27,9}(\text{Np})$	278,18	0,00000115
$\gamma_{13,1}(\text{Np})$	291,26 (20)	0,00000305 (7)
$\gamma_{16,3}(\text{Np})$	292,78 (4)	0,0000142 (2)
$\gamma_{20,5}(\text{Np})$	304,2 (2)	0,00000093 (2)
$\gamma_{16,2}(\text{Np})$	309,1 (3)	0,0000019 (3)
$\gamma_{21,5}(\text{Np})$	322,53 (3)	0,000151 (3)
$\gamma_{(-1,52)}(\text{Np})$	324,69	0,0000018 (3)
$\gamma_{(-1,53)}(\text{Np})$	329,69	0,0000011 (2)
$\gamma_{14,0}(\text{Np})$	332,36 (2)	0,000150 (3)
$\gamma_{16,1}(\text{Np})$	335,40 (3)	0,000496 (5)
$\gamma_{17,1}(\text{Np})$	337,7 (2)	0,00000488 (7)
$\gamma_{(-1,11)}(\text{Np})$	350,71	0,00000139 (5)
$\gamma_{20,3}(\text{Np})$	358,3 (2)	0,00000129 (5)
$\gamma_{16,0}(\text{Np})$	368,63 (3)	0,000214 (4)
$\gamma_{17,0}(\text{Np})$	370,94 (3)	0,0000520 (6)
$\gamma_{(-1,54)}(\text{Np})$	374,83	0,00000313 (5)
$\gamma_{21,3}(\text{Np})$	376,66 (3)	0,000137 (3)
$\gamma_{22,3}(\text{Np})$	383,80 (3)	0,0000281 (5)
$\gamma_{(-1,12)}(\text{Np})$	389,0 (3)	0,00000049
$\gamma_{(-1,13)}(\text{Np})$	390,61 (5)	0,00000573 (8)
$\gamma_{29,7}(\text{Np})$	401,68	0,00000014 (3)
$\gamma_{30,7}(\text{Np})$	406,4 (2)	0,00000137 (5)
$\gamma_{(-1,14)}(\text{Np})$	411,27	0,00000018 (4)
$\gamma_{21,1}(\text{Np})$	419,32 (4)	0,0000284 (3)
$\gamma_{22,1}(\text{Np})$	426,47 (4)	0,0000243 (7)
$\gamma_{(-1,15)}(\text{Np})$	429,9 (1)	0,00000109 (5)
$\gamma_{(-1,55)}(\text{Np})$	440,63	0,00000056 (3)
$\gamma_{(-1,16)}(\text{Np})$	442,81 (7)	0,00000331 (7)
$\gamma_{35,13}(\text{Np})$	446,68	0,00000011 (2)
$\gamma_{21,0}(\text{Np})$	452,5 (3)	0,00000236 (6)
$\gamma_{26,2}(\text{Np})$	454,66 (8)	0,00000953 (7)
$\gamma_{22,0}(\text{Np})$	459,68 (10)	0,00000355 (6)
$\gamma_{29,5}(\text{Np})$	463,22 (20)	0,000001
$\gamma_{30,5}(\text{Np})$	468,06 (15)	0,00000269 (5)
$\gamma_{(-1,17)}(\text{Np})$	486,05	0,00000105 (6)
$\gamma_{28,4}(\text{Np})$	487,64	0,00000062 (5)
$\gamma_{(-1,56)}(\text{Np})$	494,39	0,00000010 (2)
$\gamma_{(-1,57)}(\text{Np})$	501,39	0,00000014 (2)
$\gamma_{27,1}(\text{Np})$	512,4 (3)	0,0000021 (4)
$\gamma_{26,0}(\text{Np})$	514,2 (2)	0,0000038 (2)
$\gamma_{30,3}(\text{Np})$	522,11	0,00000099 (5)
$\gamma_{(-1,58)}(\text{Np})$	525,14	0,00000016 (3)
$\gamma_{38,13}(\text{Np})$	528,87	0,00000069 (5)
$\gamma_{(-1,59)}(\text{Np})$	532,44	0,00000008 (2)
$\gamma_{27,0}(\text{Np})$	545,7	0,00000025 (3)

	Energy keV	Photons per 100 disint.
$\gamma_{(-1,60)}$ (Np)	548,15	0,00000005 (2)
$\gamma_{(-1,61)}$ (Np)	555,25	0,00000009 (2)
$\gamma_{33,6}$ (Np)	563,48	0,00000044 (2)
$\gamma_{36,8}$ (Np)	573,94 (20)	0,00000128 (5)
$\gamma_{(-1,18)}$ (Np)	582,89	0,00000101 (6)
$\gamma_{31,2}$ (Np)	586,5 (2)	0,00000124 (5)
$\gamma_{28,0}$ (Np)	590,28 (15)	0,00000280 (5)
$\gamma_{34,6}$ (Np)	597,44 (8)	0,00000729 (8)
$\gamma_{(-1,62)}$ (Np)	600,26	0,00000022 (3)
$\gamma_{33,4}$ (Np)	619,01 (2)	0,000060 (2)
$\gamma_{38,8}$ (Np)	627,2 (2)	0,00000051 (2)
$\gamma_{32,1}$ (Np)	632,93 (15)	0,00000124 (5)
$\gamma_{(-1,63)}$ (Np)	636,9	0,00000021 (3)
$\gamma_{36,6}$ (Np)	641,46 (5)	0,00000704 (7)
$\gamma_{34,4}$ (Np)	652,98 (4)	0,0000376 (8)
$\gamma_{33,2}$ (Np)	662,41 (2)	0,000367 (5)
$\gamma_{32,0}$ (Np)	666,2 (3)	0,00000095 (7)
$\gamma_{36,5}$ (Np)	669,9 (2)	0,00000051 (7)
$\gamma_{37,5}$ (Np)	675,8 (3)	0,00000085 (5)
$\gamma_{34,3}$ (Np)	680,1 (1)	0,00000331 (7)
$\gamma_{33,1}$ (Np)	688,76 (4)	0,0000323 (5)
$\gamma_{(-1,19)}$ (Np)	693,46	0,00000354 (7)
$\gamma_{34,2}$ (Np)	696,48	0,00000517 (6)
$\gamma_{(-1,20)}$ (Np)	709,42 (5)	0,00000641 (18)
$\gamma_{(-1,64)}$ (Np)	712,5	0,00000020 (3)
$\gamma_{33,0}$ (Np)	721,98 (3)	0,000196 (4)
$\gamma_{37,3}$ (Np)	729,52	0,00000137 (5)
$\gamma_{(-1,21)}$ (Np)	731,44	0,00000046 (4)
$\gamma_{(-1,65)}$ (Np)	736,68	0,00000128 (5)
$\gamma_{35,1}$ (Np)	737,34 (5)	0,00000794 (8)
$\gamma_{(-1,66)}$ (Np)	740,51	0,00000019 (3)
$\gamma_{(-1,22)}$ (Np)	742,9 (3)	0,00000035
$\gamma_{(-1,67)}$ (Np)	745,02	0,00000009 (2)
$\gamma_{(-1,85)}$ (Np)	750,39	0,00000006 (2)
$\gamma_{34,0}$ (Np)	755,91 (5)	0,00000784 (8)
$\gamma_{(-1,23)}$ (Np)	759,5 (1)	0,00000181 (5)
$\gamma_{(-1,24)}$ (Np)	763,31	0,00000023 (2)
$\gamma_{36,1}$ (Np)	767,0 (1)	0,00000501 (3)
$\gamma_{35,0}$ (Np)	770,6 (1)	0,00000481 (5)
$\gamma_{37,1}$ (Np)	772,17	0,00000279 (3)
$\gamma_{(-1,69)}$ (Np)	774,67	0,00000011 (2)
$\gamma_{(-1,25)}$ (Np)	777,39	0,00000015 (2)
$\gamma_{(-1,26)}$ (Np)	780,53	0,00000031 (2)
$\gamma_{(-1,27)}$ (Np)	782,2 (5)	0,00000015
$\gamma_{39,3}$ (Np)	786,00 (15)	0,00000062
$\gamma_{(-1,28)}$ (Np)	789,0 (3)	0,00000042 (6)
$\gamma_{(-1,70)}$ (Np)	792,6	0,00000003 (1)

	Energy keV	Photons per 100 disint.
$\gamma_{(-1,29)}(\text{Np})$	794,92 (20)	0,00000094
$\gamma_{39,2}(\text{Np})$	801,94 (20)	0,00000123 (7)
$\gamma_{(-1,71)}(\text{Np})$	803,19	0,00000016 (3)
$\gamma_{37,0}(\text{Np})$	806,26 (30)	0,00000031
$\gamma_{(-1,30)}(\text{Np})$	811,9 (3)	0,00000063 (6)
$\gamma_{(-1,31)}(\text{Np})$	819,33	0,00000043 (6)
$\gamma_{(-1,32)}(\text{Np})$	822,21	0,00000024 (6)
$\gamma_{39,1}(\text{Np})$	828,54	0,00000021 (4)
$\gamma_{(-1,33)}(\text{Np})$	835,21	0,00000003
$\gamma_{(-1,72)}(\text{Np})$	838,88	0,00000004 (1)
$\gamma_{(-1,34)}(\text{Np})$	841,14	0,00000010 (3)
$\gamma_{(-1,73)}(\text{Np})$	843,7	0,00000097 (8)
$\gamma_{(-1,74)}(\text{Np})$	846,86	0,00000016 (3)
$\gamma_{(-1,35)}(\text{Np})$	847,4 (5)	0,00000027 (3)
$\gamma_{(-1,36)}(\text{Np})$	851,6 (10)	0,00000041 (6)
$\gamma_{(-1,37)}(\text{Np})$	854,95	0,00000023 (4)
$\gamma_{(-1,75)}(\text{Np})$	856,26	0,00000010 (3)
$\gamma_{40,2}(\text{Np})$	860,7	0,00000008 (3)
$\gamma_{39,0}(\text{Np})$	862,7 (5)	0,00000061 (6)
$\gamma_{(-1,38)}(\text{Np})$	870,63	0,00000150 (3)
$\gamma_{(-1,76)}(\text{Np})$	882	0,00000004 (1)
$\gamma_{(-1,77)}(\text{Np})$	886,53	0,00000015 (3)
$\gamma_{40,1}(\text{Np})$	887,73	0,00000033 (6)
$\gamma_{(-1,78)}(\text{Np})$	890,38	0,00000032 (5)
$\gamma_{(-1,79)}(\text{Np})$	894,47	0,00000003 (1)
$\gamma_{(-1,39)}(\text{Np})$	898,17	0,00000006 (2)
$\gamma_{(-1,40)}(\text{Np})$	902,61	0,00000033 (3)
$\gamma_{(-1,80)}(\text{Np})$	909,95	0,00000005 (1)
$\gamma_{(-1,41)}(\text{Np})$	912,4	0,00000028 (3)
$\gamma_{40,0}(\text{Np})$	922,19	0,00000019 (3)
$\gamma_{(-1,42)}(\text{Np})$	928,95	0,00000009 (2)
$\gamma_{(-1,81)}(\text{Np})$	939,2	0,00000005 (1)
$\gamma_{41,0}(\text{Np})$	946,06	0,00000010 (2)
$\gamma_{(-1,82)}(\text{Np})$	952,72	0,00000003 (1)
$\gamma_{(-1,44)}(\text{Np})$	955,91	0,00000060 (5)
$\gamma_{42,0}(\text{Np})$	962,19	0,00000004 (1)
$\gamma_{(-1,83)}(\text{Np})$	969,09	0,00000003 (1)
$\gamma_{(-1,84)}(\text{Np})$	980,84	0,00000003 (1)
$\gamma_{43,0}(\text{Np})$	1014,33	0,00000010 (2)

7 Remarks

7.1 Gamma Transitions and Conversion Electron Coefficients

Transitions (-1,x) are not placed in the decay scheme.

Transitions without uncertainty on the energy value or without transition probability are questionable.

7.2 X Radiations

Intensity of M X-rays = 6,3 (6) %

8 Main Production Modes

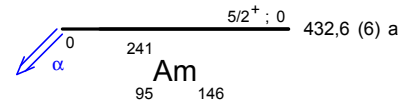
Daughter of Pu – 241

9 References

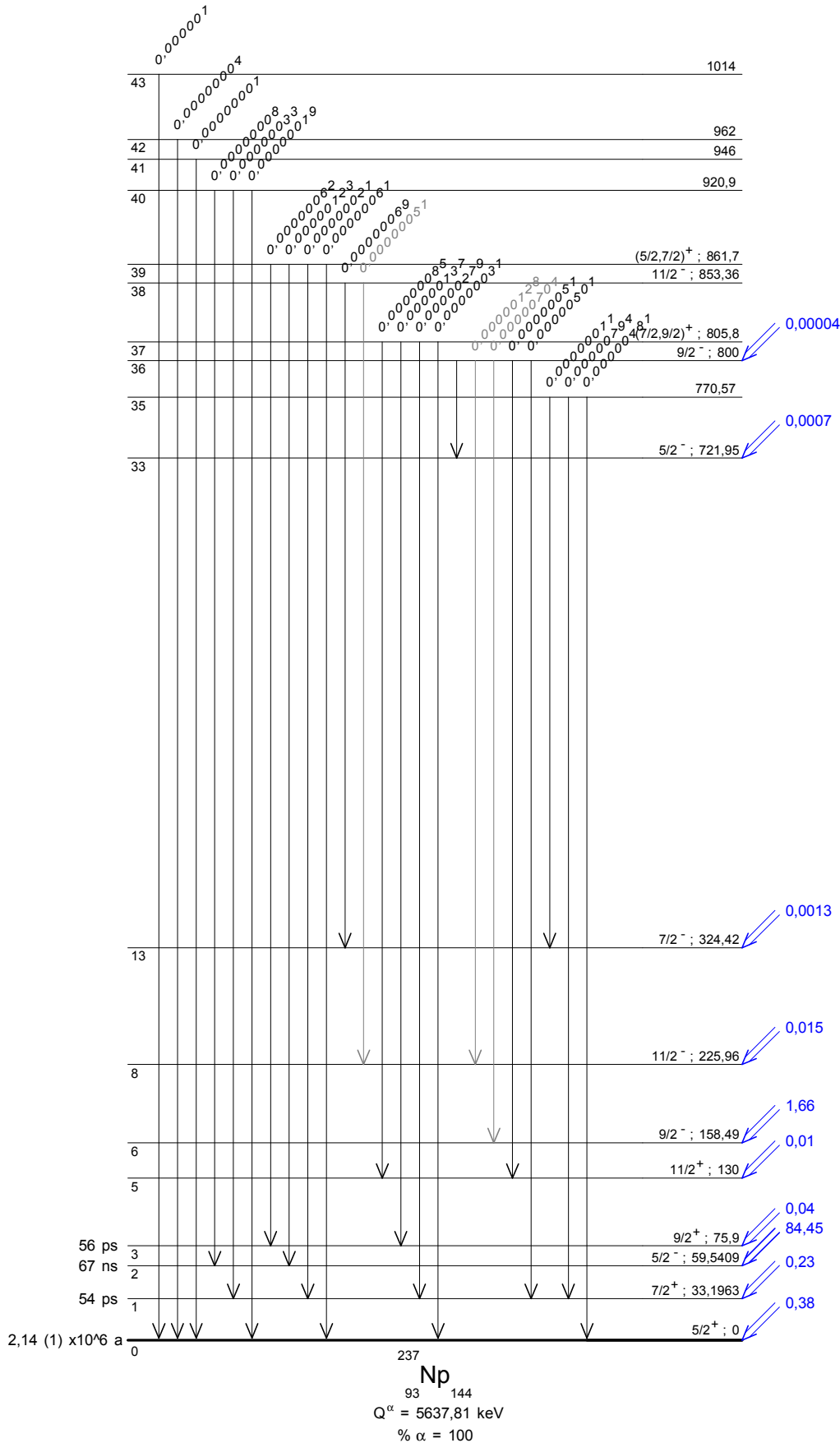
- R.B.DAY. Phys.Rev. 97 (1955) 689
(gamma-ray emission probabilities)
- LL.GOLDIN, G.I. NOVIKOVA, E.F.TRETYAKOV. Conf. Acad. Sci. USSR Moscow (1956) 226
(energies of alpha-particles, alpha-particle emission probabilities)
- L.B.MAGNUSSON. Phys.Rev. 107 (1957) 161
(gamma-ray energies and emission probabilities)
- S.ROSENBLUM, M.VALADARES, J.MILSTED. J.Phys.Radium 18 (1957) 609
(energies of alpha-particles)
- P.S.SAMOILOV. Columbia Tech. Transl. (Izv.Akad.Nauk SSSR, ser.fiz. 23 (1959) 1416) 23 (1960) 1401
(gamma-ray energy, gamma transition probabilities and multipolarities)
- C.F.LEANG. Comp. Rend. Acad. Sci. (Paris) 255 (1962) 3155
(energies of alpha-particles)
- S.A.BARANOV, V.M.KULAKOV, V.M.SHATINSKY. Nucl.Phys. 56 (1964) 252
(alpha-particle energies and emission probabilities)
- J.L.WOLFSON, J.H.PARK. Can. J.Phys. (also Erratum Can.J.Phys. 48 (1970) 2782) 42 (1964) 1387
(gamma-ray energies and multipolarities)
- L.D.MCISAAC. Report IDO-17052 (1965) 31
(gamma-ray emission probabilities)
- W.MICHAELIS. Z.Phys. 186 (1965) 42
(alpha particle energies and emission probabilities)
- W.YAMAZAKI, J.M.HOLLANDER. Nucl.Phys. 84 (1966) 505
(internal conversion probabilities)
- C.M.LEDERER, J.K.POGGENBURG, F.ASARO, J.O.RASMUSSEN, I.PERLMAN. Nucl.Phys. 84 (1966) 481
(internal conversion coefficients)
- F.L.OETTING, S.R.GUNN. J. Inorg. Nucl. Chem. 29 (1967) 2659
(half-life)
- L.N.KONDRATEV, E.F.TRETYAKOV. Bull. Acad. Sci. URSS, Phys. Ser. (IzV.Akad. Nauk SSSR, Ser. Fiz. 30 (1966) 386) 30 (1967) 393
(internal conversion probabilities)
- R.KAMOUN, R.BALLINI, S.BERGSTROM-ROHLIN, J-M.KUCHLY, P.SIFFERT. Comp. Rend. Acad. Sci. (Paris) 266 (1968) 1241
(energies of alpha-particles)
- R.W.JEWELL, W.JOHN, R.MASSEY, B.G.SAUNDERS. Nucl. Instrum. Methods 62 (1968) 68
(gamma-ray energies)
- L.C.BROWN, R.C.PROPST. J. Inorg. Nucl. Chem. 30 (1968) 2591
(half-life)
- R.E.STONE, E.K.HULET. J. Inorg. Nucl. Chem. 30 (1968) 2003
(half-life)

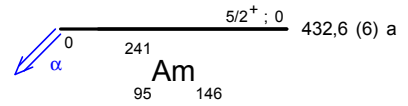
- S.A.BARANOV, V.M.KULAKOV, V.M.SHATINSKII. Sov.J.Nucl.Phys. 7 (1968) 442.
(energies of alpha-particles)
- R.E.STONE, E.K.HULET. J. Inorg. Nucl. Chem. 30 (1968) 2003
(half-life)
- G.C.NELSON, B.G.SAUNDERS. Nucl. Instrum. Methods 84 (1970) 90
(gamma-ray energies)
- E.KARTTUNEN, H.U.FREUND, R.W.FINK. Phys.Rev. 4 (1971) 1695
(MX-ray emission probability)
- R.L.WATSON, T.K.LI. Nucl.Phys. A178 (1971) 201
(LX-ray emission probabilities)
- B.GRENNBERG, A.RYTZ. Métrologia 7 (1971) 65
(energies of alpha-particle)
- R.J.GEHRKE, R.A.LOKKEN. Nucl. Instrum. Methods 97 (1971) 219
(XL- and gamma -ray emission probabilities)
- J.JOVE, R.ROBERT. Radiochem. Radioanal. Letters 10 (1972) 139
(half-life)
- J.L.CAMPBELL, L.A.MCNELLES. Nucl. Instrum. Methods 117 (1974) 519
(LX- and gamma - ray emission probabilities)
- W.J.GALLAGHER, S.J.CIPOLLA. Nucl. Instrum. Methods 122 (1974) 405
(LX- ray emission probabilities)
- R.L.HEATH. Report ANCR 1000 (1974) 2
(gamma - ray energies and emission probabilities)
- V.G.POLYUKHOV, G.A.TIMOFEEV, P.A.PRIVALOVA, P.F.BAKLANOVA. Soviet J. At. Energy 36 (1974) 402
(half-life)
- W.W.STROHM, K.C.JORDAN. Nucl. Soc. 18 (1974) 185
(half-life)
- J.LEGRAND, J.P.PEROLAT, C. BAC, J.GORRY. Int. J. Appl. Radiat. Isotop. 26 (1975) 179
(gamma - ray emission probabilities)
- H.RAMTHUN, W.MULLER. Int. J. Appl. Radiat. Isotop. 26 (1975) 589
(half-life)
- J.PLCH, J.ZDERADICKA, L.KOKTA. J.Phys. 26B (1976) 1344
(gamma-ray emission probability)
- R.GUNNINK, J.E.EVANS, A.L.PRINDLE. Report UCRL-52139 (1976)
(LX-, KX- and gamma-ray emission probabilities)
- F.P.LARKINS. At. Data. Nucl. Data Tables 20 (1977) 313
(Auger electron energies)
- A.GENOUX-LUBAIN, G.ARDISSON. Radiochem. Radioanal. Letters 33 (1978) 59
(gamma-ray energies and emission probabilities)
- V.V.OVECHKIN. Bull. Acad. Sci. URSS, Ser. Phys. (Izv.Akad. Nauk SSSR, Ser Fiz. 42(1978) 101) 42(1) (1978) 82
(gamma-ray energies and emission probabilities)
- F.RÖSEL, H.M.FRIES, K.ALDER, H.C.PAULI. At. Data. Nucl. Data Tables 21 (1978) 91
(internal conversion coefficients)
- A.GENOUX-LUBAIN, G.ARDISSON. Comp. Rend. Acad. Sci. (Paris) B287 (1978) 13
(Gamma-ray emission energies and intensities)
- C.ARDISSON, A.GENOUX-LUBAIN, V.BARCI, G.ARDISSON. Radiochem. Radioanal. Letters 40 (1979) 207
(gamma-ray energies)
- A.RYTZ. At. Data. Nucl. Data Tables 23 (1979) 507
(energies of alpha-particles)
- D.D.COHEN. Nucl. Instrum. Methods 178 (1980) 481
(LX-ray emission probabilities)
- G.BARREAU, H.G.BORNER, T.EGIDY, VON. R.W.HOFF. Z.Phys. 308 (1982) 209
(KX-ray energies)
- J.M.R.HUTCHINSON, P.A.MULLEN. Int. J. Appl. Radiat. Isotop. 34 (1983) 543
(gamma-ray emission probabilities)
- I.AHMAD, J.HINES, J.E.GINDLER. Phys.Rev. C27 (1983) 2239
(LX-, KX-ray energies and KX-, gamma-ray emission probabilities)
- K.DEBERTIN, W.PESSARA. Int. J. Appl. Radiat. Isotop. 34 (1983) 515
(gamma-ray emission probabilities)
- I.AHMAD. Nucl. Instrum. Methods 223 (1984) 319
(alpha-particle emission probabilities)

- V.V.OVECHKIN, A.E.KHOKHLOV. Izv.Akad.Nauk SSSR 48 (1984) 1032
(gamma-ray energies and emission probabilities)
- G.BORTELS, P.COLLAERS. Appl. Rad. Isotopes 38 (1987) 831
(alpha-particle emission probabilities)
- V.P.CHECHEV, N.K.KUZMENKO, V.O.SERGEEV, K.P.ARTAMONOVA. Evaluated decay data, Energoatomizdat Ed. Moscow (1988)
(gamma-ray energies)
- D.D.COHEN. Nucl. Instrum. Methods A267 (1988) 492
(LX-ray emission probabilities)
- J.H.HUBBELL. Report NIST 89-4144 (1989)
(M fluorescence yield)
- A.RYTZ. At. Data Nucl. Data Tables 47 (1991) 205
(Alpha emission energies and intensities)
- C.J.BLAND, J.MOREL, E.ETCHEVERRY, M.C.LÉPY. Nucl. Instrum. Methods A312 (1992) 323
(LX-ray emission probabilities)
- I.AHMAD. Private communication quoted in 1994Bland (1993)
(alpha-particle emission probabilities)
- M.C.LÉPY, K. DEBERTIN, H. JANSSEN, U. SCHÖTZIG. Report PTB- Ra-31 (1993)
(L X-ray emission intensities)
- C.J.BLAND. Nucl. Instrum. Methods A339 (1994) 180
(alpha-particle emission probabilities)
- M.C.LÉPY, B.DUCHEMIN, J.MOREL. Nucl. Instrum. Methods A353 (1994) 10
(LX-ray emission probabilities)
- G.AUDI, A.H.WAPSTRA. Nucl.Phys. A595 (1995) 409
(Q)
- Y.A.AKOVALI. Nucl. Data Sheets 74 (1995) 461
(Decay scheme)
- P.N.JOHNSON. Nucl. Instrum. Methods A369 (1996) 107
(evaluated gamma-ray emission probabilities and internal conversion coefficients)
- A.M.SANCHEZ, P.R.MONTERO, F.V.TOME. Nucl. Instrum. Methods A369 (1996) 593
(alpha-particle emission probabilities)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A369 (1996) 527
(Atomic data)
- C.C.BUENO, J.A.C.GONCALVES, M.D.S.SANTOS. Nucl. Instrum. Methods A371 (1996) 460
(alpha-particle emission probabilities)
- A.ABDUL-HADI. J.Radional.Nucl.Chem 231 (1998) 147
(Gamma-ray emission energies and intensities)
- A.KOVALIK, E.A. YAKUSHEV, V.M. GOROZHANKIN, M. NOVGORODOV, M.RYSAVY. J. Phys. (London) G24 (1998) 2247
(Conv. Elec. emission energies and intensities)
- Y.JANG, J.NI. Nucl. Instrum. Methods A413 (1998) 239
(Alpha emission intensities)
- E.SCHÖNFELD, G.RODLOFF. Report PTB 6.11-1, Braunscheig (1999)
(XK-ray energies and emission probabilities)
- R.G.HELMER, VAN DER C.LEUN. Nucl. Instrum. Methods A450 (2000) 35
(gamma-ray energies)
- E.SCHÖNFELD, U. SCHÖTZIG. Appl. Rad. Isotopes 54 (2001) 785
(L X-ray emission energies and intensities)

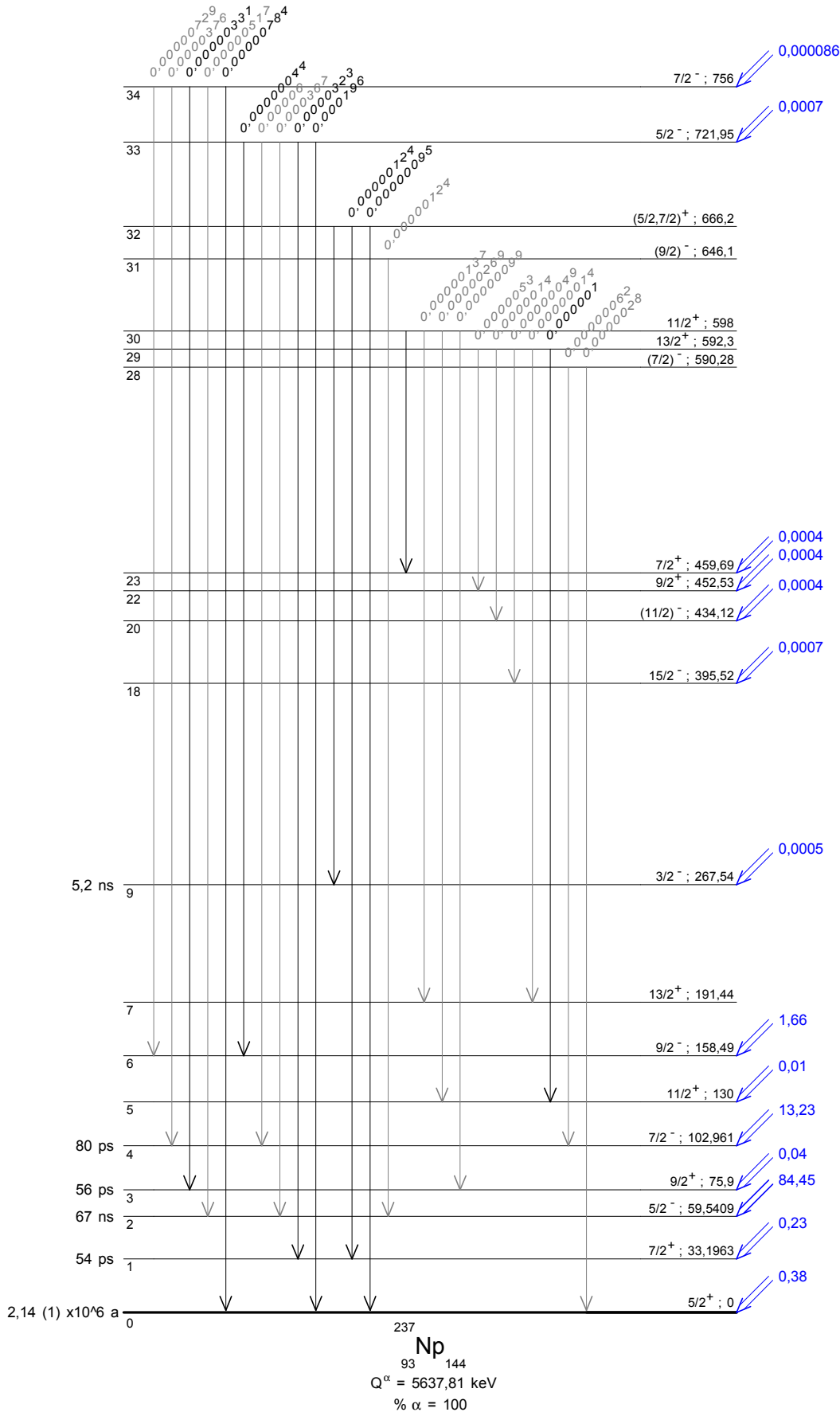


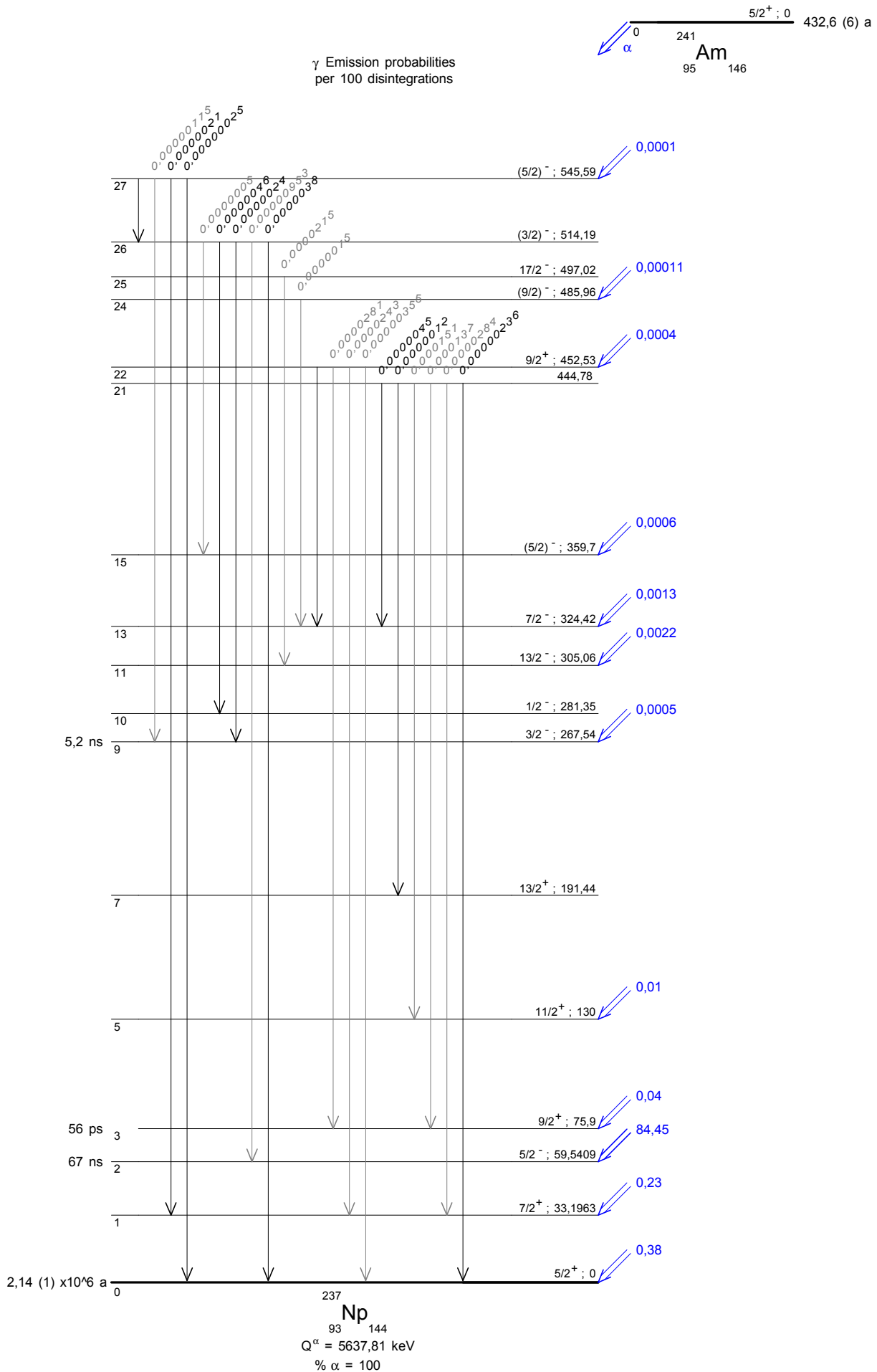
γ Emission probabilities
 per 100 disintegrations

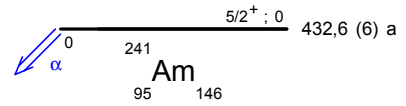




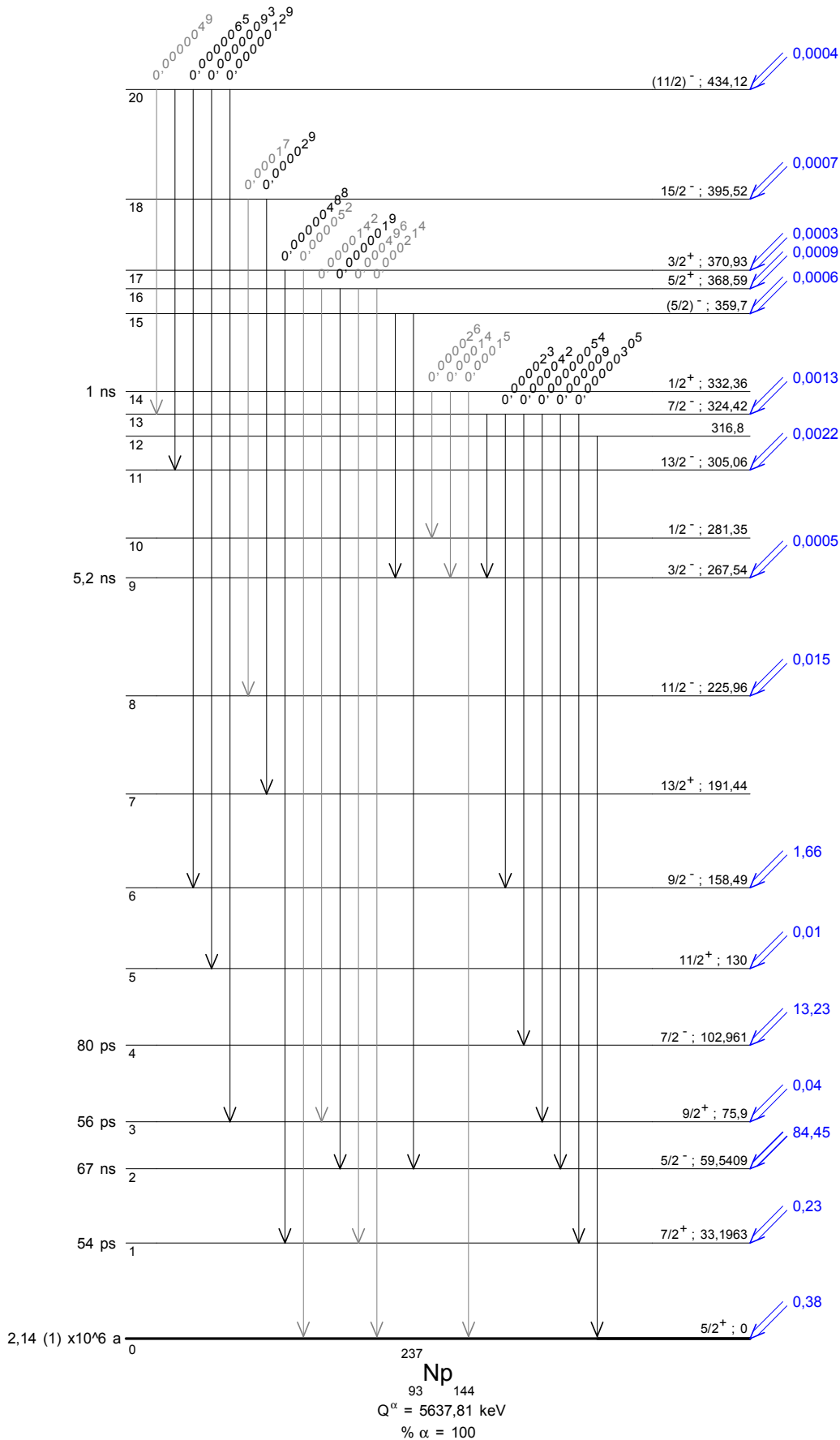
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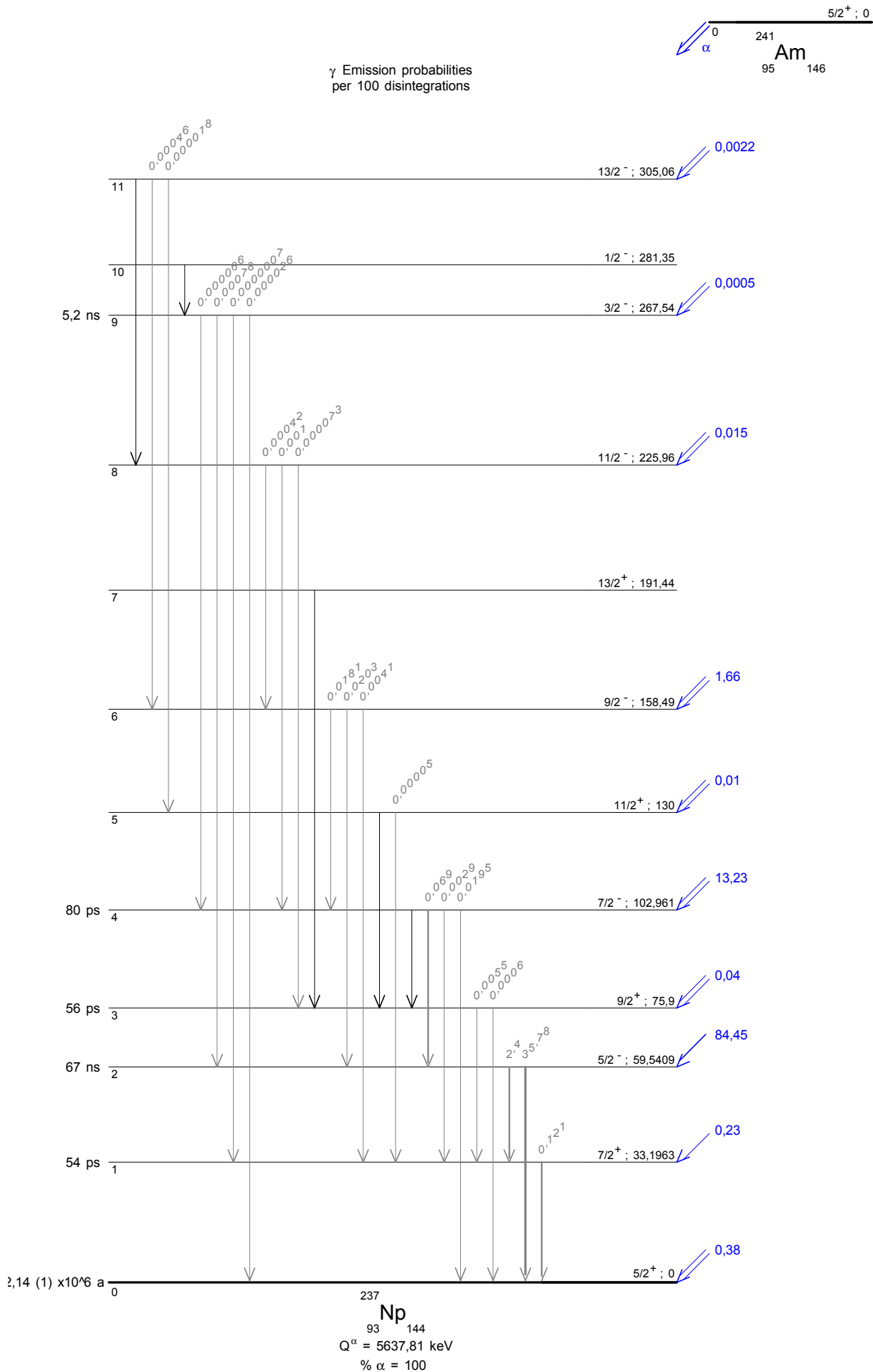


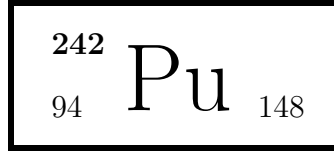




γ Emission probabilities
 per 100 disintegrations







1 Decay Scheme

Pu-242 decays 100% by alpha transitions to U-238 and by spontaneous fission with branching fraction of $5.49(9)10^{-4}$ %. Most of the alpha decay populates the U-238 ground state (76.5 %) and the U-238 first excited level with energy of 44.9 keV (23.5 %).

Le plutonium 242 se désintègre par émission alpha et par fission spontanée dans une proportion de 5,49(9) 10⁻⁴ %. L'émission alpha a lieu principalement vers le niveau excité de 44,9 keV (23,5 %) et le niveau fondamental (76,5 %) de l'uranium 238.

2 Nuclear Data

$T_{1/2}(^{242}\text{Pu})$	:	3,73	(3)	10^5	a
$T_{1/2}(^{238}\text{U})$	:	4,47	(2)	10^9	a
$Q^\alpha(^{242}\text{Pu})$	:	4984,4	(9)	keV	

2.1 α Transitions

	Energy keV	Probability $\times 100$	F
$\alpha_{0,3}$	4677,2 (9)	0,00085 (6)	602
$\alpha_{0,2}$	4836,0 (9)	0,0308 (13)	234
$\alpha_{0,1}$	4939,5 (9)	23,49 (18)	1,62
$\alpha_{0,0}$	4984,4 (9)	76,48 (18)	1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}(\text{U})$	44,915 (13)	23,52 (18)	E2		455 (9)	126 (3)	625 (13)
$\gamma_{2,1}(\text{U})$	103,50 (4)	0,0316 (13)	E2		8,43 (17)	2,35 (5)	11,61 (23)
$\gamma_{3,2}(\text{U})$	158,80 (8)	0,00085 (6)	E2	0,210 (4)	1,203 (24)	0,334 (7)	1,86 (4)

3 Atomic Data

3.1 U

ω_K	:	0,970	(4)
$\bar{\omega}_L$	:	0,500	(19)
n_{KL}	:	0,794	(5)

3.1.1 X Radiations

	Energy keV	Relative probability
X_K		
$K\alpha_2$	94,666	62,47
$K\alpha_1$	98,44	100
$K\beta_3$	110,421	}
$K\beta_1$	111,298	}
$K\beta_5''$	111,964	}
		36,06
$K\beta_2$	114,407	}
$K\beta_4$	115,012	}
$KO_{2,3}$	115,377	}
		12,33
X_L		
$L\ell$	11,62	
$L\alpha$	13,44 – 13,62	
$L\eta$	15,4	
$L\beta$	15,73 – 18,21	
$L\gamma$	19,51 – 21,73	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	71,776 – 80,954	100
KLX	88,153 – 98,429	59,6
KXY	104,51 – 115,59	8,88
Auger L	0,10 – 21,65	

4 α Emissions

	Energy keV	Probability $\times 100$
$\alpha_{0,3}$	4600,0 (9)	0,00085 (6)
$\alpha_{0,2}$	4756,1 (9)	0,0308 (13)
$\alpha_{0,1}$	4858,1 (9)	23,49 (18)
$\alpha_{0,0}$	4902,2 (9)	76,48 (18)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
e_{AL}	(U)	0,10 - 21,65	8,6 (5)
e_{AK}	(U)		0,0000019 (3)
	KLL	71,776 - 80,954	}
	KLX	88,153 - 98,429	}
	KXY	104,51 - 115,59	}
$ec_{1,0 L}$	(U)	23,157 - 27,747	17,1 (5)
$ec_{1,0 M}$	(U)	39,367 - 41,365	4,74 (15)

6 Photon Emissions**6.1 X-Ray Emissions**

		Energy keV	Photons per 100 disint.	
XL	(U)	11,62 — 21,73	8,56 (40)	
$XK\alpha_2$	(U)	94,666	0,0000180 (15)	} $K\alpha$
$XK\alpha_1$	(U)	98,44	0,0000288 (24)	}
$XK\beta_3$	(U)	110,421	}	
$XK\beta_1$	(U)	111,298	}	} $K'\beta_1$
$XK\beta_5''$	(U)	111,964	}	
$XK\beta_2$	(U)	114,407	}	
$XK\beta_4$	(U)	115,012	}	} $K'\beta_2$
$XKO_{2,3}$	(U)	115,377	}	

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}(U)$	44,915 (13)	0,0376 (8)
$\gamma_{2,1}(U)$	103,50 (4)	0,00251 (11)
$\gamma_{3,2}(U)$	158,80 (8)	0,000298 (20)

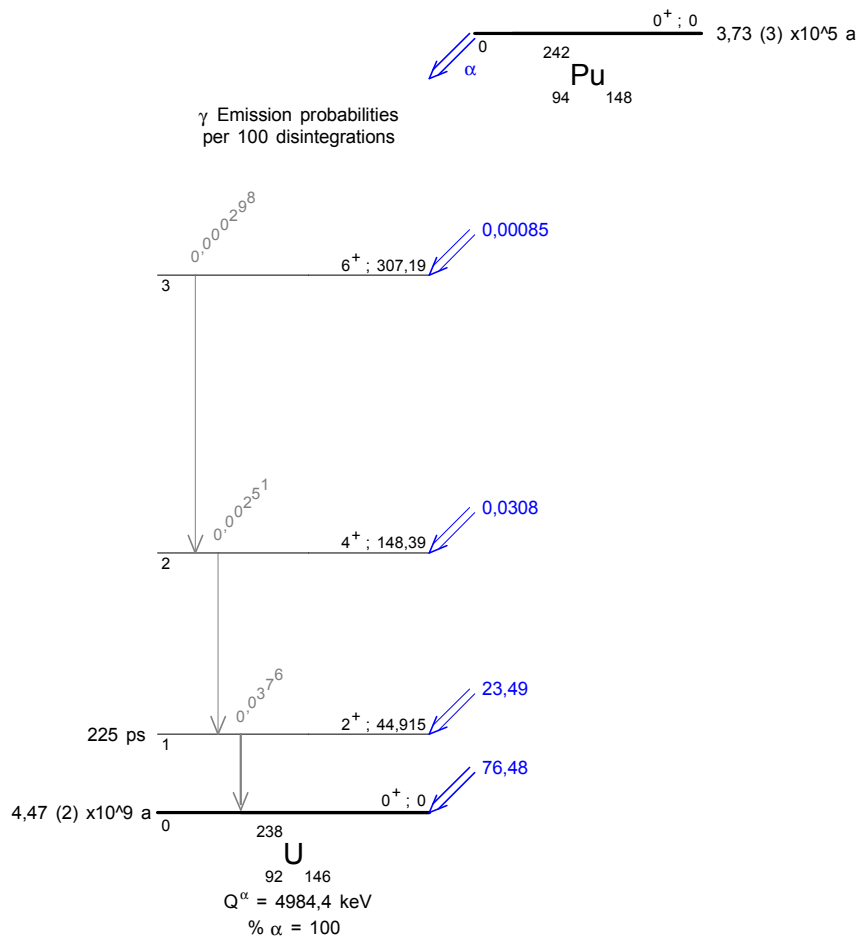
7 Main Production Modes

- Multiple n – capture from U – 238, Pu – 238
- { Pu – 241(n, γ)Pu – 242
 - { Possible impurities : Pu – 238, Pu – 239, Pu – 240, Pu – 241, Am – 241
 - { Am – 241(n, γ)Am – 242
 - { Possible impurities : Am – 241, Cm – 242

8 References

- F. ASARO. PhD Thesis, Univ. of California, Livermore, CA, Report UCRL-2180 (1953)
(Alpha-particle energies and emission probabilities)
- J.P. BUTLER, M. LOUNSBURY, J. MERRITT. Can. J. Chem. 34 (1956) 253
(Half-life)
- J.P. BUTLER, T.A. EASTWOOD, T.L. COLLINS, M.E. JONES, F.M. ROURKE, R.P. SCHUMAN. Phys. Rev. 103 (1956) 634
(Half-life, SF half-life)
- J.P. HUMMEL. Report UCRL-3456 (1956)
(Alpha-particle energies and emission probabilities)
- L.M. KONDRATEV, G.I. NOVIKOVA, Y.P. SOBOLEV, L.L. GOLDIN. Zh. Eksp. Teor. Fiz. 31 (1956) 771
(Alpha-particle energies and emission probabilities)
- J.F. MECH, H. DIAMOND, M.H. STUDIER, P.R. FIELDS, A. HIRSCH, C.M. STEPHENS, R.F. BARNES, D.J. HENDERSON, J.R. HUIZENGA. Phys. Rev. 103 (1956) 340
(Half-life, SF half-life)
- M.H. STUDIER, A. HIRCH. Private Comm. - Quoted in 1956Me37 (1956)
(SF Half-life)
- V.A. DRUIN, V.P. PERELYGIN, G.I. KHLEBNIKOV. Soviet Phys. JETP 13 (1961) 913
(SF half-life)
- L.Z. MALKIN, I.D. ALKHAZOV, A.S. KRIVOKHATSKY, K.A. PETRZHAK. At. Energ. USSR 15 (1963) 158
(SF half-life)
- J.A. BEARDEN. Rev. Mod. Phys. 39 (1967) 78
(X-ray energies)
- S.A. BARANOV, V.M. KULAKOV, V.M. SHATINSKII. Nucl. Phys. 7 (1968) 442
(Alpha-particle energies)
- C.E. BEMIS JR., J. HALPERIN, R. EBY. J. Inorg. Nucl. Chem. 31 (1969) 599
(Half-life)
- R.W. DURHAM, F. MOLSON. Can. J. Phys. 48 (1970) 716
(Half-life)
- M. SCHMORAK, C.E. BEMIS JR., M.J. ZENDER, N.B. GOVE, P.F. DITTNER. Nucl. Phys. A178 (1972) 410
(Gamma-ray energies and emission probabilities)

- D.W. OSBORNE, H.E. FLOTOW. Phys. Rev. C14 (1976) 1174
(Half-life)
- S.A. BARANOV, A.G. ZELENKOV; V.M. KULAKOV. Sov. At. Energy 41 (1976) 987
(Alpha-emission probabilities)
- L.S. BULYANITSA, A.M. GEIDELMAN, Y.S. EGOROV, L.M. KRIZHANSKII, A.A. LIPOVSKII, L.D. PREOBRAZHENSKAYA, A.V. LOVTSYUS, Y.V. KHOLNOV. Bull. Akad. Sci. USSR, Phys. Ser. 40 (1976) 42
(Half-life)
- F.P. LARKINS. At. Data Nucl. Data Tables 20 (1977) 313
(Auger electron energies)
- J.W. MEADOWS. Report BNL-NCS-24273(1978) (1978) 10
(Half-life, SF half-life)
- F. RÖSEL, H.M. FRIESS, K. ALDER, H.C. PAULI. At. Data Nucl. Data Tables. 21 (1978) 92
(Theoretical ICC)
- S.K. AGGARWAL, S.N. ACHARYA, A.R. PARAB, H.C. JAIN. Phys.Rev. C20 (1979) 1135
(Half-Life)
- N.A. KHAN, H.A. KHAN, K. GUL, M. ANWAR, G. HUSSAIN, R.A. AKBAR, A. WAHEED, M.S. SHAIKH. Nucl. Instrum. Methods 173 (1980) 163
(SF Half-life)
- A. LORENZ. IAEA Tech Rept Ser, No 261 (1986)
(Evaluated decay data)
- R. VANINBROUKX, G. BORTELS, B. DENECKE. Int. J. Appl. Radiat. Isotop. 37 (1986) 1167
(Alpha-, gamma-ray emission probabilities)
- F. LAGOUTINE, N. COURSOL, J. LEGRAND. Table de radionucléides, ISBN-2-7272-0078-1 (1987)
(Auger electron energies)
- YU.A. SELITSKY, V.B. FUNSHTEIN, V.A. YAKOVLEV. Program and Theses, Proc. 38th Ann. Conf. Nucl. Spectrosc. Struct. (1988) 131
(SF half-life)
- YU.S. POPOV, I.B. MAKAROV, D.KH. SRUROV, E.A. ERIN. Radiokhimiya 32 (1990) 2
(MX-, LX- ray relative emission probabilities)
- A. RYTZ. At. Data Nucl. Data Tables. 47 (1991) 205
(Alpha-emission energies)
- M.C. LEPY, B. DUCHEMIN, J. MOREL. Nucl. Instrum. Methods Phys. Res. A353 (1994) 10
(LX ray energies and emission probabilities)
- G. AUDI, A.H. WAPSTRA. Nucl. Phys. A595 (1995) 409
(Decay energy)
- P.N. JOHNSTON, P.A. BURNS. Nucl. Instrum. Methods Phys. Res. A361 (1995) 229
(LX-ray energies and emission probabilities)
- E. SCHÖNFELD, H. JANSSEN. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
(Atomic data)
- E. SCHÖNFELD, G. RODLOFF. Report PTB-6.11 (1999)
(KX-ray energies and relative emission probabilities)
- F.E.CHUKREEV, V.E.MAKARENKO, M.J.MARTIN. Nucl. Data Sheets 97 (2002) 129
(Decay Scheme)
- Y.A. AKOVALI. Nucl. Data Sheets 96 (2002) 177
(Decay Scheme)



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**TABLE DE RADIONUCLÉIDES
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COMMENTS ON EVALUATIONS

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Monographie BIPM-5 - Table of Radionuclides, Comments on evaluations

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Sommaire

Depuis quelques années, un groupe composé d'évaluateurs spécialistes des données de décroissance radioactive s'est formé, avec l'objectif de réaliser une évaluation soignée et documentée de ces données pour des radionucléides intervenant dans de nombreuses applications. Ces évaluateurs se sont mis d'accord sur une méthodologie commune. Ce rapport inclus les commentaires sur les évaluations des radionucléides figurant dans le rapport Monographie BIPM-5 :

${}^7\text{Be}$, ${}^{11}\text{C}$, ${}^{13}\text{N}$, ${}^{15}\text{O}$, ${}^{18}\text{F}$, ${}^{24}\text{Na}$, ${}^{32}\text{P}$, ${}^{33}\text{P}$, ${}^{44}\text{Sc}$, ${}^{44}\text{Ti}$, ${}^{46}\text{Sc}$, ${}^{51}\text{Cr}$, ${}^{54}\text{Mn}$, ${}^{56}\text{Mn}$, ${}^{57}\text{Co}$, ${}^{57}\text{Ni}$, ${}^{59}\text{Fe}$, ${}^{64}\text{Cu}$, ${}^{66}\text{Ga}$, ${}^{67}\text{Ga}$, ${}^{85}\text{Kr}$, ${}^{85}\text{Sr}$, ${}^{88}\text{Y}$, ${}^{89}\text{Sr}$, ${}^{93}\text{Nb}^{\text{m}}$, ${}^{99}\text{Mo}$, ${}^{99}\text{Tc}^{\text{m}}$, ${}^{109}\text{Cd}$, ${}^{110}\text{Ag}$, ${}^{110}\text{Ag}^{\text{m}}$, ${}^{123}\text{I}$, ${}^{123}\text{Te}^{\text{m}}$, ${}^{125}\text{Sb}$, ${}^{129}\text{I}$, ${}^{131}\text{I}$, ${}^{131}\text{Xe}^{\text{m}}$, ${}^{133}\text{Ba}$, ${}^{140}\text{Ba}$, ${}^{140}\text{La}$, ${}^{152}\text{Eu}$, ${}^{153}\text{Gd}$, ${}^{153}\text{Sm}$, ${}^{154}\text{Eu}$, ${}^{155}\text{Eu}$, ${}^{166}\text{Ho}$, ${}^{166}\text{Ho}^{\text{m}}$, ${}^{169}\text{Yb}$, ${}^{170}\text{Tm}$, ${}^{177}\text{Lu}$, ${}^{186}\text{Re}$, ${}^{198}\text{Au}$, ${}^{201}\text{Tl}$, ${}^{203}\text{Hg}$, ${}^{204}\text{Tl}$, ${}^{208}\text{Tl}$, ${}^{212}\text{Bi}$, ${}^{212}\text{Pb}$, ${}^{212}\text{Po}$, ${}^{216}\text{Po}$, ${}^{220}\text{Rn}$, ${}^{224}\text{Ra}$, ${}^{226}\text{Ra}$, ${}^{227}\text{Th}$, ${}^{228}\text{Th}$, ${}^{238}\text{Pu}$, ${}^{240}\text{Pu}$, ${}^{241}\text{Am}$, ${}^{242}\text{Pu}$.

Summary

Over the past years, an informal group of decay-data evaluators has been assembled with the goal of creating high-quality, well-documented evaluations of the decay data for a selected set of radionuclides that are of interest in various applications. These evaluators have agreed on the methodologies to be used. This report includes, for each radionuclide, the evaluator's comments on how the evaluation was carried out for the radionuclides that are in the Monographie BIPM-5 :

${}^7\text{Be}$, ${}^{11}\text{C}$, ${}^{13}\text{N}$, ${}^{15}\text{O}$, ${}^{18}\text{F}$, ${}^{24}\text{Na}$, ${}^{32}\text{P}$, ${}^{33}\text{P}$, ${}^{44}\text{Sc}$, ${}^{44}\text{Ti}$, ${}^{46}\text{Sc}$, ${}^{51}\text{Cr}$, ${}^{54}\text{Mn}$, ${}^{56}\text{Mn}$, ${}^{57}\text{Co}$, ${}^{57}\text{Ni}$, ${}^{59}\text{Fe}$, ${}^{64}\text{Cu}$, ${}^{66}\text{Ga}$, ${}^{67}\text{Ga}$, ${}^{85}\text{Kr}$, ${}^{85}\text{Sr}$, ${}^{88}\text{Y}$, ${}^{89}\text{Sr}$, ${}^{93}\text{Nb}^{\text{m}}$, ${}^{99}\text{Mo}$, ${}^{99}\text{Tc}^{\text{m}}$, ${}^{109}\text{Cd}$, ${}^{110}\text{Ag}$, ${}^{110}\text{Ag}^{\text{m}}$, ${}^{123}\text{I}$, ${}^{123}\text{Te}^{\text{m}}$, ${}^{125}\text{Sb}$, ${}^{129}\text{I}$, ${}^{131}\text{I}$, ${}^{131}\text{Xe}^{\text{m}}$, ${}^{133}\text{Ba}$, ${}^{140}\text{Ba}$, ${}^{140}\text{La}$, ${}^{152}\text{Eu}$, ${}^{153}\text{Gd}$, ${}^{153}\text{Sm}$, ${}^{154}\text{Eu}$, ${}^{155}\text{Eu}$, ${}^{166}\text{Ho}$, ${}^{166}\text{Ho}^{\text{m}}$, ${}^{169}\text{Yb}$, ${}^{170}\text{Tm}$, ${}^{177}\text{Lu}$, ${}^{186}\text{Re}$, ${}^{198}\text{Au}$, ${}^{201}\text{Tl}$, ${}^{203}\text{Hg}$, ${}^{204}\text{Tl}$, ${}^{208}\text{Tl}$, ${}^{212}\text{Bi}$, ${}^{212}\text{Pb}$, ${}^{212}\text{Po}$, ${}^{216}\text{Po}$, ${}^{220}\text{Rn}$, ${}^{224}\text{Ra}$, ${}^{226}\text{Ra}$, ${}^{227}\text{Th}$, ${}^{228}\text{Th}$, ${}^{238}\text{Pu}$, ${}^{240}\text{Pu}$, ${}^{241}\text{Am}$, ${}^{242}\text{Pu}$.

TABLE DE RADIONUCLÉIDES – COMMENTAIRES SUR LES ÉVALUATIONS

De nombreuses applications nécessitent la connaissance des données liées à la désintégration des radioéléments, telles que la période radioactive, les énergies et les intensités des divers rayonnements. Pour répondre aux demandes des utilisateurs, le Laboratoire National Henri Becquerel (BNM - LNHB, France) a, de 1982 à 1987, publié une table en quatre volumes [87Ta, 99Be]. Puis, en 1993 une coopération a été établie avec le Physikalisch-Technische Bundesanstalt (PTB, Allemagne) afin de reprendre cette étude et de la développer. En 1995, un nouveau groupe de travail international nommé Decay Data Evaluation Project (DDEP) s'est formé qui, en plus des deux laboratoires nationaux précédents, inclus : Idaho National Engineering and Environmental Laboratory (INEEL, USA), Lawrence Berkeley National Laboratory (LBNL, USA), Brookhaven National Laboratory (BNL, USA) et Khlopin Radium Institute (KRI, Russie).

Le propos de ce groupe est de fournir aux utilisateurs des données soigneusement évaluées qui puissent servir de référence. A cette fin, tous les membres du groupe suivent une méthodologie commune qui comprend :

- la lecture attentive de toutes les publications relatives à une grandeur ;
- une analyse statistique des données retenues ;
- le choix et l'utilisation des mêmes jeux de données, pour celles ayant fait l'objet d'études spécifiques par des spécialistes, tels les coefficients de conversion interne.
-

Tous ces points sont développés en détails dans le chapitre « Rules for evaluation and compilations ».

Par ailleurs, toutes les évaluations sont documentées et l'établissement des valeurs retenues explicité. Ce document est ensuite relu par deux membres du groupe.

Ce volume regroupe les commentaires liés à l'évaluation des radionucléides suivants :

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^{\text{m}}$, ^{99}Mo , $^{99}\text{Tc}^{\text{m}}$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^{\text{m}}$, ^{123}I , $^{123}\text{Te}^{\text{m}}$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^{\text{m}}$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^{\text{m}}$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

Les données de décroissance radioactive de ces radionucléides peuvent être trouvées dans la Monographie BIPM-5 de la « Table de radionucléides », dans le CD-Rom NUCLÉIDE édité par le LNHB ou sur les pages web : <http://www.nucleide.org/NucData.htm>

TABLE OF RADIONUCLIDES – COMMENTS ON EVALUATIONS

Basic properties of radionuclides, such as half-life, decay mode and branchings, radiation energies and emission probabilities are commonly used in various research fields. To meet the demand for these data the LNHB produced a table that was published in four volumes [87Ta, 99Be] from 1982 to 1987. In 1993, a cooperative agreement was established between the Laboratoire National Henri Becquerel (BNM - LNHB, France) and the Physikalisch-Technische Bundesanstalt (PTB, Germany) to continue and expand this work. In 1995, a new international collaboration was formed, the Decay Data Evaluation Project (DDEP), which has the same objectives. Along with the evaluators from LNHB and PTB, this collaboration includes others from the Idaho National Engineering and Environmental Laboratory (INEEL, USA), the Lawrence Berkeley National Laboratory (LBNL, USA), the Brookhaven National Laboratory (BNL, USA) and the Khlopin Radium Institute (KRI, Russia). Its objective has been to provide carefully produced recommended values, which may eventually become standard data. With this goal in mind, the collaboration has adopted a uniform evaluation methodology that contains the following :

- a critical review of relevant publications;
- an accounting of all measured data;
- a uniform statistical analysis of the data;
- a presentation of values for quantities such as internal conversion coefficients, etc.
- a review of evaluation by two other members of the collaboration.

These topics are described in detail in the chapter “Rules for evaluation and compilations”.

The evaluation of each individual radionuclide has a section (presented here) that describes the procedures used for deducing the recommended values. This documentation is included in order to establish the quality and completeness of each evaluation. It can also provide the basis for any future reevaluation by the DDEP or other groups.

This volume contains the procedures and comments relevant to the evaluation for the following radionuclides :

^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{24}Na , ^{32}P , ^{33}P , ^{44}Sc , ^{44}Ti , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Mn , ^{57}Co , ^{57}Ni , ^{59}Fe , ^{64}Cu , ^{66}Ga , ^{67}Ga , ^{85}Kr , ^{85}Sr , ^{88}Y , ^{89}Sr , $^{93}\text{Nb}^m$, ^{99}Mo , $^{99}\text{Tc}^m$, ^{109}Cd , ^{110}Ag , $^{110}\text{Ag}^m$, ^{123}I , $^{123}\text{Te}^m$, ^{125}Sb , ^{129}I , ^{131}I , $^{131}\text{Xe}^m$, ^{133}Ba , ^{140}Ba , ^{140}La , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{154}Eu , ^{155}Eu , ^{166}Ho , $^{166}\text{Ho}^m$, ^{169}Yb , ^{170}Tm , ^{177}Lu , ^{186}Re , ^{198}Au , ^{201}Tl , ^{203}Hg , ^{204}Tl , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{212}Po , ^{216}Po , ^{220}Rn , ^{224}Ra , ^{226}Ra , ^{227}Th , ^{228}Th , ^{238}Pu , ^{240}Pu , ^{241}Am , ^{242}Pu .

These evaluations may be found in the BIPM-5 Monographie, on the CD-Rom NUCLÉIDE published by the LNHB or in the web pages : <http://www.nucleide.org/NucData.htm>

A goal of the DDEP is to avoid future duplication of effort by disseminating these critically evaluated data with the hope that they will be included in many other collections of decay data.

REFERENCES

- [87Ta] Table de Radionucléides, F. Lagoutine, N. Coursol, J. Legrand. ISBN 2 7272 0078 1 (LMRI, 1982-1987).
- [96He] R.G. Helmer, Proceedings of the Int. Symp. "Advances in alpha-, beta- and gamma-ray Spectrometry", St. Petersburg, September 1996, p. 71.
- [96Be] M.-M. Bé, B. Duchemin and J. Lamé. Nucl. Instrum. Methods A369 (1996) 523 and Bulletin du Bureau National de Métrologie 110 (1998).
- [99In] Table de Radionucléides. Introduction, nouvelle version. Introduction, revised version. Einleitung, überarbeitete Fassung. ISBN 2 7272 0201 6, BNM-CEA/LNHB BP 52, 91191 Gif-sur-Yvette Cedex, France.
- [99Ta] M.M. Bé, E. Browne, V. Chechev, N. Coursol, B. Duchemin, R. Helmer, J. Lamé, C. Morillon, F. Piton, E. Schönfeld. Table de Radionucléides, Volume 5, CEA/DAMRI, 91191 Gif-sur-Yvette, France. 1999, ISBN 2 7272 0200 8
- [99Com] M.M. Bé, E. Browne, V. Chechev, R. Helmer, E. Schönfeld. Table de Radionucléides, Comments on evaluations, CEA/DAMRI, 91191 Gif-sur-Yvette, France. 1999, ISBN 2 7272 0211 3
- [01Br] E. Browne, M.M. Bé, D. MacMahon, R. Helmer. Report on the activities of the Decay Data Evaluation Project. Rapport CEA R-5990(E) (2001)
- [02He] R. Helmer, E. Browne, M.M. Bé. International Decay Data Evaluation Project, Journal of Nuclear Science and Technology, Supplement 2 (August 2002) 455
- [02Be] M.M. Bé, R. Helmer, V. Chisté. The Nucléide database for decay data and the "International Decay Data Evaluation Project", Journal of Nuclear Science and Technology, Supplement 2 (August 2002) 481
- [04Du] C. Dulieu, V. Chisté, M.M. Bé. A website dedicated to ionizing radiation metrology. Applied Radiation and Isotopes 60, 2-4 (2004) 133

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Toutes demandes de renseignements concernant les données recommandées et la façon dont elles ont été établies doivent être adressées directement aux auteurs des évaluations.

Information on the data and the evaluation procedures is available from the authors listed below.

Informationen über die Daten und Evaluationsprozeduren können bei den im folgenden zusammengestellten Autoren angefordert werden.

Todos los pedidos de información relativos a datos recomendados y la manera de establecerlos deben dirigirse directamente a los autores de las evaluaciones.

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RULES FOR EVALUATION AND COMPILATIONS

1. DATA SOURCES

Two main sources of data are used to obtain the recommended values:

- specific data evaluated from all available original publications (e.g., half-life),
- data already evaluated by specialists and compiled (e.g., Q-values); if a new experimental study exists, the resulting measured value may be taken into account, and its reference be included in a list of references for such a radionuclide.

2. EVALUATION RULES

All intermediate stages in the compilation and evaluation of a decay parameter are not presented in detail in order to avoid unnecessary complexity. The main stages comprise the following:

- critical analysis of published results and, if necessary, correction of these results to account for more recent values hitherto unavailable to the original experimentalists; as a rule, results without associated uncertainties are discarded, and the rejection of values is documented;
- data obtained through private communications are used only when all of the necessary information has been provided directly by the scientist who performed the measurements;
- adjustments may be made to the reported uncertainties;
- recommended values are deduced from an analysis of all measurements (or theoretical considerations), along with their standard deviations with a 1s confidence level.

2.1. Evaluation of uncertainties

Definitions from “Guide to the expression of uncertainty in measurement” [1]:

Uncertainty (of measurement): parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

Standard uncertainty: uncertainty of the result of a measurement expressed as a standard deviation.

Type A evaluation (of uncertainty): method of evaluation of uncertainty by the statistical analysis of a series of observations.

Type B evaluation (of uncertainty): method of evaluation of uncertainty by means other than the statistical analysis of a series of observations.

The uncertainties given by authors are re-evaluated by combining the standard uncertainties σ_A and σ_B through the general law of variance propagation:

$$u_c = \sqrt{\mathbf{s}_A^2 + \mathbf{s}_B^2} \quad (1)$$

where u_c is the combined standard uncertainty,
 \mathbf{s}_A is the type A standard deviation, and
 \mathbf{s}_B is the type B standard uncertainty.

When the authors give insufficient information concerning their uncertainty calculations, the combined uncertainty u_c may be estimated by the evaluator, based on a knowledge of the measurement method(s).

2.2. Determination of the best value and associated uncertainty

(a) Results obtained by one author using one method

Sometimes only the final mean value and the combined standard uncertainty are given in the original publication. The following procedure is adopted if sufficient details are known.

For n individual values a_i ($i = 1 \dots n$), the best value is the arithmetical mean:

$$\bar{a} = \sum_{i=1}^n \frac{a_i}{n} \quad (2)$$

with type A standard deviation:

$$\mathbf{s}_A(\bar{a}) = \left[\frac{\sum_i (a_i - \bar{a})^2}{n(n-1)} \right]^{1/2} \quad (3)$$

If there are m contributions σ_{Bj} ($j = 1 \dots m$) to the type B standard uncertainty that are independent of each other:

$$\mathbf{s}_B(\bar{a}) = \left[\sum_{j=1}^m \mathbf{s}_{Bj}^2 \right]^{1/2} \quad (4)$$

Combined standard uncertainty:

$$u_c(\bar{a}) = \sqrt{\mathbf{s}_A^2(\bar{a}) + \mathbf{s}_B^2(\bar{a})} \quad (5)$$

Recommended value:

$$a = \bar{a} \pm u_c(\bar{a}) \quad (6)$$

(b) Results obtained by several authors employing the same method

For n individual values \bar{a}_i ($i = 1 \dots n$) having a standard deviation σ_{Ai} and a type B uncertainty σ_{Bi} , the best value is obtained by taking the mean weighted by the inverse of the variances.

$$\bar{a} = \frac{\sum_i (\bar{a}_i / \mathbf{s}_{Ai}^2)}{\sum_i (1 / \mathbf{s}_{Ai}^2)} \quad (7)$$

The associated values σ_A , σ_B are:

$$\mathbf{s}_A(\bar{a}) = \left[\sum_i (1 / \mathbf{s}_{Ai}^2) \right]^{-1/2} \quad (8)$$

$$\mathbf{s}_B(\bar{a}) = \sum_i (\mathbf{s}_{Bi})_{\min} \quad \text{or} \quad \mathbf{s}_B(\bar{a}) = \sqrt{\sum_i (\mathbf{s}_{Bi})_{\min}^2} \quad \text{or} \quad \mathbf{s}_B(\bar{a}) = (\mathbf{s}_B)_{\min}$$

depending on the individual case, although $\mathbf{s}_B(\bar{a})$ cannot be less than the smallest σ_{Bi} .

σ_A and σ_B are combined quadratically to determine u_c :

$$u_c(\bar{a}) = \sqrt{\mathbf{s}_A^2(\bar{a}) + \mathbf{s}_B^2(\bar{a})} \quad (9)$$

and the recommended value is given by the expression:

$$a = \bar{a} \pm u_c(\bar{a}) \quad (10)$$

(c) Results obtained by different methods

When different measurement techniques have been applied, a weighted average is calculated using the combined uncertainties of the individual values as weights.

For n independent values a_i , each with a combined standard uncertainty u_{ci} , a weight p_i proportional to the inverse of the square of the individual u_{ci} can be assigned to each value.

$$a_w = \frac{\sum_{i=1}^n p_i a_i}{\sum_{i=1}^n p_i} \quad (11)$$

where the weights are $p_i = 1 / u_{ci}^2$.

An internal and an external uncertainty can be assigned to the mean value [2, 3]:

$$\mathbf{s}_{int}(a_w) = \left[\sum_i (1 / u_{ci}^2) \right]^{-1/2} \quad (12)$$

The internal variance $\mathbf{s}_{int}^2(a_w)$ is the expected uncertainty of the mean, based on the individual *a priori* variances u_{ci}^2 (by uncertainty propagation).

The external uncertainty is given by the equation:

$$\mathbf{s}_{ext}(a_w) = \left[\frac{\sum_i (a_i - a_w)^2 / u_{ci}^2}{(n-1) \sum 1 / u_{ci}^2} \right]^{1/2} \quad (13)$$

The external variance $\mathbf{s}_{ext}^2(a_w)$ includes the scatter of the data, and is based on the amount by which each a_i deviates from the mean when measured as a fraction of each given uncertainty u_{c_i} .

A measure of the consistency of the data is given by the ratio [2, 3]:

$$\mathbf{s}_{ext} / \mathbf{s}_{int} = \sqrt{\mathbf{c}^2 / (n-1)} \quad (14)$$

If this ratio is significantly greater than unity, at least one of the input data most probably has an underestimated u_{c_i} which should be increased.

A critical value of $\mathbf{c}^2 / (n-1)$ at 1 % confidence level is used as a practical test for discrepant data. The following table lists critical values of $\mathbf{c}^2 / (n-1)$ for an increasing degree of freedom $\mathbf{n} = n - 1$ [4].

n	critical $\mathbf{c}^2 / (\mathbf{n} - 1)$	n	critical $\mathbf{c}^2 / (\mathbf{n} - 1)$
1	6.6	12	2.2
2	4.6	13	2.1
3	3.8	14	2.1
4	3.3	15	2.0
5	3.0	16	2.0
6	2.8	17	2.0
7	2.6	18-21	1.9
8	2.5	22-26	1.8
9	2.4	27-30	1.7
10	2.3		
11	2.2	>30	$1 + 2.33 \sqrt{2/n}$

If $\mathbf{c}^2 / (n-1) \leq \text{critical } \mathbf{c}^2 / (n-1)$, the recommended value is given by:

$$a = a_w \pm \mathbf{s}_{int}(a_w) \quad (15)$$

If $\mathbf{c}^2 / (n-1) > \text{critical } \mathbf{c}^2 / (n-1)$, the method of limitation of the relative statistical weight [3, 5] is recommended when there are three or more values; uncertainty of a value contributing more than 50 % to the total weight is increased to reduce its contribution to 50 %. The weighted and unweighted average and critical $\mathbf{c}^2 / (n-1)$ are then recalculated:

if $\mathbf{c}^2 / (n-1) \leq \text{critical } \mathbf{c}^2 / (n-1)$, the recommended value is given by:

$$a = a_w \pm (\text{the larger of } \mathbf{s}_{int}(a_w) \text{ and } \mathbf{s}_{ext}(a_w)) \quad (16)$$

if $\mathbf{c}^2 / (n-1) > \text{critical } \mathbf{c}^2 / (n-1)$, the weighted or unweighted mean is chosen, depending on whether or not the uncertainties of the average values make them overlap with each other. If overlap occurs, the weighted average is recommended; otherwise the unweighted average is chosen. In either case, the uncertainty can be increased to cover the most accurate value.

Parameters evaluated according to these procedures and rules include half-lives, number of emitted particles, and some internal-conversion coefficients. All remaining data given in the tables of recommended data are generally taken from compilations.

2.3. Balanced decay schemes

All the probabilities for transitions and emitted radiations correspond to balanced decay schemes and permit the formulation of a fully consistent set of values. This balance implies the fulfillment of physical conservation principles as follows:

- The sum of the transition probabilities for all the transitions (α , β , ε) is equal to 1 (or 100 %); consequently, the sum of all the γ -ray transition probabilities (photons + internal conversion electrons) and all the (α , β , or ε) transitions feeding directly to the ground state is equal to 1 (or 100 %).
- For an excited nuclear level, the sum of the transition probabilities (α , β , γ , ε) feeding the level is equal to the sum of the transition probabilities depopulating this level;
- If the relative γ -ray emission probabilities $P(rel)_{g_i}$ are known, the absolute emission probability $P(abs)_{g_i}$ can be obtained from the equation:

$$P(abs)_{g_i} = P(rel)_{g_i} \times N \quad (17)$$

where N is the normalization factor, which may be determined from the equation:

$$N \sum_i P(rel)_{g_i} (1 + a_{i_i}) = 1 - B, \quad (18)$$

where α_{ti} is the total conversion coefficient, and B , the (α , β , or ε) absolute branching to the ground state. The sum in equation (18) includes all the γ -ray transitions feeding the ground state.

3. COMPILATIONS

3.1. β and electron capture transitions

Depending on the individual radionuclide, the β -particle transition energies are either evaluated from experimental data (maximum β energies), or deduced from the atomic mass differences obtained from the tabulations of Audi and Wapstra [6] and the γ transition energies. The average β -particle energies are generally computed [7], and their $\log ft$ values as well as their ε/β^+ ratios are calculated using the tables of Gove and Martin [8].

Electron-capture transition energies are deduced from atomic mass differences and γ -ray transition energies. Capture probabilities P_K , P_L ... for allowed and non-unique first forbidden transitions can be calculated from equations where the ratios of the radial wave function components of the electron [9-11] and the corrective terms for exchange X^{LK} [12-16] are evaluated from tables.

3.2. γ -ray transitions

Internal conversion coefficients of pure multipolarity transitions are evaluated and compared with theoretical values that are interpolated from the tables of either Rösler *et al.* using a cubic spline method for $30 \leq Z \leq 104$ [17], or Band *et al.* [18]. The agreement of these theoretical values with experimental results is about 3 %.

Internal-conversion coefficients are calculated as described in Ref. [19] in order to include the effects of nuclear penetration in some M1 and E2 transitions.

Internal conversion coefficients for transitions with mixed multiplicities (e.g., M1 + E2) are calculated using tables of theoretical values using mixing ratios as shown below :

$$\alpha_i(\text{M1+E2}) = \alpha_i(\text{M1}) \frac{1}{1+\delta^2} + \alpha_i(\text{E2}) \frac{\delta^2}{1+\delta^2} \quad (19)$$

where $i = \text{K, L1, L2, ... T}$, refers to the individual atomic shell.

a_p coefficients for pair production are interpolated from theoretical values [20], with a precision between 5 % and 10 %.

3.3. Level spins and parities

Level spins and parities are usually from Nuclear Data Sheets [21].

3.4. Atomic shell constants

K-shell fluorescence yields w_K and their uncertainties are taken from the evaluation of Bambynek *et al.* [22-24] with uncertainties ranging from 1 % ($Z > 35$) to 10 % ($Z = 5$), and from subsequent experimental results.

Mean L-shell fluorescence yields \bar{w}_L are taken from the evaluation of Schönfeld and Janßen [25]. This evaluation includes both experimental [26-28] and theoretical values [29], and their uncertainties are equal to 4 % (for $Z > 29$).

Mean M-shell fluorescence yields \bar{w}_M are obtained from the fitting of experimental data by Hubbell [28, 30].

Relative X-ray emission rates (KB/Ka) are taken from Schönfeld and Janßen [25], and Ka_1/Ka_2 from the theoretical values of Scofield [31]; uncertainties are assumed to be of the order of 1 %.

X-ray radiation energies are taken from the tables of Bearden [32].

Relative emission probabilities of K-Auger electron groups are deduced from the X-ray ratio, with uncertainties of the order of 3 % [25].

Energies of the K and L-Auger electrons are taken from Larkins [33].

The mean number of vacancies created in the L shell (from one K hole) n_{KL} and in the M shell (from one L hole) \bar{n}_{LM} are estimated from the preceding values.

3.5. m_0c^2 energy

m_0c^2 energy is defined as 510.998902(21) keV, as given by the CODATA Group [34].

REFERENCES

- [1] Guide to the expression of uncertainty in measurement, ISBN 92-67-20185-X ISO, Geneva, 1993.
- [2] WINKLER, G., "Data fitting and evaluation techniques for radioactive decay data", Proc. Symp. on Nuclear Data Evaluation Methodology, Brookhaven National Laboratory, USA, October 1992, World Scientific, Singapore (1993).
- [3] ZIJP, W.L., On the statistical evaluation of inconsistent measurement results illustrated on the example of the ^{90}Sr half-life, ECN Petten, Report ECN-179 (1985).
- [4] BEVINGTON, P.R., Data Reduction and Error Analysis for the Physical Sciences, Appendix C-4, McGraw-Hill (1969).
- [5] X-ray and gamma-ray standards for detector calibration, IAEA-TECDOC-619, Vienna (1991).
- [6] AUDI, G., WAPSTRA, A.H., The 1995 Atomic Mass Evaluation, Nucl. Phys. **A595** (1995) 4.
- [7] ENSDF – Logfit program, ENSDF analysis and checking codes, Brookhaven National Laboratory, USA.
- [8] GOVE, N.B., MARTIN, M.J., Nucl. Data Tables **A10** (1971) 205.
- [9] SUSLOV, Y.P., Bull. Acad. Sci. USSR Phys. Ser. **33** (1969) 74.
- [10] BEHRENS, H., JANECKE, J., in Landolt-Bornstein: Numerical Data and Functional Relationships in Science and Technology, New Series Group 1, Vol. 4: Numerical Tables for Beta Decay and Electron Capture, Springer-Verlag, Berlin (1969).
- [11] MARTIN, M.J., BLICHERT-TOFT, P.H., Nucl. Data Tables **A8** (1970) 1.
- [12] BAHCALL, J.N., Phys. Rev. **129** (1963) 2683; *ibid.*, Phys. Rev. **132** (1963) 362; *ibid.*, Nucl. Phys. **71** (1965) 267.
- [13] FAESSLER, J.A., HUSTER, E., KRAFFT, O., KRAHN, F., Z. Phys. **238** (1970) 352.
- [14] SUSLOV, Y.P., Bull. Acad. Sci. USSR Phys. Ser. **34** (1970) 91.
- [15] VATAI, E., Nucl. Phys. **A156** (1970) 541.
- [16] SCHÖNFELD, E., Appl. Radiat. Isot. **49** (1998) 1353.
- [17] RÖSEL, F., FRIES, H.M., ALDER, K., PAULI, H.C., At. Data Nucl. Data Tables **21** (1978) 91.
- [18] BAND, I.M., TRZHASKOVSKAYA, M.B., NESTOR Jr., C.W., TIKKANEN, P.O., RAMAN, S., At. Data Nucl. Data Tables **81** (2002) 1.
- [19] PAULI, H.C., RAFF, U., A computer program for international conversion coefficients and particles parameters, Computer Physics Communications **9** (1975) 392.
- [20] SCHLUTER, P., SOFF, G., At. Data Nucl. Data Tables **24** (1979) 509.
- [21] NUCLEAR DATA SHEETS, National Nuclear Data Center, Brookhaven National Laboratory, USA.
- [22] BAMBYNEK, W., CRASEMANN, B., FINK, R.W., FREUND, H.-U., MARK, H., SWIFT, C.D., PRICE, R.E., VENUGOPALA RAO, P., Rev. Mod. Phys. **44** (1972) 716.
- [23] BAMBYNEK, W., Proc. Conf. on X-Ray and Inner Shell Processes in Atoms, Molecules and Solids, 20-24 August 1984, Leipzig, Germany.
- [24] W. BAMBYNEK, "Reorganization of atomic shells after radioactive decay", Proc. 2nd Int. Summer School, Low-level measurements of man-made radionuclides in the environment, June 1990, La Rabida, Huelva, Spain, World Scientific, Singapore (1991) 156-174.
- [25] SCHÖNFELD, E., JANSZEN, H., PTB report Ra-37 (1995).
- [26] MITCHELL, I.V., BARFOOT, K.M., Particle-induced X-Ray Emission Analysis, Application to Analytical Problems, Nucl. Sci. Appl. **1** (1981) 99-162.
- [27] COHEN, D.D., Nucl. Instrum. Meth. Phys. Res. **B22** (1987) 55.
- [28] HUBBELL, J.H., Bibliography and current status of K, L, and higher shell fluorescence yields for computation of photon energy absorption coefficients. NIST internal report 89-4144 (1989).
- [29] PURI, S., MEHTA, D., CHAND, B., SINGH, N., TREHAN, P.N., X-Ray Spectrometry **22** (1993) 358.
- [30] HUBBELL, J.H., TREHAN, P.N., SINGH, N., CHAND, B., MEHTA, D., GARG, M.L., GARG, R.R., SINGH, S., PURI, S., J. Phys. Chem. Ref. Data **23** (1994) 339.
- [31] SCOFIELD, J.H., Phys. Rev. **A9** (1974) 1041.
- [32] BEARDEN, J.A., Rev. Mod. Phys. **39** (1967) 78.
- [33] LARKINS, F.P., At. Data Nucl. Data Tables **20** (1977) 313.
- [34] MOHR, P.J., TAYLOR, B.N., Rev. Mod. Phys. **72** (2000) 351.

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⁷Be - Comments on Evaluation of Decay Data by R. G. Helmer

This evaluation was originally done in 1996 by R. G. Helmer and E. Schönfeld and minor editing was added in December 2000.

1. Decay Scheme

This decay scheme is complete since the only levels in ⁷Li below the decay energy are populated.

2. Nuclear Data

The Q value is from the mass evaluation in 1995Au04.

The adopted half-life is 53.22 (6) days.

The ⁷Be half-life has been observed to vary depending on the chemical form of the ⁷Be. Some of these measured variations are:

Reference	Chemical forms compared	$(\Delta T_{1/2} \times 10^4) / T_{1/2}$
1949Se20	Be - BeO	1.5 (9)
1953Kr16	Be - BeO	1.3 (5)
	BeO- BeF ₂	6.1 (6)
	Be - BeF ₂	7.4 (5)
1956Bo36	Be - BeF ₂	12 (1)
1970Jo21	BeO- BeF ₂	11.3 (6)
	BeO - BeBr ₂	14.7 (6)
	BeO- Be ₄ O(CH ₃ COO) ₆	-7.2 (6)
	BeO- Be(C ₅ H ₅) ₂	8.0 (7)
	BeO- Be(OH ₂) ₄	-3.7 (8)
	BeF ₂ - Be ₄ O(CH ₃ COO) ₆	-18.5 (8)
	Be(C ₅ H ₅) ₂ - Be(OH ₂) ₄	-11.7 (11)
	1999Hu20	BeO - Be(OH) ₂	-149.
	BeO - Be ²⁺ (OH ₂) ₄	-98.
1999Ra12	Be in Au - Be in Al ₂ O ₃	72 (7)

Excluding the much larger changes reported by 1999Hu20 and 1999Ra12, these measured changes range from 0.01% to 0.2%, or from 0.005 to 0.10 days, or 0.08 days, if the organic compounds are also omitted.

The adopted value of 53.22 (6) is from Limitation of Relative Statistical Weight (LRSW) (1985ZiZY, 1992Ra09) analysis of 53 (2) (1940Hi01), 52.93 (22) (1949Se20), 53.61 (17) (1953Kr16), 53.0 (4) (1956Bo36), 53.5 (2) (1957Wr37), 53.1 (3) (1965En01), 53.52 (10) (1970Jo21), 53.0 (3) (1974Cr05), 53.17 (2) (1975La16), 53.16 (1) (1982ChZF), 53.284 (4) (1982RuZV), and 53.12 (7) (1996Ja10). In this analysis the uncertainty of 1982RuZV value was increased from 0.004 to 0.0088 so that its relative

weight was reduced from 83 % to 50 %. The weighted average of these values is 53.225 with an internal uncertainty of 0.006, a reduced- χ^2 of 10.5, and an external uncertainty of 0.020. This uncertainty is increased by the LRSW method to 0.06 so that the most precise value of 53.284 is included; this uncertainty also includes the next most precise value of 53.16.

The chemical forms of the samples for which these half-lives were determined are: 1949Se20 Be metal or BeO and difference is not significant, 1953Kr16 Be metal, 1956Bo36 Be metal or BeF₂ and difference is not significant, 1970Jo21 average of data for BeF₂, BeO, and Be(C₅H₅)₂, and 1975La16 isolated Be atoms in aluminum matrix.

The adopted half-life is dominated by the values of 1975La16, 1982ChZF, and 1982RuZV which contribute 10 %, 39 %, and 50 % of the relative weight, respectively. The values of 1982ChZF and 1982RuZV differ by $\sim 10\sigma$ and contribute 3.8 and 4.1 to the reduced- χ^2 value of 10.5. Since these three values differ by 0.12 days and the chemical forms in the latter two cases are not known, the chemical variation data in the above table suggest that some of this difference may be due to chemical effects. This suggests that the adopted uncertainty of 0.06 days is reasonable for general use. In any case, the data on the chemical effects indicate that the adopted value can certainly be used for Be and BeO sources.

Values not used are 54.5 (J. F. Bonner as quoted in 1953Kr16, no uncertainty); and 54.3 (5) (1947BoAA as quoted in 1953Kr16, superseded by value of 1956Bo36); and 53.694 (6), 53.416 (6), and 54.226 (6) (1999Hu20). The values of 1999Hu20 have very small uncertainties and have very large variations, up to 1.5%, with chemical form which need to be confirmed. If this large shift and that of 1999Ra12 are correct, they would invalidate the uncertainty of our adopted value.

Also, the results of 2000Hu20 and 2000Li21 were obtained after this evaluation was completed, but these results would not change the adopted value.

Recent experiments have shown that the half-life of ⁷Be increases as much as 0.7% by imbedding this radionuclide in different matrices. The recommended value presented in this evaluation should be adequate for Be and BeO samples.

2.1 Electron-capture transitions

The adopted value for the electron capture to the 477-keV level is $P_{\epsilon}(477) = 10.44\%$ (4). This value is a weighted average of 10 (+20-7) (1938RuAA), 10.7 (20) (1949Wi13), 11.8 (12) (1949Tu06), 12.3 (6) (1951Di12), 10.35 (8) (1969TaZX), 10.47 (20) (1970MuZU), 10.42 (18) (1973Po10), 10.35 (8) (1974Go26), 10.10 (45) (1983Ba15), 10.61 (23) (1983Da14), 10.6 (5) (1983Do07), 10.9 (11) (1983Kn10), 10.7 (2) (1983Ma34), 9.8 (5) (1983No03), 11.4 (7) (1984Ev01), 10.61 (17) (1984Fi10), and 10.49 (7) (1984Sk01). This weighted average has an internal uncertainty of 0.039, a reduced- χ^2 of 1.35, and an external uncertainty of 0.045. The adopted value is dominated by the values of 1969TaZX, 1974Go24, and 1984Sk01 which contribute 23 %, 23 %, and 30 % of the relative weight, respectively. The largest contribution to the reduced- χ^2 is 0.6 from 1951Di12.

Values not used are 10.32 (16) (1962Ta11, superseded by 1969TaZX) and 10.5 (2) (W. Poenitz, 1966, superseded by 1973Po10).

The P_K and P_L values of 0.908 (12) and 0.092 (12) were calculated from the tables in 1998Sc28. The values from the LOGFT code are 0.97 and 0.03, which are different.

2.2 Gamma-ray transition

The γ -ray transition energy is computed from the γ -ray energy.

The internal-conversion coefficient is the measured value of 1964Kr04 and the mixing ratio was also determined by 1964Kr04. The theoretical values interpolated from the tables of 1976Ba63 are 7.73×10^{-7} for M1 and 2.96×10^{-6} for E2.

The gamma transition probability is :

Within its uncertainty, $P_\gamma(477) = I_\gamma(477) \times (1.0 + \alpha) = P_\epsilon(477)$

With $I_\gamma(477) = 10.44$ (4) % (c.f. § 2.1)

3. Atomic Data

The fluorescence yield is from the compilation of 1994Hu23.

4. Radiations

The conversion electron emission intensity is computed from $P_\gamma(477)$ and α_K .

The γ -ray energy is from the evaluation of 2000He14.

5. Main Production Modes

⁶Li(d,n), ¹⁰B(p, α), and ¹²C(³He,2 α)

6. References

- 1938RuAA L. H. Rumbaugh, R. B. Roberts, L. R. Hafstad, Phys. Rev. **54** (1938) 657 [P _{ϵ}]
 1940Hi01 J. E. Hill, Phys. Rev. **57** (1940) 567 [T_{1/2}]
 J. F. Bonner, Jr., report AECU-107, as quoted in 1953Kr16 [T_{1/2}]
 1947BoAA P. Bouchez, Daudel, Muxart, J. Phys. et Radium **8** (1947) 336, as quoted in 1953Kr16 [T_{1/2}]
 1949Se20 E. Segre, C. E. Wiegand, Phys. Rev. **75** (1949) 39; erratum Phys. Rev. **81** (1951) 284 [T_{1/2}]
 1949Tu06 C. M. Turner, Phys. Rev. **76** (1949) 148 [P _{ϵ}]
 1949Wi13 R. M. Williamson, H. T. Richards, Phys. Rev. **76** (1949) 614 [P _{ϵ}]
 1951Di12 J. M. Dickson, T. C. Randle, Proc. Phys. Soc. (London) **64A** (1951) 902 [P _{ϵ}]
 1953Kr16 J. J. Kraushaar, E. D. Wilson, K. T. Bainbridge, Phys. Rev. **90** (1953) 610 [T_{1/2}]
 1956Bo36 P. Bouchez, J. Tobailem, J. Robert, R. Muxart, R. Mellet, P. Daudel, J. Phys. Rad. **17** (1956) 363 [T_{1/2}]
 1957Wr37 H. W. Wright, E. I. Wyatt, S. A. Reynolds, W. S. Lyon, T. H. Handley, Nucl. Sci. Eng. **2** (1957) 427 [T_{1/2}]
 1962Ta11 J. G. V. Taylor, J. S. Merritt, Can. J. Phys. **40** (1962) 926 [P _{ϵ}]
 1964Kr04 A. Kriester, Kernenergie **7** (1964) 748 [α]
 1965En01 J. B. A. England, B. L. Reece, Nucl. Phys. **72** (1965) 449 [T_{1/2}]
 1966PoAA W. Poenitz, J. Nucl. Energy **20** (1966) 825 [P _{ϵ}]
 1969TaZX J. G. V. Taylor, J. S. Merritt, report AECL-3512 (1969) [P _{ϵ}]
 1970MuZU M. Mutterer, Neutron Standards and Flux Normalization 452, AEC Symp. Series 23 (1970) [P _{ϵ}]

- 1970Jo21 H. W. Johlige, D. C. Aumann, H. J. Born, Phys. Rev. **C2** (1970) 1616 [$T_{1/2}$]
 1973Po10 W. P. Poenitz, A. Devolpi, Intern. J. Appl. Radiat. Isot. **24** (1973) 471 [P_{ϵ} , P_{γ}]
 1974Cr05 P. J. Cressy, Jr., Nucl. Sci. Eng. **55** (1974) 450 [$T_{1/2}$]
 1974Go26 I. W. Goodier, J. L. Makepeace, A. Williams, Intern. J. Appl. Radiat. Isot. **25** (1974) 373 [P_{ϵ} , P_{γ}]
 1975La16 F. Lagoutine, J. Legrand, C. Bac, Intern. J. Appl. Radiat. Isot. **26** (1975) 131 [$T_{1/2}$]
 1976Ba63 I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, At. Data Nucl. Data Tables **18** (1976) 433 [α]
 1982ChZF P. Christmas, report NBS-SP-626 (1982) 100 & 198 [$T_{1/2}$]
 1982RuZV A. R. Rutledge, L. V. Smith, J. S. Merritt, report NBS-SP-626 (1982) 5 [$T_{1/2}$]
 1983Da14 C. N. Davids, A. J. Elwyn, B. W. Filippone, S. B. Kaufman, K. E. Rehm, J. P. Schiffer, Phys. Rev. C **28** (1983) 885 [P_{ϵ}]
 1983Ba15 D. P. Balamuth, L. Brown, T. E. Chapuran, J. Klein, R. Middleton, R. W. Zurmühle, Phys. Rev. C **27** (1983) 1724 [P_{ϵ}]
 1983Do07 T. R. Donoghue, E. Sugarbaker, M. Wiescher, T. C. Rinckel, K. E. Sale, C. P. Browne, E. D. Berners, R. W. Tarara, R. E. Warner, Phys. Rev. C **28** (1983) 875 [P_{ϵ}]
 1983Kn10 D. A. Knapp, A. B. McDonald, C. L. Bennett, Nucl. Phys. **A411** (1983) 195 [P_{ϵ}]
 1983Ma34 G. J. Mathews, R. C. Haight, R. G. Lanier, R. M. White, Phys. Rev. C **28** (1983) 879 [P_{ϵ}]
 1983No03 E. B. Norman, T. E. Chupp, K. T. Lesko, J. L. Osborne, P. J. Grant, G. L. Woodruff, Phys. Rev. C **27** (1983) 1728; erratum Phys. Rev. C **28** (1983) 1409 [P_{ϵ}]
 1984Ev01 H. C. Evans, I. P. Johnstone, J. R. Leslie, W. McLatchie, H.-B. Mak, P. Skensved, T. K. Alexander, Can. J. Phys. **62** (1984) 1139 [P_{ϵ}]
 1984Fi10 S. A. Fisher, R. L. Hershberger, Nucl. Phys. **A423** (1984) 121 [P_{ϵ}]
 1984Sk01 R. T. Shelton, R. W. Kavanagh, Nucl. Phys. **A414** (1984) 141 [P_{ϵ}]
 1985ZiZY W. L. Zijp, report ECN-179 (1985) [averaging]
 1992Ra09 M. U. Rajput, T. D. MacMahon, Nucl. Instr. Meth. **A312** (1992) 289 [averaging]
 1994Hu23 J. H. Hubbell, P. N. Trehan, Nirmal Singh, B. Chand, M. L. Garg, R. R. Garg, Surinder Singh, S. Puri, J. Phys. Chem. Ref. Data **23** (1994) 339 [ω_K]
 1995Au04 G. Audi, A. H. Wapstra, Nucl. Phys. **A595** (1995) 409 [Q]
 1996Ja10 M. Jaeger, S. Wilmes, V. Kölle, G. Staudt, P. Mohr, Phys. Rev. C **54** (1996) 423 [$T_{1/2}$]
 1998Sc28 E. Schönfeld, Appl. Radiat. Isot. **49** (1998) 1353 [P_L/P_K]
 1999Hu20 C.-H. Huh, Earth Plant. Sci. Lett. **171** (1999) 325 [$T_{1/2}$]
 1999Ra12 A. Ray, P. Das, S. K. Saha, S. K. Das, B. Sethi, A. Mookerjee, C. Basu Chauduri, G. Pari, Phys. Lett. B **455** (1999) 69 [$T_{1/2}$]
 2000He14 R. G. Helmer, C. van der Leun, Nucl. Instr. Meth. A **450** (2000) 35 [E_{γ}]
 2000Hu20 C. A. Huh, L. G. Liu, Journal of Radioanalytical and Nuclear Chemistry **246** (2000) 229 [$T_{1/2}$]
 2000Li21 L. G. Liu, C. A. Huh, Earth and Planetary Science Letters **180** (2000) 163 [$T_{1/2}$]

¹¹C – Comments on evaluation of decay data by V. Chisté and M. M. Bé

1) Decay Scheme

¹¹C disintegrates by β^+ emission (99.750(13)%) and electron capture (0.250(13)%) to the ground state of the stable nuclide ¹¹B.

2) Nuclear Data

The Q value (1982.5(9) keV) is from Audi and Wapstra evaluation (1995Au04), and has been calculated with the formula:

$$Q = M(A, Z) - M(A, Z - 1),$$

where $M(A, Z)$ and $M(A, Z-1)$ are the measured atomic masses of ¹¹C and ¹¹B, respectively.

E_{β^+} , calculated from this Q value ($E_{\beta^+} = 960.5(9)$ keV), is in agreement with a weighted average value of 959.8(5) keV, which was calculated from measured values (see **b⁺ Transition and Electron Capture Transition**).

The measured ¹¹C half-life values (in minutes) are given below:

$T_{1/2}$

Reference	Value (min)
Smith (1941Sm11)	20.35 (8)
Solomon (1941So01)	20.5 (6)
Siegbahn (1944Si30)	20.0(4)
Dickson (1951Di12)	20.0 (1)
Kundu (1953Ku08)	20.74 (10)
Barber (1955Ba63)	20.26 (10)
Prokoshkin (1957Pr53)	20.8 (2)
Arnell (1958Ar15)	20.11 (13)
Kavanagh (1964Ka31)	20.34 (4)
Patterson (1965Pa10)	20.8 (4)
Awschalom (1969Aw02)	20.40 (4)
Hogstrom (1973Ho43)	19.8 (8)
Singh (1973SiYS)	20.0 (3)
Azuelos (1975Az01)	20.382 (20)
Behrens (1975Be28)	20.32 (12)

Evaluators calculated the weighted average of these 15 values using the Lweight program (version 3) as 20.369 min with an external uncertainty of 0.028 and a reduced χ^2 of 3.07. The value of Azuelos (1975Az01) has a relative statistical weight of 54%. Evaluators rejected Siegbahn's (1944Si30) value (quoted by Janecke (1960Ja12) and Raman (1978Ra21)), because they could not find the article, and therefore no details were available on how Siegbahn obtained such a value. For the remaining 14 values,

the largest contribution to the weighted average comes from the value of Azuelos (1975Az01), with a relative statistical weight of 57%. The program Lweight 3 has increased the uncertainty of the 1975Az01 value from 0,02 to 0,0231 in order to reduced its relative statistical weight to 50%. The adopted value is the weighted average : 20.370 min, with an external uncertainty of 0.029 min. The reduced χ^2 is 3.24.

b⁺ Transition and Electron capture transition

For the K/ β^+ ratio, the following values have been found in the literature:

Reference	Value (10 ⁻³)
Scobie (1957Sc02)	1.9(3)
Campbell (1967Ca21)	2.30 (+0.14;-0.11)

β^+ and electron capture probabilities have been calculated using the most recent value of K/ β^+ ratio measured by Campbell (1967Ca21), $P_K/P_{EC} = 0.9174(91)$ (See Section 2.2), and normalizing to a total probability ($P_{\beta^+} + P_{EC}$) of 100%. This leads to $P_{\beta^+} = 99.750(13) \%$ and $P_{EC} = 0.250(13)$, respectively. The uncertainties were calculated through their propagation on the above formulas.

The experimental K/ β^+ ratio of Campbell is close to the theoretical values:

- a) 2.222 10⁻³ calculated with LOGFT program;
- b) 2.00 10⁻³ calculated by Scobie (1957Sc02);
- c) 2.18 10⁻³ calculated by Campbell (1967Ca21);
- d) 2.46 10⁻³ calculated by Vatai (1968Va23);
- e) 2.316 10⁻³ given by Fitzpatrick (1973Fi13);
- f) 2.11 10⁻³ given by Bambynek (1977Ba49);

Evaluators calculated a lg ft of 3.592 for this allowed transition. The value agrees with 3.599 suggested by Ajzenberg-Selove (1980Aj01, 1985Aj01 and 1990Aj01).

The partial sub shell capture probabilities given in Section 2.2 were calculated using the program EC-Capture for an allowed transition.

The weighted mean of the β^+ end-point energy has been calculated (with the Lweight program, version 3) using the following measured values (in keV):

Reference	Values (keV)
Townsend (1940To03)	981(5)
Moore (1940Mo40)	1030(30)
Siegbahn(1944Si30)	993(1)
Richards (1950Ri07)	958(3)
Wong (1954Wo19)	968(8)
Campbell (1967Ca21)	958.2(14)
Fitzpatrick (1973Fi13)	960.2(10)
Azuelos (1975Az01)	960.0(10)
Behrens (1978Be28)	960.8(26)
Raman (1978Ra21)	960.1(11)

The weighted average of these 10 values is 967 keV with an uncertainty of 2.6 keV and a reduced χ^2 of 97. The values of 1944Si30, 1973Fi13 and 1975Az01 have a relative weight of 21%. The Townsend (1940To03), Moore (1940Mo40), Siegbahn (1944Si30) and Wong (1954Wo19) values have been rejected by the Lweight program, based on the Chauvenet's criterion. For the remaining 6 values, the largest contribution to the weighted average comes from the values of Fitzpatrick (1973Fi13) and Azuelos

(1975Az01), amounting to a statistical weight of 28%. The weighted average is 959.8 keV, with an internal uncertainty of 0,5 keV and a reduced χ^2 of 0,41. This value is in agreement with E_{β^+} (960.5(9) keV) deduced from the adopted Q value (1995Au04) in this evaluation.

3) Gamma-ray Emissions

The annihilation radiation emission probability ($I_{\gamma 511}$) is P_{β^+} (=99.750(13)%), multiplied by 2, without the correction factor for the annihilation-in-flight process in the medium. That is, $I_{\gamma 511} = 199.500(26)\%$.

References

- 1940Mo40 – B. L. Moore, Phys. Rev. 57 (1940) 355 [end-point energy].
 1940To03 – A. A. Townsend, Proc. Roy. Soc. (London) 177 (1940) 357 [end-point energy].
 1941Sm11 – J. H. C. Smith, D. B. Cowie, J. Appl. Phys. 12 (1941) 78 [$T_{1/2}$].
 1941So01 – A. K. Solomon, Phys. Rev. 60 (1941) 279 [$T_{1/2}$].
 1944Si30 – Siegbahn, Arkiv Mat. Astron. Fysik 30B (1944) 20 [$T_{1/2}$].
 1950Ri07 – H. T. Richards, R. V. Smith, Phys. Rev. 77 (1950) 752 [end-point energy].
 1951Di12 – J. M. Dickson, T. C. Randle, Proc. Phys. Soc. (London) 64A (1951) 902 [$T_{1/2}$].
 1953Ku08 – D. N. Kundu, T. W. Donaven, M. L. Pool, J. K. Long, Phys. Rev. 89 (1953) 1200 [$T_{1/2}$].
 1954Wo19 – C. Wong, Phys. Rev. 95 (1954) 765 [end-point energy].
 1955Ba63 – W. C. Barber, W. D. George, D. D. Reagan, Phys. Rev. 98 (1955) 73 [$T_{1/2}$].
 1957Pr53 – Iu. D. Prokoshkin, A. A. Tiapkin, Soviet. Phys. JETP 5 (1957) 148 [$T_{1/2}$].
 1957Sc02 – J. Scobie, G. M. Lewis, Phil. Mag. 2 (1957) 1089 [K/β^+ ratio].
 1958Ar15 – S. E. Arnell, J. Dubois, O. Almen, Nucl. Phys. 6 (1958) 196 [$T_{1/2}$].
 1960Ja12 – V. J. Janecke, Z. F. Naturf. 15A (1960) 593 [$T_{1/2}$].
 1964Ka31 – T. M. Kavanagh, J. K. P. Lee, W. T. Link, Can. J. Phys. 42 (1964) 1429 [$T_{1/2}$].
 1965Pa10 – J. R. Patterson, J. M. Poate, E. W. Tuttert, B. A. Robson, Proc. Phys. Soc. (London) 86 (1965) 1297 [$T_{1/2}$].
 1967Ca21 – J. L. Campbell, W. Leiper, K. W. Ledingham, R. W. P. Drever, Nucl. Phys. A96 (1967) 279 [K/β^+ ratio, end-point energy].
 1968Va23 – E. Vatai, Proc. Conf. Electron Capture and higher order processes in Nucl. Decay 2 (1968) 71 [K/β^+ ratio].
 1969Aw02 – M. Awschalom, F. L. Larsen, W. Schimmerling, Nucl. Inst. Meth. 75 (1969) 93 [$T_{1/2}$].
 1973Ho43 – K. R. Hogstrom, B. W. Mayes, L. Y. Lee, J. C. Allred, C. Goodman, G. S. Mutchler, C. R. Fletcher, G. C. Phillips, Nucl. Phys. A215 (1973) 598 [$T_{1/2}$].
 1973SiYS – J. Singh, Proc. Nucl. Phys. and Solid State Phys. Symp. 15B (1972) 1 [$T_{1/2}$].
 1973Fi13 – M. L. Fitzpatrick, K. W. D. Ledingham, J. Y. Gourlay, J. G. Lynch, J. Phys. A6 (1973) 713 [K/β^+ ratio, end-point energy].
 1975Az01 – G. Azuelos, J. E. Kitching, K. Ramavataram, Phys. Rev. C12 (1975) 563 [$T_{1/2}$, end-point energy].
 1975Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A248 (1975) 1 [$T_{1/2}$, end point energy, Q, log ft].
 1975Be28 – H. Behrens, M. Kobelt, L. Szybisz, W. G. Thies, Nucl. Phys. A246 (1975) 317 [$T_{1/2}$, end-point energy].
 1977Az01 – G. Azuelos, J. E. Kitching, K. Ramavataram, Phys. Rev. C15 (1977) 1847 [$T_{1/2}$].
 1977Ba49 – W. Bambynek, H. Behrens, M. H. Chen, B. Crasemann, M. L. Fitzpatrick, K. W. D. Ledingham, H. Genz, M. Muttere, R. L. Intemann, Revs. Modern Phys. 49 (1977) 77 [Electron Capture].
 1978Ra21 – S. Raman, C. A. Houser, T. A. Walkiewicz, I. S. Towner, Atomic Data and Nucl. Data Tables 21 (1978) 567 [$T_{1/2}$, end point energy, Q, log ft].
 1980Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A336 (1980) 1 [$T_{1/2}$, Q, log ft].
 1985Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A433 (1985) 1 [$T_{1/2}$, Q, log ft].
 1990Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A506 (1990) 1 [$T_{1/2}$, Q, log ft, end-point energy].
 1995Au04 – G. Audi, A.H. Wapstra, Nucl. Phys. A595 (1995) 409 [Q].
 2000Co21 – Codata Group, Revs. Modern Phys. 72 (2000) 351 [m_0c].

¹³N – Comments on evaluation of decay data by V. Chisté and M. M. Bé

1) Decay Scheme

¹³N disintegrates by β^+ emission (99,818 (13) %) and electron capture (0,182 (13) %) to the ground state of the stable nuclide ¹³C.

2) Nuclear Data

The Q value (2220,44 (27) keV) is from the evaluation of Audi and Wapstra (1995Au04), and has been calculated using the formula:

$$Q = M(A, Z) - M(A, Z - 1),$$

where M(A,Z) and M(A,Z-1) are the measured atomic masses of ¹³N and ¹³C, respectively.

The E_{β^+} deduced from this Q value ($E_{\beta^+} = 1198,45$ (27) keV) agrees with the weighted average value of 1199,00 (36) keV, deduced from measured values (see § **b⁺ Transition and Electron Capture Transition**).

The measured ¹³N half-life values (in minutes) are given below:

$T_{1/2}$

Reference	Value (min)
Ward (1939Wa35)	9,93 (3)
Siegbahn (1945Si02)	10,13 (10)
Cook (1948Co05)	10,2 (1)
Churchill(1953Ch34)	10,048 (32)
Wilkinson (1955Wi43)	10,08 (4)
Daniel (1957Da07)	9,960 (30)
Deineko (1957De22)	10,02 (10)
Norbeck (1957No17)	10,07 (6)
Arnell (1958Ar15)	9,960 (30)
King (1960Ki02)	9,93 (5)
Janecke (1960Ja12)	9,965 (5)
Ebrey (1965Eb03)	9,96 (2)
Bormann (1965Bo42)	10,05 (5)
Ritchie (1968Ri15)	9,963 (9)
Singh (1973SiYS)	10,0 (5)
Azuelos (1977Az01)	9,965(10)
Katoh (1989Ka08)	9,962 (20)

The weighted average has been calculated using the Lweight computer program (version 3).

The Siegbahn (1945Si02) and Cook (1948Co05) values have been shown to be outliers by the Lweight program, based on the Chauvenet's criterion. For the remaining 15 statistically consistent values, the largest contribution to the weighted average comes from the value of Janecke (1960Ja12), with statistical weight of 54 %. The reduced- χ^2 is 1,65.

The adopted value is the weighted average : 9,9670 min, with an uncertainty of 0,0037min.

2.1) β^+ Transition and Electron capture transition.

The β^+ and electron capture probabilities shown in Tables 2.1 and 2.2, respectively, have been deduced by using a K/β^+ ratio of $(1,68 \pm 0,12) \cdot 10^{-3}$ measured by Ledingham (1963Le06) and, normalizing to a total probability ($P_{\beta^+} + P_{EC}$) of 100%. This experimental K/β^+ ratio is close to the following theoretical values:

- 1,864 10^{-3} calculated with LOGFT program;
- 1,939 10^{-3} calculated by Fitzpatrick (1973Fi13);
- 1,800 10^{-3} given by Bambynek (1977Ba49);
- 1,78 10^{-3} given by Ledingham (1963Le06).

The uncertainties were estimated by standard error-propagation techniques.

The $lg ft$ value for β^+ transition (3,654) has been calculated with the program LOGFT for an allowed transition. This value agrees with 3,637 suggested by Ajzenberg-Selove (1981Aj01, 1986Aj01 and 1991Aj01).

The partial sub shell capture probabilities P_K and P_L were calculated for an allowed transition using the computer program EC-Capture.

A weighted average (1199,0(4) keV) of the β^+ end-point energy has been deduced (using the Lweight computer program, version 3) from the following measured values (in keV):

Reference	Values (keV)
Hornyak (1950Ho01)	1202 (5)
Grabowsky (1954Gr03)	1185 (25)
Daniel (1957Da07)	1190 (3)
Fitzpatrick (1973Fi13)	1198,5(9)
Raman (1978Ra21)	1198,7 (4)

The largest contribution (with an statistical weight of 81%) to the weighted average of these 5 values comes from the value of Raman (1978Ra21). The weighted average is 1199,00 keV, with an internal uncertainty of 0,36 and a reduced- χ^2 of 2,2. This value agrees with E_{β^+} (1198,45(27) keV), which was deduced from the adopted Q value (1995Au04) in this evaluation.

3) Gamma-ray Emissions

The annihilation radiation emission intensity ($I_{\gamma 511}$) is P_{β^+} (= 99,818 (13)), multiplied by 2, without the correction factor for the annihilation-in-flight processus in the medium. That is, $I_{\gamma 511} = 199,636$ (26) %.

4) Atomic Data

Atomic K-fluorescence yield (ω_K) is from Bambynek (1984Ba01).

References

- 1939Wa35 – W. Ward, Proc. Cambridge Phil. Soc. 35 (1939) 523 [$T_{1/2}$].
- 1945Si02 – S. Siegbahn, Arkiv F. Art. Mat. Fys. 32A (1945) 9 [$T_{1/2}$].
- 1948Co05 – C. S. Cook, L. M. Langer, C. Price Jr., M. B. Sampson, Phys. Rev. 74 (1948) 502 [$T_{1/2}$].
- 1950Ho01 – B. Hornyak, Phys. Rev. 77 (1950) 160 [end-point energy].
- 1952Aj01 – F. Ajzenberg, Rev. Mod. Phys. 24 (1952) 321 [$T_{1/2}$, end-point energy, log ft].
- 1953Ch34 – J. L. W. Churchill, W. M. Jones, S. E. Hunt, Nature 172 (1953) 460 [$T_{1/2}$].
- 1954Gr03 – N. Grabowsky, Bull. Acad. Pol. Sci. 2 (1954) 379 [end-point energy].
- 1955Wi43 – D. H. Wilkinson, Phys. Rev. 100 (1955) 32 [$T_{1/2}$].
- 1955Aj01 – F. Ajzenberg, Rev. Mod. Phys. 27 (1955) 27 [$T_{1/2}$, end-point energy, log ft].
- 1957No17 – E. Norbeck Jr., C. S. Littlejohn, Phys. Rev. 108 (1957) 754 [$T_{1/2}$].
- 1957De22 – S. Deineko, A. Ia. Taranov, A. K. Valter, Sov. Phys. - JETP 5 (1957) 201 [$T_{1/2}$].
- 1957Da07 – H. Daniel, U. Schmidt-Rohr, Z. Naturforsch 12A (1957) 750 [$T_{1/2}$].
- 1958Ar15 – S. E. Arnell, J. Dubois, O. Almen, Nucl. Phys. 6 (1958) 196 [$T_{1/2}$].
- 1958St30 – D. Strominger, J. L. Hollander, G. T. Seaborg, Rev. Mod. Phys. 30 (1958) 585 [$T_{1/2}$, end point energy, Q, log ft].
- 1960Ki02 – J. D. King, R. N. H. Haslam, R. W. Parsons, Can. J. Phys. 38 (1960) 231 [$T_{1/2}$].
- 1960Ja12 – V. J. Janecke, Z. F. Naturf. 15A (1960) 593 [$T_{1/2}$].
- 1963Le06 – K. W. D. Ledingham, J. A. Payne, R. W. P. Drever, Proc. Int. Conf. Role of Atomic Electrons in Nuclear Transformations 2 (1963) 359 [K/ β^+ ratio].
- 1965Eb03 – T. G. Ebrey, P. R. Gray, Nucl. Phys. 61 (1965) 479 [$T_{1/2}$].
- 1965Bo42 – M. Bormann, E. Fretwurst, P. Schehka, G. Wrege, Nucl. Phys. 63 (1965) 438 [$T_{1/2}$].
- 1968Va23 – E. Vatai, Proc. Conf. Electron Capture and higher order processes in Nucl. Decay 2 (1968) 71 [K/ β^+ ratio].
- 1968Ri15 – A. I. M. Ritchie, Nucl. Inst. Meth. 64 (1968) 181 [$T_{1/2}$].
- 1973SiYS – J. Singh, Proc. Nucl. Phys. and Solid State Phys. Symp. 15B (1972) 1 [$T_{1/2}$].
- 1973Fi13 – M. L. Fitzpatrick, K. W. D. Ledingham, J. Y. Gourlay, J. G. Lynch, J. Phys. A6 (1973) 713 [K/ β^+ ratio].
- 1976Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A268 (1976) 1 [$T_{1/2}$, Q, log ft].
- 1977Az01 – G. Azuelos, J. E. Kitching, K. Ramavataram, Phys. Rev. C15 (1977) 1847 [$T_{1/2}$].
- 1977Ba49 – W. Bambynek, H. Behrens, M. H. Chen, B. Crasemann, M. L. Fitzpatrick, K. W. D. Ledingham, H. Genz, M. Muttere, R. L. Intemann, Revs. Modern Phys. 49 (1977) 77 [Electron Capture].
- 1978Ra21 – S. Raman, C. A. Houser, T. A. Walkiewicz, I. S. Towner, Atomic Data and Nucl. Data Tables 21 (1978) 567 [$T_{1/2}$, end point energy, Q, log ft].
- 1981Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A360 (1981) 1 [$T_{1/2}$, Q, log ft].
- 1984Ba01 – W. Bambynek, Proc. X-ray and Inner-Shell Processes in Atoms, Molecules and Solids, Leipzig, Aug. 20-23, 1984. Edited by A. Meisel [Atomic Data]
- 1986Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A449 (1986) 1 [$T_{1/2}$, Q, log ft].
- 1989Ka08 – T. Katoh, K. Kawade, H. Yamamoto, JAERI-M-089-083 (1989) [$T_{1/2}$]
- 1991Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A523 (1991) 1 [$T_{1/2}$, Q, log ft].
- 1995Au04 – G. Audi, A.H. Wapstra, Nucl. Phys. A595 (1995) 409 [Q].
- 2000Co21 – Codata Group, Revs. Modern Phys. 72 (2000) 351 [m_0c].

¹⁵O – Comments on evaluation of decay data by V. Chisté and M. M. Bé

1) Decay Scheme

¹⁵O disintegrates by β^+ emission (99,885 (6) %) and electron capture (0,115 (6) %) to the ground state of the stable nuclide ¹⁵N.

2) Nuclear Data

The Q value has been calculated using the formula:

$$Q = E_{\beta^+} + 2m_0c^2 = 2757,0 (13) \text{ keV}$$

where $E_{\beta^+} = 1735,0 (13) \text{ keV}$ is the weighted mean of the β^+ end-point energy (see **b⁺ Transition and Electron Capture**) and, $2m_0c^2 = 1021,9978 (42) \text{ keV}$ (2000Co21). The Q value calculated here is in agreement with the value of 2754,0 (5) from the Audi and Wapstra evaluation (1995Au04), which takes into account only Raman's value (1978Ra21, 1731,9 (7) keV) to determine the recommended Q value.

The measured ¹⁵O half-life values are, in seconds:

T_{1/2}

Reference	Value (sec)
McMillan (1935Mc02)	126 (5)
Brown (1950Br29)	118,0 (6)
Kline (1954Kl36)	123,4 (13)
Bashkin(1955Ba83)	121 (3)
Kistner (1957Ki22)	122 (5)
Penning (1957Pe12)	123,95 (50)
Kistner (1959Ki99)	124,1 (5)
Janecke (1960Ja12)	122,1 (1)
Nelson (1963Ne05)	122,6 (10)
Csikai (1963Cs02)	125 (2)
Vasil'ev (1963Va23)	114 (12)
Azuolos (1977Az01)	122,23(23)

The half-life weighted average has been calculated by the Lweight program (version 3).

The weighted average of all 12 values is 122,16 s with an internal uncertainty of 0,09 and a reduced- χ^2 of 7,3. The value of 1960Ja12 has a relative weight of 76% and that of 1950Br29 contributes 4,4 to the reduced- χ^2 .

The evaluator has chosen to reject the McMillan (1935Mc02) and Csikai (1963Cs02), because they are far from the other values and with large uncertainties.

The Brown (1950Br29) and Vasil'ev (1963Va23) values have been rejected by the Lweight program, based on the Chauvenet's criterion. For the remaining 8 values, the largest contribution to the weighted average comes from the value of Janecke (1960Ja12), amounting to a statistical weight of 78% (reduced-

$\chi^2 = 4,01$). The program Lweight 3 has increased the uncertainty of the 1960Ja12 value from 0,1 to 0,186 in order to reduce its relative weight from 78% to 50%.

The adopted value is the weighted mean : 122,40 s, with an uncertainty of 0,33; or 2,041 (6) min. The reduced- χ^2 is 3,2.

2.1) β^+ Transition and Electron capture

The β^+ and electron capture probabilities have been calculated taking into account a K/β^+ ratio of $(1,07 \pm 0,06) \cdot 10^{-3}$ measured by Leiper (1972Le06) and, normalizing to a total probability ($P_{\beta^+} + P_{EC}$) of 100%. The experimental K/β^+ ratio is close of its theoretical value ($= 0,99(1) \cdot 10^{-3}$) calculated with the LOGFT program. The uncertainties were calculated through their propagation on the above formulas.

The value of $\log ft$ of the β^+ transition (3,6) has been calculated with the program LOGFT for an allowed transition, in agreement with the value suggested by Ajzenberg-Selove, which is 3,637 (1981Aj01, 1986Aj01 and 1991Aj01).

The partial sub shell capture probabilities were calculated with the program EC-Capture for an allowed transition.

The weighted mean of the β^+ end-point energy has been calculated (with the Lweight program, version 3) using the following measured values (in MeV):

Reference	Values (MeV)
Fowler (1936Fo16)	1,7 (2)
Stephens (1937St03)	1,56 (20)
Perez-Mendez (1949Pe23), Brown (1950Br29)	1,683 (5)
Kington (1955Ki39)	1,735 (8)
Kistner (1957Ki22) (solid target)	1,723 (5)
Kistner (1957Ki22) (gaseous target)	1,736 (10)
Kistner (1959Ki99)	1,739 (2)
Raman (1978Ra21)	1,7319 (7)

The values given by Fowler (1936Fo16), Stephens (1937St03), Perez-Mendez (1949Pe23) and Kistner (1957Ki22 – solid target) were shown (by the Lweight program) to be statistically inconsistent with the other values (based on the Chauvenet's criterion), thus the evaluators rejected those 4 values. The largest contribution to the weighted average of the 4 remaining values comes from the value of Raman (1978Ra21), amounting to a statistical weight of 88% (reduced- $\chi^2 = 3,8$). The program Lweight 3 has increased the uncertainty of the 1978Ra21 value from 0,0007 to 0,0019 in order to reduce its relative weight from 88% to 50%.

The adopted value is the weighted mean : 1735,0 keV, with an external uncertainty of 1,3 and a reduced- χ^2 of 2,2.

3) Gamma Emissions

The annihilation radiation emission probability ($I_\gamma(511)$), is P_{β^+} , or 99,885(6), multiplied by 2, without the correction factor for the annihilation-in-flight in the medium, that is $I_\gamma(511) = 199,770(12)\%$

4) Atomic Data

Atomic value (ω_K) is from Bambynek (1984Ba01).

References

- 1935Mc02 - E. McMillan, M. S. Livingston, Phys. Rev. 47 (1935) 452 [$T_{1/2}$].
- 1936Fo16 - W. A. Fowler, L. A. Delsasso, C. C. Lauritsen, Phys. Rev. 49 (1936) 561 [End-point energy].
- 1937St03 - W. E. Stephens, K. Djanab, T. W. Bonner, Phys. Rev. 52 (1937) 1079 [End-point energy].
- 1949Pe23 - V. Perez-Mendez, H. Brown, Phys. Rev. 76 (1949) 689 [End-point energy, ft value].
- 1950Br29 - H. Brown, V. P. Mendez, Phys. Rev. 78 (1950) 649 [$T_{1/2}$, end point energy].
- 1954Kl136 - R. M. Kline, D. J. Zaffarano, Phys. Rev. 96 (1954) 1620 [$T_{1/2}$].
- 1955Ba83 - S. Bashkin, R. R. Carlson, E. B. Nelson, Phys. Rev. 99 (1955) 107 [$T_{1/2}$].
- 1955Ki39 - J. D. Kington, J. K. Bair, H. O. Cohn, H. B. Willard, Phys. Rev. 99 (1955) 1393 [End-point energy].
- 1957Pe12 - J. R. Penning, F. H. Schmidt, Phys. Rev. 105 (1957) 647 [$T_{1/2}$].
- 1957Ki22 - O. C. Kistner, A. Schawarschild, B. M. Rustad, Phys. Rev. 105 (1957) 1339 [$T_{1/2}$, log ft, end-point energy].
- 1959Ki99 - O. C. Kistner, B. M. Rustad, Phys. Rev. 114 (1959) 1329 [$T_{1/2}$, end point energy].
- 1959Aj01 - F. Ajzenberg-Selove, T. Lauritsen, Nucl. Phys. 11 (1959) 1 [$T_{1/2}$, end point energy, Q, log ft].
- 1960Ja12 - V. J. Janecke, Z. F. Naturf. 15A (1960) 593 [$T_{1/2}$].
- 1963Ne05 - J. W. Nelson, E. B. Carter, G. E. Mitchel, R. H. Davis, Phys. Rev. 129 (1963) 1723 [$T_{1/2}$].
- 1963Cs02 - J. Csikai, G. Peto, Phys. Lett. 4 (1963) 252 [$T_{1/2}$].
- 1963Va23 - S. S. Vasil'ev, L. Ya. Shavtvalov, Bull. Acad. Sci. USSR 27 (1963) 1239 [$T_{1/2}$].
- 1970Aj01 - F. Ajzenberg-Selove, Nucl. Phys. A152 (1970) 1 [$T_{1/2}$, end point energy, Q, log ft].
- 1972Le06 - W. Leiper, R. W. P. Drever, Phys. Rev. C6 (1972) 1132 [K/β^+ ratio].
- 1973Fi13 - M. L. Fitzpatrick, K. W. D. Ledingham, J. Y. Gourlay, J. G. Lynch, J. Phys. A6 (1973) 713 [K/β^+ ratio].
- 1976Aj01 - F. Ajzenberg-Selove, Nucl. Phys. A268 (1976) 1 [$T_{1/2}$, Q, log ft].
- 1977Az01 - G. Azuelos, J. E. Kitching, K. Ramavataram, Phys. Rev. C15 (1977) 1847 [$T_{1/2}$].
- 1977Ba49 - W. Bambynek, H. Behrens, M. H. Chen, B. Crasemann, M. L. Fitzpatrick, K. W. D. Ledingham, H. Genz, M. Muttere, R. L. Intemann, Revs. Modern Phys. 49 (1977) 77 [Electron Capture].
- 1978Ra21 - S. Raman, C. A. Houser, T. A. Walkiewicz, I. S. Towner, Atomic Data and Nucl. Data Tables 21 (1978) 567 [$T_{1/2}$, end point energy, Q, log ft].
- 1981Aj01 - F. Ajzenberg-Selove, Nucl. Phys. A360 (1981) 1 [$T_{1/2}$, Q, log ft].
- 1984Ba01 - W. Bambynek, Proc. X-ray and Inner-Shell Processes in Atoms, Molecules and Solids, Leipzig, Aug. 20-23, 1984. Edited by A. Meisel [Atomic Data].
- 1986Aj01 - F. Ajzenberg-Selove, Nucl. Phys. A449 (1986) 1 [$T_{1/2}$, Q, log ft].
- 1991Aj01 - F. Ajzenberg-Selove, Nucl. Phys. A523 (1991) 1 [$T_{1/2}$, Q, log ft].
- 1995Au04 - G. Audi, A.H. Wapstra, Nucl. Phys. A595 (1995) 409 [Q].
- 2000Co21 - Codata Group, Revs. Modern Phys. 72 (2000) 351 [m_0c^2].

¹⁸F – Comments on evaluation of decay data by V. Chisté and M.M. Bé

1) Decay Scheme

¹⁸F disintegrates by β^+ emission (96.86(16)%) and electron capture (3.14(16)%) to the ground state of the stable nuclide ¹⁸O.

2) Nuclear Data

The Q value (1655.5(6) keV) is from Audi and Wapstra (1995Au04), and has been calculated with the formula:

$$Q = M(A, Z) - M(A, Z - 1),$$

where M(A,Z) and M(A,Z-1) are the measured atomic masses of ¹⁸F and ¹⁸O, respectively.

E_{β^+} , calculated from this Q value ($E_{\beta^+} = 633.5(6)$ keV), is in agreement with a weighted average value of 633.2(3) keV, which was deduced from measured values (see **b⁺ Transition and Electron Capture Transition**).

The measured ¹⁸F half-life values (in minutes) are given below:

Reference	Value (min)
Snell (1937Sn14)	112 (4)
DuBridge (1938Br47)	107 (4)
Krishnan (1941Kr12)	112 (2)
Huber (1943Hu33)	115 (4)
Blaser (1949Bl30)	112 (1)
Jarmie (1955Ja12)	111 (1)
Bendel (1958Be08)	109.8 (12)
Markowitz (1958Ma12)	112 (1)
Carlson (1959Ca63)	109.70 (54)
Yule (1960Yu15)	110,2 (2)
Rayburn (1961Ra53)	111.0 (22)
Mahony (1962Ma15)	109.74 (21)
Beg (1963Be31)	109.6 (6)
Hofmann (1964Ho09)	110.5 (6)
Mahony (1964Ma07)	109.72 (6)
Ebrey (1965Eb02)	109.87 (12)
Bormann (1965Bo38)	111 (2)
Kavanagh (1969Ka17)	109.87 (12)
Hogstrom (1973Ho21)	95 (7)
Rutledge (1980Ru02)	109.71 (2)
Katoh (1989Ka01)	109.48 (8)
Schrader (2004Sc00)	109.748(21)

The only outliers values are 107 (4) min (1938Br47), 115 (4) min (1943Hu33) and 95 (7) min (1973Ho21), which contributed with a statistical weight of just $0.378 \cdot 10^{-5} \%$ (1973Ho21) to $0.116 \cdot 10^{-4} \%$ (1938Br47 and 1943Hu33) to the weighted average. Our recommended half-life is the weighted average of 109.728 (19) min, or 1.8288 (3) h ($\chi^2/\nu = 1.98$).

b⁺ Transition and Electron capture transition

The β^+ and electron capture probabilities shown in Tables 2.1 and 2.2, respectively, have been deduced using a K/β^+ ratio of $(3.00 \pm 0.18) 10^{-2}$ measured by Drever (1956Dr02), $P_K/P_{EC} = 0.9267$ (48) (see Section 2.2) and, normalizing to a total probability ($P_{\beta^+} + P_{EC}$) of 100 %. This leads to $P_{\beta^+} = 96.86(19) \%$ and $P_{EC} = 3.14(19) \%$, respectively. The uncertainties were calculated through their propagation on the above formulas.

The experimental K/β^+ ratio of Drever is close to the theoretical values:

- a) $3.19 10^{-2}$ calculated with LOGFT program;
- e) $3.31 10^{-2}$ given by Fitzpatrick (1973Fi13);
- f) $3.14 10^{-2}$ given by Bambynek (1977Ba49);

Using the LOGFT program evaluators calculated a lg fit of 3.57 for this allowed transition. This value agrees with 3.554 suggested by Ajzenberg-Selove (1972Aj01, 1978Aj01 and 1987Aj01).

The partial sub shell capture probabilities given in Section 2.2 were calculated using the program EC-Capture for an allowed transition.

The weighted mean of the β^+ end-point energy has been calculated (with the Lweight program, version 3) using the following measured values (in keV):

Reference	Values (keV)
Blaser (1949Bl30)	635 (15)
Ruby (1951Ru40)	649 (9)
Hofmann (1964Ho09)	635 (2)
Alburger (1970Al17)	632.9 (7)
Fitzpatrick (1973Fi13)	633.3 (3)

The weighted average of these 5 values is 633.2 keV with an internal uncertainty of 0.3 keV and a reduced χ^2 of 1.4. This value is in agreement with E_{β^+} (633.5 (6) keV) deduced from the adopted Q value (1995Au04) in this evaluation.

3) Gamma-ray Emissions

The annihilation radiation emission intensity ($I_{\gamma 511}$) is P_{β^+} (=96.86(19) %), multiplied by 2, without the correction factor for the annihilation-in-flight process in the medium. That is, $I_{\gamma 511} = 193.72(27) \%$.

References

- 1937Sn14 – A. H. Snell, Phys. Rev. 51 (1937) 143 [$T_{1/2}$].
- 1938Br47 – L. A. DuBridge, S. W. Barnes, J. H. Buck, C. V. Strain, Phys. Rev. 53 (1938) 447 [$T_{1/2}$].
- 1941Kr12 – R. S. Krishnan, Nature (London) 148 (1941) 407 [$T_{1/2}$].
- 1943Hu33 – O. Huber, O. Lienhard, P. Scherrer, H. Waffler, Helv. Phys. Acta 16 (1943) 33 [$T_{1/2}$].
- 1949Bl30 – J. P. Blaser, F. Boehm, P. Marmier, Phys. Rev. 75 (1949) 1953 [End-point energy, $T_{1/2}$].
- 1951Ru40 – L. Ruby, J. R. Richardson, Phys. Rev. 83 (1951) 698 [End-point energy].
- 1955Ja12 – N. Jarmie, Phys. Rev. 98 (1955) 41 [$T_{1/2}$].
- 1956Dr02 – R. W. P. Drever, A. Moljk, J. Scobie, Phil. Mag. 1 (1956) 942 [K/β^+ ratio].
- 1958Be08 – W. L. Bendel, J. McElhinney, R. A. Tobin, Phys. Rev. 111 (1958) 1297 [$T_{1/2}$].

- 1958Ko12 – J. Konijn, B. Van. Nooijen, H. L. Hagedoorn, A. H. Wapstra, Nucl. Phys. 9 (1958) 296 [K/ β^+ ratio].
- 1958Ma12 – S. S. Markowitz, F. S. Rowland, Phys. Rev. 112 (1958) 1295 [$T_{1/2}$].
- 1959Aj01 – F. Ajzenberg-Selove, Nucl. Phys. 11 (1959) 1 [$T_{1/2}$, end point energy, Q, log ft].
- 1959Ca63 – C. H. Carlson, L. Singer, D. H. Service, W. D. Armstrong, Int. J. Appl. Rad. Isotopes 4 (1959) 210 [$T_{1/2}$].
- 1960Yu15 – H. P. Yule, A. Turkevich, Phys. Rev. 118 (1960) 1591 [$T_{1/2}$].
- 1961Ra53 – L. A. Rayburn, Phys. Rev. 122 (1961) 168 [$T_{1/2}$].
- 1962Ma15 – J. D. Mahony, S. S. Markowitz, UCRL 10624 (1963) [$T_{1/2}$].
- 1963Be31 – K. Beg, F. Brown, Int. J. Rad. Isotopes 14 (1963) 137 [$T_{1/2}$].
- 1964Ho09 – I. Hofmann, Acta. Phys. Austriaca 18 (1964) 309 [$T_{1/2}$].
- 1964Ma07 – J. D. Mahony, S. S. Markowitz, J. Inorg. Nucl. Chem. 26 (1964) 907 [$T_{1/2}$].
- 1965Eb02 – T. G. Ebrey, P. R. Gray, Nucl. Phys. 61 (1965) 479 [$T_{1/2}$].
- 1965Bo38 – M. Bormann, E. Fretwurst, P. Schehka, G. Wrege, H. Büttner, A. Lindner, H. Meldner, Nucl. Phys. 63 (1965) 438 [$T_{1/2}$].
- 1969Ka17 – R. W. Kavanagh, Nucl. Phys. A129 (1969) 172 [$T_{1/2}$].
- 1970Al17 – D. E. Alburger, D. H. Wilkinson, Phys. Lett. 32B (1970) 190 [End-point energy].
- 1972Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A190 (1972) 1 [$T_{1/2}$, end point energy, Q, log ft].
- 1973Ho43 – K. R. Hogstrom, B. W. Mayes, L. Y. Lee, J. C. Allred, C. Goodman, G. S. Mutchler, C. R. Fletcher, G. C. Phillips, Nucl. Phys. A215 (1973) 598 [$T_{1/2}$].
- 1973Fi13 – M. L. Fitzpatrick, K. W. D. Ledingham, J. Y. Gourlay, J. G. Lynch, J. Phys. A6 (1973) 713 [K/ β^+ ratio, end-point energy].
- 1977Ba49 – W. Bambynek, H. Behrens, M. H. Chen, B. Crasemann, M. L. Fitzpatrick, K. W. D. Ledingham, H. Genz, M. Muttere, R. L. Intemann, Revs. Modern Phys. 49 (1977) 77 [Electron Capture].
- 1978Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A300 (1978) 1 [$T_{1/2}$, Q, log ft].
- 1980Ru02 – A. R. Rutledge, L. V. Smith, J. S. Merritt, AECL 6692 (1980) 2 [$T_{1/2}$].
- 1987Aj01 – F. Ajzenberg-Selove, Nucl. Phys. A475 (1987) 1 [$T_{1/2}$, Q, log ft].
- 1989Ka01 – T. Katoh, K. Kawade, H. Yamamoto, JAERI-M 089-083 (1989) [$T_{1/2}$].
- 1995Au04 – G. Audi, A.H. Wapstra, Nucl. Phys. A595 (1995) 409 [Q].
- 2004Sc00 – H. Schrader, Appl. Rad. Isotopes 60 (2004) 317 [$T_{1/2}$].

Comments of ²⁴Na Evaluation by R. G. Helmer and E. Schönfeld

1 Decay Scheme

The decay scheme is complete since the four levels populated in this decay are the only excited levels in ²⁴Mg below the decay energy.

The spins, parities, and half-lives of the excited levels are from the Endt evaluation 1990En08.

2 Nuclear Data

For the half-life, the following values are available (in hours):

14.90 (2)	1949Wi10, Wilson and Bishop (1949)	
15.10 (4)	1950Co69, Cobble and Atteberry (1950)	
14.97 (2)	1953Lo09, Lockett and Thomas (1953)	
14.90	1955To07, Tobailem (1955)	omitted - no uncertainty
14.959 (10)	1958Ca20, Campion and Merritt (1958)	
14.953 (13)	1960Wo07, Wolf(1960)	
15.05 (2)	1961Wy01, Wyatt et al. (1961)	superseded by 1972Em01
15.04 (5)	1962Mo21, Monahan et al. (1962)	
15.00 (2)	1968La10, Lagoutine et al. (1968)	superseded by 1982La25
15.16 (5)	1969Ke14, Kemeny (1969)	omitted - no background subtraction
15.030 (3)	1972Em01, Emery et al. (1972)	omitted - outlier
14.969 (12)	1974Ch25, Chakraborty (1974); average of 6 values with external uncertainty	
15.09 (6)	1976Ge06, Genz et al. (1976)	
15.010 (28)	1978Da21, Davis et al. (1978)	
14.9590 (12)	1980Ho17, Houtermans et al. (1980)	
14.964 (15)	1980Mu11, Muckenheim et al. (1980)	
14.965 (10)	1980RuZY, Rutledge et al. (1980)	superseded by 1982RuZY
14.965 (10)	1982RuZV, Rutledge et al. (1982)	
14.956 (3)	1982La25, Lagoutine, Legrand (1982);	originally $\sigma=0.008$ divided by 3
14.951 (3)	1982HoZJ, Hoppes et al. (1982)	superseded by 1992Un01
14.9575 (28)	1983Wa26, Walz et al. (1983)	
15.027 (2)	1989Ab05, Abzouzi et al. (1989)	omitted - outlier
14.90 (2)	1991Bo34, Bode et al. (1991)	
14.9512 (32)	1992Un01, Unterweger et al. (1992)	
14.86 (12)	1994Mi03, Mignonsin (1994)	

14.9574 (20) adopted value, LRSW weighted average

In the final weighted average, the values of 1972Em01 and 1989Ab05 have been omitted because they are outliers; both are over 30σ from the adopted value. If these values are included, the reduced- χ^2 value is about 80. For the 17 values included, the Limitation of Relative Statistical Weight, LRSW, method (1985ZiZY, 1992Ra08) increases the uncertainty of the value of 1980Ho17 from 0.001

to 0.0016 in order to reduce its relative weight from 73% to 50%. In addition to this relative weight, those of the values of 1982La25, 1983Wa34, and 1992Un01 are between 13 and 15%. For the final weighted average the internal uncertainty is 0.0012, the reduced- χ^2 value is 3.01, and the external uncertainty is 0.0020.

1974Ch25 have measured this half-life for solid NaCl and for an aqueous solution. No change of the half-life was observed, contrary to the report of 1969Ke14.

The Q_{β^-} value is taken from the 1995Au04 evaluation.

2.1 β^- Transitions

The energies are calculated from the Q_{β^-} value and the level energies. In the following list, nine values of the experimentally determined β^- end-point energy (in keV) for the transition to the 4122-keV level are compared with the value derived from Q value.

1394 (4)	1957Po36, Porter et al. (1957)
1389 (4)	1958Da10, Daniel (1958)
1389 (2)	1961De23, 1965De25, Depommier and Chabre (1961)
1395	1963Pa20, Paul et al. (1963)
1393 (3)	1964Le09, Lehmann (1964)
1394 (2)	1965Be24, Beekhuis and De Waard (1965)
1389.2 (5)	1969Bo48, Booij et al. (1969)
1389 (2)	1972Gi17, Gils et al. (1972)
1390 (1)	1976Ge06, Genz et al. (1976)
1392.94 (16)	$Q - E(4122)$

The measured and calculated probabilities (in %) of the β^- transitions are:

Level (keV)	1950Gr01 Grant(1950)	1951Tu12 Turner (1951)	Present evaluation
5236			0.057 (7)
4239			<0.002
4122	100	100	99.939 (8)
1368	<0.01	0.003	0.003 (2)
0			< 5×10^{-10}

The 4th forbidden β^- branch to the ground state has not been observed. From the experimental limit on the number of counts in the β^- spectrum above 4140 keV, 1951Tu12 give $\lg ft > 15.1$. The $\lg ft$ systematics of 1998Si17 lists four decays of this type with $\lg ft$ values of 22.5 to 24.3. Since this is a very small set of values, we have taken the lower limit of the ²⁴Na $\lg ft$ to be 20, which corresponds to $I_{\beta^-}(0) < 5 \times 10^{-10} \%$; this value is adopted.

The β^- branch to the 4238 level is a 2nd forbidden transitions and the $\lg ft$ systematics (1998Si17) give $\lg ft > 10.6$ which corresponds to $I_{\beta^-}(4238) < 0.002\%$; this value is adopted. This small value is supported by the adopted decay scheme for which the intensity of the 998-keV γ -ray feeding this level is more [0.00151(25)] than that depopulating it [0.00024(3) + 0.00084(10)]. An unobserved γ -ray of 116 keV could also depopulate this level.

No direct measurements are reported for the β^- transitions to the 4238- and 5236-keV levels. The adopted value for the transition to the 1368-keV level is based on the measurement of 1951Tu12 [Turner and Cavanagh (1951)] who gave no uncertainty. The adopted value for the transition to the 5236-keV level was calculated from probabilities of the two de exciting γ -rays and their internal and pair conversion.

The β^- branch to the 4122-keV level is 100% less the intensity of those to the levels at 0, 1368, 4238, and 5236 keV. The sum of the latter four is 0.061(8)%, so the former is 99.939(8)%.

2.2 Gamma Transitions

The transition probabilities of the 3866- and 4237-keV γ -rays are determined from the following measurements:

	3867 keV	4237 keV
1960Ar10, Artamonova <i>et al.</i> (1960)	0.09 (2)	0.0015 (5)
1962Mo21, Monahan <i>et al.</i> (1962)	0.075 (20)	0.008 (3)
1968Va06, van Klinken <i>et al.</i> (1968)	0.063 (6)	
1970Le12, Lebowitz (1970)	0.0489 (25)	<0.0033
1972Ra21, Raman <i>et al.</i> (1972)	0.061 (5)	0.00084 (10)
Adopted value	0.056(7)	0.00084(10)

For the 3866-keV γ -ray, the adopted value is the average of all five values, which gives an internal uncertainty of 0.0026, a reduced- χ^2 value of 2.46, and an external uncertainty of 0.0041, and the final uncertainty was expanded to include the most precise value. For the 4237-keV γ -ray, the value of 1972Ra21 is adopted as it is considered to be the most reliable and it is consistent with the limit of 1970Le12.

The 996- and 2869-keV γ -ray transitions are not observed in ²⁴Na decay, but their emission probabilities can be deduced from the relative probabilities in other decays or reactions. The transition probability of 996-keV γ -ray was calculated from the measured $P_\gamma(996)/P_\gamma(3866)$ ratio. For this ratio, the measured values are :

0.017 (5)	1972Me09, Meyer <i>et al.</i> (1972) from ²³ Na(p, γ)
0.019 (2)	1973Le15, Leccia <i>et al.</i> (1973) from ²³ Na(p, γ)
0.015 (3)	1975Bo43, Boydell <i>et al.</i> (1975) from ²³ Na(p, γ)
0.0260 (17)	1981Wa07, Warburton <i>et al.</i> (1981) from ²⁴ Al ϵ decay
0.030 (4)	1990En02, Endt <i>et al.</i> (1990) from ²³ Na(p, γ)
0.022 (4)	Adopted value

The adopted value is the weighted average value of 0.0222 with an internal uncertainty of 0.0011, a reduced- χ^2 of 4.6 and an external uncertainty of 0.0024. The LRSW method increases the final uncertainty to 0.004 to include the most precise value of 0.0260. With the above value of $P_\gamma(3866)$, we obtain $P_\gamma(996) = 0.00123(27)$.

The ratio $P_\gamma(2869)/P_\gamma(4237)$ ratio has been measured as follows:

0.30 (3)	1972Me09, Meyer <i>et al.</i> (1972) from ²³ Na(p, γ)
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0.30 (3)	1972Ra21, Raman <i>et al.</i> (1972) from ²⁴ Mg(n,n'γ)
0.299 (15)	1973Le15, Leccia <i>et al.</i> (1973) from ²³ Na(p,γ)
0.267 (7)	1973Br16, Branford (1973) from ²³ Na(p,γ)
0.299 (19)	1975Bo43, Boydell (1975) from ²³ Na(p,γ)
0.304 (19)	1981Wa07, Warburton <i>et al.</i> (1981) from ²⁴ Al ε decay

0.284 (7) Adopted value

The adopted value is the weighted average of all six values after the uncertainty for the 1973Br16 value was increased from 0.007 to 0.009 to reduce its relative weight from 63% to 50%. This average has an internal uncertainty of 0.006, a reduced-χ² of 1.37, and an external uncertainty of 0.007. With the above adopted value of 0.00084(10) for P_γ(4237), one obtains P_γ(2869) = 0.00024(3).

If there are no direct feeding the ground state by β⁻ decay or the unobserved γ transitions of 4122 and 5236 keV, T_γ(1368) = 100 - T_γ(4237) = 99.99916(10) where T_γ = P_γ (1.0 + α + α_π). Upper limits for transition intensities of the 4122- and 5236-keV γ-rays can be determined from the ratios measured by 1981Wa07: P_γ(4122)/P_γ(2754) < 0.00001, or P_γ(4122) < 0.001 and P_γ(5236)/P_γ(3867) < 0.004, so P_γ(5236) < 0.00023 and by 1972Ra21 and 1967En05 which give P_γ(4122) < 0.0009 and P_γ(5236) < 0.00002. If the 4122- and 5236-keV transitions have intensities equal to the latter upper limits, the value of T_γ(1368) would reduce from 99.99916 to 99.9983. Since it is unlikely that these two values will be at the limits, we have adopted the value of T_γ(1368) = 99.9990(3) and P_γ(1368) = 99.9935(5).

The 1114-keV transition between the 5236- and 4122-keV levels has not been observed in ²⁴Na decay. In the ²⁴Al decay, 1981Wa07 have found an upper limit of the ratio P_γ(1114)/P_γ(3867) < 0.007 which yields the value of P_γ(1114) < 0.0004.

The transition probability of the 2754-keV γ-ray is calculated from the balance condition T_γ(2754) = T_γ(1368) - [T_γ(2869) + T_γ(3867) + P_{β⁻}(1368)]. This yields T_γ(2754) = 99.9990(3) - 0.059(7) = 99.940(7)%, which gives P_γ(2754) = 99.872(8)%.

From the intensity balance at the 4238-keV level, for a possible depopulating γ-ray of 116 keV, P_γ(116) = 0.0004(3) + I_γ(4238). Since this γ-ray has not been observed, it is omitted from the scheme.

The internal-conversion coefficients are interpolated from the tables of theoretical values (Band *et al.*, 1976). The mixing parameters, δ, were based on the following information:

γ energy	1960Ba19	1963Br15	1973Le15	adopted
998			-5.1 (+8-12) or -0.47 (4)	-0.47 (4)
2869	+23 (9)		> 30	+23 (9)
3867		large	-0.21 (2) or >19	pure E2

The uncertainty of the interpolated conversion coefficients is assumed to be 3 %.

The internal-pair-formation coefficients (α_γ) for the 1368- and 2754-keV γ-rays have been interpolated from calculated values of 1979Sc31 and are in reasonable agreement with measured values which are:

1368 keV	2754 keV
	0.00116 (10) 1949Ra01
	0.00076 (19) 1950Mi82

	0.00067 (10)	1951Cl50
0.00006 (1)	0.00071 (2)	1952Bl53
0.00003	0.00080	1952Sl52

In summary, the γ -ray photon and transition intensities are:

Energy (keV)	Transition (%)	Photon (%)
998	0.00151 (25)	
1114	<0.0004	
1368	99.9990 (3)	99.9935 (5)
2869	0.00024 (3)	
2754	99.940 (7)	99.872 (8)
3867	0.056 (7)	
4122	<0.0009	
4238	0.00084 (10)	
5236	<0.00002	

If P_γ is not given, it is equal to T_γ .

3 Atomic Data

The values for ω_K , the mean ω_L , and η_{KL} are taken from 1996Sc06.

3.1 X Radiation

The mean energies of the K_α radiations have been calculated from the wave lengths given by 1967Be65.

3.2 Auger Electrons

The mean energy of the KLL Auger electrons is taken from 1977La19.

4 Radiation Emission

4.1 Electron Emission

The energies and emission probabilities of the particles are the same as those given already in sect. 2.1. The energies of the electron from internal conversion and internal-pair formation are calculated from the γ -ray energies. The number of electrons per disintegration for various processes are calculated from the γ -ray emission probabilities, α_{τ} , α , and the atomic data.

4.2 Photon Emission

The energies of the two main γ -rays are from 2000He14. From the decay of ²⁴Na, the energies for the 3867- and 4238-keV γ -rays are 3867.5(3) from 1968Va06 and 1970Le12 and the 4237.4(10) keV from 1972Ra21. The energies of the 996- and 2869-keV γ -rays would then be calculated from the level energies. The adopted values for all four of these γ -rays have been taken from the decay of ²⁴Al (1981Wa07).

The number of photons per disintegration were calculated as described in sect. 2.2.

5 Main Production Modes

Taken from N. Coursol, Table de Radionucléides (1982).

References

- 1949Ra01 - E. R. Rae, Phil. Mag. **40**(149)1155 [α_π]
 1949Wi10 - R. Wilson, G. R. Bishop, Proc. Phys. Soc. (London) **62**(1949)457 [$T_{1/2}$]
 1950Co69 - J. W. Cobble, R. W. Atteberry, Phys. Rev. **80**(1950)917 [$T_{1/2}$]
 1950Gr01 - P. . Grant, Proc. Phys. Soc. (London) **63**(1950)1298 [P_{β^-}]
 1950Mi82 - W. Mims, H. Halban, R. Wilson, Nature **166**(150)1571 [α_π]
 1951Cl50 - M. R. Cleland, J. Townsend, A. L. Hughes, Phys. Rev. **84**(1951)298 [α_π]
 1951Tu12 - J. F. Turner, P. E. Cavanagh, Phil. Mag. **42**(1951)636 [P_{β^-}]
 1952Bl53 - S. D. Bloom, Phys. Rev. **88**(1952)312 [α_π]
 1952Sl52 - H. Slätis and K. Siegbahn, Arkiv f. Fysik **4**(1952)485 [α_π]
 1953Lo09 - E. E. Lockett, R. H. Thomas, Nucleonics **11**(1953)14 [$T_{1/2}$]
 1955To07 - J. Tobailem, J. Phys. Radium **16**(1955)48 [$T_{1/2}$]
 1957Po36 - F. T. Porter, F. Wagner, Jr., M. S. Freedman, Phys. Rev. **107**(1957)135 [E_{β^-max}]
 1958Ca20 - P. J. Champion and J. S. Merritt, Can. J. Phys. **36**(1958)983 [$T_{1/2}$]
 1958Da10 - H. Daniel, Nucl. Phys. **8**(1958)191 [E_{β^-max}]
 1960Ar10 - K. P. Artamonova, L. V. Gustova, Y. N. Podkapaev, O. V. Chubinskii, Soviet Phys. JETP **12**(1961)1109 [P_γ]
 1960Ba19 - R. Batchlor, A. J. Ferguson, H. E. Gove, A. E. Litherland, Nucl. Phys. **16**(1960)38 [δ]
 1960Wo07 - G. Wolf, Nukleonik **2**(1960)255 [$T_{1/2}$]
 1961De23, 1961De25 - P. Depommier, M. Chabro, J. Phys. Radium **22**(1961)656 and 674 [E_{β^-max}]
 1961Wy01 - E. I. Wyatt, S. A. Reynolds, T. H. Handlcy, W. S. Lyon, H. A. Parkcr, Nucl. Sci. Eng. **11**(1961)74 [$T_{1/2}$]
 1961Mo09 - J. E. Monahan, S. Raboy, C. C. Trail, Nucl. Phys. **33**(1962)633 [P_γ]
 1962Mo21 - J. E. Monahan, S. Raboy, C. C. Trail, Nucl. Instr. Meth. **17**(1962)225 [$T_{1/2}$]
 1963Br15 - C. Broude, H. E. Gove, Ann. Phys. (New York) **23**(1963)71 [δ]
 1963Pa20 - H. Paul, F. P. Viehböck, P. Skarek, H. Baicr, I. Hoffmann, H. Wotke, Acta Phys. Austr. **16**(1963)278 [E_{β^-max}]
 1964Le09 - J. Lehmann, J. Phys. **25**(1964)326 [E_{β^-max}]
 1965Be24 - H. Beekhuis, H. De Waard, Nucl. Phys. **74**(1965)459 [E_{β^-max}]
 1965Mu03 - G. Murray, R. L. Graham, J. S. Geiger, Nucl. Phys. **63**(1965)353 [E_γ]
 1965Re16 - J. J. Reidy, M. L. Wiedenbeck, Bull. Am. Phys. Soc. **10**(1965)1131, abstract SP2 [E_γ]
 1965Sp08 - E. Spring, Phys. Lett. **18**(1965)132 [α]
 1967Be65 - J. A. Bearden, Rev. Mod. Phys. **39**(1967)78 [E_X]
 1967En05 - P. M. Endt, C. van der Leun, Nucl. Phys. A **105**(1967)1 [P_γ]
 1968La10 - F. Lagoutine, Y. le Gallic, J. Lcgrand, Int. J. Appl. Rad. Isot. **19**(1968)475 [$T_{1/2}$]
 1968Va06 - J. van Klinken, F. Pleiter, H. T. Dijkstra, Nucl. Phys. A **112**(1968)372 [P_γ]
 1969Ke14 - P. Kemeny, Radiochem. Raccioanal. Letters **2**(1969)119 [$T_{1/2}$]
 1969Bo48 - H. M. W. Booij, E. A. Van Hoek, J. Blok, Nucl. Instr. and Meth. **72**(1969)40 [E_{β^-max}]
 1970Le12 - J. Lebowitz, A. R. Sayres, C. C. Trail, B. Weber, P. L. Zirkind, Nuovo Cim. **65A**(1970)675 [E_γ , P_γ]
 1972Gi17 - H. J. Gils, D. Flothmann, R. Löhken, W. Wiesner, Nucl. Instr. Meth. **105**(1972)179 [E_{β^-max}]
 1972Em01 - J. F. Emery, S. A. Reynolds, E. I. Wyatt, G. I. Gleason, Nucl. Sci. Eng. **48**(1972)319 [$T_{1/2}$]
 1972Me09 - M. A. Meyer, J. P. L. Reinecke, D. Reitmann, Nucl Phys. **A185**(1972)625 and Erratum Nucl.

- Phys. A196(1972)635 [E_γ, P_γ]
 1972Ra11 - F. Rahn, H. Camarda, G. Hacken, W. W. Havens, Jr., H. Liou, J. Rainwater, M. Slagowitz, S. Wynchank, Nucl. Sci. Eng. **47**(1972)372 [E_γ]
 1972Ra21 - S. Raman, N. B. Gove, J. K. Dicken, T. A. Walkiewicz, Phys. Lett. **40B**(1972)89 [E_γ, P_γ, P_β-]
 1973Br16 - D. Branford, Austral. J. Phys. **26**(1973)1995 [P_β-]
 1973Le15 - F. Leccia, M. M. Alconard, D. Castera, P. Hubert, P. Mennrath, J. Phys. **34**(1973)147 [P_γ, δ]
 1973Ra10 - S. Raman, N. B. Gove, Phys. Rev. C **7**(1973)1995 [P_β-]
 1974Ch25 - S. Chakraborty, Radiochem. Radioanal. Lett. **17**(1974)61 [T_{1/2}]
 1975Bo43 - S. G. Boydell, D. G. Sargood, Austral. J. Phys. **28**(1975)369 [P_γ]
 1976Ba63 - I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, At. Data Nucl. Data Tables **18**(1976)433 [α]
 1976Ge06 - H. Genz, J. Reisberg, A. Richter, B. M. Schmitz, G. Schrieder, K. Werner, H. Behrens, Nucl. Instr. Meth. **134**(1976)309 [T_{1/2}, E_β^{max}]
 1977La19 - F. P. Larkins, Atom. Data Nucl. Data Tables **20**(1977)311 [E_{Auger}]
 1978Da21 - M. C. Davis, W. C. Bowman, J. C. Robertson, Intern. J. Appl. Radiat. Isot. **29**(1978) 331 [T_{1/2}]
 1979Gr01 - R. C. Greenwood, R. G. Helmer, R. J. Gehrke, Nucl. Instr. and Meth. **159**(1979)465 [E_γ]
 1979Sc31 - P. Schlüter, G. Soff, At. Data Nucl. Data Tables **24**(1979)509 [P_γ]
 1980Ho17 - H. Houtermans, O. Milosevic, F. Reichel, Intern. J. Appl. Radiat. Isot. **31**(1980)153 [T_{1/2}]
 1980Mu11 - W. Muckenheim, P. Rullhusen, F. Smend, M. Schumacher, Nucl. Instr. Meth. **173**(1980)403 [T_{1/2}]
 1980RuZY - A. R. Rutledge, L. V. Smith, J. S. Merritt, AECL-6692(1980) [T_{1/2}]
 1981Wa07 - E. K. Warburton, C. J. Lister, D. E. Alburger, J. W. Olness, Phys. Rev. **C23**(1981)1242 [P_γ]
 1982HoZJ - D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger, NBS-SP-626 (1982)85 [T_{1/2}]
 1982La25 - F. Lagoutine, J. Legrand, Intern. J. Appl. Radiat. Isot. **33**(1982)711
 1982RuZV - A. R. Rutledge, L. V. Smith, J. S. Merritt, NBS-SP-626 (1982)5
 1983Wa26 - K. F. Walz, K. Debertin, H. Schrader, Intern. J. Appl. Radiat. Isot. **34**(1983)1191 [T_{1/2}]
 1985ZiZY - W. L. Zijp, report ECN FYS/RASA-85/19 (1985) [averages]
 1989Ab05 - A. Abzouzi, M. S. Antony, V. B. Ndocko Ndonguc, J. Radioanal. Nucl. Chem. **135**(1989)1 [T_{1/2}]
 1990En02 - P. M. Endt, et al., Nucl. Phys. **A510**(1990)209 [P_γ]
 1990En08 - P. M. Endt, Nucl. Phys. **A521**(1990)209; Errata and Addenda Nucl. Phys. **A529**(1991)763; and Errata Nucl. Phys. **A564**(1993)609 [J^π]
 1991Bo34 - P. Bode, M. J. J. Ammerlaan, M. Koese, Appl Radiat. Isot. **42**(1991)692 [T_{1/2}]
 1992Ra08 - M. U. Rajput, T. D. MacMahon, Nucl. Instr. Meth **A312**(1992)289 [T_{1/2}]
 1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl Instr. and Meth. **A312**(1992)349 [T_{1/2}]
 1994Hu23 - J. H. Hubbell, P. N. Trehan, Nirmal Singh, B. Chand, D. Mehta, M. L. Garg, R. R. Garg, Surinder Singh and S. Puri, J. Phys. Chem. Ref. Data **23**(1994)339 [ω_L]
 1994Mi03 - E. P. Mignonsin, Appl Radiat. Isot. **45**(1994)17 [T_{1/2}]
 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. **A595**(1995)409 [Q_β-]
 2000He14 - R. G. Helmer and C. van der Leun, Nucl. Instr. Meth. **A450**(2000)35 [γ-energies]

³²P – Comments on evaluation of decay data by V. Chisté and M. M. Bé

1) Decay Scheme

³²P disintegrates by β^- emission (100 %) to the ground state of the stable nuclide ³²S.

2) Nuclear Data

The Q value (1710,66 (21) keV) is from Audi and Wapstra evaluation (1995Au04), and has been calculated with the formula:

$$Q = M(A, Z) - M(A, Z + 1),$$

where M(A,Z) and M(A,Z+1) are the measured atomic masses of ³²P and ³²S, respectively.

This value is in agreement with a weighted average value of 1708 (7) keV, which was calculated from measured values of the β^- end-point energy (see **b⁻ Transition**).

The measured ³²P half-life values (in days) are given below:

T_{1/2}		
Reference	Value (days)	Comments
Ambrosen (1934Am01)	17,5 (11)	Omitted from analysis
Preiswerk (1935Pr20)	15,0 (15)	"
Sizoo (1936Si10)	15,0 (1)	"
Newson (1937Ne19)	14,5 (3)	"
Capron (1938Ca08)	14,5 (3)	"
Cacciapuotu (1938Ca15)	14,30 (3)	
Mulder (1940Mu04)	14,07 (3)	Omitted, outlier
Klema (1948Kl06)	14,35 (5)	
Sinclair(1951Si26)	14,60 (5)	Omitted, outlier
Locket (1953Lo19)	14,50 (4)	Omitted, outlier
Bayly (1956Ba25)	14,30 (9)	
Anders (1957An57)	14,223 (30)	Original Uc × 2
Daniel (1958Da08)	14,2 (3)	
Robert (1959Ro24)	14,55 (6)	Omitted, outlier
Marais (1961Ma01)	14,282 (20)	Original Uc × 2
Goodier (1966Go17)	14,290 (28)	Original Uc × 2
Pernaa (1969Pe16)	14,32 (1)	
Lagoutine (1969La28)	14,268 (42)	
Belyaev (1977Be21)	12 (2)	Omitted, outlier
Mudhole (1977Mu15)	14,35 (5)	
Precker (1979Pr36)	14,28 (4)	
Coursey (1994Co26)	14,26 (1)	

The first five and less precise historical values were omitted from analysis. In several cases original uncertainties have been enlarged to take into account systematic uncertainties in measurements.

The Mulder, Sinclair, Locket, Robert and Belyaev values have been shown to be outliers by the Lweight program, based on the Chauvenet's criterion. With the remaining 12 values, the weighted average is 14,284 d ; with an internal uncertainty of 0,006 d ; an external uncertainty of 0,01 and a reduced- χ^2 of 2,89.

The adopted value is the weighted average : 14,284 d, with a final uncertainty expanded to include the most precise value of Coursey ((1994Co26), 14,26 (1) days) and is 0,036 d.

The large dispersion of the original set of data (reduced- $\chi^2 = 31,4$) is explained by the fact that ³²P is mainly produced by ³²S(n, γ)³²P reaction, then, resulting samples always contain ³³P as an impurity which could be not correctly taking into account.

b⁻ Transition transition

Evaluators calculated, with LOGFT program, a *lg ft* of 7,9 for this allowed transition. The value agrees with those suggested by Endt (1967En01, 1973En01, 1978En01 and 1990En01).

The weighted mean of the β^- end-point energy (or Q) has been calculated (with the Lweight program, version 3) using the following measured values (in keV):

Reference	Values (keV)
Lyman (1937Ly11)	1690 (24)
Newson (1937Ne19)	1590 (30)
Capron (1938Ca08)	1680 (50)
Siegbahn (1946Si07)	1712 (8)
Langer (1949La21)	1689 (10)
Marshaw (1950Ma28)	1708 (8)
Agnew (1950Ag05)	1718 (10)
Jensen (1952Je12)	1704 (8)
Antoneva (1954An18)	1712 (8)
Pohm (1956Po01)	1712 (6)
Ricci (1957Ri32)	1695 (15)
Daniel (1958Da08)	1705 (4)
Johnson (1958Jo12)	1711 (3)
Nichols (1961Ni22)	1707 (1)
Fehrentz (1961Fe15)	1705 (4)
Bosch (1963Bo36)	1706 (11)
Canthy (1966Ca31)	1697 (2)
Fishbeck (1968Fi17)	1710(2)
Flothmann (1969Fl25)	1701,2 (4)
Persson (1971Pe07)	1707 (4)
Booij (1971Bo06)	1706 (4)
Zemann (1971Ze02)	1711 (2)
Moore (1976Mo13)	1712,0 (8)
Greenwood (1993Gr10)	1710,0(30)
Kojima (2001Ko20)	1708 (2)

Evaluators calculated the weighted average of these 25 values using the Lweight program (version 3) as 1705,0 keV with an uncertainty of 3,8 and a reduced- χ^2 of 9,6. The Lyman (1937Ly11), Newson (1937Ne19), Capron (1938Ca08), Langer (1949La21), Agnew (1950Ag05), Ricci (1957Ri32) and Canthy (1966Ca31) values have been shown to be outliers by the Lweight program, based on the Chauvenet's criterion. For the remaining 18 values, the weighted average is 1708,0 keV with an internal uncertainty

of 0,36 keV, an external uncertainty of 1,1 keV and a reduced- χ^2 of 8,6. The final uncertainty is 7,0 keV (expanded so range includes the most precise value of Flothmann (1969F125)). This value is in agreement with the adopted Q value (1995Au04) in this evaluation.

References

- 1934Am01 - J. Ambrosen, Z. Phys. 91 (1934) 43 [Half-life].
 1935Pr20 - P. Preiswerk, H. Von Halban, Compt. Rend. 201 (1935) 722 [Half-life].
 1936Si10 - G. J. Sizoo, C. P. Koene, Physica 3 (1936) 1053 [Half-life].
 1937Ly11 - E. M. Lyman, Phys. Rev. 51 (1937) 1 [End-point energy].
 1937Ne19 - H. W. Newson, Phys. Rev. 51 (1937) 624 [Half-life, End-point energy].
 1938Ca08 - P. C. Capron, Physica 5 (1938) 882 [Half-life, End-point energy].
 1938Ca15 - N. B. Cacciapuoti, Nuovo Cimento 15 (1938) 213 [Half-life].
 1940Mu04 - D. Mulder, G. W. Hoeksema, G. J. Sizoo, Physica 7 (1940) 849 [Half-life].
 1946Si07 - K. Siegbahn, Phys. Rev. 70 (1946) 127 [End-point energy].
 1948Kl06 - E. D. Klema, A. O. Hanson, Phys. Rev. 73 (1948) 106 [Half-life].
 1949La21 - L. M. Langer, H. C. Price Jr, Phys. Rev. 76 (1949) 641 [End-point energy].
 1950Ag05 - H. M. Agnew, Phys. Rev. 77 (1950) 655 [End-point energy].
 1950Ma28 - S. D. Marshaw, J. J. L. Chen, G. L. Appleton, Phys. Rev. 80 (1950) 288 [End-point energy].
 1951Si26 - W. K. Sinclair, A. F. Holloway, Nature 167 (1951) 365 [Half-life].
 1952Je12 - E. N. Jensen, R. T. Nichols, J. Clement, A. Pohm, Phys. Rev. 85 (1952) 112 [End-point energy].
 1953Lo19 - E. E. Lockett, R. H. Thomas, Nucleonics 11 (1953) 14 [Half-life].
 1954An18 - H. M. Antoneva, Izv. Akad. Nauk. (Ser. Fiz.) 18 (1954) 93 [End-point energy].
 1956Ba25 - J. G. Bayly, Can. J. Research 28A (1956) 520 [Half-life].
 1956Po01 - A. V. Pohm, R. C. Waddell, E. N. Jensen, Phys. Rev. 101 (1956) 1315 [End-point energy].
 1957An57 - O. U. Anders, W. W. Wayne Meinke, Nucleonics 15 (1957) 68 [Half-life].
 1957Ri32 - R. A. Ricci, Physica 23 (1957) 693 [End-point energy].
 1958Da08 - H. Daniel, Nucl. Phys. 8 (1958) 191 [Half-life, End-point energy].
 1958Jo12 - O. E. Johnson, R. G. Johnson, L. M. Langer, Phys. Rev. 112 (1958) 2004 [End-point energy].
 1959Ro24 - J. Robert, Annales de Physique 4 (1959) 89 [Half-life].
 1961Ni22 - R. T. Nichols, R. E. McAdams, E. N. Jensen, Phys. Rev. 122 (1961) 172 [End-point energy].
 1961Fe15 - D. Fehrentz, H. Daniel, Nucl. Instr. Meth. 10 (1961) 185 [End-point energy].
 1961Ma01 - P. G. Marais, J. Deist, South African J. Agricultural Science 4 (1961) 627 [Half-life].
 1963Bo36 - H. E. Bosch, T. Urstein, Nucl. Instr. Meth. 24 (1963) 109 [End-point energy].
 1966Ca31 - M. J. Canty, W. F. Davidson, R. D. Connor, Nucl. Phys. 85 (1966) 317 [End-point energy].
 1966Go17 - I. W. Goodier, D. H. Pritchard, Int. J. Appl. Rad. Isotopes 17 (1966) 121 [Half-life].
 1967En01 - P. M. Endt, C. van der Leun, Nucl. Phys. A105 (1967) 1 [End-point energy, Half-life, Q, lg ft].
 1968Fi17 - H. J. Fischbeck, Phys. Rev. 173 (1968) 1078 [End-point energy].
 1969F125 - D. Flothmann, W. Wiesner, R. Lohken, H. Rebel, Z. Phys. 225 (1969) 164 [End-point energy].
 1969Pe16 - D. W. Perna, Int. J. Appl. Rad. Isotopes 20 (1969) 613 [Half-life].
 1969La28 - F. Lagoutine, J. Legrand, Y. Le Gallic, Int. J. Appl. Rad. Isotopes 20 (1969) 868 [Half-life].
 1971Bo06 - H. M. W. Booij, E. A. van Hoek, H. van der Molen, W. F. Slot, J. Blok, Nucl. Phys. A160 (1971) 337 [End-point energy].
 1971Pe07 - B. I. Persson, I. Plessner, Nucl. Phys. A167 (1971) 470 [End-point energy].
 1971Ze01 - H. Zemmann, Nucl. Phys. A175 (1971) 385 [End-point energy].
 1973En01 - P. M. Endt, C. van der Leun, Nucl. Phys. A214 (1973) 1 [End-point energy, Half-life, Q, lg ft].
 1976Mo13 - R. B. Moore, S. I. Hayakawa, D. M. Rehfield, Nucl. Instr. Meth. 133 (1976) 457 [End-point energy].
 1977Mu15 - T. S. Mudhole, Indian J. Pure and Appl. Phys. 15 (1977) 284 [Half-life].
 1977Be21 - B. N. Belyaev, S. S. Vasilenko, A. I. Egorov, A. I. Pautov, Izv. Akad. Nauk. (Ser. Fiz.) 41 (1977) 66 [Half-life].

- 1978En01 - P. M. Endt, C. van der Leun, Nucl. Phys. A310 (1978) 1 [End-point energy, Half-life, Q, lg ft].
- 1979Pr36 - J. Precker, K. Blansdorf, Atomkernenergie 34 (1979) 136 [Half-life, End-point energy].
- 1985Wa21 - A. H. Wapstra, Nucl. Phys. A432 (1985) 1 [End-point energy].
- 1990En01 - P. M. Endt, Nucl. Phys. A521 (1990) 1 [End-point energy, Half-life, Q, lg ft].
- 1993Gr10 - R. C. Greenwood, M. H. Putnam, Nucl. Instr. Meth. Phys. Res. A337 (1993) 106 [End-point energy].
- 1994Co26 - B. M. Coursey, J. M. Calhoun, J. Cessna, D. B. Golas, F. J. Schima, M. P. Unterweger, Nucl. Instr. Meth. Phys. Res. A339 (1994) 26 [Half-life].
- 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. A595 (1995) 409 [Q].
- 1996Sc33 - E. Schonfeld, H. Janßen, Nucl. Phys. Instr. Meth. Phys. Res. A369 (1996) 527 [Atomic data].
- 2001Ko20 - Y. Kojima, M. Shibata, H. Uno, K. Kawade, A. Taniguchi, Y. Kawase, K. Shizuma, Nucl. Instr. Meth. Phys. Res. A458 (2001) 656 [End-point energy].

³³P – Comments on evaluation of decay data by V. Chisté and M. M. Bé

1) Decay Scheme

³³P disintegrates by β^- emission (100 %) to the ground state of the stable nuclide ³³S.

2) Nuclear Data

The Q value (248,5 (11) keV) is from Audi and Wapstra evaluation (1995Au04), and has been calculated with the formula:

$$Q = M(A, Z) - M(A, Z + 1),$$

where M(A,Z) and M(A,Z+1) are the measured atomic masses of ³³P and ³³S, respectively.

Q, calculated with the formula, is in agreement with a weighted average value of 248,5 (10) keV, which the evaluators have calculated from measured values of the β^- end-point energy (see **b⁻ Transition**).

The measured ³³P half-life values (in days) are given below:

T_{1/2}

Reference	Value (days)
Sheline(1951Sh22)	25 (2)
Jensen (1952Je12)	24,8 (5)
Westermarck (1952We01)	25 (2)
Nichols (1954Ni06)	24,4 (2)
Westermarck (1954We03)	25,4 (2)
Russell (1958Ru07)	25 (1)
Fogelstrom-Fineman (1960Fo14)	25,2 (5)
Reynolds (1968Re20)	25,30 (5)
Lagoutine (1972La21)	25,56 (7)

Nichol's value (24,4 (2)) is an outlier (based on Chauvenet's criterion). The weighted average of the eight remaining values (excluding Nichol's value) is 25,383 days with an internal uncertainty of 0,040 days ($\chi^2 = 1,6$). Thus we recommend a half-life of 25,383 (40) d.

b⁻ Transition

Evaluators calculated, using the LOGFT program, a *lg ft* value of 5 for this allowed transition. This value agrees with those given by Endt (1967En01, 1973En01, 1978En01, 1990En01 and 1998En01).

The evaluators have calculated a weighted mean of the β^- end-point energy (or Q) from the following measured values (in keV):

Reference	Values (keV)
Sheline (1951Sh22)	270 (20)
Jensen (1952Je12)	260 (20)
Westermarck (1952We01)	246 (5)
Nichols (1954Ni06)	249 (2)
Elbek (1954El07)	252 (5)
Elbek (1954El08)	250 (5)
Westermarck (1954We03)	246 (5)
Russell (1958Ru07)	238 (5)
Polak (1984Po09)	248,3 (13)

Evaluators calculated the weighted average of these 9 values using the Lweight program (version 3) as 248,2 keV with an internal uncertainty of 1,0 and a reduced- χ^2 of 0,87. The 2 values of Elbek (1954El07 and 1954El08) are independents measurements. The Sheline (1951Sh22), Jensen (1952Je12) and Russell (1958Ru07) values have been shown to be outliers by the Lweight program, based on the Chauvenet's criterion. For the remaining 6 values, the largest contributions to the weighted average come from the values of Polak (1984Po09), with a relative statistical weight of 59 %.

The weighted average of the six remaining input values is 248,5 keV with an internal uncertainty of 1,0 keV and a reduced- χ^2 of 0,23. This value is in agreement with the adopted Q value (1995Au04) in this evaluation.

Atomic Data

Atomic values (ω_K and n_{KL}) are from (96Sc33).

References

- 1951Sh22 – P. K. Sheline, R. B. Holtzman, C. Y. Fan, Phys. Rev. 83(1951)215; Phys. Rev. 83(1951)919 [Half-life, End-point energy].
 1952Je12 - E. N. Jensen, R. T. Nichols, J. Clement, A. Pohm, Phys. Rev. 85(1952)112 [Half-life , End-point energy].
 1952We01 – T. Westermarck, Phys. Rev. 88(1952)573 [Half-life, End-point energy].
 1954Ni06 – R. T. Nichols, E. N. Jensen, Phys. Rev. 94(1954)369 [Half-life, End-point energy].
 1954El07 and 1954El08 – B. Elbek, K. O. Nielsen, O. B. Nielsen, Phys. Rev. 95(1954)96 [End-point energy].
 1954We03 – T. Westermarck, Arkiv Fysik 7(1954)87 [Half-life, End-point energy].
 1958Ru07 – J. E. Russell, Bull. Amer. Phys. Soc. 3(1958)61 [Half-life, End-point energy].
 1960Fo14 – I. Fogelstrom-Fineman, T. Westermarck, Acta Chem. Scan. 14(1960)2046 [Half-life].
 1967En01 – P. M. Endt, C. van der Leun, Nucl. Phys. A105(1967)1 [End-point energy, Half-life, Q, lg ft].
 1968Re03 – S. A. Reynolds, J. F. Emery, E. I. Wyatt, Nucl. Sci. Eng. 32(1968)46 [Half-life].
 1972La21 – F. Lagoutine, J. Legrand, C. Perrot, J. P. Brethon, J. Morel, Int. J. Appl. Rad. Isotopes 23(1972)219 [Half-life].
 1973En01 – P. M. Endt, C. van der Leun, Nucl. Phys. A214(1973)1 [End-point energy, Half-life, Q, lg ft].
 1978En01 – P. M. Endt, C. van der Leun, Nucl. Phys. A310(1978)1 [End-point energy, Half-life, Q, lg ft].
 1984Po09 – P. Polak, L. Lindner, Radiochimica Acta 35(1984)23 [End-point energy].
 1985Wa21 – A. H. Wapstra, Nucl. Phys. A432(1985)1 [End-point energy].
 1990En01 – P. M. Endt, Nucl. Phys. A521(1990)1 [End-point energy, Half-life, Q, lg ft].
 1995Au04 – G. Audi, A. H. Wapstra, Nucl. Phys. A595(1995)409 [Q].
 1996Sc33 – E. Schönfeld, H. Janßen, Nucl. Phys. Instr. Meth. Phys. Res. A369(1996)527 [Atomic data].
 1998En01 – P. M. Endt, Nucl. Phys. A633(1998)1 [End-point energy, Half-life, Q, lg ft].

⁴⁴Sc – Comments on evaluation of decay data

by E. Browne

The *Limitation of Relative Statistical Weights*^[1] (LWM) method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. The uncertainty assigned to the recommended value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

⁴⁴Sc ($T_{1/2} = 3.97$ h) decays 94.27(5)% by β^+ , and 5.73(5)% by electron capture ($Q(\text{EC})=3653.3(19)$ keV (95Au04)^[2]) allowed transitions to levels at 1157.0-, 2656.5-, and 3301.5-keV in ⁴⁴Ca (stable). A β^+ transition from ⁴⁴Sc ($J^\pi = 2^+$) to the ground state of ⁴⁴Ca ($J^\pi = 0^+$) has not been observed. Such transition would be second-forbidden non unique, for which the systematic trend of $\log ft$ predicts a value > 10.6 (98Si17)^[4]. For ⁴⁴Sc this value corresponds to a β^+ transition probability limit of $< 0.005\%$. Therefore, I used no β^+ feeding to the ground state, and normalized the decay scheme using the sum of the relative transition probabilities of the 1157.0-, 2656.4-, and 3301.3-keV gamma rays. This procedure produced a normalization factor $N = (9.9875(3) \times 10^{-4})$, as it will be shown in below.

Nuclear Data

The recommended half-life of ⁴⁴Sc, 3.97(4) h, is a weighted average (LWM, $\sigma_{\text{int}}=0.01$, $\chi^2/\nu=8.0$) of 3.927(8) h (69Ra16)^[5], 4.00(2) h (66Ta01)^[6], and 4.05(3) h^[7]. Other values are: 4.04 h^[8], 4.01 h^[9], and 3.9 h^[10], were not used because they have no uncertainties.

Gamma Rays

Tables Ia and Ib give gamma-ray energies and relative emission probabilities, respectively, reported by 90Me15^[11], 83Gu11^[12], 76Co06^[13], 74HeYW^[14], 73Si05^[15], and 90Sc08^[16]. Recommended values (weighted averages (LWM)) are given on columns 5 and 7, respectively.

Table Ia - Gamma-Ray Energies

90Me15 ^[11] & 76Co06 ^[13] keV	83Gu11 ^[12] keV	74HeYW ^[14] keV	73Si05 ^[15] keV	Rec. Value keV	χ^2/ν
	646.55 (62)		646.5 (20)		
726.49	726.3 (15) 772.7 (12)		726.0 (15) 774		
1157.031 (15)	1157.015 (15)	1156.92 (15)	1156.9 (5)	1157.020 (15)	0.37
1499.489 (25)	1499.436 (15)	1499.20 (20)	1499.4 (3)	1499.460 (20)	1.3
2144.3 (1)	2144.43 (20)		2144.8 (8)	2144.33 (10)	0.34
2656.478 (30)	2656.435 (50)	2657.14 (20)	2656.4 (5)	2656.48 (7)	3.9
3301.3 (1)	3301.361 (55)	3301.6 (15)	3301.35 (6)	0.16	

Table Ib - Relative Gamma-Ray Emission Probabilities

Energy keV	90Me15 ^[11] & 76Co06 ^[13]	90Sc08 ^[16]	83Gu11 ^[12]	74HeYW ^[14]	73Si05 ^[15]	Rec. Value	χ^2/ν
646.5			0.040		0.043 (18)		
726.3	=0.014		0.053 (10)		0.051 (21)		
772.7	=0.0067*		0.062 (16)		0.041 (23)		
1157.020	1000(3)	1000 (1)	1000 (3) [#]	1000 (50)	1000 (3) [#]	1000 (3)	
1499.46	9.0 (2)	9.12 (15)	9.22 (37)	9.0 (10)	9.1 (4)	9.09 (15)	0.10
2144.33	0.02 (2)		0.035 (10) [#]		0.039 (7)	0.036 (7)	0.41
2656.48	1.11 (4)	1.15 (6)	1.11 (3)	1.4 (5)	1.3 (1)	1.12 (3)	0.98
3301.35	0.0064 (8)		0.016 (2)		0.018 (3)	0.017 (2) ^{&}	0.31

* From ⁴⁴K decay, relative to 9.0 for the emission probability of 1499-keV gamma ray.

Estimated by evaluator.

& Weighted average of 0.016(2) and 0.018(3).

The 726- and 772-keV gamma rays reported by 83Gu11^[12] and 73Si05^[15] were not observed by 90Me15^[11] and 76Co06^[13], who reported upper limits four and nine times lower, respectively, for their relative emission probabilities. Therefore, they probably do not belong to the decay of ⁴⁴Sc.

The 646-keV gamma ray was observed with about the same relative emission probability by both 83Gu11^[12] and 73Si05^[15]. These authors placed this gamma ray de-exciting a 3301-keV level, which is also de-excited by the 2144- and 3301-keV transitions. 90Me15^[11] and 76Co06^[13] did not report the 646-keV gamma ray. However, 76Co06^[13] have seen it in the β^- decay of ⁴⁴K. Table II shows the relative emission probabilities of the 646-, 2144-, and 3301-keV gamma rays, which de-excite the 3301-keV level, from both ⁴⁴Sc electron-capture and ⁴⁴K β^- decay.

Table II - Relative Emission Probabilities for the 646-, 2144-, and 3301-keV Gamma Rays from the 3301-keV Level

Energy keV	83Gu11 ^[12]	73Si05 ^[15]	76Co06 ^[13]
	P_γ From ⁴⁴ Sc EC Decay	P_γ	P_γ From ⁴⁴ K β^- Decay
646.5	0.040	0.043 (18)	1.5 (5)
2144.33	0.035	0.039 (7)	12.9 (8)
3301.35	0.016 (2)	0.018 (3)	5.5 (9)

R(646/2144)	1.1	1.1	0.12
R(2144/3301)	2.2	2.2	2.3

Table II shows that the ratio R(646/2144) is ten times lower from ⁴⁴K β^- decay than from ⁴⁴Sc electron-capture decay. Consequently, the 646-keV gamma-ray, observed from ⁴⁴K decay, does not de-excite the 3301-keV level, as 83Gu11 had suggested, and therefore, its existence is uncertain.

Multipolarities and Conversion Coefficients

A total measured conversion coefficient ^[17] $\alpha_t=6.3 (3)\times 10^{-5}$ for the 1157.020-keV gamma-ray suggests an E2 multipolarity for this gamma-ray. The 1499.46-keV gamma-ray has an M1+1.8 (4)% E2 multipolarity ($\delta = +0.137(7)$), determined in a $\gamma\gamma(\theta)$ measurement (68Wa21)^[3]. The theoretical conversion coefficients in Table 2.3 (Tables Section) for these transitions are from 76Ba63 ^[18]. Conversion coefficients for pair creation are theoretical values from 79Sc31^[30].

Absolute Emission Probabilities.

As mentioned before, the gamma-ray normalization factor N can be obtained as follows:

$$N = 1/[P_{\gamma(1157)}(1+\alpha_{1157}) + P_{\gamma(2256)} + P_{\gamma(3301)}] = 1/[1000 (3) (1 + 6.68 \times 10^{-5}) + 1.12 (3) + 0.064 (8)] = 9.9875(3) \times 10^{-4}$$

The internal pair conversion coefficients (from 79Sc31^[19]) for these gamma-rays are: $\alpha_{IP}(1157, E2) = 4.0 \times 10^{-6}$, $\alpha_{IP}(2256, E2) = 5.9 \times 10^{-4}$, and $\alpha_{IP}(3301, E2) = 9.0 \times 10^{-4}$. These coefficients were not included in the calculation shown above because their effect is negligible.

The fractional uncertainty in N should be added in quadrature to those in the relative emission probabilities. For the 1157.020-keV gamma-ray, which dominates this normalization, the correct propagation of this uncertainty is as follows:

$$P_{\gamma(abs,1157)} = P_{\gamma(rel, 1157)} \times N = 1000 (3)/[1000 (3) (1 + 6.68 \times 10^{-5}) + 1.12 (3) + 0.064 (8)] = 1/[1.0000668 + 1.18 (3)/1000 (3)] = 1/[1.0000668 + 0.00118 (3)] = 0.99875(3)$$

Notice that the fractional uncertainty of the relative emission probability is 0.3% , however, because of the effect of covariances, that in the absolute emission probability is just 0.003% . Table III shows the gamma-ray absolute emission probabilities.

Table III - Absolute Gamma-ray Emission Probabilities

Energy (keV)	$P_{\gamma}(\%)$
1157.020 (15)	99.875 (3)
1499.460 (20)	0.908 (15)
2144.33 (10)	$3.6 (7) \times 10^{-3}$
2656.48 (7)	0.112 (3)
3301.35 (6)	$1.7 (2) \times 10^{-3}$

Electron-Capture and b^+ Transitions

The electron-capture plus β^+ probabilities shown in the decay scheme have been deduced from gamma-ray transition intensity balances at each level. For the transition to the 1157-keV level, the values of the individual β^+ and electron-capture probabilities (given in Tables 2.2 and 2.1, respectively) are based on the recommended $\epsilon/\beta^+ = 0.0499(5)$ ratio. This ratio is a weighted average of the experimental values 0.0499(5) (83Ba41) ^[20] and 0.0497(23) (76St21) ^[21]. Theory predicts 0.0489 ^[22].

Electron-capture probabilities to the various atomic sub-shells, i.e., P_K, P_L, P_{M+} in Table 2.1 are theoretical values (98Sc28)^[23] calculated with the computer program EC-CAPTURE^[24].

90Sc08 ^[16] measured the annihilation emission probability $P_{\gamma^+}(511) = 1.88(3)$, which includes a 2.4% correction for positron annihilation-in-flight. I confirmed the value of this correction using the calculation procedure presented in Appendix D of the *Table of Radioactive Isotopes* ^[25], as described below in Table IV.

Table IV - Annihilation-in-flight Correction Factor

E(bin) keV	$\langle\beta^+\rangle^*$ keV	β^+ (%) [#] %	$E_{avg}^{\&}$ keV	$P(E_{avg})^{\wedge}$ %	$\beta^+_{fl}^{\circledast}$ %
0-10	0.000434	0.0056	7.75		
10-20	0.0056	0.0355	15.77		
20-40	0.060	0.191	31.41		
40-100	1.12	1.50	74.67	0.5	0.0075
100-300	26.8	12.6	212.69	1.0	0.126
300-600	140.0	30.7	456.03	2.1	0.645
600-1300	418.0	48.6	860.0	3.4	1.652
1300-2497	10.8	0.80	1350.0	4.8	0.038
Total β^+ branching			94.0	Correction factor	2.47

*Average β^+ energy per decay

β^+ bin probability

& Average β^+ bin energy = $100 \langle\beta^+\rangle/\beta^+(\%)$

^ Positron annihilation-in-flight probability (from Fig.3, Appendix D, *Table of Radioactive Isotopes*)

⊙ Fraction (in %) of β^+ transitions that annihilate in flight = $0.01 \times \beta^+(\%) \times P(E_{avg})$

The final result, 2.47%, agrees with 2.4%, used by 90Sc08 [16].

Then, the β^+ probability is $P_{\beta^+}(1157) = 1.88(3)/2 = 0.940(15)$. The electron-capture probability, $P_{EC}(1157) = 0.9897(5) - 0.940(15) = 0.0497(15)$, although less accurate, is in agreement with the recommended value given in Table 2.1.

Levels half-life

The following half-life values: 2.61(14) ps (1157-keV level), 30(3) fs (2656-keV level), and 35 (18) fs (3301-keV level), shown on the level scheme, are from 90En08 [26].

Atomic Data

The X-ray and Auger-electron probabilities in Section 4 have been calculated with the computer program EMISSION^[27], using the gamma-ray and electron-capture data from Section 2, and atomic data from 96Sc06^[28]

Total Average Radiation Energy

The calculated (RADLST^[29]) total average radiation energy of 3653.3(25) keV (which includes all the radiations emitted by ⁴⁴Sc), agrees very well with $Q(EC) = 3653.3(19)$ keV (1995Au04^[21]) and confirms the self consistency of the ⁴⁴Sc decay scheme.

6 References

1. M. J. Woods and A. S. Munster, *Evaluation of Half-Life Data*, National Physical Laboratory, Teddington, UK, Rep. RS(EXT) 95, (1988) - 88WoZO
2. G. Audi and A. H. Wapstra, Nucl. Phys. **A595**, 409 (1995) - 95Au04 [Q(EC)]
3. H. K. Walter, A. Weitsch, H. J. Welke, Z. Physik **213**, 323 (1968) - 68Wa21 [Gamma-ray mult. Mixing, δ]

4. B. Singh, J. L. Rodriguez, S. S. M. Wong, and J. K. Tuli, Nucl. Data Sheets 84, 487 (1998) - 98Si17
[Log ft systematics]
5. H. Ravn, J. Inorg. Nucl. Chem. **31**, 1883 (1969) - 69Ra16
[$T_{1/2}$]
6. J. R. Tatarczuk, Phys. Rev. **143**, 818 (1966) - 66Ta16
[$T_{1/2}$]
7. D. R. Sachdev and L. Yaffe, Can. J. Chem. **47**, 1667 (1969)
[$T_{1/2}$]
8. L. A. Rayburn, Phys. Rev. **122**, 168 (1961) - 61Ra06
[$T_{1/2}$]
9. C. S. Khurana and H. S. Hans, Nucl. Phys. **28**, 560 (1961)
[$T_{1/2}$]
10. L. T. Dillman, J. J. Kraushaar, J. D. McCullen, Nucl. Phys. **42**, 383 (1963) - 63Di06
[$T_{1/2}$]
11. R. A. Meyer, Fizika (Zagreb) **22**, 153 (1990) - 90Me15
[E_{γ} , P_{γ}]
12. Guanjun Yuan et al., Nucl. Sci. Eng. **84**, 320 (1983) - 83Gu11
[E_{γ} , P_{γ}]
13. G. Coleman, R. A. Meyer, Phys. Rev. **C13**, 847 (1976) - 76Co06
[E_{γ} , P_{γ}]
14. R. L. Heath, Report ANCR-1000-2 (1974) - 74HeYW
[E_{γ} , P_{γ}]
15. J. J. Simpson, Nucl. Phys. **A203**, 221 (1973) - 73Si05
[E_{γ} , P_{γ}]
16. U. Schötzig, Nucl. Instrum. Methods Phys. Res. **A286**, 523 (1990) - 90Sc08
[P_{γ} , γ_{\pm} positron annihilation radiation]
17. J. W. Blue and E. Bleuer, Phys. Rev. **100**, 1324 (1955) - 55Bl23
[ICC]
18. I. M. Band et al., At. Data Nucl. Data Tables **18**, 433 (1976) - 76Ba63
[Theor. ICC]
19. P. Schluter and G. Soff, At. Data Nucl. Data Tables **24**, 509 (1979) - 79Sc31
[Theor. Int. Pair ICC]
20. A. P. Baerg, Can. J. Phys. **61**, 1222 (1983) - 83Ba41
[ϵ/β^+ ratio]
21. H. Stocker, A. P. Baerg, Can. J. Phys. **54**, 2396 (1976) - 76St21
[ϵ/β^+ ratio]
22. P. F. Zweifel, Phys. Rev. **107**, 329 (1957)
[Theor. ϵ/β^+ ratio]
23. E. Schönfeld, Appl. Radiat. Isot. **49**, 1353 (1998) - 98Sc28
[P_K , P_L , P_M]
24. E. Schönfeld, F. Y. Chu, and E. Browne, EC-CAPTURE, a computer program to calculate electron capture probabilities to atomic sub-shells, 1998.
25. E. Browne and R. B. Firestone, Table of Radioactive Isotopes, John Wiley and Sons, Inc., New York (1986) - 86BrZQ
[Positron Annih. in flight]
26. P. M. Endt, Nucl. Phys. **A521**, 1 (1990) - 90En08
[$T_{1/2}$ level]
27. H. Janßen and E. Schönfeld, EMISSION, a computer program for calculating X-ray and Auger-electron emission probabilities, 1998.
28. E. Schönfeld and H. Janßen, Nucl. Instrum. Meth. Phys. Res. **A369**, 527 (1996) - 96Sc06
[X-ray, ω_K]
29. The Program RADLST, Thomas W, Burrows, report BNL-NCS-52142, February 29, 1988.
30. P. Schluter and G. Soff, At. Data Nucl. Data Tables **24**, 509 (1979) - 79Sc31
[Internal Pair Conversion Coefficients]

⁴⁴Ti – Comments on evaluation of decay data

by E. Browne

Evaluation Procedures

The *Limitation of Relative Statistical Weights*^[1] (LWM) method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. The uncertainty assigned to the recommended value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

⁴⁴Ti ($T_{1/2} = 60.0$ y) decays 100% by electron capture ($Q(\text{EC}) = 267.5$ (19) keV) to excited levels at 67.9- and 146.2 keV only in ⁴⁴Sc ($T_{1/2} = 3.93$ h), which subsequently decays by $\text{EC} + \beta^+$ to ⁴⁴Ca (stable).

90Sc08 measured the relative emission probabilities of the 1157-, 67.9- and 78.4-keV gamma rays from a ⁴⁴Ti - ⁴⁴Sc equilibrium source. Since the absolute emission probability of the 1157-keV gamma ray from ⁴⁴Sc is well known (0.999)^[2], this measurement provided values for the absolute emission probabilities of the 67.9- and 78.4 keV gamma rays as well, thus normalizing the decay scheme of ⁴⁴Ti.

Nuclear Data

⁴⁴Ti is of considerable interest in astrophysics, since it is one of the few long-lived gamma-ray-emitting nuclides expected to be substantially produced during a supernova explosion. Moreover, the solar system abundance of ⁴⁴Ca is believed to have originated from the nucleosynthesis of ⁴⁴Ti and the subsequent decays. The characteristic 1157-keV gamma ray from ⁴⁴Sc, which was observed from the young supernova remnant Cassiopeia A^[3], opened the possibility of deducing the mass of ⁴⁴Ti that was ejected in the explosion. For this calculation, however, it was needed (among other quantities) a reasonably precise knowledge of the ⁴⁴Ti half-life.

The recommended half-life of ⁴⁴Ti, 60.0 (11) y, is a weighted average (LWM, $\sigma_{\text{int}} = 0.5$, $\chi^2/\nu = 5.6$) of:

- 60.7 (12) y^[4] (method: decay of count rate),
- 59.0 (6) y (98Ah03^[5], method: decay of count rate),
- 60.3 (13) y (98Go05^[6], method: specific activity with beam fragmentation),
- 62 (2) y (98No06^[7], method: decay of count rate),
- 66.6 (16) y (90Al11^[8], method: decay of count rate), and
- 54.2 (21) y (83Fr27^[9], method: specific activity with accelerator mass spectroscopy).

The following results have not been included in the averaging:

- Preliminary results: 58 (10) y^[10] (method: specific activity with beam fragmentation), 39.0 (18) y^[11] (method: specific activity with beam fragmentation), and 63 (3) y (97No06^[12], method: decay of count rate).
- Older measurements: 48.2 (9) y (65Mo07^[13], method: specific activity), and 46.4 (17) y (65Wi05^[14], method: specific activity). These values significantly deviate from recent results, probably because of systematic errors.

Woosley and Diehl^[15] have recommended a half-life of 60 (1) y for ⁴⁴Ti, based on the 1998 values.

Gamma Rays

Energies

⁴⁴Ti emits gamma rays of 67.9-, 78.4-, and a very weak one of 146.2 keV. The precise gamma-ray energies for the 67.9- and 78.4-keV transitions given in Table 4.2 (and the values corrected for nuclear recoil, in Table 2.2) are weighted averages (LWM) of results from 63Kl06^[16], 67Ri06^[17], and 91We08^[18] (See Table I). Other: 88Al27^[19] (superseded by 91We08^[18]). The energy of 146.22 (3) keV for the 146-keV is from level-energy differences. A measured value is: 147.0 (15) keV (67Ri06^[17]).

Table I - ⁴⁴Ti Gamma-ray Energies

	67.9 keV	78.4 keV
91We08 ^[18]	67.8679 (14)	78.3234 (10)*
67Ri06 ^[17]	67.85 (4)	78.38 (4)
63Kl06 ^[16]	67.85 (7)	78.44 (7)
Average	67.8679 (14)	78.36 (3)
χ^2/ν	0.13	1.3

* The uncertainty of 0.0010 was increased to 0.035 to reduce the statistical weight of this measurement from 99.9% to 50%. Original $\chi^2/\nu = 2.4$.

Emission Probabilities

The relative emission probabilities are average values (LWM) from 88Al27^[19], 90Sc08^[20], and 67Ri06^[17], as given in Table II below.

Table II - ⁴⁴Ti Relative Emission Probabilities

Energy keV	67Ri06 ^[17] P _γ (rel.)	88Al27 ^[19] P _γ (rel.)	90Sc08 ^[20] P _γ (rel.)	W. Average (LWM) P _γ (rel.)	χ^2/ν
67.8679 (14)	0.942 (15)*	0.981 (11)	0.960 (15)	0.965 (16) [@]	2.3
78.36 (3)	1.000 (11)*	1.000 (11)	1.000 (13)	1.000 (11) ^{&}	
146.22 (3)	0.0010 (3)	0.00093 (6)	0.00095 (3)	0.00095 (3)	0.05

* Original uncertainties of 0.005 seemed unrealistically low. Evaluator has increased these values.

& Uncertainty is the smallest of the individual values.

[@] Internal uncertainty $\sigma_{int}=0.011$

A factor to normalize relative to absolute emission probabilities was deduced as follows:

- N= 0.955 (15), from the average relative emission probabilities given in Table III column 2, the theoretical conversion coefficients from Section 2.2, and the condition that the total transition intensity to the ground state is 100%, as shown below.

$$[P_{\gamma}(67.8)(1 + \alpha_{68}) + P_{\gamma}(146)(1 + \alpha_{146})] N = 100\%$$

- N=0.974 (13), from the emission probability of the 78-keV gamma ray (0.974 (13)) relative to an absolute probability of 0.999 (1) for the 1157-keV gamma ray in the decay of ⁴⁴Sc in equilibrium with ⁴⁴Ti (90Sc08).

The (unweighted) average of these normalization factors is N_{avg}=0.964 (13) (smallest uncertainty from input values).

Table III gives recommended relative and absolute gamma-ray emission probabilities.

Table III - Recommended Relative and Absolute Gamma-Ray Emission Probabilities

E _γ (keV)	P _γ (rel.) [*]	P _γ (abs.) ^{&}
67.9	0.965 (16)	0.930 (15)
78.36 (3)	1.000 (11)	0.964 (11)
146.22 (3)	0.00095 (3)	0.00092 (3)

* From Table II, column 5.

& Values from column 2 multiplied by N_{avg}(=0.964 (13))

Multipolarities and Conversion Coefficients

The following experimental conversion coefficients: α_K = 0.123 (23) (67Ri06^[17]), α = 0.10 (5) (63Kl06^[16]) for the 67.9-keV gamma ray, and α_K = 0.031 (5) (67Ri06^[17]), α = 0.017 (8) (63Kl06^[16]) for the 78.4-keV gamma ray, suggest E1 and M1 multipolarities for the 67.9- and 78.4-keV transitions, respectively. Spins of 0- (for the 146-keV level) and 1- (for the 67.9-keV level) require M1 multipolarity for the 78.4-keV gamma ray. The evaluator has assigned from decay scheme (0- to 2+)[M2] multipolarity to the 146-keV gamma ray.

Total conversion coefficients also may be deduced from the measured absolute gamma-ray emission probabilities of 90Sc08, by using 0.7 (3)% (88Al27, delayed-coincidence experiment) for the electron-capture feeding to the 67-keV level, and neglecting the very weak 146-keV transition. These calculations are:

α(67.9) = [1.0/0.935 (15)]-1.0 = 0.069 (17); α(78.4) = [(1.0 - 0.007 (3))/0.974 (13)]-1.0 = 0.019 (14), which agree with the measured values. Where 0.935 (15) and 0.974 (13) (90Sc08) are the experimental absolute emission probabilities of the 67.9- and 78.4-keV gamma rays, respectively. The absolute adopted emission probabilities were not used in this calculation because they are partially based on decay scheme considerations (that include the conversion coefficient of the 67.9-keV gamma ray.)

Table IV shows experimental and theoretical conversion coefficients for the 67.9-, 78.4-, and 146-keV gamma rays.

Table IV - Conversion Coefficients

E _γ keV	α _T [@] From P _γ (%)	α _T Exp.	α _T [*] Theory	α _K Exp	α _K [*] Theory	Mult.
67.8679 (14)	0.069 (17)	0.10 (5) [#]	0.0845 (25)	0.123 (23) ^{&}	0.0766 (23)	E1
78.36 (3)	0.019 (14)	0.017 (8) [#]	0.032 (1)	0.031 (5) ^{&}	0.0273 (8)	M1
146.22 (3)			0.046 (1)		0.0414 (12)	M2

* Interpolated from ⁷⁶Ba63^[21]

From ⁶³Kl06^[16]

& From ⁶⁷Ri06^[17]

@ See text

The experimental conversion coefficients in Table IV are quite imprecise, therefore, the evaluator has adopted interpolated theoretical values as the recommended conversion coefficients. The interpolation was done with the computer program ICC^[22].

Electron-Capture Transitions

The EC probability to the 146-keV level is given by:

$$\epsilon(146) = [P_{\gamma}(78.4)+e(78.4) + P_{\gamma}(146)+e(146)] \times 100 = 99.5 (11)\% + 0.096 (3)\% = 99.6 (11)\%.$$

For the EC probability to the 0+ ground state of ⁴⁴Sc (0+ to 2+, second forbidden) a log ft >10.6 is expected from the systematic trend for second forbidden transitions (⁹⁸Si17), which corresponds to $\epsilon(0) < 0.04\%$. Using $\epsilon(0)=0.04\%$ and $\epsilon(146) = 99.6 (11)\%$ gives $\epsilon(67.4) = 0.4 (11)\%$. Experimental values for this quantity are 0.7 (3)% (⁸⁸Al27^[19]), and 1.9 (15)% (⁶⁷Ri06^[17]), both measured in γ -x ray coincidence experiments.

Electron-capture probabilities to the various atomic sub-shells, ie. P_K, P_L, P_{M+} in Table 2.1, are theoretical values (⁹⁸Sc28^[23]) calculated with the computer program EC-CAPTURE^[24].

Levels half-life

Table V shows the experimental half-life values for the 67.3- and 78.4 keV levels, as well as their respective recommended (i.e., average) values.

Table V - ⁴⁴Sc Levels half-life

67.9 keV		78.4 keV	
153 (2) ns	(⁶⁷ Ri06 ^[17])	50 (3) μ s	(⁶³ Kl06 ^[16])
153 (1) ns	(⁶² Th12 ^[25])	49.5 (10) μ s	(⁶⁴ Br27 ^[27])
180 (20) ns	(⁵⁹ Cy90 ^[26])	51.2 (9)* μ s	(⁸⁸ Al27 ^[19])
166 (5) ns	(⁶³ Kl06 ^[16])		
155 (2) ns	(⁷⁵ Gu24 ^[28])		
154.8 (8) ns	(⁸⁸ Al27 ^[19])		
Avg.(LWM) = 154.2 (8) ns		Avg. (LWM) = 50.4 (7) μ s	
$\chi^2/\nu = 1.95$		$\chi^2/\nu = 0.77$	

* The uncertainty was increased from 0.3 ($\chi^2/\nu = 1.4$) to 0.9 to reduce its statistical weight from 91% to 50%.

Atomic Data

The X-ray and Auger-electron probabilities in Section 4 have been calculated using the gamma-ray and electron-capture data that are presented in Section 2, and using atomic data from ⁹⁶Sc06^[29].

Total Average Radiation Energy

Our calculated (RADLST^[30]) total average radiation energy of 268 (3) keV (which includes all the radiations emitted by ⁴⁴Ti), agrees very well with Q(EC) = 267.5 (19) keV (95Au04^[31]) and confirms the quality and completeness of the ⁴⁴Ti decay scheme.

References

1. M.J. Woods and A.S. Munster, *Evaluation of Half-Life Data*, National Physical Laboratory, Teddington, UK, Rep. RS(EXT) 95, (1988) - 88WoZO
2. Richard B. Firestone, *Table of Isotopes*, eighth edition, John Wiley & Sons, Inc., 1996.
[⁴⁴Sc $\epsilon + \beta^+$ decay, E_γ , I_γ]
3. A.F. Iyudin et al., *Astron. Astrophys.* **284**, L1 (1994)
4. F.E. Wietfeldt et al., *Phys. Rev.* **C59**, 528 (1999)
[$T_{1/2}$]
5. I. Ahmad et al., *Phys. Rev. Lett.* **80**, 2550 (1998) - 98Ah03
[$T_{1/2}$]
6. J. Gorres et al., *Phys. Rev. Lett.* **80**, 2554 (1998) - 98Go05
[$T_{1/2}$]
7. E.B. Norman et al., *Phys. Rev.* **C57**, 2010 (1998) - 98No06
[$T_{1/2}$]
8. D.E. Alburger and G. Harbottle, *Phys. Rev.* **C41**, 2320 (1990) - 90A111
[$T_{1/2}$]
9. D. Frekers et al., *Phys. Rev.* **C28**, 1756 (1983) - 83Fr27
[$T_{1/2}$]
10. J. Meissner et al., in *Nuclei in the Cosmos III*, edited by Maurizio Busso and Claudia M. Raiteri, AIP Conf. Proc. No. 327 (AIP, New York, 1995), p. 303.
[$T_{1/2}$]
11. J. Meissner, Ph. D. thesis, University of Notre Dame, 1996.
[$T_{1/2}$]
12. E.B. Norman et al., in *Proceedings of the International Conference on Nuclei in the Cosmos IV*, *Nucl. Phys.* **A621**, 92c (1997) - 97No06
[$T_{1/2}$]
13. P.E. Moreland and D. Heymann, *J. Inorg. Nucl. Chem.* **27**, 493 (1965) - 65Mo07
[$T_{1/2}$]
14. J. Wing et al., *J. Inorg. Nucl. Chem.* **27**, 487 (1965) - 65Wi05
[$T_{1/2}$]
15. Stan Woosley and Roland Diehl, *Physics World* **11**, No. 7, 22 (1998)
[$T_{1/2}$]
16. J.K. Kliwer et al., *Nucl. Phys.* **49**, 328 (1963) - 63K106
[E_γ]
17. R.A. Ristinen and A.W. Sunyar, *Phys. Rev.* **153**, 1209 (1967) - 67Ri06
[E_γ , I_γ]
18. C. Wesselborg and D.E. Alburger, *Nuc. Instrum. Meth.* **A302**, 89 (1991) - 91We08
[E_γ]
19. D.E. Alburger and E.K. Warburton, *Phys. Rev.* **C38**, 1843 (1988) - 88A127
[I_γ]

20. U. Schötzig, Nucl. Instrum. Meth. **A286**, 523 (1990) - 90Sc08
[I_γ]
21. I.M. Band et al., At. Data Nucl. Data Tables **18**, 433 (1976) - 76Ba63
[Theoretical internal conversion coefficients]
22. E. Yakusev and N. Coursol, ICC, a computer program to interpolate internal conversion coefficients, 1998.
23. E. Schönfeld, App. Rad. Isot. **49**, 1353 (1998) - 98Sc28
[P_K, P_L, P_M]
24. E. Schönfeld, F.Y. Chu, and E. Browne, EC-CAPTURE, a computer program to calculate electron capture probabilities to atomic sub-shells, 1998.
25. P. Thieberger, Arkiv Fysik **22**, 127 (1962) - 62Th12
[Level $T_{1/2}$]
26. E.W. Cybulska and L. Marquez, Nuovo Cimento **14**, 479 (1959) - 59Cy90
[Level $T_{1/2}$]
27. K. Bandi et al., Nucl. Phys. **59**, 33 (1964) - 64Br27
[Level $T_{1/2}$]
28. V.P. Gupta and D.K. Gupta, Indian J. Pure Appl. Phys. **13**, 334 (1975) - 75Gu24
[Level $T_{1/2}$]
29. E. Schönfeld and H. Janßen, Nucl. Instrum. Meth. Phys. Res. **A369**, 527 (1996) - 96Sc06
[X rays, ω_K]
30. *The Program RADLST*, Thomas W. Burrows, report BNL-NCS-52142, February 29, 1988.
31. G. Audi and A.H. Wapstra, Nucl. Phys. **A595**, 409 (1995) - 95Au04
[Q-value]
32. B. Singh, J.L. Rodriguez, S.S.M. Wong, and J.K. Tuli, Nucl. Data Sheets **84**, 487 (1998) - 98Si17
[Systematics of $\log ft$]

⁴⁶Sc - Comments on evaluation of decay data by R. G. Helmer

1 Decay Scheme

The only levels in ⁴⁶Ti below the decay energy are those populated in this ⁴⁶Sc β⁻ decay, so that portion of the decay scheme is complete. However, ⁴⁶Sc can also electron-capture decay, ε, to levels in ⁴⁶Ca with a decay energy of 1368 keV. The available levels are 0⁺ at 0 keV and 2⁺ at 1346 keV with ε branches that are 4th forbidden and 2nd forbidden, respectively. From systematics (1998Si17), the corresponding log *ft* limits are ≥ 22.5 and ≥ 10.6, and the deduced P_{ε+β⁺} limits are ≤ 1.0 × 10⁻¹² % and ≤ 2.5 × 10⁻⁶ %, respectively. Therefore, these ε branches are negligible.

The J^π values and half-lives for the excited levels are from Adopted Levels in Nuclear Data Sheets (2000Wu08).

2 Nuclear Data

Q value is from Audi and Wapstra 1995 (1995Au04).

The half-life values available are, in days:

85 (1)	(1940Wa01)	omitted from analysis
84.1 (3)	(1956Sc87)	omitted from analysis
83.89 (12)	(1957Ge07)	omitted from analysis
84.4 (2)	(1957Wr37)	omitted from analysis
83.80 (3)	(1965An07)	superseded by 1982HoZJ
84.34 (13)	(1974Cr05)	omitted as outlier
83.75 (3)	(1977MeZP)	superseded by 1980RuZY
83.819 (6)	(1980Ho17)	
83.79 (6)	(1980Ol03)	
83.752 (15)	(1980RuZY)	
83.79 (6)	(1982HoZJ)	superseded by 1992Un01
83.752 (15)	(1982RuZV)	same as 1980RuZY
83.73 (12)	(1983Wa26)	
83.83 (7)	(1992Un01)	
83.788 (22)	Adopted value	

This set of values is inconsistent which causes the adopted value to depend on the choice of the values used and the "averaging" method used. The values have decreased over time; the unweighted average of the four not superseded values before 1978 (1940Wa01, 1956Sc87, 1957Ge07, and 1957Wr37) is 84.18, whereas the same average for the five values after 1978 (1980Ho17, 1980Ol03, 1980RuZY, 1983Wa26, and 1992Un01) is 83.78. The values reported before 1960 were omitted from the analysis since it would have been difficult to determine the presence of a small amount of a longer-lived impurity with the spectroscopy methods then available.

The discrepancy among the values is illustrated by the values of 84.34(13) (1974Cr05),

83.819(6) (1980Ho17), and 83.752(15) (1980RuZY). The first two values differ by 0.52(13) and the last two by 0.067(16), or about 4σ in each case. The latter two values have the greatest weight in any weighted average, so the results will depend on how the analysis modifies their relative weight, and the first value will give the largest contribution to the χ^2 value. Of the remaining six values not superseded, that of 84.34(13) (1974Cr05) is considered an outlier and is omitted.

For the remaining five values not superseded, the following averages are obtained:

unweighted	83.784 (19)
weighted	83.810, $\sigma_{\text{int}}=0.006$, reduced- $\chi^2=4.46$, $\sigma_{\text{ext}}=0.013$
RAJEVAL	83.776 (20)
Normalized residuals	83.793 (16)
LRSW - weighted average	83.788, $\sigma_{\text{int}}=0.010$, reduced- $\chi^2=1.67$, $\sigma_{\text{ext}}=0.022$ and $\sigma_{\text{LRSW}}=0.031$

The RAJEVAL method (1992Ra08) increases both of the two smallest uncertainties, namely, 0.006 to 0.043 and 0.015 to 0.026, which causes the value of 1980RuZY to have the largest weight. The Normalized Residuals method (1992Ja06) also increases both of the two smallest uncertainties but by different amounts, namely, 0.006 to 0.022 and 0.015 to 0.028, which leaves the value of 1980Ho17 with the largest weight, but only by a small amount. In contrast, the Limitation of Relative Statistical Weight, LRSW, method (1985ZiZY, 1992Ra08) only increases the most precise uncertainty, namely that of 1980Ho17, from 0.006 to 0.014 in order to reduce its relative weight to 50% from its initial 84%. The LRSW method expands the final uncertainty to 0.031 in order to include the most precise value. [The LRSW method finally suggests the unweighted average of 83.96(14), but that choice is not accepted here.]

The results from the RAJEVAL, Normalized residuals, and LRSW methods all are in good agreement and the adopted value, 83.788(22) is taken as the latter value with its external uncertainty.

2.1 β^- Transitions

The β^- branch to the ground state of ^{46}Ti is 4th forbidden with an expected $\log ft \geq 22.5$ (1998Si17) and a corresponding $P_{\beta^-}(0) \leq 1 \times 10^{-11} \%$, the measured limit is $\leq 1 \times 10^{-4} \%$ (1954Ke04).

Similarly, for the 2nd forbidden decay to the 889 level, the expected $\log ft \geq 10.6$ which corresponds to $P_{\beta^-}(889) \leq 0.8 \%$. The measured I_{β^-} to this level are 0.096(1) (1954Ke04), 0.0036(7) (1956Wo09), ≤ 0.06 (1950Mo62), and ≤ 0.05 (1950So57). Some previous evaluators (e.g., 1986Al19) have assigned $I_{\beta^-}(889) = 0.0036(7)$ because it is consistent with the limits of 1950Mo62 and 1950So57. However, this evaluator has some reservations about the resulting precision for I_{β^-} (2009) and, therefore, has expanded the uncertainty and gives $I_{\beta^-}(889) = 0.004 \%$ (+36-4), which is consistent with the two limits and the value of 1956Wo09, and thus $I_{\beta^-}(2009) = 99.996(+4-36)$.

If symmetric uncertainties are required, as in ENSDF, for these quantities, $I_{\beta^-}(889) = 0.02(2)$ and $I_{\beta^-}(2009) = 99.98(2)$, adopted values.

The β^- average energies and $\log ft$ values are from LOGFT code.

2.2 Gamma Transitions

The J^π assignments are from the Adopted Levels in the Nuclear Data Sheets (2000Wu08) and these imply the two γ -rays have E2 multipolarities.

The internal-conversion coefficients were interpolated from the Band tables (1976Ba63).

The internal-pair-formation coefficient was interpolated from the theoretical values (1979Sc31) and is $IPFC(1120) = 0.0000022$ (4). This value is only about 2 % of the corresponding internal-conversion coefficient and, therefore, is negligible.

3 Atomic Data

The data are from 1996Sc06.

3.1 and 3.2

None

4 Radiation Emissions

4.1 Electron Emission

The emission intensities are calculated from the atomic data and the decay data.

4.2 Photon Emission

The γ -ray energies are from 2000He14 for the 889 and 1120 lines and the 2009 energy is the sum of these values corrected for nuclear recoil.

The relative γ -ray emission probability of the 2009-keV γ -ray is from 1980Fu07.

The emission probability of the 889-keV γ -ray is $[100.0 - P_\gamma(2009)] / [1.0 + \alpha(889)] = 99.999987(10)/1.000167(5) = 99.9833(5)$ where the uncertainty is 5 ppm from the $(1.0 + \alpha)$ term.

That of the 1120-keV γ -ray is $[I_\beta(2009) - P_\gamma(2009)] / [1.0 + \alpha(1120)] = 99.996(+4-36)/1.000095(3) = 99.986(+4-36)$, with symmetric uncertainties 99.98 (2). Here, $\alpha(2009)$ has been neglected.

6 References

- 1940Wa01 - H. Walke, Phys. Rev. **57**(1940)163 [T_{1/2}]
 1950Mo62 - M. L. Moon, M. A. Waggoner, A. Roberts, Phys. Rev. **79**(1950)905 [I_β-]
 1950So57 - B. N. Sorensen, B. M. Dale, J. D. Kurbatov, Phys. Rev. **79**(1950)1007 [I_β-]
 1954Ke04 - G. L. Keister, F. H. Schmidt, Phys. Rev. **93**(1954)140 [I_β-]
 1956Sc87 - R. P. Schuman, M. E. Jones, A. C. McWherter, J. Inorg. Nucl. Chem **3**(1956)160 [T_{1/2}]
 1956Wo09 - J. L. Wolfson, Can. J. Phys. **34**(1956)256 [I_β-]
 1957Ge07 - K. W. Geiger, Phys. Rev. **105**(1957)1539 [T_{1/2}]
 1957Wr37 - H. W. Wright, E. I. Wyatt, S. A. Reynolds, W. S. Lyon, T. H. Handley, Nuclear Sci. Eng. **2**(1957)427 [T_{1/2}]
 1965An07 - S. C. Anspach, L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, C. N. Smith, NP-15663 (1965) [T_{1/2}]
 1974Cr05 - P. J. Cressy, Jr., Nucl. Sci. Eng. **55**(1974)450 [T_{1/2}]
 1976Ba63 - I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, Atomic Data Nucl. Data Tables **18**(1976)433 [α]
 1977MeZP - J. S. Merritt, F. H. Gibson, AECL-5696 (1977) 40 [T_{1/2}]

- 1979Sc31 - P. Schluter, G. Soff, At. Data Nucl. Data Tables **24**(1979)509 [IPFC]
1980Fu07 - M. Fujishiro, Y. Satoh, K. Okamoto, T. Tsujimoto, Can. J. Phys. **58**(1980)1712 [P_{γ}]
1980Ho17 - H. Houtermans, O. Milosevic, F. Reichel, Int. J. Appl. Radiat. Isotop. **31**(1980)153 [$T_{1/2}$]
1980Ol03 - J. B. Olomo, T. D. MacMahon, J. Phys.(London) **G6**(1980)367 [$T_{1/2}$]
1980RuZY - A. R. Rutledge, L. V. Smith, J. S. Merritt, AECL-6692 (1980) [$T_{1/2}$]
1882HoZJ - D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger, NBS-SP-626 (1982) 85 [$T_{1/2}$]
1982RuZV - A. R. Rutledge, L. V. Smith, J. S. Merritt, NBS-SP-626 (1982) 5 [$T_{1/2}$]
1983Ru04 - A. R. Rutledge, L. V. Smith, J. S. Merritt, Nucl. Instrum. Methods **206**(1983)211 [$T_{1/2}$]
1983Wa26 - K. F. Walz, K. Debertin, H. Schrader, Int. J. Appl. Radiat. Isotop. **34**(1983)1191 [$T_{1/2}$]
1985ZiZY - W. L. Zijp, report ECN-179, Petten (1985) [analysis methodology]
1986Al19 - D. E. Alburger, Nucl. Data Sheets 49 (1986) 237 [evaluation]
1992Ra08 - M. U. Rajput, T. D. MacMahon, Nucl. Instr. Meth. **A312**(1992)289 [analysis methodology]
1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instr. Meth. Phys. Res. **A312**(1992)349 [$T_{1/2}$]
1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. **A595**(1995)409 [Q]
1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instr. Meth. **A369**(1996)527 [ω]
1998Si17 - B. Singh, J. L. Rodrigues, S. S. M. Wong, J. K. Tuli, Nucl. Data Sheets **84**(1998)487 [log ft systematics]
2000He14 - R. G. Helmer, C. van der Leun, Nucl. Instr. Meth. **A450**(2000)35 [E_{γ}]
2000Wu08 - S.-C. Wu, Nucl. Data Sheets **91**(2000)1 [J^{π} , multipolarities]

⁵¹Cr - Comments on evaluation of decay data by E. Schönfeld and R. G. Helmer

1 Decay scheme

The decay scheme is complete since there is only one excited level in ⁵¹V below the decay energy and it is populated in this decay.

The J^π and half-life of the excited level are from the 1997Zh09 evaluation.
See 1973De60 for a very complete evaluation of the nuclear and atomic data related to this decay.

2 Nuclear Data

Q value is from Audi and Wapstra (1995Au04).

The half-life data, in days, are as follows:

26.0	(10)	1940Wa02	
26.5	(10)	1940Wa02	
26		1948Ho04	
27		1948Mi12	
27.75	(30)	1952Ly17	
27.9	(2)	1956Ka33	
27.8	(1)	1956Sc87	
27.85	(2)	1957Ka65	
28.04	(16)	1957Ka65	
27.75	(30)	1957Wr37	
27.82	(20)	1963Ho17	
27.701	(6)	1964Ma56	
27.5		1965Sa09	
27.7	(2)	1967LaZZ	superseded by 1975La16
27.80	(51)	1968Bo25	
27.704	(3)	1969MeZV	superseded by 1982RuZV
27.679	(17)	1970WaAA	superseded by 1983Wa26
27.76	(15)	1972Em01	
28.1	(17)	1973ArZI	
27.721	(26)	1973LaAA	superseded by 1975La16
27.750	(9)	1973Vi13	
27.703	(8)	1974Ts01	
27.72	(3)	1975La16	
27.690	(5)	1980Ho17	
27.71	(1)	1982ChZF	
27.705	(12)	1982DeYX	superseded by 1983Wa26
27.73	(1)	1982HoZJ	superseded by 1992Un01
27.704	(3)	1982RuZV	
27.71	(3)	1983Wa26	
27.7010	(12)	1992Un01	
27.703	(3)	Adopted value	

Three sets of half-life values were analyzed with the Limitation of Relative Statistical Weight, LRSW, method (1985ZiZY,1992Ra08) ; these sets had 21, 20, and 9 values. In all three cases the LRWS analysis increases the uncertainty of the 1992Un01 value from 0.0012 to 0.0021 in order to reduce its relative weight from 76% to 50%.

For all 21 values with uncertainties and not superseded, the LRSW weighted average is 27.7034 with an internal uncertainty of 0.0015, a reduced- $\chi^2 = 5.06$, and an external uncertainty of 0.0034. The largest contribution to this reduced- χ^2 is 2.7 from the first value from 1957Ka65. If this value is removed from the data, the remaining 20 values give an LRSW weighted average is 27.7026 with an internal uncertainty of 0.0015, a reduced- $\chi^2 = 2.49$, and an external uncertainty of 0.0024.

The third analysis was done with the nine values from the set of twenty which have uncertainties of ≤ 0.03 (namely, 1964Ma56, 1973Vi13, 1974Ts01, 1975La16, 1980Ho17, 1982ChZF, 1982RuZV, 1983Wa26, and 1992Un01). In this case the LRSW analysis gives a weighted average of 27.7025, an internal uncertainty of 0.0015, a reduced- χ^2 of 4.48, and an external uncertainty of 0.0032.

The adopted value of 27.703 (3) is consistent with all three of these results.

2.1 Electron Capture Transitions

The capture branching is determined from the $P_\gamma(320)$ value (see sec. 4.2).

The P_K etc. values from LOGFT and EC-CAPTURE codes agree quite well, namely

Level	P_K	LOGFT		EC-CAPTURE		
		P_L	P_{M+N}	P_K	P_L	P_M
0	0.892	0.0927	0.0154	0.8919 (17)	0.0934 (14)	0.0144 (6)
320	0.891	0.0935	0.0156	0.8910 (17)	0.0941 (14)	0.0145 (6)

The EC-CAPTURE values have been adopted.

2.3 Gamma Transitions

The internal-conversion coefficient of $\alpha = 0.00169$ (5) and $\alpha_K = 0.00154$ (3) are from the analysis of experimental data in 1985HaZA. These results are based on $\alpha = 0.00169$ (5) (1973Wi10) and α_K values of 0.00157 (8) (1969KaAA, as quoted in 1985HaZA), 0.00156 (8) (1970Ca17), 0.00146 (13) (1970Ri11), and 0.00153 (4) (1973Wi10). From $K/L = 11.3$ (6) and $L/M = 5.1$ (6) from 1969Dr01, one obtains $\alpha_L = 0.000136$ (8) and $\alpha_M = 0.000027$ (4). [An earlier evaluation by 1973De60 had available the latter three α_K values and deduced $\alpha_K = 0.00153$ (4) and from the above K/L and L/M ratios, $a = 0.00169$ (5).] Other measured values of α are 0.00162 (16) (1955Bu01), 0.0031 (2) (1955Es15), 0.0015 (2) 1956Of03, and 0.0016 (2) (1962Gu09) and those of α_K are 0.0029 (2) (1955Es15), 0.00138 (13) (1955Of01), 0.00146 (10) (1968Ri17, superseded by 1970Ri11), and 0.001527 (36) (1969WiAA, as quoted in 1985HaZA, superseded by 1973Wi10).

The mixing ratio, δ , deduced from these α_K and α_L and the conversion coefficients interpolated from the tables of 1976Ba63 is 0.40 (4). This compares reasonable well with the value of +0.465 (20) from the evaluation of 1997Zh09 which is based on the measured values of +0.43 (3) from (γ,γ') , +0.52 (7) from Coulomb excitation, and 0.49 (3) calculated from the adopted $B(E2)$ and half-life values.

3, 3.1, and 3.2 X Radiations and Auger Electrons

Data are from 1996Sc06.

4.1 Electron Emissions

The data are from the γ -ray and atomic data in sec. 2.1, 2.2, and 3. A comparison of these intensities (in %) and those from RADLST gives :

	EMISSION	RADLST
L Auger	147.6 (10)	146.17 (16)
K Auger	66.4 (6)	66.32 (5)
K-320	0.0152 (3)	0.0166 (13)
L-320	0.00134 (8)	0.0016 (10)

The adopted values are from Emission.

4.2 Photon Emissions

The energy is from 2000He14.

The LRSW analysis of 9 P_γ values gives the weighted average of 9.87% (5) with a reduced- $\chi^2 = 0.96$. The input values are: 9.8 6 (1955Bu01), 9 1 (1955Co56), 9.72 15 (1963MeZZ), 10.20 63 (1965Dh01), 9.75 20 (average of 2 values of 1965Le24), 10.2 10 (1970Ri11), 9.85 9 (1980Sc07), 10.30 19 (1984Fi10), and 9.86 8 (1991Ba11). Others: \approx 2 (1940Wa02), 3 (1945Br02), 8 (1952Ly17), 21 (1952Ma49), 9.8 (1955Bi29), 7 (1955Co56), and 10.1 3 (1970ScAA, replaced by 1980Sc07). [From a set of five values, the evaluation of 1973De60 gives a result of 9.83% (14).]

The number of X rays was calculated, by the Emission program, from the γ -ray probabilities and atomic data in sec. 2.1, 2.2, and 3.

7. References

- 1940Wa02 - H. Walke, F. C. Thompson, J. Holt, Phys. Rev. **57** (1940) 171 [$T_{1/2}$]
 1945Br02 - H. Bradt, P. C. Gugelot, O. Huber, H. Medicus, P. Preiswerk, P. Scherrer, Helv. Phys. Acta **18** (1945) 252 [P_γ]
 1948Ho04 - H.H.Hopkins Jr., B.B.Cunningham, Phys.Rev. **73** (1948) 1406 [$T_{1/2}$]
 1948Mi12 - D.R.Miller, R.C.Thompson, B.B.Cunningham, Phys.Rev. **74** (1948) 347 [$T_{1/2}$]
 1952Ly17 - W.S.Lyon, Phys.Rev. **87** (1952) 1126 [$T_{1/2}$]
 1952Ma49 - D. Maeder, P. Preiswerk, A. Steinemann, Helv. Phys. Acta **25** (1952) 46 [P_γ , α_K]
 1955Bi29 - A.Bisi, E.Germagnoli, L.Zappa, Nuovo cimento **2** (1955) 1052 [P_γ]
 1955Bu01 - M. E. Bunker, J. W. Starner, Phys. Rev. **97** (1955) 1272 and **99** (1955) 1906 [P_γ , α , δ]
 1955Co56 - S. G. Cohen, S. Ofer, Phys. Rev. **100** (1955) 856 [Bremsstrahlung]
 1955Es15 - I. V. Estulin, E. M. Moiseeva, Sov. Phys. JETP **1** (1955) 463 [α , α_K]
 1955Of01 - Z. O'Friel, A. H. Huber, Phys. Rev. **99** (1955) 659, abstr. V5 [α_K]
 1956Ka33 - P.Kafalas, J.W.Irvine, Jr., Phys.Rev. **104** (1956) 703 [$T_{1/2}$]
 1956Of03 - Z. O'Friel, A. H. Huber, Phys. Rev. **101** (1956) 1076 [α]
 1956Sc87 - R. P. Schumann, M. E. Jones, A. C. Mewherter, J. Inorg. Chem. **3** (1956) 160 [$T_{1/2}$]
 1957Ka65 - G.M.Karavaev, S.A.Rusinova, Trudy Vsesoyuz.Nauch.- Issledovatel. Inst. Metrol. **30** (1957) 132 [$T_{1/2}$]
 1957Of07 - S. Ofer, R. Wiener, Phys. Rev. **107** (1957) 1639 [P_γ]
 1957Wr37 - H.W.Wright, E.I.Wyatt, S.A.Reynolds, W.S.Lyon, T.H.Handley, Nuclear Sci.and Eng. **2** (1957) 427 [$T_{1/2}$]
 1962Fa02 - U.Fasoli, C.Manduchi, G.Zannoni, Nuovo cimento **23** (1962) 1126 [P_K , P_L]
 1962Gu09 - U. C. Gupta, M. G. Shanani, P. K. Srivastava, J. Sci. Industr. Res. **21B** (1962) 1 [α]
 1963Ho17 - S.Hontzeas, L.Yaffe, Can.J.Chem. **41** (1963) 2194 [$T_{1/2}$]

- 1963Kr02 - I.Y.Krause, Phys.Rev. **129** (1963) 1330 [γ mixing ratio]
 1963MeZZ - J. S. Merritt, J. G. V. Taylor, AECL-1778 (1963) 31 [P_γ]
 1964Ma56 - P. J. Marais, F. J. Haasbroek, J. H. M. Karsten. S. Afr. J. Agr. Sci. 7 (1964) 881 [$T_{1/2}$]
 1965Dh01 - K. C. Dhingra, U. C. Gupta, N. P. S. Sidhu, Current Sci. (India) 34 (1965) 504 [P_γ]
 1965Le24 - J. Legrand, report CEA-R-2813 (1965) [P_γ]
 1965Sa09 - S.R.Salisbury, R.A.Chalmers, Phys.Rev. **140** (1965) B305 [$T_{1/2}$]
 1966He07 - W.Heuer, Z.Physik **194** (1966) 224 [P_K, P_L]
 1967LaZZ - F.Lagoutine, Y.Le gallic, J.Legrand, Proc.Symp.Standardization of radionuclides, Vienna, Austria(1966), Intern.At.Energy Agency, Vienna, (1967) 603; CONF-661012 [$T_{1/2}$]
 1968Bo25 - M.Bormann, A.Behrend, I.Riehle, O.Vogel, Nucl.Phys. **A115** (1968) 309 [$T_{1/2}$]
 1968Ri17 - C. Ribordy, J. Kern, L. Schellenberg, O. Huber, Helv. Phys. Acta **41** (1968) 429 [α_K]
 1969Dr01 - O.Dragoun, C.Ribordy, O.Huber, Nucl.Phys. **A124** (1969) 337 [α]
 1969KaAA - J. W. Kane, Jr., Thesis, University of Alabama (1969) [α_K]
 1969MeZV - J. S. Merritt, J. G. V. Taylor, report AECL-3512, p.30 [$T_{1/2}$]
 1969WiAA - J. B. Willet, Thesis, Indiana University (1969) [α_K]
 1970Ca17 - H. C. Carter, J. H. Hamilton, Z. Phys. **235** (1970) 383 [α_K]
 1970Ho16 - R.N.Horoshko, D.Cline, P.M.S.Lesser, Nucl.Phys. **A149** (1970) 562 [γ mixing ratio]
 1970Ri11 - C. Ribordy, O. Huber, Helv. Phys. Acta **43** (1970) 345 [E_γ, α_K]
 1970ScAA - U. Schötzig, H. M. Weiss, K. F. Walz, Wissenschaftliche Abhandlungender Phys.-Techn. Bundesanstalt **22** (1970) 76 [P_γ]
 1970WaAA - K. F. Walz, U. Schötzig, Wissenschaftliche Abhandlungen der Phys.-Techn. Bundesanstalt **22** (1970) 76 [$T_{1/2}$]
 1972Em01 - J.F.Emery, S.A.Reynolds, E.I.Wyatt, G.I.Gleason, Nucl.Sci.Eng. **48** (1972) 319 [$T_{1/2}$]
 1973ArZI - J.Araminowicz, J.Dresler, INR-1464 (1973) 14 [$T_{1/2}$]
 1973De60 - E. De Roost, F. Lagoutine, At. Energy Rev. **11** (1973) 642 [$\alpha, \delta, T_{1/2}, P_K, P_L$]
 1973LaAA - F. Lagoutine, to be published as quoted in 1973De60 [$T_{1/2}$]
 1973Vi11 - C. J. Visser, J. H. M. Karsten, F. J. Haasbroek, P. G. Marais, Agrochemophisica **5** (1973) 15 [$T_{1/2}$]
 1973Wi10 - J. B. Willett, G. T. Emery, Ann. Phys. (New York) **78** (1973) 496 [α_K, δ]
 1974Ts01 - C. W. Tse, J. N. Mundy, W. D. McFall, Phys. Rev. C **10** (1974) 838 [$T_{1/2}$]
 1975Bo07 - G.L.Borchert, W.Scheck, K.P.Wieder, Z.Naturforsch. **30a** (1975) 274 [E_γ]
 1975La16 - F. Lagoutine, J. Legrand, C. Bac, Intern. J. Appl. Radiat. Isotop. **26** (1975) 131 [$T_{1/2}$]
 1976Ba63 - I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, Atomic Data Nucl. Data Tables **18** (1976) 433 [α_K, α_L]
 1978Kr19 - K.S.Krane, At.Data Nucl.Data Tables **22** (1978) 269 [δ]
 1978Mo22 - T.Morii, Nucl.Instrum.Methods **151** (1978) 489 [E_γ]
 1980Ho17 - H. Houtermans, O. Milosevic, F. Reichel, Intern. J. Appl. Radiat. Isotop. **31** (1980) 153 [$T_{1/2}$]
 1980RuZY - A. R. Rutledge, L. V. Smith, J. S. Merritt, report AECL-6692 (1980) [$T_{1/2}$]
 1980Sc07 - U. Schötzig, K. Debertin, K. F. Walz, Nucl. Instr. and Meth. **169** (1980) 43 [E_γ, P_γ]
 1982ChZF - P. Christmas, report NBS-SP-6262 (1982) 100 [$T_{1/2}$]
 1982DeYX - K.Debertin, U.Schotzig, K.F.Walz, NBS-SP-626 (1982) 101 [$T_{1/2}$]
 1982RuZV - A. R. Rutledge, L. V. Smith, J. S. Merritt, report NBS-SP-626 (1982) 5 [$T_{1/2}$]
 1983Wa26 - K. F. Walz, K. Debertin, H. Schrader, Intern. J. Appl. Radiat. Isot. **34** (1983) 1191 [$T_{1/2}$]
 1984Fi10 - S. A. Fisher, R. I. Hershberger, Nucl. Phys. **A423** (1984) 121 [P_γ, P_ϵ]
 1985HaZA - H. H. Hansen, European Appl. Res. Rept. Nucl. Sci. Technol. **6**, 4 (1985) 777; EUR 9478 EN [α, α_K]
 1985ZiZY - W. L. Zijp, report ECN-179, Petten (1985) [analysis methodology]
 1991Ba11 - T. Barta, L. Szücs, A. Zsinka, Appl. Radiat. Isot. **42** (1991) 490 [P_γ]
 1992Ra08 - M. U. Rajput, T. D. MacMahon, Nucl. Instr. Meth. **A 312** (1992) 289 [analysis methodology]
 1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instr. and Meht. **A312** (1992) 349 [$T_{1/2}$]
 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. **A595** (1995) 409 [Q_ϵ]
 1995ScZY - E. Schönfeld, report PTB-6.33-95-2 (1995) [P_{ec}]
 1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instr. Meth. **A 369** (1996) 527 [ω]
 2000He14 - R..G. Helmer, C. van der Leun, Nucl. Instr. Meth. **A 450** (2000) 35 [E_γ]

**⁵⁴Mn - Comments on evaluation of decay data
by R. G. Helmer and E. Schönfeld**

1 Decay scheme

The decay scheme is complete since the only level in ⁵⁴Cr below the decay energy is populated in this decay. The β⁻ decay to ⁵⁴Fe is negligible.

The J^π and half-life of the excited level are from the 1993Hu04 evaluation.

2 Nuclear Data

Q value is from Audi and Wapstra 1995 (1995Au04) evaluation.

The half-life data, in days, are as follows:

291 (1)	1955Ba10	omitted from analysis
290 (6)	1956Ka33	omitted from analysis
278 (5)	1956Sc87	omitted from analysis
313.5 (7)	1961Wy01	
300	1964Be26	omitted from analysis
303 (1)	1964Ma14	omitted from analysis
311.9 (2)	1965An07	
311.9 (2)	1965An07	
312.6 (4)	1965An07	
314	1965Sa09	omitted from analysis
312 (5)	1968Ha47	
312.2 (3)	1968La10	quoted σ of 0.9 divided by 3
312.99 (5)	1968Zi01	quoted σ of 0.10 divided by 2, omitted from analysis
312.2 (9)	1969BoZX	
312.16 (11)	1973MeYE	superseded by 1982RuZV
315.40 (3)	1973Vi13	omitted from analysis
312.6 (8)	1974Cr05	
312.21 (5)	1979MeZY	superseded by 1980RuZY
312.21 (3)	1980RuZY	superseded by 1982RuZV
312.02 (4)	1982HoZJ	superseded by 1992Un01
312.21 (3)	1982RuZV	
312.19 (13)	1982RyZX	
312.15 (23)	1982RyZX	
312.028 (34)	1992Un01	
312.11 (5)	1997Ma75	
312.13 (3)	Adopted value	

The three values from before 1960 were omitted because it would have been difficult to determine the presence of impurities in the samples with the spectrometry methods available then. The two values without uncertainties were omitted. The quoted uncertainty for the value of 1968La10 was divided by 3 to convert it to a 1σ value. The values of 1964Ma14, 1968Zi01, and 1973Vi13 were omitted since they are outliers; with the latter two both included the reduced- χ^2 is 21.7 and with only 1968Zi01 included, it is 7.4.

Adopted value of 312.13 (3) is from the Limitation of Relative Statistical Weight analysis (1985ZiZY, 1992Ra08) of the 13 remaining values. For this fit, the internal uncertainty is 0.020, the reduced- $\chi^2 = 2.06$, and the external uncertainty is 0.029. In this analysis, the three values from 1992Un01, 1982RuZV, and 1997Ma75 contribute 94% of the relative weight, and the latter two which are from the same laboratory contribute 60% of the relative weight.

2.1 and 2.2 Electron-Capture and β^+ Transitions

The unique 2nd forbidden $\epsilon + \beta^+$ transition to the ⁵⁴Cr ground state has not been observed, but an upper limit can be determined from the $\log ft$ systematics (1998Si17) as well as from searches for the positrons. From these $\log ft$ systematics, $\log f_{2ut} > 13.9$ which corresponds to $\epsilon + \beta^+$ branch of $< 0.0007\%$. The experimental limits on the β^+ intensity come from searches for the 511-keV annihilation radiation. These limits are $\leq 8 \times 10^{-5}\%$ (1968Be01), $\leq 4.4 \times 10^{-6}\%$ (1989Su08), and $\leq 5.7 \times 10^{-7}\%$ (1993Da20). From the latter value and the theoretical ϵ/β^+ ratio of 638(11), one has a capture probability of $\leq 0.0004\%$. Since this limit is lower than that from the $\log ft$ systematics, it is adopted.

The P_K etc. values for the branch to the 834-keV level from the LOGFT and EC-CAPTURE codes agree quite well, namely

	P_K	P_L	P_M
LOGFT	0.8895	0.0942	0.0163
EC-CAPTURE	0.8895 (17)	0.0950 (15)	0.0150 (16)

The EC-CAPTURE values have been adopted.

2.3 β^- Transitions

This unique 2nd forbidden β^- transition to the ⁵⁴Fe ground state has not been observed. A limit on its probability can be calculated from the $\log ft$ systematics (1998Si17) which give $\log f_{2ut} \geq 13.9$ and this corresponds to $I(\beta^-) \leq 0.0005\%$.

From cosmic-ray data and a model of galactic transport of cosmic rays, 1996Du15 deduce the partial half-life for β^- decay to be between 1×10^6 and 2×10^6 years, which corresponds to a β^- branch intensity between 0.00004% and 0.00009%.

2.4 Gamma Transitions and Internal-Conversion Coefficients

The α and α_K are from the analysis of the experimental data in 1985HaZA and, are based only on the data of 1966Ha07. The corresponding theoretical values interpolated from the tables of 1976Ba63 are 0.000252(8) and 0.000224(7) were α has been computed as $\alpha_K + 1.33 \times \alpha_L$.

3, 3.1 and 3.2 Atomic Data

Data are from 1996Sc06.

4.1 Electron Emissions

The data are deduced from the γ -ray probabilities and atomic data in sec. 2.1, 2.2, and 3.

A comparison of these intensities with those from the RADLIST code for this decay scheme is:

	Radlist	EMISSION
L Auger	143.3 (4)	143.0 (6)
K Auger	63.21 (12)	63.3 (5)
K-834	0.0224 (13)	0.0224 (11)
L-834	0.002199	0.00220 (13)

4.2 Photon Emissions

The energy is from the 2000He14 evaluation.

The γ -ray emission probability is computed as $I_{\epsilon}(834) / [1.0 + \alpha(834)] = 99.9997(3) / 1.000251(11) = 99.9746(11)$. The dominant component in the final uncertainty is from the uncertainty in α .

A comparison of the computed X-ray emission probabilities is:

	RADLST	EMISSION
K _{α2}	7.659 (15)	7.66 (13)
K _{α1}	15.04 (3)	15.0 (3)
K _{β}	3.056 (6)	3.05 (6)
K	25.76 (3)	25.7 (3)

And, the measured Cr K X ray emission probabilities include:

25.7 (4)	1963Ta19
24.3 (12)	1965Le21
25.14 (17)	1967Ba50
24.90 (53)	1967PeZZ
24.92 (17)	1968Ha47
24.4 (3)	1973KoAA
24.7 (9)	1973MuAA
25.93 (14)	1978Ma06
25.1 (7)	1980Co22

which are slightly lower than the calculated values, but generally are within the uncertainties.

6. References

- 1955Ba10 - E. W. Backofen, R. H. Herber, Phys. Rev. **97**(1955)743 [T_{1/2}]
 1956Ka33 - P. Kafalas, J. W. Irvine, Jr., Phys. Rev. **104**(1956)703 [T_{1/2}]
 1956Sc87 - R. P. Schuman, M. E. Jones, and A. C. McWherter, J. Inorg. Nucl. Chem. **3**(1956)160 [T_{1/2}]
 1961Wy01 - E. I. Wyatt, S. A. Reynolds, T. H. Handley, W. S. Lyons, H. A. Parker, Nucl. Sci. Eng. **11**(1961)74 [T_{1/2}]
 1963Ta19 - J. G. V. Taylor, J. S. Merritt, Proc. Intern. Conf. Role of Atomic Electrons in Nuclear Transformations, Warsaw, vol. III, p. 465 (1963) [P_x]
 1964Be26 - G. Ben-David, Nucl. Sci. Eng. **20**(1964)281 [T_{1/2}]
 1964Ma14 - W. H. Marin, D. M. Clare, Nucl. Sci. Eng. **19**(1964)465 [T_{1/2}]
 1965An07 - S. C. Anspach, L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, C. N. Smith, report NP-15663(1965) [T_{1/2}]
 1965Ta10 - J. G. V. Taylor, J. S. Merritt, report AECL-2501(1965)26 [T_{1/2}]
 1965Le21 - K. F. Leistner, Atomkerenergie **10**(1965)311 [P_x]
 1965Sa09 - S. R. Salisbury, R. A. Chalmers, Phys. Rev. **140**(1965)B305 [T_{1/2}]
 1966Ha07 - J. H. Hamilton, S. R. Amtey, B. van Nooijen, A. V. Ramayya, J. J. Pinajian, Phys. Letters **19**(1966)682 [α]
 1967Ba50 - W. Bambynek, Z. Phys. **206**(1967)66 [P_x]
 1967PeZZ - M. Petel, H. Houtermans, "Standardization of Radionuclides", (IAEA, Vienna, 1967) 301 [P_x]
 1968Be01 - D. Berenyi, D. Varga, B. Vasvari, E. Brucher, Nucl. Phys. **A106**(1968)248 [I_{β+}]
 1968Ha47 - J. W. Hammer, Z. Phys. **216**(1968)355 [P_x]
 1968La10 - F. Lagoutine, Y. le Gallic, J. Legrand, Intern. J. Appl. Radiat. Isot. **19**(1968)475 [T_{1/2}]
 1968Zi01 - W. H. Zimmer, R. E. Dahl, Nucl. Sci. Eng. **32**(1968)132 [T_{1/2}]
 1969BoZX - P. Bock, report KFK-1116 10/14/71 (1969) [T_{1/2}]
 1973MeYE - J. S. Merritt, J. G. V. Taylor, report AECL-4657(1974)30 [T_{1/2}]
 1973KoAA - A. A. Konstantinov, T. E. Sazonova, A. Konstantinov, Proc. Intern. Conf. Inner-Shell Ionization Phenomena and Future Applications, April 1972(1973) page 144 [P_x]
 1973MuAA - A. Mukerji, Chin Lee, Proc. Intern. Conf. Inner-Shell Ionization Phenomena and Future Applications, April 1972 (1973) page 164 [P_x]
 1973Vi13 - C. J. Visser, J. H. M. Karsten, F. J. Haasbroek, P. G. Marias, Agrochemophysica **5**(1973)15 [T_{1/2}]
 1974Cr05 - P. J. Cressy, Jr., Nucl. Sci. and Eng. **55**(1974)450 [T_{1/2}]
 1976Ba63 - I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, Atomic Data and Nuclear Data Tables **18**(1976)433 [α_K, α_L]
 1978Ma06 - P. Magnier, J. Bouchard, M. Blondel, J. Legrand, J.-P. Perolat, R. Vatin, Z. Phys. **A284**(1978)383 or 389 [P_{1/2}]
 1979MeZY - J. S. Merritt, A. R. Rutledge, L. V. Smith, F. H. Gibson, report NEANDC(CAN)-51/L (1979) 12 [T_{1/2}]
 1980Co22 - D. D. Cohen, Nucl. Instr. Meth. **178**(1980)481 [P_x]
 1980RuZV - A. R. Rutledge, L. V. Smith, J. S. Merritt, report AECL-6692 (1980) [T_{1/2}]
 1982HoZJ - D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger, report NBS-SP-626 (1982) 85 [T_{1/2}]
 1982RuZV - A. R. Rutledge, L. V. Smith, J. S. Merritt, report NBS-SP-6262 (1982) 5 [T_{1/2}]
 1982RyZX - A. Rytz, report NBS-SP-6262 (1982) 32 [T_{1/2}]
 1985HaZA - H. H. Hansen, European App. Res. Reports, Nucl. Sci. and Technol. **6**, No. 4 (1985) 777; EUR 9478 EN [α]
 1985ZiZY - W. L. Zijp, report ECN-179, Petten (1985) [analysis methodology]

Comments on evaluation

- 1989Su08 - B. Sur, K. R. Vogel, E. B. Norman, K. T. Lesko, R.-M. Larimer, E. Browne, Phys. Rev. **C39**(1989)1511 [$T_{1/2}$]
- 1992Ra08 - M. U. Rajput, T. D. Mac Mahon, Nucl. Instr. Meth. **A312**(1992)289 [analysis methodology]
- 1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instr. Meth. **A312**(1992)349 [$T_{1/2}$]
- 1993Da20 - M. T. F. da Cruz, Y. Chan, A. Garcia, M. M. Hindi, G. Kenchian, R.-M. Larimer, K. T. Lesko, E. B. Norman, R. G. Stokstad, F. E. Wietfeldt, I. Zlimer, Phys. Rev. **C48**(1993)31110 [ϵ , β^+]
- 1993Hu04 - J. Huo, H. Sun, W. Zhao, Q. Zhou, Nucl. Data Sheets **68**(1993)887 [J, $T_{1/2}$]
- 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. **A595**(1995)409 [Q]
- 1996Du15 - M. A. DuVernois, Phys. Rev. **C54**(1996)A2134 [$T_{1/2}$]
- 1997Ma75 - R. H. Martin, K. I. W. Burns, and J. V. G. Taylor, Nucl. Instr. Meth. **A390**(1997)267 [$T_{1/2}$]
- 1998Si17 - B. Singh, J. L. Rodriguez, S. S. M. Wong, J. K. Tuli, Nucl. Data Sheets **84**(1998)487 [log ft systematics]
- 2000He14 - R. G. Helmer, C. van der Leun, Nucl. Instr. Meth. **A450**(2000)35 [E_γ]

Mn-56 – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: November 1999
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A reasonably simple and consistent decay scheme has been constructed from the gamma-ray measurements of 1967Au01, 1968Sh07, 1973Ar15, 1974Ti01, 1974Ho25 and 2004MiXX. Ten distinct gamma-ray emissions were identified with ⁵⁶Mn decay in these studies. An additional gamma ray at 3119.3 keV was identified by 1968Sh01, but this emission has been discarded due to a lack of evidence from the other studies.

Nuclear Data

The gamma-ray emissions of ⁵⁶Mn are reasonably well-defined, and this radionuclide has suitable decay characteristics for use as a calibrant over the gamma-ray energy range 840 to 2550 keV.

Half-life

Half-life adopted from the evaluation of Woods for the IAEA-CRP: Update of X- and Gamma-ray Decay Data Standards for Detector Calibration. The measurements of 1968Sh07, 1971GoYM, 1972Em01, 1973La12, 1980RuZY, 1992An13 and 1994Ya02 were considered.

Reference	Half-life (days)
1968Sh07	0.10771(4)
1971GoYM	0.10742(33)
1972Em01	0.10779(25)
1973La12	0.107438(8)
1980RuZY	0.107350(33)
1992An13	0.107454(4) [§]
1994Ya02	0.1040(20) [*]
Evaluated value	0.107449(18)

[§] Uncertainty increased to ± 0.000008 to ensure weighting factor not greater than 0.50.

^{*} Method development study: removed from data set due to uncharacteristically large uncertainty.

Woods evaluation for IAEA-CRP (2004WoZZ): recommended half-life of 0.107449(19) days or 2.57878 (46) h (using above data set, but also excluding 1994Ya02 data), adopted for this evaluation.

Gamma Rays

Energies

A number of well-defined gamma-ray energies were adopted from the recommended standards of 2000He14. All other gamma-ray energies were calculated from the structural details of the proposed decay scheme and the nuclear level energies of 1999Hu04 (as derived from the energy measurements of 1973Ar15, 1974Ho25 and 1974Ti01). An additional gamma ray with an energy of 3119.3(5) keV was only detected by 1968Sh01, and has been discarded due to a lack of evidence in all of the other studies.

Emission Probabilities

Weighted mean relative emission probabilities were determined for all of the gamma rays assigned to the decay scheme, using the relevant data from the measurements of 1967Au01, 1968Sh07, 1973Ar15, 1974Ho25, 1974Ti01 and 2004MiXX. All gamma-ray emissions were expressed relative to the 846.7638 keV transition, which was arbitrarily assigned an uncertainty of 3% (100(3)%).

Gamma-ray Emission Probabilities: Relative to $P_g(846.7638 \text{ keV})$ of 100%

$E_g(\text{keV})$	P_g^{rel}						
	1967Au01	1968Sh07	1973Ar15	1974Ho25	1974Ti01	2004MiXX	Recommended Values*
846.7638(19) [†]	100(3)	100(3)	100(3)	100(3)	100(3)	100.000(103)	100(3)
1037.8333(24) [†]	-	-	0.06(1)	0.03(1)	0.040(5)	-	0.040(4) [§]
1238.2736(22) [†]	-	-	0.14(3)	0.13(1)	0.10(1)	0.097(2)	0.098(2) [§]
1810.726(4) [†]	30(3)	29.4(16)	28.6(15)	26.9(13)	27.5(8)	26.610(72)	27.2(4)
2113.092(6) [†]	17.4(17)	16.0(9)	16.0(8)	14.3(7)	14.5(4)	13.956(53)	14.4(3) [§]
2523.06(5) [‡]	1.10(15)	1.6(5)	1.14(5)	1.01(5)	1.00(3)	1.025(9)	1.03(2)
2598.438(4) [†]	-	-	0.026(5)	0.02(1)	0.019(2)	-	0.020(2)
2657.56(1) [‡]	0.60(10)	0.66(6)	0.71(4)	0.66(7)	0.66(2)	0.648(8)	0.652(7) [§]
2959.92(1) [‡]	0.31(6)	0.26(3)	0.30(2)	0.32(3)	0.31(1)	0.314(6)	0.311(5) [§]
3119.3(5) [#]	-	0.08(4)	-	-	-	-	-
3369.84(4) [‡]	0.22(5)	0.20(4)	0.15(2)	0.16(2)	0.17(1)	-	0.17(1)

[†] Energy adopted from 2000He14.

[‡] Energy calculated from the nuclear level energies specified by 1999Hu04.

[#] Energy from 1968Sh07, but transition not included in proposed decay scheme.

* Weighted mean values adopted using LWEIGHT, unless stated.

[§] Recommended values adopted from a combination of the normalised residuals and Rajeval methods (see 2004MaYY).

The normalisation factor for the gamma-ray emission probabilities was calculated from the proposed decay scheme via two routes:

(a) beta population of all ⁵⁶Fe nuclear levels derived from gamma-ray depopulation/population and summed, assuming β decay to ⁵⁶Fe ground state is zero (spin and parity considerations ($3^+ \rightarrow 0^+$)).

$$\begin{aligned} \text{for all nuclear levels populated by } \beta \text{ decay } \Sigma P_{\beta i} &= (101.163 \pm 1.479) \times \text{NF} = 100 \\ \text{NF} &= 0.989 \text{ (15)} \end{aligned}$$

(b) population of ⁵⁶Fe ground state by gamma transitions, assuming β decay to ⁵⁶Fe ground state is zero.

$$\begin{aligned} \Sigma P_{\gamma i} (1 + \alpha_i) \text{NF} &= [P_{\gamma}(3369.84 \text{ keV}) + P_{\gamma}(2959.92 \text{ keV}) + P_{\gamma}(2657.62 \text{ keV}) + \\ &P_{\gamma}(846.7638 \text{ keV}) (1 + \alpha_i)] \times \text{NF} = 100 \\ 101.163(23) \times \text{NF} &= 100 \\ \text{NF} &= 0.9885(3) \end{aligned}$$

Hence, a normalisation factor of 0.9885(3) was adopted on the basis of the more accurate determination.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by 1999Hu04 has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Studies of the internal conversion coefficients of the some of these gamma transitions support the proposed transition types: (97%M1 + 3%E2) for the 1810.726 keV gamma rays (taken from 1989Co01); (99.96%M1 + 0.04%E2) and 100%E2 for the 1037.8333 and 1238.2736 keV gamma rays, respectively (taken from 1974Ho25).

Multipolarity Assignments

Reference	E _g (keV)	Multipolarity
1974Ho25	1037.83	99.96%M1 + 0.04%E2
	1238.27	E2
	1810.726(4)	96.5%M1 + 3.5%E2
	2113.092(6)	93.4%M1 + 6.6%E2
	2523.06(5)	94.1%M1 + 5.9%E2
	2598.438(4)	93.4%M1 + 6.6%E2
1989Co01	1810.726(4)	97%M1 + 3%E2
	2113.092(6)	96%M1 + 4%E2

Beta-particle Emissions

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1999Hu04 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities

The beta-particle emission probabilities were calculated from the recommended gamma-ray emission probabilities and the theoretical internal conversion coefficients of 1976Ba63 (latter estimated by interpolation of the data). Log *ft* systematics can be applied to the beta-particle transition to the ground state of ⁵⁶Fe ($\Delta J=3$, $\Delta\pi = \text{no}$), with a lower limit for log *ft* of 13.9 (1998Si17), to give a beta-particle emission probability of < 0.0005 (set to zero).

Beta-particle Emission Probabilities

E _b (keV)	P _b
	Recommended Values*
250.2(3)	0.00020(2)
325.7(3)	0.0120(3)
572.6(3)	0.00040(4)
735.6(3)	0.145(3)
1037.9(3)	0.275(4)
1610.4(3)	0.00057(6)
2848.7(3)	0.566(7)

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

7 References

- 1967Au01 - R. L. Auble, W. C. McHarris, W. H. Kelly, The Decay Schemes of ⁵⁶Co and ⁵⁶Mn and their use as Calibration Standards, Nucl. Phys., A91(1967)225-237. [P_γ]
- 1968Sh07 - A. H. Sher, B. D. Pate, The Decay of ⁵⁶Co and ⁵⁶Mn, Nucl. Phys., A112(1968)85-96. [Half-life, P_γ]
- 1971GoYM - I. W. Goodier, M. J. Woods, A. Williams, Measurements of Nuclear Decay Schemes, Proc. Int. Conf. Chemical Nucl. Data, Canterbury, Editor: M. L. Hurrell (1971)175. [Half-life]
- 1972Em01 - J. F. Emery, S. A. Reynolds, E. I. Wyatt and G. I. Gleason, Half-Lives of Radionuclides – IV, Nucl. Sci. Eng., 48(1972)319-323. [Half-life]
- 1973Ar15 - G. Ardisson and C. Marsol, Niveaux de ⁵⁶Fe Peuplés dans la Désintégration de ⁵⁶Mn, Nucl. Phys., A212(1973)424-428. [P_γ]
- 1973La12 - F. Lagoutine and J. Legrand, Use of ⁵⁶Mn to Check Measuring Equipment, Nucl. Instrum. Meth., 112(1973)323. [Half-life]
- 1974Ho25 - S. Hofmann, Kernspektroskopische Untersuchungen zu den Termschemata der Kerne ⁵⁶Fe und ⁵⁶Co, Z. Phys., 270(1974)133-147. [P_γ]
- 1974Ti01 - K. G. Tirsell, L. G. Multhauf and S. Raman, Decays of ⁵⁸Mn, ⁵⁷Mn and ⁵⁶Mn, Phys. Rev., 10C(1974)785-794. [P_γ]
- 1976Ba63 - I. M. Band, M. B. Trzhaskovskaya and M. A. Listengarten, Internal Conversion Coefficients for Atomic Numbers Z = 30, At. Data Nucl. Data Tables, 18(1976)433. [ICC]
- 1980RuZY - A. R. Rutledge, L. V. Smith and J. S. Merritt, Decay Data for Radionuclides Used for the Calibration of X- and Gamma-Ray Spectrometers, AECL-6692(1980). [Half-life]
- 1989Co01 - S. P. Collins, S. A. Eid, S. A. Hamada, W. D. Hamilton and F. Hoyler, A Search for Mixed-symmetry States in the Mass A ~ 50 Region, J. Phys., G: Nucl. Part. Phys., 15(1989)321-332. [Multipolarity]
- 1992An13 - M. S. Antony, D. Oster and A. Hachem, Precise Determination of Half-lives of ⁵⁶Mn, ¹⁹³Os and ^{197,199}Pt, J. Radioanal. Nucl. Chem. Letts., 164(1992)303-308. [Half-life]
- 1994Ya02 - T. Yassine and I. Othman, A Simple Method for the Rapid Assessment of the Half Lives of Short-Lived Radionuclides, Appl. Radiat. Isot., 45(1994)271-273. [Half-life]
- 1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys., A595(1995)409. [Q value]
- 1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res., A369(1996)527-533. [X_K, X_L, Auger electrons]

- 1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from $Z = 11$ to $Z = 100$, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]
- 1998Si17 - B. Singh, J. L. Rodriguez, S. S. M. Wong and J. K. Tuli, Nucl. Data Sheets, 84(1998)487. [log ft]
- 1999Hu04 - Huo Junde, Nuclear Data Sheets for $A = 56$, Nucl. Data Sheets, 86(1999)315. [Nuclear structure, Energies]
- 1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from $Z = 5$ to $Z = 100$, PTB Report PTB-6.11-1999-1, February 1999. [X_K]
- 2000He14 - R. G. Helmer and C. van der Leun, Recommended Standards for γ -ray Energy Calibration (1999), Nucl. Instrum. Meth. Phys. Res., A450(2000)35-70. [E_γ]
- 2004MaYY - T. D. MacMahon, A. Pearce and P. Harris, Convergence of Techniques for the Evaluation of Discrepant Data, Appl. Radiat. Isot., 60(2004)275-281. [Statistical analyses]
- 2004MiXX - H. Miyahara, Y. Ogata, K. Fujiki, K. Katoh and N. Marnada, Highly-precise Measurements of the Relative Gamma-ray Intensities for ⁵⁶Mn and ⁷²Ga, Appl. Radiat. Isot., 60(2004)295-299. [P_γ]
- 2004WoZZ - M. J. Woods, Half-life Evaluations for IAEA-CRP on “Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications” (2004). [Half-life evaluation]

⁵⁷Co - Comments on evaluation of decay data**by V. P. Chechev and N. K. Kuzmenko****1. Decay Scheme**

The 2nd forbidden electron capture (EC) transitions to the 3/2⁻ excited levels of 14,413 keV and 366,74 keV have not been observed, as well as the 2nd forbidden unique EC transition to the 1/2⁻ ground state of ⁵⁷Fe. From the log ft systematics the log ft of the 2nd forbidden transitions should be greater than 11,1 and 10,8, respectively, and for the 2nd forbidden unique transition, greater than 12,9. From these, the upper limits on the EC branch probabilities to the 14,413 keV level and ground state of ⁵⁷Fe are obtained as < 0,003 % and < 0,00035 %, and for the EC branch to the 366,74 keV level ≤ 0,002%. The calculations of the level probability balance in the decay scheme of ⁵⁷Co were made not taking into account the first two unobserved transitions. The EC branch probabilities to the levels of 136,47 keV, 366,74 keV and 706,42 keV were obtained from an probability balance of the gamma transitions.

2. Nuclear Data

Q value is from Audi and Wapstra (1995Au04).

There are available eight measurement results of the half-life of ⁵⁷Co (Table 1).

Table 1. Measurement results and evaluation of the half-life of ⁵⁷Co

Reference	Data set "1"	Data set "2"	Data set "3"
	$\chi^2=39,2$ $(\chi^2)_7^{0,05}=14,1$	$\chi^2=14,5$ $(\chi^2)_6^{0,05}=12,6$	$\chi^2=14,5$ $(\chi^2)_6^{0,05}=12,6$
1997Ma75	271,68(9)	271,68(9)	271,68(9)
1992Un01	272,11(26)	272,11(26)	272,11(26)
1983Wa26	271,84(4)	271,84(4)	271,84(4)
1981Va11	271,90(9)	271,90(9)	271,90(9)
1980Ho17	271,77(5)	271,77(5)	271,77(5)
1972La14	271,23(21)	271,23(21)	271,23(21)
1972Em01	269,8(4)	Omitted	Omitted
1965An07	271,65(13)	271,65(13)	271,65(13)
Evaluated value 271,80(5) d			

The value of 269,8(4) days from 1972Em01 was omitted on statistical considerations (because of a large contribution to χ^2 and also on the Chauvenet's criterion). This leads to the data set "2" of the seven values which coincides with the final data "3" as the LRSW method in statistical processing of the set "2" does not change the relative statistical weights.

The computer program EV1NEW 2000Ch01 has chosen the weighted mean of 271,80(5) days with the tS (or MBAYS) uncertainty as $(\chi^2)^{0,05}_{n-1} < \chi^2 < 10(\chi^2)^{0,05}_{n-1}$ (see evaluation technique in 2000Ch01). Other statistical procedures give, UWM-271,74(10), WM-271,80(3), CHV-271,83(7), UINF-271,80(4), PINF-271,80(4), BAYS-271,80(5), LWM-271,80(4), IEXW-271,75(8), NORM-271,80(4), RAJ-271,80(3). The computer program LWEIGHT leads to 271,80(3) days, the weighted mean with the internal uncertainty (the external uncertainty is 0,042). (The other evaluations of half-life of ⁵⁷Co see in 1990Ni03 and 1998Bh11).

The adopted value for the half-life of ⁵⁷Co is 271,80(5) days.

Half-life of excited levels in ⁵⁷Fe

The half-life of the excited levels (136 and 14 keV) have been evaluated being : **8,8(5)** ns [using 1989Ra17 and 1978AlZX] and **98,0(3)** ns [from 1961Cl11, 1965Ki03, 1967Ec05, 1969Ho28, 1978AlZX, 1995Ah04], respectively.

2.1. Electron Capture Transitions

The energies of the electron capture, ϵ , transitions have been calculated from the Q value and the level energies deduced from gamma transition energies.

The P_K , P_L and P_M values have been obtained from the tables of Schönfeld (1998Sc28). The experimental P_K values are available for $\epsilon_{0,2}$ EC transitions to the level of 136,47 keV: 0,885(9) in 1968Ru04 ; 0,87(2) in 1969Bo49 ; 0,922(10) in 1973 Mukerji and 0,89(4) in 1990Si03.

The electron capture probabilities of $\epsilon_{0,2}$, $\epsilon_{0,3}$ and $\epsilon_{0,4}$ have been calculated from the balance of the evaluated $P_{\gamma+ce}$ values for the 136,47 keV, 366,74 keV and 706,42 keV levels, respectively, assuming negligible EC transitions to the 14,4 keV level and the ground state of ⁵⁷Fe.

The calculated value of the sum of $P_{\gamma+ce}$ for the 4 gamma transitions to the ground state of ⁵⁷Fe is 99,996 (19) %.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are the energies of the gamma rays plus the recoil energy.

The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma ray emission intensities and the total internal conversion coefficients (ICC). The ICC have been evaluated using the experimental information on the multipolarity admixture coefficients (see below) and the theoretical values from 1976Ba63.

The values of $\delta(E2/M1)$ have been adopted from the analysis of 1978Kr19 except for $\gamma_{2,1}$ which is obtained by weighting the 4 values of +0,120 from 1972Fo05, +0,116(1) from 1973Sc15, +0,1195(10) from 1975Co22 and +0,120(4) from 1972Kr15 (see also the evaluation of 1998Bh11). The weighted average of $\delta(E2/M1)$ for $\gamma_{2,1}$ is +0,1180(12).

The adopted values of $\delta(E2/M1)$ for other gamma transitions are 0,00223(18) for $\gamma_{1,0}$, +0,02 for $\gamma_{3,2}$, +0,083(5) for $\gamma_{4,3}$, +0,025(9) for $\gamma_{3,1}$, -0,45(5) for $\gamma_{3,0}$, +0,097(8) for $\gamma_{4,2}$ and -0,465(8) for $\gamma_{4,1}$.

There are many experimental values of ICC and the ratios of the fractional intensities of conversion electrons for $\gamma_{1,0}$, $\gamma_{2,1}$ and $\gamma_{3,0}$ which, with the exception of 1996Me11, support the adopted values of ICC:

$\gamma_{1,0}$	$\alpha_K=7,76(23)$, $\alpha_L=0,804(24)$ from 1976Ba63 $\alpha_K=7,35(19)$ from 1985HaZA K:L:M+=100:9,59(13):1,48(15) from 1971Po05
$\gamma_{2,1}$	$\alpha_K=0,0214(12)$, K/L+=8,2(6) from 1967Ha06 K:L:M+=100:9,0:1,5 from 1955Co31
$\gamma_{3,0}$	$\alpha_K=0,122(13)$, K/L+=8,6(5), $\alpha_T/\alpha_K=1,118(5)$ from 1967Ha06

There are 6 experimental values for the total ICC (α_T) of the low-energy gamma transition $\gamma_{1,0}$ (14,413 keV): 9,0(5) and 8,9(6) from 1965Ki03 ; 8,26(22) from 1965Mo22 ; 8,25(46) from 1966Sp06 ; 8,26(22) from 1968Ru04 and 8,19(18) from 1970Jo30. They can be compared to the adopted value of $\alpha_T=8,58(18)$.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The X-ray energies are based on the wavelengths in the compilation of 1967Be65 (Bearden).

The relative $K\beta/K\alpha$ emission probability is taken from 1998Be and 1997Lepy. They have shown that taking into account double-electron transitions with a simultaneous emission of a photon and Auger electron (the radiative Auger effect RAE) increases the value of $K\beta/K\alpha$ = from 0,1368(14) (1996Sc06) to 0,1419(19) (1998Be) or 0,1423(17) (1997Lepy). From these we have adopted $K\beta/K\alpha = 0,142(2)$.

The ratio $K\alpha_2/K\alpha_1$ is from 1996Sc06

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins).

The ratios $P(KLX)/P(KLL)$ and $P(KXY)/P(KLL)$ are taken from 1996Sc06.

4. Photon Emissions

4.1 X-Ray Emissions

The total absolute emission intensity of KX-rays (P_{XK}) has been computed using the adopted value of ω_K , the evaluated total absolute emission probabilities (sums) of K conversion electrons (P_{ceK}) and K electron capture ($P_{\epsilon K}$).

The absolute emission intensities of the KX-ray components have been computed from the total P_{XK} using the relative probabilities from sect. 3.2.

Below the measured values of $P_{K\alpha}$ and P_{XK} are compared to our calculated (evaluated) values:

	<i>Measured</i>		<i>Calculated</i>	
	1989 Debertin	1994Ar22	(evaluated)	
$P_{K\alpha}$, %	50,6(9)	50,1(5)	50,0(6)	

	<i>Measured</i>			<i>Calculated</i>	
	1968Ru04	1973 Mukerji	1978 Vylov	1989 Debertin	(evaluated)
P_{XK} , %	56,9(8)	58,4(17)	55,3(15)	56,0(11)	57,1(9)

The total absolute emission intensity of LX-rays has been computed using absolute sums P_{CeL} , P_{CeK} , P_{EK} , P_{EL} and atomic data of section 3.1 (ω_K , ω_{KL} , n_{KL}).

4.2. Gamma Emissions

The energies of the gamma rays $\gamma_{2,1}$ and $\gamma_{3,0}$ have been adopted from 1976Bo16 and 2000He14. The energies of other gamma rays have been obtained as the weighted means of measurement results listed in Table 2 or calculated from the decay scheme of ⁵⁷Co. The corrections to the revised energetic scale in 2000He14 (lowering the values by 5,80 ppm) do not change these values.

The evaluator has assumed no EC feeding to the ground and first excited states and used the total gamma-ray transition probabilities to these two states (except that for the 14,4-keV transition) to normalize the decay scheme (using adopted relative photon intensities from Table 3, conversion coefficients from Section 2.2). This procedure has produced a normalization factor of 0,8551(6).

The absolute gamma ray emission intensity for $\gamma_{1,0}$ (14,413 keV) has been computed as follows: $P'_\gamma(\gamma_{1,0}) = P'_{\gamma+ce}(\gamma_{1,0})/(1+\alpha_T(\gamma_{1,0}))$, where $P'_{\gamma+ce}(\gamma_{1,0}) = 87,57(16)$ comes from decay-scheme probability balance at the 14,4-keV level, and $\alpha_T(\gamma_{1,0})=8,58$. The deduced value of $P'_\gamma(\gamma_{1,0})=9,15(17)$ % can be compared with the experimental values, such as 9,5(2) % (1978Vylov), 9,54(12) % (1992ScZZ) and 9,16(15) % (1989Debertin). It agrees extremely well with the CRP experimental result from 1989 Debertin.

It should be noted also that the evaluated sum $P'_\gamma(\gamma_{2,0})+P'_\gamma(\gamma_{1,0})=19,86(23)$ % agrees well with the measured value of 19,84(17)% in 1971Ko19.

Table 2 - Measured and adopted energies of gamma-rays in the decays of ⁵⁷Co → ⁵⁷Fe and ⁵⁷Mn → ⁵⁷Fe

	1965Ki03	1965Sp06	1970Gr13	1971Ko19	1972He42	1974Ti01 ^a	1976Bo16	1980Ve05	WM	Adopted
$\gamma_{1,0}$			14,408(5)		14,41247(29)	14,410(6)			-	14,41295(31) ^b
$\gamma_{2,1}$			122,07(3)	122,06(2)		122,063(4)	122,06065(12)		-	122,06065(12)
$\gamma_{2,0}$			136,473(4)	136,47(3)		136,473(4)	136,47356(29)		-	136,47356(29)
$\gamma_{3,2}$	229,8(10)	230,6(6)	230,4(5)	230,4(6)		230,25(4)		230,29(2)	230,27(3)	230,27(3)
$\gamma_{4,3}$	339,7(4)	339,7(5)	339,7(3)	339,68(28)		339,60(6)		339,54(18)	339,61(9)	339,67(3) ^b
$\gamma_{3,1}$	352,5(4)	352,4(5)	352,5(3)	352,23(27)		352,32(3)		352,36(1)	352,34(2)	352,34(2)
$\gamma_{3,0}$	366,8(5)	366,7(5)	336,8(4)	367,0(5)		366,73(4)		366,75(1)	366,74(3)	366,74(3) ^b
$\gamma_{4,2}$	570,0(4)	570,3(4)	570,1(3)	570,04(28)		569,93(5)		569,92(4)	569,94(4)	569,94(4)
$\gamma_{4,1}$	692,1(3)	692,1(3)	692,1(2)	692,44(6)		692,00(3)		692,03(2)	692,02(2)	692,01(2) ^b
$\gamma_{4,0}$	706,4(4)	706,8(4)	706,6(3)	706,46(34)		706,54(22)		706,40(20)	706,50(20)	706,42(2) ^b

a Experimental values from the decay of ⁵⁷Mn

b Calculated from decay scheme using the energies of $\gamma_{2,1}$, $\gamma_{2,0}$, $\gamma_{3,2}$, $\gamma_{3,1}$, $\gamma_{4,2}$

Table 3 - Relative emission probabilities of gamma rays in the decay of ⁵⁷Co

γ	E_γ	1965Ki03	1965Ma38	1971Ko19	1974 HeYW	1980Sc07 ^a	1982Gr10	Average	Adopted
$\gamma_{1,0}$	14			$1,14(5) \cdot 10^4$					$10,70(20)$ ^b
$\gamma_{2,1}$	122	10^5	10^5	10^5	10^5	10^5	10^5	10^5	100
$\gamma_{2,0}$	136	$1,25(8) \cdot 10^4$	$1,20(1) \cdot 10^4$	$1,30(4) \cdot 10^4$	$1,29(7) \cdot 10^4$	$1,236(9) \cdot 10^4$	$1,245(30) \cdot 10^4$	$1,253(18) \cdot 10^4$ ^c	$12,53(18)$
$\gamma_{3,2}$	230		0,2(2)	0,5(5)					$4(4) \cdot 10^{-4}$
$\gamma_{4,3}$	340		2,9(3)	4,5(4)					$0,0045(4)$ ^d
$\gamma_{3,1}$	352		2,0(2)	3,7(4)					$0,0037(4)$ ^d
$\gamma_{3,0}$	367		0,7(1)	1,5(4)					$0,0015(4)$ ^d
$\gamma_{4,2}$	570		16(1)	19,4(11)	10(10)			$18(2)$ ^e	$0,018(2)$
$\gamma_{4,1}$	692		188(5)	183(11)	190(30)			$186(7)$ ^f	$0,186(7)$
$\gamma_{4,0}$	706		5,5(6)	6,2(6)				$5,8(6)$ ^g	$0,0058(6)$

^a In 1980Sc07 the absolute gamma-ray emission probabilities are reported: $P_{\gamma_{2,0}(136)}=10,58(8)\%$ and $P_{\gamma_{2,1}(122)}=85,59(19)\%$. Their ratio is $0,1236(9)$.

^b Calculated as described in the text

^c The LWEIGHT program (version 1.2) has used an unweighted average and expanded the uncertainty so range includes the most precise value of 1980Sc07 . It is reasonable choice because of disagreement of the experimental values some uncertainties of which are only statistical.

^d Adopted from 1971Ko19.

^e LWEIGHT has used a weighted average and expanded the uncertainty so range includes the most precise value of 1965Ma38.

^f The method of Limitation of Relative Statistical Weights (LRSW) increased the uncertainty of 1965Ma38 to 10,3.

^g The experimental uncertainty is adopted as the uncertainty of the evaluated value.

5. Electron emissions

The energies of the conversion electrons have been calculated from the gamma transition energies given in sect. 2.2 and the electron binding energies.

The emission intensities of the conversion electrons have been calculated using the transition probabilities given in sect. 2.1 and 2.2, the atomic data given in sect. 3, and the internal conversion coefficients given in sect. 2.2.

The low energy electron spectrum from the decay of ⁵⁷Co has been analysed in 1997KoZJ using a combined electrostatic spectrometers. They obtained the following intensity ratios for the main spectrum components: (LMM+LXY) / KLL / KLLX / KMX / K-14,4 / L-14,4 / (M+N)-14,4 = 49,3(38): 59,6(23): 15,2(6): 1,2(2): 49,9(18): 5,1(3): 0,80(4). These values agree mainly with our evaluated data on electron emissions apart from the intensity of L Auger electrons. Perhaps, the latter is connected with difficulties of the electron spectrum measurement in the energy region of 0,6-0,7 keV. The discrepancy takes place also for the L/(M+N) and K/(M+N) ratios.

Also in 1997KoZJ $L_1/L_2 = 15,7(5)$, $L_1/L_3=39,3(16)$, $M_{2,3}/M_1=0,076(4)$ have been measured for the gamma transition $\gamma_{1,0}$ (14,4 keV).

References

- 1955Co31 J. M. Cork, M. K Brice, L. C Schmid, Phys. Rev. 99 (1955) 703.
(Relative conversion electron intensities)
- 1965An07 S. C. Anspach, L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, C. N. Smith, In: NP-15663 1965. (Half-life)
- 1965Ki03 O. C. Kistner, A.W. Sunyar, Phys. Rev. 139 (1965) B295.
(Experimental ICC, gamma ray energies and relative emission probabilities)
- 1965Ma38 J. M. Mathiesen, J. P. Hurley, Nucl. Phys. 72 (1965) 475.
(Relative gamma ray emission probabilities)
- 1965Mo22 G. Moreau, G. Ambrosino, Compt. Rend. 261 (1965) 5438.
(Experimental ICC)
- 1966Sp06 E. H. Spejewski, Nucl. Phys. 82 (1966) 481.
(Experimental ICC and gamma ray energies)
- 1967Be65 J. A. Bearden, Revs. Modern Phys. 39 (1967) 78.
(X-ray energies)
- 1967Ha06 D. C. Hall, R. G. Albridge, Nucl. Phys. A91 (1967) 495.
(Experimental ICC)
- 1968Ru04 W. Rubinson, K. P. Gopinathan, Phys. Rev. 170 (1968) 969.
(Experimental ICC, P_K and P_{XK} values)
- 1969Bo49 H. E. Bosch, M. A. Farioli, N. Martin, M. C. Simon, Nuclear Instrum. Methods 73 (1969) 323. (Experimental P_K values)
- 1970Gr13 R. C. Greenwood, R. G. Helmer, R. J. Gehrke, Nuclear Instrum. Methods 77 (1970) 141.
(Gamma ray energies)
- 1970Jo30 D. P. Johnson, Phys. Rev. B1 (1970) 3551.
(Experimental ICC)
- 1971Ko19 J. Konijn, E. W. A. Lingeman, Nuclear Instrum. Methods 94 (1971) 389.
(Gamma ray energies and emission probabilities)

- 1971Po05 F. T. Porter, M. S. Freedman, Phys. Rev. C3 (1971) 2285.
(Relative conversion electron intensities)
- 1972Fo05 R. A. Fox, W. D. Hamilton, M. J. Holmes, Phys. Rev. C5 (1972) 853.
(Mixing ratios E2/M1 for gamma transitions)
- 1972He42 U. Heim, O. W. B. Schult, Z. Naturforsch.27a (1972) 1861.
(14,4 keV gamma ray energy)
- 1972Kr15 K. S. Krane, W. A. Steyert, Phys. Rev. C6 (1972) 2268.
(Mixing ratios E2/M1 for gamma transitions)
- 1972La14 F. Lagoutine, J. Legrand, C. Perrot, J. P. Brethon, J. Morel, Intern. J. Appl. Radiat. Isotop. 23 (1972) 219. (Half-life)
- 1973 Mukerji A. Mukerji, Lee Chin, In: Proc. of the Intern. Conf. on Inner-Shell Ionization Phenomena and future Applications, April 17-22, 1972, Conf-720404, USAEC-Technical Information Center, Oak Ridge, Tenn. (1973). (Experimental P_K and P_{XK} values)
- 1973Sc15 E. Schoeters, R. E. Silverans, L. Vanneste, Z. Phys. 260 (1973) 337.
(Mixing ratios E2/M1 for gamma transitions)
- 1974HeYW R. L. Heath, Gamma-Ray Spectrum Catalogue (1974), ANCR-1000-2.
(Relative gamma ray emission probabilities)
- 1974Ti01 K. G. Tirsell, L. G. Multhauf, S. Raman, Phys. Rev. C10 (1974) 785.
(Gamma ray energies)
- 1975Co22 E. J. Cohen, A. J. Becker, N. K. Cheung, H. E. Henrikson, Hyperfine Interact.1 (1975) 193. (Mixing ratios E2/M1 for gamma transitions)
- 1976Ba63 I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, At. Data Nucl. Data Tables 18 (1976) 433. (Theoretical ICC)
- 1976Bo16 G. I. Borchert, Z. Naturforsch. 31a (1976) 387.
(Gamma ray energies)
- 1977La19 F. P. Larkins, At. Data Nucl. Data Tables 20 (1977) 311.
(Auger electron emission)
- 1978Kr19 K. S. Krane, At. Data Nucl. Data Tables 22 (1978) 269.
(Mixing ratios E2/M1 for gamma transitions)
- 1978 Vylov C. Vylov, Preprint JINR R6-10416, Dubna, 1977.
(Experimental P_{XK} and $P(\gamma_{14,4 \text{ keV}})$ values)
- 1980Ho17 H. Houtermans, O. Milosevic, F. Reichel, Intern. J. Appl. Radiat. Isotop. 31 (1980) 153.
(Half-life)
- 1980Sc07 U. Schötzig, K. Debertin, K. F. Walz, Nuclear Instrum. Methods 169 (1980) 43.
(Relative gamma ray emission probabilities)
- 1980Ve05 R. Vennink, J. Kopecky, P. M. Endt, P. W. M. Glaudemans, Nucl. Phys. A344 (1980) 421. (Gamma ray energies)
- 1981Va11 R. Vaninbroukx, G. Grosse, W. Zehner, J. Appl. Radiat. Isotop. 32 (1981) 589.
(Half-life)
- 1982Gr10 A. Grutter, Intern. J. Appl. Radiat. Isotop. 33 (1982) 533.
(Relative gamma ray emission probabilities)
- 1983Wa26 K. F. Walz, K. Debertin, H. Schrader, Intern. J. Appl. Radiat. Isotop. 34 (1983) 1191.
(Half-life)
- 1985HaZA H. H. Hansen, In: European App. Res. Rept. Nucl. Sci. Technol. 6, No 4 (1985) 777.
(Compilation of experimental ICC)
- 1989 Debertin K. Debertin, U. Schötzig, informal IAEA CRP paper GS/55 (1989), quoted in IAEA-TecDoc-619 (1991) (Experimental KX and $\gamma_{1,0}$ (14,4 keV) absolute emission probabilities)

Comments on evaluation

- 1990Ni03 A. L. Nichols, Nucl. Instrum. Methods Phys. Res. A286 (1990) 467.
(Half-life)
- 1990Si03 K. Singh, T. S. Gill, K. Singh, Appl. Radiat. Isot. 41 (1990) 333.
(Experimental P_K values)
- 1992ScZZ U. Schötzig, H. Schrader, K. Debertin. In: Proc. Inter. Conf. Nuclear Data for Science and Technology, Julich, Germany, 1992. P.562.
(Experimental $P_\gamma(14,4 \text{ keV})$ value)
- 1994Ar22 D. Arnold, G. Ulm, Nucl. Instrum. Methods Phys. Res. A339 (1994) 43.
(Experimental $K\alpha$ absolute emission probability)
- 1995Au04 G. Audi, A. H. Wapstra, Nucl. Phys. A595 (1995) 409.
(Q value)
- 1996Me11 R. Ya. Metskhvarishvili, Z. N. Miminoshvili, M. A. Elizbarashvili, L. V. Nekrasova, I. R. Metskhvarishvili, N. G. Khazaradze, N. M. Marchilashvili, I. V. Zhorzholiani, Yad. Fiz. 59, No 5 (1996) 773, Phys. Atomic Nuclei 59 (1996) 737.
(Relative conversion electron intensities and experimental ICC)
- 1996Sc06 E. Schönfeld, H. Janssen Nucl. Instrum. Methods Phys. Res. A369 (1996) 527.
(Atomic data)
- 1997 Lépy M.-C. Lépy, M.-M. Bé, J. Plagnard, In: CAARI'96 Conference proceedings AIP Press, 1067 (1997). (Experimental $K\beta/K\alpha$)
- 1997Ma75 R. H. Martin, K. I. W. Burns, J. G. V. Taylor, Nucl. Instrum. Methods Phys. Res. A390 (1997) 267. (Half-life)
- 1997KoZJ A. Kovalik, M. Rysavy, V. M. Gorozhankin, Ts. Vylov, D. V. Filosofov, M. A. Mahmoud, A. Minkova, N. Coursol, P. Casette, Ch. Briancon. Program and Thesis, Proc. 47th Ann. Conf. on Nucl. Spectrosc. Struct. At. Nuclei, Obninsk, 1997. P. 277.
(Relative low energy electron emission probabilities)
- 1998 Be M.- M. Bé, M.- C. Lépy, J. Plagnard, B. Duchemin, Applied Radiation Isotopes 49 (1998) 1367. (Experimental $K\beta/K\alpha$)
- 1998Bh11 M. R. Bhat, Nucl. Data Sheets 85 (1998) 415.
(Mixing ratios E2/M1 for gamma transitions)
- 1998Sc28 E. Schönfeld, Appl. Radiat. Isot. 49 (1998) 1353.
(Fractional electron capture probabilities P_K, P_L, P_M)
- 2000Ch01 V. P. Chechev, A. G. Egorov, Appl. Radiat. Isot. 52 (2000) 601.
(Evaluation technique)
- 2000He14 R. G. Helmer, C. van der Leun, Nucl. Instrum. Methods Phys. Res. A450 (2000) 35.
(Gamma ray energies)

⁵⁷Ni – Comments on evaluation of decay data by Shiu-Chin Wu

The *Limitation of Relative Statistical Weight* (1988WoZO) (LWM) method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. For two discrepant values, the method chooses the unweighted average. The uncertainty assigned to the recommended values was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

1. Decay Scheme

⁵⁷Ni decays by EC + β^+ to ⁵⁷Co states at 1377.65, 1504.81, 1757.58, 1919.55 and 2804.27 keV. The total β^+ branching has been measured by 1967Li08, 1962Ch20, 1958Ko60 and 1964Ru06. The weighted average of the results gives (45.9 ± 1.0) %, in agreement with the value of 43.5% predicted by theory [1; 1957Zw01].

2. Nuclear Data

The following values of the half-life of ⁵⁷Ni have been used to deduce a recommended value:

1	35.54(5) h	Dickens (1986)
2	35.65(5) h	Grutter (1982)
3	36.16(11) h	Rothman et al. (1974)
4	35.99(12) h	Ebrey and Gray (1965)
5	35.7(2) h	Rudstam (1964)
6	36.4(7) h	Friedlander et al. (1950)
7	35.7(10) h	Maienschein and Meem (1949)

The recommended half-life of ⁵⁷Ni, 35.9(3) h, is an average ($\chi^2/N-1=5.83$, LWM) of the seven values listed above. The LWM method changed the uncertainty of the averaged value from 0.1 h to 0.3 h, in order to overlap with the most precise value of 35.54 h. The value of 43.7(9) h by Rayburn (1961Ra06) differs from the average by about 8 σ , and was not included. Rudstam (1956Ru45) had previously reported a value of 37.6(5) h, which has been superseded by the more precise value of 35.7(2) h (1964Ru06) given above.

2.1 Electron Capture Transitions

Electron-capture energies given in Tables 2.2 have been deduced from the Q value and the level energies. EC + β^+ feedings to the levels are from gamma-ray emission probability balances. The electron-capture and positron emission probabilities to the individual levels are based on theoretical [1] β^+ /EC ratios. The fractional atomic shell electron-capture probabilities are theoretical values [1977Ba48] calculated with the EC-CAPTURE computer program [2]. EC decay to the ground state of ⁵⁷Co has not been observed. This transition would be 2nd forbidden non-unique, with a systematic *lg ft* value of 11.0 or higher. Its

corresponding probability, calculated with the LOGFT computer program [3], is less than 0.01%. Similarly, the EC decay to the 1st excited state has a probability of less than 0.001%.

2.2 Positrons Transitions

Electron-capture and β^+ end-point energies given in Tables 2.1 and 2.2 are equal to $Q_{EC} = 3264.2(26)$ keV (1995Au04) minus the individual level energies, and to the electron-capture energies minus $2 m_0c^2$ (1022 keV), respectively.

2.3 Gamma Rays

Gamma-ray energies were measured with Ge(Li) detectors by Scardino *et al.* (1990Sc23); Rothman *et al.* (1974HeYW); Gatrousis *et al.* (1969Ga14); Lingeman *et al.* (1967Li08) and Piluso *et al.* (1966Pi01). The energies adopted here are the LWM averages, which are usually dominated by the values of 90Sc23.

Adopted	1990Sc23	1974HeYW	1969Ga14	1967Li08	1966Pi01	χ^2_R
127.164(3)	127.164(3)	127.192(25)	127.1(1)	127.6(5)**	127.2(1)	0.59
161.86(3)	161.86(3)		161.8(3)			0.04
304.1(1)	304.1(1)					
379.94(2)	379.94(2)		380.0(2)			0.09
541.9(1)	541.9(1)					
673.44(4)	673.44(4)		673.4(2)			0.04
696.0(4)	696.0(4)					
755.3(1)	755.3(1)					
906.98(5)	906.98(5)		906.8(3)			0.35
1046.54(14) [#]	1046.68(3)		1046.4(2)			0.98
1223.8(3) [#]	1224.00(4)		1223.5(4)			0.78
1279.99(6)	1279.99(6)					
1350.52(6)	1350.52(6)					
1377.62(4)	1377.63(3)	1377.59(4)	1377.6(2)	1378.0(5)	1378.1(2)	1.7
1603.28(6)	1603.28(6)					
1730.45(6)	1730.44(6)		1730.6(3)			0.27
1757.55(3)	1757.55(3)	1757.48(8)	1757.6(2)	1758.2(6)**	1757.7(2)	0.45
1897.0(5) [#]	1897.42(4)		1896.5(4)			2.6
1919.62(14)	1919.52(5)	1919.43(8)	1919.5(2)	1919.9(6)	1920.2(1)	11
2133.04(5)	2133.04(5)		2132.9(3)			0.21
2730.76(14)	2730.91(4)		2730.6(2)	2731(2)		0.61
2804.08(15)	2804.20(3)		2803.9(2)	2805.1(9)		1.2
3177.27(5)	3177.28(5)		3176.9(3)	3177.3(12)		0.78

** Statistical outlier, omitted.

[#] The LWM chose the unweighted average for these discrepant values.

Gamma-ray emission probabilities relative to that of the 1377.62 keV γ -ray measured with Ge(Li) detectors were reported by Scardino *et al.* (1990Sc23); Grutter (1982Gr10); Rothman *et al.* (1974HeYW); Gatrousis *et al.* (1969Ga14); Lingeman *et al.* (1967Li08) and Piluso *et al.* (1966Pi01). The LWM averages have been adopted here.

E_γ keV	Adopted	1990Sc23	1982Gr10	1974HeYW	1969Ga14	1967Li08	1966Pi01	χ^2_R
127.164(3)	19.8(6)	20.4(4)	20.3(2)	16.6(10)	20.0(6)	17.6(9)	15.0(9)	10
161.86(3)	0.025(3) [#]	0.0278(8)			0.022(11)			14
304.1(1)	0.0024(7)	0.0024(7)						
379.94(2)	0.089(7) [#]	0.082(2)			0.10(5)			4.2
541.9(1)	0.0045(6)	0.0045(6)						
673.44(4)	0.0600(18)	0.0601(18) ¹⁾			0.06(3)			0.38
696.0(4)	0.0011(8)	0.0011(8)						
755.3(1)	0.0066(8)	0.0066(8)						
906.98(5)	0.092(18) [#]	0.075(2)			0.110(6)			20
1046.54(14)	0.163(4)	0.164(4)			0.16(1)			0.20
1223.8(3)	0.094(16) [#]	0.077(3)			0.110(6)			18
1279.99(6)	0.0118(9)	0.0118(9)						
1350.52(6)	0.0024(12)	0.0024(12)						
1377.62(4)	100(2)	100	100	100	100	100	100	
1603.28(6)	0.0048(8)	0.0048(8)						
1730.45(6)	0.068(4) [#]	0.064(3) ²⁾			0.072(4)			2.5
1757.55(3)	7.5(5)	7.04(20)	7.63(20)	9.1(8)	7.7(2)	9.5(5)	6.9(3)	6.1
1897.0(5)	0.031(3) [#]	0.034(3)			0.028(14)			2.0
1919.62(14)	15.4(7)	15.0(3)	17.0(4)	18.9(12)	17.0(5)	22.4(11) ³⁾	14.7(2)	10
2133.04(5)	0.041(6) [#]	0.035(2) ²⁾			0.047(24)			13
2730.76(14)	0.024(4)	0.0243(6)			0.03(2)	0.015(2)		18
2804.08(15)	0.126(21)	0.120(4)			0.17(1)	0.088(9)		23
3177.27(5)	0.019(5)	0.0136(7)			0.024(1)	0.021(3)		21

¹⁾ The relative intensity of the 673.44-keV γ -ray was listed in 1990Sc23 as 0.0601(15), and corrected as 0.0601(8) by Bhat (1992Bh05). However, a relative uncertainty of 1% for such a weak peak seems too low, it is probably a typographical error. We used 0.0601(18) here.

²⁾ As suggested by Bhat (1992Bh05), the intensity given in 1990Sc23 for the 1730.44 keV γ -ray (0.0614(3)) was changed to 0.064(3); and the uncertainty of the 2133.04 keV γ -ray (0.0350(2)) was increased by a factor of 10 here (possible typographical errors).

³⁾ Statistical outlier, omitted.

[#] The LWM chose the unweighted average for these discrepant values.

EC + β^+ feeding to the ground state of ^{57}Co has not been observed. A systematic $lg ft \geq 11.0$ for a second forbidden non-unique transition corresponds to $I_{\text{EC}} \leq 0.01\%$ for a possible EC transition to the ground state of ^{57}Co . Thus, we used the sum of the relative emission probabilities of the 1224.00 keV, 1377.63 keV, 1757.55 keV, 1897.42 keV, 1919.52 keV, 2133.04 keV, 2730.91 keV, 2804.20 keV and 3177.28 keV γ -rays to normalize the decay scheme. The 1377.62 keV gamma ray is the strongest transition, for which we used a fractional uncertainty of 2%, suggested by 1992Bh05. Similarly, for the first excited state at 1224 keV, a possible EC + β^+ transition would have a systematic $lg ft \geq 12.6$, which corresponds to an intensity $I_{\text{EC}} \leq 0.001\%$. Conversion coefficients used in these calculations are those of Band *et al.* [1976Ba63].

3. Atomic Data

The X-ray and Auger electron emission probabilities given in section 3 are values calculated by using the computer program EMISSION [4], the electron capture probabilities from section 2.2, and atomic data from 1996Sc06.

4. Radiation Emission

4.1 Electron Emission

The emission probabilities of the Auger electrons have been calculated here using the adopted nuclear and atomic electron capture transition data, and the program EMISSION [4]. The emission probabilities of conversion electrons were calculated using the adopted γ -ray emission probabilities and conversion coefficients (section 2.2).

4.2 Photon Emission

The emission probabilities of X-rays were calculated using the adopted nuclear and atomic electron capture transition data, and the program EMISSION [4]. The evaluation of the gamma-ray emission probabilities was discussed in section 2.3.

Total Average Radiation Energy

The total released average radiation energy (electron capture, neutrinos, nuclear recoil, photons and electrons) in the EC + β^+ decay of ⁵⁷Ni (calculated by using the computer program RADLST [5]) is 3264(32) keV. This value agrees well with 3264.2(26) keV from mass differences (1995Au04), and thus confirms the quality and completeness of the decay scheme.

References

- [1] - P. F. Zweifel, *Capture-Positron Branching Ratios*, Phys. Rev. **96**, 1572 (1954)
- [2] - Eckart Schönfeld, Frank Chu and Edgardo Browne, *EC-Capture*, a computer program to calculate electron-capture probabilities to various atomic shells for allowed and first-forbidden non-unique transitions. PTB, LBNL, Dec. 23, 1997.
- [3] - *The Program LOGFT*, National Nuclear Data Center, September 3, 1993.
- [4] - Herbert Janßen and Eckart Schönfeld, *EMISSION*, a computer program to calculate X-ray and Auger electron emission probabilities. PTB, Nov. 18, 1997.
- [5] - *The Program RADLST*, Thomas W. Burrows, report BNL-NCS-52142, February 29, 1988.
- 1949Ma38 F. Maienschein and J. L. Meem, Jr., *Coincidence Experiments in ⁶⁵Ni, ⁵⁷Ni, ¹¹⁰Ag and ¹¹⁴In*. Phys. Rev. **76**, 899 (1949)
- 1950Fr10 G. Friedlander, M. L. Perlman, D. Alburger, A. W. Sunyar, *Measurement of Absolute Electron Capture Rates with an Application to the Decay of ⁵⁷Ni*. Phys. Rev. **80**, 30 (1950)
- 1956Ru45 G. Rudstam, *Spallation of Medium Weight Elements*. Thesis, University of Uppsala (1956)
- 1957Zw01 P. F. Zweifel, *Allowed Capture-Positron Branching Ratios*, Phys. Rev. **107**, 329 (1957)

Comments on evaluation

- 1958Ko60 J. Konijn, H. L. Hagedoorn, B. van Nooijen, *Further Study on the Decay of ⁵⁷Ni*. Physica 24, 129 (1958)
- 1961Ra06 L. A. Rayburn, *14.4 MeV (n,2n) Cross Sections*. Phys. Rev. 122, 168 (1961)
- 1962Ch20 G. Chilosi, S. Monaro, R. A. Ricci, *Excited Levels in ⁵⁷Co from the Decay of ⁵⁷Ni*. Nuovo Cimento 26, 440 (1962)
- 1964Ru06 G. Rudstam, *Peripheral Reactions in Copper Induced by 19 GeV Protons*. Nucl. Phys. 56, 593 (1964).
- 1965Eb01 T. G. Ebrey, P. R. Gray, Precision, *Half-Life Measurements of Fourteen Positron-Emitting Nuclei*. Nucl. Phys. 61, 479 (1965).
- 1966Pi01 C. J. Piluso, D. O. Wells, D. K. McDaniels, *The Decay of ⁵⁶Ni and ⁵⁷Ni*. Nucl. Phys. 77, 193(1966).
- 1967Li08 E. W. A. Lingeman, J. Konijn, F. Diederix, B. J. Meijer, *The Decay of ⁵⁷Ni*. Nucl. Phys. A100, 136 (1967).
- 1969Ga14 C. Gatrousis, R. A. Meyer, L. G. Mann, J. B. McGrory, *Single-Particle and Core-Coupled States in ⁵⁷Co from the Decay of ⁵⁷Ni*. Phys. Rev. 180, 1052 (1969).
- 1974Ro18 S. J. Rothman, N. L. Peterson, W. K. Chen, J. J. Hines, R. Bastar, L. C. Robinson, L. J. Nowicki, J. B. Anderson, *Half-Lives of Nine Radioisotopes*. Phys. Rev. C9, 2272 (1974).
- 1976Ba63 I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, *Internal Conversion Coefficients for Atomic Numbers Z < 30*. At. Data Nucl. Data Tables 18, 433 (1976).
- 1977Ba48 W. Bambynek, H. Behrens, M. H. Chen, B. Crasemann, M. L. Fitzpatrick, K. W. D. Ledingham, H. Genz, M. Mutterer and R. L. Intemann, *Orbital Electron Capture by the Nucleus*, Rev. Mod. Phys. **49**, 77 (1977)
- 1982Gr10 A. Grutter, *Decay Data of ⁵⁵⁻⁵⁸Co, ⁵⁷Ni, ^{60,61}Cu and ^{62,63}Zn*. Int. J. Appl. Radiat. Isotop. 33, 533 (1982).
- 1986Di02 J. K. Dickens, *Half Life of ⁵⁷Ni*. J. Radioanal. Nucl. Chem. 103, 273 (1986).
- 1988WoZO M. J. Woods and A. S. Munster, *Evaluation of Half-Life Data*. NPL RS(EXT)95 (1988).
- 1990Sc23 A. M. S. Scardino, O. Helene, P. R. Pascholati, V. R. Vanin, *Beta Decay of ⁵⁷Ni*. Z. Phys. A336, 313 (1990).
- 1992Bh05 M. R. Bhat, *Nuclear Data Sheets Update for A = 57*. Nucl. Data Sheets 67, 195 (1992).
- 1995Au04 G. Audi and A. H. Wapstra, *The 1995 Update to the Atomic Mass Evaluation*. Nucl. Phys. **A595**, 409 (1995).
- 1996Sc06 E. Schönfeld and H. Janßen, *Evaluation of Atomic Shell Data*, Nucl. Instr. Meth. in Phys. Res. **A369**, 527 (1996).

⁵⁹Fe – Comments on evaluation of decay data by M.M. Bé and V. Chisté

1. Decay scheme

This decay scheme was well studied (Bérenyi, Béraud, Collin, Ferguson, Heath, Pancholi, Metzger, Raman, etc.) so that the existence of beta transitions and the spin and parity of the ⁵⁹Co levels are clearly established. Some authors (Mukerji, Raman) carried out experiments in order to measure the weak β- branches. No clear evidence of a β-branching to the 1190 keV level was found, if this transition exists its branching ratio has an upper limit of 1×10^{-4} .

2. Nuclear Data

⁵⁹Fe half-life (in days)

Author	NSR	Value	Uc	Method
Metzger	52Me53	45.0	3.0	NaI
Keene	58Ke26	44.56	0.03	ionisation chamber
Pierroux	59Pi43	45.60	0.08	Electrometer à lames vibrantes
Fuschini	60Fu03	63.1	0.8	
Heath	60He06	45.0	5.0	NaI
Subba Rao	60Su10	46.5	1.0	
Wortman	63Wo01	45.0	3.0	
Emery	72Em01	44.5	0.2	NaI
Visser	73Vi13	44.75	0.04	NaI (s x 3)
Alstad	75Al02	45.3	0.3	Gas flow proportional counter
Houtermans	80Ho17	44.496	0.007	4π-γ
Walz	83Wa26	44.53	0.07	4π-γ ionisation chamber
Unterweger	92Un01	44.5074	0.0072	
Martin	97Ma75	44.472	0.008	4π-γ ionisation chamber

The value from Fuschini was omitted due to its large deviation from the others.

The values from Subba Rao, Pierroux were rejected as outlier (Chauvenet' s criteria).

With this set of eleven remaining values, the reduced χ^2 is 6.4 and the Lweight program recommends the unweighted mean and expanded the uncertainty : 44.74 ± 0.24 .

With these eleven values the weighted mean and the external uncertainty are : 44.498 ± 0.011 .

Taking into account the most precise values (Keene, Visser, Houtermans, Walz, Unterweger and Martin) :

- the value from Visser was rejected as outlier;

- then the reduced $\chi^2 = 4$;

- the weighted mean is 44.495 with an external uncertainty of 0.008.

Regarding the fact that the four more recent measurements are compatible with this value and (for three of them) have a similar uncertainty, the recommended value is :

44.495 ± 0.008 d

Half-lives of ⁵⁹Co excited levelsLevel 1100 keV

- Sidhu : ≤ 50 ps
- Béraud < 14 ps

Level 1291 keV (in ns)

Author	NSR	Value	Uc
Sidhu :	67Si01	0.60	0.05
Agarwal :	67Ag03	0.59	0.02
Béraud :	67Be60	0.575	0.011
Garg :	72Ga39	0.538	0.004
Green :	72Gr05	0.564	0.020
Arens :	71Ar07	0.564	0.005

The value from Chauhan (0.516 (6)) was not taken into account : it seems that the experiment is the same as those described in Garg *et al.*

For the six values above the reduced χ^2 is 5.45 and the critical $\chi^2 = 3$. Then, the uncertainty on the value given by Garg was increased by 1.08 in order to reduce its relative weight to 50 %. The reduced χ^2 is 5.10. This set of value is not consistent and the unweighted mean is adopted : **0.572 (34) ns**.

Level 1434 keV

Arens : 210 (20) ps

2.1 Beta Transitions**Beta transition energies**

The adopted Q-value 1565.2 (6) keV is from Audi and Wapstra. It was determined from the measurements of Wortman and Metzger (see Table below)

The adopted energies and uncertainties of beta transitions are deduced from the Q-value and the levels energies and their uncertainties.

Measured beta energies are summarized in the following table :

keV	1565	475	273	132	85
Wortman	1573 \pm 3	475 \pm 3	273 \pm 5		
Berenyi		455 \pm 5	275 \pm 5		
Metzger	1560 \pm 8	462 \pm 3	271 \pm 3		
Mukerji	1566			132	85
Subba Rao	1580 \pm 20	470 \pm 6	280 \pm 6	150 \pm 10	
Raman	1575 \pm 20	461 \pm 10	268 \pm 10	128	80
<i>Evaluated</i>	1572 \pm 3	463.4 \pm 2.2	273.0 \pm 2.1	137 \pm 8	82.5 \pm 2.5
Adopted	1565.2 \pm 0.6	465.9 \pm 0.6	273.6 \pm 0.6	130.9 \pm 0.6	83.6 \pm 0.6

The 1565 keV transition is second forbidden non unique, with the shape factor given by Wortman (see below) the mean energy is 521 keV ; with the shape factor from Raman the mean energy is 584 keV ; these calculations were done with the SPEBETA program. In the Russian book Kolobachkin *et al.* the mean energy was calculated to be 523 keV.

Expecting a confirmation, the adopted value is 522 (2) keV.

Beta transition probabilities

The emission probabilities are calculated from gamma transition probability imbalance on each level. That was done for all the transitions, except for the weak 1565-keV to the ground state, the resulting values are in agreement with the experimental values (see Table below).

Taking into account the consistency of the decay scheme :

- the sum of all the transitions to the Co-59 ground state must be equal to 100 ; this leads to an intensity value of 0.12 (32) for the 1565 keV transition. This important uncertainty comes from the propagation of the uncertainties on the gamma transitions.
- the sum of all the beta transitions leaving from Fe-59 must be equal to 100 ; this gives a value of 0.13 (34) for the 1565 transition.

However, several authors measured this transition intensity and found values from 0.18 (4) % to 0.3 (1) % (Table below).

It must also be pointed out that the authors gave measured gamma emission probabilities after corrections, with a value of the $I_{\beta}(gs)$ taken as :

- 0.3% by Legrand, Béraud, Pancholi ;
- 0.18% by Miyahara.

From the previous remarks, it follows that the $I_{\beta}(gs)$ intensity is certainly greater than 0.10% (decay scheme) and less than 0.40% (experiments).

The adopted value is then : 0.25 (15) %.

Table : Measured I_{β}

Metzger (52Me53)			
1573 keV	$I_{\beta} = 0.3 (1)\%$	$\lg ft = 10.9$	
475 keV	$I_{\beta} = 54.8 (20)\%$	$\lg ft = 6.7$	
273 keV	$I_{\beta} = 44.9 (20)\%$	$\lg ft = 5.9$	
Wortman. (63Wo01) (No uncertainty given)			
1573 keV	$I_{\beta} = 0.30\%$	$\lg ft = 10.96$	shape factor $p^2 + 3.3 q^2$
475 keV	$I_{\beta} = 51.2\%$	$\lg ft = 6.74$	
273 keV	$I_{\beta} = 48.5\%$	$\lg ft = 5.92$	
Raman (74Ra13)			
1573 keV	$I_{\beta} = 0.18 (4)\%$	$\lg ft = 11.15 \pm 0.11$	shape factor $p^2 + 1.7 q^2$
475 keV	$I_{\beta} = 51 (3)\%$		
273 keV	$I_{\beta} = 47 (4)\%$		
(80-128)	$I_{\beta} = (1.4)\%$		
Berényi (60Be06) (No uncertainty given)			
1573 keV	$I_{\beta} < 0.5 \%$		
475 keV	$I_{\beta} = 55.4\%$	$\lg ft = 6.1$	
273 keV	$I_{\beta} = 44.6\%$	$\lg ft = 5.3$	

β - γ circular polarization asymmetry coefficients

Behrens (70BeZx) recommends :

For 466 β - 1099 γ : $A = -0.164 (7)$

For 273 β - 1292 γ : $A = -0.15 (2)$

2.2 Gamma transitions and internal conversion coefficients

1291 keV transition

Assuming a pure E2 transition, the theoretical ICC (from Band's tables) $a_T = 1.22 \cdot 10^{-4}$ is consistent with the experimental one from Metzger (52Me53) $\alpha_T = 1.35 (6) \cdot 10^{-4}$.

Other measurements :

Metzger (52Me53), $\alpha_K = 1.19 (6) \cdot 10^{-4}$

Hinman (53Hi02), $\alpha_T = 1.06 (16) \cdot 10^{-4}$

Collin (64Co34), $\alpha_T = 1.07 (8) \cdot 10^{-4}$

K.S.Krane *et al.* (1976Kr10) suggests a M3/E2 mixture of $\delta = -0.033 (30)$, that does not change the ICC value significantly.

1099 keV transition

Assuming a pure E2 transition, the theoretical ICC (from Band's tables) $a_T = 1.75 \cdot 10^{-4}$ is consistent with the experimental one from Metzger (52Me53) $\alpha_T = 1.87 (7) \cdot 10^{-4}$.

Other measurements :

Metzger(52Me53), $\alpha_K = 1.35 (6) \cdot 10^{-4}$

Hinman(53Hi02), $\alpha_T = 1.84 (27) \cdot 10^{-4}$

Collin(64Co34), $\alpha_T = 1.36 (10) \cdot 10^{-4}$

334 keV transition E2/M1

The measured values of the mixing ratio are the following :

Author	Delta
Pancholi	- 0.12 (6)
Eriksson	- 0.12 (4)
Arens	+ 0.05 + 0.03 - 0.07 or - 1.8 + 0.4 - 0.6
Adopted value	- 0.12 (6)
ICC (Band)	0.002 (1)

142 keV transition E2/M1

The measured values of the mixing ratio are the following :

Author	Delta
Pancholi	- 0.15 (6) < δ < 0.026
Eriksson	- 0.006 (12)
Arens	0.028 + 0.009 - 0.014 or - 1.78 + 0.15 - 0.20
Adopted value (from Krane 1977Kr13)	- 0.008 (7)
ICC (Band)	0.0160 (1)

192 keV transition E2/M1

The measured values of the mixing ratio are the following :

Author	Delta
Pancholi	- 0.22 (2)
Eriksson	0.21 (2)
Arens	- 0.21 (2) or $\delta > 14$
Bajaj	0.22 (2)
Collin	- 0.296 (23)
Adopted value	0.21 (1)
ICC (Band)	0.00899 (15)

Gamma emissionsGamma emission energies

The gamma emission energy of the following lines are from Helmer (2000He14) :

142.651 ± 0.002

192.349 ± 0.005

1099.245 ± 0.003

1291.590 ± 0.006

Others are from Pancholi.

Gamma emission intensities

Eight published papers describe measurements of the gamma emission intensities, all the values are given in absolute values.

Heath *et al.* do not give uncertainty, therefore these values are omitted.

The results given by Béraud *et al.* are with uncertainties of the order of 10%, they are not omitted but their relative weight is generally weak, as well as those of the values given by Mukerji *et al.*

J.Legrand *et al.* (70Le03), carried out β - γ coincidences measurements and deduced I_γ absolute values, assuming that the β branching to the ground state is 0.3%. The uncertainty adopted by Legrand is the sum of the statistical uncertainty assessed at 3σ and the systematic uncertainty at 1σ ; consequently, the standard deviation cannot be obtained dividing the original uncertainty by 3 and we divided the given uncertainties by 2 only.

Pancholi *et al.* (73Pa18), measured the relative values and normalized them such as $I(1099 + 1292 + 1481) = 99.7\%$, assuming $I\beta(gs) = 0.3\%$.

Miyahara *et al.* (1989Mi07), carried out activity measurements and deduced absolute values. This paper is the most recent one and gives the most precise values which contribute more than 50% in the adopted result for the two intense lines : 1099 and 1291 keV.

The following table summarizes all the values taken into account and the adopted results.

These different set of data are consistent, except for the original set of seven data for the 335 keV line where two values are outliers and are omitted (o). The adopted values are the weighted means.

keV	142	192	335	381
Mukerji	1.1 ± 0.16	3.3 ± 0.3	0.27 ± 0.03	
Legrand	0.98 ± 0.02	2.95 ± 0.04	0.24 ± 0.02	0.023 ± 0.002
Béraud	0.79 ± 0.8	2.50 ± 0.25	0.25 ± 0.05	0.022 ± 0.005
Collin	0.8 ± 0.2	2.8 ± 0.3	0.7 ± 0.3 ^(o)	
Miyahara	0.955 ± 0.030	2.851 ± 0.048	0.262 ± 0.016	
Ferguson	0.85 ± 0.15	2.4 ± 0.4	0.34 ± 0.07 ^(o)	
Pancholi	1.02 ± 0.04	3.08 ± 0.1	0.27 ± 0.01	0.018 ± 0.003
$\chi^{**2}/N-1$ (critical)	1.5 (2.8)	1.9 (2.8)	0.5	0.97
Adopted value	0.972 ± 0.015	2.918 ± 0.029	0.264 ± 0.007	0.0215 ± 0.0016

keV	1099	1291	1481
Mukerji	57.5 ± 3	42.4 ± 2.3	0.052 ± 0.006
Legrand	55.5 ± 0.8	44.1 ± 0.6	0.09 ± 0.01
Béraud	56.2 ± 5.6	43.5 ± 4.3	0.056 ± 0.012
Collin	56.5 ± 1.5	43.2 ± 1.5	
Miyahara	56.68 ± 0.22	42.99 ± 0.30	
Ferguson	56 ± 3	44 ± 3	
Pancholi	56.5 ± 1.5	43.2 ± 1.1	0.059 ± 0.006
$\chi^{**2}/N-1$ (critical)	0.4	0.5	3.6 (3.8)
Adopted value	56.59 ± 0.21	43.21 ± 0.25	0.0603 ± 0.0037

Angular correlation coefficients

Several authors determined the angular correlation coefficients. Some of them are summarized here as a matter of interest.

$192\gamma - 1099\gamma_{3/2}(M1+E2)3/2(E2)7/2$:

Author	NSR	A2	uc	A4	uc
Heath	60He06	0.024	0.005		
Rao	70Ra00	0.028	0.003	0.008	0.007
Arens	71Ar07	0.008	0.007		
Bajaj	72Ba**	0.008	0.004	0.004	0.008
Eriksson	73Er11	0.011	0.004	-0.003	0.004

$335\gamma - 1099\gamma_{1/2}(M1+E2)3/2(E2)7/2$:

Author	A2	uc	A4	uc
Rao	-0.043	0.003	-0.004	0.003
Arens	-0.064	0.011	-0.008	0.025
Eriksson	-0.040	0.010	-0.006	0.0006
Bajaj	-0.099	0.012		

$143\gamma - 1292\gamma, 1/2^-(M1+E2)3/2^-(E2)7/2^- :$

Author	A2	uc	A4	uc
Heath	- 0.069	0.005		
Rao	- 0.065	0.004	- 0.006	0.005
Arens	- 0.065	0.004		
Bajaj	- 0.070	0.005	0.014	0.015
Subrahmanyam	- 0.09	0.01		
Eriksson	- 0.070	0.003		

Conversion electrons

Conversion electron intensities were calculated from the gamma transition probabilities and the internal conversion coefficients.

Hinman(53Hi02) gives the ratio of the number of conversion electrons from the 1099 keV transition to the number of conversion electrons from the 1291 keV transition, to be equal to 1.91 (9).

There is a good agreement with the ratio (1.87) obtained from the calculated values in this evaluation.

References

- F. R. Metzger ; Phys. Rev. ; 88 (1952) 1360 ; T ICC, Half-life
 G. HINMAN ; D. BROWER, R. LEAMER ; Phys. Rev. ; 90 (1953) 370A ; T ICC
 J. P. KEENE ; L. A. MACKENZIE, C. W. GILBERT ; Phys. in Med. Biol. ; 2 (1958) 360 ; Half-life
 J. M. Ferguson ; Nucl. Phys. ; 12 (1959) 579 ; Gamma-ray emission probabilities
 A. Pierroux ; G. Guében, J. Govaerts ; Bull. Soc. Royale Sci. Liège ; 28, 7-8 (1959) 180 ; Half-life
 E. Fuschini et al ; Nuovo Cim. ; XVI,5 (1960) 1910 ; Half-life
 R. L. Heath ; C. W. Reich, D. G. Proctor ; Phys. Rev. ; 118,4 (1960) 1082 ; Half-life
 B. N. SUBBA RAO ; Proceeding of the Indian Acad. of Sciences ; 3A (1960) 130 ; Half-life
 D. E. Wortman ; L. M. Langer ; Phys. Rev. ; 131,1 (1963) 325 ; Half-life
 W. Collin et al ; Z. Physik ; 180 (1964) 143 ; Gamma-ray emission probabilities, mixing ratio
 Y. K. Agarwal ; C. V. K. Baba, S. K. Bhattacharjee ; Nucl. Phys. ; A99 (1967) 457 ; 1291 keV level half-life
 R. Béraud et al ; Comp. Rend. Acad. Sci. (Paris) ; 265-B (1967) 1354 ; Gamma-ray emission probabilities
 N. P. S. Sidhu ; U. C. Gupta ; Nucl. Phys. ; A91 (1967) 557 ; 1291 keV level half-life
 J. LEGRAND ; J. MOREL, C. CLEMENT ; Nucl. Phys. ; A142 (1970) 63 ; Gamma-ray emission probabilities
 I. ARENS ; H. J. KORNER ; Z. Phys. ; 242 (1971) 138 ; Mixing Ratio, Half-life
 M. I. Green ; P. F. Kenealy, G. B. Beard ; Nucl. Instrum. Methods ; 99 (1972) 445 ; 1291 keV level half-life
 R. K. Garg et al ; Z. Physik ; 257 (1972) 124 ; 1291 keV level half-life
 J. F. Emery ; S. A. Reynolds, E. I. Wyatt ; Nucl. Sci. Eng. ; 48 (1972) 319 ; Half-life
 S. C. PANCHOLI ; J. J. PINAJIAN, N. R. JOHNSON, A. KUMAR, S. K. SONI, M. M. BAJAJ, S. L. GUPTA, N. L. SAHA ; Phys. Rev. ; C8 (1973) 2277 ; Gamma-ray emission probabilities, Spin and Parity, Mixing Ratio
 C. J. Visser et al ; Agrochemophysica ; 5 (1973) 15 ; Half-life
 L. Eriksson ; L. Gidefeldt ; Physica Scripta ; 7 (1973) 169 ; Mixing ratio
 A. Mukerji ; D. Palazzo, J. D. Ullman ; Phys. Rev. ; C10,2 (1974) 949 ; Gamma-ray emission probabilities
 M. M. BAJAJ ; A. KUMAR, S. K. SONI, S. C. Pancholi, S. L. GUPTA, N. K. SAHA ; Proceeding of the nuclear physics and solid state physics symposium ; 14B,2 (1974) 375 ; Mixing ratio
 S. Raman et al ; Phys. Rev. ; C9,6 (1974) 2463 ; Beta emission probabilities and energies
 J. Alstad ; I. R. Haldorsen, A. C. Pappas, M. Skarestad ; J. Inorg. Nucl. Chem. ; 37 (1975) 873 ; Half-life
 K. S. Krane ; S. S. Roseblum, W. A. Steyert ; Phys. Rev. ; C 14,2 (1976) 653 ; 1291 keV Mixing ratio

K. S. Krane ; At. Data Nucl. Data Tables (19 (1977) 363 ; 142 keV Mixing ratio
H. HOUTERMANS ; O. MILOSEVIC, F. REICHEL ; Int. J. Appl. Radiat. Isotop. ; 31 (1980) 153 ; Half-life
K. F. WALZ ; H. M. WEISS, K. DEBERTIN ; Int. J. Appl. Radiat. Isotop. ; 34 (1983) 1191 ; Half-life
H. Miyahara et al ; Appl. Rad. Isotopes ; 40,4 (1989) 343 ; Gamma-ray emission probabilities
G. Audi ; A. H. Wapstra ; Nucl. Phys. ; A595 (1995) 409 ; Q
R. H. Martin ; K. I. W. Burns, J. G. V. Taylor ; Nucl. Instrum. Methods ; A390 (1997) 267 ; Half-life
R. G. Helmer ; C. van der Leun ; Nucl. Instrum. Methods ; A450 (2000) 35 ; Gamma ray energies

Additional references

SPEBETA, a program to calculate beta spectra. P. Cassette. Note LPRI/92/307. CEA-LNHB, F-91191 Gif-sur-Yvette
Kolobachkin *et al.* Moscow Atomizdat, UDK 539 163(031), in Russian (1978)
M. M. Bajaj, A. KUMAR, S. K. SONI, S. C. Pancholi, S. L. GUPTA, N. K. SAHA. Report B.A.R.C. – 614(1972)41. Angular correlation coefficients. (72Ba**)
D. Berényi, G. Y. Mathé, T. Scharbert. Nucl. Phys. 14(1960)459. Beta emission energies and probabilities. (60Be06)
H. Behrens. Kerforschungszentrum Karlsruhe KFK 1249(1970)1. β - γ Asymmetry coefficients. (70BeZX)
S. D. Chauhan *et al.* Proceeding of the nuclear physics and solid state physics symposium 14B-2 (1972). 1291 keV level half-life. (72Ch**)
K. V. Ramana Rao *et al.* Proceeding of the nuclear physics and solid state physics symposium V2 (1970) 387. Angular correlation coefficients. (70****)
V. Subrahmanyam. J. Inorg. Nucl. Chem. 34(1972)3319. Angular correlation coefficients. (72Su06)

⁶⁴Cu - Comments on evaluation of decay data by R. G. Helmer

1 Decay Scheme

The only levels in ⁶⁴Zn and ⁶⁴Ni below the decay energies are those populated in this decay, so the decay scheme is complete.

The J^π values and half-lives for the excited levels are from Adopted Levels in Nuclear Data Sheets (1996Si12).

The decay scheme for the electron capture to ⁶⁴Ni is consistent since the sum of the average energies of all of the radiations, as computed by RADLST, is 1020 (10) keV compared to the value of 1020 (8) from the Q_e value and the branching fraction.

2 Nuclear Data

Q values from 1995Au04 are for β^- decay 578.7 (9) and for e decay 1675.10 (20) keV.

The change in the half-life as a function of the chemical form or electron environment has been studied by several authors. These results are tallied after those used for the half-life evaluation.

The half-life values considered are, in hours:

10	(1935Am01)	omitted, no uncertainty
12.8 (1)	(1936Va02)	
12.5	(1937He05)	omitted, no uncertainty
12.8 (3)	(1938Ri)	as cited in 1968Ke12
12.8 (3)	(1939Sa02)	as cited in 1968Ke12
11.9 (10)	(1943Hu03)	
11.9 (10)	(1944Hu05)	omitted, same data as 1943Hu03
12.80 (4)	(1950Ra62)	as cited in 1968Ke12
12.74 (7)	(1951Sc56)	
12.88 (3)	(1951Si91)	
12.80 (3)	(1955To07)	as cited in 1968Ke12
12.90 (6)	Rudstam	as cited in 1968Ke12
12.87 (5)	(1957Wr37)	superseded by 1972Em01
12.85 (5)	(1959Po64)	
13.9	(1965He08)	omitted, no uncertainty
12.86 (3)	(1965Pa18)	
12.70 (3)	(1966Fu14)	
12.86 (3)	(1966Li09)	

12.8	(1967Vi08)	omitted, no uncertainty
12.701 (11)	(1968He20)	as cited in 1973De56
12.80 (4)	(1968Ke12)	
12.65 (17)	(1969Bo11)	
12.715 (7)	(1972Em01)	
12.701 (7)	(1972MeZM)	as cited in 1996Si12
12.72 (4)	(1972WyZZ)	superseded by 1972Em01
12.6 (10)	(1973ArZI)	
12.699 (2)	(1973De56)	
12.82 (4)	(1973Ne02)	
12.704 (6)	(1974Ry01)	
12.701 (3)	(1980RuZY, 1982RuZV)	

12.701 (2) Adopted value

The set of 23 unsuperseded values with uncertainties is inconsistent. The unweighted average is 12.73 (4) hours and the weighted average is 12.7029 with an internal uncertainty of 0.0015, a reduced- χ^2 of 6.8, and an external uncertainty of 0.0039. It has been suggested that many of the older measurements give longer half-lives due to the presence of unidentified impurities. The value of 12.699 (2) given by 1973De56, and used here, differs slightly from the weighted average of 12.6973 (16) computed by the evaluator for their 22 measured values. The input value of 12.715 (7) is the evaluator's weighted average of the three values given in the paper of 1972Em01.

The adopted half-life was taken from the weighted average of the 6 values (those from 1968He20, 1972Em01, 1972MeZM, 1973De56, 1974Ry01, and 1980RuZY) with uncertainties less than 0.03 hours. This average is 12.7007 with internal and external uncertainties of 0.0015 and a reduced- χ^2 of 1.04. As noted below, changes in this half-life of the order of 1 part in 10^4 have been reported depending on the chemical form. Since these changes are comparable to the calculated uncertainty, the adopted uncertainty has been increased to 0.002.

This half-life has been measured, and reported, many times primarily to identify the radionuclide observed, for example, in the process of cross section measurements. Some of these values, which are not included above are: 13 (1948Mi12); 12.8 (1950Ho26); and 13.8 (14), 13.6 (7), and 12.4 (17) (1972Cr02).

Since ⁶⁴Cu decays, in part, by electron capture, there have been several measurements of the variation in the decay constant with the chemical form or atomic environment. The results from 1968 to 1975 are tallied in 1976Ha66 and given in the following table.

Reference and first author	Forms compared	Dl / l · 10 ⁴
1972Au Auric	Cu phtalocyanine in two forms	10.0 (16)
1972Em01 Emery	Cu metal Cu(NO ₃) ₂	15 (15)

Reference and first author	Forms compared	Dl/l · 10 ⁴
1973Ha60 Harbottle	Cu metal CuO	0 (3)
1973De56 Dema	Cu phtalocyanine in two forms	0.4 (20)
1974Je Jenschke	Cu metal Cu(H ₂ O) ₆ SO ₄	1.12 (9)
	Cu metal Cu(H ₂ O) ₄ (NO ₃) ₂	0.81 (10)
	Cu metal Cu(2)	2.94
	Cu metal Cu(3)	1.86
1974Jo17 Johnson	Cu phtalocyanine in two forms	1.4 (23)
	Cu phtalocyanine in two forms	3.7(58)
	Cu metal CuO	0.0 (23)
1975MaXN	Cu metal Cu ₂ S	2.3 (10)
	Cu metal CuInS ₂	1.5 (10)
	Cu metal Cu ₂ SnS ₃	1.5 (10)
	CuInS ₂ Cu ₂ SnS ₃	0 (1)
1979Eh01 Ehrhart	Cu metal atom % Cu in Ag	
	2	1.7 (3)
	5	1.6 (4)
	25	0.9 (4)
	50	0.7 (5)
75	0.2 (4)	
1979Ko31 Koran	Cu metal atom % Cu in Au	
	2	3.1 (4)
	5	3.0 (4)
	25	1.4 (4)
	50	0.7 (5)
75	-0.2 (9)	

The earliest measurements gave larger values of $\Delta\lambda/\lambda$, but the values beginning in 1973 range from 0 to 0.00037 (6). These values are similar in magnitude to the uncertainty of 1.5 parts in 10⁴ assigned to the adopted value. A set of measurements is also given in 1968Ke12, but the units of the results are not clear.

2.1 β^- Transitions

See comments in section 2.3.

2.2 β^+ Transitions

See comments in section 2.3.

2.3 Electron Capture Transitions

The probabilities of the β^- , β^+ , and e branches have been determined by a series of separate, but partially correlated, measurements by 1983Ch47 and 1986Ka03. These measurements include the β^- spectrum, the β^+ spectrum, 4p β - γ coincidences, liquid scintillation counting, and the γ -ray spectrum. The analysis of 1983Ch47 included a least-squares fit to the various measured quantities and ratios of quantities. Since over 90% of the decays are to the ground states of ⁶⁴Ni and ⁶⁴Zn, this set of data provides very accurate results. The results are: % ϵ = 43.1 (5) [from 43.10 (46) (1983Ch47) and 43.2 (5) (1986Ka03)], % β^- = 39.0 (3) [from 1986Ch47, other: 38.3 (6) (1986Ka03)], and % β^+ = 17.86 (14) [from 1986Ch47, other: 17.93 (20) (1986Ka03)].

A recent, and unpublished, determination of % β^- has been made by mass spectrometric measurements of the number of atoms of ⁶⁴Ni and ⁶⁴Zn produced in the decay of a ⁶⁴Cu sample (2002We). Their results is 38.06 (3). This result suggests that future evaluations may result in a small decrease in this value and the corresponding increase in % ϵ .

From β^- and β^+ spectra, the ratio of their emission rates is 2.181 (6) (1986Ch47) and 2.138 (32) (1986Ka03). (Earlier and less precise measurements of these quantities are tallied in 1983Ch47.) The average particle energies to the ⁶⁴Ni and ⁶⁴Zn ground states are 278.21 (9) and 190.4 (4), respectively, and are from the LOGFT code. The log ft values to the ⁶⁴Ni ground state and 1345 level are 4.973 (3) and 5.506 (10), respectively, and to the ⁶⁴Zn ground state 5.294 (4), all of which are consistent with being allowed transitions from the 1⁺ parent.

2.4 Gamma Transitions

The γ -ray energy is 1345.77 (16) from 1974HeYW and its emission intensity is 0.475% (10), a weighted average of 0.471% (11) (1983Ch47) and 0.487 (20) (1986Ka03).

The J^π assignments are from the Adopted Levels in the Nuclear Data Sheets (1996Si12) and these imply the γ -ray has E2 multipolarity. The internal-conversion coefficients were interpolated from the tables of Band et al. (1976Ba63) and are $\alpha_K = 0.000112$, $\alpha_L = 0.0000108$, and $\alpha_T = 0.000126$.

The internal-pair-formation coefficient was interpolated from the theoretical values (1979Sc31) and is IPFC(1345) = 0.000034.

3 Atomic Data

The data are from 1996Sc06.

3.1 and 3.2

None

4 Radiation Emissions

4.1 Electron Emissions

Auger electron emission intensities are deduced from the evaluated data set.

4.2 Photon Emissions

See section 2.4.

X-ray emission intensities are deduced from the evaluated data set.

5 Main production modes

They are taken from : Table de Radionucléides, F; Lagoutine, N. Coursol, J. Legrand. ISBN 2 7272 0078-1

6 References

- 1935Am01 - E. Amaldi, O. D'Agostino, E. Fermi, B. Pontecorvo, F. Rasetti, E. Segre, Proc. Roy. Soc. (London) 149A(1935)522 [T_{1/2}]
- 1936Va02 - S. N. Van Voorhis, Phys. Rev. 50(1936)895 [T_{1/2}]
- 1937He05 - F. A. Heyn, Physica 4(1937)1224 [T_{1/2}]
- 1938Ri - L. N. Ridenour, Phys. Rev. 53(1938)770 [T_{1/2}]
- 1939Sa02 - R. Sagane, Phys. Rev. 55(1939)31 [T_{1/2}]
- 1943Hu03 - O. Huber, O. Lienhard, H. Waffler, Helv. Phys. Acta 16(1943)226 [T_{1/2}]
- 1944Hu05 - O. Huber, O. Lienhard, H. Waffler, Helv. Phys. Acta 17(1944)195 [T_{1/2}]
- 1948Mi12 - D. R. Miller, R. C. Thompson, B. B. Cunningham, Phys. Rev. 74(1948)347 [T_{1/2}]
- 1950Ho26 - H. H. Hopkins, Phys. Rev. 77(1950)717 [T_{1/2}]
- 1950Ra62 - E. Rabinowicz, Proc. Phys. Soc.(London) 63A(1950)1040 [T_{1/2}]
- 1951Sc56 - R. P. Schuman, A. Camilli, Phys. Rev. 84(1951)158 [T_{1/2}]
- 1951Si91 - L. M. Silver, Can. J. Phys. 29(1951)59 [T_{1/2}]
- 1955To07 - J. Tobailem, J. Phys. Radium 16(1955)48 [T_{1/2}]
- 1957Wr37 - H. W. Wright, E. I. Wyatt, S. A. Reynolds, W. S. Lyon, T. H. Handley, Nuclear Sci. and Eng. 2(1957)427 [T_{1/2}]
- 1959Po64 - A. Poularikas, R. W. Fink, Phys. Rev. 115(1959)989 [T_{1/2}]
- 1965He08 - Z. He-Sung, N. S. Maltseva, V. N. Mekhedov, V. N. Rybakov, Soviet J. Nucl. Phys. 1(1965)132 [T_{1/2}]
- 1965Pa18 - V. A. Paulsen, H. Liskien, Nukleonik 7(1965)117 [T_{1/2}]
- 1966Fu14 - K. Fujiwara, O. Sueka, J. Phys. Soc. Japan 21(1966)1947 [T_{1/2}]
- 1966Li09 - H. Liskien, A. Paulsen, Proc. Intern. Conf. Radiat. Meas. Nucl. Power, Berkeley, Engl., D. J. Littler, Ch., Editorial Panel, Inst. Phys. and the Physical. Society, London, Conf. Series No.2, (1966) p. 352 [T_{1/2}]

- 1967Vi08 - G. P. Vinitzkaya, V. N. Levkovsky, V. V. Sokolsky, I. V. Kazachevsky, Sov. J. Nucl. Phys. 5(1967)839 [T_{1/2}]
- 1968He20 - F. Heinrich, G. Philippin, Helv. Phys. Acta 41(1968)431 [T_{1/2}]
- 1968Ke12 - P. Kemény, Rev. Roumaine Phys. 13(1968)901 [T_{1/2}]
- 1969Bo11 - M. Bormann, B. Lammers, Nucl. Phys. A130(1969)195 [T_{1/2}]
- 1972Au - P. Auric, J. I. Vargas, Chem. Phys. Lett. 15(1972)366 [T_{1/2}]
- 1972Cr02 - D. F. Crisler, H. B. Eldridge, R. Kunselman, C. S. Zaidins, Phys. Rev. C5(1972)419 [T_{1/2}]
- 1972Em01 - J. F. Emery, S. A. Reynolds, E. I. Wyatt, G. I. Gleason, Nucl. Sci. Eng. 48(1972)319 [T_{1/2}]
- 1972MeZM - J. S. Merritt, J. G. V. Taylor, AECL-4257(1972) p. 25 [T_{1/2}]
- 1972WyZZ - E. I. Wyatt, ORNL-4749(1972) p.61 [T_{1/2}]
- 1973ArZI - J. Araminowicz, J. Dresler, INR-1464(1973) p.14 [T_{1/2}]
- 1973De56 - I. Dema, G. Harbottle, Radiochem. Radioanal. Lett. 15(1973)261 [T_{1/2}]
- 1973Ha60 - G. Harbottle, C. Koehler, R. Withnell, Rev. Sci. Instr. 44(1973)55 [T_{1/2}]
- 1973Ne02 - D. A. Newton, S. Sarkar, L. Yaffe, R. B. Moore, J. Inorg. Nucl. Chem. 35(1973) 361 [T_{1/2}]
- 1974HeYW - R. L. Heath, ANCR-1000-2(1974) [E_γ]
- 1974Je - B. Jenschke, German Phys. Soc., Spring Conf.(1974) [T_{1/2}]
- 1974Jo17 - J. A. Johnson, I. Dema, G. Harbottle, Radiochim. Acta 21(1974)196 [T_{1/2}]
- 1974Ry01 - T. B. Ryves, K. J. Zieba, J. Phys.(London) A7(1974)2318 [T_{1/2}]
- 1976Ba63 - I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, Atomic Data Nucl. Data Tables **18** (1976) 433 [α]
- 1976Ha66 - H. P. Hahn, H. J. Born, J. I. Kim, Radiochim. Acta 23(1976)23 [T_{1/2}]
- 1979Sc31 - P. Schluter, G. Soff, At. Data Nucl. Data Tables **24** (1979)509 [IPFC]
- 1980RuZY - A. R. Rutledge, L. V. Smith, J. S. Merritt, AECL-6692(1980) [T_{1/2}]
- 1982RuZV - A. R. Rutledge, L. V. Smith, J. S. Merritt, NBS-SP-626(1982) p.5 [T_{1/2}]
- 1983Ch47 - P. Christmas, S. M. Judge, T. B. Ryves, D. Smith, G. Winkler, Nucl. Instr. Meth. 215(1983)397 [P_{β-}, P_{β+}, P_γ, P_ε]
- 1986Ka03 - Y. Kawada, Intern. J. Appl. Radiat. Isot. 37(1986)7 [P_{β-}, P_{β+}, P_γ, P_ε]
- 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. **A595** (1995)409 [Q]
- 1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instr. Meth. **A369** (1996)527 (ω)
- 1996Si12 - B. Singh, Nucl. Data Sheets **78** (1996)395 [J^π. multipolarities]
- 2002We - G. Wermann, D. Alber, W. Pritzkow, G. Riebe, J. Vogl, W. Görner. Appl. Rad. Isotopes 56, 1-2 (2002) 145 [%β-]

⁶⁶Ga – Comments on evaluation of decay data by E. Browne

1. Statistical Analysis of Data

The *Limitation of Relative Statistical Weight* (LWM) [1985ZiZY] method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

2. Decay Scheme

⁶⁶Ga decays 56 (4) % by positron (β^+) emission and 44 (4) % by electron capture (ϵ) to ⁶⁶Zn ($Q(\epsilon) = 5175(3)$ keV (1995Au04)). About 140 γ -rays de-exciting 31 nuclear levels in ⁶⁶Zn are known. Emission of conversion electrons is very low and negligible compared to that of γ rays (photons) because of the low atomic number ($Z = 30$) of the daughter nucleus (⁶⁶Zn) and the high energy (> 1000 keV) of the most intense γ -ray transitions. Consequently, neither conversion coefficients (most of them $< 2 \times 10^{-4}$) nor a list of conversion electrons is given in this evaluation.

Evaluator has normalized the decay scheme using experimental results from 1960Sc06, decay-scheme information, and theory. As expected from the spins and parities of ⁶⁶Ga (0+) and ⁶⁶Zn (0+), there is a significant $\epsilon + \beta^+$ feeding (51(4)%) to the ground state of ⁶⁶Zn. Electron-capture and β^+ transition probabilities to excited states in ⁶⁶Zn given in Section 2.1 are from γ -ray transition probability balance at each level and theoretical ϵ/β^+ ratios. The decay scheme shown here is that of 1998Bh02 with the addition of levels half-lives from 2002Ga20.

3. Nuclear Data

The recommended half-life of ⁶⁶Ga, 9.49(7) hours, is a weighted average (LWM, $\chi^2/\nu=2.9$) of 9.57(6) hours (1956Ru45), 9.50(10) hours (1959Ca15), and 9.33(8) hours (1964Ru06). Other values are: 9.45 hours (1950La55), and 9.35 hours (1967Va13).

$Q(\epsilon)=5175(3)$ keV is from 1995Au04.

4. Gamma Rays

Energies

γ -ray energies in Table 1 given in boldface are from 2000He14. These values are based on a revised energy scale that uses the new adjusted fundamental constants and wave lengths deduced from an updated value of the lattice spacing of Si crystals [Cohen and Taylor [1]]. Helmer and van der Leun (2000He14) fitted the adjusted γ -ray energies of ⁶⁶Ga to a level scheme, and deduced their recommended values from level-energy differences. Less precise energies are from 1993Al15 and 1994En02, but adjusted to those of 2000He14 using a least-squares procedure. Evaluator has considered the difference between these two energy scales to be a systematic adjustment that he applied to the recommended energies given here. Thus, the uncertainties in the γ -ray energies given in this evaluation are just statistical, as reported by authors. See Table 1.

Emission Intensities

The relative emission probabilities of the most intense γ rays (given in boldface) in Table 2 are values recommended in 2002Ba38 and in this evaluation. These are weighted averages (LWM) of results from Berkeley, Budapest, and of 2000Ra36. Some of the uncertainties given in 2002Ba38, however, may be smaller than those given here, which are always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

Relative emission probabilities of other γ rays are weighted averages (LWM) of values from 1970Ph01, 1971Ca14, and 1994En02, each corrected by evaluator for a systematic error in the detector efficiency above ~ 1100 keV. This error was caused by an inadequate extrapolation of the detector efficiency to higher energies, and affected its value by as much as 30% at 4806 keV (1975Mc07).

The correction factor ($F = 1.116 - 0.155 E_{\gamma}(\text{MeV}) + 0.0397 E_{\gamma}^2(\text{MeV})$) given in 2002Ba38 has been used here. Uncertainties in the recommended relative emission probabilities are only statistical and have been deduced from those given in the individual measurements (see Table 2).

Absolute emission intensities given here are based on experimental results and decay-scheme normalization arguments as follows:

$$I_{\text{ce}}(1039 \gamma)/I_{\beta^+}(\text{gs}) = 2.08(10) \times 10^{-4} \quad (1960\text{Sc06})$$

$$I_{\beta^+}(\text{gs})/\Sigma I_{\beta_i^+} = 0.8697 \quad (1960\text{Sc06})$$

$$I_{\text{ce}}(1039 \gamma, E2)/I_{\gamma}(1039 \gamma) = 2.69(8) \times 10^{-4} \quad (\text{Theory, 1978Rö22}).$$

Therefore,

$$I_{\gamma}(1039 \gamma)/\Sigma I_{\beta_i^+} = 2.08(10) \times 10^{-4} \times 0.8697/2.69(8) \times 10^{-4} = 0.67(4).$$

Also $\Sigma I_{\beta_i^+}/\Sigma I_{e_i} = 1.265$ from decay scheme and theoretical values of $I_{\beta_i^+}/\epsilon_i$ for each level. Using

$$\Sigma I_{\beta_i^+} + \Sigma I_{e_i} = 100 \%, \text{ gives } \Sigma I_{\beta_i^+} = 55.8(24) \%, \text{ and}$$

$$I_{\gamma}(1039 \gamma) = 0.67(4) \times 55.8(24) = 37(3) \%.$$

Absolute γ -ray emission intensities given in Section 5.2 are relative values multiplied by 0.37(3).

5. Positron (β^+) Transitions

Positron end-point energies given in section 2.1.1 ($E_{\beta^+} = Q(\epsilon) - E(\text{keV}) - 1022$) are evaluator's values deduced using $Q(\epsilon) = 5175(3)$ keV (1995Au04) and level energies ($E(\text{keV})$) from decay scheme. Absolute β^+ emission probabilities are from γ -ray intensity balance at each nuclear level and theoretical $I_{\beta_i^+}/\epsilon_i$ ratios.

6. Electron Capture (ϵ) Transitions

ϵ transition energies ($E(\epsilon) = Q(\epsilon) - E(\text{keV})$) are evaluator's values deduced using $Q(\epsilon) = 5175(3)$ keV (1995Au04) and level energies ($E(\text{keV})$) from decay scheme. Absolute ϵ transition probabilities are from γ -ray probability balance at each nuclear level and theoretical $I_{\beta_i^+}/\epsilon_i$ ratios. Fractional atomic shell electron-capture probabilities (P_K, P_L, P_M) are evaluator's values calculated using the EC-CAPTURE computer program [2] and the nuclear level energies presented here.

7. Atomic Data

The X-ray and Auger electron energies given in sections 3, 4 are from Schönfeld and Rodloff [4] and [5], respectively. Emission intensities are evaluator's values calculated using the EMISSION (Version V.3.04) [3] program, atomic data from 1996Sc06, and the recommended γ -ray emission intensities from section 5.2.

References

1. *The 1986 Adjustment of the Fundamental Physical Constants*, E.R. Cohen and B.N. Taylor, Rev. Mod. Phys. **59**, 1121 (1987).
 2. *The Program EC-CAPTURE*, E. Schönfeld, F. Chu, and E. Browne. An interactive computer program for calculating electron capture probabilities P_K , P_L , P_M , and P_N to the K, L, M, and N atomic shells, respectively (1997).
 3. *The Program EMISSION* (version 3.04 (2002)), E. Schönfeld and H. Janssen. A computer program for calculating emission probabilities of X-rays and Auger electrons emitted in nuclear disintegration processes.
 4. *Tables of the energies of K-Auger electrons for elements with atomic numbers in the range from Z=11 to Z=100*, E. Schönfeld, G. Rodloff, Report PTB-6.11-98-1, October 1998.
 5. *Energies and relative emission probabilities of K X-rays for elements with atomic numbers in the range from Z=5 to Z=100*, E. Schönfeld, G. Rodloff, Report PTB-6.11-1999-1, February 1999.
- 1960Sc06 - A. Schwarzschild, L. Grodzins, Phys. Rev. **119**, 276 (1960).
- 1970Ph01 - M. E. Phelps, D. G. Sarantites, W. G. Winn, Nucl. Phys. **A149**, 647 (1970).
(relative γ -ray emission probabilities)
- 1971Ca14 - D. C. Camp, G. L. Meredith, Nucl. Phys. **A166**, 349 (1971).
(relative γ -ray emission probabilities)
- 1975Mc07 - G. J. MacCallum, G. E. Coote, Nucl. Instrum. Methods **124**, 309 (1975).
(relative γ -ray emission probabilities)
- 1978Rö22 - F. Rösel, H. M. Friess, K. Alder, H. C. Pauli, At. Data. Nucl. Data Tables **21**, 92 (1978).
(theoretical conversion coefficients)
- 1985ZiZY - W. L. Zijp, Report ECN FYS/RASA-85/19 (1985).
(Discrepant Data Limited Relative Statistical Weight Method).
- 1993A115 - C. Alderliesten, J. A. van Nie, A. P. Slok, P. M. Endt, Nucl. Instrum. Methods. Phys. Res. **A335**, 219 (1993).
(γ -ray energies)
- 1994En02 - P. M. Endt, C. Alderliesten, Nucl. Phys. **A575**, 297 (1994).
(γ -ray energies and relative emission probabilities)
- 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. **A595**, 409 (1995).
(Q_α)
- 1996Sc06 - E. Schönfeld, H. Janssen, Nucl. Instrum. Methods. Phys. Res. **A369**, 527 (1996).
(Atomic data, X-rays, Auger electrons)
- 1998Bh02 - M. R. Bhat, Nuclear Data Sheets 83, 789 (1998).
(⁶⁶Ga decay scheme)
- 2000He14 - R. G. Helmer, C. van der Leun, Nucl. Instrum. Methods. Phys. Res. **A450**, 35 (2000).
(Precise evaluated γ -ray energies)
- 2000Ra36 - S. Raman, C. Yonezawa, H. Matsue, H. Imura, N. Shinohara, Nucl. Instrum. Methods. Phys. Res. **A454**, 89 (2000).
(Precise relative γ -ray emission probabilities)
- 2002Ba38 - C. M. Baglin, E. Browne, E. B. Norman, G. L. Molnar, T. Belgya, Zs. Revay, F. Szelecsenyi, Nucl. Instrum. Meth. Phys. Res. **A481**, 365(2002).
(Precise relative γ -ray emission probabilities)
- 2002Ga20 - A. Gade, H. Klein, N. Pietralla, and P. von Brentano, Phys. Rev. C **65**, 054311 (2002)
(Levels half-life in ⁶⁶Zn)

Table 1. ⁶⁶Ga Gamma-Ray Energies

1993Al15, 1994En02	1993Al15 DE _g (keV)	2000He14 E _g (keV)	2000He14 DE _g (keV)	Fitted E _g (keV)
171.9	0.2			171.9 (2)
283.87	0.03			283.87 (3)
290.808	0.011			290.8105(11)
347.77	0.05			347.77 (5)
375.396	0.017			375.398 (17)
410.177	0.012			410.178 (12)
412.915	0.016			412.916 (16)
442.872	0.014			442.873 (14)
448.725	0.02			448.73 (2)
459.682	0.014			459.683 (14)
494.336	0.013			494.336 (13)
499.59	0.006			499.590 (6)
551.284	0.022			551.284 (22)
554.28	0.03			554.28 (3)
557.13	0.05			557.13(5)
562.241	0.01			562.241 (10)
578.54	0.019			578.540 (19)
600.789	0.021			600.788 (21)
653.569	0.014			653.568 (14)
658.57	0.03			658.57 (3)
670.252	0.014			670.251 (14)
680.56	0.1			680.56 (10)
<u>686.084</u>	0.007	686.080	0.006	686.080 (6)
705.033	0.015			705.031 (15)
708.36	0.05			708.36 (5)
718.97	0.05			718.97 (5)
723.17	0.05			723.17 (5)
749.68	0.1			749.68 (10)
763.64	0.03			763.64 (3)
796.21	0.05			796.21 (5)
800.13	0.05			800.13 (5)
<u>833.537</u>	0.003	833.5324	0.0021	833.5324 (21)
<u>853.046</u>	0.009	853.038	0.008	853.038 (8)
856.53	0.01			856.527 (10)
857.096	0.009			857.093 (9)
862.929	0.013			862.926 (13)
867.93	0.03			867.93 (3)
873.395	0.021			873.392 (21)
885	0.05			885.00 (5)
907.394	0.019			907.390 (19)
914.392	0.014			914.388 (14)
929.68	0.03			929.68 (3)
953.93	0.09			953.93 (9)
954.12	0.07			954.12 (7)
963.896	0.015			963.892 (15)
980.938	0.013			980.934 (13)
1008.593	0.012			1008.588 (12)
1010.962	0.019			1010.957 (19)
1015.086	0.018			1015.081 (18)
<u>1039.231</u>	0.006	1039.22	0.003	1039.220 (3)

1993Al15, 1994En02	1993Al15	2000He14	2000He14	Fitted
E_g (keV)	DE_g (keV)	E_g (keV)	DE_g (keV)	E_g (keV)
1060.056	0.011			1060.051 (11)
1065.31	0.009			1065.305 (9)
1066.455	0.012			1066.450 (12)
1082.754	0.02			1082.75 (2)
1106.54	0.24			1106.53 (24)
1129.929	0.018			1129.923 (18)
1135.48	0.09			1135.47 (9)
<u>1147.9</u>	0.012	1147.896	0.010	1147.896 (10)
<u>1190.297</u>	0.008	1190.287	0.007	1190.287 (7)
1195.33	0.09			1195.32 (9)
1232.271	0.008			1232.264 (8)
1232.487	0.015			1232.480 (15)
1248.786	0.022			1248.779 (22)
1274.51	0.03			1274.50 (3)
1298.96	0.07			1298.95 (7)
1305.815	0.021			1305.807 (21)
<u>1333.12</u>	0.006	1333.112	0.005	1333.112 (5)
1356.112	0.009			1356.104 (9)
1356.328	0.015			1356.320 (15)
1357.258	0.012			1357.250 (12)
1409.36	0.24			1409.35 (24)
<u>1418.763</u>	0.006	1418.754	0.005	1418.754 (5)
1425.256	0.02			1425.25 (2)
1433.64	0.04			1433.63 (4)
<u>1458.67</u>	0.012	1458.662	0.012	1458.662 (12)
1468.98	0.05			1468.97 (5)
<u>1508.175</u>	0.011	1508.158	0.007	1508.158 (7)
1515.172	0.02			1515.162 (20)
1523.289	0.015			1523.279 (15)
1534.61	0.04			1534.60 (4)
1554.63	0.03			1554.62 (3)
1559.637	0.01			1559.627 (10)
1577.318	0.02			1577.308 (20)
1634.47	0.07			1634.46 (7)
1703.6	0.05			1703.59 (5)
1713.614	0.012			1713.602 (12)
<u>1740.918</u>	0.018	1740.904	0.016	1740.904 (16)
1787.45	0.09			1787.44 (9)
1797.95	0.09			1797.94 (9)
1868.118	0.02			1868.105 (20)
1872.753	0.006			1872.740 (6)
<u>1898.832</u>	0.009	1898.823	0.008	1898.823 (8)
<u>1918.341</u>	0.006	1918.329	0.005	1918.329 (5)
1927.97	0.04			1927.96 (4)
2009.643	0.016			2009.628 (16)
2026.031	0.025			2026.016 (25)
<u>2065.792</u>	0.008	2065.778	0.007	2065.778 (7)
2085.88	0.04			2085.86 (4)
2089	0.013			2088.985 (13)
<u>2173.334</u>	0.018	2173.319	0.015	2173.319 (15)
<u>2189.631</u>	0.009	2189.616	0.006	2189.616 (6)

1993Al15, 1994En02	1993Al15	2000He14	2000He14	Fitted
E_g (keV)	DE_g (keV)	E_g (keV)	DE_g (keV)	E_g (keV)
<u>2213.19</u>	0.011	2213.181	0.009	2213.181 (9)
2265.86	0.24			2265.84 (24)
2292.188	0.013			2292.171 (13)
2341.691	0.011			2341.673 (11)
<u>2393.153</u>	0.01	2393.129	0.007	2393.129 (7)
<u>2422.544</u>	0.009	2422.525	0.007	2422.525 (7)
2433.826	0.018			2433.807 (18)
2467.99	0.07			2467.97 (7)
2492.44	0.03			2492.42 (3)
2537.11	0.05			2537.09 (5)
2588.573	0.013			2588.553 (13)
2631.46	0.09			2631.44 (9)
2698.94	0.05			2698.92 (5)
2713.75	0.05			2713.73 (5)
<u>2751.852</u>	0.006	2751.835	0.005	2751.835 (5)
<u>2780.12</u>	0.018	2780.095	0.016	2780.095 (16)
2785.7	0.3			2785.7 (3)
2802.8	0.5			2802.8 (5)
2843.153	0.016			2843.130 (16)
<u>2933.395</u>	0.017	2933.358	0.009	2933.358 (9)
<u>2977.12</u>	0.05	2977.083	0.043	2977.083 (43)
<u>2993.25</u>	0.04	2993.208	0.032	2993.208 (32)
<u>3046.697</u>	0.011	3046.684	0.009	3046.684 (9)
3085.4	0.4			3085.4 (4)
3212.526	0.019			3212.499 (19)
<u>3228.824</u>	0.009	3228.800	0.006	3228.800 (6)
3256.048	0.009			3256.021 (9)
3331.379	0.014			3331.351 (14)
<u>3380.882</u>	0.01	3380.850	0.006	3380.850 (6)
<u>3422.075</u>	0.012	3422.040	0.008	3422.040 (8)
<u>3432.343</u>	0.01	3432.309	0.007	3432.309 (7)
3738.13	0.05			3738.10 (5)
<u>3766.893</u>	0.018	3766.850	0.009	3766.850 (9)
3791.036	0.008			3791.004 (8)
3810.62	0.05			3810.59 (5)
<u>4085.875</u>	0.012	4085.853	0.009	4085.853 (9)
4295.224	0.01			4295.187 (10)
<u>4461.247</u>	0.013	4461.202	0.009	4461.202 (9)
<u>4806.06</u>	0.018	4806.007	0.009	4806.007 (9)
4865.91	0.04			4865.87 (4)
5005.62	0.23			5005.6 (3)

Y= A + BX and input energies (X) from 1994En02.

Table 2: ⁶⁶Ga Relative

Eg (keV)	1970Ph01		1971Ca14		Gamma-Ray 1994En02 lg	Emission 1994En02* lg(Corr.)	Intensities			Remarks	
	1970Ph01 lg	1970Ph01* lg(Corr.)	1971Ca14 lg	1971Ca14* lg(Corr.)			2000Ra00 lg	Berkeley lg	Budapest lg		Recomm. lg
171.9 (2)	0.028 (1)	0.028 (1)								0.028 (1)	O
283.87 (3)					0.0097 (21)	0.0097 (21)				0.0097 (21)	I
290.8105 (11)	0.150 (10)	0.150 (10)	0.131 (2)	0.131 (2)	0.146 (6)	0.146 (6)				0.133 (4)	A
347.77 (5)					0.0048 (15)	0.0048 (15)				0.0048 (15)	I
375.398 (17)					0.0058 (16)	0.0058 (16)				0.0058 (16)	I
410.178 (12)	0.300 (20)	0.300 (20)	0.172 (24)	0.172 (24)	0.177 (7)	0.177 (7)				0.177 (7)	I
412.916 (16)					0.0091 (13)	0.0091 (13)				0.0091 (13)	I
442.873 (14)					0.042 (3)	0.042 (3)				0.042 (3)	I
448.73 (2)	0.290 (10)	0.290 (10)	0.279 (58)	0.279 (58)						0.290 (10)	C
459.683 (14)	0.240 (10)	0.240 (10)	0.206 (35)	0.206 (35)						0.237 (10)	C
494.336 (13)					0.0152 (20)	0.0152 (20)				0.0152 (20)	I
499.590 (6)					0.013 (3)	0.013 (3)				0.013 (3)	I
551.284 (22)					0.0189 (16)	0.0189 (16)				0.0189 (16)	I
554.28 (3)					0.0122 (13)	0.0122 (13)				0.0122 (13)	I
557.13(5)					0.0166 (17)	0.0166 (17)				0.0166 (17)	I
562.241 (10)					0.0179 (17)	0.0179 (17)				0.0179 (17)	I
578.540 (19)	0.160 (10)	0.160 (10)	0.156 (20)	0.156 (20)						0.159 (10)	C
600.788 (21)					0.0365 (23)	0.0365 (23)				0.0365 (23)	I
653.568 (14)					0.0036 (12)	0.0036 (12)				0.0036 (12)	I
658.57 (3)					0.0203 (21)	0.0203 (21)				0.0203 (21)	I
670.251 (14)					0.0110 (18)	0.0110 (18)				0.0110 (18)	I
680.56 (10)					0.0040 (11)	0.0040 (11)				0.0040 (11)	I
686.080 (6)	0.690 (20)	0.690 (20)	0.645 (40)	0.645 (40)						0.681 (20)	C
705.031 (15)					0.0102 (11)	0.0102 (11)				0.0102 (11)	I
708.36 (5)					0.0234 (19)	0.0234 (19)				0.0234 (19)	I
718.97 (5)					0.0268 (20)	0.0268 (20)				0.0268 (20)	I
723.17 (5)					0.0093 (13)	0.0093 (13)				0.0093 (13)	I
749.68 (10)					0.0037 (11)	0.0037 (11)				0.0037 (11)	I
763.64 (3)					0.0240 (20)	0.0240 (20)				0.0240 (20)	I
796.21 (5)					0.0079 (17)	0.0079 (17)				0.0079 (17)	I
800.13 (5)					0.0027 (14)	0.0027 (14)				0.0027 (14)	I
833.5324 (21)	16.2 (7)	16.2 (7)	15.92 (17)	15.92 (17)			16.02 (24)	15.94 (14)	15.92 (6)	15.93 (6)	K
853.038 (8)			0.200 (5)	0.200 (5)	0.232 (12)	0.232 (12)				0.205 (5)	D
856.527 (10)			0.315 (10)	0.315 (10)	0.280 (12)	0.280 (12)				0.301 (17)	D

Comments on evaluation

⁶⁶Ga

Recomm. E _g (keV)	1970Ph01 lg	1970Ph01* lg(Corr.)	1971Ca14 lg	1971Ca14* lg(Corr.)	1994En02 lg	1994En02* lg(Corr.)	2000Ra00 lg	Berkeley lg	Budapest lg	Recomm. lg	Remarks
857.093 (9)					0.040 (12)	0.040 (12)				0.040 (12)	I
862.926 (13)					0.0410 (20)	0.0410 (20)				0.0410 (20)	I
867.93 (3)					0.0117 (14)	0.0117 (14)				0.0117 (14)	I
873.392 (21)					0.046 (3)	0.046 (3)				0.046 (3)	I
885.00 (5)					0.0051 (13)	0.0051 (13)				0.0051 (13)	I
907.390 (19)	0.300 (20)	0.300 (20)	<0.034 (10)		0.059 (4)	0.059 (4)				0.059 (4)	E
914.388 (14)	0.190 (10)	0.190 (10)	<0.030 (10)		0.073 (4)	0.073 (4)				0.073 (4)	E
929.68 (3)					0.0123 (15)	0.0123 (15)				0.0123 (15)	I
953.93 (9)					0.0027 (3)	0.0027 (3)				0.0027 (3)	I
954.12 (7)					0.0121 (17)	0.0121 (17)				0.0121 (17)	I
963.892 (15)					0.039 (3)	0.039 (3)				0.039 (3)	I
980.934 (13)	0.150 (20)	0.150 (20)	0.130 (5)	0.130 (5)						0.131 (5)	C
1008.588 (12)	0.183 (10)	0.183 (10)	0.138 (4)	0.138 (4)						0.160 (20)	C
1010.957 (19)					0.073 (4)	0.073 (4)				0.073 (4)	I
1015.081 (18)					0.033 (8)	0.033 (8)				0.033 (8)	I
1039.220 (3)	100	100	100	100	100	100	100.0 (16)	100.0 (9)	100.0 (3)	100.0 (3)	K
1060.051 (11)			0.033 (10)	0.033 (10)	0.043 (3)	0.043 (3)				0.042 (3)	F
1065.305 (9)					0.0063 (12)	0.0063 (12)				0.0063 (12)	I
1066.450 (12)					0.0064 (12)	0.0064 (12)				0.0064 (12)	I
1082.75 (2)					0.036 (2)	0.0358 (20)				0.0358 (20)	I
1106.53 (24)					0.0033 (10)	0.0033 (10)				0.0033 (10)	I
1129.923 (18)					0.0370 (21)	0.0367 (21)				0.0367 (21)	I
1135.47 (9)					0.0128 (13)	0.0128 (13)				0.0128 (13)	I
1147.896 (10)	0.22 (3)	0.22 (3)	0.211 (17)	0.211 (17)						0.212 (17)	C
1190.287 (7)	0.42 (4)	0.42 (4)	0.34 (1)	0.34 (1)						0.345 (19)	C
1195.32 (9)					0.0025 (9)	0.0025 (9)				0.0025 (9)	I
1232.264 (8)	1.14 (20)	1.12 (20)	1.38 (4)	1.36 (4)						1.35 (5)	C
1232.480 (15)	0.4 (2)	0.4 (2)	0.14 (4)	0.14 (4)						0.15 (5)	C
1248.779 (22)					0.0027 (9)	0.0027 (9)				0.0027 (9)	I
1274.50 (3)					0.0192 (15)	0.0189 (15)				0.0189 (15)	I
1298.95 (7)					0.0105 (12)	0.0103 (12)				0.0103 (12)	I
1305.807 (21)					0.0109 (12)	0.0107 (12)				0.0107 (12)	I
1333.112 (5)	3.28 (5)	3.21 (5)	3.25 (4)	3.18 (4)			3.17 (5)	3.20 (3)	3.171 (13)	3.175 (13)	K
1356.104 (9)	0.83 (30)	0.81 (30)	1.00 (10)	0.98 (10)						0.96 (10)	C
1356.320 (15)	0.3 (1)	0.29 (10)	0.35 (5)	0.34 (5)						0.33 (5)	C

Comments on evaluation

⁶⁶Ga

Recomm. E _g (keV)	1970Ph01 lg	1970Ph01* lg(Corr.)	1971Ca14 lg	1971Ca14* lg(Corr.)	1994En02 lg	1994En02* lg(Corr.)	2000Ra00 lg	Berkeley lg	Budapest lg	Recomm. lg	Remarks
1357.250 (12)	0.7 (2)	0.69 (20)	0.39 (10)	0.38 (10)						0.44 (13)	C
1409.35 (24)					0.0044 (18)	0.0043 (18)				0.0043 (18)	I
1418.754 (5)	1.65 (3)	1.61 (3)	1.700 (27)	1.659 (27)				1.640 (23)	1.659 (8)	1.657 (8)	M
1425.25 (2)					0.0167 (13)	0.0163 (13)				0.0163 (13)	I
1433.63 (4)					0.0050 (10)	0.0050 (10)				0.0050 (10)	I
1458.662 (12)	0.25 (7)	0.24 (7)	0.268 (6)	0.261 (6)						0.261 (6)	C
1468.97 (5)					0.0038 (10)	0.0037 (10)				0.0037 (10)	I
1508.158 (7)	1.48 (9)	1.44 (9)	1.520 (24)	1.478 (24)				1.503 (23)	1.496 (7)	1.497 (7)	M
1515.162 (20)					0.0172 (15)	0.0167 (15)				0.0167 (15)	I
1523.279 (15)					0.0152 (13)	0.0148 (13)				0.0148 (13)	I
1534.60 (4)					0.016 (4)	0.0155 (40)				0.016 (4)	I
1554.62 (3)					0.051 (3)	0.049 (3)				0.050 (3)	I
1559.627 (10)					0.061 (4)	0.059 (4)				0.059 (4)	I
1577.308 (20)					0.0111 (16)	0.0108 (16)				0.0108 (16)	I
1634.46 (7)					0.0098 (15)	0.0095 (15)				0.0095 (15)	I
1703.59 (5)					0.015 (5)	0.015 (5)				0.015 (5)	I
1713.602 (12)					0.068 (3)	0.066 (3)				0.066 (3)	I
1740.904 (16)	0.19 (4)	0.18 (4)	0.0800 (10)	0.0773 (10)						0.0773 (10)	G
1787.44 (9)					0.025 (2)	0.0240 (20)				0.0240 (20)	I
1797.94 (9)					0.0053 (14)	0.0051 (14)				0.0051 (14)	I
1868.105 (20)					0.0076 (15)	0.0073 (15)				0.0073 (15)	I
1872.740 (6)					0.064 (4)	0.062 (4)				0.062 (4)	I
1898.823 (8)	1.15 (3)	1.11 (3)	1.09 (4)	1.05 (4)				1.062 (23)	1.050 (8)	1.051 (8)	M
1918.329 (5)	5.65 (2)	5.45 (2)	5.625 (80)	5.427 (80)			5.33 (8)	5.44 (6)	5.360 (23)	5.368 (23)	K
1927.96 (4)					0.0063 (20)	0.0061 (20)				0.0061 (20)	I
2009.628 (16)					0.0086 (17)	0.0083 (17)				0.0083 (17)	I
2026.016 (25)					0.0073 (16)	0.0070 (16)				0.0070 (16)	I
2065.778 (7)	0.098 (16)	0.095 (16)	0.086 (4)	0.083 (4)						0.084 (4)	C
2085.86 (4)					0.006 (4)	0.0058 (40)				0.006 (4)	I
2088.985 (13)					0.032 (7)	0.031 (7)				0.031 (7)	I
2173.319 (15)	0.38 (3)	0.37 (3)	0.236 (12)	0.228 (12)						0.228 (12)	G
2189.616 (6)	15.0 (3)	14.5 (3)	15.06 (18)	14.56 (18)			14.54 (21)	14.50 (13)	14.39 (6)	14.42 (6)	K
2213.181 (9)	0.38 (5)	0.37 (5)	0.365 (12)	0.353 (12)						0.354 (12)	C
2265.84 (24)					0.0038 (14)	0.0037 (14)				0.0037 (14)	I
2292.171 (13)			0.110 (10)	0.107 (10)	0.047 (3)	0.046 (3)				0.046 (3)	H

Comments on evaluation

⁶⁶Ga

Recomm. E _g (keV)	1970Ph01 lg	1970Ph01* lg(Corr.)	1971Ca14 lg	1971Ca14* lg(Corr.)	1994En02 lg	1994En02* lg(Corr.)	2000Ra00 lg	Berkeley lg	Budapest lg	Recomm. lg	Remarks
2341.673 (11)					0.0089 (17)	0.0086 (17)				0.0086 (17)	I
2393.129 (7)	0.64 (2)	0.62 (2)	0.670 (20)	0.651 (20)						0.635 (20)	C
2422.525 (7)	5.06 (10)	4.93 (10)	5.16 (5)	5.023 (5)			5.12 (8)	5.15 (6)	5.072 (24)	5.085 (24)	K
2433.807 (18)					0.0206 (17)	0.0201 (17)				0.0201 (17)	I
2467.97 (7)					0.0234 (19)	0.0228 (19)				0.0228 (19)	I
2492.42 (3)			0.063 (6)	0.061 (6)	0.061 (4)	0.060 (4)				0.060 (4)	F
2537.09 (5)					0.014 (3)	0.014 (3)				0.014 (3)	I
2588.553 (13)			0.073 (7)	0.072 (7)	0.072 (4)	0.071 (4)				0.071 (4)	F
2631.44 (9)					0.008 (3)	0.008 (3)				0.008 (3)	I
2698.92 (5)					0.0101 (17)	0.0100 (17)				0.0100 (17)	I
2713.73 (5)					0.017 (5)	0.017 (5)				0.017 (5)	I
2751.835 (5)	60.9 (8)	60.3 (8)	61.2 (6)	60.6 (6)			61.2 (8)	61.5 (6)	61.34 (26)	61.35 (26)	K
2780.095 (16)	0.33 (2)	0.33 (2)	0.337 (8)	0.334 (8)						0.334 (8)	C
2785.7 (3)					0.0081 (14)	0.0080 (14)				0.0080 (14)	I
2802.8 (5)					0.0040 (11)	0.0040 (11)				0.0040 (11)	I
2843.130 (16)					0.0045 (9)	0.0045 (9)				0.0045 (9)	I
2933.358 (9)	0.57 (3)	0.57 (3)	0.574 (8)	0.576 (8)						0.576 (8)	C
2977.083 (43)			0.062 (6)	0.062 (6)						0.062 (6)	N
2993.208 (32)			0.084 (8)	0.085 (8)						0.085 (8)	N
3046.684 (9)	0.17 (2)	0.17 (2)	0.150 (6)	0.152 (6)						0.154 (6)	C
3085.4 (4)					0.0052 (13)	0.0053 (13)				0.0053 (13)	I
3212.499 (19)					0.0049 (10)	0.0050 (10)				0.0050 (10)	I
3228.800 (6)	3.85 (6)	3.96 (6)	3.96 (4)	4.08 (4)			4.06 (8)	4.07 (4)	4.087 (22)	4.082 (22)	K
3256.021 (9)	0.31 (3)	0.32 (3)	0.241 (5)	0.249 (5)	0.270 (14)	0.279 (14)				0.254 (10)	A
3331.351 (14)					0.0059 (8)	0.0061 (8)				0.0061 (8)	I
3380.850 (6)	3.68 (4)	3.85 (4)	3.78 (4)	3.95 (4)			3.96 (8)	3.99 (4)	3.950 (23)	3.960 (23)	K
3422.040 (8)	2.10 (9)	2.21 (9)	2.18 (4)	2.29 (4)				2.29 (3)	2.321 (16)	2.314 (16)	M
3432.309 (7)	0.73 (3)	0.77 (3)	0.740 (10)	0.778 (10)						0.777 (10)	C
3724.8 (10)			0.0060 (10)	0.0065 (10)						0.0065 (10)	N
3738.10 (5)			0.032 (3)	0.035 (3)	0.0353 (20)	0.0385 (20)				0.0374 (20)	F
3766.850 (9)	0.37 (2)	0.41 (2)	0.364 (14)	0.399 (15)						0.403 (15)	C
3791.004 (8)	2.63 (11)	2.89 (11)	2.675 (32)	2.940 (35)			2.96 (5)	2.96 (4)	2.929 (24)	2.941 (24)	K
3806.3 (10)			0.0060 (10)	0.0066 (10)						0.0066 (11)	N
3810.59 (5)			0.0210 (20)	0.0231 (22)	0.025 (3)	0.028 (3)				0.0248 (22)	F
3827.5 (8)			0.0170 (20)	0.0190 (22)						0.0190 (22)	N

Recomm.	1970Ph01	1970Ph01*	1971Ca14	1971Ca14*	1994En02	1994En02*	2000Ra00	Berkeley	Budapest	Recomm.	Remarks
E _g (keV)	I _g	I _g (Corr.)	I _g	I _g (Corr.)	I _g	I _g (Corr.)	I _g	I _g	I _g	I _g	
4085.853 (9)	2.91 (6)	3.33 (7)	3.07 (4)	3.52 (5)			3.38 (8)	3.42 (4)	3.455 (20)	3.445 (20)	K
4295.187 (10)	9.2 (2)	10.88 (24)	9.17 (11)	10.84 (13)			10.24 (26)	10.54 (15)	10.25 (7)	10.30 (8)	K, L
4461.202 (9)	1.84 (4)	2.23 (5)	1.875 (22)	2.277 (27)				2.20 (4)	2.275 (23)	2.26 (3)	M
4806.007 (9)	3.96 (6)	5.10 (6)	3.82 (4)	4.92 (4)			4.93 (11)	5.00 (7)	5.04 (3)	5.03 (3)	K
4865.87 (4)					0.0058 (5)	0.0075 (6)				0.0075 (6)	I
5005.6 (3)					0.0025 (3)	0.0033 (4)				0.0033 (4)	I

*γ-ray intensities (I_γ) corrected for a systematic inaccuracy in the detector efficiency curve above 1050 keV.

Correction factor $f = 1.116 - 0.155 E_{\gamma} (\text{MeV}) + 0.0397 E_{\gamma} \times E_{\gamma}$ (2002Ba38). Uncertainties are statistical values given by authors.

A: Weighted average of values from 1970Ph01, 1971Ca14, and 1994En02

B: Weighted average of values from 1971Ca14 and 1994En02. Value from 1970Ph01 is too high (peak may contain impurities).

C: Weighted average of values from 1970Ph01 and 1971Ca14.

D: Weighted average of values from 1970Ph01 and 1994En02.

E: From 1994En02. Value from 1970Ph01 is too high (peak may contain impurities).

F: Weighted average of values from 1971Ca14 and 1994En02.

G: From 1971Ca14. Value from 1970Ph01 is too high (peak may contain impurities).

H: From 1994En02. Value from 1971Ca14 is too high (peak may contain impurities).

I: From 1994En02.

K: Weighted average (in boldface) of values from 2000Ra36, from Berkeley, and from Budapest, as given in 2002Ba38 (except for the recommended uncertainties, which are never smaller than the smallest experimental uncertainty).

L: After correction for single-escape contribution from the 4806-keV line.

M; Weighted average (in boldface) of values from Berkeley and Budapest, as given in 2002Ba38

N: From 1971Ca14

O: Reported only by 1970Ph01.

**⁶⁷Ga – Comments on evaluation of decay data
by V.P. Chechev and N.K. Kuzmenko**

This evaluation was completed in March 2000, the half-life value has been updated in March 2004.

1. Decay Scheme

Up to the recent time a main uncertainty of evaluations of the ⁶⁷Ga decay scheme was connected with the lack of measurements of the absolute intensity of the internal conversion electron component P(ec_{1,0}) from the 93 keV gamma-transition (2000Si03). This value determines directly the probability of the allowed, but l-forbidden electron capture transition to the ground state of ⁶⁷Zn. In many evaluations including 1991Bh06 it has been adopted equal zero.

This evaluation of the ⁶⁷Ga decay scheme has taken into account two recent measurements of P(ec_{1,0}) (1998At04 and 2000Si03) as well as an analysis 2000Si03 and based on the average of the above two measurement results which gives P(ec_{1,0}) = 32.5 ± 0.4 per 100 disintegrations (see comments in 4.2) and leads to the probability of the electron capture transition to the ⁶⁷Zn ground state P(ε_{0,0}) = 3.6 ± 2.0 per 100 disintegrations.

There are two levels 604.5 keV and 814.8 keV among the adopted levels in 1991Bh06 which are placed below the decay energy and which could be fed by the 3rd and 2nd EC transitions, respectively. From the lg *ft* systematics their corresponding lg *ft* should be more than 17.6 and 11. From here the upper limits on the EC branch intensities are obtained negligible: < 4·10⁻¹² % and 10⁻⁶ %.

2 Nuclear Data

Q value is from Audi and Wapstra (1995Au04)

Since 1972 the eight accurate measurements of the ⁶⁷Ga half-life have been carried out. They gave the following values, in days:

3.261(1)	1972Le37
3.264(1)	1978La21
3.261(1)	1978Me10
3.2594(12)	1979De42
3.2607(8)	1980Ho17
3.26154(54)	1982HoZJ, 1992Un01, 2002Un02
3.2623(15)	2003Schrader
3.2634(16)	2003Silva

The other available values are, in days: 3.29(8) (1938MA01); 3.46 (1948HO04); 3.26(2) (1948MC32); 3.33 (1950HO26); 3.246(13) (1955TO27); 3.30(7) (1964RU06); 3.27(6), 3.26(5), 3.53(10), 3.30(6), 2.90(15), 3.51(5), 3.78(18), 3.49(18) (1972CR02). These values were omitted due to their large uncertainties.

Statistical processing of the above data set leads to the unweighted mean (UWM) of 3.2616(6) and weighted mean (WM) of 3.2613(6) with an internal uncertainty of 0.00033 and an external uncertainty of 0.00038. The LWEIGHT computer program has chosen WM and the internal uncertainty. The EV1NEW computer program has chosen WM and the minimum input uncertainty of 0.00054.

The adopted value for the ⁶⁷Ga half-life is 3.2613(5) days.

2.1. Electron Capture Transitions

The energies of the electron capture, ε, transitions have been calculated from the Q value and the level energies deduced from gamma transition energies

The P_K, P_L and P_M values have been computed from the tables of Schönfeld (1998Sc28).

The experimental values of P_K are available for ε_{0,2} and ε_{0,3} being obtained in 1988Be55 for ω_K=0.479(30) from 72Bb16; P_K(ε_{0,2}) = 0.89(4); P_K(ε_{0,3}) = 0.88(3).

The electron capture probabilities have been calculated from the balance of the evaluated $P_{\gamma+ce}$ values taking into account the evaluated absolute intensity $P(ec_{1,0}) = 32.5 \pm 0.4$ per 100 disintegrations (see comments in 1. and 4.2) that allows normalizing the total ground-state gamma transition probability to 96.4(20) per 100 disintegrations.

2.2. Gamma Transitions and Internal Conversion Coefficients.

The evaluated energies of gamma transitions are the energies of gamma rays with adding the recoil energy.

The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma-ray emission probabilities and the total internal conversion coefficients (ICC). The ICC have been evaluated using the experimental information on the multipolarity admixture coefficients (see the table below) and the theoretical values from 1978Ro22.

Most of gamma-transitions have the multipolarity of M1+E2. The multipolarities of the $\gamma_{1,0}$ and $\gamma_{4,1}$ transitions are pure E2 (for $\gamma_{4,1}$ the admixture of M3 is possible). Below the measured admixture coefficients $\delta(E2/M1)$ and adopted $|\delta|$ are given. The values $|\delta|$ have been adopted mainly from the most accurate gamma-gamma directional-correlation measurements of 1973Ba54 and 1978Lo06.

	1962 Ri09	1964 Al28	1966 Fr12	1973 Ba54	1974 Ni01	1975 Th01	1975 We08	1978 Du04	1978 Lo06	Adopted $|\delta|$
$\gamma_{2,1}$	$|\delta| \leq 0.07$		+ 0.1(1)			+ 0.06(5)	-0.15(3), 2.6(3)			0.06(5)
$\gamma_{2,0}$	+ 0.51(7)	+0.085 + 0.415 -0.07	+ 0.38(8)	- 0.350(35)	- 0.8 < δ $\delta < -0.1$	+ 0.48(11)	-0.17(7)	+ 0.08(4), - 5.0(8)		0.35(4)
$\gamma_{3,2}$			- 0.02(2)	+ 0.035(21)	+ 0.02(4)	+ 0.01(20)	+ 0.08(5), - 5.7(20)	- 0.10(6), + 3.6(8)		0.035(21)
$\gamma_{3,1}$			- 0.1(2)	- 0.178(5)	- 0.21(5)	+ 0.05(7)	- 0.11(4), 2.3(3)	+ 0.20(8), 3.1(4)		0.18(1)
$\gamma_{3,0}$			+ 0.07(8)	+ 0.043(10)	+ 0.11(6)	- 0.01(18)	0.09(2), 3.2(2)	- 0.17(8), - 2.1(3)		0.043(10)
$\gamma_{4,3}$			- 0.14(8)		+ 0.8 + 1.9 - 0.3	0.57	0.06(4), 2.8(4)	- 0.17(8), - 1.7(6)	0.14(3)	0.14(3)
$\gamma_{4,1}$ M3/ E2					+ 0.22 - 0.04 - 0.10	0.46(11)		- 0.1(1)	0.04(4)	0.04(4)
$\gamma_{4,0}$						- 0.81(47)		+ 0.9(3)	- 0.96(9)	0.96(9)

The measurements of $ICC(\alpha_K)$ have been made in 1966Fr12. Below their results are compared with the adopted α_K .

	Measured α_K	Adopted α_K
$\gamma_{1,0}$	0.77(8)	0.751(15)
$\gamma_{2,0}$	0.0156(10)	0.0158(6)
$\gamma_{3,2}$	0.0075(7)	0.00811(17)
$\gamma_{3,1}$	0.00337(30)	0.00356(15)
$\gamma_{3,0}$	0.00192(15)	0.00174(4)
$\gamma_{4,3}$	0.0019(15)	0.00104(3)
$\gamma_{4,0}$	$3.4(7) \cdot 10^{-4}$	$3.2(3) \cdot 10^{-4}$

As seen from this table the adopted α_K agree satisfactorily with the measured ones.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The X-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission probabilities are taken from 1996Sc06.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Table (Table de Radionucléides).

The ratios $P(KLX)/P(KLL)$ and $P(KXY)/P(KLL)$ are taken from 1996Sc06.

4. Photon Emissions

4.1. X-Ray Emissions

The total absolute emission probability of KX-rays (P_{XK}) has been computed using the adopted value of ω_K , the evaluated total absolute emission probabilities of K conversion electrons (P_{ceK}) and the electron capture (P_{EK}). The absolute emission probabilities of the KX-ray components have been computed from P_{XK} using the relative probabilities from 96Sc06.

Below the measured in 1979De42 the $P(XK\alpha)/P(\gamma_{2,0})$ and $P(XK\beta)/P(\gamma_{2,0})$ values are given in comparison with our calculated (evaluated) values:

	Measured 1979De42	Calculated (evaluated)
$P(XK\alpha)/P(\gamma_{2,0})$	2.37(5)	2.38(8)
$P(XK\beta)/P(\gamma_{2,0})$	0.331(7)	0.338(11)

The total absolute emission probability of LX-rays has been computed using total absolute sums P_{ceL} , P_{ceK} , P_{EK} , P_{EL} and atomic data of section 3 (ω_K , ω_L , n_{KL}).

4.2. Gamma Emissions

The gamma ray energies have been adopted from 1978Me10 as the most accurate with corrections to the revised energetic scale in 2000He14 (lowering by 5.80 ppm). The complete list of the gamma ray energy measurements is given below in Table 1.

Table 1. Measured energies of gamma-rays in the decays of ⁶⁷Ga → ⁶⁷Zn and ⁶⁷Cu → ⁶⁷Zn

	1958Ch08	1966Fr12	1969Ra15	1974Ar22	1974HeYW*	1974HeYW	1978Du04	1978Me10	1990Me15	Adopted
γ _{2,1}	91.22(4)	91.275(20)	91.26(10)		91.31(3)	91.31(5)		91.266(5)	91.237(35)	91.265(5)
γ _{1,0}	93.26(4)	93.317(20)	93.25(10)	93.2(2)	93.32(2)	93.32(2)	93.30(5)	93.311(5)	93.291(30)	93.310(5)
γ _{2,0}	184.46(27)	184.60(4)	184.53(10)	184.0(2)	184.56(2)	184.56(2)	184.63(3)	184.577(10)	184.569(30)	184.576(10)
γ _{3,2}		208.96(6)	208.95(10)		208.93(2)	208.93(2)	208.91(4)	208.951(10)	208.970(30)	208.950(10)
γ _{3,1}		300.24(7)	300.22(10)		300.24(6)	300.18(2)	300.24(5)	300.219(10)	300.230(25)	300.217(10)
γ _{3,0}		393.65(6)	393.60(10)		393.56(7)	393.47(3)	393.54(3)	393.529(10)	393.539(25)	393.527(10)
γ _{4,3}		494.31(10)				494.19(8)	494.10(6)	494.169(15)	494.132(30)	494.166(15)
γ _{4,2}		703.6(2)					703.2(3)	703.110(15)	703.078(50)	703.106(15)
γ _{4,1}		794.7(2)				794.49(20)	794.39(8)	794.386(15)	794.378(50)	794.381(15)
γ _{4,0}		888.0(2)				887.68(15)	887.67(7)	887.693(15)	887.664(40)	887.688(15)

) In 74HeYW the gamma ray energies have been measured in the decay of ⁶⁷Cu → ⁶⁷Zn

The gamma ray absolute emission probabilities have been computed from the evaluated relative emission probabilities given in Tables 2, 3 and the absolute emission probability of $\gamma_{1,0}$ (93 keV). The latter has been obtained from the evaluated $P(ec_{1,0})=32.5(4)$ per 100 disintegrations and the total ICC from 1978Ro22 for E2 gamma-transition $\gamma_{1,0}$: $P(\gamma_{1,0})=P(ec_{1,0})/\alpha_T(\gamma_{1,0})=37.8(9)$.

The evaluated value of $P(ec_{1,0})$ is based on measurements 1998At04 and 2000Si03. In 2000Si03 two measurement results are given for two experimental data sets: 32.13(14) and 31.82(27). The weighted mean of them with the external uncertainty increased by Student's factor is 32.06(23). In fact, this is a final experimental result of Simpson and Ntsoane (2000Si03). Combining it with the somewhat discrepant value of Attie et al. (1998At04) of 32.9(4) we have an evaluation for $P(ec_{1,0})=32.5(4)$ which is the unweighted average and obtained also on other statistical procedures (Limitation of Relative Statistical Weight, Chauvenet's Criteria and Permanent Inflation methods). The Uniform Chi-Square Inflation method gives 32.5(3), the Iterative Extensive Weighting method – 32.5(5). (See 1994Ka08). Simpson and Ntsoane recommended $P(ec_{1,0})=32.5(1)$ but such an uncertainty does not correspond to discrepancy of the two experimental results and evidently is underestimated.

The results of statistical data processing for the relative gamma emission probabilities are given in Table 3.

Table 2. Relative emission probabilities of gamma rays in the decay of ⁶⁷Ga

		1966 Fr12	1967 Vr03	1974 HeYW	1975 Th01	1978 Me10	1979 De42	1990 Me15	1991 HiZZ**	Evaluated
$\gamma_{2,1}$	91	7.4(26)*		21.0(19)*	15.1(6)	14.49(10)	15.0(5)	13.8(11)	14.9(7)	14.7(2)
$\gamma_{1,0}$	93	314(22)*		161(11)		181.2(11)	185(6)	169(10)	184(5)	181(3)
$\gamma_{2,0}$	184	100	100	100	100	100	100	100	100	100
$\gamma_{3,2}$	208	10.8(13)	10.9(5)	11.5(9)		11.38(8)	11.35(15)	11.1(7)	11.3(4)	11.34(9)
$\gamma_{3,1}$	300	70(5)	75.6(50)	81(6)		81.2(5)	79.9(11)	76.5(37)	79.2(11)	80.2(6)
$\gamma_{3,0}$	393		20.4(12)	22.6(19)		22.72(15)	22.0(3)	20.7(10)	22.1(3)	22.3(2)
$\gamma_{4,3}$	494	0.43(4)	0.24(3)	0.60(6)*		0.332(4)	0.322(7)	0.32(5)	0.326(7)	0.328(7)
$\gamma_{4,2}$	703	0.065(10)	0.05(1)			0.0529(10)	0.060(5)	0.046(5)	0.050(4)	0.053(2)
$\gamma_{4,1}$	794	0.26(5)	0.23(2)	0.24(3)		0.248(9)	0.251(8)	0.244(17)	0.255(9)	0.249(8)
$\gamma_{4,0}$	888	0.69(9)	0.58(6)	0.69(7)		0.612(10)*	0.712(11)	0.69(4)	0.703(15)	0.703(11)

* Omitted as outliers. For $\gamma_{4,0}$ the value of 1978Me10 has been omitted as it increases considerably χ^2 for the data set.

** In 1991HiZZ the absolute emission probabilities have been given but the details of the measurements are absent. Photons per 100 disintegrations: $\gamma_{2,1}$ -3.16(9), $\gamma_{1,0}$ - 39.3(10); $\gamma_{2,0}$ -21.20(28); $\gamma_{3,2}$ - 2.40(7); $\gamma_{3,1}$ -16.80(22); $\gamma_{3,0}$ -4.68(6); $\gamma_{4,3}$ -0.061(14); $\gamma_{4,2}$ -0.0106(9); $\gamma_{4,1}$ -0.0540(18); $\gamma_{4,0}$ -0.149(3) .

Table 3. The results of statistical data processing for the relative gamma emission probabilities

	E γ	n	WM	σ	S	χ^2		Final uncertainty and its type
						set	table	
$\gamma_{2,1}$	91	5	14.7	0.23	0.16	2.0	9.5	0.2 (σ) *
$\gamma_{1,0}$	93	5	181	2.4	2.8	5.5	9.5	3 (S) *
$\gamma_{3,2}$	208	7	11.34	0.09	0.04	1.2	12.6	0.09 (σ)
$\gamma_{3,1}$	300	7	80.2	0.52	0.63	8.8	12.6	0.6 (S) *
$\gamma_{3,0}$	393	6	22.3	0.14	0.21	10.7	11.1	0.2 (S) *
$\gamma_{4,3}$	494	6	0.328	0.0034	0.0062	16.6	11.1	0.007 (tS) *
$\gamma_{4,2}$	703	6	0.053	0.0018	0.0019	6.0	11.1	0.002 (S) *
$\gamma_{4,1}$	794	7	0.249	0.0046	0.0024	1.6	12.6	0.008 (σ)
$\gamma_{4,0}$	888	6	0.703	0.0094	0.0092	4.8	5.0	0.011 (σ_{min}) **

*Limitation of Relative Statistical Weight (LRSW) method increased the uncertainty of 1978Me10.

**LRSW method increased the uncertainty of 1979De42.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies,

The emission probabilities of the conversion electrons have been calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3, and the conversion coefficients given in 2.2.

7. References

- 1938MA01 Mann, W. B. (1938): Nuclear Transformations Produced in Zinc by alpha- Particle Bombardment. Phys. Rev. 54, 649. (Half-life)
- 1948HO04 Hopkins, H. H., Jr.; Cunningham, BB (1948): Nuclear Reactions of Arsenic with 190-MeV Deuterons. Phys. Rev. 73, 1406. (Half-life)
- 1948MC32 McCown, D. A.; Woodward, L. L.; Pool, M. L. (1948): Radioactive Isotopes of Ga and Ge. Phys. Rev. 74, 1311. (Half-life)
- 1950HO26 Hopkins, H. H. (1950): Spallation Products of Arsenic with 190-MeV Deuterons. Phys. Rev. 77, 717. (Half-life)
- 1955TO27 Toboalem, J. (1955): No title. Ann. Phys. (Paris) 10, 783. (Half-life)
- 1958Ch08 Chupp, E. L.; Dumond, J. W. M.; Gordon, F. J.; Jopson, R. C.; Mark, H.: Precision Determination of Some Energy Levels in Fe57, Zn67, and Tc99. Phys. Rev. 109 (1958) 2036. (Gamma-ray energies)
- 1962RI09 Ritter, R. C.; Stelson, P. H.; McGowan, F. K.; Robinson, R. L. (1962): Coulomb Excitation with Ne20 Ions. Phys. Rev. 128, 2320. (mixing ratio (E2/M1) for gamma-transitions)
- 1964AI28 Alkhazov, D. G.; Vasilev, V. D.; Gusinskii, G. M.; Lemberg, I. K.; Nabichvrishvili, V. A. (1965): Angular Distribution of Gamma Radiation Emitted in Coulomb Excitation of Odd-A Nuclei. Bull. Acad. Sci. USSR, Phys. Ser. 28, 1575. (Izv. Akad. Nauk. SSSR, Ser. Fiz. 28, 1683 (1964)) (mixing ratio (E2/M1) for gamma-transitions)
- 1964RU06 Rudstam, G. (1964): Peripheral Reactions in Copper Induced by 19 GeV Protons. Nucl. Phys. 56, 593. (Half-life)
- 1966Fr12 Freedman, M. S.; Porter, F. T.; Wagner, F.: Internal Conversion, Multipole Mixing, and Auger Spectrum in Zn67 from Ga67 Decay. Phys. Rev. 151 (1967) 886. (Priv. Comm.; June 1966) (mixing ratio E2/M1 for gamma-transitions, ICC, gamma-ray energies and emission probabilities)
- 1967Be65 Bearden, J. A. (1967): Rev. Mod. Phys. 39, 78. (X-ray energies)
- 1967Vr03 Vrzal, J.; Dzhelpev, B. S.; Liptak, J.; Moskvina, L. N.; Prikhodtseva, V. P.; Sabirov, B. M.; Tishin, V. G.; Urbanets, J.; Tsaritsyna, L. G.: Gamma Radiation from 66Ga, 67Ga and 72Ga. Bull. Acad. Sci. USSR, Phys. Ser. 31 (1968) 1687 (Izv. Akad. Nauk. SSSR, Ser. Fiz. 31 (1967) 1647) (Gamma-ray emission probabilities)
- 1969Li04 Li-Scholz, A.; Bakhru, H.: Branching Ratio of the gamma Rays from the 184.6-keV State in Zn67. Phys. Rev. 177 (1969) 1629. (Gamma-ray emission probabilities, gamma-mixing, ICC)
- 1969Ra15 Raman, S.; Pinajian, J. J.: Decay of 67Cu. Nucl. Phys. A131 (1969) 393. (Gamma-ray energies)
- 1972Bb16 Bambynek, W.; Crasemann, B.; Fink, R. W.; Freund, H. -U.; Mark, H.; Swift, C. D.; Price, R. E.; Rao, P. Venugopala: X-Ray Fluorescence Yields, Auger, and Coster-Kronig Transition Probabilities. Rev. Mod. Phys. 44 (1972) 716. (KX-Ray Fluorescence Yield)
- 1972CR02 Crisler, D. F.; Eldridge, H. B.; Kunselman, R.; Zaidins, C. S. (1972): Reactions Induced by He3 Ions on Zn64. Phys. Rev. C5, 419. (Half-life)
- 1972Le37 Lewis, V. E.; Woods, M. J.; Goodier, I. W. Int. J. Appl. Radiat. Isotopes 23 (1972) 279. (Half-life)
- 1973Ba54 Bargholtz, C.; Eriksson, L.; Gidefeldt, L. (1973): Mixing Ratios in 67Zn Determined by Gamma-Gamma Angular Correlations. Z. Phys. 263, 89 (mixing ratio (E2/M1) for gamma-transitions)
- 1974Ar22 Aronsson, P. O.; Johansson, B. E.; Rydberg, J.; Skarnemark, G.; Alstad, J.; Bergersen, B.; Kvale, E.; Skarestad, M.: SISAK-a New Technique for Rapid, Continuous (Radio) Chemical Separations. J. Inorg. Nucl. Chem. 36 (1974) 2397. (Gamma-ray energies)
- 1974HeYW Heath, R. L. (1974): Gamma-Ray Spectrum Catalogue. Ge(Li) and Si(Li) Spectrometry. In: ANCR-1000-2. (Gamma-ray energies and emission probabilities)
- 1974Ni01 Nilsson, A.; Sawa, Z. P.: On 1f2p Nuclei. Gamma Ray Spectroscopy on States in 65Zn and 67Zn Using 62,64Ni(a,n) Reactions. Phys. Scripta 9 (1974) 83. (mixing ratio (E2/M1) for gamma-transitions)
- 1975Th01 Throop, M. J.; Cheng, Y. T.; McDaniels, D. K.: Coulomb Excitation of 67Zn and Core-Quasiparticle Coupling in f-5/2 Nuclei. Nucl. Phys. A239 (1975) 333. (mixing ratio (E2/M1) for gamma-transitions, gamma-ray emission probabilities)
- 1975We08 Wender, S. A.; Cameron, J. A.: Integral Rotation of 3/2- Levels in 65Zn and 67Zn. Nucl. Phys. A241 (1975) 332. (Mixing ratio (E2/M1) for gamma-transitions, gamma-ray emission probabilities)
- 1977La19 Larkins, F. P.: Atomic Data and Nuclear Data Tables, 20 (1977) 313 (Auger electron energies)

- 1978Du04 Duffait, R.; Charvet, A.; Chery, R.: Low-Spin States in ⁶⁷Zn. Phys. Rev. C17 (1978) 2031. (Gamma-ray energies)
- 1978La21 Lagoutine, F.; Legrand, J.; Bac, C. : Int. J. Appl. Radiat. Isotopes 29 (1978) 269. (Half-life)
- 1978Lo06 Lornie, P. R. G.; Kogan, A.; Jones, G. D.; Nixon, M. R.; Price, H. G.; Wadsworth, R.; Twin, P. J. (1978): Gamma-Ray Studies of the Odd-Parity States in Zn Isotopes. II. Levels Below 2.0 MeV in Excitation Energy in ⁶⁷Zn. J. Phys. (London) G4,923. (mixing ratio (E2/M1) for gamma-transitions)
- 1978Me10 Meyer, R. A.; Prindle, A. L.; Myers, W. A.; Hopke, P. K.; Dieterly, D.; Koops, J. E.: Multiparticle Configurations in the Odd-Neutron Nuclei ⁶¹Ni and ⁶⁷Zn Populated by Decay of ⁶¹Cu, ⁶⁷Cu, and ⁶⁷Ga. Phys. Rev. C17 (1978) 1822. (Half-life, gamma-ray energies and emission probabilities)
- 1978Ro22 Rösel, F.; Fries, H. M.; Alder, K.; Pauli, H. C.: Atomic Data and Nuclear Data Tables, 21 (1978) 91 (Internal conversion coefficients)
- 1979De42 Debertain, K. et al. : Int. J. Appl. Radiat. Isotopes 30(1979)551. (Half-life and X- and gamma-ray emission probabilities)
- 1980Ho17 Houtermans, H.; Milosevic, O.; Reichel, F.: Int. J. Appl. Radiat. Isotopes 31(1980)153. (Half-life)
- 1982HoZJ Hoppes, D. D.; Hutchinson, J. M. R.; Schima, F. J.; Unterweger, M. P. (1982): Nuclear Data for X- or Gamma-Ray Spectrometer Efficiency Calibrations. In: NBS-SP-626, p 85. (Half-life)
- 1987Table Lagoutine, F.; Coursol, N.; Legrand, J. : Table de Radionucléides. ISBN-2-7272-0078-1. LMRI, 1982-1987, BP 52, 91 191 Gif-sur-Yvette Cedex, France (energy of Auger electrons)
- 1988Be55 Begzhanov, R. B.; Azimov, K. Sh.; Ilkhamdzhanov, N. A.; Magrupov, R. A.; Mirakhmedov, Sh. A.; Mukhammadiev, A.; Narzikulov, M.: Probability of K Capture in the Decay of ⁶⁷Ga at Levels of ⁶⁷Zn. Bull. Acad. Sci. USSR, Phys. Ser., 52(11) (1988) 88. (Experimental PK values)
- 1990Me15 Meyer, R. A.: Multigamma-Ray Calibration Standards. Fizika (Zagreb) 22 (1990) 153. Part 1(Gamma-ray energies and emission probabilities)
- 1991Bh06 Bhat, M. R.: Nuclear Data Sheets Update for A = 67. Nucl. Data Sheets 64 (1991) 875. (Decay scheme)
- 1991HiZZ Hirshfeld, A. T.; Hoppes, D. D.; Schima, F. J. (1991): A Direct Measurement of the Probabilities of Gamma Rays Following the Decay of ⁶⁷Ga. (Priv. Comm.) (Gamma-ray emission probabilities)
- 1992Un01 Unterweger, M. P.; Hoppes, D. D.; Schima, F. J.: Nucl. Instrum. Methods. A312 (1992) 349. (Half-life)
- 1994KA08 Kafala, S. I.; MacMahon, T. D.; Gray, P. W. (1994): Testing of Data Evaluation Methods. Nucl. Instrum. Methods Phys. Res. A339, 151.(Evaluation technique)
- 1995Au04 Audi, G.; Wapstra, A. H. : Nucl. Phys. A595 (1995) 409.(Q value)
- 1996Sc06 Schönfeld, E.; Janßen, H.: Nucl. Instr. Meth. Phys. Res., A369 (1996) 527 (Atomic data)
- 1998At04 Attie, M. R. P.; Koskinas, M. F.; Dias, M. S.; Fonseca, K. A.: Appl. Radiat. Isot. 49 (1998) 1175 (Internal conversion electron intensities)
- 1998Sc28 Schönfeld, E. : Appl. Rad. Isotopes, 49 (1998) 1353.(Fractional electron capture probabilities)
- 2000He14 Helmer, R. G.; van der Leun, C.: Recommended Standards for gamma-Ray Energy Calibration (1999). Nucl. Instrum. Methods Phys. Res. A450, 35 (2000) (γ -ray energies)
- 2000Si03 Simpson, B. R. S.; Ntsoane, T. P. (2000) : Decay scheme of ⁶⁷Ga. Appl. Rad. Isotopes, 52 (2000) 551 (Internal conversion electron intensities, electron capture branching ratio to the ground state)
- 2002Un02 Unterweger, M. P. : Appl. Rad. Isotopes 56(2002)125 (Half-life)
- 2003Schrader Schrader, H. : Appl. Rad. Isotopes 60,2-3 (2004) 317 (Half-life)
- 2003Silva da Silva, M. A. L.; de Almeida, M. C. M.; da Silva, C. J.; Delgado, J. U.: Appl. Rad. Isotopes 60,2-3 (2004) 301 (Half-life)

⁸⁵Kr – Comments on evaluation of decay data by V. Chisté and M. M. Bé

This evaluation was completed in July 2003 and the half life value has been updated in May 2004.

1) Decay Scheme

⁸⁵Kr disintegrates by β^- emission to the ⁸⁵Rb ground state (99.562(10)%) and to the second excited level at 513.998(5) keV (0.438(10)%). The decay scheme is based mainly on the measurements of the 514 keV γ -emission intensity (see § 4. Radiation Emission, 4.2 Gamma Ray Emissions).

2) Nuclear Data

The Q value is from Audi and Wapstra (1995Au04)

Level energies, spins and parities are from R. A. Meyer (1980Me06).

The measured ⁸⁵Kr half-life values are, in years:

$T_{1/2}$

Reference	Value (a)	Comments
Thode (1948Th06)	9.4 (4)	
Turner (1953Tu22)	10.57 (14)	
Wanless (1953Wa17)	10.27 (18)	
Lerner (1963Le07)	10.76 (2)	
Anspach (1965An07)	10.75 (3)	
Johnston (1974Jo12)	10.714 (57)	
Walz (1983Wa15)	10.702(8)	Superseded by 2003Sc49
Unterweger (1992Un03)	10.7720(38)	Superseded by 2002Un04
Eberszkorn (1996Er06)	10.757 (49)	
Unterweger (2002Un04)	10.7756(33)	
Schrader (2003Sc49)	10.724(7)	

Evaluators calculated the weighted average of these 9 values using the Lweight program (version 3) as 10.750 years with an external uncertainty of 0.011 and a reduced- χ^2 of 6.34. Evaluators rejected the Thode (1948Th06), Turner (1953Tu22) and Wanless (1953Wa17) values based on the Chauvenet's criterion. For the remaining 6 values, the largest contribution to the weighted average comes from the value of Unterweger (2002Un04), amounting to 79%. The program Lweight 3 increased the uncertainty for the 2002Un04 value from 0.0033 to 0.0064 in order to reduce its relative weight from 79% to 50%.

The adopted value is the weighted mean : 10.752 a, with an uncertainty of 0.023 (expanded so range includes the most precise value of Unterweger (2002Un04)) and a reduced- χ^2 of 6.

2.1) β^- Transitions

The β^- probabilities and the associated uncertainties have been deduced from γ transition probability balance at each level of the decay scheme, i. e., $P_{\beta}(0,0) = 99.562(10)\%$ and $P_{\beta}(0,2) = 0.438(10)\%$. The values of $\log ft$ have been calculated with the program LOGFT for the Allowed and 1st Unique Forbidden transitions.

2.2) Gamma Transitions

Probabilities

The transition probabilities have been calculated from the gamma emission intensities and the internal conversion coefficients (see § 4.2) **Gamma Ray Emissions**).

Mixing ratios and internal conversion coefficients

The adopted δ ($= 0.072(4)$) for the 151 keV γ -transition and the gamma transition multiplicities of the 362 keV ((E3)) and of the 513 keV (M2, from ⁸⁵Sr ground state decay) were adopted from Sievers (1991Si01).

The theoretical internal conversion coefficients (table 1) have been interpolated from values in 1978Ro22 using the ICC Computer Code (program Icc99v3a – GETICC dialog).

Table 1:

E_{γ} (keV)	Multipolarity	Value of α_K	Value of α_L	Value of α_T
151.18 (3)	M1 + 0.52(4)% E2	0.0430(13)	0.00485(14)	0.0488(14)
362.81 (3)	(E3)	0.0292(9)	0.0040(1)	0.0340(10)
513.998 (5)	M2	0.00635(19)	0.00072(2)	0.00721(21)

For the 151 keV γ -transition, the α_T is calculated as follows:

$$\alpha_T(M1) * \%(M1) + \alpha_T(E2) * \%(E2) = (0.00479(14) * 0.9948(4)) + (0.213(6) * 0.0052(4)) = 0.0488(14)$$

Calculations of ICC uncertainties for transitions:

* For the all transitions, uncertainties in α_T , α_K and α_L calculated values with ICC Computer Code (program Icc99v3a) are taken to be 3% .

3) Atomic Data

Atomic values (ω_K , ω_L and n_{KL}) are from Schönfeld (1996Sc33).

The X-ray and Auger probabilities are calculated by Emission program.

4) Radiation emissions

4.2) Gamma ray emissions

Gamma ray energies (in keV) are from R. A. Meyer (1980Me06).

Emission probability values are deduced from measured values of the 514 keV absolute γ -emission intensity in Table 2 and using values relative to 514-keV transition for the other gamma-rays (1980Me06) shown in Table 3.

Table 2:

Reference	514 keV γ -emission intensity (%)	Comments
Geiger (1961Ge19)	0.46 (4)	
Eastwood (1964Ea01)	0.431(17)	
Denecke (1967De05)	0.435 (13)	
Weighted Average (Lweight 3)	0.435 (10)	Reduced- $\chi^2 = 0.22$

Table 3:

Energy (keV)	Relative γ -emission intensity measured by R. A. Meyer (1980Me06) (%)	Absolute γ -emission intensity (%)
151	0.0005 (3)	0.0000022(13)
362	0.0005 (1)	0.00000218(44)
514	100	0.435(10)

With these values shown in table 3, and the values of α_T calculated using the ICC Computer Code (table 1, section 2.2), evaluators deduced the γ -transition probability (table 4).

Table 4:

Energy (keV)	Transition probability (%)
151	0.0000023(14)
362	0.00000225(45)
514	0.438(10)

References

- 1948Th06 – H. G. Thode, *Nucleonics* 3(1948)14 [Half-life].
 1953Tu22 – J. F. Turner, *AERE – N/R* 1254(1953) [Half-life].
 1953Wa17 – R. K. Wanless, H. G. Thode, *Can. J. Phys.* 31(1953)517 [Half-life].
 1961Ge19 – K. W. Geiger, J. S. Merritt, J. G. V. Taylor, *Nucleonics* 19(1961)97 [514 γ -Branching ratio].
 1963Le07 – J. Lerner, *J. Inorg. Nucl. Chem.* 25(1963)749 [Half-life].
 1964Ea01 – T. A. Eastwood, F. Brown, R. D. Werner, *Can. J. Phys.* 42(1964)218 [514 γ -Branching ratio].
 1965An07 – S. C. Anspach, L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, C. N. Smith, *NP – 15663*(1965) [Half-life].
 1967De05 – B. Denecke, E. de Roost, A. Spornol, R. Vaninbrouckx, *Nucl. Sci. Eng.* 28(1967)305 [514 γ -Branching ratio].
 1971Ho05 – D. J. Horen, *Nucl. Data Sheets* B5(1971)131 [Multipolarities, mixing ratio, half-life, J^π].
 1974Jo12 – J. W. Johnston, *BNWL – B – 369*(1974) [Half-life].
 1978Ro22 – F. Rösel et al, *At. Data Nucl. Data Tables* 21(1978)91 [ICC].
 1980Me06 – R. A. Meyer, J. E. Fontanilla, N. L. Smith, C. F. Smith, R. C. Ragaini, *Phys. Rev.* C21(1980)2590 [Energy and emission probability].
 1980Si01 – H. Sievers, *Nucl. Data Sheets* 30(1980)501 [Multipolarities, mixing ratio, half-life, J^π].
 1983Wa15 – K. F. Walz, K. Debertin, H. Schrader, *Int. J. Appl. Rad. Isotopes* 34(1983)1191 [Half-life].
 1991Si01 – H. Sievers, *Nucl. Data Sheets* 62(1991)271 [Multipolarities, mixing ratio, half-life, J^π].
 1992Un03 – M. P. Unterweger, D. D. Hoppes, F. J. Schima, *Nucl. Instr. Meth. Phys. Research* A312(1992)349 [Half-life].
 1995Au04 – G. Audi, A. H. Wapstra, *Nucl. Phys.* A565(1995)1 [Q-value].
 1996Er06 – L. Erbeszkorn, Á. Szörényi, J. Vágvolgyi, *Nucl. Instr. Meth. Phys. Research* A369(1996)463 [Half-life].
 1996Sc33 – E. Schönfeld, H. Janßen, *Nucl. Instr. Meth. Phys. Research* A369(1996)527 [Atomic Data].
 2002Un04 – M. P. Unterweger, *Appl. Rad. Isotopes* 56(2002)125 [Half-life].
 2003Sc49 – H. Schrader, *Appl. Rad. Isotopes* 60, 2-3 (2004) 317 [Half-life].

⁸⁵Sr - Comments on evaluation of decay data by E. Schönfeld, R. Dersch

1 Decay Scheme

The decay scheme is taken from Torti et al. (1972) and Meyer et al. (1980). A level at 951 keV which is depopulated by four gamma transitions (see Section 4.3) was observed by Barnard et al. (1973) in n, γ reactions. An EC transition to this level in the ⁸⁵Sr disintegration would be second forbidden. An upper limit of $3 \cdot 10^{-7}$ was estimated for this transition. The existence of EC transitions to the levels at 281 keV (unique third forbidden) and 151 keV (third forbidden) is also questionable.

Below the Q_{EC} value there are also levels at 919,7 keV (possibly two levels, $1/2^-$ or $3/2^-$ and $5/2^-$, populated in the decay of 68 min ⁸⁵Sr^m and several reactions) and 731,822 keV ($3/2^-$, populated in the decay of 4 h ⁸⁵Kr^m and several reactions). EC transitions from ⁸⁵Sr ground state to these levels would be both 3rd forbidden, γ rays from these levels have not been observed in the decay of ⁸⁵Sr.

The main transitions in the EC decay of ⁸⁵Sr are the EC transition populating the 514 keV level of ⁸⁵Rb and the γ transition of 514 keV depopulating this level. Besides these transitions there is an EC transition to the 869 keV level which is mainly depopulated by 869 keV γ rays.

The half-lives of the excited levels were taken from Sievers (1991). The half-life of the 514 keV level was determined by Siekman (1956), Löbner (1964), Miller *et al.* (1972) and Walz and Weiß (1976). Sievers took the value of Miller et al. which claims to be the most accurate one.

2 Nuclear Data

The following values of the half-life of ⁸⁵Sr have been considered ($T_{1/2}$ in d):

1	66	Dubridge and Marshall (1940)
2	65,0(7)	Herrmann and Strassmann (1956)
3	64,0(2)	Wright et al. (1957)
4	63,9(27)	Sattler (1962)
5	65,19(13)	Anspach et al. (1965)
6	66,6(6)	Grotheer et al. (1969)
7	64,93(22)	Emery et al. (1972)
8	64,68(23)	Lagoutine et al. (1972)
9	65,0(49)	Araminowicz and Dressler (1972)
10	65,0(50)	Vatai et al. (1974)
11	64,84(3)	Merritt and Gibson (1976); replaced by value 13
12	64,84(1)	Thomas (1978)
13	64,845(9)	Rutledge et al. (1980)
14	64,856(7)	Houtermans et al. (1980)
15	64,851(6)	Hoppes et al. (1982); replaced by value 17
16	64,85(14)	Walz et al. (1983)
17	64,8530(81)	Unterweger et al. (1992)
18	64,847(3)	unweighted mean of 12, 13, 14, 16, 17
19	64,850(7)	LWM (0,004 (int), 0,003 (ext), reduced χ^2 0,46), uncertainty enlarged to the uncertainty of the most accurate single value for the same five values

Values 1 - 11 are only of historical interest. They were not included in the averaging procedure.

The Q_{EC} value was taken from Audi and Wapstra (1995).

2.1 Electron capture Transitions

The main EC transition $\epsilon_{0,3}$ to the 514 keV level in ⁸⁵Rb is allowed ($\lg ft = 6,2$). A transition leading directly to the ground state ($\epsilon_{0,0}$) is unique 1st forbidden. The transition probability of this transition was estimated by Yoshizawa and Inoue (1991) by using the average $\lg ft$ value (according to Gove and Martin (1971)) of $9,47 \pm 0,17$ for seven neighbouring nuclei with uncertainty of 2σ . Their result is 0,8(4)%. The probability for the EC transition $\epsilon_{0,4}$ is deduced from the probabilities of the depopulating γ ray transitions. Concerning EC transitions $\epsilon_{0,2}$ and $\epsilon_{0,1}$ see Section 1. The data for the population and depopulation of the 151 keV level are discrepant as $P_{\gamma+ce}(4,1) + P_{\gamma+ce}(3,1) + P_{\gamma+ce}(2,1)$ is larger than $P_{\gamma+ce}(1,0)$. This can be explained (for example) by a too small value for $P_{\gamma+ce}(1,0)$. Moreover, it supports the assumption that an EC transition to the first excited level of ⁸⁵Rb at 151 keV does not exist.

Double K shell ionization was found by Schupp and Nagy (1984) $6,0(5) 10^{-5}$ per disintegration.

2.2 Gamma Transitions

The transition probability of 0,8(4)% for the EC transition directly feeding the ground state of ⁸⁵Rb yields for $P_{\gamma+ce}(514 \text{ keV}) = 99,2(4)\%$. Furthermore, with the total conversion coefficient of the 514 keV transition $I_{\gamma}(514) = 98,5(4)\%$. The transition probabilities of the other gamma transitions are derived from the measured emission probabilities (Sect. 4.2).

The conversion coefficients are interpolated from the tables of Rösel et al. (1978). The main transition $\gamma_{3,0}$ is assumed to have pure M2 multipolarity. The conversion coefficients of the other transitions have little influence on the balancing procedure because the emission probabilities of the assigned transitions are very small.

3 Atomic data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energies are based on the wavelengths of Bearden (1967). The relative probabilities are taken from Schönfeld and Janßen (1996).

3.2 Auger electrons

The energies are taken mainly from Larkins (1977). The relative probabilities are taken from Schönfeld and Janßen (1996).

4 Radiation Emission

4.1 Electron emission

The energies of the Auger electrons are the same as above. The energies of the conversion electrons are calculated from the transition energy and the binding energies. The number of Auger electrons per disintegration are calculated using the above mentioned atomic shell data and the program EMISSION. The number of conversion electrons related to the 514 keV γ -transition are calculated from the transition probability and the conversion coefficients.

4.1 X-ray emission

For the total K X-ray emission intensity, it was found three measured values :

Comments on evaluation

1	59,59(35)	Grotheer et al. (1969)
2	58,6(3)	Bambynek and Reher (1970)
3	58,66(47)	Thomas (1978)
4	59,04(34)	Weighted mean
5	58,95(32)	Unweighted mean
6	59,2 (6)	calculated from P_e , P_K , ω_K , P_{g+ce} This is the adopted value.

4.2 Photon Emission

The accuracy of the γ ray energy of the main line has improved during the last years, in keV :

1	514,0	Sattler (1962), Vartanov (1966)
2	513,98(3)	Legrand et al. (1968)
3	513,998	Ragaini et al (1972), Meyer et al. (1980)
4	514,009(12)	Helmer et al. (1978)
5	514,0076(22)	Kumahora et al. (1983)
6	514,00492(50)	Chang et al. (1993)
7	514,0048(22)	Helmer and van der Leun (2000), evaluation

The γ ray energies of the other transitions are taken from Sievers (1991).

From the balance of the decay scheme $P_{\gamma+ce}$ (514 keV) is calculated to be 99,2(4)%.

The ratio of the emission probabilities of the 869 keV and the 514 keV transitions were determined to be:

1	$1,7 \cdot 10^{-4}$	Sattler (1962)
2	$1,0(2) \cdot 10^{-4}$	Vartanov et al. (1966)
3	$1,4(2) \cdot 10^{-4}$	Vatai et al. (1974)
4	$1,154(63) \cdot 10^{-4}$	Pratt (1977)
5	$1,25(5) \cdot 10^{-4}$	Thomas (1978)
6	$1,25(5) \cdot 10^{-4}$	Meyer et al. (1980)
7	$1,23(3) \cdot 10^{-4}$	LWM of values 2 - 6

With the above-mentioned $I_\gamma(514) = 98,5(4) \%$ this yields $I_\gamma(869) = 0,0121(4) \%$.

Barnard *et al.* (1973) have observed in (n,n' γ) measurements a level at 951,3 keV in ^{85}Rb which is depopulated by the following gamma transitions: 951,3 keV (86 %), 800,2 keV (9 %), 670,3 keV (4 %) and 437,7 keV (1 %). If this level with the populated in the ^{85}Sr decay, the corresponding EC transition is second forbidden ($9/2^+ \rightarrow 5/2^+$; $\lg ft > 11,2$; transition energy 114(4) keV). Meyer *et al.* (1980) observed a 951 keV gamma ray in two spectra with high counting statistics and estimated an upper limit of $3 \cdot 10^{-7}$ for the emission probability of these gamma rays.

Levels at 731,9 keV ($3/2^-$) and 921 keV ($1/2^-$, $3/2^-$) in ^{85}Rb have not been found to be populated in the studies of the ^{85}Sr decay carried out by Meyer *et al.* (1980).

A level in ^{85}Rb at 281 keV, found by Barnard *et al.* (1973), is depopulated according to Meyer *et al.* (1980) by 129,8 keV gamma rays with an emission probability of $< 5 \cdot 10^{-3}$. As this is an upper limit the existence of this transition is not sure. Therefore, the population and depopulation of this level is given in the above decay scheme by dashed lines.

The gamma ray emission intensities in Table 5.2 and the corresponding values of the transition probabilities $P_{\gamma+ce}$ given in Table 2.2 are from Meyer *et al.* (1980) (129,8/151,1/355,0/362,8 keV) whereas the value for the 717,8 keV gamma rays is from Jerbic-Zorc (1990). The origin of the values for the 514 keV and 869 keV gamma rays were already explained above.

5 Main Production Modes

The main production modes are taken from Sievers (1991).

6 References

- L. A. Dubridge, J. Marshall, *Phys. Rev.* 58 (1940) 7
 [$T_{1/2}$]
 G. Herrmann, F. Strassmann, *Z. Naturforschg.* 11a (1956) 946
 [$T_{1/2}$]
 J. G. Siekman, *Nuclear Physics* 2 (1956/57) 254
 [$T_{1/2}$ 514 keV level]
 H. W. Wright, E. L. Wyatt, S. A. Reynolds, W. S. Lyon, T. H. Handley, *Nucl. Sci. Eng.* 2 (1957) 427
 [$T_{1/2}$]
 M. K. Ramaswamy, B. A. Bishara, P. S. Jastram, *Bull. Am. Phys. Soc.* 7 (1962) 341
 [P_{γ}]
 A. R. Sattler, *Phys. Rev.* 127 (1962) 854
 [$T_{1/2}$, P_{γ}]
 K. E. G. Löbner, *Nuclear Physics* 58 (1964) 49
 [$T_{1/2}$ 514 keV level]
 S. C. Anspach L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, C. N. Smith, *NBS Misc. Publ.* 260-9 (1965)
 [$T_{1/2}$]
 J. Legrand, J. P. Boulanger, J. P. Brethon, *Nucl. Phys.* A107 (1968) 177
 [E_{γ}]
 M. McDonnell, M. K. Ramaswamy, *Nuclear Physics* A127 (1969) 531
 [Q_{EC}]
 H.-H. Grotheer, J. W. Hammer, K.-W. Hoffmann, *Z. Physik* 225 (1969) 293
 [$T_{1/2}$]
 I. F. Bubb, S. I. H. Naqui, J. L. Wolfson, *Nucl. Phys.* A167 (1971) 252
 [P_{γ}]
 J. F. Emery, S. A. Reynolds, E. I. Wyatt, G. I. Gleason, *Nucl. Sci. Eng.* 48 (1972) 319
 [$T_{1/2}$]
 J. Araminowicz, R. Dresler, *Report INR-1464* (1973) 14
 [$T_{1/2}$]
 R. C. Ragaini, C. F. Smith, R. A. Meyer, *Bull. Am. Phys. Soc.* 17 (1972) 444
 [levels]
 F. Lagoutine, J. Legrand, C. Perrot, J. P. Brethon, J. Morel, *Int. J. Appl. Rad. and Isot.* 23 (1972) 219
 [$T_{1/2}$]
 J. F. Emery, S. A. Reynolds, E. I. Wyatt, *Nucl. Science and Eng.* 48 (1972) 319
 [$T_{1/2}$]
 R. P. Torti, V. M. Cottles, V. R. Dave, J. A. Nelson, R. M. Wilenzick, *Phys. Rev.* 6C (1972) 1686
 [E_{γ} decay scheme]
 P. D. Bond, G. J. Kumbartzki, *Nucl. Phys.* A205 (1973) 239
 [J^{π} , P_{γ}]
 J. S. Merritt and F. H. Gibson, *AECL-5315* (1976) 37
 [$T_{1/2}$]
 R. G. Helmer, R. C. Greenwood, R. J. Gehrke, *Nucl. Instr. and Meth.* 155 (1978) 189
 [E_{γ}]
 Y. Yoshizawa, *Jaeri-M* 7567 (1978)
 [P_{γ}]
 G. Schupp, H. J. Nagy, *Phys. Rev.* 29 (1984) 1414
 [double K shell ionization]

For other references see Chapter “References” in the Table Part.

⁸⁸Y – Comments on evaluation of decay data by E. Schönfeld

This evaluation was completed by E. Schönfeld (PTB) in November 1998.
The half-life evaluation was updated by M.-M Bé (LNHB) in February 2003.

1 Decay Scheme

Below the Q -value of 3622,6 keV there are two additional levels at 3486,6 and 3523,6 keV (both probably 2^+). They are not shown in the decay scheme because they are not populated in the disintegration of ⁸⁸Y. Ardisson *et al.* (1974) did not find the 3523,6 keV level but they confirmed the 3584,7 keV level which is populated in the ⁸⁸Y decay. Up to now these levels were observed only in other disintegration processes, for example in the decay of ⁸⁸Rb (17,78 min).

An EC or β^+ transition to the ground state of ⁸⁸Sr was also not observed. This is due to the high forbiddenness of such a transition ($4^- \rightarrow 0^+$). Thus, the decay scheme shown above is almost complete.

The half-lives of the excited levels and the $lg ft$ values were taken from Müller (1988).

2 Nuclear Data

The following measured values of the half-life were taken into consideration :

Reference	Value (in days)	Uncertainty	Comments
DuBridge (1940)	105	5	Omitted, too large uncertainty
Peacock (1948); Lazar (1956)	104		Omitted, no uncertainty
Ramaswamy (1960)	105		Omitted, no uncertainty
Wyatt (1961)	108,1	0,3	Omitted, outlier
Anspach (1965)	106,52	0,03	Replaced by Hoppes
Anspach (1965)	106,67	0,03	Replaced by Hoppes
Grotheer (1969)	108,4	0,9	Omitted, outlier
Lagoutine (1975)	106,6	0,4	Superseded by Amiot
Bormann (1976)	107,1	1,4	
Konstantinov (1977)	107,15	0,65	
Houtermans (1980)	106,612	0,032	Original uncertainty = 0,014
Debertin (1982)	106,64	0,08	Superseded by Walz
Hoppes (1982)	106,64	0,05	Superseded by Unterweger
Walz (1983)	106,66	0,06	
Unterweger (1992)	106,626	0,044	
Martin (1997)	106,65	0,13	
Amiot <i>et al.</i> (2003)	106,63	0,05	
Recommended value	106,626	0,021	

An analysis of these values was done using the “Limitation of relative statistical weight” program. The first three values have been omitted from the analysis, the Grother and Wyatt’s (Grother *et*

al., 1969) value have been omitted as outliers as suggested by Chauvenet's criterion (Chauvenet, 1976) and the uncertainty on the Houtermans's value (Houtermans *et al.*, 1980) has been increased to 0,032 to ensure that its value has the same "weight" as the most recent values. The reduced χ^2 of this set of data is 0,22. Finally, the recommended value is the weighted mean of the seven remaining values.

The Q -value is taken from Audi and Wapstra (1995).

2.1 Electron Capture Transitions

The fractional capture probabilities P_K, P_L, P_M were calculated on the basis of the paper of Schönfeld (1998). The corresponding values for the transition $\epsilon_{0,1}$ have been estimated by the evaluator.

2.2 Positron Transitions

A positron transition to the ground state was not observed. However, sufficient energy for a positron transition is available for a transition to the 1836 keV level. The maximum energy of these positrons were determined to be 767,1(10) keV by Barkov *et al.* (1974) while there emission probability were determined to be 0,00203(16) per disintegration by the same authors. The corresponding EC/β^+ ratio was found to be 26(3) which agrees with the theoretical value of 25,6(8) for an unique first forbidden transition interpolated from the table of Gove and Martin (1971). For the value given for the positron emission probability in Table 2.2, the theoretical value was used. The maximum beta energy of the β^+ spectrum was found by Antonewa *et al.* (1974) to be 764,6(15) keV corresponding to a Q value of 3622,6(15) keV.

2.3 Gamma Transitions

The level differences have been calculated from the gamma ray energies (Table 4.2) and the recoil energies. The probabilities $P_{\gamma+ce}$ were calculated from the gamma ray emission probabilities and the total conversion coefficients. The multipolarities were taken from Müller (1988).

Conversion coefficients were measured as follows:

	a_K	a_L	K/L+M+...
898 keV	0,000301(21) [1]	0,000345(24) [1]	7,0(5) [1]
E1	0,00025(3) [2]	0,00028(3) [2]	8,0(2) [2]
		0,00034(7) [3]	
		0,00027 [4]	
	0,00028(2) [5]	0,00032(3) [5]	
	0,000274 [6]	0,000310 [6]	7,6 [4]
	0,000277(20) [7]	0,000315(23) [7]	7,3 [5]
1836 keV	0,000124(16) [2]	0,000140(16) [2]	7,8(3) [2]
E2		0,00017(4) [3]	
		0,00013 [4]	
	0,000146 [6]		
	0,000135(14) [7]	0,000152(15) [7]	7,9(3) [7]

- [1] Hamilton *et al.* 1966
- [2] Allan 1971
- [3] Metzger and Amacher (1952)

- [4] Peacock and Jones cited in [2]
- [5] weighted mean of [1] and [2]
- [6] theory, interpolated from the tables of Rösel *et al.* (1978)
- [7] adopted value

All the other conversion coefficients were interpolated from the tables of Rösel *et al.* (1978).

The mixing ratio parameter for the 898 keV transition has been evaluated in the basis of four publications by Müller (1988) to be $\delta = -0,002(9)$, i. e. this transition is an almost pure E1 transition. For the 1382 keV transition, δ was found to be 0,057(18) corresponding to 99,7 % M1 and 0,3 % E2. As the conversion coefficients for these multipolarities are very close together ($a_2 = 0,000287$ for E2 and 0,000292 for M1) the uncertainty of this mixing ratio has a very small influence on the finally adopted value for the conversion coefficient of this transition.

The internal pair creation coefficients were determined experimentally by Allan (1971) as follows:

- 1836 keV $a_\pi = 0,00023(3)$ in good agreement with the theoretical value of 0,00023 for E2 multipolarity
- 2734 keV $a_\pi = 0,00033(5)$ in fair agreement with the theoretical value of 0,00044 for E3 multipolarity

3 Atomic data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiations

The energies are based on the wavelengths of Bearden (1967). The relative probabilities have been taken from Schönfeld and Janßen (1996). The relative probability of the L X rays is calculated from the absolute value setting $P(K_{a_1}) = 1$.

3.2 Auger Electrons

The energies are taken from the compilation of Larkins (KLL, KLX) or estimated by the evaluator (KXY). The relative probabilities of K Auger electrons are taken from Schönfeld and Janßen (1996). The relative probability of the L Auger electrons is calculated from the absolute value setting $P(KLL) = 1$.

4 Radiation Emissions

4.1 Electron Emissions

The energies of the Auger electrons are the same as above. The energies of the conversion electrons are calculated from the transition energies and the binding energies. The number of Auger electrons per disintegration are calculated using the above-mentioned atomic shell data and the program EMISSION (PTB 1997). The numbers of conversion electrons per disintegration are calculated from the transition probabilities and the conversion coefficients.

4.2 Photon Emissions

The energies of the X rays are the same as above. The number of X rays per disintegration are calculated using the above given atomic shell data and the program EMISSION.

The energy of the gamma radiation was determined to be (in keV)

1	1836,2(3)	898,2(4)	Robinson et al. 1964
2	1836,08(7)	898,01(7)	Black and Heath 1967
3	1836,17(12)	-	White and Groves 1967
4	1836,07(10)	897,90(10)	Ramayya et al. 1967
5	1836,20(8)	898,09(5)	Legrand et al. 1968
6	1836,127	898,020	Gunnink et al. 1968
7	1836,03(11)	897,99(4)	Strauss et al. 1969
8	1836,030(30)	898,010(30)	Kern 1970
9	1836,064(13)	898,042(4)	Helmer et al. 1979
10	1836,052(13)	898,036(4)	Helmer and Van der Leun 1998

Values 10 are adopted and are based on 411,80205(17) keV for the strong line emitted after the decay of ¹⁹⁸Au.

The energies of the other gamma rays were taken from Müller (1988) after adjusting to the same scale.

The relative emission probabilities were determined as follows:

E in keV	850	898	1382	1836	2734	3219
1	-	94,0(7)	-	100	0,597(25)	-
2	-	91	3(?)	100	0,97	0,03
3	-	-	-	100	0,63(4)	0,0095(3)
4	-	94,9(5)	-	100	-	-
5	0,066(13)	92,0(7)	0,021(6)	100	0,724(70)	0,0071(20)
6	-	92,1	-	100	0,54(9)	0,007
7	-	95,2(5)	-	100	-	-
8	0,030(4)	93,8(11)	0,014(3)	100	-	-
9	-	94,4(3)	-	100	-	-
10	-	94,9(4)	-	100	-	-
11	-	94,8(9)	-	100	-	-
12	0,048(18)	94,54(22)	0,016(3)	100	0,618(25)	0,007(2)

- 1 Peelle (1960)
- 2 Shastry and Bhattacharyya (1964)
- 3 Sakai et al. (1966)
- 4 Schötzig et al. (1973), replaced by value 11
- 5 Ardisson et al. (1974); upper limit for a 3522 keV line: 0,001
- 6 Heath (1974)
- 7 Debertain et al. (1977); $P_\gamma = 0,946(5)$ for the 898 keV line from source activity and Ge(Li) measurements, replaced by value 11
- 8 Antoneva et al. (1979); upper limit for a 484 keV line: $9 \cdot 10^{-4}$
- 9 Yoshizawa et al. (1980)
- 10 Hoppes et al. (1982)
- 11 Schötzig (1989)
- 12 Adopted value 898 keV: LWM of values 1, 9, 10, 11. Value 5 is classified as outlier, values 2 and 6 are not taken into account because leak of uncertainties ; reduced $\chi^2 = 0,57$; 2734 keV: LWM of values 1, 3, 5, 6, reduced $\chi^2 = 1,2$. LWM has used weighted average and ext. uncertainty.

The normalisation factor is derived from a cut between the ground state and the first excited level of ⁸⁸Sr:

	$P_{\gamma}(\text{rel})(1 + \alpha_t)(1 + \alpha_{\pi})$	$P_{\gamma+\text{ce}}(\text{abs.})$
$\gamma_{1,0}$ 1836 keV	100,059	0,99379
$\gamma_{2,0}$ 2734 keV	0,618	0,00614
$\gamma_{3,0}$ 3219 keV	0,007	0,00007

From these figures the absolute emission probability of the 1836 keV gamma rays is calculated to be 0,9932(3) photons per disintegration and $P_{\gamma+\text{ce}}$ is found to be 0,9938(3).

5 Main production Modes

Taken from the "Table de Radionucléides", LMRI, 1985

6 References

- L. A. DuBridge and J. Marshall. *Phys. Rev.* 58 (1940) 7 [$T_{1/2}$]
W. C. Peacock, J. W. Jones. Report *AECD*, 1812 (1948) [P_{β^+} , $T_{1/2}$]
M. K. Ramaswamy and P. S. Jastram. *Nucl. Phys.* 19 (1960) 243 [Max. beta plus energy, $T_{1/2}$]
R. W. Peelle. report *ORNL*, 3016 (1960), 110 [P_{γ}]
J. I. Rhode, O. E. Johnson, W. G. Smith. *Phys. Rev.* 129 (1963) 815 [Max. beta plus energy, $T_{1/2}$]
S. Shastry and R. Bhattacharyya. *Nucl. Phys.* 55 (1964) 397 [P_{γ}]
R. L. Robinson, P. H. Stelson, F. K. McGowan, J. L. C. Ford, Jr. And W. T. Milner. *Nucl. Phys.* 74 (1964) 281 [E_{γ}]
J. H. Hamilton et al. *Phys. Letters* 19 (1966) 682 [\mathbf{a}_K , \mathbf{a}_t]
M. Sakai, T. Yamazaki, J. M. Hollander. *Nucl. Phys.* 84 (1966) 302 [P_{ϵ} , P_{γ}]
W. W. Black and R. L. Heath. *Nucl. Phys.* A90 (1967) 650 [E_{γ}]
D. H. White and D. J. Groves. *Nucl. Phys.* A91 (1967) 453 [E_{γ}]
A. V. Ramayya, J. H. Hamilton, S. M. Brahmavar and J. J. Pinajian. *Physics Letters* 24B (1967) 49 [E_{γ}]
J. Legrand, J. P. Boulanger and J. P. Brethon. *Nucl. Phys.* A107 (1968) 177 [E_{γ}]
R. Gunnink, R. A. Meyer, J. B. Niday and R. P. Anderson. *Nucl. Instr. Meth.* 65 (1968) 26 [E_{γ}]
A. Luukko and P. Holmberg. *Comm. Phys.-math.* 33 (1968) 1 [angular corr.; spin and parity of levels]
S. C. Anspach, L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, C. N. Smith. private Mitteilung (1968) [$T_{1/2}$]
H. Lycklama, N. P. Archer, T. J. Kenneth. *Can. J. Phys.* 47 (1969) 393 [J^{π} , E_{γ}]
M. G. Strauss, F. R. Lenkszus and J. J. Eichholz. *Nucl. Instr. Meth.* 76 (1969) 285 [E_{γ}]
H. H. Grotheer, J. W. Hammer, K. W. Hoffmann. *Z. Phys.* 225 (1969) 293 [P_{β^+}]
J. Kern. *Nucl. Instr. Meth.* 79 (1970) 233 [E_{γ}]
N. B. Gove and M. J. Martin. *Nuclear Data Tables* 10 (1971) 205 [$\log f$]
C. J. Allan. *Nucl. Instr. and Meth.* 91 (1971) 117 [α_K , α_t , α_{π}]
L. J. Jardine. *Nucl. Instr. and Meth.* 96 (1971) 259 [P_{γ}]
W. Bambynek, D. Reher. *Z. Phys.* 264 (1973) 253 [$P_K w_K$]
A. Heß and H. Schneider. *Z. Phys.* 262 (1973) 231 [mixing ratio, angular correlations]
G. Ardisson, S. Laribi, C. Marsol. *Nucl. Phys* A223 (1974) 616 [P_{γ}]
A. V. Barkow, W. M. Winogradow, A. W. Solotawin, W. M. Makarow, T. M. Usypko. *Programm and abstracts of 24. Conference on nuclear spectroscopy and nuclear structure*, Kharkov, 29 Jan. -1 Febr. 1974, AN SSSR, Moscow, 1974, 58 [β^+ , \mathbf{a}_p]
R. L. Heath. Gamma-ray Spectrum Catalogue. *USAEL*, Rep. ANCR 1000-2 (1974) [E_{γ} , P_{γ}]

- F. Lagoutine, J. Legrand, C. Bac. *Int. J. Appl. Radiat. Isot.* 26 (1975) 131 [$T_{1/2}$]
- M. Bormann, H.-K. Feddersen, H.-H. Hölscher, W. Scobel and H. Wagner. *Z. Physik A277* (1976) 203 [$T_{1/2}$]
- N. J. Aminaraschwili, V. A. Dzhashi, W. L. Tschichladse, S. D. Shawgulidse, *Conference: 27. annual conference on nuclear spectroscopy and nuclear structure*, Tashkent, USSR, 22-25 Mar 1977 [a_K]
- W. Bambynek *et al.*, *Rev. Mod. Phys.* 49 (1977) 77 [w_K]
- A. A. Konstantinov, T. E. Sazonowa and S. W. Sepman. *Conference: 27. Annual conference on nuclear spectroscopy and nuclear structure*, Tashkent, USSR, 22-25 Mar 1977, p. 6 [$T_{1/2}$]
- R. C. Greenwood, R. G. Helmer, R. J. Gehrke. *Nucl. Instr. and Meth.* 159 (1979) 465 [E_γ]
- R. G. Helmer, J. W. Starner, M. E. Bunker. *Nucl. Instr. and Meth.* 158 (1979) 489 [E_γ]
- N. M. Antoneva, V. M. Vindgradov, E. P. Grigorev, P. P. Dmitriev, A. V. Zolotavin, G. S. Katykhin, N. Krasnov, V. N. Makarov. *Bull. Ac. Sci. USSR, Phys. Ser.* 43 (1979) 155 [P_{β^+} , α , E_γ , P_γ]
- H. Houtermans, O. Milosevic, F. Reichel. *Int. J. Appl. Radiat. Isot.* 31 (1980) 153 [$T_{1/2}$]
- Y. Yoshizawa, Y. Iwata, T. Kaku, T. Katoh, J. Ruan, T. Kojima, Y. Kawada. *Nucl. Instr. and Meth.* 174 (1980) 109 [P_γ]
- K. Debertin, U. Schötzig, K. F. Walz. *NBS-SP 626* (1982) 101 [$T_{1/2}$, P_γ]
- D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger. *NBS-SP 626* (1982) 85 [$T_{1/2}$, P_γ]
- K. F. Walz, K. Debertin and H. Schrader. *Int. J. Appl. Radiat. Isot.* 34 (1983) 1191 [$T_{1/2}$]
- H.-W. Müller. *Nuclear Data Sheets* 54 (1988) 1 [lg *ft*]
- U. Schötzig. *Nucl. Instr. Meth.* A286 (1990) 523 [P_γ]
- A. A. Konstantinov, T. E. Sazonova, S. V. Sepman, A. V. Zanevsky, N. I. Karmalitsyn. *Nucl. Instr. Meth.* A339 (1994) 200
- E. Schönfeld and H. Janßen. *Nucl. Instr. Meth.* A369 (1996) 527 [Atomic Data]
- R. H. Martin, K. I. W. Burns, J. G. V. Taylor. *Nucl. Instr. Meth.* A390 (1997) 267 [$T_{1/2}$]
- M.N. Amiot, J. Bouchard, M.-M. Bé, J.B. Adamo. To be published in *Appl. Rad. Isotop.* (2004) [$T_{1/2}$]

⁸⁹Sr – Comments on evaluation of decay data by E. Schönfeld

This evaluation was completed by E. Schönfeld (PTB) in November 1999.
The half-life evaluation was up-dated by M.-M. Bé (LNHB) in November 2002.

1 Decay Scheme

Below the Q -value there are no other levels of ⁸⁹Y. Thus, the decay scheme is complete. Spins and parities of the levels and $\lg ft$ values are taken from Sievers (1989). The half-life of the isomeric level at 909 keV was determined by Yule (1967) to be 16,06(4) s and by Durrani and Köhler (1966) to be 15,91 (17) s. The weighted mean is 16,05 (4) s. Earlier determinations were carried out by Swann and Metzger (1955) and Sattler (1962). The excited levels of ⁸⁹Y were studied by Robinson *et al.* (1969).

2 Nuclear Data

For the half-life evaluation the following measurements, carried out since 1954, were considered ($T_{1/2}$ in d):

Reference	Value (days)	Uncertainty	Comments
Herrmann (1954)	50,4	0,5	Superseded by the 2 nd value
Herrmann and Strassmann (1955)	50,5	0,2	
Kjelberg and Papas (1956)	51	1	Omitted, outlier
Osmond and Overs (1959)	50,36	0,18	
Sattler (1952)	53,6	0,4	Omitted, outlier
Marsden and Yaffee	50		Omitted, no uncertainty
Flynn <i>et al.</i>	52,7	0,5	Omitted, outlier
Anspach <i>et al.</i> (1965)	50,70	0,19	
Anspach <i>et al.</i> (1965)	50,52	0,04	Original uncertainty = 0,03
Baba <i>et al.</i> (1971)	50,55	0,09	
Lagoutine <i>et al.</i> (1972)	50,75	0,25	Superseded by Amiot
Amiot <i>et al.</i> (2003)	50,65	0,05	
Recommended value	50,57	0,03	Weighted mean

Four values have been omitted from the analysis, the uncertainty on the second Anspach value (Anspach *et al.*, 1965) has been multiplied by 1,33 in order to reduce its relative weight to 50 % in the calculation of the weighted mean and because it seems optimistic when compared with the other data. The set of six values taken into account in this analysis has a reduced- χ^2 of 1,2. Finally, the adopted value (half-life, uncertainty) is the weighted mean and the external uncertainty.

The Q -value is taken from Audi and Wapstra (1995).

2.1 b- Transitions

The shape of the unique 1st forbidden β spectrum of ⁸⁹Sr was measured by Wohn and Talbert (1970). They found the end-point energy to be 1488(4) keV. The shape corrected $\lg ft$ was calculated by these authors to be 8,36. Earlier, the maximum beta end-point energy was determined to be 1463(5) keV by Bisi *et al.* (1955). This value is too small compared with the result of Wohn and Talbert and the larger value taken from the compilation of Audi and Wapstra (1995) which is the here adopted one.

Internal bremsstrahlung accompanying the first forbidden beta decay of ⁸⁹Sr was measured by Babu et al. (1987), Sayibaba et al. (1987), Basha et al. (1991) and Dhaliwal et al. (1994). Sayibaba et al. carried out their measurements with a HPGe detector and a multichannel analyzer along with a standard geometrical set-up. Their results are satisfactorily accounted for by the KUB theory. Basha et al. compared also their measurements with the theoretical spectra. Dhaliwal et al. measured the spectra using an extrapolation procedure with a beta stopper method. Their results are in agreement with the Lewis and Ford theory in the whole energy region covered by the present measurements and do not favour the KUB and Nilsson theories beyond a photon energy of 400 keV.

2.2 Gamma Transition

The energy of the gamma rays following the ⁸⁹Sr β⁻ decay was measured by Merritt et al. (1982) to be 909,12(7) keV whereas Sievers gives 908,96(4) keV as unweighted average from several (n,γ)-reactions and from the decay of ⁸⁹Zr (T_{1/2} = 78,4 h). In the present evaluation 909,0(1) keV is adopted. The transition probability of the gamma transition is calculated from the gamma ray emission probability of the 909 keV transition (see section 4.2) and the conversion coefficient of this transition. The conversion coefficients are interpolated from the tables of Rösel et al. (1978).

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energies are based on the wavelengths of Bearden (1967). The relative probabilities are taken from Schönfeld and Janßen (1996).

3.2 Auger Electrons

The energies of the Auger electrons are taken mainly from Larkins (1977). The ratios $P(\text{KLX})/P(\text{KLL})$ and $P(\text{KXY})/P(\text{KLL})$ are taken from Schönfeld and Janßen (1996).

4 Radiation Emission

4.1 Electron Emission

The energies and emission probabilities of the β particles correspond to the data given already in Section 2.1. The number of conversion electrons per disintegration has been calculated using the gamma ray emission probability P_γ and the conversion coefficient as given in Section 2.2. The emission probabilities of the Auger electrons have been calculated with the PTB program EMISSION using the atomic data as given in Section 3.

4.2 Photon Emissions

The gamma ray emission intensity, per one disintegration, was found to be:

1	9,71(24) 10 ⁻⁵	Merritt et al. (AECL)	1980	replaced by value 3
2	9,65(29) 10 ⁻⁵	Hoppes et al. (NBS)	1980	
3	9,54(16) 10 ⁻⁵	Merritt et al. (AECL)	1982	
4	9,61(13) 10 ⁻⁵	Schötzig (PTB)	1990	
5	9,555(34) 10 ⁻⁵	Schima (NIST)	1998	
6	9,56(6) 10 ⁻⁵	adopted value	1999	

Value 1 is replaced by value 3, value 6 is the LWM of values 2, 3, 4 and 5. The reduced χ^2 of this set is 0,19.

The emission probabilities of K-X rays are very small. This is caused by the small values of $P_{\gamma+ce}$ and α_K . Lyon and Rickard (1955) were the first who detected these weak gamma rays.

The number of emitted KX rays due to K-shell internal-ionization probabilities in nuclear beta decay were measured in comparison to the absolute beta decay rate by Hansen and Parthasaradhi (1974). Their experimental

result is $8,6 (7) 10^{-4}$ quanta per decay. The contribution of K conversion of the 909 keV γ -transition is only $5,1 10^{-7}$ per decay.

5 Main Production Modes

The production mode are taken from Sievers (1989).

6 References

- G. Herrmann, *Z. f. Elektrochemie* 58 (1954) 626
 [$T_{1/2}$]
 W. S. Lyon and R. R. Rickard, *Phys. Rev.* 100 (1955) 112
 [$T_{1/2}$]
 C. P. Swann and F. R. Metzger, *Phys. Rev.* 100 (1955) 1329
 [$T_{1/2}$ isomeric level]
 A. Bisi, S. Terrani and L. Zappa, *Il Nuovo Cimento II* (1955) 1297
 [E_{β}]
 G. Herrmann and F. Strassmann, *Z. Naturforschg.* 10A (1955) 146
 [$T_{1/2}$]
 A. Kjelberg and A. C. Papas, *Nucl. Phys.* 1 (1956) 322
 [$T_{1/2}$]
 R. G. Osmond, N. J. Owers, *J. inorg. Nucl. Chem.* 9 (1959) 96
 [$T_{1/2}$]
 A. R. Sattler, *Nucl. Phys.* 36 (1962) 648
 [$T_{1/2}$]
 D. A. Marsden and L. Yaffee, *Can. J. Chem.* 43 (1965) 249
 [$T_{1/2}$]
 K. F. Flynn, L. G. Glendenin and E. E. Steinberg, *Nucl. Sci. Eng.* 22 (1965) 416
 [$T_{1/2}$]
 S.C. Anspach, L.M. Cavallo, S.B. Garfinkel, J.M.R. Hutchinson, C.N. Smith, *NP-15663* (1965)
 [$T_{1/2}$]
 J. A. Bearden, *Rev. Mod. Phys.* 39 (1967) 78
 [$E(KX)$]
 E. L. Robinson, R. C. Hagenauer and E. Eichler, *Nucl. Phys.* A123 (1969) 471
 [E_{γ} , P_{γ}]
 F. K. Wohn and W. L. Talbert, Jr., *Nucl. Phys.* A146 (1970) 33
 [E_{β}]
 S. Baba, H. Baba and H. Natsume, *J. Inorg. Nucl. Chem.* 33 (1971) 589
 [$T_{1/2}$]
 F. Lagoutine, J. Legrand, C. Perrot, J. P. Brethon and J. Morel, *Int. J. Appl. Rad. Isot.* 23 (1972) 219
 [$T_{1/2}$]
 H. H. Hansen and K. Parthasaradhi, *Phys. Rev.* C9 (1974) 1143
 [P_{XK}]
 F. P. Larkins, *Atomic Data and Nuclear Data Tables* 20 (1977) 313
 [$E(KLL)$, $E(KLX)$]
 F. Rösel, H. M. Fries, K. Alder, H. C. Pauli, *At. Data Nucl. Data Tables* 21 (1978) 91
 [α_t]
 J. S. Merritt, K. M. Ophel, A. R. Rutledge and L. V. Smith, *AECL 7102* (1980) 32
 [P_{γ}]
 J. S. Merritt, A. R. Rutledge and L. V. Smith, *Int. J. Appl. Radiat. Isot.* 33 (1982) 77
 [E_{γ} , P_{γ}]
 T. Sayibaba, K. Narasimha Murty and C. R. Rao, *Il Nuovo Comento*, 97A (1987) 365
 [Bremsstrahlung]
 B. R. S. Babu, P. Venkataramaiah and H. Sanjeeviah, *Nucl. Instr. Meth.* A255 (1987) 96
 [Bremsstrahlung]
 H. Sievers, *Nuclear Data Sheets* 58 (1989) 351
 [production modes, spins, parities]
 U. Schötzgig, *Nucl. Instr. Methods* A286 (1990) 523
 [P_{γ}]

- A. M. Basha, E. I. Khalil, M. Hussein and H. Ragab, *Indian J. Phys.* 65A (1991) 120
[Bremsstrahlung]
- A. S. Dhaliwal, M. S. Powar and M. Singh, *J. Phys. G Nucl. Part. Phys.* 20 (1994) 135
[Bremsstrahlung]
- G. Audi, A. H. Wapstra, *Nucl. Phys.* A595 (1995) 409
[Q]
- E. Schönfeld and H. Janßen, *Nucl. Instr. Methods* A369 (1996) 527
[ω_K , ω_L , K_β/K_α , n_{KL}]
- F. J. Schima, *Appl. Radiat. Isot.* 49 (1997) 1359
[P_γ]
- M. N. Amiot, J. Bouchard, M.-M. Bé, J. B. Adamo. To be published (2004)
[$T_{1/2}$]

⁹³Nb^m – Comments on evaluation of decay data by V. P. Chechev and N. K. Kuzmenko

1 Decay scheme

The ⁹³Nb^m decay scheme is very simple. It includes the single 30,77 keV gamma transition with the well-established multipolarity of M4 (1972Ko59, 1997Ba13).

2 Nuclear Data

Q(IT) value is the energy of the isomeric transition to the ground state of ⁹³Nb (1977Mo07).

There are available the seven measurements of the ⁹³Nb^m half-life, in years:

~ 4	1954Sc74
13,6(3)	1965Fl02
11,4(9)	1976Hegedues
16,4(4)	1977Ll01
15,3(13)	1980Vaninbroukx
16,11(19)	1981Ll01
16,16(15)	1983Va25

The measurement result of 1954Sc74 was omitted as crude. The 1977Ll01 and 1980Vaninbroukx values measured by Lloret and by Vaninbroukx, respectively, were only preliminary results. They were obtained from observations over relatively short periods. In both cases the measurements have been continued over about four more years. Consequently only the final values of 1981Ll01 and 1983Va25 have been used by the evaluator for statistical processing. Then, the low values of 1965Fl02 and 1976Hegedues were omitted as less precise and disagreed with the two best measurements of 1981Ll01 and 1983Va25.

Averaging of these latter values gives the unweighted mean of 16,12(1) and the weighted mean of 16,12 with an internal uncertainty of 0,12 and an external uncertainty of 0,01. As the measurement method was the same in both cases, the minimum input uncertainty of 0,15 has been chosen for the final uncertainty of the weighted mean. Thus, the evaluated ⁹³Nb^m half-life is 16,12 (15) years.

2.1 Gamma Transition and Internal Conversion Coefficients.

The energy of the gamma transition, 30,77(2) keV, has been taken from the 1977Mo07 measurement. The 1972FIZM measurement value of 30,4(3) keV is significantly less accurate.

The multipolarity of the gamma transition, M4, is determined confidently from measured subshell ratios :

$$K/(L+M) = 0,18(2) \text{ (1964Ho08),}$$

$$K/L = 0,21(2) \text{ (1964Ho08),}$$

$$K/(L+M+\dots) = 0,19(2) \text{ (1982Re09)}$$

$$L/(M+N+\dots) = 3,8(4) \text{ (1982Re09).}$$

The internal conversion coefficient (α_K) is obtained by the interpolation from the ICC tables of 1978Ro22 using database IC4 of 2000Co05. The relative uncertainty of α_K has been adopted as 3% in accordance with the available estimations of the reliability of the calculations of the theoretical ICC with a pure multipolarity (see 2000Co05). The adopted value of α_K conforms well to $\alpha_K(\text{experimental}) = 2,58 (15) 10^4$ (1976Ju04) and disagrees with $\alpha_K(\text{experimental}) = 1,7 (3) 10^4$ calculated in (1977Mo07) from the measured ratio $P_\gamma/P_{XK} = 8(1) 10^{-5}$. See also 1987Table : $\alpha_K = 2,63 (6) 10^4$

The adopted value of α_K is supported by the recent measurement result of $2,4(9) 10^4$ obtained by the quite different method–investigation of "electron bridge" in ⁹³Nb^m decay (1999ZhZY).

The evaluated α_L , α_M , α_T are also theoretical values for M4 multipolarity.

3 Atomic Data.

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The X-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative K X-ray emission probabilities are taken from 1999Schönfeld.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Table (Table de Radionucléides).

The ratios $P(\text{KLX})/P(\text{KLL})$ and $P(\text{KXY})/P(\text{KLL})$ are taken from 1996Sc06.

4 Photon Emissions.

4.1 X-Ray Emissions

The total K X-ray absolute emission probability computed with use of the ICC α_T , α_K and the K-fluorescence yield $\omega_K=0,751(4)$ is 10,99(40) per 100 disintegrations. It coincides with the averaged value [10,99(22)] of three measurement results of 10,7(3) (1982Alberts), 11,04(28) (1985Gehrke), 11,12(22) (1990Co17). The other measurements have given slightly higher

values: 11,6(4) (1978Bambynek, 1980Vaninbroukx) and 11,5(3) (1983Va25). (See these references also in 1991BaZS).

The adopted value of the total K X-ray absolute emission probability is 10,99(22).

The absolute emission probabilities of the K X-ray components have been computed from P_{XK} using the relative probabilities from 1996Sc06.

The total L X-ray absolute emission probability has been computed with use of the ICC α_L and the atomic data of $\omega_L=0.0347(9)$, $n_{KL}=1.045(4)$ from 1996Sc06.

4.2 Gamma Emissions

The energy of the gamma ray, 30,77(2) keV, is from the 1977Mo07.

The absolute emission probability of the gamma ray is computed from the decay scheme using the ICC α_T .

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.1 and the electron binding energies.

The total emission probability of the conversion electrons has been obtained as $P_{(ec1,0T)} = 100 - P_\gamma$ (per 100 disintegrations). The emission probabilities of the K-, L-, M-, NO-conversion electrons have been calculated using the conversion coefficients given in 2.1.

The values of the emission probabilities of K-Auger electrons have been calculated using the gamma transition probability given in 2.1, the atomic data given in 3, and the conversion coefficients given in 2.1.

6. References

- 1954SC74 - R. P. Schuman, Phys. Rev. 96(1954)121 (Half-life)
 1964Ho08 - K. Hohmuth, G. Muller, J. Schinthmeister, Nucl. Phys. 52(1964)590 (ICC subshell ratios)
 1965Fl02 - K. F. Flynn, L. E. Glendenin, E. P. Steinberg, Nucl. Sci. Eng. 22(1965)416 (Half-life)
 1967Be65 - J. A. Bearden, Rev. Mod. Phys. 39(1967)78. (X-ray energies)
 1972FLZM - K. F. Flynn, (1972): No title. (Priv Comm) (Gamma-ray energies)
 1972Ko59 - D. C. Kocher, Nucl. Data Sheets 8(1972)527 (multipolarity)
 1976Hegedues - F. Hegedues, Report EUR 5667E I(1976)757 (Half-life)
 1976Ju04 - M. Jurcevic, A. Ljubicic, D. Rendic, Fizika (Zagreb) 8(1976)81 (K ICC)
 1977La19 - F. P. Larkins, Atomic Data and Nuclear Data Tables 20(1977)313 (Auger electron energies)
 1977LI01 - R. L. Lloret, Radiochem. Radioanal. Lett. 29(1977)165 (Half-life)
 1977Mo07 - J. Morel, J.-P. Pérolat, N. Coursol, Compt. Rend. B284(1977)223 (X-ray and gamma-ray energies and emission probabilities, K ICC)
 1978Bambynek - W. Bambynek, D. Reher, R. Vaninbroukx, Proc. Int. Conf. on Neutron Physics and Nuclear Data for Reactors and other Applied Purposes, Harwell, September 1978, OECD Nuclear Energy Agency, Paris,(1978)778 (K X-ray emission probability)
 1978Ro22F - Rosel et al., Atomic Data Nuclear Data Tables 21(1978)92 (ICC)
 1980Vaninbroukx - R. Vaninbroukx, Liquid Scintillation Counting (D. L. Horrockx, E. L. Alpen Eds.) Academic Press, New York, Vol.1(1980)43 (K X-ray emission probability)

- 1981Ll01 - R. Lloret, Radiochem. Radioanal. Lett. 50(1981)113 (Half-life)
- 1982Albets -W. G. Albets, R. Hollnagel, K. Knauf, W. Pessara. Proc. 4th ASTM-EURATOM Symposium on Reactor Dosimetry (F.B.K. Kam Ed.), NUREG/CP-0029, Gaithersburg 1(1982)433 (K X-ray emission probability)
- 1982Re09 - D. Reher, Int. J. Appl. Radiat. Isotop. 33, 537 (1982) (ICC subshell ratios, multipolarity)
- 1983Va25 - R. Vaninbroukx, Int. J. Appl. Radiat. Isotopes 34(1983)1211 (Half-life, K X-ray emission probability)
- 1985Gehrke - R. J. Gehrke, J. W. Rogers, J. D. Baker, Proc. 5th ASTM-EURATOM Symposium on Reactor Dosimetry, Geesthacht, FRG, 24-28 September 1984, Dordrecht 1(1985)319 (K X-ray emission probability)
- 1987Table - F.Lagoutine, N. Coursol, J. Legrand, Table de Radionucleides. ISBN-2-7272-0078-1. LMRI, 1982-1987, BP 52, 91 191 Gif-sur-Yvette Cedex, France (ICC, multipolarity)
- 1990Co17 - B. M. Coursey et al, Nuclear Instrument Methods A290(1990)537 (K X-ray emission probability)
- 1991BaZS - W. Bambynek, T. Barta, R. Jedlovsky, P. Christmas, N. Coursol, K. Debertin, R. G. Helmer, A. L. Nichols, F. J. Schima, Y. Yoshizawa, TECDOC-619, IAEA. X-ray and gamma-ray standards for detector calibration. Vienna (1991) (K X-ray emission probability)
- 1996Sc06 - E. Schönfeld, H. Janßen, Nuclear Instrument Methods Phys. Res. A369(1996)527 (Atomic data)
- 1997Ba13 - E. Baglin, Nuclear Data Sheets 80(1997)1 (Decay scheme)
- 1999Schönfeld - E. Schönfeld, G. Rodloff, Report PTB-6 11-1999-1 (1999) (Atomic data)
- 1999ZhZY - V. A. Zheltonozhsky, A. G. Zelinsky, Yu. M. Shevchenko, E. G. Shemchuk, Program and Thesis, Proc.49th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Dubna, p.100 (1999) (Electron, X-ray and gamma-ray emission probabilities, K ICC)
- 2000Co05 - N. Coursol, V. M. Gorozhankin, E. A. Yakushev, C. Briancon, Ts. Vylov, Appl. Radiat. Isot. 52, 557 (2000) (ICC)

⁹⁹Mo - Comments on evaluation of decay data
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This evaluation was completed in December 2000 with minor editing in September 2001. Updated half-life value in 2004.

1- DECAY SCHEME

Molybdenum 99 disintegrates to the technetium 99 excited levels by beta minus transitions. The 1205 keV (3/2-) and 1321 keV (1/2-) levels could be fed by non-unique 1st forbidden β⁻ decays. From lg ft systematic and with lg ft ≥ 8, the β⁻ branches to 1205 keV and 1321 keV levels, if they exist, would be expected ≤ 0,010% and ≤ 0,00014%, respectively. Forbiddenness of other possible β⁻-transitions is still greater. Therefore, all of these unobserved branches can be considered negligible.

Unlike the decay scheme of Peker based mainly on Goswamy (1992Go22), we have not found any justification for placing β⁻- transition to the 534 keV level. The P_{γ+ce} balance for this level has led to the evaluated probability of β⁻- transition of the order of 0,0010(10) %. Also because of the significant lg ft, the attribution of 3/2+ to the 534 keV level seems to be unlikely.

Apart from that, in comparison with 1994Pe15 we have shown a β⁻-transition feeding the 1072 keV level. The spin and parity of this level are not defined exactly. Other J^π values are from Peker.

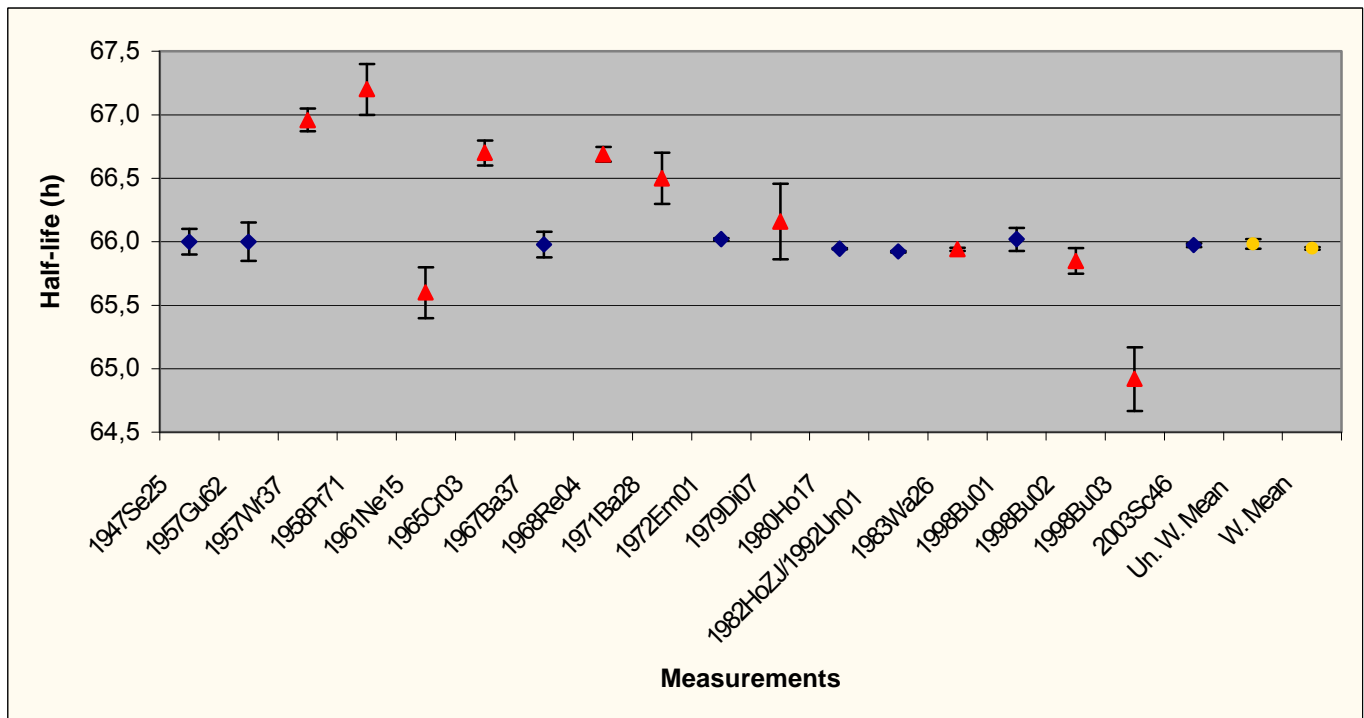
For this evaluation Mo-99 and Tc-99m are considered being in equilibrium. Therefore, the ratio of their activities is 1,1.

2- NUCLEAR DATA

Q⁻ is from Audi and Wapstra 1995 (95Au04).

- The measured **half-life** values are, in hours :

66,0(1)	Seiler (1947Se25)	²³⁵ U(n,f) ic
66,00(15)	Gunn <i>et al.</i> (1957Gu62)	²³⁵ U(n,f),Mo(n,γ) pc
66,96(9)	Wright <i>et al.</i> (1957Wr37)	⁹⁸ Mo(n,γ)
67,2(2)	Protopopov <i>et al.</i> (1958Pr71)	²³⁵ U(n,f) GM
65,6(2)	Newman (1961Ne15)	²³⁵ U(n,f) pc
66,7(1)	Crowther and Eldridge (1965 Cr03)	⁹⁸ Mo(n,γ) well scin
65,98(10)	Baldwin (1967Ba37)	Mo(n,γ) from 2 meas. pc + scin
66,69(6)	Reynolds <i>et al.</i> (1968Re04)	²³⁵ U(n,f) ic
66,5(2)	Baba <i>et al.</i> (1971Ba28)	²³⁸ U(p,f)
66,02(1)	Emery <i>et al.</i> (1972Em01)	²³⁵ U(n,f)
66,16(30)	Dickens (1979Di07)	
65,945(3)	Houtermans <i>et al.</i> (1980Ho17)	ic
65,924(6)	Hoppes <i>et al.</i> (1982HoZJ)	ic
	Unterweger <i>et al.</i> (1992Un01)	
65,942(12)	Walz <i>et al.</i> (1983Wa26)	Superseded by 2003Sc49
66,02(9)	Butsev <i>et al.</i> (1998)	⁹⁸ Mo(n,γ)
65,85(10)	Butsev <i>et al.</i> (1998)	²³⁵ U(n,f)
64,92(25)	Butsev <i>et al.</i> (1998)	181Ta(12C,x) ⁹⁹ Mo
65,974(14)	Schrader <i>et al.</i> (2003Sc49)	ic



Looking at the graphical representation given above, it appears that 5 values are $\geq 66,5$ h and 12 are in the range $> 65,5$ and $< 66,5$. The five high values are rejected of the statistical treatment (Chauvenet's criterion). The last value given by V.S. Butsev (1998) has also been rejected : $^{181}\text{Ta}(^{12}\text{C},x)^{99}\text{Mo}$ is an exotic reaction, and the result is clearly outlier.

When processing the 17 values, the LWEIGHT program has detected 1957W37, 1958Pr71, 1961Ne15, 1965Cr03, 1968Re04, 1971Ba28, 1979Di07 and 2 values of 1998Bu (65,85(10) and 64,92(25)) to be outliers, based on Chauvenet's criterion. The Limited Relative Statistical Weight method increases the uncertainty for the 1980Ho17 value from 0,003 to 0,00481 and used the unweighted mean of 65,983(38) with the large uncertainty that does not correspond to the most accurate measured values (1980Ho17, 1982HoZJ or 1992Un01 and 2003Sc49).

With the set of the 5 most recent values (1972Em01, 1980Ho17, 1982HoZJ or 1992Un01, 1998Bu01 and 2003Sc49), the Limited Relative Statistical Weight method increases the uncertainty for the 1980Ho17 value from 0,003 to 0,00482 and used the weighted mean of 65,949 (14), where 0,014 is the external uncertainty, the reduced- χ^2 is 10,4.

The adopted value is 65,949(14) h or 2,7479(6) d.

- The measured half-life values of the 140,5 keV level of Tc-99 are in ns:

0,277	(14)	STEINER <i>et al.</i> (1969St04)
0,160	(20)	MCDONALD (1971Do02)
0,205	(4)	ALFTER <i>et al.</i> (1993Al23)
0,237	(14)	SHENOY <i>et al.</i> (1973Sh21)

The value of Steiner (1969) given here, is from the original article ; the NDS value (1994Pe15) from the same reference is very different : 0,192 ns.

The value of 0,160(20) ns from J.McDonald (1971) is very far from the others and is not taken into account.

The values from Alfter and Shenoy were determined by using the Moessbauer effect.

The uncertainty on the Alfter *et al.* (1993) value was increased 2,47 times by LRSW.

Reduced- $\chi^2 = 8,94$

LWEIGHT has used the weighted average and the external uncertainty.

The adopted value from the LWEIGHT program is : **0,221(20) ns**

- The measured half-life value of the 181 keV level is **3,61(7) ns** (McDonald (1971))
- The values of the level energies are from NDS 73,1.

2.1 BETA-MINUS TRANSITIONS

The energies of β^- -transitions have been computed from the Q value and the adopted level energies. The probabilities of β^- -transitions have been obtained from the $P_{\gamma+ce}$ balance for each level based on the P_γ normalization factor of 0,1212(15) (see section 4.2.3).

The sum of all the beta transition probabilities leaving the molybdenum must be equal to 100 %; this leads to a probability of 82,1(15)% for the beta transition feeding the 142 keV level, taking into account the gamma transitions feeding this level.

The measured energies and probabilities of some β^- -transitions are given below for comparison with calculated data:

	Measured ^a		Calculated	
	Energy, keV	Probability (%)	Energy, keV	Probability (%)
$\beta^-_{0,12}$	245	0,2	228,1(10)	0,011 (1)
$\beta^-_{0,9}$	450(10)	14	436,6(10)	16,45 (30)
$\beta^-_{0,4}$	840(5)	2	848,1(10)	1,18 (3)
$\beta^-_{0,2}$	1214(1)	80(2)	1214,5(10)	82,1 (15)

^a Nagarajan (1971Na01) except $P(\beta^-_{0,2})$ for which unweighted mean of six experimental results quoted in Kholnov (1982KhZW) is given.

2.2 - GAMMA TRANSITIONS and INTERNAL CONVERSION COEFFICIENTS

The evaluated energies of the gamma transitions are the sums of the energies of gamma rays and the recoil energy.

2.2.1- INTERNAL CONVERSION COEFFICIENTS

The ICC have been evaluated using experimental information for the multipolarity admixture coefficients and the theoretical values from 1978Ro22 (Rösel *et al.*) and 1976Ba63 (Band *et al.*) (for $\gamma_{2,1}$).

The relative uncertainties of ICC were adopted to be 2%, for pure multiplicities. The ICC uncertainties for mixed multiplicities were evaluated by taking into account the uncertainties of the respective multipolarity admixture coefficients given in the referenced papers.

The internal conversion coefficients adopted in this evaluation are the theoretical values deduced from the Rösel et al. (1978Ro22) tables. They have been compared with experimental values.

Transition 3-1 : 40,584 keV

Internal Conversion Coefficients α_T

Some authors measured the mixing ratio δ :

δ	First author and NSR code	Transition	α_T (Rösel <i>et al.</i>)
-0,008 (8)	GARDULSKI (1974Ga01)	M1 + 0,0064%E2	3,80
0,03 (3)	SINGH (1982Si16)	M1 + 0,09%E2	3,87
-0,119 (8)	ALFTER (1993Al23)	M1 + 1,4%E2	4,18
	MCDONALD (1971Mc02)	M1 + 1,4(2)%E2	4,18(13) (adopted)

The E2 admixture of 1,4(2) % for $\gamma_{3,1}(40,6 \text{ keV})$ has been adopted from 1971Mc02. The $\gamma\gamma(\theta)$ precise measurement of 1993Al23 confirmed this value ($\delta=-0,119(8)$) and rejected the 0,0064 % value of 1974Ga01 which was adopted in Peker's evaluation (1994Pe15). This increases the total ICC for $\gamma_{3,1}$ from 3,76 to 4,18 and improves the intensity balance for the 140,5 keV and 181,1 keV levels.

Internal Conversion Coefficients α_K

α_K	Transition	First author and year
3,2 (2)	M1 transition	Ranakumar (1969)
3,7 (5)	M1 transition	Bashandy (1969Ba03)
3,27 (19)	Weighted average, external uncertainty	LWEIGHT ($\chi^2=0,86$)
Adopted: 3,50 (8)	M1+1,4(2)%E2	Rösel <i>et al.</i> (with the adopted admixture)

Internal Conversion Coefficients α_L

From the measurement of the K/L ratio of the conversion electron emission probabilities and, with $\alpha_K=3,50(8)$, the α_L value is deduced :

K/L	α_L	First author and year
9,3 (20)	0,38(8)	RAVIER (1961)
8,3 (9)	0,42(5)	BASHANDY (1969Ba03)
	0,41(4)	LWEIGHT ($\chi^2=0,18$)
Adopted:	0,560 (13)	Rösel <i>et al.</i> for M1+1,4(2)%E2

Transition 1-0 : 140,511 keV

Internal Conversion Coefficients α_T

Experimental measurements :

0,118 (8)	AMTEY <i>et al.</i> (1966)
0,113 (6)	DICKENS and LOVE (1980)
0,122 (5)	VUORINEN (1969)
0,118 (3)	LEGRAND <i>et al.</i> (1973)
0,1181(23)	LWEIGHT (reduced- $\chi^2=0,44$ weighted average and internal uncertainty)
Adopted: 0,119(3)	Rösel <i>et al.</i> (1978) for M1+3,2(3)%E2

Dickens and Love (1980) have determined α_T from the α_K value given by Gardulski and Wiedenbeck (1974) and the K/L/MN values reported by Hager and Selzer and by Medsker (NDS - 12-4 - 1974).

α_T was evaluated by Vuorinen (1969) from measurements of conversion electrons in coincidence with fluorescence X-rays.

Multipolarity

There are a significant number of measurements. However most authors gave different values with and without large uncertainties: these multiplicities make it possible to calculate the total internal conversion coefficients. We have assigned a 5% uncertainty to α_T :

/d/	Transition	α_T (Rösel)	
0,31 (2)	M1 + 8,25% E2	0,132(7)	SINGH and SAHOTA (1982Si16)
0,178 (12)	M1 + 3,1% E2	0,119(6)	ALFTER <i>et al.</i> (1993Al23)
	M1 + 4%(2) E2	0,121(6)	MCDONALD <i>et al.</i> (1971Mc02)
	M1+<3%E2		VOINOVA <i>et al.</i> (1971Vo06)
0,194(30)	M1+E2		VUORINEN (1969Vu03)
	M1+<8%E2		VAN EIJK <i>et al.</i> (1968Va14),calculated from ICCk
	M1+9%(5)E2	0,134(7)	VAN EIJK <i>et al.</i> (1968), calculated from K/L ratio
	M1+2,8%E2	0,118(6)	COOK <i>et al.</i> (1969 Co18)
	M1+7(3)%E2	0,129(7)	MEYER (1974)
	M1+1,4%E2	0,114(6)	DICKENS and LOVE (1980Di16)
	M1+6,5(40)E2	0,128(7)	AGEEV <i>et al.</i> (1969Ag04)
0,118(6)	M1+1,4(2)%E2	0,114(6)	GARDULSKI and WIEDENBECK (1974Ga01)
	M1+2,8(3)%E2	0,118(6)	GEIGER (1968GeZW)
	M1+9%E2		SIMONITS <i>et al.</i> (1982Si15)
	M1+E2		AMTEY <i>et al.</i> (1966Am04)
	M1		BASHANDY (1969Ba54)
		0,120(2)	LWEIGHT (reduced- $\chi^2= 1,16$), weighted average and external uncertainty= 0,0015
0,186 (8)	M1 + 3,2(3)%E2	0,119 (3)	Adopted (Rösel <i>et al.</i>)

From each determination of the multipolarity of the transition, the Rösel theoretical internal coefficient was calculated. From the set of the 10 deduced ICC values the LWEIGHT program recommends a weighted mean of 0,120(2). The value obtained is very close to that obtained by considering the 4 experimental values for α_T (see table above).

Internal Conversion Coefficients α_K

Experimental values:

0,096 (6)	VOINOVA <i>et al.</i> (1971Vo06)
0,093 (6)	VOINOVA <i>et al.</i> (1971Vo06)
0,102 (7)	VAN EIJK <i>et al.</i> (1968Va14)
0,094 (8)	VUORINEN (1969Vu03)
0,102 (5)	DICKENS and LOVE (1980Di16)
0,096 (3)	LWEIGHT ($\chi^2=0,35$; weighted average and internal uncertainty)
0,104 (3)	Rösel <i>et al.</i> (1978) (adopted)

- α_K was measured by Voinova *et al.* (1971) with a spectrometer which provided simultaneous measurement of conversion electrons and γ -ray spectra.
- Van Eijk *et al.*(1968) calculated ICCk from measurements of the 140,5 keV gamma-ray emission probability (P_γ) relative to the gamma-ray emission probability of the 661,6 keV gamma transition in decay of Cs-137 and from measurements of the conversion electron emission probability P_{ce} of the 140,5 keV K-conversion line relative to the conversion electron emission probability of the 661,6 keV K-conversion line in decay of Cs-137. With $P_{ceK} = 6,84(19)$; $P_\gamma = 6,00(35)$; $\alpha_K(661,6 \text{ keV}) = 0,0896(15)$ (Helmer in BÉ 1999 (1999BeZQ)), the value becomes 0,102(7).
- Vuorinen (1969) evaluated the internal conversion coefficient α_K by measuring the electron conversion emissions following the conversion of the 140 keV gamma ray in coincidence with fluorescence X-rays.

- α_K given by Dickens and Love (1980) was computed from the tables of Hager and Seltzer for a M1 transition and a 1,4% E2 admixture. An 5% uncertainty assigned to α_K reflects the added uncertainty to the usual 3% assignment due to the rapid change of α_K with admixture. This value is not taken into account in our calculations.

Internal Conversion Coefficients α_L

From each measurement of the K/L ratios of the conversion electron emission probabilities, and with $\alpha_K = 0,104(3)$, a value for α_L is deduced :

K/L	α_L	
8,1 (5)	0,0125(8)	BASHANDY(1969Ba03)
7,70 (30)	0,0132(7)	VAN EIJK <i>et al.</i> (1968Va14)
8,3 (3)	0,0122(6)	RAVIER <i>et al.</i> (1961Ra04)
7,63 (32)	0,0133(7)	BRAHMAVAR (1968)
7,8 (3)	0,0130(6)	GEIGER (1968GeZW)
	0,0128(3)	LWEIGHT has used the weighted average and the internal uncertainty. Reduced- $\chi^2 = 0,52$
Adopted	0,0129 (4)	Rösel <i>et al.</i> (1978)

Transition 2-0: 142,683 keV

Internal Conversion Coefficients α_T

For a M4 transition the theoretical value from Rösel is : **40,9(8)**.

Internal Conversion Coefficients α_K

- The 2 following values were calculated from experimental data and given by the authors :

23 (6)	Van Eijk <i>et al.</i> (1968)
30 (3)	Bashandy (1969Ba54)

Van Eijk *et al.* (1968) calculated the K ICC value from the ratios of $K(142,7)/K(140,5) = 0,072(32)$ and $I_\gamma(142,7)/I_\gamma(140,5) = 0,00030(6)$ after correction for $\alpha_K(661,6 \text{ keV, Cs-137}) = 0,0896(15)$

Bashandy (1969) calculated the K ICC from internal conversion spectra and photon emission probabilities $I_\gamma(142)/I_\gamma(140) = 0,00030(6)$

- The following α_K coefficients are calculated from the $K(142,7)/K(140,5)$ ratio given by the authors and based on the ratio $I_\gamma(142,7)/I_\gamma(140,5) = 0,00030(6)$ given by Van Eijk *et al.* (1968) and on $\alpha_K(140,5) = 0,104(3)$.

$K(142,7)/K(140,5)$	$\alpha_K(142,7)$	
0,072(4)	24 (6)	AMTEY <i>et al.</i> (1966Am04)
0,0746(12)	25 (6)	GEIGER (1968GeZW)
0,075 (8)	26 (6)	AGEEV <i>et al.</i> (1969Ag04)

If we take into account the ratio $I_\gamma(142,7)/I_\gamma(140,5) = 0,00021(3)$ given by Dickens and Love (1980Di16), with $\alpha_K(140,5) = 0,104(3)$, the same calculations give higher results for $\alpha_K(142,7)$:

$K(142,7)/K(140,5)$	$\alpha_K(142,7)$	
0,072(4)	34 (6)	AMTEY <i>et al.</i> (1968)
0,0746 (12)	36 (5)	GEIGER (1968)
0,075 (8)	36 (7)	AGEEV <i>et al.</i> (1969)

If we have taken into account all the six possible data, the weighted average, with the external uncertainty, calculated by LWEIGHT is 29,5(18) (reduced- $\chi^2=0,87$)

The **adopted** theoretical K conversion coefficient, for a M4 transition, is : **29,3(6)** (Rösel *et al.* (1978)).

Internal Conversion Coefficients α_L

From the measurement of the ratio of the conversion electron intensities (BASHANDY and IBRAHIEM), with $\alpha_K = 29,3(6)$, α_L can be deduced. This value is close to the adopted theoretical value:

K/L	α_L		
2,9 (5)	10,1 (18)	M4 transition	BASHANDY and IBRAHIEM
Adopted:	9,35 (20)	M4 transition	Rösel <i>et al.</i> (1978)

Transition 3-0 : 181,094 keV

Internal Conversion Coefficients α_T

0,140(5) DICKENS and LOVE (1980Di16)

GARDULSKI and WIENBECK (1974Ga01) measured a low multipole mixing ratio of 0,002(7) for a M3/E2 transition.

For a E2 transition, the theoretical value is : **0,149(3)** (Rösel *et al.* (1978))

Internal Conversion Coefficients α_K

0,13(3)		RAVIER <i>et al.</i> (1961)
0,127(11)*	E2 \leq 12%M1	VAN EIJK <i>et al.</i> (1968)
0,133(20)	E2 transition	BASHANDY (1969Ba54)
0,12(1)		VOINOVA <i>et al.</i> (1972)
0,125(7)		LWEIGHT (reduced- $\chi^2 = 0,16$, weighted average and the internal uncertainty)
0,125 (3)	E2 transition	Rösel <i>et al.</i> (adopted)

(*) value corrected for $\alpha_K(661\text{keV Cs-137})=0,0896(15)$ (Helmer in Bé 1999)

Internal Conversion Coefficients α_L

From the measurement of ratio K/L of conversion electron intensities, with $\alpha_K = 0,125(3)$, α_L can be deduced:

K/L	α_L	Transition	
4,9 (1)	0,025(6)		RAVIER <i>et al.</i> (1961)
6,8 (7)	0,0184(20)		BASHANDY (1969Ba03)
Adopted:	0,0191 (4)	E2	Rösel <i>et al.</i> (1978)

Transition 4-2 : 366,422 keV

Internal Conversion Coefficients α_T

0,0081 (2)		DICKENS and LOVE (1980)
0,00915 (18)	M1 transition	Rösel <i>et al.</i> (1978) (adopted)

Internal Conversion Coefficients a_K

0,0072 (10)		BASHANDY (1969Ba54)
0,00802(16)	M1 transition	Rösel <i>et al.</i> (1978) (adopted)

Transition 13-7 : 380,13 keV

Internal Conversion Coefficients a_K

0,009 (1)	M1+E2	BASHANDY (1969Ba54)
0,0091 (7)	M1+63(22)%E2	Rösel <i>et al.</i> (1978) (adopted)

- From the value of Bashandy (1969Ba54), it can be deduced a M1+63%E2 transition and multipole mixing ratio $\delta = 1,3(6)$.

Transition 14-7 : 410,27 keV

Internal Conversion Coefficients a_K

0,0060 (8)		BASHANDY (1969Ba54)
0,0065 (2)	M1+20(3)%E2	Rösel <i>et al.</i> (1978) (adopted)

Transition 9-4 : 411,492 keV

Internal Conversion Coefficients a_K

0,0030 (5)	E1 transition	BASHANDY (1969Ba54)
0,00226(5)	E1 transition	Rösel <i>et al.</i> (1978) (adopted)

Transition 12-6 : 457,60 keV

The E2 admixture of 72(55) % has been adopted from the evaluation of Kholnov (1982KhZW).

Internal Conversion Coefficients a_K

0,0054 (6)		BASHANDY (1969Ba54)
0,0054 (4)	M1+72(55)%E2	Rösel <i>et al.</i> (1978) (adopted)

Transition 6-2 : 528,790 keV

Internal Conversion Coefficients a_K

0,0050 (6)	E2 transition	BASHANDY (1969Ba54)
0,00375(8)	E2 transition	Rösel
0,00331(7)	M1 transition	Rösel <i>et al.</i> (1978) (adopted)

Transition 8-1: 621,771 keV**Internal Conversion Coefficients α_K**

0,0020 (4)		BASHANDY (1969Ba54)
0,00227 (5)	M1 transition	Rösel <i>et al.</i> (1978) (adopted)

Transition 9-3 :739,503 keV**Internal Conversion Coefficient α_K**

0,0016 (4)	M1 or E2	BASHANDY(1969Ba54)
0,00154 (40) *		VAN EIJK et a.l. (1968)
0,00151 (3)	E2+7,6%M1	Rösel <i>et al.</i> (1978) (adopted)

*value corrected for $\alpha_K(661\text{keV Cs-137}) = 0,0896(15)$ (Helmer in BÉ 1999)

The multipole mixing ratio : $\delta = 3,58(20)$ measured by Gardulski and Wiedenbeck (1974), leads to an E2 + 7,2% M1 transition.

Singh and Sahota (1982) indicated an E2 + 8,0(1)%M1 multipolarity.

Transition 9-2 : 777,924 keV**Internal Conversion Coefficient α_K**

0,0005 (1)		BASHANDY (1969Ba54)
0,000518 (10)	E1 transition	Rösel <i>et al.</i> (1978) (adopted)

Transition 10-3 : 822,976 keV**Internal Conversion Coefficient α_K**

0,0004 (1)		BASHANDY(1969Ba54)
0,0004 (1)	E1+1%M2 transition	SINGH (1982)
0,000461(9)	E1 transition	Rösel <i>et al.</i> (1978) (adopted)

For an E1+1%M2 transition, the theoretical value would be higher than the experimental values and we do not accept this type of transition.

Transition 13-3 : 960,759 keV**Internal Conversion Coefficient**

Based on $\alpha_K = 0,0024(5)$ Bashandy deduced a M2 multipolarity. From the decay scheme Singh gave a M2 + E3 multipolarity. This is not consistent with the adopted spins and parities which lead to a M1+E2 transition. For a M1 transition, $\alpha_T = 0,00097$ from the Rösel tables.

Transition 13-1 : 1001,348 keV

Internal Conversion Coefficient

Based on $\alpha_K = 0,0018(3)$ Bashandy deduced a M2+E3 multipolarity. This is not consistent with the adopted spins and parities which lead to a E2+M3 transition. For a E2 transition, $\alpha_T = 0,00083$ from the Rösler tables.

2.2.2 GAMMA TRANSITION PROBABILITIES

The gamma transition probabilities have been calculated from the gamma emission probabilities and the internal conversion coefficients for the transitions occurring above the 142 keV level.

The total gamma and beta transition probabilities populating the 142 keV level is : 87,65(19)%.

Within the Tc-99m decay, the 2,17 keV gamma transition probability (from the level 2 to the level 1) is deduced to be : 99,0(4)%; the 142 keV gamma transition probability is evaluated to be : 1,0(1) % and the 140 keV gamma transition probability is 99,0(4)%.

So, the transition probabilities are deduced to be : 86,8(19)% and 0,88(6)% for the 2,17 keV and the 142 keV, respectively. Taking into account the level balance, the 140 keV transition probability is deduced to be 92,1(19) %.

3. Atomic Data

3.1. Fluorescence yields

- ω_K is from Bambynek (1984)
- ω_L , η_{KL} , η_{LM} are from Schönfeld and al.(1996)
- ω_M is from Hubbell and al. (1994)

3.2. X Radiations

The X-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative K X-ray emission $K\beta/K\alpha$ and $K\alpha_2/K\alpha_1$ probabilities are taken from 1996Sc06.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La** (Larkins).

The ratios $P(KLX)/P(KLL)$ and $P(KLY)/P(KLL)$ are taken from 1996Sc06.

4. Photon Emissions

4.1. X-Ray Emissions

The total absolute emission probability of K X-rays (P_{XK}) has been computed using the adopted value of ω_K and the evaluated total absolute emission probability of K conversion electrons (P_{ceK}). The absolute emission probabilities of the K X-ray components have been computed from P_{XK} using the relative probabilities from 1996Sc06.

The measured values of the total absolute emission probability of K X-rays ($P_{XK} \times 100$) are given below in comparison with the calculated (adopted) value:

Dickens and Love	Goswamy	Calculated (adopted)
11,3(5)	11,5(4)	11,2(2)

Above agreement of the measured and calculated values shows concord between the evaluated data for ⁹⁹Mo including the gamma-ray emission probabilities, gamma-multipolarity admixtures, ICC α_K and the fluorescence yield ω_K .

The total absolute emission probability of L X-rays has been computed using total absolute sums P_{ceL} , P_{ceK} , and atomic data of section 3 (ω_K , ω_L , η_{KL}).

M X-ray and Auger spectra have been investigated in Gerasimov. The influence of the chemical state on the K X-ray intensity has been studied in Yoshihara (1981Yo08).

4.2. GAMMA RAY EMISSIONS

4.2.1 GAMMA RAY ENERGIES

The γ -ray energies of $\gamma_{2,1}$ (2,17 keV), $\gamma_{3,1}$ (40,6 keV) and $\gamma_{1,0}$ (140,5 keV) are taken from Gerasimov (1981Ge05), Gardulski (1972Ga37) and Helmer (2000He14), respectively. These values are based on the most accurate measurements with the electrostatic spectrometer ($E\gamma_{2,1}$, see also Lacasse (1971La12)) and curved-cristal spectrometer ($E\gamma_{3,1}$ and $E\gamma_{1,0}$, see also Helmer (1981He15)). The energies of $\gamma_{2,0}$ (142,7 keV), $\gamma_{3,0}$ (181,1 keV), $\gamma_{7,0}$ (761,7 keV) and $\gamma_{11,0}$ (1072,2 keV) have been computed from the Q value and the adopted energies of other gamma transitions using gamma cascades in the decay scheme. The energy of $\gamma_{15,4}$ (689,6 keV) is taken from 1969Co18 (this γ -ray was seen also by Goswamy *et al.* (1992Go22) but was defined as some contamination in the source). All other gamma-ray energies have been adopted from the recent measurements with large volume Ge(Li) and high-purity Ge detectors by R.A. Meyer (1990Me15).

4.2.2 GAMMA RAY RELATIVE EMISSION PROBABILITIES

Several authors measured the relative emission probabilities to the emission probability of 739 keV line, and others to the emission probability of the 140,5 keV line.

In this evaluation the 739 keV line is taken as the reference line rather than the 140 keV line because the 739 line is not a part of the Tc-99m decay scheme, and the measurements carried out relative to this line, are more recent.

Measurements relative to the 140,5 keV line have been taken into account by converting the data so that they are relative to the 739 keV line.

The available experimental values for the γ -ray relative emission probabilities are given in Table 1. Where necessary, these data (including uncertainties) have been converted by the evaluators to values relative to the $\gamma_{9,3}$ (739,5 keV) taken as 100. Some old references differ widely far from more recent studies and are not included in the statistical processing.

The adopted (evaluated) values are displayed in last column of Table 1. Reasons for adopting specific data are given in Table 2 which includes the following designations :

R indicates that the value was rejected due to Chauvenet criteria.

n is the number of values taken into account, WM is the weighted mean, *s* and *S* are the internal and external uncertainties of WM, respectively;

" χ^2 -table" is $(\chi^2)^{0,05}_{n-1}$, "reduced χ^2 -set" is $\chi^2/(n-1)$ for the given data set; s_{min} is the minimum experimental uncertainty for the given data set, *tS* is the external uncertainty multiplied by the Student's factor *t*, "MBAYS" is the uncertainty from a modified Bayesian analysis.

The doublet $\gamma_{14,7}+\gamma_{9,4}$ (410-411 keV) has been calculated as two different lines because several authors were able to distinguish separated values.

For the doublet $\gamma_{7,3}+\gamma_{8,3}$ (580-581 keV) several authors measured only one line, except Meyer (see Table 1).

For the doublet $\gamma_{12,4}+\gamma_{8,1}$ (620-622 keV) the emission intensity was computed for the two combined lines in order to take into account most of the measurements, and then these lines were separated by using the intensity ratio for components deduced from the measurements of Meyer of 0,09(3).

Table 1. Experimental and evaluated values for γ -ray relative emission probabilities

	keV	Van Eijk	Cook	Gehrke Heath	Morel	Dickens 1980	Yang 1980	Singh	Chen Da	Meyer 1990	Goswamy 1992	Evaluated
$\gamma_{3,1}$	40,58		6,9(8)	4,6(18) <i>R</i>	5,9(15)	8,68(27)		7,7(6)		8,6(5)	8,49(25)	8,43(20)
$\gamma_{1,0}$	140,5	649(25)	704(45)	730(49)	743(19)	747(12)	759(20)	686(49)	752(28)	755(26)	739(11)	739(11)
$\gamma_{2,0}$	142,6	0,195(40)				0,149(25)				0,189(11)		0,174(14)
$\gamma_{9,7}$	158,8		0,10(3)	0,095(30)	0,112(15)			0,11(4)		0,139(8)	0,156(6)	0,12(4)
$\gamma_{6,4}$	162,4			0,073(22)	0,067(15)			0,078(13)		0,097(5)	0,098(5)	0,094(5)
$\gamma_{3,0}$	181	48,7(23)	49,9(34)	49,6(42)	49,1(16)	50,1(7)		49,8(33)	48,7(13)	50,3(17)	49,4(8)	49,6(7)
$\gamma_{10,7}$	242,3		0,0070(25)					0,0118(44)		0,0117(17)	0,021(4)	0,0114(28)
$\gamma_{9,6}$	249	0,039(20)	0,05(2)					0,04(3)		0,024(3)	0,032(4)	0,0285(30)
$\gamma_{4,2}$	366,4	10,6(8)	10,7(6)	10,0(9)	9,8(3)	9,52(32)		9,8(8)		9,92(25)	9,82(15)	9,85(15)
$\gamma_{13,7}$	380,1	0,071(20)	0,07(2)	0,058(15)	0,045(15)			0,07(2)		0,075(3)	0,086(7)	0,075(4)
$\gamma_{5,2}$	391,7	0,016(4)									0,026(5)	0,021(5)
$\gamma_{14,7}$	410,3	0,010(5)						0,009(9)		0,016(4)		0,013(3)
$\gamma_{9,4}$	411,5	0,18(2)	0,13(2)	0,36(4) <i>R</i>	0,134(23)			0,14(2)		0,120(6)		0,133(10)
$\gamma_{12,6}$	457,6	0,039(20)	0,08(2)					0,04(2)		0,056(5)	0,067(5)	0,061(5)
$\gamma_{10,5}$	469,6		0,0060(15) <i>R</i>							0,022(4)	0,022(4)	0,022(4)
$\gamma_{6,2}$	528,8	0,39(5)	0,49(5)	0,36(4)	0,43(6)			0,44(4)		0,447(15)	0,47(2)	0,446(15)
$\gamma_{11,5}$	537,8		0,0100(25)					0,009(3)		0,013(5)	0,027(5)	0,012(4)
$\gamma_{7,3}$	580,5	0,026(7)						0,021(8)		0,036(4)	0,026(4)	0,0294(31)
$\gamma_{8,3}$	581,3									0,008(4)		0,008(4)
$\gamma_{12,4}^+$	620	0,21(3)	0,217(22)	0,19(6)	0,30(4)			0,26(2)		0,232(11)	0,24(4)	0,236(11)
$\gamma_{8,1}$	621,7											

	keV	Van Eijk	Cook	Gehrke Heath	Morel	Dickens 1980	Yang 1980	Singh	Chen Da	Meyer 1990	Goswamy 1992	Evaluated
$\gamma_{15,4}$	689,6		0,0035(15)									0,0035(15)
$\gamma_{9,3}$	739,5	100	100	100	100	100	100	100	100	100	100	100
$\gamma_{7,0}$	761,8		0,019(5)							0,0092(8)	0,033(3)	0,019(11)
$\gamma_{9,2}$	777,9	35,1(24)	34,9(20)	35,8(30)	35,5(10)	35,8(9)		34,8(19)		35,3(12)	35,1(5)	35,3(5)
$\gamma_{10,3}$	822,9	1,04(8)	1,11(8)	1,09(10)	1,09(5)	1,09(5)		1,10(7)		1,06(4)	1,10(2)	1,09(2)
$\gamma_{10,2}$	861,2		0,006(2)	0,015(6)				0,005(3)			0,006(3)	0,006(2)
$\gamma_{13,3}$	960,722	0,78(7)	0,78(6)	0,80(8)	0,76(4)	0,84(4)		0,79(6)		0,76(4)	0,78(2)	0,78(2)
$\gamma_{12,2}$	986,4	0,013(5)	0,014(4)	0,016(4)						0,0108(9)	0,012(4)	0,0112(8)
$\gamma_{13,1}$	1001	0,045(13)	0,036(16)	0,027(4)	0,052(15)			0,045(12)		0,033(1)	0,045(4)	0,035(3)
$\gamma_{15,3}$	1017	0,006(3)									0,005(2)	0,0055(21)
$\gamma_{15,2}$	1056,2		0,008(2)					0,007(3)		0,0083(9)	0,0089(7)	0,0085(7)
$\gamma_{11,0}$	1072,2							0,010(4)				0,010(4)

Table 2. Results of data statistical processing on relative γ -ray emission probabilities

	n	WM	s	S	c^2		Final uncertainty and type
					table	set	
$\gamma_{3,1}$	6	8,43	0,16	0,20	14,07	1,82	0,20 (S)
$\gamma_{1,0}$	10	739	5,7	7,6	18,31	2	11 (S_{min})
$\gamma_{2,0}$	3	0,174	0,014	0,014		1	0,014 (S)*
$\gamma_{9,7}$	6	0,12 ^d	0,0047	0,0078	11,07	3	0,04 (S)
$\gamma_{6,4}$	5	0,094	0,0033	0,0042	9,49	1,6	0,005 (S_{min})
$\gamma_{3,0}$	10	49,6	0,42	0,20	16,92	0,13	0,7 (S_{min})
$\gamma_{10,7}$	4	0,0114	0,0014	0,0024	7,82	2,96	0,0028 (tS)
$\gamma_{9,6}$	5	0,0285	0,0027	0,0026	9,49	0,9	0,0030 (S_{min})*
$\gamma_{4,2}$	9	9,85	0,11	0,08	15,51	0,58	0,15 (S_{min})
$\gamma_{13,7}$	7	0,075	0,0037	0,0042	12,59	1,3	0,004 (S)*
$\gamma_{5,2}$	2	0,021	0,0035	0,005		2	0,005 (S)*
$\gamma_{14,7}$	3	0,013	0,003	0,002		0,56	0,003 (S)
$\gamma_{9,4}$	5	0,133	0,007	0,01		1,81	0,01 (S)*
$\gamma_{12,6}$	5	0,061	0,0034	0,0040	9,49	1,4	0,005 (S_{min})
$\gamma_{10,5}$	3	0,022 ^b					0,004 ^b
$\gamma_{6,2}$	7	0,446	0,010	0,012	12,59	1,1	0,015 (S_{min})
$\gamma_{11,5}$	4	0,012	0,0017	0,0032	7,82	3,6	0,0038 (tS)
$\gamma_{7,3}$	4	0,0294	0,0025	0,0031		1,6	0,0031 (S)
$\gamma_{8,3}$	1	0,008					0,004
$\gamma_{12,4} + \gamma_{8,1}$	7	0,236	0,0083	0,0085	12,59	1	0,011 (S_{min})*
$\gamma_{15,4}$		0,0035 ^c					0,0015 ^c
$\gamma_{9,3}$		100					
$\gamma_{7,0}$	3	0,019	0,0018	0,0077	5,99	18	0,011 (MBAYS)*
$\gamma_{9,2}$	9	35,3	0,34	0,17	15,51	0,2	0,5 (S_{min})
$\gamma_{10,3}$	8	1,09	0,015	0,0063	14,07	0,1	0,02 (S_{min})*
$\gamma_{10,2}$	4	0,006	0,0014	0,0012	7,82	0,6	0,002 (S_{min})
$\gamma_{13,3}$	9	0,78	0,014	0,0083	15,51	0,08	0,02 (S_{min})
$\gamma_{12,2}$	5	0,0112	0,0015	0,0008	9,49	0,44	0,0008 (S)
$\gamma_{13,1}$	7	0,035	0,0017	0,0026	12,59	1,9	0,0028 (tS)*
$\gamma_{15,3}$		0,0055 ^d					0,0021 ^d
$\gamma_{15,2}$	4	0,0085	0,00056	0,00025	7,82	0,22	0,0007 (S_{min})*
$\gamma_{11,0}$		0,010 ^e					0,004 ^e

^a Adopted from Goswamy (1992Go22)

^b Adopted from Meyer (1990Me15) and 1992Go22 (the same values)

^c Adopted from Cook (1969Co18)

^d Unweighted average

^e Adopted from Singh (1982Si16)

* LRSW increased an uncertainty for one of the values(1992Go22 or 1990Me15).

All values for relative γ -ray emission probabilities are given for the equilibrium mixture $^{99}\text{Mo} + ^{99}\text{Tc}^m$.

For $\gamma_{2,0}$ (142,7 keV) the following measured intensity ratios of $\gamma_{2,0}/\gamma_{1,0}$ (140,5 keV) have been used: $3,0(6) \cdot 10^{-4}$ (Van Eijk), $2,0(2) \cdot 10^{-4}$ (Ageev), $2,0(3) \cdot 10^{-4}$ (Dickens, 1980Di16), $2,50(9) \cdot 10^{-4}$ (Meyer, 1990Me15). The weighted average of these values is $2,29(16) \cdot 10^{-4}$ with an external uncertainty; in terms of the $\gamma_{9,3}$ (739,5 keV) a relative intensity of 0,169(12) is obtained.

For $\gamma_{11,0}$ (1072,2 keV) the relative γ -ray emission probability is taken from Singh (1982Si16).

4.2.3 GAMMA RAY ABSOLUTE EMISSION PROBABILITIES

Several absolute measurements of the emission intensity of the 739 keV line are available to give a consistent set of data.

Emission 9 - 3 : 739,500(17) keV**Absolute measurement : photon emission per 100 decays**

11,9 (3)	Chen Da - 1985 (Ge(Li) gamma spectrometer) (measured)
12,3 (3)	Simonits (1981)
12,14 (22)	Dickens and Love(1980) (calculated)
12,00 (33)	Meyer (Fizika - 22 - p153 (1990))

Lweight has used the weighted average and the internal uncertainty. Reduced- $\chi^2=0,45$

Adopted absolute g emission probability: 12,12(15)%

This absolute γ -ray emission probability can be compared with the value obtained by considering the balance of the decay scheme. The γ -ray absolute emission probabilities P_γ have been computed using relative ($\gamma+ce$)-probabilities (relatively to the 739,5 keV gamma ray) and the ^{99}Tc ground state intensity balance, which assumes no β -feeding to the g.s. and the 140,5 keV level as confirmed by the high degree of forbiddenness. The P_γ intensity of the 739 keV line has been deduced to be 12,18(17)% taking into account the correlation $\Sigma P_\beta=1$ and the factor of 1,100 for the gamma transitions in Tc-99m.

All the absolute gamma ray emission probabilities are given per 100 disintegrations of Mo-99 (in equilibrium with Tc-99m) taking into account the correction factor of 1,100 for $\gamma_{2,1}(2,17 \text{ keV})$, $\gamma_{2,0}(142,7 \text{ keV})$ and $\gamma_{1,0}(140,5 \text{ keV})$ intensities.

It should be noted that Singh and Sahota (1982Si16) have reported nine controversial γ -rays at energies of 38,4; 163,4; 319,8; 321,0; 352,9; 599,6; 721,7; 940 and 1082,0 keV. These γ -rays have not been confirmed by Goswamy *et al.* (1992Go22) and are not placed in the decay scheme; neither are the 344,6 keV γ -ray observed by Cook *et al.* (1969Co18) and the 89,4; 455,84; 490,53 keV γ -rays observed by Meyer (1990Me15).

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies. The emission probabilities have been calculated using the conversion coefficients given in 2.2. and the gamma emission probabilities.

Many measurements of conversion electron spectra for ^{99}Mo in equilibrium with $^{99}\text{Tc}^m$ have been made (1968Va14, 1969Ag04, 1969Ba03, 1969Ba54, 1969Ra01, 1971La12, 1971Vo06, 1973Le29, 1981Ge05). However the computed values of the conversion electron energies and emission probabilities are more accurate.

The values of the emission probabilities of K-Auger electrons have been calculated using the gamma transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.2.

Experimental Auger spectra can be found in 1981Ge05.

BETA-MINUS EMISSIONS

The β^- transition energies are derived from the level energies.

T. NAGARAJAN (1971Na01) analysed the β spectrum of Mo-99. This study revealed four β groups with end points :

	Energy keV	Transition probability
$\beta_{0,2}$	1214(1)	84
$\beta_{0,4}$	840(5)	2
$\beta_{0,9}$	450(10)	14
$\beta_{0,12}$	245	<0,2

No evidence was found for a β group with endpoint higher than 1214 keV.

These values are in a rough agreement with those established by considering the balance of the decay scheme (paragraph 2.1).

REFERENCES

- J. A. SEILER, Report ANL-4000(1947)119 [Half-life]
S. R. GUNN, H. G. HICKS, H. B. LEVY, P. C. STEVENSON, Phys. Rev. 107(1957)1642 [Half-life]
H. W. WRIGHT, E. I. WYATT, S. A. REYNOLDS, W. S. LYON, T. H. HANDLEY, Nucl. Sci. Eng. 2(1957) 427 [Half-life]
A. N. Protopopov , G. M.Tolmachev et al., J. Nucl. Energy 10A(1959)80 [Half-life]
J. RAVIER, P. MARGUIN, A. MOUSSA, J. Phys. Radium 22(1961)249 [K/L]
R. D. Newman, Priv. Comm. (1961) [Half-life]
P. CROWTHER, Nucl. Phys. 66(1965)472 [Half-life, Gamma emission probabilities, T ICC, K ICC]
S. R. AMTEY, J. H. HAMILTON, M. J. ZENDER, Phys. Lett. 23-10(1966)581 [K ICC, L ICC, M ICC]
J. A. Bearden, Rev. Mod. Phys., 39,1(1967)78 [X-Rays energies]
M. N. BALDWIN, Nucl. Sci. Eng. 30(1967)144 [Half-life]
C. W. E. VAN EIJK, B. VAN NOOIJNEN, F. SCHUTTE, Nucl. Phys. A121(1968)440 [Gamma-ray energies, K-Conv. Elec. , Gamma-ray emission probabilities]
J. S. GEIGER, AECL-3166 PR-P-79(1968)29 [Gamma-ray energies, K-Conv. Elec., Gamma emission probabilities]
S. M. BRAHMAVAR, J. H. Hamilton, J. J. Pinajian, Quoted in Nucl. Phys. A121(1968)440 [ICC]
S. A. Reynolds, J. F. Emery, E. I. Wyatt, Nucl. Sci. Eng. 32(1968)46 [Half-life]
N. RANAKUMAR, R. W. FINK, P. V. RAO, Nucl. Phys. A217(1969)683 [K ICC]
W. B. COOK, L. SCHELLENBERG, M. W. JOHNS, Nucl. Phys. A139(1969)277 [Gamma-ray energies, Gamma-ray emission probabilities]
E. BASHANDY, Z. Naturforsch 24A(1969)1893 [K ICC]
V. A. AGEEV et al., Bull. Ac. Sc. USSR, Phys. Ser. 33(1969)1183 [Conv. Elec. emission probabilities]
A. VUORINEN, Ann. Acad. Sci. Fenn. Ser. A VI.(1969)311 [T ICC]
E. BASHANDY, N. IBRAHIEM, Z. Phys. 219(1969)337 [K ICC, K/L]
P. STEINER, E. Gerdau, W. Hautsch, D. Streenken, Z. Physik 221(1969)281 [Level half-life]
N. A. VOINOVA et al., Bull. Ac. Sc. URSS, Phys. Ser. 35(1971)794 [K ICC]
J. Mc DONALD, A. BACKLIN, S. G. MALMSKOG, Nucl. Phys. A162(1971)365 [Mean half-life, Multipolarity mixing ratio]
T. NAGARAJAN, M. RAVINDRANATH, K.V. REDDY, Phys. Rev. C3(1971)247 [Beta emission energies]
W. M. Lacasse, J. H. Hamilton, Nucl. Phys. A171(1971)641 [Gamma ray energies]
S. BABA, H. BABA, H. NATSUME, J. Inorg. Nucl. Chem. 33(1971)589 [Half-life]
P. L. GARDULSKI, M. L. WIEDENBECK, Nucl. Instrum. Methods 105(1972)169 [Gamma-ray energies]
N. A. VOINOVA, A. I. EGOROV, Y. V. KALINICHEV, A. G. SERGEEV, Bull. Ac. Sc. URSS, Phys. Ser. 35(1972)794 [K ICC]
J. F. EMERY, S. A. REYNOLDS, E. Y. WYATT, G. I. GLEASON, Nucl. Sci. Eng. 48(1972)319 [Half-life]

- G. K. SHENOY, G. ABSTREITER, G. M. KALVIUS, K. SCHWOCHAU, K. H. LINSE, J. Phys. A (London) 6(1973)L144 [Level half-life]
- J. LEGRAND et al., Report CEA-R-4427(1973) [Gamma-ray emission probabilities, Conv. Elec. emission probabilities]
- R. J. GEHRKE, L. D. Mac ISSAC, R. L. HEATH, Report ANCR-1129(1973)23 [Gamma-ray energies, Gamma-ray emission probabilities]
- P. L. GARDULSKI, M. L. WIEDENBECK, Phys. Rev. C9(1974)262 [Spin and Parity, Mixing Ratio]
- R. L. HEATH, Report ANCR-1002(1974) [Gamma-ray energies, Gamma-ray emission probabilities]
- R. A. MEYER, Report UCRL-76207(1974) [Spin and Parity]
- F. P. Larkins, At. Data Nucl. Data Tables 20,4(1977)338 [Auger Electrons]
- J. MOREL, J. P. PEROLAT, Report CEA-N-2043(1978) [Gamma-ray emission probabilities]
- J. K. DICKENS, T. A. LOVE, Radiochem. Radioanal. Letters 39(1979)107 [Gamma-ray emission probabilities]
- H. HOUTERMANS, D. MILOSEVIC, F. REICHEL, Int. J. Appl. Radiat. Isotop. 31(1980)153 [Half-life]
- J. K. DICKENS, T. A. LOVE, Nucl. Instrum. Methods 175(1980)535 [Gamma-ray emission probabilities]
- Yang Chunxiang et al., Chin. J. Nucl. Phys. 2(1980)41 [Gamma-ray emission probabilities]
- R. G. HELMER, A. J. CAFFREY, R. J. GEHRKE, R. C. GREENWOOD, Nucl. Instrum. Methods 188(1981)671 [Gamma-ray energies]
- K. Yoshihara, A. Hibino, I. Yamoto, H. Kaji, Radiochem. Radioanal. Lett. 48(1981)303 [KX-ray intensities]
- A. SIMONITS, J. Radioanal. Nucl. Chem. 67(1981) [Gamma-ray emission probabilities]
- V. N. Gerasimov et al., Yadern. Fiz. 34(1981)3 [Gamma ray energies]
- K. SINGH, H. S. SAHOTA, J. Phys. Soc. Jap. 51,12(1982)153 [Multipole mixing ratio]
- D. D. HOPPE, J. M. R. HUTCHINSON, F. J. SCHIMA, M. P. UNTERWEGER, NBS-SP-626(1982)85 [Half-life]
- Y. V. KHOLNOV, Handbook, Energoizdat, Moscou (1982) [Beta emission probabilities]
- K. F. WALZ, K. DEBERTIN, H. SCHRADER, Appl. Rad. Isot. 34(1983)1191 [Half-life]
- W. Bambynek, X-84 Proc. X-Ray and Inner-Shell Processes in Atoms, Molecules and Solids, A. Meisel Ed., Leipzig Aug. 20-23(1984) [K fluorescence yield]
- CHEN DA, ZHANG QIAOLIAN, CHANG YONGFU, IEEE-Transactions on Nuclear Science, Vol.32- n°1 (1985)153 [Gamma-ray emission probabilities]
- R. A. MEYER, Fizika 22(1990)153 [Gamma-ray energies, Gamma-ray emission probabilities]
- J. GOSWAMY, B. CHAND, D. MEHTA, N. SINGH, P. N. TREHAN, Appl. Rad. Isotopes 43(1992)1467 [Gamma-ray emission probabilities]
- I. ALFTER, E. BODENSTEDT, B. HAMER, W. KNICHEL, R. MÜSSELER, R. SAJOK, T. SCHAEFER, J. SCHÜTH, R. VIANDEN, Z. Physik A347(1993)1 [Level half-life]
- L. K. PEKER, Nucl. Data Sheets 73,1(1994)1 [Spin and Parity]
- J. H. Hubbell, P. N. Trehan, Nirmal Singh, B. Chand, D. Mehta, M. L. Garg, R. R. Garg, Surinder Singh, S. J. Puri, Phys. Chem. Ref. Data 23-2(1994)339 [M fluorescence yield]
- G. AUDI, A. H. Wapstra, Nucl. Phys. A595(1995)409 [Q]
- E. SCHÖNFELD, H. Janssen, Nucl. Instrum. Methods A369(1996)527 [L fluorescence yield]
- V. S. BUTSEV, G. L. BUTSEVA, D. CHULTEM, P. I. GOLUBEV, D. KISS, E. J. LANGROCK, R. A. ZULKARNEV, Heavy Ion Physics 8(1998)227 [Half-life]
- M.-M. BÉ, E. Browne, V. Chechev, R. Helmer, E. Schönfeld, Table de Radionucléides, ISBN 2 7272 0200 8, CEA, F-91191 Gif sur Yvette ; (1999) [T ICC (Cs-137)]
- R. G. HELMER, C. van der Leun, Nucl. Instrum. Methods A450(2000)35 [Gamma ray energies]
- H. SCHRADER, Appl. Rad. Isotopes, 60(2004)317 [Half-life]

⁹⁹Tc^m - Comments on evaluation of decay data
by C. Morillon*, M. M. Bé*, V. Chechev, A. Egorov****

This evaluation was completed in December 2000. The half-life has been updated in January 2004.

1. DECAY SCHEME

Tc-99m mainly decays to the ground level of Tc-99.

Very weak beta minus transitions to the ground and two excited levels of Ru-99 have been observed. The J^π values and the level energies are from Peker(1994Pe15).

2. NUCLEAR DATA

Q_{IT} (⁹⁹Tc^m) from the 142,7 keV level energy
 Q (⁹⁹Tc^m) from Audi and Wapstra (1995)

2.1 HALF-LIFE

- The measured half-life values are, in hours:

1	6,13(5)	CROWTHER and ELDRIDG	(1965)	1965Cr03	rejected
2	6,006(7)	GOODIER and WILLIAMS	(1966)	1966Go22	
3	6,014 (4)	VUORINEN	(1969)	1969Vu03	
4	6,031 (12)	LEGRAND et al.	(1970)	1970Le07	
5	6,007 (2)	SANTRY and BOWES	(1989)	1989Sa**	
6	6,03 (13)	DECOMBAZ et al.	(1972)	1972De76	
7	6,02 (1)	EMERY et al.	(1972)	1972Em01	
8	6,049 (35)	EMERY et al.	(1972)	1972Em01	rejected
9	6,02 (3)	MEYER	(1974)	1974Me**	
10	6,008 (4)	RUTLEDGE et al.	(1980)	1980RuZY	TcO ₄ Na
11	6,006 (2)	HOUTERMANS et al.	(1980)	1980Ho17	No precision
12	6,0072 (10)	AYRES and HIRSHFELD	(1982)	1982Ay**	Normal saline solution
13	6,0170(19)	AYRES and HIRSHFELD	(1982)	1982Ay**	Acid solution
	6,0062 (7)	WALZ et al.	(1983)	1983Wa26	Superseded by 2003Sc49
14	6,020(2)	KOLTSOV et al.	(1998)	1998Ko**	TcO ₄ Na
15	6,0058(12)	SCHRADER	(2004)	2004Sc49	TcO ₄ Na
16	6,0071(21)	Da SILVA et al.	(2004)	2004Si04	TcO ₄ Na

The chemical medium probably has an influence on the half-life. Changes in the half-life values have been observed with the modification of external environment or chemical composition (influence on internal conversion of electrons of 2,17 keV transition in external shells : Mazaki (1980Ma03), Koltsov, and others).

Comparisons of the decay constant of Tc-99m in different chemical environments were made. In the following table λ_0 is the decay constant for Tc-99m in the form of pertechnetate (TcO₄).

Author	Type of source	Source pair	Relative variation of decay constant, %
Koltsov	Sulfide	$[\lambda_0 - \lambda (\text{Tc}_2\text{S}_7)] / \lambda_0$	0,14 (8)
Koltsov	Silver	$[\lambda_0 - \lambda (\text{Ag})] / \lambda_0$	0,35 (7)
Koltsov	Gold	$[\lambda_0 - \lambda (\text{Au})] / \lambda_0$	0,25 (7)
Mazaki	Sulfide	$[\lambda_0 - \lambda (\text{Tc}_2\text{S}_7)] / \lambda_0$	0,32 (7)
Mazaki	Sulfide - metal	$[\lambda (\text{Tc}_2\text{S}_7) - \lambda (\text{Metal})] / \lambda (\text{Metal})$	0,056 (3)
Ayres		Acid solution – Normal saline	0,16

If we consider the set of 16 measured values given in the table above, where :

- Emery *et al.* (1972) and Ayres and Hirshfeld (1982) measured the half-life of Tc-99m by 2 different methods or 2 media: both values were taken into account. (NB : the experiment and results described by Ayres and Hirshfeld are the same as those described by Hoppes *et al.* in NBS-SP-626 (1982) 85 and by Unterweger *et al.* in NIM A312 (1992) 349) ;
- the value of Crowther and Eldridge (1965) and the second value of Emery *et al.* (1972) are rejected due to the Chauvenet criterion.

With the set of 14 remaining values, LWEIGHT recommended the unweighted average (Reduced- $\chi^2 = 5,3$) and expanded the uncertainty to include the most precise value of 6,0072 (Ayres *et al.* 1983). This leads to 6,014 (7) h.

With the 7 most recent values (from 10 to 16) (>1980), the LWEIGHT program derived the weighted mean and expanded the uncertainty: the recommended value is 6,0089 (19) h. (Reduced- $\chi^2 = 10,2$).

Nevertheless, the most commonly used chemical composition is sodium pertechnetate (TcO₄Na) in a physiological saline solution, this solution is chemically stable. This is the result of the way of production of ⁹⁹Tc^m for medical purposes. The metallic matrix have been made for very specific studies and do not correspond to a general use.

Then, taking into consideration the most recent values obtained from a (TcO₄Na) solution, i.e. values 10 – 12 – 14 – 15 – 16 ; the value 14 (Koltsov) is outlier, omitting it the weighted mean is 6,006 7 (7) with the internal uncertainty, the reduced χ^2 is 0,32.

Conclusions :

- Due to the fact that the pertechnetate solution is a stable solution and the most commonly used, *the adopted half-life is : 6,006 7 (10) h*, uncertainty of the most precise measurement value.
- Uncertainty should be enlarged to 0,009, to take into account a possible chemical effect of 0,15% for other solutions, then the half life would be : 6,007 (9) h.

DECAY Tc-99m to Tc-99

- Measured half-life of the 140,5 keV level in ns:

0,277 (14)	STEINER <i>et al.</i> (1969St04)
0,160 (20)	MCDONALD <i>et al.</i> (1971Mc02)
0,205 (4)	ALFTER <i>et al.</i> (1993A123)
0,237 (14)	SHENOY <i>et al.</i> (1973Sh21)

The value of Steiner *et al.*(1969) is from the original article; the NDS value from the same reference has been adjusted to 0,192 ns.

The value of 0,160(20) ns from McDonald *et al.* (1971) deviates far from the others and is not taken into account.

The Steiner *et al.*(1969) and Shenoy *et al.*(1973) values were determined using the Mössbauer effect.

The uncertainty in the Alfter *et al.* (1993) value was increased 2,47 times by LWEIGHT.

Reduced- $\chi^2 = 8,94$

LWEIGHT has used the weighted average and the external uncertainty.

The adopted value is : **0,221(20) ns**

· **Level energy of technetium 99**

The values of the level energies are from NDS 73,1

Level 2 142,6833 (11)

Level 1 140,5108 (10)

2.2 GAMMA TRANSITIONS and INTERNAL CONVERSION COEFFICIENTS

The energies of the gamma transitions are derived from the energies of the gamma rays, taking recoil into account. The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma-ray emission probabilities and the total internal conversion coefficients (ICC).

INTERNAL CONVERSION COEFFICIENTS

The ICC have been evaluated using the experimental information of the multipolarity admixture coefficients and the theoretical values from Rösels *et al.* and Band *et al.* (for $\gamma_{2,1}$ 2,17 keV).

For pure multipolarities the uncertainties on the ICC values are adopted to be 2%. For mixed multipolarities the uncertainties of ICC were evaluated taking into account the uncertainties of respective multipolarity admixture coefficients.

The ICC adopted values are compared with the measured values, and are, generally, in good agreement.

Transition 2-1: 2,17 keV

No experimental value has been found. Band theoretical values (1976Ba63):

$$\alpha_T = 1,35 (4) 10^{10} \quad \text{and} \quad \alpha_M = 1,19 (3) 10^{10}$$

Transition 1-0: 140,511 keV

Total Internal Conversion Coefficient α_T

Experimental measurements :

0,118 (8)	AMTEY <i>et al.</i> (1966)
0,113 (6)	DICKENS and LOVE (1980)
0,122 (5)	VUORINEN (1969)
0,118 (3)	LEGRAND <i>et al.</i> (1973Le29)
0,1181(23)	LWEIGHT (reduced $\chi^2 = 0,44$; weighted average and internal uncertainty)
Adopted: 0,119(3)	Rosel <i>et al.</i> for M1+3,3(3)%E2

Dickens and Love (1980) determined α_T from the α_k value given by Gardulski and Wiedenbeck (1974) and the K/L/MN values reported by Hager and Selzer and by Medsker (NDS 12-4 - 1974)

α_T was evaluated by Vuorinen (1969) from measurements of conversion electrons in coincidence with fluorescence X-rays.

Multipolarity

Large number of measurements have been made. However, most of the authors gave different values without, or with a large uncertainty. These multipolarities permit the calculation of the total internal conversion coefficients, to which we have assigned a 5% uncertainty:

/d/	Transition	a_T (Rösel)	
0,31 (2)	M1 + 8,25% E2	0,132(7)	SINGH and SAHOTA (1982Si16)
0,178 (12)	M1 + 3,1% E2	0,119(6)	ALFTER (1993Al23)
	M1 + 4%(2) E2	0,121(6)	MCDONALD <i>et al.</i> (1971Mc02)
	M1+<3%E2		VOINOVA <i>et al.</i> (1972Vo06)
0,194(30)	M1+3,8%E2		VUORINEN (1969Vu03)
	M1+<8%E2		VAN EIJK <i>et al.</i> (1968Va14) calculated from ICCk
	M1+9%(5)E2	0,134(7)	VAN EIJK <i>et al.</i> (1968) calculated from K/L ratio
	M1+2,8%E2	0,118(6)	COOK <i>et al.</i> (1969Co18)
	M1+7(3)%E2	0,129(7)	MEYER (1974)
	M1+1,4%E2	0,114(6)	DICKENS and LOVE (1980Di16)
	M1+6,5(40)E2	0,128(7)	AGEEV <i>et al.</i> (1969Ag04)
0,118(6)	M1+1,4(2)%E2	0,114(6)	GARDULSKI and WIEDENBECK (1974Ga01)
	M1+2,8(3)%E2	0,118(6)	GEIGER (1968GeZW)
	M1+9%E2		SIMONITS <i>et al.</i> (1981Si15)
	M1+E2		AMTEY <i>et al.</i> (1966Am04)
	M1		BASHANDY (1969Ba54)
		0,120(2)	LWEIGHT (reduced- $\chi^2= 1,16$), weighted average and external uncertainty= 0,002
0,186 (8)	M1+ 3,2(3)%E2	0,119(3)	Adopted (Rösel <i>et al.</i>)

From each determination of the multipolarity of the transition, the Rösel theoretical internal coefficient was calculated. From the set of the 10 deduced ICC values the LWEIGHT program recommends a weighted mean of 0,120(2). The value is very closed to that obtained by considering the 4 experimental values for α_T (see table above).

Internal Conversion Coefficients a_K

Experimental values:

0,096(6)	VOINOVA <i>et al.</i> (1971Vo06)
0,093 (6)	VOINOVA <i>et al.</i> (1971Vo06)
0,102 (7)	VAN EIJK <i>et al.</i> (1968Va14)
0,094 (8)	VUORINEN (1969Vu03)
0,102 (5)	DICKENS and LOVE (1980Di16)
0,096 (3)	LWEIGHT ($\chi^2=0,35$; weighted average and internal uncertainty)
0,104 (3)	Rösel <i>et al.</i> (1978) (adopted)

- α_K was measured by Voinova *et al.* (1971) with a spectrometer which provided simultaneous measurement of conversion electrons and γ -ray spectra.

- Van Eijk *et al.*(1968) calculated α_K from measurements of the 140,5 keV gamma-ray emission probability (P_γ) relative to the gamma-ray emission probability of the 661,6 keV gamma transition in the decay of Cs-137, and from measurements of the conversion electron emission probability P_{ce} of the 140,5 keV K-conversion line relative to the conversion electron emission probability of the 661,6 keV K-conversion line in the decay of Cs-137: $P_{ceK} = 6,84(19)$; $P_\gamma = 6,00(35)$; $\alpha_K(661,6 \text{ keV}) = 0,0896(15)$ (Helmer in 1999BeZQ).
- Vuorinen (1969) evaluated the internal conversion coefficient α_K by measuring the electron conversion emissions following the conversion of the 140 keV gamma-ray in coincidence with fluorescence X-rays.
- α_K given by Dickens and Love (1980) was computed from the tables of Hager and Seltzer for a M1 transition and a 1,4% E2 admixture. An 5% uncertainty assigned to α_K reflects the added uncertainty to the usual 3% due to the rapid change of α_K with admixture. This value is not taken into account in our calculations.

Internal Conversion Coefficients α_L

α_L can be deduced from measurements of the K/L ratio of the conversion electron emission probabilities, and with $\alpha_K = 0,104(3)$:

K/L	α_L	
8,1 (5)	0,0125(8)	BASHANDY(1969Ba03)
7,70 (30)	0,0132(7)	VAN EIJK <i>et al.</i> (1968Va14)
8,3 (3)	0,0122(6)	RAVIER <i>et al.</i> (1961Ra04)
7,63 (32)	0,0133(7)	BRAHMAVAR (1968)
7,8 (3)	0,0130(6)	GEIGER (1968 GeZW)
	0,0128(3)	LWEIGHT has used the weighted average and the internal uncertainty. Reduced- $\chi^2 = 0,52$
Adopted	0,0129(4)	Rösel <i>et al.</i> (1978)

Transition 2-0: 142,683 keV

Internal Conversion Coefficients α_T

For a M4 transition the theoretical value from Rösel is : **40,9(8)**.

Internal Conversion Coefficients α_K

- The two following values were calculated from experimental data, and listed by the authors:

23 (6) VAN EIJK *et al.* (1968)
 30 (3) BASHANDY (1969Ba54)

Van Eijk *et al.* (1968) calculated the K ICC from the ratios of $K(142,7)/K(140,5) = 0,072(32)$ and $I_\gamma(142,7)/I_\gamma(140,5) = 0,00030(6)$, after correction for $\alpha_K(661,6 \text{ keV, Cs-137}) = 0,0896(15)$

Bashandy (1969) calculated the K ICC from internal conversion spectra and photon emission probabilities $I_\gamma(142)/I_\gamma(140) = 0,00030(6)$

- The following α_K coefficients are calculated from the $K(142,7)/K(140,5)$ ratio given by the authors, based on the ratio $I_\gamma(142,7)/I_\gamma(140,5) = 0,00030(6)$ [Van Eijk (1968)] and $\alpha_K(140,5) = 0,104(3)$.

$K(142,7)/K(140,5)$	$\alpha_K(142,7)$	
0,072(4)	24 (6)	AMTEY (1966Am04)
0,0746(12)	25 (6)	GEIGER (1968GeZW)
0,075 (8)	26 (6)	AGEEV <i>et al.</i> (1969Ag04)

If we take into account the ratio $I_{\gamma}(142,7)/I_{\gamma}(140,5) = 0,00021(3)$ given by Dickens and Love (1980Di16), with $\alpha_K(140,5) = 0,104(3)$ the same calculations give higher results for $\alpha_K(142,7)$:

K(142,7)/K(140,5)	$\alpha_K(142,7)$	
0,072(4)	34 (6)	AMTEY (1966)
0,0746 (12)	36 (5)	GEIGER (1968)
0,075 (8)	36 (7)	AGEEV <i>et al.</i> (1969)

If we take into account all the six possible data, the weighted average, with the external uncertainty, calculated by LWEIGHT is 29,5(18) (reduced- $\chi^2 = 0,87$)

The **adopted** theoretical K conversion coefficient, for a M4 transition, is : **29,3(6)** (Rösel *et al.* (1978)).

Internal Conversion Coefficients α_L

From the measurement of the ratio of the conversion electron intensities, with $\alpha_K = 29,3(6)$, it can be deduced that α_L (BASHANDY and IBRAHIEM) is closed to the adopted theoretical value:

K/L	α_L		
2,9 (5)	10,1 (18)	M4 transition	BASHANDY and IBRAHIEM (1969Ba03)
Adopted:	9,35 (20)	M4 transition	RÖSEL <i>et al.</i> (1978)

3. ATOMIC DATA

3.1. FLUORESCENCE YIELDS

The fluorescence yields are taken from Schönfeld and Janßen (96Sc06).

3.2. X RADIATIONS

The X-ray energies are based on the wavelengths given by Bearden and were converted into energy with $1\text{Å} = 1,00001481(92) \cdot 10^{-10}\text{m}$

The emission intensities are calculated with the EMISSION program from PTB. No experimental data have been found.

3.3. AUGER ELECTRONS

The energies of Auger electrons are from 1977La** (Larkins).

The ratios P(KLX)/P(KLL) and P(KLY)/P(KLL) are taken from 1996Sc06.

4. PHOTON EMISSIONS

4.1. X-RAY EMISSIONS

The absolute emission probabilities of K X-rays (P_{XK}) have been computed using the adopted value of ω_K , the evaluated internal conversion coefficients and the emission probabilities.

4.2. GAMMA RAY EMISSIONS

4.2.1 GAMMA RAY ENERGIES

The γ -ray energies of $\gamma_{2,1}(2,17\text{ keV})$ and $\gamma_{1,0}(140,5\text{ keV})$ are taken from Gerasimov *et al.* (1981Ge05) and Helmer (2000He14), respectively. These values are based on the most accurate measurements with an

electrostatic spectrometer ($E\gamma_{2,1}$, see also 1971La12 – Lacasse and Hamilton) and curved-crystal spectrometer ($E\gamma_{1,0}$, see also 1981He15 – Helmer *et al.*). The energy of $\gamma_{2,0}$ (142,7 keV) has been computed as the sum of the adopted energies of $\gamma_{2,1}$ (2,17 keV) and $\gamma_{1,0}$ (140,5 keV) .

4.2.2 GAMMA RAY EMISSION INTENSITIES

140,511 keV (1,0)

Absolute values (per 100 decays)

88,20 (26)	Chen Da (1985)
87,30(21)	Simonits <i>et al.</i> (1981Si15)
88,75 (14)	Rutledge <i>et al.</i> (1980Ru20)
87,2 (5)	Dickens and Love (1980Di16) (calculated)
88,0 (24)	Legrand <i>et al.</i> (1973Le29)

LWEIGHT has been used to derive the weighted average and expand the uncertainty so that the range includes the most precise value of 88,75(14). This leads to the average of 88,4(4) % (reduced- $\chi^2 = 2,24$). Omitting the calculated value of Dickens and Love (1980) and the value of Simonits (1981) from statistical considerations, we have a weighted average of 88,5 % with an external uncertainty of 0,2. LWEIGHT has increased the uncertainty of Rutledge *et al.* (1980) to 0,258. Reduced- $\chi^2 = 1,14$. The **adopted** value is : **88,5(2)%**

142,675 keV (2,0)

Relative measurements of the $\gamma_{1,0}$ (140,5 keV) line are not precise: from 0,00020(3) of Dickens *et al.*(1980) to 0,00030(6) of Van Eijk *et al.* (1969). The ratio of $I_{\gamma+ce}(142,7)/I_{\gamma+ce}(140,5)$ from the ⁹⁹Mo+⁹⁹Tc^m evaluation for the “slow” component of the 140,5 keV transition is 0,0097(7), corresponding to $I_{\gamma}(142,7)/I_{\gamma}(140,5) = 0,00026(2)$ and $P_{\gamma}(142,7) = \mathbf{0,023(2)\%}$ (**adopted value**).

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies. Emission probabilities have been calculated using the conversion coefficients given in 2.2. and the adopted gamma emission probabilities.

Measurements of conversion electron spectra for ⁹⁹Tc^m (in equilibrium with ⁹⁹Mo) have been made in many studies (Van Eijk-1968Va14, Ageev-1969Ag04, Bashandy-1969Ba03, Bashandy-1969Ba54, Ravier-1961Ra01, Lacasse-1971La12, Voinova-1971Vo06, Legrand-1973Le29, Gerasimov-1981Ge05). However, the computed values of the conversion electron energies and emission probabilities are more accurate.

The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.2.

Experimental Auger spectra can be found in 1981Ge05 (Gerasimov *et al.*).

Tc-99m to Ru-99 b- DECAY

From Alburger *et al.* (1980Al02) the total transition probability of the β -transition is: 0,0037(6)%

2- NUCLEAR DATA

Level energy of Ru-99

The values of the level energies are from Peker (NDS 73,1)

Level 2	322,38 (6)
Level 1	89,68 (5)

2.1- b-TRANSITIONS

Only Alburger *et al.* (1980) have totally studied the beta decay of Tc-99m.

The lg ft values were calculated by Singh *et al.* (1998) and derived from measurements by Alburger *et al.* (1980):

Transition	Energy	lg ft Singh <i>et al.</i>	lg ft Alburger <i>et al.</i>	Nature
0-0	434,8 (26)	9,4	9,39(11)	unique first-forbidden
0-1	346,7(20)	8,7	8,66(8)	first-forbidden
0-2	113,8 (20)	8,50	7,79(3)	first-forbidden

The adopted values of lg ft and average beta energies have been calculated using the LOGFT program and the level energies from ENSDF.

2.2 GAMMA TRANSITIONS and INTERNAL CONVERSION COEFFICIENTS

Multipolarity

Transition 322 keV M1+(E2)

Transition 233 keV (M1+E2)

Transition 89 keV 29%M1+E2 ($\delta = -1,56(2)$ measured by Kistner (1976Ki02))

Internal Conversion Coefficients

No experimental data have been found in the known literature.

The Rösler tables were used to deduce theoretical coefficients :

keV	a_T	a_K	a_L	a_M
322,4	0,01747	0,01519		
232,8	0,0478	0,0412		
89,6	1,492	1,171	0,270	0,0512

3. ATOMIC DATA

The fluorescence yields taken from 96Sc06 (Schönfeld and Janßen) are:

$$\omega_K = 0,796(4), \omega_L = 0,0453(11), n_{KL} = 1,000(4)$$

4. PHOTON EMISSIONS

4.1 X-RAY EMISSIONS

The emission intensities are very low and have not been calculated.

4.2 GAMMA EMISSIONS

Energy, keV	Relative emission probability	Absolute emission intensity	Author(s)
322	0,97*10 ⁻⁶ (15) 1,10*10 ⁻⁶ (10) 1,13*10 ⁻⁶ (9) 1,09*10 ⁻⁶ (6)	0,96*10 ⁻⁴ (6)	Jones and Griffin (1970Jo24) Decombaz <i>et al.</i> (1972De76) Alburger <i>et al.</i> .(1980Al02) LWEIGHT reduced- $\chi^2 = 0,42$ weighted mean and internal uncertainty
232	0,95*10 ⁻⁷ (17)	0,84*10 ⁻⁵ (15)	Alburger <i>et al.</i> (1980)
89		1,04*10 ⁻³ (20)	deduced from the level balance

For the 322 keV and the 232 keV gamma-rays, the measured emission probabilities are relative to the 140,5 keV emission probability. The absolute emission probabilities are deduced from the adopted absolute emission probability of the 140,5 keV gamma-ray: 88,5(2) %.

For the 89 keV line, no experimental value is available.

The 89 keV level is mainly fed by the beta transition from Tc-99m. With a beta transition probability of $2,6(5) \times 10^{-3}$ and $a_T = 1,49(5)$, the absolute emission probability is : $1,04(20) \times 10^{-3}$.

5. ELECTRON EMISSIONS

For the 434,8 and 346,7 keV β^- transitions, the energies and transition probabilities were measured by Alburger (1980).

For the third β^- transition of 113,8 keV, no direct experimental data was found.

The energy is estimated by Alburger *et al.* (1980), and the absolute transition probability is derived from 3 experimental and relative values :

$$\begin{array}{ll} P_{\gamma}(322)/P_{\gamma}(140,5) = 1,10(6) \times 10^{-6} & \text{Decombaz } et al.(1972) \\ P_{\gamma}(322)/P_{\gamma}(140,5) = 0,97(15) \times 10^{-6} & \text{Jones and Griffin (1970Jo24)} \\ P_{\gamma}(322)/P_{\gamma}(140,5) = 1,113(9) \times 10^{-6} & \text{Alburger } et al.(1980) \end{array}$$

The weighted mean of γ emission probability relative to the 140 keV-line calculated by Alburger *et al.* (1980) is: $1,10(6) \times 10^{-6}$.

The gamma transitions probabilities are calculated from the gamma emission probabilities and the internal conversion coefficients :

$$\begin{array}{l} P_{\gamma}(322) = P_{\gamma}(322) \times (1 + \alpha_T(322)) \\ P_{\gamma}(322) = 1,10 \times 10^{-6} \times P_{\gamma}(140,5) \\ P_{\gamma}(322) = 1,10 \times 10^{-6} \times 88,5 \times 1,0175 = 0,99 \times 10^{-4} \end{array}$$

As the level 0 is feeding by 93% of the transitions starting from the 322 keV-level, the probability of the 322-keV β transition can be deduced : $0,99 \times 10^{-6}/0,93 = \mathbf{1,06(6) \times 10^{-4}}$.

References

- K. T. Bainbrige, M. Goldhaber, E. Wilson. Phys. Rev. 90 (1953) 430 ; Half-life
 J. RAVIER, P. MARGUIN, A. MOUSSA. J. Phys. Radium 22 (1961) 249 ; K/L
 P. CROWTHER, J. S. Eldridge. Nucl. Phys. 66 (1965) 472 ; Half-life
 S. R. AMTEY. Phys. Lett. 23-10 (1966) 581 ; M ICC, multipolarity
 I. W. GOODIER, A. WILLIAMS. Nature 210 (1966) 614 ; Half-life
 C. W. E. Van EIJK, B. VAN NOOIJNEN, F. SCHUTTE. Nucl. Phys. A121 (1968) 440 ; Gamma-ray energies, Conv. Elec. emission probabilities
 S. M. BRAHMAVAR, J. H. Hamilton, J. J. Pinajian. Quoted in Nucl. Phys. A121 (1968) 440 ; ICC
 J. S. GEIGER. AECL-3166 PR-P-79 (1968) 29 ; Gamma-ray energies, K-Conv. Elec. emission probabilities
 P. STEINER, E. GERDAU, W. HAUTSCH, D. STEENKEN. Z. Phys. 221 (1969) 281 ; Half-life
 W. B. COOK, L. Schellenberg, M. W. Johns. Nucl. Phys. A139 (1969) 277 ; Multipole mixing ratio
 P. STEINER. Z.Phys. 221 (1969) 281 ; Half-life
 E.BASHANDY, N. Ibrahiem. Z. Phys. 219 (1969) 337 ; K/L ratio
 V. A. AGEEV et al. Izv. Akad. Nauk SSSR, Ser. Fiz. 33 (1969) 1279 ; Conv. Elec. emission probabilities
 A. VUORINEN. Ann. Acad. Sci. Fenn. Ser. A VI (1969) 311 ; ICC, ; Half-life
 E. BASHANDY. Z. Naturforsch 24A (1969) 1893 ; K ICC, Multipolarity
 J. LEGRAND, F. Lagoutine, J. P. Brethon. Int. J. Appl. Rad. Isot. 21 (1970) 139 ; Half-life
 J. D. JONES, H. C. GRIFFIN. Radiochem. Radioanal. Letters 4-6 (1970) 381 ; Beta emission probabilities, Gamma-ray energies

- J. Mc DONALD, A. BÄCKLIN, S. G. MALMSKOG. Nucl. Phys. A162) 365 ; Multipolarity, Half-life, Gamma-ray emission probabilities
- W. M. LACASSE, J. H. HALMILTON. Nucl. Phys. A171 (1971) 641 ; M ICC/N ICC, Gamma-ray energies
- N. A. VOINOVA, A. I. EGOROV, Yu. V. KALINICHEV, A. G. SERGEEV. Bull. Ac.Sc URSS, Phys. Ser. 35 (1972) 794 ; K ICC, K/L, Multipolarity
- J. F. EMERY. Nucl. Sci. Eng. 48-3 (1972) 319 ; Half-life
- M. DECOMBAZ, J. J. GOSTELY, P. LERCH. Radiochem. Radioanal. Letters 10 (1972) 119 ; Gamma emission probabilities
- G. K. SHENOY. J. Phys. (London) A6 (1973) L144 ; Half-life
- J. Legrand, M. Blondel, P. Magnier, C. Perrot, J. P. Brethon. Report CEA-R-4427 (1973) ; Gamma-ray emission probabilities, Conv. Elec. emission probabilities
- R. A. MEYER. Report UCRL-76207 (1974) ; Half-life
- P. L. GARDULSKI, M. L. WIEDENBECK. Phys. Rev. C9,1 (1974) 262 ; Multipole mixing ratio
- I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten. Atomic Data and Nuclear Data Tables 18 (1976) 433 ; K and L-shell internal conversion coefficients
- O. C. KISTNER, A. H. LUMPKIN. Phys. Rev. C13 (1976) 1132 ; Multipolarities
- H. HOUTERMANS, D. MILOSEVIC, F. REICHEL. Int. J. Appl. Radiat. Isotop. 31 (1980) 153 ; Half-life
- D. E. ALBURGER, P. RICHARDS, T. H. KU. Phys. Rev. C21 (1980) 705 ; Beta emission probabilities, Beta emission energies
- H. MAZAKI, S. KAKIUCHI, T. MUKOYAMA, M. MATSUI. Phys. Rev. C21 (1980) 344 ; Half-life
- J. K. DICKENS, T. A. Love. Nucl. Inst. Meth. 175 (1980) 535 ; Gamma-ray emission probabilities, X-ray emission probabilities, K ICC, T ICC
- A. R. RUTLEDGE, L. V. SMITH, J. S. MERRIT. Report AECL-6692 (1980) ; Half-life
- R. G. HELMER, A. J. CAFFREY, R. J. GEHRKE, R. C. GREENWOOD. Nucl. Instrum. Methods 188 (1981) 151 ; Gamma-ray energies
- V. N. GERASIMOV, A. G. ZELENKOV, V. M. KULAKOV, V. A. PCHELIN, A. A. SOLDATOV. Sov. J. Nucl. Phys. 34-1 (1981) 1 Multipolarity, Gamma ray energies
- A. Simonits, L. Moens, F. De Corte, A. De Wispelaere, J. Hoste. J. Radioanal. Chem. 67 (1981) 61 ; Gamma-ray emission probabilities
- K. Singh, H. S. Sahota. J. Phys. Soc. Jap. 51-12 (1982) 3766 ; Multipole mixing ratio
- R. L. AYRES, A. T. HIRSCHFELD. Int. J. Appl. Rad. Isot. 33-10 (1982) 835 ; Half-life
- K. F. WALZ, K. Debertin, H. Schrader. Int. J. Appl. Rad. Isot. 34-8 (1983) 1191 ; Half-life
- CHEN DA. IEEE-Transactions on Nuclear Science 32-1 (1985) 71 ; Gamma-ray emission probabilities
- D. C. SANTRY, G. C. BOWES. Health Physics 57-4 (1989) 673 ; Half-life
- I. ALFTER, Z. Phys. A347 (1993) 1 Nuclear levels ; Half-life
- L. K. PEKER. Nucl. Data Sheets 73,1 (1994) 1 ; Level energies, Spin and Parity
- G. Audi, A. H. Wapstra. Nucl. Phys. A 595 (1995) 409 ; Q
- E. Schönfeld, H. Janssen. Nucl. Instrum. Methods A369 (1996) 527 ; Fluorescence yields
- B. Singh, J. L. Rodriguez, S. S. M. Wong, J. K. Tuli. Nucl. Data Sheets 84,3 (1998) ; lg ft
- V. KOLTSOV, L. G. Mashirov, D. N. Suglovov. Bull. Acad. Sci. USSR, Phys. Ser. 62,5 (1998) 789 ; Half-life
- M.-M. BÉ, E. BROWNE, V. CHECHEV, R. HELMER, E. SCHÖNFELD. Table de Radionucléides, ISBN 2 7272 0200 8, CEA, F-91191 Gif sur Yvette (1999) ; T ICC (Cs-137)
- R. G. HELMER, C. van DER LEUN. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35 ; Gamma ray energies
- H. SCHRADER. Appl. Rad. Isotopes 60(2004)317 ; Half-life.
- M. A. L. da SILVA, M. C. M. de ALMEIDA, C. J. da SILVA, J. U. DELGADO. Appl. Rad. Isotopes 60(2004)301 ; Half-life.

**¹⁰⁹Cd - Comments on evaluation of decay data
by E. Schönfeld, R. Dersch**

1 Decay Scheme

The main transition in the decay of ¹⁰⁹Cd is the allowed EC transition $\epsilon_{0,1}$ to the 88 keV level in ¹⁰⁹Ag. If there is a EC branch to the ground state of ¹⁰⁹Ag, it would have $\Delta J = 2$ with no change of parity, so it would be 2nd forbidden. From the paper of S. Raman et al. (1973) it is then expected to have a $\lg ft$ greater than 11,0, and this corresponds to an EC branch of less than 0,005 %.

Below the decay energy of ¹⁰⁹Cd there is beside the 88 keV level in ¹⁰⁹Ag a level at 132.74(11), 9/2+ or 7/2+, 2.60(12) ns. This level has been observed in the decay of ¹⁰⁹Pd but not in the decay of ¹⁰⁹Cd. This level is much more of a problem. If it has $J^\pi = 7/2+$, the decay to it would be allowed; then if the $\lg ft$ were the same as that to the 88-keV level, the branch to it would be about 30 % or smaller. Since the total conversion coefficient of the resulting 44-keV gamma would be much less than that of the 88-keV gamma, the 44-keV photons should be observed along with the conversion electrons. If the 132-keV level has $J^\pi = 9/2+$, the EC branch is 2nd forbidden with an expected $\lg ft$ greater than 11,0 and an emission probability of less than 0,0003 %. This assignment is more probable than the first assumption as up to now no 44-keV photons have been observed. The J^π data and $T_{1/2} = 39,6(2)$ s (88 keV) are taken from Blachot (1984).

2 Nuclear Data

The following values of the half-life have been considered ($T_{1/2}$ in d):

1	470(8)	Gum and Pool (1950)
2	453(2)	Leutz et al. (1965)
3	459(6)	East and Murphy (1968)
4	450(5)	Reynolds et al. (1968)
5	461,9(3)	Vaninbroukx et al. (1981)
6	463,1(8)	Lagoutine and Legrand (1982); uncertainty 3 σ
7	463,2(6)	Hoppes et al. (1982)
8	460,2(2)	Martin and Taylor (1996)
9	462,6(7)	IAEA-TECDOC-619 (1991) derived from values 4 - 7
10	461,4(12)	adopted value, present evaluation

The uncertainty of the value No. 6 is related to 3 σ . For the calculation of the weighted mean it has been reduced to 0,3 d. For the weighted mean only the values 5 - 8 have been used. No. 8 contributes just 50 % to the mean. The internal uncertainty for the average of the values 5 - 8 is 0,14 days with the reduced- χ^2 is 26,6. It should be noted that the adopted value does not fall within the 1- σ range of any of the four values. Also, the values 8 and 6 differ by 2,9(4) d or about 7 σ . From the reduced- χ^2 and these statements it must be concluded that the 4 values are very discrepant although they are all from metrology laboratories. There is need to clarify this situation by new measurements. According to the agreed rules LWM has used the weighted average and expanded the uncertainty so that the uncertainty of the adopted value 10 includes the most precise value 8.

Makaryunas and Makaryunene (1984) searched for a chemical alteration of the probability of EC by the ¹⁰⁹Cd nucleus. Metallic Cd, CdS and CdTe have been used. No significant change ($\Delta\lambda/\lambda < 1 \cdot 10^{-4}$) could be found from a 1000 d measurement with NaI(Tl) detector equipped with Be window and collimation.

The Q_{EC} value 213,8(27) is taken from Audi and Wapstra (1995). There are some discrepancies in the Q_{EC} value: 183,9 keV is derived from internal bremsstrahlung measurements (Gopinathan et al. (1968)); 201(3) keV from $P(L)/P(K) = 0,193(3)$ (Goedbloed (1968), Goedbloed et al. (1970)) exp. measured;

220(3) keV from $P(L, M, N)/P(K) = 0,227(2)$ (average from Leutz et al. (1965), Goedbloed (1968), Goedbloed et al. (1970) exp. measured). Kozub and Hindi (1994) have attempted (but so far failed) to resolve this discrepancy by remeasuring the internal bremsstrahlung endpoint. The most probable value extracted from the measurements is 201,8(1,3) keV. This situation is not satisfying.

In the present evaluation $P(L)/P(K) = 0,184(3)$ and $P(L, M, N)/P(K) = 0,232(4)$ was derived starting from the Audi and Wapstra Q -value whereas in the Table de Radionucléides (1982) for this ratio 0,218 and $Q_{EC} = 182(3)$ keV is given.

2.1 Electron Capture Transitions

The transition energy of the allowed transition to the 88 keV level in ¹⁰⁹Ag is calculated from the Q_{EC} value (Audi and Wapstra, 1995) and the level energy. P_K, P_L, P_M are calculated using this transition energy and the report of Schönfeld (1995).

For comparison:

	P_K	P_L	P_{M+}	P_L/P_K	P_{LMN}/P_K	
1	-	-	-	0,28(3)		Der Mateosian (1953)
2	-	-	-	0,32(4)		Bertolini et al. (1954)
3	0,805(27)	-	-	-	0,24(4)	Wapstra and van der Eijk (1957)
4	0,814(2)	0,159	0,027	0,195(5)	0,228(3)	Leutz et al. (1965)
5	0,778(25)	0,184	0,038	0,237(15)	0,332(15)	Moler and Fink (1965)
6	0,794(25)	-	-	-	0,26(4)	Durosini-Etti (1966)
7	0,816(2)	0,157(5)	0,027	0,193(3)	0,226(3)	Goedbloed et al. (1970) Goedbloed (1968)
8	0,780(15)	-	-	-	0,282	Plch et al. (1979)
9	0,815(2)					weighted mean 3-8 reduced- $\chi^2 = 1,8$
10	0,788(10)	0,172(5)	0,040(4)	0,218	0,269	Table de Radionucléides (1982)
11	0,812(3)	0,150(3)	0,038(1)	0,185(3)	0,232	Present evaluation (Theory)

Theoretical values other than value 11 are not given because they depend critically on the transition energy

$Q_{EC} - E_\gamma$ and are based on very different values for Q_{EC} . The present value for P_K is in good agreement with the values 4 and 7, i. e. the most confident values, and also with the weighted mean which is dominated by these two values. The values of item 10 are significantly different from those of 11 because they are based on a much lower Q_{EC} value of 184 keV.

Vatai (1970) discussed the measurements of Moler and Fink (1965) and pointed out that the values for P_L/P_M measured with multi-wire proportional counter (MWPC) are not so reliable, as was thought. Fink (1969) revised the original value measured by Moler and Fink (1965), $P_M/P_L = 0,232(20)$ using gaseous sources in a MWPC to give the new value $P_L/P_M = 0,202(20)$.

2.2 Gamma Transitions

The level difference is calculated from the gamma ray energy (4.2) and the recoil energy. The total conversion coefficient is calculated from the experimental determined gamma-ray emission probability (4.2). a_K and a_L are calculated from the ratios $a_K/a_L/a_i = 11,35 / 12,43 / 26,78$ as given by the theory (Rösel et al., 1978), interpolated by cubic spline method.

The value of $a_i = 26,58(20)$ of the present evaluation is between the theoretical value 26,78 and the experimental value 26,4(4) of Dragoun et al. (1976). The evaluated value is by 0,8 % lower than the

theoretical value. This tendency is qualitatively in agreement with that found by Nemeth and Veres (1990) for E3 and M3 transitions.

3 Atomic data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energy values are calculated from the wavelengths in Å* as given by Bearden (1967). The relative emission probabilities $P(K_\beta)/P(K_\alpha)$ and $P(K_{a_2})/P(K_{a_1})$ are taken from Schönfeld and Janßen. The ratio for $P(K_{b_2})/P(K_{b_1})$ is taken from the calculation of Scofield (1974). The ratio $P(X_L)/P(K_{a_1})$ is calculated from the absolute emission probabilities (Section 4.2). The total K-X ray emission probability is (assumed that there is no EC transition to the ground state)

$$P(KX) = w_K \{P_K + [a_K/(1 + a_t)]\}$$

$P(KX)$ is calculated from $P(KX)/P_g$ with the here adopted value of P_γ .

	$P(KX)$	$P(KX)/P_\gamma$	
1	1,225(25)	33,8(7)	Wapstra and van der Eijk (1957)
2	0,950(22)	26,2(6)	Leutz et al. (1965)
3	0,805(22)	22,2(6)	Jansen and Wapstra (1966)
4	1,055(36)	29,1(10)	Freedman et al. (1966)
5	1,088(145)	30(4)	Foin (1968)
6	0,928(33)	25,6(9)	Campbell and Mc Nelles (1972)
7	0,979(11)	27,0(3)	Dragoun et al. (1976)
8	0,990(22)	27,3(6)	Plch et al. (1979)
9	0,991(10)	27,34(27)	Hoppes and Schima (1982)
10	1,026(30)	28,3(9)	Geidelman et al. (1988)
11	1,012(14)	27,9(4)	Yegorov et al. (1989)
12	1,002(17)		Unweighted mean without values 1 and 3
13	0,990(8)		Weighted mean without values 1 and 3; reduced- $\chi^2 = 1,9$
14	0,994(10)		Rec. by Bambynek in IAEA-TECDOC-619 (1991)
15	1,014(7)	29,0(2)	Present evaluation using the above equation together with the adopted values of $\omega_K, P_K, \alpha_K, \alpha_t$

Value 15 is larger than values 12 to 14. Values 1 and 3 have been rejected from statistical considerations. These values differ by a factor 1,52, both claiming an uncertainty of less than 3 %. The unweighted mean (value 12) avoids an unjustified influence of single values with possibly overestimated accuracies. The more up-to-date values 7 to 11 are in reasonable agreement with the adopted value 15.

3.2 Auger Electrons

The energy values are taken from Larkins (1977) (KLL) and the Table de Radionucléides (1982; LMRI).

The ratios $P(KLX)/P(KLL)$ and $P(KXY)/P(KLL)$ are taken from Schönfeld and Janßen (1996).

The ratio $P(e_{AL})/P(KLL)$ is calculated from the absolute emission probabilities (Section 4.1).

A precise measurement of the Ag KLL Auger spectrum has been carried out by Kawakami et al. (1986).

4 Radiation Emission

4.1 Electron Emission

The Auger electron energies are the same as above. The conversion electron energies are calculated from the transition energy and the binding energies of the electrons of the corresponding shells. The number of

electrons per disintegration are based on P_K , P_L , P_M as given in Section 2.1, a_K , a_L as given in Section 2.2 and the atomic data as given in Section 3.

4.2 Photon Emission

	E_γ in keV	
1	88,008(42)	Freedman et al. (1966)
2	88,041(87)	Schima and Hutchinson (1967)
3	88,05(5)	Libert (1967)
4	88,033(42)	Pierson and Marsh (1967)
5	88,09(3)	Foin et al. (1968)
6	88,21(3)	Furuta and Rhodes (1968)
7	88,036(8)	Heath (1969)
8	88,036(8)	Greenwood et al. (1970)
9	88,035(6)	Raeseide (1970)
10	88,035(4)	Morii (1978)
11	88,0341(11)	Helmer et al. (1978)
12	88,0336(1)	R. G. Helmer and C. van der Leun (2000), here adopted

The X-ray energies are the same as above. The γ ray energy is taken from Helmer and van der Leun (1996). The number of X ray photons per disintegration are based on P_K , P_L , P_M as given in Section 2.1, a_K , a_L as given in Section 2.2 and the atomic data as given in Section 3.

The following values for the number of γ ray photons per disintegration have been taken into account:

	P_γ	correspond. a_t	
1	0,0365(4)	26,4(3)	Plch et al. (1979)
2	0,03594(19)	26,82(14)	Plch and Suran (1988)
3	0,0367(7)	26,2(6)	Martin (AECL, 1988)
4	0,0365(3)	26,40(23)	Gostely (IER, 1988)
5	0,0370(6)	26,0(5)	Park et al. (KSRI, 1988)
6	0,03600(10)	26,78(8)	Chauvenet (LMRI, 1988)
7	0,0357(10)	27,0(8)	Woods and Smith (NPL, 1988)
8	0,0365(8)	26,4(6)	Szörenyi et al. (OMH, 1988)
9	0,03675(18)	26,21(15)	Ballaux et al. (1988)
10	0,0366(5)	26,3(4)	Hino and Kawada (1989)
11	0,0368(7)	26,2(5)	Funck and Schötzig (1989), Schötzig et al. (1991)
12	0,0365(5)	26,4(4)	Chechev (1989)
13	0,03614(12)	26,67(12)	Ratel (1994) based on measurements in the framework of a BIPM intercomparison including the results measured by the others of values 2 to 8
14	0,0389(7)	24,7(5)	Leutz et al. (1965); from a_t
15	0,0397(21)	24,2(14)	Sen and Durosini-Etti (1965); from a_t
16	0,0329(25)	29,4(25)	Foin et al. (1968); from a_t
17	0,0379(7)	25,4(5)	Legrand et al. (1973) ; from a_t
18	0,0360	26,8	Rysavy (1976); from theoretical a_t
19	0,0365(5)	26,4(4)	Dragoun et al. (1976); from a_t
20	0,03600	26,78	Rösel et al. (1978); from theoretical a_t
21	0,0365(3)	26,4(5)	Table de Radionucléides (1982); evaluation
22	0,0365(7)	26,0(3)	Hansen (1985); evaluation
23	0,03632(12)	26,53(9)	IAEA-TECDOC-619 (1991)
24	0,03626(26)	26,58(20)	present evaluation, weighted mean direct exp. values 1 - 12 and 14 - 17, 19

The weighted mean is calculated from all experimentally determined values. Value 2 does not supersede value 1; it is an independent measurement. Value 2 through 8 were determined in the frame of an BIPM

intercomparison, summarized by Ratel (value 13). When calculating the weighted mean (value 24) the largest weights come from values 2, 6 and 9. Whereas 2, 6 and also 13 are in excellent agreement, the value 9 is somewhat larger than these. [Values 21 to 23 are given only for comparison. In contrast to the above, for the calculation of value 23 the uncertainties of the values 9 and 6 has been increased by a factor of 2 on the basis of statistical considerations.] Value 6 agrees well with values 2 and 13 and value 9 is to be considered as a result of a careful work. For the present purpose the originally given uncertainties have not been changed. The weighted mean is 0,03626(7), but LWM has expanded the uncertainty so as to include the most precise value 6. The adopted value (line 24) is in agreement with values 13 (BIPM intercomparison), 18, 20 (from theoretical conversion coefficient) and the results of other evaluations (21 - 23).

Davidonis et al. (1988), compared measured ratios (88 keV) $L_1 : L_2$, $L_1 : L_3$, $L_2 : L_3$, $M_{4+5} : M_{1+2+3}$, $N : M$ with the corresponding theoretical values, interpolated from the Tables of Hager-Seltzer, Rösel et al. and Band and Trzhazkovskaya (Dirac-Fock-Slater and Dirac-Fock approximation). Generally there is agreement within the uncertainties.

Experimentally and theoretically determined conversion coefficients are compiled in the following table:

	a_K	a_t	a_K/a_L	$a_K/(a_L+a_M+a_N)$	
1	12,4(10)	-	-	0,85(2)	Brunner et al. (1953)
2	10,3(5)	-	-	-	Wapstra and van der Eijk (1957)
3	-	-	0,95(3)	-	Boyd et al. (1964)
4	11,0(3)	24,7(5)	-	-	Leutz et al. (1965)
5	11,3(4)	24,2(14)	-	-	Sen and Durosini-Etti (1965)
6	12,7(9)	29,4(25)	0,94	0,76(2)	Foin et al. (1968)
7	-	-	-	0,76(2)	Planskoy (1969)
8	10,6(5)	-	-	-	Bashandy (1970)
9	-	25,4(5)	-	-	Legrand et al. (1973)
10	11,4(3)	26,4(4)	0,933	0,760	Dragoun et al. (1976)
11	9,6(2)	-	-	-	Prochazka et al. (1978)
12	11,4(3)	26,4(3)	-	-	Plch et al. (1979)
13	-	26,21(14)	-	-	Ballaux et al. (1988)
14	-	26,67(9)	-	-	Ratel (1994)
15	11,28(12)	26,62(9)	0,913	0,736	weighted mean of experimental values
16	11,4	26,8	0,91	0,740	Rysavy (1976), theory
17	11,35	26,78	0,913	0,736	Rösel et al. (1978), theory
18	11,1(2)	26,0(3)	-	-	Hansen (1985), evaluation
19	11,3(2)	26,4(5)	0,904	0,748	Table de Radionucléides (1982)
20	11,28(12)	26,58(20)	0,913(9)	0,736(7)	present evaluation; the value for α_t corresponds to the evaluated value of P_γ

As a_t and P_γ are closely connected, further experimental values can be found in papers which are dealing with the determination of P_γ (above table). The most confident experimental values of conversion coefficients have been measured by Dragoun et al. (1976) (Entry 10). They have measured also $a_{L_1} = 0,63(13)$, $a_{L_2} = 5,48(18)$, $a_{L_3} = 6,11(20)$, $a_M = 2,40(8)$, and $a_{NO} = 0,405(21)$. In order to obtain finally adopted values of the conversion coefficients, we follow here the procedure of Hansen (1985), who took into consideration only the values 4, 5, 9, 10 and 12 where the first two have been recalculated. The recommended values derived from this set are given under line 18. Values 16 and 17 are from theory, the latter is taken as cited in the IAEA-TECDOC-619 (1991). Shevelev et al. (1978) have measured the following ratios for the conversion coefficients of the 88 keV transition in ^{109}Ag : $K / L / M / N = 0,98(5) / 1 / 0,20(1) / 0,050(5)$ and $L_1 / L_2 / L_3 = 0,185(15) / 1 / 1,163(27)$. The ratios found by Shevelev et al. are in poor agreement with those of Dragoun. Davidonis et al. (1980) determined the ratios $L_1 / L_2 / L_3$ in sources containing Cd, CdTe and CdSe to be $0,148(7) / 0,86(2) / 1$ and $(N+O):M = 0,178(3)$ in good agreement with the corresponding theoretical values of Dragoun et al. (1976) and Rösel et al. (1978). A former measurement of Brenner and Perlman (1972) gave $L_1 / L_2 / L_3 = 0,132(8) / 0,830(20) / 1$. Martin

et al. (1975) measured also the $L_1 / L_2 / L_3$ -ratio for the 88 keV E3 transition in ¹⁰⁹Ag^m and found no significant departures from theory.

Nemeth and Veres (1973) pointed out that the internal conversion coefficients calculated by Hager and Seltzer are considered to be systematically 2 - 3 % higher for high multipole electromagnetic transitions than the experimental value. This was found already by Raman et al. (1973). Again, Nemeth and Veres (1990) compare theoretical conversion coefficient interpolated from the tables of Rösel et al. (1978) and came to the conclusion that for third and fourth order the theoretical values give better agreement with experimental values when they are multiplied by 0,975. For the 88 keV transition in ¹⁰⁹Ag the ratio between the adopted value and the Rösel value is 0,993. Band and Trzhaskovskaya (1993) have calculated ICCs for some high-multipole-order transitions using Dirac-Fock electron wave functions in different approximations. For the 88 keV E3 transition they found a_K values between 11,1 and 11,6 in reasonable agreement with value 18.

Double K-shell vacancy creation in the decay of ¹⁰⁹Cd has been measured by van Eijk and Wijnhorst (1977): $P_{KK}(IC) = 2,8(7) \cdot 10^{-5}$ per K internal conversion. In a later paper van Eijk et al. (1979) determined the probability $P_{KK}(IC)$ of double K-shell vacancy creation per K internal conversion of the 88 keV E 3 transition in the decay of ¹⁰⁹Ag^m by means of a K_α -X-ray-K-X-ray coincidence experiment on ¹⁰⁹Pd to be

$(13,0 \pm 1,1) \cdot 10^{-5}$. From a similar experiment on ¹⁰⁹Cd the probability $P_{KK}(EC)$ of double K-shell vacancy production per K-electron capture decay of ¹⁰⁹Cd has been determined to be $(1,02 \pm 0,36) \cdot 10^{-5}$. The energy shift of the hypersatellite Ag $K_{\alpha 1}^H$ -X-ray line was found to be (532 ± 6) eV. Martin et al. (1975) measured ratios of L subshell conversion electrons. By Nagy et al. (1975) the probability that a double K-shell vacancy is formed per K-shell internal conversion was found to be $1,53(24) \cdot 10^{-4}$. Horvath and Ilakovac (1985) measured the decay of the double-K-shell vacancy state in ¹⁰⁹Ag^m the probability of creation of double K-shell vacancies per ¹⁰⁹Cd decay was determined to be $6,07(12) \cdot 10^{-5}$. Probability ratios of several hypersatellite peaks of K_α and K_β are determined. Inteman (1985) calculated the total probability per K-capture event for the ionization of the remaining K electron for a dozen nuclides of interest using a semirelativistic theory and compared them with experimental values. Ilakovac et al. (1988) searched for Double Photon Decay of the ¹⁰⁹Ag metastable state at 88 keV and found an experimental upper limit of the relative transition probability $P_{\gamma\gamma}/P_\gamma < 6 \cdot 10^{-7}$ using a pair of Ge detectors and a fast-slow coincidence system.

5 Main Production Modes

Taken from the „Table de Radionucléides“, LMRI, 1982.

6 References

References are given only in those cases where the reference is not already included in the list of references in the Tables Part.

- J. R. Gum and M. L. Pool, *Phys. Rev.* 80 (1950) 315 [$T_{1/2}$]
 E. Der Mateosian *Phys. Rev.* 92 (1953) 938 [P_L/P_K]
 J. Brunner, O. Huber, R. Joly and D. Maeder, *Helv. Phys. Acta* 26 (1953) 588 [$a_K, a_K/(a_L + a_M + a_N)$]
 G. Bertolini, A. Bisi, E. Lazzarini and L. Zappa, *Nuovo Cimento* 11 (1954) 539 [P_L/P_K]
 A. H. Wapstra and W. van der Eijk, *Nucl. Phys.* 4 (1957) 325 [$P_K, P_{LMN}/P_K$]
 H. W. Boyd, J. H. Hamilton, A. R. Sattler and P. F. A. Goudsmit, *Physica* 30 (1964) 124 [a_K/a_L]
 J. W. F. Jansen and A. H. Wapstra, Internal Conversion Processes (ed. J. H. Hamilton; Academic Press, New York, 1966, p. 237) [P_{KK}/P_γ]
 M. S. Freedman, F. T. Porter and F. Wagner, *Phys. Rev.* 151 (1966) 886 [P_{KK}/P_γ]
 J. A. Bearden, *Rev. Mod. Phys.* 39 (1967) 78 [E_X]

- F. J. Schima and J. M. R. Hutchinson, *Nucl. Phys. A* 102 (1967) 667 [E_γ]
 J. Libert, *Nucl. Phys. A* 102 (1967) 477 [E_γ]
 W. R. Pierson and R. H. Marsh, *Nucl. Phys. A* 104 (1967) 511 [E_γ]
 L. V. East and H. M. Murphy, Jr., *Nucl. Phys. A* 107 (1968) 382 [$T_{1/2}$]
 S. A. Reynolds, J. F. Emery and E. I. Wyatt, *Nucl. Sci. Eng.* 32 (1968) 46 [$T_{1/2}$]
 K. C. Foin, A. Gizon and J. Oms, *Nucl. Phys. A* 113 (1968) 241 [P_{KX}/P_γ]
 T. Furuta and J. R. Rhodes, *Intern. J. Appl. Rad. Isotopes* 19 (1968) 483 [E_γ]
 R. W. Fink, *Phys. Rev.* 180 (1969) 1220 [P_L/P_M]
 R. L. Heath, Proc. Int. Conf. on Radioactivity in Nucl. Spectroscopy, Nashville, USA (1969) [E_γ]
 B. Planskoy, *Nucl. Instr. Meth.* 73 (1969) 205 [$a_K/a_L + a_M + a_N$]
 E. Vatai, *Acta Physica Hungarica* 28 (1970) 103 [P_L/P_M]
 R. C. Greenwood, R. G. Helmer and R. J. Gehrke, *Nucl. Instr. and Meth.* 77 (1970) 141 [E_γ]
 D. E. Raeside, *Nucl. Instr. and Methods* 87 (1970) 7 [E_γ]
 E. Bashandy, *Z. Phys.* 236 (1970) 130 [a_K]
 D. S. Brenner and M. L. Perlman, *Nucl. Phys. A* 181 (1972) 207 – 216 [$L_1/L_2/L_3$]
 J. Legrand, M. Blondel and P. Magnier, *Nucl. Instr. and Methods* 112 (1973) 101 [a_L]
 S. Raman, T. A. Walkiewicz, R. Gunnink and B. Martin, *Phys. Rev. C* 7 (1973) 2531 [a_L]
 Zs. Nemeth and A. Veres, *Phys. Rev. C* 35 (1973) [a_K]
 J. H. Scofield, *Phys. Rev. A* 9 (1974) 1041 [$P_{K_{b_1}} / P_{K_{b_2}}$]
 B. Martin, D. Merkert and J. L. Campbell, *Z. Physik A* 274 (1975) 15 [$L_1/L_2/L_3$]
 H. J. Nagy, G. Schupp, R. R. Hurst, *Phys. Rev. C* 11 (1975) 205 [P_{KK}]
 C. W. E. van Eijk and J. Wijnhorst, *Phys. Rev. C* 15 (1977) 1068 [$P_{KK}(IC)$]
 F. P. Larkins, *Atomic Data and Nuclear Data Tables* 20 (1977) 312 [$E(KLL, KLX)$]
 G. A. Shevelev, A. G. Troitskaya and V. M. Kartashov, *Izv. Akad. Nauk SSSR, Ser. Fiz* 42 (1978) 211
 [K/L/M/N]
 T. Morii, *Nucl. Instr. and Methods* 151 (1978) 489 [$T_{1/2}$]
 R. G. Helmer, R. C. Greenwood and R. J. Gehrke, *Nucl. Instr. and Methods* 155 (1978) 189 [E_γ]
 I. Prochazka, T. I. Kracikova, V. Jahelkova, Z. Hons, M. Friser, and J. Jursik, *Czech. J. Phys.* B28 (1978)
 134 [a_K]
 C. W. E. van Eijk, J. Wijnhorst, M. A. Popelier, *Phys. Rev. C* 19 (1979) 1047 [$P_{KK}(IC)$]
 R. I. Davidonis, R. K. Zhirgulyavichyus, R. A. Kalinauskas, V. I. Kerskulis, K. V. Makaryunas, *Izv. Akad. Nauk SSSR, Ser. Fiz.* 44 (1980) 1060 [$L_1/L_2/L_3$]
 K. V. Makaryunas and E. K. Makaryunene, *Izv. Akad. Nauk SSSR, Ser. Fiz.* 48 (1984) 23 – 27 [$T_{1/2}$]
 J. Blachot (NDS 41, No. 2, 1984, p. 157) [$T_{1/2}$]
 R. L. Inteman, *Phys. Rev. C* 31 (1985) 1961 [P_{KK}]
 H. Horvath, K. Ilakovac, *Phys. Rev. A* 31 (1985) 1543 [$P_{KK}(IC)$]
 H. Kawakami, K. Nisimura, T. Ohshima and others, Tokyo Univ., Tanashi (Japan) Inst. for Nuclear Study, Report INS-613 (1986) [KLL]
 K. Ilakovac, G. Jerbic-Zorc, M. Bozin, R. Posic, W. Horvat, *Fizika (Zagreb)* 20 (1988) 91 [$P_{\gamma\gamma}$]
 R. Ju. Davidonis et al., Proc. 7th Seminar on Precise Measurements in Nuclear Spectroscopy, Vilnius (1988) 24 [$L_1/L_2/L_3$]
 R. L. Kozub and M. M. Hindi (Research in nuclear physics: Progress report, June 1, 1993 - July 31, 1994, Tennessee Technological Univ., Cookeville, TN (United States). Dept. of Physics Funding Organisation: USDOE, Washington, DC (United States)) [Q_{EC} , inner bremsstr. endpoint energy]
 Zs. Nemeth and A. Veres, *Nucl. Instr. and Meth. A* 286 (1990) 601 – 606 [a_K]

¹¹⁰Ag – Comments on evaluation of decay data by R. G. Helmer

1) Decay Scheme

The β^- emission to ¹¹⁰Cd from the ¹¹⁰Ag ground state occurs in 99,70% (6) of the decays and the remaining 0,30% (6) is by electron capture to ¹¹⁰Pd.

2) Q values and half-lives

The Q values from the 1995Au04 evaluation for the decay of the ¹¹⁰Ag ground state are 2892,2 (16) keV for the β^- decay and 892 (11) keV for the electron-capture decay.

The half-life of the ¹¹⁰Ag ground state has been determined from the following data (in seconds):

1935Am01	22	omitted, no uncertainty
1938Po03	22	omitted, no uncertainty
1938Re04	23	omitted, no uncertainty
1944F101	24	omitted, no uncertainty
1946Hi06	24,5 (3)	
1954Bo39	24 (2)	
1957Se19	24,2 (12)	
1962Ma38	24,42 (14)	
1967Yu01	24,93 (22)	
1970Va08	24,7 (7)	
Adopted	24,56 (11)	

The adopted value is the weighted average of the six values with uncertainties, and the reduced- χ^2 value is 0,82, so the values are consistent.

3) g-ray data

The energies for the γ -rays from the decay of ¹¹⁰Ag (24 s) were determined as shown in Table 1. The precise energies from the ¹¹⁰Ag^m (249 d) isomer decay are adopted where appropriate.

Table 1. γ -ray energies from the β^- decay of ¹¹⁰Ag (24 s).

1970Va08	1972Ka34 ^a	Adopted ^b
	295,3 (1)	295,3 (2)
657,8 (2)	657,6 (1)	657,7600 (11) ^c
815,5 (3)	815,5 (1)	815,5 (2)
817,8 (12)	818,2 (1)	818,0244 (18) ^c
	1074,0 (1)	1074,0 (2)
1125,9 (3)	1125,8 (1)	1125,699 (20) ^d
1186,4 (7)	1186,3 (1)	1186,3 (2)

1421,8 (13)	1421,4 (1)	1421,5 (2)
1475,8 (13)	1475,8 (1)	1475,7792 (23) ^c
1630,0 (12)	1629,9 (1)	1629,9 (2)
1674,2 (9)	1674,3 (1)	1674,3 (2)
1783,3 (13)	1783,6 (7)	1783,46 (3) ^d
	2004,4 (2)	2004,4 (2)

^a The author's uncertainties are quoted to 0,01 keV, but the energies are only given to 0,1 keV, so the last digit in the uncertainty is of no use.

^b For energies from 1972Ka34 and 1970Va08, a minimum uncertainty of 0,2 keV has been used for the adopted value.

^c From evaluation of 2000He14,

^d From adopted value from ¹¹⁰Ag^m decay.

The relative emission probabilities of the γ -rays from the decay of ¹¹⁰Ag (24 s) were determined from the measurements in Table 2 :

Table 2: Relative emission probabilities of the γ -rays from the decay of ¹¹⁰Ag (24 s)

E _{γ} (keV)	1970Va08	1972Ka34	Adopted
295		0,17 (3)	0,17 (3)
657	100,	100,	100,
815	0,79 (12)	0,85 (2)	0,85 (2)
818	0,10 (9)	0,20 (1)	0,20 (1)
1074		0,02 (1)	0,02 (1)
1125	0,36 (3)	0,34 (1)	0,34 (1)
1186	0,056 (2)	0,06 (1)	0,06 (1)
1421	0,044 (30)	0,05 (1)	0,05 (1)
1475	0,11 (5)	0,08 (1)	0,08 (1)
1629	0,048 (30)	0,05 (1)	0,05 (1)
1674	0,15 (6)	0,16 (1)	0,16 (1)
1783	0,17 (9)	0,10 (1)	0,10 (1)
2004		0,08 (1)	0,08 (1)

The normalization of the relative emission probabilities for the γ -rays from the decay of ¹¹⁰Ag (24 s) depends on the probability of the β branch to the ground state of ¹¹⁰Cd and the fact that 0,30(6)% of the decays are by electron capture to ¹¹⁰Pd (1961Fr01). The intensity of the β branch to the ¹¹⁰Cd ground state can be obtained from the ratio of the emission probabilities for the branches to the 657-keV level and the ground state, $I_{\beta}(657)/I_{\beta}(0)$, as deduced from the decomposition of the β^- spectrum. However, the following results for this ratio are very inconsistent.

	$I_{\beta^-}(657)/I_{\beta^-}(0)$
1962Ka07	0,14 (5)
1963Da03	0,21
1963Fr07	0,0465 (25)
1967Mo12	0,070 (22)
Adopted	0,047 (4)

The adopted value is the weighted average of the three values with uncertainties. For this average the internal uncertainty is 0,0025 and the external uncertainty is 0,0038. Although the reduced- χ^2 value is 2,30, this does not necessarily imply an inconsistent set since one has only three values. If one does consider it an inconsistent set and applies the Limitation of Relative Statistical Weight rule (1985ZiZY, 1992Ra08) of reducing the relative weight of the 1963Fr07 value from 98% to 50%, the weighted average becomes 0,064 with an internal uncertainty of 0,014, a reduced- χ^2 value of 1,6, and an external uncertainty of 0,018.

From this β^- branching ratio, the 0,30 (6)% electron-capture, and 0,1% β^- branching to higher energy levels, the branch to the ground state is 95,1(4) % and that to the 657-keV level is 4,5(4) %. The emission probability of the 657-keV γ -ray is then 4,6 (4) % of the decays of the ground state including both the direct and indirect feeding.

Table 3: Absolute emission probabilities for the γ -rays from the decay of the ¹¹⁰Ag ground state.

E_{γ}	P_{γ} (%)
295	0,0078 (16)
657	4,6 (4)
815	0,039 (4)
818	0,0092 (9)
1074	0,0009 (5)
1125	0,0156 (14)
1186	0,0028 (5)
1421	0,0023 (5)
1475	0,0037 (6)
1629	0,0023 (5)
1674	0,007 (1)
1783	0,0046 (8)
2004	0,0037 (6)

The γ -ray multiplicities and mixing ratios were taken from the 2000De11 evaluation and are as follows:

E1: 1421 -keV
 E2: 657, 815, 1074, 1186,1475, 1783, 2004 -keV
 M1+E2: 818 [d = - 1,36 (7)] ; 1125 [d = + 0,33 (8)]
 E2(+M1): 1629 [d = + 0,06 (3)]
 (E1): 295 -keV

4) Atomic data

From the EMISSION code and the decay data, the following information was obtained.

Quantity	Pd (Z=46)	Cd (Z=48)
ω_K	0,820(4)	0,842(4)
ω_L average	0,0536 (13)	0,0632 (16)
n_{KL}	0,975 (4)	0,953 (4)
$K_{\alpha 2}/K_{\alpha 1}$	0,5293 (25)	0,5317 (25)
K_{β}/K_{α}	0,2099 (17)	0,2151 (18)

Due to the high energy of the strong transitions, the Auger electrons are negligible and no related data are included here.

The K X-ray emission probabilities are calculated as follows:

From the decay of ¹¹⁰Ag (24 s), the Pd X-rays per 100 decays of parent:

$K_{\alpha 2}$	0,060 (12)
$K_{\alpha 1}$	0,114 (23)
K_{β}	0,037 (8)

and the Cd X-rays per 100 decays of parent:

$K_{\alpha 2}$	0,00322 (28)
$K_{\alpha 1}$	0,0061 (6)
K_{β}	0,00200 (18)

5) β^- decay intensities

The β^- decay intensities for the decay of the ¹¹⁰Ag ground state are simply deduced from the above data and the γ -ray probability balances.

6) References

- 1935Am01 - E. Amaldi, O. D'Agostino, E. Fermi. B. Pontecorvo, R. Rasetti, and E. Segrè, Proc. Roy. Soc. (London) 149A(1935)522 [$T_{1/2}$ as cited in 1962Ma38].
 1938Po03 - M. L. Pool, Phys. Rev. 53(1938)116 [$T_{1/2}$].
 1938Re04 - H. Reddemann, Naturwiss. 26(1938)124 [$T_{1/2}$ as cited in 1962Ma38].
 1944Fl01 - A. Flammersfeld, Naturwiss. 32(1944)36 [$T_{1/2}$ as cited in 1962Ma38].
 1946Hi06 - O. Hirzel, H. Wäffler, Helv. Phys. Acta 19(1946)214 [$T_{1/2}$ as cited in 1953Ho01 and/or 1962Ma38].
 1954Bo39 - F. I. Boley, Phys. Rev. 94(1954)1078 [$T_{1/2}$].
 1957Se19 - M. L. Seghal, Indian J. Phys. 31(1957)630 [$T_{1/2}$ as cited in 1962Ma38].
 1962Ka07 - T. Katoh, Y. Yoshizawa, Nucl. Phys. 32(1962)5 [E_{β} , I_{β} , E_{γ} , α_K , Mult].
 1962Ma38 - S. Malmskog, J. Konijn, Nucl. Phys. 38(1962)196 [$T_{1/2}$].
 1963Da03 - H. Daniel, O. Mehling, D. Schotte, Zeits. f. Phys. 172(1963)202 [E_{β} , P_{β}].

- 1963Fr07 - L. Frevert, P. H. Heckmann, A. Flammersfeld, Zeits. f. Phys. 175(1963)221 [E_β, P_β].
 1963Su07 - T. Suter, P. Reyes-Suter, W. Scheuer, Nucl. Phys. 47(1963)251 [E_γ, I_{e-}].
 1964Ne05 - W. B. Newbolt, J. H. Hamilton, Nucl. Phys. 530(1964)353 [E_γ, I_{e-}, α_K, Mult].
 1965Fr01 - L. Frevert, R. Schöneberg, A. Flammersfeld, Zeits. f Phys. 182(1965)439 [I_{e-}].
 1967Mo12 - J. A. Moragues, P. Reyes-Suter, T. Suter, Nucl. Phys. A99(1967)652 [E_β, I_β, E_γ, I_γ].
 1967Yu01 - H. P. Yule, Nucl. Phys. A94(1967)442 [T_{1/2}].
 1970Kr03 - K. S. Krane, R. M. Steffen, Phys. Rev. C2(1970)724 [δ].
 1970Su03 - S. P. Sud, P. C. Mangal, P. N. Trehan, Aust. J. Phys. 23(1970)87 [δ].
 1970Va08 - J. R. Van Hise, M. C. Kelley, R. G. Lanier, N. R. Johnson, Phys. Rev. C1(1970)8161 [T_{1/2}, E_γ, I_γ].
 1972Ka34 - Y. Kawase, K. Okano, S. Uehara, T. Hayashi, Nucl. Phys. A193(1972)204 [E_γ, I_γ].
 1973Ga10 - P. L. Gardulski, M. L. Wiedenbeck, Phys. Rev. C7(1973)2080 [δ].
 1973Jo08 - P. D. Johnston, N. J. Stone, Nucl. Phys. A206(1973)273 [δ].
 1978Wa07 - G. W. Wang, A. J. Becker, L. M. Chirovsky, J. L. Groves, C. S. Wu, Phys. Rev. C18(1978)476 [δ].
 1979Sc31 - P. Schlüter, G. Soff, Atomic Data Nuclear Data Tables 24(1979)509 [α_π].
 1979Ve03 - H. R. Verma, A. K. Sharma, R. Kaur, K. K. Suri, P. N. Trehan, J. Phys. Soc. Japan 47(1979)16 [E_γ, I_γ, δ].
 1985ZiZY - W. L. Zijp, Report ECN FYS/RASA-85/19 (1985) [averages].
 1992Ra08 - M. U. Rajput, T. D. MacMahon, Nucl. Instr. Meth. A312(1992)289 [averages].
 1993Ka37 - V. M. Kartashov, A. I. Oborovsky, A. G. Troitskaya, Bull. Russ. Acad. Sci. 57(1993)1554 [I_{e-}].
 1993Ki18 - L. L. Kiang, P. K. Teng, G. C. Kiang, W. S. Chang, P. J. Tu, J. Phys. Soc. Japan 62 (1993)888 [E_γ, I_γ, δ].
 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. A595(1995)409 [Q].
 2000De11 - D. DeFrenne, E. Jacobs, Nucl. Data Sheets 89(2000)481 [J^π, multipolarities, δ].
 2000He14 - R. G. Helmer, C. van der Leun, Nucl. Instr. Meth. A450(2000)35 [E_γ].

**¹¹⁰Ag^m – Comments on evaluation of decay data
by R. G. Helmer**

1) Decay Scheme

The β^- decay of the ¹¹⁰Ag^m (249 d) isomer to levels in ¹¹⁰Cd occurs in 98,64(8) % of the decays and the remaining 1,36(8) % is by an isomeric transition to the ¹¹⁰Ag ground state (24 s). The β^- emission to ¹¹⁰Cd from the ground state occurs in 99,70(6) % of the decays and the remaining 0,30(6) % is by electron capture to ¹¹⁰Pd. The comments on the decay ¹¹⁰Ag (24 s) ground state are provided under that decay.

2) Q values and half-lives

The Q values from the 1995Au04 evaluation for the decay of the ¹¹⁰Ag ground state are 2892,2 (16) keV for the β^- decay so the decay energy for the β^- decay of the ¹¹⁰Ag^m (249 d) isomer is then 3009,8 (16) keV.

The half-life of the ¹¹⁰Ag^m isomeric state has been determined from the following data (in days):

1938Li07	225 (20)	omitted, large uncertainty
1950Gu54	270	omitted, no uncertainty
1976WaZH	249,78 (4)	superseded by 1983Wa26
1980Ho17	249,74 (5)	
1983Wa26	249,79 (2)	
Adopted	249,78 (2)	

The adopted value is the weighted average of the last two values, and the reduced- χ^2 value is 0,86.

3) g-ray data

Several of the γ -rays from the decay of the isomer ¹¹⁰Ag^m (249 d) have precisely measured energies; these values were taken from the evaluation 2000He14 and are on a scale for which the energy of the strong line from the decay of ¹⁹⁸Au is 411,80205(17) keV. The other energies were determined as shown in Table 1 from the data of 1979Ve03, 1981Ma09, 1990Me15, and 1993Ki18. In order to provide a set of energies consistent with those of 2000He14, the values 1990Me15 were adjusted by additive amounts of 0 to 15 eV as shown in the table. No additional uncertainty was assigned for these adjustments. The values of the remaining references were not adjusted.

Table 1. γ -ray energies (keV)

1979Ve03	1981Ma09 ^a	1993Ki18	1990Me15	1990Me15 adjusted & rounded	2000He14	Adopted
			116,485 (46)	116,48 (5)		116,48 (5)
120,4 (2)	120,3 (1)	120,2 (2)	120,226 (26)	120,23 (3)		120,23 (3)
133,3 (2)	133,4 (1)	133,2 (1)	133,333 (7)			133,333 (7)
219,2 (2)	219,4 (1)	219,4 (1)	219,348 (8)			219,348 (8)

1979Ve03	1981Ma09 ^a	1993Ki18	1990Me15	1990Me15 adjusted & rounded	2000He14	Adopted
221,0 (1)	221,0 (1)	221,1 (2)	221,079 (10)			221,079 (10)
229,3 (2)	229,4 (1)	229,4 (3)	229,423 (23)			229,423 (23)
	264,4 (1)	264,1 (3)	264,254 (58)	264,25 (6)		264,25 (6)
266,9 (2)	267,0 (1)	267,0 (3)	266,913 (12)			266,913 (12)
	341,4 (1)	340,9 (5)	341,2 (2)			341,3 (2)
	356,4 (1)	356,5 (2)	356,43 (10)			356,43 (10)
360,7 (2)	360,0 (1)	360,2 (5)	360,228 (75)	360,23 (8)		360,23 (8)
365,54 (10)	365,4 (1)	365,3 (1)	365,450 (10)	365,448 (10)		365,448 (10)
387,2 (2)	387,1 (1)	387,1 (6)	387,075 (9)	387,073 (9)		387,073 (9)
397,1 (2)	396,8 (1)	396,5 (6)	396,897 (23)	396,895 (23)		396,895 (23)
	409,6 (1) ^d	409,6 (4)	409,330 (45)	409,33 (5)		409,4 (5)
446,87 (5)		446,8 (2)	446,808 (8)		446,812 (3)	446,812 (3)
466,9 (2)	466,9 (1)	465,8 (7)	467,029 (36)	467,03 (4)		467,03 (4)
493,8 (2)	493,0 (1)	493,6 (1)	493,432 (91)	493,43 (9)		493,43 (10)
554,8 (2)	544,5 (1)	544,9 (5)	544,555 (45)	544,55 (5)		544,55 (5)
	572,7 (1)	573,1 (7)	573,0 (4)			572,8 (2)
	603,1 (1)	603,1 (4)	603,065 (90)	603,06 (9)		603,08 (10)
620,45 (5)		620,4 (1)	620,362 (1)		620,3553 (17)	620,3553 (17)
626,24 (5)	626,1 (1)	626,4 (2)	626,262 (10)	626,258 (10)		626,258 (10)
	630,6 (1)	630,7 (4)	630,626 (55)	630,62 (6)		630,62 (6)
	648,2 (10)	647,8 (4)				647,8 (4)
657,75 (5)		657,7 (2)	657,766 (5)		657,7600 (11)	657,7600 (11)
	666,1 (2)	667,1 (1)				666,6 (5)
	676,6 (1)		676,58 (10)			676,58 (10)
677,72 (5)		677,6 (1)	677,623 (7)		677,6217 (12)	677,6217 (12)
687,10 (5)			687,005 (11)		687,0091 (18)	687,0091 (18)
706,74 (5)			706,688 (8)		706,6760 (15)	706,6760 (15)
	708,3 (1)	708,6 (5)	708,133 (20)	708,128 (20)		708,128 (20)
	714,9 (1)	715,0 (3)				714,9 (1)
744,35 (5)			744,279 (8)		744,2755 (19)	744,2755 (18)
763,98 (5)			763,947 (8)		763,9424 (17)	763,9424 (17)
	774,8 (1)	774,6 (1)	774,8 (2)			774,70 (10)
818,00 (5)			818,037 (8)		818,0244 (18)	818,0244 (18)
884,65 (5)			884,037 (8)		884,6781 (13)	884,6781 (13)

1979Ve03	1981Ma09 ^a	1993Ki18	1990Me15	1990Me15 adjusted & rounded	2000He14	Adopted
937,55 (5)			937,505 (13)		937,485 (3)	937,485 (3)
957,3 (2)	957,4 (1)	957,6 (7)	957,368 (85)	957,35 (9)		957,35 (10)
997,12 (5)	997,2 (1)	997,2 (4)	997,258 (15)	997,243 (15)		997,243 (15)
1019,0 (2)	1019,1 (1)	1018,8 (5)	1018,893 (50)	1018,88 (5)		1018,95 (8)
	1050,1 (3)	1051,8 (6)				1050,5 (5)
1085,7 (1)	1085,5 (1)	1085,3 (4)	1085,462 (14)	1085,447 (14)		1085,447 (14)
1117,7 (2)	1117,5 (1)	1117,2 (3)	1117,474 (28)	1117,46 (3)		1117,46 (3)
1125,7 (2)	1125,6 (1)	1125,6 (4)	1125,714 (20)	1125,699 (20)		1125,699 (20)
1163,5 (2)	1163,1 (2)	1163,1 (3)	1163,159 (75)	1163,14 (8)		1163,14 (8)
1165,6 (2)	1164,5 (2)	1165,2 (8)	1164,959 (85)	1164,94 (9)		1164,94 (9)
	1186,7 (1)	1186,5 (2)	1186,7 (2)			1186,7 (1)
1251,2 (2)	1251,0 (1)	1251,2 (3)	1251,057 (42)	1251,04 (4)		1251,04 (4)
1300,0 (2)	1300,1 (1)	1300,3 (4)	1300,03 (12)	1300,02 (12)		1300,05 (10)
1334,53 (10)	1334,4 (1)	1334,3 (3)	1334,341 (17)	1334,326 (17)		1334,326 (17)
1384,47 (5)			1384,305 (8)		1384,2931 (20)	1384,2931 (20)
	1421,1 (1)	1420,9 (5)	1420,081 (50)	1420,07 (5)		1420,07 (5)
	1465,6 (1)	1465,6 (1)				1465,6 (1)
1475,80 (5)			1475,305 (12)		1475,7792 (23)	1475,7792 (23)
1505,05 (5)			1505,039 (8)		1505,0280 (20)	1505,0280 (20)
1562,37 (5)			1562,305 (9)		1562,2940 (18)	1562,2940 (18)
	1572,3 (2)		1572,4 (2)			1572,4 (2)
1592,8 (1)	1593,0 (2)	1593,1 (4)	1592,672 (95)	1592,66 (10)		1592,80 (15)
	1630,0 (2)	1630,0 (1)	1629,692 (63)	1629,68 (6)		1629,75 (15)
	1698,5 (2)	1698,9 (1)				1698,8 (2)
1775,6 (2)	1775,4 (1)	1775,4 (2)	1775,422 (39)	1775,41 (4)		1775,41 (4)
1783,4 (2)	1783,6 (1)	1783,4 (2)	1783,480 (30)	1783,46 (3)		1783,46 (3)
1903,9 (2)	1903,4 (1)	1904,1 (8)	1903,530 (35)	1903,52 (4)		1903,52 (4)
	2004,6 (1)	2003,8 (8)	2004,74 (10)	2004,72 (10)		2004,65 (10)

^a The uncertainties of 0,1 keV are from a general statement and not specific to each γ -ray.

^d Reported to be a doublet.

The relative γ -ray intensities for the decay of $^{110}\text{Ag}^m$ (249 d) are given in Table 2. The adopted values are the weighted averages computed by the Limitation of Relative Statistical Weight method (1985ZiZY, 1992Ra09) and take into account the measurements from 1976De, 1977Ge12, 1979Ve03, 1980Ro22, 1980Yo05, 1981Ma09, 1990Me15, and 1993Ki18.

The γ -ray energies in Table 2 that are flagged with a "c" are from the evaluation 2000He14 and are considered especially suitable for energy calibration.

Table 2. Relative γ -ray intensities for ¹¹⁰Ag^m decay

Energy (keV)	1969Br03 1972Ph04 ^a	1976De	1977Ge12	1979Ve03	1980Ro22	1980Yo05	1981Ma09	1990Me15	1993Ki18	LRSW average	χ_R^2 if > 1,0	σ_{int}	σ^{ext}	σ_{LWM}
116,48 (5)	isomeric decay							0,085 (3)						
120,23 (3)	<0,15			0,17 (3)			0,18 (1)	0,19 (1)	0,66(1) ^e	0,179 (9)				
133,333(7)	0,9 (2)			0,86 (13)			0,80 (5)	0,77 (3)	0,78 (2)	0,780 (16)				
219,348(8)	1,3 (3)			0,80 (6)			0,77 (5)	0,70 (2)	0,81 (1) ⁱ	0,76 (5)	5,8	0,013	0,030	0,046
221,079 (10)	1,1 (3)			0,80 (11)			0,74 (5)	0,72 (1)	0,67 (3)	0,716 (10)	1,1	0,009	0,010	
229,423 (23)	0,32 (15)			0,19 (5)			0,11 (1)	0,128 (8) ⁱ	0,22 (3)	0,126 (14)	4,7	0,007	0,014	
264,25 (6)							0,070 (7)	0,059 (5)	0,11 (3)	0,064(6)	2,0	0,004	0,006	
266,913 (12)	0,5 (1)			0,65 (6)			0,37 (2)	0,43 (1) ⁱ	0,53 (4)	0,43 (4)	9,5	0,012	0,037	
341,3 (2)							0,06 (3)	0,022 (4)	0,13 (9)	0,023 (5)	1,5	0,004	0,005	
356,43(10)							0,06 (3)	0,045 (3)	0,04 (2)	0,045 (3)				
360,23 (8)				0,14 (2)			0,11 (5)	0,035(7) ⁱ	0,09 (5)	0,08 (5)	5,4	0,012	0,028	0,048
365,448 (10)	1,1 (2)			1,27(14)		0,91 (19)	0,92 (5)	1,02 (8)	1,10 (12)	0,98 (5)	1,8	0,038	0,050	
387,073(9)	0,43 (9)			0,54 (13)		0,8 (4)	0,54 (3)	0,55 (1)	0,61 (24)	0,549 (9)				
396,895 (23)	0,36 (8)			0,68 (12)		0,6 (3)	0,35 (2)	0,43 (1) ⁱ	0,30 (10)	0,39 (4)	3,8	0,014	0,027	0,036
409,4 (5)							0,08 (4)	0,068 (7)	0,01 (4)	0,067 (7)	1,1	0,007	0,007	
446,812 (3) ^c	35 (2)		38,6 (4)	41,8 (6) ^e	39,0 (12)	39,55 (28)	39 (2)	38,9 (6)	38,22 (12) ⁱ	38,7 (5)	2,9	0,15	0,25	0,48
467,03 (4)				0,35 (5)			0,26 (2)	0,26 (5)	0,21 (5)	0,264 (19)	1,4	0,016	0,019	
493,43(10)				0,06 (2)			0,10 (2)	0,11 (1)	0,13 (4)	0,101 (11)	1,8	0,008	0,011	
544,55 (5)				0,10 (2)			0,19 (1)	0,22 (1)	0,15 (6)	0,19 (3)	9,8	0,007	0,021	0,027
572,8 (2)							0,19 (1)	0,13 (3)	0,14 (6)	0,183 (13)	2,1	0,009	0,013	

Energy (keV)	1969Br03 1972Ph04 ^a	1976De	1977Ge12	1979Ve03	1980Ro22	1980Yo05	1981Ma09	1990Me15	1993Ki18	LRSW average	χ_R^2 if > 1,0	σ_{int}	σ^{ext}	σ_{LWM}
603,08(10)							0,20 (3)	0,042 (9) ⁱ	0,30 (12)	0,12 (8)	8,2	0,021	0,059	0,081
620,3553 (17) ^c	29 (2)		29,3 (3)	29,5 (4)	31,4 (13)	29,65 (19)	28,0 (14)	29,4 (5)	28,00 (15) ⁱ	28,8 (8)	10,1	0,10	0,32	0,8
626,258 (10)	1,85 (20)			2,2 (2)		2,28 (14)	2,3 (1)	2,48 (4)	2,10 (3) ⁱ	2,27 (17)	12,7	0,025	0,09	0,17
630,62 (6)							0,30 (2)	0,40 (1) ⁱ	0,30 (8)	0,35 (5)	6,6	0,014	0,035	0,050
647,8 (4)							0,19 (4)		0,186 (4)	0,185 (5)	1,6	0,004	0,005	
657,7600 (11) ^c	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000				
666,6 (5)							0,16 (2) ⁱ		0,43 (5)	0,30 (14)	14,6	0,035	0,14	
676,58(10)								1,5 (1)						
677,6217 (12) ^c	122 (7)		113,1(11)	111 (2)	112,6 (29)	110,9 (8)	112 (6)	112 (2)	112,6 (11)	111,9 (5)				
687,0091 (18) ^c	74 (6)		68,5 (7)	75,8 (14) ^e	69,0 (27)	68,0 (6)	67 (3)	68,5 (5) ⁱ	69,2 (21)	68,3 (3)				
706,6760 (15) ^c	172 (7)	175 (10)	176,7 (18)	175,4 (20)	176,2 (22)	176,6 (10)	174 (7)	172,8 (5) ⁱ	176,9 (26)	174,6 (7)	1,9	0,5	0,6	
708,128 (20)							2,0 (2)	2,9 (2)	2,4 (3)	2,4 (5)	5,1	0,11	0,29	0,46
714,9 (1)							0,09 (2)		0,17 (6)	0,098 (24)	1,6	0,019	0,024	
744,2755 (18) ^c	44 (4)		49,2 (5)	52,3 (8)	49,5 (16)	50,00 (27)	48,0 (25)	49,3 (8)	50,2 (14)	49,9 (3)	2,0	0,21	0,31	
763,9424 (17) ^c	240 (8)	237 (2)	236,0 (24)	243,7 (30)	237,4 (31)	235,5 (9)	243 (12)	236 (3)	239,1 (53)	236,4 (7)	1,1	0,70	0,74	
774,70 (10)							0,03 (2)	0,02 (1)	0,092 (4) ⁱ	0,06 (3)	15,4	0,006	0,025	0,035
818,0244 (18) ^c	78 (3)		77,3 (8)	80,5 (10)	77,4 (17)	77,6 (4)	79 (4)	77,1 (5)	78,8 (18)	77,7 (4)	1,7	0,27	0,35	
845,8 (1)							0,10 (3)		0,10 (2)	0,10 (2)				
884,6781 (13) ^c	796 (20)	775 (5)	769 (8)	811 (10)	780 (10)	767,6 (26)	800 (40)	771 (10)	706,6 (12) ⁱ	784 (12)	13,3	1,5	5,3	12,5
927,6 (1)							0,065 (10)		0,067 (8)	0,063 (6)				
937,483 (3) ^c	365 (11)	366 (3)	362,2 (36)	380 (4)	369 (4)	363,1 (12) ⁱ	374 (18)	363 (6)	376 (8)	365,7 (26)	2,7	1,2	1,9	2,6

Energy (keV)	1969Br03 1972Ph04 ^a	1976De	1977Ge12	1979Ve03	1980Ro22	1980Yo05	1981Ma09	1990Me15	1993Ki18	LRSW average	χ_R^2 if > 1,0	σ_{int}	σ^{ext}	σ_{LWM}
957,35(10)				0,28 (5)			0,11 (1)	0,08 (1)	0,14 (5)	0,099 (19)	6,2	0,007	0,017	0,019
997,243 (15)	1,4 (2)			1,6 (1)		1,42 (5)	1,4 (1)	1,32 (4)	1,33 (10)	1,36 (4)	1,8	0,033	0,043	
1018,95(8)	0,3 (1)			0,17 (5)			0,15 (1)	0,15 (1)	0,08 (5)	0,149 (7)				
1050,5 (5)							0,08 (1)		0,08 (6)	0,08 (1)				
1085,447 (14)	0,58 (8)			0,95 (10)		0,66 (12)	0,74 (4)	0,71 (2)	0,81 (24)	0,76 (4)	1,2	0,035	0,0371	
1117,46(3)	0,39 (7)			0,55 (20)		0,41 (6)	0,52 (3)	0,52 (1)	0,38 (20)	0,517 (9)				
1125,699 (20)	0,26 (6)			0,35 (10)		0,38 (8)	0,34 (2)	0,30 (2)	0,22 (21)	0,322 (14)				
1163,14(8)				1,5 (1)			0,54 (5) ⁱ	0,79 (7)	1,0 (4)	0,78 (24)	23,4	0,04	0,19	0,24
1164,94(9)				0,96 (10) ^e			0,42 (5)	0,50(5)	0,47 (4)	0,46 (3)				
1186,7 (1)								0,015 (5)	0,0170 (5)	0,0170 (5)				
1251,04(4)	0,58 (19)			0,52 (5)		0,24 (7)	0,31 (2)	0,26 (1) ⁱ	0,25 (2)	0,28 (3)	7,5	0,0090	0,0260	
1300,05 (10)				0,20 (2)		0,25 (8)	0,19 (1)	0,21 (1)	0,22 (11)	0,200 (7)				
1334,326 (17)	1,55 (20)			1,8 (1)		1,49 (6)	1,40 (7)	1,49 (5) ⁱ	1,55 (33)	1,50 (5)	2,8	0,03	0,05	
1384,2931 (20) ^c	277 (8)	261 (2)	257,0 (26)	277,9 (30)	271 (5)	256,6 (8) ⁱ	278 (14)	261 (5)	276,6 (26)	262 (5)	12,8	0,8	2,9	5,0
1420,07(5)						0,39 (3)	0,27 (2)	0,24 (2)	0,37 (9)	0,28 (4)	6,2	0,013	0,032	0,041
1465,6 (1)							0,019 (2)							
1475,7792 (23) ^c	45,0 (20)		42,1 (4)	44,8 (6)	44,9 (12)	42,22 (17) ⁱ	45 (2)	42,4 (8)	45,7 (13)	42,7 (5)	4,6	0,20	0,43	0,5
1505,0280 (20) ^c	148 (4)	139 (1)	138,4 (14)	145,2 (16)	147,0 (29)	137,8 (5) ⁱ	151 (7)	140,1 (19)	149,2 (28)	139,4 (16)	6,1	0,45	1,1	1,6
1562,2940 (18) ^c	13,3 (6)		12,50(13) ⁱ	13,2 (2)	14,0 (8)	10,87 (7)	13,0 (7)	12,6 (6)	13,5 (4)	12,8 (3)	3,4	0,11	0,21	0,30
1572,4 (2)								0,012 (3)						
1592,80 (15)				0,4 (1)		0,221 (13)	0,20 (2)	0,22 (1)	0,34 (18)	0,219 (8)	1,2	0,007	0,0081	

Energy (keV)	1969Br03 1972Ph04 ^a	1976De	1977Ge12	1979Ve03	1980Ro22	1980Yo05	1981Ma09	1990Me15	1993Ki18	LRSW average	χ_R^2 if > 1,0	σ_{int}	σ^{ext}	σ_{LWM}
1629,75 (15)						0,061 (11)	0,036 (4)	0,046 (5)	0,11 (5)	0,042 (5)	2,6	0,003	0,005	
1698,8 (2)							0,019 (2)		0,012 (4)	0,018 (3)	2,4	0,002	0,003	
1775,41(4)				0,067(10)		0,067 (11)	0,076 (4)	0,063 (4)	0,07 (6)	0,069 (3)	1,4	0,0026	0,0031	
1783,46(3)				0,085 (30)		0,103 (11)	0,110 (6)	0,092 (3)	0,07 (4)	0,107 (5)				
1903,52(4)				0,20 (2)		0,158 (15)	0,18 (1)	0,16 (1)	0,15 (2)	0,169 (7)	1,5	0,006	0,007	
2004,65 (10)							0,012(1) ⁱ	0,011 (2)	0,028 (4)	0,013 (4)	7,7	0,0013	0,0035	

a The values from these two articles, by the same authors, are for comparison and were not used in the calculated averages.

c γ -ray energy is from the 2000He14 evaluation and is useful for energy calibrations.

e Value was not used in the calculation of the average.

i The published uncertainty, which is given, was increased in the LRSW analysis to reduce the relative weight to 50 %.

The mixing ratios for the M1+E2 γ -rays have been evaluated in this work (from references 1962Ka07, 1963Su07, 1964Ne05, 1970Kr03, 1973Jo08, 1978Wa07, 1979Ve03, 1980Ru03, 1990Ke02, and 1993Ki18). The results are very similar to those in the most recent ENSDF evaluation (2000De11), so those from ENSDF have been used. From the measurements of 1979Ve03, mixing ratios for M3 contributions to predominantly E2 transitions are quoted in ENSDF. The δ (M3/E2) values that do not include 0,0 in their uncertainties are those of 763 and 1562-keV γ -rays; both are $\delta = -0,10 (+2-3)$. Although the conversion coefficients are small, the high precision of the relative γ -ray intensities makes them significant; for example, $\alpha_{(657)} = 0,00318$.

The normalization of the relative emission probabilities for the γ -rays from the decay of ¹¹⁰Ag^m (249 d) is determined by requiring that the sum of the γ -ray transition intensities to the ground states of ¹¹⁰Cd and ¹¹⁰Ag be 100 % of the decays of the isomeric state. However, the 657 keV γ -ray occurs in both the direct β^- decay and that which follows the isomeric decay. Since 4,6(4) % the ground-state decays lead to the 657-keV γ ray, the intensity of the isomeric decay is reduced by this fraction in computing the intensity feeding the ground states.

Then, in the units of Table 2, one has $I_{\gamma(116)}[1+\alpha_{(116)}][0,954] + I_{\gamma(657)}[1+\alpha_{(657)}] + I_{\gamma(1475)} + I_{\gamma(1783)} = 0,085[169][0,954] + 1000[1,003] + 42,7 + 0,107$. If an uncertainty of 5 % is assigned to $\alpha_{(116)}$, this sum is 1059,5 (9), so the normalization factor for the γ -ray intensities in Table 2 is 0,09438 (8).

The resulting intensity of the isomeric decay branch is then $0,085[0,09438][169] = 1,36$ with an uncertainty of 0,08 and that of the β^- decay is 98,64 (8) %. This gives the 657-keV photon intensity of 94,38 (8) per 100 decays of the isomeric state.

The isomeric decay of ¹¹⁰Ag^m (249 d) occurs via an M4 γ -ray of 116,48 (5) keV with $\alpha = 168$ [i.e., $P_{\gamma} = 0,0080$ (4)] followed by an E1 γ -ray of 1,113 keV energy. The γ -rays following the β^- decay of the ground state are all very weak due to the small isomeric decay branch (1,36 %) and the large β^- branch to the ground state (95,1 %). Also, the 4,6 % branch to the 657 level is already included in Table 2. Therefore, the remaining γ -rays following the β^- decay of the ground state are neglected.

The γ -ray multipolarities and mixing ratios were taken from the 2000De11 evaluation and are as follows:

E1: 603, 1421-keV

E1(+M2): 409 [$\delta = -0,029(23)$]; 997 [$\delta = -0,30(46)$]; 1117 [$\delta = +0,021(44)$]; 1300 [$\delta = +0,0(1)$]

E2: 626, 657, 884, 1085, 1334, 1475, 1592, 1783, 2004

(E2): 467; 774

M1(+E2): 120 [$\delta = -0,13(33)$]

M1+E2: 446 [$\delta = -0,38(2)$]; 544; 620 [$\delta = -0,50(4)$]; 677 [$\delta = 0,36(2)$]; 687 [$\delta = -1,76(6)$]; 706 [$\delta = -1,42$ (7)]; 708 [$\delta = -0,15(9)$]; 818 [$\delta = -1,36(7)$]; 957 [$\delta = -0,9(7)$]; 1018 [$\delta = -0,56(35)$]; 1125 [$\delta = +0,33(8)$]; 1163 [$\delta = -0,03(+6-9)$]; 1164 [$\delta = +0,0(3)$]; 1384 [$\delta = -0,44(2)$]; 1505 [$\delta = -1,21(4)$]; 1629 [$\delta = +0,06(3)$]; 1697; 1775

E2(+M3): 744 [$\delta = -0(+16-10)$]; 937 [$\delta = -0,07(+7-3)$]; 1562 [$\delta = -0,10(+2-3)$]

M3+E2: 763 [$\delta = -0,10 (+2-3)$]

4) Atomic data

From the EMISSION code and the decay data, the following information was obtained.

Quantity	Ag (Z=47)	Cd (Z=48)
ω_K	0,831 (4)	0,842 (4)
ω_L average	0,0583 (14)	0,0632 (16)
n_{KL}	0,964 (4)	0,953 (4)
$K_{\alpha 2}/K_{\alpha 1}$	0,5305 (25)	0,5317 (25)
K_{β}/K_{α}	0,2125 (17)	0,2151 (18)

Due the high energy of the strong transitions, the Auger electrons are negligible and no related data are included here.

The K X-ray emission probabilities are calculated as follows:

For the decay of ¹¹⁰Ag^m (249 d), Ag KX-rays per 100 decays of parent

$K_{\alpha 2}$	0,198 (12)
$K_{\alpha 1}$	0,372 (22)
K_{β}	0,121 (7)

Cd KX-rays per 100 decays of the parent

$K_{\alpha 2}$	0,153 (9)
$K_{\alpha 1}$	0,288 (16)
K_{β}	0,095 (6)

5) β^- decay intensities

The β^- decay intensities for the decay of the ¹¹⁰Ag ground state are simply deduced from the above data and the γ -ray intensity balances. Since the spin of the isomeric state is large, namely 6, there are several β^- decay branches for which the $\log ft$ systematics (1998Si17) given lower limits on the intensities than can be derived from the intensity balances. These data are given in Table 3

Table 3. Data used to deduce β^- decay intensities and $\log ft$ values.

Level(keV)	J^π	$\Delta J, \Delta \pi$	$\log ft$ limit	I_β from $\log ft$ limit	I_β from intensity balance	I_β adopted	$\log ft$
0	0 ⁺	6,no			1,3 (4)	0	
657	2 ⁺	4,no	>22	<10 ⁻¹⁰	-1,2 (12)	0	
1475	2 ⁺	4,no	>22	<10 ⁻¹⁰	0,08 (8)	0	
1522	4 ⁺	2,no	>10,6	<6	0,8 (13)	<2	>11
1783	2 ⁺	4,no	>22	<10 ⁻¹¹	0,0156 (23)	0	
2078	3 ⁻	3,yes	>16,5	<10 ⁻⁶	0,002 (8)	<10 ⁻⁶	>16,5
2162	3 ⁺	3,no	>13,9	<0,0004	-0,01 (19)	<0,0004	>13,9
2220	4 ⁺	2,no	>10,6	<0,6	0,06 (9)	<0,15	>11,2

Level(keV)	J ^π	ΔJ,Δπ	logft limit	I _β from logft limit	I _β from intensity balance	I _β adopted	logft
2250	4 ⁺	2,no	>10,6	<0,6	0,06 (5)	0,06 (5)	11,5
2287	2 ⁺	4,no	>22	<2x10 ⁻¹²	0,0040 (5)	0	
2356	(1 ⁺ ,2 ⁺)	4 or 5, no	>22	<10 ⁻¹²	0	0	
2433	3 ⁺	3,no	>13,9	<0,0001	-0,008 (6)	0	
2479	6 ⁺	0,no			30,8 (3)	30,8 (3)	8,282
2539	5 ⁻	1,yes			0,060 (4)	0,060 (4)	10,82
2561	4 ⁺	2,no	>10,6	<0,1	-0,003 (7)	<0,005	>11,8
2659	5 ⁻	1,yes			0,031 (4)	0,031 (4)	10,67
2662					0	0	
2705	4 ⁺	2,no	>10,6	<0,03	0,006 (23)	<0,029	>10,5
2707	4 ⁺	2,no	>10,6	<0,03	-0,010 (7)	0	
2793	4 ⁺	2,no	>10,6	<0,03	-0,013 (7)	0	
2842	5 ⁻	1,yes			0,0252 (10)	0,0252 (10)	9,73
2876	6 ⁺	0,no			0,392 (18)	0,392 (18)	8,23
2926	5 ⁺	1,no			67,5 (6)	67,5 (6)	5,36

6) References

- 1938Li07 - J. J. Livingood, G. T. Seaborg, Phys. Rev. 54 (1938) 88 [T_{1/2}]
1950Gu54 - J. R. Gum, M. L. Pool, Phys. Rev. 80 (1950) 315 [T_{1/2}]
1963Su07 - T. Suter, P. Reyes-Suter, W. Scheuer, Nucl. Phys. 47 (1963) 251 [E_γ, I_{e-}]
1964Ne05 - W. B. Newbolt, J. H. Hamilton, Nucl. Phys. 53 (1964) 353 [E_γ, I_{e-}, α_K, Mult]
1964Sc06 - J. Schintlmeister, L. Werner, Nucl. Phys. 51 (1964) 383 [E_β, I_⊙, I_{e-}]
1969Br03 - S. M. Brahmavar, J. H. Hamilton, A. V. Ramayya, E. F. Zganjar, C. E. Bemis Jr., Nucl. Phys. A125 (1969) 217 [E_γ, I_γ]
1970Kr03 - K. S. Krane, R. M. Steffen, Phys. Rev. C2 (1970) 724 [δ]
1970Su03 - S. P. Sud, P. C. Mangal, P. N. Trehan, Aust. J. Phys. 23 (1970) 87 [δ]
1972Ph04 - G. B. Philips, S. M. Brahmavar, J. H. Hamilton, T. Kracikova, Nucl. Phys. A182 (1972) 606 [E_γ, I_γ]
1973Ga10 - P. L. Gardulski, M. L. Wiedenbeck, Phys. Rev. C7 (1973) 2080 [δ]
1973Jo08 - P. D. Johnston, N. J. Stone, Nucl. Phys. A206 (1973) 273 [δ]
1974Pr07 - W. W. Pratt, J. Inorg. Nucl. Chem. 36 (1974) 1199 [E_γ, I_γ]
1976De - K. Debertain, U. Schötzig, K. F. Walz, H. M. Weiss, Proc. ERDA Symposium on X- and Gamma-ray Sources and Applications, Ann. Arbor. (1976) 59 [I_γ]
1976WaZH - K. F. Walz, H. M. Weiss, K. Debertain, Priv. Comm. (Octobre 1976) [T_{1/2} as cited in Nuclear Data Sheets 38 (1983) 545]
1977Ge12 - R. J. Gehrke, R. G. Helmer, R. C. Greenwood, Nucl. Instr. Meth. 147 (1977) 405 [I_γ]
1978Ke14 - J. Kern, S. Schwitz, Nucl. Instr. Meth. 151 (1978) 549 [E_γ]
1978Wa07 - G. W. Wang, A. J. Becker, L. M. Chirovsky, J. L. Groves, C. S. Wu, Phys. Rev. C18 (1978) 476 [δ]

- 1979Co14 – E. J. Cohen, H. R. Andrews, T. F. Knott, F. M. Pipkin, D. C. Santry, Phys. Rev. C20 (1979) 847 [δ]
- 1979Ve03 – H. R. Verma, A. K. Sharma, P. Kaur, K. K. Suri, P. N. Trehan, J. Phys. Soc. Japan 47 (1979) 16 [E_γ , I_γ , δ]
- 1979Sc31 - P. Schlüter, G. Soff, Atomic Data Nuclear Data Tables 24 (1979) 509 [α_π]
- 1980Ba58 – V. V. Babenko, I. N. Vishnevskii, V. A. Zheltonozhskii, V. P. Svyato, V. V. Trishin, Bull. Acad. Sci. (USSR), Phys. Ser. 44,#5, (1980) 132 [$\gamma\gamma(\theta)$, δ]
- 1980Ho17 – H. Houtermans, O. Milosevic, F. Reichel, Intern. J. Appl. Radiat. Isot. 31 (1980) 153 [$T_{1/2}$]
- 1980Ro22 - W. M. Roney, Jr., W. A. Seale, Nucl. Instr. Meth. 171 (1980) 389 [I_γ]
- 1980Ru03 - W. D. Ruhter, D. C. Camp, Nucl. Instr. Meth. 173 (1980) 489 [δ]
- 1980Yo05 – Y. Yoshizawa, Y. Iwata, T. Katu, T. Katoh, J.-Z. Ruan, T. Kojima, Y. Kawada, Nucl. Instr. Meth. 174 (1980) 109 [I_γ]
- 1981Ma09 - G. Mallet, J. Phys. Soc. Japan 50 (1981) 384 [E_γ , I_γ]
- 1981Ma25 - G. Mallet, J. Dalmasso, H. Maria, G. Ardisson, J. Phys. G – Nucl. Phys. 7 (1981) 1259 [scheme]
- 1983Me17 - R. A. Meyer, T. N. Massey, Intern. J. Appl. Radiat. Isot. 34 (1983) 1073 [E_γ]
- 1983Wa26 – K. F. Walz, K. Debertain, H. Schrader, Inter. J. Appl. Radiat. Isot. 34 (1983) 1191 [$T_{1/2}$]
- 1985ZiZY - W. L. Zijp, Report ECN FYS/RASA-85/19 (1985) [averages]
- 1988Kr03 - K. S. Krane, N. S. Schulz, Phys. Rev. C37 (1988) 747 [δ]
- 1990Me15 - R. A. Meyer, Fizika 22 (1990) 153 [E_γ , I_γ]
- 1991Ba63 – I. M. Band, M. B. Trzhaskovskaya, Bull. Acad. Sci. (USSR) , Phys. Ser. 55,#11 (1991) 39 [α]
- 1992Gr18 – R. C. Greenwood, R. G. Helmer, M. A. Lee, M. H. Putnan, M. A. Oates, D. A. Strttrmann, K. D. Watts, Nucl. Instr. Meth. A314 (1992) 514 [I_β]
- 1992Ra08 - M. U. Rajput, T. D. MacMahon, Nucl. Instr. Meth. A312 (1992) 289 [averages]
- 1993Ki18 – L. L. Kiang, P. K. Teng, G. C. Kiang, W. S. Chang, P. J. Tu, J. Phys. Soc. Japan 62 (1993) 888 [E_γ , I_γ , δ]
- 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. A595 (1995) 409 [Q]
- 1998Si17 – B. Singh, J. L. Rodriguez, S. S. M. Wong, J. K. Tuli, Nucl. Data Sheets 84 (1998) 487 [logft systematics]
- 2000De11 - D. DeFrenne, E. Jacobs, Nucl. Data Sheets 89 (2000) 481 [J^π , multipolarities, δ]
- 2000He14 - R. G. Helmer, C. van der Leun, Nucl. Instr. Meth. A450 (2000) 35 [E_γ]

¹²³I – Comments on evaluation of decay data by V. Chisté and M.M. Bé

1) Decay Scheme

There are 2 excited levels at 247 keV and 532 keV in ¹²³Te that have not been reported here. The 247 keV isomer ($T_{1/2} = 119,7$ d) is not populated in the electron capture decay of ¹²³I, and the expected electron capture population to the level 532 keV, if any, is very small.

2) Nuclear Data

The Q value is from Audi and Wapstra (1995Au04)

Level energies, spin and parities are from S. Ohya and T. Tamura (1993Oh07).

For level E= 687 keV, there are two possible spin values : 3/2+ and 5/2+. The 5/2+ value was suggested by Schoeters (1979Sc23) not after a measurement but by considering a proposal from Walters (1976Wa13). On the other hand, the 3/2+ value was measured by Sergolle ($\gamma\gamma$ coincidence (1969Se09) and Coulomb excitation (1970Se03)), Lien ((d,p) reaction (1975Li22)) and Andreev (Coulomb excitation (1975An16)). Then, the adopted value is 3/2+.

The half-life value, calculated by the Lweight program (version 3), is the weighted mean of :

$T_{1/2}$

Reference	Value (h)	Comments
Anderson (1964An03)	13,30 (5)	
Hupf (1968Hu01)	13,02 (4)	
Jonsson (1968Jo02)	13,4 (5)	
Karim (1973Ka01)	13,50 (11)	
Lagoutine (1982La13)	13,21 (2)	
Hoppes (1982Ho26)	13,219 (7)	Superseded 1992Un03
Unterweger (1992Un03)	13,2235 (19)	
Silva (2003Si04)	13,2228 (29)	
Schrader (2003Sc49)	13,232 (6)	

The original uncertainty given by Hupf (1968Hu01) (= 0,02) seems under estimated and has been multiplied by 2 by the evaluator. The uncertainty adopted by Lagoutine (1982La13) is the sum of the statistical uncertainty assessed at 3σ and the systematic uncertainty at 1σ ; consequently, the standard deviation cannot be obtained dividing the original uncertainty by 3 and we adopted the value 0,02. With this set of data, the reduced χ^2 is 4,7. The largest contribution comes from the value of Unterweger (1992Un03), amounting to 62%. The program Lweight 3 increases the uncertainty for the 1992Un03 value from 0,0019 to 0,00242 in order to reduce its relative weight from 62% to 50%.

The adopted value is the weighted mean : 13,2234 h, with the external uncertainty of 0,0037 h.

2.1) Electron Capture Transitions

The partial sub-shell capture probabilities are calculated with the program EC-Capture for the Allowed and 1st Forbidden transitions.

The electron capture probabilities and the related uncertainties have been deduced from the imbalance on each level of the decay scheme, assuming no EC transition to the ground state and to the 599 keV level. If this transition exists its intensity is of the order of a few per thousands.

2.3) Gamma Transitions

For the 159, 280, 346, 440 and 624 keV gamma transitions, the adopted δ (mixing of different multipolarities) are from the Krane evaluation (1977Kr06) of experimental measurements in which angular distribution and correlation data have been analyzed. For other transitions, the values of δ are from S. Ohya and T. Tamura (1993Oh07).

The internal conversion coefficients are calculated by ICC Computer Code (program Icc99v3a – GETICC dialog). The adopted values are interpolated from Rösels tables.

For the 159 keV gamma transition, many values of δ^2 have been found in the literature, as shown in the following table:

Reference	Value of d^2	Value of α_T
Goldberg et al – Phys. Rev. 100(1955)1350	0,013(1)	1,919 10 ⁻¹
Fagg et al – Phys. Rev. 100(1955)1299	0,0034(20)	1,905 10 ⁻¹
Chu et al – Phys. Rev. 133(1964)B1361	0,0067(11)	1,909 10 ⁻¹
Gupta et al – Nucl. Phys. 80(1966)471	0,011(8)	1,916 10 ⁻¹
Alkhozov et al – Phys. Serv. 28(1964)1575	0,004(5)	1,906 10 ⁻¹
Törnkvist et al – Nucl. Phys. A130(1969)604	0,0119(9)	1,917 10 ⁻¹
Krane et al - Atomic Data and Nuclear Data Tables 19(1977)19	0,01232 (47) (adopted value)	1,918 10 ⁻¹

It can be noted that even with values of δ^2 quite different the resulting α_T values are close with differences smaller than 1%; thus the adopted uncertainty is 1%.

For the 440 keV gamma transition, the following values of δ^2 have been found in the literature:

Reference	Value of d^2	Value of α_T
Sergolle et al – Nucl. Phys. A139(1969)554	0,149	0,0129912
Sergolle et al – Nucl. Phys. A145(1970)351	0,16	0,0129803
Roney et al – Nucl. Phys. A236(1974)165	4,41	0,0120886
Schoeters et al – Nucl. Phys. A323(1979)1	10,11	0,0119637
Krane - et al - Atomic Data and Nuclear Data Tables 19(1977)19	4,41 (adopted value)	0,0120886

In his articles (1969 and 1970), Sergolle deduced two values of δ for the 440 keV transition from 2 values of δ^2 for the 159 keV transition. The one reported here ($\delta^2(440)=0,149$) was calculated with $\delta^2(159) = 0,0119$ (Törnkvist). Nevertheless, this value is not close to the adopted one.

The 1% mixture of the 505 transition is from Sergolle (1969).

For the other transitions, measurements aren't precise, and only ranges of values are given for δ^2 .

Uncertainties calculations:

* For the 257 and 330 keV transitions (E2 pure), the α_T , α_K and α_L uncertainties are taken to be 3% from the calculated values with ICC Computer Code (program Icc99v3a).

* For the other transitions, the uncertainties calculations were made as follow : α_T was calculated for a pure M1(or M3) transition and for a pure E2 transition. The difference between these values, normalized by α_T , is the uncertainty (%) of α_T . The same method is used for α_K and α_L uncertainties.

3) Atomic Data

Atomic values (ω_K , ω_L and n_{KL}) are from Schönfeld (1996Sc33).

The X-ray and Auger electron emission probabilities are calculated from the data set values by using the program EMISSION.

4) Radiation emissions

4.2) Gamma ray emissions

Gamma ray emission energies are from S. Ohya and T. Tamura (1993Oh07) and W. B. Walters (1976Wa13).

The measured emission intensities are given in table 1, they are relative to a value of 100 for the 159 keV gamma ray. Energy values are in keV.

Remarks to table 1 :

The original uncertainties given by Jacquemin (1987Ja10) for the 440, 528 and 538 lines have been multiplied by 2 by the evaluator to take into account some important factors:

- 1) During the measurement, there was a contamination that was not taken into account (Te-123m) by the author ;
- 2) As the value given is an absolute value, the uncertainty on the relative intensity given in table 1, has been estimated using the normalization factor and its uncertainty taking from the reference quoted by Jacquemin.

Two sets of values (R. C. Ragaine (1968Ra11) and E. H. Spejewski(1970Sp03)) were omitted in several cases from the analysis due to discrepancy with the other data.

For the 528 keV gamma line, the value given by R. K. Gupta (1960Gu14) was also omitted because it did not agree with the other values.

The normalization factor to convert the relative emission intensities to absolute intensities is calculated with the formula:

$$\text{Normalization} = \frac{100}{(\sum(1 + a_T)P_{rel})}$$

where the sum is to be done over all the gamma transitions to the ground state.

From the calculated α_T and the evaluated relative emission intensities (Table 1), the deduced normalization factor is **83,25 (2I)**. The uncertainties were calculated through their propagation on the above formula.

Absolute emission intensities are given on the last line in table 1.

4.2) Conversion electrons

The conversion electron emission intensities were deduced from the ICC values and from the gamma-ray emission probabilities. To our knowledge, there are no measured values for the conversion electron emission intensities.

Additional Reference

F. Lagoutine, Table de Radionucléides, CEA-LMRI(1984)

References

- 1960Gu14 - R.K. Gupta, Nucl. Phys. 14(1960)606 [E_γ , P_γ , I_γ]
 1964Ch08 - Y.Y. Chu, O.C. Kistner, A.C. Li, S. Monaro, M.L. Perlman, Phys. Rev. B133(1964)1316 [δ]
 1964Ch09 - Y. Y. Chu, M. L. Perlman, Phys. Rev. B135(1964)319 [α]
 1964An03 - G. Anderson, G. Rudstam, G. Sorensen, Ark. Fys. 28(1964)3 [$T_{1/2}$]
 1965Ha05 - E.N. Hatch, G.W. Eakins, G.C. Nelson, R.E. Mc Adams, Proc. Inter. Conf.: Internal Conversion Process (1965) [α]
 1966Gu01 - R. K. Gupta et al, Nucl. Phys. 80(1966)471 [δ]
 1967Se05 - H. Sergole, G. Albouy, J. Bouloume, J. M. Lagrange, L. Marcus, M.Pautrat, Le journal de Physique 28(1967)383 [E_γ , P_γ , I_γ]
 1968Hu01 - H.B. Hupf, J.S. Eldridge, J.E. Breaver, Int. J. Appl. Radiat. Isotop.. 19(1968)345 [$T_{1/2}$]
 1968Jo02 - G.G. Jonsson, B. Forkman, Nucl. Phys. A107(1968)52 [$T_{1/2}$]
 1968Ra11 - R.C. Ragaini, W.B. Walters, G.E. Gordon, P.A. Baedeker, Nucl. Phys. A115(1968)611 [E_γ , P_γ , I_γ]
 1968Ra02 - B.V.N. Rao, Swani Jnanananda, Phys. Rev.165(1968)1296 [E2 transitions]
 1968Se06 - H. Sergole, G. Albouy, M. Jourdain, J.M. Lagrange, N. Poffe, M. Pautrat, Le journal de Physique C1(1968)187 [E_γ , P_γ , I_γ]
 1969Se09 - H. Sergole, J. Vanhorenbeeck, Nucl. Phys. A139(1969)554 [E_γ , P_γ , δ]
 1969To02 - S. Törnkvist, S. Strom, L. Hasselgren, Nucl. Phys. A130(1969)604 [δ]
 1970Sc21 - H. Schrader, R. Stippler, F. Munich, Nucl. Phys. A151(1970)331 [E_γ , P_γ , I_γ]
 1970Se03 - H. Sergolle et al, Nucl. Phys. A145(1969)351 [E_γ , P_γ]
 1970Sp03 - E. H. Spejewski, P.K. Hopke, F. W. Loeser Jr., Nucl. Phys. A146(1970)182 [E_γ , I_γ]
 1971Ho02 - A. Hogleend, S.G. Malmstog, F. Munich, H. Schrader, Nucl. Phys. A165(1971)513 [M1 and E2 Transitions]
 1971Ch43 - H.C. Cheung, S.K. Mark, Nucl. Phys. A176(1971)489 [$T_{1/2}$]
 1971St08 - R. Stippler, D. Code, H. Schrader, F. Munich, Z. Phys. 242(1971)121 [E_γ , P_γ , I_γ , α_K]
 1972Ra07 - S. Raman, Nucl. Instrum. Methods 103(1972)407 [α]
 1973Ka01 - H.M.A. Karim, Radiochim. Acta 19(1973)1 [$T_{1/2}$]
 1973So04 - V.J. Sodd, J.W. Blue, K.L. Scholz, M.C. Oselka, Int. J. Appl. Radiot. Isotop. 24(1973)171 [E_γ , I_γ]
 1974Ro40 - W.N. Roney, D.W. Gebbie, R.R. Borchers, Nucl. Phys. A236(1974)165 [δ]
 1975Li22 - Lien et al, Nucl. Phys. A253(1975)165 [E_γ , I_γ , Spin]
 1975An16 - Andreev et al, Bull. Acad. Sci. USSR, Phys. Serv. 39(1975)55, n° 8 [E_γ , I_γ , Spin]
 1976Wa13 - W.B. Walters, R. A. Meyer, Phys. Rev. C14(1976)1925 [E_γ , I_γ]
 1977Fo02 - D.B. Fossan et al., Phys. Rev. C15(1977)1732 [Gamma-ray transitions, Spin]
 1977Ha09 - U. Hagemann, H-J. Keller, H-F Brinckman, Nucl. Phys. A289(1977)292 [E_γ , I_γ]
 1977Kr06 - K. S. Krane, At. Data Nucl. Data Tables 19(1977)19 [δ]
 1979Sc23 - E. Schoeters, J. Geenen, C. Nuytten, L. Vanneste, Nucl. Phys. A323(1979)1 [Spin, δ]
 1982Ho26 - D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger, NBS-SP-626(1982)85 [Half-life]
 1982La13 - F. Lagoutine, J. Legrand, Int. J. Appl. Radiot. Isotop. 33(1982)711 [$T_{1/2}$]
 1982Sh08 - R.E. Shroy et al., Phys. Rev. C26(1982)1089 [E_γ , I_γ]
 1986Ag01 - V.A. Ageev - Report INIS-SU 392(1986)1 [E_γ , P_γ , I_γ]

- 1987Ja10 - R. Jacquemin, Appl. Rad. Isotopes 38(1987)1087 [$T_{1/2}$, I_{γ}]
1992Un03 - M.P. Unterweger, D.D. Hoppes, F.J. Schima, Nucl. Instrum. Meth. A312(1992)349 [$T_{1/2}$]
1993Go01 - R. Goswani, B. Sethi, P. Barnerjee, P. K. Chattopadhyay, Phys. Rev. C47(1993)1013 [E_{γ}]
1993Oh07 - S. Ohya and T. Tamura, Nucl. Data Sheets 70(1993)531 [E_{γ} , I_{γ} , Spin]
1995Au04 - G. Audi, A.H. Wapstra, Nucl. Phys. A595(1995)409 [Q]
1996Sc33 - E. Schönfeld, H. Janßen, Nucl. Instrum. Meth. A369(1996)527 [Atomic data]
2004Si04 - M. A. L. da Silva, M. C. M. de Almeida, C. J. da Silva, J. U. Delgado, Appl. Rad. Isotopes 60(2004)301 [Half-life].
2004Sc49 - H. Schrader, Appl. Rad. Isotopes 60(2004)317 [Half-life].

Table 1.I-123, gamma emission intensities, relative values to the 158 keV and, absolute values

04/12/01

Ref	174,2	182,61	192,17	197,26	198,25	206,82	207,82	242,32	247,96	257,51	278,36
60Gu14											
68Ra11		0,03(2)	0,03(2)						0,08(1)		
70Sp03		0,03(1)	0,03(2)						0,07(2)		
73So04		0,028(4)	0,025(4)		0,005(2)		0,0022(16)		0,068(6)		
76Wa13	0,0010(3)	0,0155(5) [⊠]	0,0238(8)	0,0004(2)	0,004(1)	0,004(1)	0,0013(4)	0,0004	0,0854(15)**	0,0018(5)	0,0027(5)
86Ag01									0,0864(31)	0,0026(12)	
87Ja10											
Adopted	0,0010(3)	0,022(6)	0,0239(8)	0,0004(2)	0,0042(9)	0,004(1)	0,00135(4)	0,0004	0,0838(27)	0,0019(5)	0,0027(5)
N	1	4	4	1	2	1	2	1	5	2	1
chi**2/N-1	0	2,07	0,09	0	0,2	0	0,3	0	2,16	0,38	0
Method		LWM, exp.unc	LWM, int. unc.		LWM, int. unc.		LWM, int. unc.		LWM, ext. unc.	LWM, int. unc.	
Abs. Value	0,00083(25)	0,0183(50)	0,0199(7)	0,00033(17)	0,0035(7)	0,0033(8)	0,00112(32)	0,0003330(8)	0,0698(23)	0,00160(22)	0,00225(42)

** = Input uncertainty multiplied by 1,75 in the program LWEIGHT

⊠ = Input uncertainty multiplied by 7,30 in the program LWEIGHT

exp.unc. = LWM expanded the uncertainty so range includes the most precise value.

int.unc. = internal uncertainty

ext.unc. = external uncertainty

Normalization factor = 83,25 (21)

Table 1.I-123, gamma emission intensities, relative values to the 158 keV and, absolute values

04/12/01

Ref	281,03	295,09	329,38	330,7	343,73	346,35	405,02	437,5	440,02	454,76	505,33
60Gu14	0,14(3) £			0,012(3)		0,16(3)			0,44(9)		0,280(6)
68Ra11	0,08(1)					0,12(2) (O)			0,42(2) (O)		0,31(5)
70Sp03	0,08(3)					0,11(3) (O)			0,42(8) (O)		0,32(8)
73So04	0,09(1)			0,017(6)		0,12(1)			0,46(2)	0,004(1)	0,27(3)
76Wa13	0,095(1)	0,0019	0,0031(7)	0,0139(5)	0,0051(5)	0,151(1)	0,0035(7)	0,0009(9)	0,514(6)	0,0047(6)	0,379(3)
86Ag01	0,095(44)			0,0142(7)	0,0055(5)	0,152(6)	0,0036(3)		0,524(21)	0,0051(3)	0,376(2)
87Ja10									0,450(29) ®		
Adopted	0,0948(1)	0,0019	0,0031(7)	0,01398(40)	0,00530(35)	0,151(1)	0,00358(28)	0,0009(9)	0,508(5)	0,00495(26)	0,32(5)
N	5	1	1	4	2	4	2	1	5	3	6
chi**2/N-1	0,68	0	0	0,27	0,32	3,22	0,02	0	2,98	0,66	3,8
Method	LWM, int. unc.			LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.		LWM, int. unc.	LWM, int. unc.	LWM, int. unc.
Abs. Value	0,0789(9)	0,0015818(40)	0,0026(6)	0,01164(33)	0,00441(29)	0,1257(9)	0,00298(23)	0,0007(7)	0,4229(43)	0,00412(22)	0,266(42)

® = Initial uncertainty multiplied by 2 by the evaluator

int.unc. = internal uncertainty

£ = Data rejection parameters for deviation from weighted average
(Chauvenet's criteria)

(O) = omitted value

Normalization factor = 83,25 (21)

Table 1.I-123, gamma emission intensities, relative values to the 158 keV and, absolute values

04/12/01

Ref	528,96	538,54	556,05	562,79	578,26	599,69	610,05	624,57	628,26	687,95	735,78
60Gu14	2,0(3) (O)										
68Ra11	1,27(11) (O)	0,32(2) (O)						0,08(1)		0,03(1)	0,04(1) (O)
70Sp03	1,26(24) (O)	0,31(6) (O)						0,07(2) (O)		0,04(2) £	0,05(2) (O)
73So04	1,40(5)	0,38(4)	0,0033(4)	0,0012(3)				0,085(5)		0,030(2)	0,06(3)
76Wa13	1,670(5)	0,458(5)	0,0037(5)	0,0013(5)	0,0018(5)	0,0031(11)	0,0013(4)	0,100(1)*	0,0019(3)	0,0321(15)	0,0739(14)
86Ag01	1,66(5)	0,460(21)		0,0014(1)	0,0015(1)	0,0032(2)		0,101(5)	0,0020(2)	0,0329(9)	0,0742(35)
87Ja10	1,41(6)®	0,379(31)®									
Adopted	1,58(10)	0,455(5)	0,00346(31)	0,00138(9)	0,00151(1)	0,0032(2)	0,0013(4)	0,0958(24)	0,00197(17)	0,0323(7)	0,074(1)
N	4	4	2	3	2	2	1	4	2	4	3
chi**2/N-1	8,34	3,3	0,39	0,21	0,35	0,01	0	3,28	0,08	0,5	0,11
Method	LWM, exp.unc.	LWM, int. unc.	LWM, int. unc.	LWM, int.unc.	LWM, int.unc.	LWM, int. unc.		LWM, ext. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.
Abs. Value	1,32(8)	0,3788(43)	0,00288(26)	0,00115(7)	0,00126(8)	0,00266(17)	0,00108(33)	0,0798(20)	0,00164(14)	0,0269(6)	0,0616(8)

* = Input uncertainty multiplied by 3,33 in the program LWEIGHT

exp.unc. = LWM expanded the uncertainty so range includes the most precise value

® = Initial uncertainty multiplied by 2 by the evaluator

int.unc. = internal uncertainty
ext.unc. = external uncertainty

£ = Data rejection parameters for deviation from weighted average (Chauvenet's criteria)

(O) = omitted value

Normalization factor = 83,25 (21)

Table 1.I-123, gamma emission intensities, relative values to the 158 keV and, absolute values

04/12/01

Ref	783,59	837,1	877,52	894,8	909,12	1036,63	1068,12
60Gu14							
68Ra11	0,05(1) (O)						
70Sp03	0,05(2) (O)						
73So04	0,068(5)	0,0008(2)	0,0010(2)	0,0017(5)	0,0017(4)	0,0010(2)	0,0014(2)
76Wa13	0,0713(14)	0,0006(1)	0,0013(8)	0,0011(3)	0,0016(3)	0,0012(3)	0,0017(1)
86Ag01	0,0718(35)	0,00070(1)	0,0010(1)	0,0012(1)	0,0017(1)	0,0012(1)	0,0018(1)
87Ja10							
Adopted	0,0712(13)	0,000699(10)	0,00100(9)	0,00121(9)	0,00169(9)	0,00116(9)	0,00171(8)
N	3	3	3	3	3	3	3
chi**2/N-1	0,22	0,62	0,07	0,55	0,05	0,41	1,61
Method	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int.unc.	LWM, int. unc.	LWM, ext.unc.
Abs. Value	0,0591(11)	0,000582(8)	0,00083(7)	0,00101(7)	0,00141(8)	0,00097(7)	0,00142(7)

(O) = omitted value

int.unc. = internal uncertainty

ext.unc. = external uncertainty

Normalization factor = 83,25 (21)

¹²³Te^m - Comments on evaluation of decay data by M. M. Bé and V. Chisté

This evaluation was completed in October 1993 and has been updated in September 2002.

Several measurements of the gamma emission intensity and of the total internal conversion coefficient of the 159-keV line were carried out. The decay scheme has been constructed mainly from these measurements.

Nuclear Data

- Spins and parities are from the LPRI “Table de Radionucléides” [1]-

- The half-life value is the weighted average of : 119,7(3) (Emery 1970 – 1970EmZY) and 119,2(1) (Coursey 1992 – 1992Co11) ; its uncertainty is the internal uncertainty.

Gamma Transitions

- 88-keV gamma transition

For this M4 transition, the various theoretical conversion coefficients differ by about 5%. They are compared with measured values in the following table :

	Th. value Band 2002 – (2002Ba85)	Th. Value Rösel 1978 – (1978Ro22)	Exp. Value Kalinauskas 1969 – (1968Ka20)	Exp. Value Raman 1973 – (1973Ra32)	Exp. value Chu 1964 – (1964Ch18)
α_T	1099	1151	1000 (70)	1080 (40)	
α_K	463	483			455 (9)
α_L	493	517			482 (14)
α_M	118	124			

Values interpolated from the new Band *et al.* tables (2002Ba85), have been adopted following the recommendations of Gorozhankin (2002) [3].

The transition probability has been deduced from the decay scheme balance at the 159-keV level.

- 247-keV gamma transition

The conversion coefficients, for this E5 transition, were calculated using the new tables of Band *et al.* (2002Ba85) as suggested by Gorozhankin [2, 3]. The theoretical α_T (7,75 (30)) agrees with the measured value (8,1(4)) given by Raman (1973Ra32).

The transition probability has been deduced using this theoretical value for α_T and the gamma emission intensity (see below).

- 159-keV gamma transition

For the 159-keV gamma transition, the following values of the mixing ratio squared δ^2 have been found in the literature :

Reference	d ²	a _T
Goldberg <i>et al.</i> – (1955Go25)	0,013(1)	1,919 10 ⁻¹
Fagg <i>et al.</i> – (1955Fa40)	0,0034(20)	1,905 10 ⁻¹
Chu <i>et al.</i> – (1964Ch08)	0,0067(11)	1,909 10 ⁻¹
Gupta <i>et al.</i> – (1966Gu02)	0,011(8)	1,916 10 ⁻¹
Alkhazov <i>et al.</i> – (1964Al28)	0,004(5)	1,906 10 ⁻¹
Törnkvist <i>et al.</i> – (1969To02)	0,0119(9)	1,917 10 ⁻¹
Krane – (1977Kr13)	0,01232 (47) (adopted value)	1,918 10 ⁻¹

The internal conversion coefficients were calculated by ICC Computer Code [2] by interpolation of the Rösler tables (1978Ro22).

Elsewhere, the following measurements of the α_T coefficients were carried out :

Chu1964 (1964ch08)	0,1964 (74)
Hatch1966 (1966Ha03)	0,1979 (54)
Janssen1992 (1999Ja15)	0,1932 (46)
Janssen1992 (1999Ja15)	0,1895 (13)

The weighted mean of the above values is 0,1904 with a reduced-χ² of 1,14 ; the internal uncertainty is 0,0012; the external uncertainty 0,0013. This value is in good agreement with the theoretical adopted α_T (0,1918(19)).

The transition probability was deduced from the evaluated value (see below) of the emission intensity, using the adopted α_T.

Gamma Ray Emissions

- 159-keV gamma ray emission intensity is the weighted mean of :

83,65	0,50	(Chu – 1964Ch08)
83,48	0,38	(Hatch – 1966Ha03)
83,2	0,5	(Schötzig 1991 – [5])
83,9	0,6	(Coursey – 1992Co11)
83,81	0,32	(Janssen – 1992Ja15)
84,07	0,09	(Janssen – 1992Ja15)

The adopted value 83,99 is the weighted mean with an internal uncertainty of 0,08, and a reduced-χ² of 1,18.

[From the decay scheme and the α_T = 0,1918(19), the expected value is 83,90(14).]

- From α_T = 1099(33) and the decay scheme, the 88-keV gamma ray emission intensity is 0,0909(27). This value agrees with I_γ(88) = 0,0927(34), deduced from the ratio I_γ(159)/I_γ(88) = 906(33) measured by Raman (1972Ra07), using I_γ(159) = 83,99(8).

- The 247-keV gamma ray emission intensity of 0,000344(34) has been deduced from the ratio $I_{\gamma}(247)/I_{\gamma}(159) = 4,1(4) 10^{-6}$ measured by Raman (1973Ra32).

Conversion electrons

The conversion electron emission intensities have been calculated using conversion coefficients and gamma-ray emission intensities.

Atomic Data

The ω_K value is from Bambynek (1984) [6].

The ω_L value is from Schönfeld (1996Sc06).

The X-ray and Auger electron emission intensities have been calculated by using the program EMISSION (version 3.01) [4]

References

- [1] F. Lagoutine, N. Coursol, J. Legrand.
Table de Radionucléides, CEA/DIMRI, F-91191 Gif-sur-Yvette cedex, ISBN 2 7272 0078 1
- [2] V. M. Gorozhankin, N. Coursol, E. A. Yakushev. ICC99v3a: A computer program for interpolating internal conversion coefficients from Hager and Seltzer, Rosel et al., and from Band et al. (1999), BNM-CEA/LNHB
- [3] V. M. Gorozhankin, N. Coursol, E. A. Yakushev.
Appl. Rad. Isot. **56**, 189 (2002)
- [4] E. Schönfeld, H. Janssen. The program EMISSION Computer Code, PTB
Appl. Radiat. Isot. **52**, 595 (2000).
- [5] U. Schötzgig, H. Schrader, K. Debertin. Proc. Int. Conf. Nuclear Data Sci. Techn., Jülich, 13-17 May (1991)
- [6] W. Bambynek. X-84 Proc. X-Ray and Inner-Shell Processes in Atoms, Molecules and Solids, A. Meisel Ed., Leipzig Aug. 20-23 (1984)
- 1955Fa40 – L. W. Fagg, E. A. Woliki, R. O. Bondelid, K. L. Dunning, S. Snyder.
Phys. Rev. **100**, 1299 (1955).
- 1955Go21 – N. Goldberg, S. Frankel.
Phys. Rev. **100**, 1350 (1955).
- 1964Al28 – D. G. Alkhozov, V. D. Vasilev, G. M. Gusinskii, I. K. Lemberg, V. A. Nabichvrishvili.
Bull. Acad. Sci. USSR, Phys. Ser. **28**, 1575 (1965).
- 1964Ch18 – Y. Y. Chu, M.L. Perlman.
Phys. Rev. **135**, B319 (1964).
- 1964Ch08 – Y. Y. Chu, O. C. Kistner, A. C. Li, S. Monaro, M. L. Perlman.
Phys. Rev. **133**, B1361 (1964).
- 1966Gu02 – S. L. Gupta, M. M. Bajaj, N. K. Saha.
Nucl. Phys. **80**, 471 (1966).
- 1966Ha03 – E. N. Hatch, G. W. Eakins, G. C. Nelson, R. E. McAdams.
Proc. Intern. Conf. Internal Conversion Process, Nashville, Tenn. (1965), J.H. Hamilton, Ed., Academic Press, Inc., New York, p. 183 (1966).
- 1968Ka20 - R. A. Kalinauskas, K. V. Makaryunas, E. K. Makaryunene, R. I. Davidonis.
Bull. Acad. Sci. USSR, Phys. Ser. **32**, 187 (1969).
- 1969To02 – S. Tornkvist, S. Strom, L. Hasselgren.
Nucl. Phys. **A130**, 604 (1969).
- 1970EmZY – J. F. Emery, S. A. Reynolds, E. I. Wyatt.
ORNL-4466, p. 75 (1970).

- 1972Ra07 – S. Raman
Nucl. Instrum. Methods **103** (1972) 407
- 1973Ra32 – S. Raman, R. L. Auble, W. T. Milner.
Phys. Lett. **47B**, 19 (1973).
- 1974RaZO – S. Raman, R. L. Auble, W. T. Milner, T. A. Walkiewickz, R. Gunnink, B. Martin.
Report ORNL-4937, p. 144 (1974).
- 1977Kr13 – K. S. Krane.
At. Data Nucl. Data Tables **19**, 363 (1977).
- 1978Ro22 – F. Rosel, H. M. Fries, K. Alder, H. C. Pauli.
At. Data Nucl. Data Tables **21**, 92 (1978).
- 1992Ja15 – H. Janssen, E. Schönfeld, R. Klein.
Appl. Radiat. Isot. **43**, 1309 (1992).
- 1992Co11 – B. M. Coursey, D. B. Golas, D. H. Gray, D. D. Hoppes, F. J. Schima.
Nucl. Instrum. Methods Phys. Res. **A312**, 121 (1992).
- 1996Sc06 – E. Schönfeld, H. Janssen.
Nucl. Instrum. Methods Phys. Res. **A369**, 527 (1996).
- 2002Ba85 – I. M. Band, M. B. Trzhaskovskaya, C. W. Nestor, Jr., P. O. Tikkanen, S. Raman.
At. Data Nucl. Data Tables **81**, 1 (2002).

¹²⁵Sb -Comments on evaluation
by R. G. Helmer

1. Decay Scheme

¹²⁵Sb decays by β^- emission to levels in ¹²⁵Te.

The γ ray at 109 keV depopulates the isomeric level at 144 keV (half-life of 57.4 days), so its intensity depends on any chemical separation and its grow-in time. It takes about 1 year for it to be in equilibrium with the other γ rays to within 1%. The level at 35 keV is primarily fed from higher-lying levels, but 27% of the 35-keV γ -ray intensity comes via the isomeric level when it is at equilibrium. So, for a chemically separated source, it needs about 8 months grow-in to be at equilibrium at the 1% level.

The population of the isomer is 23.9 (9)% calculated from this adopted scheme.

2. Nuclear Data

The decay energy of 766.7 (21) keV is from the 2003 mass evaluation (2003Au03).

For the adopted decay scheme, the total radiation energy per decay is calculated to be 767 (8) keV, which agrees well with the decay energy of 766.7 (21) keV and confirms the internal consistency of this decay scheme.

The population of several additional levels has been reported, especially by 1998Sa55, but these levels are uncertain; they are : 402-, 538-, 652- and 728- keV. Verification of the associated γ rays is needed. Thus, β and γ transitions to and from these levels have not been included here.

The adopted parent half-life is 1007.54 (9) days, or 2.75855 (25) years, from the following data:

2.7 y	1950Le09
2.6 (1) y	1960Kl04
2.78 (4) y	1961Wy01
2.71 (2) y	1965F102
2.81 (5) y	1966La13
1007.3 (3) d	1980Ho17
1008.1 (8) d	1983Wa26
1007.3 (3) d	1992Un01, superseded by 2002Un02
1007.56 (10) d	2002Un02
1007.54 (9) d	Weighted average

Adopted value is the weighted average of the three precise values (which are from after 1970) which are not superseded. The reduced- χ^2 value for this average is 0.58 and the value from 2002Un02 has 89% of the relative weight.

The values from other evaluations are 2.75856 (25) years from 1999Ka26, which did not have available the value from 2002Un02, and 1007.48 (21) days from 2004Wo02 where the relative weight of the value from 2002Un02 was presumably reduced to 50%.

The level half-lives are also taken from the evaluation 1999Ka26 and are as follows:

Energy (keV)	Half-life
0	Stable
35	1.48 (1) ns
144	57.40 (15) d
321	0.673 (13) ns
443	19.1 (6) ps
463	13.2 (5) ps
525	<160 ns
636	40 (20) ps
642	≤ 70 ps
671	1.26 (6) ps

The references that provide measured values of the level half-lives are: 1965An05, 1966In02, 1967Vo21, 1968Ho05, 1968Ko08, 1969Ho42, 1970Ba69, 1970Be47, 1970Be51, 1970Ma20, 1972Be21, 1972La21, 1972Sa08, 1972Sa33, 1988GeZS, and 1992De26. Half-lives for the levels at 443, 463, and 671 keV were calculated from B(E2) values from Coulomb excitation studies (1999Ka26).

2.1 β^- Transitions

The probabilities for the β^- transitions branches are computed from the intensity balances from the γ -ray transitions for the excited states above 150 keV. Upper limits for the β^- probabilities to the 0- and 35-keV levels can be computed from the log ft systematics (1998Si17); these values are 0.002% and 1.9%, respectively. In the adopted level scheme it is assumed that both of these values are 0. The resulting values are :

Level (keV)	P_{β^-} (%)	Character	log ft
0	<0.002	unique 2 nd forb.	>13.9
35	≡0	2 nd forb.	>10.6
144	15.2(9)	unique 1 st forb.	9.77
321	7.10 (10)	1 st forb.	9.34
443	0.087 (10)	2 nd forb.	11.06
463	39.8 (4)	allowed	8.04
525	1.585 (24)	1 st forb.	9.12
636	17.95 (22)	allowed	7.23
642	5.75 (6)	allowed	7.66
671	13.42 (15)	allowed	6.93

For comparison, the measured values to the 144-keV level are 13.6 (9)% by 1998Gr13, 13.4% by 1959Na06,

and 13.7% by 1964Ma30.

2.2 γ Transitions

The γ -ray multiplicities and mixing ratios have been taken from 1999Ka26 and the internal-conversion coefficients are interpolated from the tables of 1978Ro22, except the E5 which is from 1976Ba63. These values are as given in the following table. The uncertainties in the internal-conversion coefficients are taken to be 3% of the value, unless otherwise given.

Energy (keV)	Multi-polarity.	Δ	%E2 or M2	α	α_K
19	[M1]			11.3	0.0
35	M1+E2	0.029 (+3-2)	0.084 (18)	14.3	12.1
109	M4			364	186
117	E1			0.127	0.109
144	[E5]			265	39.8
172	M1(+E2)	-0.004 (8)	<0.014	0.151	0.130
176	M1+E2	-0.60 (2)	26.5 (18)	0.167	0.130
178	M1+E2			0.18 (4)	0.147 (26)
198	[E2]			0.154	0.123
204	M1+E2	+1.60 (3)	72 (3)	0.128	0.104
208	M1+E2	+0.105 (14)	1.1 (3)	0.091	0.079
227	(M1+E2)			0.084 (13)	0.070 (11)
315	(E1)			0.00839	0.00726
321	E1			0.00798	0.0691
380	E2			0.0183	0.0154
408	M1+E2	+1.50 (7)	69 (6)	0.0152	0.0129
427	M1+E2	-0.538 (11)	22.4 (9)	0.0138	0.0119
443	M1+E2	-2.3 (1)	84 (7)	0.0118	0.0100
463	E2			0.0102	0.0086
497	[M2]			0.0318	0.0271
600	E2			0.00498	0.00420
606	E2			0.00485	0.00413
635	M1+E2	+0.332 (3)	9.9 (2)	0.00526	0.00455
672	E2			0.00373	0.00320

The references that provide data on the multiplicities and mixing ratios are: 1968An15 [from α_K], 1970Na12 [α_K , K/L], 1970Wy01 [$\gamma\gamma(\theta)$], 1971Kr11 [$\gamma(\theta)$ oriented nuclei], 1971Ro17 [$\gamma\gamma(\theta)$], 1971Sa24 [$\gamma\gamma(\theta)$], 1972Ba12 [$\gamma\gamma(\theta)$], 1972Br02 [L_i/L_j], 1975Ma32 [M_i/M_j], 1982Mu02 [α_K], 1982Si18 [$\gamma\gamma(\theta)$], 1983Si14 [$\gamma\gamma(\theta)$], 1997De38 [$\gamma\gamma(\theta)$], 1998Ro20 [$\gamma\gamma(\theta)$], 1998Sa36 [α_K , K/L], 1998Sa55 [α_K], and 1999Sa73 [α_K].

The γ -ray energies have been reported by 1969Ch09, 1970Na12, 1973Gu10, 1976Wa13, 1990He05, 1998Sa55, and 2000He14, with the last three references giving the more precise values. The calibration details are not given in 1998Sa55, so it is not possible to compare these values with the others. The values of 2000He14 are on the most recent energy scale on which the energy of the strong γ ray from the decay of ^{198}Au is 411.80205 (17) keV, while those from 1990He05 are on a scale for which this energy is 411.8044 (11) keV. No correction is made here for this difference. The energies are taken from 2000He14 if they are available there, from 1990He05 as a second choice, and as indicated otherwise. (Often these values are from use of energy combinations so they can not be averaged with direct measurements). These values are: from 2000He14: 176.314 (2), 204.138 (10), 208.077 (5), 427.874 (4), 443.555 (9), 463.365 (4), 600.597 (2), 606.713 (3), 635.950 (3), and 671.441 (6); from 1990He05: 35.489 (5), 172.719 (8), 178.842 (5), 198.654 (11), 227.891 (10), 380.452 (8), and 408.065 (10); 1976Wa13 and 1998Sa55: 19.981 (6), 110.86 (7), 314.96 (8), and 497.38 (9); 1973Gu10, 1976Wa13, and 1998Sa55: 109.27 (11), and 116.95 (7).

The recommended relative and absolute γ -ray emission probabilities are discussed in section 4.2.

3. Atomic Data

3.1 X rays and Auger electrons

The fluorescence yield data are from Schönfeld and Janßen (1996Sc06) and the EMISSION code; these values are ω_K , 0.875(4); mean ω_L , 0.086 (4); and η_{KL} , 0.917 (4).

The EMISSION code also supplies the Auger electron emission probabilities; these values are: KLL, 6.45 (28); KLX, 2.92 (13); and KXY, 0.331 (16).

4 Emissions

4.1 K x-rays

The relative K x-ray emission probabilities are from 1996Sc06 and the absolute probabilities have been computed from these relative probabilities, the above γ -ray emission probabilities, and internal-conversion coefficients.

The relative emission probabilities are: $K_{\alpha 2}$, 0.5370 (25); $K_{\alpha 1}$, 1.0000; and K_{β} , 0.3483 (35) and the absolute probabilities (in %) are $K_{\alpha 2}$, 19.5 (6); $K_{\alpha 1}$, 36.3 (11); and K_{β} , 12.7 (4).

4.2 γ rays

The measured relative γ -ray emission probabilities (or intensities) are given in the following table. The values for the 109-keV γ ray are for a source in equilibrium.

Part 1

Energy	68An15 ^a	68Se11 ^b	69Ch09	70Na12	73Gu10	74Il02 ^c	76Wa13	77Ar10	77Ge12
19.9							0.068 (33)		
35.5				19.6 (20)		1.42 (9)			
58.3									
109.3		0.3	0.3 (1)	0.39 (4) ^f	0.18 (2)	0.36 (4)			
110.8		~ 0.05				0.170 (23)	0.0031 (3)		
117.0		0.75		1.13 (1) ^f	0.75 (4) ^f	0.96 (7)	0.866 (14)	0.89 (4)	0.910 (29)
172.6		0.8	0.9 (1)	0.90 (10)	0.65 (4)	0.47 (3)	0.618 (10)	0.65 (5)	
176.3		20.5	21.2 (11)	24.9 (20)	23.9 (8)	23.2 (13)	23.06 (7) ^g	22.9 (7)	23.9 (7)
178.7		~0.1			0.08 (1)	0.05 (1)	0.092 (14)	0.10 (2)	
198.6		~0.04			0.04 (1)		0.044 (10)	0.055 (10)	
204.1		0.9	1.0 (1)	1.15 (10)	1.21 (5)	1.10 (8)	1.097 (14)	0.99 (5)	1.15 (4)
208.1		0.7	0.8 (1)	0.85 (8)	0.90 (4)	0.83 (5)	0.802 (14)	0.79 (4)	0.829 (25)
227.9	0.4 (1)	0.4		0.44 (4)	0.47 (2)	0.64 (4)	0.448 (14)	0.45 (2)	
315.0							0.0143 (14)	0.020 (4)	
321.0	1.4 (2)	1.25	1.4 (1)	1.41 (10)	1.42 (5)	1.6 (1)	1.393 (14)	1.41 (7)	1.422 (16)
380.4	5 (1)	5	5.0 (4)	5.27 (40)	5.22 (17)	5.43 (32)	5.16 (3)	5.15 (20)	5.10 (5)

Energy	68An15 ^a	68Se11 ^b	69Ch09	70Na12	73Gu10	74Il02 ^c	76Wa13	77Ar10	77Ge12
408.1	0.9 (4)	0.6		0.62 (6)	0.59 (3)	0.50 (3)	0.62 (2)	0.59 (3)	
427.9	100.	100.	100.	100.	100.	100.	100.0 (3)	100.	100.0 (10)
443.4	0.5 (3)	1		1.03 (10)	1.07 (4)	1.10 (7)	1.03 (2)	1.05 (5)	
463.4	33 (4)	35.5	35.3 (20)	35.4 (28)	35.3 (13)	35.2 (23)	35.50 (7)	35.2 (10)	35.26 (37)
497.0							0.0122(14)	0.011 (2)	
600.6		61	61.2 (34)	61.5 (49)	59.6 (18)	53.6 (32)	60.39 (10)	60.1 (18)	60.6 (6)
606.6		17	17.1 (12)	16.4 (12)	16.9 (6)	19.0 (11)	17.052 (34)	16.8 (5)	17.12 (17)
635.9	42 (2)	37	37.0 (22)	37.31 (30)	38.2 (12)	35.6 (23)	38.45 (7)	38.4 (11)	38.6 (4)
671.4	6.5 (5)	6	5.6 (5)	6.0 (5)	6.09 (20)	6.24 (38)	6.11 (14)	6.02 (24)	6.18 (6)

Part 2

Energy	79Pr08	80Ro22	83Si14	84Iw03	86Wa35	93Fa02	98Sa55	90He05
19.9			0.068 (2)			0.072 (6)	0.068 (3)	
35.5			14.53 (35)			14.79 (8) ^d	17.7 (2)	
58.3			0.091 (4)			0.093 (2)	0.0042 (20)	
109.3	0.26 (4)		0.232 (5)	0.241 (24)		0.235 (16)	0.232 (6)	
110.8	0.02 (1) ^h		0.0042 (3)				0.0039 (3)	
117.0	0.91 (5)	1.01 (12)	1.060(10) ^f	0.867 (25)		0.885 (5) ^j	0.945 (15)	0.867 (24)
172.6	0.74 (6)	0.89 (6)	0.86 (2) ^f	0.69 (4)		0.72 (4)	0.67 (4)	0.659 (11)

Energy	79Pr08	80Ro22	83Si14	84Iw03	86Wa35	93Fa02	98Sa55	90He05
176.3	22.9 (6)	25.45 (60)	24.5 (8)	22.62 (21)	22.91 (41)	23.65 (34)	23.09 (20)	22.96 (24)
178.7	0.11 (1)		0.130 (5)	0.11 (4)		0.099 (6)	0.121 (2) ^j	
198.6	0.06 (1)		0.081 (4) ^f	0.030 (11)		0.046 (9)	0.044 (3)	
204.1	1.12 (4)	1.19 (22)	1.14 (4)	1.08 (3)		1.19 (5)	1.014 (10)	1.080 (23)
208.1	0.80 (4)	0.96 (10)	0.82 (2)	0.788 (21)		0.89 (3)	0.860 (10)	0.825 (16)
227.9	0.42 (2)	0.42 (7)	0.44 (2)	0.433 (12)		0.465 (25)	0.442 (9)	0.443 (23)
315.0			0.013 (2)				0.0144 (15)	
321.0	1.48 (6)	1.46 (8)	1.30 (5)	1.391 (24)		1.45 (5)	1.43 (2)	1.41 (3)
380.4	5.18 (20)	5.26 (10)	6.02 (25) ^f	5.06 (4)	5.12 (15)	5.09 (3)	5.17 (4)	5.14 (5)
408.1	0.57 (4)	0.66 (8)	0.61 (3)	0.608 (21)		0.59 (2)	0.624 (7)	0.630 (19)
427.9	100.	100.	100.	100.0 (7)	100.	100.	100.	100.0 (8)
443.5	1.06 (2)	1.03 (8)	1.12 (5)	0.989 (23)		1.03 (1)	1.05 (11)	1.019 (29)
463.4	35.1 (8)	35.45 (84)	35.50 (7)	35.23 (14)	35.4 (9)	35.64 (10)	35.12 (18)	35.07 (28)
497.0			0.015 (3)	0.009 (8)		0.018 (3)	0.009 (1)	
600.6	60.4 (11)	59.3 (12)	60.50 (10)	59.54 (22)	60.95 (67)	59.70 (10)	59.22 (18)	59.09 (45)
606.6	16.6 (5)	16.25 (62)	17.2 (3)	16.94 (7)	16.97 (26)	16.98 (21)	16.92 (6)	16.70 (14)
635.9	38.7 (8)	37.7 (10)	39.1 (2)	37.87 (14)	37.47 (27)	38.78 (32)	38.32 (12)	37.52 (30) ^h
671.4	6.04 (16)	6.92 (14) ^f	5.9 (3)	6.039 (24)	5.65 (12)	5.97 (11)	6.03 (2)	6.05 (6)

Part 3

Energy	Adopted	wtd. avg.	S _{int}	reduce d-χ ²	σ _{ext}	σ _{LWM}	P _γ (%) x0.292 (3)	90Lo03 eval.	1999Ka26 eval.
19.9	0.0683 (16)	0.0683	0.0016	0.14			0.0199 (5)	0.068 (2)	0.069 (3)
35.5	20.0 (2) ⁱ	16.0	0.13	43	0.9	1.7	5.84 (8)	14.53 (35)	15.2 (10)
58.3		^e						0.091 (4)	0.05 (4)
109.3	0.231 (4)	0.2310	0.0036	1.3	0.0041		0.0675 (14)	0.233 (5)	
110.8	0.0037 (3)	0.00373	0.00017	3.6	0.00033		0.00108 (9)	0.0036 (6)	0.0035 (4)
117	0.890 (9)	0.890	0.006	2.5	0.009		0.260 (4)	1.03 (4)	0.887 (9)
172.6	0.65 (3)	0.649	0.007	4.6	0.014	0.031	0.190 (9)	0.75 (5)	0.646 (24)
176.3	23.09 (15)	23.09	0.09	2.6	0.15		6.74 (8)	23.06 (14)	23.11 (5)
178.7	0.116 (5)	0.116	0.002	5.0	0.005		0.0339 (15)	0.110 (9)	0.114 (8)
198.6	0.0448 (24)	0.0448	0.0024	0.9			0.0131 (7)	0.054 (11)	0.0432 (20)
204.1	1.06 (5)	1.061	0.007	4.6	0.015	0.047	0.310 (15)	1.105 (11)	1.070 (21)
208.1	0.833 (27)	0.833	0.006	2.3	0.009	0.027	0.243 (8)	0.808 (9)	0.837 (14)
227.9	0.443 (9)	0.443	0.005	0.5			0.129 (3)	0.437 (12)	0.443 (6)
315	0.0144 (9)	0.0144	0.0009	0.8			0.0042 (3)	0.0138 (9)	0.0136 (16)
321	1.409 (8)	1.409	0.008	0.9			0.411 (5)	1.40 (2)	1.404 (9)
380.4	5.145 (13)	5.145	0.012	1.2	0.013		1.502 (15)	5.13 (4)	5.124 (19)
408.1	0.617 (5)	0.617	0.005	0.7			0.1802 (24)	0.611 (12)	0.623 (6)
427.9							29.2 (3)	100	100
443.5	1.033 (7)	1.033	0.007	1.0			0.302 (4)	1.03 (2)	1.035 (6)

Energy	Adopted	wtd. avg.	s_{int}	reduce $d-\chi^2$	σ_{ext}	σ_{LWM}	P_{γ} (%) x0.292 (3)	90Lo03 eval.	1999Ka26 eval.
463.4	35.47 (4)	35.47	0.04	1.0			10.36 (10)	35.47 (5)	35.45 (10)
497	0.0109 (11)	0.0109	0.0007	2.4	0.0011		0.0032 (3)	0.013 (2)	0.014 (8)
600.6	60.1 (4)	60.07	0.05	6.0	0.13	0.43	17.55 (21)	60.36 (11)	59.62 (16)
606.6	16.997 (27)	19.997	0.027	1.0			4.96 (5)	17.03 (3)	16.83 (6)
635.9	38.31 (14)	38.31	0.05	4.7	0.11	0.14	11.19 (12)	38.36 (15)	37.9 (3)
671.4	6.036 (17)	6.036	0.014	1.5	0.017		1.763 (19)	6.06 (2)	6.049 (19)

^a All values from this reference omitted from analysis since 5 out of 8 were outliers in an initial averaging.

^b All values from this reference omitted from analysis since they do not have uncertainties.

^c All values from this reference omitted from analysis since 9 out of 19 were outliers in an initial averaging.

^d Uncertainty increased from 0.08 to 0.20 by evaluator.

^e No value adopted; data are very inconsistent, namely, 0.091, 0.093, and 0.004.

^f Omitted from average, outlier.

^g Uncertainty increased from 0.07 to 0.20 by evaluator.

^h Typographical error in reference. A portion of the feeding of this γ ray is via the 58-day isomer. Most papers do not give sufficient experimental detail to know if their source was at equilibrium. The value adopted was chosen by the evaluator to give an intensity balance at the 35-keV level.

^j Uncertainty increased in analysis to reduce relative weight to 50%.

Other γ rays have been reported in various papers, but have not been included in the scheme adopted here. For those from 1998Sa55 the energies and relative emission probabilities are listed here and for the other references only the energies are given. These lines are:

1968An15: 122.4, 489.8;

1968Se11: 105.8, 391.5;

1973Gu10: 81.8, 122.4;

1974II02: 81.8, 489.8;

1976Wa13: 146.1;

1979Pr08: 81.8, 122.1, 366.0, 402.0;

1983Si14: 642.1, 693.2, 729.8; and

1998Sa55: [I_γ]: 61.8 [0.0067 (27)]; 81.0 [0.017 (1)]; 132.8 [0.0029 (19)]; 209.3 [0.152 (9)]; 331.8 [0.0085 (8)]; 366.5 [0.027 (2)]; 401.9 [0.0221 (2)]; 489.7 [0.0046 (23)]; 491.2 [0.016 (8)]; 503.1 [0.013 (6)]; 538.6 [0.0047 (25)]; 617.4 [0.018 (2)]; and 652.8 [0.009 (3)].

The normalization of the relative γ -ray emission probabilities has been done by setting the total feeding of the ground state to 100%; this gives a normalization factor of 0.292 (3). The resulting γ -ray emission probabilities are given in the third from the last column. The last two columns give the relative probabilities from the evaluations of 1990Lo03 and 1999Ka26. The agreement is very good except for the lines at 35 keV, where this evaluator has taken a value from the intensity balance, and 117 and 172 where 1990Lo03 gives larger values.

The γ ray at 109 keV depopulates the isomeric level at 144 keV (half-life of 58 days), so its intensity depends on any chemical separation and its grow-in time. It takes about 1 year for it to be in equilibrium with the other γ rays to within 1%. The level at 35 keV is primarily fed from higher-lying levels, but 27% of the 35-keV γ -ray intensity comes via the isomeric level when it is at equilibrium. So, for a chemically separated source, it needs about 8 months grow-in to be at equilibrium at the 1% level.

The population of the isomer was measured to be 24.3 (3) % (1998Gr13) compared to the 23.9 (9)% calculated from this adopted scheme.

4.3 Conversion electrons

From the adopted γ -ray intensities, and the conversion coefficients, one obtains the following conversion electron emission probabilities:

γ energy (keV)	shell	electron energy	emission prob. (%)
19.80	L	14.86	0.180 (7)
	M	18.79	0.0362 (14)
	N	19.63	0.0076 (3)
35.49	K	3.675	71 (3)
	L	30.55	9.6 (4)
	M	34.48	1.93 (9)
	N	35.35	0.406 (16)
109.28	K	77.46	12.6 (5)
	L	104.33	9.3 (4)
	M	108.27	2.18 (8)

γ energy (keV)	shell	electron energy	emission prob. (%)
	N	109.11	0.451 (18)
116.96	K	85.14	0.0284 (11)
	L	112.02	0.00367 (15)
172.72	K	140.90	0.0247 (10)
	L	167.78	0.0032 (1)
176.31	K	144.50	0.94 (3)
	L	171.37	0.149 (6)
	M	175.30	0.030 (1)
178.84	K	147.03	0.0050 (8)
	L	173.90	0.0009 (3)
198.65	K	166.84	0.00161 (10)
204.14	K	172.32	0.0322 (19)
	L	199.19	0.0059 (4)
	M	203.13	0.00120 (7)
208.08	K	176.26	0.0192 (8)
	L	203.13	0.00248 (10)
227.89	K	196.08	0.0090 (15)
	L	222.95	0.0014 (5)
321.04	K	289.23	0.00284 (11)
380.45	K	348.64	0.0231 (9)
	L	375.51	0.0035 (1)
408.06	K	376.25	0.00232 (9)
427.87	K	396.06	0.347 (14)
	L	422.94	0.0450 (18)
	M	426.87	0.0090 (3)
443.56	K	411.74	0.00302 (12)
463.36	K	431.55	0.090 (4)
	L	458.43	0.0128 (5)
	M	462.36	0.0026 (1)
600.60	K	568.78	0.074 (3)

γ energy (keV)	shell	electron energy	emission prob. (%)
	L	595.66	0.0101 (4)
	M	599.59	0.0020 (1)
606.72	K	574.90	0.0206 (8)
	L	601.77	0.0028 (1)
635.95	K	604.14	0.0509 (20)
	L	631.01	0.0063 (2)
671.44	K	639.62	0.00564 (22)
	L	666.50	0.0008

References

- 1950Le09 - G. R. Leader, W. H. Sullivan, *NNES* **9** (1950) 934 [$T_{1/2}$]
- 1959Na06 - R. S. Narcisi, Thesis, Harvard University (1959); AECU-4336 (1959) [I_{β}]
- 1960Kl04 - E. H. Klehr, A. F. Voigt, *J. Inorg. Nuclear Chem.* **16**(1960)8 [$T_{1/2}$]
- 1961Wy01 - E. I. Wyatt, S. A. Reynolds, T. H. Handley, W. S. Lyon, H. A. Parker, *Nucl. Sci. Eng.* **11**(1961)74 [$T_{1/2}$]
- 1965An05 - G. Andersson, G. Rudstam, G. Sorensen, *Ark. Fys.* **28**(1965)37 [$T_{1/2}$ level]
- 1965Fl02 - K. F. Flynn, L. E. Glendenin, E. P. Steinberg, *Nucl. Sci. Eng.* **22**(1965)416 [$T_{1/2}$]
- 1966In02 - T. Inamura, T. Iwashita, S. Kageyama, *J. Phys. Soc. Japan* **21**(1966)2425 [$T_{1/2}$ level]
- 1966La13 - F. O. Lawrence, W. R. Daniels, D. C. Hoffman, *J. Inorg. Nucl. Chem.* **28**(1966)2477 [$T_{1/2}$]
- 1968An15 - D. S. Andreev, V. K. Bondarev, L. N. Laperin, A. Z. Ilyasov, I. K. Lemberg, *Bull. Acad. Sci. USSR, Phys. Ser.* **32**(1969)225 [I_{γ} , multipolarity]
- 1968Ho05 - C. Hohenemser, R. Rosner, *Nucl. Phys.* **A109**(1968)364 [$T_{1/2}$ level]
- 1968Ko08 - J. Kownacki, J. Ludziejewski, M. Moszynski, *Nucl. Phys.* **A113**(1968)561 [$T_{1/2}$ level]
- 1968Se11 - H. Sergolle, *Compt. Rend.* **267B**(1968)1042 [I_{γ}]
- 1969Ch09 - P. R. Christensen, A. Berinde, I. Neamu, N. Scintei, *Nucl. Phys.* **A129**(1969)337 [E_{γ} , I_{γ}]
- 1969Ho42 - R. R. Hosangdi, P. N. Tandon, S. H. Devare, *Indian J. Pure Appl. Phys.* **7**(1969)604 [$T_{1/2}$ level]
- 1970Ba69 - M. M. Bajaj, S. L. Gupta, N. K. Saha, *Proc. Nat. Inst. Sci. India* **36A**(1970)176 [$T_{1/2}$ level]
- 1970Be47 - E. E. Berlovich, V. V. Lukashevich, A. V. Popov, V. M. Romanov, *Sov. J. Nucl. Phys.* **12**(1971)117 [$T_{1/2}$ level]

- 1970Be51 - B. Bengtson, M. Moszynski, Nucl. Instrum. Methods **85**(1970)133 [$T_{1/2}$ level]
- 1970Ma20 - A. Marelius, J. Lindskog, Z. Awwad, K. G. Valivaara, S. E. Hagglund, J. Pihl, Nucl. Phys. **A148**(1970)433 [$T_{1/2}$ level]
- 1970Na12 - T. S. Nagpal, R. E. Gaucher, Can. J. Phys. **48**(1970)2978 [E_γ , I_γ , multipolarity]
- 1970Wy01 - L. D. Wyly, J. B. Salzberg, E. T. Patronis, Jr., N. S. Kendrick, C. H. Braden, Phys. Rev. **C1**(1970)2062 [Multipolarity]
- 1971Kr11 - K. S. Krane, J.R. Sites, W. A. Seyert, Phys. Rev. **C4**(1971)565 [Multipolarity]
- 1971Ro17 - M. Rots, R. Silverans, R. Coussement, Nucl. Phys. **A170**(1971)240 and private communication.(March 1972) [Multipolarity]
- 1971Sa24 - G. Satyanarayana, V. Lakshminarayana, Curr. Sci. (India) **40**(1971)458 [Multipolarity]
- 1972Ba12 - T. Badica, S. Dima, A. Gelberg, I. Popescu, Z. Phys. **249**(1972)321 [Multipolarity]
- 1972Be21 - B. Bengtson, M. Moszynski, Nucl. Instrum. Methods **100**(1972)293 [$T_{1/2}$ level]
- 1972Br02 - D. S. Brenner, M. L. Perlman, Nucl. Phys. **A181**(1972)207 [Multipolarity]
- 1972Sa08 - G. Satyanarayana, V. Lakshminarayana, D. S. Murty, Can. J. Phys. **50**(1972)600 [$T_{1/2}$ level]
- 1972Sa33 - G. Satyanarayana, V. V. Ramamurty, V. Lakshminarayana, J. Phys. (London) **A5**(1972)1243 [$T_{1/2}$ level]
- 1973Gu10 - J. B. Gupta, N. C. Singhal, J. H. Hamilton, Z. Phys. **261**(1973)137 [E_γ , I_γ]
- 1974II02 - P. Ila, K. Sudhakar, K. L. Narasimham, V. Lakshminarayana, Curr. Sci. (India) **43**(1974) 176 [I_γ]
- 1975Ma32 - B. Martin, D.Merkert, J.L. Campbell. Z. Phys. **A274**(1975)15 [Multipolarity]
- 1976Ba63 - I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, Atomic Data Nucl. Data Tables **18**(1976)433 [α]
- 1976Wa13 - W.B. Walters, R.A. Meyer, Phys. Rev. **C14**(1976)1925 [E_γ , I_γ]
- 1977Ar10 - G. Ardisson, K. Abdmeziem, Radiochem. Radioanal. Lett. **29**(1977)1 [I_γ]
- 1977Ge12 - R. J. Gehrke, R.G. Helmer, R. C. Greenwood, Nucl. Instrum. Methods **14**(1977)405 [I_γ]
- 1978La21 - F. Lagoutine, J. Legrand, C. Bac, Int. J. Appl. Radiat. Isotop. **29**(1978)269 [$T_{1/2}$ level]
- 1978Ro22 - F. Rösler, H. M. Fries, K. Alder, H. C. Pauli, Atomic Data Nucl. Data Tables **21**(1978)92 [α]
- 1979Pr08 - R.Prasad, Czech. J. Phys. **B29**(1979)737 [I_γ]
- 1980Ho17 - H. Houtermans, O. Milosevic, F. Reichel, Int. J. Appl. Radiat. Isotop. **31**(1980)153 [$T_{1/2}$]
- 1980Ro22 - W. M. Roney, Jr., W. A. Seale, Nucl. Instrum. Methods **171**(1980)389 [I_γ]

- 1982Mu02 - P. Mukherjee, S. Bhattacharya, S. Sarkar, I. Mukherjee, B. K. Dasmahapatra, Phys. Rev. **C25**(1982)2120 [Multipolarity]
- 1982Si18 - K. Singh, H. S. Sahota, Indian J. Phys. **56A**(1982)291 [Multipolarity]
- 1983Si14 - K. Singh, H. S. Sahota, Indian J. Pure Appl. Phys. **21**(1983)19 [I_γ]
- 1983Wa26 - K. F. Walz, K. Debertin, H. Schrader, Int. J. Appl. Radiat. Isotop. **34** (1983)1191 [$T_{1/2}$]
- 1986Wa35 - Wang Xinlin, Li Xiaodi, Du Hongshan, Chin. J. Nucl. Phys. **8**(1986)371 [I_γ]
- 1988GeZS - A. M. Geidelman, Yu. S. Egorov, N. K. Kuzmenko, V. G. Nedovesov, V. P. Chechev, G. E. Shukin, Proc. Intern. Conf. Nuclear Data for Science and Technology, Mito, Japan, 1988, p.909 [$T_{1/2}$ level]
- 1990He05 - R. G. Helmer, Appl. Radiat. Isot. **41**(1990)75 [E_γ , I_γ]
- 1990Lo03 - L. Longoria-Gandara, M. U.Rajput, T. D. Mac Mahon, Nucl. Instrum. Methods Phys. Res. **A286**(1990)529 [I_γ evaluation]
- 1992De26 - C. C. Dey, B. K. Sinha, R. Bhattacharya, Nuovo Cim. **105A**(1992)523 [$T_{1/2}$ level]
- 1993Fa02 - N. I. Fawwaz, N. M. Stewart, J. Phys. (London) **G19**(1993)113 [I_γ]
- 996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instrum. Methods **A369**(1996)527 [ω]
- 1997De38 - C. C. Dey, B. K. Sinha, R. Bhattacharya, Can. J. Phys. **75**(1997)591 [Multipolarity]
- 1998Gr13 - A. Grau Carles, L. Rodriguez Barquero, A. Jimenez de Mingo, Appl. Radiat. Isot. **49** (1998)1377 [I_β]
- 1998Ro20 - M. Roteta, E. Garcia-Torano, Appl. Radiat. Isot. **49**(1998)1349 [Multipolarity]
- 1998Sa36 - M. Sainath, K. Venkataramaniah, Nuovo Cim. **111A**(1998)223 [Multipolarity]
- 1998Sa55 - M. Sainath, K. Venkataramaniah, P. C. Sood, Phys. Rev. **C58** (1998)3730 [E_γ , I_γ , multipolarity]
- 1998Si17 - B. Singh, J. L. Rodriguez, S. S. M. Wong, J. K. Tuli, Nucl. Data Sheets **84**(1998)487 [log ft sys.]
- 1999Ka26 - J. Katakura, Nucl. Data Sheets **86**(1999)955 [evaluation]
- 1999Sa73 - M.Sainath, K.Venkataramaniah, P.C.Sood, Pramana **53**(1999)289 [Multipolarity]
- 2000He14 - R.G.Helmer, C.van der Leun, Nucl. Instrum. Methods Phys. Res. **A450**(2000)35 [E_γ]
- 2002Un02 - M.P.Unterweger, Appl. Radiat. Isot. **56**(2002)125 [$T_{1/2}$]
- 2003Au03 - G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. **A729**(2003)337 [Q]
- 2004Wo02 - M.J. Woods, S.M. Collins, Appl. Radiat. Isot. **60**(2004)257 [$T_{1/2}$ evaluation]

¹²⁹I - Comments on evaluation of decay data by V. P. Chechev and V. O. Sergeev

1- Decay Scheme

The 2nd unique forbidden β^- -transition to the $1/2^+$ ground state of ¹²⁹Xe was not observed. In 1954 Der Matiosian and Wu (1954De17) showed experimentally that this β^- -branch intensity did not exceed 1 %. This limit gives a $\log f_{2ut} = 14.9$ (or $\log f_{0t} = 15.8$), which is consistent with the $\log f_{2ut}$ values of 14.6 – 15.8 tallied in 1998Si17 for ten cases from A=22 to A=138, excluding ¹⁰Be, with 13.8, and ²⁰⁹Po, with 14.36. The highest value of 15.8 corresponds to 0.13% for the transition considered.

Therefore, we have adopted the probability of the 2nd unique forbidden β^- -transition to the $1/2^+$ ground state of ¹²⁹Xe $P(\beta^-_{0,0}) = 0.05(5)\%$ with the uncertainty which provides the limits from 0 to 1% according to 1954De17.

2- Nuclear Data

The Q value has been computed on the basis of the spectrometric measurement of the $\beta^-_{0,1}$ energy by N. Coursol (1979CoZG) and the evaluated gamma-ray energy. This measurement gives a more accurate Q value than 194(3) keV, presented in the atomic mass evaluation (1995Au04).

The following four experimental values for the ¹²⁹I half-life are available (in units of 10⁷ years).

1.72(9)	1951 Ka16
1.56(6)	1957Ru65
1.57(4)	1972Em01
1.97(14)	1973Ku17

Use of the LRSW method leads to a higher uncertainty (0.047) in 1972Em01. Our recommended value has been obtained as the weighted mean with the external uncertainty 0.06 expanded due to the Student's factor (or MBAYS uncertainty) : 1.61(7). Thus our recommended value for the ¹²⁹I half-life is $1.61(7) \times 10^7$ years.

2.1. β^- -Transitions

The energy of the $\beta^-_{0,1}$ transition has been adopted from 1979CoZG (Coursol). For the probabilities $P(\beta^-_{0,1})$ and $P(\beta^-_{0,0})$ see discussion in sect.1.Decay Scheme.

2.2. Gamma-ray Transitions and Internal Conversion Coefficients

The correction for recoil has not changed the γ -ray transition energy.

The emission probability of the γ -ray transition (photons + electrons) has been adopted as 99.5(5)%. (see discussion in sect.1).

The multipolarity of the γ -ray transition was measured in 1965Ge04 (M1) and 1974Ra26 (M1 + 0.073(27)% E2).

ICC's have been interpolated from theoretical values of 1978Ro22 for the adopted multipolarity of $M1 + 0.07(3)\% E2$. The uncertainties in the theoretical values are as follows: 1% for α_K and 3% for α_L , α_M , α_{NO} . The ratio α_{NO}/α_M has been taken from 1971Dr11. The ICC interpolated from other tables (1968Ha53, 1969Ha61, 1978Band) agree with the adopted values within the limits of the stated uncertainties.

The interpolated value $\alpha_K^{\text{theory}} = 10.59(11)$ can be compared with the following experimental values: 10.6 (1968ReZY), 9.8(9) (1970Gy01), 10.2(4) (1970SaZI), 10.2(5) (1977Ra23), and 10.6(4) (1985Ba73), which have an unweighted average of 10.3.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yields have been taken from 1996Sc06 (Schönfeld and Janßen).

3.2. X rays

X-ray energies are based on the wavelengths given in the compilation of 1967Be65 (Bearden).

The relative K x-ray emission probabilities have been taken from 1996Sc06 and 1999Schönfeld.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1998Schönfeld.

The ratios $P(KLX)/P(KLL)$ and $P(KXY)/P(KLL)$ have been taken from 1996Sc06.

4. Electron emissions

The energies of the conversion electrons have been calculated from the γ -ray transition energy given in sect. 2.2 and the electron binding energies. Their absolute emission probabilities have been calculated using the conversion coefficients given in 2.2 and the absolute γ -ray emission probability.

For the L-shell the ratios $L_1:L_2:L_3 = 100:8.9(4):3.13(14)$ obtained from theoretical conversion coefficients can be compared with the experimental $L_1:L_2:L_3 = 100:10.0(4):3.1(3)$ from $^{129}\text{Cs} \rightarrow ^{129}\text{Xe}$ decay (1965Ge04).

Values of the emission probabilities of K-Auger electrons have been calculated using our recommended $P(\text{ceK})$ and $P(\text{ceL})$ values and atomic data given in 3.1.

The maximum energy of β^- particles with energy of 151 keV has been taken from 1979CoZG(Coursol). The average energy of β^- particles calculated with the LOGFT program, which uses an allowed spectral shape, is 40.6(3) keV. The SPEBETA program gives a different value of 37 keV (2001 Be). In 2001Be the shape factor $C(W) = q^2 + (0.10 \pm 0.01)p^2$ was used that given by E. der Matiosian and C. S. Wu (1953DE10) (measurement with a magnetic spectrometer). The value of 37 keV is supported also by the calculation of Kolobachkin et.al. (See the book "Beta emissions of fission products", authors: V. M. Kolobachkin, P. M. Rubtsov, V. G. Alexankin and P. A. Ruzhanskiy . – Moscow, Atomizdat, 1978, p.189. In Russian). They found 36 keV for the average energy of β^- particles of ^{129}I . So we adopt 37(1) keV as the recommended value.

5. Photon Emissions

5.1 X-Ray Emissions

Our recommended value for the total K x-ray absolute emission intensity has been calculated as $P_{\text{XK}}^{\text{eval.}} = \omega_{\text{K}}\alpha_{\text{K}}P_{\gamma}(39.6) = 69.8(11)\%$, based on the adopted value of ω_{K} , a theoretical value of α_{K} , and our recommended value of $P_{\gamma}(39.6) = 7.42(8)\%$. This K x-ray emission probability agrees well with the result of the measurement $P_{\text{XK}}^{\text{exp.}} = 70.2(8)\%$ in 1985Ba73, relative to $P_{\gamma}(39.6) = 7.46\%$ (or $69.8(8)\%$, relative to $P_{\gamma}(39.6) = 7.42\%$), and it also agrees with the less accurate experimental result from 1977Ra23: $73(6)\%$.

The absolute emission probabilities of the K x-ray components have been deduced from the total P_{XK} using the relative probabilities from sect. 3.2.

The total absolute emission probability of L x-rays has been deduced using the adopted values of $\overline{\omega}_{\text{L}}$ and n_{KL} and the recommended values of $P(\text{ce}_{\text{K}}) = 78.6(12)$ and $P(\text{ce}_{\text{L}}) = 10.8(4)\%$.

5.2. Gamma Emissions

A γ -ray energy of $39.578(4)$ keV has been adopted from 1985Ba73 from an accurate measurement made with a planar HPGe detector. The adopted value coincides with $39.578(2)$ keV for the energy of the first excited level in ^{129}Xe (1996Te01), deduced from the decay of ^{129}Cs .

Other less accurate experimental values of $E(\gamma_{1,0})$ are (in keV): $39.58(3)$ (1965Ge04), $39.6(2)$ (1966Re10), $39.4(3)$ (1967Gr05), $39.58(5)$ (1972Ta15), and $39.581(15)$ (1976Me16).

The absolute γ -ray emission probability (P_{γ}) has been computed as $P(\beta_{1,0})/(1+\alpha_{\text{T}})$. The uncertainty in P_{γ} includes the uncertainty of 0.5% in $P(\beta_{1,0})$, and 1% in α_{T} .

References

- 1951KA16 S. Katcoff, O. A. Schaeffer, J. M. Hastings, Phys. Rev. 82(1951)688. (Half-life)
 1953DE10 Der E. Mateosian, C. S. Wu, Phys. Rev. 91(1953)497A. (Beta spectrum shape factor)
 1954DE17 Der E. Mateosian, C. S. Wu, Phys. Rev. 95(1954)458. (Gamma ray energy)
 1957RU65 H. T. Russell, Report ORNL – 2293(1965). (Half-life)
 1965GE04 J. S. Geiger, R. L. Graham, I. Bergstrom, F. Brown, Nucl. Phys. 68(1965)352. (Gamma ray energy, multipolarity)
 1966RE10 I. Rezanka, A. Spalek, J. Frana, A. Mastalka, Nucl. Phys. 89(1966)609. (Gamma ray energy)
 1967BE65 J. A. Bearden, Revs. Modern Phys. 39(1967)78. (X-ray energies)
 1967GR05 G. Graeffe, W. B. Walters, Phys. Rev. 153(1967)1321. (Gamma ray energy, K ICC)
 1968HA53 R. S. Hager, E. C. Seltzer. Nucl. Data Tables A4(1968)1. (Theoretical ICC)
 1968REZY S. A. Reynolds, J. F. Emery, ORNL-4343 (1968) p 78. (K ICC)
 1969HA61 R. S. Hager, E. C. Seltzer, Nucl. Data Tables A6(1969)1. (Theoretical ICC)
 1970GY01 F. N. Gyax, R. F. Jenefsky, H. J. Leisi, Phys. Letters 32B(1970)359. (K ICC)
 1970SAZI K. S. R. Sastry, R. E. Wood, J. M. Palms, P. V. Rao, Bull. Am. Phys. Soc. 15(4), JE12(1970)623. (K ICC)
 1971DR11 O. Dragoun, Z. Plajner, F. Schmutzler, Nucl. Data Tables A9(1971)119. (Theoretical ICC)
 1972Em01 J. F. Emery, S. A. Reynolds, E. I. Wyatt, G. I. Gleason, Nucl. Sci. Eng. 48(1972)319. (Half-life)

- 1972TA15 H. W. Taylor, B. Singh, J. Phys. Soc. Japan 32(1972)1472. (Gamma ray energy)
- 1973KU17 J. G. Kuhry, G. Bontems, Radiochem. Radioanal. Letters 15(1973)29. (Half-life)
- 1974MA24 G. Marest, R. Haroutunian, I. Berkes, M. Meyer, M. Rots, J. De Raedt, H. Van de Voorde, Van de, H. Oonis, R. Coussement, Phys. Rev. C10(1974)402. (Multipolarity)
- 1974RA26 K. Venkata Ramaniah, T. Seshi Reddy, K. Venkata Reddy, Current Sci. (India) 43 (1974)406. (Multipolarity, K ICC)
- 1976ME16 R. A. Meyer, F. F. Momyer, J. H. Landrum, E. A. Henry, R. P. Yaffe, W. B. Walters, Phys. Rev. C14(1976)1152. (Gamma ray energy)
- 1977RA23 T. K. Ragimov, D. F. Rau, V. I. Timoshin, Bull. Akad. Sci. USSR, Phys. Ser. (1977), 1941(6), 97. Izv Akad Nauk SSSR. Ser. Fiz. 41(1977)1222 (K ICC)
- 1979COZG N. F. Coursol, Thesis, Univ de Paris (1979). (K ICC, M ICC, β^- emission energy)
- 1985BA73 G. Barci-Funel, M. C. Kouassi, G. Ardisson, Nuclear Instrum. Methods 24(1985)252 (K ICC, gamma ray energy, gamma ray and K X-ray emission probabilities)
- 1995AU04 G. Audi and A. H. Wapstra, Nucl.Phys. A595(1995)409. (Q value)
- 1996SC06 E. Schönfeld, H. Janßen, Nucl. Instrum. Methods Phys. Res. A369(1996)527. (Atomic data)
- 1996TE01 Y. Tendow, Nucl. Data Sheets 77(1996)631 (Level energies)
- 1998Schönfeld E. Schönfeld and G. Rodloff, report PTB-6,11-98-1, Braunschweig, October 1998. (Energies of Auger electrons)
- 1998Si17 B. Singh, J. L. Rodriguez, S. S. M. Wong, J. K. Tuli, Nucl. Data Sheets 84(1998)487. (Systematics of log ft values)
- 1999Schönfeld E. Schönfeld and G. Rodloff, report PTB-6.11-1999-1999-1, Braunschweig, February 1999. (KX ray energies and relative emission probabilities)
- 2001Be M. M. Bé, INDC(NDS)-422, IAEA, Vienna, P.112. (Average β^- energy)

¹³¹I – Comments on evaluation of decay data by V. Chisté and M. M. Bé

1) Decay Scheme

¹³¹I disintegrates by β^- emission via the excited levels of ¹³¹Xe, included the isomeric state ¹³¹Xe^m ($T_{1/2} = 11,930(16)$ d).

The state of ideal balance, where the activity of ¹³¹I is equal to the activity of ¹³¹Xe^m, is obtained in 13,994(1) days :

$$tm = \frac{1,44 \times T_{1/2}({}^{131}\text{I}) \times T_{1/2}({}^{131}\text{Xe}^m) \times \ln(T_{1/2}({}^{131}\text{Xe}^m)/T_{1/2}({}^{131}\text{I}))}{T_{1/2}({}^{131}\text{Xe}^m) - T_{1/2}({}^{131}\text{I})}$$

The decay of Xe-131m will interfere with the decay of I-131 only with the 163,9 keV gamma line. For this line, the gamma emission intensity is given at *tm* (see above).

2) Nuclear Data

The Q value is from Audi and Wapstra (1995Au04)

Level energies, spins and parities are from Yu. V. Sergeenkov (1994Se07).

The measured ¹³¹I half-life values are, in days:

$T_{1/2}$

Reference	Value (d)	Comments
Livingood (1938Li01)	8,0 (2)	
Sreb (1951Sr10)	8,1409 (62)	
Sinclair (1951Si26)	8,04 (4)	
Lockett (1953Lo19)	8,06 (2)	
Seliger (1953Se45)	8,075 (22)	
Bartholomew (1953Ba03)	8,05 (1)	
Burkinshaw (1958Bu12)	8,054(10)	
Keene (1958Ke24)	8,067(7)	
Kemeny (1968Ke32)	8,04(4)	
Zoller (1971Zo46)	8,117(12)	
Emery (1972Em09)	8,040(1)	
Karsten (1974Ka18)	8,031(4)	
Lagoutine (1978La13)	8,020(3)	
Houtermans (1980Ho21)	8,0213(9)	
Hoppes (1982Ho45)	8,020(2)	Superseded by 1992Un03
Walz (1983Wa15)	8,0207(1)	Superseded by 2003Sc49
Unterweger (1992Un03)	8,0197(22)	
Silva (2004Si04)	7,999 (9)	
Schrader (2004Sc49)	8,0252(6)	

The half-life weighted average has been calculated by the Lweight program (version 3).

The evaluator has chosen to take only the seven most recent values (74Ka18, 78La13, 80Ho21, 92Un03, 2004Si04 and 2004Sc49) for the calculation. The Silva(2003Si04) value is rejected by the Lweight program, based on the Chauvenet's criterion. The largest contribution to the weighted average comes from the value of Schrader (2004Sc49), amounting to 63%. The program Lweight 3 increases the uncertainty for the 2004Sc49 value from 0,0006 to 0,00079 in order to reduce its relative weight from 63% to 50%.

The adopted value is the weighted mean : 8,0233 d, with an uncertainty of 0,0019 (expanded so range includes the most precise value of Schrader (2004Sc49)) and a χ^2 of 4.

2.1) β^- Transitions

The β^- probabilities and the associated uncertainties have been deduced from γ transition intensity balance at each level of the decay scheme, assuming no β^- transition to the ground state. The values of log ft have been calculated with the program LOGFT for the Allowed, 1st Forbidden and 1st Unique Forbidden transitions.

2.2) Gamma Transitions

Probabilities

For the 163 gamma transition probability, the adopted value is 1,086(7), measured by Meyer (1974Me21). Other transition probabilities have been calculated from the gamma emission intensities and the internal conversion coefficients.

Mixing ratios and internal conversion coefficients

For the 177, 272, 318, 324, 325, 364, 404 and 722 keV gamma transitions, the adopted δ (mixing ratio) are from Krane's evaluation (1977Kr06) of experimental values deduced from angular distribution and correlation data. For other transitions, the values of δ are from Yu. V. Sergeenkov (1994Se07).

The internal conversion coefficients have been calculated using the ICC Computer Code (program Icc99v3a – GETICC dialog). The adopted values have been interpolated from Rösler tables. For the 163 gamma transition (isomeric state), the adopted value is from the new tables of Band (2001Go04) (see "**Comments on evaluation**" for $^{131}\text{Xe}^m$).

For the 364 keV gamma transition, many values of δ^2 have been found in the literature, as shown in the following table:

Reference	Value of δ^2	Value of a_T
Johnson et al – Phys. Rev. 120(1960)1777	44,89(25)	2,285 10^{-2}
Daniel et al – Z. Phys. 179(1964)62	22,09(9)	2,290 10^{-2}
Langhoff et al – Nucl. Phys. A158(1970)657	11,56(36)	2,299 10^{-2}
Krane et al – Phys. Rev. C5(1972)1671	10,89(36)	2,299 10^{-2}
Koene et al – Nucl. Phys. A219(1974)563	20,521(14)	2,290 10^{-2}
Irving et al – J. Phys. G5(1979)1595	14,40(9)	2,295 10^{-2}
Naviliat-Cuncic et al – Nucl. Phys. A514(1990)145	14,40(9)	2,295 10^{-2}
Krane et al - Atomic Data and Nuclear Data Tables 19(1977)363	20,521(14) (adopted value)	2,29 10^{-2}

It can be shown that even with values of δ^2 quite different the resulting α_T values are close, and their differences are smaller than 1 % ; thus the adopted uncertainty on the ICC value is 1 %.

For the 325 keV gamma transition, a value of δ^2 (=19(3)) measured by Koene (1975Ko31) is not close to the adopted one ($\delta^2 = 0,053(2)$) which is from Krane's evaluation, and the two resulting α_T values deviate from 3 %, that correspond to the uncertainty taken into account for the α_T , α_K and α_L values for this transition.

For the 404 keV gamma transition, a value of δ^2 (= 66(32)) has been found in the literature, from Irving (79Ir09). The calculated α_T (=0,01664) for this δ^2 is far from the adopted one ($\alpha_T = 0,0179$) and the resulting α_T value deviates from the adopted one of 7 %.

For the 722 keV gamma transition, the following values of δ^2 have been found in the literature:

Reference	Value of δ^2	Value of α_T
Koene – Nucl. Phys. A219(1974)563	0,0428	0,00461
Irving – J. Phys. G5(1979)1595	0,0144	0.00464
Krane - et al - Atomic Data and Nuclear Data Tables 19(1977)363	0,0428 (adopted value)	0,0046

The adopted uncertainty on the α_T , α_K and α_L values for the 722 keV transition is 1 % .

For the other transitions, measurements aren't precise, and only ranges of values are given for δ^2 .

Calculations of ICC uncertainties for the other transitions:

* For the pure transitions (known E2: 284, 503, 636 keV; presumed E1/ or E2: 232, 295, 302, 642 keV), uncertainties in α_T , α_K and α_L calculated values with ICC Computer Code (program Icc99v3a) are taken to be 3 % .

* For the mixed gamma transitions with unknown mixing ratio (M1+ X% E2) (85 and 358 keV), the uncertainties for α_T , α_K and α_L are taken to be 3 % from each possibility and the average values are adopted as uncertainties.

* For the transitions with known δ , the uncertainties calculations were made as follow : α_T was calculated for a pure M1(or M3) transition and for a pure E2 transition. The difference between these values, normalized by α_T , is the uncertainty (%) of α_T . The same method was used for α_K and α_L uncertainties.

3) Atomic Data

Atomic values (ω_K , ω_L and n_{KL}) are from Schönfeld (1996Sc33).

The X-ray and Auger electron emission probabilities have been calculated from γ -ray and conversion-electron data by using the program EMISSION.

4) Radiation emissions

4.2) Gamma ray emissions

Gamma ray energies (in keV) are from Yu. V. Sergeenkov *et al.* (1994Se07) and R. A. Meyer (1990Me15). Energy values are in keV.

The measured emission intensities listed in Table 1 are given in values relative to that of the 364 keV line.

The sets of values from 1952Be19, 1963Ju13, 1963Ha04, 1964Da19, 1967Ga32 and 1967Yt26 were omitted in several cases from the analysis due to discrepancies with those mentioned in Table 1.

Emission probability values from Meyer (1974Me21) have been converted to 100 for the 364 keV line by the evaluator.

The normalization factor to convert the relative emission intensities to absolute intensities was calculated using the formula:

$$N = \left(\frac{100 - P_{abs}(163keV)}{(\sum(1 + \alpha_T)P_{rel})} \right) \times 100$$

where the sum was done over all gamma transition probabilities to the ground state.

For the 163 gamma transition probability, $P_{abs}(163 keV)$, an absolute value of 1,086 (7), determined by Meyer, has been accepted.

From the calculated α_T and the evaluated relative emission intensities (Table I), the deduced normalization factor is **81,2 (8)**. The uncertainties were calculated through their propagation on the above formula.

4.2) Conversion electrons

The conversion electron emission probabilities were deduced from the gamma-ray emission probabilities using theoretical ICC values. To our knowledge, there are no measured values for the conversion electron emission probabilities.

Energy conservation

The available energy for one disintegration is 970,8 (6) keV (Q^-), the total average energy calculated from the data of this evaluation is 969 (6) keV confirming the consistency of the decay scheme.

Additional Reference

F. Lagoutine, Table de Radionucléides, CEA-LMRI (1984)

References

- 1938Li01 – J. J. Livingood, G. T. Seaborg, Phys. Rev. 54 (1938) 775 [$T_{1/2}$]
- 1951Sr10 – J. H. Sreb, Phys. Rev. 81 (1951) 643 [$T_{1/2}$]
- 1951Si26 – W. K. Sinclair, A. F. Holloway, Nature (London) 167 (1951) 365 [$T_{1/2}$]
- 1952Be19 – R. E. Bell, R. L. Graham, Phys. Rev. 86 (1952) 212 [E_γ , I_γ]
- 1953Lo19 – E. E. Lockett, R. H. Thomas, Nucleonics 11 (1953) 14 [$T_{1/2}$]
- 1953Se45 – H. H. Seliger, L. Cavallo, S. V. Culpepper, Phys. Rev. 90 (1953) 443 [$T_{1/2}$]

- 1953Ba03 – R. M. Bartholomew, F. Brown, R. C. Hawkings, W. F. Merritt, L. Yaffe, *Can. J. Chem.* 31 (1953) 120 [$T_{1/2}$]
- 1958Bu12 – L. Burkinshaw, *Phys. in Med. Biol.* 2 (1958) 255 [$T_{1/2}$]
- 1958Ke24 – J. P. Keene, L. A. Mackenzie, C. W. Gilbert, *Phys. in Med. Biol.* 2 (1958) 360 [$T_{1/2}$]
- 1963Ju13 – H. Jungclaussen, J. Schintlmeier, H. Sodan, *Nucl. Phys.* 43 (1963) 650 [E_γ , I_γ]
- 1963Ha04 – C. K. Hargrove, K. W. Geiger, A. Chatterjee, *Nucl. Phys.* 40 (1963) 566 [E_γ , I_γ]
- 1964Da19 – H. Daniel, O. Mehling, P. Schmidlin, D. Schotte, E. Thummernicht, *Z. Phys.* 179 (1964) 62 [E_γ , P_γ , δ]
- 1966Mo26 – G. A. Moss, D. O. Wells, D. K. McDaniels, *Nucl. Phys.* 82 (1966) 289 [E_γ , I_γ]
- 1967Ga32 – G. Graeffe, W. B. Walters, *Phys. Rev.* 153 (1967) 1321 [E_γ , I_γ]
- 1967Yt26 – C. Ythier, G. Ardisson, *C. R. Acad. Sc. Paris* 264C (1967) 944 [E_γ , I_γ]
- 1968Ke32 – P. Kemeny, *Rev. Roumaine Phys.* 13 (1968) 485 [$T_{1/2}$]
- 1971Zo46 – W. H. Zoller, P. K. Hopke, J. L. Fasching, E. S. Macias, W. B. Walters, *Phys. Rev.* C3 (1971) 1699 [$T_{1/2}$]
- 1972Em09 – J. F. Emery, S. A. Reynolds, E. I. Wyatt, G. I. Gleason, *Nucl. Scien. Eng.* 48 (1972) 319 [$T_{1/2}$]
- 1972Si12 – N. Singh, S. S. Bhati, R. L. Dhingra, P. N. Trehan, *Nucl. Phys. and Solid State Phys. Symp., Chandigarh – India* (1972) [E_γ , I_γ]
- 1974Ka18 – J. H. M. Karsten, P. G. Marais, F. J. Haasbroek, C. J. Visser, *Agrochemophysica* 6 (1974) 25 [$T_{1/2}$]
- 1974Ko35 – B. K. S. Koene, H. Postman, *Nucl. Phys.* A219 (1974) 563 [δ]
- 1974Me21 – R. A. Meyer, F. Momyer, W. B. Walters, *Z. Phys.* 268 (1974) 387 [E_γ , I_γ]
- 1975Ko31 – B. K. S. Koene, H. Postman, H. Ligthart, *Nucl. Phys.* A250 (1975) 38 [δ]
- 1977Kr06 – K. S. Krane, *At. Data Nucl. Data Tables* 19 (1977) 363 [δ]
- 1978La13 – F. Lagoutine, J. Legrand, C. Bac, *Int. J. Appl. Radia. Isot.* 29 (1978) 269 [$T_{1/2}$]
- 1979Ir09 – A. D. Irving, P. D. Forsyth, I. Hall, D. G. E. Martin, *J. Phys.* G5 (1979) 1595 [δ]
- 1980Ho21 – H. Houtermans, O. Milosevic, F. Reichel, *Int. J. Appl. Radia. Isot.* 31 (1980) 153 [$T_{1/2}$]
- 1982Ho45 – D. D. Hoppes, *NBS-SP* 626 (1982) 93 [$T_{1/2}$]
- 1983Wa15 – K. F. Walz, K. Debertain, H. Schrader, *Int. J. Appl. Radia. Isot.* 34 (1983) 1191 [$T_{1/2}$]
- 1989Ch45 – B. Chand, J. Goswamy, D. Mehta, N. Singh, P. N. Trethan, *Nucl. Inst. Meth.* A284 (1989) 393 [E_γ , I_γ]
- 1990Me15 – R. A. Meyer, *Fisika (Zagreb)* 22 (1990) 153 [E_γ , I_γ]
- 1992Un03 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, *Nucl. Instrum. Meth.* A312 (1992) 349 [$T_{1/2}$]
- 1994Se07 – Yu. V. Sergeenkov, Yu. L. Khazov, T. W. Burrows, M. R. Bhat, *Nucl. Data Sheets* 72 (1994) 487 [E_γ , I_γ , Spin]
- 1995Au04 – G. Audi, A. H. Wapstra, *Nucl. Phys.* A595 (1995) 409 [Q]
- 1996Sc33 – E. Schönfeld, H. Janßen, *Nucl. Instrum. Meth.* A369 (1996) 527 [Atomic data]
- 2001Go04 – V. M. Gorozhankin, N. Coursol, E. A. Yakushev, Ts. Vylov, C. Briancon, *Applied Rad. Isotop.* 56 (2002) 189 [M4 transition]
- 2004Si04 – M. A. L. da Silva, M. C. M. de Almeida, C. J. da Silva, J. U. Delgado, *Applied Rad. Isotop.* 60(2004)301 [$T_{1/2}$].
- 2004Sc49 – H. Schrader, *Applied Rad. Isotop.* 60(2004)317 [$T_{1/2}$].

Table 1 – Gamma emission intensities, relative and absolute values

Ref	80,1853	85,918	177,214	232,175	272,501	284,3047	295,848	302,444	318,093
52Be19	2,71(19) (O)					6,6(25) (O)			
63Ju13	2,6(4) (O)					6,0(10) (O)			
63Ha04	3,5(8) (O)		0,29(6) (O)			7,9(8) (O)			
64Da19	3,1(2) (O)		0,27(10) (O)			6,6(3) (O)			
66Mo26	3,10(18) £		0,313(26)			7,4(6)			
67Ga32	2,72(15) (O)		0,36(2) (O)		0,08(1)	7,05(40) (O)			0,110(15) (O)
67Yt26	3,4(4) (O)	~ 0,1	0,38(8) (O)		~ 0,07	8,2(8) £			~ 0,05
72Si12	3,210(5)		0,30(2)			7,49(5)			0,110(5)
74Me21	3,226(37)	0,00011(6)	0,3263(25)	0,0017(10)	0,0695(12)	7,457(12)	0,00087(50)	0,0056(11)	0,0980(37)
89Ch45	3,26(7)		0,334(6)	0,0039(5)	0,0735(18)	7,56(8)	0,0022(10)	0,0057(8)	0,096(2)
90Me15	3,23(6)	0,00011(6)	0,326(7)	0,0017(10)	0,0695(19)	7,46(15)	0,00087(50)	0,0056(11)	0,0980(42)
Adopted	3,212(9)	0,00011(6)	0,3269(22)	0,00317(47)	0,0705(9)	7,461(12)	0,00102(33)	0,0056(6)	0,0980(15)
N	4	2	5	3	4	5	3	3	4
chi**2/N-1	0,247	0	0,8923	3,23	1,55	0,4973	0,7862	0,004016	2,253
Method	LWM, int. unc.		LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.
Absolute Val.	2,607(27)	0,000089(49)	0,2654(32)	0,00257(38)	0,0572(9)	6,06(6)	0,00083(27)	0,00455(49)	0,0796(15)

(O) = omitted value

£ = Data rejection parameters for deviation weighted average (Chauvenet's criterion)

ext. unc. = external uncertainty

int. unc. = internal uncertainty

Table 1 – Gamma emission intensities, relative and absolute values (Cont.)

Ref	324,6307	325,791	358,419	364,49	404,816	503,005	636,991	642,7237	722,909
52Be19				100			11,6(19) (O)		3,5(31) £
63Ju13							9,0(10) (O)		3,0(4) £
63Ha04		0,35(8) (O)		100		0,52(17) (O)	8,8(7) (O)		2,05(16) (O)
64Da19		0,26(10) (O)		100		0,54(5) (O)	8,3(3) (O)		1,9(1) (O)
66Mo26		0,279(25)		100		0,45(6)	9,1(11)		2,05(26)
67Ga32	0,04(1) (O)	0,45(3) £	0,020(4) (O)	100	0,080(7) (O)	0,36(2) (O)	8,0(4) (O)	0,180(15) (O)	2,10(15) (O)
67Yt26		0,37(5) (O)		100	~ 0,06	0,37(8) (O)	8,2(8) (O)		1,8(2) (O)
72Si12		0,32(1)		100	0,022(5) £	0,30(5) £	7,79(10) £	0,13(1) (O)	1,79(9) £
74Me21	0,0273(50)	0,3089(50)	0,01129(25)	100	0,0695(25)	0,4442(37)	8,945(25)	0,2705(25)	2,221(12)
89Ch45	0,025(8)	0,361(5)	0,0304(11)	100	0,066(2)	0,438(5)	8,75(9)	0,269(5)	2,19(2)
90Me15	0,0273(50)	0,309(8)	0,01129(33)	100	0,0695(28)	0,444(12)	8,95(21)	0,270(7)	2,22(7)
Adopted	0,0269(32)	0,329(32)	0,0121(27)	100	0,0679(14)	0,4421(29)	8,940(23)	0,2702(21)	2,213(10)
N	3	5	3		3	4	4	3	4
chi**2/N-1	0,03458	17,05	14,47		0,8191	0,3456	2,353	0,03637	0,723
Method	LWM, int. unc.	LWM, exp. unc.	LWM, ext. unc.		LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.
Absolute Val.	0,0218(26)	0,267(26)	0,0098(22)	81,2(8)	0,0551(13)	0,3589(43)	7,26(8)	0,2193(28)	1,796(20)

(O) = omitted value

£ = Data rejection parameters for deviation weighted average (Chauvenet's criterion)

ext. unc. = external uncertainty

int. unc. = internal uncertainty

¹³¹Xe^m – Comments on evaluation of decay data by V. Chisté and M. M. Bé

1) Decay Scheme

¹³¹Xe^m decays by a strongly converted gamma transition.

2) Nuclear Data

Level energy, spin and parity are from Yu. V. Sergeenkov (94Se07).

The ¹³¹Xe^m measured half-life values are, in days:

$T_{1/2}$	
Reference	Value (d)
Andersson (64An08)	11,8 (1)
Knauf (66Kn09)	11,94 (4)
Emery (72Em09)	12,00 (2)
Meyer (74Me21)	11,770 (12)
Hoffman (75Ho12)	11,92 (3)
Tam (90Ta02)	11,9 (2)
Unterweger (92Un03)	11,934(21)

The half-life weighted average was calculated with the Lweight program (version 3)

The value from Meyer (74Me21) was omitted from the analysis because it disagrees with the other values. The Emery (72Em09) and Anderson (64An08) values were rejected by the Lweight program, based on Chauvenet's criteria. The adopted value is the weighted mean : $11,930$ d, with an internal uncertainty of $0,016$ and a χ^2 of $0,08$.

2.1) Gamma Transitions

The only gamma transition is of M4 multipolarity. The various theoretical conversion coefficients for this transition (Band *et al.*, Hager *et al.*, Rösel *et al.*) differ by 2 – 4 %. The value interpolated from the new Band *et al.* tables (ICC Computer Code (program Icc99v3a)) was adopted, following the recommendations of Gorozhankin (2002Go00).

The uncertainties in α_T , α_K and α_L have been estimated as 3%.

3) Atomic Data

Atomic quantities (ω_K , $\bar{\omega}_L$ and n_{KL}) are from Schönfeld (96Sc33).

The X-ray and Auger electron emission probabilities have been calculated from γ -ray and conversion electron data by using the program EMISSION.

4) Radiation emissions

4.1) Conversion electrons

The conversion electron emission probabilities were deduced from the ICC values and from the gamma-ray emission probability.

The total conversion electron emission probability is deduced from :

$$P_{ek} = 100 - P\gamma = 100 - (1,98 \pm 0,06) = 98,02 \pm 0,06$$

To our knowledge, there are no measured values for the conversion electron emission probabilities.

4.2) Gamma-ray emissions

Gamma-ray emission energy is from Yu. V. Sergeenkov et al. (94Se07) and R. A. Meyer (90Me15).

The gamma-ray emission intensity has been deduced from the transition probability and using the theoretical α_T to be : **1,98(6)**.

We have not found measured values for this emission, the ¹³¹Xe^m radioisotope being alone.

Additional Reference

F. Lagoutine, Table de Radionucléides, CEA-LMRI (1984)

References

- 62Ge01 J. S. Geiger, R. L. Graham, F. Brown, Can. J. Phys. 40 (1962) 1258
[α_K]
- 64An08 G. Andersson, Arkiv for Fysik 28 (1964) 37
[$T_{1/2}$]
- 66Kn09 K. Knauf, H. Sommer, H. Klewe-Nebenius, Z. Phys. 197 (1966) 101
[$T_{1/2}$, α_K]
- 68Fr03 K. Fransson, P. Erman, Arkiv for Fysik; 39 (1968) 7
[Multipolarity]
- 72Em09 J. F. Emery, S. A. Reynolds, E. I. Wyatt, G. I. Gleason, Nucl. Sci. Eng. 48 (1972) 319
[$T_{1/2}$]
- 73Be06 P. A. Benson, H. Y. Gee, M. W. Nathans, J. Inorg. Nucl. Chem. 35 (1973) 2614
[Branching Ratio]
- 74Me21 R. A. Meyer, F. Momyer, W. B. Walters, Z. Phys. 268 (1974) 387
[Total Branch, $T_{1/2}$]
- 75Ca11 J. L. Campbell, B. Martin, Z. Phys. A274 (1975) 9
[α_K]
- 75Ho12 D. C. Hoffman, J. W. Barnes, B. J. Drolesky, F. O. Lawrence, G. M. Kelley, M. A. Ott, J. Inorg. Nucl. Chem. 37 (1975) 2336
[$T_{1/2}$]
- 76Au08 R. L. Aube, H. R. Hiddleston, C. P. Browne, Nucl. Data Sheets 17 (1976) 573
[I_γ , Spin, Parity]
- 90Ta02 N. C. Tam, A. Veres, I. Pavlicsek, L. Lakosi, J. Phys. G16 (1990) 1215
[$T_{1/2}$]
- 92Un03 M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instrum. Meth. A312 (1992) 349
[$T_{1/2}$]
- 94Se07 Yu. V. Sergeenkov, Yu. L. Khazov, T. W. Burrows, M. R. Bhat, Nucl. Data Sheets 72 (1994) 487
[E_γ , I_γ , Spin]
- 95Au04 G. Audi, A. H. Wapstra, Nucl. Phys. A595 (1995) 409
[Q]
- 96Sc33 E. Schönfeld, H. Janßen, Nucl. Instrum. Meth. A369 (1996) 527
[Atomic data]
- 2002Go00 V. M. Gorozhankin, N. Coursol, E. A. Yakushev, Ts. Vylov, C. Briançon, Appl. Rad. Isotopes 56 (2002) 181
[M4 transition]

¹³³Ba - Comments on evaluation of decay data

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This evaluation was done in May 1999, and revised in April 2000. The literature available by April 2000 was included. The half-life was revised in January 2004 using new references available by 2004.

1. Decay Scheme

Since ¹³³Ba has spin and parity 1/2⁺, it decays primarily by allowed ε branches to the 1/2⁺ and 3/2⁺ levels at 437 and 383 keV. As to the intensities of the other possible ε branches to the levels at 0, 81 and 161 keV they can be estimated from log *ft* systematics. From that of 1998Si17, one expects the log *ft* of the unique 2nd forbidden decay to the ground state to be greater than 13.9 which corresponds to a branch of less than 0.0005%. Similarly, the log *ft* of the 2nd forbidden decays to the 81- and 161-keV levels are expected to be greater than 10.6 which corresponds to branches of less than 0.7% and 0.3%, respectively. Our evaluations for these two branches from the gamma intensity balance agree very well with this expectation (see section 2.1)

From the measured γ-ray emission probabilities and the internal conversion coefficients, the intensity balances at the 81- and 161 keV levels give branching to these levels of 0.0(16) % and 0.11(18)%, respectively.

Therefore, all of these unobserved β branches can be considered negligible.

For comparison see also the evaluations made by R. B. Firestone (1990Fi03), A. L. Nichols (1993Nichols) and Shaheen Rab (1995Ra12) as well as the analysis by F. E. Chukreev (1992Chukreev).

Q value is from Audi and Wapstra (1995Au04).

The ¹³³Ba half-life values available from 1961 are, in days:

3908(73)	1961Wy01	
2849(37)	1968La10	Rejected, large deviation from mean
3894(44)	1968Re04	
3781(15)	1970Wa19	Rejected, revised in 1983Wa26
3981(37)	1972Em01	Rejected by Chauvenet's criterion
4127(260)	1973LI01	Rejected by Chauvenet's criterion
3850(55)	1979HaYC	
3785(27)	1980RuZY	
3848.0(11)	1980Ho17	
3828(11)	1982HoZJ	Rejected, revised in 1992Un01
3885.9(43)	1983Ki08	
3842(18)	1983Wa26	
3853.6(36)	1992Un01	Rejected, revised in 2002Un02
3848.9(7)	1997Ma75	
3854.7(28)	2002Un02	
3840.5(65)	2003Schrader	
3849.7(22)	Mean value	

The values before 1961 were struck off due to their large uncertainties (more than 1 year).

The values of 1970Wa19, 1982HoZJ and 1992Un01 had been omitted since they have been replaced by later values from the same group when the data set of the thirteen remained values was formed.

Then the value of 1968La10 (7.8±0.1 y) was omitted on statistical considerations because of a great contribution into the χ² value (27 σ from adopted value).

Use of the LWEIGHT computer program on the remaining twelve half-life values led to subsequent omitting outliers of 1973LI01 and then 1972Em01 by Chauvenet's criterion. The uncertainty of 1997Ma75 was increased to 0.98 days to adjust weights according to the Limitation of Relative

Statistical Weight method. In consequence the LWEIGHT program chose the weighted average of 3849.7 days and external uncertainty of 2.2 days.

It should be noted that in the weighted average of the two values of 1980Ho17 and 1997Ma75 have altogether 90% of the relative weight. Since these two values agree, any weighted average will be about 3849 days that differs slightly from an unweighted average of about 3856 days.

The adopted value for the ¹³³Ba half-life is 3849.7(22) in days and 10,540(6) in years.

2.1. Electron Capture Transitions

The energies of the electron capture, ϵ , transitions have been calculated from the Q value and the level energies deduced from gamma transition energies (see also 1995Ra12) .

The electron capture probabilities $\epsilon_{0,4}$ and $\epsilon_{0,3}$ have been calculated from the intensity balance for the 437 level and the 384 level, respectively, using the evaluated $P_{\gamma+ce}$ values. Similarly, the electron capture probabilities $\epsilon_{0,2}$ and $\epsilon_{0,1}$ are obtained from the intensity balance for 161 and 81 keV levels respectively, as (0.11±0,18) and (0.0±1.6) per 100 disintegrations. Hence the upper limits for them are ($P\epsilon_{0,2} < 0.3$) and ($P\epsilon_{0,1} < 2$) per 100 disintegrations. However the upper limit for $\epsilon_{0,1}$ can be decreased with use of the correlation of $P\epsilon_{0,1} = 100 - P\epsilon_{0,4} - P\epsilon_{0,3} - P\epsilon_{0,2} = 0.0(7)$, i.e. , $P\epsilon_{0,1} < 0.7$ per 100 disintegrations.

The P_K , P_L and P_M values for transitions $\epsilon_{0,4}$ and $\epsilon_{0,3}$ to the 437 keV and 384 keV levels, respectively, have been computed from the tables of Schönfeld (1998Sc28).

The available experimental P_K values are:

	$P_K(\epsilon_{0,4})$	$P_K(\epsilon_{0,3})$	$P_K(\epsilon_{0,2})$	$P_K(\epsilon_{0,1})$
1968Na16	0.68(5)			
1972Sc08	0.72(4)	0.80(7)		
1974Da09	0.76(6)	0.87(14)		
1975Ni07	0.75(10)			
1983Si17	0.75(4)	0.80(4)	0.92(13)	0.95(6)
1983Si22	0.71(11)	0.79(5)		
1988BeYQ	0.78(4)			
1990Da11	0.76(4)			
1990Bh01	0.730(12)	0.81(3)	0.91(7)	0.94(6)
1992Sa28	0.65(3)	0.74(4)	0.79(3)	0.88(4)
adopted	0.672(5)	0.7734(21)	0.79(3)	0.88(4)

Most of these values were obtained in 1974-1990 using the method of the X-, gamma-ray sum peak measurements. The results exceed the theoretical P_K values for the allowed $\epsilon_{0,4}$, $\epsilon_{0,3}$ - transitions and depend also on adopted conversion coefficients α_K and fluorescence yield ω_K .

The new measurement results obtained in 1992 agree better with the adopted values of P_K . Hence for P_K of the 2nd forbidden transitions $\epsilon_{0,2}$, $\epsilon_{0,1}$ we have adopted the values of 1992Sa28 (as the expression in 1998Sc28 do not apply to 2nd forbidden transitions).

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are the energies of gamma rays with adding the recoil energy .

The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma-ray emission probabilities and the total internal conversion coefficients (ICC). The ICC have been evaluated using the information of the multipolarity admixture coefficients from 1977Kr13, 1980Kr22 and 1995Ra12 and the theoretical values from 1978Ro22.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schonfeld and Janßen).

3.2. X Radiations

The X-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission $K\beta/K\alpha$ and $K\alpha_2/K\alpha_1$ probabilities are taken from 1996Sc06. In order to calculate the $K\beta'_1/K\alpha_1$ and $K\beta'_2/K\alpha_1$ ratios the value of $K\beta'_2/K\beta'_1$ measured in 1989Ma60 (0,2525(23)) has been adopted.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins).

The ratios $P(KLX)/P(KLL)$ and $P(KLY)/P(KLL)$ are taken from 1996Sc06.

4. Photon Emissions

4.1. X-Ray Emissions

The total absolute emission probability of KX-rays (P_{XK}) has been computed using the adopted value of ω_K , the evaluated total absolute emission probability of K conversion electrons (P_{ceK}) and the electron capture (P_{EK}). The absolute emission probabilities of the KX-ray components have been computed from P_{XK} using the relative probabilities from 1996Sc06 and 1989Ma60 for $K\beta'_2/K\beta'_1$ and 1996Sc06 for all others.

The measured values of the total absolute emission probability of KX-rays ($P_{XK} \times 100$) are given below in comparison with the calculated (adopted) value:

1972Sc08	1977Sc31	1989Egorov	Adopted
123.1(17)	117.4(22)	119.7(11)	119.7(13)

The total absolute emission probability of LX-rays has been computed using total absolute sums P_{ceL} , P_{ceK} , P_{EK} , P_{EL} and atomic data of section 3 (ω_K , ω_L , n_{KL}).

4.2. Gamma-Ray Emissions

The γ -ray energies are taken from the evaluation 2000He14 where the values are deduced on the revised energy scale. For the γ -ray of 81 keV see also the measurement of 1991We08.

The γ -ray absolute emission probabilities have been computed using the evaluated γ -ray relative probabilities and the absolute emission probability for the γ -ray 356 keV of 0.6205(19) measured in 1980Chauvenet, 1983Ch11. This experimental value for the most intensive γ -ray in the decay of ¹³³Ba was obtained as a result of the international intercomparison ICRM -S- 6 (1980Chauvenet). It is more preferable for normalizing of gamma-ray absolute emission probabilities than having been obtained from a ground state intensity balance 0.621(10)-because of uncertainties in multipolarity admixtures (and thus in ICC) as well as possible ambiguity in determination of some spins (see 1992Chukreev).

At the same time the relative gamma ray emission probabilities from ICRM-S-6 measured at the fifteen laboratories are used below in Table 1 equally with other measurements for averaging all the available data (the evaluation technique is given in 2000Ch01). The measurements of ICRM-S-6 have been lettered CRP and deduced from absolute emission probabilities published in 1980Chauvenet excluding an activity uncertainties ~0.2 %.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.2.

Table 1. The experimental and evaluated values for γ -ray relative emission probabilities

	γ_{53}	γ_{80}	γ_{81}	γ_{161}	γ_{223}	γ_{276}	γ_{303}	γ_{356}	γ_{384}
1967B115	3,8(8)	3,8(4)	53(4)	1,1(3)	0,7(3)	11,0(7)†	30(2)	100	14,5(1)
1968A116	3,3(5)	-	-	1,20(6)†	0,74(6)	12,0(4)†	30,6(9)†	100	14,2(5)
1968Bo04	4,2(2)†	4,0(4)	58,2(15)	1,07(5)	0,78(6)	11,8(3)	29,8(8)	100	14,3(10)
1968Do10	3,2(4)	5,5(7)†	52(7)	0,99(10)	0,72(8)	11,6(8)	29,4(2)	100	14,3(10)
1968No01	3,78(9)	4,9(6)	60(7)	1,21(5)†	0,80(3)†	11,61(17)	29,75(29)	100	14,18(26)
1969Gu15	2,91(5)	4,54(7)	53,7(17)	1,13(15)	-	11,2(3)	29,3(5)	100	14,03(26)†
1972Sc08	3,54(5)	3,9(2)	52,6(10)	1,16(5)	0,74(4)	11,4(3)	30,2(6)	100	14,4(3)
1973In06	-	-	-	0,98(7)	0,76(5)	11,6(5)	29,6(11)	100	14,9(6)†
1973Legrand	-	3,7(4)	56(6)	1,4(2)†	0,66(2)†	11,35(25)	29,4(6)	100	14,3(3)
1973Mc18	-	-	-	-	-	11,43(23)	29,3(6)	100	14,5(3)
1977Ge12	3,0(4)	5,6(15)†	52(4)	1,12(8)	0,85(7)†	11,7(8)	29,87(21)	100	14,4(11)
1977Sc31	3,49(8)	4,29(12)	55,8(16)	0,97(3)	0,73(3)	11,41(16)	29,4(3)	100	14,33(21)
1978He21	3,54(18)	3,1(3)†	49,2(26)	1,08(4)	0,745(25)	11,7(4)	29,8(4)	100	14,36(20)
1978Vylov	3,57(12)	4,16(18)	54,6(17)	0,98(8)	0,71(4)	11,4(3)	28,8(8)†	100	14,3(5)
1980Ro22	-	-	-	1,03(7)	0,72(5)	11,69(16)	29,9(4)	100	14,79(27)†
1983Yo03	-	-	-	1,035(28)	0,756(16)	11,57(7)	29,55(18)	100	14,36(9)
1987Lakshn	2,96(9)	4,67(14)	55,3(16)	-	-	-	-	100	-
1989Da11	3,6(5)	3,7(5)	52,3(7)	1,032(10)	0,713(8)	11,51(8)	29,51(23)	100	13,99(9)†
1990Me15	3,48(7)	3,77(9)	51,2(4)	1,05(3)	0,71(2)	11,3(2)	29,2(3)	100	14,5(2)
1998Hw07	-	-	-	0,950(18)	0,715(10)	11,64(13)	29,31(40)	100	14,52(17)
CRP-1	-	-	-	1,11(9)	0,85(5)†	11,7(4)	29,9(11)	100	14,5(5)
CRP-2	3,56(14)	-	53,1(19)	0,99(4)	0,729(28)	11,7(3)	30,1(9)	100	14,4(5)
CRP-3	3,53(8)	4,20(12)	54,8(12)	1,031(24)	0,69(3)	11,51(14)	29,5(3)	100	14,37(16)
CRP-4	3,53(7)	4,18(11)	54,6(12)	1,037(20)	0,730(22)	11,48(14)	29,5(4)	100	14,41(16)
CRP-5	3,9(7)	4,00(15)	51,5(19)	1,020(27)	0,728(22)	11,5(3)	29,5(9)	100	14,2(5)
CRP-6	3,45(8)	4,73(12)	57,6(14)	1,020(25)	0,728(18)	11,68(28)	29,7(7)	100	14,5(4)
CRP-7	3,56(8)	4,73(12)	58,9(15)	1,070(27)	0,738(18)	11,50(28)	29,6(7)	100	14,3(4)
CRP-8	-	-	-	-	-	11,22(27)	29,3(6)	100	14,53(28)
CRP-9	-	-	-	-	-	11,22(24)	29,3(5)	100	14,26(25)
CRP-10	-	-	-	-	-	11,48(25)	29,3(5)	100	14,20(22)
CRP-11	-	-	-	-	-	11,57(19)	29,4(4)	100	14,34(26)
CRP-12	3,69(18)	4,37(16)	55,3(18)	1,050(19)	0,741(15)	11,53(16)	29,5(4)	100	14,36(20)
CRP-13	2,92(16)	-	-	-	0,75(3)	11,9(4)	30,2(11)	100	14,6(5)
CRP-14	3,53(8)	4,39(11)	55,9(12)	1,015(20)	0,735(10)	11,61(13)	29,6(4)	100	14,34(18)

	γ_{53}	γ_{80}	γ_{81}	γ_{161}	γ_{223}	γ_{276}	γ_{303}	γ_{356}	γ_{384}
CRP-15	3,36(18)	-	-	1,05(4)	0,758(28)	11,7(5)	29,6(10)	100	14,3(4)
CRP-16	3,26(17)	-	-	1,05(4)	0,764(26)	11,7(4)	29,7(6)	100	14,3(3)
CRP-19	3,53(5)	-	-	1,063(17)	0,725(17)	11,61(12)	29,7(3)	100	14,53(13)
CRP-20	3,53(6)	4,05(8)	55,1(9)	1,05(5)	0,72(4)	11,49(21)	29,4(6)	100	14,51(22)
CRP-21	3,62(6)	4,15(12)	55,8(9)	1,039(15)	0,705(11)	11,57(17)	29,5(4)	100	14,40(20)
Number of input values	27	20	24	29	28	36	36		34
Reduced χ^2	7,21	5,54	4,08	1,68	0,79	0,37	0,29		0,20
Weighted average	3,45	4,27	53,4	1,032	0,726	11,54	29,55		14,41
Internal uncertainty	0,017	0,029	0,23	0,0048	0,0035	0,030	0,064		0,037
External uncertainty	0,046	0,068	0,47	0,0062	0,0031	0,018	0,035		0,016
Adopted value	3,45(5) ^a	4,27(8) ^a	53,1(5) ^b	1,028(8) ^c	0,730(5) ^c	11,54(7) ^a	29,55(18) ^a	100	14,41(9) ^a

† Omitted as outliers

^a The least uncertainty of experimental values

^b Adopted value has been changed slightly from the weighted average for a precise ground state intensity balance to get. Such a small change only for one gamma-ray supports the adopted experimental value of 62,05(19) % for the 356 keV γ -ray absolute emission probability and confirms the decay scheme. The adopted uncertainty of 0,5 is external.

^c Computed using the absolute emission probability measured in 1996Mi26.

In that work a special precise measurements of the absolute emission probabilities only for the two weak 161 and 223 keV gamma-rays were made by using a $4\pi\beta(\text{ppc})-\gamma(\text{HPGe})$ coincidence system.

References

- 1961Wy01 Wyatt, E. I.; Reynolds, S. A.; Handley, T. H.; Lyon, W. S.; Parker, H. A. (1961): Half-Lives of Radionuclides. II. Nucl. Sci. Eng. 11, 74.
[Half-life]
- 1965Be65 Bearden, J. A. (1965): Rev. Mod. Phys. 39, 78.
[Half-life]
- 1967Bl15 Blasi, P.; Bocciolini, M.; Maurenzig, P. R.; Sona, P.; Taccetti, N. (1967): The Decay of ¹³³Ba and Nuclear Transitions in ¹³³Cs. Nuovo Cimento 50B, 298.
[γ-ray emission probabilities]
- 1968Al16 Alexander, P.; Lau, J. P. (1968): Nuclear Structure in ^{133,135}Xe and ^{133,135}Cs. Nucl. Phys. A121, 612.
[γ-ray emission probabilities]
- 1968Bo04 Bosch, H. E.; Haverfield, A. J.; Szichman, E.; Abecasis, S. M. (1968): High-Resolution Studies in the Decay of ¹³³Ba with Semiconductor Counters. Nucl. Phys. A108, 209.
[γ-ray emission probabilities]
- 1968Do10 Donnelly, D. P.; Reidy, J. J.; Wiedenbeck, M. L. (1968): High-Resolution Gamma-Ray Spectroscopic Study of the Decay ¹³³Ba → ¹³³Cs. Phys. Rev. 173, 1192.
[γ-ray emission probabilities]
- 1968La10 Lagoutine, F.; Le Gallic, Y.; Legrand, J. (1968): Détermination Précise de Quelques Périodes Radioactives. Intern. J. Appl. Radiat. Isotop. 19, 475.
[Half-life]
- 1968Na16 Narang, V.; Houtermans, H. (1968): The P(L)/P(K) Capture in ¹³³Ba. In: Proc. Conf. Electron Capture and Higher Order Processes in Nucl. Decays, Debrecen, Hungary, D. Berenyi, Ed. Eotvos Lorand Phys Soc, Budapest, p 97.
[L/K-capture ratio]
- 1968No01 Notea, A.; Gurfinkel, Y. (1968): Transitions in ¹³³Cs from the Decay of ¹³³Ba. Nucl. Phys. A107, 193.
[γ-ray emission probabilities]
- 1968Re04 Reynolds, S. A.; Emery, J. F.; Wyatt, E. I. (1968): Half-Lives of Radionuclides - III. Nucl. Sci. Eng. 32, 46.
[Half-life]
- 1969Gu15 Gunnink, R.; Niday, J. B.; Anderson, R. P.; Meyer, R. A. (1969): Gamma-Ray Energies and Intensities. In: UCID-15439 (1969); Gunnink, R.; Nethaway, D. – Priv. Comm.
[γ-ray emission probabilities]
- 1970Wa19 Walz, K. F.; Weiss, H. M. (1970): Messung der Halbwertszeiten von ⁶⁰Co, ¹³⁷Cs and ¹³³Ba. Z. Naturforsch. 25a, 921.
[Half-life]
- 1972Em01 Emery, J. F.; Reynolds, S. A.; Wyatt, E. I.; Gleason, G. I. (1972): Half-Lives of Radionuclides - IV. Nucl. Sci. Eng. 48, 319.
[Half-life]
- 1972Sc08 Schmidt-Ott, W.-D.; Fink, R. W. (1972): The Determination by an Independent Method of P(K) Electron Capture Probabilities in ¹³³Ba and ¹³⁹Ce Decays. Gamma Decay of ¹³³Ba. Z. Phys. 249, 286.
[K-capture probability, absolute XK emission probability, γ-ray emission probabilities]
- 1973In06 Inoue, H.; Yoshizawa, Y.; Morii, T. (1973): Gamma-Ray Energies and Relative Intensities of ⁷⁵Se, ^{108m}-Ag, ¹¹³Sn, ¹³¹I and ¹³³Ba. J. Phys. Soc. Japan 34, 1437.
[γ-ray emission probabilities]
- 1973Legrand Legrand, J. (1973). Nucl. Instrum. Methods, 112 ,229
[γ-ray emission probabilities]
- 1973Ll01 Lloyd, R. D.; Mays, C. W. (1973): A Note on the Half-Period of ¹³³Ba. Intern. J. Appl. Radiat. Isotop. 24, 189.
[Half-life]

- 1973Mc18 McNelles, L. A. ; Campbell, J. L. (1973): Absolute Efficiency Calibration of Coaxial Ge(Li) Detectors for the Energy Range 160-1330 keV. Nucl. Instrum. Methods 109, 241.
[γ -ray emission probabilities]
- 1974Da09 Mahapatra, B. K. Das; Mukherjee, P. (1974): K-Capture Probability in the Decay of ^{133}Ba from X-Ray-Gamma-Ray Summing in Ge(Li) Detectors. J. Phys. (London) A7, 388.
[K-capture probability]
- 1975Ni07 Nicaise, W. F.; Waltner, A. W. (1975): A Single Detector Method for the Determination of P(K-1) in ^{133}Ba . Nucl. Instrum. Methods 131, 477.
[K-capture probability]
- 1977Ge12 Gehrke, R. J.; Helmer, R. G.; Greenwood, R. C. (1977): Precise Relative gamma-Ray Intensities for Calibration of Ge Semiconductor Detectors. Nucl. Instrum. Methods 147, 405.
[γ -ray emission probabilities]
- 1977Kr13 Krane, K. S. (1977): E2, M1 Multipole Mixing Ratios in Odd-Mass Nuclei, 59 LE A LE 149. Atomic Data and Nuclear Data Tables 19, 363.
[E2/M1 mixing ratio]
- 1977La19 Larkins, F. P. (1977) Atomic Data and Nuclear Data Tables 20, 313
[Auger electron energies]
- 1977Sc31 Schötzig, U.; Debertain, K.; Walz, K. F. (1977): Standardization and Decay Data of ^{133}Ba . Intern. J. Appl. Radiat. Isotop. 28, 503.
[XK-ray and γ -ray emission probabilities]
- 1978He21 Helmer, R. G.; Greenwood, R. C.; Gehrke, R. J. (1978): Reevaluation of Precise gamma-Ray Energies for Calibration of Ge(Li) Spectrometers. Nucl. Instrum. Methods 155, 189.
[γ -ray emission probabilities]
- 1978Ro22 Rosel, F.; Friess, H. M.; Alder, K.; Pauli, H. C. (1978): Internal Conversion Coefficients for all Atomic Shells ICC Values for $Z = 30-67$. At. Data Nucl. Data Tables 21, 92.
[Internal conversion coefficients]
- 1978Vylov Vylov, C. ; Osipenko, B. P.; Chumin, V. G. (1988) In: Elementarnie chastitsi and atomnie yadra (Particles & Nuclei), 1988, V.9, issue 6, P.1350. (in Russian).
[γ -ray emission probabilities]
- 1979HaYC Hansen, H. H.; Mouchel, D. (1979): Studies on the Decay of ^{133}Ba . In: NEANDC(E) 202U; Vol III, p 28.
[Half-life]
- 1980Chauvenet Chauvenet, B. ; Morel, J.; Legrand, J. (1980) Report ICRM-S-6(December 1980).
[Absolute γ -ray emission probabilities]
- 1980Ho17 Houtermans, H.; Milosevic, O.; Reichel, F. (1980): Half-lives of 35 Radionuclides. Intern. J. Appl. Radiat. Isotop. 31, 153.
[Half-life]
- 1980Kr22 Krane, K. S. (1980): E2, M1 Multipole Mixing Ratios, Supplement and Corrections through December 1979. At. Data Nucl. Data Tables 25, 29.
[E2/M1 mixing ratio]
- 1980Ro22 Roney, W. M., Jr; Seale, W. A. (1980): Gamma Ray Intensity Standards for Calibrating Ge(Li) Detectors for the Energy Range 200-1700 keV. Nucl. Instrum. Methods 171, 389.
[γ -ray emission probabilities]
- 1980RuZY Rutledge, A. R.; Smith, L. V.; Merritt, J. S. (1980): Decay Data for Radionuclides used for the Calibration of X- and gamma-Ray Spectrometers. In: AECL 6692.
[Half-life]
- 1982HoZJ Hoppes, D. D.; Hutchinson, J. M. R.; Schima, F. J.; Unterweger, M. P. (1982): Nuclear Data for X- or Gamma-Ray Spectrometer Efficiency Calibrations. In: NBS-SP-626, p 85.
[Half-life]

- 1983Ch11 Chauvenet, B.; Morel, J.; Legrand, J. (1983): An International Intercomparison of Photon Emission-rate Measurements of X- and gamma-Rays Emitted in the Decay of ¹³³Ba. Intern. J. Appl. Radiat. Isotop. 34, 479.
[Absolute γ -ray emission probabilities]
- 1983Ki08 Kits, J.; Latal, F.; Choc, M. (1983): The Half-Life of ¹³³Ba. Intern. J. Appl. Radiat. Isotop. 34, 935.
[Half-life]
- 1983Si17 Singh, K.; Sahota, H. S. (1983): K-Capture Probabilities in the Decay of ¹³³Ba. J. Phys. Soc. Japan 52, 2336.
[K-capture probability]
- 1983Si22 Singh, K.; Sahota, H. S. (1983): A New Approach to K-Electron-Capture Probabilities to the 437 and 384 keV Levels in the Decay of ¹³³Ba. J. Phys. (London) G9, 1565
[K-capture probability]
- 1983Wa26 Walz, K. F.; Debertain, K.; Schrader, H. (1983): Half-Life Measurements at the PTB. Intern. J. Appl. Radiat. Isotop. 34, 1191.
[Half-life]
- 1983Yo03 Yoshizawa, Y.; Iwata, Y.; Katoh, T.; Ruan, J. -Z.; Kawada, Y. (1983): Precision Measurements of Gamma-Ray Intensities IV. Low Energy Region: ⁷⁵Se and ¹³³Ba. Nucl. Instrum. Methods 212, 249.
[γ -ray emission probabilities]
- 1987Lakshn Lakshn; Reddy, S. B.; Reddy, K. B. (1987) Curr. Sci., 1987, V.50, P.407.
[γ -ray emission probabilities]
- 1988BeYQ Begzhanov, R. B.; Azimov, K. Sh.; Magrupov, R. D.; Mirakhmedov, Sh. A.; Mukhammadiev, A.; Narzikulov, M.; Salimov, S. Kh. (1988): K-Capture Probabilities in ¹³³Ba Decay. In: Program and Theses, Proc. 38th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Baku, p 93.
[K-capture probabilities]
- 1989DA11 Danilenko, V. N.; Konstantinov, A. A.; Kurenkov, N. V.; Kurchatova, L. N.; Malinin, A. B.; Mamelin, A. V.; Matveev, S. V.; Sazonova, T. E.; Stepanov, E. K.; Sepman, S. V.; Toporov, Yu. G. (1989): Methods of Producing Radionuclides for Spectrometric Gamma-Ray Sources and Their Standardization - 1. Barium-133. Appl. Radiat. Isotop. 40, 707.
[γ -ray emission probabilities]
- 1989Egorov Egorov, A. G.; Egorov, Yu. S.; Nedovesov, V. G.; Shchukin, G. E.; Yakovlev, K. P. (1989): In: Program and Thesis, Proc. 39th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Leningrad, p 505.
[X K-ray emission probabilities]
- 1989Ma60 Martins, M. C.; Marques, M. I.; Parente, F.; Ferreira, J. G. (1989): Some K X-Ray Relative Transition Probabilities for Z=47,49,52,55 and 56. J. Phys. (London) B22, 3167.
[$K\beta^2/K'\beta_1$ ratio]
- 1990Bh01 Rao, K. Bhaskara; Rao, S. S.; Rao, V. S.; Padhi, H. C. (1990): K-Capture Probabilities in the Decay of ¹³³Ba. Nuovo Cimento 103A, 683.
[K-capture probability]
- 1990Da11 Dasmahapatra, B.; Bhattacharya, S.; Sen, S.; Saha, M.; Goswami, A. (1990): Accurate Measurement of P(K) for the 437 keV State of ¹³³Cs in the Decay of ¹³³Ba (10.5y). J. Phys. (London) G16, 1227.
K-captureprobability]
- 1990Fi03 Firestone, R. B. (190): Analysis of alpha-,beta-, and gamma-Ray Emission Probabilities. Nucl. Instrum. Methods Phys. Res. A286, 584.
[Decay scheme]
- 1990Me15 Meyer, R. A. (1990): Multigamma-Ray Calibration Standards. Fizika (Zagreb) 22, 153.
[γ -ray emission probabilities]
- 1991We08 Wesselborg, C.; Alburger, D. E. (1991): Precision Energy Measurements of Gamma Rays from ⁴⁴Ti and ¹³³Ba. Nucl. Instrum. Methods Phys. Res. A302, 89.
[γ -ray energies]

- 1992Chukreev Chukreev F. E. (1992): Regarding to Selection of Radioactive Sources Problem for Gamma-ray Spectrometer Calibration. In: Voprosi Atomnoi Nauki i Tekhniki, Ser.: Yadernie konstanti, 1992, v.2, P.92 (in Russian).
[Decay scheme]
- 1992Sa28 Sahota, G. P. S.; Singh, H.; Binarh, H. S.; Pallah, B. S.; Sahota, H. S. (1992): Sum Peak Comparison Measurement of K-Capture Probabilities to the Levels of ¹³³Cs. J. Phys. Soc. Japan 61, 3518.
[K-capture probability]
- 1992Un01 Unterweger, M. P.; Hoppes, D. D.; Schima, F. J. (1992): New and Revised Half-Life Measurements Results. Nucl. Instrum. Methods Phys. Res. A312, 349.
[Half-life]
- 1993Nichols Nichols, A. L. (1993) AEA Technology Report AEA-RS-5449
[Decay Scheme]
- 1995Au04 Audi, G.; Wapstra, A. H. (1995). Nucl. Phys. A595, 409.
[Q value]
- 1995Ra12 Rab, S. (1995): Nucl. Data Sheets Update for A=133. Nucl. Data Sheets 75, 491.
[Decay scheme]
- 1996Mi26 Miyahara, H.; Usami, K.; Mori, C. (1996): Precise Measurement of the Emission Probabilities for the Weak 161 and 223 keV Gamma-Rays of ¹³³Ba. Nucl. Instrum. Methods Phys. Res. A374, 193.
[γ-ray emission probabilities]
- 1996Sc06 Schönfeld, E.; Janßen, H. (1996). Nucl. Instrum. Methods Phys. Res. A369. P.527.
[Atomic Data]
- 1997Ma75 Martin, R. H.; Burns, K. I. W.; Taylor, J. G. V. (1997). A Measurement of the Half-Lives of ⁵⁴Mn, ⁵⁷Co, ⁵⁹Fe, ⁸⁸Y, ⁹⁵Nb, ¹⁰⁹Cd, ¹³³Ba, ¹³⁴Cs, ¹⁴⁴Ce, ¹⁵²Eu. Nucl. Instrum. Methods Phys. Res. A390, 267.
[Half-life]
- 1998Hw07 Hwang, H. Y.; Lee, C. B.; Park, T. S. (1998): Appl. Rad. Isotopes 49, 1201.
[γ-ray emission probabilities]
- 1998Sc28 Schönfeld, E. (1998): Calculation of Fractional Electron Capture Probabilities. Appl. Rad. Isotopes 49, 1353.
[PK, PL, PM electron capture probabilities]
- 1998Si17 Singh, B.; Rodriguez, J. L.; Wong, S. S.; Tuli, J. K. (1998): Nucl. Data Sheets 84, 487.
[lg ft]
- 2000Ch01 Chechev, V. P.; Egorov, A. G. (2000): Appl. Rad. Isot. 52, 601.
[Evaluation Technique]
- 2000He14 Helmer, R. G.; van der Leun, C. (2000): Nucl. Instrum. Methods Phys. Res. A450, 35.
[γ-ray energies]
- 2002Un02 Unterweger, M. P. (2002): Half-Life Measurements at the National Institute of Standards and Technology. Appl. Radiat. Isot. 56, 125.
[Half-life]
- 2003Schrader Schrader, H. (2004) Appl. Radiat. Isot. 60, 317
[Half-life]

¹⁴⁰Ba - Comments on evaluation of decay data by R. G. Helmer

1 Decay Scheme

There are 34 reported levels in ¹⁴⁰La below the β^- decay energy, so some levels in addition to the six reported here may be weakly populated in this decay.

2 Nuclear Data

Q value is from Audi and Wapstra 1995 mass evaluation (1995Au04).

The half-life values available are, in days:

12.80	(5)	1965Si17
12.789	(6)	1971Ba28
12.746	(10)	1982DeYX, replaced by 1983Wa26
12.753	(2)	1982HoZJ, replaced by 1992Un01 and 2002Un02
12.739	(22)	1983Wa26
12.751	(5)	1983Wa26
12.7527	(23)	1992Un01 and 2002Un02
12.753	(4)	Adopted value

The value of 1971Ba28 disagrees with all of the later values, so the evaluator increased its uncertainty from 0.006 to 0.020. In the Limitation of Relative Statistical Weight, LRSW, method (1985ZiZY, 1992Ra09), the uncertainty of 1992Un01 is increased from 0.0023 to 0.0047 to reduce its weight from 81% to 50%. Then, the weighted average is 12.753 days with a σ_{int} of 0.003, a reduced- χ^2 of 1.17, and an σ_{ext} of 0.004; these values are adopted. If the original uncertainty for the 1971Ba28 value is used, the reduced- χ^2 is 10.3.

2.1 β^- Transitions

The probabilities for the β^- branches are from the intensity balances from the γ -ray transitions; this is straightforward because one has a direct measurement of some of the γ -ray emission probabilities (1977De34, 1975Ha50, and 1976Li06). The limits for the very weak β^- branches are:

Level (keV)	Comment
0	This is a nonunique 3 rd forbidden transition. The $\log ft$ systematics of 1998Si17 list only one nonunique 3 rd forbidden β^- decay and it has a $\log ft$ of 17.5. If we assume that this class of decays all have $\log ft \geq 15$, the corresponding I_{β^-} is $\leq 1.10^{-5}\%$.
63	Similarly, this β^- branch is unique 3 rd forbidden for which 1973Ra10 lists $\log ft$ values of 18.1 and 20.9. (The corresponding values in 1998Si17 are the $\log f^{\beta^-}t$ values of 20.7 and 21.4.). If we assume that this class has $\log ft > 18$, I_{β^-} is $< 1 \cdot 10^{-8}\%$. The intensity balance from the adopted decay scheme gives 0.00019% (16). This nonzero value, at the 1σ level, suggests that either (1) the true $P_{\gamma}(63)$ and $\alpha(63)$ are both at the low end of the 1σ range, or (2) there is a very weak γ ray from either the 467 (an M3 γ) or 581 level (an E4 γ) to the 63 level. Such a γ ray would only need to be about 1% as intense as the weakest γ rays reported in this energy

region.

2.2 g Transitions

The multiplicities are from the adopted γ data in the Nuclear Data Sheets (1994Pe19). Mixing is 0.010% (6) E2 for 13-keV gamma; mixing is less than or equal to 0.008% E2 for 29-keV gamma; mixing is less than or equal to 0.064% E2 for 162 gamma; mixing is less than or equal to 1% E2 for 304-keV gamma.

See sect. 4.2 for comments on the γ -ray and level energies and the normalization of relative photon emission probabilities to absolute values.

3 Atomic Data

The data are from Schönfeld and Janßen (1996Sc06).

3.1 and 3.2

The desired data were computed by RADLST with the Schönfeld atomic data (1996Sc06, 1996ScZX).

4 Emissions

4.1 Electron Emission

Data were computed by the RADLST program, except the average β^- energies are from the LOGFT program.

4.2 Photon Emission

The level energies were computed from a least-squares fit to the measured γ -ray energies, corrected for recoil, which simultaneously includes all of the individual values from 1990Me03, 1982Ad02, 1970Ju04, 1970Ke09 (including values quoted from 1961Ge01), 1969Ka33, and 1966Mo16; plus the 537-keV value from 1979Bo26; and excluding the 30-keV value from 1966Mo16 and all unplaced lines. γ rays of 183 and 275 keV are reported by 1990Me03, but their nuclide assignment was questionable, so they have been omitted. The uncertainties in the deduced level and γ -ray energies include a factor of the square root of the reduced- χ^2 value.

The γ -ray energies from these references are:

1990Me03	1982Ad02	1979Bo26	1970Ke09	1961Ge01	1970Ju04 *	1969Ka33	1966Mo16
	13.85(5)			13.846(15)			
29.961(5) 8	29.955(2)				29.9653(7)		30.45(3)
63.185(6) *							
99.49(2)							
113.514(31)	113.55(3)		113.56(3)	113.54(3)			
118.837(3)	118.905(22)			118.84(3)	118.81 (5)	118.84(12)	119.0(5)
132.687(1)	132.716(14)			132.69(3)	132.68 (3)	132.84(12)	
162.660(1)	162.672(2)	162.369(6) ?			162.656(3)	162.64(5)	163.10(9)
183.83(9)							
275.18(18)							
304.849(3)	304.874(7)		304.840(20)		304.83(3)	304.83(6)	304.82(3)
418.44(4)							
423.722(1)	423.732(4)		423.69(3)	423.70(9)		423.81(8)	423.69(4)
437.575(2)	437.589(9)		437.55(3)	437.50(9)		437.60(3)	437.55(5)
						467.57(5)	
537.261(9)	537.311(3)	537.261(33)	537.250(20)	537.17(10)		537.32(8)	537.38(3)
551.08(4)	551.2(5)						

* from ¹³⁹La(n, γ)

The reduced- $\chi^2 = 6.0$ for this fit, which implies that the uncertainties are generally too small by a factor of 2.4, or more likely, for some energies the uncertainties are too small by a larger factor. Since a major portion of this reduced- χ^2 value is from the data of 1990Me03, their uncertainties of 0.001 keV were increased to 0.002 keV and the fit repeated. The reduced- χ^2 value was then 5.2 and the χ^2 value is 259. These large values can result from inconsistencies between the values for one γ ray and/or inconsistencies between different γ rays. These cases are illustrated in the following table which shows the conflicts within the values for the 118, 162, and 537 keV, whereas for the 304- and 423-keV lines, only one values has a large contribution to the χ^2 value. The lines in this table provide 172 to the χ^2 value of 259.

Reference	E_γ ^a	ΔE_γ	final E_γ	δ/σ ^b
1990Me03	118.837 (3)	0.068 (22)	118.849 (4)	-3.9
1982Ad02	118.905 (22)			+2.6
1990Me03	162.660 (2)	0.012 (3)	162.6628 (24)	-1.4
1982Ad02	162.672 (2)	0.016 (4)		+4.6
1970Ju04	162.656 (3)	0.44 (9)		-2.3
1966Mo16	163.10 (9)			+4.9
1990Me03	304.849 (3)	0.025 (8)	304.872 (4)	-7.8
1982Ad02	304.874 (7)			+0.2
1990Me03	423.722 (2)	0.010 (4)	423.721 (4)	+0.6
1982Ad02	423.732 (4)			+2.8
1990Me03	537.261 (9)	0.050 (10)	537.303 (6)	-4.7
1982Ad02	537.311 (3)			+2.6

^a Difference between the E_γ on the line and the one on the next line.

^b δ is (E_γ - final E_γ) and s is the uncertainty in E_γ .

This method of analysis does not give an average value for each individual line from the data for that line. Rather, the final γ -ray energies are computed from the deduced level energies, corrected for recoil. This also means that precise energies are obtained for some γ rays for which no precise measurements have been made.

The adopted energies are: 13.849 (4), 29.9656 (15), 63.184 (13), 99.479 (13), 113.582 (7), 118.849 (4), 132.6972 (25), 162.6628 (24), 304.872 (4), 423.721 (4), 437.569 (3), 537.303 (6), and 551.152 (8) keV.

For the relative γ -ray emission probabilities, the following data were used. Many values have been scaled from their original normalizations. All the values of 1966Mo16 are omitted since they do not have uncertainties. Several lines from 1969Ka33 are not included here because they have not been reported again; these are at 144, 177, 498, 512, 602, 637, and 661 keV. The weighted averages from the LRSW method have been adopted.

γ -ray energy (keV)	1991Ch05	1990Me03	1982Ad0 2	1977Ge12	1977De34	1976Li06	1975Ha50	1970Ke0 9	1969Ka3 3	Adopted
L x	54.1(22)		32(6)							53 (7)
13.8	4.69(12)	5.0(7)	4.9(6)						7.2(25)	4.71(12)
29.9	58.4(10)	61.0(40)	60(3)					55(8)	72(12)	58.7(9)
K α	6.10(18)		6.5(5)						10.0(20)	6.4 (5)
K β	1.47(7)		1.60(15)						<2.0(3)	1.49 (6)
43.8	0.054(7)		<0.007					<0.005		
63.1		0.00012(6)								0.00012(6)
99.4		0.00008(5)								0.00008(5)
113.6	0.072(6)	0.066(5)	0.077(16)					0.074(8)		0.070(3)
118.9	0.25(1)	0.250(3)	0.27(3)				1.56(16)	0.28(3)	0.21(2)	0.248(7)
132.7	0.81(2)	0.83(2)	0.90(8)				2.14(31)	0.84(5)	0.83(7)	0.824(13)
162.7	25.3(3)	25.45(29)	28.0(8)	26.4(8)	25.5(3)	25.9(7)	27.6(16)	25.1(10)	28.4(9)	25.65 (26)
304.9	17.54(15)	17.6(2)	17.8(5)	17.67(18)	17.63(21)	18.5(7)	17.9(19)	17.2(7)	17.3(7)	17.61(9)
418.4		0.015(1)	<0.04							
423.7	12.65(12)	12.7(1)	12.8(5)	12.73(14)	12.92(16)	13.0(6)	14.8(12)	12.7(5)	12.8(6)	12.74(6)
437.6	7.91980	7.91(4)	7.80(25)	7.82(9)	7.91(16)	8.5(5)	8.9(4)	7.8(3)	7.8(4)	7.90(4)
467.7	0.29(3)	<0.002	<0.01							
537.3	100(1)	100.0(3)	100(-)	100.0(10)	100.0(9)	100.0(23)	100.0(23)	100.0(20)	100	100.0
551.2	0.028(4)	0.0128(8)	0.027(9)							0.020 (8)
848.9			0.02							

For the lines at 43.8 and 467 keV, there are limits that are much lower than the other reported values, so they are not included in the decay scheme. Other lines that are not adopted are 418 and 848 for which only one value has been reported.

These relative emission probabilities have been scaled by **0.2439 (22)** to obtain absolute values based on the measured γ -emission rates for five lines and the source activity by 1977De34. Other normalization factors are 0.257 (6) (1975Ha50) and 0.236 (5) (1976Li06) where both were determined for the 1596 line from ¹⁴⁰La decay. The discrepancy between the latter two values is 9% and may result from difficulties in determining the γ efficiency at 1596 keV where there is a dearth of efficiency calibration lines. If the three values are averaged, the weighted mean is dominated by the 1977De34 value and is 0.2442 with $\sigma_{\text{int}}=0.0019$ and $\sigma_{\text{ext}}=0.0036$.

6 References

- 1961Ge01 - J. S. Geiger, R. L. Graham, G. T. Ewan, Bull. Am. Phys. Soc. 6 (1961) 71 [E_{γ}]
- 1965Si17 - P. Simonet, G. Boile, G. Simonet, report CEA-R-2461 (1965) [$T_{1/2}$]
- 1966Mo16 - G. A. Moss, D. K. McDaniels, Nucl. Phys. **85** (1966) 513 [E_{γ}]
- 1969Ka33 - V. G. Kalinnikov, H. L. Ravn, Bull. Acad. Sci. USSR, Phys. Ser. **33** (1970) 1283 [E_{γ} , P_{γ}]
- 1970Ju04 - E. T. Jurney, R. K. Sheline, E. B. Shera, H. R. Koch, B. P. K. Maier, U. Gruber, H. Baader, D. Breitig, O. W. B. Schult, J. Kern, G. L. Struble, Phys. Rev. C 2 (1970) 2323 [E_{γ}]
- 1970Ke09 - J. Kern, G. Mauron, Helv. Phys. Acta **43** (1970) 272 [E_{γ} , P_{γ}]
- 1971Ba28 - S. Baba, H. Baba, H. Natsume, J. Inorg. Nucl. Chem. **33** (1971) 589 [$T_{1/2}$]
- 1975Ha50 - J. T. Harvey, J. L. Meason, J. C. Hogan, H. L. Wright, Nucl. Sci. Eng. **58**, (1975) 431 [P_{γ}]
- 1976Li06 - C.-C. Lin, J. Inorg. Nucl. Chem. **38** (1976) 1409 [P_{γ}]
- 1977De34 - K. Debertin, U. Schötzig, K. F. Walz, Nucl. Sci. Eng. **64** (1977) 784 [P_{γ}]
- 1977Ge12 - R. J. Gehrke, R. G. Helmer, R. C. Greenwood, Nucl. Instrum. Methods **147** (1977) 405 [P_{γ}]
- 1979Bo26 - H. G. Börner, W. F. Davison, J. Almeida, J. Blachot, J. A. Pinston, P. H. M. Van Assche, Nucl. Instrum. Methods **164** (1979) 579 [E_{γ}]
- 1982Ad02 - I. Adam, N. M. Antoneva, V. B. Brudanin, M. Budzynski, Ts. Vylov, V. A. Dzhashi, A. Zhumamuratov, A. I. Ivanov, V. G. Kalinnikov, A. Kugler, V. V. Kuznetsov, Li Zon Sik, T. M. Muminov, A. F. Novgorodov, Yu. N. Podkopaev, Z. D. Shavgulidze, V. L. Chikhladze, Izv. Akad.

- Nauk. SSSR, Ser. Fiz. **46** (1982) 2 [E_γ , P_γ]
- 1982DeYX - K. Debertin, U. Schötzig, K. F. Walz, report NBS-SP-626 (1982) 101 [$T_{1/2}$]
 - 1982HoZJ - D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger, report NBS-SP-626 (1982) 85 [$T_{1/2}$]
 - 1983Wa26 - K. F. Walz, K. Debertin, H. Schrader, Int. J. Appl. Radiat. Isotop. **34** (1983) 1191 [$T_{1/2}$]
 - 1985ZiZY - W. L. Zijp, report ECN FYS/FYSRASA-85/19 (1985) [averages]
 - 1990Me03 - R. A. Meyer, K. V. Marsh, H. Seyfarth, S. Brant, M. Bogdanovic, V. Paar, Phys. Rev. C **41** (1990) 1172 [E_γ , P_γ]
 - 1991Ch05 - B. Chand, J. Goswamy, D. Mehta, N. Singh, P. N. Trehan, Can. J. Phys. **69** (1991) 90 [P_γ]
 - 1992Ra08 - M. U. Rajput, T. D. MacMahon, Nucl. Instr. Meth. **A312** (1992) 289 [averages]
 - 1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instr. Methods **A312** (1992) 349 [$T_{1/2}$]
 - 1994Pe19 - L. K. Peker, Nucl. Data Sheets **73** (1994) 261 [J^π , multipolarities]
 - 1995Au04 - G. Audi, A. H. Wapsrta, Nucl. Phys. **A595** (1995) 409 [Q]
 - 1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instr. Meth. **A369** (1996) 527 [ω]
 - 1996ScZX - E. Schönfeld, H. Janßen, report PTB-6.11-1999-1 (Feb. 1999) [P_x]
 - 1998Si17 - B. Singh, J. L. Rodriguez, S. S. M Wong, J. K. Tuli, Nucl. Data Sheets **84** (1998) 487 [$\log ft$ systematics]
 - 2002Un02 - M. P. Unterweger, Appl. Radiat. Isot. **56** (2002) 125 [$T_{1/2}$]

¹⁴⁰La - Comments on evaluation of decay data by R. G. Helmer

1 Decay scheme

There are many levels in ¹⁴⁰Ce below the β⁻ decay energy of 3762 keV that are not reported in these decay data, so some other levels may be weakly populated. However, all of the known levels (1994Pe19) below 2600 keV are populated in this decay.

If the γ rays from the decay of ¹⁴⁰La are used to determine the amount of ¹⁴⁰Ba that is present in a sample, a correction must be made for the fact that their decay rates are different. After they have come into "equilibrium," the ¹⁴⁰La decay rate is larger by a factor of $T_{1/2}({}^{140}\text{Ba}) / [T_{1/2}({}^{140}\text{Ba}) - T_{1/2}({}^{140}\text{La})] = 1.1516$ (7), so the deduced amount of ¹⁴⁰Ba should be divided by 1.1516.

The J^π are from the ¹⁴⁰Ce Adopted Levels of the Nuclear Data Sheets (1994Pe19).

2 Nuclear Data

Q value is from Audi and Wapstra 1995 mass evaluation (1995Au04).

The half-life values available are, in hours:

40.224 (20)	1954Ki08	
40.31 (6)	1954Ya02	
40.27 (5)	1957Pe09	
40 (2)	1960Wi10	
40.23 (3)	1965Si17	
40.2 (2)	1967Ka12	
40.2 (2)	1968Re04	
40.272 (7)	1977DeYO,	superseded by 1983Wa26
40.232 (67)	1978Da21	
40.280 (6)	1980Ho17	
40.295 (5)	1980Ol03	
40.279 (17)	1982HoZJ,	superseded by 1992Un01
40.270 (29)	1983Wa26	
40.284 (5)	1989Ab18	
40.293 (12)	1992Un01 and 2002Un02	
40.34 (4)	2002Ad02	
40.284 (4)	Weighted average, adopted	

The adopted value of 40.284 (4) hours, or 1.67850 (17) days, is the weighted average of the fourteen unsuperseded values, the internal uncertainty is 0.0027, and the reduced-χ² is 1.88.

2.1 β^- Transitions

The level energies used to compute the β^- transition energies are from a least-squares fit to the γ -ray energies.

The probabilities for the β^- branches are from the balances from the γ -ray transition probabilities at each level.

The β^- branches to the levels at 0, 1903, and 2107 keV are nonunique 3rd forbidden. The $\log ft$ systematics of 1998Si17 give only one value, 17.5, for this class of β^- decays. From the data of 1998Si17, it is reasonable to assume a lower limit of $\log ft > 15$ for this class. The corresponding I_{β^-} limits are then $< 1. \times 10^{-4} \%$; $< 1. \times 10^{-5} \%$, ; and $< 1. \times 10^{-5} \%$, respectively. Although there have been many analyses of the β^- spectrum, only 1966Dz05 has reported a branch to the ground state. Their intensity of $5 \times 10^{-5} \%$ (2) is compatible with the limit from the $\log ft$ systematics; however, since others have not seen this branch, this value is assumed to be too large. In any case, the value is negligible in determining the normalization of the γ -ray emission probabilities. These three I_{β^-} are all set to zero in this scheme.

The average β^- energies and the $\log ft$'s are from the LOGFT program.

2.2 Gamma Transitions and Internal Conversion Coefficients

The multipolarities and mixing ratios are from the Adopted γ data in the Nuclear Data Sheets (1994Pe19). For the 131-keV : M1 + 1.7% (+14-5) E2 ; 241-keV : M1 + 0.2% (+8-2)E2 ; 266-keV : M1 + 99.8% (+2-5) E2 ; 328-keV : M1 + 0.24% (6) E2 ; 751-keV : M1 + 11.5% (17) E2 ; 815-keV : M1 + 0.005% (+20-5) E2 ; 867-keV : E1 + 0.16% (+20-12) M2 ; 925-keV : M1 + 1.0% (+9-6) E2.

See sect. 4.2 for comments on normalization of relative photon emission probabilities to absolute values.

3 Atomic data

3.1 Fluorescence yields

The data are from Schönfeld and Janßen (1996Sc06).

3.2 X-ray radiations

Relative emission probabilities are from Schönfeld and Janßen (1996ScZX).

4 Radiations

4.1 Electron Emission

The conversion electron data were computed from the internal-conversion coefficients interpolated from the tables of Rösel (1978Ro21) and of Band (1976Ba63) and the multipolarities are from the evaluation of 1994Pe19. The adopted internal pair coefficient for the 1596-keV γ ray is 0.000106 (1) deduced from the measured value of $\alpha(\text{pair})/\alpha_K = 0.156$ (15) from 1968Be57; the theoretical value is 0.000115 (1979Sc31).

4.2 Photon Emissions

The γ -ray energies were determined from the reported values in Table 1. All of these 197 energies were entered into a simultaneous least-squares fit to determine the energies of the 18 excited levels. The possible γ rays at 936 and 2533 keV, which were reported only once, are not included in the adopted decay scheme or the list of γ rays. The adopted γ -ray energies were then computed from the differences between these level energies, with the corrections for recoil. As a result, the consistency of the several values for a single γ ray is not determined, but the consistency of the whole set is determined. For this fit, the reduced- χ^2 value is 1.07 indicating that the input uncertainties are quite reasonable. This method occasionally produces γ -ray energy

uncertainties that are much smaller than would be determined from the measurements for that γ ray alone.

The relative γ -ray intensities were determined from the data in Table 2. Several of these sets of data were published as emission probabilities and have been scaled by the evaluator to obtain values relative to the 1596-keV γ ray. The Limitation of Relative Statistical Weight method, as implemented in the LWEIGHT program, was used to compute the average values. In this calculation, if a particular value contributes more than 50% of the relative weight and the initial fit has a reduced- χ^2 of more than the critical reduced- χ^2 for the number of input values, the uncertainty of the most precise value is increased to reduce its relative weight to 50%. The critical reduced- χ^2 values are: 6.6 for 2 input values; 4.6 for 3; 3.8 for 4; 3.3 for 5; 3.0 for 6; 2.5 for 9; 2.4 for 10; 2.3 for 11; and 2.2 for 12 or 13. Some values have been deleted from the averaging, as indicated in the table and the evaluator has arbitrarily increased a few input uncertainties.

At the time many of these measurements were made, there was a lack of good Ge detector efficiency calibration standards in the region of 1596 keV. Therefore, the evaluator has introduced an energy-dependent scaling factor based on the emission probabilities from ¹⁹⁷⁷De34 for thirteen lines from 266 to 2521 keV. This factor, which is shown in Table 2 and varies by 3%, corrects for this assumed systematic deviation of the Ge detector efficiencies. The total γ -ray feeding of the ground state is set to 100%, with no direct β^- decay, to obtain a normalization factor of 0.9540 (8) to convert these relative γ emission probabilities to absolute probabilities as given in the last column of Table 2.

Table 1. Measured g-ray energy values

1964Re09	1967Ka12	1968Ba18	1968Gu05	1970Ka18	1970Ke06	1972GeZG	1978Ar28	1979Bo26	1980Ka32	1982Ad02	Adopted
	24.595(4)										24.595(4)
	64.130(7)	64.135(10)									64.129(4)
	68.916(6)	69.0(3)									68.923(5)
	109.417(6)	109.418(7)				109.47(20)				109.422(11)	109.417(4)
	131.122(8)	131.121(8)				131.15 (20)			130.97(20)	131.117(8)	131.121(4)
	173.550(11)	173.536(12)				173.50(20)			173.49(17)	173.543(9)	173.546(5)
241.97(3)	241.961(22)	241.966(12)				241.90(8)	241.88(10)		242.06(9)	241.933(30)	241.959(6)
266.52(6)	266.547(22)	266.551(14)				266.61(6)	266.58(10)		266.67(7)	266.543(12)	266.554(5)
		306.9(2)				306.5(4)			307.1(2)	306.9(2)	307.08(4)
328.789(15)		328.768(12)	328.752(30)		328.745(15)	328.76(5)	328.80(10)	328.746(25)	328.78(5)	328.762(8)	328.761(4)
	397.8(3)	397.79(11)				397.66(10)			397.8(1)	397.52(5)	397.674(6)
432.55(8)	432.62(6)	432.530(29)			432.490(20)	432.52(4)	432.51(10)		432.66(4)	432.493(12)	432.513(8)
				438.5 (4)					438(1)	438.5(5)	438.178(6)
									445(1)	445.5(5)	444.57(4)
487.027(24)	487.042(29)	487.029(19)	487.032(30)		486.995(30)	487.009(30)	487.09(10)	487.15(25)	486.99(3)	487.021(12)	487.022(6)
		618.2(7)				617.7(3)			618.2(1)	618.12(5)	618.12(4)
752.42(33)	751.75(8)	751.83(8)				751.655(35)	751.66(10)		751.65(4)	751.637(18)	751.653(7)
815.82(10)	815.85(7)	815.80(9)			815.735(40)	815.775(30)	815.80(10)		815.78(4)	815.772(19)	815.781(6)
867.9(5)	867.87(15)	867.82(14)				867.842(35)	867.85(10)		867.80(4)	867.856(20)	867.839(16)
	919.63(15)	919.5(2)				919.54(4)	919.63(10)		919.48(6)	919.550(23)	919.533(10)
924.1(6)	925.24(9)	925.20(17)				925.188(35)	925.21(10)		925.14(6)	925.189(21)	925.198(7)

				936.9(4)						none	
	950.9(3)	951.1(4)		951.4(4)		951.00(6)			950.95(6)	950.987(26)	950.988(20)
										992.9(5)	992.64(18)
						1045.2(3)			1045.0(1)	1045.05(24)	1045.02(9)
						1097.2(3)			1097.2(2)	1097.20(23)	1097.58(9)
									1303.3(1)	1303.5(4)	1303.34(7)
						1404.5(2)			1404.9(2)	1405.20(17)	1404.66(9)
1596.34(25)	1596.49(24)	1596/6(2)	1596.20(4)		1596.170(25)	1596.17(6)	1596.22(10)		1596.17(6)	1596.210(35)	1596.203(13)
										1877.29(19)	1877.33 (18)
	1903.15(30)								1903 (1)		1903.28(4)
						1924.2(3)			1924.4(1)	1924.62(13)	1924.5 (2)
									2082.9(2)	2083.2(5)	2083.219(14)
	2348.1(7)	2348.8 (6)				2347.80(6)			2347.82(6)	2347.88(5)	2347.847(14)
				2465.3(8)					2464.0(1)	2464.1(5)	2464.031(20)
2519.7(34)	2521.7(5)	2522.2(4)				2521.32(6)	2522.03(10)		2521.36(6)	2521.40(5)	2521.390(14)
				2533.4(7)							none
	2547.1(8)	2548.6(8)		2547.5(6)		2547.14(6)			2547.19(7)	2547.34(11)	2547.180(23)
	2900(2)	2899.7(5)		2899.7(8)		2899.5(2)			2899.5(2)	2899.61(16)	2899.53(7)
	3119(2)	3118.3(7)		3119.0(8)		3118.52(15)			3118.4(2)	3118.51(16)	3118.49(10)
	3322(4)	3319.7(25)		3319.6(9)		3319.4(6)			3319.3(3)	3320.4(6)	3319.52(24)

Table 2. Measured relative g-ray emission probabilities – Part 1 : references from 1962 to 1975

E_γ	1962Ha14	1967Ka12	1968Ba18	1969KuZV	1970Ka18	1974HeYW	1975Ha50
K_α					2.4 (7)		
K_β					0.36 (8)		
64					~ 0.01		
68			0.065 (13)		0.064 (16)		
109		0.50 (20)	0.27 (4)	0.23 (2)	0.210 (15)	0.17 (4)	0.20 (4)
131		1.05 (15)	0.61 (9)	0.47 (3)	0.50 (3)	0.42 (5)	0.58 (4)
173			0.13 (5)		0.130 (20)	0.60 (20)	
241		0.83 (10)	0.45 (6)	0.58 (6)	0.410 (30)	0.51 (8)	0.66 (3)
266		0.83 (10)	0.56 (6)	0.53 (4)	0.490 (30) @	0.50 (5)	0.34 (3)
307			0.022 (11)		0.035 (17)		
328		25.4 (20)	21.4 (11)	22.4 (4)	19.4 (1) @	19.6 (13)	18.8 (5)
397			0.054 (25)		0.110 (35)	0.12 (3)	
432		3.5 (3)	3.11 (16)	3.06 (9)	2.85 (15)	2.94 (20)	3.0 (2)
438					0.021 (10)		
444					~ 0.25		
487		49.6 (32)	49.4 (25)	48.2 (5)	45.0 (2) @	44.7 (30)	39.7 (5)
618		0.4 (3)	0.044 (22)		~ 0.045		
751		4.5 (4)	4.40 (22)	4.66 (23)	4.40 (20)	4.5 (3)	4.9 (2)
815		23.5 (20)	24.1 (12)	24.9 (2)	23.5 (7)	24.2 (15)	26.8 (11)

867		5.6 (5)	5.64 (28)	5.91 (24)	5.60 (30)	5.7 (3)	6.5 (1)
919		2.5 (6)	2.73 (16)	2.59 (10)	2.64 (16)	2.89 (20)	3.4 (2)
925		6.8 (6)	7.24 (43)	6.94 (21)	7.10 (30)	7.2 (4)	7.9 (3)
950		0.8 (3)	0.56 (5)	0.62 (9)	0.550 (30)	0.56 (4)	
992							
1045							
1097							
1303							
1405							
1596	100.	100.	100.	100.	100.	100.	100.
1877						0.05 (2)	
1924						0.023 (5)	
2083							
2347	0.86 (17)	1.0 (2)	0.901 (45)	0.85 (6)	0.90 (6)	0.89 (6)	
2464					0.0018 (6) #		
2521	3.0 (6)	3.5 (2)	3.52 (18)	3.37 (10)	3.60 (18)	3.59 (18)	4.9 (4)
2547		0.11 (2)	0.122 (9)		0.110 (7)	0.110 (6)	
2899	0.082 (17)	0.060 (10)	0.070 (5)		0.065 (6)	0.073 (8)	
3118	0.035 (10)	0.030 (10)	0.027 (3)		0.027 (4)	0.028 (3)	
3320			0.008 (4)		0.0047 (15)	0.050 (3)	

Table 2. Measured relative g-ray emission probabilities – Part 2 : references from 1976 to 1991

E _γ (keV)	1976Li06	1977De34	1977Ge12	1978Ar28	1980Ka32	1982Ad02	1991Ch05	Wtd. Avg.	reduced χ ²	scaling factor	Adopted	Emission probability (%)
K _α						1.77 (6)	1.72 (4)	1.74 (3)		1.027	1.79 (3)	1.71 (3)
K _β						0.45 (2)	0.395 (14)	0.406 (16)	2.8	1.027	0.417 (16)	0.398 (15)
64						0.011 (4)	0.015 (2)	0.0142 (18)		1.027	0.146 (18)	0.139 (17)
68					0.070 (16)	0.080 (6)	0.079 (2)	0.0785 (19)		1.027	0.0806 (19)	0.0769 (18)
109	0.20 (9)				0.170 (10) @	0.220 (10)	0.230 (4)	0.221 (6)	1.9	1.027	0.227 (6)	0.217 (6)
131	0.46 (9)				0.44 (1) @	0.48 (3)	0.49 (1) *	0.479 (15)	2.9	1.027	0.492 (15)	0.469 (14)
173					0.120 (10)	0.110 (10)	0.133 (4)	0.129 (5)	2.2	1.027	0.132 (5)	0.126 (5)
241	0.52 (18)	0.6 (1)		0.51 (9)	0.450 (10)	0.460 (30)	0.434 (8) *	0.445 (10)	2.7	1.027	0.457 (10)	0.436 (10)
266	0.53 (6)	0.7 (1)		0.50 (3)	0.520 (10)	0.500 (30)	0.488 (8)	0.502 (9)	2.3	1.027	0.516 (19)	0.492 (9)
307					0.022 (6)	0.020 (5)	0.026 (7)	0.022 (3)		1.027	0.023 (3)	0.022 (3)
328	21.2 (6)	22 (2)	21.46 (22)	21.5 (6)	21.5 (4)	21.7 (4)	21.1 (3)	21.2 (3)	5.0	1.027	21.8 (3)	20.8 (3)
397					0.078 (3)	0.070 (5)	0.077 (5)	0.0763(24)	1.15	1.027	0.0784 (25)	0.0748 (24)
432	3.0 (4)	3.5 (2)	3.08 (3)	2.96 (16)	3.05 (3)	2.97 (15)	3.04 (3)	3.056 (17)	1.01	1.027	3.139 (17)	2.995 (16)
438					0.006 (3) *	<0.0014	0.041 (10)	0.0 18 (10)	4.1	1.027	0.018 (10)	0.017 (10)
444					0.005 (3)	0.0036 (12)	0.003 (1)	0.0034 7)		1.027	0.0035 (7)	0.0033 (7)
487	46.2 (11)	47 (2)	47.7 (5)	47.3 (9)	46.6 (9)	46.4 (8)	47.7 (6)	47.0 (4)	2.6	1.027	48.3 (4)	46.1 (4)
618					0.049 (6)	0.014 (3) #	0.039 (4)	0.042 (3)	1.12	1.015	0.043 (3)	0.041 (3)
751	4.40 (17)	4.6 (1)	4.65 (5)	4.37 (22)	4.45 (5)	4.36 (16)	4.54 (4)	4.536 (25)	1.10	1.015	4.604 (25)	4.392 (24)

815	23.8 (6)	24.2 (4)	24.85 (25)	24.1 (5)	24.0 (4)	23.5 (7)	24.4 (2)	24.49 (13)	1.43	1.015	24.86 (13)	23.72 (12)
867	6.0 (5)	5.8 (3)	5.90 (6)	5.69 (10)	5.69 (6)	5.56 (19)	5.77 (7)	5.77 (3)		1.015	5.85 (3)	5.58 (3)
919	3.1 (4)	2.6 (2)	2.91 (4)	2.57 (14)	2.83 (4)	2.80 (9)	2.79 (3)	2.812 (24)	1.65	1.015	2.862 (24)	2.730 (23)
925	7.3 (8)	7.2 (3)	7.42 (8)	7.25 (16)	7.26 (8)	7.10 (21)	7.23 (7)	7.27 (4)		1.015	7.38 (4)	7.04 (4)
950	0.63 (12)	0.67 (6)			0.553 (7)	0.56 (3)	0.544 (7)	0.549 (5)		1.015	0.557 (5)	0.531 (5)
992						0.009 (3)	0.014 (5)	0.0103 (26)		1.015	0.0105 (26)	0.0100 (25)
1045					0.024 (4)	0.016 (4)	0.026 (15)	0.0202 (29)	1.08	1.015	0.021 (3)	0.020 (3)
1097					0.024 (5)	0.022 (5)	0.024 (5)	0.0233 (29)		1.015	0.024 (3)	0.023 (3)
1303					0.046 (6)	0.050 (7)	0.044 (7)	0.047 (4)		1.000	0.047 (4)	0.045 (4)
1405					0.066 (9)	0.068 (8)	0.062 (7)	0.065 (5)		1.000	0.065 (5)	0.062 (5)
1596	100.0	100.0 (3)	100 (1)	100.0 (3)	100.0	100.	100.0 (15)	100.0		1.000	100.0	95.40 (8)
1877						0.042 (6)	0.043 (4)	0.043 (3)		1.000	0.043 (3)	0.041 (3)
1924					0.014 (3)	0.006 (2)	0.014 (2)	0.0115 (28)	5.0	1.000	0.012 (3)	0.011 (3)
2083					0.045 (3)	0.007 (2) #	0.031 (2)	0.038 (7)	11	1.000	0.038 (7)	0.036 (7)
2347		0.90 (4)	0.891 (16)		0.89 (1)	0.89 (3)	0.89 (3)	0.890 (7)		0.996	0.886 (7)	0.845 (7)
2464					0.012 (1)	0.008 (1)	0.012 (2)	0.0102 (14)	4.4	0.996	0.0102 (14)	0.0097 (13)
2521		3.5 (2)	3.62 (7)	3.65 (18)	3.58 (5)	3.61 (9)	3.63 (4)	3.591 (25)		0.996	3.577 (25)	3.412 (24)
2547			0.109 (3)		0.105 (2)	0.109 (5)	0.106 (3)	0.1070 (13)		0.996	0.1066 (13)	0.1017 (12)
2899			0.069 (1)		0.070 (1)	0.069 (3)	0.070 (2)	0.0695 (6)		0.996	0.0692 (6)	0.0660 (6)
3118			0.027 (1)		0.027 (1)	0.028 (2)	0.026 (1)	0.0269 (5)		0.996	0.0268 (5)	0.0256 (5)
3320					0.0040 (3)	0.0045 (4)	0.0040 (3)	0.00413 (19)		0.996	0.00411 (19)	0.00392 (18)

Comments on Table 2 :

* Uncertainties were increased in LRSW analysis to reduce relative weight to 50%; this change is only made if the reduced- χ^2 is greater than the associated critical value. These changes were: 131 keV, 1991Ch05 0.010 to 0.012; 241, 1991Ch05 0.008 to 0.0087; and 438 keV, 1980Ka32 0.003 to 0.007.

@ Uncertainties were increased by evaluator due to large deviation from average. These changes were: 109 keV, 1980Ka32 0.01 to 0.02; 131, 1980Ka32 0.01 to 0.02; 266, 1970Ka18 0.03 to 0.06; 328, 1970Ka18 0.1 to 0.3; and 487, 1970Ka18 0.2 to 0.5.

Deleted from calculation.

The K x-ray intensities are from the measured data.

6 References

- 1954Ki08 - H. W. Kirby, M. L. Salutsky, Phys. Rev. **93**, (1954) 1051 [T_{1/2}]
- 1954Ya02 - L. Yaffe, H. G. Thode, W. F. Merritt, R. C. Hawkings, F. Brown, R. M. Bartholomew, Can. J. Chem. **32** (1954) 1017 [T_{1/2}]
- 1957Pe09 - D. F. Peppard, G. W. Mason, S. W. Moline, J. Inorg. Nuclear Chem. **5** (1957) 141 [T_{1/2}]
- 1960An05 - S. F. Antonova, S. S. Vasilenko, M. G. Kaganskii, D. L. Kaminskii, Soviet Phys. JETP **11** (1960) 554 [P_γ]
- 1960Wi10 - R. G. Wille, R. W. Fink, Phys. Rev. **118** (1960) 242 [T_{1/2}]
- 1962Ha14 - P. G. Hansen, K. Wilsky, Nucl. Phys. **30** (1962) 405 [P_γ]
- 1964Re09 - J. J. Reidy, report TID-21826 (1964) [E_γ]
- 1965Si17 - P. Simonet, G. Boile, G. Simonet, report CEA-R-2461 (1965) [T_{1/2}]
- 1966Ba36 - H. W. Baer, J. J. Reidy, M. L. Wiedenbeck, Nucl. Phys. **86** (1966) 332 [E_γ]
- 1966Dz09 - B. S. Dzelepov, N. N. Zhukovskii, A. G. Maloyan, V. P. Prikhodtseva, Bull. Acad. Sci. USSR, Phys. Ser. **30** (1967) 410 [P_γ]
- 1966Ha20 - G. I. Harris, D. V. Breitenbecher, Phys. Rev. **145** (1966) 866 [P_γ]
- 1967Ka12 - S.-E. Karlsson, B. Svahn, H. Pettersson, G. Malmsten, E. Y. De Aisenberg, Nucl. Phys. **A100** (1967) 113 [E_γ, P_γ]
- 1968Ba18 - H. W. Baer, J. J. Reidy, M. L. Wiedenbeck, Nucl. Phys. **A113** (1968) 33 [E_γ, P_γ]
- 1968Be57 - B. N. Belyaev, S. S. Vasienko, V. S. Gvozdev, Soviet J. Nucl. Phys. **8** (1969) 135 [α^π]
- 1968Gu05 - R. Gunnink, R. A. Meyer, J. B. Niday, R. P. Anderson, Nucl. Instr. Methods **65**(1968)26 [E_γ] 1968Re04 - S. A. Reynolds, J. F. Emery, E. I. Wyatt, Nucl. Sci. Eng. **32** (1968) 46 [T_{1/2}]
- 1969GuZV - R. Gunnink, J. B. Niday, R. P. Anderson, R. A. Meyer, report UCID-15439 (1969) [P_γ]
- 1970Ka18 - V. G. Kalinnikov, H. L. Ravn, H. G. Hansen, N. A. Lebedev, Bull. Acad. Sci. USSR, Phys. Ser. **34** (1971) 815 [E_γ, P_γ]

- 1970Ke06 - J. Kern, Nucl. Instr. Methods **79** (1970) 233 [E_γ]
- 1972GeZG - R. J. Gehrke, report ANCR-1088, (1972) 392 [E_γ]
- 1974HeYW - R. L. Heath, report ANCR-1000-2 (1974) [P_γ]
- 1975Ha50 - J. T. Harvey, J. L. Meason, J. C. Hogan, H. L. Wright, Nucl. Sci. Eng. **58** (1975) 431 [P_γ]
- 1976Ba63 - I. M. Band, M. B. Trzhaskovskaya, M. A. Listengarten, Atomic Data Nucl. Data Tables **18** (1976) 433 [α]
- 1976Li06 - C.-C. Lin, J. Inorg. Nucl. Chem. **38** (1976) 1409 [P_γ]
- 1977De34 - K. Debertin, U. Schötzig, K. F. Walz, Nucl. Sci. Eng. **64** (1977) 784 [P_γ]
- 1977DeYO - K. Debertin, U. Schötzig and K. F. Walz, INDC(Ger)-10/L+Special (1977) 83 [T_{1/2}]
- 1977Ge12 - R. J. Gehrke, R. G. Helmer, R. C. Greenwood, Nucl. Instrum. Methods **147** (1977) 405 [P_γ]
- 1978Ar28 - G. Ardisson, Nucl. Instr. Methods **151** (1978) 505 [E_γ,P_γ]
- 1978Da21 - M. C. Davis, W. C. Bowman, J. C. Robertson, Int. J. Appl. Radiat. Isotop. **29** (1978) 331 [T_{1/2}]
- 1978Ro21 - F. Rösel, H. M. Fries, K. Alder, H. C. Pauli, Atomic Data Nucl. Data Tables **21** (1978) 269 [α]
- 1979Bo26 - H. G. Börner, W. F. Davidson, J. Almeida, J. Blachot, J. A. Pinston, P. H. M. Van Assche, Nucl. Instr. Methods **164** (1979) 579 [E_γ]
- 1979Sc31 - P. Schlüter, G. Soff, Atomic Data Nucl. Data Tables **24** (1979) 509 [αⁿ]
- 1980Ho17 - H. Houtermans, O. Milosevic, F. Reichel, Int. J. Appl. Radiat. Isotop. **31** (1980) 153 [T_{1/2}]
- 1980Ka32 - R. Kaur, A. K. Sharma, S. S. Sooch, P. N. Trehan, J. Phys. Soc. Japan. **49** (1980) 2122 [E_γ,P_γ]
- 1980Ol03 - J. B. Olomo, T. D. MacMahon, J. Phys. (London) **G6** (1980) 367 [T_{1/2}]
- 1982Ad02 - I. Adam, N. M. Antoneva, V. B. Brudanin, M. Budzynski, Ts. Vylov, V. A. Dzhashi, A. Zhumamuratov, A. I. Ivanov, V. G. Kalinnikov, A. Kugler, V. V. Kuznetsov, Li Zon Sik, T. M. Muminov, A. F. Novgorodov, Yu. N. Podkopaev, Z. D. Shavgulidze, V. L. Chikhladze, Izv. Akad. Nauk SSSR, Ser. Fiz. **46** (1982) 2 [E_γ,P_γ]
- 1982HoZJ - D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger, report NBS-SP-626 (1982) 85 [T_{1/2}]
- 1983Wa26 - K. F. Walz, K. Debertin, H. Schrader, Int. J. Appl. Radiat. Isotop. **34** (1983) 1191 [T_{1/2}]
- 1989Ab18 - A. Abzouzi, M. S. Antony, V. B. Ndocko Ndongue, J. Radioanal. Nucl. Chem. **137** (1989) 381 [T_{1/2}]
- 1991Ch05 - B. Chand, J. Goswamy, D. Mehta, N. Singh, P. N. Trehan, Can. J. Phys. **69** (1991) 90 [P_γ]
- 1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instr. Methods **A312** (1992) 349 [T_{1/2}]
- 1994Pe19 - L. K. Peker, Nucl. Data Sheets **73** (1994) 261 [Jⁿ, multipolarities]
- 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. **A595** (1995) 409 [Q]
- 1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instr. Meth. **A 369** (1996) 527 [fluorescence yields]
- 1998Si17 - B. Singh, J. L. Rodriguez, S. S. M. Wong, J. K. Tuli, Nucl. Data Sheets **84** (1998) 565 [log ft systematics]
- 1999ScZX - E. Schönfeld, H. Janßen, laboratory report PTB-6.11-1999-1 (Feb. 1999) [P_X]

¹⁵²Eu – Comments on evaluation of decay data

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We used the *Limitation of Relative Statistical Weights* (LWM) method (1985ZiZY, 1992Ra08) for averaging quantities throughout this evaluation. This method provides a uniform approach for the analysis for discrepant data.

Decay Scheme

¹⁵²Eu decays by electron capture (EC) to ¹⁵²Sm, and by β⁻ to ¹⁵²Gd. Only excited levels are populated in the daughter nuclei since decay to the respective ground states are highly hindered by spin selection rules. Therefore, we used the sum of the total γ-ray transition emission probabilities (photons + electrons) to the ground states of ¹⁵²Sm and ¹⁵²Gd to normalize the decay scheme of ¹⁵²Eu. We have deduced the following branchings: 72.1(3)% (EC), and 27.9(3)% (β⁻). This normalization is virtually the same as that based on the measurement of the absolute γ-ray emission probabilities (See **Gamma Rays**).

Nuclear Data

We have considered the following measured values of the half-life of ¹⁵²Eu for deducing a recommended value.

1.	4934.1 (23) d	2004Sc04	Duration of measurement: about 26 years
2.	4936.6 (20) d	1998Si12	Duration of measurement: 20 years
3.	4948 (7) d	1997Ma75	Duration of measurement: about 2 years
4.	4945.5 (23) d	1992Un01	Duration of measurement: 13.5 years
5.	4943 (4) d	1986Wo05	
6.	4792(37) d	1983Ba29	
7.	4939 (6) d	1983Wa26	
8.	4892.3 (82) d	1980RuZX	
9.	4785 (19) d	1978La21	
10.	4821 (110) d	1972Em01	

Our recommended value of 4939 (6) d (or 13.522 (16) a) is a weighted average (LWM) ($\chi^2/\nu=12$) of the results from 2004Sc04, 1997Ma75, 1992Un01, 1986Wo05, and 1980RuZX. Values given by 1978La21, 1972Em01, and 1983Ba29 have not been included because they significantly disagree with most of the other results, suggesting that they may have been affected by systematic uncertainties. 1983Wa26 and 1998Si12 have been superseded by 2004Sc04 (same research groups, PTB).

Electron Capture, Positrons (β^+), and β^- Transitions

EC and positron transition energies to levels in ¹⁵²Sm have been deduced from $Q(\text{EC}) = 1874.3$ (7) keV (1995Au04) and the individual level energies. Transition probabilities (P_{EC}) are from γ -ray transition probability balance at each level. They are given as branchings ($P_{\text{EC}} \times 100$) in Sections 2.1 – 2.3. Fractional atomic sub-shell electron-capture probabilities (i.e., P_{K} , P_{L} , P_{M} , P_{N}) are theoretical values (1998Sc28) calculated with the computer program EC-CAPTURE [1].

Positrons are energetically possible and allowed by spin selection rules to the 121- and 366-keV levels only. Their transition probabilities, presented here as branchings ($P_{\beta^+} \times 100$), have been deduced from theoretical β^+/EC ratios (1957Zw01).

β^- endpoint energies for the decay to levels in ¹⁵²Gd have been deduced from $Q(\beta^-) = 1818.8$ (11) keV (1995Au04). Their transition probabilities, presented here as branchings ($P_{\beta^-} \times 100$), have been deduced from γ -ray transition probability balance at each level.

Gamma Rays

Energies. The precise energies of strong γ rays given here are from 2000He14. These values are based on a revised energy scale that uses the new fundamental constants and wave lengths deduced from an updated value of the lattice spacing in Si crystals (1987Co39). All other (less precise) energies are values adjusted to the new energy scale and recommended in 1996Ar09 evaluation.

Emission Probabilities. For a γ -ray transition, its absolute transition probability (photons + electrons) is given by $P_{\gamma}(1 + \alpha) \times 100$, where P_{γ} is the absolute γ -ray emission intensity, and α , its theoretical (1978Ro22, [4]) conversion coefficient. We have deduced the P_{γ} values used here as follows:

1 By averaging (LWM) the experimental relative emission intensities reported by 1970No06, 1970Ri19, 1971Ba63, 1972Ba05, 1977Ge12, 1980Sh15, 1984Iw03, 1986Me10, 1989Da12, 1990Me15, 1990St02, 1992Ya12, 1993Ka30, 1998Hw07, and from the fourteen measurements (ICRM01, ICRM02, ICRM08, ICRM10, ICRM12, ICRM15, ICRM16, ICRM17, ICRM18, ICRM20, ICRM25, ICRM27, ICRM28, and ICRM29) of the study participants [5] from the International Committee on Radioactivity Measurements (ICRM), which 1991BaZS considered reliable. These data are presented in Table 1 and Table 2.

2 By normalizing the above mentioned relative emission intensities to absolute values. We normalized these scales by using $P_{\gamma}(1408) = 0.2085$ (8), which was determined from an inter-comparison of measured absolute emission intensities produced by participants from various laboratories and coordinated by the ICRM [5]. This value agrees very well with $P_{\gamma}(1408) = 0.2086$ (21), deduced by evaluators from the sum of the relative γ -ray transition probabilities (photons + electrons) to the respective ground states of ¹⁵²Sm and ¹⁵²Gd. The larger uncertainty in the latter value is due mostly to that in the conversion coefficient of the 121-keV γ -ray (taken as 3%). We used 47.46 (20) for the relative intensity of the 1086-keV γ ray that de-excites the 1086-keV level in ¹⁵²Sm. We deduced this value from our recommended relative emission intensity of 48.63 (20) for the 1086-“doublet” (See Table 2) and subtracting 1.17 (4) for the contribution of the 1084-keV γ ray (1990Me15). The excellent agreement between these two normalizations confirms the completeness and self-consistency of the ¹⁵²Eu decay scheme and the good quality of our recommended data. We have preferred not to statistically combine these normalizations because of the correlations that exist between them. Absolute γ -ray emission intensities (P_{γ}) are given in Section 4.1.

Conversion Coefficients. Values given in Section 2.3 are the result of theoretical calculations (1978Ro22, [4]), interpolated for the recommended transition energies presented here, and for adopted multiplicities and mixing ratios from the 1996Ar09 evaluation, uncertainties have been taken being 3 %. For transitions with E0 multipolarity, the adopted values are derived from experiments.

Atomic Data

X-Rays. X-ray energies and relative emission probabilities are from Schönfeld and Rodloff [6]. Absolute X-ray emission probabilities have been calculated with the computer program EMISSION [2] using absolute γ -ray emission probabilities from Section 4.1, theoretical conversion coefficients (1978Ro22) from Section 2.3, and fluorescence yields from 1996Sc06. These calculated X-ray emission probabilities agree well with the experimental results shown in Table 2, and thus support the correctness of our recommended γ -ray data and the self-consistency of the ¹⁵²Eu decay scheme.

Electron Emission

Conversion-electron energies are from γ -ray energies given in Section 4.2 and the atomic binding energies reported by Larkins [7]. Absolute electron emission intensities are from γ -ray emission probabilities given in Section 4.1, and the theoretical (1978Ro22) conversion coefficients presented in Section 2.3.

Energies of K-Auger electrons are from Schönfeld and Rodloff [8]. Absolute emission intensities of Auger electrons are values calculated with the computer program EMISSION [2] using absolute γ -ray emission intensities from Section 4.2, theoretical conversion coefficients (1978Ro22) given in Section 2.3, and the electron-capture probabilities presented in Section 2.1. The same emission probabilities, but renormalized to a scale where $P_{KLL} = 1.0$, are given as relative emission probabilities in Section 3.2.

Total Average Radiation Energy

We show below the total average radiation energy released (by β^- , β^+ , neutrinos, γ rays, atomic electrons, and nuclear recoil) in the electron-capture and β^- decay of ¹⁵²Eu, as well as the total decay energies from mass differences, Q-values, and decay branchings (1995Au04).

	Total Average Radiation Energy* (keV)	Total Decay Energy ^{&} (Q x branching) (keV)
¹⁵² Eu EC decay	1345 (18)	1351 (6)
¹⁵² Eu β^- decay	508 (2)	507 (5)

* Calculated with the computer program RADLST [3], and using the recommended radiation data given in this evaluation.

[&] Q-values (Q(EC) and Q(β^-)) are from 1995Au04. Branchings are from this evaluation.

The agreement between these values confirms the quality, completeness, and self-consistency of the ¹⁵²Eu decay scheme presented in this evaluation.

References

- [1] E. Schönfeld, F.Y. Chu, E. Browne,
EC-CAPTURE, a computer program to calculate electron-capture probabilities to atomic sub-shells, 1998.
[P_K , P_L , P_M , P_N]
- [2] H. Janßen and E. Schönfeld,
EMISSION, a computer program to calculate X-ray and Auger-electron emission probabilities, 1998.
[X-ray, Auger-electron probabilities]
- [3] Thomas W. Burrows,
The Program RADLST, Report BNL-NCS-52142, February 1988.
[Average radiation energy]
- [4] E. Yakusev and N. Coursol,
ICC, a computer program to interpolate internal conversion coefficients, 1998.
[Theor. internal conversion coefficients]
- [5] K. Debertin, Nucl. Instrum. Methods **158**, 479 (1979);
K. Debertin, Report PTB-Ra-7 (and Report ICRM-S-3) (1978);
K. Debertin, Preliminary Summary communicated to ICRM study participants (1977);
K. Debertin, private communication (1987). Reference quoted in 91BaZS.
[Rel. P_γ]
- [6] E. Schönfeld, G. Rodloff,
Report PTB-6.11-1999-1, February 1999
[X-ray energies, P_{KX}]
- [7] F. B. Larkins,
At. Data and Nucl. Data Tables **20**, 313 (1977).
[Atom. electron binding energies]
- [8] E. Schönfeld, G. Rodloff,
Report PTB-6.11-98-1, October 1998.
[X rays, ω_K]

1957Zw01 - P. F. Zweifel, Phys. Rev. **107**, 329 (1957). [Theor. β^+ /EC ratios]

1970No06 - A. Notea, E. Elias, Nucl. Instrum. Methods **86**, 269 (1970). [Rel. P_γ]

1970Ri19 - L. L. Riedinger, N. R. Johnson, J. H. Hamilton, Phys. Rev. C **2**, 2358 (1970).

[Rel. P_γ]

1971Ba63 - J. Barrette, M. Barrette, A. Boutard, G. Lamoureux, S. Monaro, S. Markiza, Can. J. Phys. **49**, 2462 (1971). [Rel. P_γ]

1972Ba05 - K. R. Baker, J. H. Hamilton, A. V. Ramayya, Z. Phys. **256**, 387 (1972). [Rel. P_γ]

1972Em01 - Emery J. F., Reynolds S. A., Wyatt E. I., Gleason G. I., Nucl. Sci. Eng. **48**, 319 (1972). [$T_{1/2}$]

1977Ge12 - R. J. Gehrke, R. G. Helmer, R. C. Greenwood, Nucl. Instrum. Methods **147**, 405 (1977) [Rel. P_γ]

1978La21 - Lagoutine F., Legrand J., Bac C., Int. J. Appl. Radiat. Isot. **29**, 269 (1978) [$T_{1/2}$]

1978Ro22 - F. Rösel, H. M. Friess, K. Alder, H. C. Pauli, At. Data Nucl. Data Tables **21**, 92 (1978). [Theor. ICC]

1980RuZX - Rutledge A. R., Smith L. V., Merritt J. S., NBS Special Publication 626, 5 (1982).
Compilation of work published in AECL Reports 3668 (1970), 4205 (1972), 5546 (1976), 5802 (1977), 6788 (1980). Quoted in 91BaZS. [$T_{1/2}$]

- 1980Sh15 - A. K. Sharma, R. Kaur, H. R. Verma, P. N. Trehan, J. Phys. Soc. Jpn. **48**, 1407 (1980). [Rel. P_γ]
- 1983Ba29 - Baba S., Ichikawa K., Gunji K., Sekine T., Baba H., Komori T., Int. J. Appl. Radiat. Isot. **34**, 891 (1983). [$T_{1/2}$]
- 1983Wa26 - Walz K., Debertain K., Schraeder H., Int. J. Appl. Radiat. Isot. **34**, 1191 (1983). [$T_{1/2}$]
- 1984Iw03 - Y. Iwata, M. Yasuhara, K. Maeda, Y. Yoshizawa, Nucl. Instrum. Methods **219**, 123 (1984). [Rel. P_γ]
- 1985ZiZY - W. L. Zijp, Report FYS/RASA-85/19 (1985) [Limitation of Relative Statistical Weights]
- 1986Me10 - D. Mehta, M. L. Garg, J. Singh, N. Singh, T. S. Cheema, P. N. Trehan, Nucl. Instrum. Methods Phys. Res. **A219**, 447 (1986). [Rel. P_γ]
- 1986Wo05 - M. J. Woods, S. E. M. Lucas, Int. J. Appl. Radiat. Isot. **37**, 1157 (1986). [$T_{1/2}$]
- 1987Co39 - E. R. Cohen and B. N. Taylor, Rev. Mod. Phys. **59**, 1121 (1987) [Fundamental Constants]
- 1989Da12 - V. N. Danilenko, N. P. Gromova, A. A. Konstantinov, N. V. Kurenkov, A. B. Malinin, S. V. Matveev, T. E. Sazonova, E. K. Stepanov, S. V. Sepman, I. N. Tronova, Appl. Radiat. Isot. **40**, 711 (1989). [Rel. P_γ]
- 1990Me15 - R. A. Meyer, Fizika (Zagreb) **22**, 153 (1990). [Rel. P_γ]
- 1990St02 - N. M. Stewart, E. Eid, M. S. S. El-Daghmah, J. K. Jabber, Z. Phys. **A335**, 13 (1990). [Rel. P_γ]
- 1991BaZS - W. Bambynek, T. Barta, R. Jedlovsky, P. Christmas, N. Coursol, K. Debertain, R. G. Helmer, A. L. Nichols, F. J. Schima, Y. Yoshizawa, Report IAEA-TECDOC-**619** (1991) [Rel. P_γ]
- 1992Ra08 - M. U. Rajput, T. D. Mac Mahon, Nucl. Instrum. Methods Phys. Res. **A312**, 289 (1992). [Limitation of Relative Statistical Weights]
- 1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instrum. Methods Phys. Res. **A312**, 349 (1992). [$T_{1/2}$]
- 1992Ya12 - Y. Yan, H. Sun, D. Hu, J. Huo, Y. Liu, Z. Phys. **A344**, 25 (1992). [Rel. P_γ]
- 1993Ka30 - Kawaldeep, V. Kumar, K. S. Dhillon, K. Singh, J. Phys. Soc. Jpn. **62**, 901 (1993). [Rel. P_γ]
- 1995Au04 - G. Audi and A. H. Wapstra, Nucl. Phys. **A595**, 409 (1995). [Q(EC), Q(β^-)]
- 1996Ar09 - Agda Artna-Cohen, Nucl. Data Sheets **79**, 1 (1996). [E_γ , Rel. P_γ , Multp.]
- 1996Sc06 - E. Schönfeld, H. Janssen, Nucl. Instrum. Methods Phys. Res. **A369**, 527 (1996) [K-Fluorescence Yield ω_K]
- 1997Ma75 - R. H. Martin, K. I. W. Burns, J. G. V. Taylor, Nucl. Instrum. Methods Phys. Res. **A390**, 267 (1997) [$T_{1/2}$]
- 1998Hw07 - H.Y. Hwang, T. S. Park, J. M. Lee, Appl. Radiat. Isot. **49**, 1201 (1998). [Rel. P_γ]
- 1998Sc28 - E. Schönfeld, Appl. Radiat. Isot. **49**, 1353 (1998). [P_K , P_L , P_M , P_N]
- 1998Si12 - H. Siegert, H. Schraeder, U. Schotzig, Appl. Radiat. Isot. **49**, 1397 (1998). [$T_{1/2}$]
- 2000He14 - R. G. Helmer, C. van der Leun, Nucl. Instrum. Methods in Phys. Res. **A450**, 35 (2000). [E_γ]

Table 1. Relative g-Ray Emission Probabilities Evaluated in this Revision (Uncertainty given below the value)

E(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
121.8	145.0	138.5	132.9	144.6	141.0	140.6	136.9	136.7	139.0	136.2	136.6		133.5	136.9
	4.1	6.4	4.0	4.7	4.0	2.8	1.3	0.7	1.0	1.6	1.8		1.8	3.9
125.7										0.057	0.115			
										0.009	0.013			
148.0			0.077			0.154				0.190	0.218		0.231	
			0.026			0.013				0.040	0.026		0.026	
166.9											0.051		0.010	
											0.013		0.004	
173.1										0.002	0.038		0.081	
										0.001	0.013		0.003	
192.6										0.033	0.023	0.031	0.029	
										0.001	0.006	0.008	0.005	
202.6										0.018	0.028			
										0.009	0.006			
207.6			0.064	0.035		0.038				0.021	0.031	0.022	0.035	
			0.038	0.012		0.013				0.006	0.006	0.003	0.003	
209.4			0.077	0.038		0.026				0.021	0.038	0.027	0.026	
			0.038	0.026		0.013				0.006	0.013	0.003	0.013	
212.6		0.086	0.103	0.097		0.103				0.094	0.115		0.077	
		0.037	0.026	0.029		0.026				0.003	0.026		0.026	
237.3			0.051							0.045	0.064		0.012	
			0.026							0.004	0.026		0.004	
239.4				0.321							0.051		0.019	
				0.154							0.013		0.004	
244.7	39.4	36.2	35.8	36.4	36.6	35.8	36.2	36.5	36.5	35.9	38.0			36.8
	1.3	1.8	1.0	1.2	1.1	0.6	0.3	0.4	0.3	0.6	0.5			0.9
251.6		0.333	0.372	0.359		0.359				0.300	0.321		0.308	
		0.051	0.064	0.051		0.013				0.010	0.026		0.026	
269.9				0.015						0.039				
				0.006						0.004				

Comments on evaluation

¹⁵²Eu

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
271.1#		0.359	0.359	0.374		0.410				0.389	0.372		0.436	
		0.051	0.064	0.038		0.026				0.011	0.026		0.013	
275.5		0.141	0.154	0.154		0.218				0.161	0.205		0.128	
		0.038	0.038	0.013		0.026				0.050	0.026		0.013	
286.0										0.053	0.064		0.044	
										0.005	0.026		0.004	
295.9	2.37	1.94	2.09	2.04		2.06	2.13	2.22	2.12	2.11	2.21		2.08	
	0.19	0.12	0.14	0.06		0.05	0.04	0.04	0.02	0.05	0.06		0.05	
315.2#		0.218	0.237	0.228		0.308				0.253	0.231		0.231	
		0.038	0.043	0.040		0.026				0.008	0.038		0.038	
316.2			0.045	0.023						0.010				
			0.019	0.012						0.006				
320.0										0.008				
										0.003				
324.8		0.333	0.385	0.346		0.359				0.360	0.346			
		0.038	0.064	0.051		0.026				0.010	0.013			
329.4		0.564	0.615	0.577		0.628	0.707			0.590	0.603		0.410	
		0.051	0.103	0.064		0.038	0.015			0.010	0.026		0.038	
330.5				0.029						0.360				
				0.008						0.050				
340.4			0.103	0.117						0.130	0.141		0.182	
			0.051	0.012						0.030	0.038		0.010	
344.3	128.2	128.2	128.2	128.2	127.2	128.2	127.1	126.9	128.2	127.5	128.2		128.2	128.2
	3.6	5.9	3.8	4.2	1.3	2.6	0.7	0.9	0.8	0.9	1.7		1.8	2.9
351.7			0.077	0.086		0.103				0.043	0.090		0.103	
			0.026	0.018		0.026				0.003	0.026		0.026	
357.3										0.023			0.013	
										0.003			0.004	
367.8	3.78	4.04	4.14	4.08	4.19	4.15	4.13	4.14	4.18	4.05	4.05		4.04	4.13
	0.32	0.23	0.15	0.14	0.04	0.09	0.04	0.07	0.04	0.08	0.06		0.08	0.10
379.4										0.004	0.051			
										0.001	0.013			

Comments on evaluation

¹⁵²Eu

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
385.7				0.109						0.024	0.269		0.167	
				0.049						0.003	0.026		0.026	
387.9										0.014	0.017		0.018	
										0.001	0.006		0.005	
391.3										0.006				
										0.001				
395.0											0.038		0.026	
											0.013		0.013	
406.7										0.004				
										0.001				
411.0	10.14	10.32	10.77	10.59	10.71	10.55	10.84	10.73	10.80	10.70	10.82		10.72	10.70
	0.54	0.51	0.38	0.27	0.11	0.22	0.07	0.10	0.10	0.10	0.15		0.23	0.29
416.0		0.487	0.513	0.500		0.513				0.530	0.526		0.500	
		0.051	0.064	0.051		0.026				0.010	0.026		0.026	
423.5										0.013	0.027	0.022	0.013	
										0.003	0.006	0.010	0.005	
440.9										0.052			0.069	
										0.009			0.006	
444.0		13.2	13.5	13.6										
		0.8	0.5	0.8										
444.0		1.15	1.67	1.28										
		0.38	0.26	0.26										
444.0@	15.47	14.36	15.13	14.87	15.00	14.95	15.01	14.81	14.90	14.80	15.06		15.18	13.78
	0.33	0.86	0.57	0.81	0.15	0.13	0.11	0.13	0.20	0.20	0.22		0.22	0.39
482.3		0.141	0.115	0.128		0.167				0.130	0.154			
		0.026	0.026	0.026		0.013				0.010	0.026			
488.7		1.90	1.95	1.91	1.98	1.95	2.03		1.95	1.95	2.01		1.95	1.97
		0.12	0.13	0.06	0.02	0.03	0.02		0.04	0.02	0.04		0.05	0.05
493.5		0.115	0.154	0.218		0.179				0.190	0.179		0.103	
		0.051	0.038	0.038		0.026				0.010	0.026		0.026	
496.3				0.038		0.051				0.044	0.064		0.040	
				0.015		0.013				0.003	0.026		0.009	

Comments on evaluation

¹⁵²Eu

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
503.5		0.705	0.718	0.705		0.718	0.768			0.730	0.782		0.474	
		0.038	0.077	0.038		0.026	0.018			0.010	0.051		0.256	
520.2		0.231	0.269	0.256		0.282				0.257	0.231			
		0.051	0.038	0.038		0.026				0.007	0.026			
523.1			0.051	0.031						0.071	0.103		0.096	
			0.026	0.010						0.004	0.038		0.123	
526.9			0.051	0.046		0.064				0.063	0.077		0.060	
			0.026	0.014		0.026				0.003	0.026		0.029	
534.4			0.179	0.179										
			0.051	0.051										
535.4#		0.205	0.218	0.205		0.231				0.206	0.192		0.167	
		0.051	0.053	0.052		0.026				0.005	0.038		0.026	
538.3										0.020				
										0.003				
556.6										0.091	0.077			
										0.005	0.013			
556.5#			0.115	0.090		0.051				0.110	0.128		0.090	
			0.026	0.026		0.026				0.006	0.018		0.013	
557.9										0.019	0.051			
										0.004	0.013			
561.2				0.013						0.005				
				0.006						0.001				
562.9				0.18										
				0.06										
564.0#		2.40	2.46	2.38		2.31	2.43		2.36	2.36	2.32			
		0.19	0.19	0.09		0.06	0.04		0.06	0.05	0.05			
566.4		0.526	0.564	0.577		0.679	0.640			0.620	0.551		0.697	
		0.128	0.128	0.051		0.038	0.060			0.010	0.026		0.022	
571.8										0.023			0.025	
										0.004			0.008	
586.3		2.08	2.28	2.22	2.24	2.27	2.19		2.22	2.20	2.24			2.14
		0.27	0.14	0.09	0.05	0.05	0.08		0.05	0.05	0.05			0.05

Comments on evaluation

¹⁵²Eu

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
595.6											0.154		0.015	
											0.051		0.008	
616.1			0.064	0.049		0.038				0.043	0.051	0.038	0.064	
			0.026	0.015		0.026				0.004	0.013	0.013	0.026	
644.4			0.064	0.029		0.038				0.028	0.051	0.027	0.028	
			0.038	0.009		0.026				0.004	0.013	0.010	0.009	
656.5	0.590		0.744	0.679		0.654	0.710			0.690	0.718		0.692	
	0.064		0.090	0.051		0.038	0.050			0.010	0.038		0.026	
664.8			0.045	0.017		0.038				0.090	0.064		0.051	
			0.019	0.008		0.026				0.010	0.026		0.038	
671.3	0.059		0.090	0.109		0.064				0.110	0.077	0.091	0.051	
	0.027		0.051	0.038		0.026				0.010	0.038	0.009	0.026	
674.7	0.385		0.744	0.615										
	0.103		0.103	0.064										
675.0#	0.846		0.872	0.744		0.949	0.940			0.890	0.936		0.846	
	0.154		0.115	0.082		0.038	0.050			0.030	0.051		0.038	
678.6	2.06		2.31	2.19	2.30	2.31	2.28		2.21	2.21	2.41		2.24	2.22
	0.15		0.14	0.14	0.03	0.06	0.05		0.03	0.04	0.08		0.05	0.07
686.6			0.192	0.128						0.092				
			0.051	0.051						0.008				
688.7	3.88		4.15	4.14	4.12	4.08	4.20		4.12	4.09	4.06		4.17	4.06
	0.22		0.22	0.27	0.04	0.10	0.04		0.05	0.08	0.08		0.08	0.11
696.9											0.077		0.014	
											0.038		0.005	
703.3				0.073						0.025	0.103		0.013	
				0.022						0.004	0.038		0.009	
712.8	0.346		0.462	0.423		0.487				0.460	0.474			
	0.090		0.077	0.090		0.038				0.010	0.038			
719.3#	1.42		1.64	1.53		1.67	1.67		1.51	1.56	1.62		1.58	
	0.13		0.17	0.13		0.05	0.03		0.02	0.03	0.04		0.04	
719.3			0.283	0.282										
			0.077	0.038										

Comments on evaluation

¹⁵²Eu

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
728.0				0.044		0.051				0.054	0.064	0.051	0.064	
				0.009		0.013				0.050	0.026	0.013	0.013	
735.4										0.028				
										0.005				
756.1										0.026			0.301	
										0.004			0.013	
764.9		0.821	0.910	0.885			0.950			0.840	0.962		0.936	
		0.141	0.103	0.115			0.050			0.040	0.051		0.038	
768.9		0.372	0.397	0.346		0.410				0.430	0.500		0.449	
		0.103	0.064	0.038		0.038				0.040	0.038		0.038	
778.9		59.7	62.6	59.9	62.6	62.5	62.16	62.1	62.2	61.9	62.1		62.5	63.7
		2.9	1.4	0.7	0.6	1.2	0.22	0.5	0.4	0.8	0.9		1.3	1.4
794.8		0.192	0.141	0.141		0.192				0.118	0.192		0.136	
		0.051	0.064	0.090		0.026				0.006	0.038		0.014	
805.7				0.077						0.061	0.090		0.050	
				0.026						0.005	0.026		0.009	
810.5		1.38	1.56	1.50		1.55	1.56		1.51	1.52	1.55		1.50	
		0.12	0.10	0.06		0.05	0.04		0.02	0.02	0.04		0.03	
839.4			0.077	0.079						0.079	0.064		0.077	
			0.038	0.045						0.005	0.013		0.013	
841.6			0.769	0.769						0.780	0.769		0.859	
			0.090	0.115						0.010	0.038		0.051	
867.4		19.23	20.09	19.31	20.54	20.29	20.33	20.36	20.40	19.90	20.33		20.45	20.92
		0.90	0.49	0.35	0.21	0.51	0.10	0.17	0.30	0.40	0.27		0.42	0.48
896.6											0.269		0.323	
											0.051		0.010	
901.2		0.295	0.385	0.359		0.346	0.400			0.440	0.397		0.449	
		0.090	0.064	0.077		0.038	0.050			0.030	0.038		0.038	
906.0										0.072			0.087	
										0.006			0.008	
919.3		1.88	2.06	1.91		2.14	2.08		2.09	2.09	2.04		2.05	2.05
		0.14	0.24	0.07		0.06	0.06		0.04	0.05	0.05		0.06	0.12

Comments on evaluation

¹⁵²Eu

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
926.3		1.167	1.308	1.218		1.333	1.380		1.290	1.270	1.346		1.359	1.340
		0.103	0.128	0.115		0.051	0.060		0.040	0.040	0.641		0.051	0.058
930.6		0.308	0.333	0.346		0.359	0.370			0.350	0.385		0.308	
		0.077	0.064	0.051		0.038	0.060			0.010	0.038		0.038	
937.1				0.010						0.015	0.051			
				0.004						0.005	0.026			
958.6			0.064	0.077		0.064				0.110	0.103			
			0.038	0.038		0.026				0.010	0.038			
963.4			0.628	0.487										
			0.103	0.103										
964.1#		67.44	69.86	68.08	70.40	70.45	70.14	71.03	70.50	69.20	69.67		70.50	67.96
		3.33	1.79	1.79	0.70	1.41	0.23	0.40	0.60	0.90	0.95		1.49	1.93
974.1			0.045	0.051		0.064				0.069	0.090		0.065	
			0.019	0.013		0.013				0.005	0.026		0.009	
990.2		0.167	0.128	0.154		0.179				0.148	0.167		0.179	
		0.051	0.064	0.051		0.026				0.006	0.038		0.038	
1001.1										0.019			0.023	
										0.009			0.005	
1005.3		3.04	3.13	3.00	3.57	3.59	3.08		3.35	3.10	3.46		2.73	3.11
		0.31	0.32	0.21	0.07	0.13	0.02		0.04	0.07	0.13		0.12	0.13
1086.0		47.69	50.64	47.59	48.70	49.62	48.15	47.84	49.60	48.70	49.19		49.60	47.96
		2.82	1.54	0.86	0.50	1.28	0.16	0.31	0.40	0.80	0.67		0.94	1.06
1089.7		8.00	8.46	7.90	8.26	8.59	8.35	8.19		8.20	7.97		8.19	8.19
		0.64	0.77	0.37	0.09	0.26	0.04	0.10		0.10	0.51		0.17	0.19
1109.2			0.897	0.808			1.000			0.880				
			0.385	0.179			0.050			0.020				
1112.0#		63.59	65.77	63.99	65.00	65.64	65.67	65.45	65.90	65.80	65.23		62.47	
		3.21	1.85	0.87	0.70	1.28	0.22	0.78	0.50	0.90	0.99		1.12	
1112.0			64.87	63.18			64.67			64.90				
			1.79	0.86			0.21			0.90				
1139.0										0.006			0.006	
										0.002			0.002	

Comments on evaluation

¹⁵²Eu

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
1170.9		0.167	0.167	0.167		0.256				0.171	0.231		0.141	
		0.038	0.038	0.038		0.026				0.006	0.038		0.038	
1206.1			0.064	0.038		0.038				0.072	0.064		0.051	
			0.038	0.013		0.026				0.005	0.026		0.013	
1212.9		6.55	7.05	6.74	6.67	6.72	6.85		6.83	6.70	6.97		6.85	6.70
		0.35	0.26	0.26	0.07	0.14	0.05		0.05	0.08	0.18		0.15	0.19
1249.9		0.795	0.885	0.833		0.962	0.875			0.880	0.923		0.859	0.921
		0.090	0.077	0.064		0.038	0.024			0.050	0.051		0.064	0.039
1261.3		0.154	0.167	0.167		0.192				0.157	0.192		0.162	
		0.038	0.038	0.038		0.026				0.006	0.026		0.060	
1292.8		0.487	0.474	0.474		0.500	0.460			0.490	0.641		0.654	
		0.090	0.077	0.077		0.026	0.030			0.030	0.064		0.077	
1299.1		7.71	8.23	7.88	7.76	7.97	7.80		7.88	7.80	7.94		8.08	
		0.40	0.41	0.44	0.08	0.19	0.05		0.06	0.10	0.19		0.36	
1314.7			0.019	0.018		0.038					0.038	0.024	0.026	
			0.009	0.006		0.013					0.013	0.005	0.013	
1348.1		0.058	0.090	0.081		0.090				0.081	0.090	0.078	0.115	
		0.023	0.013	0.010		0.013				0.006	0.013	0.008	0.013	
1363.8		0.108	0.128	0.126		0.141				0.117	0.128		0.132	
		0.031	0.013	0.015		0.013				0.005	0.013		0.012	
1390.4			0.026	0.019						0.023	0.031	0.024	0.015	
			0.013	0.006						0.006	0.010	0.005	0.010	
1408.0		99.5	103.6	97.7	100.0	99.9	100.0	100.0	100.0	100.0	99.2		102.6	
		5.0	2.7	2.8	1.0	1.9	0.3	0.6	0.5	0.3	1.1		1.4	
1457.6		2.45	2.46	2.40	2.52	2.46	2.39		2.35	2.36	2.38			
		0.13	0.19	0.13	0.09	0.05	0.03		0.03	0.05	0.10			
1486.0											0.027		0.014	
											0.012		0.005	
1528.1		1.67	1.28	1.46		1.27	1.35		1.38	1.27	1.26		1.47	
		0.09	0.08	0.09		0.04	0.01		0.02	0.03	0.10		0.05	
1537.4		0.007		0.010		0.012								
		0.003		0.003		0.004								

Comments on evaluation

E _g (keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
1605.6		0.035	0.038	0.037		0.051				0.036	0.038	0.044	0.041	
		0.008	0.008	0.008		0.013				0.003	0.013	0.004	0.009	
1608.4		0.029	0.023	0.027						0.024	0.027	0.029		
		0.006	0.008	0.006						0.002	0.006	0.004		
1635.2										0.0007				
										0.0002				
1643.6		0.024				0.005								0.009
		0.005				0.003								0.003
1647.4		0.033	0.028	0.031		0.038					0.041	0.024	0.031	
		0.006	0.006	0.006		0.013					0.006	0.004	0.003	
1674.3										0.029				
										0.004				
1769.0		0.042	0.041	0.042		0.038				0.042	0.038	0.049	0.046	
		0.004	0.006	0.005		0.013				0.003	0.013	0.003	0.006	

* Evaluators considered unwarranted the precision of the values given by 98Hw07. Their uncertainties have been doubled.

Value includes the contribution from the weakest component of the doublet.

@ Value is the sum of the components of the doublet.

Table 1. Relative g-Ray Emission Probabilities Evaluated in this Revision (Uncertainty given below the value), continuation

Eg (keV)	ICRM01	ICRM02	ICRM08	ICRM10	ICRM12	ICRM15	ICRM16	ICRM17	ICRM18	ICRM20	ICRM25	ICRM27	ICRM28	ICRM29
121.8	135.0	135.7	136.4	131.5	135.8		133.4		139.2	137.0		136.4	132.5	134.8
	1.9	0.8	0.5	4.3	0.9		1.4		2.9	1.0		3.0	2.9	2.0
244.7	35.5	35.5	36.3	36.2	35.9		36.3	36.7		35.7	35.7		36.3	36.4
	0.5	0.3	0.2	1.0	0.5		0.3	1.1		0.4	0.4		0.7	0.4
344.3	128.9	127.2	127.4	123.9	127.6	130.6	130.4	127.1		127.2	126.7	126.2	128.9	128.8
	1.5	0.8	0.6	2.8	0.4	2.9	1.2	1.1		1.0	1.1	3.4	2.4	1.3
411.0	10.46	10.67	10.80	10.27	10.75	10.77	10.90	10.71	10.90	10.72	10.90	10.62	10.72	10.86
	0.16	0.07	0.06	0.22	0.04	0.12	0.12	0.11	0.23	0.10	0.33	0.67	0.26	0.12
444.0@	14.68	14.84	14.96	14.35	15.07	15.25	15.33	14.88	15.3	14.95	14.73	14.64	15.15	15.22
	0.21	0.09	0.07	0.4	0.06	0.12	0.18	0.15	0.26	0.13	0.43	0.89	0.32	0.15
778.9	62.4	62.6	62.25		62.12	62.6	62.4	62.6	61.8	61.9	61.1	61.0	62.0	62.4
	0.8	0.4	0.19		0.23	0.4	1.2	0.6	1.2	0.4	0.9	1.0	1.0	0.5
964.1	69.62	69.82	70.10		70.41	70.40	69.80	70.30	69.90	70.30	70.90	69.30	68.40	70.10
	0.84	0.42	0.23		0.22	0.60	0.90	0.70	1.00	0.40	1.00	1.00	1.10	0.50
1086.0	48.89	48.61	49.13	47.43	48.83	49.10	47.90	48.70	48.90	48.40		48.50		48.59
	0.59	0.29	0.19	0.60	0.14	0.40	0.60	0.50	0.50	0.30		0.90		0.30
1112.0	64.28	64.45	65.25	64.00	65.26	65.70	64.70	64.30	66.70	64.90	67.20	64.50	65.50	65.30
	0.77	0.32	0.27	0.80	0.20	0.70	0.40	0.60	0.80	0.50	0.90	1.10	1.00	0.50
1408.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	1.2	0.5	0.3	1.5	0.3	0.9	0.9	1.0	1.2	0.5	1.2	1.5	2.3	0.7

Eg (keV)	ICRM30	ICRM31	ICRM34	ICRM35
121.8	136.8	135.5	138.9	134.9
	4.1	2.0	4.3	1.2
244.7	37.9	35.6		36.4
	1.2	0.5		0.2
344.3	132.7	126.6	133.9	126.4
	4.0	1.3	5.5	0.9
411.0	11.21	10.52	11.18	10.57
	0.39	0.14	0.53	0.08
444.0		14.89	16.15	14.81
		0.19	0.73	0.16

Eg (keV)	ICRM30	ICRM31	ICRM34	ICRM35
778.9	61.2	61.3	64.2	62.0
	1.9	0.7	2.1	0.5
964.1	69.80	70.00	71.20	69.90
	2.20	0.80	2.30	0.50
1086.0	50.70	48.00	50.00	
	1.50	0.50	1.20	
1112.0	64.70	65.40	66.50	64.20
	2.00	0.80	1.50	0.70
1408.0	100.0	100.0	100.0	100.0
	3.0	1.0	2.9	1.2

Table 2. Recommended Relative g-Ray Emission Probabilities (Uncertainty given below the value).

E_g(keV)	Recommended	c2/n	Remarks	E_g(keV)	Recommended	c2/n	Remarks	E_g(keV)	Recommended	c2/n	Remarks
121.8	136.35	1.3		271.1	0.374	1.9	[2]	379.4	0.004		[5]
	0.25				0.014				0.001		
125.7	0.09	9.9		275.5	0.155	2.3		385.7	0.024		[6]
	0.03				0.008				0.003		
148.0	0.166	5.8		286.0	0.048	1.2		387.9	0.0142		[5]
	0.024				0.003				0.0010		
166.9			[18]	295.9	2.123	1.6		391.3	0.006		[13]
					0.013				0.001		
173.1			[18]	315.2	0.238	1.1	[3]	395.0			[18]
					0.008						
192.6	0.0326	1.1		316.2	0.015		[3]	406.7	0.004		[13]
	0.0010				0.005				0.001		
202.6			[18]	320.0	0.008		[13]	411.0	10.735	0.95	
					0.003				0.020		
207.6	0.0285	2.1		324.8	0.354	0.27		416.0	0.523	0.4	
	0.0019				0.007				0.008		
209.4	0.0266	0.60		329.4	0.62	11		423.5	0.0155	1.7	
	0.0025				0.03				0.0023		
212.6	0.094	0.23		330.5	0.029		[4]	440.9	0.064	2.5	
	0.003				0.008				0.005		
237.3	0.012		[1]	340.4	0.151	4.6		444.0	13.46		[7]
	0.004				0.016				0.09		
239.4	0.036	3.2		344.3	127.53	0.66		444.0	1.53		[7]
	0.016				0.20				0.09		
244.7	36.23	1.5		351.7	0.067	2.2		444.0	14.99	1.2	[7]
	0.08				0.011				0.03		
251.6	0.322	2.4		357.3	0.0194	4.0		482.3	0.141	1.3	
	0.007				0.0024				0.008		
269.9	0.029	8.0		367.8	4.136	0.77		488.7	1.985	1.8	
	0.012				0.018				0.008		

Eg(keV)	Recommended	c2/n	Remarks	Eg(keV)	Recommended	c2/n	Remarks	Eg(keV)	Recommended	c2/n	Remarks
493.5	0.178	2.1		571.8	0.023	0.10		719.3	1.29	0.33	[12]
	0.016				0.004				0.06		
496.3	0.044	0.31		586.3	2.215	0.57		719.3	0.282	0.0	[12]
	0.004				0.019				0.035		
503.5	0.735	1.0		595.6	0.015		[11]	728.0	0.051	0.37	
	0.008				0.008				0.006		
520.2	0.257	0.46		616.1	0.044	0.32		735.4	0.028		[13]
	0.006				0.003				0.005		
523.1	0.054	2.7		644.4	0.030	0.65		756.1	0.026		[13]
	0.010				0.003				0.004		
526.9	0.062	0.39		656.5	0.689	0.63		764.9	0.912	0.94	
	0.003				0.008				0.021		
534.4	0.176	0.56	[8]	664.8	0.046	6.6		768.9	0.424	1.5	
	0.009				0.014				0.016		
535.4	0.029		[8]	671.3	0.093	1.3		778.9	62.17	0.8	
	0.010				0.006				0.09		
538.3	0.020			674.7			[18]	794.8	0.126	2.3	
	0.003								0.005		
556.6			[18]	675.0	0.897	1.3		805.7	0.060	1.0	
					0.021				0.004		
556.5	0.085	1.7	[9]	678.6	2.256	1.3		810.5	1.519	0.57	
	0.005				0.015				0.011		
557.9	0.021	5.5	[9]	686.6	0.096	2.1		839.4	0.077	0.29	
	0.003				0.008				0.004		
561.2	0.0052	1.7		688.7	4.037	0.60		841.6	0.782	0.62	
	0.0010				0.021				0.009		
562.9	0.18		[4]	696.9	0.014		[11]	867.4	20.35	1.3	
	0.06				0.005				0.07		
564.0	2.19		[10]	703.3	0.025	3.6		896.6	0.321	1.0	
	0.06				0.004				0.010		
566.4	0.628	3.2		712.8	0.461	0.48		901.2	0.404	1.0	
	0.018				0.009				0.016		

Eg(keV)	Recommended	c2/n	Remarks	Eg(keV)	Recommended	c2/n	Remarks	Eg(keV)	Recommended	c2/n	Remarks
906.0	0.077	2.2		1112.0			[18]	1528.1	1.349	4.4	
	0.005								0.021		
919.3	2.06	1.1		1139	0.006		[13]	1537.4			[18]
	0.02				0.002						
926.3	1.309	0.73		1170.9	0.175	2.2		1605.6	0.0388	0.54	
	0.019				0.006				0.0020		
930.6	0.350	0.37		1206.1	0.065	1.7		1608.4	0.0255	0.38	
	0.009				0.004				0.0016		
937.1	0.013	1.4		1212.9	6.79	0.95		1635.2	0.0007		[13]
	0.003				0.03				0.0002		
958.6	0.101	1.10		1249.9	0.894	0.89		1643.6	0.0070	0.89	[16]
	0.009				0.015				0.0020		
963.4	0.644		[14]	1261.3	0.161	0.56		1647.4	0.0305	1.1	
	0.009				0.005				0.0019		
964.1	69.55	0.62	[14]	1292.8	0.499	1.6		1674.3	0.029		[13]
	0.10				0.015				0.004		
974.1	0.066	0.76		1299.1	7.83	0.48		1769.0	0.0441	0.63	
	0.004				0.03				0.0016		
990.2	0.151	0.39		1314.7	0.023	0.73					
	0.006				0.003						
1001.1	0.022	0.15		1348.1	0.084	1.2					
	0.005				0.004						
1005.3	3.19	9.6		1363.8	0.123	0.75					
	0.11				0.004						
1086.0	48.63	1.9	[17]	1390.4	0.023	0.36					
	0.20				0.003						
1089.7	8.30	0.78		1408.0	100.00	0.22					
	0.03				0.12						
1109.2	0.892		[15]	1457.6	2.388	0.82					
	0.018	1.7			0.017						
1112.0	64.30		[15]	1486.0			[18]				
	0.09										

REMARKS

- Evaluator's recommended relative γ -ray emission probabilities deduced using the *Limitation of Relative Statistical Weights* method, unless otherwise specified.
- For absolute intensity per 100 disintegrations, multiply by 0.2085 (8).

- [1]. From 1993Ka30.
- [2]. $I_\gamma =$ weighted average ($I_\gamma(271)$ doublet) - $I_\gamma(269) = 0.403$ (7) - 0.029 (12) = 0.374 (14). $\chi^2/\nu = 1.9$.
- [3]. $I_\gamma =$ weighted average ($I_\gamma(315)$ doublet) - $I_\gamma(316) = 0.253$ (7) - 0.015 (5) = 0.238 (8). $\chi^2/\nu = 1.1$.
- [4]. From 72Ba05.
- [5]. From 1990Me15. Value agrees with <0.006 (1990St02).
- [6]. From 1990Me15. Author removed double-escape contribution from 1408-keV γ ray.
- [7]. $I_\gamma =$ weighted average ($I_\gamma(444)$ doublet) - $I_\gamma(444, 810 \text{ level}) = 14.99$ (3) - 1.53 (9) = 13.46 (9).
 $\chi^2/\nu = 1.2$. $I_\gamma(444, 810 \text{ level})$ is from ¹⁵²Eu(9.3h) EC decay branching.
- [8] $I_\gamma =$ weighted average ($I_\gamma(535)$) - $I_\gamma(534) = 0.205$ (5) - 0.176 (9)= 0.029 (10)
- [9]. $I_\gamma =$ weighted average ($I_\gamma(556.5)$ doublet) - weighted average $I_\gamma(557.8) = 0.106$ (5) - 0.021 (4) = 0.085 (6)
- [10]. $I_\gamma =$ weighted average ($I_\gamma(563.8)$ doublet) - $I_\gamma(562.9) = 2.37$ (2) - 0.18 (6) = 2.19 (6). $\chi^2/\nu = 0.64$.
 $I_\gamma(562.9) = 2.37$ (2) from transition intensity balance.
- [11]. From 1993Ka30, close to upper limit of ⁹²Yb12.
- [12]. $I_\gamma =$ weighted average ($I_\gamma(719)$ doublet, $\chi^2/\nu = 3.4$) - weighted average $I_\gamma(719.4) = 1.57$ (2) - 0.282 (35) = 1.29 (6).
- [13]. From 1990Me15.
- [14]. $I_\gamma =$ weighted average ($I_\gamma(964)$ doublet) - $I_\gamma(963) = 70.19$ (10) - 0.644 (9) = 69.55 (10).
 $I_\gamma(963) = 0.644$ (9) is from ¹⁵²Eu(9.3h) EC decay branching.
- [15]. $I_\gamma =$ weighted average ($I_\gamma(1112)$ doublet, $\chi^2/\nu = 1.5$) - weighted average $I_\gamma(1109, \chi^2/\nu = 1.7) = 65.19$ (9) - 0.895 (18) = 64.30 (9)
- [16]. Weighted average of values from 1980Sh15 and 1993Ka30.
- [17] $I_\gamma = I_\gamma(1084) + I_\gamma(1086) = 1.17$ (4) (1990Me15) + 47.46 (20) = 48.63 (20)
- [18]. Existence is uncertain.

Table 3. Absolute Emission Probabilities of KX Rays

P_{KX}*	70No06	Faerman[†]	72Da23	Bylov[‡]	79De36, 83De11	85Se18	86Me10	93Ka30	P_{KX} (Avg.)^{&}	P_{KX}(Cal.)[@]
Sm KA	0.492(35)	0.592(21)	0.501(16)	0.595(9)	0.591(12)	0.595(9)	0.589(9)	0.595(90)	0.584(11)	0.585(7)
Sm KB	0.122(9)	0.173(9)	0.122(8)	0.143(8)	0.149(3)	0.143(8)	0.144(2)	0.137(5)	0.144(3)	0.1482(24)
Gd KA			0.0068(2)	0.00636(14)	0.00648(22)	0.00636(14)	0.00459(11) [#]		0.00645(8)	0.00680(18)
Gd KB			0.00167(50)	0.00163(4)	0.00176(18)	0.00163(4)	0.00171(3)		0.00167(2)	0.00174(5)

* Absolute emission probabilities renormalized to Pg(121)=0.2841(13), Pg(344)=0.2658(12), or Pg(1408)=0.2084(9).

& Weighted average (LWM).

Outlier, not used for calculating the average.

† Faermann S, Notea A., Segal Y., Trans. Am. Nuc. Soc. 14, 500 (1971).

‡ Bylov T., Osipenko B.D., Chudin V.G., EchA Ya no. 9, 1350 (1978) (quoted by 85Se18).

@ Calculated by evaluators using recommended γ -ray data and K-fluorescence yields.

¹⁵³Gd - Comments on evaluation of decay data by R. G. Helmer and E. Schönfeld

1 Decay Scheme

In addition to the 5 levels populated in the daughter nucleus, there may be a few others with $J \leq 7/2$ in ¹⁵³Eu, so the completeness of the scheme depends on the failure to observe other γ -rays.

There are some serious discrepancies and ambiguities in the data for some of these five levels.

The recent mass evaluations give the decay energy as 484 keV. However, several measurements of the K-capture probability to the 172-keV level of ¹⁵³Eu (1962Bl11, 1964Cr08, 1967Bo11, 1980Se01, and 1985Si03) have been interpreted to indicate that the decay energy is 235 to 245 keV. In an attempt to resolve this conflict, 1981Gr19 looked for the 166-keV γ -ray which deexcites the 269-keV level and reported an emission probability of 0.0003(3) per 100 decays; so this result is not definitive since it allows 'no population' within the 1σ uncertainty. The problem with the K-capture probability measurements or their interpretation, if any, has not been resolved.

2 Nuclear Data

Q value is from Audi and Wapstra 1995 (1995Au04).

The half-life values available are, in days:

225	1949Ke01	as quoted in 1990Le13
236 (3)	1950He18	
200	1958An34	as quoted in 1990Le13
242 (1)	1963Ho15	
240.9 (6)	1970LyZZ	superseded by 1972Em01 2 nd value
241.6 (2)	1972Em01	
240.9 (6)	1972Em01	
239.63 (4)	1982HoZJ	superseded by 1992Un01 value
226.7 (21)	1989Po21	
239.47 (7)	1992Un01	
240.4 (10)	Adopted value, from LRSW weighted average	

The weighted average of the six remaining values with uncertainties is 239.71 with σ_{int} of 0.07, a reduced- χ^2 of 30.0, and σ_{ext} of 0.36. In the Limitation of Relative Statistical Weight (LRSW) method (1985ZiZY, 1992Ra09), the uncertainty for the 1992Un01 value is increased from 0.07 to 0.185 so that its relative weight is reduced from 88% to 50%. The weighted average is then 240.44 with σ_{int} of 0.13, a reduced- χ^2 of 21.8, and σ_{ext} of 0.61. This method then increases the final uncertainty from 0.61 to 1.0 to include the most precise value, namely, 239.47. In this LRSW analysis, the values of 1972Em01 and 1992Un01 provide 43% and 50% of the relative weight, respectively. The values of 1972Em01, 1989Po21, and 1992Un01 contribute 6.7, 8.6, and 5.5, respectively, to the reduced- χ^2 value.

The value from 1989Po21 differs from this average by about 6σ . The omission of this value would not make a significant difference; in the LRSW analysis without this value the weighted average

would only change to 240.49 with a reduced- χ^2 of 16.6. A more aggressive analysis would increase the uncertainties for the extreme values of 226.7(21) and 241.6(2) and thereby drive the result nearer the value of 1992Un01 and give a smaller final uncertainty. However, the evaluator feels that the larger uncertainty of 1.0 is justified by the large spread in the measured values. This large spread is illustrated by the fact that none of the 1σ ranges of the other five values overlap the value from 1992Un01.

2.1 Electron Capture Transitions

The probabilities for the ϵ branches are from the intensity balances from the γ -ray transition probabilities. It is possible to derive the ϵ intensities because one has a direct measurement of the 97-keV γ -ray emission probability (1987Co04). There is a question as to whether the 151-keV and 269-keV levels are fed in the ¹⁵³Gd decay; see the discussion in section 4.2. In the decay scheme adopted here, they are omitted.

2.2 Gamma Transitions

The multiplicities and mixing ratios are from the ¹⁵³Eu Adopted γ data in the Nuclear Data Sheets (1998He06).

3 Atomic Data

The atomic data are from 1996Sc06.

3.1 and 3.2

The relative K x-ray probabilities are from 1996Sc06.

The x-ray emission probabilities (in %) are:

	RADLST	EMISSION	Measured
K_a	97.2 (21)	96.6 (23)	94.2 (30)
K_b	24.8 (7)	24.6 (7)	24.0 (8)

The EMISSION values were adopted.

The K Auger electron intensities are from RADLST.

4.1 Electron Emission

Data were computed with RADLST for the conversion electrons and for the Auger electrons.

4.2 Photon Emission

From the Helmer and van der Leun evaluation (2000He14), the curved-crystal spectrometer data for the decay of ¹⁵³Sm and ¹⁵³Gd give the energies for the γ -rays of 69.6, 75.4, 83.3, 89.4, 97.4, 103.1, and 172.8 keV on a scale on which the strong line from the decay of ¹⁹⁸Au is 411.80205 (17) keV. In addition, the values from the ¹⁵²Eu(n, γ) study of 1970Mu04 have been adjusted to this energy scale and are used for the γ -rays at 54.1, 68.2, 96.8, 118.1, 151.6, 166.5, and 172.3 keV. The remaining two γ -ray energies, 14.0 and 19.8 keV, were computed from the deduced level energies.

The adopted values for the relative γ -ray emission probabilities were generally taken to be the

weighted averages of the data in the table below. The values for several γ -rays are very discrepant (e.g., χ_R^2 greater than 3.0) and are discussed below. The uncertainties have been chosen by the evaluator as shown in the table. The relative γ -ray emission probabilities given in 1990GeZZ have not been included since they are the same as those in 1992Ch16.

The 21.2-keV γ -ray has not been placed in the scheme.

The values for the 19-keV γ -ray form two groups, namely, the large values of 0.089 (9), 0.072 (11), and 0.06 (2) and the small values of < 0.03, 0.019 (3), and 0.006 (1); so the weighted average does not give a useful value. If one assumes that there is no electron capture feeding of the 83-keV level, a requirement of an intensity balance at this level gives the transition intensity of the 19-keV γ -ray as 1.55 (14) in the units of the table. Then, with $\alpha(19,E2) = 3290$, the γ intensity is $1.55/3291 = 0.00047$ (5). Also, from conversion electron data of 1963Gr09 (a private communication to the ENSDF system), $I_{ce}(LM) = 1.17$ (in the table units), which, with $\alpha(19,E2) = 3290$, gives the γ intensity of 0.0004. If these two independent values are correct, then none of the values in the table are correct, except the upper limit.

The measured intensities of the γ -ray which are proposed to depopulate the 151-keV level are not consistent with those from other modes of populating this level (see the 1998He06 for the other modes of population). These values are :

E_γ	Relative I_γ			
	¹⁵³ Sm β^-	(n, γ)	(d,3n γ)	¹⁵³ Gd ϵ
54	17.1 (18)	26 (4)	25 (3)	330 (130)
68	11 (3)	21.0 (21)	326 (47)	
151	100 (13)	100 (8)	100 (17)	100 (16)

If the ϵ feeding of the 151-keV level in the ¹⁵³Gd decay is simply computed from the intensities of the reported intensities of the 54- and 68-keV γ -rays, it is about 0.2%. On the other hand, the log ft systematics for 2nd forbidden transitions (1998Si17) give log $ft > 11.0$ which corresponds to an upper limit of branch intensity 0.02%. (Also, the intensity data in the table on the next page for the 54- and 151-keV lines are quite discrepant, with reduced- χ^2 values of 121 and 9.1, respectively.) Therefore, no adopted values are given for the 54- and 68-keV γ -rays. [A good new measurement of the intensities of the weak lines is desirable.]

As noted in section 1, it is not known if the level at 269 keV in ¹⁵³Eu is populated in this decay. If it is, the depopulating γ -rays are at 96.8, 118.1, 166.5, and 172.3 keV as shown from other modes of population. From the reported intensity of the 166-keV γ -ray (1981Gr19), this level would be fed in 0.008 (8) % of the decays. This level is omitted here.

The relative γ -ray intensities were normalized to γ 's per 100 decays based on the absolute intensity for the 97-keV line reported by 1990GeZZ; this gives a scaling factor of 0.290 (8), where the published 2σ uncertainty has been divided by 2.

The relative intensities of the K x-rays, on the scale of the table below, are $K_\alpha = 333$ (8) and $K_\beta = 84.8$ (24) as calculated from the decay scheme and 325 (5) and 82.6 (12), respectively, as adopted from the measured values in the table.

Relative Gamma emission Intensities

γ -ray energy (keV)	1974HeYW	1974Se08	1985Si03	1988Su13	1988Ve05	1992Ch16	1992Ch44	1993Eg05	1995Ku34	Weighted average ^e value	σ_{int}	χ_{R^2}	σ_{ext}	σ_{LRSW}	Adopted value
K α_2						114 (2) ^d		114 (4) ^d							
K α		321 (11)	150 (4) ^a	340 (4)	313 (8)		302 (8)		323 (8)	325 (2)		4.5	(5)	(15)	325 (5)
K α_1						204 (4) ^d		208 (8) ^d							
K β_1'						65.2 (14) ^d		65 (3) ^d	69.2 (19)						
K β		78 (11)	32.9 (5) ^a	84.9 (8)	78.9 (11)		76.4 (21)			82.6 (5)		5.3	(12)	(23)	82.6 (12)
K β_2'						17.5 (4) ^d		17.5 (7) ^d	16.84 (26)						
14.0			0.054 (9)	0.146 (15)	0.09 (1)		0.11 (3)	0.10 (3)	0.051 (5) ^g	0.068 (4)		9.2	(13)	(17)	0.068 (17)
19.8			0.089 (9)	0.072 (11)	0.006 (1) ^g		0.06 (2)	< 0.03	0.019 (3)	0.018 (2)		27.5	(10)	^f	0.0004 ⁱ
21.2				0.07 (2)				< 0.03	0.078(16)	0.075 (12)		0.10	(12)	(12)	0.075 (12) ^h
54.1		<0.01	0.091 (3)	0.058 (8)					0.027 (2) ^g	0.057 (2)		121	(22)	(30)	
68.2		0.04 (1)		0.071 (11)	0.035 (14)		0.064 (17)		0.071(11)	0.056 (5)		2.2	(8)	(16)	
69.6	7.8 (2)	8.4 (3)	8.35 (32)	8.60 (15)	8.31 (13)	8.41 (22)	7.97 (20)		8.20 (26)	8.28 (7)		1.9	(10)	(10)	8.28 (10)
75.4	0.30 (3)	0.26 (8)	0.26 (8)	0.278 (31)	0.27 (1) ^g		0.28 (2)		0.26 (2)	0.272 (8)		0.25	(8)	(8)	0.272 (8)
83.3	0.80 (8)	0.70 (7)	0.69 (7)	0.67 (4)	0.69 (3)		0.66 (2)		0.71 (4)	0.680 (14)		0.68	(14)	(14)	0.680 (14)
89.4	0.30 (3)	0.23 (7)	0.23 (6)	0.218 (26)	0.22 (2)		0.29 (2)		0.22 (2)	0.245 (10)		2.12	(14)	(45)	0.245 (14)
97.4	100 (5)	100.	100.	100.	100.0	100 (3)	100.0 (15)	100.	100.0	100					100
103.1	73.5 (10)	71.0 (15)	71.1 (15)	74.8 (7)	69.6 (10)	73.4 (17)	73.7 (12)		72.1 (14)	72.9 (4)		3.2	(7)	(19)	72.9 (7)
151.6	0.0130 (13)	<0.06	0.31 ^b	0.060 (15)	0.02 (1)		<0.010		0.021 (1)	0.0172 (9)		9.1	(27)	(38)	0.017 (4) ^h
172.8	0.130 (13)	0.10 (10)	0.28 ^c	0.144 (26)	0.10 (2)		0.13 (1)		0.12 (1)	0.125 (6)		0.56	(6)	(6)	0.125 (6)

^a Value is uniquely low, omitted from weighted average calculation.

^b Value is uniquely high, omitted from weighted average calculation.

^c No uncertainty, omitted from weighted average calculation.

^d Sum of K α_1 and K α_2 and sum of K β_1' and K β_2' used in weighted average calculation.

^e Limits are omitted from weighted average calculation.

^f LRSW method gives unweighted average of 0.049 (43).

^g LRSW method increased uncertainty in order to reduce relative weight to 50%.

^h Value is not consistent with one upper limit.

ⁱ Computed from γ -ray intensity balance at 83-keV level and $\alpha(19,E2)$ and from internal-conversion electron data and $\alpha(19,E2)$.

6 References

- 1949Ke01 - B. H. Kettle, ORNL-229(1949)34 [T_{1/2}]
 1950He18 - R. E. Hein, A. F. Voigt, Phys. Rev. **79**(1950)783 [T_{1/2}]
 1954Le08 - M. E. Lee, R. Katz, Phys. Rev. **93**(1954)155 [T_{1/2}]
 1958An34 - N. M. Antoneva, A. A. Bashilov, B. S. Dzhelepov, B. K. Preobrazhenskii, Columbia Tech. Transl. **22**(1959)134 [T_{1/2}]
 1958Co76 - J. M. Cork, M. K. Brice, R. G. Helmer, R. M. Woods, Jr., Phys. Rev. **110**(1958)526 [T_{1/2}]
 1961Ca24 - M. J. Cabell, J. Inorg. Nucl. Chem. **24**(1961)749 [T_{1/2}]
 1961Gr18 - R. E. Green, W. H. Walker, Can. J. Phys. **39**(1961)1216 [T_{1/2}]
 1961Wy01 - E. I. Wyatt, S. A. Reynolds, T. H. Handley, W. S. Lyon, H. A. Parker, Nucl. Sci. Eng. **11** (1961)74 [T_{1/2}]
 1962Bl11 - L. Blok, W. Goedbloed, E. Mastenbroek, J. Blok, Physica **28**(1961)993 [P_K]
 1963Ho15 - D. C. Hoffman, J. Inorg. Nucl. Chem. **25**(1963)1196 [T_{1/2}]
 1964Al09 - P. Alexander, Phys. Rev. **134** 1964)B499 [P_γ]
 1964Cr08 - T. Cretzu, K. Hohmuth, G. Winter, Nucl. Phys. **56**(1964)415 [P_K]
 1966Bl06 - P. H. Blichert-Toft, E. G. Funk, J. W. Mihelich, Nucl. Phys. **79**(1966)12 [P_γ]
 1967Bo11 - P. Boyer, P. Chedin, J. Oms, Nucl. Phys. **A99**(1967)213 [P_K]
 1969Pa03 - Y. Patin, Compt. Rend. **268B**(1969)574 [E_γ, P_γ]
 1969Sm04 - R. Smither, E. Bieber, T. von Egidy, W. Kaiser, K. Wien, Phys. Rev. **187**(1969)1632 [E_γ]
 1969Un03 - J. Ungrin, M. W. Johns, Nucl. Phys. **A127**(1969)353 [E_γ, P_γ]
 1970Ch09 - Y. Y. Chu, E. M. Franz, G. Friedlander, Phys. Rev. **C1**(1970)1826 [T_{1/2}]
 1970LyZZ - W. S. Lyon, H. H. Ross, L. C. Bate, F. F. Dyer, J. S. Eldridge, J. F. Emery, T. H. Handley, H. Kubota, S. B. Lupica, S. A. Reynolds, E. Ricci, J. E. Strain, H. E. Zittel, K. J. Northcutt, ORNL-4636 (1970)24 [T_{1/2}]
 1970Mu04 - K. Muhlbauer, Z. Phys. **230**(1970)18 [E_γ]
 1971Ba28 - S. Baba, H. Baba, H. Natsume, J. Inorg. Nucl. Chem. **33**(1971)589 [T_{1/2}]
 1972Em01 - J. F. Emery, S. A. Reynolds, E. I. Wyatt, G. I. Gleason, Nucl. Sci. Eng. **48**(1972)319 [T_{1/2}]
 1974HeYW - R. L. Heath, report ANCR-1000-2 (1974)[P_γ]
 1974Se08 - V. A. Sergienko, V. M. Lebedev, Bull. Acad. Sci. USSR, Phys. Ser. **38**, no. 4 (1974)122 [P_γ]
 1980Se01 - V. A. Sergienko, Ts. Vylov, S. M. Sergeev, S. L. Smolskii, Bull. Acad. Sci. USSR, Phys. Ser. **44**, No. 1 (1980)100 [P_K]
 1982HoZJ - D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger, NBS-SP-626(1982)85 [T_{1/2}]
 1985Si03 - K. Singh, B. S. Grewal, H. S. Sahota, J. Phys. (London) **G11**(1985)399 [P_K]
 1985Ab08 - S. Abdel-Malak, S. M. Darwish, M. Abou-Leila, N. Walley El-Din, A. M. Hassan, Z. Phys. **A322**(1985)163 [E_γ, P_γ]
 1985ZiZy - W. L. Zijp, report ECN-179, Petten (1985) [analysis methodology]
 1986BrZQ - E. Browne, R. B. Firestone, Table of Radioactive Isotopes, Appendix C, Table 7a (John Wiley & Sons, New York, 1986) [P_x]
 1987Co04 - B. M. Coursey, D. D. Hoppes, F. J. Schima, M. P. Unterweger, Appl. Radiat. Isot. **38**(187)31 [P_γ]
 1988Su13 - S. Subrahmanyeswara Rao, K. Bhaskara Rao, V. Seshagiri Rao, H. C. Padhi, J. Phys. G: Nucl. Phys. **14**(1988)1259 [P_γ]
 1988Ve05 - N. Venkateswara Rao, G. S. Sri Krishna, S. Bhuloka Reddy, C. V. Raghavaiah, G. Satyanarayana, D. L. Sastry, Il Nuove Cimento **99A**(1988)303 [P_γ]
 1989Po21 - Yu. S. Popov, N. Yu. Nezgovorov, G. A. Timofeev, Sov. J. Radiochem. **31**(1989)1 [T_{1/2}]
 1990GeZZ - A. M. Geidelman, A. G. Egorov, Yu. S. Egorov, V. G. Nedovesov, G. E. Shchukin, Ann. Conf. Nucl. Spectrosc. Struct. Atomic Nuclei(1990)485 [P_γ]
 1990Le13 - M. A. Lee, Nucl. Data Sheets **60**(1990)419 [T_{1/2} data]
 1992CH16 - V. P. Chechev, A. G. Egorov, Nucl. Instr. Meth. **A312**(1992)378 [P_γ]
 1992Ch44 - B. Chand, J. Goswamy, D. Mehta, N. Singh, P. N. Trehan, Appl. Radiat. Isot. **43**(1992)997 [P_γ]
 1992Ra08 - M. U. Rajput, T. D. Mac Mahon, Nucl. Instr. Meth. **A 312**(1992)289 [analysis methodology]
 1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instr. Meth. **A312**(1992)349 [T_{1/2}]
 1993Eg05 - A. G. Egorov, V. P. Chechev, G. E. Shchukin, Bull. Russ. Acad. Sci. Phys. **57**, no. 5 (1993) 911 [P_γ]
 1994Co02 - B. M. Coursey, J. M. Calhoun, J. Cessna, D. B. Golas, F. J. Schima, M. P. Unterweger, Nucl. Instr. Meth. **A339**(1994)26 [T_{1/2}]
 1995Au04 - G. Audi, A. H. Wapsrta, Nucl. Phys. **A595**(1995)409 [Q]
 1995Ku34 - V. Kumar, Kawaldeep, K. Singh, J. Radioanal. Nucl. Chem. **189**(1995)3 [P_γ]

Comments on evaluation

- 1995ScZY - E. Schönfeld, Appl. Radiat. Isot. **49**(1998)1353 [P_K,P_L]
1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instr. Meth. **A369**(1996)527 [P_x]
1998He06 - R. G. Helmer, Nuclear Data Sheets **83**(1998)285 [Multipolarities]
2000He14 - R. G. Helmer and C. van der Leun, Nucl. Instr. Meth **A450**(2000)35 [E_γ]

**¹⁵³Sm - Comments on evaluation of decay data
by R. G. Helmer and E. Schönfeld**

1 Decay Scheme

There are many levels in ¹⁵³Eu below the decay energy, so other levels may be weakly populated in this decay.

2 Nuclear Data

Q value is from Audi and Wapstra 1995 (1995Au04).

The half-life values available are, in hours:

47 (1)	1942Ku03	as quoted in 1990Le13
46	1946Mi06	as quoted in 1990Le13
46.5 (10)	1952Ru10	as quoted in 1990Le13
47.0 (3)	1954Le08	as quoted in 1990Le13
47.1 (1)	1958Co76	
46.7 (16)	1958Gu09	
45 (8)	1960Wi10	
46.2 (1)	1961Gr18	
46.8 (1)	1961Wy01	
47.1 (1)	1962Ca24	
46.5 (5)	1963Ho15	
46.75 (9)	1970Ch09	
46.44 (8)	1971Ba28	
46.27 (1)	1987Co04	superseded by 1992Un01
46.70 (5)	1989Ab05	
45.6 (16)	1989Po21	
46.2853 (14)	1992Un01 & 1994Co02	
46.29 (4)	1996ScZX	superseded by 1999Sc12
46.285 (4)	1998Bo18	
46.274 (7)	1999Sc12	

46.2838 (26) h or 1.92849 (11) d Adopted

Data are very discrepant, ranging from 46.2853(14) to two values of 47.1(1), a difference of about 8σ . For a weighted average of the twelve un-superseded values with $\sigma < 1.0$ hours, the result is 46.2857 with a σ_{int} of 0.0013, a reduced- χ^2 of 24.3, and an σ_{ext} of 0.0064. For this average, the value of 1992Un01 contributes 86% of the weight. (The values with $\sigma \geq 1.0$ would have very small weights and would not significantly influence the result.) In the Limitation of Relative Statistical Weight, LRSW, analysis (1985ZiZY, 1992Ra08), the uncertainty for the 1992Un01 value is increased by a factor of 2.5 from 0.0014 to 0.0034 in order to reduce the relative weight to 50%. Then, the values of 1992Un01 and 1998Bo18 contribute 87% of the relative weight and the weighted average is 46.2866 with a σ_{int} of 0.0024, a reduced- χ^2 of 24.3, and a σ_{ext} of 0.012. If one considers only the un-superseded measurements since 1970 with uncertainties < 1.0 hours, the reduced- χ^2 is still 20.4.

The average of the measured values has decreased with time and the last three unreplaced values, which are from metrology laboratories, are among the lowest values and they are consistent. After the uncertainty of the 1992Un01 value is increased by a factor of 2.5 to reduce its relative weight from 86% to 50%, the weighted average of these three values is 46.2838 with a σ_{int} of 0.0025, a reduced- χ^2 of 1.12, and a

σ_{ext} of 0.0026. This weighted average and the external uncertainty are adopted. Although the weighted average is almost independent of the data selection process, the final uncertainty changes from 0.012 to 0.0026 as a result of this selection.

2.1 β^- Transitions

The probabilities for the β^- branches are primarily from the intensity balances from the γ -ray transition probabilities for all levels including the ground state. This is possible because one has measurements of the emission probabilities for the 69- and 103-keV γ -rays (1987Co04, 1998Bo18, 1999Sc12).

The measured β^- probabilities (in %) from the decomposition of the β^- spectra are:

Level (keV)	Values
0	15 (1952Ba49), 20 (1954Gr19), 21 (1954Le08), 20 (1955Ma62), 22 (1956Du31), 20 (1957Jo24), and 20 (1958Co76) compared to the adopted value of 18.4(18).
103	67 (1950Hi17), 35 (1952Ba49), 49 (1954Gr19), 70 (1954Le08), 35 (1955Ma62), 38 (1956Du31), 65 (1957Jo24), and 40 (1958Co76) which have an average of 50(14) compared to the adopted value of 49.6(19)% from the intensity balance.
172	50 (1952Ba49), 30 (1954Gr19), 43 (1955Ma62), 40 (1956Du31), 15 (1957Jo24), and 40 (1958Co76) which have an average of 36(11) compared to the adopted value of 31.1(10)% from the intensity balance.

2.2 Gamma Transitions

The multiplicities are from the adopted gamma data in the Nuclear Data Sheets (1998He06) and they are based on the internal-conversion electron data of 1961Mo07, 1962Su01, 1969Sm04, and 1970PaZI.

3 Atomic Data

The fluorescence yields and K x-ray relative intensities are from 1996Sc06.

The calculated with EMISSION and measured (1999Sc12) x-ray emission probabilities (in %) are

	Decay scheme	Measured
L	11.3 (6)	10.04 (15)
K $_{\alpha}$	49.1 (16)	45.6 (5)
K $_{\beta}$	12.5 (4)	11.56 (18)

The measured values were adopted with the components calculated from the theoretical ratios.

4 Emissions

4.1 Electron Emission

Data were computed by RADLST for the Auger and conversion electrons and with LOGFT for the average β^- energies.

4.2 Photon Emission

From the evaluation 2000He14, the curved-crystal spectrometer data for the decay of ¹⁵³Sm and ¹⁵³Gd give the

energies for the γ -rays of 69, 75, 83, 89, 97, 103, and 172 keV on a scale on which the strong line from the decay of ¹⁹⁸Au is 411.80205(17). The γ -ray energies from the (n, γ) study of 1970Mu04 have been adjusted to this energy scale to provide values at 54, 68, 96, 118, 151, 166, and 172 keV. The values for 14 and 19 keV are from level energy differences.

The other γ -ray energies are from the data in the following table 1.

Table 1: Gamma-ray energies

1969Un03	1985Ab08	1969Pa03	Adopted	
412.05 (20)	412.26 (30)	411.9 (1)	412.05 (20)	doubly placed
424.38 (20)	424.79 (32)	424.2 (2)	424.4 (3)	
	431.65 (10)			
436.83 (20)	437.10 (30)	436.7 (2)	436.9 (3)	
	443.24 (45)		443.2 (5)	
		462.0 (3)	462.0 (3)	
463.67 (15)	463.93 (35)	463.4 (2)	463.6 (2)	
485.03 (20)	485.12 (40)	484.5 (2)	485.0 (2)	
	487.75 (23)		487.75 (23)	
509.11 (15)	510.36 (35)	509.0 (1)	509.15 (20)	
521.28 (15)	521.62 (26)	521.1 (1)	521.3 (25)	
		523.8 (6)		
531.38 (15)	531.43 (34)	531.6 (3)	531.40 (15)	
533.34 (15)	533.17 (25)	533.1 (1)	533.2 (2)	
539.03 (10)	539.10 (20)	539.2 (3)	539.1 (2)	
542.60 (20)	543.01 (45)	542.7 (6)	542.7 (2)	
545.75 (15)	545.68 (42)		545.75 (15)	
554.94 (10)	554.73 (37)	555.0 (1)	554.94 (10)	
	555.71 (15)			
574.01 (30)	574.32 (51)		574.1 (3)	
578.66 (15)	578.94 (30)	578.8 (1)	578.75 (20)	
584.49 (20)	584.67 (32)	584.8 (5)	584.55 (20)	
587.47 (20)	587.73 (22)	587.7 (6)	587.60 (25)	
	589.3			
590.96 (20)	591.03 (21)	590.7 (6)	590.96 (20)	
596.72 (15)	596.29 (30)	596.9 (2)	596.7 (2)	
598.4 (3)	598.13 (30)		598.3 (3)	doubly placed
603.39 (15)	604.04 (26)	603.5 (2)	603.6 (4)	doubly placed
609.22 (10)	610.21 (42)	609.4 (1)	609.5 (3)	doubly placed
		612 (1)		
615.41 (20)	616.28 (22)	615.5 (6)	615.8 (4)	doubly placed
617.71 (20)	618.07 (24)	618.0 (6)	617.9 (3)	
	623.73 (24)			
630.70 (30)	630.33 (26)	630 (1)	630.5 (4)	
634.61 (30)	634.92 (32)		634.8 (3)	
636.45 (25)	636.73 (30)	636.4 (2)	636.5 (2)	
657.55 (25)	657.68 (25)	657.4 (4)	657.55 (25)	doubly placed
		662.4 (6)	662.4 (6)	
676.9 (5)	677.09 (30)	676 (1)	677.0 (3)	
		682.0 (6)	682.0 (6)	
685.6 (3)	686.64 (21)	685.9 (3)	686.0 (4)	
694.4 (4)	694.02 (25)	694 (1)	694.1 (3)	
701.5 (4)	702.08 (24)	701.7 (10)	701.8 (4)	
706.2 (4)	707.29 (28)	706 (1)	706.8 (5)	
713.6 (3)	713.98 (22)	714.1 (6)	713.9 (3)	
718.5 (4)	719.26 (28)	719.1 (6)	719.0 (4)	
760.2 (3)	760.92 (38)	760.3 (6)	760.5 (4)	
	763.8	763.8 (6)	763.8 (6)	

For the relative γ -ray emission probabilities, the data listed in Table 2 were available. The values of 1969Un03 and 1985Ab08 were not used in the averaging since they do not have individual uncertainties and those of 1969Sm04 were not used because the ¹⁵³Sm was just a background in an (n, γ) study. For all cases with three or more values, the weighted average is computed by the Limitation of Relative Statistical Weight method. If the reduced- χ^2 is > 1.0 and one value has a relative weight $> 50\%$, the uncertainty of this value is increased in order to reduce the relative weight to 50% and this is noted in the table. If the reduced- χ^2 is ≤ 1.0 , no such change is made, but if the relative weight is over 70% this is noted. For all weighted averages the internal uncertainty is given, and if the reduced- χ^2 is > 1.0 the external uncertainty is also given. In some cases the LRSW method expands the uncertainty to include the most precise value; this uncertainty is given as σ_{LRSW} . The adopted values are given in the last column.

The relative γ -ray emission probabilities adopted in Table 2 were normalized to γ 's per 100 decays by consideration of the absolute emission probabilities measured by 1987Co04, 1998Bo18, and 1999Sc12. Of the five γ rays that are given in all three papers, the three strongest, at 69, 97, and 103 keV, were considered. Since the weighted average of the data for the 97-keV γ -ray gave a reduced- χ^2 value of 20, it was omitted. For the 69-keV γ -ray, the weighted average of the three values [4.85(7), 4.67(5), 4.65(5), respectively] is 4.70 γ 's per 100 decays with an internal uncertainty of 0.03, a reduced- χ^2 of 2.97, and an external uncertainty of 0.05. The latter uncertainty was adopted. For the 103-keV γ ray, the weighted average of the three values [29.8(4), 28.5(5), 29.23(18), respectively] is 29.26 γ 's per 100 decays with an internal uncertainty of 0.22, a reduced- χ^2 of 2.07, and an external uncertainty of 0.32. The value of 29.26(32) was adopted. In the latter average, the LRSW method increased the uncertainty of 0.18 to 0.31 in order to decrease its relative weight from 75% to 50%.

6 References

- 1942Ku03 - J. D. Kurbatov, D. C. MacDonald, M. L. Pool, L. L. Quill, Phys. Rev. **61**(1942)106A [$T_{1/2}$]
 1946Mi06 - L. C. Miller, L. F. Curtiss, Phys. Rev. **70**(1946)983 [$T_{1/2}$]
 1950Hi17 - J. M. Hill, L. R. Shepherd, Proc. Phys. Soc. (London) **63A**(1950)126 [P_{β}]
 1952Ba49 - R. C. Bannerman, Proc. Phys. Soc. (London) **65A**(1952)565 [P_{β}]
 1952Ru10 - W. C. Rutledge, J. M. Cork, S. B. Burson, Phys. Rev. **86**(1952)775 [$T_{1/2}$]
 1954Gr19 - R. L. Graham, J. Walker, Phys. Rev. **94**(1954)794A [P_{β}]
 1954Le08 - M. E. Lee, R. Katz, Phys. Rev. **93**(1954)155 [$T_{1/2}, P_{\beta}$]
 1955Ma62 - N. Marty, J. Phys. Radium **16**(1955)458 [P_{β}]
 1956Du31 - V. S. Dubey, C. E. Mandeville, M. A. Rothman, Phys. Rev. **103**(1956)1430 [P_{β}]
 1957Jo24 - M. C. Joshi, B. N. Subba Rao, B. V. Thosar, Proc. Indian Acad. Sci. **45A**(1957)390 [P_{β}]
 1958Co76 - J. M. Cork, M. K. Brice, R. G. Helmer, R. M. Woods, Jr., Phys. Rev. **110**(1958)526 [$T_{1/2}, P_{\beta}$]
 1958Gu09 - G. Gueben, J. Govaerts, Inst. Interuniv. Sci. Nucleaires (Bruxelles), Monographie No. 2 (1958) [$T_{1/2}$]
 1960Su08 - R. E. Sund, M. L. Wiedenbeck, Phys. Rev. **120**(1960)1792 [I_{γ}, ce]
 1960Wi10 - R. G. Wille, R. W. Fink, Phys. Rev. **118**(1960)242 [$T_{1/2}$]
 1961Gr18 - R. E. Green, W. H. Walker, Can. J. Phys. **39**(1961)1216 [$T_{1/2}$]
 1961Mo07 - E. Monnard, A. Moussa, Nuclear Phys. **25**(1961)292 [ce]
 1961Ru01 - L. I. Rusinov, R. L. Aptekar, V. S. Gvozdev, S. L. Sakharov, Yu. L. Khazov, Soviet Phys. JETP **13** (1961)55 [I_{γ}]
 1961Wy01 - E. I. Wyatt, S. A. Reynolds, T. H. Handley, W. S. Lyon, H. A. Parker, Nucl. Sci. Eng. **11**(1961)74 [$T_{1/2}$]
 1962Ca24 - M. J. Cabell, J. Inorg. Nuclear Chem. **24**(1962)749 [$T_{1/2}$]
 1962Su01 - T. Suter, P. Reyes-Suter, S. Gustafsson, I. Marklund, Nuclear Phys. **29**(1962)33 [ce]
 1963Ch25 - P. Chedin, A. Moussa, J. Phys. **24**(1963)930 [ce]
 1963Ho15 - D. C. Hoffman, J. Inorg. Nucl. Chem. **25**(1963)1196 [$T_{1/2}$]
 1964Al09 - P. Alexander, Phys. Rev. **134**(1964)B499 [I_{γ}]
 1964No08 - T. Novakov, J. M. Hollander, Nucl. Phys. **60**(1964)593 [ce]
 1966Bl06 - P. H. Blichert-Toft, E. G. Funk, J. W. Mihelich, Nucl. Phys. **79**(1966)12 [I_{γ}]
 1966Ne06 - H. A. Neumann, Z. Naturforsch. **21a** (1966)1328 [ce]

Comments on evaluation

- 1968Re04 - S. A. Reynolds, J. F. Emery, E. I. Wyatt, Nucl. Sci. Eng. **32**(1968)46 [T_{1/2}]
 1969Pa03 - Y. Patin, Compt. Rend. **268B**(1969)574 [E_γ, I_γ]
 1969Sm04 - R. K. Smither, E. Bieber, T. von Egidy, W. Kaiser, K. Wien, Phys. Rev. **187**(1969)1632 [I_γ, ce]
 1969Un03 - J. Ungrin, M. W. Johns, Nucl. Phys. **A127**(1969)353 [E_γ, I_γ]
 1970Ch09 - Y. Y. Chu, E. M. Franz, G. Friedlander, Phys. Rev. **C1**(1970)1826 [T_{1/2}]
 1970Me26 - R. Y. Metskhvarishvili, M. A. Elizbarashvili, V. M. Gachechiladze, L. V. Bodokiya, Bull. Acad. Sci. USSR, Phys. Ser. **34**(1971)1993 [ce]
 1970Mi15 - J. Milanovic, R. Stepic, D. Krpic, Fizika **2**(1970)109 [ce]
 1970Mu04 - K. Muhlbauer, Z. Phys. **230**(1970)18 [E_γ]
 1970PaZI - Y. Patin, Thesis, Paris Univ. (1970); NP-18835 (1970) [ce]
 1971Ba28 - S. Baba, H. Baba, H. Natsume, J. Inorg. Nucl. Chem. **33**(1971)589 [T_{1/2}]
 1974HeYW - R. L. Heath, report ANCR-1000-2 (1974) [I_γ]
 1985Ab08 - S. Abdel-Malak, S. M. Darwish, M. Abou-Leila, N. Walley El-Din, A. M. Hassan, Z. Phys. **A322**(1985)163 [E_γ, I_γ]
 1985ZiZY - W. L. Zijp, report ECN FYS/RASA-85/19 (1985) [averaging methods]
 1987Co04 - B. M. Coursey, D. D. Hoppes, F. J. Schima, M. P. Unterweger, Appl. Radiat. Isot. **38**(1987)31 [T_{1/2}, P_γ]
 1989Ab05 - A. Abzouzi, M. A. Antony, V. B. Ndocko Ndongue, J. Radioanal. Nucl. Chem. **131**(1989)1 [T_{1/2}]
 1989Po21 - Yu. S. Popov, N. Yu. Nezhgorov, G. A. Timofeev, Sov. J. Radiochem. **31**(1989)1 [T_{1/2}]
 1990Le13 - M. A. Lee, Nucl. Data Sheets **60**(1990)419 [T_{1/2}]
 1992Ch44 - B. Chand, J. Goswamy, D. Mehta, N. Singh, P. N. Trehan, Appl. Radiat. Isot. **43**(1992)997 [I_γ]
 1992Ra08 - M. U. Rajput and T. D. MacMahon, Nucl. Instr. Meth. **A312**(1992)289 [averaging methods]
 1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instr. Meth. **A312**(1992)349 [T_{1/2}]
 1994Co02 - B. M. Coursey, J. M. Calhoun, J. Cessna, D. B. Golas, F. J. Schima, M. P. Unterweger, Nucl. Instr. Meth. **A339**(1994)26 [T_{1/2}]
 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. **A595**(1995)409 [Q]
 1995Ch70 - V. P. Chechev, V. O. Sergeev, Bull. Rus. Acad. Sci. Phys. **59**(1995)900
 1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instr. Meth. **A369**(1996)572 [P_x]
 1996ScZX - U. Schotzig, Priv. Comm. (1996); quoted by 1997ScZZ [T_{1/2}]
 1998Bo18 - N. E. Bowles, S. A. Woods, D. H. Woods, S. M. Jerome, M. J. Woods, P. de Lavison, S. Lineham, J. Keightley, and I. Poupaki, Appl. Radiat. Isot. **49**(1998)1345 [P_γ, T_{1/2}]
 1998He06 - R. G. Helmer, Nuclear Data Sheets **83**(1998)285 [multipolarities]
 1999Sc12 - U. Schötzig, E. Schönfeld, E. Günther, R. Klein, H. Schrader, Appl. Radiat. Isot. **51**(1999)169 [T_{1/2}, P_γ]
 2000He14 - R. G. Helmer and C. van der Leun, Nucl. Instr. Meth. **A450**(2000)35 [E_γ]

Table 2: Gamma relative emission intensities

γ-ray energy (keV)	1964Al09	1966Bl06	1969Pa03	1969Sm04	1969Un03	1974HeYW	1985Ab08	1987Co04	1992Ch44	1998Bo18	1999Sc12	Weighted average				Adopted	
	(x100)	(x0.010)			(x3.546)	(x100)	(x365.4)		(x100)	(x35088)	(x34211)	value	σ _{int}	χ _R ²	σ _{ext}	σ _{LRSW}	
L x																	3430 (50)
K α																	15600 (170)
K β x									3693 (104)		4000 (44)						3950 (60)
14.0																	
54.1	0.58 (12)				12.4		0.73										0.65 (12)
68.2	0.43 (12)						<1.1										0.43 (12)
69.6	1730 (100)			2080 (146)	1433	1620 (140)	1930	1626 (21)	1620 (50)	1639 (18)	1591 (17)	1618 (10)	1.06 (11)	(-)			1618 (11)
75.4	61 (4)			75 (4)	213	110 (12)	50.4	117 (5)	55 (2) ^a	65 (4)	80 (7)	66.4 (16)	29 (87)	(114)			66 (9)
83.3	75 (4)			85 (4)	50	63 (6)	55	68 (4)	63 (2)	58 (4)	72 (4)	65.5 (14)	2.8 (23)	(25)			65.5 (25)
89.4	58 (3)			62 (4)	46	32 (4)	51		59 (2)		53.4 (24)	54.4 (13)	13 (46)	(-)			54 (5)
96.8					2.5		<2.2										2.5
97.4	263 (13)			254 (8)	252	233 (20)	222	284 (4)	255 (4)	279 (6)	258.3 (24) ^a	264.3 (18)	8.8 (52)	(60)			264 (6)
103.1	10000	same	same	same	same	same	same	same	same	same	same	same	same	same	same	same	10000
118.1					0.11		<0.13		0.06 (1)								0.08 (2)
151.6	3.2 (5)		5.1 (16)		4.08	3.0 (5)	4.38		3.5 (1) ^a		3.93 (21)	3.62 (13)	1.43 (15)	(-)			3.62 (15)
166.5					0.21		<0.25		0.21 (1)								0.21 (2)
172.3					0.14		<0.19										0.14
172.8	21 (2)		24 (5)	22.9 (18)	28	28 (3)	29.6	27.0 (4)	25.0 (4)	25.3 (11)	24.50 (24) ^a	25.19 (19)	5.4 (44)	(69)			25.2 (7)
412.0 ^b		0.64 (20)	0.73 (13)	0.7 (3)	0.82	0.8 (1)	0.98		0.65 (2) ^c		0.65 (4)	0.656 (17)	0.63 (-)	(-)			0.656 (17)
424.4		0.75 (20)	0.60 (12)		0.82	0.7 (1)	0.84		0.65 (2) ^c		0.62 (4)	0.646 (17)	0.29 (-)	(-)			0.646 (17)
436.9		0.48 (12)	0.5 (1)		0.64	0.8 (1)	0.77		0.53 (2)		0.57 (3) ^a	0.58 (4)	1.56 (5)	(-)			0.58 (5)
443.2							0.132		0.030 (5)								0.030 (5)
462.0			0.5 (1) ^c						0.7 (2)			0.54 (9)	0.80 (-)	(-)			0.54 (9)
463.6		5.1 (8)	4.7 (4)		5.50	5.3 (4)	5.30		4.3 (8)		4.34 (6) ^a	4.64 (18)	1.17 (19)	(-)			4.64 (19)
485.0		0.12 (6)	0.12 (6)		0.14		0.150		0.13 (1) ^c		0.12 (3)	0.129 (9)	0.03 (-)	(-)			0.129 (9)
487.7							0.124										0.124
509.1		0.85 (16)	0.61 (20)		0.78	1.0 (1)	0.84		0.62 (3) ^a		0.63 (6)	0.68 (3)	3.4 (6)	(-)			0.68 (6)
521.3		3.5 (7)	2.5 (9)	2.1 (4)	2.66	2.8 (2)	2.81		2.3 (1)		2.31 (4) ^a	2.36 (6)	2.05 (9)	unw			2.36 (9)
531.4		22.3 (20)	23 (3)	15.0 (12)	22.7	23.8 (20)	19.9		18.9 (13) ^a	19.3 (21)	18.37 (21)	18.70 (15)	3.06 (25)	unw			18.7 (3)
533.2		11.6 (10)	8.8 (25)		11.3	11.9 (8)	11.6		10.4 (1)	9.8 (21)	10.02 (9) ^a	10.23 (7)	2.81 (12)	(21)			10.23 (21)
539.1		9.1 (14)	8.2 (25)	5.4 (8)	7.1	8.6 (6)	7.3		7.2 (2)		7.04 (9) ^a	7.21 (13)	2.04 (19)	unw			7.21 (19)
542.7			0.6 (5)		0.96	1.4 (1)	1.06		0.77 (8)		0.75 (6) ^a	1.06 (7)	7.6 (19)	(31)			1.1 (3)
545.7					0.35	0.3 (1)	0.48		0.26 (1)		0.41 (17)	0.261 (10)	0.47 (-)	(-)			0.261 (10)

Comments on evaluation

¹⁵³Sm

554.9	1.93 (30)	1.60 (13)		1.81	2.0 (2)	1.51	1.61 (4)	1.62 (3) ^a	1.624 (26)	1.19 (29)	(-)	1.62 (3)
574.1				0.04		<0.09	0.053 (18)					0.053 (18)
578.7	1.38 (20)	1.15 (23)		1.17	1.3 (2)	1.21	1.07 (3)	1.17 (3)	1.125 (21)	2.00 (30)	unw	1.12 (3)
584.5	0.54 (10)	0.45 (15)		0.30	0.4 (1)	0.39	0.36 (1) ^c	0.352 (27)	0.361 (9)	0.96 (-)	(-)	0.361 (9)
587.6		0.1 (1)		0.121	0.20 (3)	0.18	0.16 (4)	0.161 (27)	0.172 (18)	0.55 (-)	(-)	0.172 (18)
590.9		0.45 (15)		0.32	0.5 (1)	0.34	0.38 (1) ^a	0.421 (27)	0.403 (18)	0.76 (-)	(-)	0.403 (18)
596.7	4.4 (7)	4.2 (6)	2.1 (4)	4.08	4.5 (3)	3.22	3.8 (1)	3.56 (10)	3.74 (7)	2.9 (11)	unw	3.74 (11)
598.3 ^b				0.53	0.4 (1)	0.99	0.61 (9)	0.70 (3)	0.61 (5)	3.1 (8)	(9)	0.61 (9)
603.6 ^b	2.0 (4)	1.8 (3)		1.10	1.9 (2)	1.43	1.53 (5)	1.49 (3) ^a	1.53 (3)	1.58 (4)	(-)	1.53 (4)
609.5 ^b	5.5 (8)	5.2 (8)	3.6 (5)	4.50	5.1 (4)	5.08	4.5 (1) ^a	4.04 (14)	4.36 (9)	3.2 (16)	unw	4.36 (25)
615.8 ^b	0.60 (12)	0.21 (10)		0.28	0.3 (1)	0.33	0.14 (2) ^a	0.233 (24)	0.188 (16)	3.1 (28)	(48)	0.19 (5)
617.9		0.32 (14)		0.39	0.3 (1)	0.25	0.20 (2) ^a	0.304 (24)	0.252 (16)	3.4 (30)	(50)	0.25 (5)
630.5		0.04 (2)		0.04		0.040	0.034 (5) ^c		0.034 (5)	0.08 (-)	(-)	0.034 (5)
634.8				0.11	0.20 (3)	0.17	0.20 (5)	0.15 (3)	0.179 (20)	0.80 (-)	(-)	0.179 (20)
636.5	0.81 (15)	0.74 (8)		0.67	0.7 (1)	0.84	0.70 (2) ^a	0.595 (27)	0.660 (17)	2.7 (28)	(40)	0.66 (4)
657.5 ^b	0.13 (3)	0.12 (3)		0.14	0.10 (3)	0.130	0.14 (1) ^c	0.140 (24)	0.135 (8)	0.48 (-)	(-)	0.135 (8)
662.4		0.03 (1)					0.007 (2) ^a		0.018 (7)	2.6 (12)	(-)	0.018 (12)
677.0		<0.005		0.004		0.014	0.016 (5)					0.015 (5)
682.0	0.09 (3)	<0.005					0.009 (3) ^a		0.049 (21)	3.6 (40)	(-)	0.05 (4)
686.0		0.09 (1)		0.082		0.066	0.077 (8)	0.072 (21)	0.081 (6)	0.62 (-)	(-)	0.081 (6)
694.1		<0.005		0.007		0.028	0.007 (2)					0.007 (2)
701.8		<0.005		0.0087		0.029	0.010 (2)					0.010 (2)
706.8		<0.005		0.0053		0.012						0.008 (4)
713.9	0.11 (3)	0.066 (20)		0.067	0.10 (3)	0.080	0.077 (8) ^c	0.09 (4)	0.079 (7)	0.54 (-)	(-)	0.079 (7)
719.0		0.007 (4)		0.007		0.023	0.009 (2) ^c		0.0086 (18)	0.20 (-)	(-)	0.0086 (18)
760.5	0.013 (4)	0.027 (15)		0.0089		0.023	0.010 (2) ^c		0.0108 (18)	0.81 (-)	(-)	0.0108 (18)
763.8		0.011 (6)					0.017 (5)		0.015 (4)	0.59 (-)	(-)	0.015 (4)

^a Uncertainty increased in LRSW analysis to reduce the relative weight to 50%.

^b γ is doubly placed.

^c Value, dominates weighted average, but since the reduced- $\chi^2 \leq 1.00$, the uncertainty is not increased.

¹⁵⁴Eu – Comments on evaluation of decay data by V. P. Chechev and N. K. Kuzmenko

This evaluation was done in June 1999, and revised in January 2003. The literature available by 2003 was included.

1. Decay Scheme

The decay scheme is based on the evaluation of Reich (1998Re22).

The ¹⁵⁴Eu→¹⁵⁴Gd decay scheme has not been completed yet as there are a few unplaced ¹⁵⁴Gd gamma transitions. These transitions are weak, so they do not greatly influence the intensity balances.

The 3rd forbidden β⁻ transitions to the ground states of ¹⁵⁴Gd and ¹⁵⁴Sm have not been observed. From the log ft systematics (1998Si17), their log ft values should be greater than 17,6 and the corresponding upper limits of their intensities would be expected less than 5·10⁻⁵ % and less than 3·10⁻⁷ %, respectively.

In the “Adopted Levels” of 1998Re22, there are several ¹⁵⁴Gd levels with energies below Q⁻ that have not been observed in the ¹⁵⁴Eu β⁻ decay. Their energies are 1900,2; 1911,5; 1912,1; 1943,9; 1948,5 and 1963,8 keV. Their respective spins and parities are not known exactly except those for the 1911,5 keV, which is a 6⁺ level. The β⁻ transition to this 1911,5 keV level is 3rd forbidden and its intensity is expected to be less than 5·10⁻¹⁰ % (log ft > 17,6). On the assumption that the remaining levels can be populated by β⁻ transitions with an order of forbiddenness not lower than 2, their log ft values should be greater than 11 and their corresponding branch intensities expected to be less than 0,001%.

Likewise, the intensity of the 3rd forbidden electron-capture transition to the ¹⁵⁴Sm 543,7 keV 6⁺ level in the decay ¹⁵⁴Eu→¹⁵⁴Sm is expected to be less than 10⁻⁸ % (from log ft > 17,6).

Therefore, all of the above transitions can be neglected, and thus they are not shown in the ¹⁵⁴Eu decay scheme.

2. Nuclear Data

Q⁺, Q⁻ values are from 1995Au04.

The evaluated half-life of ¹⁵⁴Eu has been obtained by applying the evaluation procedure from 2000Ch01 (Chechev and Egorov). This value is based on the measured results given in Table .

Table 1. Set of experimental data for the evaluation of ¹⁵⁴Eu half-life (in days)

Reference	Author	Data set "1" $\chi^2=22,83$ $(\chi^2)_8^{0,05}=15,51$	Data set "2" $\chi^2=22,79$ $(\chi^2)_7^{0,05}=14,07$	Data set "3" $\chi^2=22,79$ $(\chi^2)_7^{0,05}=14,07$
2002Un02	Unterweger	3145,2(11) ^a	3145,2(11)	3145,2(11)
1998Si12	Siegert et.al	3138,1(16) ^b	3138,1(16)	3138,1(16)
1998Si12	Siegert et.al	3146(11) ^c	3146(11)	3146(11)
1983Th04	Thompson et.al	3170(55)	3170(55)	3170(55)
1992ScZZ	Schötzig et.al	3139,0(20)	3139,0(20)	3139,0(20)
1988RaZM	Rajput et.al	3143(59)	3143(59)	3143(59)
1986Wo05	Woods et.al	3138,0(20)	3138,0(20)	3138,0(20)
1983Wa26	Walz et.al	3136(4)	3136(4)	3136(4)
1972Em01	Emery et.al	3105(180)	Omitted ^d	-

^a Latest value from this laboratory. Previous measurements at NIST gave 3101(41) – 1982 HoZJ and 3138,2(61) – 1992Un01.

^b Measured with a pressured 4πγ ionization chamber.

^c Measured with semiconductor detectors.

^d Omitted on the basis of statistical considerations.

Data set "1" is the original data; set "2" has the discrepant values deleted, and set "3" would have the uncertainty increased for any value having more than 50% of the relative weight. There are none of the latter values, so set "3" is the same as set "2".

It should be noted that there are available the early half-life measurement results which have been omitted because of the very low accuracy: 5,4 years (without uncertainty) – 1949Ha04 and 16(4) years – 1952Ka26. There are also unpublished measurement results of 1978ScZO (7,45- 10,5 years) and 1978GrZR (8,8(1) years) which have not been included in the set "1".

The weighted mean of data from the final set "3" is 3141,5(14) where the uncertainty has been obtained as an external uncertainty 1,35 multiplied by the Student's coefficient at the confidence level of 0,68 for 7 degrees of freedom (see 2000Ch01). The internal uncertainty is 0,75.

The adopted value of the ¹⁵⁴Eu half-life is 3141,5(14) days, or 8,601(4) years (converted to years with 365,24219 d/y).

2.1. β^- Transition and Electron Capture Transition

2.1.1. β^- Transitions

The energies of β^- transitions have been computed from the Q^- value and the level energies adopted from 1998Re22. The corrections to the level energies taking into account the evaluated values of gamma transition energies from section 2.2 are negligible.

The probabilities of β^- transitions have been obtained from the $P(\gamma+ce)$ balance for each level of ¹⁵⁴Gd based on the $P(\gamma)$ normalization factor of 0,3489(34) (see section 4.2.). Since 0,018 % (13) of the decays are *via* electron capture, the value of $P_{\beta_1}=10,3(5)$, to the first excited level in ¹⁵⁴Gd, has been obtained from $P_{\beta_1}=99,982(13) - \sum P_{\beta_i}, i>1$. From the $P(\gamma+ce)$ balance for this level $P_{\beta_1}= 10,5(13)$. The more precise value has been adopted.

The more inaccurate experimental values from 1966Ha36 and 1968Ng01 obtained by direct measurements using magnetic beta-spectrometry and beta-gamma coincidences do not conflict with the calculated ones, as seen from Table 2 (except $\beta_{0,2}$).

Table 2. Comparison of the measured and evaluated (calculated) values of b- transition probabilities.

	E_{β} , keV	P_{β} , % 1966Ha36	P_{β} , % 1968Ng01	Evaluated (calculated) values
$\beta_{0,26}$	248,8(11)		29,1(25)	28,32(22)
$\beta_{0,16}$	570,9(11)		37,8(35)	36,06(35)
$\beta_{0,8}$	840,6(11)		17,0(39)	17,33(18)
$\beta_{0,6}$	972,1(11)		4,6(38)	2,82(18)
$\beta_{0,5}$	1152,9(11)		0,67(49)	0,33(3)
$\beta_{0,2}$	1597,4(11)	0,19(5)		0,31(7)
$\beta_{0,1}$	1845,3(11)	9,2(15)	10,8(12)	10,3(5)

We are listing below the ¹⁵⁴Gd levels from the ¹⁵⁴Eu β⁻ decay (see 1998Re22).

Level number	Energy, keV	Spin and parity	Half-life	Probability of β ⁻ transition (× 100)
0	0,0	0 ⁺	Stable	
1	123,071	2 ⁺	1,18 ns	10,3(5)
2	371,00	4 ⁺	45 ps	0,31(7)
3	680,66	0 ⁺	4,0 ps	
4	717,7	6 ⁺	7,8 ps	
5	815,5	2 ⁺	6,4 ps	0,33(3)
6	996,26	2 ⁺	0,95 ps	2,82(18)
7	1047,6	4 ⁺		0,108(18)
8	1127,8	3 ⁺		17,33(18)
9	1136,0	1,2 ⁺		
10	1233,2			
11	1241,3	1 ⁻		
12	1251,6	3 ⁻		0,289(6)
13	1263,78	4 ⁺		0,707(7)
14	1277,0			
15	1294,2	(2) ⁺		
16	1397,5	2 ⁻		36,06(35)
17	1414,4	1 ⁻		
18	1418	2 ⁺		0,075(2)
19	1510,1	(1 ⁻)		0,021(2)
20	1531,3	2 ⁺		0,330(13)
21	1560,0	(4 ⁻)		0,100(4)
22	1617,1	3 ⁻		1,78(3)
23	1645,8	4 ⁺		0,148(4)
24	1660,9	3 ⁺		0,849(9)
25	1698,5	(4 ⁺)		0,0100(4)
26	1719,56	2 ⁻		28,32(22)
27	1770,2	5 ⁺		0,0022(4)
28	1790,2	(4 ⁺)		0,022(1)
29	1797,0	3 ⁻		0,060(6)
30	1838,6	2 ⁺		0,017(5)
31	1861,5	4 ⁻		0,034(3)
32	1878,5			0,0042(3)
33	1894,7	2 ⁺		0,0035(6)

2.1.2. Electron Capture Transitions

The energies of the electron capture, ε, transitions have been calculated from the Q⁺ value and the level energies from 1998Re22 (see below).

List of ¹⁵⁴Sm levels from the ¹⁵⁴Eu electron capture decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of electron capture (× 100)
0	0,0	0 ⁺	Stable	
1	81,98	2 ⁺	3,02 ns	0,013(13)
2	266,79	4 ⁺	172 ps	0,0047(8)
3	543,73	6 ⁺	22,7 ps	

The transition probabilities have been obtained from the $P(\gamma+ce)$ balance for each ¹⁵⁴Sm level using a $P(\gamma)$ normalization factor of 0,3489(34).

Fractional electron capture probabilities P_K , P_L , P_M have been calculated from 1998Sc28 using the program EC-CAPTURE.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions include the recoil energy of $E_\gamma^2/2Mc^2$, where M is mass of the daughter nucleus (¹⁵⁴Gd or ¹⁵⁴Sm).

The gamma-ray transition probabilities have been deduced from their emission probabilities and total internal conversion coefficients (ICC).

The ICC are theoretical values from 1978Ro22 for the adopted energies and multiplicities. Other values have been taken from the evaluation 1998Re22, based on experimental data from 1957Ke08, 1962Lu03, 1966Za02, 1969An01, 1972Na21, 1977Ya04 and 1996Al31. Total ICC values for $\gamma_{1,0}(\text{Gd})$ have been obtained as weighted averages of measured values, 1,200(20) - 1962Lu03 and 1,194(19) - 1995Ma03, and taking into account the rule of “the smallest experimental uncertainty” (see 2000Ch01).

The relative uncertainties of α_K , α_L , α_M for pure multiplicities have been adopted 2%.

3. ATOMIC DATA

3.1. Fluorescence Yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X-Radiations

The X-ray energies are based on their wavelengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission probabilities have been taken from 1996Sc06 and 1999Schönfeld.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Lagoutine.

The ratios $P(\text{KLX})/P(\text{KLL})$, $P(\text{KXY})/P(\text{KLL})$ are taken from 1996Sc06.

4. PHOTON EMISSIONS

4.1. X-Ray Emissions

The total absolute emission probability of Gd KX-rays has been computed using the adopted value of $\omega_K(\text{Gd})$ and the evaluated total absolute emission probability of K conversion electrons in the decay ¹⁵⁴Eu→¹⁵⁴Gd, namely, $P_{ceK} = 27,3(6)\%$. The emission probability of Sm KX-rays has been computed using the adopted value of $\omega_K(\text{Sm})$, the evaluated probability of K electron capture to ¹⁵⁴Sm levels $P_{eK} = 0,015(11)\%$ and the evaluated emission probability of K conversion electrons in the decay ¹⁵⁴Eu→¹⁵⁴Sm, namely, $P_{ceK} = 0,007(4)\%$.

The absolute emission probabilities of the Gd KX-ray components have been computed using the relative probabilities from Section 3.2 and the total value of $P_{XK}(\text{Gd}) = 25,4(6)\%$.

4.2. Gamma-Ray Emissions

The energies of prominent gamma-rays $\gamma_{1,0}(123,1)$, $\gamma_{2,1}(247,9)$, $\gamma_{5,2}(444,5)$, $\gamma_{26,8}(591,7)$, $\gamma_{6,2}(625,2)$, $\gamma_{5,1}(692,4)$, $\gamma_{26,6}(723,3)$, $\gamma_{8,2}(756,8)$, $\gamma_{24,5}(845,4)$, $\gamma_{6,1}(873,2)$, $\gamma_{13,2}(892,8)$, $\gamma_{26,5}(904,1)$, $\gamma_{12,1}(1128,5)$, $\gamma_{13,1}(1140,7)$, $\gamma_{22,2}(1246,1)$, $\gamma_{16,1}(1274,4)$, $\gamma_{22,1}(1494,0)$, $\gamma_{26,1}(1596,5)$ have been taken from 2000He14 (Helmer and Van der Leun).

The energies of the gamma rays $\gamma_{26,20}(188,2)$, $\gamma_{16,6}(401,2)$, $\gamma_{26,12}(467,8)$, $\gamma_{26,11}(478,3)$, $\gamma_{3,1}(557,6)$, $\gamma_{16,5}(582,0)$, $\gamma_{7,2}(676,6)$, $\gamma_{20,5}(715,8)$, $\gamma_{5,0}(815,5)$, $\gamma_{20,3}(850,6)$, $\gamma_{12,2}(880,6)$, $\gamma_{7,1}(924,6)$, $\gamma_{6,0}(996,3)$,

$\gamma_{8,1}(1004,7)$, $\gamma_{11,1}(1118,5)$, $\gamma_{20,2}(1160,4)$, $\gamma_{21,2}(1188,1)$, $\gamma_{11,0}(1241,4)$, $\gamma_{24,2}(1290,5)$, $\gamma_{19,1}(1397,4)$, $\gamma_{24,1}(1537,8)$ have been evaluated using the experimental data of 1990He05, 1992Sm02, 1990Me15 along with taking into account a correction of the gamma-ray energetic scale in 2000He14 (lowering by 5,8 ppm) (Table 3).

Table 3. Measured and evaluated values of some gamma ray energies in the decay of ¹⁵⁴Eu (keV)

	1990He05	1990Me05	1992Sm02	Evaluated
$\gamma_{26,20}$	188,252(8)	188,22(4)	188,29(7)	188,24(2)
$\gamma_{16,6}$	401,258(14)	401,30(5)		401,259(14)
$\gamma_{26,12}$	467,84(5)			467,84(5)
$\gamma_{26,11}$		478,26(5)	478,29(7)	478,27(5)
$\gamma_{3,1}$		557,56(5)	557,61(7)	557,58(5)
$\gamma_{16,5}$		582,00(5)	582,03(7)	582,01(5)
$\gamma_{7,2}$	676,600(12)	676,60(5)		676,596(12)
$\gamma_{20,5}$	715,786(18)	715,77(5)	715,75(7)	715,77(3)
$\gamma_{5,0}$		815,57(5)	815,45(7)	815,53(5)
$\gamma_{20,3}$	850,643(12)	850,66(5)	850,61(7)	850,64(3)
$\gamma_{12,2}$	880,61(3)			880,60(3)
$\gamma_{7,1}$	924,64(5)			924,63(5)
$\gamma_{6,0}$	996,262(6)	996,35(4)	996,21(3)	996,25(5)
$\gamma_{8,1}$	1004,725(7)	1004,79(4)	1004,67(3)	1004,718(7)
$\gamma_{11,1}$		1118,53(6)		1118,52(6)
$\gamma_{20,2}$	1160,37(8)			1160,36(8)
$\gamma_{21,2}$	1188,10(4)	1188,60(10)		1188,34(17)
$\gamma_{11,0}$	1241,38(5)	1241,62(9)		1241,43(10)
$\gamma_{24,2}$	1290,51(10)			1290,50(10)
$\gamma_{19,1}$	1397,35(5)			1397,34(5)
$\gamma_{24,1}$	1537,80(4)	1537,84(5)		1537,81(4)

The energies of the gamma rays $\gamma_{15,8}(165,9)$, $\gamma_{22,17}(202,5)$, $\gamma_{14,7}(229,0)$, $\gamma_{22,5}(801,2)$ have been taken from 1992E111. The energy of the gamma ray $\gamma_{1,0}$ Sm (82,0) has been adopted from measurements of conversion electrons (1958Ch36). The unplaced gamma ray 197 keV has been reported in 1980Sh15 and 1989Ki10. The energy of the gamma ray $\gamma_{7,4}(329,9)$ has been adopted from 1974HeYW. The energy 533,1 keV (twice placed - $\gamma_{24,8}$ and $\gamma_{29,13}$) has been computed from the level energies. The energy and relative emission probability of the gamma ray $\gamma_{3,0}(680,7)$ has been taken from 1969An01. The energy of the unplaced gamma-ray γ 1316,4 keV has been adopted from 1970Ri19.

The energies of the remaining weak gamma rays have been taken from 1968Me18.

The measured and evaluated values of relative gamma ray emission probabilities are shown in Table 4.

Table 4. Measured and evaluated values of relative gamma ray emission probabilities in the decay of ¹⁵⁴Eu

keV	1968Me18	1969Va09	1970RiZY	1980Ro22	1980Sh15	1984Iw03	1986Wa35	1989Ki10	1989 Schima	1990Me15	1990He05	1992E111	1992Ha02	1992Sm02	1992Sa04	Evaluated value
58,4	0,0113(11)															0,0113(11)
80,4	0,008(4)															0,008(4)
82,0	0,009(6)															0,009(6)
123,1			116(6)		115,4(23)	118,5(13)	111,7(16)	122,1(36)	117,0(11)	114,1(20)	116,5(12)		115,6(15)	113,0(15)	115,4(7)	115,9(8)
125,4	0,0197(56)															0,020(6)
129,5	0,039(6)															0,039(6)
131,6	0,0310(14)				0,037			0,025					0,035(3)			0,0317(13)
134,8	0,0203(11)				0,03			0,024					0,027(6)			0,0205(11)
146,0	0,073(3)		0,085(27)		0,12(1)			0,078(28)					0,075(10)			0,074(3)
156,2	0,0282(12)				0,025			0,019					0,027(3)			0,0280(11)
159,9	<0,003												0,0030(15)			0,0030(15)
162,1	0,0028(14)												0,0035(17)			0,0031(11)
165,9	0,0065(14)				0,021			0,019					0,012(4)			0,0071(14)
180,7	0,0127(28)	0,0058(58)			0,015			<0,001					0,0116(17)			0,0115(17)
184,7	0,0113(28)				0,017			0,003					0,010(3)			0,011(3)
188,2		0,692(17)	0,61(12)		0,70(12)			0,88(10)		0,682(22)			0,658(27)	0,651(15)		0,684(15)
195,5	0,0056(28)															0,006(3)
197					0,005			0,004								0,0045(5)
202,5												0,08(2)				0,08(2)
209,4	0,0068(23)												0,0072(16)			0,0071(16)
219,4	0,0065(25)												0,0067(19)			0,0066(19)
229,0	0,0056(22)												0,0085(25)			0,0069(22)
232,0	0,0677(30)		0,079(43)		0,081(40)			0,059(22)					0,068(6)			0,068(3)
237,0	0,017(11)				0,026			0,024					0,019(9)			0,018(9)
247,9			20,1(10)	20,51(20)	19,34(37)	19,91(14)	19,615(98)	23,04(59)	19,82(16)	19,72(32)	19,8(2)		19,65(44)	19,5(2)	19,857(93)	19,76(9)
260,9	0,0056(25)							0,017					0,0066(20)			0,0062(20)
267,4	0,039(2)				0,023			<0,001					0,037(7)			0,039(2)
269,8	0,0197(28)				0,01			0,017					0,022(4)			0,0205(28)
274,0	0,0113(6)												0,0105(12)			0,0111(6)
279,9	0,0085(4)												0,0092(21)			0,0085(4)
290,0	0,0096(5)												0,010(2)			0,0096(5)
295,7	0,0068(4)												0,0073(15)			0,0068(4)
296,0	0,0039(25)															0,004(3)
301,3	0,0282(12)				0,032			0,03					0,032(2)			0,0292(12)
305,1	0,0496(22)	0,058(12)			0,07			0,078					0,055(7)			0,050(2)
308,2	≤0,005				0,01								0,0068(17)			0,0068(17)
312,3	0,0414(19)	0,055(12)			0,06			0,069					0,059(5)			0,053(4)
315,4	0,0130(7)	0,037(12)			0,03			0,027					0,027(6)			0,021(4)
320	0,0028(20)															0,0028(20)

keV	1968Me18	1969Va09	1970RiZY	1980Ro22	1980Sh15	1984Iw03	1986Wa35	1989Ki10	1989 Schima	1990Me15	1990He05	1992Ei11	1992Ha02	1992Sm02	1992Sa04	Evaluated value
322,0	0,189(9)	0,193(9)	0,16(4)		0,21(4)			0,168(22)					0,189(10)			0,189(9)
329,9	0,0259(4)		0,036(26)		0,032			0,023					0,031(10)			0,0260(14)
346,7	0,085(3)				0,067								0,075(6)			0,083(3)
368,2	0,0085(4)												0,0081(17)			0,0085(4)
370,7	0,015(4)				0,03			0,007					0,018(6)			0,016(4)
375,2	0,0051(28)												0,0059(23)			0,0056(23)
382,0	0,0285(12)				0,028			0,006					0,027(3)			0,0283(12)
397,1	0,085(3)	0,066(9)	0,12(5)		0,12(4)			0,070(16)					0,076(8)			0,082(3)
401,3		0,55(3)	0,58(10)		0,57(8)	0,49(4)		0,58(6)		0,56(3)	0,543(6)		0,54(3)			0,543(6)
403,5	0,076(3)		0,054(32)		0,042(40)								0,067(8)			0,075(3)
414,3	0,0141(18)												0,015(2)			0,0142(18)
419,4	0,011(6)												0,0094(41)			0,010(6)
422,1	≤0,0034												0,0062(24)			0,0062(24)
435,9	≤0,0073												0,011(3)			0,011(3)
444,5		1,64(4)	1,69(15)	1,53(6)	1,54(3)	1,63(3)	1,87(11)	2,11(6)		1,58(3)	1,600(15)		1,66(7)	1,628(17)	1,564(38)	1,606(15)
463,9	0,0121(7)												0,019(8)			0,0122(7)
467,8	0,161(7)	0,173(17)	0,20(9)		0,16(8)			0,18(3)					0,184(7)			0,173(7)
478,2		0,605(22)	0,69(15)		0,63(10)	0,626(27)		0,64(5)		0,68(3)	0,644(6)		0,63(3)	0,648(12)		0,643(6)
480,6	0,0138(8)															0,0138(8)
483,7	0,0141(8)				0,04			0,045					0,033(12)			0,0142(8)
484,6	0,0113(6)															0,0113(6)
488,3	0,020(9)												0,021(10)			0,020(9)
506,4	0,017(6)							0,017					0,018(4)			0,018(4)
510	0,103(5)		0,17(8)		0,14(8)			0,28(5)					0,19(3)			0,17(2)
512,0	≤0,17	0,092(20)														0,092(20)
518,0	0,132(6)	0,144(26)	0,16(9)		0,18(8)			0,17(5)					0,144(18)			0,135(6)
533,1 \$	0,031(6)				0,032			0,04					0,034(8)			0,032(6)
545,6	0,047(6)	0,035(29)											0,036(6)			0,041(6)
557,6		0,75(3)	0,74(10)		0,72(10)	0,758(24)		0,80(10)		0,73(3)	0,778(11)		0,75(3)	0,767(12)		0,767(11)
563,4												0,008(2)				0,008(2)
569,2	0,0282(12)				0,044			0,024					0,0410(64)			0,0286(23)
582,0		2,62(7)	2,53(23)	2,86(11)	2,45(5)	2,61(3)	2,45(5)	2,72(12)		2,51(3)	2,543(2)		2,53(3)	2,53(23)		2,54(2)
591,7		14,44(31)	14,8(8)	13,62(24)	13,57(26)	14,35(6)	14,05(14)	15,84(66)	14,19(11)	14,14(15)	14,21(11)		14,18(31)	14,0(14)	14,338(117)	14,18(7)
597,5	0,0158(9)															0,0158(9)
598,3	0,0172(10)				0,026								0,0280(54)			0,0176(21)
600,0	0,017(11)															0,017(11)
602,8					0,1			0,15					0,096(8)			0,096(4)
613,3	0,262(11)	0,288(20)	0,22(8)		0,25(8)			0,29(7)					0,265(19)			0,267(11)
620,5	0,0262(14)												0,023(6)			0,0260(14)
625,2		0,922(32)	0,89(12)		0,84(5)	0,927(21)	0,90(4)	0,92(9)		0,90(3)			0,91(2)	0,906(10)		0,909(10)
642,4	0,011(6)							0,040(28)					0,013(5)			0,013(5)

keV	1968Me18	1969Va09	1970RiZY	1980Ro22	1980Sh15	1984Iw03	1986Wa35	1989Ki10	1989 Schima	1990Me15	1990He05	1992Ei11	1992Ha02	1992Sm02	1992Sa04	Evaluated value
649,4	0,214(9)		0,28(11)		0,25(8)			0,30(10)					0,26(2)			0,223(9)
650,6	0,0282(12)															0,0282(12)
664,7	0,082(3)				0,072			0,03					0,088(15)			0,082(3)
668,9	0,034(8)				0,042			0,031					0,042(7)			0,038(7)
676,6		0,432(30)	0,43(11)		0,52(10)	0,47(5)	0,45(27)	0,53(11)		0,45(3)			0,46(5)			0,45(3)
692,4		5,07(13)	4,97(30)	4,86(8)	4,92(10)	5,182(29)	5,14(5)	5,75(15)		5,10(9)	5,09(4)		5,13(12)	5,04(5)	5,085(59)	5,12(3)
715,8		0,40(6)	0,32(13)		0,61(8)			0,27(12)		0,592(28)			0,52(2)	0,57(3)		0,54(3)
723,3		56,5(12)	60,1(31)	55,40(41)	55,33(106)	58,19(27)	57,23(46)	64,9(21)	57,6(4)	57,2(6)	57,3(4)		57,78(89)	56,9(6)	58,107(276)	57,46(27)
737,6	≤0,024												0,018(7)			0,018(7)
756,8		12,71(23)	12,9(6)	12,51(11)	12,62(24)	13,18(8)	12,89(13)	13,61(20)		12,99(15)	12,9(11)		13,02(24)	12,8(2)	13,035(127)	12,98(8)
774,4	0,028(14)												0,022(11)			0,024(11)
790,1	0,031(8)												0,029(9)			0,030(8)
800,2	0,092(14)							0,09					0,088(30)			0,091(14)
815,6		1,38(6)	1,38(18)	1,45(8)	1,47(10)	1,51(5)	1,48(3)	1,63(12)		1,44(3)	1,455(14)		1,52(4)	1,481(15)		1,467(14)
830,3	≤0,0141				0,02								0,023(8)			0,023(8)
845,4		1,614(62)	1,60(22)		1,58(10)	1,687(22)	1,64(10)	1,61(61)		1,66(3)	1,737(20)		1,69(3)	1,659(17)		1,68(2)
850,7		0,663(30)	0,60(13)		0,67(8)	0,692(23)		0,68(13)		0,68(3)			0,68(2)	0,699(14)		0,692(14)
873,2		33,72(75)	34,8(17)	33,6(25)	34,47(70)	35,18(16)	34,66(21)	35,7(13)	34,95(31)	34,65(30)	34,81(28)		35,01(44)	34,5(4)	34,342(266)	34,87(16)
880,6	0,231(10)	0,14(6)	0,20(8)		0,28(8)			0,22(11)					0,26(4)			0,231(10)
892,8		1,41(4)	1,31(10)	1,38(12)	1,43(3)	1,497(26)	1,55(3)	1,51(10)		1,49(3)			1,48(5)	1,416(16)		1,473(16)
898,4	0,0056(14)															0,0056(14)
904,1		2,45(7)	2,42(17)	2,47(8)	2,49(5)	2,62(3)	2,65(8)	2,74(13)		2,54(6)	2,537(22)		2,58(5)	2,54(3)		2,551(22)
906,1	0,0338(16)															0,0338(16)
919,2	0,0352(16)												0,025(11)			0,0350(16)
924,5	0,166(8)	0,173(29)	0,19(10)		0,18(10)			0,13(6)					0,189(8)			0,177(8)
928,4	≤0,0141												0,013(6)			0,013(6)
981,3	0,023(6)												0,025(5)			0,024(5)
984,5	0,018(11)												0,029(6)			0,027(6)
996,3		29,39(71)	29,4(15)	29,7(21)	30,30(65)	30,09(15)	30,87(12)	31,0(19)	29,9(3)	30,14(30)	29,78(23)		30,29(51)	29,9(3)	29,206(269)	30,1(1)
1004,7		50,4(11)	50,6(25)	50,93(32)	51,40(103)	52,04(25)	52,05(31)	54,84(225)	51,9(5)	51,8(6)	51,55(40)		52,07(89)	51,6(4)	51,233(276)	51,17(25)
1012,8	0,0082(34)															0,008(3)
1023	0,020(8)												0,019(7)			0,019(7)
1033,4	0,0338(16)												0,029(8)			0,0336(16)
1047,4	0,141(7)				0,23(10)			0,17(6)					0,16(5)			0,142(7)
1049,4	0,0493(22)															0,0493(22)
1072,2	≤0,0113												0,010(4)			0,010(4)
1110	0,008(6)															0,008(6)
1118,5		0,403(58)	0,30(8)		0,37(10)			0,04		0,296(25)			0,31(3)			0,31(4)
1124,2	0,0197(28)															0,020(3)
1128,5		0,89(6)	0,79(9)		0,94(8)	0,90(4)		0,88(6)		0,885(25)	0,952(15)		0,89(5)	0,892(10)		0,91(1)
1136,1	0,0211(28)							0,042								0,021(3)

keV	1968Me18	1969Va09	1970RiZY	1980Ro22	1980Sh15	1984Iw03	1986Wa35	1989Ki10	1989 Schima	1990Me15	1990He05	1992E111	1992Ha02	1992Sm02	1992Sa04	Evaluated value
1140,7		0,634(30)	0,69(10)		0,73(8)	0,671(14)		0,75(6)		0,65(3)	0,671(8)		0,68(4)	0,682(11)		0,673(8)
1153,1	0,039(11)												0,024(10)			0,031(10)
1160,3	0,124(6)		0,10(3)		0,13(10)			0,12(4)					0,131(12)			0,125(6)
1170,7	0,012(6)												0,010(3)			0,010(3)
1188,6		0,27(1)	0,23(5)		0,29(8)			0,25(4)		0,25(3)			0,265(20)			0,266(20)
1216,8	≤0,010												0,0096(28)			0,010(3)
1232,1	0,026(17)												0,021(14)			0,023(14)
1241,6		0,43(3)	0,30(7)		0,40(5)	0,38(5)		0,45		0,366(17)			0,38(4)			0,380(17)
1246,1		2,54(7)	2,40(22)	2,35(5)	2,48(10)	2,49(4)	2,52(5)	2,51(12)		2,48(3)	2,449(23)		2,45(8)	2,48(2)	2,403(48)	2,470(23)
1274,4	100	100	100	100	100	100	100	100	100	100	100		100	100	100	100
1290,1	0,0324(15)		0,068(26)		0,086(20)			0,064					0,077(9)			0,071(9)
1292,0	0,0369(17)												0,035(3)			0,0364(15)
1295,5	0,0254(29)				0,026(3)			0,061					0,027(3)			0,026(3)
1316,4			0,074(29)		0,053(10)			0,029(19)								0,050(10)
1387,0	0,056(6)	<0,029											0,055(5)			0,055(5)
1397,4	0,0084(28)							0,012					0,0093(22)			0,0090(22)
1408,5	0,059(8)				0,082(10)								0,063(8)			0,066(8)
1415,0	0,0113(6)				0,004			0,02					0,017(6)			0,0114(6)
1418,6	0,0208(12)		0,027(16)		0,039			0,041(11)					0,037(5)			0,031(5)
1419,0	0,0056(3)															0,0056(3)
1425,9	0,0037(22)												0,0031(19)			0,0034(19)
1489,6	0,0084(14)												0,0081(12)			0,0082(12)
1494,0			1,88(9)	2,10(4)	1,91(8)	2,058(17)	1,99(2)	1,72(8)		1,99(4)	1,979(16)		2,04(8)	2,00(3)		2,00(2)
1510,0	0,0141(28)	<0,012											0,013(4)			0,014(3)
1522	0,0017(8)															0,0017(8)
1531,4	0,0172(12)		0,009(5)		0,018(5)								0,018(2)			0,0171(12)
1537,9			0,15(2)		0,15(1)			0,12(1)		0,155(6)			0,160(13)			0,151(6)
1554	≤0,004												0,0032(15)			0,0032(15)
1596,5			5,15(26)	5,19(8)	4,81(10)	5,247(30)	5,237(84)	4,54(18)	5,08(5)	5,13(8)	5,078(40)		5,12(17)	5,08(5)	5,083(22)	5,11(3)
1667,3	0,0056(8)												0,0053(12)			0,0055(8)
1674,9	0,0039(11)				0,006(1)			0,004					0,0041(16)			0,0049(11)
1716,9	0,0017(11)							0,0017(9)					0,0017(9)			0,0017(9)
1773	0,0008(6)							0,0010(6)					0,0010(6)			0,0010(6)
1838,0	0,0023(6)							0,0027(11)					0,0027(11)			0,0024(6)
1895	0,0017(6)							0,0020(9)					0,0020(9)			0,0018(6)

§ This energy corresponds to the two gamma-rays: $\gamma_{24,8}$ and $\gamma_{29,13}$. The former one was added in 1998Re22 with a relative emission probability of 0,020(7). Considering the experimental intensity of 0,032(5) as a sum of intensities $\gamma_{24,8}$ and $\gamma_{29,13}$, it leads to the $\gamma_{29,13}$ relative emission probability of 0,012(8)-see section 4.2.

The gamma ray emission probabilities have been computed from their relative evaluated emission probabilities given in Table 3 using the normalization factor $K = 0,3489(34)$. This value has been obtained from the intensity balance for gamma transitions to the ground states of ¹⁵⁴Gd and ¹⁵⁴Sm assuming that the ground states are not populated directly by beta or electron capture decay. Then, $P_{\gamma+ce}(\gamma_{i,0} \text{ Sm}) + \sum P_{\gamma+ce}(\gamma_{i,0} \text{ Gd}) = 100\%$ where $i=1, 3, 5, 6, 9, 11, 17, 18, 19, 20, 30, 33$.

There are several measurements of the absolute emission probabilities (P_γ) of some prominent gamma rays in the decay ¹⁵⁴Eu → ¹⁵⁴Gd.

The evaluated (calculated) value of $P_{\gamma_{1,0}}$ (123,07 keV) = 40,4(5)% agrees well with the value of 40,6(7)% measured in 1991ZaZZ.

The evaluated value of $P_{\gamma_{16,1}}$ (1274,43 keV) = 34,9(3)% agrees well with the value of 34,8(2)% measured in 1994Co02, and it differs somewhat from the value of 35,32(12)% obtained in 1992Ha02.

The values of $P_{\gamma_{2,1}}$ (247,93 keV) = 6,96(8) % and $P_{\gamma_{6,0}}$ (996,26 keV) = 10,36(18)% measured in 1997Ka47 agree with the evaluated (calculated) values of 6,89(7)% and 10,50(10)%, respectively.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies given in 2.2 and the electron binding energies.

The emission probabilities of conversion electrons have been deduced from the evaluated P_γ and ICC values.

The absolute total emission probabilities of Gd and Sm K Auger electrons have been computed by using their corresponding evaluated total $P(\text{ce}_K)$ for Gd and Sm and their adopted ω_K from section 3.

The absolute total emission probabilities of Gd and Sm L Auger electrons have been computed using their corresponding evaluated total $P(\text{ce}_K)$ and $P(\text{ce}_L)$ for Gd and Sm and their adopted $\bar{\omega}_L$ and n_{KL} from section 3.

Average energies of β^- spectrum components have been calculated using the LOGFT program.

6. References

- 1949Ha04 - R. J. Hayden, J. H. Reynolds, M. G. Inghram - Phys. Rev. 75(1949)1500 [Half-life].
 1952Ka26 - D. G. Karraker, R. J. Hayden, M. G. Inghram - Phys. Rev. 87(1952)901 [Half-life].
 1957Ke08 - V. M. Kelman, V. A. Romanov, R. Y. Metskhvarishvili and V. A. Kolyunov - Nucl. Phys. 2(1957)395 [Gamma multipolarities].
 1958Ch36 - E. L. Chupp, J. W. M. DuMond, F. J. Gordon, R. C. Jopson, H. Mark - Phys. Rev. 112(1958)518 [Gamma-ray energies].
 1962Lu03 - D.S. Lu and R. S. Dingus - Phys. Lett. 3(1962)44 [Gamma multipolarities, experimental internal conversion electrons].
 1966Ha36 - P.C. Hansen, H. L. Nielsen and K. Wilsky - Nucl. Phys. 89(1966)571 [Beta transition probabilities].
 1966Ja02 - J. S. W. Jansen, J. H. Hamilton and E. F. Zganjar - Proc. Intern. Conf. Internal Conversion Process, Nashville, Tenn. (1965), J.H. Hamilton, Ed., Academic Press, Inc., New York, (1966)257 [Experimental ICC, gamma multipolarities].
 1967Be65 - J. A. Bearden - Rev. Mod. Phys. 39(1967)78 [X-ray energies].
 1968Me18 - R. A. Meyer - Phys. Rev. 174(1968)1478 [Gamma-ray energies and relative emission probabilities].
 1968Ng01 - L. K. Ng, K. S. Mann and T. G. Walton - Nucl. Phys. A116(1968)433 [Beta transition probabilities].
 1969An01 - G. I. Anderson and G. T. Evans - Nucl. Phys. A123 (1969)609 [Gamma multipolarities].
 1969Va09 - L. Varnell, J. D. Bowman and J. Trischuk - Nucl. Phys. A127(1969)270 [Gamma-ray relative emission probabilities].
 1970Ri19 - L. L. Riedinger, N. R. Johnson, J. H. Hamilton - Phys. Rev. C2(1970)2358 [Gamma-ray energies].
 1970RiZY - L. L. Riedinger, E. Eichler, J. Fuglsang G.B.Hagemann and B.Herskind - Proc. Intern. Conf. Nucl. Reactions Induced by Heavy Ions, Heidelberg, Germany (1969) R. Bock, W. R. Hering, Eds., North-Holland Publishing Co., Amsterdam. (1970) 442 [Gamma-ray relative emission probabilities].

- 1972Em01 - J. F. Emery, S. A. Reynolds, E. I. Wyatt and G. I. Gleason - Nucl. Sci. Eng. 48(1972)319 [Half-life].
- 1972Na21 - T. S. Nagpal and R. E. Caucher – Can. J. Phys. 50(1972)2688 [Gamma multipolarities].
- 1974HeYW - R. L. Heath, Gamma-Ray Spectrum Catalogue. In: ANCR 1000 2(1974) [Gamma-ray energies].
- 1977La19 - F. P. Larkins - Atomic Data and Nuclear Data Tables 20(1977)313 [Auger electron energies].
- 1977Ya04 - H. Yamada, H. Kawakami, M. Koike and K. Komura – J. Phys. Soc. Jap. 42(1977)1448 [Gamma multipolarities].
- 1978GrZR - G.-F. Grisham, (1978): No title. (Priv. Comm; June) [Half-life].
- 1978Ro22 - F. Rosel, H. M. Friess, K. Alder and H. C. Pauli - At. Data Nucl. Data Tables 21(1978)92. [Theoretical ICC].
- 1978ScZO - K. Schreckenbach, (1978): No title. (Priv. Comm; July) [Half-life].
- 1980Ro22 - W. M. Roney, Jr., and W. A. Seale – Nucl. Instr. Meth. 171(1980)389 [Gamma-ray relative emission probabilities].
- 1980Sh15 - A. K. Sharma, R. Kaur, H. R. Verma and P. N. Trehan – J. Phys. Soc. Jap. 48(1980)1407 [Gamma-ray relative emission probabilities].
- 1982HoZY - D. D. Hopes, J. M. R. Hutchinson, F. J. Schima and M. P. Unterweger - NBS-SP 626(1982)85 [Half-life]
- 1983Wa26 - K. F. Walz, K. Debertin and H. Schrader - Intern. J. Appl. Radiat. Isotop. 34(1983)1191 [Half-life].
- 1984Iw03 - J. Iwata, M. Yasuhara, K. Maeda and Y. Yoshizawa - Nucl. Instr. Meth. 219(1984)123 [Gamma-ray relative emission probabilities].
- 1986Wa35 - Wang Xinlin, Li Xiaodi and D. Hongshan - Chin. J. Nucl. Phys. 8(1986)371 [Gamma-ray relative emission probabilities].
- 1986Wo05 - M. J. Woods and S. F. M. Lucas - Intern. J. Appl. Rad. Isot. 37(1986)1157 [Half-life].
- 1987Lagoutine - F. Lagoutine, N. Coursol and J. Legrand. Table de Radionucleides, ISBN-2-7272-0078-1 (LMRI, 1982-1987) [Energy of Auger electrons].
- 1988RaZM - M. U. Rajput and T. D. Mac Mahon - ZFK-732. (1988)313 [Half-life].
- 1989Ki10 - L. L. Kiang, G. C. Kiang, P. K. Teng, G. C. Jon, T. H. Yuan and Y. M. Hsu - Z. Phys. A333(1989)19 [Gamma-ray relative emission probabilities].
- 1989Schima - F. J. Schima (1989), IAEA-CRP informal report GS/59; Cited in IAEA-TECDOC-619 (1991) [Gamma-ray relative emission probabilities].
- 1990He05 - R. G. Helmer - Appl. Rad. Isot. 41(1990)75 [Gamma-ray energies and relative emission probabilities].
- 1990Me15 - R. A. Meyer - Fizika (Zagreb) 22(1990)153 [Gamma-ray energies and relative emission probabilities].
- 1991ZaZZ - A. V. Zanevsky, G. A. Isaakyan, N. V. Kurenkov, A. B. Malinin, T. E. Sazonova and S. V. Sepman- Program and Thesis, Proc. 41st Ann. Conf. Nuclear Spectrosc. Struct. At. Nuclei, Minsk. (1991)477 [123 keV gamma-ray absolute emission probabilities].
- 1992El11 - S. U. El-Kameesy, M. S. Abdel-Wahab, L. Al-Houty and H. Abou-Leila - Acta Phys. Acad. Sci. Hung. 71(1992)161 [Gamma-ray relative emission probabilities].
- 1992Ha02 - M. A. Hamed, I. M. Lowles and T. D. Mac Mahon - Nucl. Instr. Meth. Phys. Res. A312(1992)308 [Gamma-ray relative emission probabilities and 1274 keV gamma-ray absolute emission probability].
- 1992Sa04 - T. E. Sazonova, G. A. Isaakyan, N. I. Karmalitsyn, S. V. Sepman and A. V. Zanevsky - Nucl. Instrum. Methods Phys. Res. A312(1992)372 [Gamma-ray relative emission probabilities].
- 1992ScZZ - U. Schötzig, H. Schrader and K. Debertin - Proc. Intern. Conf. Nuclear Data for Science and Technology, Julich, Germany. (1992)562 [Half-life].
- 1992Sm02 - D. Smith, D. H. Woods, S. A. Woods, J. L. Makepeace, R. A. Mercer and C. W. A. Downey - Nucl. Instrum. Methods Phys. Res. A312(1992)353 [Gamma-ray energies and emission probabilities].
- 1992Un01 - M. P. Unterweger, D. D. Hoppes and F. J. Schima - Nucl. Instrum. Methods Phys. Res. A312(1992)349 [Half-life]
- 1993Th04 - J. L. Thompson and A. R. Cartwright - Appl. Radiat. Isot. 44(1993)707 [Half-life].
- 1994Co02 - B. M. Coursey, J. M. Calhoun, J. Cessna, D. B. Golas, F. J. Schima and M. P. Unterweger - Nucl. Instrum. Methods Phys. Res. A339(1994)26 [1274 keV gamma-ray absolute emission probability].
- 1995Au04 - G. Audi and A. H. Wapstra - Nucl. Phys. A595(1995)409 [Q-value].

- 1995Ma03 - N. Mach and B. Fogerberg - Phys. Rev. C51 (1995)509 [Experimental internal conversion electrons].
- 1996AL31 - I. Alfter, E. Bodenstedt, W. Knichel, J. Schuth - Z. Phys. A355(1996)277 [Experimental gamma multiplicities].
- 1996Sc06 - E. Schönfeld and H. Janßen - Nucl. Instrum. Methods Phys. Res. A369(1996)527 [Atomic data].
- 1997Ka47 - S. I. Kafala, T. D. Mac Mahon and S. V. Borzakov - J. Radioanal. Nucl. Chem. 215(1997)193 [248 keV and 996 keV gamma-ray absolute emission probability].
- 1998Si12 - H. Siegert, H. Schrader and U. Schotzig - Appl. Radiat. Isot. 49(1998)1397 [Half-life].
- 1998Sc28 - E. Schönfeld - Appl. Radiat. Isot. 49(1998)1353 [Fractional electron capture probabilities P_K , P_L , P_M].
- 1998Re22 - C. W. Reich, R. G. Helmer - Nuclear Data Sheets 85(1998)171 [Level scheme, multiplicities, total ICC].
- 1999Schönfeld - E. Schönfeld and G. Rodloff - PTB-6.11-1999-1999-1, Braunschweig, Februar 1999 [KX-ray energies and relative emission probabilities].
- 2000Ch01 - V. P. Chechev and A. G. Egorov - Appl. Rad. Isot. 52(2000)601[Evaluation technique].
- 2000He14 - R. G. Helmer and C. van der Leun - Nucl. Instrum. Methods Phys. Res. A450(2000)35 [Gamma-ray energies].
- 2002Un02 - M. P. Unterweger - Appl. Rad. Isot. 56(2002)125 [Half-life].

¹⁵⁵Eu – Comments on evaluation of decay data

by V. P. Chechev and V. O. Sergeev

1. DECAY SCHEME

The ¹⁵⁵Eu decay scheme is complete. The most intense allowed β^- -transitions occur to the excited levels with energy of 105.31 keV (46.1%) and 86.55 keV (25.5%).

The 1st forbidden β^- -transitions populate the 60.01 keV (9.2%) and 146.07 keV (1.9%) levels.

The ground state in ¹⁵⁵Gd is populated by the intense allowed β^- -transition (16.6%).

The 2nd forbidden β^- -transition to the excited level of 107.58 keV was not observed. From the log ft systematics its log ft should be more than 11.1 and the upper limit on this β^- branch intensity is expected less than 0.01%.

2. NUCLEAR DATA

Q value is from 1995Au04 .

The evaluated value of the ¹⁵⁵Eu half-life has been taken from 2000Ch01 (Chechev and Egorov). It is based on the measurement results given in Table 1.

Table 1. Set of experimental data for the evaluation of ¹⁵⁵Eu half-life (in days)

Reference	Author	Data set "1" $\chi^2 = 334.9$ $(\chi^2)_6^{0.05} = 14.1$	Data set "2" $\chi^2 = 6.14$ $(\chi^2)_5^{0.05} = 12.6$	Data set "3" $\chi^2 = 5.68$ $(\chi^2)_5^{0.05} = 12.6$
1998Si12	Siegert <i>et al.</i>	1739(8)	1739(8)	1739(8)
1993Th04	Thompson <i>et al.</i>	1735(22)	1735(22)	1735(22)
1992Un01	Unterweger <i>et al.</i>	1739.0(5)	1739.0(5)	1739(7) ^b
1983Wa26	Walz <i>et al.</i>	1737(23)	1737(23)	1737(23)
1974Da24	Daniels <i>et al.</i>	1708(18)	1708(18)	1708(18)
1972Em01	Emery <i>et al.</i>	1812(4)	Omitted ^a	-
1972Su09	Subba Rao	1653(51)	1653(51)	1653(51)
1970Mo23	Mowatt <i>et al.</i>	1698(74)	1698(74)	1698(74)

^a The value from 1972Em01 has been omitted on the basis of statistical considerations.

^b The rule of "50% weight"(LRSW) leads to a significant increase of the 1992Un01 uncertainty.

In 2002Un02 the new NIST measurement result was published for the ¹⁵⁵Eu half-life: $T_{1/2} = 1739.06(45)$ d. It does not differ practically from 1992Un01 and its use instead of 1992Un01 does not change this evaluation.

The weighted mean of the experimental values from the final data “set 3” is 1736(5) days where the uncertainty is internal. The adopted value of the ¹⁵⁵Eu half-life is 1736(5) days, or 4.753(14) years.

2.1. b⁻-Transitions

The energies of the β⁻ transitions have been computed from the Q value and the level energies adopted from 1986Sc25, where the reaction ¹⁵⁴Gd(n,γ)¹⁵⁵Gd was studied. For the level energies see also the evaluation in Nuclear Data Sheets (1994Re10).

The probabilities of the β⁻ transitions have been obtained from the P_{γ+ce} balance for each level based on the P_γ normalization factor of 0.307(3) (see sect.4.2.3). The calculated P(β_{0,0}) agrees with the unweighted mean of 18(4)% of the five measurement results of 1949Ma58, 1954Le08, 1956Du31, 1959Am16, 1960Su04.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are energies of gamma rays (E_γ) with adding the recoil energy of E_γ² / 2Mc² where M – mass of the ¹⁵⁵Gd nucleus. The latter changes the energy only for γ_{6,0}.

The gamma transition probabilities have been calculated from the gamma emission probabilities and the internal conversion coefficients (ICC).

For gamma transitions with energies more than 25 keV the ICC have been evaluated using theoretical values from 1978Ro22 for the adopted multipolarities. For these transitions the following uncertainties for theoretical values have been adopted 1% for α_K and 3% for α_L, α_M, α_{NO}. The ICC interpolated from other tables (1968Ha53, 1978Band) do not differ from the evaluated values within limits of adopted uncertainties.

For low-energy gamma transitions γ_{5,4}, γ_{3,2}, γ_{4,2} the ICC have been evaluated using theoretical values from 1993Ba60. The ICC values in 1968Ha53 and 1978Ro22 for these energies differ considerably or are absent.

The adopted E2 admixtures for (M1+E2)-transitions γ_{5,4}, γ_{3,2}, γ_{5,2}, γ_{1,0} and γ_{2,0} have been evaluated using measurement results from 1959De29, 1961Su13, 1962Ha24, 1966As02, 1967Fo11, 1967Ko12, 1975Ch04, 1975Kr04, 1986Sc25 and 1990GoZS. In these works the intensity ratios L₁:L₂:L₃ were measured for conversion electrons in decays of ¹⁵⁵Eu and ¹⁵⁵Tb and also in the ¹⁵⁴Gd(n,γ) reaction. Also γγ(θ)-correlations were studied in ¹⁵⁵Tb decay and in Coulomb excitation of the ¹⁵⁵Gd levels - ¹⁵⁵Gd (p, p γ) (see Table 2).

Table 2. Measured and evaluated E2 admixtures for the (M1+E2) multipolarities of gamma transitions in the decay of ¹⁵⁵Eu

E _γ , keV	Measurement result, % E2	NSR code	Method	Evaluated (adopted) value, % E2
10.418	0.11(5) 0.4(3)	1975Ch04 1967Fo11	L ₁ ; L ₂ ; L ₃ , ¹⁵⁵ Tb L ₁ ; L ₂ ; L ₃ , ¹⁵⁵ Eu	0.11(5)
18.763	7.4(6) 6.3(8) 7.1(4) 5.6(12) 6.3(14)	1990GoZS 1967Fo11 1975Ch04 1962Ha24 1975Kr04	L ₁ ; L ₂ ; L ₃ , ¹⁵⁵ Eu L ₁ ; L ₂ ; L ₃ , ¹⁵⁵ Eu L ₁ ; L ₂ ; L ₃ , ¹⁵⁵ Tb L ₁ ; L ₂ ; L ₃ , ¹⁵⁵ Tb γγ, ¹⁵⁵ Eu	7.1(4) WM
31.444	17(5)	1986Sc25	L ₁ ; L ₂ ; L ₃ , ¹⁵⁴ Gd(n,γ)	17(5)

60.009	4.0(4) 3.3(10) 4.4(4) 3.7(10) 3.5(9) 3.8(10) 4.9(24)	1967Fo11 1967Ko12 1986Sc25 1962Ha24 1975Kr04 1961Su13 1966As62	L ₁ ; L ₂ ; L ₃ , ¹⁵⁵ Eu L ₁ ; L ₂ ; L ₃ , ¹⁵⁵ Tb L ₁ ; L ₂ ; L ₃ , ¹⁵⁴ Gd(n,γ) L ₁ ; L ₂ ; L ₃ , ¹⁵⁵ Tb γγ, ¹⁵⁵ Eu γγ, ¹⁵⁵ Eu ¹⁵⁵ Gd (p, p' γ)	4.1(4) WM
86.059	2.5(6) 3.5(10) 4.9(15) 3.5(16)	1986Sc25 1975Kr04 1966As02 1959De29	L ₁ ; L ₂ ; L ₃ , ¹⁵⁴ Gd(n,γ) γγ, ¹⁵⁵ Eu ¹⁵⁵ Gd (p, p' γ) ¹⁵⁵ Gd (p, p' γ)	3.0(6) WM

3. ATOMIC DATA

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The X-ray energies are based on the wavelengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission probabilities are taken from 1996Sc06, 1999Schönfeld and 1974Sa28.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Table. The ratios P(KLX)/P(KLL) and P(KLY)/P(KLL) are taken from 1996Sc06.

4. PHOTON EMISSIONS

4.1 X-Ray Emissions

The total absolute emission probability of KX-rays (P_{XK}) has been computed using the adopted value of ω_K and the evaluated total absolute emission probability of K conversion electrons $P_{ce_K} = 25.17(46)$ per 100 disintegrations. The absolute emission probabilities of the KX-ray components have been computed from P_{XK} using the relative probabilities from Sect.3.2.

The measured values of the total absolute emission probability of KX-rays given below can be compared to the calculated (adopted) value of $P_{XK}^{eval} = 23.6(5)$ per 100 disintegrations:

1967Fo11	1967Bl11	1968Om01	1969Me09	1971Ge11	1994Eg01	WM
22.9(10)	25.2(25)	21.3(23)	21.1(6)	22.5(12)	23.50(19)	23.3(2) ^a

^a Weighted mean of all 6 values. The value of 1969Me09 gives the 80% contribution to χ^2 . With omitting this value the weighted mean of 5 values is 23.5(2).

The total absolute emission probability of LX-rays has been computed using the adopted values of ω_L and n_{KL} and the evaluated values of $P(ce_K) = 25.17(46)$ and $P(ce_L) = 21.2(24)\%$.

4.2. Gamma-Ray Emissions

4.2.1. Gamma-Ray Energies

The measured and evaluated values of gamma ray energies are given in Table 3.

The evaluated values of E_γ have been obtained as weighted means omitting outliers contradicting to the energies of excited levels measured in 1986Sc25. The values of 1969Me09 have been omitted as the author in 1990Me15 replaces them.

4.2.2. Gamma-Ray Relative Emission Probability

The measured and evaluated values of relative gamma ray emission probabilities ($P'\gamma$) are shown in Table 4.

The evaluated values of $P'\gamma$ have been obtained as weighted means apart from $P'(\gamma_{5,4})$ and $P'(\gamma_{4,2})$. The $P'(\gamma_{5,4})$ has been evaluated from the intensity balance for the 107.58 keV- level. The $P'(\gamma_{4,2})$ has been calculated from data on conversion electrons (1967Fo11) and the adopted ICC using the measured in 1967Fo11 ratio $P(\text{ce}_{4,2} \text{L3})/P(\text{ce}_{3,0} \text{K}) = 0,115(6)$ and the adopted values of $\alpha_{\text{L3}}(\gamma_{4,2})$ and $\alpha_{\text{K}}(\gamma_{3,0})$.

The values of 1969Me09 have been omitted as the author in 1990Me15 replaces them. Other values have been omitted due to absence of uncertainties or as statistical outliers.

Our evaluated value $P'(\gamma_{3,0}) = 68.8(14)$ for the intense gamma ray with energy of 105.31 keV is supported by the results of measurements of the intensity ratio $P(\text{ce}_{3,0} \text{K})/P(\text{ce}_{2,0} \text{K}) = 0.408(8)$ in 1967Fo11 (see Table 5) which leads to the value $P'(\gamma_{3,0}) = 68.7(17)$ if the adopted α_{K} in sect.2.2 is used.

4.2.3. Gamma-Ray Absolute Emission Probabilities

Two absolute measurements of the emission probability are available for the 86,55 keV gamma ray: 31.1(4)% in 1994Co02 and 30.5(3)% in 1994Eg01. The weighted mean of these values has been adopted as the evaluated $P(\gamma_{2,0}) = 30.7(3)\%$. Here the uncertainty is the external one of WM.

The absolute emission probabilities of other gamma rays have been computed from the evaluated emission probabilities (P') given in Table 4 and the evaluated absolute emission probability of $\gamma_{2,0}$ (86.55 keV).

It should be noted that the absolute emission probability of $\gamma_{3,0}$ (105.31 keV) was measured in 1992Sa04: $P(\gamma_{3,0}) = 20.39(13)\%$. This value is considerably less than the evaluated one and measured in 1994Eg01 and 1996Ch27. If it is adopted without changing of the evaluated $P(\gamma_{2,0}) = 30.7(3)\%$ the relative emission probability of $\gamma_{3,0}$ will be 66.4(9), essentially less than the average of the eight measurement results (Table 4 and comment in sect.4.2.2.). On other hand, if the value of 1992Sa04 is adopted together with the evaluated $P'(\gamma_{3,0}) = 68.8(14)$, the $P(\gamma_{2,0})$ will be obtained as 29.6(6)%, less than both results of direct measurement of the absolute emission probability of this gamma ray (1994Co02 and 1994Eg01).

Therefore we consider the value of 1999Sa04 as too small and do not take it into account.

Table 3. Measured and evaluated values of gamma ray energies in the decay of ¹⁵⁵Eu

	1959Ha07	1967Fo11	1969Me09	1970Re08	1970Ra37	1975Ch04 ^a	1975Kr04	1986Sc25 ^b	1990Me15	1990GoZS	Evaluated (adopted) value
$\gamma_{5,4}$		10.40(2)*				10.40(2)*		10.4183(13)			10.4183(13)
$\gamma_{3,2}$		18.776(35)*	18.776(35)*			18.749(19)*	18.73(3)*	18.760(4)	18.784(35)*	18.764(2)	18.763(2) ^c
$\gamma_{4,2}$		21.02(2)				21.02(2)		21.030(10)		21.036(4)	21.035(4)
$\gamma_{2,1}$			26.513(21)*				26.49(5)	26.530(23)	26.532(21)		26.531(21)
$\gamma_{5,2}$			31.40(10)*	31.55(12)				31.444(7)	31.40(10)		31.444(7)
$\gamma_{3,1}$	45.29(1)	45.3(2)*	45.299(13)*	45.299(2)	45.2972(13)		45.27(5)*	45.3000(10)	45.295(13)		45.2990(10)
$\gamma_{5,1}$			57.983(30)*	57.970(26)	57.9805(20)		57.99(4)	57.989(1)	57.986(30)		57.989(1)
$\gamma_{1,0}$	60.00(2)		60.019(15)*	60.006(4)	60.0100(18)		60.01(4)	60.008(2)	60.022(15)	60.0086(10)	60.0086(10) ^c
$\gamma_{6,1}$		86.01(20)	86.0(5)	86.062(23)	86.062(5)		86.03(7)	86.0590(10)			86.05910(10)
$\gamma_{2,0}$	86.56(1)	86.82(20)	86.539(15)*	86.541(3)	86.5452(33)		86.53(3)	86.5470(10)	86.554(15)		86.5479(10)
$\gamma_{3,0}$	105.32(3)	105.28(20)	105.315(15)*	105.302(4)	105.308(3)		105.30(3)	105.3090(10)	105.338(15)		105.3083(10)
$\gamma_{3,0}$			146.05(2)*	146.061(5)			146.04(10)	146.0710(10)	146.090(90)		146.0710(10)

^a Decay of ¹⁵⁵Tb^b Reaction ¹⁵⁴Gd(n, γ)¹⁵⁵Gd^c The data of 1976Me10 (decay of ¹⁵⁵Tb) have been taken into consideration additionally: E($\gamma_{3,2}$)=18.769(15) keV and E($\gamma_{1,0}$)=60.012(3) keV.

* Omitted from averaging. Values of 1969Me09 are superseded by those of 1990Me15.

Table 4. Measured and evaluated values of relative gamma ray emission probabilities in the decay of ¹⁵⁵Eu.

	E _γ , keV	1959Ha07	1967Be11	1968Al01	1969Me09	1970Re08	1971Ge11	1975Kr04	1990Me15	1994Eg01	1996Ch27	Evaluated value
γ _{5,4}	10.418											0.0115(13) ^a
γ _{3,2}	18.763	≈0,1*			0.16(4)*		0.17(3)	0.13(3)	0.16(4)			0.16(2) ^{b,c}
γ _{4,2}	21.035											1.5(3)·10 ⁻³ ^d
γ _{2,1}	26.531	≈4*		≈1*	1.03(6)*		1.00(10)	1.10(13)	1.03(6)			1.03(6) ^c
γ _{5,2}	31.444				0.023(5)*	0.03(2)			0.023(5)			0.023(5) ^c
γ _{3,1}	45.299	2.3*		2.8(7)*	4.18(17)*	3.6(7)	4.1(3)	3.95(40)	4.21(20)	4.36(12)	4.3(10)	4.27(12) ^c
γ _{5,1}	51.989			0.20(3)	0.217(18)*	0.22(5)		0.23(3)	0.221(18)	0.213(30)		0.217(18) ^c
γ _{1,0}	60.009	4,0*	5.1(20)*	3.8(2)	3.60(10)*	4.3(3)	3.9(9)	3.8(4)	3.60(10)	3.99(12)	3.9(9)	3.96(12) ^c
γ _{6,1}	86.059			0.50(5)		0.49(5)		0.54(11)				0.50(5) ^c
γ _{2,0}	86.548	100	100	100	100	100	100	100	100	100	100	100
γ _{3,0}	105.308	64*	65.7(65)	67.9(35)	66.8(27)*	68.3(27)	68(4)	69.9(35)	66.8(27)	68.5(14)	69.5(16)	68.8(14) ^{c,e}
γ _{6,0}	146.071		0.16(5)		0.167(10)*	0.19(2)		0.14(2)	0.167(10)			0.166(10) ^c

^a Evaluated from the intensity balance for the 107.58 keV level

^b In addition the value of 0.16(2) from 1974HeYW has been taken into account

^c Weighted mean

^d Evaluated from the conversion electron intensity and ICC

^e In addition the value of 69.1(9) from 1982Co05 has been taken into account

* Omitted from averaging. Values of 1969Me09 are superseded by those of 1990Me15.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using the evaluated P_{γ} and ICC. In Table 5 the relative intensities of conversion electrons $P'_{ce}(exp.)$ measured in 1967Fo11 are compared to the relative intensity values $P'_{ce}(calc.)$ calculated from the evaluated absolute emission probabilities (in units $P'(ce_{3,0} K) = 1000$).

Table 5. Comparison of experimental and calculated values of relative intensity of conversion electrons in the ^{155}Eu decay.

	Energy, keV	$P'_{ce}(exp)$	$P'_{ce}(calc.)$
ec _{5,4} L	2.043-3.175	305(27)	206(30)
ec _{1,0} K	9.770(3)	1870(100)	2000(130)
ec _{3,2} L	10.387-11.520	2730(110)	3080(400)
ec _{4,2} L	12.659-13.792	212(8)	218(30)
ec _{6,1} K	35.820(3)	66(5)	91(12)
ec _{2,0} K	36.309(3)	2450(50)	2440(50)
ec _{3,1} L	36.923-38.053	90(5)	100(5)
ec _{1,0} L	51.633-52.766	420(10)	418(16)
ec _{3,0} K	55.069(3)	1000	1000
ec _{2,0} L	78.172-79.305	380(9)	382(13)
ec _{3,0} L	96.933-98.066	152(6)	152(8)

As seen from Table 5 the experimental and calculated values agree well with the exception of ec_{5,4} L and ec_{6,1} K. The disagreement for ec_{5,4} L can be connected with experimental difficulties of measurement of the 2-3 keV conversion electrons on the background of intense L Auger electrons, and for ec_{6,1} K – of measurement on the background of intense conversion line of ec_{2,0} K.

The total absolute emission probability of K Auger electrons has been computed using the total $P(ce_K) = 25.17(46)\%$ and the adopted ω_K in sect.3.

The total absolute emission probability of L Auger electrons has been computed using the evaluated total $P(ce_K)$ and $P(ce_L) = 21.2(24)\%$ and the adopted $\bar{\omega}_L$ and n_{KL} in sect.3.

The values of β^- average energies have been calculated using the LOGFT program.

References

- 1949MA58 - J. A. Marinsky, L. E. Glendenin, F. Metzger, In: MIT-LNS Progr Rept. p.67 (1949) NP-1272. (Beta emission energies and probabilities)
- 1954LE08 - M. R. Lee, R. Katz, Phys. Rev. 93(1954)155. (Beta emission energies and probabilities)
- 1956DU31 - V. S. Dubey, C. E. Mandeville, M. A. Rothman, Phys. Rev. 103(1956)1430 (Beta emission energies and probabilities)
- 1959AM16 - M. C. Joshi, B. V. Thosar, Proc. Indian Acad. Sci. 50A(1959)342. (Beta emission energies and probabilities)
- 1959DE29 - J. de Boer, M. Martin, P. Marmier, Helv. Phys. Acta. 32(1959)658.(Multipolarity mixing ratios)
- 1959HA07 - E. N. Hatch, F. Boehm, Z. Phys. 155(1959)609.(Gamma ray energies and relative emission probabilities)
- 1960SU04 - B. N. Subba Rao, Nuovo Cimento 16(1960)283. (Beta emission energies and probabilities)
- 1961SU13 - B. N. Subba Rao, Nucl. Phys. 28(1961)503.(Multipolarity mixing ratios)
- 1962HA24 - B. Harmatz, T. H. Handley, J. W. Mihelich, Phys. Rev. 128(1962)1186. (Multipolarity mixing ratios)
- 1966AS02 - D. Ashery, A. E. Blaugrund, R. Kalish, Nucl. Phys. 76(1966)336.(Multipolarity mixing ratios)
- 1967BE11 - R. E. Berg, J. L. Snelgrove and E. Kashy, Phys. Rev. 153(1967)1165. (Gamma ray relative emission probabilities)
- 1967BL11 - P. H. Blichert-Toft, E. G. Funk, J. W. Mihelich, Nucl. Phys. A96(1967)190. (KX ray emission probabilities)
- 1967FO11 - C. Foin, J. Oms, J.-L. Barat, J. Phys. (Paris) 28(1967)861.(Gamma ray energies, KX-ray emission probabilities, conversion electron emission probabilities, multipolarity mixing ratios)

- 1967KO12 - J. Kormicki, H. Niewodniczanski, Z. Stachura, K. Zuber, A. Budziak, Nucl. Phys. A102(1967)253. (Multipolarity mixing ratios)
- 1968AL01 - P. Alexander, Nucl. Phys. A108(1968)145.(Gamma ray relative emission probabilities)
- 1968HA53 - R. S. Hager, E. C. Seltzer, Nucl. Data Tables A4(1968)1.(Theoretical ICC)
- 1968OM01 - J. Oms, C. Foin, A. Baudry, Compt. Rend. 266B(1968)1292.(KX ray emission probabilities)
- 1969ME09 - R. A. Meyer, J. W. T. Meadows, Nucl. Phys. A132(1969)177. (Gamma and KX ray energies and emission probabilities)
- 1970MO23 - R. S. Mowatt, Can. J. Phys. 48(1970)1933. (Half-life)
- 1970RA37 - D. E. Raeside, Nuclear Instrum. Methods 87(1970)7. (Gamma ray energies)
- 1970RE08 - J. D. Reiersen, G. C. Nelson, E. N. Hatch, Nucl. Phys. A153(1970)109.(Gamma ray energies and relative emission probabilities)
- 1971GE11 - R. J. Gehrke, R. A. Lokken, Nuclear Instrum. Methods 97(1971)219. (Gamma ray relative emission probabilities)
- 1972EM01 - J. F. Emery, S. A. Reynolds, E. I. Wyatt, G. I. Gleason, Nucl. Sci. Eng. 48(1972)319 (Half-life)
- 1972SU09 - B. N. Subba Rao, Current Sci. (India) 41(1972)692. (Half-life)
- 1974DA24 - W. R. Daniels, D. W. Barr, G. F. Grisham, F. O. Lawrence, J. Inorg. Nucl. Chem. 36(1974) 3874. (Half-life)
- 1974HEYW - R. L. Heath, Report ANCR 1000-2 (1974). (Gamma ray relative emission probabilities)
- 1974SA28 - S. I. Salem, S. L. Panossian, R. A. Krause, At. Data Nucl. Data Tables 14(1974)91. (KX ray relative emission probabilities)
- 1975CH04 - P. Christmas, P. Cross, J. Phys. (London) G1(1975)113. (Gamma ray energies, multipolarity mixing ratios)
- 1975KR04 - H. J. Krell, S. Hofmann, Z. Phys. A272(1975)257. (Gamma ray energies and relative emission probabilities, multipolarity mixing ratios)
- 1976ME10 - R. A. Meyer, R. Gunnink, C. M. Lederer, E. Browne, Phys. Rev. C13(1976)2466. (Gamma ray energies)
- 1977LA19 - F. P. Larkins, Atomic Data and Nuclear Data Tables 20(1977)313 (Auger electron energies)
- 1978BAND - I. M. Band, M. B. Trzhaskovskaya, Special report of Leningrad nuclear physics institute, 1978. (Theoretical ICC)
- 1978RO22 - F. Rösel, H. M. Friess, K. Alder, H. C. Pauli, At. Data Nucl. Data Tables 21(1978)92. (Theoretical ICC)
- 1982CO05 - B. M. Coursey, D. D. Hoppes, F. J. Schima, Nuclear Instrum. Methods 193(1982)1. (Gamma ray relative emission probabilities)
- 1983WA26 - K. F. Walz, K. Debertin, H. Schrader, Int. J. Appl. Radiat. Isotop. 34(1983)1191. (Half-life)
- 1986SC25 - H. H. Schmidt, W. Stoffl, T. Egidy, P. Hungerford, H. J. Scheerer, K. Schreckenbach, H. G. Börner, D. D. Warner, R. E. Chrien, R. C. Greenwood, C. W. Reich, J. Phys. (London) G12(1986)411. (Gamma ray and level energies, multipolarity mixing ratios)
- 1987Table - F. Lagoutine, N. Coursol, J. Legrand, Table de Radionucléides - ISBN-2-7272-0078-1 (LMRI, 1982-1987) (Energy of Auger electrons)
- 1990GOZS - V. M. Gorozhankin, A. Kovalik, L. E. Ir, M. A. Makhmud, Ya. Novak, A. F. Novgorodov. In: Program and Thesis, Proc. 40th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Leningrad, (1990) p 97. (Gamma ray energies, multipolarity mixing ratios)
- 1990ME15 - R. A. Meyer, Fizika (Zagreb) 22(1990)153. (Gamma ray energies and relative emission probabilities)
- 1992SA04 - T. E. Sazonova, G. A. Isaakyan, N. I. Karmalitsyn, S. V. Sepman, A. V. Zanevsky, Nucl. Instrum. Methods Phys. Res. A312(1992)372. (105,31 keV gamma ray absolute emission probability)
- 1992UN01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instrum. Methods Phys. Res. A312(1992)349. (Half-life)
- 1993BA60 - I. M. Band, M. B. Trzhaskovskaya, At. Data Nucl. Data Tables 55(1993)43(Theoretical ICC)
- 1993TH04 - J. L. Thompson, A. R. Cartwright, Appl. Radiat. Isot. 44(1993)707. (Half-life)
- 1994CO02 - B. M. Coursey, J. M. Calhoun, J. Cessna, D. B. Golas, F. J. Schima, M. P. Unterweger, Nucl. Instrum. Methods Phys. Res. A339(1994)26. (86,55 keV gamma ray absolute emission probability)
- 1994EG01 - A. G. Egorov, V. P. Chechev, Nucl. Instrum. Methods Phys. Res. A339(1994)248. (Gamma and KX ray absolute emission probabilities)
- 1994RE10 - C. W. Reich, Nucl. Data Sheets 71(1994)709.(Decay scheme and level energies)
- 1995AU04 - G. Audi, A. H. Wapstra, Nucl. Phys. A595(1995)409. (Q value)
- 1996Ch27 - V. P. Chechev, A. G. Egorov, G. E. Shchukin, Appl. Radiat. Isot. 47(1996)329 (Gamma ray relative emission probabilities)
- 1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instrum. Methods Phys. Res. A369(1996)527.(Atomic data)
- 1998Si12 - H. Siegert, H. Schrader, U. Schötzgig, Appl. Radiat. Isot. 49(1998)1397 (Half-life)
- 1999Schönfeld E. Schönfeld, G. Rodloff, PTB-6.11-1999-1, Braunschweig, February 1999 (KX ray energies and relative emission probabilities)
- 2000Ch01 - V. P. Chechev, A. G. Egorov, Appl. Radiat. Isot. 52(2000)601. (Evaluation of half-life)
- 2002Un02 - M. P. Unterweger, Appl. Radiat. Isot. 56(2002)125. (Half-life)

¹⁶⁶Ho - Comments on evaluation of decay data by E. Schönfeld and R. Dersch

1 Decay Scheme

Below the Q value of 1854,5 keV there are several other excited levels of ¹⁶⁶Er which are populated in the disintegration of ¹⁶⁶Ho^m ($T_{1/2} = 1200$ a) and ¹⁶⁶Tm ($T_{1/2} = 7,70$ h). Beta transitions from ¹⁶⁶Ho to these levels, if existing, would have high degrees of forbiddenness so that they are not populated in the ¹⁶⁶Ho decay (or with extremely low transition probabilities). Thus, the decay scheme, given on page 1, can be considered as complete. Spins, parities and half-lives of the excited levels, and $lg f_t$ were taken from Ignatovkin et al. (1987).

2 Nuclear Data

Following half-life measurements have been taken into account ($T_{1/2}$ in h):

1	27,5	Inghram and Hayden	1947
2	26,8(4)	Grant and Hill	1949
3	26,9(1)	Cork et al.	1958
4	26,8(2)	Funke et al.	1963
5	26,74(5)	Daniel and Kaschl	1966
6	27,00(4)	Venkata Ramaniah et al.	1976
7	26,827(5)	Abzouzi et al.	1989
8	26,78(1)	Calhoun et al.	1991
9	26,7663(44)	Unterweger et al.	1992
10	26,795(29)	adopted value	1999

Value 1 is only of historical interest. Value 8 is replaced by value 9, value 6 is considered as outlier (or its accuracy is overestimated). The adopted value is the LWM of values 2-5, 7 (with doubled uncertainty to take account for systematical errors) and 9. LWM has used weighted average and expanded the uncertainty so range includes the most precise value 9. The rather large uncertainty reflects the discrepancy between the values 7 and 9.

2.1 β^- Transitions

The maximum beta energy of the transition to the ground state of ¹⁶⁶Er and the transition probability of this transition have been determined as follows:

1	1840	25 %	Sunyar 1954
2	1854(5)	51,6 %	Graham et al. 1955
3	1839(5)	47 %	Cork et al. 1958
4	1844	52 %	Marklund et al. 1960
5	1840	46 %	Cline et al. 1962
6	1859(3)	48,8 %	Funke et al. 1963
7	1857(3)	48,8 %	Daniel and Kaschl 1966
8	1854,7(15)	51,2 %	Grigoriev et al. 1974
9	1845(2)	52 %	Venkata Ramaniah et al. 1976
10	1854,8(17)		weighted average of values 2, 6 - 9 (see text below)
11	1854,5(9)		Audi and Wapstra 1995. Here adopted too

For the calculation of the average value 10, the originally given uncertainty of value 9 has been doubled before inserting it in the averaging procedure because the uncertainty seems to be overestimated. The unweighted average for the transition probability to the ground state (including values 2 to 9) is 49,6 %. This value agrees satisfactorily with the adopted value 48,2(15) % which was derived in the balancing procedure from the gamma transition probabilities.

2.2 Gamma Transitions

The energies of the gamma transitions are calculated from the gamma ray energies (section 4.2) taking the recoil energies into account which can be neglected in most cases. The probabilities P_{g+ce} are calculated from the gamma ray emission probabilities and the total conversion coefficients.

The conversion coefficients are interpolated from the tables of Röseler et al. (1978). Very much work has been spent for the study of the conversion of the 80,57 keV gamma transition. The K conversion coefficient of this transition was found to be

1	1,69(9)	Ramaswamy and Brahmavar	1963
2	1,63(5)	Falkstroem et al.	1968
3	1,72(6)	Nelson and Hatch	1969
4	1,69(6)	Campbell et al.	1971
5	1,66(6)	Campbell et al.	1972
6	1,65(5)	interpolated from Röseler et al.	1978; adopted value

For the K/L ratio the following values were found:

1	0,390(18)	Bogdanovic et al.	1968
2	0,426(11)	Nilsson et al.	1968
3	0,414(13)	Kartashov et al.	1977
4	0,411(12)	interpolated from Röseler et al.	1978; adopted value

Kartashov et al. (1977) have also determined the ratios M/L, N/M and O/N. From their measurements the following set can be derived:

$$\begin{aligned}\alpha_K &= 1,650(33) \\ \alpha_L &= 3,983(170) \\ \alpha_M &= 0,990(50) \\ \alpha_N &= 0,200(12) \\ \alpha_{OP} &= 0,048(3) \\ \alpha_t &= 6,87(18)\end{aligned}$$

The total conversion coefficient of this transition was determined by Brandtley et al. (1966) to be $\alpha = 6,94(48)$. Several other authors have determined L subshell ratios (Hermann et al. (1966), Gellertly et al. (1966, 1967), Karlsson et al. (1966), Zyllicz et al. (1966), Arnoux and Gizon (1967), Bogdanovic et al. (1968)). Also M and N subshell ratios were determined (Hoegberg et al. (1968), Dragoun et al. (1972), Bulgakov et al. (1981)).

The conversion coefficients contained in table 2.2 are interpolated from the tables of Röseler et al. (1978).

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energies are based on the X ray wave lengths compiled by Bearden (1967). The relative probabilities are calculated using the ratios $P(K_{\beta_2})/P(K_{\alpha_1})$ and $P(K_{\beta_1})/P(K_{\alpha_1})$ as given by Schönfeld and Janßen (1996). The relative probability of X_L radiation is calculated from the absolute value putting $P(K_{\alpha_1}) = 100$.

3.2 Auger Electrons

The energies are taken mainly from the report of Larkins (1977). The relative probabilities are calculated using the ratios $P(KLX)/P(KLL)$ and $P(KXY)/P(KLL)$ as given in the cited report of Schönfeld and Janßen (1995). The relative probability of e_{AL} electrons is calculated from the absolute value putting $P(KLL) = 100$.

4 Radiation Emission

4.1 Electron Emission

The numbers of Auger electrons per disintegration are calculated using the program EMISSION and the atomic data as given in Section 3. The numbers of conversion electrons per disintegration are calculated using the conversion coefficients and the probabilities $P_{\gamma+ce}$ as given in 2.2. Spectra of the conversion electrons from the 80,6 keV

transition, the 1379,4 keV transition and the $0^+ \rightarrow 0^+$ 1460 keV E0 transition were measured by Grigoriev et al. (1974). The data for the emission of β particles are those already given in 2.1.

4.2 Photon Emission

Most of the gamma-ray energies were taken from Ardisson et al. (1992) ($\gamma_{1,0}$, $\gamma_{4,3}$, $\gamma_{3,1}$, $\gamma_{3,0}$, $\gamma_{4,1}$, $\gamma_{5,0}$, $\gamma_{6,1}$, $\gamma_{6,0}$, $\gamma_{8,1}$, $\gamma_{7,0}$, $\gamma_{8,0}$).

The following measurements of relative photon emission probabilities have been taken into account (the relative emission probability of the 1379,4 keV line was arbitrarily set to 1):

E in keV	1	2	3	4	5	6	7
80,6	6,67(43)	-	7,04(30)	6,72(70)	7,22(8)	6,56(40)	7,02(14)
184,4	-	0,0022(5)	-	0,0013(3)	0,0023(1)	0,0010(1)	0,0016(7)
521,0	-	-	-	0,00032(11)	0,0005(2)	0,00038(1)	0,00038(2)
674,2	0,032(2)	0,022(2)	0,034(2)	0,0176(9)	0,023(1)	0,0201(4)**	0,0212(18)
705,4	0,020(3)	0,016(2)	0,023(1)	0,0137(7)	0,0170(10)	0,0144(3)**	0,0156(13)
785,9	0,016(3)	0,014(2)	0,012(5)	0,0125(7)	0,0140(10)	0,0128(3)**	0,01288(27)
1263,0	-	-	-	0,0015(2)	0,0017(1)	0,0016(3)	0,00166(9)
1379,4	1	1	1	1	1	1	1
1447,5	-	-	-	0,00105(10)	0,0012(1)	0,0014(5)	0,00113(10)
1528,2	-	-	-	0,0002	-	0,00010(1)	0,00015(5)
1581,8	0,206(10)	0,195(10)	0,215(10)*	0,197(7)	0,199(5)	0,197(5)	0,1994(28)
1662,4	0,129(7)	0,125(6)	0,099(5)*	0,130(5)	0,127(4)	0,130(2)**	0,126(5)
1731,5	-	-	-	-	-	0,00005(2)	0,00005(2)
1749,8	0,033(1)*	0,027(2)	0,030(17)	0,028(2)	0,028(1)	0,0285(6)**	0,0292(9)
1812,8	-	-	-	-	-	0,00006(2)	0,00006(2)
1830,5	0,0100(8)*	0,0086(11)	0,0081(5)	0,0089(5)	0,0085(2)	0,0089(3)	0,0087(2)

1 Burson et al. 1967

2 Reich and Cline 1970

3 Venkata Ramaniah et al. 1976

4 Allab et al. 1977

5 Chand et al. 1989

6 Ardisson et al. 1992

7 values adopted in this evaluation (LWM)

* classified as outlier (appearing only in values of references 1 and 3)

** input uncertainty slightly increased (only for some values of reference 6 and one value of reference 5)

Earlier results of Marklund et al. (1960), Hansen et al. (1961), Cline et al. (1962), Funke et al. (1963) and Neumann (1966) were not taken into account because they are less accurate, incomplete and given without uncertainties.

The absolute emission probability for the gamma rays from the transition $\gamma_{1,0}$ (80,6 keV) has been determined as follows (gamma rays per 100 disintegrations):

1	6,55(30)	Venkata Ramaniah et al. 1976
2	6,25(60)	Allab et al. 1977
3	6,60(40)	Sekine and Baba 1981
4	6,55(8)	Calhoun et al. 1991; Coursey et al. 1994

In the present evaluation value 4 is adopted. Combining it with the relative emission probability of the 80,6 keV transition, the normalization factor 0,933(16) is obtained.

5 Main Production Modes

Taken from Firestone (1995).

6 References

- M. G. Inghram and R. J. Hayden, *Phys. Rev.* 71 (1947) 130
[$T_{1/2}$]
- P. J. Grant and J. M. Hill, *Nature* 163 (1949) 524
[$T_{1/2}$]
- M. Antoneva, A. A. Bashilov, B. S. Dzhelepov, *Izv. Acad. Nauk SSSR* 14 (1950) 299
[$T_{1/2}$]
- J. M. Cork, M. K. Brice, R. G. Helmer, R. M. Woods Jr., *Phys. Rev.* (2) 110 (1958) 526
[$T_{1/2}$]
- D. C. Hoffman, *J. Inorg. Nucl. Chem.* 25 (1963) 1196
[$T_{1/2}$]
- M. K. Ramaswamy and S. M. Brahmavar, *Curr. Sci.* (India) 32 (1963) 451
[α_K]
- W. H. Brantley, A. R. Polderman and W. H. G. Lewin, *Bull. Amer. Phys. Soc.* 11 (1966) 824
[α_4]
- H. A. Neumann, *Z. Naturforschg.* 21a (1966) 1328
[P_γ]
- P. Erman, G. T. Emery and M. L. Perlman, *Phys. Rev.* 147 (1966) 858
[$L_1/L_2/L_3$]
- W. Gelletly, J. S. Geiger and R. L. Graham, *Bull. Amer. Phys. Soc.* 11 (1966) 352
[$L_1/L_2/L_3$]
- S. E. Karlsson, I. Andersson, O. Nilsson, G. Malmsten, C. Nordling and K. Siegbahn, *Nucl. Phys.* 89(1966) 513
[$L_1/L_2/L_3$]
- J. Zylicz, M. H. Jorgensen, O. B. Nielsen and O. Skilbreid, *Nucl. Phys.* 81 (1966) 88
[K/L/M]
- M. Arnoux and A. Gizon, *Compt. Rend. Acad. Sci.* (Paris) 264 (1967) 1518
[L/M]
- W. Gelletly, J. S. Geiger and R. L. Graham, *Phys. Rev.* 157 (1967) 1043
[L/M]
- J. A. Bearden, *Rev. Mod. Phys.* 39 (1967) 78
[E(KX)]
- M. Bogdanovic, M. Mladjenovic and R. Stepic, *Z. Phys.* 216 (1968) 267
[K/L]
- M. Bogdanovic, M. Mladjenovic and R. Stepic, *Nucl. Phys.* A106 (1968) 209
[K/L]
- E. Falkstroem, S. Nilsson and S. Boreving, *Ark. Phys.* 39 (1968) 1
[α_K]
- S. Hoegberg, J. E. Bergmark, G. Malmsten and O. Nilsson, *Nucl. Phys.* A120 (1968) 569
[$M_1/M_2/M_3/M_4/M_5$]
- O. Nilsson, I. Thoren, G. Malmsten and S. Hoegberg, *Nucl. Phys.* A120 (1968) 561
[K/L]
- G. C. Nelson and E. N. Hatch, *Nucl. Phys.* A127 (1969) 560
[α_K]
- J. L. Campbell, J. J. Smith and I. K. MacKenzie, *Nucl. Instr. Meth.* 92 (1971) 237
[α_K]
- J. L. Campbell, R. J. Goble and J. J. Smith, *Radioactivity in Nuc. Spec.* J. H. Amilton and J. C. Manthuruthil (eds.) Gordon and Breach, New York (1972) p. 1387
[α_K]
- O. Dragoun, B. Martin, D. Merkert and M. Vinduska, *Nucl. Phys.* A183 (1972) 390
[$N_1/N_2/N_3/N_4/N_5$]
- F. P. Larkins *Atomic Data and Nuclear Data Tables* 20 (1977) 313
[E(KLL), E(KLX)]
- V. V. Bulgakov, V. I. Gavriyuk, A. A. Klyuchnikov, A. P. Lasko, P. N. Muzalev, N. V. Strelchuk, A. I. Feokistov and Y. E. Frantsev, *Summaries of the 30. Conf. Nucl. Spectr. and Struct.*, Samarkand, (1981) p. 293
[L/M/N]
- R. B. Firestone and V. S. Shirley, *Table of Isotopes*, Wiley, New York, 1996
[Production modes]

Other references can be found in the Tables Part.

¹⁶⁶Ho^m - Comments on evaluation of decay data by E. Schönfeld, R. Dersch

1 Decay Scheme

The decay scheme was taken from Ardisson *et al.* 1992. It contains 54 gamma transitions between 17 excited levels of ¹⁶⁶Er or to the ground state of this nuclide. This decay scheme is not complete. 12 additional gamma rays have been reported, six of them from branching in Tm-166 EC decay (see 2.2).

The half-lives of the excited level in ¹⁶⁶Er indicated in the decay scheme are taken from Shursikow and Timofeeva (1992).

2 Nuclear Data

The half-life was determined by Faler (1965) to be 1200 a. The uncertainty was estimated to be 180 a. New measurements are desirable. The Q-value is 6,0 keV above Q(¹⁶⁶Ho). This is the energy difference between the isomer level and the ground state of ¹⁶⁶Ho. The Q-value of ¹⁶⁶Ho was derived from β-ray endpoint energies to be 1854,5(9) keV. Thus, the Q-value of ¹⁶⁶Ho^m is 1860,5(9) keV.

2.1 β⁻ Transitions

There are seven β transitions to excited levels of ¹⁶⁶Er. The most important transitions are the allowed transitions to levels no. 17 and 16 (17,2(4) % and 74,8(12) %). Weak transitions are feeding the levels 11, 10, 9, 6 and 3. Transitions to the levels 15, 14, 13, 12, 8, 7, 5, 4, 2, 1 and the ground state (ΔJ₀ = 7) have not been observed. All these transitions are at least second forbidden except a transition to level 8 which is unique first forbidden.

The energies of these transitions were calculated by subtracting the level energy from the Q-value. The transition probabilities P_β were calculated from the transition probabilities P_{γ+ec} using the relations which correspond to the decay scheme.

2.2 Gamma transitions

The level differences are equal to the gamma-ray energies as the recoil energies are small compared with the uncertainties of the latter. The gamma-ray energy of the 80,6 keV emission has been determined as follows (energy in keV):

1	80,573	Reich and Cline 1970
2	80,589(5)	Morii et al. 1975 .
3	80,572(15)	Souch et al. 1982
4	80,585(15)	Adam et al. 1988
5	80,574(8)	Hardell and Nilsson 1962; cryst.-spektr.
6	80,5725(13)	Helmer and van der Leun 2000; here also adopted

The energies of gamma transitions between the levels 0, 1, 2, 3, 5, 6, 7, 8, 9, 10 and the transitions γ_{16,5} and γ_{17,3} are taken from Helmer and van der Leun (2000). The energies of all other transitions are either taken from Ardisson *et al.* (1992) or based on values given by these authors.

The probabilities $P_{\gamma+ce}$ were calculated from the gamma-ray emission probabilities P_{γ} using the values for the total conversion coefficients α_t . The conversion coefficients α_K , α_L and α_t were interpolated from the tables of Rösler *et al.* (1978). The normalization factor which is necessary to convert relative emission probabilities (related to 100 for the 184 keV gamma rays) can be calculated from balancing conditions using cuts between the levels 0 and 1, 1 and 2, 2 and 3. This is possible because the levels 2, 1 and 0 (the ground state) are not populated by β transitions. The cut between the levels 0 and 1 contains the emission probability of the 80,6 keV gamma transition. The conversion coefficient of this transition has a relatively large uncertainty, the calculation of the normalization factor from the cuts 1-2 and 2-3 is therefore preferred here. Moreover, the normalization factor was determined using absolute activity measurements:

1	0,732(37)	Reich and Cline, 1970
2	0,699(14)	Danilenko et al., 1989
3	0,7258(22)	Miyahara et al., 1994
4	0,7021(35)	Morel et al., 1996
5	0,7235(67)	Hino et al., preliminary value, 1999
6	0,7214(72)	from cut between levels 1 and 2, this evaluation 1999
7	0,7298(75)	from cut between levels 2 and 3, this evaluation 1999
8	0,725(3)	adopted value

The value 8 is the LWM between values 1, 3, 5, 6 and 7 where the uncertainty of value 3 has been doubled in order to contribute less than 50 % to the mean. Values 2 and 4 are considered to be significantly too low by the evaluator and were not included in the averaging procedure. The reduced χ^2 of the LWM is 0,2. The adopted value of the normalization factor is in excellent agreement with the value 0,726(9) evaluated by Shursikow and Timofeeva (1992).

The K-conversion coefficients were calculated using the tables of Rösler *et al.* (1978). The multiplicities of the transitions were determined from the spin and parity assignments as made by Ardisson *et al.* (1992) and Shursikow and Timofeeva (1992). There is reasonable agreement between measured and calculated conversion coefficient for the 80,6 keV transition:

1	1,76(15)	Marklund et al. 1960
2	1,72(6)	Nelson and Hatch 1969
3	1,69(6)	Campbell et al. 1971
4	1,65(3)	E2 Theory, Rösler et al. 1978

The following gamma rays are not included in the decay scheme and in the tables 2.2 and 4.2:

E_{γ} in keV	P_{rel} (related to 100 for the 184,4 keV line)	
96,85(5)	0,00307	*
170,31(3)	0,0184(11)	*
255,20(12)	0,0059(13)	
410,80(5)	0,0231(7)	*
520,945(15)	0,00039(7)	*
617,0(5)	0,031(9)	
712,89(13)	0,41(12)	*
736,02(8)	0,19(2)	
1446,72(13)	< 0,01	
1521,99(4)	0,018(5)	
1562,57(4)	0,0040(11)	

* Deduced from branching in Tm-166 EC decay where also the 73 keV transition, contained in Table 2, occurs. These data are taken from Shursikow and Timofeeva (1992), see also Adam *et al.* (1979).

For several transitions, mixing ratios were determined from γ - γ angular correlation measurements. Most of them are compiled in the following table:

E2-M1 mixing ratios for γ -transitions in ¹⁶⁶Er following the decay of ¹⁶⁶Ho^m

E_r in keV	d	d (adopted)	% M1
119,0	$\pm 1,79(12)[1]$ $1,75(12)[2]$	1,79(12)	24(2)
140,7	$\pm 1,43(10)[1]$ $1,67(11)[2]$	1,43(10)	33(3)
160,1	$1,45(11)[1]$	1,45(11)	32(4)
464,8	$-(3,1+1,5-0,9)[3]$ $-80<\delta<+30[4]$ $-(32+98-14)[5]$ $-(63+19-12)[6]$	-50(20)	(0,04+0,07-0,02)
529,8	$-(85+8-45)[7]$ $-25(3)[4]$ $-5,0(25)[3]$ $-(25+5-4)[5]$ $-(62+40-17)[8]$ $-(60+45-19)[8]$	-30(20)	(0,11+0,9-0,07)
594,1	$-(9+319-5)[4]$ $(9+8-5)[5]$ $-(12+29-5)[8]$ $-(8+15-3)[8]$ $-(59+74-21)[2]$	-10(5)	(1+3-0,5)
644,5	$|\delta|>2[4]$ $+1,6+1,0-0,55[3]$ $-0,75(20)[3]$ $<-1 \text{ or } >+4[8]$ $-(13,4+3,3-2,2)[2]$	3-2+3	(10+40-7)
670,5	$6,3+8-2,9[3]$ $-(1,15+0,80-0,35)[3]$ $-(20+90-9)[4, 5]$ $(10,0+1,6-1,2)[8]$ $9,4+2,9-1,6[8]$ $(19+5-3)[2]$	12(5)	(0,69+1,31-0,35)
691,3	$3,3+3,0-1,2[9]$ $-(10+27-4)[4]$ $-(16+27-4)[5]$ $-(28+7-5)[2]$ $-(16+8-9)[8]$ $-(16+8-10)[8]$	-16(8)	(0,39-0,22+1,15)
705,2	$|\delta|=25[10]$ $38+8-24[9]$ $19+38-9[9]$ $-(55+13-9)[2]$	50(10)	(0,04+0,02-0,01)
778,8	$-(20+8-13)[3]$ $-(18+8-9)[4]$ $-(19+8-10)[5]$ $-(20+4-2)[8]$ $-(18+8-5)[8]$ $-(109+26-17)[2]$	18(6)	(0,31+0,35-0,14)
810,3	$37+10-7[7]$ $-16,4+3,2-2,3[11]$ $-20(4)[4]$ $-(84+8-57)[3]$ $-(20+4-3)[5]$ $-(36+11-7)[6]$ $-21(2)[8]$ $-15(1)[8]$	25(5)	(0,16+0,09-0,05)
830,6	$70+260-30[7]$ $-(42+25-13)[11]$ $-(22+7-5)[4,5]$ $-(37+8-17)[3]$ $-(18+3-2)[6]$ $-23(4)[8]$ $-(16,6+1,8-1,5)[8]$ $-(15,3+2,3-1,7)[2]$	-18(3-2)	0,31(8)

- [1] Wagner 1992, measured
- [2] Wagner 1992, calculated
- [3] West et al. 1976
- [4] Baker et al. 1975
- [5] Lange et al. 1981
- [6] Alzner et al. 1985
- [7] Reich and Cline 1965
- [8] Krane and Moses 1981
- [9] Domingos et al. 1972
- [10] McGowan et al. 1978
- [11] Miyokawa et al. 1972 as cited in the paper of Krane and Moses 1981

Some of the measurements are discrepant. However, the influence of the results on the conversion coefficients is in most cases small. Gerdau et al. (1963) determined some mixing ratios from γ - γ -angular correlations. Some of them deviate from the results of later publications (411 keV 95 % E1 + 5 % M2; 712 keV 99,6 % E1 + 0,4 % M2; 810 keV 99,1 % E2 + 0,9 % M1; 831 keV 96,1 % E2 + 3,9 % M1).

If two multiplicities are mentioned in Table 2.2, then the mixing ratio was taken into account when calculating the conversion coefficients. If a second multiplicity is given in brackets, then the conversion coefficients are calculated for the first multiplicity but an admixture of the second multiplicity is not ruled out.

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiations

The energies are based on the wavelengths of Bearden (1967). The relative probabilities are taken from Schönfeld and Janßen (1996). The relative probability of the L X rays is calculated from the absolute value (Table 4) setting $P(K_{\alpha 1}) = 1$.

3.2 Auger electrons

The energies are taken mainly from Larkins (1977). The relative probabilities are taken from Schönfeld and Janßen (1996). The relative probability of the L Auger electrons is calculated from the absolute value (Table 4) setting $P(KLL) = 1$.

4 Radiation Emissions

4.1 Electron Emissions

The energies of the Auger electrons are the same as in 3.2. The energies of the conversion electrons are calculated from the transition energy (2.2) and the binding energies. The emission probabilities of the Auger electrons are calculated from P_{γ} 's and conversion coefficients using the program EMISSION (PTB, 1997).

The emission probabilities of the conversion electrons are calculated using the conversion coefficients given in Table 2.2, the atomic data given in Section 3, and the emission probabilities of the gamma rays given in Table 4.2.

4.2 Photon Emissions

The energies of the X rays are the same as in Table 3.1. Measured KX-ray emission probabilities (Chand *et al.* 1988, Morel *et al.* 1996) are in good agreement with the calculated values. If the measured values are related to the here adopted emission probability of the 184-keV gamma rays, the following values are obtained (quanta per 100 disintegrations):

	E in keV	P_X (Chand)	P_X (Morel)	P_X (calc)
Er $K_{\alpha 2}$	48,221	10,95(23)	10,63(8)	10,81(21)
Er $K_{\alpha 1}$	49,128	18,4(3)	19,17(13)	19,2(4)
Er $K'_{\beta 1}$	55,624	5,70(9)	6,03(5)	6,24(14)
Er $K'_{\beta 2}$	57,239	1,41(3)	1,594(20)	1,62(5)

The calculated emission probabilities of the X-rays (calculated from P_{γ} 's and conversion coefficients using the program EMISSION (PTB, 1997)) are compiled in the last column.

The energies of the gamma rays are taken either from Helmer and van der Leun (2000) or from Ardisson *et al.* (1992) (see Sect. 2.2). Their uncertainties are to be considered as standard uncertainties.

The relative emission probabilities of gamma rays (related to 100 for the emission probabilities of the 184,4 keV transition $\gamma_{2,1}$) as measured by 17 authors are compiled in the following table. The last column in this table contains the LWM except of $\gamma_{1,0}$ where balance conditions are taken into account. The transition probability of the transition $\gamma_{1,0}$ is very well known as there is only one other transition to the ground state which is very weak ($\gamma_{4,0}$):

$$f_N [P_{\text{rel}}(\gamma_{1,0}) (1 + \alpha_t) + P_{\text{rel}}(\gamma_{4,0}) (1 + \alpha_t)] = 100$$

The conversion coefficient is, of course, to put for the assigned gamma transition. This yields for the transition $\gamma_{1,0}$

$$P_{g^{+ce}} = 100 - f_N P_{\text{rel}}(\gamma_{4,0}) (1 + \alpha_t)$$

$$\text{With } f_N = 0,725(3), P_{\text{rel}}(\gamma_{4,0}) = 0,026(5), \alpha_t(\gamma_{4,0}) = 0,00566(12)$$

we obtain :

$P_{g^{+ce}}(\gamma_{1,0}) = 99,981(4)$ per 100 disintegrations. With the conversion coefficient of the transition $\gamma_{1,0}$ this yields:

$$P_\gamma(\gamma_{1,0}) = 12,66(23) \text{ per 100 disintegrations, in relative units: } 17,46(31).$$

Gamma relative emission intensities, references 1 to 6 :

$g_{i,r}$	E_g (keV)	1	2	3	4	5	6
$\gamma_{1,0}$	80,577(7)	14,5(29)	14,55(47)	17,1(9)	14,48(48)	16,83(42)	16,7(10)
$\gamma_{16,15}$	94,679(9)	0,16(3) ¹⁾	-	0,19(1)	0,3	0,21(3)	-
$\gamma_{8,7}$	119,035(10)	-	-	0,24(3)	-	0,23(3)	-
$\gamma_{16,14}$	121,175(10)	0,7(5) ¹⁾	-	0,36(5)	0,78(18) ¹⁾	0,54(5) ¹⁾	-
$\gamma_{17,15}$	135,257(14)	0,1(1)	-	0,14(2)	-	-	-
$\gamma_{9,8}$	140,702(20)	-	-	0,059(14)	-	-	-
$\gamma_{10,9}$	160,077(20)	0,35(10)	-	0,134(16)	0,36(15) ¹⁾	0,16(3)	-
$\gamma_{17,14}$	161,707(14)	-	-	0,15(2)	-	0,16(3)	-
$\gamma_{3,2}$	184,404(7)	100	100	100	100	100	100
$\gamma_{16,13}$	190,747(16)	-	-	0,30(3)	-	0,31(4)	-
$\gamma_{16,12}$	214,79(3)	-	-	0,75(10) ¹⁾	-	-	-
$\gamma_{8,5}$	215,871(10)	3,8(4)	4,15(7)	3,6(4)	3,94(9)	3,96(8)	4,1(2) ²⁾
$\gamma_{17,12}$	231,32(4)	0,3(2)	0,32(5)	0,33(4)	0,36(3) ¹⁾	0,31(4)	-
$\gamma_{9,7}$	259,70(3)	1,8(5) ¹⁾	1,42(10)	1,50(11)	1,77(12) ¹⁾	1,52(5)	-
$\gamma_{9,2}$	280,468(7)	39,5(28)	43,6(6) ¹⁾	40,7(29)	38,61(46)	39,63(126)	40,2(18)
$\gamma_{10,9}$	300,731(9)	4,8(4)	5,45(8)	5,12(37)	4,77(9)	4,92(12)	4,97(22)
$\gamma_{9,6}$	305,03(5)	-	-	-	-	-	-
$\gamma_{11,9}$	339,75(5)	-	-	0,23(3)	-	0,23(4)	-
$\gamma_{6,3}$	365,736(9)	2,9(3) ¹⁾	3,72(8)	3,44(25)	2,93(6)	3,25(10)	3,30(11)
$\gamma_{16,10}$	410,950(8)	15,8(12)	16,8(3) ¹⁾	15,8(12)	15,50(19)	14,77(30)	15,27(50)
$\gamma_{17,10}$	451,528(9)	3,5(7)	4,30(9)	4,18(30)	3,48(7) ¹⁾	3,84(13)	3,99(13)
$\gamma_{10,6}$	464,819(12)	2,0(4)	1,66(8)	1,68(14)	2,00(7)	1,50(8)	-
$\gamma_{15,9}$	476,38(6)	0,4(2) ¹⁾	-	-	-	-	-
$\gamma_{12,8}$	496,86(4)	-	-	-	-	-	-
$\gamma_{4,2}$	520,85(5)	-	-	-	-	-	-
$\gamma_{8,3}$	529,811(10)	10,3(10) ¹⁾	13,00(42)	13,9(10)	10,16(32) ¹⁾	12,36(25)	12,78(42)
$\gamma_{16,9}$	570,940(10)	6,8(7)	7,08(16)	7,86(56)	6,77(14)	7,04(14)	7,45(24)
$\gamma_{5,2}$	594,536(24)	1,2(4) ¹⁾	0,74(10)	0,96(8) ¹⁾	1,28(18) ¹⁾	0,70(5)	-
$\gamma_{17,9}$	611,620(17)	1,4(10)	1,59(32)	1,90(15)	1,48(27)	1,67(9)	-
$\gamma_{11,7}$	615,84(9)	-	-	-	-	-	-
$\gamma_{13,7}$	639,97(9)	-	-	0,22(7) ¹⁾	-	-	-
$\gamma_{11,6}$	644,689(15)	0,27(15)	0,31(105) ¹⁾	0,25(3)	-	-	-
$\gamma_{9,3}$	670,565(12)	7,0(7)	7,35(30)	7,88(56)	7,01(25)	6,98(16)	7,37(24)
$\gamma_{7,2}$	691,304(12)	1,9(4)	1,62(8)	2,09(15) ¹⁾	1,85(9)	1,60(10) ¹⁾	1,800(59)
$\gamma_{4,1}$	705,09(7)	-	-	-	-	-	-
$\gamma_{16,8}$	711,680(8)	72,5(60)	71,5(10)	80,2(57) ¹⁾	71,65(68)	71,10(142)	74,5(25)
$\gamma_{13,5}$	736,70(7)	0,45(15)	0,50(5)	0,14(5) ¹⁾	0,46(4)	0,45(5)	-
$\gamma_{17,8}$	752,332(10)	16,1(12)	15,20(34) ¹⁾	17,9(13)	16,06(40)	15,98(32)	16,57(54)
$\gamma_{8,1}$	778,862(12)	3,8(3)	3,88(7)	4,51(33)	3,72(7)	4,16(12)	4,13(13)
$\gamma_{4,0}$	785,81(7)	-	-	-	-	-	-
$\gamma_{8,2}$	810,325(10)	76(8)	76,40(110)	85,7(61) ¹⁾	76,38(82)	75,71(151)	78,1(28)
$\gamma_{10,3}$	830,601(15)	12,5(10)	12,90(32)	14,5(11)	12,07(28)	12,83(26)	13,26(44)
$\gamma_{7,1}$	875,63(5)	1,15(15)	0,91(4)	1,08(10)	1,14(7)	1,00(9)	0,979(32)
$\gamma_{9,2}$	950,963(10)	3,6(6)	3,16(13) ¹⁾	4,15(30) ¹⁾	3,50(14) ¹⁾	3,74(16)	3,68(12)
$\gamma_{11,3}$	1010,27(6)	-	0,11(340)	0,12(2)	-	-	-
$\gamma_{14,3}$	1120,35(5)	-	0,26(2)	0,31(3)	0,30	-	-
$\gamma_{15,3}$	1146,81(9)	0,38(6) ¹⁾	0,26(2)	0,30(3)	0,38(5) ¹⁾	-	0,274(9)
$\gamma_{16,3}$	1241,52(2)	1,25(25)	1,06(4)	1,37(10) ¹⁾	1,22(5)	1,17(12)	1,098(37)
$\gamma_{17,3}$	1282,06(6)	0,80(15) ¹⁾	0,22(2)	0,31(3)	0,38(4) ¹⁾	0,24(5)	0,241(8)
$\gamma_{12,2}$	1306,60(15)	-	-	-	-	-	-
$\gamma_{13,2}$	1331,04(13)	-	-	-	-	-	-
$\gamma_{14,2}$	1400,79(2)	0,93(9) ¹⁾	0,72(2)	0,75(6)	0,86(5) ¹⁾	-	0,670(22)
$\gamma_{15,2}$	1427,24(2)	0,69(7)	0,69(2)	0,81(6) ¹⁾	0,65(3)	-	0,665(23)
-	1446,7(2)	-	-	-	-	-	-

Gamma relative emission intensities, references 7 to 12 :

$g_{i,f}$	E_g (keV)	7	8	9	10	11	12
$\gamma_{1,0}$	80,577(7)	17,51(61)	16,56(8)	17,8(4)	16,97(13)	17,2(8)	16,59(39)
$\gamma_{16,15}$	94,679(9)	0,221(12)	-	0,22(1)	0,20(1)	0,190(26)	-
$\gamma_{8,7}$	119,035(10)	0,222(12)	-	0,27(2) ¹⁾	0,24(1)	0,243(13)	-
$\gamma_{16,14}$	121,175(10)	0,337(15)	-	0,45(2) ¹⁾	0,35(2)	0,346(14)	-
$\gamma_{17,15}$	135,257(14)	0,126(10)	-	0,14(1)	0,14(1)	0,128(6)	-
$\gamma_{9,8}$	140,702(20)	0,059(9)	-	0,06(1)	0,07(1)	0,060(4)	-
$\gamma_{10,9}$	160,077(20)	0,109(8)	-	0,14(1)	0,14(2)	0,124(4)	-
$\gamma_{17,14}$	161,707(14)	0,135(8)	-	0,15(1)	0,15(2)	0,140(7)	-
$\gamma_{3,2}$	184,404(7)	100	100	100	100	100	100
$\gamma_{16,13}$	190,747(16)	0,304(15)	-	0,31(1)	0,33(2)	0,291(10)	-
$\gamma_{16,12}$	214,79(3)	0,586(23)	-	0,61(2)	0,61(2)	-	0,60(5)
$\gamma_{8,5}$	215,871(10)	3,54(13)	4,04(4)	3,67(9)	3,60(13)	4,14(17) ²⁾	3,61(13)
$\gamma_{17,12}$	231,32(4)	0,284(15)	-	0,30(1)	0,33(3)	0,289(11)	0,263(20)
$\gamma_{9,7}$	259,70(3)	1,446(52)	-	1,53(3)	1,52(3)	1,47(5)	1,50(5)
$\gamma_{9,2}$	280,468(7)	40,79(141)	41,26(28)	41,0(5)	40,6(5)	40,4(15)	40,9(8)
$\gamma_{10,9}$	300,731(9)	5,12(18)	5,22(4)	5,17(8)	5,11(8)	5,04(19)	5,13(10)
$\gamma_{9,6}$	305,03(5)	-	-	-	0,023(3)	0,030(3)	-
$\gamma_{11,9}$	339,75(5)	0,234(16)	-	0,21(1)	0,21(3)	0,222(8)	-
$\gamma_{6,3}$	365,736(9)	3,327(117)	3,30(3)	3,49(6)	3,46(6)	3,33(12)	3,44(7)
$\gamma_{16,10}$	410,950(8)	15,25(53)	15,65(10)	15,9(2)	15,5(4)	15,3(5)	15,93(28)
$\gamma_{17,10}$	451,528(9)	4,02(15)	3,85(5)	4,17(5)	4,04(11)	4,00(14)	4,12(9)
$\gamma_{10,6}$	464,819(12)	1,651(61)	-	1,67(3)	1,73(7)	1,59(5)	1,69(6)
$\gamma_{15,9}$	476,38(6)	-	-	-	0,052(6)	0,050(3)	-
$\gamma_{12,8}$	496,86(4)	-	-	0,18(3)	0,17(1)	0,170(6)	-
$\gamma_{4,2}$	520,85(5)	-	-	0,22(3)	0,21(1)	0,20(3)	0,240(24) ¹⁾
$\gamma_{8,3}$	529,811(10)	13,10(45)	12,48(10)	13,3(2)	13,18(34)	12,83(39)	13,46(26)
$\gamma_{16,9}$	570,940(10)	7,53(27)	7,22(6)	7,65(9)	7,64(20)	7,42(24)	7,81(15)
$\gamma_{5,2}$	594,536(24)	0,773(34)	-	0,77(2)	0,80(9)	0,769(24)	0,80(4)
$\gamma_{17,9}$	611,620(17)	1,951(72)	-	1,86(4)	1,86(12)	1,85(7)	1,95(11)
$\gamma_{11,7}$	615,84(9)	-	-	-	0,044(13)	0,163(8)	-
$\gamma_{13,7}$	639,97(9)	0,122(16)	-	0,12(1)	0,11(1)	0,124(6)	-
$\gamma_{11,6}$	644,689(15)	0,213(19)	-	0,19(1)	0,23(6)	0,186(6)	-
$\gamma_{9,3}$	670,565(12)	7,37(26)	7,28(6)	7,53(9)	7,16(20)	7,32(22)	7,60(14)
$\gamma_{7,2}$	691,304(12)	1,871(69)	-	1,87(4)	1,86(9)	1,79(6)	1,84(5)
$\gamma_{4,1}$	705,09(7)	-	-	-	0,011(1)	0,025(15)	-
$\gamma_{16,8}$	711,680(8)	74,48(258)	72,37(39)	75,7(8)	75,33(177)	73,8(32)	76,4(14)
$\gamma_{13,5}$	736,70(7)	0,506(26)	-	0,51(2)	0,50(4)	0,530(18)	0,547(23)
$\gamma_{17,8}$	752,332(10)	16,57(56)	16,26(12)	17,0(2)	17,08(43)	16,5(5)	16,98(33)
$\gamma_{8,1}$	778,862(12)	4,17(15)	4,00(3)	4,25(6)	4,22(14)	4,13(13)	4,27(8)
$\gamma_{4,0}$	785,81(7)	-	-	-	0,019(4)	0,023(3)	-
$\gamma_{8,2}$	810,325(10)	78,66(273)	76,94(44)	80,1(8)	79,31(177)	78,2(26)	80,3(12)
$\gamma_{10,3}$	830,601(15)	13,34(47)	12,99(10)	13,5(2)	13,51(35)	13,3(4)	13,62(26)
$\gamma_{7,1}$	875,63(5)	0,993(35)	-	0,99(4)	1,00(5)	0,987(31)	1,002(25)
$\gamma_{9,2}$	950,963(10)	3,71(14)	3,65(4)	3,89(6)	3,87(12)	3,74(12)	3,85(8)
$\gamma_{11,3}$	1010,27(6)	0,096(8) ¹⁾	-	0,11(1)	0,13(3) ¹⁾	0,107(4)	-
$\gamma_{14,3}$	1120,35(5)	0,327(15) ¹⁾	-	0,35(1) ¹⁾	0,28(5)	0,268(8)	-
$\gamma_{15,3}$	1146,81(9)	0,271(14)	-	0,30(1)	0,29(4)	0,279(9)	0,281(26)
$\gamma_{16,3}$	1241,52(2)	1,142(41)	-	1,21(4)	1,21(6)	1,118(34)	1,12(4)
$\gamma_{17,3}$	1282,06(6)	0,246(13)	-	0,29(1)	0,28(4)	0,240(11)	0,271(19)
$\gamma_{12,2}$	1306,60(15)	-	-	-	0,010(2)	0,0044(4)	-
$\gamma_{13,2}$	1331,04(13)	-	-	-	0,010(1)	0,0051(6)	-
$\gamma_{14,2}$	1400,79(2)	0,686(25)	-	0,74(2)	0,76(4)	0,672(21)	0,720(27)
$\gamma_{15,2}$	1427,24(2)	0,667(25)	-	0,72(2)	0,77(4) ¹⁾	0,673(22)	0,708(21)
-	1446,7(2)	-	-	-	<0,01	<0,0006	-

Gamma relative emission intensities, references 13 to 17 :

$g_{i,f}$	$E_g(\text{keV})$	13	14	15	16	17	18
$\gamma_{1,0}$	80,577(7)	17,00(22)	16,7(5)	17;6(4)	16,050(120)	17,18(15)	17,46(31)
$\gamma_{16,15}$	94,679(9)	0,208(10)	0,198(5)	0,23(3)	-	0,1977(50)	0,202(5)
$\gamma_{8,7}$	119,035(10)	-	0,236(7)	0,23(3)	-	0,2384(72)	0,238(4)
$\gamma_{16,14}$	121,175(10)	0,307(11)	0,326(9)	0,38(3)	-	0,343(9)	0,333(9)
$\gamma_{17,15}$	135,257(14)	-	0,1358(35)	0,15(3)	-	0,142(9)	0,1350(25)
$\gamma_{9,8}$	140,702(20)	-	0,0584(19)	0,07(1)	-	0,051(7)	0,059(3)
$\gamma_{10,9}$	160,077(20)	0,153(7)	0,139(3)	0,14(3)	-	0,140(11)	0,134(5)
$\gamma_{17,14}$	161,707(14)	-	0,160(5)	0,15(3)	-	0,1580(80)	0,151(5)
$\gamma_{3,2}$	184,404(7)	100	100	100	100	100	100
$\gamma_{16,13}$	190,747(16)	-	0,273(8) ¹⁾	0,31(3)	-	0,3010(62)	0,296(6)
$\gamma_{16,12}$	214,79(3)	-	0,671(17)	0,61(4)	-	0,600(10)	0,614(14)
$\gamma_{8,5}$	215,871(10)	3,594(37)	3,60(9)	3,49(14)	3,447(26)	3,566(85)	3,67(24)
$\gamma_{17,12}$	231,32(4)	0,283(6)	0,260(7)	0,30(4)	-	0,2933(55)	0,302(8)
$\gamma_{9,7}$	259,70(3)	1,529(34)	1,507(34)	1,45(5)	1,434(25)	1,480(12)	1,487(9)
$\gamma_{9,2}$	280,468(7)	41,41(51)	41,8(9)	39,8(9)	40,634(167)	40,66(29)	40,75(21)
$\gamma_{10,9}$	300,731(9)	5,339(58)	5,29(12)	4,98(13)	5,079(39)	5,118(36)	5,15(4)
$\gamma_{9,6}$	305,03(5)	-	0,020(10)	0,023(3)	-	0,026(6)	0,0252(16)
$\gamma_{11,9}$	339,75(5)	-	0,221(6)	0,22(3)	-	0,2250(36)	0,2229(27)
$\gamma_{6,3}$	365,736(9)	3,589(45)	3,51(9)	3,34(9)	3,439(47)	3,404(24)	3,39(4)
$\gamma_{16,10}$	410,950(8)	16,49(19)	16,02(36)	15,0(4)	15,424(74)	15,81(11)	15,65(22)
$\gamma_{17,10}$	451,528(9)	4,235(60)	4,11(10)	3,89(13)	4,023(30)	4,062(42)	4,02(5)
$\gamma_{10,6}$	464,819(12)	1,729(35)	1,73(4)	1,66(7)	2,027(31)	1,665(19)	1,73(6)
$\gamma_{15,9}$	476,38(6)	-	0,0494(26)	0,052(7)	-	-	0,0500(18)
$\gamma_{12,8}$	496,86(4)	-	0,175(4)	0,17(3)	-	0,174(16)	0,173(4)
$\gamma_{4,2}$	520,85(5)	-	0,276(14) ¹⁾	0,21(3)	-	0,212(13)	0,211(8)
$\gamma_{8,3}$	529,811(10)	13,19(15)	-	12,6(4)	13,380(126)	13,33(10)	13,0(6)
$\gamma_{16,9}$	570,940(10)	7,964(91)	-	7,27(23)	7,505(71)	7,71(6)	7,49(27)
$\gamma_{5,2}$	594,536(24)	0,761(22)	-	0,78(7)	-	0,880(20)	0,80(8)
$\gamma_{17,9}$	611,620(17)	2,097(26)	-	1,86(11)	1,952(60)	1,911(36)	1,81(29)
$\gamma_{11,7}$	615,84(9)	-	0,138(11)	0,044(13)	-	0,160(10)	0,13(4)
$\gamma_{13,7}$	639,97(9)	-	0,137(4)	0,11(2)	-	0,138(9)	0,130(4)
$\gamma_{11,6}$	644,689(15)	-	0,206(5)	0,21(4)	-	0,189(12)	0,198(5)
$\gamma_{9,3}$	670,565(12)	7,718(84)	-	6,98(22)	7,618(45)	7,56(6)	7,36(28)
$\gamma_{7,2}$	691,304(12)	1,872(40)	-	1,78(9)	1,914(17)	1,862(21)	1,82(10)
$\gamma_{4,1}$	705,09(7)	-	0,0272(7)	0,011(2)	-	-	0,019(9)
$\gamma_{16,8}$	711,680(8)	77,51(62)	-	72,0(19)	76,30(35)	76,3(6)	75,7(16)
$\gamma_{13,5}$	736,70(7)	0,510(12)	-	0,49(4)	-	0,524(16)	0,514(7)
$\gamma_{17,8}$	752,332(10)	17,16(14)	-	16,2(5)	16,973(84)	16,98(12)	16,8(4)
$\gamma_{8,1}$	778,862(12)	4,279(56)	-	4,04(14)	4,257(28)	4,242(33)	4,15(11)
$\gamma_{4,0}$	785,81(7)	-	0,0312(11)	0,019(4)	-	-	0,026(5)
$\gamma_{8,2}$	810,325(10)	80,81(59)	-	76,1(20)	80,52(38)	80,3(6)	79,1(14)
$\gamma_{10,3}$	830,601(15)	13,87(18)	-	12,9(4)	13,639(79)	13,64(10)	13,41(23)
$\gamma_{7,1}$	875,63(5)	1,003(21)	-	0,97(6)	-	0,501(9) ¹⁾	0,994(11)
$\gamma_{9,2}$	950,963(10)	3,898(48)	-	3,68(12)	3,789(25)	3,793(30)	3,785(21)
$\gamma_{11,3}$	1010,27(6)	-	0,1113(28)	0,11(2)	-	0,107(6)	0,1095(21)
$\gamma_{14,3}$	1120,35(5)	-	0,281(8)	0,28(3)	-	0,278(10)	0,275(5)
$\gamma_{15,3}$	1146,81(9)	0,290(6)	0,289(8)	0,27(3)	-	0,279(6)	0,284(3)
$\gamma_{16,3}$	1241,52(2)	1,211(10)	-	1,14(5)	-	1,121(14)	1,17(4)
$\gamma_{17,3}$	1282,06(6)	0,268(12)	0,263(7)	0,27(3)	-	0,2434(30)	0,252(9)
$\gamma_{12,2}$	1306,60(15)	-	0,00610(3)	0,010(2)	-	-	0,0076(15)
$\gamma_{13,2}$	1331,04(13)	-	0,0025(10)	0,010(2)	-	-	0,0059(16)
$\gamma_{14,2}$	1400,79(2)	0,707(17)	-	0,70(3)	-	0,689(7)	0,700(7)
$\gamma_{15,2}$	1427,24(2)	0,705(28)	-	0,68(3)	-	0,696(12)	0,687(7)
$\gamma_{15,2}$	1427,24(2)	-	-	-	<0,01	-	-

¹)Outlier

²)214, 8 + 215, 8 keV doublet

Upper limits for a possible 1446,7 keV transition have been determined by authors 10, 11, 16.

1	Burson et al. 1967
2	Gunther and Parsignault 1967
3	Reich and Cline 1970
4	Lavi 1973
5	Lingeman et al. 1974
6	Gehrke et al. 1977
7	Sampson 1978
8	Blagojevic and Wood 1982
9	Sooch et al. 1982
10	Ogandaga et al. 1986
11	Adam et al. 1988 (give also values for six additional very weak transitions)
12	Danilenko et al. 1989
13	Wang Xin Lin 1992
14	Wagner 1992 (gives additionally four weak transitions)
15	Ardisson 1992
16	Miyahara et al. 1994
17	Morel et al. 1996
18	Adopted value

The final values of Hino et al. (2000) were not available when this evaluation was carried out. The absolute emission probabilities (Table 4.2) are calculated by multiplying the relative values by the normalization factor $f_N = 0,725$ (3). The transition probabilities (Table 2.2) are calculated by multiplying the emission probabilities by $(1 + \alpha_t)$.

5 Main Production Mode

Taken from Firestone (1996).

6 References

References are given only in those cases where the reference is not already included in the list of references in the Tables Part.

- C. W. Reich and J. E. Cline, *Phys. Rev.* 137 (1965) B1424 [δ]
 J. M. Domingos, G. D. Symons and A. C. Douglas, *Nucl. Phys.* A180 (1972) 600 [δ]
 T. Miyokawa, I. Katayama, S. Morinobu and H. Ikegami, *Int. Conf. on Nuclear Moments and Nuclear Structure*, Osaka, Japan, 1972, edited by H. Horie and K. Sugimoto, *J. Phys. Soc. Jpn. Suppl.* 34 (1972) 247 [δ]
 K. R. Baker, J. H. Hamilton, J. Lange, A. V. Ramayya, L. Varnell, V. Maruhn-Rezwani, J. J. Pinajian and A. Maruhn, *Phys. Lett.* 57B (1975) 441 [δ]
 R. L. West, E. G. Funk, A. Visvanathan, J. P. Adams and J. W. Mihelich, *Nucl. Phys.* A270 (1976) 300 [δ]
 F. K. McGowan, W. T. Milner, R. L. Robinson, P. H. Stelson and Z. W. Grabowski, *Nucl. Phys.* A297 (1978) 51 [δ]
 J. Lange, K. R. Baker, J. H. Hamilton, A. V. Ramayya, L. Varnell, J. J. Pinajian, V. Maruhn-Rezwani, *Z. Phys.* A303 (1981) 31 [δ]
 K. S. Krane and J. D. Moses, *Phys. Rev.* C24 (1981) 654 [δ]
 A. Alzner, E. Bodenstedt, B. Gemünden, J. van den Hoff and H. Reif, *Z. Phys.* A322 (1985) 467 [δ]
 W. Wagner, *Bull. Russ. Ac. Sci.* 56 (1992) 675 [δ]

¹⁶⁹Yb - Comments on evaluation of decay data by M. M. Bé and E. Schönfeld

1. Decay Scheme

The decay scheme tries to be complete : the confirmed gamma rays (even the weakest, are placed), the questionable gamma transitions are mentioned but not placed.

The J^π values and the level half-lives are taken from NDS 64,2 (1991).

2. Nuclear Data

- To determine the half-life of ¹⁶⁹Yb the following values have been taken in account ($T_{1/2}$ in d):

1	31,83(21)	Walker 1949 (49Wa23)
2	31,97(5)	Lagoutine et al. 1975 (75La16)
3	32,022(8)	Houtermans et al. 1980 (80Ho17)
4	32,015(9)	Rutledge et al. 1980 (80RuZY)
5	32,032(20)	Funck et al. 1983 (83Fu12)
6	32,07(8)	Kits et al. 1988 (88Ki12)
7	31,88(12)	Parker 1990 (90Pa08)
8	32,0147(93)	Unterweger et al. 1992 (92Un01)
9	32,001(34)	Iwahara et al. 1999
10	32,018(5)	weighted mean, adopted value

Value 1 was measured with a Geiger counter, value 2 with a proportional counter, value 7 with a Ge(Li) detector. For all the other measurements an ionisation chamber was used.

This set is a consistent one with a reduced- χ^2 of 0,59. The largest weights are those of values 3 (36 %), 4 (28 %) and 8 (27 %).

Several others values with greater or without uncertainty can be found: 33,0(15) d (Bothe 1946); 32,4 d (Cork 1954), 33,0(15) d (Don Martin 1951), 32 d (Michel, 1954), 30,6(2) d (Cork 1956).

- The Q value is from Audi and Wapstra (1995).

2.1 Electron Capture Transitions

The probabilities and uncertainties are deduced from the gamma transition probability balance on each level.

The balance on level 13 (570 keV) introduces the possible existence of a second forbidden transition to populate this level. This solution is preferred to those of a possible gamma transition from level 19 (878 keV) with energy 307,5 keV, this gamma line being not mentioned in any publication. The existence of gamma rays from levels 14, 16, 17 has not been pointed out in any process.

From spin and parity it follows that a transition to the ground state ($\Delta J^\pi = 3^+$) would be unique second forbidden and an EC transition to the 8,4 keV ($\Delta J^\pi = 2^+$) level would be non-unique second forbidden. If these transitions exit, the limits of their probabilities, which are based on $\lg ft$ systematics, are 0,001% and 0,1% respectively.

EC transitions to the 118 keV ($J^\pi = 5/2^+$) and 139 keV ($J^\pi = 7/2^+$) levels of the rotational band ($K^\pi = 1/2^+$) could also be possible and would both be allowed. Nevertheless the projection of the angular momentum J on the rotational symmetry axis K, is $\frac{1}{2}$, this involves a transfer of 3 units of angular momentum rather than the 0 or 1 unit indicated by the J value. Due to the fact that this nucleus is a deformed nucleus and from $\lg ft > 9$, it results that the intensities of the EC transitions, if exist, are very low.

In the proposed decay scheme the sum of the electron capture transition probabilities is 100,0 (19)

From experimental emission probabilities and balancing conditions, and taking into account the uncertainties of the gamma transitions feeding and leaving these levels, it seems not necessary to introduce the EC transitions mentioned to the 118 keV and 139 keV levels.

The fractional capture probabilities given in section 2.1 have been calculated on the basis of the table of Schönfeld (1998) and the Q value of Audi and Wapstra (1995). Sahota *et al.* (1982) have determined experimental values of P_K with a relative uncertainty of 3 to 5 % [$P_K(472) = 0,812(29)$; $P_K(379) = 0,823(34)$; $P_K(316) = 0,825(43)$]; their values agree within the uncertainties with the more accurate theoretical values.

The $lg ft$ values were calculated from the half-life, the evaluated EC transition probabilities and the transition energies using the $log-f$ tables for beta decay of Gove and Martin (1971).

2.2 Gamma Transitions

Precise γ -ray energies of the main γ -rays have been determined by Borchert *et al.* 1975 and Kessler *et al.* 1979. The values of nine lines (i. e., 63, 93, 109, 118, 130, 177, 197, 261, and 307) given in the table in Section 4.2 are taken from Helmer (2000He14). They are based on a value of 411,80205(17) keV for the 412 keV line following the ^{198}Au decay. The energies of the weaker γ -rays are taken from Vagner (1990). The remaining energies (316, 328, 425, 614 keV) were computed from these energies and the relationships in the decay scheme. In order to calculate the level differences which are given in section 2.2 the recoil energies have been taken in account. The γ -ray energies can be found in section 4.2.

The transition probabilities $P_{\gamma + ce}$ were calculated from the measured relative γ -ray emission probabilities (see section 4.2), the total conversion coefficients and from the absolute intensity value of the 198 keV line 35,93(12) which was derived from statistical treatment of measured values (see section 4.2).

The conversion coefficients were interpolated from the table of Rösel *et al.* 1978. Mixing ratios are taken from angular correlation measurements and from $L_1/L_2/L_3$ ratios respectively $M_1/M_2/M_3/M_4/M_5$ ratios (Günther *et al.* 1969, Agnihotry *et al.* 1972, Krane *et al.* 1972, Akhmetov *et al.* 1985, Davaa *et al.* 1987, Kracikova *et al.* 1987, Wagner *et al.* 1990). The mixing ratio were derived by comparing the subshell ratios from theory and experiment.

The uncertainties of the conversion coefficients are assumed to be 1,5 % for the three well studied transitions 2,1; 4,3; 4,2; 10 % for the less accurate measured transitions 6,3; 7,3; 7,4 and those above 330 keV, and 3 % for all other transitions.

Recently Dey *et al.* (1997) found from angular correlation measurements evidence for a pure M1 character of the 94 keV transition, almost pure E2 character for the 198 keV transition and only 4 % E2 admixture in the 177 keV transition. The corresponding change in $\alpha_i(94)$ from 3,89 to 3,88 is negligible, the change in $\alpha_i(177)$ from 0,59 to 0,62 is small, but $\alpha_i(198)$ would become markedly lower and lead to disagreement when determining the normalisation factor from different cuts through the decay scheme. Also, considering the recent measurements carried out by Baratova *et al.* (1993) who found a E2 admixture of : 3,4 % in the 94 keV; 16 % in the 177 keV and, 11 % in the 198 keV transition these results being in agreement with the other experiments; the values of Dey *et al.* (1997) were not used for the present evaluation.

Comparison between measured α_k and theoretical value from Rösel and from new tables of Band *et al.*(1993) for some important lines which are M1+E2 or E2 :

Eg	93,6	109,8	130	177,2	198	307,8
Adopted admixture %E2	3,25 (25)	2,17 (4)	100	15,8 (3)	9,0 (6)	100
Grabowski (1962)	3,3 (3)	2,15 (20)		0,52 (4)	0,41 (3)	0,048 (5)
Agnihotry (1972)				0,445 (35)	0,30 (2)	0,049
Zheltonozhsky (1995)		2,04 (2)	0,545 (5)	0,515 (5)	0,388 (4)	
α_K theoretical Rösler	3,18 (10)	2,03 (3)	0,538 (17)	0,484 (7)	0,370 (6)	0,0482 (15)
α_K theoretical Band	3,06 (10)	1,95 (3)	0,529 (16)	0,467 (6)	0,358 (5)	0,0477 (14)

3. Atomic data

- The values of ω_K , ω_L , n_{KL} are taken from Schönfeld and Janßen 1996.
- The energies of the X rays are based on the wavelengths given by Bearden (1967).

4.1 X-ray emissions

The emission intensities of the L- and K- X-rays are calculated with the EMISSION program (version 102) from the data set evaluated in this study : electron capture transition probabilities, gamma emission probabilities and from the internal conversion coefficients (α_K , α_{L1} , α_{L2} , α_{L3}) from Rösler *et al.* and the partial capture coefficients P_K , P_L taken from the PTB EC-CAPTURE program with the ratio $P_{L2} / P_{L1} = 0,0527$.

These values are compared with experimental values (see table enclosed), they are generally in good agreement within the uncertainty limits. The measurements were performed with a Si-Li detector for Reference 1-E, an HP-Ge for References 7-E, 10-E1,10-E2 and 3, a Si-Li and HP-Ge for References 1 and 2 and a low energy photon spectrometer for Reference 4.

4.2 Gamma Emissions

The gamma emission probabilities taken in consideration are from the EUROMET exercise 410 (Morel *et al.*) and from several other authors.

List of laboratories which took part in the EUROMET exercise (all details can be found in the report- 1999MoZV) :

- Institute for Physics and Nuclear Engineering (Romania)
- Institut de Radiophysique Appliquée (Switzerland)
- Institute for Reference Materials and Measurements (Belgium)
- V.G. Khlopin Radium Institute (Russia)
- Laboratorio Nacional de Metrologia das Radiações Ionizantes (Brazil- Iwahara *et al.*)
- Laboratoire Primaire des Rayonnements Ionisants (France)
- National Physical Laboratory (U.K.)
- National Office of Measures (Hungary)
- Radioisotope Centre POLATOM (Poland)
- Physikalisch-Technische Bundesanstalt (Germany – Schönfeld *et al.*)
- D.I.Mendeleyev Institute for Metrology (Russia – Sazonova *et al.*)

An arbitrary code number was assigned to each participant. The same code number is used here to reference the results.

The recent references : Schönfeld *et al.* (1999), Sazonova *et al.*(2000), Iwahara *et al.* (2000) have not been included as independent reference because they were participants in the EUROMET exercise and then, their results are *de facto* included.

In the EUROMET exercise 410, references 1-E to 11-E, the values were given in absolute value, they have been converted relatively to the 198 keV line.

The other references used are :

1: Artomonova *et al.* 1976 (below 308 keV) and Balalaev *et al.* 1972 (above 308 keV), in this reference the values are given relatively to the 307 keV gamma-ray. As described, from V.S Aleksandrov the absolute intensity for this ray was taken as 10,1(5) % and those of the 198 keV gamma-ray is 34,34 (264). For this study the values given by Balalaev were converted relatively to the 198 keV ray taken as 100, with respect to the above absolute values used in the quoted paper.

2: Gehrke *et al.* 1977

3: Funck *et al.* 1983 (below 308 keV), Georgieva and Tumbev 1976 (above 308 keV)

4: Mehta *et al.* 1986 (uncertainties above 130 keV multiplied by a factor 2 to be compatible with the results of other authors)

5: Vagner *et al.* 1990, this work is supposed to be the continuation of the work of I. Adam, V.

Vagner *et al.* (1986).

6: Bhattacharya *et al.* 1996

7: Miyahara 1998

The less accurate values of the following references were not taken into account for the present evaluation:

Alexander and Boehm 1963

Brown and Hatch 1967

Sen *et al.* 1972

Agnihotry *et al.* 1972

Potnis *et al.* 1972

Lavy *et al.* 1973

Aleksandrov *et al.* 1973

Verma *et al.* 1976

• Other remarks :

- The gamma given at the 205,99 energy by Vagner and at the 206,2 energy by Mehta are processed together in the same line.

- The intensity of the 51 keV is from the imbalance of level 7.

- Some weak gamma transitions were seen in only one spectrum :

105,2 ; 193,1 ; 213,9 ; 226,3 ; 291,2 ; 294,5 ; 316,2 ; 328,0 ; 356,7 ; 425,0 ; 500,3 ; 507,8 ; 546,1 ; 614,1 ; 633,3 ; 693,5 ; 710,3 ; 739,4 ; 760,2 and 781,6 lines.

The 616,2 and the 614,1 lines can not be placed in the decay scheme.

- Four EUROMET participants and Funck made the measurement of the resulting gamma emission of the 8,4 keV transition with the $L_{\beta 2}$ and $L_{\beta 15}$ X-rays emission. The LWEIGHT program running on these 5 values gives for this line ($\gamma_{8,4} + L_{\beta 2,15}$) = 4,68(14)%

On the other hand, we obtain with the EMISSION program : $L_{\beta 2,15} = 3,93(10)\%$ for the X-ray emission.

The gamma emission absolute intensity can be deduced : $4,68 - 3,93 = 0,75(17)\%$

From the balance on the levels 1 and 0 of the decay scheme, a probability of 95,1 % for the 8,4 keV transition is deduced. As the decay scheme is quite consistent in every part, this value is certainly good.

The consequence is that the deduced ICC total is : 125(16)

This is not consistent with the theoretical ICC obtained from the Rosel table for a $M1+0,108\%E2$ transition which is = 273(13)

It can be noted that with a pure M1 transition the Rosel ICC is 177(8)

The E2 admixture to the M1 multipolarity is deduced from the M1/M2/M3/M4/M5 ratio measured by T.A. Carlsson, *et al.* They compared their measured ratio with those from the Tables of Hager and Seltzer. Their calculations, taking the Rösler *et al.* conversion coefficients, were repeated and confirmed their result of 0,108(5) % E2 admixture. There are also some older less accurate values giving 0,10(2) %.

It also exists an old measurement of $\alpha_{MN} = 106(6)$ from G. Charpak and F. Suzor (1959).

Without other confirmation of this value, we will stay with the theoretical ICC for a M1+0,108%E2 transition calculated from Rösler *et al.*

This leads to the **adopted absolute value of 0,347(17)%** for the emission intensity.

This approach was also followed by Artomonova who gave a value of 0,33(4)% for the 8,4 keV gamma line emission intensity.

- Determination of the absolute emission intensity of the 198 keV line

During the EUROMET exercise the absolute activity measurement of Yb-169 sources was carried out by several methods and the absolute intensity of the 198 gamma-ray line deduced. This gives 8 measurements made by independent laboratories (references from 1-E to 11-E), moreover 3 others absolute measurements are available (references 3, 7, 8). In these conditions a statistical treatment by using the program LWEIGHT has been done to determine the absolute emission intensity of the 198 keV line.

Absolute values of the 198 keV line from EUROMET exercise and others :

1-E	(36,26 ± 0,18)	EUROMET, 1999
3-E	(37,3 ± 0,5)	EUROMET, 1999
4-E	(35,7 ± 0,6)	EUROMET, 1999
7-E	(36,3 ± 1,1)	EUROMET, 1999
8-E	(35,9 ± 0,8)	EUROMET, 1999
9-E	(35,49 ± 0,39)	EUROMET, 1999
10-E1	(36,06 ± 0,15)	EUROMET, 1999
11-E	(35,9 ± 0,5)	EUROMET, 1999
3	(36,0 ± 0,5)	Funck et al. 1983
7	(35,14 ± 0,28)	Miyahara et al. 1999
8	(35,5 ± 0,4)	Coursey et al. 1994

The reference 3-E is rejected due to deviation from the weighted average (Chauvenet criteria), this leads to process 10 values. No value contributes more than 50%, the reduce- χ^2 is 1,64 ; the weighted mean and external uncertainty is chosen. Then **the adopted value is 35,93(12)%**.

This value is quite close to those obtained by Schönfeld et al. (35,91(13)) by considering the balance of the decay scheme.

5. Electron Emissions

Auger Electrons

The energies of the KLL Auger electrons are taken from Larkins (1977), the others are calculated from the binding energies using approximations. The probabilities of L- and K-Auger electrons are calculated with the PTB program Emission (version 102).

Conversion Electron Emissions

The energies were calculated from the gamma transition energies and from the binding electron energies on the electronic shells.

The emission probabilities were calculated using the adopted gamma emission probabilities and conversion coefficients.

The comparison between measured internal conversion electron intensities and calculated values gives a good agreement which confirms the consistency of the evaluated data set.

E gamma	Agnihotry (1972)	Artamonova (1976)	Calculated
8,4 keV - Ie M		71 (7)	76 (5)
20,7 keV - Ie L		7,5 (4)	8,6 (3)
Ie M		1,7 (1)	1,93 (7)
63 keV - Ie K		36 (7)	39,6 (12)
- Ie L		7,16 (15)	7,2 (3)
93 keV - Ie K		7,5 (7)	8,18 (27)
- Ie L		1,5 (1)	1,4 (5)
109 keV - Ie K		34,9 (11)	35,2 (6)
- Ie L		5,7 (1)	5,68 (9)
118 keV - Ie K		1,28 (6)	1,30 (4)
- Ie L			1,37 (4)
130 keV - Ie K		6,2 (3)	6,1 (2)
- Ie L		5,4 (2)	5,3 (2)
177 keV - Ie K	10,1 (5)	10,7 (7)	10,8 (2)
- Ie L		2,1 (1)	1,94 (3)
198 keV - Ie K	10,8 (5)	13,5 (5)	13,29 (22)
- Ie L		2,16 (5)	2,17 (3)
240 keV - Ie K	0,0043 (4)	0,0045 (5)	0,0042 (5)
- Ie L		0,0010 (5)	0,00075 (8)
261 keV - Ie K	0,047 (7)	0,040 (4)	0,040 (1)
- Ie L			0,0060 (2)
307 keV - Ie K	0,53	0,50 (2)	0,484 (15)
- Ie L		0,15 (2)	0,142 (4)

6. Main Production Modes

From Firestone (1996) and Shirley (1991)

References of the programs used

LWEIGHT : A computer program to calculate averages, D. MacMahon, E. Browne

EC-CAPTURE : Calculation of electron capture probabilities. PTB

EMISSION-102 : Calculation of X-rays and Auger electrons emission probabilities. PTB

ICC Database : ICC computer code, CEA-BNM/LNHB technical note LPRI/98/002

References not used

Von W. Bothe. Z. Naturforschg. 1 (1946) 173

J. M. Cork *et al.* Phys. Rev. 78,2 (1950) 95

Don S. Martin *et al.* Phys. Rev. 82,5 (1951) 579

M. C. Michel *et al.* Phys. Rev. 93 (1954) 1422

J. M. Cork *et al.* Phys. Rev. 101,3 (1956) 1042

E. N. Hatch *et al.* Phys. Rev. 104,3 (1956) 745

Other quoted references can be found in the Tables Part.

**¹⁷⁰Tm - Comments on evaluation of decay data
by V. P. Chechev and N. K. Kuzmenko**

1. Decay Scheme

Since ¹⁷⁰Tm has spin and parity 1⁻, it decays with detectable probability to the 0⁺ ground states and 2⁺ first excited levels in both ¹⁷⁰Yb and ¹⁷⁰Er. The only other levels below the decay energies are at 277 keV (4⁺) and 573 keV (6⁺) in ¹⁷⁰Yb and 260 keV in ¹⁷⁰Er. From the log *ft* systematics of 1998Si17, one expects the log *ft*'s of the 3rd forbidden decays to the 4⁺ levels to be greater than 16, which corresponds to a β branch of less than 0,000 002% to the 4⁺ level of ¹⁷⁰Yb and weaker branch to 4⁺ in ¹⁷⁰Er. Since the branch to the 6⁺ level will be a 5th forbidden decay, it will be even much weaker. Therefore, all of these unobserved β branches will be negligible.

For decay scheme see also Baglin (1996Ba01).

2. Nuclear Data

Q value is from Audi and Wapstra (1995Au04).

The ¹⁷⁰Tm half-life values are available, in days

125 (2)	1962Bo12	
134,2 (8)	1965Fl02	Omitted as outlier
128 (1)	1967Ke13	
128,6 (3)	1968Re04	
127,1 (3)	1969La34	(the original value of uncertainty is 3σ = 0,9)
127,8 (6)	Average	

The outlier value of 1965Fl02 was omitted on the statistical considerations of its large deviation from the mean.

For statistical processing one third of the total 3σ-uncertainty, 0,9 days, stated in 1969La34, was used. Then, the weighted average is 127,8 d with an internal uncertainty of 0,21 d, a reduced-χ² of 4,85 and an external uncertainty of 0,45 d. In this case the different statistical procedures using the weighted average give the following values for a final uncertainty, in days: UINF - 0,45; PINF - 0,45; BAYS - 0,79; MBAYS - 0,56; LWM - 0,77; tS- 0,54. The LWEIGHT program using the LWM method has expanded the uncertainty to 0,77 d to include the accurate value of the 1968Re04. The EV1NEW program chooses the tS or MBAYS procedure for this case and gives 0,6 d. The latter value was adopted for the final uncertainty of the average.

It should be noted that without rejecting 1965Fl02 the Normalised Residuals technique leads almost to the same average of 127,9(6) days. It inflates the uncertainty of the 1965Fl02 value to 2,7 days and of each of the 1968Re04 and 1969La34 to 0,5 days.

A considerable discrepancy of few available experimental data on the ¹⁷⁰Tm half-life, all obtained before 1970, requires new ¹⁷⁰Tm half-life measurements.

2.1 b⁻ - Transitions

The β⁻-decay probabilities have been computed from the P_{γ+ce}(Yb) of section 2.3 and balance correlations.

2.2. Electron Capture Transitions

The values of the electron capture probabilities to the ¹⁷⁰Er ground state and the level of 78,6 keV have been obtained from the balance correlations including the X K- and gamma emission probabilities. Indeed, we can write:

$$P_{XK}(Yb) = \omega_K(Yb) \alpha_K(84) P\gamma(84)$$

$$P_{XK}(Er) = \omega_K(Er) [P_K^{0,0} P(\epsilon_{0,0}) + P_K^{0,1} P(\epsilon_{0,1}) + \alpha_K(79) P\gamma(79)]$$

From here:

$$S \equiv \frac{P_{XK}(Er)}{P_{XK}(Yb)} = \frac{w_K(Er)}{w_K(Yb)} \cdot \frac{1}{a_K(84) \cdot P\mathbf{g}(84)} [P_K^{0,0} \cdot P(\mathbf{e}_{0,0}) + P_K^{0,1} \cdot P(\mathbf{e}_{0,1}) + a_K(79) \cdot P\mathbf{g}(79)]$$

Finally, for $P(\epsilon_{0,0})$ and $P(\epsilon_{0,1})$ the following expressions are obtained (see also 1988Kuzmenko):

$$P(\mathbf{e}_{0,0}) = \frac{P\mathbf{g}(84)}{P_K^{0,0}} \left\{ a_K(84) \cdot S \cdot \frac{w_K(Yb)}{w_K(Er)} - \frac{P\mathbf{g}(79)}{P\mathbf{g}(84)} [a_K(79) + P_K^{0,1} (1 + a_T(79))] \right\}$$

$$P(\mathbf{e}_{0,1}) = P\mathbf{g}(79) \cdot (1 + a_T(79))$$

In this calculation, the adopted values of ICC, P_K , ω_K , P_γ and the ratio of $S = 0,035(1)$ measured in 1986Ve05 were used.

The fractional electron capture probabilities to the specific atomic shells (P_K , P_L , P_M ...) have been deduced from the tables of Schönfeld (1998Sc28).

2.3. Gamma Transitions and Internal Conversion Coefficients

The energies of gamma transitions are the energies of gamma rays with the recoil energy added. The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the gamma-ray emission probabilities and the total internal conversion coefficients (ICC).

The theoretical values of ICC from Rosel et al. (1978Ro21) have been adopted for the gamma transitions which have the same multipolarity E2. The evaluated α_{NO} values have been computed from $\alpha_M(\text{theoretical})$ using the ratio $\alpha_M / \alpha_{NO} = 3,77(9)$ (1968Ni06).

The weighted mean of the eight measurement results for $\alpha_K(\gamma 84)$ [1,48 (5) (1966Di02), 1,41 (4) (1969Ne02), 1,37 (4) (1970Mo07), 1,41 (5) (1971Ca08), 1,46 (7) (1973Pi08), 1,39 (3) (1985Me18), 1,41 (3) (1986Ve01), and 1,43 (4) (1990Ke01)] is 1,41 with an internal uncertainty of 0,014 ; a reduced χ^2 of 0,6 and an external uncertainty of 0,011. Taking into account that a systematic error of the measurement method can contribute mainly to the measurement uncertainties, the smallest of the input uncertainties has been chosen as a final uncertainty of the weighted mean. The average value of $\alpha_K(\gamma 84)$ (experimental), equal 1,41 (3), agrees well with the theoretical value of 1,39(2). The relative uncertainty of the theoretical ICC has been adopted of 1,5%. This value of uncertainty provides overlapping $\alpha_K(\gamma 84)$ (theoretical) and $\alpha_K(\gamma 84)$ (experimental).

3. Atomic Data

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janßen). The X-ray energies are based on the wavelengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission $K\beta/K\alpha$, $K\alpha_2/K\alpha_1$, $K'\beta_2/K'\beta_1$ probabilities and the ratios $P(KLX)/P(KLL)$, $P(KLY)/P(KLL)$ are taken from 1996Sc06. The energies of Auger electrons are from 1977La19 (Larkins).

4. Photon Emissions

4.1. X-Ray Emissions

The absolute XK(Er), XK(Yb), XL(Yb) emission probabilities have been computed on the basis of the relative intensities P_X/P_γ (84) measured in 1985Me18 and 1986Ve05. The absolute measurement results of 1989Egorov for XK(Yb) [$K\alpha_2 = 1,00(2)$, $K\alpha_1 = 1,69(4)$, $K'\beta_1 = 0,54(2)$, $K'\beta_2 = 0,14(1)$] agree well with our evaluated values. The total absolute XK(Er) emission probability of 0,089(5) measured in 1990EgZY disagrees with the evaluated value of section “X Radiations”.

The weighted mean of the two measurement results for the Yb $K\alpha_1$ -ray, 0,675(17), was adopted as the evaluated value and the values on $K\alpha_2$, $K'\beta_1$, $K'\beta_2$ were computed from the relative probabilities from 1996Sc06. The analogous procedure was made for the Er with the $K\alpha_1$ value from the measurements of 1986Ve05 and the other values from the relative probabilities from 1996Sc06.

P_{XK}/P_γ (84) for Er

Er	1985Me18	1986Ve05	adopted
$K\alpha_2$	} 0,0248 (6)	0,0133 (4)	0,0134 (4)
$K\alpha_1$	}	0,0238 (4)	0,0238 (4)
$K'\beta_1$	6,3 (2)·10 ⁻³	7,7 (3)·10 ⁻³	0,0077 (3)
$K'\beta_2$	1,45 (6)·10 ⁻³	2,2 (1)·10 ⁻³	0,0020 (1)

P_{XK}/P_γ (84) for Yb

Yb	1985Me18	1986Ve05	average (EV1NEW)	adopted
$K\alpha_2$	0,377 (9)	0,381 (11)	0,379 (9)	0,383 (9)
$K\alpha_1$	0,680 (17)	0,668 (20)	0,675 (17)	0,675 (17)
$K'\beta_1$	0,2145 (32)	0,228 (7)	0,221 (12)	0,222 (7)
$K'\beta_2$	0,0533 (9)	0,0604 (19)	0,057(1)	0,058 (2)

P_{XL}/P_γ (84) for Yb

Yb	adopted (1985Me18)
Ll	0,0238 (8)
$L\alpha+L\eta$	0,573 (18)
$L\beta$	0,603 (19)
$L\gamma$	0,0974 (31)
ΣXL	1,297 (27)

The total absolute Er LX emission probability has been computed using the adopted values of ω_K , ω_L , n_{KL} , the evaluated total KX absolute emission probability and the evaluated total absolute emission probabilities of L conversion electrons and electron capture.

It should be noticed that the absolute XK- emission probabilities of $P_{XK}(Er)=0,113(6)$ and $P_{XK}(Yb)=3,27 (12)$ per 100 disintegrations, calculated from the adopted values of ω_K , the evaluated total absolute emission probabilities of K conversion electrons (P_{ceK}) and the electron capture (P_{eK}), agree well with the evaluated, 0,116 (3) and 3,31 (8), respectively.

For $P_{XL}(Yb)$ such a calculation gives 2,93 (15) per 100 disintegrations - in comparison with the value of 3,22 (13), adopted from experimental data on P_{XL}/P_γ (84).

The evaluated values of $P_{XK}(Er) = 0,116$ (3)%, $P_{XK}(Yb) = 3,31$ (8)% and $P_{XL}(Yb) = 3,22$ (13)% have been obtained directly from relative measurements of the intensity of peaks in the ¹⁷⁰Tm photon spectrum ($P_X/P_\gamma(84)$) with use of the $P_\gamma(84)$ value evaluated from independent experimental data. Unlike that the calculated value of $P_{XK}(Er) = 0,113(6)$ has been founded on the adopted semiempirical and theoretical values ω_K , $P_K(\epsilon_{0,1})$, and $\alpha_K(\gamma79)$ as well as the evaluated $P_\gamma(79)$. In the calculation of $P_{XK}(Yb) = 3,27$ (12)% the same value of $P_\gamma(84)$ is used as in the evaluation of 3,31 (8)%. However, the adopted $\omega_K(Yb)$ and theoretical value of $\alpha_K(\gamma84)$ have been used instead of the experimental relative intensity $P_{XK}/P_\gamma(84)$.

Above agreement of the evaluated and calculated values shows a concordance of the obtained decay characteristics for ¹⁷⁰Tm.

4.2. Gamma Emissions

The energy of 78,6 keV γ -ray has been obtained as the weighted mean of the following three measurements results: 78,59 (2) keV (1958Ch36), 78,7 (5) keV (1969Ha20) and 78,6 (4) keV (1970Mo07).

The 84,25 keV γ -ray energy has been adopted from 2000He14.

The absolute emission probability for the γ -ray of 84,25 keV (per 100 disintegrations) has been obtained with use of the weighted mean of the three measurement results: 2,54 (6) (1973PI08), 2,56 (4) (1987GeZU, 1988GeZS) and 2,37 (4) (1990Ke01). This weighted average is 2,48 with an internal uncertainty of 0,03, a reduced- χ^2 of 6,3 and an external uncertainty of 0,06. In this case the different statistical procedures using the weighted average give the following values for a final uncertainty: UINF - 0,064; PINF - 0,064; BAYS - 0,091; MBAYS - 0,091; LWM - 0,109; tS - 0,084. The EVINEW program has chosen MBAYS for this case and hence the uncertainty of 0,09. This value was adopted as the uncertainty of the evaluated $P_\gamma(84)$. It should be noted that the Rajeval technique leads to the same result of 2,48(9). The normalised Residuals technique gives only slightly greater value of 2,51(4).

The absolute emission probability for the γ -ray of 78,6 keV has been obtained with use of the weighted mean of the results of measurements of the ratio of $P_\gamma(79)/P_\gamma(84)$: 0,00122 (24) (1970Mo07), 0,0015 (2)(1985Me18) and 0,00140 (8) (1986Ve01). The LRSW method has expanded the uncertainty of the 1986Ve01 from 0,00008 to 0,00015 in order to reduce its relative weight from 79% to 50%. Then, the weighted mean is 0,00139 with an internal uncertainty of 0,00011, a reduced- χ^2 value of 0,4 and an external uncertainty of 0,00007. The adopted value of $P_\gamma(79)/P_\gamma(84)$ is 0,00139 (11).

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.3 and the electron binding energies. The energies of the Auger electrons are taken from 1977La19 (Larkins).

The emission probabilities of the conversion electrons have been calculated using the conversion coefficients given in 2.3. The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.3.

6. References

- | | |
|----------|--|
| 1958Ch36 | E. L. Chupp <i>et al.</i> , Phys. Rev., 1958, V.112. P.518. [Energy of $\gamma79$] |
| 1962Bo12 | Bonner <i>et al.</i> , Phys. Rev., 1962, V. 127. P. 217. [Half-life] |
| 1965F102 | K. F. Flynn <i>et al.</i> , Nucl. Sci. Eng., 1965, V. 22. P. 416. [Half-life] |
| 1966Di02 | R. S. Dingus <i>et al.</i> , Nucl. Phys., 1966, V. 83. P.545. [$\alpha_K(\gamma84)$] |
| 1967Be65 | J. A. Bearden, Rev. Mod. Phys., 1967, V.39. P.78. [X-ray energies] |
| 1967Ke13 | W. I. Kerrigan, J. Inorg. Nucl. Chem., 1967, V. 29. P. 2657. [Half-life] |
| 1968Ni06 | O. Nilsson <i>et al.</i> , Nucl. Phys., 1968, V. A120. P.561. [α_M/α_{NO}] |

- 1968Re04 S. A. Reynolds *et al.*, Nucl. Sci. Eng., 1968, V.32. P.46. [Half-life]
- 1969Ha20 H. H. Hansen, S. Hellström, Z. Phys., 1969, Bd.223. S.139. [Energy of γ 79]
- 1969La34 F. Lagoutine *et al.*, Int. J. Appl. Rad. Isot., 1969, V. 20. P. 868. [Half-life]
- 1969Ne02 G. C. Nelson, E. N. Hatch, Nucl. Phys., 1969, V. A127. P.560. [$\alpha_K(\gamma$ 84)]
- 1970Mo07 S. Mohan, Phys. Rev., 1970, V. C1, N1. P. 254. [$\alpha_K(\gamma$ 84), energy and relative probability of γ 79]
- 1971Ca08 J. L. Campbell *et al.*, Nucl. Instrum. Meth., 1971, V.92. P.237. [$\alpha_K(\gamma$ 84)]
- 1973Pl08 J. Plch, J. Zderadicka, L. Kokta, Czech. J. Phys., 1973, V. 23, N 4. P. 1181. [$\alpha_K(\gamma$ 84), absolute γ 84 emission probability]
- 1977La19 F. P. Larkins, Atomic Data and Nuclear Data Tables, 1977, V.20. P.313. [Auger electron energies]
- 1978Ro21 F. Rösel, H. M. Fries, K. Alder, H. C. Pauli, Atomic Data and Nuclear Data Tables, 1978, V.21. P. 293. [Internal conversion coefficients]
- 1985Me18 D. Mehta *et al.*, Nucl. Instrum. Meth., 1985, V. A242, N1. P.149. [$\alpha_K(\gamma$ 84), $P_X/P_\gamma(84)$, $P_\gamma(79)/P_\gamma(84)$]
- 1986Ve01 Rao N. Venkateswara *et al.*, J. Phys.(London), 1986, V. G12. P.45. [$\alpha_K(\gamma$ 84), $P_\gamma(79)/P_\gamma(84)$]
- 1986Ve05 Rao N. Venkateswara *et al.*, Indian J. Phys., 1986, v.60A. P.162. [$P_X/P_\gamma(84)$]
- 1987GeZU A. M. Geidelman *et al.*, Abstracts of 37th Conference on Nuclear Spectroscopy and Atomic Nuclear Structure, Yurmala, 14-17 April, 1987, LO Nauka, Leningrad, 1987.P. 133. [Absolute γ 84 emission probability]
- 1988GeZS A. M. Geidelman, Yu. S. Egorov, N. K. Kuzmenko, V. G. Nedovesov, V. P. Chechev, G. E. Shukin, Proc. Intern. Conf. Nuclear Data for Science and Technology, Mito, Japan, 1988, p 909. [Absolute γ 84 emission probability]
- 1988Kuzmenko N. K. Kuzmenko, V. G. Nedovesov, V. P. Chechev, Izmeritel'nay Tekhnika, 1988, N 9, P. 47. [1988 decay data evaluation, absolute γ 84 emission probability]
- 1989Egorov A. G. Egorov, Yu. S. Egorov, V. G. Nedovesov, G. E. Shchukin, K. P. Yakovlev, Program and Thesis, Proc. 39th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Leningrad, 1989, p 505. [Yb XK-ray emission probabilities]
- 1990EgZY A. G. Egorov, V. G. Nedovesov, G. E. Shchukin, K. P. Yakovlev, Program and Thesis, Proc. 40th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Leningrad, 1990, p 486. [Er X K-ray emission probability]
- 1990Ke01 T. Kempisty *et al.*, Nucl. Instrum. Meth. Phys. Res., 1990, V. A286, P. 535. [Absolute γ 84 emission probability, $\alpha_K(\gamma$ 84)]
- 1995Au04 G. Audi and A. H. Wapstra, Nucl. Phys. , 1995, V. A595, P. 409.[Q values]
- 1996Ba01 C. M. Baglin, Nuclear Data Sheets, 1996, V.77, N1. P.125.[Decay scheme]
- 1996Sc06 E. Schönfeld, H. Janßen, Nucl. Instr. Meth. Phys. Res., 1996, V.A369. P.527.[Atomic data]
- 1998Sc28 E. Schönfeld, Appl. Rad. Isotopes, 1998, V.49. P.1353. [Fractional electron capture probabilities]
- 1998Si17 B. Singh, J. L. Rodriguez, S. S. Wong, J. K. Tuli, Nucl. Data Sheets, 1998, 84, 487. [lg f_t]
- 2000He14 R. G. Helmer and C. van der Leun, Nucl. Instrum. Meth., 2000, V. A450, P. 35. [γ -ray energies]

¹⁷⁷Lu - Comments on Evaluation of Decay Data for β^- Decay
F. G. Kondev

Evaluation Procedures

The *Limitation of Relative Statistical Weight* (LWM) [1] method for averaging numbers has been applied throughout this evaluation.

1. Decay Scheme

The decay scheme for ¹⁷⁷Lu is taken from the recent evaluations of Kondev (2002KoXX) and Browne (1993Br06). The ground state has been assigned $J^\pi = 7/2^+$ and the $7/2^+[404]$ ($g_{7/2}$) Nilsson configuration. It decays via β^- emission ($P_{\beta^-} = 100\%$) to levels of the stable ¹⁷⁷Hf daughter isotope. While the decay branches to the ¹⁷⁷Hf ground state ($J^\pi = 7/2^-$) and to the 112.9499 keV ($J^\pi = 9/2^-$), and 321.3162 keV ($J^\pi = 9/2^+$) levels are well established, there is some ambiguity in the literature regarding the direct β^- -decay feeding into the $J^\pi = 11/2^-$ level at 249.6744 keV.

2. Nuclear Data

Half-life

The half-life of the ¹⁷⁷Lu ground state has been measured by several authors and the results are summarized in Table 1. In all cases the source was prepared using the ¹⁷⁶Lu(n, γ) reaction, where a three-quasiparticle isomer ($K^\pi = 23/2^-$ and excitation energy of 970 keV), with a half-life that is significantly longer ($T_{1/2} = 160.44(6)$ d), when compared to that for the ¹⁷⁷Lu ground state, is also produced. Since the isomer de-excites partially via gamma emission ($P_\gamma = 21.4\%(8)$), its half-life and relative population should be taken into account when determining the $T_{1/2}$ for the ground state. The recommended value for the ¹⁷⁷Lu ground state half-life is $T_{1/2} = 6.647(4)$ d. It is the weighted average of the 6.645(30) d (1982La25), 6.65(1) d (2001Zi01) and 6.646(5) d (2001Sc23) values. The half-lives reported by 1958Be41, 1960Sc19, 1972Em01 and 1990Ab02 were excluded from this analysis since authors did not consider the effect of the ¹⁷⁷Lu^m isomer ($T_{1/2} = 160.44$ d) was not taken into account. Although the relative statistical weight of the 2001Sc23 value was 78.3%, its uncertainty was not increased since the set is consistent. It should be noted that there are may be a systematic uncertainty in the recommended $T_{1/2}$ value for the ¹⁷⁷Lu ground state, due to possible differences in the half-life values of ¹⁷⁷Lu^m and its population intensity that were used in 1982La25, 2001Zi01 and 2001Sc23.

Table 1 Measured and recommended values for the ¹⁷⁷Lu ground state half-life.

Reference	$T_{1/2}$, d	Comment
1958Be41	6.75 (5) #	
1960Sc19	6.74 (4) #	
1972Em01	6.71 (1) #	
1990Ab02	6.7479 (7) #	
1982La25	6.645 (30)	$T_{1/2}({}^{177m}\text{Lu}) = 159.5$ d (7) was used in the fitting procedure.
2001Zi01	6.65 (1)	Corrections for $T_{1/2}({}^{177m}\text{Lu})$ have been applied, but the value has not been reported.
2001Sc23	6.646 (5)	$T_{1/2}({}^{177m}\text{Lu}) = 160.4$ d was used in the fitting procedure.
Adopted	6.647 (4)	$c2/(N-1) = 0.07$

Contributions from the decay of the ¹⁷⁷Lu^m (T_{1/2} = 160.44 d) isomer have not been taken into account. The value is not used in the analysis.

Q value

The Q(β⁻) = 498.3(8) keV is from 1995Au04. It is in agreement with that of 496.8(17) keV (1962E102), deduced from the β⁻-decay endpoint energy to the ¹⁷⁷Hf ground state. The total average decay energy released in the β⁻-decay of the ¹⁷⁷Lu ground state is calculated using RADLST [2] as 497.4(25) keV. It agrees very well with the Q(β⁻) value that is reported by Audi (1995Au04), thus suggesting that the decay scheme is complete.

2.1 b- Decay Transitions

The β⁻ transition endpoint energies were determined from Q(β⁻) = 498.3(8) keV (1995Au04) and the individual level energies. The latter were deduced from a least-squares fit to the adopted gamma-ray energies that are given in Table 3. The β⁻ transition endpoint energies are in agreement with values measured by 1962E102 and 1955Ma12. The adopted values for the β⁻ transition probabilities per 100 disintegrations were determined from the total (photons + conversion electrons) transition probability balances at each level. In general, values deduced in the present evaluation are consistent with those from 2001Sc23, 1975E107 and 1993Br06, albeit in 2001Sc23 there is no report on a direct β⁻ -decay feeding into the J^π = 11/2⁻ level.

Table 2 Measured and adopted values for the ¹⁷⁷Lu b⁻-decay transition probabilities

Reference	P _{β⁻} to J ^π = 7/2 ⁻	P _{β⁻} to J ^π = 9/2 ⁻	P _{β⁻} to J ^π = 11/2 ⁻	P _{β⁻} to J ^π = 9/2 ⁺
2001Sc23	79.3 (5)	9.1 (5)		11.58 (12)
1975E107	78.6 (10)	9.1 (10)	0.05 (2)	12.2 (7)
1993Br06				
1967Ha09	87.2 (11)	6.0 (8)	0.07 (2)	6.7 (3)
1964Al04	86.3 (13)	7 (1)	0.03 (3)	6.7 (3)
1962E102	90 (4)	2.95 (3)	0.31 (6)	6.72 (25)
1956Wi39	96	1.3	0.2	2.6
1955Ma12	90	3		7
1949Do05	65	17		
Adopted	79.3 (5)	9.1 (5)	0.012 (8)	11.64 (10)

There are, however, significant differences with the 1967Ha09, 1964Al04, 1962E102, 1956Wi39, 1955Ma12 and 1949Do05 work, as summarized in Table 2. The log *ft* values were calculated using the program LOGFT [3] using the adopted β⁻ transition probabilities.

2.2 Gamma Transitions and Internal Conversion Coefficients

The measured values for gamma-ray transition energies that follow the decay of the ¹⁷⁷Lu ground state are presented in Table 3. The gamma-ray energies reported by Matsui et al. (1989Ma56) were adopted in the present evaluation. These were measured with a high precision using a germanium spectrometer. The total (photon + conversion electrons) transition probabilities were deduced by multiplying the adopted values for the relative gamma-ray intensities (Table 10) by a normalization factor that was deduced from the values for the absolute intensity per 100 disintegrations of the 208.3662 keV gamma ray (Table 11). The total electron conversion coefficients were interpolated from the tables of Rösel (1978Ro22). Transition multipolarities are taken from 2002KoXX and 1996Br06. They are based on comparisons

between the measured electron conversion coefficients with theoretical values (1978Ro22), as well as on available angular correlation data.

Table 3 Measured and adopted values for gamma ray transition energies following b⁻ decay of ¹⁷⁷Lu

Reference	$\gamma_{1,0}$	$\gamma_{2,1}$	$\gamma_{2,0}$	$\gamma_{3,2}$	$\gamma_{3,1}$	$\gamma_{3,0}$
1989Ma56	112.9498 (4)	136.7245 (5)	249.6742 (6)	71.6418 (6)	208.3662 (4)	321.3159 (6)
1981Hn03	112.95 (2)	136.72 (2)	249.7 (5)	71.646	208.35 (2)	321.27 (5)
1967Ha09	112.95 (2)	136.72 (5)	249.65 (6)	71.66 (6)	208.34 (6)	321.32 (12)
1965Ma18	112.952 (2)	136.730 (6)	249.868 (25)	71.646 (2)	208.359 (10)	321.330 (40)
1964Al04	112.97 (2)	136.68 (2)	249.69 (10)	71.64 (2)	208.36 (6)	321.36 (20)
1961We11	112.97 (2)	136.70 (10)	249.70 (10)	71.60 (10)	208.38 (2)	321.34 (3)
1955Ma12	112.965 (20)		250.0 (5)	71.644 (20)	208.362 (20)	321.36 (10)
Adopted	112.9498 (4)	136.7245 (5)	249.6742 (6)	71.6418 (6)	208.3662 (4)	321.3159 (6)

Details about the mixing ratios values for E1+M2 and M1+E2 transitions are given below. The electron conversion coefficients are interpolated values from the tables of Rösler (1978Ro22). The quoted uncertainties reflect the corresponding uncertainties in the mixing ratios values. Adopted α_K , α_{L1} , α_{L2} , α_{L3} , and α_M values were also used as an input for the RADLST [2] and EMISSION (2001Sc08) programs.

2.2.1 112.9498 keV ($g_{1,0}$)

Values used in the analysis of the mixing ratios are summarized in Table 4. The unweighted average value is adopted, but its uncertainty was increased to 0.4, so that the range includes the most precise value of $\delta(\gamma_{1,0}) = -4.85(5)$ (1992De53). During the analysis, the uncertainty of the 1992De53 value was also increased to 0.056, so that its relative statistical weight is scaled down from 55.8% to 50%.

Table 4 Measured and adopted mixing ratios values for the 112.9498 keV transition

Reference	$\delta(\gamma_{1,0})$	Comment
1974Kr12	-4.7 (2)	From $\gamma(\theta)$ in ^{177m} Lu ($T_{1/2} = 160.44$ d) decay.
1974Ag01	-3.99 (25)	From $\gamma\gamma(\theta)$ in ¹⁷⁷ Lu ($T_{1/2} = 6.647$ d) β^- decay.
1970Hr01	-3.7 (3)	From $\gamma\gamma(\theta)$ in ¹⁷⁷ Lu ($T_{1/2} = 6.647$ d) β^- decay.
1961We11	-4.0 (2)	From $\gamma\gamma(\theta)$ in ¹⁷⁷ Lu ($T_{1/2} = 6.647$ d) β^- decay.
1972Ho54	-4.75 (7)	From $\gamma\gamma(\theta)$ in ¹⁷⁷ Lu ($T_{1/2} = 6.647$ d) β^- decay.
1972Ho39	-4.5 (3)	From ICC ratios in ¹⁷⁷ Lu ($T_{1/2} = 6.647$ d) β^- decay.
1977Ke12	-4.8 (2)	From $\gamma(\theta)$ in ¹⁷⁷ Lu ($T_{1/2} = 6.647$ d) β^- decay.
1992De53	-4.85 (5)	From $\gamma\gamma(\theta)$ in ¹⁷⁷ Lu ($T_{1/2} = 6.647$ d) β^- decay.
Adopted	-4.4 (4)	$c2/(N-1) = 5.61$

2.2.2 136.7245 keV ($g_{2,1}$)

The adopted mixing ratios values of $\delta(\gamma_{2,1}) = -3.0 (7)$ is from 1974Kr12.

2.2.3 321.3159 keV ($g_{3,0}$)

Values used in the analysis of the mixing ratios are summarized in Table 5. The unweighted average value is adopted, but the uncertainty was expanded so that the range includes the most precise value of $\delta(\gamma_{1,0}) = +0.17(1)$ (1974Kr12). The sign of $\delta(\gamma_{3,0})$ was determined to be positive by 1974Kr12.

Table 5 Measured and adopted mixing ratios values for the 321.3159 keV transition

Reference	$|\delta(\gamma_{3,0})|$	Comment
1974Kr12	0.17 (1)	From $\gamma(\theta)$ in ^{177m} Lu ($T_{1/2} = 160.44$ d) decay
	0.42 (1)	From comparison between experimental $\alpha_K = 0.087(3)$, weighted average from values reported by 1972Gr35, 1974Ag01, 1974Je02 and 1961We11, and theoretical $\alpha_K(E1)$, and $\alpha_K(M2)$ values from 1978Ro22.
	0.42 (1)	From comparison between experimental $\alpha_L = 0.0169(8)$, weighted average from values reported by 1972Gr35, 1974Ag01, 1974Je02 and 1961We11, and theoretical $\alpha_L(E1)$, and $\alpha_L(M2)$ values from 1978Ro22.
Adopted	0.34 (17)	$c^2/(N-1) = 208.33$

2.2.4 208.3662 keV ($g_{3,1}$)

Values used in the analysis of the mixing ratios are given in Table 6. The weighted average and the internal uncertainty were adopted. The sign of $\delta(\gamma_{3,1})$ is uncertain. It has been reported to be positive by 1974Kr12, but negative by 1977Ke12 and 1961We11.

Table 6 Measured and adopted mixing ratios values for the 208.3662 keV transition

Reference	$|\delta(\gamma_{3,1})|$	Comment
1974Kr12	0.07 (2)	From $\gamma(\theta)$ in ^{177m} Lu ($T_{1/2} = 160.44$ d) decay
1977Ke12	0.08 (2)	From $\gamma(\theta)$ in ¹⁷⁷ Lu ($T_{1/2} = 6.647$ d) β^- decay
1961We11	0.07 (3)	From $\gamma\gamma(\theta)$ in ¹⁷⁷ Lu ($T_{1/2} = 6.647$ d) β^- decay
Adopted	0.074 (13)	$c^2/(N-1) = 0.07$

2.2.5 71.6418 keV ($g_{3,2}$)

Values used in the analysis of the mixing ratios are shown in Table 7. None of them has a relative statistical weight greater than 50%, and hence the weighted average value was adopted. The sign of $\delta(\gamma_{3,2})$ is negative as determined by 1974Kr12 and 1970Hr01.

Table 7 Measured and adopted mixing ratios values for the 71.6418 keV transition

Reference	$|\delta(\gamma_{3,2})|$	Comment
1974Kr12	0.051(37)	From $\gamma(\theta)$ in ^{177m} Lu ($T_{1/2} = 160.44$ d) decay.
1974Ag01	0.049 (15)	From comparison between experimental $\alpha_K = 0.90(11)$ from 1974Ag01 and theoretical $\alpha_K(E1)$, and $\alpha_K(M2)$ values from 1978Ro22.
1970Hr01	0.017 (7)	From $\gamma\gamma(\theta)$.
	0.016 (6)	From comparison between experimental $\alpha_{L1} = 0.076(5)$, weighted average from values reported by 1972Gr35 and 1974Ag01, and theoretical $\alpha_{L1}(E1)$, and $\alpha_{L1}(M2)$ values from 1978Ro22.
	0.034 (14)	From comparison between experimental $\alpha_{L2} = 0.029(3)$, weighted average from values reported by 1972Gr35 and 1974Ag01, and theoretical $\alpha_{L2}(E1)$, and $\alpha_{L2}(M2)$ values from 1978Ro22.
Adopted	0.018 (4)	$c^2/(N-1) = 0.37$

3. Atomic Data

3.1 Hf

The data are from Schönfeld and Janssen (1996Sc06).

3.1.1 X Radiation

While the energies for $XK\alpha_2$ (Hf) and $XK\alpha_1$ (Hf) are from Schönfeld and Rodloff (1999ScZX), the $XK\beta$ and XL energies are from Firestone (1996FiZX). Relative emission probabilities were calculated using the program EMISSION (2001Sc08).

3.1.2 Auger Electrons

The energies for KLL (Hf), KLX (Hf) and KXY (Hf) are from Schönfeld and Rodloff (1998ScZM). Relative emission probabilities were calculated using the program EMISSION (2001Sc08).

4. Photon Emission

4.1 X-Ray Emission

While the energies for $XK\alpha_2$ (Hf) and $XK\alpha_1$ (Hf) are from Schönfeld and Rodloff (1999ScZX), the $XK\beta$ and XL energies are from Firestone (1996FiZX). The adopted absolute intensities per 100 disintegrations were calculated using the program EMISSION (2001Sc08). Comparisons between calculated values and the experimental data in 2001Sc23 and 1987Me17, as well as values calculated using the program RADLST [2], are presented in Table 8. In general the agreement between various entries is fairly good, thus suggesting that the ¹⁷⁷Lu ground state decay scheme is complete.

Table 8 comparison between various X-ray emission intensities per 100 disintegration

	Energy KeV	2001Sc23	1987Me17	RADLST	EMISSION
XLI (Hf)	6.960	0.0735 (25)	0.087 (5)		0.0613 (16)
XL α_2 (Hf)	7.844	}	}		0.137 (4)
XL α_1 (Hf)	7.899	}	1.51 (3)	1.59 (6)	1.21 (3)
XL η (Hf)	8.139	}	}		0.0313 (9)
XL β_4 (Hf)	8.905	}	}		0.0335 (12)
XL β_1 (Hf)	9.023	}	1.34 (3)	}	1.15 (4)
XL β_6 (Hf)	9.023	}	}	1.76 (7)	0.0147 (4)
XL β_3 (Hf)	9.163	}	}		0.0435 (15)
XL $\beta_{2,15}$ (Hf)	9.342	0.274 (7)	}		0.248 (7)
XL γ_1 (Hf)	10.516	}	0.231 (6)	}	0.222 (6)
XL γ_6 (Hf)	10.733	}	}	}	0
				0.292 (12)	
XL γ_2 (Hf)	10.834	}	0.0223 (14)	}	0.00835 (19)
XL γ_3 (Hf)	10.890	}	}		0.0115 (4)
XL				3.08 (7)	3.18 (6)
XK α_2 (Hf)	54.6120 (7)	1.55 (3)	1.65 (3)	1.59 (5)	1.59 (3)
XK α_1 (Hf)	55.7909 (8)	2.73 (6)	2.84 (5)	2.78 (9)	2.78 (6)
XK β_1 (Hf)	62.985-63.662	0.885 (15)	0.919 (16)		0.917 (23)
XK β_2 (Hf)	64.942-65.316	0.238 (5)	0.252 (5)		0.245 (8)
XK β (Hf)				1.16 (4)	1.16 (3)

4.2 Gamma Emission

The measured relative intensities for transitions following the β^- decay of ¹⁷⁷Lu and their adopted values are presented in Table 9. The original values were normalized to $I_\gamma = 100.0$ for the 208.3662 keV ($\gamma_{3,1}$) gamma ray. The uncertainty in I_γ for the 321.3159 keV ($\gamma_{3,0}$) gamma ray was increased 1.86 times so that its statistical weight was lowered from 77.6% to 50%.

The measured absolute intensities for the 208.3662 keV ($\gamma_{3,1}$) gamma ray and its corresponding adopted value are presented in Table 10. The latter was used to normalize the relative intensities (Table 9) to absolute values per 100 disintegrations.

Table 9 - Relative gamma-ray intensities for transitions following β^- decay of ¹⁷⁷Lu

	$\gamma_{1,0}$	$\gamma_{2,1}$	$\gamma_{2,0}$	$\gamma_{3,2}$	$\gamma_{3,1}$	$\gamma_{3,0}$
2001Sc23	59.6 (6)	0.448 (8)	1.918 (17)	1.674 (21)	100.0	2.002 (19) *
1987Me17	59.6 (11)	0.457 (8)	2.00 (3)	1.71 (5)	100.0	2.17 (4)
1974Ag01	60 (5)	0.52 (5)	1.90 (20)	1.50 (10)	100.0	2.00 (20)
1964Al04	58 (4)	0.43 (3)	1.93 (14)	1.40 (10)	100.0	1.99 (14)
1961We11	62 (2)	0.47 (15)	2.00 (20)	0.30 (10) #	100.0	2.28 (10)
1955Ma12	45.5 #		1.36 #	0.91 #	100.0	1.45 (29) #
Adopted	59.7 (5)	0.453 (6)	1.938 (15)	1.663 (19)	100.0	2.08 (8)
c²/(N-1)	0.38	0.76	1.45	3.58		3.62

* The uncertainty was increased 1.86 times in order to reduce its statistical weight from 77.6% to 50%.

Value not used in the analysis.

Table 10 - Absolute emission probabilities per 100 disintegrations for the 208.3662 keV gamma ray

	Absolute Intensity for $\gamma_{3,1}$ per 100 disintegrations, %
2001Sc23	10.36 (7)
1964Cr02	10.7 (5)
1961We11	11.4 (6)
Adopted	10.38 (7)
c²/(N-1)	1.69

5. Electron Emission

The electron energies and emission probabilities were calculated using the RADLST [2] program. The average β^- energies were calculated using the LOGFT [3] program. The β^- transition endpoint energies were determined using $Q(\beta^-) = 498.3(8)$ keV (1995Au04) and the individual level energies that were deduced from a least-squares fit to the recommended gamma-ray energies. The adopted values for the β^- transition emission probabilities were determined from the total (photons + electrons) gamma-ray emission probability balances at each level.

References

[1] M. J. Woods and A. S. Munster, National Physics Laboratory, Teddington, UK, Rep. RS(EXT) 95, (1988)
 [2] The program RADLST, T. W. Burrows, report BNL-NCS-52142, February 29, 1988
 [3] The program LOGFT, NNDC
 1949Do05 - D. G. Douglas, Phys. Rev. 75, 1960 (1949) [P_{β^-}]
 1955Ma12 - P. Marmier, F. Boehm, Phys. Rev. 97, 103 (1955) [P_{β^-} , E_γ , I_γ]
 1956Wi39 - T. Wiedling, Thesis, Univ. Stockholm (1956) [P_{β^-}]
 1958Be41 - R. H. Betts, O. F. Dahlinger, D. M. Munro, Can. J. Phys. 36, 73 (1958) [$T_{1/2}$]

- 1960Sc19 - L. C. Schmid, W. P. Stinson, Nucl. Sci. Eng. 7, 477 (1960) [$T_{1/2}$]
 1961We11 - H. I. West, Jr., L. G. Mann, R. J. Nagle, Phys. Rev. 124, 527 (1961) [E_γ , I_γ , δ , ICC]
 1962El02 - M. S. El-Nesr, E. Bashandy, Nucl. Phys. 31, 128 (1962) [P_{β^-}]
 1964Al04 - P. Alexander, F. Boehm, E. Kankeleit, Phys. Rev. 133, B284 (1964) [P_{β^-} , E_γ , I_γ]
 1964Cr02 - D. F. Crouch, L. D. McIsaac, IDO-16932, p.26 (1964) [I_γ]
 1965Ma18 - B. P. K. Maier, Z. Physik 184, 153 (1965) [E_γ]
 1967Ha09 - A. J. Haverfield, F. M. Bernthal, J. M. Hollander, Nucl. Phys. A94, 337 (1967) [P_{β^-} , E_γ , I_γ]
 1970Hr01 - B. Hrastnik, I. Basar, M. Diksic, K. Ilakovac, V. Kos, A. Ljubicic, Z. Phys. 239, 25 (1970) [δ]
 1972Em01 - J. F. Emery, S. A. Reynolds, E. I. Wyatt, G. I. Gleason, Nucl. Sci. Eng. 48, 319 (1972) [$T_{1/2}$]
 1972Gr35 - V. N. Grigorev, D. M. Kaminker, Y. V. Sergeenkov, Izv. Akad. Nauk SSSR, Ser. Fiz. 36, 842 (1972); Bull. Acad. Sci. USSR, Phys. Ser. 36, 762 (1973) [ICC]
 1972Ho39 - S. Hogberg, R. Jadrny, S. E. Karlsson, G. Malmsten, O. Nilsson, Z. Phys. 254, 89 (1972) [δ]
 1972Ho54 - L. Holmberg, V. Stefansson, J. Becker, C. Bargholtz, L. Gidefeldt, Phys. Scr. 6, 177 (1972) [δ]
 1974Ag01 - A. P. Agnihotry, K. P. Gopinathan, H. C. Jain, Phys. Rev. C9, 336 (1974) [I_γ , ICC, δ]
 1974Je02 - B. D. Jeltama, F. M. Bernthal, Phys. Rev. C10, 778 (1974) [ICC]
 1974Kr12 - K. S. Krane, C. E. Olsen, W. A. Steyert, Phys. Rev. C10, 825 (1974) [$\gamma(\theta)$]
 1975El07 - Y. A. Ellis, B. Harmatz, Nucl. Data Sheets 16, 135 (1975) [nuclear data]
 1977Ke12 - H. E. Keus, W. J. Huiskamp, Physica 85B, 137 (1977) [δ]
 1978Ro22 - F. Rosel, H. M. Friess, K. Alder, H. C. Pauli, At. Data Nucl. Data Tables 21, 92 (1978) [ICC]
 1981Hn03 - V. Hnatowicz, Czech. J. Phys. B31, 260 (1981) [E_γ , I_γ]
 1982La25 - F. Lagoutine, J. Legrand, Int. J. Appl. Radiat. Isotop. 33, 711 (1982) [$T_{1/2}$]
 1987Me17 - D. Mehta, B. Chand, S. Singh, M. L. Garg, N. Singh, T. S. Cheema, P. N. Trehan, Nucl. Instrum. Methods Phys. Res. A260, 157 (1987) [I_γ]
 1989Ma56 - S. Matsui, H. Inoue, Y. Yoshizawa, Nucl. Instrum. Methods Phys. Res. A281, 568 (1989) [E_γ]
 1990Ab02 - A. Abzouzi, M. S. Antony, A. Hachem, V. B. Ndocko Ndongue, J. Radioanal. Nucl. Chem. 144, 359 (1990) [$T_{1/2}$]
 1992De53 - C. C. Dey, B. K. Sinha, R. Bhattacharya, Nuovo Cim. 105A, 1307 (1992) [δ]
 1993Br06 - E. Browne, Nucl. Data Sheets 68, 747 (1993) [nuclear data]
 1995Au04 - G. Audi, A. H. Wapstra, Nucl. Phys. A595, 409 (1995) [atomic masses]
 1996FiZX - R. B. Firestone, Table of Isotopes, 8th Ed., V. S. Shirley, C. M. Baglin, S. Y. F. Chu, J. Zipkin Eds., John Wiley and Sons, Inc., New York, Vol.2 (1996) [nuclear data]
 1996Sc06 - E. Schönfeld and H. Janssen, Nucl. Instrum. and Methods A369, 527 (1996) [atomic data]
 1998ScZM - E. Schönfeld, G. Rodloff, PTB-6.11-98-1 (1998) [KLL, KLX, KXY energies]
 1999ScZX - E. Schönfeld, G. Rodloff, PTB-6.11-1999-1 (1999) [X-ray energies]
 2001Sc08 - E. Schönfeld, U. Schötzig, Appl. Radiat. Isot. 54, 785 (2001) [Emission probabilities]
 2001Sc23 - U. Schötzig, H. Schrader, E. Schönfeld, E. Gunther, R. Klein, Appl. Radiat. Isot. 55, 89 (2001) [P_{β^-} , $T_{1/2}$, I_γ]
 2001Zi01 - B. E. Zimmerman, M. P. Unterweger, J. W. Brodack, Appl. Radiat. Isot. 54, 623 (2001) [$T_{1/2}$]
 2002KoXX - F. G. Kondev, Nuclear Data Sheets, 98, 801 (2003) [nuclear data]

¹⁸⁶Re - Comments on evaluation of decay data by E. Schönfeld and R. Dersch

This evaluation was completed in November 1998 and the half-life value has been updated in May 2004.

1 Decay Scheme

The decay scheme is taken from Baglin (1997). It is based mainly on the work of Fogelberg (1972), Seegmiller et al. (1972) and Maly et al. (1964). The latter two authors did not only study gammas, but also conversion electrons. There are EC branches to the 122 keV level and the ground state of ¹⁸⁶W (together 7,53 %) and beta branches to the ground state (70,9 %) and the excited states (21,5 %) in ¹⁸⁶Os. Spins and parities of the levels are taken from Baglin (1997), also the half-lives of the excited levels in ¹⁸⁶Os. The splitting into the EC and the beta part was calculated from the measured total W K-X ray emission probability. Beside the four excited levels of ¹⁸⁶Os given in the decay scheme, there is a level at 868,94(4) keV (6+). A direct beta transition to this level would be fifth forbidden and, therefore, would be too weak to be observed. The next higher level in ¹⁸⁶Os is at 1070,5 keV which is already above the adopted Q_{β} -value if the latter is correct.

¹⁸⁶W has below the Q_{EC} value a further level at 396,26 keV (4+; 36 ps). An EC transition to this level would be third forbidden, so this branch will be very weak, thus the decay scheme given on page 1 can be considered to be complete.

2 Nuclear Data

The following values of the half-life have been considered ($T_{1/2}$ in d):

1	3,750	Sinma et al. (1939); Fajans et al. (1940); Chu (1950)
2	3,792	Cork et al. (1940); Grant <i>et al.</i> (1945); Dybvig <i>et al.</i> (1950)
3	3,867(8)	Yamasaki et al. (1940)
4	3,867(8)	Goodman and Pool (1947)
5	3,704(8)	Porter et al. (1956)
6	3,775(13)	Gueben and Govaerts (1958)
7	3,777(4)	Michel and Herpers (1971)
8	3,775(1)	Abzouzi et al. (1989)
9	3,7187(29)	Unterweger et al. (1992)
10	3,7183(11)	Schönfeld et al. (1994) ; superseded by 11
11	3,7186(5)	Schrader (2004)
12	3,7186(17)	by the present evaluator adopted value

The adopted value is mainly based on values 9 and 11. The values 1 to 4 are considered to be only of historical interest. The remaining six values are discrepant: there is a group of three low values (5, 9, 11) and three high values (6, 7, 8). If values 6, 7 and 8 would be included in an averaging procedure, the mean value would be larger than value 12 and also its uncertainty. The present evaluator has not included values 6, 7 and 8 into the averaging procedure because of the well agreeing values 9, 10 and 11 which were measured in well equipped national instituts by experienced scientists whereas the consideration of radioactive impurities and other systematical uncertainties is not convincing in the papers 7 and 8. The value 10 is superseded by value 11 and was then not used for the mean.

Both Q values are taken from Audi and Wapstra (1995).

2.1 β^- Transitions

The maximum beta energy of the transition to the 137 keV level have been measured to be (values in keV)

1	934,3(13)	Porter et al. (1956)
2	927(2)	Johns et al. (1956)
3	937(14)	Bashandi and El Nesr (1963)
4	939(3)	Maly et al. (1964)
5	927(3)	Andre and Liaut (1968)
6	945(5)	Trudel et al. (1970)
7	932,8(21)	weighted mean

By adding the level energy of 137,1 keV to the weighted mean we obtain 1069,9 keV for the Q value which is in good agreement with the value given for Q_{β^-} by Audi and Wapstra: 1069,5(9) keV.

The energy of the $\beta_{0,1}$ transition in table 2.1 is deduced from the adopted Q_{β} value and the gamma ray energy. The spectra of the β transitions to the ground state and to the 137 keV level which are both non-unique first forbidden were found to have an almost allowed shapes. The total beta emission probability is calculated by subtracting the total EC probability (Section 2.2) from 1.

2.2 Electron Capture Transitions

The fractional capture probabilities of the transitions $\epsilon_{0,1}$ and $\epsilon_{0,0}$ were calculated using the data of Schönfeld (1998). The energies are derived from the Q values and the level energies. From the emission probability of the 122 keV γ ray (which was found to be 0,00603(6); original value of Schönfeld et al., 1994) and the conversion coefficient of this transition, the transition probability $P_{\gamma+ce}$ (which is also the transition probability of the electron capture branch to the 122 keV level) is obtained to be $P_{\gamma+ce} = P_{EC}(0,1) = 0,0169(3)$.

The transition probability of the electron capture transition feeding the ground state of ^{186}W can be calculated from the total emission probability of W KX rays. This emission probability is given by

$$P(\text{W KX}) = \left\{ P_{EC}(0,1) \left[P_K(0,1) + \mathbf{a}_K / (1 + \mathbf{a}_t) \right] + P_{EC}(0,0) P_K(0,0) \right\} \mathbf{w}_K.$$

Using the known values for P_K (Table 2.2), the conversion coefficients \mathbf{a}_K and \mathbf{a}_t (Table 2.3), and the fluorescence yield \mathbf{w}_K for tungsten, the transition probability $P_{EC}(0,0)$ can be extracted from the above expression. Using $P(\text{W KX}) = 0,0602(8)$ as determined by Schönfeld et al. (1994), one obtains $P_{EC}(0,0) = 0,0584(12)$.

Thus, the total electron capture probability amounts to $P_{EC}(0,1) + P_{EC}(0,0) = 0,0169(3) + 0,0584(12) = 0,0753(12)$.

2.3 Gamma Transitions

Concerning the energies see Sect. 4.2. The transition probabilities $P_{\gamma+ce}$ are calculated from the emission probabilities (Sect.4.2) and the total conversion coefficients. The conversion coefficients were interpolated from the tables of Rösler et al. (1978). Maly et al. have determined the K conversion coefficients as follows: $\alpha_K(122 \text{ keV}) = 0,53(5)$, $\alpha_K(137 \text{ keV}) = 0,44(2)$. Both are pure E2 transitions.

These values are in agreement with the theoretical ones. Maly et al. have also determined the ratios K/L/M/N for these two transitions. Mixing ratios for the transitions $\gamma_{4,3}$, $\gamma_{4,2}$, $\gamma_{3,1}$ and $\gamma_{4,1}$ were taken from Baglin (1997).

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energy values are calculated from the wave lengths in Å* as given by Bearden (1967). The relative emission probabilities of K X rays are taken from Schönfeld and Janßen (1996). The relative emission probabilities of L X rays is calculated from the absolute emission probability given in Table 4.2 setting $P(K_{a_1}) = 1$.

3.2 Auger Electrons

The energy values are taken from Larkins (1977) (KLL) and the Table de Radionucléides (LMRI 1982) (KLX, KXY). The relative emission probabilities of K Auger electrons are taken from Schönfeld and Janßen (1996). The relative emission probabilities of the L Auger electrons is calculated from the value in the table 4.1 putting $P(KLL) = 1$.

4 Radiation Emission

4.1 Electron Emission

The energies of the Auger electrons are the same as in 3.2. The energies of the conversion electrons are calculated from the transition energy (2.2) and the binding energies.

The emission probabilities of the conversion electrons are calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of the Auger electrons are calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3, and the conversion coefficients given in 2.2 using the Programm EMISSION.

4.2 Photon Emission

The energy of the X rays are from 3.1. The energy of the 137 keV gamma rays was determined by Marklund and Lindström (1963) using a curved-crystal spectrometer. The energies of the other γ rays are taken from Baglin (1997) who took into account also coulomb excitation and n, γ reactions.

The emission probability (photons per disintegration) of the 137 keV γ rays in ¹⁸⁶Os has been determined to be 0,0945(16) by Coursey et al. (1991) and 0,0939(9) by Schönfeld et al. (1994). Together with Baglin (1997) we take the unweighted mean 0,0942(6) as adopted value in the present evaluation in order to compare the results of different authors who carried out relative measurements. Then we have (normalized to this value) the following emission probabilities:

	1	2	3	4	5
W L X	0,0308(?)	-	-	0,0192(2)	0,0166(4)
W K _{a₂}	0,0178(4)	-	0,0172(5)	0,0176(4)	0,01736(30)
W K _{a₁}	0,0312(4)	-	0,0297(8)	0,0303(6)	0,0302(5)
W K _a	0,0490(6)	0,0445(13)	0,0469(10)	0,0479(8)	0,0475(8)
W K' _{b₁}	0,0109(2)	-	0,0099(4)	0,00989(20)	0,01000(23)
W K' _{b₂}	0,0034(2)	-	0,0026(2)	0,00269(6)	0,00274(8)
W K _b	0,0143(3)	-	0,0125(4)	0,01258(21)	0,1273(29)
W K X	0,0633(7)	-	0,0594(11)	0,0605(8)	0,0603(10)
Os L X	0,0300(3)	-	-	0,0306(34)	0,0299(7)
Os K _{a₂}	0,0114(2)	-	0,0113(4)	0,0112(3)	0,01128(26)
Os K _{a₁}	0,0199(4)	-	0,0193(6)	0,0196(4)	0,0194(5)
Os K _a	0,0313(5)	0,0286(6)	0,0306(7)	0,0308(5)	0,0307(7)
Os K' _{b₁}	0,0067(2)	-	0,0066(3)	0,00635(14)	0,00650(18)
Os K' _{b₂}	0,00198(20)	-	0,00170(6)	0,00186(4)	0,00182(6)
Os K _b	0,0087(2)	-	0,0083(3)	0,00821(15)	0,00833(23)
Os K X	0,0400(6)	-	0,0389(7)	0,0390(5)	0,0390(9)
W γ 122	0,00603(20)	0,00598(10)	0,00604(23)	0,00605(6)	0,00603(6)
Os γ 137	≅0,0942(6)	≅0,0942(6)	≅0,0942(6)	≅0,0942(6)	≅0,0942(6)
Os γ 630	-	0,00032(3)	0,000292(6)	0,000294(6)	0,000293(6)
Os γ 767	-	0,00037(4)	0,000324(7)	0,000328(6)	0,000327(6)

1 Seegmiller et al. (1972)

2 Coursey et al. (1991)

3 Goswamy et al. (1991)

4 Schönfeld et al. (1994)

5 calculated with EMISSION (X rays); values adopted by the present evaluator (gammas)

In all cases there is excellent agreement. Relative values for the emission probabilities of the gamma rays were also determined by Johns et al. (1956), Maly et al. (1964) and Rao et al. (1969). These values are less accurate and were not taken into account in the present evaluation. The emission probabilities and the energies of the gamma rays of the very weak gamma transitions in ¹⁸⁶Os (not contained in the above table) were determined by Fogelberg (1972) which is the only one to report these values.

Multiplying the adopted value for $P_\gamma(122)$ by $1 + a_t(122)$ we obtain, in agreement with table 2.2, $P_{EC}(122) = 0,0169$.

Values, recently measured by Miyahara *et al.* (2000) and Woods *et al.* (2000) are also in good agreement with the here adopted values.

5 Main Production Modes

Taken from the „Table des Radionucléides“, LMRI, 1982.

6 References

- K. Sinma and H. Yamasaki, *Phys. Rev.* 55 (1939) 320
 $[T_{1/2}]$
- K. Fajans and W. H. Sullivan, *Phys. Rev.* 58 (1940) 276
 $[T_{1/2}]$
- J. M. Cork, R. G. Shreffler and C. M. Fowler, *Phys. Rev.* 74 (1940) 1657
 $[T_{1/2}]$
- H. Yamasaki and K. Sinma, *Sci. Pap. Inst. Phys. Chem. Res. Tokyo* 37 (1940) 10
 $[T_{1/2}]$
- P. J. Grant and R. Richmond, *Proc. Phys. Soc.* 62A (1945) 573
 $[T_{1/2}]$
- L. J. Goodman and M. L. Pool, *Phys. Rev.* 71 (1947) 288
 $[T_{1/2}]$
- A. T. Dybvig and M. L. Pool, *Phys. Rev.* 80 (1950) 126
 $[T_{1/2}]$
- T. C. Chu, *Phys. Rev.* 79 (1950) 582
 $[T_{1/2}]$
- D. Guss, L. Killion, F. T. Porter, *Phys. Rev.* 95 (1954) 627
 $[E, \lg ft]$
- M. W. Johns, C. C. Mac Mullen, I. R. Williams, S. V. Nablo, *Can. J. Phys.* 34 (1956) 69
 $[P_{\beta}]$
- F. T. Porter, M. S. Freedman, T. B. Novey, F. Wagner jr., *Phys. Rev.* 103 (1956) 921
 $[E_{\gamma}, P_{\beta}]$
- T. B. Novey, M. S. Freedman, F. T. Porter, F. Wagner, Jr., *Phys. Rev.* 103 (1956) 942
 $[E_{\beta}, E_{\gamma}, \text{angular correlation}]$
- E. L. Chupp, A. F. Clark, J. W. M. Dumond, F. J. Gordon, H. Mark, *Phys. Rev.* 107 (1957) 745
 $[E_{\gamma}]$
- G. Gueben and J. Govaerts, *Monographie* Nr. 2, Inst. Interuniv. Sciences Nucleares, Bruxelles (1958)
 $[T_{1/2}]$
- G. T. Emery, W. R. Kane, M. Mac Keown, M. L. Perlman, G. Scharff-Goldhaber,
Phys. Rev. 129 (1963) 2597
 $[E_{\gamma}, P_{\gamma}]$
- B. Harmatz, T. H. Handley, *Nucl. Phys.* 56 (1964) 1
 $[E_{\gamma}]$
- R. Michel, U. Herpers, *Radiochim. Acta* 16 (1971) 115
 $[T_{1/2}]$
- A. Abzouzi, M S. Antony, V. B. Ndocko Ndongue, *J. Radioanal. Cl. Chem. Letters* 137 (1989) 381
 $[T_{1/2}]$

For additional references see also § References in the Tables Part.

¹⁹⁸Au - Comments on evaluation of decay data by E. Schönfeld and R. Dersch

1 Decay Scheme

In addition to the 411,8 keV level (2+) and the 1087,7 keV level (2+), ¹⁹⁸Hg has an excited level at 1048,5 keV (4+, half-life 1,80(8) ps) which is below the Q value. Its spin 4 was deduced from $\gamma\gamma$ angular correlation in ¹⁹⁸Tl EC decay and its positive parity from the E2 character of the γ transition to the 2+ level. A β transition from the ¹⁹⁸Au (2-) ground state to this level ($\Delta J = 2$ and parity change, $E_b^{\max} = 323,7$ keV) would be unique 1st forbidden and was not observed. From $\lg ft$ systematics ($\lg ft \geq 8,5$) an upper limit of 0,004 for the transition probability to this level was derived.

Iwata and Yoshizawa (1980) estimated the probability of a possible EC transition leading to the ground state of ¹⁹⁸Pt (unique first forbidden) to be less than 0,0017 % from $\lg ft$ systematics, i. e. negligible for most purposes.

2 Nuclear Data

The following values of the half-life have been considered ($T_{1/2}$ in d):

1	2,7	Mc Millan et al. (1937)
2	2,73(2)	Diemer and Groendijk (1946)
3	2,69(1)	Silver (1949)
4	2,69	Saxon and Heller (1949)
5	2,73(2)	Sinclair and Holloway (1951)
6	2,66(1)	Cavanagh et al. (1951)
7	2,697(3)	Lockett and Thomas (1953)
8	2,699(3)	Bell and Yaffe (1954)
9	2,686(5)	Tobailem (1955)
10	2,697(3)	Johansson (1956)
11	2,694(6)	Sastre and Price (1956)
12	2,704(4)	Keene et al. (1958)
13	2,699(4)	Robert (1960)
14	2,687(5)	Starodubtsev (1964)
15	2,694(4)	Anspach et al. (1965)
16	2,693(5)	Reynolds et al. (1966)
17	2,697(5)	Lagoutine et al. (1968)
18	2,695(7)	Goodier (1968)
19	2,695(2)	Vuorinen and Kaloinen (1969)
20	2,696(4)	Costa Paiva and Martinho (1970)
21	2,6946(10)	Cabell and Wilkins (1970)
22	2,693(3)	Debertin (1971)
23	2,6937(2)	Merritt and Gibson (1977)
24	2,6935(4)	Rutledge et al. (1980)
25	2,695(2)	Hoppes et al. (1982)
26	2,6966(7)	Abzouzi et al. (1990)
27	2,69517(21)	Unterweger et al. (1992)
28	2,6837(50)	Mignonsin (1994)
29	2,6944(8)	LWM, adopted value

Values 1 - 6 are only of historical interest. Value 25 is not used because it is replaced by value 27. Value 28 was rejected because identified as outlier by LWM. The adopted value 29 is a weighted average of 20 values with expanded uncertainty so range includes the most precise value 23 which contributes 43 % to the mean. The reduced

χ^2 is 2,9. The adopted value 29 is very close to the value recommended in the IAEA-TECDOC 619 (2,6943(8)) - based on 16, 17, 18, 19 - 22, 24, 25.

Nyikos et al. (1973) studied the influence of the chemical surrounding on the half-life of ¹⁹⁸Au and found $\lambda(\text{Au}) - \lambda(\text{Au}_2\text{O}_3)/\lambda(\text{Au}) = (1,0 \pm 0,3) \cdot 10^{-4}$. If this result is correct, it would need to be taken into account if any additional very precise values are reported. This chemical shift is comparable to the uncertainties for values 23 and 27.

The *Q* value was calculated by adding the level difference $\gamma_{1,0}$ (411,8 keV) to the evaluated maximum beta energy of the beta transition $\beta_{0,1}$ (960,4 keV). This value is 1372,2(10) compared to the Audi and Wapstra (1995) value of 1372,4(5) keV.

2.1 b⁻ Transitions

For the evaluation of the maximum energy of the beta transition $\beta_{0,1}$ the following values were considered:

1	958,8(16)	weighted mean of eight results 1948 - 1954 cited by Dzhelepov et al. 1955
2	959,0(25)	Elliott et al. 1954
3	960(2)	Porter 1956
4	962(1)	Depommier and Chabre 1961, as recalculated by Beekhuis and de Waard
5	964(3)	Graham 1961, as recalculated by Beekhuis and de Waard
6	960(3)	Hamilton et al. 1962
7	957(5)	Sharma et al. 1962
8	959(2)	Lewin et al. 1963
9	965(2)	Lehmann 1964
10	960,5(8)	Keeler and Connor 1965
11	961,0(12)	Paul 1965
12	962(1)	Lewin 1965
13	959,4(5)	Beekhuis and de Waard 1965, value which is cited in their text
14	960,4(5)	LWM with external uncertainty; reduced $\chi^2 = 1.54$
15	960,4(10)	adopted value with an uncertainty enlarged to cover the most precise value 13

The values of Wapstra et al. (1958) and de Vries (1960) were not used; they are replaced by value 8. The values 4 and 5 are recalculated by Beekhuis and de Waard (1965). The most precise values are 4 and 10 to 13. The maximum beta energies of the other beta transitions were calculated from the maximum beta energy of the transition $\beta_{0,1}$ and level differences taken from γ ray measurements.

2.2 Gamma Transitions

The energies of the level differences are calculated from the γ ray energies (section 4.2) and the recoil energies.

The probabilities $P_{\gamma+ce}$ were calculated from the γ ray emission probabilities (see section 4.2) and the conversion coefficients.

For the conversion coefficients of the 411,8 keV γ transition the following values were considered:

	a_K	a_L	a_M	a_t	
1	0,0301(5)				Lewin et al. 1963
2	0,0302(4)				Bergkvist and Hultberg 1964
3	0,0299(4)	-	-	0,0444(5)	Keeler and Connor 1964
4	0,0308(9)				Petterson et al. 1965
5	0,0299(2)				Paul 1965
6	0,0302(4)	-	-	0,0447(6)	Bosch and Szichman 1967
7	0,0301(3)				Nagarajan et al. 1972
8	0,03035(45)				El-Nesr and Mousa 1973
9	0,0300(3)	-	-	0,043(4)	Reddy 1976

10	0,03005(12)			0,0445(4)	LWM of the exp. values
11	0,03016	0,01073	0,00268	0,04439	interpol. from Rösel et al. 1978 (theory)
12	0,0301(2)	-	-	0,044(2)	Hansen 1985 evaluated
13	0,0301(2)	0,01091(25)	0,0027(2)	0,0447(5)	adopted in the present eval.

For a_K there is good agreement between measured values and the theory (value 10 and value 11). The arithmetic mean between 10 and 11 is taken as finally adopted value. It coincides with the value 12 evaluated by Hansen (1985). The uncertainty is estimated from the difference between theory and experiment and the spread of the experimental values. The values given for a_L and a_M are calculated from the adopted value for a_K and the adopted ratios (see below). A value for a_t is calculated as the sum of a_K , a_L and a_{MNO} , where a_{MNO} is calculated from the ratio $MNO/L = 0,347(6)$ according to Kel'man and Metskhvarisvili. The result is 0,0448(4). With respect to the experimental value 10 the finally adopted value for a_t was taken to be 0,447(5).

For the ratios of the conversion coefficients the following values were found:

	K/L	K/LM	K/LMN	
1	2,69(2)	2,15(4)	2,00(4)	Kel'man and Metskhvarishvili 1959
2	-	-	2,08(6)	Bosch and Szichman 1967
3	-	2,06	-	Keeler and Connor 1964
4	2,79(4)	-	-	Herrlander and Graham 1964
5	-	2,17(8)	-	Kurey and Roy 1963
6	2,54(6)	-	1,98(5)	Parsignault 1966
7	2,75(10)	-	-	Bogdanovich et al. 1968
8	-	-	2,36(60)	Reddy 1976
9	2,70(5)	2,16(4)	2,01(3)	LWM of exp. values
10	2,81	2,25	2,12	Theory (Rösel et al., 1978)
11	2,76(6)	2,21(6)	2,06(6)	In this evaluation adopted values

Herrlander and Graham (1964) cited for K/L taken from theory 2,72 (Sliv and Band, 1958) and 2,75 (Rose, 1958). These values are slightly lower than the value which was interpolated from the tables of Rösel (value 10). The adopted values are in all cases the unweighted mean between experiment (values 9) and theory (value 10). The uncertainties of the adopted values were taken with a look to the differences experiment - theory and the spread of the experimental values. The one value without uncertainty in the above table was not included in the averaging procedure. L and M subshell ratios were determined by Kel'man and Metskhvarishvili 1959, Herrlander and Graham 1964 and Dragoun et al. 1972.

Values for the K conversion coefficients of the two other γ transitions are:

	1	2	3	4
676 keV	0,0224(19)	0,019(5)	0,03(1)	0,0211(15)
1088 keV	0,00450(31)	0,0046(6)	0,0046(6)	0,00419(12)

- 1 Elliot et al. 1954 based on $a_K(412) = 0,0317$; $K/L = 5,7(5)$ and $6,3(5)$
- 2 Volpe and Hinman 1956
- 3 Bosch and Szichman 1967
- 4 Theory, Rösel et al. 1978; the value for the 676 keV transition is based on a mixing ratio of 44(5) % M1 + 56(5) % E2.

There is agreement between experiment and theory within the quoted uncertainties.

From the conversion electron ratio measured by Elliot et al. (1954) a value for the emission probability of the 676 keV gamma quanta can be derived:

$$P_g(676) = \frac{ce_K(676)}{ce_K(412)} \cdot \frac{a_K(412)}{a_K(676)} \cdot P_g(412)$$

The three factors on the right hand side are 0,0059(2) (from Elliot et al.), 1,43(5) (from theory) and 0,9554(7) (from the present evaluation). This gives $P_g(676) = 0,00806(39)$ in excellent agreement with the present evaluation but with a greater uncertainty.

The M1 admixture to the 676 keV E2 + M1 transition was determined to be:

	% M1	δ	
1	52(5)	- 0,96(10)	Schrader et al. 1953
2	40(10)	- 1,22(22)	Schiff and Metzger 1953
3	32(6)		Elliot et al. 1954
4	36(23)		Volpe and Hinmann 1956
5	33(4)	- 1,43(14)	Sakai et al. 1964
6	45(5)	- 1,1	Béraud et al. 1965
7	39(4)	- 1,26(8)	Uhl and Wahaneck 1966
8	36(4)	- 1,34(9)	Koch et al. 1967
9	43(6)	- 1,14(16)	Pakkanen 1971
10	54(2)		Venkata Ramana 1972
11	39,4(25)		Kawamura and Tomiyama 1974
12	44,3(25)		weighted mean of 1 - 11
13	44(5)		adopted value with an uncertainty enlarged to cover the most precise value, value 11

Values 1, 2 and 4 - 11 were derived from $\gamma\gamma$ angular correlation measurements of the 676-412 keV cascade. For the 1088 keV transition we assumed pure E2 character and assigned an uncertainty of 3 % to the conversion coefficients interpolated from the tables of Rösels et al. (1978).

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energy values are calculated from the wave lengths in Å* as given by Bearden (1967).

The relative emission probabilities of K X rays are taken from Schönfeld and Janßen (1996).

The relative emission probability of L X rays is calculated from the value in table 4.2 putting $P(K_{a_1}) = 1$.

3.2 Auger Electrons

The energy values are taken from Larkins (1977) (KLL) and the Table de Radionucléides (LMRI 1982) (KLX, KXY). The relative emission probabilities of K Auger electrons are taken from Schönfeld and Janßen (1996).

The relative emission probabilities of the L Auger electrons is calculated from the value in table 4.1 putting $P(KLL) = 1$.

4 Radiation Emission

4.1 Electron Emission

The energies of the Auger electrons are the same as in 3.2. The energies of the conversion electrons are calculated from the transition energy (2.2) and the binding energies.

The emission probabilities of the conversion electrons are calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of the Auger electrons are calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3 and the conversion coefficients given in 2.2. and the program EMISSION.

4.2 Photon Emission

The energy of the X rays are the same as in 3.1. The energies of the gamma rays were taken from Helmer (2000). They are mainly based on measurements of Deslattes et al. (1980).

The emission probabilities of the K X rays were determined with the program EMISSION using the evaluated atomic data, transition probabilities and conversion coefficients. The total emission probabilities of L X rays was also calculated with the help of the program EMISSION.

For the relative γ -ray emission probabilities the following values were taken into account:

	411,8 keV	675,9 keV	1087,7 keV
1	100	1,5	0,4
2	100	1,4(1)	0,25(5)
3	100	1	0,2
4	100	1,3	0,25
5	100	0,842(56)	0,170(12)
6	100	1,11(5)	0,26(2)
7	100	1,0	0,28
8	100	0,75	0,15
9	100	0,841(5)	0,1664(22)
10	100	0,846(11)	0,165(4)
11	100	0,844(7)	0,166(3)

- 1 Cavanagh et al. 1951
- 2 Hubert 1951
- 3 Brosi et al. 1951
- 4 Maeder et al. 1954
- 5 Elliott et al. 1954
- 6 Dzhelepov et al. 1955
- 7 Keeler and Connor 1965
- 8 Bosch and Szichman 1967
- 9 Iwata and Yoshizawa 1980, recalculated from 100,0(4) to 100 for the 411,8 keV line
- 10 Chand et al. 1989, recalculated from 100,0(8) to 100 for the 411,8 keV line
- 11 Adopted values (LRSW of 5, 9 and 10)

The normalization factor f_N was calculated from

$$\left[P_g(412) \left(1 + a_t(412) \right) + P_g(1088) \left(1 + a_t(1088) \right) \right] \cdot f_N = 1 - P_b(1372)$$

With the evaluated values of the total conversion coefficients and $P_\beta(1372) = 0,00025(5)$ as measured by Elliot et al. 1954, we obtained $f_N = P_\gamma(412) = 0,9554(7)$.

Concerning KX/γ ratios there is excellent agreement between the values recommended by Campbell and Mc Nelles (1975) and the values evaluated in the present paper:

	Campbell	calculated
$P(K_{\alpha})/P_{\gamma}(412)$	0,0229(5)	0,0228(2)
$P(K_{\beta})/P_{\gamma}(412)$	0,00635(15)	0,00630(10)

For the emission probabilities of X rays the following values were considered:

	Energy in keV	1	2	3
L_{ℓ}	8,7213(6)	0,00027(3)	0,00020(16)	-
L_{α}	9,90-9,99	0,00592(17)	0,00440(30)	-
L_{β}	10,6514(9)	0,000105(15)	0,00008(1)	-
L_{η}	11,36-12,56	0,00643(19)	0,00483(35)	-
L_{γ}	13,41-14,47	0,00124(5)	0,00130(10)	-
L_{total}	8,72-14,47	0,01397	0,01081	0,0121(2)
K_{a_2}	68,8952(12)	0,00816(24)	-	0,00809(8)
K_{a_1}	70,8196(12)	0,0141(4)	-	0,01372(12)
K'_{b_1}	79,82-80,75	0,00485(12)	-	0,00466(8)
K'_{b_2}	82,44-83,04	0,00137(7)	-	0,00136(4)
K_{total}	68,89-83,04	0,0285(5)	-	0,02784(22)

1 Chand et al. 1989

2 Beghzanov et al. 1987

3 calculated values = adopted values in this evaluation

In the case of the K X rays there is agreement between measured and calculated values within the quoted uncertainties.

5 Main Production Modes

Taken from Zhou Chunmei (1995).

6 References

- E. Mc Millan, M. Kamen, S. Ruben, *Phys. Rev.* 52 (1937) 531
 $[T_{1/2}]$
 C. Diemer, H. Groendijk, *Physica* 11 (1946) 396
 $[T_{1/2}]$
 L. M. Silver, *Can. J. Phys.* 29 (1950) 59; *Phys. Rev.* 76 (1949) 589
 $[T_{1/2}]$
 D. Saxon, R. Heller, *Phys. Rev.* 75 (1949) 909
 $[T_{1/2}]$
 A. Brosi, B. Ketelle, H. Zeldes, E. Fairstein, *Phys. Rev.* 84 (1951) 586
 $[P_{\gamma}]$
 M. Hubert, *Compt. Rend.* 232 (1951) 2201
 $[P_{\gamma}]$
 W. K. Sinclair, A. F. Holloway, *Nature* 167 (1951) 365
 $[T_{1/2}]$
 P. E. Cavanagh, J. F. Turner, D. V. Booker, H. J. Dunster, *Proc. Phys. Soc. (London)* 64A (1951) 13
 $[T_{1/2}, P_{\gamma}]$
 D. Schiff and F. R. Metzger, *Phys. Rev.* 90 (1953) 849

- [δ 676 keV]
 C. D. Schrader, E. B. Nelson and J. A. Jacobs, *Phys. Rev.* 90 (1953) 159
- [δ 676 keV]
 E. E. Lockett, R. H. Thomas, *Nucleonics* 11 (1953) 14
- [$T_{1/2}$]
 D. Maeder, R. Mueller, V. Wintersteiger, *Helv. Phys. Acta* 27 (1954) 3
- [P_γ]
 R. E. Bell, L. Yaffe, *Can. J. Phys.* 32 (1954) 416
- [$T_{1/2}$]
 B. S. Dzhelepov, N. N. Zhukovski, V. P. Prikhodtseva and Iu. V. Kholnov, *Bull. Acad. Sci.(USSR)* 19 (1955) 247
- [P_γ]
 J. Tobailem, *J. Phys. Rad.* 16 (1955) 48
- [$T_{1/2}$]
 J. Volpe and G. Hinmann, *Phys. Rev.* 104 (1956) 753
- [δ 676 keV]
 F. T. Porter, M. S. Friedman, T. B. Novey and F. Wagner Jr., *Phys. Rev.* 103 (1956) 921
- [E_β]
 K.-E. Johansson, *Arkiv Fysik* 10 (1956) 247
- [$T_{1/2}$]
 C. Sastre, G. Price, *Nucl. Sci. Eng.* 1 (1956) 325
- [$T_{1/2}$]
 J. P. Keene, L. A. Mackenzie, C. W. Gilbert, *Phys. Med. Biol.* 2 (1958) 360
- [$T_{1/2}$]
 J. Robert, *J. Phys.Rad.* 21 (1960) 808
- [$T_{1/2}$]
 R. L. Graham (1961), privat communication quoted by Depommier and Chabre (1961)
- [E_β]
 J. H. Hamilton et al., *Nuclear Physics* 36 (1962) 567
- [E_β]
 R. P. Sharma, S. H. Devare and B. Saraf, *Phys. Rev.* 125 (1962) 2071
- [E_β]
 V. Starodubtsev et al., *Izv. Akad. Nauk.U SSR, Ser. Fiz.-Mat. Nauk* 2 (1963) 44;
Nucl. Sci. Abstr. 18 (1964) 9348
- [$T_{1/2}$]
 W. H. G. Lewin, B. van Nooyen, C. W. E. van Eijk and A. H. Wapstra, *Nucl. Phys.* 48 (1963) 159
- [E_β]
 T. J. Kurey, Jr. and P. R. Roy, *Nucl. Phys.* 44 (1963) 670
- [K/LM]
 M. Sakai, M. Nozawa, H. I. Kegami and T. Yamazaki, *Nucl. Phys.* 53 (1964) 529
- [δ]
 J. Lehmann, *J. Phys.* 25 (1964) 326
- [E_β]
 S. C. Anspach, L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, NBS Misc. Publ. 260-9 (1965);
 NP-15663
- [$T_{1/2}$]
 D. Parsignault, Internal Conversion Processes, J. H. Hamilton (ed.), Acad. Press,
 New York (1966) p. 173
- [K/L, K/LMN]
 M. Uhl, H. Warhanek, *Oesterr. Akad. Wiss. Sitzber. Math-Nat. Kl., Abt. II* 175 (1966) 77
- [δ 676 keV]
 S. A. Reynolds, J. F. Emery, E. I. Wyatt, *Nucl. Sci. Eng.* 32 (1966) 46
- [$T_{1/2}$]
 J. A. Bearden, *Rev. Mod. Phys.* 39 (1967) 78
- [E_X]
 J. Koch, F. Münnich and U. Schötzig, *Nucl. Phys.* A103 (1967) 300
- [δ 676 keV]
 F. Lagoutine, Y. Le Gallic, J. Legrand, *Int. J. Appl. Rad. Isotopes* 19 (1968) 475
- [$T_{1/2}$]
 I. W. Goodier, *Int. J. Appl. Rad. Isotopes* 19 (1968) 823
- [$T_{1/2}$]

- M. Bogdanovich, M. Mladjenovich, R. Stepich, *Nucl. Phys.* A106 (1968) 209
 [K/L]
 O. Dragoun, B. Martin, D. Merkert and M. Vinduska, *Nucl. Phys.* A183 (1972) 390
 [a_M , a_N , a_O]
 P. Nyikos, H. B. Bier, P. Huberit, H. R. Kobel, H. Leuenberger, *Helv. Phys. Acta* 46 (1973) 444
 [$T_{1/2}$]
 J. L. Campbell, L. A. Mc Nelles, *Nucl. Instr. Meth.* 125 (1975) 205
 [X/ γ]
 R. G. Deslattes, E. G. Kessler, W. C. Sauder, A. Henins, *Ann. Phys. (New York)* 129 (1980) 378
 [E_γ]
 T. S. Reddy, thesis Andhra Univ., Waltair, India (1976)
 [a_K]
 B. Chand, J. Goswamy, D. Mehta, N. Singh, P. N. Trehan, *Nucl. Instr. Meth.* A284 (1989) 393
 [P_γ , P_X]
 E. P. Mignonsin, *Appl. Radiat. Isotopes* 45 (1994) 17
 [$T_{1/2}$]
 Zhou Chunmei, Nuclear Data Sheets Update for A = 198, *NDS* 74 (1995) 259
 [production modes]
 E. Schönfeld and H. Janßen, *Nucl. Instr. Meth.* A369 (1996) 527
 [ω_K , ω_L , n_{KL} , K_β/K_{α_1} , KLX/KLL , KXY/KLL]

²⁰¹Tl - Comments on evaluation of decay data by E. Schönfeld

This evaluation was completed in May 1997 and the half life value has been updated in May 2004.

1 Decay Scheme

Above the 167 keV level and below available energy there are three levels of ²⁰¹Hg: 384,601(18) keV (5/2-), 414,522(17) keV (7/2-) ; 21,3 ps, and 464,41(3) keV (5/2-); 2,6 ps. EC transitions to these levels would be (in the above order) unique first forbidden / nonunique third forbidden and unique first forbidden. But, these transitions have not been observed in the decay of ²⁰¹Tl. If these transitions do not exist, then the decay scheme on page 1 is complete.

2 Nuclear Data

The following values of the half-life have been considered ($T_{1/2}$ in d):

1	3,00(13)	Neumann and Perlman (1950)
2	3,063(33)	Herrlander et al. (1960)
3	3,0380(7)	Debertin et al. (1979) ; superseded by 6
4	3,0408(14)	Lagoutine and Legrand (1982); originally given $3\sigma = 0,0040$ d
5	3,0447(9)	Hoppes et al. (1982) ; superseded by 7
6	3,043(3)	Schrader (1989) ; superseded by 10
7	3,0456(15)	Unterweger et al. (1992)
8	3,0400(28)	Simpson and Meyer (1994)
9	3,038(17)	de Souza (2004)
10	3,0486(30)	Schrader (2004)
11	3,0421(17)	adopted value with external uncertainty, present evaluation

Values 1 and 2 are only of historical interest. Value 5 is superseded by value 7 and value 3 by value 6 and then by value 10. The LWM of values 4, 7, 8, 9 and 10 is given as value 11, the reduced χ^2 is 4,3.

The Q_{EC} value 483(15) keV is taken from Audi and Wapstra (1995).

2.1 Electron Capture Transitions

The adopted values P_K , P_L , P_M , P_N were calculated from the table of Schönfeld (1995) using the Q_{EC} value of Audi and Wapstra (1995) and the binding energies of Hg. These values are:

ΔE keV	P_K	P_L	P_M	P_{NO}
316(15)	0,724(7)	0,206(7)	0,054(2)	0,016(2)
451(15)	0,758(3)	0,181(3)	0,0461(12)	0,025(2)
483(15)	0,763(3)	0,178(3)	0,0451(12)	0,014(2)

The above values are in excellent agreement with the values calculated by Funck and Nylandstedt Larsen (1983) although the latter have no assigned uncertainties:

to level keV	P_K	P_L	P_M
167	0,7230	0,2016	0,0549
32	0,7567	0,1813	0,0474
1,6 and 0	0,7613	0,1779	0,0464

They are also in agreement with the values given by Lagoutine in the Table des Radionucléides (1984). It has to be mentioned that Lagoutine used different transition energies. His values are:

ΔE keV	P_K	P_L	P_{MN}
321(15)	0,730(5)	0,206(3)	0,064(2)
456(15)	0,762(5)	0,182(3)	0,056(2)
488(15)	0,767(5)	0,178(3)	0,055(2)

The transition probabilities of the EC transitions were calculated by

$$P_{e_{0,4}} = P_{g+ce_{4,0}} + P_{g+ce_{4,1}} + P_{g+ce_{4,2}} + P_{g+ce_{4,3}}$$

$$P_{e_{0,3}} = P_{g+ce_{3,0}} + P_{g+ce_{3,1}} + P_{g+ce_{3,2}} - P_{g+ce_{4,3}}$$

$$P_{e_{0,1}} + P_{e_{0,0}} = 1 - (P_{e_{0,4}} + P_{e_{0,3}})$$

2.2 Gamma Transitions

The energies of the main transitions are measured by Herrlander et al. (1960) via the conversion energies. The present values are taken from S. Rab (1994).

Herrlander et al. (1960) have measured the $L_1/L_2/L_3$ ratios of the 30,6 keV, 32,19 keV, 135,34 keV and 167,43 keV. By comparing the experimental values with theoretical ones the multipolarity of all this transitions were proved to be M1. For the 165,88 keV an E 2 mixture of up to 7 % could not be excluded. The present multipolarities and conversion coefficients are taken from Rab (1994). The transition probabilities are calculated from the gamma-ray emission probabilities (4.2) and the total conversion coefficients.

3 Atomic data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energy values are calculated from the wavelengths in Å* as given by Bearden (1967).

The relative emission probabilities of K X rays are taken from Schönfeld and Janßen (1996).

3.2 Auger Electrons

The energy values are taken from Larkins (1977) (KLL) and the Table de Radionucléides (LMRI 1982) (KLX, KXY). The relative emission probabilities of K Auger electrons are taken from Schönfeld and Janßen (1996). The relative emission probabilities of the L Auger electrons is calculated from the value in the table 4.1 putting $P(KLL) = 1$.

4 Radiation Emission

4.1 Electron Emission

The energies of the Auger are the same as in 3.2. The energies of the conversion electrons are calculated from the transition energy (2.2) and the binding energies.

The emission probabilities of the conversion electrons are calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of the Auger electrons are calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3 and the conversion coefficients given in 2.2.

4.2 Photon Emission

The energy of the X rays are the same as in 3.1. For the relative K X ray emission probabilities and the relative γ ray emission probabilities it has been found

E_γ in keV	1	2	3	4	5	6	7	8	9
30,60	2,2(2)	3,10(13)	2,35(25)	2,57(6)	2,60(8)	2,60(8)	2,53(5)	2,58(5)	-
32,19	2,2(2)	2,85(12)	2,69(34)	2,60(9)	2,60(7)	2,72(6)	2,58(5)	2,63(5)	-
68,90 K_{a_2}		274(9)	243(15)	261(7)		270(4)		268(4)	273(5)
70,82 K_{a_1}		466(14)	412(25)	446(12)		442(6)		446(6)	464(7)
K_a		740(23)	655(29)	707(14)	722(13)	712(7)		715(7)	737(11)
80,2 K_{b_1}				153(4)				153(4)	157(4)
82,5 K_{b_2}				45,9(15)				45,9(15)	46,1(13)
K_b		205(7)	182(11)	199(16)	205(4)	195(5)		202(5)	203(5)
135,34	26,5(13)	26,5(10)	31(4)	26,4(3)	26,5(4)	27,2(5)	25,65(18)	26,04(22)	-
165,88	1,6(1)	1,80(20)	1,6(3)	1,5(2)	1,46(20)	1,45(2)	1,55(5)	1,47(2)	-
167,43	100	100,0(17)	100(8)	100,0(11)	100,0(10)	100,0(12)	100	100,0(10)	-

1: Hofmann and Walcher (1975)

2: Nass (1977)

3: Martin (1976)

4: Debertain et al. (1978)

5: Funck et al. (1983)

6: Kawada et al. (1990)

7: Coursey et al. (1990)

8: LWM (without 3)

9: Calculated from atomic data, EC data and conversion coefficients. Adopted and recommended values for the X rays.

The values in column 8 are the LWM from 1, 2, 4 - 7 (the values 3 are less reliable). The uncertainties were taken not smaller than the minimum of a single value. Between values 8 and 9 there is not in all cases 1σ overlapping. The transformation from relative emission probabilities to absolute emission probabilities was made using the absolute transition probability for the 167 keV transition $P_\gamma(167) = 0,1000(10)$ as determined by Coursey et al. (1990) from absolute activity measurements..

5 Main Production Modes

Taken from the "Table de Radionucléides", LMRI, 1982.

6 References

R. K. Gupta, *Arkiv Fysik* 17 (1960) 337

C. J. Herrlander, R. Stockendal, R. K. Gupta, *Arkiv Fysik* 17 (1960) 315

[KLL, KXL, KXY]

D. Reyes-Suter, T. Suter, *Arkiv Fysik* 20 (1961) 415

[$T_{1/2}$ 32 keV level in ²⁰¹Hg]

S. Rab, *Nuclear Data Sheets* 71 (1994) 421

[Multipolarities]

M. Neumann, I. Perlman, *Phys. Rev.* 78 (1950) 191

[$T_{1/2}$]

And also see the Tables Part.

²⁰³Hg – Comments on evaluation of decay data by A.L. Nichols

Evaluated: April 2001

Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

The simple and consistent decay scheme is dominated by beta decay to the first excited state of ²⁰³Tl, followed by a single gamma transition to the ground state.

Nuclear Data

The single well-characterised gamma ray at 279.1952(10) keV and the 46.6-day half-life of ²⁰³Hg make this radionuclide of some value as a standard in the calibration of γ -ray detectors.

Half-life

Half-life adopted from the evaluation of Woods et al (2004) for the IAEA-CRP: Update of X- and Gamma-ray Decay Data Standards for Detector Calibration. The measurements of 1968La10, 1972Em01, 1980Ho17, 1980RuZY, 1983Wa26 and 1992Un01 were considered.

Reference	Half-life (days)
1968La10	47.000(30)*
1972Em01	46.760(80)*
1980Ho17	46.582(2)#
1980RuZY	46.600(10)
1983Wa26	46.612(19)
1992Un01	46.619(27)
Recommended value	46.593(7)

* Removed from evaluated data set due to large deviation from mean.

Uncertainty adjusted to ± 0.008 to reduce weighting below 0.5.

Woods evaluation for IAEA-CRP (2004WoZZ): recommended half-life of 46.594(12) days (using above dataset).

Gamma Rays

Energy

The gamma-ray energy and uncertainty recommended by 2000He14 were adopted. This energy is in good agreement with the nuclear level energy of the first excited state of ²⁰³Tl as specified by 1985Sc23 and 1993Ra11.

Emission Probability

The 279.1952 keV gamma transition is of mixed M1 + E2 multipolarity, and α_{tot} of 0.2271(12) and α_{K} of 0.1640(10) have been adopted from the evaluation of 1985HaZA, in good agreement with various measurements (1962Ta06, 1964He19, 1974Ha29, 2000Sc05). A small uncertainty was assigned to these two parameters because of the high degree of confidence in the data. The gamma transition probability of 0.9999(1) was deduced as described below, and used in conjunction with α_{tot} to calculate an absolute emission probability of 0.8148(8).

Multipolarity and Internal Conversion Coefficients of 279.1952 keV Gamma Ray

The comprehensive assessment of 1985HaZA provides accurate estimates for α_{tot} of 0.2271(12) and α_{K} of 0.1640(10), and a multipolarity of close to 25%M1 + 75%E2. These values have been adopted, and used to calculate the other α components in terms of the recommended value of α_{tot} . The selected data set used by 1985HaZA to determine α_{tot} and α_{K} is included in the table below (see footnotes); not all measurements are listed (see 1985HaZA for further details).

Internal conversion coefficients for 279.1952 keV gamma ray – selected measurements

	1956Wa30	1958Ni28	1960Pe22	1961Su10	1962Ta06*	1963Bu09*
α_{tot}	-	-	0.227(8)	-	0.2273(24) [#]	-
α_{K}	0.164(5) [#]	0.163(3) [#]	0.164(6) [#]	0.164(4) [#]	0.1642(21) [#]	0.165(9) [#]
α_{L}	0.049(2)	0.0487(12)	-	-	-	-
$\alpha_{\text{M+}}$	-	-	-	-	-	-

	1963Cr14	1964He19	1972Sa34	1972WaYL*	1974Ha29	2000Sc05
α_{tot}	-	-	0.149(9) 0.156(9)	0.2267(16) [#]	0.2279(24) [#]	0.2250(12)
α_{K}	0.162(3) [#]	0.163(3) [#]	-	-	0.1653(17) [#]	-
α_{L}	-	0.0484(6)	-	-	0.0475(13)	-
$\alpha_{\text{M+}}$	-	0.0153(4)	-	-	-	-

* Data adjusted by 1985HaZA from the published values.

[#] Values adopted in an evaluation by 1985HaZA.

Internal conversion coefficients of 279.1952 keV gamma ray – theoretical values and 1985HaZA evaluation

	1978Ro22*	1985HaZA [‡]	Recommended Values
α_{tot}	0.231(7)	0.2271(12)	0.2271(12)
α_{K}	0.161(5)	0.1640(10)	0.1640(10)
α_{L}	0.053(2)	-	0.0476(2)
$\alpha_{\text{M+}}$	0.017(5)	-	0.0155(2)

* Interpolated values for 25%M1 + 75%E2, with 3% uncertainty.

[‡] Hansen used three α_{tot} and nine α_{K} values (see previous table) to derive recommended values, which were originally selected from six α_{tot} and twenty-eight α_{K} values respectively.

Beta-particle Emissions

Energies

The beta-particle energies were calculated from the proposed decay scheme. The nuclear level energies of 1993Ra11 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the first excited state (dominant) and ground level.

Emission Probabilities

The beta-particle emission probabilities were calculated from the limits set on the beta transition to the ground state by 1955Ma40 and 1956Wo09. Beta-decay branch to $\frac{1}{2}^+$ Ground State of ²⁰³Tl:

	1955Ma40	1956Wo09	Recommended Values
$P_{\beta} (5/2^- \rightarrow 1/2^+)$	<0.00004	<0.0003	0.0001(1)
$\log f^{int}$	-	>11.3	11.6(4)

A value of 0.0001(1) was recommended from these studies. Hence, the beta-particle emission probability was defined as 0.9999(1) for the transition to the first excited state of ²⁰³Tl ($5/2^- \rightarrow 3/2^+$).

Beta-particle Emission Probabilities

$E_b(\text{keV})$	P_b
	Recommended Values*
212.6(12)	0.9999(1)
491.8(12)	0.0001(1)

* Recommended emission probabilities derived from the postulated limit of the beta branch to the ²⁰³Tl ground state.

Atomic Data

The X-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

References

- 1955Ma40 - N. Marty, Sur la Désintégration de ²⁰³Hg, C. R. Acad. Sc. Paris, 240B(1955)291-294. [P_β]
 1956Wa30 - A. H. Wapstra and G. J. Nijgh, Indications for a Strong Influence of the Nuclear Size on Magnetic Dipole Conversion Coefficients, Nucl. Phys. 1(1956)245-258. [ICC]
 1956Wo09 - J. L. Wolfson, High-energy Forbidden β-ray Transitions from Cs¹³⁴ (2.3 y), Co⁶⁰ (5.3 y), Sc⁴⁶ (84 d) and Hg²⁰³ (47.9 d), Can. J. Phys. 34(1956)256-264. [P_β, transition type]
 1958Ni28 - G. J. Nijgh, A. H. Wapstra, L. Th. M. Ornstein, N. Salomons-Grobbe, J. R. Huizenga and O. Almén, Conversion Coefficients of Gamma Transitions in ²⁰³Tl, Nucl. Phys. 9(1958/59)528-537. [ICC]
 1960Pe22 - R. W. Peelle, Determination of the Internal Conversion Coefficient of the 279-keV Gamma Ray in Tl²⁰³ by Absolute Coincidence Techniques, Oak Ridge National Laboratory Report ORNL 3016(1960)116-125. [ICC]
 1961Su10 - Z. Sujkowski, Beta Spectrometric Study on the Decay of Pb²⁰³ and the K Auger Spectrum of Tl, Ark. Fys. 20, No. 16 (1961) 243-267. [ICC]
 1962Ta06 - J. G. V. Taylor, The Total Internal Conversion Coefficient of the 279-keV Transition Following the Decay of Hg²⁰³ as Measured by a New Coincidence Method, Can. J. Phys. 40(1962)383-392. [ICC]

- 1963Bu09 - R. Burmeister, H. Graber, J. Schintlmeister and R. Weibrecht, Bestimmung des K Konversionskoeffizienten des 279 keV-Übergangs in Tl²⁰³, Nucl. Phys. 42(1963)56-61. [ICC]
- 1963Cr14 - W. L. Croft, B. G. Pettersson and J. H. Hamilton, The K-conversion Coefficient of the 279 keV Transition in Tl²⁰³ by a Coincidence Technique and Establishment as a Standard, Nucl. Phys. 48(1963)267-272. [ICC]
- 1964He19 - C. J. Herrlander and R. L. Graham, Penetration Effects in the K and L Internal Conversion Coefficients of the 279 keV Transition in Tl²⁰³, Nucl. Phys. 58(1964)544-560. [ICC]
- 1968La10 - F. Lagoutine, Y. Le Gallic and J. Legrand, Determination Precise de Quelques Periodes Radioactives, Int. J. Appl. Radiat. Isot. 19(1968)475-482. [Half-life]
- 1972Em01 - J. F. Emery, S. A. Reynolds, E. I. Wyatt and G. I. Gleason, Half-Lives of Radionuclides – IV, Nucl. Sci. Eng. 48(1972)319-323. [Half-life]
- 1972Sa34 - H. S. Sahota, On the Measurement of K-shell Internal Conversion Coefficients with an X-ray Scintillation Spectrometer, Indian J. Phys. 46(1972)86-92. [ICC]
- 1972WaYL - K. F. Walz, H. M. Weiß and E. Funck, Bestimmung des Koeffizienten der inneren Konversion beim 279 keV-Übergang des ²⁰³Hg, PTB Jahresbericht 1971 (1972)150-151. [ICC]
- 1974Ha29 - H. H. Hansen and D. Mouchel, Internal Conversion Coefficients and Penetration Effect for the 279 keV Transition in ²⁰³Tl, Z. Phys. 267(1974)371-377. [ICC]
- 1978Ro22 - F. Rösel, H. M. Fries, K. Alder and H. C. Pauli, Internal Conversion Coefficients for all Atomic Shells, ICC Values for Z = 68-104, At. Data Nucl. Data Tables 21(1978)291-514. [ICC]
- 1980Ho17 - H. Houtermans, O. Milosevic and F. Reichel, Half-lives of 35 Radionuclides, Int. J. Appl. Radiat. Isot. 31(1980)153. [Half-life]
- 1980RuZY - A. R. Rutledge, L. V. Smith and J. S. Merritt, Decay Data for Radionuclides Used for the Calibration of X- and Gamma-Ray Spectrometers, AECL-6692(1980). [Half-life]
- 1983Wa26 - K. F. Walz, K. Debertain and H. Schrader, Half-Life Measurements at the PTB, Int. J. Appl. Radiat. Isot. 34(1983)1191. [Half-life]
- 1985HaZA - H. H. Hansen, Evaluation of K-shell and Total Internal Conversion Coefficients for Some Selected Nuclear Transitions, European Appl. Res. Rept. - Nucl. Sci. Technol. 6, No.4(1985)777-816; EUR 9478 EN. [ICC]
- 1985Sc23 - M. R. Schmorak, Nuclear Data Sheets for A = 203, Nucl. Data Sheets 46(1985)287. [Nuclear structure, Energies]
- 1992Un01 - M. P. Unterweger, D. D. Hoppes and F. J. Schima, New and Revised Half-Life Measurements Results, Nucl. Instrum. Meth. Phys. Res. A312(1992)349-352. [Half-life]
- 1993Ra11 - S. Rab, Nuclear Data Sheets Update for A = 203, Nucl. Data Sheets 70(1993)173. [Nuclear structure, Energies]
- 1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409. [Q value]
- 1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527-533. [X_K, X_L, Auger electrons]
- 1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]
- 1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]
- 2000He14 - R. G. Helmer and C. van der Leun, Recommended Standards for γ -ray Energy Calibration (1999), Nucl. Instrum. Meth. Phys. Res. A450(2000)35-70. [E _{γ}]
- 2000Sc05 - E. Schönfeld, H. Janßen and R. Klein, Redetermination of the Total Internal Conversion Coefficient of the 279 keV Transition Following the Decay of ²⁰³Hg, Appl. Radiat. Isot. 52(2000)955-956. [ICC]
- 2004WoZZ - M. J. Woods, Half-life Evaluations for IAEA-CRP on “Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications” (2004). [Half-life evaluation]

²⁰⁴Tl – Comments on evaluation
by M. M. Bé and V. Chisté

The electron capture transition to the Hg-204 ground state is first forbidden unique, so the P_K/P_L ratio strongly depends on the decay energy. In this evaluation the Q^+ value from Audi and Wapstra has been adopted. However, if this value changes, P_K and P_L , as well as the decay branching ratios, must be reevaluated.

Nuclear Data

Spin and parity assignments are from Schmorak (1994Sc24).

Experimental Q^+ values

The following experimental values have been noted from publications :

Reference	Value in keV	Uc	
Biavati(1962Bi04)	310	10	393 quoted in Klein
Leutz (1962Le05)	410	+30 – 23	As quoted by Christmas
Christmas (1964Ch17)	313	+17 – 14	
Klein (1966Kl02)	324	+21 – 16	
Lancman (1973La17)	385	20	
Zide (1979Zi02)	357	15	
Audi (1995Au04)	347,5	15	
Audi (2002)	345,0	13	Adopted

In the 1995Au04 publication, Audi recommended 347,5(15) keV for the Q^+ energy, but a new mass determination of Hg-204 (2002Be) leads to the value of 345,0(13) keV (Audi on the AMDC web site) from the atomic mass differences. As these mass measurements were performed with Penning trap facility, the resulting Q value is considered to be more reliable than the other values quoted in the above table.

Adopted Q values

Q^- value is from Audi and Wapstra (1995Au04)

$Q^- = 763,72 (18) \text{ keV}$

$Q^+ = 345,0 (13) \text{ keV}$

Half-life

Reference	Value (years)	Uc	Comments
Anspach (1965An07)	3,754	0,004	
Horroks (1968Ho07)	3,825	0,003	
Bortels (1969Bo24)	3,774	0,008	Uc for 1 σ
Jordan (1969Jo02)	3,7730	0,0028	Uc for 1 $\sigma \times 1,5$
Harbottle (1970Ha32)	3,793	0,005	
Adopted	3,788	0,015	

The uncertainty for one standard deviation given by Jordan has been multiply by 1,5. The set of five values quoted above is quite discrepant with a reduced- χ^2 of 64,3. The Lweight program has calculated a weighted average of 3,788 years with an external uncertainty of 0,013, which was increased to 0,015 to include the most precise value.

Electron capture sub shell probabilities

The adopted values have been calculated with the LOGFT program for a unique 1st forbidden transition and $Q = 345,0$ (13) keV.

$$P_K = 0,5843(14) ; P_L = 0,3024(10) ; P_{M^+} = 0,1133(5)$$

Several measurements of the P_L/P_K ratio were carried out :

Reference	P_L/P_K	P_K/P_{b^-}	Branching ratio %
Christmas (1964Ch17)	0,600 (55)	0,01590 (36)	2,54 (12)
Joshi (1961JO12)	0,42 (5)	0,0155 (10)	
Leutz (1962Le05)	0,41 (3)		
Klein (1966KI02)	0,55 (5)	0,0153 (5)	2,15 (6)
Weighted mean	0,47 (3)		
Adopted values	0,518 (2)		2,92 (13)

Branching ratios

From the Xk emissions intensities measured by Schötzig (1990Sc08), $I_{XK} = 1,64(7)$, and using $P_K = 0,5843(14)$ and $\omega_K = 0,962(4)$, the electron capture branching ratio $P\epsilon$ becomes:

$$P\epsilon = I_{XK} / (P_K \times \omega_K) = 2,92(13) \%$$

$$\text{And then } P\beta^- = 97,08(13) \%$$

Atomic data

All the atomic data : $\omega_K = 0,962(4)$ etc. and ratio K_β/K_α etc. are from Schönfeld (1996Sc06).

Photons emissions*X-ray emissions*

The X_K emission intensities are those measured by Schötzig.

Reference		I(%)	Uc
Schotzig (1990Sc08)	Hg- $K_{\alpha 2}$	0,474	0,020
	Hg- $K_{\alpha 1}$	0,812	0,034
	Hg- $K_{\beta 1}$	0,273	0,010
	Hg- $K_{\beta 2}$	0,081	0,003
	Pb- $K_{\alpha 2}$	$4,4 \cdot 10^{-3}$	0,3
	Pb- $K_{\alpha 1}$	$6,1 \cdot 10^{-3}$	0,3
	Pb- $K_{\beta 1}$	$2,7 \cdot 10^{-3}$	0,2
	Pb- $K_{\beta 2}$	$7,3 \cdot 10^{-4}$	0,2

The X_L emission intensities have been calculated by using the Emission program after addition of the PL1, etc. values.

The ratio $K\text{-Auger} / \beta^- = 6,7(8) \cdot 10^{-4}$, deduced from the evaluated data, can be compared with the measured value, $K\text{-Auger} / \beta^- = 4,9(28) \cdot 10^{-4}$ given by Park and Christmas (1967Pa08).

Internal bremsstrahlung

Internal bremsstrahlung accompanying capture of orbital electrons is about (3×10^{-5}) photons per K capture.

References

- 1962Bi04 M. H. Biavati, S. J. Nassiff, C. S. Wu, Phys. Rev. 125,4 (1961) 1364 ; Q
 1961Jo12 B. R. JOSHI, Proc. Phys. Soc. 77 (1961) 1205 ; PL/PK
 1962Le05 H. LEUTZ, K. ZIEGLER, Z. Phys. 166 (1962) 582 ; Q, P_L / P_K
 1964Ch17 P. CHRISTMAS, Nucl. Phys. 55 (1964) 577 ; Q
 1965An07 S. C. Anspach et al., Report NBS 260-9 (1965) ; $T_{1/2}$
 1966Ki02 H. KLEIN, H. LEUTZ, Nucl. Phys. 79 (1966) 27 ; Q
 1967Pa08 J. J. H. Park, P. Christmas, Can. J. Phys. 45 (1967) 2621 ; $K\text{-Auger} / \beta^-$
 1968Ho07 D. L. HORROCKS, Nucl. Phys. A110 (1968) 238 ; $T_{1/2}$
 1969Bo24 G. BORTELS, Int. J. Appl. Radiat. Isotop. 20 (1969) 613 ; $T_{1/2}$
 1969Jo02 K. C. JORDAN, J. H. BIRDEN, B. C. BLANKE, J. Inorg. Nucl. Chem. 31 (1969) 2641 ; $T_{1/2}$
 1970Ha32 G. HARBOTTLE, Radiochim. Acta 13 (1970) 132 ; $T_{1/2}$
 1973La17 H. Lancman, A. Bond, Phys. Rev. C 7, 6 (1973) 2600 ; Q
 1979Zi02 A. ZIDE, H. LANCMAN, Phys. Rev. C19 (1979) 1053 ; Q
 1990Sc08 U. Schötzig, Nucl. Instrum. Methods A286 (1990) 523 ; KX emission intensities
 1994Sc24 M. R. Schmorak, Nucl. Data Sheets 72,3 (1994) 409 ; spin and parity
 1995Au04 G. Audi, A. H. Wapstra, Nucl. Phys. A 595 (1995) 409 ; Q
 1996Sc06 E. Schönfeld, H. Janssen, Nucl. Instrum. Methods A369 (1996) 527 ; atomic data
 2002Be I. Bergström et al., Nucl. Instrum. Methods A487 (2002) 618 ; Q^+

**²⁰⁸Tl – Comments on evaluation of decay data
by A. L. Nichols**

Evaluated: July/August 2001

Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A consistent decay scheme has been derived, assuming no direct beta decay to the 2614.55 keV and ground states of ²⁰⁸Pb (based on spin-parity considerations). This decay scheme is primarily based on the gamma-ray measurements of 1960Em01, 1960Sc07, 1961Si11, 1969Au10, 1969Pa02, 1969La23, 1972Ja25, 1972DaZA, 1975Ko02, 1977Ge12, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07, 1992Li05 and 1993El08.

Nuclear Data

²²⁸Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ²³²Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (²²⁴Ra alpha decay to ²²⁰Rn; ²¹²Bi and ²⁰⁸Tl gamma-ray emissions).

Half-life

The half-life is the weighted mean of the measurements of 1957Ba05, 1967La20, 1970Mu21 and 1971Ac02, with the uncertainty increased artificially to encompass the most precise study. Further measurements are merited to confirm the recommended value of 3.060(8) min.

Reference	Half-life (min)
1957Ba05	3.090(15)
	3.099(12)
1967La20	3.055(6)
1970Mu21	3.17(5)
1971Ac02	3.0527(33)*
Recommended Value	3.060(8)#

* Uncertainty adjusted to ± 0.0050 to reduce weighting below 0.5.

Weighted mean adopted, with uncertainty increased to include most precise value.

Gamma Rays

Energies

Both the 583.187(2)- and 2614.511(10)-keV gamma-ray energies were taken from 2000He14. All other gamma-ray transition energies were calculated from the structural details of the proposed decay scheme; the nuclear level energies of 1986Ma17 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

A consistent decay scheme has been constructed from the gamma-ray measurements of 1960Em01, 1960Sc07, 1961Si11, 1969Au10, 1969Pa02, 1969La23, 1972Ja25, 1972DaZA, 1975Ko02, 1977Ge12,

1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07, 1992Li05 and 1993El08. The study of 1975Ko02 is particularly comprehensive, along with the gamma-ray measurements of 1993El08 below 1000 keV. Gamma-ray emission probabilities have been expressed relative to the 2614.51 keV transition, and specific sets of data were adjusted accordingly (some of the original measurements were quantified relative to the 583.19 keV gamma ray or as absolute emission probabilities, while minor modifications were made to the relevant emission probabilities for the partially resolved 277.37, 510.7 and 583.19 keV gamma rays as reported by 1983Sc13). 1993El08 observed additional gamma rays (808.3 and 835.9 keV) that were introduced into the proposed decay scheme, along with the previously unplaced 1125.7 and 1647.5 keV gamma rays.

Published Gamma-ray Emission Probabilities

E _g (keV)	P _g						
	1960Em01	1960Sc07	1961Si11		1969Au10*	1969La23	1969Pa02
211.4(2)	-	-	-	-	-	0.20(5)	0.17(8)
233.3(1)	-	0.3	-	-	-	0.30(5)	0.33(17)
252.5(2)	1.5(7)	1.1	-	-	-	0.8(1)	0.70(11)
277.37(3)	6.9(8)	8.6	-	7.2(7)	-	6.9(5)	6.5(4)
485.8(1)	-	0.1(1)	-	-	-	0.07(4)	0.05(2)
510.7(1)	23(2)	25.3(12)	24(3)	22.5(25)	-	23(1)	22.5(12)
583.187(2)	86.4(56)	85.1(40)	81(5)	84(5)	100	85(4)	86(4)
587.8(2)	-	-	-	-	-	-	-
650.2(2)	-	-	-	-	-	-	-
705.3(2)	-	-	-	-	-	-	-
722.0(1)	-	-	)	-	-	0.3(1)	0.27(8)
748.7(2)	-	-	) 22.5(20)	-	-	-	-
763.2(1)	1.9(5)	3.4(2)	)	3.6(7)	-	2.0(2)	1.68(8)
808.3(2)	-	-	-	-	-	-	-
821.1(2)	-	-	-	-	-	-	0.09(4)
835.9(2)	-	-	-	-	-	-	-
860.56(3)	11.4(12)	14.2(6)	15.3(20)	15.2(15)	-	13(1)	12.0(8)
883.4(2)	-	-	-	-	-	-	-
927.6(2)	-	-	-	-	-	0.15(5)	0.13(3)
982.7(2)	-	-	-	-	-	0.20(5)	0.20(3)
1004(2)	-	-	-	-	-	-	~ 0.01
1093.9(1)	-	0.7(1)	~ 2	-	-	0.5(1)	0.38(5)
1125.7(4)	-	-	-	-	-	-	-
1160.8(2)	-	-	-	-	-	-	-
1185.2(3)	-	-	-	-	-	-	-
1282.8(3)	-	-	-	-	-	-	0.05(2)
1381.1(5)	-	-	-	-	-	-	0.02(1)
1647.5(7)	-	-	~ 3	-	-	-	~ 0.01
1743.9(2)	-	-	-	-	-	-	-
2614.511(10)	100	(100)	100	100	116.7(24)	100	100

Published Gamma-ray Emission Probabilities (cont.)

E _g (keV)	P _g (cont.)					
	1972DaZA	1972Ja25	1975Ko02	1977Ge12*	1978Av01	1982Sa36†
211.4(2)	0.16(4)	-	0.17(2)	-	-	-
233.3(1)	~ 0.2	-	0.31(3)	-	-	-
252.5(2)	0.8(2)	-	0.80(5)	-	0.62(4)	0.28(3)
277.37(3)	6.6(13)	6.2(7)	6.8(3)	-	6.1(2)	2.4(1)
485.8(1)	0.04(1)	-	0.050(5)	-	-	-
510.7(1)	22.9(23)	21.9(7)	21.6(9)	-	22.8(7)	7.8(4)
583.187(2)	85.0(85)	86.0(4)	86(3)	100	85	30.0(14)
587.8(2)	~ 0.04	-	0.04(2)	-	-	-
650.2(2)	-	-	0.036(5)	-	-	-
705.3(2)	~ 0.02	-	0.022(4)	-	-	-
722.0(1)	0.21(6)	-	0.203(14)	-	0.27(2)	-
748.7(2)	0.05(1)	-	0.043(4)	-	-	-
763.2(1)	1.7(3)	-	1.64(9)	-	1.82(9)	0.7(1)
808.3(2)	-	-	-	-	-	-
821.1(2)	0.04(1)	-	0.040(4)	-	-	-
835.9(2)	-	-	-	-	-	-
860.56(3)	11.8(12)	11.5(10)	12.0(4)	14.79(15)	13.9(6)	4.2(2)
883.4(2)	~ 0.025	-	0.031(3)	-	-	-
927.6(2)	0.13(4)	-	0.125(1)	-	-	-
982.7(2)	0.20(6)	-	0.197(15)	-	-	-
1004(2)	-	-	< 0.005	-	-	-
1093.9(1)	0.37(7)	-	0.37(4)	-	-	-
1125.7(4)	-	-	0.005(2)	-	-	-
1160.8(2)	-	-	0.011(3)	-	-	-
1185.2(3)	-	-	0.017(5)	-	-	-
1282.8(3)	~ 0.05	-	0.052(5)	-	-	-
1381.1(5)	-	-	0.007(3)	-	-	-
1647.5(7)	-	-	0.002(1)	-	-	-
1743.9(2)	-	-	0.002(1)	-	-	-
2614.511(10)	100	(100)	100	118.5(16)	(100)	-

Published Gamma-ray Emission Probabilities (cont.)

E _g (keV)	P _g (cont.)				
	1983Sc13 [‡]	1983Va22 [#]	1984Ge07 [*]	1992Li05	1993El08 [¶]
211.4(2)	-	-	0.228(20)	-	0.18(1)
233.3(1)	-	-	0.31(4)	-	0.30(1)
252.5(2)	-	-	0.955(13)	-	0.77(2)
277.37(3)	2.33(7)	2.29(4)	7.55(6)	2.54(7) [§]	6.88(12)
485.8(1)	-	-	-	-	0.055(11)
510.7(1)	7.90(23)	8.31(14)	26.9(9)	-	22(1)
583.187(2)	30.7(8)	30.8(6)	100.0(6)	29.4(7) [§]	86(3)
587.8(2)	-	-	-	-	0.07(1)
650.2(2)	-	-	-	-	0.065(11)
705.3(2)	-	-	-	-	-
722.0(1)	-	-	0.31(6)	-	0.27(2)
748.7(2)	-	-	-	-	0.054(9)
763.2(1)	0.73(5)	-	2.15(2)	0.651(40)	1.72(8)
808.3(2)	-	-	-	-	0.029(7)
821.1(2)	-	-	-	-	0.041(17)
835.9(2)	-	-	-	-	0.075(11)
860.56(3)	4.55(12)	-	14.78(9)	4.32(15)	12.6(7)
883.4(2)	-	-	-	-	-
927.6(2)	-	-	-	-	0.13(1)
982.7(2)	-	-	-	-	0.21(1)
1004(2)	-	-	-	-	-
1093.9(1)	-	-	0.525(8)	-	0.47(4)
1125.7(4)	-	-	-	-	-
1160.8(2)	-	-	-	-	-
1185.2(3)	-	-	-	-	-
1282.8(3)	-	-	-	-	0.049(13)
1381.1(5)	-	-	-	-	-
1647.5(7)	-	-	-	-	-
1743.9(2)	-	-	-	-	-
2614.511(10)	35.6(11)	-	119.1(21)	-	98.1(13)

* Emission probabilities relative to P_γ(583.19 keV) of 100.

† Emission probabilities relative to P_γ(583.19 keV) of 30.0.

‡ Emission probabilities relative to P_γ(583.19 keV) of 30.7.

Emission probabilities relative to P_γ(583.19 keV) of 30.8.

¶ Absolute emission probabilities.

§ Unresolved overlap with another gamma-ray emission.

Specific emission probabilities deviated significantly from the equivalent measurements from other laboratories:

252.5 keV gamma ray: 1960Em01 and 1978Av01;

485.8 keV gamma ray: 1960Sc07;

510.7 keV gamma ray: 1960Sc07;

583.19 keV gamma ray: 1961Si11;

763.2 keV gamma ray: 1960Sc07 and 1961Si11;

860.56 keV gamma ray: 1960Sc07, 1961Si11 and 1978Av01;

927.6 keV gamma ray: 1969La23;

1093.9 keV gamma ray: 1960Sc07.

These particular values were judged to be outliers, and were not included in the weighted-mean analyses. Other gamma-ray emission probabilities were not reported with uncertainties within 1960Sc07, along with the 583.19 keV gamma-ray emission in 1978Av01; these data were also not included in the weighted-mean analyses. 1982Sa36 and 1983Va22 reported measurements that did not include the main 2614.511 keV gamma-ray transition: the evaluated relative emission probability of the 583.19 keV gamma ray was adopted to create data sets comparable with the other studies, hence the assumed P_γ(583.19 keV) was not included in the analyses under these circumstances.

An uncertainty of 2% was determined for the relative emission probability of the 2614.511 keV gamma ray, as derived from the emission probabilities and uncertainties reported by 1969Au10, 1977Ge12, 1983Sc13, 1984Ge07 and 1993El08:

Reference	P _g (2614.551 keV)
1969Au10	100(2)
1977Ge12	100.0(14)
1983Sc13	100(3)
1984Ge07	100(2)
1993El08	100.0(13)
Recommended Value	100(2)

Gamma-ray Emission Probabilities: Relative to P_g(2614.551 keV) of 100

E _g (keV)	P _g ^{rel}						
	1960Em01	1960Sc07	1961Si11		1969Au10	1969La23	1969Pa02
211.4(2)	-	-	-	-	-	0.20(5)	0.17(8)
233.3(1)	-	0.3 [§]	-	-	-	0.30(5)	0.33(17)
252.5(2)	1.5(7) [†]	1.1 [§]	-	-	-	0.8(1)	0.70(11)
277.37(3)	6.9(8)	8.6 [§]	-	7.2(7)	-	6.9(5)	6.5(4)
485.8(1)	-	0.1(1) [†]	-	-	-	0.07(4)	0.05(2)
510.7(1)	23(2)	25.3(12) [†]	24(3)	22.5(25)	-	23(1)	22.5(12)
583.187(2)	86.4(56)	85.1(40)	81(5) [†]	84(5)	85.7(18)	85(4)	86(4)
587.8(2)	-	-	-	-	-	-	-
650.2(2)	-	-	-	-	-	-	-
705.3(2)	-	-	-	-	-	-	-
722.0(1)	-	-	)	-	-	0.3(1)	0.27(8)
748.7(2)	-	-	) 22.5(20) [‡]	-	-	-	-
763.2(1)	1.9(5)	3.4(2) [†])	3.6(7) [†]	-	2.0(2)	1.68(8)
808.3(2)	-	-	-	-	-	-	-
821.1(2)	-	-	-	-	-	-	0.09(4)
835.9(2)	-	-	-	-	-	-	-
860.56(3)	11.4(12)	14.2(6) [†]	15.3(20) [†]	15.2(15) [†]	-	13(1)	12.0(8)
883.4(2)	-	-	-	-	-	-	-
927.6(2)	-	-	-	-	-	0.15(5) [†]	0.13(3)
982.7(2)	-	-	-	-	-	0.20(5)	0.20(3)
1004(2)	-	-	-	-	-	-	~ 0.01
1093.9(1)	-	0.7(1) [†]	~ 2	-	-	0.5(1)	0.38(5)
1125.7(4)	-	-	-	-	-	-	-
1160.8(2)	-	-	-	-	-	-	-
1185.2(3)	-	-	-	-	-	-	-
1282.8(3)	-	-	-	-	-	-	0.05(2)
1381.1(5)	-	-	-	-	-	-	0.02(1)
1647.5(7)	-	-	~ 3	-	-	-	~ 0.01
1743.9(2)	-	-	-	-	-	-	-
2614.511(10)	100	(100)	100	100	100(2)	100	100

Gamma-ray Emission Probabilities: Relative to $P_g(2614.551 \text{ keV})$ of 100 (cont.)

E_g (keV)	P_g^{rel} (cont.)					
	1972DaZA	1972Ja25	1975Ko02	1977Ge12	1978Av01	1982Sa36
211.4(2)	0.16(4)	-	0.17(2)	-	-	-
233.3(1)	~ 0.2	-	0.31(3)	-	-	-
252.5(2)	0.8(2)	-	0.80(5)	-	0.62(4) [†]	0.80(9)
277.37(3)	6.6(13)	6.2(7)	6.8(3)	-	6.1(2)	6.8(3)
485.8(1)	0.04(1)	-	0.050(5)	-	-	-
510.7(1)	22.9(23)	21.9(7)	21.6(9)	-	22.8(7)	22.2(11)
583.187(2)	85.0(85)	86.0(4)	86(3)	84.4(11)	85 [§]	[85.2(3)] [#]
587.8(2)	~ 0.04	-	0.04(2)	-	-	-
650.2(2)	-	-	0.036(5)	-	-	-
705.3(2)	~ 0.02	-	0.022(4)	-	-	-
722.0(1)	0.21(6)	-	0.203(14)	-	0.27(2)	-
748.7(2)	0.05(1)	-	0.043(4)	-	-	-
763.2(1)	1.7(3)	-	1.64(9)	-	1.82(9)	2.0(3)
808.3(2)	-	-	-	-	-	-
821.1(2)	0.04(1)	-	0.040(4)	-	-	-
835.9(2)	-	-	-	-	-	-
860.56(3)	11.8(12)	11.5(10)	12.0(4)	12.48(13)	13.9(6) [†]	11.9(6)
883.4(2)	~ 0.025	-	0.031(3)	-	-	-
927.6(2)	0.13(4)	-	0.125(1)	-	-	-
982.7(2)	0.20(6)	-	0.197(15)	-	-	-
1004(2)	-	-	< 0.005	-	-	-
1093.9(1)	0.37(7)	-	0.37(4)	-	-	-
1125.7(4)	-	-	0.005(2)	-	-	-
1160.8(2)	-	-	0.011(3)	-	-	-
1185.2(3)	-	-	0.017(5)	-	-	-
1282.8(3)	~ 0.05	-	0.052(5)	-	-	-
1381.1(5)	-	-	0.007(3)	-	-	-
1647.5(7)	-	-	0.002(1)	-	-	-
1743.9(2)	-	-	0.002(1)	-	-	-
2614.511(10)	100	(100)	100	100.0(14)	(100)	-

Gamma-ray Emission Probabilities: Relative to $P_g(2614.511 \text{ keV})$ of 100 (cont.)

E_g (keV)	P_g^{rel} (cont.)				
	1983Sc13	1983Va22	1984Ge07	1993El08	Recommended Values*
211.4(2)	-	-	0.19(2)	0.18(1)	0.18(1)
233.3(1)	-	-	0.26(3)	0.31(1)	0.31(1)
252.5(2)	-	-	0.80(1)	0.78(2)	0.78(2)
277.37(3)	6.5(2)	6.3(1)	6.34(5)	7.01(12)	6.6(3)
485.8(1)	-	-	-	0.056(11)	0.049(4)
510.7(1)	22.2(6)	23.0(4)	22.6(8)	22(1)	22.6(2)
583.187(2)	85.8(22)	[85.2(3)] [#]	84.0(5)	88(3)	85.2(3)
587.8(2)	-	-	-	0.07(1)	0.06(2)
650.2(2)	-	-	-	0.066(11)	0.05(2)
705.3(2)	-	-	-	-	0.022(4)
722.0(1)	-	-	0.26(5)	0.28(2)	0.24(4)
748.7(2)	-	-	-	0.055(9)	0.046(3)
763.2(1)	2.05(14)	-	1.81(2)	1.75(8)	1.79(3)
808.3(2)	-	-	-	0.030(7)	0.030(7)
821.1(2)	-	-	-	0.042(17)	0.041(4)
835.9(2)	-	-	-	0.076(11)	0.076(11)
860.56(3)	12.8(3)	-	12.41(8)	12.8(7)	12.5(1)
883.4(2)	-	-	-	-	0.031(3)
927.6(2)	-	-	-	0.13(1)	0.125(1)
982.7(2)	-	-	-	0.21(1)	0.205(8)
1004(2)	-	-	-	-	-
1093.9(1)	-	-	0.441(7)	0.48(4)	0.43(2)
1125.7(4)	-	-	-	-	0.005(2)
1160.8(2)	-	-	-	-	0.011(3)
1185.2(3)	-	-	-	-	0.017(5)
1282.8(3)	-	-	-	0.050(13)	0.052(5)
1381.1(5)	-	-	-	-	0.007(3)
1647.5(7)	-	-	-	-	0.002(1)
1743.9(2)	-	-	-	-	0.002(1)
2614.511(10)	100(3)	-	100(2)	100.0(13)	100(2)

* Weighted mean values adopted when appropriate; remainder derived from proposed decay scheme; normalisation factor of 0.9979(1) calculated from total theoretical internal conversion coefficient of 2614.511 keV (0.00210(6)) and transition probability of 100% (1.00), with no direct β^- decay to the ground state of ^{208}Pb .

† Data rejected as outliers, and not included in weighted-mean analyses.

§ No uncertainty quoted; data not included in the weighted-mean analyses.

‡ Unresolved data not included in the weighted-mean analysis.

Measurements did not include determination of the 2614.511 keV gamma ray; therefore, relative emission probability of 85.2(3) for the 583.19 keV gamma ray was used to convert all other data in this study to comparable relative values – under these circumstances, $P_\gamma(583.19 \text{ keV})$ was not included in the weighted-mean analysis.

ψ unresolved overlap with another gamma-ray emission, and measurement did not include 2614.51-keV γ ray; therefore relative emission probability of 85.2 (3) was used for the 583.19-keV γ ray to convert other data in this study to comparable relative values – under these circumstances, $P_\gamma(583.19 \text{ keV})$ were not included in the weighted-mean analysis.

Multipolarities and Internal Conversion Coefficients

The major 583.19 and 2614.51 keV gamma rays were identified as E2 and E3 transitions, respectively. Many other gamma rays have mixed M1 + E2 multiplicities; these transitions were generally assumed to be 100%M1, although estimated mixing ratios were used to determine specific multiplicities and theoretical internal conversion coefficients: ((98%M1 + 2%E2) for 211.4, 233.3 and 252.5 keV, (99.73%M1 + 0.27%E2) for 510.7 keV, (91.2%M1 + 8.8%E2) for 722.0 keV, (99.99%M1 + 0.01%E2) for 763.2 keV, and (66.5%M1 + 33.5%E2) for 860.56 keV gamma rays). The assigned multipolarity of the 860.56 keV gamma ray is particularly important in achieving the desired population-depopulation balance for the 2614.55 keV nuclear level.

A normalisation factor of 0.9979(1) was calculated for the relative emission probabilities of the gamma rays, assuming no direct beta decay to the ground state of ^{208}Pb :

transition probability of 2614.511 keV gamma ray = 100% (1.00)

total theoretical internal conversion coefficient (2614.511 keV E3 transition) = 0.00210(6)

[78Ro22] $\rightarrow 100/[(1 + 0.00210(6)) P_{\gamma}^{\text{rel}}(2614.51 \text{ keV})] = 0.9979(1)$.

Beta-particle Emissions

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1986Ma17 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities

The beta-particle emission probabilities were calculated from gamma-ray probability balances, using the recommended gamma-ray emission intensities and the theoretical internal conversion coefficients of 1978Ro22. All beta-particle transitions were classified as or assumed to be first forbidden non-unique.

Beta-particle Emission Probabilities per 100 Disintegrations of ^{208}Tl

$E_b(\text{keV})$	P_b			
	1960Em01	1960Sc07	1967Os01	Recommended Values*
521(2)	-	-	-	0.053(5)
618(2)	-	-	-	0.017(5)
643(2)	-	-	4.5(15)	0.045(7)
678(2)	-	-	-	0.005(2)
690(2)	-	-	-	0.076(11)
705(2)	-	-	-	0.048(6)
718(2)	-	-	-	0.030(7)
739(3)	-	-	-	0.002(1)
821(2)	-	-	-	0.231(9)
876(2)	-	-	-	0.18(2)
1005(3)	-	-	-	0.007(3)
1040(2)	3.6	4.6(2)	< 0.6	3.26(7)
1055(2)	-	-	-	0.048(3)
1081(2)	-	-	-	0.64(6)
1293(2)	24.3	23.9(8)	21(2)	24.1(3)
1526(2)	20.6	22.7(7)	22(2)	22.2(7)
1803(2)	51.3	48.8(27)	52(1)	49.0(9)

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

References

1957Ba05 - D. L. Baulch, H. A. David and J. F. Duncan, The Half-Life of Thorium C", Australian J. Chem. 10(1957)85. [Half-life]

1960Em01 - G. T. Emery and W. R. Kane, Gamma-ray Intensities in the Thorium Active Deposit, Phys. Rev. 118(1960)755. [P_{β} , P_{γ}]

1960Sc07 - G. Schupp, H. Daniel, G. W. Eakins and E. N. Jensen, Transition Intensities in the Tl^{208} Beta Decay, the $\text{Bi}^{212} \rightarrow \text{Po}^{212}$ Decay Scheme, and the Bi^{212} Branching Ratio, Phys. Rev. 120(1960)189. [P_{β} , P_{γ}]

- 1961Si11 - L. Simons, M. Brenner, L. Kåld, K-E. Nystén and E. Spring, Angular Correlations of Gamma-Gamma Cascades in Pb^{208} , Soc. Sci. Fennica Comm. Phys. Math. 26(1961) part 6. [P_γ]
- 1967La20 - N. O. Lassen and N. Hornstrup, Half-Life of ^{208}Tl (ThC"), Kgl. Danske Videnskab. Selskab., Mat.-Fys. Medd. 36, No.4 (1967). [Half-life]
- 1967Os01 - H. Ostertag and K. H. Lauterjung, Der β -Zerfall des ^{208}Tl , Z. Phys. 199(1967)25. [P_β]
- 1969Au10 - G. Aubin, J. Barrette, G. Lamoureux and S. Monaro, Calculated Relative Efficiency for Coaxial and Planar Ge(Li) Detectors, Nucl. Instrum. Meth. 76(1969)85. [P_γ]
- 1969La23 - J. S. Larsen and B. C. Jørgensen, The Decay of ^{208}Tl : Gamma-ray Measurement, Z. Phys. 227(1969)65. [P_γ]
- 1969Pa02 - A. Pakkanen, J. Kantele and P. Suominen, Levels in ^{208}Pb Populated in the Decay of ^{208}Tl (ThC"), Z. Phys. 218(1969)273. [P_γ]
- 1970Mu21 - V. H. Mundschenk, Über ein Verfahren zur Abtrennung kurzlebiger Radionuklide unter Ausnutzung des Rückstoßeffektes, Radiochim. Acta 14(1970)72. [Half-life]
- 1971Ac02 - R. Ackerhalt, P. Ellerbe and G. Harbottle, The Half-Life of $^{208}Tl/ThC"$, Radiochem. Radioanal. Lett. 8(1971)75. [Half-life]
- 1972DaZA - J. Dalmaso, Recherches sur le Rayonnement Gamma de Quelques Radioéléments Naturels Appartenant à la Famille du Thorium, PhD thesis, University of Nice (1972); J. Dalmaso, H. Maria and C. Ythier, Étude du Rayonnement γ du Thorium 228 et de ses Dérivés, et plus Particulièrement du Thallium 208 (ThC"), C. R. Acad. Sci. Paris 277B(1973)467. [P_γ]
- 1972Ja25 - P. Jagam and D. S. Murty, Multipole Mixing Ratios of γ -transitions in ^{208}Pb , Nucl. Phys. A197(1972)540. [P_γ , multipolarity]
- 1975Ko02 - M. Kortelahti, A. Pakkanen and J. Kantele, Electromagnetic Transition Rates in ^{208}Pb , Nucl. Phys. A240(1975)87. [P_γ , multipolarity]
- 1977Ge12 - R. J. Gehrke, R. G. Helmer and R. C. Greenwood, Precise Relative γ -ray Intensities for Calibration of Ge Semiconductor Detectors, Nucl. Instrum. Meth. 147(1977)405. [P_γ]
- 1978Av01 - F. T. Avignone and A. G. Schmidt, γ -ray and Internal-conversion Intensity Studies of Transitions in the Decay of ^{228}Th , Phys. Rev. C17(1978)380. [P_γ , multipolarity]
- 1978Ro22 - F. Rösel, H. M. Fries, K. Alder and H. C. Pauli, Internal Conversion Coefficients for all Atomic Shells, ICC Values for $Z = 68-104$, At. Data Nucl. Data Tables 21(1978)291-514. [ICC]
- 1982Sa36 - S. Sadasivan and V. M. Raghunath, Intensities of Gamma Rays in the ^{232}Th Decay Chain, Nucl. Instrum. Meth. 196(1982)561. [P_γ]
- 1983Sc13 - U. Schötzig and K. Debertin, Photon Emission Probabilities per Decay of ^{226}Ra and ^{232}Th in Equilibrium with their Daughter Products, Int. J. Appl. Radiat. Isot. 34(1983)533. [P_γ]
- 1983Va22 - R. Vaninbrouckx and H. H. Hansen, Determination of γ -ray Emission Probabilities in the Decay of ^{228}Th and its Daughters, Int. J. Appl. Radiat. Isot. 34(1983)1395. [P_γ]
- 1984Ge07 - R. J. Gehrke, V. J. Novick and J. D. Baker, γ -ray Emission Probabilities for the ^{232}U Decay Chain, Int. J. Appl. Radiat. Isot. 35(1984)581. [P_γ]
- 1986Ma17 - M. J. Martin, Nuclear Data Sheets for $A = 208$, Nucl. Data Sheets 47(1986)797. [Nuclear structure, energies]
- 1992Li05 - W-J. Lin and G. Harbottle, Gamma-ray Emission Intensities of the ^{232}Th Chain in Secular Equilibrium, of ^{235}U and the Progeny of ^{238}U , J. Radioanal. Nucl. Chem. 157(1992)367. [P_γ]

- 1993E108 - O. El Samad, J. Dalmaso, G. Barci-Funel and G. Ardisson, Fast Radiochemical Separation and γ Spectroscopy of Short-lived Thallium Isotopes, *Radiochim. Acta* 62(1993)65. [P_γ]
- 1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, *Nucl. Phys. A* 595(1995)409. [Q value]
- 1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, *Nucl. Instrum. Meth. Phys. Res. A* 369(1996)527. [X_K , X_L , Auger electrons]
- 1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from $Z = 11$ to $Z = 100$, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]
- 1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from $Z = 5$ to $Z = 100$, PTB Report PTB-6.11-1999-1, February 1999. [X_K]
- 2000He14 - R. G. Helmer and C. van der Leun, Recommended Standards for γ -ray Energy Calibration (1999), *Nucl. Instrum. Meth. Phys. Res. A* 450(2000)35. [E_γ]

**²¹²Bi – Comments on evaluation of decay data
by A. L. Nichols**

Evaluated: July/August 2001

Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

²¹²Bi undergoes beta decay to ²¹²Po (BF = 64.07(7)%), and alpha decay to ²⁰⁸Tl (BF = 35.93(7)%). The alpha branching fraction was calculated as the weighted mean of the measurements of 1960Sc07, 1962Be09, 1962Fl03 and 1965Wa09, with the uncertainty increased to include the most precise value of 36.00(3)%.

Reference	α-decay Branching Fraction (BF) %
1960Sc07	35.96(6)
1962Be09	35.81(4)
1962Fl03	36(1)
1965Wa09	36.00(3)*
Recommended Value	35.93(7)

*Uncertainty increased slightly so that weighting does not exceed 0.5.

A reasonably consistent decay scheme has been constructed from a combination of alpha-particle studies by 1951Ry17(two main emissions modified), 1960Wa14, and 1962Be09, and the gamma-ray measurements of 1960Sc07, 1962Be09, 1962Fl03, 1967Be19, 1968Yt02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05.

Nuclear Data

²²⁸Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ²³²Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (²²⁴Ra alpha decay to ²²⁰Rn; ²¹²Bi and ²⁰⁸Tl gamma-ray emissions).

Half-life

The recommended half-life is the unweighted mean of two somewhat elderly measurements (1914Le01 and 1961Ap03). Further studies are merited to determine this value with greater confidence.

Reference	Half-life (min)
1914Le01	60.480(52)
1961Ap03	60.600(43)
Recommended Value	60.54(6)

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1986Ma17 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

The gamma-ray measurements of 1960Sc07, 1962Be09, 1962Fl03, 1967Be19, 1968Yt02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05 were used to determine the emission probabilities of the major gamma rays. These data have been measured relative to widely differing decay parameters: beta-decay mode, alpha-decay mode, per decay of ²¹²Bi (ie., absolute emission probabilities), and relative to the 583.19 and 2614.51 keV gamma rays of ²⁰⁸Tl. All of these measured data were adjusted to absolute emission probabilities when appropriate, and weighted mean values determined.

Absolute emission probabilities were estimated for the 180.2 and 1800.9 keV gamma rays in the beta-decay mode, and the 433.7, 492.7, 580.5, 620.4, 759 and 807 keV gamma rays in the alpha-decay mode. The latter values were derived from measurements of the low-intensity alpha-particle emission probabilities by 1960Wa14, and involved the introduction of uncertainty estimates that varied between 10% and 50% (depending on the number of significant figures quoted in the measurement of the relevant alpha emission probability).

Published Gamma-ray Emission Probabilities

E_g (keV)	P_g							
	1960Sc07	1962Be09	1962Fl03	1967Be19	1968Yt02	1972DaZA	1978Av01	1982Sa36
	*		‡	#	s	s	Δ	¶
39.858(4) [α]	-	-	-	-	-	-	-	0.9(1)
180.2(2) [β ⁻]	-	-	-	-	-	-	-	-
288.08(6) [α]	-	0.775(40) [#]	-	0.82(2)	-	0.9(2)	0.97(5)	0.32(3)
327.94(6) [α]	-	0.299(23) [#]	-	0.33(1)	-	0.36(7)	-	-
433.7(2) [α]	-		-	0.04(1)	-	~ 0.025	-	-
452.8(1) [α]	-		-	0.84(2)	-	0.88(17)	1.10(6)	0.42(5)
		1.18(5) [#]						
473.6(2) [α]	-		-	0.122(8)	-	0.10(3)	-	-
492.7(1) [α]	-		-	< 0.008	-	-	-	-
580.5(3) [α]	-	-	-	-	-	-	-	-
620.4(3) [α]	-	-	-	-	-	-	-	-
727.33(1) [β ⁻]	11.1(7)		11.8(24)	-	-	17.6(17)	21.0(8)	6.9(4)
759(1) [α]	-	100 [†]	-	-	-	-	-	-
785.37(9) [β ⁻]	1.70(26)		-	-	-	2.8(6)	3.26(16)	1.01(7)
807(1) [α]	-	-	-	-	-	-	-	-
893.41(2) [β ⁻]	0.66(7)	4.9(3) [†]	0.5(1)	-	-	0.94(19)	-	0.49(8)
952.12(2) [β ⁻]	0.16(4)	-	-	-	-	0.46(9)	-	-
1073.6(2) [β ⁻]			-	-	-	~ 0.03	-	-
	0.99(8)	10.1(4) [†]						
1078.63(11) [β ⁻]			0.7(1)	-	-	1.4(2)	-	-
1512.70(8) [β ⁻]	0.49(5)	3.4(3) [†]	-	-	0.99(15)	0.8(1)	-	-
1620.74(1) [β ⁻]	2.81(20)	20.0(6) [†]	3.0(6)	-	4.85(50)	3.9(4)	-	-
1679.45(1) [β ⁻]	-	-	-	-	0.230(7)	0.16(3)	-	-
1800.9(2) [β ⁻]				-	-	-	-	-
	0.17(3)	1.4(2) [†]	0.5(1)					
1805.96(10) [β ⁻]				-	0.41(10)	0.25(5)	-	-

Published Gamma-ray Emission Probabilities (cont.)

E _g (keV)	P _g (cont.)			
	1983Sc13 ^ψ	1983Va22 ^ψ	1984Ge07 ^Δ	1992Li05 ^ψ
39.858(4) [α]	-	-	3.49(28)	-
180.2(2) [β ⁻]	-	-	-	-
288.08(6) [α]	0.274(23)	-	1.106(10)	0.389(57)
327.94(6) [α]	0.120(4)	-	0.423(20)	3.23(12)
433.7(2) [α]	-	-	-	-
452.8(1) [α]	0.256(23)	-	1.191(11)	0.370(49)
473.6(2) [α]	-	-	-	-
492.7(1) [α]	-	-	-	-
580.5(3) [α]	-	-	-	-
620.4(3) [α]	-	-	-	-
727.33(1) [β ⁻]	6.56(15)	7.00(18)	21.63(13)	6.93(18)
759(1) [α]	-	-	-	-
785.37(9) [β ⁻]	1.07(5)	-	3.62(4)	1.05(5)
807(1) [α]	-	-	-	-
893.41(2) [β ⁻]	0.352(36)	-	1.25(6)	-
952.12(2) [β ⁻]	-	-	-	-
1073.6(2) [β ⁻]	-	-	-	-
1078.63(11) [β ⁻]	0.58(4)	-	1.85(6)	0.555(41)
1512.70(8) [β ⁻]	0.276(42)	-	-	-
1620.74(1) [β ⁻]	1.38(8)	-	4.88(10)	1.44(9)
1679.45(1) [β ⁻]	-	-	-	-
1800.9(2) [β ⁻]	-	-	-	-
1805.96(10) [β ⁻]	-	-	-	-

* Emission probabilities expressed in terms of ²¹²Bi β⁻ decay mode only.

† Emission probabilities expressed in terms of (727 + 785) keV gamma rays of ²¹²Bi.

‡ Emission probabilities relative to ²¹²Po α decay.

Emission probabilities expressed in terms of ²¹²Bi α decay mode only.

§ Emission probabilities relative to P_γ(2614.51 keV) of ²⁰⁸Tl.

Δ Emission probabilities relative to P_γ(583.19 keV) of ²⁰⁸Tl.

¶ Emission probabilities relative to P_γ(238.63 keV) of ²¹²Pb specified as 0.430(20), compared with recommended value of 0.435(4).

ψ Absolute emission probabilities.

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ²¹²Bi

E _g (keV)	P _g ^{abs}							
	1960Sc07	1962Be09	1962Fl03	1967Be19	1968Yt02	1972DaZA	1978Av01	1982Sa36
39.858(4) [α]	-	-	-	-	-	-	-	0.9(1)
180.2(2) [β ⁻]	-	-	-	-	-	-	-	-
288.08(6) [α]	-	0.278(14)	-	0.29(1)	-	0.3(1)	0.35(2)	0.32(3)
327.94(6) [α]	-	0.107(8)	-	0.12(1)	-	0.13(3)	-	-
433.7(2) [α]	-		-	0.014(4)	-	~ 0.009	-	-
452.8(1) [α]	-		-	0.30(1)	-	0.32(6)	0.40(2)	0.42(5)
		0.424(18)						
473.6(2) [α]	-		-	0.044(3)	-	0.04(1)	-	-
492.7(1) [α]	-		-	< 0.003	-	-	-	-
580.5(3) [α]	-	-	-	-	-	-	-	-
620.4(3) [α]	-	-	-	-	-	-	-	-
727.33(1) [β ⁻]	7.11(45)		7.6(15)	-	-	6.3(6)	7.6(3)	7.0(4)
759(1) [α]	-	[7.85]	-	-	-	-	-	-
785.37(9) [β ⁻]	1.09(17)		-	-	-	1.0(2)	1.17(6)	1.02(7)
807(1) [α]	-	-	-	-	-	-	-	-
893.41(2) [β ⁻]	0.42(4)	0.38(2)	0.32(6)	-	-	0.34(7)	-	0.50(8) ^s
952.12(2) [β ⁻]	0.10(3)	-	-	-	-	0.17(3)	-	-
1073.6(2) [β ⁻]			-	-	-	~ 0.01		-
	0.63(5)	0.79(3)						
1078.63(11) [β ⁻]			0.45(6)	-	-	0.50(7)	-	-
1512.70(8) [β ⁻]	0.31(3)	0.27(2)	-	-	0.36(5)	0.29(4)	-	-
1620.74(1) [β ⁻]	1.80(13)	1.57(5)	1.9(4)	-	1.74(18)	1.4(1)	-	-
1679.45(1) [β ⁻]	-	-	-	-	0.083(3) [†]	0.06(1)	-	-
1800.9(2) [β ⁻]				-	-	-	-	-
	0.11(2)	0.11(2)	0.32(6)					
1805.96(10) [β ⁻]				-	0.15(4)	0.09(2) [†]	-	-

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ²¹²Bi (cont.)

E _g (keV)	P _g ^{abs} (cont.)				Recommended Values*
	1983Sc13	1983Va22	1984Ge07	1992Li05	
39.858(4) [α]	-	-	1.07(9) [¶]	-	1.01(3) [†]
180.2(2) [β ⁻]	-	-	-	-	0.003(1)
288.08(6) [α]	0.274(23)	-	0.339(3) [¶]	0.389(57)	0.32(2)
327.94(6) [α]	0.120(4) [¶]	-	0.129(6)	3.23(12) ^ψ	0.121(3)
433.7(2) [α]	-	-	-	-	0.0095(20) [‡]
452.8(1) [α]	0.256(23)	-	0.365(3) [¶]	0.370(49)	0.34(3)
473.6(2) [α]	-	-	-	-	0.044(3)
492.7(1) [α]	-	-	-	-	0.04(1) [‡]
580.5(3) [α]	-	-	-	-	0.0010(2) [‡]
620.4(3) [α]	-	-	-	-	0.0038(6) [‡]
727.33(1) [β ⁻]	6.56(15)	7.00(18)	6.62(4) [¶]	6.93(18) ^ψ	6.74(12)
759(1) [α]	-	-	-	-	0.00036(18) [‡]
785.37(9) [β ⁻]	1.07(5)	-	1.11(1)	1.05(5)	1.11(1)
807(1) [α]	-	-	-	-	0.000039(4) [‡]
893.41(2) [β ⁻]	0.352(36)	-	0.383(18)	-	0.38(1)
952.12(2) [β ⁻]	-	-	-	-	0.14(4)
1073.6(2) [β ⁻]	-	-	-	-	0.015(5) [#]
1078.63(11) [β ⁻]	0.58(4)	-	0.566(18) [¶]	0.555(41)	0.55(2)
1512.70(8) [β ⁻]	0.276(42)	-	-	-	0.29(1)
1620.74(1) [β ⁻]	1.38(8)	-	1.49(3) [¶]	1.44(9)	1.51(3)
1679.45(1) [β ⁻]	-	-	-	-	0.07(1)
1800.9(2) [β ⁻]	-	-	-	-	0.004(2)
1805.96(10) [β ⁻]	-	-	-	-	0.12(3)

* Weighted mean values adopted when appropriate; remainder derived from proposed decay scheme (see other footnotes).

† Determined directly from proposed decay scheme (calculated transition probability and total theoretical internal conversion coefficient).

‡ Calculated from low-intensity alpha-particle emission probabilities of 1960Wa14.

Estimated from the approximate measurement of 1972DaZA, and used to define P_γ for 180.2 and 1800.9 keV gamma rays.

¶ Uncertainty increased so that weighting does not exceed 50%.

§ Datum rejected as outlier, and not included in weighted mean analysis.

ψ Unresolved overlap with other gamma-ray emission(s); data not included in the weighted-mean analysis.

Multipolarities and Internal Conversion Coefficients

Many of the M1 + E2 gamma transitions in the alpha-decay mode were assumed to be close to 100%M1, based on the studies of 1978Av01 and 1982Be09. Specific exceptions to this assumption include:

- 99.55 %M1 + 0.45 %E2 for 288.08keV,
- 99.2 %M1 + 0.8 %E2 for 785.37 keV,
- 99.8 %M1 + 0.2 %E2 for 893.41 keV,
- 70 %M1 + 30 %E2 for 952.12 keV,
- 98.2 %M1 + 1.8 % E2 for 1078.63 keV,
- 90 %M1 + 10 %E2 for 1620.74 keV gamma rays.

Multipolarity Assignments

Reference	E _g (keV)	Multipolarity
1978Av01	288.08(6) [α decay]	M1 + E2
	452.8(1) [α decay]	72%M1 + 28%E2
	727.33(1) [β^- decay]	E2
	785.37(9) [β^- decay]	98%M1 + 2%E2
1982Be09	785.37(9) [β^- decay]	99.2%M1 + 0.8%E2
	893.41(2) [β^- decay]	M1 (+ \leq 0.25%E2)
	952.12(2) [β^- decay]	70%M1 + 30%E2
	1078.63(11) [β^- decay]	98.2%M1 + 1.8%E2

Reasonable consistency was achieved from the proposed gamma-ray emission probabilities, internal conversion coefficients and alpha-particle emission probabilities. The 39.858 keV gamma ray is particularly important in the alpha branch, and further measurements are required to determine the emission probability of this transition with greater confidence. A value of 1.01(3)% (0.0101(3)) was adopted on the basis of the relevant alpha-particle emission probability, gamma-ray transition probability and a total internal conversion coefficient of 24.6(7).

Alpha-particle EmissionsEnergies

All alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies specified by 1986Ma17 and 1992Ar05, and Q-values were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

The main alpha-particle emission probabilities emitted directly by ²¹²Bi were calculated from the evaluated gamma-ray emission probabilities (see above) and theoretical internal conversion coefficients, combined with an alpha branching fraction of 0.3593(7). These data are in excellent agreement with the measured emission probabilities of the two main alpha transitions (1951Ry17, 1960Wa14 and 1962Be09), but deviate considerable for the low-intensity transitions that are poorly resolved. Under such circumstances, the low-intensity alpha-particle data of 60Wa14 were adopted when appropriate, while others were derived from the gamma-ray studies.

Alpha-particle Emission Probabilities

E _a (keV)	P _a ^{rel}			P _a ^{abs}	
	1951Ry17	1960Wa14	1962Be09		Recommended Values*
5298(1)	0.016	0.00011(1)	-	-	5298(1)
5345(1)	0.147	0.001	-	-	5345(1)
5481.3(3)	-	0.014	~ 0.04	~ 0.02	5481.3(3)
5606.63(14)	1.08	1.19	)	)	5606.63(14)
			) 1.35(6)	) 1.22(2)	
5625.4(2)	-	0.1625	)	)	5625.4(2)
5768.27(10)	1.67	1.78	1.63(11)	1.67(2)	5768.27(10)
6050.92(4)	69.86 [#]	69.7	70.2(3)	70.2(2)	6050.92(4)
6090.02(4)	27.16 [#]	27.1	27.0(5)	26.8(2)	6090.02(4)
9498.79(12) [†]	-	-	-	-	9498.79(12) [†]
10432.95(12) [†]	-	-	-	-	10432.95(12) [†]
10552.1(3) [†]	-	-	-	-	10552.1(3) [†]

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities, theoretical internal conversion coefficients and alpha branching fraction of 0.3593(7), unless stated otherwise (expressed per 100 disintegrations of ²¹²Bi).

‡ Data reported by 1960Wa14 were adopted and adjusted for alpha branch; uncertainties were estimated when not quoted.

† Arises from $\beta^- \alpha$ decay (long-range alpha particles).

Data reported incorrectly; re-assigned by evaluator.

Alpha-particle emissions from the $\beta\alpha$ decay mode have been observed at energies greater than 9 MeV by 1951Ry17, 1962Be09 and 1965Le08. Some of the excited states of ²¹²Po populated by the beta of ²¹²Bi undergo subsequent alpha decay (in competition with the gamma-ray decay). These nuclear levels at 1800.9, 1679.45 and 727.33 keV emit high-energy alpha particles (energies of 10552.1, 10432.95 and 9498.79 keV, respectively). All measurements were expressed relative to 10⁶ emission probability for the 8785.18 keV alpha particle of ²¹²Po, but with no quoted uncertainties. These long-range alpha particles constitute part of the ²¹²Bi decay; and their emission probabilities were determined from the measurements of 1951Ry17, 1962Be09 and 1965Le08:

Alpha-particle Emissions ($\beta\alpha$ Decay)

E_a (keV)	P_a^{rel}			
	1951Ry17	1962Be09	1965Le08	Mean Value
[8785.18(11)]*	10 ⁶	10 ⁶	10 ⁶	10 ⁶
9498.79(12)	35	45	34	38
10432.95(13)	20	17	10	16
10552.1(3)	170	167	160	166
Total α (of $\beta\alpha$)	225	229	204	219(15)

*²¹²Po alpha decay.

Total α emissions from $\beta\alpha$ decay have an estimated mean value of 219 relative to 10⁶ for the emission probability of the 8785.18 keV alpha particle of ²¹²Po, with an uncertainty of 15 to cover the range of measured data. Therefore, a mean value of 0.00014 was estimated for the $\beta\alpha$ branching fraction, combined with an uncertainty of approximately 7% ($BF(\beta\alpha) = 0.00014(1)$). Absolute alpha-particle emission probabilities for this small branch were calculated from the mean values and $BF(\beta\alpha)$.

Beta-particle Emissions

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1992Ar05 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities

The beta-particle emission probabilities were calculated from gamma-ray transition intensity balances, using the recommended gamma-ray emission probabilities and the theoretical internal conversion coefficients of 1978Ro22.

Beta-particle Emission Probabilities

E_b (keV)	P_b	
	1957Bu34	Recommended Values*
448(2)	8.5	0.68(5)
453(2)	-	0.029(1)
575(2)	-	0.21(5)
633(2)	6	1.90(4)
741(2)	-	1.45(2)
1527(2)	10	4.58(21)
2254(2)	63	55.23(21)

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities, theoretical internal conversion coefficients, beta branching fraction of 64.06(7) % and beta-alpha branching fraction of 0.00014(1) (expressed per 100 disintegrations of ²¹²Bi).

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

References

- 1914Le01 - F. V. Lerch, Verdampfungerscheinungen der ThB- und ThC-Verbindungen, Sitzber. Akad. Wiss., Wien, Math.-Naturw. Kl. Abt. Ila 123(1914)699. [Half-life]
- 1951Ry17 - A. Rytz, Nouvelles Expériences sur le Spectre Magnétique Alpha du Thorium C et des Longs Parcours du Thorium C', C. R. Acad. Sci. Paris 233(1951)790. [E_{α} , P_{α}]
- 1957Bu34 - J. Burde and B. Rozner, Beta Spectrum of Bi²¹² (ThC), Phys. Rev. 107(1957)531. [P_{β}]
- 1960Em01 - G. T. Emery and W. R. Kane, Gamma-ray Intensities in the Thorium Active Deposit, Phys. Rev. 118(1960)755. [P_{γ} , high-energy α]
- 1960Sc07 - G. Schupp, H. Daniel, G. W. Eakins and E. N. Jensen, Transition Intensities in the Tl²⁰⁸ Beta Decay, the Bi²¹² \rightarrow Po²¹² Decay Scheme, and the Bi²¹² Branching Ratio, Phys. Rev. 120(1960)189. [P_{γ} , BF]
- 1960Wa14 - R. J. Walen and G. Bastin-Scoffier, Spectre α du ²¹⁴Bi et Remarques sur Quelques Émetteurs α du Bi, Nucl. Phys. 16(1960)246. [P_{α}]
- 1961Ap03 - K. R. Applegate, E. M. Morimoto, M. Kahr and J. D. Knight, Redetermination of the Half-Life of Bismuth (ThC), J. Inorg. Nucl. Chem. 19(1961)375. [Half-life]
- 1962Be09 - G. Bertolini, F. Cappellani, G. Restelli and A. Rota, Excited States of Tl-208 and Po-212, Nucl. Phys. 30(1962)599. [P_{α} , P_{γ} , BF]
- 1962Fl03 - F. C. Flack and J. E. Johnson, The Gamma Radiation from ²¹²Po (ThC'), Proc. Phys. Soc. (London) 79(1962)10. [P_{γ} , BF]
- 1965Le08 - C-F. Leang, Spectres α de Long Parcours des Poloniums 214 (RaC') et 212 (ThC'), C. R. Acad. Sci. Paris 260(1965)3037. [high-energy α]
- 1965Wa09 - J. Walker and T. Salgir, The Branching Ratio of ²¹²Bi (ThC), Proc. Phys. Soc. (London) 86(1965)423. [BF]
- 1967Be19 - R. Benoit, G. Bertolini, F. Cappellani and G. Restelli, Decay of the Excited Levels of ²⁰⁸Tl, Nuovo Cimento 49B(1967)125. [P_{γ}]
- 1968Yt02 - C. Ythier, H. Forest, G. Ardisson and H. Maria, Sur le Rayonnement γ de Haute Énergie Accompagnant la Désintégration du Bismuth-212, C. R. Acad. Sci. Paris Series B 267(1968)1362. [P_{γ}]
- 1972DaZA - J. Dalmasso, Recherches sur le Rayonnement Gamma de Quelques Radioéléments Naturels Appartenant à la Famille du Thorium, PhD thesis, University of Nice (1972); J. Dalmasso, H. Maria and C. Ythier, Étude du Rayonnement γ du Thorium 228 et de ses Dérivés, et plus Particulièrement du Thallium 208 (ThC''), C. R. Acad. Sci. Paris 277B(1973)467. [P_{γ}]
- 1978Av01 - F. T. Avignone and A. G. Schmidt, γ -ray and Internal-conversion Intensity Studies of Transitions in the Decay of ²²⁸Th, Phys. Rev. C17(1978)380. [P_{γ} , multipolarity]
- 1978Ro22 - F. Rösel, H. M. Fries, K. Alder and H. C. Pauli, Internal Conversion Coefficients for all Atomic Shells, ICC Values for Z = 68-104, At. Data Nucl. Data Tables 21(1978)291-514. [ICC]
- 1982Be09 - B. Bengtson, H. L. Nielsen, N. Rud and K. Wilsky, Half-life of the α -emitting Excited 0⁺ State in ²¹²Po, Nucl. Phys. A378(1982)1. [Multipolarity]
- 1982Sa36 - S. Sadasivan and V. M. Raghunath, Intensities of Gamma Rays in the ²³²Th Decay Chain, Nucl. Instrum. Meth. 196(1982)561. [P_{γ}]
- 1983Sc13 - U. Schötzgig and K. Debertin, Photon Emission Probabilities per Decay of ²²⁶Ra and ²³²Th in Equilibrium with their Daughter Products, Int. J. Appl. Radiat. Isot. 34(1983)533. [P_{γ}]
- 1983Va22 - R. Vaninbrouckx and H. H. Hansen, Determination of γ -ray Emission Probabilities in the Decay of ²²⁸Th and its Daughters, Int. J. Appl. Radiat. Isot. 34(1983)1395. [P_{γ}]
- 1984Ge07 - R. J. Gehrke, V. J. Novick and J. D. Baker, γ -ray Emission Probabilities for the ²³²U Decay Chain, Int. J. Appl. Radiat. Isot. 35(1984)581. [P_{γ}]
- 1986Ma17 - M. J. Martin, Nuclear Data Sheets for A = 208, Nucl. Data Sheets 47(1986)797. [Nuclear structure, energies]
- 1992Ar05 - A. Artna-Cohen, Nuclear Data Sheets for A = 212, Nucl. Data Sheets 66(1992)171. [Nuclear structure, energies]
- 1992Li05 - W-J. Lin and G. Harbottle, Gamma-ray Emission Intensities of the ²³²Th Chain in Secular Equilibrium, of ²³⁵U and the Progeny of ²³⁸U, J. Radioanal. Nucl. Chem. 157(1992)367. [P_{γ}]
- 1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409. [Q values]
- 1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527. [X_K , X_L , Auger electrons]
- 1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]
- 1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]

**²¹²Pb – Comments on evaluation of decay data
by A. L. Nichols**

Evaluated: July/August 2001

Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A reasonably simple and consistent decay scheme has been constructed from the gamma-ray measurements of 1960Ro16, 1961Gi02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05. Only five distinct gamma-ray emissions were identified with ²¹²Pb decay in all of these studies. A further gamma ray has been added in the evolution of the decay scheme (energy of 123.45 keV) to achieve the necessary population-depopulation balance of the 115.183 keV nuclear level of ²¹²Bi.

Low-energy gamma transitions have been postulated to exist in the decay scheme of ²¹²Pb (with energies between 40 and 60 keV). However, this possibility was rejected on the basis of insufficient experimental evidence in the open literature. Further studies are required to resolve this issue, and confirm the correctness of the proposed decay scheme.

Nuclear Data

²²⁸Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ²³²Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (²²⁴Ra alpha decay to ²²⁰Rn; ²¹²Bi and ²⁰⁸Tl gamma-ray emissions).

Half-life

The recommended half-life is the weighted mean of three elderly measurements (1952Bu72, 1953Ma26 and 1955To11). Further studies are merited to determine this value with greater confidence.

Reference	Half-life (h)
1952Bu72	10.67(5)
1953Ma26	10.64(3)
1955To11	10.643(12)
Recommended Value	10.64(1)

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1992Ar05 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

Weighted mean relative emission probabilities were determined for the 115.183, 176.64, 238.632 and 300.09 keV gamma rays, using the relevant data from the measurements of 1960Ro16, 1961Gi02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05. The relative emission probability of the 415.27 keV gamma ray was adopted from the studies of 1961Gi02, while a further gamma ray has been added in the evolution of the decay scheme (energy of 123.45 keV) to achieve the necessary population-depopulation balance of the 115.183 keV nuclear level of ²¹²Bi.

Gamma-ray Emission Probabilities: Relative to P_g(238.632 keV) of 100

E _g (keV)	P _g ^{rel}				
	1960Ro16	1961Gi02	1972DaZA	1978Av01	1982Sa36
115.183(5)	[observed]	1.4(3)	1.3(3)	1.4(1)	1.65(12)
123.45(1)	-	-	-	-	-
176.64(1)	~ 0.5	0.50(10)	0.10(3)	-	-
238.632(2)	100	100	100	100(3)	100(5)
300.09(1)	7.7(4)	6.9(4)	7.7(15)	6.3(2)	6.7(5)
415.27(1)	~ 0.3	0.33(5)	-	-	-

E _g (keV)	P _g ^{rel} (cont.)				
	1983Sc13	1983Va22	1984Ge07	1992Li05	Recommended Values*
115.183(5)	-	-	1.37(2)	-	1.43(5)
123.45(1)	-	-	-	-	0.22(1)
176.64(1)	-	-	0.12(1)	-	0.12(1)
238.632(2)	100(3)	100(1)	100(1)	100(2)	100(1)
300.09(1)	7.5(2)	7.3(1)	7.6(1)	7.6(3)	7.3(3)
415.27(1)	-	-	-	-	0.33(5)

* Weighted mean values adopted when appropriate using LWEIGHT; remainder derived from proposed decay scheme.

A weighted mean normalisation factor of 0.436(3) was calculated for the emission probabilities from the measurements of 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05.

Absolute Gamma-ray Emission Probabilities: Normalisation Factor

E _g (keV)	P _g ^{abs}					Recommended Value*
	1982Sa36	1983Sc13	1983Va22	1984Ge07	1992Li05	
238.632(2)	0.430(20)	0.435(12)	0.440(6)	0.433(4)	0.441(10)	0.436(3)

* Weighted mean value adopted from LWEIGHT.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by 1992Ar05 has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Limited studies of the internal conversion coefficients support the proposed transition types: 100%M1 for the 115.183, 238.632 and 300.09 keV gamma rays (1957Ni11, 1957Kr49, 1959Se59, 1960Ro16, 1963Da11, 1969Kr06 and 1978Av01); the 176.64 and 415.27 keV gamma rays were also assigned 100%M1 multipolarity, while the 123.45 keV gamma transition was defined as E2.

Multipolarity Assignments

Reference	E _g (keV)	Multipolarity
1957Ni11	115.183(5)	M1 [K/L = 5(1)]
1957Kr49	115.183(5)	M1
	176.64(1)	E0 [K/L = 1 : 0.18(2)]
	238.632(2)	M1
	300.09(1)	M1

1959Se59	115.183(5)	M1 [L _I :L _{II} :L _{III} → 100 : 10.4(3) : 0.88(10)]
	238.632(2)	M1 [L _I :L _{II} :L _{III} → 100 : 10.4(2) : 0.74(5)]
1960Ro16	115.183(5)	M1 [α _K = 5.8(9)]
	238.632(2)	M1 [α _K = 0.74(7)]
1963Da11	238.632(2)	M1
	415.27(1)	M1 [α _K ~ 0.35]
1969Kr06	238.632(2)	M1
1978Av01	115.183(5)	E2
	238.632(2)	M1 (+ E2)
	300.09(1)	M1 + E2

Beta-particle Emissions

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1992Ar05 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities

The beta-particle emission probabilities were calculated from gamma-ray transition probability balances, using the recommended gamma-ray emission probabilities and the theoretical internal conversion coefficients of 1978Ro22:

415.272 keV nuclear level:

[Σ P_{γ_i} (1 + α_i) depopulating 415.27 keV level]NF was calculated to be 11.65(47)NF; since NF = 0.436(3), beta-particle emission probability is calculated to be 5.1(2)% (0.051(2));

238.632 keV nuclear level:

{[Σ P_{γ_i} (1 + α_i) depopulating 238.63 keV level] - P_γ(176.64 keV)(1 + α(176.64 keV))}NF was calculated to be 192.7(34)NF; since NF = 0.436(3), beta-particle emission probability is calculated to be 84.0(14)% (0.840(14));

115.183 keV nuclear level:

spin and parity considerations support zero beta decay to this level;

population/depopulation by gamma transitions require balance of the form

Σ P_{γ_i} (1 + α_i) populating 115.18 keV level should equal P_γ(115.18 keV)(1 + α(115.18 keV));

hence, derivation of transition probability P_γ(123.45 keV) = 0.85(4)NF

ground state (0.0 keV):

(i) through population of ground state: [Σ P_{γ_i} (1 + α_i) populating ground state]NF + P_{b_{0,0}} = 100

and NF = 0.436(3) to give P_{b_{0,0}} = 10.9(14)% (0.109(14))

(ii) through summation of beta decay and NF = 0.436(3)

$$P_{b_{0,0}} = 10.9(14)\% (0.109(14))$$

Beta-particle Emission Probabilities per 100 Disintegrations of ²¹²Pb

E _b (keV)	P _b	
	1948Ma30	Recommended Values*
159(2)	-	5.1(2)
335(2)	-	84.0(14)
574(2)	12(2)	10.9(14)

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

References

- 1948Ma30 - D. G. E. Martin and H. O. W. Richardson, The Nuclear β -spectra of Thorium B \rightarrow C and C \rightarrow C', and the Intensities of Some β -ray Lines of Thorium (B+C+C'), Proc. Phys. Soc. (London) 195A(1948)287. [P_β]
- 1952Bu72 - H. V. Buttlar, Neubestimmung der Halbwertszeit des ThB (²¹²Pb), Naturwissenschaften 39(1952)575. [Half-life]
- 1953Ma26 - P. Marin, G. R. Bishop and H. Halban, The Absolute Standardization of the 2.615 MeV Gamma-Rays of ThC'' and the Cross Section for the Photodisintegration of the Deuteron at this Energy, Proc. Phys. Soc. (London) 66A(1953)608. [Half-life]
- 1955To11 - J. Tobailem and J. Robert, Mesure de la Periode du ThB (²¹²Pb), J. Phys. Radium 16(1955)115. [Half-life]
- 1957Ni11 - K. O. Nielsen, O. B. Nielsen and M. A. Waggoner, Internal Conversion Coefficients for M1 Transitions in ⁸³Bi²¹⁴, ⁸⁴Po²¹⁴ and ⁸³Bi²¹², Nucl. Phys. 2(1956/57)476. [P_{ce} , multipolarity]
- 1957Kr49 - E. M. Krisyouk, A. G. Sergejev, G. D. Latyshev and V. D. Vorobyov, Decay Scheme of Pb²¹², Nucl. Phys. 4(1957)579. [P_{ce} , multipolarity]
- 1959Se59 - A. G. Sergejev, V. D. Vorobyev, A. S. Remenny, T. I. Kolchinskaya, G. D. Latyshev and Yu. S. Yegorov, Influence of the Finite Dimensions of the Nucleus on the Relative Conversion Coefficients in the L-subshells, Nucl. Phys. 9(1958/59)498. [P_{ce} , multipolarity]
- 1960Ro16 - P. G. Roetling, W. P. Ganley and G. S. Klaiber, The Decay of Pb²¹², Nucl. Phys. 20(1960)347. [P_γ , multipolarity]
- 1961Gi02 - M. Giannini, D. Prosperi and S. Sciuti, Decay Scheme of ²¹²Pb, Nuovo Cimento 21(1961)430. [P_γ]
- 1963Da11 - H. Daniel and G. Lührs, Aufbau eines Automatisch Arbeitenden $\pi\sqrt{2}$ -Spektrometers und Untersuchung des Konversionslinienspektrums von In^{114m} und ThB mit Folgeprodukten, Z. Phys. 176(1963)30. [P_{ce} , multipolarity]
- 1969Kr06 - D. Krpic, R. Stepic, M. Bogdanovic and M. Mladenovic, K/L₃, M/L and (N + O +)/M Ratios for 239 keV M1 Transition in ²¹²Bi, Fizika 1(1969)171. [P_{ce} , multipolarity]
- 1972DaZA - J. Dalmaso, Recherches sur le Rayonnement Gamma de Quelques Radioéléments Naturels Appartenant à la Famille du Thorium, PhD thesis, University of Nice (1972); J. Dalmaso, H. Maria and C. Ythier, Étude du Rayonnement γ du Thorium 228 et de ses Dérivés, et plus Particulièrement du Thallium 208 (ThC), C. R. Acad. Sci. Paris 277B(1973)467. [P_γ]
- 1978Av01 - F. T. Avignone and A. G. Schmidt, γ -ray and Internal-conversion Intensity Studies of Transitions in the Decay of ²²⁸Th, Phys. Rev. C17(1978)380. [P_γ , multipolarity]
- 1978Ro22 - F. Rösel, H. M. Fries, K. Alder and H. C. Pauli, Internal Conversion Coefficients for all Atomic Shells, ICC Values for Z = 68-104, At. Data Nucl. Data Tables 21(1978)291-514. [ICC]
- 1982Sa36 - S. Sadasivan and V. M. Raghunath, Intensities of Gamma Rays in the ²³²Th Decay Chain, Nucl. Instrum. Meth. 196(1982)561. [P_γ]
- 1983Sc13 - U. Schötzgig and K. Debertin, Photon Emission Probabilities per Decay of ²²⁶Ra and ²³²Th in Equilibrium with their Daughter Products, Int. J. Appl. Radiat. Isot. 34(1983)533. [P_γ]
- 1983Va22 - R. Vaninbrouckx and H. H. Hansen, Determination of γ -ray Emission Probabilities in the Decay of ²²⁸Th and its Daughters, Int. J. Appl. Radiat. Isot., 34(1983)1395. [P_γ]
- 1984Ge07 - R. J. Gehrke, V. J. Novick and J. D. Baker, γ -ray Emission Probabilities for the ²³²U Decay Chain, Int. J. Appl. Radiat. Isot. 35(1984)581. [P_γ]
- 1992Ar05 - A. Artna-Cohen, Nuclear Data Sheets for A = 212, Nucl. Data Sheets 66(1992)171. [Nuclear structure, energies]
- 1992Li05 - W-J. Lin and G. Harbottle, Gamma-ray Emission Intensities of the ²³²Th Chain in Secular Equilibrium of ²³⁵U and the Progeny of ²³⁸U, J. Radioanal. Nucl. Chem. 157(1992)367. [P_γ]
- 1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409. [Q value]
- 1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527. [X_K , X_L , Auger electrons]
- 1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]
- 1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]

²¹²Po – Comments on evaluation of decay data by A. L. Nichols

Evaluated: July/August 2001

Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

²¹²Po is an extremely short-lived radionuclide populated via the beta decay of ²¹²Bi and the alpha decay of ²¹⁶Rn. Alpha decay of ²¹²Po occurs directly to the ground state of ²⁰⁸Pb.

Nuclear Data

Half-life

Po-212 is an extremely short-lived radionuclide populated primarily via the alpha decay of Rn-216 and the beta decay of Bi-212. The recommended half-life of $3.00(2) \times 10^{-7}$ sec is based on the weighted mean of five sets of measurements (1949Bu09, 1962F103, 1963As02, 1972Mc29 and 1975Sa06).

Reference	Half-life (s)
1949Bu09	$3.04(4) \times 10^{-7}$
1962F103	$3.05(25) \times 10^{-7}$
1963As02	$3.05(5) \times 10^{-7}$
1972Mc29	$3.04(8) \times 10^{-7}$
	$3.00(8) \times 10^{-7}$
1975Sa06	$2.96(2) \times 10^{-7*}$
Recommended Value	$3.00(2) \times 10^{-7}$

* Uncertainty adjusted to $\pm 0.03 \times 10^{-7}$ to reduce weighting below 0.5.

Alpha-particle Emission

Energy

The Q-value of 1995Au04 was used to determine the energy and uncertainty of the single alpha-particle transition to the ground state of ²⁰⁸Pb, while allowing for the significant recoil component. Thus, an alpha-particle energy of 8785.18(11) keV was calculated.

Emission Probability

The emission probability of the single alpha particle was defined as 100% (1.00).

Alpha-particle Emission Probabilities per 100 Disintegrations of ²¹²Po

E_a(keV)	P_a
	Recommended Value*
8785.18(11)	100.0

* Only one α transition directly to the ground state of ²⁰⁸Pb.

References

1949Bu09 - D. E. Bunyan, A. Lundby and W. Walker, Experiments with the Delayed Coincidence Method, Including a Search for Short-Lived Nuclear Isomers, Proc. Phys. Soc. (London) 62A(1949)253. [Half-life]

1962Fl03 - F. C. Flack and J. E. Johnson, The Gamma Radiation from ²¹²Po (ThC), Proc. Phys. Soc. (London) 79(1962)10. [Half-life]

1963As02 - G. Astner, I. Bergstrom, L. Eriksson, U. Fagerquist, G. Holm and A. Persson, A Hindered E2 Ground State Transition in Po²⁰⁷, Nucl. Phys. 45(1963)49. [Half-life]

1972Mc29 - G. W. McBeth and R.A. Winyard, Isotope Identification and Radioassay by Time Interval Analysis, Int. J. Appl. Radiat. Isotop. 23(1972)527. [Half-life]

1975Sa06 - S. Sanyal, R. K. Garg, S. D. Chauhan, S. L. Gupta and S. C. Pancholi, Half-Life Measurement of the ²¹²Po Ground State, Phys. Rev. C12(1975)318. [Half-life]

1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409. [Q value]

**²¹⁶Po – Comments on evaluation of decay data
by A. L. Nichols**

Evaluated: July/August 2001

Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A simple decay scheme was derived from the gamma-ray studies of 1977Ku15, with an absolute emission probability of 0.0019(3)% for the single 804.9 keV gamma ray. This value and theoretical internal conversion coefficients were used to calculate the alpha-particle emission probabilities. Alpha-particle studies are required to confirm the validity of the proposed decay scheme.

Nuclear Data

The ²²⁸Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ²³²Th.

Half-life

The recommended half-life is the weighted mean of three somewhat elderly measurements (1911Mo01, 1942Wa04 and 1963Di05). Further studies are merited to determine this value with greater confidence.

Reference	Half-life (s)
1911Mo01	0.145(15)
1942Wa04	0.158(8)
1963Di05	0.145(2)*
Recommended Value	0.150(5)

*Uncertainty adjusted to ± 0.007 to reduce weighting below 0.5.

Gamma Ray

Energy

The single gamma-ray energy was based on the nuclear level energy of 804.9(5) keV from 1992Ar05.

Emission Probability

The absolute emission probability of the 804.9(5) keV gamma ray was determined from the measurement of 1977Ku15, adjusted for the change from 3.95% (0.0395) to 4.12% (0.0412) of $P_{\gamma}(240.986 \text{ keV})$ for ²²⁴Ra.

Published Gamma-ray Emission Probabilities per 100 Disintegrations of ²¹⁶Po

E_g (keV)	P_g
	1977Ku15 [†]
804.9(5)	0.0018(3)

[†] Absolute value in measurements that include $P_\gamma(240.986$ keV) of 3.95% for ²²⁴Ra.

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ²¹⁶Po

E_g (keV)	P_g^{abs}	
	1977Ku15 [†]	Recommended Value
804.9(5)	0.0019(3)	0.0019(3)

[†] Adjusted with respect to evaluated $P_\gamma(240.986$ keV) of 4.12(3)% (0.0412) for ²²⁴Ra.

Multipolarity and Internal Conversion Coefficients

The decay scheme specified by 1992Ar05 has been used to define the multipolarity of the gamma transition on the basis of the known spins and parities of the two nuclear levels. Theoretical internal conversion coefficients were interpolated from the tabulations of 1978Ro22.

Alpha-particle EmissionsEnergies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1992Ar05 and the Q-value (1995Au04) were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

Both alpha-particle emission probabilities were derived from the weighted mean emission probability of the single gamma transition and theoretical internal conversion coefficients.

Alpha-particle Emission Probabilities per 100 Disintegrations of ²¹⁶Po

E_a (keV)	P_a	
	1962Wa28	Recommended Values*
5988.6(10)	0.0021(4)	0.0019(3)
6778.6(5)	~ 100	99.9981(3)

* Recommended emission probabilities derived from evaluated gamma-ray emission probability and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

References

1911Mo01 - H. G. J. Moseley and K. Fajans, LIX. Radio-Active Products of Short Life, Phil. Mag. 22(1911)629. [Half-life]

1942Wa04 - A. G. Ward, A New Method of Determining Half-Value Periods from Observations with a Single Geiger Counter, Proc. Roy. Soc. (London) 181A(1942)183. [Half-life]

1962Wa28 - R. J. Walen, Spectrographie α du Radium 224 et de ses Dérivés, C. R. Acad. Sci. Paris 255(1962)1604. [P_{α}]

1963Di05 - H. Diamond and J. E. Gindler, Alpha Half-Lives of ²¹⁶Po, ²¹⁷At and ²¹⁸Rn, J. Inorg. Nucl. Chem. 25(1963)143. [Half-life]

1977Ku15 - W. Kurcewicz, N. Kaffrell, N. Trautmann, A. Plochocki, J. Zylicz, M. Matul and K. Stryczniewicz, Collective States Fed by Weak α -transitions in the ²³²U Chain, Nucl. Phys. A289(1977)1. [P_{γ}]

1978Ro22 - F. Rösel, H. M. Fries, K. Alder and H. C. Pauli, Internal Conversion Coefficients for all Atomic Shells, ICC Values for Z = 68-104, At. Data Nucl. Data Tables 21(1978)291-514. [ICC]

1992Ar05 - A. Artna-Cohen, Nuclear Data Sheets for A = 212, Nucl. Data Sheets 66(1992)171. [Nuclear structure, energies]

1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409. [Q value]

1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527. [X_K , X_L , Auger electrons]

1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Augur Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]

1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]

²²⁰Rn – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A simple decay scheme has been derived from the gamma-ray studies of 1972DaZA, 1977Ku15, and 1984Ge07. The single 549.76 keV gamma ray had a weighted mean emission probability of 0.115(15)% (0.00115(15)), and this value and theoretical internal conversion coefficients were used to calculate the absolute emission probabilities of the 5748.46 and 6288.22 keV alpha particles to the 549.76 keV and ground states of ²¹⁶Po, respectively. Alpha-particle studies are required to confirm the validity of the proposed decay scheme.

Nuclear Data

²²⁸Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ²³²Th.

Half-life

The recommended half-life is the weighted mean of measurements by 1955Sc81, 1961Ro14, 1963Gi17 and 1966Hu20. Further studies are merited to confirm the most recent studies of 1963Gi17 and 1966Hu20.

Reference	Half-life (s)
1955Sc81	51.5(10)*
1961Ro14	56.6(8)
	56.3(2)
1963Gi17	55.3(3)
1966Hu20	55.61(4)#
Recommended Value	55.8(3)

* Defined as outlier.

Uncertainty adjusted to ± 0.16 to reduce weighting below 0.5.

Gamma Ray

Energy

The single gamma-ray energy was based on the nuclear level energy of 549.76(4) keV from 1997Ar04.

Emission Probability

The absolute emission probability of the 549.76(4) keV gamma ray was determined from measurements by 1972DaZA, 1977Ku15 and 1984Ge07. A weighted mean value of 0.115(15)% (0.00115(15)) was derived through LWEIGHT.

Published Gamma-ray Emission Probabilities

E_g (keV)	P_g			
	1956Ma28 [†]	1972DaZA [‡]	1977Ku15 [¶]	1984Ge07 [#]
549.76(4)	0.025	0.29(9)	0.0950(80)	0.43(4)

[†] Defined as accurate to within a factor of 2; rejected from evaluation.

[‡] Relative to $P_\gamma(2614.511$ keV) of ²⁰⁸Tl.

[¶] Absolute value in measurements that include $P_\gamma(240.986$ keV) of 3.95% for ²²⁴Ra.

[#] Relative to $P_\gamma(583.19$ keV) of ²⁰⁸Tl.

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ²²⁰Rn

E_g (keV)	P_g^{abs}			
	1972DaZA [†]	1977Ku15 [†]	1984Ge07 [†]	Recommended Value [*]
549.76(4)	0.104(32)	0.0991(83)	0.130(3)	0.115(15)

[†] Data adjusted on the basis of the footnotes given above.

^{*} Weighted mean value adopted.

Multipolarity and Internal Conversion Coefficients

The decay scheme specified by 1997Ar04 has been used to define the multipolarity of the gamma transition on the basis of the known spins and parities of the two nuclear levels. Theoretical internal conversion coefficients were interpolated from the tabulations of 1978Ro22.

Alpha-particle EmissionsEnergies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar04 and the Q-value (1995Au04) were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

Both alpha-particle emission probabilities were derived from the weighted mean emission probability of the single gamma transition and theoretical internal conversion coefficients.

Alpha-particle Emission Probabilities per 100 Disintegrations of ²²⁰Rn

E_a (keV)	P_a		
	1962Wa28	1977Ku15 [#]	Recommended Values [*]
5748.46(14)	0.07(2)	0.097(8)	0.118(15)
6288.22(10)	~ 100	99.9	99.882(15)

[#] Data were deduced from gamma-ray studies.

^{*} Recommended emission probabilities derived from evaluated gamma-ray emission probability and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

References

- 1955Sc81 - H. Schmied, R. W. Fink and B. L. Robinson, The Half-Life of Emanation-220, J. Inorg. Nucl. Chem. 1(1955)342. [Half-life]
- 1956Ma28 - L. Madansky and F. Rasetti, Decay of Rn²²⁰ and Rn²²², Phys. Rev. 102(1956)464. [P_γ]
- 1961Ro14 - H. Rodenbusch and G. Herrmann, Ein Verfahren zur Bestimmung von Halbwertszeiten kurzlebiger gasförmiger Radioisotope. Die Halbwertszeiten des Thorons (²²⁰Rn) und Actinons (²¹⁹Rn), Z. Naturforsch. 16a(1961)577. [Half-life]
- 1962Wa28 - R. J. Walen, Spectrographie α du Radium 224 et de ses Dérivés, C. R. Acad. Sci. Paris 255(1962)1604. [P_α]
- 1963Gi17 - J. E. Gindler and D. W. Engelkemeir, Half-Life Determination of ²²⁰Rn, Radiochim. Acta 2(1963)58. [Half-life]
- 1966Hu20 - J. B. Hursh, Thoron Half-Life, J. Inorg. Nucl. Chem. 28(1966)2771. [Half-life]
- 1972DaZA - J. Dalmaso, Recherches sur le Rayonnement Gamma de Quelques Radioelements Naturels Appartenant a la Famille du Thorium, PhD thesis, University of Nice (1972); J. Dalmaso, H. Maria and C. Ythier, Étude du Rayonnement γ du Thorium 228 et de ses Dérivés, et plus Particulièrement du Thallium 208 (ThC"), C. R. Acad. Sci. Paris 277B(1973)467. [P_γ]
- 1977Ku15 - W. Kurcewicz, N. Kaffrell, N. Trautmann, A. Plochocki, J. Zylicz, M. Matul and K. Stryczniewicz, Collective States Fed by Weak α-transitions in the ²³²U Chain, Nucl. Phys. A289(1977)1. [P_γ]
- 1978Ro22 - F. Rösel, H. M. Fries, K. Alder and H. C. Pauli, Internal Conversion Coefficients for all Atomic Shells, ICC Values for Z = 68-104, At. Data Nucl. Data Tables 21(1978)291-514. [ICC]
- 1984Ge07 - R. J. Gehrke, V. J. Novick and J. D. Baker, γ-ray Emission Probabilities for the ²³²U Decay Chain, Int. J. Appl. Radiat. Isot. 35(1984)581. [P_γ]
- 1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409. [Q value]
- 1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527. [X_K, X_L, Auger electrons]
- 1997Ar04 - A. Artna-Cohen, Nuclear Data Sheets for A = 216, 220, Nucl. Data Sheets 80(1997)157. [Nuclear structure, energies]
- 1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]
- 1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]

**²²⁴Ra – Comments on evaluation of decay data
by A. L. Nichols**

Evaluated: July/August 2001

Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A relatively simple decay scheme was constructed from the alpha-particle studies of 1962Wa28, 1969Pe17, 1971So15 and 1984Bo15, and the gamma-ray measurements of 1969Pe17, 1972DaZA, 1977Ku15, 1982Sa36, 1983Sc13, 1983Va22, 1984Bo15, 1984Ge07 and 1992Li05. Only the gamma-ray studies of 1977Ku15 provide any detail beyond the 240.986 keV gamma ray; all other measurements are dedicated to the determination of the absolute emission probability of the 240.986 keV gamma ray. A weighted mean emission probability was determined for this transition, and the other emission probabilities as measured by 1977Ku15 were subsequently adjusted.

Cluster decay has been observed by 1985Pr01 and 1991Ho15, and reviewed by 1995Ar33 and 1997Tr17. ¹⁴C emissions were detected with a branching fraction of 5(1)E-11. However, this decay mode has not been included in the decay-data summary section.

Nuclear Data

²²⁸Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ²³²Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (²²⁴Ra alpha decay to ²²⁰Rn; ²¹²Bi and ²⁰⁸Tl gamma-ray emissions).

Half-life

The recommended half-life represents the unweighted mean of two somewhat elderly studies (1962Li02 and 1971Jo14) and a much more recent measurement (2004ScZZ). Further measurements are required to determine this half-life with greater confidence.

Reference	Half-life (d)
1962Li02	3.62(1)
1971Jo14	3.665(38)
2004ScZZ	3.6319(23)
Recommended Value	3.627(7)

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar04 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

Absolute emission probabilities were determined from measurements of the 240.986 keV gamma ray by 1969Pe17, 1972DaZA, 1982Sa36, 1983Sc13, 1983Va22, 1984Bo15, 1984Ge07 and 1992Li05. A weighted mean value of 4.12(3)% was derived through LWEIGHT, and the uncertainty was increased slightly to the lowest measured value of ± 0.04 to give 4.12(4)% (0.0412(4)).

Only 1977Ku15 has measured the emission probabilities of other low-intensity gamma transitions identified with ²²⁴Ra alpha decay; these data are reported relative to a value of 39500(1300) for the 240.986 keV gamma emission, as taken from 1969Pe17. Hence, the low-intensity emission probabilities have been subsequently adjusted on the basis of $P_\gamma(240.986 \text{ keV})$ of 4.12(4)% (0.0412(4)).

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ²²⁴Ra

E_g (keV)	P_g^{abs}				
	1969Pe17	1972DaZA [‡]	1977Ku15 [†]	1982Sa36	1983Sc13
240.986(6)	3.95(13)	3.9(7)	[3.95(13) →	3.9(2)	4.04(17)
292.70(11)	-	-	4.12(4)]	-	-
404.5(1)	-	-	0.0063(7)	-	-
422.04(11)	-	-	0.0022(5)	-	-
645.44(9)	-	~ 0.007	0.0030(5)	-	-
			0.0054(9)		

E_g (keV)	P_g^{abs} (cont.)				
	1983Va22	1984Bo15	1984Ge07	1992Li05	Recommended Values [*]
240.986(6)	4.05(9)	4.05(9)	4.17(4)	4.11(12)	4.12(4)
292.70(11)	-	-	-	-	0.0063(7)
404.5(1)	-	-	-	-	0.0022(5)
422.04(11)	-	-	-	-	0.0030(5)
645.44(9)	-	-	-	-	0.0054(9)

[‡] Data expressed relative to $P_\gamma(2614.511 \text{ keV})$ of ²⁰⁸Tl have been adjusted.

[†] Data adjusted on the basis of $P_\gamma(240.986 \text{ keV})$ of 4.12(4)%.

^{*} Recommended gamma-ray emission probabilities above 241 keV taken from adjusted data of 1977Ku15.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by 1997Ar04 has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Recommended internal conversion coefficients have been interpolated from the theoretical tabulations of 1978Ro22.

Alpha-particle EmissionsEnergies

All alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar04 and the Q-value of 1995Au04 were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

Alpha-particle emission probabilities to the first excited states of ²²⁰Rn have been directly measured by 1969Pe17, 1971So15, 1984Bo15 and 1993Ba72, and these data can be used to calculate the alpha-particle emission probability directly to the ground state of ²²⁰Rn:

Alpha-particle emission probability data of 1969Pe17 are effectively normalised to 94.95(5)% and 5.05(5)%, similarly for the equivalent data of 1971So15, with normalised values of 95.1(4)% and 4.9(4)%, and 1984Bo15, with normalised values of 94.94(4)% and 5.06(4)%.

1993Ba72: two alpha-particle emissions are quantified that sum to 100.03%, and the two associated uncertainties are effectively inconsistent; data adjusted so that uncertainties correspond ($\pm 0.04\%$) to give:

$P_{\alpha}(5685.50 \text{ keV})$ of 95.10%, and uncertainty of $\pm 0.04\%$;
and $P_{\alpha}(5448.81 \text{ keV})$ of 4.93%, and uncertainty of $\pm 0.04\%$.

A weighted mean value of 95.00(4)% (0.9500(4)) can be determined for $P_{\alpha}(5685.50 \text{ keV})$, and matched with a value of 5.01(4)% (0.0501(4)) for $P_{\alpha}(5448.81 \text{ keV})$. Thus, a discrepancy exists between measurements of the absolute emission probability of the 240.986 keV gamma ray and measurements of the direct alpha-particle emission probability to the ground state of Rn-220:

(i) assuming that the measured gamma-ray emission probabilities are absolute (as quoted in the various references) and $P_{\gamma}(240.986 \text{ keV})$ is 0.0412(4), $NF = 1.000$, $P_{\alpha}(5685.50 \text{ keV})$ of 0.9472(7) can be calculated taking into account the low-intensity gamma-ray transition probabilities populating the 240.986 keV nuclear level:

$$P_{\alpha}(5448.81 \text{ keV}) = P_{\gamma}(240.986 \text{ keV})(1 + \alpha_{\text{tot}}(240.986 \text{ keV})) - [\sum P_{\gamma_i} (1 + \alpha_i) \text{ populating nuclear level}] = [0.0412(4) \times 1.280(8)] - 0.000125(18) = 0.0526(7)$$

and $P_{\alpha}(5685.50 \text{ keV}) = 0.9472(7)$

(ii) if gamma-ray emission probabilities are judged to be not strictly absolute and $P_{\alpha}(5685.50 \text{ keV})$ of 0.9500(4) is adopted as the weighted mean of the alpha-particle measurements, $NF = 0.947(8)$ and $P_{\gamma}(240.986 \text{ keV})$ is 0.0390(3).

Although this problem cannot be resolved on the basis of the known measurements, the gamma-ray data were judged to be more reliable. Therefore, the recommended alpha-particle emission probabilities were determined from the gamma-ray data and theoretical internal conversion coefficients, rather than available alpha-particle measurements. These calculations resulted in an absolute emission probability of 0.0526(7) for the 5448.81 keV alpha particle (compared with a weighted mean value of 0.0501(4) from the alpha-particle measurements), and 0.9472(7) for the 5685.50 keV alpha particle. Further spectroscopic measurements are required to resolve the discrepancies between the alpha-particle and gamma-ray data (ie., decay-data studies involving the 240.986 keV and ground states of ²²⁰Rn).

Alpha-particle Emission Probabilities per 100 Disintegrations of ²²⁴Ra

$E_{\alpha}(\text{keV})$	P_{α}							Recommended Values*
	1953As31	1962Wa28	1969Pe17	1971So15	1977Ku15 [#]	1984Bo15	1993Ba72	
5034.31(25)	-	0.0031	-	-	0.0029(5)	-	-	0.0030(5)
5051.58(24)	-	0.0072	-	-	0.0073(10)	-	-	0.0076(14)
5161.34(25)	-	0.0073	-	-	0.0069(8)	-	-	0.0074(8)
5448.81(16)	4.9	5.5	5.05(5)	4.9(4)	[5.0(16)]	5.06(4)	[4.93(4)] [¶]	5.26(7)
5685.50(15)	95.1	94	[94.95(5)]	95.1(4)	94.98(16)	[94.94(4)]	[95.10(4)] [¶]	94.72(7)

[#] Data were deduced from gamma-ray studies.

[¶] Relative data are quoted as 4.93(3) and 95.1(6), and have been adjusted to give consistent uncertainties.

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

References

1953As31 - F. Asaro, F. Stephens and I. Perlman, Complex Alpha Spectra of Radiothorium (Th^{228}) and Thorium-X (Ra^{224}), Phys. Rev. 92(1953)1495. [P_{α}]
 1962L102 - R. D. Lloyd, C. W. Mays, D. R. Atherton and D. O. Clark, The Half-Period of Ra^{224} (Thorium X), COO 225(1962)88. [Half-life]
 1962Wa28 - R. J. Walen, Spectrographie α du Radium 224 et de ses Dérivés, C. R. Acad. Sci. Paris 255(1962)1604. [P_{α}]

- 1969Pe17 - A. Peghaire, Mesures Precises d'Intensities Absolues de Rayonnements γ pour des Emitteurs α , Nucl. Instrum. Meth. 75(1969)66. [P_α , P_γ]
- 1971Jo14 - K. C. Jordan, G. W. Otto and R. P. Ratay, Calorimetric Determination of the Half-Lives of ²²⁸Th and ²²⁴Ra, J. Inorg. Nucl. Chem. 33(1971)1215. [Half-life]
- 1971So15 - J. C. Soares, J. P. Ribeiro, A. Gonçalves, F. B. Gil and J. G. Ferreira, Sur les Intensités Relatives et Quelques Énergies des Spectres α de ²³⁸Pu, ²³²U et ²²⁴Ra, C. R. Acad. Sci. Paris 273B(1971)985. [P_α]
- 1972DaZA - J. Dalmaso, Recherches sur le Rayonnement Gamma de Quelques Radioelements Naturels Appartenant la Famille du Thorium, PhD thesis, University of Nice (1972); J. Dalmaso, H. Maria and C. Ythier, Étude du Rayonnement γ du Thorium 228 et de ses Dérivés, et plus Particulièrement du Thallium 208 (ThC"), C. R. Acad. Sci. Paris 277B(1973)467. [P_γ]
- 1977Ku15 - W. Kurcewicz, N. Kaffrell, N. Trautmann, A. Plochocki, J. Zylicz, M. Matul and K. Stryczniewicz, Collective States Fed by Weak α -transitions in the ²³²U Chain, Nucl. Phys. A289(1977)1. [P_γ]
- 1978Ro22 - F. Rösel, H. M. Fries, K. Alder and H. C. Pauli, Internal Conversion Coefficients for all Atomic Shells, ICC Values for Z = 68-104, At. Data Nucl. Data Tables 21(1978)291-514. [ICC]
- 1982Sa36 - S. Sadasivan and V. M. Raghunath, Intensities of Gamma Rays in the ²³²Th Decay Chain, Nucl. Instrum. Meth. 196(1982)561. [P_γ]
- 1983Sc13 - U. Schötzig and K. Debertin, Photon Emission Probabilities per Decay of ²²⁶Ra and ²³²Th in Equilibrium with their Daughter Products, Int. J. Appl. Radiat. Isot. 34(1983)533. [P_γ]
- 1983Va22 - R. Vaninbrouckx and H. H. Hansen, Determination of γ -ray Emission Probabilities in the Decay of ²²⁸Th and its Daughters, Int. J. Appl. Radiat. Isot. 34(1983)1395. [P_γ]
- 1984Bo15 - G. Bortels, D. Reher and R. Vaninbrouckx, Emission Probabilities for the 5.449-MeV Alpha Particles and 241 keV Gamma Rays in ²²⁴Ra-²²⁰Rn Decay, Int. J. Appl. Radiat. Isot. 35(1984)305. [P_α , P_γ]
- 1984Ge07 - R. J. Gehrke, V. J. Novick and J. D. Baker, γ -ray Emission Probabilities for the ²³²U Decay Chain, Int. J. Appl. Radiat. Isot. 35(1984)581. [P_γ]
- 1985Pr01 - P. B. Price, J. D. Stevenson, S. W. Barwick and H. L. Ravn, Discovery of Radioactive Decay of ²²²Ra and ²²⁴Ra by ¹⁴C Emission, Phys. Rev. Letts. 54(1985)297. [Cluster decay]
- 1991Ho15 - E. Hourani, L. Rosier, G. Berrier-Ronsin, A. Elayi, A. C. Mueller, G. Rappenecker, G. Rotbard, G. Renou, A. Lièbe, L. Stab and H. L. Ravn, Fine Structure in ¹⁴C Emission from ²²³Ra and ²²⁴Ra, Phys. Rev. C44(1991)1424. [Cluster decay]
- 1992Li05 - W-J. Lin and G. Harbottle, Gamma-ray Emission Intensities of the ²³²Th Chain in Secular Equilibrium of ²³⁵U and the Progeny of ²³⁸U, J. Radioanal. Nucl. Chem. 157(1992)367. [P_γ]
- 1993Ba72 - T. Babeliowsky and G. Bortels, ALFA: A Program for Accurate Analysis of Complex Alpha-particle Spectra on a PC, Appl. Radiat. Isot. 44(1993)1349. [P_α]
- 1995Ar33 - G. Ardisson and M. Hussonnois, Radiochemical Investigations of Cluster Radioactivities, Radiochim. Acta 70/71(1995)123. [Cluster decay]
- 1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409.[Q value]
- 1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527. [X_K , X_L , Auger electrons]
- 1997Ar04 - A. Artna-Cohen, Nuclear Data Sheets for A = 216, 220, Nucl. Data Sheets 80(1997)157. [Nuclear structure, Energies]
- 1997Tr17 - S. P. Tretyakova and V. L. Mikheev, Experimental Investigation of the Cluster Radioactivity of Atomic Nuclei, Nuovo Cimento 110(1997)1043. [Cluster decay]
- 1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]
- 1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]
- 2004ScZZ - H. Schrader, Half-life Measurements with Ionization Chambers: A Study of Systematic Effects and Results, Appl. Radiat. Isot. 60(2004)317. [Half-life]

**²²⁶Ra - Comments on evaluation of decay data
by M.M. Bé, V. Chisté**

Ra-226 disintegrates by alpha emissions to excited levels and to the ground state of Rn-222.

The alpha emission intensities were measured only once (Bastin-Scoffier) and the results were given without uncertainties in the original paper.

On the other hand, a certain number of measurements of the 186-keV gamma intensity were carried out, so this intensity can be considered to have a good level of confidence.

Therefore, the decay scheme given here was built using this 186-keV gamma-ray intensity.

Nuclear Data

Q value is from Audi and Wapstra (1995Au04).

Spin and parity of the nuclear levels are from Akovali (1996El01).

Half-life

Experimental values are, in years :

Reference	Half-life	Uncertainty
Ramthun (1966Ra13)	1599	7
Martin (1959Ma12)	1602	8
Gorshkov (1959Go80)	1577	9
Sebaoun (1956Se10)	1617	12
Kohman (1949Ko01)	1622	13
Weighted mean	1600	7

The five values are statistically consistent (reduced χ^2 of 2,9). The internal uncertainty is 4 and the external uncertainty is 7.

The recommended value is the weighted mean with the external uncertainty.

Alpha Transitions

The alpha transition intensities have been deduced from the Rn-222 decay scheme balance at each level.

Below, comparison is done between the one and only measured values by Bastin-Scoffier (1963Ba62) and the calculated ones :

Alpha emission energy (keV)	Measured intensities ^c	Calculated intensities
4784,34 (25) ^a	94,45 (5)	94,03 (8)
4601 (1) ^a	5,55 (5)	5,96 (8)
4340 ^b	0,0065 (3)	0,0065 (16)
4191 ^b	0,0010 (1)	0,0008
4160 ^b	0,00027 (5)	0,0002

^a Energy data are from Rytz (1991Ry01)

^b Energy data are from Bastin-Scoffier

^c Intensities are from Bastin-Scoffier with uncertainties given by Rytz

Gamma transitions and internal conversion coefficients

The internal conversion coefficients were interpolated from the tables of Rösel (1978Ro21), uncertainties are assumed to be 3%. Theoretical values are compared with measured values below :

	De Pinho (1973De50)	Rösel
α_K	0,200(9)	0,190 (6)
α_{L1}	0,031 (6)	0,0327 (10)
α_{L2}	0,226 (16)	0,212 (6)
α_{L3}	0,124 (8)	0,122 (4)
α_L	0,380 (20)	0,367 (11)

The gamma transition probabilities were determined from the gamma emission intensities and the theoretical ICC data.

Photon emissions

Gamma emission intensities

186-keV γ -ray

The strongest γ -ray, namely 186-keV, absolute emission intensity is taken from Helmer (IAEA - CRP). This study was done for the ²²⁶Ra decay chain, all available relative and absolute measurements of gamma rays were taken into account, the most intense line of this chain is the 609,3 keV line which occurs in the disintegration of ²¹⁴Bi. Its intensity was determined as : 45,16 (33)% by Helmer (IAEA - CRP).

The 186 keV line from Ra-226 and the 609 keV line from Bi-214 intensity measurements are given below in Tables 1 and 2 :

Table 1 - Absolute gamma-ray emission intensities, results of measurements :

Energy (keV)	1969Li11	1983OI01	1983Sc13	1991Li11	1998Mo14	Weighted average	S _{int} ; S _{ext}	reduced- χ^2
186,1 (Ra-226)		3,50 (5)	3,51 (6)	3,59 (6)		3,53	0,03	0,74
609,3 (Bi-214)	42,8 (40)	45,0 (7)	44,6 (5)	46,1 (5)	44,8 (6)	45,16	0,28 ; 0,33	1,39

Table 2 - Relative gamma-ray emission intensity, results of measurements :

Energy (keV)	1975Ha31	1982Ak03	2000Sa32	2002De03	Molnar	Weighted average	S _{int}	reduced- χ^2
186,1	8,7 (11)	9,2 (10)	7,6 (8)	7,812 (31)	7,85 (5)	7,824	0,026	0,76

These data are relative to the 609-keV line in Bi-214.

Table 3 - Combination of absolute and relative emission probabilities :

Energy (keV)	P _{γ} - table 1	P _{γ} - table 2	Weighted average	S _{int}	reduced- χ^2
186,211 (13)	3,53 (3)	3,533 (12)	3,533	0,021	0,01
609,316 (3)	45,16 (33)	reference			

The absolute emission intensity recommended by Helmer, and adopted here, for the 186 keV emission intensity is then : 3,533 (21) %,

262-keV γ -ray

This line was measured relatively to the 609-keV line of Bi-214 :

- Sardari (2000Sa32) : 0,012 (4) converted to the absolute value of 0,0054 (18) %

- Diallo (1993Di09,) : 0,012 (4) converted to the absolute value of 0,0054 (18) %

The adopted value is the weighted mean : 0,0054 (13) %

414-, 449- and 600-keV γ -rays

These three γ -emissions were reported by Lourens (1971Lo19) and Stephens (1960St20), no uncertainties were given,

The adopted values are those of Lourens converted to absolute values using $I_{\gamma}(186) = 3,533 (21)\%$

γ -ray energies

The γ -ray energies are from Lourens (1971Lo19).

Multipolarities are from Lagoutine *et al.* (1983La**).

X-ray emissions

Several measurements were carried out, they are summarized in the table below and compared to the calculated values deduced from the decay scheme :

	Delgado (2002De03)	Schötzig (1983Sc13)	De Pinho ^a (1973De50)	Calculated
K α 1	0,215 (3)			0,315 (11)
K α 2	0,156 (39)			0,191 (7)
K α	0,371 (39)	0,418 (21)		0,505 (17)
K β 1	0,079 (5)			0,109 (4)

K β 2	0,020 (4)			0,0349 (14)
K β	0,099 (6)	0,145 (9)		0,144 (5)
XK	0,47 (4)	0,563 (23)	0,689 (25)	0,649 (21)
XL1			0,0180 (25)	0,0149 (5)
XL2			0,417 (28)	0,431 (14)
XL3			0,399 (14)	0,367 (11)
XL			0,837 (43)	0,813 (17)

^a Calculated with $I_{\gamma}(186) = 3,533 (21)$

The calculated values based on the assumption that $I_{\gamma}(186) = 3,533 (21)$ are significantly greater than those measured by Delgado or Schötzig, except for the K β ray.

Nevertheless, with $I_{\gamma}(186) = 3,28 (3) \%$, based on an α - transition to the 186-keV level of 5,55 (5)% and with the same calculation method, we obtain : XK = 0,603 (20) %. This value is consistent with those of Schötzig but the Delgado's value remains unexplained. It can be noted that Schötzig gave an absolute intensity of 3,51 (6)% for the 186-keV line, consistent with the recommended one.

The calculated data are in agreement, within the uncertainty values, with the experimental ones of De Pinho, who used a Ra-226 source from which the descendants were removed. Schötzig and Delgado, however, carried out measurements with sources in equilibrium with their daughters radionuclides.

References

- 1949Ko01 T.P.Kohman, D.P.Ames, J.Sedlet. NNES 14B (1949) 1675
Half-life
- 1956Se01 W.Sebaoun. Ann. Phys. 1 (1956) 680
Half-life
- 1959Ma12 G.R.Martin, D.G.Tuck. Int. J. Appl. Radiat. Isotop. 5 (1959) 141
Half-life
- 1959Go80 G.V.Gorshkov et al. Atomnaya Energ., Atomic Energy (USSR) 7 (1959) 912
Half-life
- 1960St20 F.S.Stephens, F.Asaro, I.Perlman. Phys. Rev. 119 (1960) 796
Gamma-ray emission probabilities
- 1963Ba62 G.Bastin-Scoffier, C.F Leang, R.J Walen. Le Journal de Physique (Paris) 24 (1963) 854
Alpha emission energies, Alpha emission probabilities
- 1966Ra13 H.Ramthun. Nucleonics 8 (1966) 244
Half-life
- 1969Li11 E.W.A.Lingeman, J.Konijn, P.Polak, A.H.Wapstra. Nucl. Phys. A133 (1969) 630
Gamma-ray emission intensities
- 1971Lo19 W.Lourens, A.H.Wapstra. Z. Phys. 247 (1971) 147
Gamma-ray energies and emission probabilities
- 1973De50 A.G. de Pinho, M.Weksler. Z. Naturforsch. 28a (1973) 1635
X-ray emission intensities
- 1975Ha31 A.Hachem. Comp. Rend. Acad. Sci. (Paris) 281 Serie B (1975) 45
Gamma-ray emission intensities

- 1978Ro21 F.Rösel, H.M.Friess, K.Alder, H.C.Pauli. *At. Data. Nucl. Data Tables* 21 (1978) 92
Theoretical internal conversion coefficients
- 1982Ak03 H.Akçay, G.Mouze, D.Maillard, C.Ythier. *Radiochem. Radioanal. Lett.* 51 (1982) 1
Gamma-ray emission intensities
- 1983La** F.Lagoutine, N.Coursol, J.Legrand, *Table de Radionucléides*, ISBN 2 7272 0078 1 (LMRI, 1982- 1987)
- 1983Ol01 D.G.Olson. *Nucl. Instrum. Methods* 206 (1983) 313
Gamma-ray emission intensities
- 1983Sc13 U.Schötzig, K.Debertin. *Int. J. Appl. Radiat. Isotop.* 34,2 (1983) 533
Gamma-ray emission intensities, X-ray emission intensities
- 1990Mo** G.Mouze, C.Ythier, J.F.Comanducci. *Rev. Roumaine Phys.* 35 (1990) 337
Gamma-ray emission intensities
- 1991Li11 W.J.Lin, G.Harbottle. *J. Radioanal. Nucl. Chem. Lett.* 153 (1991) 137
Gamma-ray emission intensities
- 1991Ry01 A.Rytz. *At. Data. Nucl. Data Tables* 47 (1991) 205
Alpha emission energies, Alpha emission probabilities
- 1993Di09 O.Diallo, G.Mouze, C.Ythier, J.F.Comanducci. *Nuovo Cim.* 106A,10 (1993) 1321
Gamma-ray emission intensities
- 1993Au05 G.Audi, A.H.Wapstra. *Nucl. Phys.* A595 (1995) 409
Q
- 1996El01 Y.A.Akovi. *Nucl. Data Sheets* 77 (1996) 271
Spin and Parity
- 1998Mo14 J.Morel, M.Etcheverry, J.L.Piccolo. *Appl. Rad. Isotopes* 49 (1998) 1387
Gamma-ray emission intensities
- 2000Sa32 D.Sardari, T.D.MacMahon. *J. Radioanal. Nucl. Chem.* 244,2 (2000) 463
Gamma-ray emission intensities
- 2002De03 J.U.Delgado, J.Morel, M.Etcheverry. *Appl. Rad. Isotopes* 56 (2002) 137
Gamma-ray emission intensities, X-ray emission intensities
- 2003Mo** G.L.Molnar, ZS.Révay, T.Belgya. 11th Int. Symp. On Capture gamma-ray Spectroscopy, 2-6 Sep 2002, Pruhonice, Ed. J.Kvasil, P.Cejnar, M.Krticka (2003) 522
Gamma-ray emission intensities
- 2004He** R.G.Helmer. IAEA - CRP Report To be published (2004)
186-keV gamma ray intensity

²²⁷Th – Comments on evaluation of decay data by E. Browne

1) Evaluation Procedures

The *Limitation of Relative Statistical Weight* (LWM) [1985ZiZY] method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation. This evaluation was completed in August 2001, with minor editing done in March 2002.

2) Decay Scheme

²²⁷Th decays 100% by emission of α particles, 24,2(9)% populates the ground state of ²²³Ra. Evaluator normalized the decay scheme using measured values of the absolute emission probability of the 50.13-keV γ -ray, as described here in Section 5. There are several low-energy γ -rays, many of them with very large and not well-known conversion coefficients that have limited the accuracy of their respective total transition probabilities. For this reason the individual feedings, deduced from transition-intensity balances at each level, are also inaccurate. Thus such feedings have not been shown here. The α -particle probabilities (in percent) to individual levels presented in the decay scheme are experimental values from α -spectroscopic measurements of 1964Ba33. α -hindrance factors given in the decay scheme are from 2001Br31, calculated by using a radius parameter r_0 (²²³Ra) = 1.536, average of r_0 (²²²Ra) = 1.5383(8) and r_0 (²²⁴Ra) = 1.5332(8) (1998Ak04). The level energies, spins, parities, as well as γ -ray multipolarities and mixing ratios shown in the decay scheme are from 2001Br31.

3) Nuclear Data

Table 1. ²²⁷Th measured half-life values

Half-life (days)	Reference
18.169 (84)	1954Ha60
18.729 (48)	1963Ei10
18.7176 (52)	1967JoZX
18.738 (54)	1987Mi10

The (unpublished) value given in 1954Ha60 significantly disagrees with the other measured values. The ²²⁷Th source used in 1954Ha60 contained several daughter radionuclides from the decay chain. Moreover, they used proportional counters to detect alpha particles, without any elemental discrimination. This situation may have introduced a systematic error in their half-life. Thus, the evaluator excluded this value from the statistical analysis. The recommended half-life of ²²⁷Th is the weighted average (LWM) ($\chi^2/\nu = 0.1$) of the other three measured values, 18.718(5) days.

$Q_\alpha = 6146.43(15)$ keV is from 1995Au05.

4) Alpha Particles

Alpha particle energies and absolute probabilities presented in Section 4 are evaluated values from 2001Br31. Most α -particle energies are from 1964Ba33, increased by 1.7 keV to correct them for a systematic deviation (2001Br31). The energies of $\alpha_{(0,12)}$, $\alpha_{(0,3)}$, and $\alpha_{(0,0)}$ are from 1971Gr17, as recommended by 1991Ry01. Absolute α -particle probabilities are from 1964Ba33.

5) Gamma Rays

Energies

The recommended γ -ray energies given in Sections 2.2 and 6.2 are weighted averages (LWM) of values from 1993Ab01, 1990Br23, 1972He18, and 1969Br27, unless otherwise specified in Table 2.

Emission Probabilities

The recommended relative γ -ray emission probabilities given in Table 2 are weighted averages (LWM) of values from 1993Ab01, 1972He18, and 1969Br27, unless otherwise specified in this table.

Excepting the 304.50-keV gamma ray, all the conversion coefficients given in Section 2.2 are theoretical values from 1978Ro22 interpolated by using program ICC [1] for the recommended γ -ray energies and multipolarities. The 304.50-keV gamma ray has an E0 component, thus the conversion coefficients given here for this transition are experimental values.

The γ -ray emission (and total transition) probabilities given in Sections 6.2 and 2.2, respectively, have been normalized to an absolute scale (per 100 α decays) using a normalization factor $N = 0.126(6)$. Evaluator deduced this value from $I_{\text{avg}}(50.13 \gamma) = 8.20(17)\%$, weighted average of the following measured absolute γ -ray emission probabilities: $I_{\gamma}(50.13) = 8.18(17)\%$ (1990Ko40) and $I_{\gamma}(50;13) = 8.4(6)\%$ (1969Pe17).

A normalization factor $N = 0.127(11)$ may be obtained by using the decay scheme and the sum of all the relative γ -ray transition probabilities (photons + electrons) to the ground state and to the first excited state at 29 keV, then equating this sum to 72.9(10)% (that is, to $100\% - I_{\alpha}(\text{gs} + 29\text{-keV level}) = 100\% - 27.1(10)\% = 72.9(10)\%$). This value, although less precise, is in good agreement with the one given before, and it confirms the correctness and consistency of the decay scheme.

6) Atomic Data

X-ray and Auger (relative and absolute) electron emission probabilities given in Sections 3, 6.1 and 5, respectively, have been calculated by means of the computer code EMISSION (version 3,01, Nov. 3, 1999) [2]), which makes use of the atomic data from 1996Sc06, from reference [3], and from the evaluated γ -ray data given in Sections 2.2 and 6.2. In addition, internal conversion electron energies and absolute emission probabilities for the strongest lines are presented in Section 5. Electron energies have been calculated using electron binding energies from 1977La19, and γ -ray energies from Section 2.2. Absolute electron emission probabilities have been calculated using absolute γ -ray emission probabilities given in Section 6.2 and conversion coefficients from Section 2.2.

7) References

[1] V. M. Gorozhankin, N. Coursol, E. A. Yakushev. ICC99: A computer program for interpolating internal conversion coefficients from Hager and Seltzer, Rösler et al., and from Band et al. (1999). (Internal conversion coefficients)

- [2] E. Schönfeld, H. Janssen. *Applied Radiation Isotopes* **52**, 595 (2000). (X-ray and Auger electron emission probabilities).
- [3] Eckart Schönfeld, Gisela Rodloff. Report PTB-**6.11-98-1**, Braunschweig, October 1998. (Auger electron energies).
- 1954Ha60 - G. R. Hagee, M. L. Curtis, G. R. Grove. *Phys. Rev.* **96**, 817A (1954). (Half-life)
- 1963Ei10 - J. F. Eichelberger, G. R. Grove, L. V. Jones, E. A. Rembold. *MLM-1155*, p.12 (1963). (Half-life)
- 1967JoZX - K. C. Jordan, B. C. Blanke. *Proc. Symp. Standardization of Radionuclides, Vienna, Austria* (1966), Intern. At. Energy Agency, Vienna, p.567 (1967); CONF-661012-4 (1967). (Half-life)
- 1969Pe17 - A. Peghaire. *Nucl. Instr. Methods* **75**, 66 (1969). (Absolute γ -ray emission probability)
- 1969Br27 - C. Briançon, R. Walen. *J. Phys. (Paris)* **30**, 753 (1969) (γ -ray energies and emission probabilities).
- 1971Gr17 - B. Grennberg, A. Rytz. *Metrologia* **7**, 65 (1971) (α -particle energies).
- 1972He18 - W. H. A. Hesselink, A. H. Wapstra, J. G. Kromme, E. J. Haighton, M. Van Kampen, W. Hutjes, K. E. M. Dijkman. *Nucl. Phys.* **A191**, 283 (1972). (γ -ray energies and emission probabilities).
- 1977La19 - F. P. Larkins. *At. Data Nucl. Data Tables* **20**, 311 (1977). (Atomic electron binding energies).
- 1978Ro22 - F. Rosel, H. M. Fries, K. Alder, H. C. Pauli. *At. Data Nucl. Data Tables* **21**, 92 (1978). (γ -ray theoretical internal conversion coefficients).
- 1985ZiZY - W. L. Zijp, Report ECN FYS/RASA-**85/19** (1985). (Discrepant Data. Limited Relative Statistical Weight Method).
- 1987Mi10 - G. J. Miller, J. C. McGeorge, I. Anthony, R. O. Owens. *Phys. Rev.* **C36**, 420 (1987). (Half-life).
- 1990Br23 - Ch. Briancon, S. Cwiok, S. A. Eid, V. Gree, W. D. Hamilton, C. F. Liang, R. J. Walen. *J. Phys. (London)* **G16**, 1735 (1990). (γ -ray energies).
- 1990Ko40 - K. Komura, M. Yamamoto, K. Ueno. *Nucl. Instrum. Methods. Phys. Res.* **A295**, 461 (1990). (Atomic data, X-rays, Auger electrons).
- 1991Ry01- A. Rytz. *At. Data Nucl. Data Tables* **47**, 205 (1991). (α -particle energies).
- 1993Ab01 - A. Abdul-Hadi, V. Barci, B. Weiss, H. Maria, G. Ardisson, M. Hussonnois, O. Constantinescu. *Phys. Rev.* **C47**, 94 (1993). (γ -ray energies and emission probabilities).
- 1995Au04 - G. Audi, A. H. Wapstra. *Nucl. Phys.* **A595**, 409 (1995). (Q_α)
- 1996Sc06 - E. Schönfeld, H. Janssen. *Nucl. Instrum. Methods. Phys. Res.* **A369**, 527 (1996). (Atomic data, X-rays, Auger electrons).
- 1998Ak04 - Y.A. Akovali. *Nucl. Data Sheets* **84**, 1 (1998). (Alpha decay. Radius parameter of even-even nuclei).
- 2001Br31 - E. Browne. *Nucl. Data Sheets* **93**, 763 (2001). (Evaluated data (ENSDF) for nuclei with $A=227$. Corrected α -particle energies).

Table 2. ²²⁷ Th Alpha Decay - Gamma-Ray Energies and Relative Emission Probabilities											
1993Ab01(E _γ)	1993Ab01(I _γ)	1990Br23(E _γ)	1990Br23(I _γ)	1972He18(E _γ)	1972He18(I _γ)	1969Br27(E _γ)	1969Br27(I _γ)	Adopted E _γ ^a	Adopted I _γ ^b	χ ² /ν(E _γ)	χ ² /ν(I _γ)
6.5 (3)	0.7 (2)	6.3				6		6.5 (3)*	0.7 (2)*		
8.3 (2)	0.06 (2)	8				8.0 (2)		8.15 (20)	0.06 (2)*	1.1	
20.19 (5)	1.9 (2)	20.30 (5)	0.769			20.3 (2)	1.5 (5)	20.25 (5)	1.84 (20)	1.3	0.55
20.8 (2)	0.05 (2)	20.95 (5)						20.94 (5)	0.05 (2)*	0.53	
22.0 (2)	0.07 (7)							22.0 (2)*	0.07 (7)*		
24.13 (5)	0.68 (5)							24.13 (5)*	0.68 (5)*		
27.32 (5)	0.23 (4)	27.50 (10)	0.154					27.41 (9)	0.23 (4)*	1.6	
		29.60 (3)	0.046					29.60 (3)**	0.046**		
29.86 (5)	0.56 (8)	29.86 (1)	0.769			29.9 (2)	0.8 (2)	29.86 (1)	0.59 (8)	0.02	0.87
31.56 (5)	0.51 (8)	31.58 (1)	0.692			31.6 (2)	0.62 (17)	31.58 (1)	0.53 (8)	0.08	0.34
33.3 (2)	0.06 (2)	33.40 (8)	0.108					33.39 (8)	0.06 (2)*	0.22	
40.20 (3)	0.12 (3)	40.20 (10)	0.154	40.1				40.20 (3)	0.12 (3)*	0.01	
41.91 (5)	0.12 (3)	42.2 (3)	0.308	42.2 (5)	0.70 (26)	42.1 (3)	0.31 (6)	41.93 (5)	0.22 (10)	0.52	4.3
43.75 (5)	1.6 (1)	43.80 (5)	1.538	43.5 (5)	2.1 (6)	43.8 (2)	1.77 (21)	43.77 (5)	1.65 (10)	0.27	0.69
				43.8 (5)	0.43 (17)			43.8 (5)&	0.43 (17)&		
44.33 (5)	0.4 (1)	44.10 (5)	0.046	44.1	0.06 (3)	44.1		44.22 (12)	0.41 (10)	5.3	0.04
		44.40 (5)		44.3 (5)	0.11 (5)	44.4	0.15	44.40 (5)**			
		46.45 (5)						46.45 (5)**			
				48.3 (5)							
48.1 (2)	0.12 (3)	48.30 (3)	0.077	48.5 (5)	0.39 (10)	48.3	0.08 (1)	48.30 (3)	0.11 (4)	0.57	4.5
49.75 (5)	3.5 (5)	49.90 (7)	4.615	49.8 (3)	1.7 (13)	49.9	4.6 (14)	49.82 (5)	3.3 (7)	1.2	1.2
50.11 (2)	63 (2)	50.13 (1)	61.538	50.2 (2)	75.7 (52)	50.2 (2)	65 (3)	50.13 (1)	65 (3)	0.36	2.7
50.8 (2)	0.11 (5)	50.85 (5)	0.031	50.7 (5)	0.14 (6)			50.85 (5)	0.12 (5)	0.07	0.15
				51.2				51.2&			
54.1 (1)	0.05 (1)	54.20 (4)	0.008	54.2				54.19 (4)	0.05 (1)*	0.86	
		56.00 (6)	0.038	56.1	0.01 (1)	56.1	0.08 (2)	56.00 (6)**	0.038**		
56.3 (2)	0.12 (2)	56.55 (3)	0.077			56.6	0.13 (4)	56.42 (14)	0.07 (6)	0.78	10
				59.6 (5)	0.08 (3)			59.6 (5)&	0.08 (3)&		
61.42 (5)	0.70 (8)	61.44 (2)	0.846	61.5		61.5 (2)	0.69 (14)	61.44 (2)	0.70 (8)	0.12	
				62							

1993Ab01(E γ)	1993Ab01(I γ)	1990Br23(E γ)	1990Br23(I γ)	1972He18(E γ)	1972He18(I γ)	1969Br27(E γ)	1969Br27(I γ)	Adopted E γ ^a	Adopted I γ ^b	χ^2/ν (E γ)	χ^2/ν (I γ)
62.33 (5)	1.5 (2)	62.45 (5)	1.385	62.5 (3)	2.2 (5)	62.5 (2)	1.54 (23)	62.45 (5)	1.57 (20)	2.6	0.86
62.7 (2)	0.05 (2)	62.65 (4)	0.077	62.7 (3)	0.08 (3)			62.68 (3)	0.056 (20)	0.5	0.45
64.5 (2)	0.19 (3)	64.30 (10)	0.115	64.5 (5)	0.24 (9)			64.35 (10)	0.20 (3)	0.45	0.28
65.2 (1)	0.13 (3)	64.70 (10)	0.077					64.95 (25)	0.13 (3)*	12	
				66.2 (5)	0.05 (3)			66.2 (5)&	0.05 (3)&		
				66.4 (5)	0.06 (3)			66.4 (5)&	0.06 (3)&		
		68.70 (10)	0.046	68.7	0.01 (1)			68.70 (10)**	0.046**		
68.72 (5)	0.53 (4)	68.75 (3)	0.346	68.8 (5)	0.24 (10)	68.8 (2)	0.44 (7)	68.74 (3)	0.45 (8)	0.12	3.2
69.8 (3)	0.08 (3)			69.8 (5)	0.08 (3)			69.8 (3)	0.08 (3)		
72.85 (5)	0.32 (4)	72.80 (10)	0.231	72.9	0.03 (3)	72.9 (1)	0.22 (4)	72.85 (5)	0.19 (15)	0.25	12
73.8 (2)	0.07 (2)	73.60 (5)	0.077	73.7 (5)	0.15 (5)	73.7 (1)	0.15 (2)	73.63 (5)	0.11 (4)	0.53	4.3
75.00 (5)	0.29 (3)	75.1	0.154	75.3 (5)	0.08 (5)	75.1 (3)	0.18 (5)	75.01 (5)	0.21 (8)	0.23	7
						77.4 (4)	0.08	77.4 (4)#	0.08#		
79.66 (3)	15.1 (5)	79.72 (1)	15.385	79.7 (2)	15.7 (44)	79.8 (2)	15.4 (15)	79.69 (2)	15.1 (5)	0.78	0.04
		84									
89.17 (8)	0.03 (1)	90.0 (3)	0.031	89.9				89.6 (4)	0.03 (1)*	3.8	
93.86 (5)	11.9 (5)	93.90 (10)	10.000	94.0 (2)	11.7 (3)	94.0 (2)	10.8 (11)	93.88 (5)	11.7 (3)	0.31	0.28
94.9 (1)	0.30 (4)	94.99 (5)	0.092	95		95	0.09 (1)	94.97 (5)	0.19 (11)	0.65	14
96.02 (5)	0.6 (1)	96.1 (2)	0.462	96.1 (5)	0.39 (17)	96.1 (2)	0.54 (13)	96.03 (5)	0.54 (10)	0.1	0.57
99.5 (2)	0.20 (5)	99.60 (10)	0.100	99.5				99.58 (10)	0.20 (5)*	0.2	
		99.60 (20)	0.015	99.7				99.60 (20)**	0.1**		
100.2 (2)	0.7 (2)	100.27 (3)	0.731	100.4 (5)	0.7 (3)	100.3	0.62 (12)	100.27 (3)	0.65 (12)	0.1	0.08
		102.50 (10)	0.009	102.5				102.50 (10)**	0.009**		
106.1 (2)	0.03 (1)	105.20 (10)	0.077					105.20 (10)**	0.077**		
107.9 (2)	0.05 (2)	107.75 (7)	0.046	108	0.06 (3)	107.5 (5)	0.07 (2)	107.76 (7)	0.060 (20)	0.39	0.25
108.9 (3)	0.03 (1)	108.00 (10)	0.000	109.6 (5)	0.05 (2)			109.2 (4)	0.041 (12)	0.98	0.84
110.7 (2)	0.04 (1)	110.65 (5)	0.062	110.6	0.01 (1)			110.65 (5)	0.025 (16)	0.06	4.8
				112.6 (5)	0.07 (3)			112.6 (5)&	0.07 (3)&		
113.06 (2)	6.6 (3)	113.16 (2)	5.385	113.1 (2)	4.7 (6)	113.1 (2)	5.5 (6)	113.11 (5) ^c	5.9 (8)	4.2	3.6
117.20 (5)	1.7 (1)	117.20 (5)	1.308	117.0 (3)	1.4 (3)	117.2 (2)	1.38 (14)	117.20 (5)	1.54 (11)	0.15	1.6
		117.20 (5)	0.077	117.5 (5)	0.10 (3)			117.5 (5)&	0.10 (3)&		

1993Ab01(E γ)	1993Ab01(I γ)	1990Br23(E γ)	1990Br23(I γ)	1972He18(E γ)	1972He18(I γ)	1969Br27(E γ)	1969Br27(I γ)	Adopted E γ ^a	Adopted I γ ^b	χ^2/ν (E γ)	χ^2/ν (I γ)
123.6 (1)	0.14 (2)	123.5 (2)	0.154	123.6 (5)	0.07 (2)	123.6	0.08	123.58 (10)	0.11 (4)	0.1	6.1
124.4 (2)	0.04 (2)	125	0.023	124.4	0.01 (1)	124.4	0.02	124.44 (20)	0.032 (17)	0.31	0.28
				124.7 (5)	0.03 (2)						
128.02 (2)	0.025 (4)							128.02 (2)*	0.025 (4)*		
129.4 (2)	0.010 (5)							129.4 (2)*	0.010 (5)*		
134.6 (1)	0.30 (5)	134.5 (3)	0.154	134.2 (3)	0.26 (5)	134.6 (2)	0.23 (5)	134.6 (1)	0.26 (5)	0.56	0.49
138.4 (1)	0.11 (2)	138	0.018					138.4 (1)*	0.11 (2)*		
140.5 (3)	0.05 (2)	141.0 (5)	0.038	140.5 (3)	0.28 (5)			140.6 (3)	0.17 (2)	0.42	11
141.34 (5)	1.1 (1)	141.50 (5)	1.000	141.2 (3)	0.57 (13)	141.4 (2)	1.00 (15)	141.42 (5)	0.92 (18)	1.9	5.4
150.1 (2)	0.07 (3)	150.2 (2)	0.038	149.8 (5)	0.16 (3)	150.3 (5)	0.07 (2)	150.14 (20)	0.086 (24)	0.23	2.1
162.2 (1)	0.07 (2)	162.1 (3)	0.062	162.2 (5)	0.05 (2)	162.1 (5)	0.07	162.19 (10)	0.060 (20)	0.04	0.5
164.5 (1)	0.11 (2)	164.8	0.077			164.9 (5)	0.12 (3)	164.52 (10)	0.113 (20)	0.62	0.08
168.4 (1)	0.11 (2)	168.25 (15)	0.100	168.3 (3)	0.12 (3)	168.7 (5)	0.12 (3)	168.36 (10)	0.115 (20)	0.4	0.06
169.7 (2)	0.06 (2)	170.0 (1)	0.031	170.1 (5)	0.03 (2)			169.95 (10)	0.043 (17)	0.95	1.5
171.5 (2)	0.03 (1)			171.4				171.5 (2)*	0.03 (1)*		
173.45 (5)	0.16 (2)	173.40 (10)	0.123	173.4 (5)	0.10 (3)	173.5 (3)	0.12	173.45 (3)	0.135 (20)	0.09	1.5
				175.8 (3)	0.16 (3)			175.8 (3)&	0.16 (4)&		
181.1 (3)	0.02 (1)	181	0.015					181.1 (3)*	0.02 (1)*		
182.3 (2)	0.03 (1)							182.3 (2)*	0.03 (1)*		
184.65 (5)	0.29 (3)	184.65 (5)	0.262	184.7 (3)	0.23 (4)	184.7 (3)	0.31 (5)	184.65 (5)	0.28 (3)	0.02	0.73
197.5 (1)	0.07 (2)	197.60 (10)	0.077	197.6 (5)	0.09 (3)	197.8 (5)	0.12 (3)	197.56 (10)	0.10 (3)	0.25	0.4
200.5 (1)	0.17 (2)	200.5 (2)	0.154	200.5	0.02 (2)	201.0 (4)	0.25 (6)	200.50 (10)	0.10 (7)		23
201.7 (1)	0.16 (2)	201.60 (10)	0.138	201.8 (3)	0.19 (3)			201.64 (10)	0.184 (20)	1.1	0.88
				202.5 (5)	0.05 (2)			202.5 (5)&	0.05 (2)&		
204.2 (1)	1.7 (2)	204.14 (10)	1.538	204.2 (3)	2.0 (4)	204.3 (2)	1.6 (4)	204.14 (10)	1.76 (20)	0.19	0.44
204.9 (1)	1.2 (2)	205.02 (10)	0.769	205.2 (3)	1.5 (3)	205.0 (2)	1.2 (3)	204.98 (10)	1.27 (20)	0.45	0.38
206.05 (6)	1.9 (2)	206.10 (5)	1.538	206.1 (3)	2.3 (4)	206.2 (2)	1.7 (4)	206.08 (5)	1.97 (20)	0.25	0.89
		206.3	0.062	206.4	0.02 (2)			206.4&	0.02 (2)&		
210.58 (5)	9.4 (3)	210.65 (5)	8.462	210.6 (2)	11.0 (8)	210.7 (2)	8.5 (9)	210.62 (5)	9.7 (7)	0.39	2.4
212.76 (5)	0.63 (5)	212.65 (4)	0.615	212.6 (3)	0.74 (13)	212.2	0.38 (10)	212.70 (4)	0.61 (7)	1.3	1.3
				212.7 (3)	0.15 (4)	213	0.46 (12)	212.7 (3)&	0.15 (4)&		

216.0 (1)	0.002 (1)							216.0 (1)*	0.002 (1)*		
218.89 (5)	0.83 (8)	219.0 (2)	0.538	218.8 (3)	0.48 (9)	219.0 (2)	0.85 (10)	218.90 (5)	0.85 (8)	0.22	0.05
		219.0 (2)	0.231	219.0 (3)	0.39 (9)			219.0 (2)&	0.39 (9)&		
222.8 (2)	0.04 (1)	223.60 (15)	0.015					223.2 (4)*	0.04 (1)*	8	
225.9 (1)	0.07 (2)	225.5 (5)	0.015	224.7 (5)	0.13 (3)	225.5 (10)	0.03	225.5 (3)*	0.07 (2)*	1.3	
229.4 (2)	0.03 (1)	230.3 (3)	0.005	230.4				229.9 (5)*	0.03 (1)*	4.5	
234.7 (1)	3.4 (3)	234.80 (10)	3.615	234.9 (3)	5.0 (10)	234.9	3.1 (6)	234.76 (10)	3.5 (4)	0.37	1.4
235.94 (3)	100	235.97 (2)	100.000	236.0 (2)	100 (4)	236.0 (2)	100 (8)	235.96 (2)	100 (2)	0.26	
246.1 (1)	0.10 (3)	246.1 (3)	0.077	246.4 (5)	0.10 (3)	246.2 (3)	0.08 (3)	246.12 (10)	0.095 (17)	0.14	0.18
248.1 (1)	0.19 (4)							248.1 (1)*	0.19 (4)*		
				249.6 (5)	0.06 (2)			249.6 (5)&	0.06 (2)&		
250.1 (2)	0.08 (2)	250.15 (5)	3.231	250.2 (3)	2.4 (4)	250.2		250.15 (5)	0.069 (13)	0.04	0.52
250.19 (3)	4.0 (3)	250.35 (5)	1.077	250.4 (3)	0.61 (17)	250.4	3.1 (6)	250.27 (8)	3.5 (3)	2.7	1.6
252.50 (5)	0.9 (2)	252.6 (4)	0.769	252.5 (5)	1.0 (3)	252.6	0.77 (19)	252.50 (5)	0.86 (12)	0.03	0.21
254.62 (3)	5.6 (3)	254.67 (10)	5.385	254.7 (3)	7.9 (10)	254.7	3.9 (8)	254.63 (3)	5.5 (10)	0.15	4.9
256.22 (2)	54 (1)	256.25 (2)	56.154	256.2 (2)	55 (4)	256.3 (2)	57 (3)	256.23 (2)	54.3 (10)	0.42	0.46
260.6 (2)	0.04 (1)							260.6 (2)*	0.04 (1)*		
262.85 (5)	0.9 (1)	262.90 (10)	0.769	262.7 (5)	0.87 (17)	263.0 (2)	0.77 (9)	262.87 (5)	0.83 (6)	0.26	0.49
265.3 (2)	0.04 (1)							265.3 (2)*	0.04 (1)*		
267.0 (2)	0.08 (2)	267.1 (2)	0.019	267				267.05 (20)	0.08 (2)*	0.13	
267.7 (2)	0.06 (2)	268.0 (2)	0.077	267.9		268.0 (5)	0.05 (2)	267.86 (20)	0.055 (20)	0.6	0.13
				270.5							
270.6 (2)	0.16 (3)	270.5 (2)	0.062	270.7 (5)	0.28 (10)			270.56 (20)	0.22 (7)	0.1	0.72
272.90 (5)	3.9 (2)	272.90 (10)	3.846	273.0 (3)	4.3 (6)	273.0 (2)	3.9 (6)	272.91 (5)	3.94 (20)	0.11	0.2
279.7 (5)	0.35 (5)	279.7 (10)	0.462	279.7 (3)	0.78 (17)	279.8 (2)	0.38	279.80 (5)	0.42 (10)	0.03	2.7
280.4 (2)	0.02 (1)	281.0 (2)	0.054	281				280.7 (3)	0.02 (1)*	4.5	
281.42 (5)	1.4 (1)	281.40 (10)	1.231	281.4 (3)	1.3 (3)	281.4 (2)	1.3 (3)	281.42 (5)	1.38 (9)	0.01	0.09
284.2 (1)	0.4 (1)	284.4 (2)	0.385	284.3	0.22 (10)			284.24 (10)	0.31 (10)	0.8	1.6
285.6 (2)	0.25 (5)	285.50 (10)	0.385	285.6 (3)	0.48 (9)	285.4 (3)	0.38 (10)	285.52 (10)	0.34 (9)	0.14	2.2
286.06(2)	15 (1)	286.12 (2)	11.538	286.2 (2)	14.3 (7)	286.2 (2)	12.3 (6)	286.09 (2)	13.5 (12)	1.7	3.8
289.6 (1)	15 (3)	289.5 (3)	0.054	289.6	0.02 (2)			289.59 (10)	15 (3)*	0.1	

1993Ab01(E γ)	1993Ab01(I γ)	1990Br23(E γ)	1990Br23(I γ)	1972He18(E γ)	1972He18(I γ)	1969Br27(E γ)	1969Br27(I γ)	Adopted E γ ^a	Adopted I γ ^b	χ^2/ν (E γ)	χ^2/ν (I γ)
289.8 (1)	0.15 (3)	289.5 (3)	0.012					289.77 (10)	0.15 (3)*	0.9	
292.41 (5)	0.52 (6)	292.40 (10)	0.538	292.3 (5)	0.48 (10)	292.5 (3)	0.54 (13)	292.41 (5)	0.51 (6)	0.05	0.08
296.50 (5)	3.3 (3)	296.50 (5)	3.769	296.6 (3)	3.4 (6)	296.6 (2)	3.7 (5)	296.50 (5)	3.4 (3)	0.12	0.24
299.95 (3)	17.3 (5)	300.00 (3)	16.923	300.0 (2)	16.4 (12)	300.0 (2)	16.9 (17)	299.98 (3)	17.1 (5)	0.47	0.25
300.8 (2)	0.11 (2)	300.35 (3)	0.846	300.3 (3)	2.4 (4)			300.50 (16)	0.11 (2)*	1.8	
304.47 (3)	8.6 (5)	304.52 (2)	7.692	304.4 (3)	12 (1)	304.5 (2)	7.7 (8)	304.50 (2)	8.9 (10)	0.68	5.2
306.1 (3)	0.08 (3)							306.1 (3)*	0.08 (3)*		
308.40 (5)	0.14 (2)	308.40 (10)	0.108	308.5 (5)	0.13 (3)	308.4 (3)	0.11 (3)	308.40 (3)	0.131 (20)	0.01	0.35
312.69 (3)	4.0 (3)	312.70 (10)	3.846	312.6 (3)	4.5 (9)	312.7 (2)	3.9 (6)	312.69 (3)	4.0 (3)	0.03	0.16
		314.75 (10)	0.269	314.8 (5)	0.22 (9)			314.75 (10)	0.27**	0.01	
314.85 (4)	3.7 (3)	314.85 (10)	3.385	314.8 (3)	4.7 (9)	314.9 (2)	3.6 (5)	314.85 (4)	3.8 (3)	0.03	0.62
		318.4 (2)	0.046	318.8 (5)	0.05 (2)			318.46 (20)	0.052 (17)&	0.55	
319.24 (5)	0.30 (3)	319.2 (2)	0.231	319.2 (5)	0.16 (4)	319.2 (2)	0.26 (3)	319.24 (5)	0.25 (5)	0.03	4
324.8 (2)	0.08 (2)	324.9 (2)	0.046					324.88 (20)	0.08 (2)*	0.29	
325.7 (3)	0.07 (3)	326.10 (10)	0.231	325.2 (5)	0.04 (2)			325.99 (18)	0.049 (20)	0.89	0.69
326.7				326.2	0.01 (1)	326.4 (5)	0.23				
329.85 (2)	21.7 (5)	329.85 (3)	21.538	329.9 (2)	25.2 (14)	329.9 (2)	21.5 (19)	329.85 (2)	22.8 (12)	0.04	2.2
332.2 (2)	0.013							332.2 (2)*	0.013 (4)*		
334.36 (2)	8.2 (3)	334.38 (2)	8.462	334.4 (3)	10.0 (9)	334.5 (2)	8.5 (11)	334.37 (2)	8.8 (6)	0.31	1.3
339.6 (2)	0.03 (1)	339.80 (10)	0.012	339.8				339.76 (10)	0.03 (1)*	0.8	
342.56 (4)	3.4 (1)	342.50 (10)	3.231	342.5 (3)	1.7 (4)	342.5 (2)	3.2 (6)	342.55 (4)	2.7 (7)	0.13	9.3
346.48 (5)	0.10 (1)	346.45 (1)	0.077	346.3 (5)	0.07 (2)	346.5 (5)	0.08 (3)	346.45 (1)	0.093 (10)	0.15	1
				348.5 (5)	0.05 (2)			348.5 (5)&	0.052 (17)&		
350.66 (2)	0.9 (2)	350.40 (10)	0.923	350.5 (3)	0.70 (17)	350.5 (2)	0.92 (14)	350.54 (7)	0.85 (14)	1.3	0.54
		352.60 (10)	0.100	352.6 (5)	0.08 (2)	352.7 (3)	0.10 (3)	352.61 (10)	0.078 (17)&	0.01	
362.7 (1)	0.04 (1)	362.4 (2)	0.038	362.5 (5)	0.03 (2)	362.6 (2)	0.04 (1)	362.63 (10)	0.393 (10)	0.63	0.04
369.5 (5)	0.05 (1)	369.35 (5)	0.046	369.4 (5)	0.03 (2)	369.4	0.05 (1)	369.35 (5)	0.048 (10)	0.05	0.33
371.0 (1)	0.06 (2)	370.85 (5)	0.054	370.9	0.01 (1)	370.9	0.05 (1)	370.93 (8)	0.031 (21)	1.1	5.8
		374.8 (2)	0.012	375.1		374.5 (1)	0.01	374.8 (2)**	0.012**		
376.0 (3)	0.04 (1)	376.30 (10)	0.005					376.27 (10)	0.04 (1)*	0.9	
379.4 (1)	0.08 (2)							379.4 (1)*	0.08 (2)*		

1993Ab01(E _γ)	1993Ab01(I _γ)	1990Br23(E _γ)	1990Br23(I _γ)	1972He18(E _γ)	1972He18(I _γ)	1969Br27(E _γ)	1969Br27(I _γ)	Adopted E _γ ^a	Adopted I _γ ^b	χ ² /ν(E _γ)	χ ² /ν(I _γ)
381.9 (1)	0.05 (1)	382.4 (6)	0.046	382.4 (5)	0.05 (2)	382.5 (1)	0.05	382.2 (3)	0.050 (10)	6.1	
383.51 (4)	0.37 (5)	383.50 (10)	0.385	383.6	0.01 (1)	383.6 (2)	0.38 (8)	383.51 (4)	0.19 (18)	0.11	
				392.4 (5)	0.08 (2)			392.4 (5)&	0.078 (17)&		
398.2 (2)	0.011 (3)	399.0 (4)	0.015			399.0 (15)	0.02	398.6 (3)	0.011 (3)**	1.1	
401.9 (1)	0.10 (3)	402.50 (10)	0.092	402.5	0.02 (2)	402.6 (3)	0.09 (3)	402.2 (3)	0.06 (4)	9.8	3.4
415.1 (1)	0.016 (3)	415.1 (2)	0.014	415.2		415.2 (3)	0.01	415.11 (10)	0.011 (5)	0.05	3
432.4 (5)	0.030 (4)	432.30 (10)	0.038	432.5 (5)	0.03 (2)	432.4 (2)	0.04 (1)	432.33 (10)	0.032 (4)	0.12	0.45
						442.5 (10)	0.00046	442.5 (10)#	0.00046#		
						445	0.0039 (39)	445#	0.004 (4)#		
						448.0 (6)	0.00115	448.0 (6)#	0.0011#		
452.9 (3)	0.002 (5)					452.7 (6)	0.00077	452.9 (3)	0.002 (5)*	0.09	
						457.5 (1)	0.00054	457.5 (1)#	0.00054#		
						462 (1)	0.00038	462 (1)#	0.00038#		
466.8 (2)	0.004 (2)					466.5 (10)	0.00038	466.8 (2)	0.004 (2)*	0.09	
469.0 (2)	0.007 (2)							469.0 (2)*	0.007 (2)*		
						480 (1)	0.0023 (7)	480 (1)#	0.0023 (7)#		
						482 (1)	0.0011 (3)	482 (1)#	0.0011 (3)#		
						493.1 (2)	0.0042 (6)	493.1 (2)#	0.0042 (6)#		
507.5 (1)	0.007 (2)					507.4 (3)	0.0031 (6)	507.5 (1)	0.0051 (20)	0.1	1.9
516.7 (3)	0.003 (1)					516.4 (3)	0.0013 (3)	516.6 (3)	0.0022 (8)	0.5	1.3
521.8 (3)	0.003 (1)							521.8 (3)*	0.003 (1)*		
524.7 (4)	0.0018 (4)					524.3 (4)	0.00115 (23)	524.5 (4)	0.0015 (3)	0.5	1.3
534.5 (4)	0.001					535.0 (12)	0.00077 (23)	534.6 (4)	0.00077 (23)#	0.16	
536.9 (1)	0.013 (2)					537.0 (3)	0.085 (12)	536.9 (1)	0.0085 (13)#	0.1	
540.2 (3)	0.002 (1)							540.2 (3)*	0.002 (1)*		
						552.4 (5)	0.0018 (3)	552.4 (5)#	0.0018 (4)#		
556.0 (2)	0.004 (1)					556.5 (5)	0.0017 (3)	556.1 (2)	0.0029 (12)	0.86	2.7
565.4 (1)	0.011 (2)							565.4 (1)*	0.011 (2)*		
569.4 (5)	0.010 (2)					569.0 (3)	0.0046 (7)	569.1 (3)	0.0046 (7)#	0.47	
576.0 (2)	0.004 (1)					575.7 (7)	0.0010 (2)	576.0 (2)	0.0025 (15)	0.31	4.5

1993Ab01(E _γ)	1993Ab01(I _γ)	1990Br23(E _γ)	1990Br23(I _γ)	1972He18(E _γ)	1972He18(I _γ)	1969Br27(E _γ)	1969Br27(I _γ)	Adopted E _γ ^a	Adopted I _γ ^b	χ ² /ν(E _γ)	χ ² /ν(I _γ)
579.0 (2)	0.006 (2)					578.5 (7)	0.0010 (2)	579.0 (2)	0.0035 (25)	0.47	3.1
585.8 (1)	0.007 (2)							585.8 (1)*	0.007 (2)*		
						589.0 (6)	0.00046 (12)	589.0 (6)#	0.00046 (12)#		
						596 (1)	0.00008	596 (1)#	0.00008#		
598.9 (2)	0.005 (1)							598.9 (2)*	0.005 (1)*		
607.8 (3)	0.002 (1)					607.5 (4)	0.0014 (3)	607.7 (3)	0.0014 (3)	0.36	0.33
						621.4 (5)	0.00046 (12)	621.4 (5)#	0.00046 (12)#		
623.8 (5)	0.002 (1)					623.8 (5)	0.0012 (3)	623.8 (5)	0.0013 (3)		0.59
						632.3 (7)	0.00108 (22)	632.3 (7)#	0.0011 (2)#		
						641.0 (5)	0.00015 (5)	641.0 (5)#	0.00015 (5)#		
644.3 (3)	0.0010 (3)					644.2 (5)	0.00038 (12)	644.3 (3)	0.0007 (3)	0.03	2.1
						648.5 (5)	0.00046 (14)	648.5 (5)#	0.00015 (5)#		
662.5 (3)	0.003 (1)					663.1 (5)	0.00046 (14)	662.8 (4)	0.00046 (14)#	0.72	
						692.0 (7)	0.00031 (9)	692.0 (7)#	0.00031 (9)#		
						704.3 (5)	0.00062 (12)	704.3 (5)#	0.00062 (12)#		
						707.2 (7)	0.00031 (9)	707.2 (7)#	0.00031 (9)#		
						718.5 (10)	0.00023 (9)	718.5 (10)#	0.00023 (9)#		
						722.1 (6)	0.0029 (9)	722.1 (6)#	0.0029 (9)#		
723.5 (1)	0.008 (2)					723.6 (6)	0.0029 (9)	723.5 (1)	0.0021 (8)#	0.03	
						734.4 (5)	0.0008 (3)	734.4 (5)#	0.0008 (3)#		
735.4 (2)	0.002 (1)					735.5 (5)	0.0012 (4)	735.4 (2)	0.0013 (4)	0.03	0.55
						738.4 (10)	0.00054 (13)	738.4 (10)#	0.00054 (13)#		
						746.4 (7)	0.0008 (3)	746.4 (7)#	0.0008 (3)#		
749.2 (1)	0.004 (1)					748.5 (5)	0.0023 (5)	748.8 (4)	0.0032 (9)	0.98	1.4
754.1 (2)	0.003 (1)					754.0 (6)	0.00077 (19)	754.1 (2)	0.0019 (11)	0.02	2.5
						756.9 (2)	0.0015 (4)	756.9 (2)#	0.0015 (4)#		
757.7 (1)	0.010 (2)					756.9 (2)	0.0062 (15)	757.3 (4)	0.0081 (19)	8	1.8
763.1 (2)	0.003 (1)					762.2 (5)	0.0020 (4)	762.6 (5)	0.0021 (4)	1.6	0.86
						766.3 (5)	0.0023 (5)	766.3 (5)#	0.0023 (5)#		
773.5 (4)	0.0013 (3)					773.0 (8)	0.0010 (4)	773.4 (4)	0.0012 (3)	0.31	0.36
776.3 (1)	0.013 (2)					775.3 (2)	0.0115 (12)	775.8 (5)	0.012 (1)	13	0.2

1993Ab01(E _γ)	1993Ab01(I _γ)	1990Br23(E _γ)	1990Br23(I _γ)	1972He18(E _γ)	1972He18(I _γ)	1969Br27(E _γ)	1969Br27(I _γ)	Adopted E _γ ^a	Adopted I _γ ^b	χ ² /ν(E _γ)	χ ² /ν(I _γ)
781.5 (2)	0.0025 (8)					780.5 (3)	0.0025 (5)	781.0 (5)	0.0025 (5)	5.6	
						784.2 (5)	0.00077 (19)	784.2 (5)#	0.00077 (19)#		
787.7 (5)	0.0011 (3)					787.4 (5)	0.00069 (17)	787.6 (5)	0.00089 (21)	0.18	0.9
						787.4 (5)	0.00031 (8)	787.4 (5)#	0.00031 (8)#		
						792.6 (6)	0.00031 (8)	792.6 (6)#	0.00031 (8)#		
						792.6 (6)	0.00023 (6)	792.6 (6)#	0.00023 (6)#		
797.7 (1)	0.008 (1)					796.8 (2)	0.0062 (6)	797.3 (5)	0.0071 (9)	10	1.6
804.2 (1)	0.009 (1)					803.5 (2)	0.0075 (8)	803.9 (4)	0.005 (4)	6.1	34
808.6 (4)	0.0006 (2)					807.5	0.00038	808.6 (4)#	0.0006 (2)#		
813.0 (1)	0.024 (5)					812.2 (2)	0.0208 (21)	812.6 (4)	0.013 (2)	8	9.6
818.1 (2)	0.0019 (5)					818.0 (10)	0.00077 (23)	818.1 (2)	0.0013 (6)	0.01	2.6
						818.0 (10)	0.00023 (9)	818.0 (10)#	0.00023 (9)#		
823.8 (1)	0.024 (5)					823.1 (2)	0.0192 (19)	823.4 (4)	0.020 (2)	6.1	0.86
826.9 (5)	0.0012 (4)					826.0 (10)	0.0015 (5)	826.7 (5)	0.0013 (4)	0.65	0.22
						828.5 (5)	0.0015 (4)	828.5 (5)#	0.0015 (4)#		
829.0 (2)	0.0060 (2)					828.5 (5)	0.00008 (3)	828.9 (2)	0.0060 (2)*	0.86	
838.2 (2)	0.005 (1)					837.3 (3)	0.0031 (3)	837.8 (5)	0.0041 (9)	4.5	1.8
842.8 (1)	0.007 (1)					842.2 (3)	0.0046 (5)	842.5 (3)	0.0069 (10)	2	0.15
						846.7 (5)	0.00115 (23)	846.7 (5)#	0.00115 (23)#		
847.8 (3)	0.003 (1)					848.7 (5)	0.00046 (14)	848.3 (6)	0.0021 (9)	0.4	1.6
						854.3 (5)	0.00054 (11)	854.3 (5)#	0.00054 (11)#		
						857.3 (7)	0.00046 (14)	857.3 (7)#	0.00046 (14)#		
858.9 (2)	0.003 (1)					858.8 (3)	0.0019 (3)	858.9 (2)	0.0020 (3)	0.08	1.1
						863 (1)	0.00015 (6)	863 (1)#	0.00015 (6)#		
867.1 (5)	0.004 (1)					867.5 (5)	0.00054 (11)	867.3 (5)	0.0023 (17)	0.32	6
876.5 (5)	0.0023 (6)					876.2 (4)	0.0012 (4)	876.3 (4)	0.0018 (6)	0.22	1.7
878.2 (4)	0.0015 (5)					878.2 (4)	0.0009 (3)	878.2 (4)	0.0011 (3)		1.1
						891 (1)	0.00015 (5)	891 (1)#	0.00015 (5)#		
						893 (1)	0.00010 (3)	893 (1)#	0.00010 (3)#		
						896.1 (5)	0.00085 (21)	896.1 (5)#	0.00085 (21)#		
908.9 (1)	0.021 (2)					908.2 (2)	0.0161 (24)	908.6 (4)	0.0185 (25)	6.1	3.1

1993Ab01(E γ)	1993Ab01(I γ)	1990Br23(E γ)	1990Br23(I γ)	1972He18(E γ)	1972He18(I γ)	1969Br27(E γ)	1969Br27(I γ)	Adopted E γ ^a	Adopted I γ ^b	χ^2/ν (E γ)	χ^2/ν (I γ)
						910 (1)	0.00012 (5)	910 (1)#	0.00012 (5)#		
						920.0 (5)	0.00009 (2)	920.0 (5)#	0.00009 (2)#		
						927 (1)	0.00005 (2)	927 (1)#	0.00005 (2)#		
						938.0 (8)	0.00008 (3)	938.0 (8)#	0.00008 (3)#		
						941.6 (3)	0.00055 (8)	941.6 (3)#	0.00055 (8)#		
						958.7 (3)	0.00048 (10)	958.7 (3)#	0.00048 (10)#		
970.3 (2)	0.0020 (5)					970.0 (4)	0.00023 (5)	970.2 (2)	0.0011 (9)		6.3
						971.7 (10)	0.00008 (4)	971.7 (10)#	0.00008 (4)#		
						988 (1)					
						990.0 (7)	0.00027 (7)	990.0 (7)#	0.00027 (7)#		
						995 (1)	0.00005	995 (1)#	0.00005 (3)#		
						999.8 (5)	0.00023 (6)	999.8 (5)#	0.00023 (6)#		
						1015.2 (7)	0.00012 (3)	1015.2 (7)#	0.00012 (3)#		
						1020 (1)	0.00015 (5)	1020 (1)#	0.00015 (5)#		
						1025 (1)	0.00012 (3)	1025 (1)#	0.00012 (3)#		
* From 93Ab01											
** From 90Br23											
& From 72He18											
# From 69Br27											
a Weighted average (LWM) of values from 93Ab01, 90Br23, 72He18, 69Br27, unless otherwise specified.											
b Weighted average (LWM) of values from 93Ab01, 72He18, 69Br27, unless otherwise specified.											
c Double											

**²²⁸Th – Comments on evaluation of decay data
by A. L. Nichols**

Evaluated: July/August 2001

Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

²²⁸Th ($T_{1/2} = 698.6$ days) decays 100% by alpha-particle emission ($Q(\alpha) = 5520.12(22)$ keV) to various excited levels and the ground state of ²²⁴Ra ($T_{1/2} = 3.64$ days). A reasonably well-defined decay scheme was derived from the alpha-particle studies of 1970Ba20, 1976BaZZ, 1969Pe17, and 1993Ba72, and the gamma-ray measurements of 1977Ku15, 1982Sa36 and 1984Ge07. An additional gamma transition was added to the proposed decay scheme from equivalent studies of ²²⁴Fr decay by 1981Ku02: 908.28 keV gamma ray depopulating the 992.65 keV nuclear level of ²²⁴Ra. Weighted mean relative emission probabilities were calculated for the 131.61, 166.41, 205.99 and 215.985 keV gamma rays, while equivalent data for the other gamma transitions were adopted from the measurements of 1977Ku15; all of these relative emission probabilities were defined in terms of the 84.373 keV gamma ray. Estimates were made of the uncertainties of the 700.4 and 992.65 keV gamma rays.

Cluster decay has also been observed, and reviewed by 1995Ar33 and 1997Tr17. O-20 emissions were detected, with an estimated branching fraction of 1.1(2)E-13. However, this decay mode has not been included in the decay-data summary section.

Nuclear Data

²²⁸Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ²³²Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (²²⁴Ra alpha decay to ²²⁰Rn; ²¹²Bi and ²⁰⁸Tl gamma-ray emissions). ²⁰⁸Tl in particular emits high-energy gamma rays that represent a well-defined spectroscopic signature for this decay chain.

Half-life

Half-life was adopted from the evaluation of Woods for the IAEA-CRP: Update of X- and Gamma-ray Decay Data Standards for Detector Calibration. The measurements of 1956Ki16, 1971Jo14 and 1992Un01 were considered.

Reference	Half-life (d)
1956Ki16	697.8(7)
1971Jo14	698.77(32)*
1992Un01	698.60(36)
Recommended Value	698.60(23)

*Uncertainty adjusted to ± 0.33 to reduce weighting below 0.5.

Woods evaluation for IAEA-CRP (2004WoZZ): recommended half-life of 698.60(23) days (using above dataset).

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar05 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

Gamma-ray emission probabilities have been partially or fully determined in the measurements of 1977Ku15, 1982Sa36 and 1984Ge07. Weighted mean relative emission probabilities were calculated for the 131.61, 166.41, 205.99 and 215.985 keV gamma rays, while equivalent data for the other gamma transitions were directly adopted from the measurements of 1977Ku15. An additional gamma transition was added to the proposed decay scheme from equivalent studies of ^{224}Fr decay by 1981Ku02 as 908.28 keV gamma ray depopulating the 992.65 keV nuclear level of ^{224}Ra to maintain consistency. All of these relative emission probabilities were defined in terms of the 84.373 keV gamma ray. Estimates were made of the uncertainties of the 700.4 and 992.65 keV gamma rays.

Published Gamma-ray Emission Probabilities

E_g (keV)	P_g			
	1969Pe17	1977Ku15 [†]	1982Sa36 [‡]	1984Ge07
74.4(1)	-	4.0(14)	-	-
84.373(3)	1.21(6)	12100(600)	1.9(1)	100.0(16)
131.612(4)	-	1240(60)	0.17(2)	10.70(15)
142.7(1)	-	0.013(4)	-	-
166.410(4)	-	960(50)	0.13(1)	8.49(12)
182.3(1)	-	0.052(18)	-	-
205.99(4)	-	184(9)	-	-
215.985(4)	-	2390(130)	0.30(2)	1.61(5)
228.4(2)	-	0.18(3)	-	20.78(25)
700.4(1)	-	~ 0.03	-	-
741.87(1)	-	0.014(4)	-	-
832.0(1)	-	0.14(2)	-	-
908.28(1)	-	-	-	-
992.65(6)	-	~ 0.015	-	-

[†] Emission probabilities expressed in terms of photons per 10^6 disintegrations.

[‡] Emission probabilities published relative to $P_\gamma(238.63 \text{ keV})$ for ^{212}Pb of 43.0%.

Gamma-ray Emission Probabilities: Relative to $P_g(84.373 \text{ keV})$ of 100

E_g (keV)	P_g^{rel}			
	1977Ku15	1982Sa36	1984Ge07	Recommended Values*
74.4(1)	0.033(12)	-	-	0.033(12)
84.373(3)	100(5)	100(5)	100.0(16)	100.0(16)
131.612(4)	10.25(50)	8.9(10)	10.70(15)	10.6(2)
142.7(1)	0.00011(3)	-	-	0.00011(3)
166.410(4)	7.9(4)	6.8(5)	8.49(12)	8.0(5)
182.3(1)	0.00043(15)	-	-	0.00043(15)
205.99(4)	1.52(7)	-	1.61(5)	1.58(5)
215.985(4)	19.8(11)	15.8(11)	20.78(25)	19.3(15)
228.4(2)	0.0015(3)	-	-	0.0015(3)
700.4(1)	~ 0.00025	-	-	0.00025(8)
741.87(1)	0.00012(3)	-	-	0.00012(3)
832.0(1)	0.0012(2)	-	-	0.0012(2)
908.28(1)	-	-	-	0.00014(4)
992.65(6)	~ 0.00012	-	-	0.00012(3)

* Weighted mean values adopted when judged appropriate; remainder derived from proposed decay scheme.

The normalisation factor was calculated for the gamma-ray emission probabilities by averaging the values determined by three different routes:

(i) from direct population of the ²²⁴Ra ground state

$$[\sum P_{\gamma_i}(1 + \alpha_i) \text{ to ground state}] \text{NF} + 0.732(2) = 1.00$$

$$\text{NF} = 0.000117(5)$$

(ii) population/depopulation of the 84.373 keV nuclear level of ²²⁴Ra

$$[P_{\gamma}(84.373 \text{ keV})(1 + \alpha(84.373 \text{ keV})) - \sum P_{\gamma_i}(1 + \alpha_i) \text{ to } 84.373 \text{ keV level}] \text{NF} = 0.262(2)$$

$$\text{NF} = 0.000117(6)$$

(iii) all α transitions

$\sum P_{\alpha} \text{NF} = 1.00$, and adopting α -particle emission probability to ²²⁴Ra ground state of 0.732(2)
(see section on alpha-particle emissions),
NF = 0.000117(7)

An average value of 0.000117(5) has been adopted.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by 1997Ar05 has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Limited studies of the internal conversion coefficients support the proposed transition types: E2 for both the 84.373 and 166.410 keV gamma rays (1953As31, 1966Co40, 1969Du06 and 1969Pe17). The 908.28 keV gamma ray was identified as the only mixed multipolarity transition, and was arbitrarily assigned 50%M1 + 50%E2.

All of the recommended internal conversion coefficients have been interpolated from the theoretical tabulations of 1978Ro22. Uncertainties of $\pm 2\%$ were adopted for all of the E1 and E2 (+M3) gamma transitions (with minor upward adjustments associated with the significant figures for α_L and α_{M+}), while an uncertainty of $\pm 10\%$ was assigned to the ICCs for the 908.28-keV (50 %M1 + 50 %E2) gamma transition.

Internal Conversion Coefficients

Reference	E _g (keV)	a				
		a _L	a _{LII}	a _{LIII}	a _{M+}	a _{total}
1953As31	84.373	-	-	-	-	16
	166.410	-	-	-	-	1.2
1966Co40	84.373	14(3)	7.6	6.3	3.8(9)	18(4)
1968Du06	84.373	-	-	-	-	19.6(14)
1969Pe17	84.373	-	-	-	-	21.4(9)

Alpha-particle Emissions

Energies

All alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar05 and the Q-value (1995Au04) were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

An alpha-particle emission probability of 73.2(2) % was derived for the alpha decay directly to the ground state of ²²⁴Ra, based on the various alpha-particle studies. This value and the gamma-ray data were used in conjunction with the theoretical internal conversion coefficients to determine a normalisation factor of 0.0117(5), per 100 disintegrations, for the relative emission probabilities of the gamma rays (see above).

Published Alpha-particle Emission Probabilities per 100 Disintegrations of ²²⁸Th

E _a (keV)	P _a				
	1953As31	1969Pe17	1970Ba20	1976BaZZ	1993Ba72
4448.0(3)	-	-	-	-	-
4523.0(3)	-	-	-	-	-
4952.5(4)	-	-	-	-	-
4997.8(3)	-	-	-	-	-
5138.01(26)	-	-	~ 0.05	-	-
5176.89(23)	20	-	0.18	-	-
5211.08(22)	40	-	0.36	-	-
5340.38(22)	28	26.7(2)	26.7	26.6(5)	26.0(8)
5423.28(22)	71	[73.3(2)]	72.7	72.4(10)	74.0(6)

Alpha-particle emission probability data of 1969Pe17 are effectively normalised to 73.3(2)% and 26.7(2)%.

1976BaZZ measurements require normalisation to $(100 - 0.38 - 0.20 - 0.036) = 99.384$
 $(72.4 + 26.6) N = 99.384$

$N = 1.0039$ to give P_α(5423.28 keV) of 72.7%, and uncertainty of ± 0.5;
 and P_α(5340.38 keV) of 27.3%, and uncertainty of ± 0.5.

1993Ba72 studies also require normalisation to give P_α(5423.28 keV) of 73.5%
 and uncertainty of ± 0.6;
 and P_α(5340.38 keV) of 26.5%, and uncertainty of ± 0.6.

A weighted mean value of 73.2(2)% (0.732(2)) was determined for P_α(5423.28 keV), which has been matched with a value of 26.2(2)% (0.262(2)) for P_α(5340.38 keV).

Adjusted Alpha-particle Emission Probabilities per 100 Disintegrations of ²²⁸Th

E _a (keV)	P _a					Recommended Values*
	1953As31	1969Pe17	1970Ba20	1976BaZZ	1993Ba72	
4448.0(3)	-	-	-	-	-	4.4(12) x 10 ⁻⁶
4523.0(3)	-	-	-	-	-	1.7(3) x 10 ⁻⁵
4952.5(4)	-	-	-	-	-	2.5(5) x 10 ⁻⁵
4997.8(3)	-	-	-	-	-	1.0(3) x 10 ⁻⁵
5138.01(26)	-	-	~ 0.05	-	-	0.036(7)
5176.89(23)	20	-	0.18	-	-	0.20(2)
5211.08(22)	40	-	0.36	-	-	0.38(3)
5340.38(22)	28	26.7(2)	26.7	27.3(5)	26.5(6)	26.2(2)
5423.28(22)	71	[73.3(2)]	72.7	72.7(5)	73.5(6)	73.2(2)

*P_α(5423.28 keV) of 73.2(2) is effectively the weighted mean of the normalised studies, which is subsequently matched against P_α(5340.38 keV) of 26.2(2); recommended emission probabilities of the low-intensity α transitions were derived from the evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

The absolute emission probabilities of all other alpha particles were calculated from population-depopulation of the nuclear level of ^{224}Ra and the gamma-ray normalisation factor. Although a consistent decay scheme was derived, further detailed alpha-particle measurements are required to develop and support the overall correctness of the proposed decay scheme.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

References

1953As31 - F. Asaro, F. Stephens and I. Perlman, Complex Alpha Spectra of Radiothorium (Th^{228}) and Thorium-X (Ra^{224}), Phys. Rev. 92(1953)1495. [P_α , P_γ , ICC]

1956Ki16 - H. W. Kirby, G. R. Grove and D. L. Timma, Neutron-Capture Cross Section of Actinium-227, Phys. Rev. 102(1956)1140. [Half-life]

1966Co40 - M. O. Costa and M. R. S. Grade, Spectre d'Électrons de Conversion Interne Associés à la Transmutation du Thorium-228 en Radium-224, Port. Phys. 4(1966)267. [P_{ce} , ICC]

1968Du06 - C. L. Duke and W. L. Talbert, Total Internal-conversion Coefficients for Low-energy E2 Transitions in Ra^{224} , Th^{228} , U^{234} , U^{236} and Pu^{240} , Phys. Rev. 173(1968)1125. [ICC]

1969Pe17 - A. Peghaire, Mesures Precises d'Intensities Absolues de Rayonnements γ pour des Emetteurs α , Nucl. Instrum. Meth. 75(1969)66. [P_α , P_γ , ICC]

1970Ba20 - S. A. Baranov, V. M. Shatinskii, V. M. Kulakov and Yu. F. Rodionov, Investigation of the α Decay of the Two Isotopes Th^{228} and Th^{229} , Sov. J. Nucl. Phys. 11(1970)515. [P_α]

1971Jo14 - K. C. Jordan, G. W. Otto and R. P. Ratay, Calorimetric Determination of the Half-Lives of ^{228}Th and ^{224}Ra , J. Inorg. Nucl. Chem. 33(1971)1215. [Half-life]

1976BaZZ - S. A. Baranov, A. G. Zelenkov and V. M. Kulakov, The Experimental Investigation of the Alpha Decay of Transactinium Isotopes, IAEA-186, Vol III (1976)249, IAEA Vienna. [P_α]

1977Ku15 - W. Kurcewicz, N. Kaffrell, N. Trautmann, A. Plochocki, J. Zylicz, M. Matul and K. Stryczniewicz, Collective States Fed by Weak α -transitions in the ^{232}U Chain, Nucl. Phys. A289(1977)1. [P_γ]

1978Ro22 - F. Rösel, H. M. Fries, K. Alder and H. C. Pauli, Internal Conversion Coefficients for all Atomic Shells, ICC Values for $Z = 68-104$, At. Data Nucl. Data Tables 21(1978)291-514. [ICC]

1981Ku02 - W. Kurcewicz, E. Ruchowska, N. Kaffrell, T. Björnstad and G. Nyman, Collective Excitations in the Transitional Nuclei $^{224,226}\text{Ra}$, Nucl. Phys. A356(1981)15. [908.28 keV P_γ]

1982Sa36 - S. Sadasivan and V. M. Raghunath, Intensities of Gamma Rays in the ^{232}Th Decay Chain, Nucl. Instrum. Meth. 196(1982)561. [P_γ]

1984Ge07 - R. J. Gehrke, V. J. Novick and J. D. Baker, γ -ray Emission Probabilities for the ^{232}U Decay Chain, Int. J. Appl. Radiat. Isot. 35(1984)581. [P_γ]

1992Un01 - M. P. Unterweger, D. D. Hoppes and F. J. Schima, New and Revised Half-Life Measurements Results, Nucl. Instrum. Meth. Phys. Res. A312(1992)349. [Half-life]

1993Ba72 - T. Babeliowsky and G. Bortels, ALFA: A Program for Accurate Analysis of Complex Alpha-particle Spectra on a PC, Appl. Radiat. Isot. 44(1993)1349. [P_{α}]

1995Ar33 - G. Ardisson and M. Hussonnois, Radiochemical Investigations of Cluster Radioactivities, Radiochim. Acta 70/71(1995)123. [Cluster decay]

1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409. [Q value]

1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527. [X_K , X_L , Auger electrons]

1997Ar05 - A. Artna-Cohen, Nuclear Data Sheets for A = 224, Nucl. Data Sheets 80(1997)227. [Nuclear structure, Energies]

1997Tr17 - S. P. Tretyakova and V. L. Mikheev, Experimental Investigation of the Cluster Radioactivity of Atomic Nuclei, Nuovo Cimento 110(1997)1043. [Cluster decay]

1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]

1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]

2004WoZZ - M. J. Woods, Half-life Evaluations for IAEA-CRP on "Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications" (2004). [Half-life evaluation]

²³⁸Pu – Comments on evaluation of decay data by V. P. Chechev

This evaluation was completed in March 2003. The literature available by 2003 has been included here.

1. Decay Scheme

The decay scheme is based on the evaluation of Akovali (1994Ak05). It can be basically considered complete though several expected gamma transitions have not been observed in ²³⁸Pu α -decay and thus have been adopted from the decay of ²³⁴Pa and ²³⁴Np and from the existing ²³⁴U level scheme. These gamma transitions are weak, consequently they do not significantly influence the intensity balances.

2. Nuclear Data

Q(α) value is from 1995Au04.

The evaluated half-life of ²³⁸Pu is based on the experimental results given in Table 1.

Table 1. Experimental values of ²³⁸Pu half-life (in years)

Reference	Author(s)	Original value ^a	Re-estimated value ^a	Measurement method	Used for final averaging
1950Jaffey	Jaffey and Lerner	89.59(37)	89.3(9) ^b	Direct decay (4 samples)	No
1951Jaffey-1	Jaffey and Magnusson	77	-	Growth of ²³⁸ Pu from ²³⁸ Np	No
1951Jaffey-2	Jaffey	89(9)	-	Direct decay	No
1951Seaborg	Seaborg et al.	92(2)	-	Growth of ²³⁸ Pu from ²⁴² Cm	No
1954Jo10	Jones et al.	89	-		No
1957Ho71	Hoffman et al.	86.41(30)	86.4(5) ^b	Growth of ²³⁸ Pu from ²⁴² Cm	No
1965Eichelberr	Eichelberger et al.	87.60(6)	-	Calorimetry	No
1967Jordan	Jordan	87.22(52)	-	Calorimetry	No
1969Benson	Benson	87.75(5)	-	Calorimetry	No
1974StYG	Strohm and Jordan	87.77(3)	-	Calorimetry	Yes
1976Po08	Polyukhov et al.	86.98(20)	87.0(7) ^c	Specific activity	Yes
1977Di04	Diamond et al.	87.71(3)	-	Growth of ²³⁸ Pu from ²⁴² Cm	Yes
1981Ag06	Aggarwal et al.	87.98(51)	-	Relative activity ²³⁸ Pu/ ²³⁹ Pu	Yes
1981 Sevastyanov	Sevastyanov and Yarina	86.51(30)	86.5(9) ^d	Direct decay (1 sample)	No

^a Uncertainty at the level of 1 σ

^b Re-estimated in 1977Di06

^c Re-estimated by evaluator using the analysis of 1977Di06

^d Re-estimated by evaluator

By omitting three values reported without uncertainties, the weighted average of the remaining 11 values is 87.73 with an internal uncertainty of 0.019 and $\chi^2/\nu = 2.0$. The average value of 87.73(3) could be adopted for the half-life of ²³⁸Pu. However several calorimetric results obtained in the same laboratory

(MLM) may be correlated. In fact, the value 87.77(3) (1974StYZ) comes from the latest calorimetric measurement at this laboratory. Also, the early inaccurate experimental results published in 1950 – 1957 may be omitted, as they were obtained with samples of low isotopic purity. Besides, there are grounds for omitting the result of 1981Sevastyanov (V. D. Sevastyanov and V. P. Jarina, Voprosi Atomnoi Nauki i Tekhniki, seriya Jadernie Konstanti. 5(44) (1981) 21), as it was obtained only from one sample using an inaccurate method of direct decay.

Therefore, the four best experimental results obtained by different methods have been used for the final statistical analysis. These are 87.77(3) – 1974StYG; 87.0(7) – 1976Po08; 87.71(3) – 1977Di04 and 87.98(51) – 1981Ag06. The weighted average of these data sets is 87.74 with an internal uncertainty of 0.021 and $\chi^2/\nu = 1.1$. The adopted value of the ²³⁸Pu half-life is 87.74(3) years where the uncertainty is the smallest experimental uncertainty.

The evaluated spontaneous fission half-life of ²³⁸Pu has been based on the experimental results given in Table 2. The weighted average of 5 selected values (with reported uncertainties) is 4.74 with an internal uncertainty 0.081 and $\chi^2/\nu = 0.72$.

The adopted value of the ²³⁸Pu spontaneous fission is 4.74(12)·10¹⁰ years where the uncertainty is the smallest experimental uncertainty.

Table 2. Experimental values of ²³⁸Pu spontaneous fission half-life (in 10¹⁰ years)

Reference	Author(s)	Original value ^a	Re-estimated value ^a	Measurement method	Used for final averaging
1949Jaffey	Jaffey and Hirsch	4.9(4)	4.7(6) ^b	Ioniz. chamber	Yes
1952Se67	Segre	2.6	3.9 ^b	Ioniz. chamber	No
1961Dr04	Druin et al.	5.0(6)	5.1(6) ^b	Photoemulsion	Yes
1972Ha11	Hastings and Strohm	4.77(14)	-	Si(Au)	Yes
1975GaZX	Gay and Sher	4.63(12)	-	Fission fragm. coincid. in mica	Yes
1988SeZY	Selitsky et al.	5.01(21)	-	2 π ioniz. chamber	Yes

^a Uncertainty at the level of 1 σ

^b Adjusted in 1972Ha11 to a ²³⁸Pu half-life of 87.77 yr. See also 2000Ho27

2.1. Alpha Transitions

The energies of the alpha transitions have been calculated from the Q value and the level energies given in Table 3 from 1994Ak05.

Table 3. ²³⁴U levels populated in ²³⁸Pu α decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α -transition (x100)
0	0,0	0+	2.455 10 ⁵ yr	71.04(6)
1	43.498(1)	2+	0.25 ns	28.85(6)
2	143.350(4)	4+		0.105(3)
3	296.070(4)	6+		0.00297(4)
4	497.04(4)	8+		6.85(23)·10 ⁻⁶
5	786.29(3)	1-		8.21(16)·10 ⁻⁶
6	809.88(3)	0+	<0.1 ns	1.0(4)·10 ⁻⁴
7	849.30(5)	3-		7.4(22)·10 ⁻⁸

8	851.70(10)	2+	>1.74 ps	$8.2(17) \cdot 10^{-6}$
9	926.74(5)	2+	1.4 ps	$1.30(5) \cdot 10^{-6}$
10	947.85(15)	4+		$1.7(4) \cdot 10^{-7}$
11	989.45(5)	2-	0.76 ns	$1.52(16) \cdot 10^{-7}$
12	1023.7(2)	4+		$\sim 2.0 \cdot 10^{-7}$
13	1044.53(4)	0+		$1.17(7) \cdot 10^{-6}$
14	1085.30(15)	2+		$\sim 1.2 \cdot 10^{-6}$

The probabilities of the most intensive transitions $\alpha_{0,0}$ and $\alpha_{0,1}$ have been obtained by averaging experimental data (Table 4). The probabilities of all the remaining α -transitions have been deduced from the P(γ +ce) balances for the relevant levels in ²³⁴U.

Table 4. Experimental and evaluated values of α -transition probabilities ($\times 100$) in the decay of ²³⁸Pu

	Energy keV	1954 As07	1957 Ko33	1970 Ba72	1971 So15	1984 Ah06	1984 Bo41	1984 Burns	1987 Bo25	1998 Ya17	Evaluated
$\alpha_{0,0}$	5499	72 ^a	71.1(12)	72.2 ^a	70.7(2)	70.9(1)	70.91(10)	71.11(4)	71.3(6)	71.14(10)	71.04 (6) ^b
$\alpha_{0,1}$	5456	28 ^a	28.7(12)	27.8 ^a	29.3(2)	29.0(1)	28.98(10)	28.78(4)	28.6(4)	28.74(10)	28.85 (6) ^b
$\alpha_{0,2}$	5358		0.13(1)	0.068 ^a	0.1 ^a	0.106(3)	0.105(5)	0.1002(17)		0.114(10)	0.105 (3) ^c
$\alpha_{0,3}$	5208		0.005(1)	0.0018 ^a		0.036(5)	0.0030(1)				0.00297 (4) ^{d,e}
$\alpha_{0,4}$	5010			$\sim 4 \cdot 10^{-6}$							$6.85(23) \cdot 10^{-6}$ ^e
$\alpha_{0,5}$	4726			$2.2 \cdot 10^{-5}$							$8.21(16) \cdot 10^{-6}$
$\alpha_{0,6}$	4703			$5 \cdot 10^{-5}$							$1.0(4) \cdot 10^{-4}$ ^{e,f}
$\alpha_{0,7}$	4664										$7.4(22) \cdot 10^{-8}$ ^e
$\alpha_{0,8}$	4662			$< 2 \cdot 10^{-5}$							$8.2(17) \cdot 10^{-6}$ ^e
$\alpha_{0,9}$	4588			$(1,2 \cdot 10^{-5})$							$1.30(5) \cdot 10^{-6}$ ^e

^a Omitted from averaging because no uncertainty was reported

^b Weighted average of 7 experimental values; uncertainty is external

^c Weighted average of 5 experimental values (with quoted uncertainties) is 0,104(3); the value calculated from P(γ +ce) balance is 0,1050(24); adopted value is 0,105(3)

^d Agrees well with the experimental value from 1984Bo41

^e Evaluated from P(γ +ce) balance

^f A value of $1,2(4) \cdot 10^{-4}$ was obtained by α - γ and α -ce coincidences in 1963Bj03

2.2. Gamma Transitions and Internal Conversion Coefficients

Gamma-ray transition probabilities have been deduced from their emission probabilities and total internal conversion coefficients (ICC). ICC's are theoretical values from 1978Ro22 for the adopted energies and multipolarities taken from the analysis of Akovali (1994Ak05), and using 2% fractional uncertainties in α_K , α_L , and α_M for pure multipolarities.

The emission probabilities of E0 and (E0+E2)- transitions have been obtained by using experimental conversion electron intensities from ²³⁴Pa and ²³⁴Np decays (1994Ak05), as well as from α -decay of ²³⁸Pu (1963Bj03, 1964Le17, 1964Le22).

3. ATOMIC DATA

3.1. Fluorescence yields

Fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The U KX-ray energies have been taken from 1999Schönfeld (E. Schönfeld and G. Rodloff - PTB-6.11-1999-1999-1, Braunschweig, Februar 1999) where the calculated values based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the adopted values of U KX-ray energies are compared with experimental values.

The relative K X-ray emission probabilities have been taken from 1999Schönfeld (see above).

Table 5. Experimental and adopted (calculated) values of K X-ray energies (keV)

	1976GuZN	1982Ba56	1983Ah02	Adopted
K α_2	94.655(5)	94.656(2)	94.67(2)	94.666
K α_1	98.442(5)	98.435(2)	98.45(2)	98.440
K β_3	110.42 ^a	110.416(3)	110.42(3)	110.421
K β_1	111.30 ^a	111.300(2)	111.31(2)	111.298
K β_5	-	111.868(5)- K β_5 ^{''} 111.868(5)- K β_5 [']	112.01(5)	111.964
K $\beta_{2,4}$	114.54 ^a	-	114.50(3)	114.46
KO $_{2,3}$	115.40 ^a	-	115.40(5)	115.377

The energies of U LX-rays have been taken from 1994Le37 where the fine structure of LX-radiation was measured in decays of ²³⁹Pu, ²⁴⁰Pu. Other measurements of U LX-ray energies can be found in 1954As07, 1982GeZP, 1984BaYT, 1983Ah02, 1984Bo41, 1984DrZX, 1990Po14, 1992Ba08, 1994Le28 and 1995Jo23.

In 1983Ah02 the electron capture decay of ²³⁵Np was investigated. The U LX-ray energies measured in 1984Bo41 are 11.6 keV (L γ), 13.5 keV (L α), 17.4 keV (L β) and 20.4 keV (L γ). In 1984DrZX and 1995Jo23 the energies and intensities of finer L X-ray lines were measured. These agree with theoretical estimates.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Lagoutine (F. Lagoutine, N. Coursol and J. Legrand, ISBN-2-7272-0078-1 (LMRI, 1982-1987)).

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4. Alpha Emissions

The energy of alpha particles corresponding to the alpha transition to the ground state of ²³⁴U, E(a_{0,0}) has been adopted from the absolute measurement of 1971Gr17 by using a correction of -0.18 keV, recommended by A. Rytz in 1991Ry01 because of changes in calibrations energies.

The energies of all other alpha particles have been calculated from E(a_{0,0}) and the level energies taking into account the recoil energies (see also 1994Ak05).

In Table 6 the deduced (evaluated) values of a – emission energies are compared with the experimental results obtained by using magnetic spectrometry.

Table 6. Experimental and evaluated α emission energies (keV) in the decay of ²³⁸Pu.

	Measured ^a						Evaluated
	1954As07	1957Ko33	1962Le11	1968Ba25	1970Ba72	1971Gr17	
α _{0,0}	5499	5497,7(10)	5499,2(8)	5499,2(10)	5499,2(8) ^c	5499,03(20) ^b	5499,03(20) ^b
α _{0,1}	5456	5454,7(10)	5456,3(8)	5456,1(10)	5456,1	5456,3(4)	5456,26(20)
α _{0,2}	5358	5358,6(10)	5362(1)		5357,7		5358,09(20)
α _{0,3}		5215(5)			5205,6		5207,94(20)
α _{0,4}					≈5015		5010,36(21)
α _{0,5}					4724		4725,98(21)
α _{0,6}					4704		4702,79(21)
α _{0,7}					-		4664,03(21)
α _{0,8}					4661		4661,67(23)
α _{0,9}					≈4590		4587,89(21)

^a Original values have been adjusted for changes in calibration energies as suggested in 1991Ry01

^b Absolute measurement; this value has been adopted as recommended in 1991Ry01 (see text above)

^c Value is from 1962Le11; adopted in 1970Ba72 as calibration energy

5. ELECTRON EMISSIONS

Energies of conversion electrons have been deduced from the gamma transition energies given in section 2.2 using atomic-electron binding energies.

The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values. I am comparing below experimental L1:L2:L3 conversion electron subshell intensities (1969Am02) with theoretical values for the most intense E2 transition of 43,498 keV.

Calculated	Measured
3,82(11):112(3):100	3,99(22):114,7(20):100

The total absolute emission probabilities of K Auger electrons have been computed by using the evaluated total P(XK) and the adopted ω_K from section 3.

The total absolute emission probability of L Auger electrons have been computed using the total evaluated P(XL) and the adopted ω_L from section 3.

6. Photon Emissions

6.1. X-Ray Emissions

6.1.1. M X-Rays

The total absolute emission probability of M X-rays is based on the measurement (1990Po14) of the relative emission probability $P(MX)/P(LX) = 0.194(24)$.

6.1.2. L X-Rays

The calculation of the total absolute emission probability of L X-rays [$P(XL)$] using the adopted value $\omega_L = 0.500(19)$ from section 3.1 and the evaluated total absolute emission probability of L conversion electrons, namely, $P(ce_L) = 21.2(6) \%$ leads to the value $P(XL) = 10.6(5) \%$. The analogous calculation using the computer code EMISSION 2000Schönfeld (E. Schönfeld and H.Janßen, Appl. Rad. Isot. 52(2000) 595) gives $P(XL) = 10.62(25) \%$. The available experimental results for $P(XL)$ are discrepant: 13 %: 1954As07; 10.6(3) %: 1964Ha14; 12.83(14) %: 1968By01; 9.2(1) %: 1968Salgueiro; 11.2(4) %: 1968Swinth; 11.4(3) %: 1971Swinth; 14.18(11) %: 1976Va23; 11.38(10) %: 1977Bemis; 11.55(18) %: 1984Bo41; 10.62(32) %: 1984DrZX and 1984BaYT; 10.63(8) %: 1995Jo23.

The result of the most accurate and latest measurement (1995Jo23) agrees well with the calculated values and with a value from 1984DrZX where also the fine structure of L X-radiation was measured. The value from 1995Jo23 has been adopted as the recommended absolute emission probability of U LX-rays from the decay of ²³⁸Pu: $P(XL) = 10.63(8) \%$ (per 100 disintegrations).

For the evaluation of emission probabilities of the L X-ray components L_I , $L\alpha$, $L\beta\eta$, $L\gamma$ the measured values given in Table 7 were renormalized by the evaluator to the adopted value $P(XL)=10.63(8)\%$ and then averaged. In Table 8 the evaluated emission probabilities are compared with values calculated in 1995Jo23 from alpha-branching ratios, theoretical ICC and theoretical atomic branching ratios.

Table 7. Experimental absolute emission probabilities of LX rays from the α decay of ²³⁸Pu

	1976Va23	1977Bemis	1984Bo41	1995Jo23
L_I	-	0.26(1)	0.260(7)	0.231(3)
$L\alpha$	5.05(6)	4.15(7)	4.06(6)	3.81(3)
$L\beta\eta$	7.41(9)	5.61(7)	5.85(9)	5.31(4)
$L\gamma$	1.48(2)	1.36(2)	1.38(2)	1.29(1)

Table 8. Renormalized experimental, evaluated, and theoretical absolute emission probabilities of LX rays from the α decay of ²³⁸Pu

	1976Va23	1977Bemis	1984Bo41	1995Jo23	Evaluated	Calculated (1995Jo23) (theory)
Ll	-	0.24(1)	0.239(7)	0.231(3)	0.235(4) ^b	0.234
L α	3.77(5)	3.88(7)	3.74(6)	3.81(3)	3.80(3) ^c	3.78
L $\beta\eta$	5.53(7) ^a	5.24(7)	5.38(8)	5.31(4)	5.31(4) ^c	5.42
L γ	1.10(2) ^a	1.27(2)	1.27(2)	1.29(1)	1.28(1) ^c	1.26

^a Omitted from averaging based on statistical considerations

^b Weighted average; uncertainty is internal

^c Weighted average; uncertainty is the smallest experimental one

6.1.3. KX-Rays

The absolute KX-ray emission probability ($P(K\alpha_2)$) with energy 98.44 keV (U $K\alpha_2$) has been adopted from 1976GuZN. The uncertainty of $P(K\alpha_2)$ includes a 2 % from the detector efficiency. The absolute emission probabilities of all other X-rays have been computed from their relative emission probabilities using the adopted $P(K\alpha_2) = 1.69(4) \cdot 10^{-4}$ %.

The total absolute K X-ray emission probability $P(XK) = 3.56(5) \cdot 10^{-4}$ %, obtained by summing the individual K X-ray emission probabilities, exceeds the value calculated from ω_K and the total emission probability of K-conversion electrons $P^{(ce)}(XK) = 2.6 \cdot 10^{-4}$ %. This disagreement may be due to an inaccurate estimation of conversion electron intensities from E0 and E0+E2 transitions in the decay of ²³⁸Pu.

6.2. Gamma-Ray Emissions

6.2.1. Gamma-Ray Energies

The energies of prominent gamma-rays such as $\gamma_{1,0}$ (43.5 keV), $\gamma_{2,1}$ (99.9 keV) and $\gamma_{3,2}$ (152.7 keV) have been taken from 1984He19, which includes a correction of 5.8 ppm in the gamma-ray energy scale (2000He14). The energy of $\gamma_{4,3}$ (201.0 keV) has been taken from the decay of 6.75-h ²³⁴Pa β^- decay (1994AK05). The energies of $\gamma_{14,7}$ (235.9 keV) and $\gamma_{14,5}$ (299.2 keV) have been adopted from 1969LeZX. The energies of $\gamma_{13,5}$ (258.2 keV) and $\gamma_{5,1}$ (742.8 keV) are from 2000Ni13 (Y. Nir-El, Radiochim. Acta 88(2000)83). The energies of unobserved gamma-rays from ²³⁸Pu α -decay have been taken from the decay of ²³⁴Pa and ²³⁴Np, and from the existing ²³⁴U level energies (1994Ak05). The energies of gamma-rays with energy greater than 700 keV have been adopted from the decay of ²³⁴Pa and ²³⁴Np (1969LeZX). The experimental gamma-ray energy from 1971GuZY and 1976GuZN agree with values in 1969LeZX and with those adopted here (Table 9).

Table 9. Experimental and recommended gamma-ray energies (keV) from ²³⁸Pu^a α decay

	1969LeZX	1971GuZY	1972Sc01	1976GuZN	1984He19	Adopted
γ _{1,0}		43.492(10)	43.491(9)	43.477(5)	43.498(1)	43.498(1)
γ _{2,1}	99.84(4)	99.871(10)	99.85(1)	99.864(5)	99.853(3)	99.852(3)
γ _{3,2}	152.71(5)	152.77(3)	152.719(19)	152.68(2)	152.720(2)	152.719(2)
γ _{4,3}	200.9(2)	200.98	201.017(30)	200.98		200.97(3)
γ _{14,7}	235.9(3)					235.9(3)
γ _{13,5}	258.3(2)	258.23				258.227(3)
γ _{14,5}	299.2(2)					299.2(2)
γ _{7,2}	706.1(3)	705.6		705.6		705.9(1)
γ _{8,2}	708.4(2)	708.4		708.4		708.4(2)
γ _{5,1}	742.77(10)	742.82		742.82		742.813(5)
γ _{6,1}	766.39(10)	766.41(2)		766.41		766.38(2)
γ _{5,0}	786.30(10)	786.30		786.30		786.27(3)
γ _{7,1}	805.8(3)	805.42		805.4		805.80(5)
γ _{8,1}	808.25(15)	808.23		808.2		808.20(10)
γ _{8,0}	851.70(10)	851.73		851.7		851.70(10)
γ _{12,2}	880.5(3)					880.5(1)
γ _{9,1}	883.23(10)	883.21				883.24(4)
γ _{10,1}	904.37(15)	904.34				904.3(2)
γ _{9,0}	926.72(15)	926.73				926.74(5)
γ _{14,2}	941.9(2)	942.02				941.94(10)
γ _{11,1}	946.0(3)	946.12				946.00(3)
γ _{13,1}	1001.03(15)	1001.10				1001.03(3)
γ _{14,1}	1041.8(3)	1041.90				1041.7(2)
γ _{14,0}	1085.4(3)	1085.40				1085.4(2)

^a Other much more inaccurate measurements results can be find in 1954As07, 1955Ch02, 1956Ne17, 1971Cl03 and 1971Ma68. They agree with those given in Table 9.

6.2.2. Gamma-Ray Emission Probabilities

Experimental and evaluated gamma-ray emission probabilities for γ-rays with energies < 200 keV are given in Table 10. The evaluated P(γ) values have been obtained by averaging several experimental results. They agree well with calculated values obtained from intensity balances in ²³⁴U levels using P(α) and total ICC.

Table 10. Experimental and evaluated absolute emission probabilities (per 10⁴ α-decays) for < 200-keV gamma-rays from the decay of ²³⁸Pu

	Energy (keV)	1976 GuZN	1976 Um01	1979 Vanin brouk x	1984 Bo41	1984 He19	1984 Ov01	1994 Ba91	Evaluated ^a	Calculated ^b
γ _{1,0}	43.5	3.93(8)	4.11(8)	3.93(12)	3.96(10)	3.82(8)			3.97(8)	3.96(8)
γ _{2,1}	99.8	0.724(14)			0.730(11)	0.743(8)	0.631(38) ^c		0.735(8)	0.735(30)
γ _{3,2}	152.7	0.0956(20)			0.0928(14)	0.0936(10)	0.086(4) ^c	0.0923(7)	0.0930(7)	0.094(4)

^a Weighted averages; uncertainties are the smallest experimental values

^b Calculated from P(α) values and adopted total ICC's

^c Omitted based on statistical considerations

The emission probabilities of γ_{14,7}(235.9 keV), γ_{13,8}(258.2 keV) and γ_{14,5}(299.2 keV) have been adopted from 1969LeZX.

The P(γ) of gamma-rays that were not observed in the ²³⁸Pu α-decay have been deduced from the decay of ²³⁴Pa and ²³⁴Np (1994Ak05) using experimental relative gamma ray emission probabilities.

The absolute emission probabilities of all other weak gamma-rays (most of them with energies > 700 keV) have been computed from their evaluated relative emission probabilities given in Table 11. The value P(γ₇₆₆) = 2.19(5) · 10⁻⁷ measured in 1976GuZN (the uncertainty includes a 2% detector efficiency uncertainty) was used as a normalization factor. This value agrees well with 2.19(6) · 10⁻⁷, calculated from the results in 1979Ce04(P(γ₇₈₆) = 3.16(9) · 10⁻⁸) and the relative intensity ratio of γ₇₆₆/γ₇₈₆; as well as with the value of 2.21(15) · 10⁻⁷ measured in 1984Ov01. The latter value has been obtained by evaluator from authors' P_γ renormalized to P(γ₁₅₃) = 9.30(7) · 10⁻⁶.

Table 11. Experimental and evaluated relative emission probabilities of > 200-keV gamma-rays from the decay of ²³⁸Pu

		1969LeZX	1971GuZY	1971Ma68	1976GuZN	1979Ce04	1984Ov01	Evaluated
γ _{4,3}	201.0	15(3)	17.8(3)		18.6(4)	17.0(5)		17.9(4)
γ _{14,7}	235.9	0.04(2)						0.04(2)
γ _{13,5}	258.2	0.35(5)	0.28(6)					0.32(5)
γ _{14,5}	299.2	0.20(5)						0.20(5)
γ _{7,2}	705.9	0.42(6) ^a	0.225(23)		0.23(10)		0.25(10)	0.23(5)
γ _{8,2}	708.4	1.15(9) ^a	2.24(23)	2.5(6)	2.29(23)	2.5(6)	1.7(3)	2.22(14)
γ _{5,1}	742.8	23.2(4)	23.1(2)	25.7(15)	23.6(5)	23.8(4)	22.6(12)	23.3(2)
γ _{6,1}	766.4	100	100	100	100	100	100	100
γ _{5,0}	786.3	14.5(3)	14.7(2)	14.9(10)	15.0(3)	14.4(4)	13.7(5)	14.6(2)
γ _{7,1}	805.8	0.56(6)	0.56(6)		0.59(3)		0.7(2)	0.58(3)
γ _{8,1}	808.2	3.40(8)	3.57(10)	3.2(5)	3.65(13)	3.52(18)	4.0(4)	3.50(8)
γ _{8,0}	851.7	5.79(20)	5.79(11)	6.6(6)	5.89(17)		4.9(5)	5.81(11)
γ _{12,2}	880.5	0.7(2)					0.65(16)	0.68(16)

		1969LeZX	1971GuZY	1971Ma68	1976GuZN	1979Ce04	1984Ov01	Evaluated
$\gamma_{9,1}$	883.2	3.43(15)	2.72(27)	3.3(5)		3.54(25)	3.2(6)	3.30(17)
$\gamma_{10,1}$	904.3	0.30(4)	0.26(8)				0.25(10)	0.28(5)
$\gamma_{9,0}$	926.7	2.53(10)	2.56(10)	2.7(6)		2.58(13)	2.4(3)	2.55(10)
$\gamma_{14,2}$	941.9	2.06(9)	2.19(9)	2.2(6)		2.23(27)	1.9(4)	2.13(9)
$\gamma_{11,1}$	946.0	0.40(6)	0.43(9)					0.42(6)
$\gamma_{13,1}$	1001.0	4.39(14)	5.42(33) ^a	4.0(7)		4.61(18)	4.1(5)	4.46(14)
$\gamma_{14,1}$	1041.7	0.84(7)	0.95(10)	0.7(3)			1.3(3)	0.90(7)
$\gamma_{14,0}$	1085.4	0.34(4)	0.95(10) ^a	1.1(4) ^a			0.5(2)	0.35(4)

^a Omitted on the basis of statistical considerations.

References

- 1949Jaffey - A. H. Jaffey and A. Hirsch, Report ANL-4286 (1949) [Spontaneous fission half-life].
1950Jaffey - A. H. Jaffey and J. Lerner, Report ANL-4411 (1950) [Half-life].
1951Jaffey-1 - A. H. Jaffey and L. B. Magnusson, Paper No. 14.2. National Nuclear Energy Plutonium Project Record Div. IV. Vol. 14B. Part II. p. 978. McGraw-Hill, New York (1951) [Half-life].
1951Jaffey-2 - A. H. Jaffey, Paper No. 2.2. National Nuclear Energy Plutonium Project Record Div. IV. Vol. 14B. Part I. p. 89. McGraw-Hill, New York (1951) [Half-life].
1951Seaborg - G. T. Seaborg, R. A. James and A. Giorso, The Transuranium Elements (Edited by G. T. Seaborg, J. J. Katz and W. M. Manning). Paper No. 14.2. National Nuclear Energy Series, Plutonium Project Record, Div. IV. Vol. 14B. Part II, p. 978. McGraw-Hill, New York (1951) [Half-life].
1952Se67 - E. Segre, Phys. Rev. 86(1952)21 [Spontaneous fission half-life].
1954As07 - F. Asaro and I. Perlman, Phys. Rev. 94(1954)381 [Alpha-particle energies and emission probabilities].
1954Jo10 - K. W. Jones, R. A. Douglas, M. T. McEllistrem and H. T. Richards, Phys. Rev. 94(1954)947 [Half-life].
1955Ch02 - E. L. Church and A. W. Sunyar, Phys. Rev. 98(1955)1186A [Gamma-ray energies].
1956Ne17 - J. O. Newton, B. Rose and J. Milsted, Phil. Mag. 1(1956)981 [Gamma-ray energies].
1957Ho71 - D. C. Hoffman, G. P. Ford and F. O. Lawrence, J. Inorg. Nucl. Chem. 5(1957)6 [Half-life].
1957Ko33 - L. N. Kondratev, G. I. Novikova, V. B. Dedov and L. L. Goldin, Izv. Akad. Nauk SSSR, Ser Fiz 21(1957)907 [Alpha-particle energies and emission probabilities].
1961Dr04 - V. A. Druin, V. P. Perelygin and G. I. Khlebnikov, Soviet Phys. JETP 13(1961)913; Zhurn. Eksptl. i Teoret. Fiz. 40(1961)1296 [Spontaneous fission half-life].
1962Le11 - C. F. Leang, Compt. Rend. 255(1962)3155 [Alpha-particle energies and emission probabilities].
1963Bj03 - S. Bjornholm, C. M. Lederer, F. Asaro and I. Perlman, Phys. Rev. 130(1963)2000 [Alpha transition probabilities].
1964Ha14 - J. W. Halley, D. Engelkemeir, Phys. Rev. 134(1964)A24 [L X-ray emission probabilities].
1964Le17 - F. Les, Acta. Phys. Polon. 26(1964)951 [E0+E2 transition probabilities].
1964Le22 - C. M. Lederer, Priv. Comm. Quoted by 67Le24, unpublished (1964) [E0+E2 transition probabilities].
1965Eichelberger - J. F. Eichelberger, G. R. Grove and L. V. Jones, MLM-1238(1965) [Half-life].
1967Be65 - J. A. Bearden, Rev. Mod. Phys. 39(1967)78 [X-ray energies].
1967Jordan - K. C. Jordan, Part of Mound Laboratory Progress Report for Chemistry, Report No. MLM-1443, July–September (1967), p. 11 [Half-life].
1968Ba25 - S. A. Baranov V. M. Kulakov and V. M. Shatinskii, Nucl. Phys. 7(1968)442.; Yadern. Fiz. 7(1968)727 [Alpha-particle energies and emission probabilities].
1968By01 - J. Byrne, W. Gelletly, M. A. S. Ross and F. Shaikh, Phys. Rev. 170(1968)80 [L X-ray emission probabilities].
1968Salgueiro - L. Salgueiro et al., C. R. Acad. Sci. 267B(1968)1293 [L X-ray emission probabilities].
1968Swinth - K. L. Swinth, Nucleonics in Aerospace, Ed. P. Polishuk, N. Y. Plenum Press, 1968, p. 279 [L X-ray emission probabilities].
1969Am02 - S. R. Amtey, J. H. Hamilton, A. V. Ramayya et al., Nucl. Phys. A126(1969)201 [Conversion electron relative intensities] 1969Benson - D. Benson, Priv. Comm. (1969). Cited in 1981Ag06 [Half-life].
1969LeZX - C. M. Lederer, F. Asaro and I. Perlman, UCRL-18667(1969)3 [Gamma-ray energies and emission probabilities].

- 1970Ba72 - S. A. Baranov V. M. Kulakov, V. M. Shatinskii and Z. S. Gladkikh, Soviet J. Nucl. Phys. 12(1971)604; Yad. Fiz. 12 (1970) 1105 [Alpha-particle energies and emission probabilities].
- 1971Cl03 - J. E. Cline, IN-1448 Rev. (1971) [Gamma-ray energies and emission probabilities].
- 1971Gr17 - B. Grennberg and A. Rytz, Metrologia 7(1971)65 [Alpha-particle energies].
- 1971GuZY - R. Gunnink, R. J. Morrow, UCRL-51087(1971) [Gamma-ray energies and emission probabilities].
- 1971Ma68 - A. I. Makarenko, L. A. Ostretsov and N. V. Forafontov, Izv. Akad. Nauk SSSR, Ser. Fiz. 35(1971)2335; Bull. Acad. Sci. USSR, Phys. Ser. 35(1972)2118 [Gamma-ray energies and emission probabilities].
- 1971So15 - J. C. Soares, J. P. Ribeiro, A. Goncalves, F. B. Gil and J. C. Ferreira, Compt. Rend. 273B(1971)985 [Alpha-particle energies and emission probabilities].
- 1971Swinth - K. L. Swinth, IEEE Transactions Nuclear Science 18(1971)125 [L X-ray emission probabilities]
- 1972Ha11 - J. D. Hastings and W. W. Strohm, J. Inorg. Nucl. Chem. 34(1972)25 [Spontaneous fission half-life].
- 1972Sc01 - M. Schmorak, C. E. Bemis, Jr., M. J. Zender, N. B. Gove and P. F. Dittner, Nucl. Phys. A178 (1972)410 [Gamma-ray energies].
- 1974StYG - W. W. Strohm and K. C. Jordan, Nucl. Soc. 18(1974)185 [Half-life].
- 1975GaZX - R. R. Gay and R. Sher, Bull. Am. Phys. Soc. 20(2)(1975)160,GB13 [Spontaneous fission half-life].
- 1976GuZN - R. Gunnink, J. E. Evans and A. L. Prindle, UCRL-52139(1976) [Gamma-ray energies and emission probabilities].
- 1976Po08 - V. G. Polyukhov, G. A. Timofeev, P. A. Privalova, V. Y. Gabeskiriya and A. P. Chetverikov, Soviet. J. At. Energy 40(1976)66 ; At. Energ. 40(1976)61 [Half-life]
- 1976Um01 - H. Umezawa, T. Suzuki and S. Ichikawa, J. Nucl. Sci. Technol. 13(1976)327 [Gamma-ray and emission probabilities].
- 1976Va23 - D. G. Vasilik and R. W. Martin. Nucl. Instrum. Methods 135(1976)405 [L X-ray emission probabilities].
- 1977Bemis - C. E. Bemis Jr. and L. Tubbs, Report ORNL-5297(1977)93 [L X-ray emission probabilities]
- 1977Di04 - H. Diamond, W. C. Bentley, A. H. Jaffey and K. F. Flynn, Phys. Rev. C15(1977)1034 [Half-life].
- 1977La19 - F. P. Larkins, Atomic Data and Nuclear Data Tables 20(1977)313 [Auger electron energies]
- 1978Ro22 - F. Rosel, H. M. Friess, K. Alder and H. C. Pauli - At. Data Nucl. Data Tables 21(1978)92 [Theoretical ICC].
- 1979Vaninbroucx - R. Vaninbroucx, G. Grosse and W. Zehner, Report CBNM/RN/45/79(1979) [Gamma-ray emission probabilities].
- 1979Ce04 - A. Cesana, G. Sandrelli, V. Sangiust and M. Terrani, Energia Nucl. (Milan) 26(1979)526 [Gamma-ray energies and emission probabilities].
- 1981Ag06 - S. K. Aggarwal, A. V. Jadhav, S. A. Chitambar, K. Raghuraman, S. N. Acharya, A. R. Parab, C. K. Sivaramakrishnan and H. C. Jain, Radiochem. Radioanal. Lett. 46(1981)69 [Half-life].
- 1981Sevastyanov - V. D. Sevastyanov and V. P. Jarina, Voprosi Atomnoi Nauki i Tekhniki, Seriya Jadernie Konstanti 5(44)(1981)21 [Half-life].
- 1982Ba56 - G. Barreau, H. G. Borner, T. von Egidy, R. W. Hoff, Z. Phys. A308(1982)209 [K X-ray energies].
- 1982GeZP - A. M. Geidelman, Yu. S. Egorov, V. G. Nedovesov et al, Program and Theses, 32nd Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, (1982) Kiev, p. 511 [L X-ray emission probabilities].
- 1983Ah02 - I. Ahmad, J. Hines, J. E. Gindler, Phys. Rev. C27(1983)2239 [K X-ray energies].
- 1984Ah06 - I. Ahmad, Nucl. Instrum. Meth. 223(1984)319 [Alpha-particle energies and emission probabilities].
- 1984BaYT - L. M. Bak, P. Dryak, V. G. Nedovesov, S. A. Sidorenko, G. E. Shukin, K. P. Yakovlev, Program and Theses, Proc. 34th Ann. Conf. Nucl. Spectrosc. At. Nuclei, Alma-Ata, (1984), p. 541 [L X-ray emission probabilities].
- 1984Bo41 - G. Bortels, B. Denecke, R. Valninbroucx, Nucl. Instrum. Meth. 223(1984)329 [Alpha-particle, gamma-ray and L X-ray energies and emission probabilities].
- 1984Burns - P. A. Burns, P. N. Johnston and J. R. Moroney, Priv. Comm. (1984).Cited in 1986LoZT: A. Lorenz, IAEA Tech. Report, Ser. No 261(1986)147 [Alpha-particle energies and emission probabilities].
- 1984DrZX - P. Dryak, Yu. S. Egorov, V. G. Nedovesov, I. Plkh, G. E. Shukin, Program and Theses, Proc. 34th Ann. Conf. Nucl. Spectrosc. At. Nuclei, Alma-Ata, (1984), p. 540 [L X-ray emission probabilities].
- 1984He19 - R. G. Helmer and C. W. Reich, Int. J. Appl. Radiat. Isotop. 35(1984)1067 [Gamma-ray energies and emission probabilities].
- 1984Ov01 - V. V. Ovechkin, V. M. Chesalin and I. A. Shkabura, Izv. Akad. Nauk. SSSR, Ser. Fiz. 48(1984)1029 [Gamma-ray energies and emission probabilities].
- 1987Bo25 - G. Bortels and P. Collaers, Appl. Radiat. Isot. 38(1987)831 [Alpha-particle energies and emission probabilities].
- 1987Lagoutine - F. Lagoutine, N. Coursol and J. Legrand, ISBN-2-7272-0078-1 (LMRI, 1982-1987) [Energy of Auger electrons].
- 1988SeZY - Yu. A. Selitsky, V. B. Funshtein, V. A. Yakovlev, Program and Theses, Proc.38th Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, Baku, p. 131(1988) [Spontaneous fission half-life].
- 1990Ah01 - I. Ahmad, R. R. Betts, T. Happ, D. J. Henderson, F. L. H. Wolfs and A. H. Wuosmaa, Nucl. Instrum. Meth. Phys. Res. A299(1990)201 [Alpha-particle energies].

- 1990Po14 - Yu. S. Popov, I. B. Makarov, D. Kh. Srurov, E. A. Erin, Sov. Radiochem. 32(1990)425; Radiokhimiya 32(1990)2 [M X-ray emission probability].
- 1991Jo02 - P. N. Johnston, J. R. Moroney and P. A. Burns, Appl. Radiat. Isot. 42(1991)245 [Alpha-particle energies].
- 1991Ry01 - A. Rytz, At. Data Nucl. Data Tables 47(1991)205 [Alpha-particle energies].
- 1992Ba08 - G. Barci-Funel, J. Dalmaso and G. Ardisson, Appl. Radiat. Isot. 43(1992)37 [L X-ray emission probabilities].
- 1994Ak05 - Y. A. Akovali, Nuclear Data Sheets 71(1994)181 [Level energies and data from ^{234}Pa and ^{234}Np decays].
- 1994Ba91 - D. T. Baran, Appl. Radiat. Isot. 45(1994)1177 [Gamma-ray emission probabilities].
- 1994Ka08 - S. I. Kafala, T. D. MacMahon, P. W. Gray, Nucl. Instrum. Methods Phys. Res. A339(1994)151 [Evaluation technique].
- 1994Le28 - M. C. Lépy, B. Duchemin, J. Morel, Nucl. Instrum. Methods Phys. Res. A339(1994)218 [L X-ray energies and emission probabilities].
- 1994Le37 - M. C. Lépy, B. Duchemin, J. Morel, Nucl. Instrum. Methods Phys. Res. A353(1994)10 [L X-ray energies and emission probabilities].
- 1995Au04 - G. Audi and A. H. Wapstra, Nucl. Phys. A595(1995)409 [Decay energy].
- 1995Jo23 - P. N. Johnston and P. A. Burns, Nucl. Instrum. Meth. Phys. Res. A361(1995)229 [L X-ray energies and emission probabilities].
- 1996Sc06 - E. Schönfeld and H. Janßen, Nucl. Instrum. Meth. Phys. Res. A369(1996)527 [Atomic data].
- 1998Ya17 - J. Yang and J. Ni, Nucl. Instrum. Meth. Phys. Res. A413(1998)239 [Alpha-particle energies and emission probabilities].
- 1999Schonfeld - E. Schönfeld and G. Rodloff - PTB-6.11-1999-1999-1, Braunschweig, February 1999 [K X-ray energies and relative emission probabilities].
- 2000Ch01 - V. P. Chechev, A. G. Egorov, Appl. Rad. Isot. 52(2000)601 [Evaluation technique].
- 2000He14 - R. G. Helmer and C. van der Leun, Nucl. Instrum. Meth. Phys. Res. A450(2000)35 [Gamma-ray energies].
- 2000Ho27 - N. E. Holden, D. C. Hoffman, Pure Appl. Chem. 72(2000)1525 [Spontaneous fission half-life].
- 2000Ni13 - Y. Nir-El, Radiochim. Acta 88(2000)83 [Gamma-ray energies].
- 2000Schönfeld - E. Schönfeld and H. Janßen. Appl. Rad. Isot. 52(2000)595 [L X-ray and Auger electron emission probabilities].

²⁴⁰Pu – Comments on evaluation of decay data by V. P. Chechev

This evaluation was completed in August 2003. The literature available by July 2003 was included.

1. DECAY SCHEME

The decay scheme is based on the evaluation of Schmorak (1991Sc08) and taken from 1996Firestone. It can be considered as basically completed though several weak gamma transitions were not observed in ²⁴⁰Pu alpha decay. They have been taken from data on nuclear reactions and ²³⁶Pa, ²³⁶Np decays (1984Mi02, 1991Sc08).

The alpha transitions to ²³⁶U highly excited levels with energy of 958, 960 and 967 keV were not observed either. They are expected from data on level spins and gamma rays de-excited the above levels.

2. NUCLEAR DATA

Q(α) value is from 1995Au04.

The evaluated half-life of ²⁴⁰Pu is based on the experimental results given in Table 1. Re-estimated values were used for averaging where necessary.

Table 1. Experimental values of the ²⁴⁰Pu half-life (in years)

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1951In03	Inghram et al.	6580(40)	6500(45) ^{b,c}	Mass-Spectrometry
1951We21	Westrum	6240(120)		α-Particle Counting
1954Fa11	Farwell et al.	6300(600)		α-Particle Counting
1956Bu92	Butler et al.	6600(100)	6610(55) ^b	α-Particle Counting
1959Do64	Dokuchaev	6620(50)		α-Particle Counting
1968Oe02	Oetting	6524(10)	6537(15) ^d	Calorimetry
1978Ja11	Jaffey et al.	6569(6)	6569(7) ^c	α-Particle Counting
1984Be19	Beckmann et al.	6574(6) ^a	6574(7) ^c	Mass-Spectrometry
1984St06	Steinkruger et al.	6571(9) ^a		α-Particle Counting
1984Lu04	Lucas and Noyce	6552.2(20)	6552.2(66) ^c	α-Particle Counting
1984Ru04	Rudy et al.	6552.4(17)	6552.4(66)	Calorimetry

^a Quoted uncertainties, corresponding to 95% confidence level, have been reduced by a factor 2.

^b Re-estimated in 1978Ja11.

^c Re-estimated in 1986IAEA. According to the criterion adopted by the members of the CRP, a minimum uncertainty of 0,1% on the half-life of long-lived nuclides should be attributed to all measured values.

^d Re-estimated in 1986IAEA. The quoted uncertainty has been increased since no measurements were made to demonstrate the absence of ²³⁸Pu.

With omitting the value of 1951We21 as outlier the weighted mean of the remaining 10 values is 6561 yr with the internal uncertainty 3.1 yr and external uncertainty 4.0 yr.

According to the criterion adopted by the members of the CRP (1986IAEA) a minimum uncertainty of the recommended ²⁴⁰Pu half-life should be attributed as 7 years.

Therefore, the adopted value of the ²⁴⁰Pu half-life is 6561(7) years.

The evaluated spontaneous fission half-life of ²⁴⁰Pu is based on the experimental results given in Table 2.

Table 2. Experimental values of the spontaneous fission ²⁴⁰Pu half-life (in 10¹¹ years)

Reference	Author(s)	Measurement value	Measurement method	Used for final averaging
1953Ki72	Kinderman	1.314(26)	Low geometry α -counting	No
1954Ba14	Barclay et al.	1.225(30)	Low geometry α -counting	No
1954Ch74	Chamberlain et al.	1.20	Low geometry α -counting	No
1959Mi90	Mikheev et al.	1.20	Low geometry α -counting	No
1962Wa13	Watt et al.	1.340(15)	Low geometry α -counting	No
1963Ma50	Malkin et al.	1.45(2)	Low geometry α -counting	No
1967White	White	1.27(5)	No details available	No
1967Fi13	Fieldhouse et al.	1.176(25) ^a	SF neutron emission rates	Yes
1979BuZC	Budtz-Jorgensen et al.	1.15(3)	Fragment spectra, ionization chamber	Yes
1984An25	Androsenko et al.	1.15(3)	SF neutron emission rates	Yes
1988SeZY	Selickij et al.	1.17(3)	Fragment detection in 2p geometry	Yes
1989Dy01	Dytlewski et al.	1.12(2)	Neutron coincidences and low geometry α -counting	Yes
1991Iv01	Ivanov et al.	1.15(2)	$\lambda_{SF} / \lambda_{\alpha}$ in ²⁴⁰ Pu standards	Yes

^a Re-estimated in Holden 2000. Original value is 1.170(25).

Early measurement values have been omitted from averaging according to analysis of Holden and Hoffman (2000Ho27). The weighted mean of 6 selected values is 1.15 with the internal uncertainty 0.010 and external uncertainty 0.0087.

The adopted value of the ²⁴⁰Pu spontaneous fission is 1.15(2)·10¹¹ years where the uncertainty is the smallest quoted uncertainty.

2.1 Alpha Transitions

The energies of the alpha transitions have been calculated from the Q value and the level energies given in Table 3 from 1991Sc08, 1996Firestone.

Table 3. ²³⁶U levels populated in the ²⁴⁰Pu α -decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α -transition (x 100)
0	0.0	0 ⁺	2.342·10 ⁷ yr	72.74(11)
1	45.242(3)	2 ⁺	234 ps	27.16(11)
2	149.476(15)	4 ⁺	124 ps	0.0863(18)
3	309.783(8)	6 ⁺	58 ps	0.001082(18)
4	522.24(5)	8 ⁺	24 ps	4.7(5)·10 ⁻⁵
5	687.60(5)	1 ⁻	3.8 ns	1.93(4)·10 ⁻⁵
6	744.15(8)	3 ⁻	< 0.1 ns	
7	919.21(17)	0 ⁺		≈ 6.5·10 ⁻⁷
8	957.99(17)	(2 ⁺)		< 1.7·10 ⁻⁷
9	960.3 (3)	(2 ⁺)		< 1.3·10 ⁻⁷
10	966.63(9)	1 ⁻		< 1·10 ⁻⁷

The probabilities of the most intensive transitions $\alpha_{0,0}$ and $\alpha_{0,1}$ have been obtained by averaging experimental data (Table 4). The probabilities of all the remaining α -transitions have been evaluated from the P(γ +ce) balances for corresponding levels of ²³⁶U.

Table 4. Experimental and evaluated values of α -transition probabilities ($\times 100$) in the decay of ²⁴⁰Pu

	α -particle energy keV	1956 Ko67	1956 Go43	1952 As28 1957 As83	1969 Le05	1977 Ba69	1984 Ah06	1990 An33	1992 Bl13	1994 Ra27	1994 Sa63	1996 Vi07	2003 Sibbens	Evaluated
$\alpha_{0,0}$	5168	75.5	75.5	76		73.51 (36)	72.8 (1)	73.0 (5)	72.55 (20)	73.1 (1)	72.5 (11)	74 (2)	72.56 (6)	72.74(11) ^a
$\alpha_{0,1}$	5124	24.4	24.5	24		26.39 (21)	27.1 (1)	27.0 (5)	27.35 (10)	26.8 (1)	27.5 (11)	26 (2)	27.35 (7)	27.16(11) ^a
$\alpha_{0,2}$	5021	0.091 (6)	0.085 (15)	0.1		0.096 (5)	0.090 (5)		0.10 (2)					0.0863(18) ^b
$\alpha_{0,3}$	4864	0.0032 (1)				0.001								0.001082(18) _b
$\alpha_{0,4}$	4655													4.7(5) $\cdot 10^{-5}$ ^b
$\alpha_{0,5}$	4492				2.1(4) 10^{-5}									1.93(4) $\cdot 10^{-5}$ ^b

^a MBAYS procedure was used for obtaining the final uncertainty as the data set is discrepant (see 2000Ch01)

^b Calculated from (γ +ce)-intensity balance for corresponding levels

2.2. Gamma Transitions and Internal Conversion Coefficients

The gamma-ray transition probabilities have been deduced from their gamma-ray emission probabilities and total internal conversion coefficients (ICC). The experimental values of ICC have been adopted for gamma rays $\gamma_{5,1}$ (642.4 keV) and $\gamma_{5,0}$ (687.6 keV). The remaining ICC are theoretical values from 1978Ro22 for the adopted energies and multipolarities. The latter ones have been taken from the analysis of Schmorak (1991Sc08) and 1996Firestone. The relative uncertainties of α_K , α_L , α_M for pure multipolarities have been adopted as 2%.

3. ATOMIC DATA

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The energies of U LX-rays have been taken from 1994Le28 and 1994Le37 where the fine structure of LX radiation was measured in the decay of ²⁴⁰Pu. Other measurements of U LX-rays can be found in 1983Ah02, 1984Bo41, 1992Ba08 and 1995Jo23.

The U KX-ray energies have been taken from 1999Schönfeld where the calculated values based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the adopted values of U KX-ray energies are compared with experimental values.

Comments on evaluation

The relative KX-ray emission probabilities have been taken from 1999Schönfeld and from data on α -decay of ²³⁸Pu.

Table 5. Experimental and adopted (calculated) values of U KX-ray energies (keV)

	1976GuZN	1982Ba56	1983Ah02	Adopted
K α_2	94.655(5)	94.656(2)	94.67(2)	94.666
K α_1	98.442(5)	98.435(2)	98.45(2)	98.440
K β_3	110.42	110.416(3)	110.42(3)	110.421
K β_1	111.30	111.300(2)	111.31(2)	111.298
K β_5	-	111.868(5)- K β_5 '' 111.868(5)- K β_5 '	112.01(5)	111.964
K $\beta_{2,4}$	114.54	-	114.50(3)	114.46
KO _{2,3}	115.40	-	115.40(5)	115.377

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Lagoutine.

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4. ALPHA EMISSIONS

The energy of the alpha particles corresponding to the alpha transition to a ground state of ²³⁶U, E($\alpha_{0,0}$), has been adopted from the absolute measurement of 1972Go33 taking into account the correction of -0.17 keV recommended by A. Rytz in 1991Ry01.

The energies of all other α -emission energies have been calculated from E $\alpha_{0,0}$ and the level energies taking into account the recoil energies (see also 1994Ak05).

In Table 6 the calculated (evaluated) values of α -emission energies are compared with the experimental results obtained with using alpha spectrometry.

Table 6. Experimental and evaluated α -emission energies in the decay of ²⁴⁰Pu, keV

	Measured ^a						Evaluated
	1956Ko67	1956Go43	1952As28 1957As83	1962Le11	1972Go33	1977Ba69	
$\alpha_{0,0}$	5166	5165	5168(4)	5167.7(7)	5168.13(15) ^b	5168.13(15) ^b	5168.13(15) ^b
$\alpha_{0,1}$	5122	5121	5123(5)	5123.3(7)	5123.26(23)	5123.45(25)	5123.64(15)
$\alpha_{0,2}$	5021(2)	5020	5019			5021.3(5)	5021.15(15)
$\alpha_{0,3}$	4858(5)	4856				4863.4(5)	4863.51(15)

^a Original values have been adjusted taking into account changes in calibration energies as suggested in 1991Ry01

^b Absolute measurement; the value has been adopted as recommended in 1991Ry01 (see text above)

It should be noted that Sibbens and Pomme (2003Sibbens) measured (using a 50 mm² high-resolution planar silicon detector) the energies of ²⁴⁰Pu alpha particles relatively to reference peaks of ²³⁸Pu and ²³⁹Pu for a ^{238,239,240}Pu mixture. They obtained E($\alpha_{0,0}$)= 5168.54(1) keV and E($\alpha_{0,1}$)= 5124.10(2) keV discrepant with published data. However these results can depend on the spectrum de-convolution algorithm used. New experiments for pure ²⁴⁰Pu sources need to be done.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma transition energies given in section 2.2 and the electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated $P(\gamma)$ and ICC values. The experimental spectrum of the conversion electrons in the decay of ²⁴⁰Pu is given in 1958Sa21.

The absolute total emission probability of K Auger electrons have been computed by using the evaluated total emission probability of K-conversion electrons $P(ce_K) = 9.04(18) \cdot 10^{-5} \%$ and the adopted ω_K from section 3.

The absolute total emission probability of L Auger electrons have been computed using the adopted total absolute emission probability of U LX-rays and the adopted ω_L from section 3.

6. PHOTON EMISSIONS

6.1. X-Ray Emissions

6.1.1. LX-Rays

The evaluated absolute emission probabilities of U LX-rays have been obtained as weighted means of measurement values from 1994Le28 and 1994Le37. The uncertainties are the smallest quoted uncertainties.

The total absolute emission probability of U LX-rays $P(XL) = 9.9(5) \%$, calculated using the value $\omega_L = 0.500(19)$ from section 3.1 and the evaluated total absolute emission probability of L conversion electrons $P(ce_L) = 19.8(6) \%$, differs slightly from the value $P(XL) = 10.34(15) \%$ adopted from measurements of 1994Le28, 1994Le37. The measurement result of 1970Swinth (11.5(3) %) disagrees with the adopted and calculated values.

6.1.2. KX-Rays

The total absolute KX -ray emission probability $P(XK) = 8.77(18) \cdot 10^{-5} \%$ has been computed using the value $\omega_K = 0.970(4)$ from section 3.1 and the evaluated total emission probability of K-conversion electrons $P(ce_K) = 9.04(18) \cdot 10^{-5} \%$

6.2. Gamma Ray Emissions

6.2.1. Gamma Ray Energies

The energies of gamma rays accompanying α -decay of ²⁴⁰Pu to levels with energy less than 700 keV have been obtained on the basis of the available experimental data from ²⁴⁰Pu α -decay (Table 7) and data from ²³⁶Pa, ²³⁶Np decays (1984Mi02, 1991Sc08). The adopted gamma ray energies correspond to the decay scheme from 1991Sc08, 1996Firestone. Other much more inaccurate measurements results can be found in 1958Sa21, 1959Tr37 and 1972CIZS.

Table 7. Measured in the decay of ²⁴⁰Pu and adopted values of gamma ray energies (keV)

	1969Le05	1971GuZY	1972Sc01	1974HeYW	1975OtZX	1976GuZN	1981He16	Adopted
$\gamma_{1,0}$		45.235(20)	45.242(6)			45.232(5)	45.244(3)	45.242(3) ^a
$\gamma_{2,1}$		104.233(10)	104.233(5)	104.15(2)		104.244(5)	104.234(6)	104.234(6) ^b
$\gamma_{3,2}$		160.35(50)	160.310(8)	160.27(2)	160.312(10)	160.280(15)	160.308(3)	160.307(3) ^c
$\gamma_{4,3}$			212.4(1)		212.48(5)			212.46(5) ^a
$\gamma_{5,2}$	538.05(30)				538.09(15)			538.11(10) ^a
$\gamma_{5,1}$	642.43(10)			642.48(15)	642.33(10)	642.48		642.35(9) ^a
$\gamma_{5,0}$	687.77(15)			688.01(15)	687.57(10)	687.7		687.60(5) ^a
$\gamma_{7,1}$	873.91(20)				873.92(15)			873.92(15) ^a

^a Obtained by averaging experimental data with corrections where necessary according to the adopted decay scheme

^b Taken from 1981He16

^c Taken from 1981He16 with the correction according to 2000He14

6.2.2. Gamma-Ray Emission Probabilities

The experimental and evaluated gamma ray emission probabilities for γ -rays with energy less than 200 keV are given in Table 8. The evaluated P(γ) values have been obtained by averaging several experimental results(except P($\gamma_{1,0}$) that calculated from intensity balance).

Table 8. Experimental and evaluated emission probabilities of gamma rays in the decay of ²⁴⁰Pu with energy less than 200 keV (per 10⁴ α -decays)

	Energy keV	1971 GuZY	1972 Sc01	1975 OtZX	1976 GuZN	1976 Um01	1981 He16	1981 Morel	1994 Ba91	Evaluated
$\gamma_{1,0}$	45.24	4.50 (10) ^a	4.50 ^b		4.53 (9) ^d	4.61 (14) ^e	4.35 (9)			4.50 (9) ^f
$\gamma_{2,1}$	104.23	0.700 (14) ^a	0.91(5) ^c	0.70 ^b	0.698 (14) ^d		0.718 (7)			0.714 (7) ^g
$\gamma_{3,2}$	160.31	0.0420 (8) ^a	0.049 (12) ^c	0.0408 (10)	0.0402 (8) ^d		0.0402 (4)	0.0402 (7)	0.04065 (17)	0.04045 (22) ^h

^a Omitted from averaging as the data of 1971GuZY have been revised in 1976GuZN

^b Omitted from averaging as uncertainty is not quoted

^c Omitted on statistical considerations

^d The uncertainty quoted in 1976GuZN has been recalculated in 1986IAEA to include a 2% detector efficiency uncertainty

^e The uncertainty quoted in 1976Um01 has been recalculated in 1986IAEA to include a 2% detector efficiency uncertainty and 1% from the sample isotopic composition

^f Calculated from the P(α) values and the adopted total ICC $\alpha_T(\gamma_{1,0}) = 604(12)$; agreed with the weighted mean of 1976GuZN, 1976Um01 and 1981He16: 4.47(10)

^g Weighted mean of 1976GuZN and 1981He16; the uncertainty is the smallest quoted uncertainty

^h Weighted mean of 5 experimental values; the uncertainty is internal.

The emission probabilities of $\gamma_{4,3}$ (212 keV) and $\gamma_{5,2}$ (538 keV) have been adopted from absolute measurements of 1975OtZX. The emission probabilities of $\gamma_{5,1}$ (642 keV) and $\gamma_{5,0}$ (687 keV) have been obtained by averaging experimental data (Table 9).

Table 9. Experimental and evaluated emission probabilities of gamma rays de-exciting the ^{236}U level with energy of 687.6 keV in the decay of ^{240}Pu (per 10^8 α -decays)

	Energy, keV	1969Le05	1971GuZY	1975OtZX	1975Dr05	1976GuZN	Evaluated
$\gamma_{5,2}$	538.1	$\approx 0.23^a$		0.147(12)			0.147(12)
$\gamma_{5,1}$	642.4	14.5 ^a	14.5(5) ^b	12.6(4)	13(1)	12.45(30)	12.6(3) ^c
$\gamma_{5,0}$	687.6	3.77(11)	3.70(15) ^b	3.30(13)		3.55(9)	3.56(16) ^d

^a Omitted from averaging as uncertainty is not quoted

^b Omitted from averaging as the data of 1971GuZY have been revised in 1976GuZN

^c Weighted mean of 3 experimental values; the uncertainty is the smallest quoted uncertainty

^d Weighted mean of 3 experimental values; the uncertainty is external one increased by Student's coefficient (2000Ch01)

The emission probability of $\gamma_{7,1}$ (874 keV) has been obtained as a weighted average of measurement results from 1969Le05 and 1975OtZX. Weak gamma rays with energy more than 900 keV are reported in 1969Le05 and 1976GuZN. They are expected from the decay scheme but their emission probabilities ($< 10^{-7}$ per 100 decays) have not been determined with a great accuracy.

REFERENCES

- 1951In03 M.G. Inghram, D.C. Hess, P.R. Fields, G.L. Pyle, Phys. Rev. 83 (1951) 1250.
(Half-life)
- 1951We21 E.F. Westrum, Phys. Rev. 83 (1951) 1249.
(Half-life)
- 1952As28 F. Asaro, I. Perlman, Phys. Rev. 88 (1952) 828.
(α -transition energies and probabilities)
- 1953Ki72 E.M. Kinderman, Hanford Lab. Report HW 27660 (1953).
(SF half-life)
- 1954Ba14 F.R. Barclay, W. Galbraith, K.M. Glover, G.R. Hall, W.J. Whitehouse, Proc. Phys. Soc. (London) 67A (1954) 646.
(SF half-life)
- 1954Ch74 O. Chamberlain, G.W. Farwell, E. Segre, Phys. Rev. 94 (1954) 156.
(SF half-life)
- 1954Fa11 G. Farwell, J.E. Roberts, A.C. Wahl, Phys. Rev. 94 (1954) 363.
(Half-life)
- 1956Bu92 J.P. Butler, T.A. Eastwood, T.L. Collins, M.E. Jones, F.M. Rourke, R.P. Schuman, Phys. Rev. 103 (1956) 634.
(Half-life)
- 1956Go43 L.L. Goldin, G.I. Novikova, E.F. Tretyakov, Phys. Rev. 103 (1956) 1004.
(α -transition energies and probabilities)
- 1956Ko67 L.M. Kondratev, G.I. Novikova, Y.P. Sobolev, L.L. Goldin, Zh. Eksp. Teor. Fiz. 31 (1956) 771.
(Soviet Phys. JETP 4 (1956) 645).
(α -transition energies and probabilities)
- 1957As83 F. Asaro, S.G. Thompson, F.S. Stephens, Jr. I. Perlman, Priv. Comm, (1957), quoted by 1964Hy02
(α -transition energies and probabilities)
- 1958Sa21 P.S. Samoilo, Atomnaya Energ. 4 (1958) 81. (Soviet. J. At. Energy 4 (1958) 102).
(Gamma ray energies)
- 1959Do64 Ya. P. Dokuchaev, Atomnaya Energ. 6 (1959) 74.
(Half-life)
- 1959Mi90 V.L. Mikheev, N.K. Skobelev, V.A. Druin, G.N. Flerov, Zhur. Eksptl. i Teoret. Fiz. 37 (1959) 859. (Soviet Phys. JETP 10 (1960) 612).
(Half-life)
- 1959Tr37 E.F. Tretyakov, L.N. Kondratev, G.I. Khlebnikov, L.L. Goldin, Zh. Eksp. Teor. Fiz. 36 (1959) 362. Soviet Phys. JETP 9 (1959) 250.
(Gamma ray energies)

Comments on evaluation

- 1962Le11 C.F. Leang, *Compt. Rend.* 255 (1962) 3155.
(α -transition energies)
- 1962Wa13 D.E. Watt, F.J. Bannister, J.B. Laidler, F. Brown, *Phys. Rev.* 126 (1962) 264.
(SF half-life)
- 1963Ma50 L. Z. Malkin, I. D. Alkhazov, A. S. Krivokhatsky, K. A. Petrzhak, *At. Energ. USSR* 15 (1963)158.
(Soviet. *J. At. Energy* 15 (1964) 851).
(SF half-life)
- 1964Hy02 E.K. Hyde, I. Perlman, G.T. Seaborg, (1964): *The Nuclear Properties of the Heavy Elements, Vol II.* Prentice-Hall, Inc, Englewood Cliffs, N J.
(α -transition energies and probabilities)
- 1967Be65 J.A. Bearden, *Rev. Mod. Phys.* 39 (1967) 78.
(X-ray energies)
- 1967Fi13 P. Fieldhouse, D.S. Mather, E.R. Culliford, *J. Nucl. Energy* 21 (1967) 749.
(SF half-life)
- 1967White P.H. White, priv. comm., cited in *J.Nucl.Energy* 21, 749 (1967) and in 2000Ho27.
(SF half-life)
- 1968Oe02 F.L. Oetting, In: *Proc. Symp. Thermodyn. Nucl. Mater. With Emphasis on Solution Syst.*, Vienna, Austria (1967), Intern. At. Energy Agency, Vienna, p 55 (1968).
(Half-life)
- 1969Le05 C.M. Lederer, J.M. Jaklevic, S.G. Prussin, *Nucl. Phys.* A135 (1969) 36.
(α -transition energies and probabilities)
- 1970Swinth K.L. Swinth, *IEEE Nuclear Science Symp.*, 1970, Vol. 4, p.125.
(LX-ray emission probabilities)
- 1971GuZY R. Gunnink, R.J. Morrow, In: *UCRL 51087* (1971).
(Gamma ray energies and emission probabilities)
- 1972CIZS J.E. Cline, R.J. Gehrke, L.D. McIsaac, In: *ANCR 1069* (1972).
(Gamma ray energies)
- 1972Go33 D.J. Gorman, A. Rytz, H.V. Michel, *Compt. Rend.* B275 (1972) 291.
(α -transition energies)
- 1972Sc01 M. Schmorak, C.E. Bemis, Jr, M.J. Zender, N.B. Gove, P.F. Dittner, *Nucl. Phys.* A178 (1972) 410.
(Gamma-ray energies and emission probabilities)
- 1974HeYW R.L. Heath, *Gamma-Ray Spectrum Catalogue.* In: *ANCR 1000 2*(1974)
(Gamma ray energies)
- 1975Dr05 T. Dragnev, K. Scharf, *Intern. J. Appl. Radiat. Isotop.* 26 (1975) 125.
(Gamma ray emission probabilities)
- 1975OtZX H. Ottmar, P. Matussek, I. Piper In: *Proc Int Symp Neutron Capture Gamma Ray Spectroscopy and Related Topics*, 2nd, Petten, The Netherlands (1974), K Abrahams, F Stecher-Rasmussen, P Van Assche, Eds, *Reactor Centrum Nederland*, p 658 (1975).
(Gamma-ray energies and emission probabilities)
- 1976GuZN R. Gunnink, J.E. Evans and A.L. Prindle, *UCRL-52139* (1976).
(Gamma-ray energies and emission probabilities)
- 1976Um01 H. Umezawa, T. Suzuki, S. Ichikawa, *J. Nucl. Sci. Technol.* 13 (1976) 327.
(Gamma-ray emission probabilities)
- 1977Ba69 S.A. Baranov, V.M. Shatinskii, *Yad. Fiz.* 26 (1977) 461. (*Soviet J. Nucl. Phys.* 26 (1977) 244).
(α -transition energies and probabilities)
- 1977La19 F.P. Larkins, - *Atomic Data and Nuclear Data Tables.* 20 (1977) 313.
(Auger electron energies)
- 1978Ja11 A.H. Jaffey, H Diamond, W.C. Bentley, D.G. Graczyk, K.P. Flynn, *Phys. Rev.* C18 (1978) 969.
(Half-life)
- 1978Ro22 F. Rosel, H.M. Friess, K. Alder and H.C. Pauli - *At. Data Nucl. Data Tables.* 21 (1978) 92.
(Theoretical ICC)
- 1979BuZC C. Budtz-Jorgensen, H.-H. Knitter, In: *NEANDC(E) 202U; Vol III*, p 9 (1979).
(SF half-life)
- 1981He16 R.G. Helmer, C.W. Reich, *Intern. J. Appl. Radiat. Isotop.* 32 (1981) 829.
(Gamma-ray energies and emission probabilities)
- 1981Morel J. Morel et al., LMRI, Saclay, private communication, 1981 Cited in IAEA, Vienna, *Tec. Rep.* 261, 1986.
(Gamma-ray emission probabilities)
- 1982Ba56 G. Barreau, H.G. Borner, T. von Egidy, R.W. Hoff. *Z. Phys.* A308 (1982) 209.
(KX-ray energies)
- 1983Ah02 I. Ahmad, J. Hines, J.E. Gindler, *Phys. Rev.* C27 (1983) 2239.
(KX-ray energies)

- 1984Ah06 I. Ahmad, Nuclear Instrum. Methods 223 (1984) 319.
(α -transition probabilities)
- 1984An25 A.A. Androsenko, P.A. Androsenko, Yu. V. Ivanov, A.E. Konyaev, V.F. Kositsyn, E.M. Tsenter, V.T. Shchebolev, At. Energ. 57 (1984) 357, (Sov. At. Energy 57, (1984) 788).
(SF half-life)
- 1984Be19 R.J. Beckman, S.F. Marsh, R.M. Abernathy, J.E. Rein, Intern. J. Appl. Radiat. Isotop. 35 (1984) 163.
(Half-life)
- 1984Bo41 G. Bortels, B. Denecke, R. Vaninbrouckx, Nuclear Instrum. Methods 223 (1984) 329.
(LX-ray energies)
- 1984Lu04 L.L. Lucas, J.R. Noyce, Intern. J. Appl. Radiat. Isotop. 35 (1984) 173.
(Half-life)
- 1984Mi02 S. Mirzadeh, Y.Y. Chu, S. Katcoff, L.K. Peker, Phys. Rev. C29 (1984) 985.
(Gamma-ray energies)
- 1984Ru04 C.R. Rudy, K.C. Jordan, R. Tsugawa, Intern. J. Appl. Radiat. Isotop. 35 (1984) 177.
(Half-life)
- 1984St06 F.J. Steinkruger, G.M. Matlack, R.J. Beckman, Intern. J. Appl. Radiat. Isotop. 35, (1984) 171.
(Half-life)
- 1986IAEA Decay Data of the Transactinium Nuclides, IAEA, Vienna, Tec. Rep. Ser. 261, 1986.
(Gamma-ray emission probabilities)
- 1987Lagoutine F. Lagoutine, N. Coursol and J. Legrand, ISBN-2-7272-0078-1 (LMRI, 1982-1987).
(Energy of Auger electrons)
- 1988SeZY Yu.A. Selitsky, V.B. Funshtein, V.A. Yakovlev, Program and Theses, Proc. 38th Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, Baku, Acad. Sci. USSR, (1988) 131.
(SF half-life)
- 1989Dy01 N. Dytlewski, M.G. Hines, J.W. Boldeman, Nucl. Sci. Eng. 102 (1989) 423.
(SF half-life)
- 1990An33 S.V. Anichenkov, Yu.S. Popov, Radiokhimiya 32 (1990) 109. (Sov. Radiochem. 32 (1991) 401).
(α -transition probabilities)
- 1991Iv01 Yu.V.Ivanov, A.E.Konyaev, V.F.Kositsyn, E.A.Kholnova, V.T.Shchebolev, M.F.Yudin, At.Energ. 70 (1991) 396. (Sov.At.Energy 70 (1991) 491).
(SF half-life)
- 1991Ry01 A. Rytz, At. Data Nucl. Data Tables. 47 (1991) 205.
(α -transition energies)
- 1991Sc08 M.R.Schmorak, Nucl.Data Sheets 63 (1991) 139.
(Decay scheme, ^{236}U level energies, gamma ray multipolarities)
- 1992Ba08 G. Barci-Funel, J. Dalmasso, G. Ardisson, Appl. Radiat. Isot. 43 (1992) 37.
(X ray energies)
- 1992Bl13 C.J.Bland, J.Truffly Appl.Radiat.Isot. 43 (1992) 1241.
(α -transition probabilities)
- 1994Ba91 D.T.Baran, Appl.Radiat.Isot. 45 (1994) 1177.
(α -transition probabilities)
- 1994Le28 M.C.Lepy, B.Duchemin, J.Morel, Nucl.Instrum.Methods Phys.Res. A339 (1994) 218.
(LX ray energies and emission probabilities)
- 1994Le37 M.C.Lepy, B.Duchemin, J.Morel, Nucl.Instrum.Methods Phys.Res. A353 (1994) 10.
(LX ray energies and emission probabilities)
- 1994Ra27 W.Raab, J.L.Parus Nucl.Instrum.Methods Phys.Res. A339 (1994) 116.
(α -transition probabilities)
- 1994Sa63 A.M.Sanchez, F.V.Tome, J.D.Bejarano Nucl.Instrum.Methods Phys.Res. A340 (1994) 509.
(α -transition probabilities)
- 1995Au04 G.Audi and A.H. Wapstra, Nucl. Phys. A595 (1995) 409.
(Decay energy)
- 1995Jo23 P.N.Johnston, P.A.Burns, Nucl.Instrum.Methods Phys.Res. A361 (1995) 229.
(U LX ray energies and emission probabilities)
- 1996Firestone R.B. Firestone, V.S. Shirley, C.M. Baglin, S.Y.F. Chu, J. Zipkin, 1996. Table of Isotopes. Eighth Edition, Volume II: A=151-272, 2800-2801.
(Decay scheme, ^{236}U level energies, gamma ray multipolarities)
- 1996Vi07 L.L.Vintro, P.I.Mitchell, O.M.Condren, M.Moran, J.Vives i Batlle, J.A.Sanchez-Cabeza, Nucl.Instrum.Methods Phys.Res. A369 (1996) 597.
(α -transition probabilities)
- 1999Schonfeld E. Schonfeld and G. Rodloff - PTB-6.11-1999-1999-1, Braunschweig, Februar 1999
(KX-ray energies and relative emission probabilities)

Comments on evaluation

- 2000Ch01 V.P. Chechev, A.G. Egorov, Appl. Rad. Isot. 52 (2000) 601.
(Evaluation technique)
- 2000Ho27 N.E. Holden, D.C. Hoffman, Pure Appl. Chem. 72 (2000) 1525.
(SF half-life)
- 2003Sibbens G.Sibbens, S.Pommé, Appl. Rad. Isot. 60, 2-3 (2004) 155
(α -transition energies and probabilities)

**²⁴¹Am -Comments on evaluation of decay data
by V.P. Chechev and N.K. Kuzmenko**

This evaluation was completed in October 2002 and revised in January 2004. The literature available by October 2002 was included.

1. Decay scheme

The scheme of ²⁴¹Am decay is rather complex. It contains more than forty excited levels in ²³⁷Np populated by alpha- and gamma-transitions (1995Ak01). For high levels the decay scheme is not completed as great number of observed gamma transitions are not placed in the level scheme and some expected gamma transitions have not been seen.

However the intensive population takes place only for lower levels with the energy less than 230 keV (8 excited levels and ground state in ²³⁷Np) and in this part of the decay scheme is mainly defined. Nevertheless here also there are gamma-transitions scarcely studied and expected but not certainly observed such as 27,02; 54,1; 96,7 keV. This leads to the not very good intensity balance for some levels.

The population of all higher levels does not exceed 0,1% in total.

2. Nuclear Data

Q value is from Audi and Wapstra (1995Au04).

The evaluated value of the ²⁴¹Am half-life has been obtained by averaging the experimental values, in years, given below:

432,7(7)	1967Oe01	Calorimetry
433(7)	1968Br22	Specific Activity Determination
436,6(30)	1968St02	Specific Activity Determination
426,3(21)	1972Jo07	Calorimetry
432,5(7)	1974StYG	Calorimetry
435,0(7)	1974StYZ	Specific Activity Determination
432,8(16)	1974Po16	Specific Activity Determination
432,0(2)	1975Ra35	Calorimetry

The values before 1967 have been omitted due to their large systematic uncertainties (those values lead to the ²⁴¹Am half-life of 458 years).

The eight values were used for statistical processing. The uncertainty of 1975Ra35 was increased to 0,38 y to adjust weights according to the LRSW method.

Statistical processing of the final data set with the reduced χ^2 of 3,58 gives the unweighted mean (UWM) of 432,6(11) and weighted mean (WM) of 432,6 with an internal uncertainty of 0,27 and an external uncertainty of 0,51.

The EVINEW computer program has chosen WM and the tS (or MBAYS) uncertainty of 0,55. The LWEIGHT program has also chosen WM and expanded the uncertainty so range includes the most precise value of 432,0 (1975Ra35) giving the value of 432,6(6) as result coinciding with the EVINEW final value.

The adopted value of the ²⁴¹Am half-life is 432,6(6) years.

2.1. Alpha Transitions

The energies of the alpha transitions have been calculated from the Q value and the level energies given in Table 1 from 1995Ak01, with corrections for the 8 lower levels to take into account the adopted energies of gamma transitions from section 2.2.

Table 1. ²³⁷Np levels displayed in the ²⁴¹Am α -decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α -transition (x100)
0	0,0	5/2 ⁺	2,14 10 ⁶ yr	0,38(1)
1	33,1963(3)	7/2 ⁺	54(24) ps	0,23(1)
2	59,5409(1)	5/2 ⁻	67(2) ns	84,45(10)
3	75,900(3)	9/2 ⁺	~56 ps	<0,04
4	102,961(3)	7/2 ⁻	80(40) ps	13,23(10)
5	130,00(3)	11/2 ⁺		~0,01
6	158,49(2)	9/2 ⁻		1,66(3)
7	191,44(10)	13/2 ⁺		
8	225,96(2)	11/2 ⁻		0,015(5)
9	267,54(2)	3/2 ⁻	5,2(2) ns	5·10 ⁻⁴
10	281,35(2)	1/2 ⁻		
11	305,06(4)	13/2 ⁻		0,0022(3)
12	316,8(2) ?			
13	324,42(5)	7/2 ⁻		0,0013
14	332,36(3)	1/2 ⁺	≤1 ns	
15	359,7(1)	(5/2 ⁻)		6·10 ⁻⁴
16	368,59(3)	5/2 ⁺		9·10 ⁻⁴
17	370,93(3)	3/2 ⁺		3·10 ⁻⁴
18	395,52(5)	15/2 ⁻		7·10 ⁻⁴
19	418(4) ?			
20	434,12(16)	(11/2 ⁻)		4·10 ⁻⁴
21	444,78(10) ?			
22	452,53(5)	9/2 ⁺		~4·10 ⁻⁴
23	459,69(4)	7/2 ⁺		~4·10 ⁻⁴
24	485,96(12)	(9/2 ⁻)		1,1·10 ⁻⁴
25	497,02(6)	17/2 ⁻		
26	514,19(6)	(3/2 ⁻)		
27	545,59(16)	(5/2 ⁻)		1·10 ⁻⁴
28	590,28(15)	(7/2 ⁻)		
29	592,3(10)	13/2 ⁺		
30	598,0(2)	11/2 ⁺		
31	646,1(2)	(9/2 ⁻)		
32	666,2(2)	(5/2 ⁺ , 7/2)		
33	721,95(5)	5/2 ⁻		7·10 ⁻⁴
34	756,00(10)	7/2 ⁻		8,6·10 ⁻⁵
35	770,57(5)			
36	800,00(10)	9/2 ⁻		4(3)·10 ⁻⁵

37	805,8(2)	(7/2 ⁺ , 9/2)	
38	853,36(20)	11/2 ⁻	
39	861,7(5)	(5/2 ⁺ , 7/2)	
40	920,9(5)		
41	946(2)		
42	962(3) ?		
43	1014(3) ?		

The probabilities of the alpha transitions $\alpha_{0,0}$, $\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,4}$ and $\alpha_{0,6}$ have been obtained by averaging measured values from spectrometric measurements (Table 2).

Table 2. Measured and adopted probabilities (x100) of the five most intensive alpha transitions

	1984Ah06 1993Ahmad	1987Bo25	1994B112	1996 Bueno	1996 Sanchez	1998Ya17	Adopted (WM)
$\alpha_{0,0}$	0,36(1)	0,34(5)	0,36(5)	0,5(2)	0,36(3)	0,394(9)	0,38(1)
$\alpha_{0,1}$	0,23(1)	0,22(3)	0,22(6)	-	0,28(3)	0,224(7)	0,23(1)
$\alpha_{0,2}$	84,6(2)	84,7(9)	84,69(28)	84,5(8)	84,5(3)	84,30(7)	84,45(10)
$\alpha_{0,4}$	13,1(1)	13,0(3)	13,08(24)	12,5(3)	13,2(3)	13,40(8)	13,23(10)
$\alpha_{0,6}$	1,65(8)	1,6(1)	1,66(6)	1,6(2)	1,65(7)	1,67(2)	1,66(3)

The $\alpha_{0,2}$ and $\alpha_{0,4}$ probability values of 1984Ah06 have been revised by the same author in 1993Ahmad cited in 1994B112. In Table 2 the revised values are given.

The probabilities of the alpha transitions $\alpha_{0,3}$, $\alpha_{0,5}$, $\alpha_{0,9}$, $\alpha_{0,13}$, $\alpha_{0,15}$ ÷ $\alpha_{0,33}$ have been adopted from magnetic spectrometer measurements of 1964Ba26. The probabilities of the $\alpha_{0,8}$ and $\alpha_{0,11}$ transitions have been obtained from measurements of 1955Go57, 1964Ba26 and 1965Mi06. The probabilities of the $\alpha_{0,34}$ and $\alpha_{0,36}$ transitions have been computed from the intensity balance of gamma transitions.

2.2. Gamma Transitions and Internal Conversion Coefficients

The energies of gamma transitions are the energies of gamma rays.

The probabilities of the intensive anomalously converted gamma transitions $\gamma_{2,1}$ and $\gamma_{2,0}$ as well as that of $\gamma_{1,0}$ have been adopted from the analysis of Peter N. Johnston (1996Jo28) made in search of optimized values of parameters for low energy photons in the decay of ²⁴¹Am including LX-rays. The decay scheme balance for lower levels of ²³⁷Np is better in 1996Jo28 than previous attempts.

ICC for $\gamma_{2,1}$ and $\gamma_{2,0}$ transitions have been obtained from the evaluation of the gamma ray and L-conversion electron probabilities in 1996Jo28. ICC for $\gamma_{1,0}$ transition have been taken from 1966Le13.

Multipolarities for all other gamma transitions have been adopted from measurements of 1959Sa10, 1964Wo03, 1966Ko06 and 1966Ya05. For these transitions the ICC have been evaluated using the above experimental information on the multipolarity admixture coefficients and the theoretical values from 1978Ro22.

The multipolarity admixture coefficient for $\gamma_{4,2}$ has been obtained by averaging four measurement results from 1963Wo03, 1966Ko06, 1966Ya05 and 1998Ko61.

The probabilities of the gamma transitions, $P_{\gamma+ce}$, have been computed using the evaluated absolute gamma -ray emission probabilities and the total internal conversion coefficients.

3. Atomic Data

3.1. Fluorescence yields

The ω_K and ω_L fluorescence yields are taken from 1996Sc06 (Schönfeld and Janßen).

ω_M is from 1989Hubbell.

3.1.1. X Radiations

The XL -ray energies are taken from 2001Sc08

The XK -ray energies are taken from 1999Schönfeld. Below these calculated (adopted) values are compared with the measurement results of 1982Ba56 and 1983Ah02:

	Calculated (1999 Schönfeld)	Measured in 1982Ba56	Measured in 1983Ah02
$K\alpha_2$	97,069	97,069(3)	97,08(2)
$K\alpha_1$	101,059	101,057(3)	101,07(2)
$K\beta_3$	113,303	113,308(4)	113,30(2)
$K\beta_1$	114,234	114,244(3)	114,24(2)
$K\beta_5$	114,912	-	114,95(2)
$K\beta_2$	117,463		}
$K\beta_4$	117,876		} 117,51(3)
$KO_{2,3}$	118,429	-	118,45(5)

The relative emission probabilities of XK -rays are taken from 1999Schönfeld.

3.1.2. Auger electrons

The energies of Auger electrons are from 1977Larkins.

The ratios $P(KLX)/P(KLL)$ and $P(KXY)/P(KLL)$ are taken from 1996Sc06.

4. Alpha Emissions

The energies of alpha particles, E_α , have been calculated from the energies of alpha transitions taking into account the recoil energies (see also 1995Ak01). The recommended energies of alpha-particles and emission probabilities of the most intensive alpha transitions are given also in 1991Ry01.

The experimental values E_α from spectrometric measurements are given in 1971GR17, 1968Ba25, 1968Ka09, 1965Mi06, 1964Ba26, 1962Le11, 1957Ro20, 1955Go57. They have the lesser accuracy in comparison with the calculated values.

5. Electron emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.2. The total emission probability of L-Auger electrons has been calculated from the evaluated $P(XL)$ and ω_L .

6. Photon emissions

6.1 X - Ray emissions

The total absolute emission probability of MX - rays is the measurement result of 1971Ka48.

The absolute emission probabilities of LX - rays have been obtained by averaging of measurement results (per 100 disintegrations) shown in Table 3.

Table 3. Measured and evaluated absolute emission probabilities of LX rays in the decay of ²⁴¹Am

	1971 Ge11	1971 Wa28	1974 Ca16	1974 Ga40	1976 GuZN	1980 Cohen	1988 Co07	1992 Bl07	1994 Le37	Adopted (WM)
Ll	0,81(7)	0,87(6)	0,86(2)	-	0,806(40)	0,87(3)	0,83(3)	0,837(10)	0,864(12)	0,848(10) ^a
L α	12,6(9)	13,5(12)	13,20(25)	-	13,2(7)	13,2(3)	12,7(4)	13,01(10)	13,03(13)	13,03(10) ^a
L β	19,1(14)	19,1(14)	19,25(40)	19,46(16)	19,2(10)	19,78(36)	18,3(6)	18,61(15)	18,39(19)	18,86(15) ^b
L γ	4,75(35)	4,75(35)	4,85(15)	-	4,94(25)	4,96(20)	4,8(2)	4,815(38)	4,74(8)	4,81(4) ^c

^a The smallest uncertainty of the measurement results.

^b tS – external uncertainty (or MBAYS).

^c Internal uncertainty of WM.

In 2001Sc08 also the measurement results of 1993Lepy (per 100 disintegrations) are given which are not included in averaging: Ll-0,875(18), L α -13,10(21), L β -18,5(4), L γ -4,84(8).

The total absolute emission probability of LX - rays is obtained by summing of the adopted data in the last column of Table 3: $P(XL) = 37,6(3)$ per 100 disintegrations. This value can be compared with that calculated using total absolute sums P_{ceL} , P_{ceK} , and atomic data of sect.3 (ω_K , ω_L , n_{KL}). The latter is 38,6(16) per 100 disintegrations.

The absolute emission probabilities of XK -rays have been computed from the total XK - ray absolute emission probability $P(XK) = 0,00389(8)$ per 100 disintegrations and the relative emission probabilities of XK - rays given in 1999Schönfeld. The above value $P(XK)$ has been calculated using the adopted value of ω_K and the evaluated absolute emission probabilities of K conversion electrons from

section 5. It agrees with measurements of 1976GuZN which give $P(XK)=0,0040(1)$ per 100 disintegrations.

Below the experimental data of 1976GuZN are compared with the calculated (adopted) values of absolute emission probability of KX – ray components:

	1976GuZN (measured)	Calculated (adopted)
$K\alpha_2$	0,00118(3)	0,00116(3)
$K\alpha_1$	0,00189(5)	0,00185(4)
$K\beta_3$	$2,4(1) \cdot 10^{-4}$	$2,14(5) \cdot 10^{-4}$
$K\beta_1$	$4,7(2) \cdot 10^{-4}$	$4,19(9) \cdot 10^{-4}$
$K\beta_5$	}	
$K\beta_{2,4}$	} $2,29 \cdot 10^{-4}$	$2,24(6) \cdot 10^{-4}$
$KO_{2,3}$	}	

6.2. Gamma emissions

The energies of gamma rays $\gamma_{2,0}$ and $\gamma_{2,1}$ have been adopted from 2000He14.

The energy of gamma ray $\gamma_{1,0}$ has been computed as the difference $E\gamma_{2,0} - E\gamma_{2,1}$.

The energies of gamma rays $\gamma_{4,3}$, $\gamma_{3,1}$, $\gamma_{4,2}$ have been taken from 1998Ko61.

The energies of gamma rays $\gamma_{6,4}$, $\gamma_{8,6}$, $\gamma_{4,1}$, $\gamma_{3,0}$, $\gamma_{6,2}$, $\gamma_{4,0}$, $\gamma_{6,1}$, $\gamma_{29,22}$, $\gamma_{11,6}$, $\gamma_{8,3}$, $\gamma_{29,20}$, $\gamma_{9,4}$, $\gamma_{13,6}$, $\gamma_{18,8}$, $\gamma_{11,5}$, $\gamma_{25,11}$, $\gamma_{9,2}$, $\gamma_{13,4}$, $\gamma_{26,10}$, $\gamma_{26,9}$, $\gamma_{21,7}$, $\gamma_{13,2}$, $\gamma_{9,0}$, $\gamma_{20,6}$, $\gamma_{13,1}$, $\gamma_{16,3}$, $\gamma_{20,5}$, $\gamma_{21,5}$, $\gamma_{14,0}$, $\gamma_{16,1}$, $\gamma_{17,1}$, $\gamma_{20,3}$, $\gamma_{16,0}$, $\gamma_{17,0}$, $\gamma_{21,3}$, $\gamma_{22,3}$, $\gamma_{32,9}$, $\gamma_{30,7}$, $\gamma_{21,1}$, $\gamma_{22,1}$, $\gamma_{30,5}$, $\gamma_{27,1}$, $\gamma_{26,0}$, $\gamma_{36,8}$, $\gamma_{31,2}$, $\gamma_{28,0}$, $\gamma_{34,6}$, $\gamma_{33,4}$, $\gamma_{32,1}$, $\gamma_{36,6}$, $\gamma_{34,4}$, $\gamma_{33,2}$, $\gamma_{34,3}$, $\gamma_{33,1}$, $\gamma_{709,42}$ keV, $\gamma_{33,0}$, $\gamma_{35,1}$, $\gamma_{34,0}$, $\gamma_{36,1}$, $\gamma_{35,0}$, $\gamma_{39,2}$ have been adopted from the evaluations of 1988ChZL. Those values were obtained as weighted averages based on the measurements of 1955Da02, 1964Wo03, 1966Ko06, 1976GuZN, 1978Ge06, 1959Sa10, 1968Je01, 1978Ge17, 1978Ov01, 1984Ov02, 1970Ne11, 1966Ya05, 1979Ar11.

The energy of gamma ray $\gamma_{8,4}$ has been obtained as the weighted average of measurement results of 1974HeYW, 1976GuZN, 1978Ge06 and 1998Ko61.

The gamma rays with energies of 128,05 keV, 129,2 keV, 135,3 keV, 136,7keV and 138,5 keV were not observed by others and have been taken from 1979Ar11.

The remaining gamma ray energies have been taken from measurements 1978Ge06, 1978Ge17, and 1976GuZN and 1998Ab43.

The absolute emission probabilities of gamma rays $\gamma_{2,1}$, $\gamma_{1,0}$ and $\gamma_{2,0}$ have been adopted from the detailed Johnston's analysis (1996Jo28) that is based on experimental works of 1983De11, 1957Ma17, 1971Ge11, 1974Ca16, 1976GuZN, 1978Ge06, 1983Ah02, 1984Ov02, 1955Da02, 1975Le09, 1976PI05, 1983Hu04, 1965Mc12.

The remaining gamma ray absolute emission probabilities have been taken from 1978Ge06, 1978Ge17, 1976GuZN and 1998Ab43.

References

- R.B. Day, Phys. Rev. 97 (1955) 689
(gamma-ray emission probabilities)
- L.L.Goldin, G.I.Novikova, E.F.Tretyakov. In: Conf Acad Sci USSR Peaceful Uses of Atomic Energy, Session Div Phys Math Sci, Moscow, p. 226 (1955); Consultants Bureau Transl 1956, p. 167
(energies of alpha-particles, alpha-particle emission probabilities)
- L.B.Magnusson, Phys. Rev. 107 (1957) 161
(gamma-ray energies and emission probabilities)
- S.Rosenblum, M.Valadares, J.Milsted, J. Phys. Radium 18 (1957) 609
(energies of alpha-particles)
- P.S.Samoilov, Columbia Tech. Transl. 23 (1960) 1401, (Izvest. Akad. Nauk SSSR, Ser. Fiz. 23 (1959) 1416)
(gamma-ray energy, gamma transition probabilities and multipolarities)
- C.F.Leang, Compt. Rend. 255 (1962) 3155
(energies of alpha-particles)
- S.A.Baranov, V.M.Kulakov, V.M.Shatinsky, Nucl. Phys. 56 (1964) 252
(alpha-particle energies and emission probabilities)
- J.L.Wolfson, J.H.Park, Can J Phys 42 (1964) 1387. See also Erratum. Can. J. Phys. 48 (1970) 2782
(gamma-ray energies and multipolarities)
- L.D.McIsaac, In: IDO-17052 (1965), p. 31
(gamma-ray emission probabilities)
- W.Michaelis, Z. Phys. 186 (1965) 42
(alpha particle energies and emission probabilities)
- L.N.Kondratev, E.F.Tretyakov, Bull. Acad. Sci. USSR, Phys. Ser. 30 (1967) 393 (Izv Akad Nauk SSSR, Ser Fiz 30 (1966) 386)
(internal conversion probabilities)
- C.M.Lederer, J.K.Poggenburg, F.Asaro, J.O.Rasmussen, I.Pperlman, Nucl. Phys. 84 (1966) 481
(internal conversion coefficients)
- T.Yamazaki, J.M.Hollander, Nucl. Phys. 84 (1966) 505
(internal conversion probabilities)
- F.L.Oetting, S.R.Gunn, J. Inorg, Nucl. Chem. 29 (1967) 2659
(half-life)
- S.A.Baranov, V.M. Kulakov, V.M.Shatinskii, Soviet J. Nucl. Phys. 7 (1968) 442
(energies of alpha-particles)
- L.C.Brown, R.C.Propst, J. Inorg. Nucl. Chem. 30 (1968) 2591
(half-life)
- R.W. Jewell, W.John, R.Massey, B.G.Saunders, Nuclear Instrum. Methods 62 (1968) 68.
(gamma-ray energies)
- R.Kamoun, R.Ballini, S.Bergstrom-Rohlin, J-M.Kuchly, P.Siffert, Compt. Rend. 266B (1968) 1241
(energies of alpha-particles)
- R.E.Stone, E.K.Hulet, J. Inorg, Nucl. Chem. 30 (1968) 2003
(half-life)
- G.C.Nelson, B.G.Saunders, Nuclear Instrum. Methods 84 (1970) 90
(gamma-ray energies)
- R.J. Gehrke, R.A.Lokken, Nuclear Instrum. Methods 97 (1971) 219
(LX- and gamma –ray emission probabilities)
- B.Grennberg, Rytz,A, Metrologia 7 (1971) 65
(energies of alpha-particles)
- E.Karttunen, H.U.Freund, R.W.Fink, Phys. Rev. A4 (1971) 1695
(MX-ray emission probability)
- R.L.Watson, T.K.Li, Nucl. Phys. A178 (1971) 201
(LX-ray emission probabilities)
- J.Jove, R.Robert, Radiochem. Radioanal. Letters 10 (1972) 139
(half-life)

- J.L.Campbell, L.A.McNelles, Nuclear Instrum. Methods 117 (1974) 519
(LX- and gamma - ray emission probabilities)
- W.J.Gallagher, S.J.Cipolla, Nuclear Instrum. Methods 122 (1974) 405
(LX- ray emission probabilities)
- R.L.Heath, Ancr 1000 (1974) 2
(gamma - ray energies and emission probabilities)
- V.G.Polyukhov, G.A.Timofeev, P.A.Privalova, P.F.Baklanova, Soviet. J. At. Energy 36 (1974) 402.
(At Energ 36 (1974) 319)
(half-life)
- W.W.Strohm, K.C.Jordan, Nucl. Soc. 18 (1974) 185
(half-life)
- J.Legrand, J.P. Perolat, C.Bac, J.Gorry, J. Appl. Radiat. Isotop. 26 (1975) 179
(gamma - ray emission probabilities)
- H.Ramthun, W.Muller, Intern. J. Appl. Radiat. Isotop. 26 (1975) 589
(half-life)
- R.Gunnink, J.E.Evans, A.L. Prindle, UCRL-52139, 1976
(LX-, KX- and gamma-ray emission probabilities)
- J.Plch, J.Zderadicka, L.Kokta, J. Phys. 26B (1976) 1344
(gamma-ray emission probability)
- F.P.Larkins, Nuclear Data Tables 20 (1977) 313
(Auger electron energies)
- A.Genoux-Lubain, G.Ardisson, Radiochem. Radioanal. Letters 33 (1978) 59
(gamma-ray energies and emission probabilities)
- A.Genoux-Lubain, G.Ardisson, Compt. Rend, B 287 (1978) 13
(gamma-ray energies and emission probabilities)
- V.V.Ovechkin, Bull. Acad. Sci. USSR, Phys. Ser. 42(1) (1978) 82. (Izv Akad Nauk SSSR, Ser Fiz 42 (1978) 101)
(gamma-ray energies and emission probabilities)
- R.Fösel, H.M.Fries, K.Alder, H.C.Pauli // Nuclear Data Tables, 21 (1978) 91
(internal conversion coefficients)
- C.Ardisson, A.Genoux-Lubain, V.Barci, G.Ardisson, Radiochem. Radioanal. Letters 40 (1979) 207.
(gamma-ray energies)
- D.D.Cohen, Nuclear Instrum. Meth. 178 (1980) 481
(LX-ray emission probabilities)
- G.Barreau, H.G.Borner, T.Egidy, von; R.W.Hoff, Z. Phys. A308 (1982) 209
(KX-ray energies)
- I.Ahmad, J.Hines; J.E.Gindler, Phys. Rev. C27 (1983) 2239
(LX-, KX-ray energies and KX-, gamma-ray emission probabilities)
- K.Debertin, W.Pessara, Intern. J. Appl. Radiat. Isotop. 34 (1983) 515
(gamma-ray emission probabilities)
- J.M.R Hutchinson, P.A. Mullen, J. Appl. Radiat. Isotop.34 (1983) 543
(gamma-ray emission probabilities)
- I.Ahmad, Nuclear Instrum. Methods 223 (1984) 319
(alpha-particle emission probabilities)
- V.V.Ovechkin, A.E.Khokhlov, Izv. Akad. Nauk SSSR, Ser. Fiz. 48 (1984) 1032
(gamma-ray energies and emission probabilities)
- G.Bortels, P.Collaers, Appl. Radiat. Isot. 38 (1987) 831
(alpha-particle emission probabilities)
- V.P.Chechev, N.K.Kuzmenko, V.O.Sergeev, K.P.Artamonova: Evaluated Decay Data of
Transuranium Radionuclides, Handbook. Publishing House Energoatomizdat, Moscow (1988)
(gamma-ray energies)
- D.D.Cohen, Nucl. Instrum. Methods Phys. Res. A267 (1988) 492
(LX-ray emission probabilities)
- J.H.Hubbell, NIST Internal Report 89-4144 (1989)
(M Fluorescence Yields)

- A. Rytz, *At. Data Nucl. Data Tables*. 47 (1991) 205
(Alpha-particle energies and emission probabilities)
- C.J.Bland, J Morel, E.Etcheverry, M.C.Lepy, *Nucl. Instrum. Methods Phys. Res.* A312 (1992) 323.
(LX-ray emission probabilities)
- I.Ahmad, private communication, cited in 1994B112
(alpha-particle emission probabilities)
- M.-C.Lepy, K.Debertin, H.Janszen, U.Schotzig, (1993) PTB Report PTB-Ra-31. Cited in- 2001Sc08.
(LX -ray emission probabilities)
- C.J.Bland, *Nucl.Instrum. Methods Phys. Res.* A339 (1994) 180
(alpha-particle emission probabilities)
- M.C.Lepy, B.Duchemin, J.Morel, *Nucl.Instr.Meth. Phys.Res.*, A353 (1994) 10
(LX-ray emission probabilities)
- Y.A.Akovali, *Nucl. Data Sheets* 74 (1995) 461
(decay scheme)
- G.Audi and A.H.Wapstra, *Nucl. Phys.* A595 (1995) 409
(decay energy)
- C.C.Bueno, J.A.C.Goncalves, M.D.S.Santos, *Nucl.Instr.Meth. Phys.Res.*, A371 (1996) 460
(alpha-particle emission probabilities)
- P.N.Johnson, *Nucl.Instr.Meth. Phys.Res.*, A369 (1996) 107
(evaluated gamma-ray emission probabilities and internal conversion coefficients)
- A.M.Sanchez, P.R.Montero, F.V.Tome, *Nucl.Instr.Meth. Phys.Res.* A369 (1996) 593
(alpha-particle emission probabilities)
- E.Schönfeld, and H.Janßen, *Nucl.Instr.Meth. Phys.Res.* A369 (1996) 527
(atomic data)
- A.Abdul-Hadi, *J.Radional.Nucl.Chem.* 231 (1998) 147
(gamma-ray energies and emission probabilities)
- A.Kovalik, E.A.Yakushev, V.M.Gorozhankin, M.Novgorodov, M.Rysavy, *J.Phys.(London)* G24
(1998) 2247
(energies and emission probabilities of conversion electrons)
- Y. Jang, J.Ni, *Nucl.Instrum.Methods Phys.Res.* A.413 (1998) 239
(alpha-particle Emission Probabilities)
- E.Schönfeld, G.Rodloff // PTB-6. 11-1999-1, Braunschweig, Februar 1999
(KX-ray energies and emission probabilities)
- R.G.Helmer, and van der C.Leun, *Nucl.Instr.Meth. Phys.Res.*, A450 (2000) 35
(gamma-ray energies)
- E.Schonfeld, U.Schotzig, *Appl.Radiat.Isot.* 54 (2001) 785
(LX -ray energies and emission probabilities)

²⁴²Pu – Comments on evaluation of decay data by V. P. Chechev

This evaluation was completed in December 2003. The literature available by December 2003 was included.

1. DECAY SCHEME

The decay scheme can be basically considered completed though weak alpha transitions to some ²³⁸U levels with energy more than 307 keV (see 2002Ak06) are possible. These alpha transitions to ²³⁸U highly excited levels were not observed either. They are expected from data on level spins and Q(α) value. The above alpha transitions cannot influence the intensity balances for the four lower levels well established.

2. NUCLEAR DATA

Q(α) value is from 1995Au04.

The evaluated half-life of ²⁴²Pu is based on the experimental results given in Table 1. Re-estimated values were used for averaging where necessary.

Table 1. Experimental values of the ²⁴²Pu half-life (in 10⁵ years)

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1956Bu64	Butler et al.	3,73(5)	3,65(5) ^a	²⁴² Pu/ ²³⁸ Pu, mass- and α-spectrometry
1956Bu92	Butler et al.	3,79(5)		Specific activity, ionization chamber
1956Me37	Metch et al.	3,88(10)	3,85(10) ^a	²⁴² Pu/ ²⁴⁰ Pu, mass- and α-spectrometry
1969Be06	Bemis et al.	3,869(16)	3,82(3) ^b	²⁴² Pu/ ²³⁹ Pu, mass- and α-spectrometry
1970Du02	Durham and Molson	3,66(7)	3,67(7) ^a	²⁴² Pu/ ²³⁸ Pu, mass- and α-spectrometry
1976Bulaynitsa	Bulaynitsa et al.	3,702(7) ^c		Specific activity, 4πα-X coincidences
1976Osborn	Osborn and Flotov	3,763(9)		Calorimetry
1978Meadows	Meadows	3,736(25)	3,708(29) ^a	²⁴² Pu/ ²³⁹ Pu, mass- and α-spectrometry
1979Ag03	Aggarwal et al.	3,742(24)		²⁴² Pu/ ²³⁹ Pu, mass- and α-spectrometry
1979Ag03	Aggarwal et al.	3,766(25)		²⁴² Pu/ ²³⁸ Pu, mass- and α-spectrometry

^a Re-estimated in 1979Ag03 using the values of 87,74 yr for ²³⁸Pu half-life and 24110 yr for ²³⁹Pu half-life

^b Re-estimated in 1976Bulaynitsa as a result of analysis of systematic uncertainties in 1969Be06 and using better values of auxiliary half-lives (see also 1979Ag03)

^c Quoted uncertainty, corresponding to 95% confidence level, have been reduced by a factor 2.

The weighted average of the ten values is 3,7304 with the internal uncertainty 0,0051 and external uncertainty 0,0116 and $\chi^2/\nu = 3,16$. The uncertainty of 1976Bulaynitsa was increased to 0,00724 to adjust weights according to the Limitation of Relative Statistical Weight method.

The LWEIGHT program has used the weighted average and expanded the uncertainty to 0,0284 so range includes the most precise values of 3,702(7) (1976Bulaynitsa).

The adopted value of the ²⁴²Pu half-life is 3,73(3) 10⁵ years.

The evaluated spontaneous fission half-life of ²⁴²Pu is based on the experimental results given in Table 2.

Table 2. Experimental values of the spontaneous fission ²⁴²Pu half-life (in 10¹⁰ years)

Reference	Author(s)	Original value	Re-estimated value ^a	Measurement method
1956Studier	Studier and Hirsch	6,7(7)		Quoted by Mech et al.(1956); no details available
1956Me37	Mech et al.	7,06(19)	6,79(19)	α /SF; low geometry α -counting and Ar-CH ₃ counter for SF
1956Bu92	Butler et al.	6,64(10)	6,65(10)	α /SF; ionization chamber
1961Dr04	Druin et al.	6,6(7)		Gas scintillator; relative to α half-life of ²³⁸ Pu
1963Ma50	Malkin et al.	7,45(17)		Gas scintillator; specific activity
1978Meadows	Meadows	6,80(5)	6,74(5)	α /SF; relative to half-life of ²³⁹ Pu
1980Kh05	Khan et al.	7,43		Mica fission track detector
1988SeZY	Selickij et al.	6,86(26)		Fission fragment detection in 2p geometry

^a Re-estimated in 2000Ho27

Omitting the value of 1980Kh05 reported without uncertainty, the weighted average of the seven remaining values is 6,79 with the internal uncertainty 0,032 and external uncertainty 0,090 and $\chi^2/\nu = 2,94$.

The adopted value of the ²⁴²Pu spontaneous fission is 6,79(10) 10¹⁰ years where the uncertainty is the smallest quoted uncertainty.

2.1 Alpha Transitions

The energies of the alpha transitions have been calculated from the Q value and the level energies given in Table 3 from 2002Ch52.

Table 3. ²³⁸U levels populated in the ²⁴²Pu α -decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α -transition (x100)
0	0,0	0 ⁺	4,468 10 ⁹ yr	76,48(18)
1	44,915(13)	2 ⁺	225 ps	23,49(18)
2	148,39(3)	4 ⁺		0,0308(13)
3	307,19(8)	6 ⁺		0,00085(6)

The probabilities of the most intense transitions $\alpha_{0,0}$ and $\alpha_{0,1}$ have been obtained by averaging experimental data taking into account the values calculated on the basis of gamma transition probability balances using the measured, in 1986Va33, gamma ray emission intensities and adopted total internal conversion coefficients. The probability of the $\alpha_{0,2}$ -transition has been obtained by averaging the single experimental value of 1986Va33 and the value calculated from the gamma transition probability balance for the ²³⁸U level of 148,39 keV.

It should be noted that in 1986Va33 the independent measurements were carried out for alpha intensities (with Si(Au) detector) and gamma intensities (with two Ge detectors). The correlation between these measurements can be only due to the same used sources but it is negligible taking into account a large difference between the methods and detectors. Determination of the ²⁴²Pu disintegration rates for six sources for the absolute gamma intensity measurements was made using absolute alpha particle counting under well-defined low solid angles, i.e. out of connection with the alpha intensity measurements.

The probability of the $\alpha_{0,3}$ -transition has been evaluated from the P(γ +ce) balance for the ²³⁸U level of 307,19 keV (Table 4).

Table 4. Experimental, calculated and evaluated values of α -transition probabilities ($\times 100$) in the decay of ²⁴²Pu

	α -particle energy, keV	1953Asaro	1956Hu96	1976Baranov	1986Va33	Weighted average	Calculated ^d	Evaluated
$\alpha_{0,0}$	4902	80(6) ^a	74(4) ^a	79,7(20) ^b	76,45(17)	76,47(18) ^c	76,7(7)	76,48(18) ^e
$\alpha_{0,1}$	4858	20(6) ^a	26(4) ^a	20,2(20) ^b	23,52(17)	23,50(18) ^c	23,3(7)	23,49(18) ^e
$\alpha_{0,2}$	4756	-	-	-	0,0290(14)		0,0323(13)	0,0308(13) ^f
$\alpha_{0,3}$	4600	-	-	-	-		0,00085(6)	0,00085(6) ^d

^a No uncertainties are quoted by the authors. The uncertainties adopted here are estimated by R. Vaninbroukx from the spectra shown in the papers (1986LoZT).

^b The uncertainties of 2,7 for 79,7 and 1,1 for 20,2 quoted by the authors are re-estimated by R. Vaninbroukx (1986LoZT).

^c Weighted average of 4 experimental values, uncertainty is external.

^d Calculated from P(γ +ce)-probability balances for corresponding levels.

^e Weighted average of the mean of experimental values and calculated value.

^f Weighted average of the experimental and calculated values, uncertainty is the smallest quoted uncertainty.

2.2. Gamma Transitions and Internal Conversion Coefficients

The gamma-ray transition probabilities have been deduced from their adopted gamma-ray emission probabilities and total internal conversion coefficients (ICC). The ICC are theoretical values from 1978Ro22 for the adopted energies and E2 multipolarities. The relative uncertainties of α_K , α_L , α_M , α_T have been adopted 2%.

3. ATOMIC DATA

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The energies of U LX-rays have been taken from 1994Le37 where the fine structure of LX radiation was measured in the decay of ²⁴⁰Pu.

The relative U LX-ray emission probabilities have been deduced from experimental data on α -decay of ²⁴⁰Pu (1994Le37) and from data on α -decay of ²³⁸Pu (1995Jo23). They agree for these even-even plutonium isotopes in limits better than 2%. The relative U LX-ray emission probabilities measured in 1990Po14 directly in the ²⁴²Pu decay [5,6(9)-L β ; 71,6(72)-L α ; 100-L $\eta\beta$; 24,5(25)-L γ] agree with the adopted values but much less accurate.

The U KX-ray energies have been taken from 1999Schönfeld where the calculated values based on X-ray wavelengths from 1967Be65.

The relative KX-ray emission probabilities have been taken from 1999Schönfeld and from data on α -decay of ²³⁸Pu.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 and 1987Lagoutine.
The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4. ALPHA EMISSIONS

The α -emission energies have been calculated from Q value and the level energies taking into account the recoil energies (2002Ch52). In Table 5 the calculated (evaluated) values of α -emission energies are compared with the experimental results obtained using alpha spectrometry and also with the recommended data by A. Rytz (1991Ry01).

Table 5. Experimental and evaluated α -emission energies in the decay of ²⁴²Pu, keV

	Measured ^a				Recommended in 1991Ry01	Evaluated
	1953Asaro	1956Hu96	1956Ko67	1968Ba25		
$\alpha_{0,0}$	4904,6(20)	4903,7(30)	4907,2(30)	4900,4(12)	4902,3(14)	4902,2(9) ^b
$\alpha_{0,1}$	4860,6(20)	4859,7(30)	4863,2(30)	4856,1(12)	4858,1(15)	4858,1(9)
$\alpha_{0,2}$	-	-	-	-	-	4756,1(9)
$\alpha_{0,3}$	-	-	-	-	-	4600,0(9)

^a Original values have been adjusted taking into account changes in calibration energies as suggested in 1991Ry01

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma transition energies given in section 2.2 and the electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The total emission probability of K Auger electrons have been computed using the evaluated total emission probability of K-conversion electrons $P(\text{ce}_K) = 6,26(50) \cdot 10^{-5} \%$ and the adopted $\omega_K = 0,970(4)$ from section 3.1.

The absolute total emission probability of L Auger electrons have been computed using the adopted total absolute emission probability of U LX-rays and the adopted $\omega_L = 0,500(19)$ from section 3.1.

6. PHOTON EMISSIONS

6.1. X-Ray Emissions

The absolute emission probability of U MX-rays ($\alpha\beta$) in the decay of ²⁴²Pu has been calculated from the relative intensity $P(\text{XM}\alpha\beta)/P(\text{XL}\eta\beta) = 0,41(4)$ measured in 1990Po14.

The total emission probability of U LX-rays $P(\text{XL}) = 8,56(40) \%$ has been calculated using the value $\omega_L = 0,500(19)$ from section 3.1 and the evaluated total emission probability of L conversion electrons $P(\text{ce}_L) = 17,12(50)\%$.

The total KX -ray emission probability $P(\text{XK}) = 6,07(50) \cdot 10^{-5} \%$ has been computed using the value $\omega_K = 0,970(4)$ from section 3.1 and the evaluated emission probability of K-conversion electrons $P(\text{ce}_K) = 6,26(50) \cdot 10^{-5} \%$

6.2. Gamma Ray Emissions

The energies of gamma rays have been adopted from 1972Sc01.

The absolute emission intensities of the gamma rays $\gamma_{1,0}$ (44,915 keV) and $\gamma_{2,1}$ (103,50 keV) have been calculated from the evaluated $P(\alpha)$ values (Table 4) and the adopted total ICC on the basis of intensity balances for corresponding levels. The emission intensity of the gamma ray $\gamma_{3,2}$ (158,80 keV) has been adopted from the measurements of 1986Va33 (Table 6).

Table 6. Experimental, calculated and adopted emission probabilities of gamma rays ($\times 100$) in the ²⁴²Pu decay

	Energy, keV	1972Sc01	1986Va33	Calculated	Adopted
$\gamma_{1,0}$	44,915	-	0,0372(7)	0,0376(8)	0,0376(8)
$\gamma_{2,1}$	103,50	0,0081(9) ^a	0,00263(9)	0,00251(11)	0,00251(11)
$\gamma_{3,2}$	158,80	0,005(2) ^a	0,000298(20)	-	0,000298(20)

^a Not used in the evaluation as considered in 1986LoZT

7. References

- 1953Asaro - F. Asaro, Thesis, Univ. of California, Livermore, CA, Rep. UCRL-2180(1953) [Alpha-particle energies and emission probabilities].
- 1956Bu64 - J.P. Butler, M. Lounsbury, J. Merritt, Can. J. Chem. 34(1956)253 [Half-life].
- 1956Bu92 - J.P. Butler, T.A. Eastwood, T.L. Collins, M.E. Jones, F.M. Rourke, R.P. Schuman, Phys. Rev. 103(1956)634 [Half-life, SF half-life].
- 1956Hu96 - J.P. Hummel, Thesis, Univ. California, Livermore, CA, Rep UCRL-3456. (1956) [Alpha-particle energies and emission probabilities].
- 1956Ko67 - L.M. Kondratev, G.I. Novikova, Y.P. Sobolev, L.L. Goldin, Zh. Eksp. Teor. Fiz. 31(1956)771; Soviet Phys. JETP 4(1956)645 [Alpha-particle energies and emission probabilities].
- 1956Me37 - J.F. Mech, H. Diamond, M.H. Studier, P.R. Fields, A. Hirsch, C.M. Stephens, R.F. Barnes, D.J. Henderson, J.R. Huizenga, Phys. Rev. 103(1956)340 [Half-life, SF half-life].
- 1956Studier - M.H. Studier and A. Hirsch, Private Communication. Quoted in 1956Me37 [SF Half-life].
- 1961Dr04 - V.A. Druin, V.P. Perelygin and G.I. Khlebnikov, Zhurn. Eksptl. i Teoret. Fiz. 40(1961)1296; Soviet Phys. JETP 13(1961)913 [SF half-life].
- 1963Ma50 - L.Z. Malkin, I.D. Alkhazov, A.S. Krivokhatsky, K.A. Petrzhak, At. Energ. USSR 15(1963)158; Soviet. J. At. Energy 15(1964)851 [SF half-life].
- 1967Be65 - J.A. Bearden, Rev. Mod. Phys. 39(1967)78 [X-ray energies]
- 1968Ba25 - S.A. Baranov, V.M. Kulakov, V.M. Shatinskii, Yadern. Fiz. 7(1968)727; Nucl. Phys. 7(1968)442 [Alpha-particle energies]
- 1969Be06 - C.E. Bemis, Jr., J. Halperin, R. Eby, J. Inorg. Nucl. Chem. 31(1969)599 [Half-life].
- 1970Du02 - R.W. Durham, F. Molson, Can. J. Phys. 48(1970)716 [Half-life].
- 1972Sc01 - M. Schmorak, C.E. Bemis, Jr, M.J. Zender, N.B. Gove, P.F. Dittner, Nucl. Phys. A178(1972)410 [Gamma-ray energies and emission probabilities].
- 1976Baranov - S.A. Baranov, A.G. Zelenkov; V.M. Kulakov, Soviet At. Energy 41(1976)987 [Alpha-emission probabilities].
- 1976Bu23 - L.S. Bulyanitsa, A.M. Geidelman, Y.S. Egorov, L.M. Krizhanskii, A.A. Lipovskii, L.D. Preobrazhenskaya, A.V. Lovtsyus, Y.V. Kholnov, Izv. Akad. Nauk. SSSR, Ser. Fiz. 40(1976)2075; Bull. Acad. Sci. USSR, Phys. Ser. 40(10)(1976)42 [Half-life].
- 1976Os05 - D.W. Osborne, H.E. Flotow, Phys. Rev. C14(1976)1174 [Half-life].
- 1977La19 - F.P. Larkins, At. Data Nucl. Data Tables 20(1977)313 [Auger electron energies].
- 1978MeZL - J.W. Meadows, BNL-NCS-24273, (1978)10 (A830926) [Half-life, SF half-life].
- 1978Ro22 - F. Rosel, H.M. Friess, K. Alder, H.C. Pauli, At. Data Nucl. Data Tables. 21(1978)92 [Theoretical ICC].
- 1979Ag03 - S.K. Aggarwal, S.N. Acharya, A.R. Parab, H.C. Jain, Phys. Rev. C20(1979)1135 [Half-Life].
- 1980Kh05 - N.A. Khan, H.A. Khan, K. Gul, M. Anwar, G. Hussain, R.A. Akbar, A. Waheed, M.S. Shaikh, Nucl. Instrum. Methods. 173(1980)163 [SF Half-life].
- 1986LoZT - A. Lorenz, IAEA Tech. Rept. Ser., No 261(1986) (A871001 M881119 Part 2) [Evaluated decay data].

- 1986Va33 - R. Vaninbroukx, G. Bortels, B. Denecke, Int. J. Appl. Radiat. Isotop. 37(1986)1167 [Alpha-, gamma-ray emission probabilities].
- 1987Lagoutine - F. Lagoutine, N. Coursol, J. Legrand, ISBN-2-7272-0078-1 (LMRI, 1982-1987) [Auger electron energies].
- 1988SeZY - Yu.A. Selitsky, V.B. Funshtein, V.A. Yakovlev, Program and Theses, Proc. 38th Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, Baku, Acad. Sci. USSR, (1988)131 [SF half-life].
- 1990Po14 - Yu.S. Popov, I.B. Makarov, D.Kh. Srurov, E.A. Erin, Radiokhimiya. 32(1990)2; Sov. J. Radiochemistry 32(1990)425 [MX-, LX- ray relative emission probabilities].
- 1991Ry01 - A. Rytz, At. Data Nucl. Data Tables 47(1991)205 [Alpha-emission energies].
- 1994Le37 - M.C. Lépy, B. Duchemin, J. Morel, Nucl. Instrum. Meth. Phys. Res. A353(1994)10 [LX ray energies and emission probabilities].
- 1995Au04 - G. Audi, A.H. Wapstra, Nucl. Phys. A595(1995)409 [Decay energy].
- 1995Jo23 - P.N. Johnston, P.A. Burns, Nucl. Instrum. Meth. Phys. Res. A361(1995)229 [LX-ray energies and emission probabilities].
- 1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instrum. Meth. Phys. Res. A369(1996)527 [Atomic data].
- 1999Schonfeld - E. Schönfeld, G. Rodloff, PTB-6.11-1999-1999-1, Braunschweig, Februar 1999 [KX-ray energies and relative emission probabilities].
- 2002Ak06 - Y.A. Akovali, Nucl. Data Sheets 96(2002)177 [Decay Scheme].
- 2002Ch52 - F.E.Chukreev, V.E.Makarenko, M.J.Martin, Nucl. Data Sheets 97(2002)129 [Decay Scheme].