NIOSH Response to SC&A Review of the Ames Site Profile Document Regarding Uranium Internal Exposures

Rev 0

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1.0 PURPOSE

Sanford Cohen and Associates (SC&A) presented their review of the *Site Profile for Ames Laboratory*, ORAUT-TKBS-0055 (ORAUT 2012a) to the Advisory Board on Radiation and Worker Health (Advisory Board) in SCA-TR-SP2013-0044 (SC&A 2013). In this report SC&A presented 22 two "findings," 11 of which included comments on some aspect or technical issue regarding methods of reconstructing internal dose from uranium at the Ames Laboratory. This paper provides additional evaluation and discussion to assist the National Institute for Occupational Safety and Health (NIOSH) with its response to comments on intakes of uranium, and ultimately in a revision to the Ames Site Profile.

2.0 SUMMARY

The current *Site Profile for Ames Laboratory* (ORAUT 2012a), or Technical Basis Document (TBD), provides intake rates of uranium for different job categories from the three buildings previously used to process uranium. The TBD also provides environmental uranium intakes. The various uranium intakes in the TBD are based on surrogate air sampling data from other facilities and exposure models.

SC&A has made numerous comments on the validity and basis of the TBD intakes, which are summarized in the findings listed in Section 3.1 below. SC&A also suggested some surrogate data from another site be used for estimating intakes from blowout incidents. NIOSH has reviewed the comments, the TBD methods, and available references and agrees that the uranium intakes in the TBD need to be reevaluated.

In this paper, NIOSH proposes to replace the uranium intakes in the TBD with intakes derived from bioassay data from 1944 and 1945 of workers engaged in uranium production, which includes some of the peak uranium production months at Ames during World War II. This is the bioassay data discussed in the SC&A report. Intakes in subsequent years are then derived from the production era intake rates. None of the current methods used to model intakes in the TBD, and to which SC&A had comments, are being retained in the proposed changes. Thus, this paper does not attempt to respond to each technical issue identified by SC&A, although Section 3.2 identifies the method being proposed to resolve each finding.

3.0 SC&A Review

3.1 Findings on Uranium Intakes

SC&A identified 22 findings, 11 of which pertain to internal dose from uranium exposures. The 11 applicable findings are listed below. Some of the findings also contain comments that apply to issues other than uranium; e.g., some are written to be applicable to both uranium and thorium

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intakes. This paper only addresses uranium intakes so the findings summarized below have been edited to include only the pertinent information on internal uranium exposure. NOTE: The finding numbers are not contiguous.

- Finding 1: Derived environmental intakes of U, as given in Table 4-7 of the TBD, are improperly referenced and appear without technical basis.

- Finding 2: NIOSH provides no basis for the "assumed" losses of 0.1% of U to the environment and fails to identify a value for re-suspension.

- Finding 7: The nearly "instantaneous" 100-fold reduction of U environmental intakes that represent the transition of the uranium metal production facilities at the end of 1953 to research and development (R&D) facilities in 1954 is improperly modeled. Also not included in the model are the contribution of blowouts to environmental contamination and the persistence of these radionuclides in the environment post-1953.

- Finding 9: Uranium blowouts represent significant environmental events that should be included in Section 4.5 of the Ames TBD for the assessment of environmental exposures.

- Finding 10: Available empirical bioassay and air-sampling data for Annex 1 workers are substantially higher than modeled/surrogate data assigned by NIOSH.

- Finding 11: NIOSH further minimized the intake value of 853 pCi/d for Annex 1 production workers by assigning the "distribution" as a constant.

- Finding 12: Default intake rates defined in Table 5-8 of the Ames TBD are improper for absorption Types F or S.

- Finding 13: The scaling of uranium intake values based on (1) facility and (2) job function is without technical support and conflicts with statements given in the Ames Site Profile.

- Finding 14: Although NIOSH briefly acknowledged the occurrence of "frequent fires and explosions" associated with the production of uranium metal, no attempt was made to assess potential intakes of these episodic events.

- Finding 15: *Technical Basis for Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities*, ORAUT-OTIB-0004, Rev. 03 (ORAUT 2006), is referenced for estimating non-operational intakes. OTIB-0004 was canceled before Rev. 03 of the Ames Site Profile (ORAUT 2012a) was issued. Moreover, the much higher intake values for inhalation and ingestion during non-operating years (i.e., 1954-1976) are

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inconsistent with intake values for operating years (1942-1953) as given in Table 5-8 of the Ames TBD.

- Finding 20: By means of documented anecdotes/testimonials regarding potential frequencies of blowouts, technical data for a specific blowout documented at Feed Materials Production Center (FMPC), and reasonable assumptions, SC&A derived significant U intakes and associated organ doses that are applicable to workers at the Ames Laboratory, but were not considered/included in ORAUT-TKBS-0055 (ORAUT 2012a).

3.2 Summary of the Issues and NIOSH Resolutions

Findings 1, 2, 7, and 9 all concern the basis for the dose models used in the TBD (ORAUT 2012a) for environmental intakes. This paper addresses those comments by proposing a new method to calculate intakes. The uranium intakes presented herein include a "Low" exposure category based on bioassay data from workers who were incidentally exposed to uranium during the production years, as discussed below. This method should account for environmental intakes from all sources, including blowouts. Additionally, methods are presented to estimate intakes from a gradually depleted source term after the end of uranium production.

In Findings 10, 11, and 12, SC&A summarizes the results of their evaluation that the TBD intakes for the uranium processing facilities do not account for the high bioassay results from workers during the uranium production years. NIOSH is now proposing to use the bioassay data to estimate intakes, although the methods presented by NIOSH result in intake rates somewhat higher than the estimates presented in the SC&A report.

Finding 13 says the TBD does not justify the scaling of intakes based on facility and job function. NIOSH now proposes a simpler more favorable method to assign intakes and is proposing to limit the scaling of uranium intakes to three levels: High, Medium, and Low exposure categories, which is synonymous with intakes for operators, other exposed workers, and incidentally exposed workers, respectively.

In Finding 14 and 20, SC&A identifies the lack of evaluation of intakes from blowouts, fires, and explosions during uranium production. They propose NIOSH use data from Fernald to estimate intakes at Ames from those events. The NIOSH method to evaluate Ames bioassay should account for intakes from these events and be more representative of intakes than data from another site.

Finding 15 notes that the TBD references a canceled document and says that some workers' intakes are inexplicably higher after the end of uranium production. The NIOSH evaluation of bioassay data and proposed new methods does not use the obsolete reference and resolves the discrepant intakes noted by SC&A.

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This paper recommends a new approach be used for all uranium intakes. NIOSH determined that the use of uranium bioassay data collected during 1944 and 1945 is a superior approach than the methods used in the Ames TBD. Many of the findings above discuss discrepancies, omissions, and the lack of justification for methodologies that NIOSH will not be using in the next version of the TBD. Thus NIOSH has made no attempt to explain the rationale or to revise the existing TBD models in response to SC&A comments.

A summary of Ames work with uranium is provided in Section 4. Section 5 has intake estimates based on bioassay data for workers during the uranium production and post-production periods.

4.0 Ames Laboratory Uranium Work

This section provides a summary of the uranium work at Iowa State College (ISC) and Ames Laboratory. Ames Laboratory was established at ISC after the end of World War II. Uranium work at Ames began in February 1942 when the U.S. Office of Scientific Research and Development (OSRD) entered into a research contract with ISC for development of methods of producing large quantities of high purity uranium metal in a short period of time. The Ames Project was under the direction of Dr. F. H. Spedding.

The uranium work initially involved very small quantities of uranium for research, but evolved into uranium metal production during World War II. ISC produced a significant amount of virgin uranium metal and recovered metal from scrap from 1942 through the end of the war in 1945. In total over 1,000 tons of virgin uranium metal and recovered uranium scrap metal was produced.

4.1 Virgin Uranium Metal Production

The Physical Chemistry Laboratory (Chemistry Building) on the ISC campus was used for research and early production of uranium metal. By June 1942 ISC had developed and proven a method suitable for producing uranium metal from green salt (UF_4), and by August 1942 they had developed a process that could be expanded into a production operation. The actual process continued to change during production as better methods were developed (ISC undateda).

The experiments on uranium metal production from green salt resulted in the production of an 11 pound cylinder of uranium metal on September 21, 1942. Within a week ISC was under contract to produce 100 pounds of uranium metal per day. With this new contract, the Ames Project evolved into both research and uranium metal production (Payne 1992, pdf pp. 91-96).

A floor plan of the Chemistry Building and the rooms where the early uranium work was done was provided by Payne (Payne 1992, pdf p. 253). It shows room 101 where most of the early metal production was done. A small reduction furnace in the Chemistry Building was utilized for

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metal production in 1942. Two tons of uranium metal were produced in the Chemistry Building and shipped to Chicago for use in the first self-sustaining nuclear reaction at Stagg Field on December 2, 1942 (Payne 1992, pdf pp. 91-96).

In October 1942, ISC signed a contract to set up a pilot plant to produce uranium metal. The pilot plant was called Physical Chemistry Annex (Annex 1). Annex 1 was an existing one story wooden frame building that was modified and expanded to function as a temporary production facility until industry completed construction of uranium metal production facilities. In November 1942, a production contract was issued for Annex 1. Uranium reduction (UF_4 to metal) in Annex 1 began in December 1942, although recasting of uranium metal continued to be done in the Chemistry Building until installation of equipment for that operation was completed in Annex 1 in late January 1943 (ISC undateda).

Production of virgin uranium metal went from 100 pounds per day in December 1942, to 5,600 pounds per week by the third week of January 1943. On July 1, 1943, the peak rate of production was reached at 130,000 pounds per month, at which time the production rate was gradually reduced. Regular virgin metal production ended in November 1944 (ISC undateda; ISC undatedb).

Although regular production ended in late 1944, relatively significant amounts of green salt, 2,000 pounds per week, continued to be shipped to Ames in 1945 for use in development work (Simons and Hitchcock 1945). Annex 1 operated 24 hours per day, 7 days per week, during peak production periods (Payne 1992, pdf p. 108).

In total more than 1.4 million pounds (700 tons) of virgin uranium metal was produced at Ames during the war (ISC undateda, p. 11).

4.2 Uranium Scrap Recovery

Large quantities of uranium scrap were generated from uranium metal machining at the various uranium metal processing sites during 1943 through 1945. Ames developed a method to recover uranium from that scrap material (ISC undateda, p. 12).

A new plant, Annex 2, was built for scrap recovery, and scrap recovery production operations in Annex 2 began April 26, 1944 (Annex 2 was also used to store green salt). The uranium turnings were washed and dried, inspected by hand to separate foreign objects, and pressed in briquettes one inch thick by four and one-fourth inches in diameter. One reference indicates the briquettes were then sent to the casting room in Annex 1 to be melted and cast into ingots (ISC undatedb, p. 91).

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The scrap recovery operations initially processed 3,000 pounds of uranium per day. Plans were in place to increase production to 5,000 to 6,000 pounds per day by August 1, 1944 (ISC undatedb, p. 49). It was reported ISC was recovering 4,000 pounds per day in October 1944, and that the backlog of stored turnings would be gone such that production would be reduced to about 2,000 pounds per day by December 1944 (ISC undatedb, p. 67). In total over 600,000 pounds (300 tons) of uranium metal was recovered at ISC between April 1944 and the end of scrap recovery operations in late 1945 (ISC undateda, pp. 12-13).

4.3 Peak Production Months

The peak production rate for virgin uranium metal production was reported to be on July 1, 1943, at a rate of 130,000 per month (4,300 pounds per day), after which the production rate gradually declined as the raw material was gradually diverted to industry. The peak production month for scrap recovery is not available, but the highest production rate for scrap recovery work reported in available records was 4,000 pounds per day in October 1944. Records indicate regular production of virgin metal ended in November 1944, so some relatively small quantities of virgin metal would have also been produced in October 1944, but the amounts are not known. Records indicate all scrap recovery and virgin metal production ended in August 1945, although it is also reported that the scrap recovery operation was phased out in November 1945. As indicated above, during peak production periods ISC operated the pilot plant 24 hours per day, 7 days per week.

5.0 Uranium Intakes Based on Bioassay Data

As noted previously SC&A identified some issues with the way uranium intakes were derived in the TBD (ORAUT 2012a), and NIOSH agrees that some changes are needed. The uranium bioassay data from 1944 and 1945 that was discussed in the SC&A report was also discussed in the Evaluation Report for SEC 0038 (NIOSH 2006), and both reports considered the bioassay data to be useful for estimating intakes. NIOSH has reviewed that data and determined that it provides a better means to estimate occupational intakes during the uranium production period at ISC than the methods presented in the TBD. NIOSH plans to eliminate the multiple facility-specific uranium intake rates that are currently in the TBD because neither the bioassay data nor information on worker location is sufficient for that determination.

5.1 Analysis of Bioassay Data

The Ames bioassay data are reported by Ferretti, et al. (1951, pdf pp. 267-279). The bioassay data were collected for a study on the urinary excretion of uranium at some Manhattan Project sites. The data from Tables 7.1 through 7.4 in that reference are data from the Ames project and were used to estimate intakes from uranium production operations at Ames. These data are

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believed to be the best available data for estimating intakes for uranium operations at Ames. Table 1 below presents the Ames bioassay data from Ferretti et al. (1951).

Table 1: Bioassay Data			
Group	**Sample**	**Case**	**Concentration (µg/L)**
1	1	1	40
1	2	1	96
1	3	2	52
1	4	3	86
1	5	3	50
1	6	4	100
1	7	4	44
1	8	4	70
1	9	4	200
1	10	5	126
1	11	5	96
1	12	5	74
1	13	6	84
1	14	6	200
1	15	6	73
1	16	7	48
1	17	7	40
1	18	8	29
1	19	9	25
1	20	10	12
1	21	11	31
2	1	12	15
2	2	13	17
2	3	14	13
2	4	15	38
2	5	16	21
2	6	17	40
2	7	18	21
2	8	19	33
2	9	19	58
2	10	20	33
2	11	21	54
2	12	22	64
2	13	23	10
2	14	23	16

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Table 1: Bioassay Data			
Group	**Sample**	**Case**	**Concentration (µg/L)**
2	15	24	11
2	16	24	11
2	17	25	87
2	18	25	64
2	19	25	80
2	20	26	130
2	21	27	80
2	22	28	108
2	23	29	64
2	24	29	64
2	25	30	28
2	26	31	43
3	1	32	24
3	2	33	27
3	3	34	7
3	4	35	9
3	5	36	19
3	6	37	22
3	7	38	22
3	8	38	18
3	9	38	3
3	10	38	3
3	11	39	5
3	12	40	18
3	13	41	15
3	14	42	33
4	1	43	<3
4	2	44	<3
4	3	45	7
4	4	46	<3
4	5	47	<3
4	6	48	9

Source: Ferretti et al., 1951

The data reported 67 sample results from 48 workers, who were ranked by their supervisor into four exposure categories according to potential for exposure to uranium. Group 1 was expected to be the highest (greatest amount of uranium exposure); Group 2 (next highest amount of uranium exposure); Group 3 (very little, but continuous exposure); and Group 4, the lowest exposure (occasional incidental exposure). The workers were given strict instructions to avoid

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sample contamination. Samples were submitted between September 1944 and July 1945 (Ferretti et al. 1951).

Bioassay sample dates were not provided; however, the data reflect that some individuals were assessed more than once, at intervals of a few weeks or months. For this analysis, all unique combinations of individual (Case) and group (Group) are considered to be unique individuals. If an individual has more than one result, a mean was calculated, thereby having one result for each individual. A One-Person, One-Statistic (OPOS) approach, as described in ORAUT-RPRT-0053, *Analysis of Stratified Coworker Datasets* (ORAUT 2014a), was performed. A regression on order statistics (ROS) fit to the OPOS data was performed, providing the following data:

Geometric Mean (GM) = 24.69 µg/L; Geometric Standard Deviation (GSD) = 2.788

From these parameters:

The 50th percentile bioassay result is estimated by:

$$50th\ Percentile = GM * 1.4 \frac{L}{day}$$

giving:

$$\left(24.69 \frac{\mu\mathrm{g}}{\mathrm{L}}\right)\left(1.4 \frac{\mathrm{L}}{\mathrm{day}}\right) = 34.57 \frac{\mu\mathrm{g}}{\mathrm{day}}$$

The 84th percentile bioassay result is estimated by:

$$84th\ Percentile = GM * GSD * 1.4 \frac{L}{day}$$

giving:

$$\left(24.69 \frac{\mu\mathrm{g}}{\mathrm{L}}\right)(2.788)\left(1.4 \frac{\mathrm{L}}{\mathrm{day}}\right) = 96.37 \frac{\mu\mathrm{g}}{\mathrm{day}}$$

These data were evaluated with Integrated Modules for Bioassay Analysis (IMBA) to obtain uranium intake rates for calculation of internal doses to workers. The following parameters were used.

- Start of chronic intake is 9/1/1942 (production of uranium metal began in earnest in September 1942 at Ames).

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- Date of the urine sample is 1/31/1945, which is midway between 9/1/1944 and 7/1/1945 (date range given in Ferretti et al. [1951] for bioassay samples).
- The chronic intake continues through the effective sample date of 1/31/1945.
- The specific activity of natural uranium (0.68296 pCi/μg) was used to convert the mass intake rates to activity intake rates.
- Based on process information, it is presumed that workers could have been exposed to solubility Types F, M, or S materials.

The 50th percentile intake rates are:

- Type F: 86.46 pCi/day
- Type M: 354.5 pCi /day
- Type S: 6932 pCi /day

The 84th percentile intake rates are:

- Type F: 241.1 pCi/day
- Type M: 988.4 pCi /day
- Type S: 19,326 pCi /day

5.2 Worker Exposure Categories

In accordance with ORAUT-OTIB-0060, *Internal Dose Reconstruction* (ORAUT 2014b):

> *Coworker dose is applied as a best estimate for individuals with a potential for intakes of radioactive material but who lack bioassay data or have unmonitored intervals. Workers with a significant potential for intake should be assigned doses at the 95th percentile with a constant distribution, while those with less potential are assigned the 50th percentile with a lognormal distribution.*

ORAUT-OTIB-0014, *Assignment of Environmental Internal Doses for Employees Not Exposed to Airborne Radionuclides in the Workplace* (ORAUT 2004), provides guidance on job categories and potential for exposure.

Dose reconstructors will use the information from these references and the category information below to assign intakes to Ames workers.

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High (Assign 95th percentile intakes) – Individuals who operated the process equipment and/or routinely handled radiological materials. This category would include operators, maintenance workers, laboratory workers, health physics monitors, etc. Doses will be applied as a constant.

Medium (Assign 50th percentile intakes) – Individuals who routinely worked in the production areas and may have been periodically in the vicinity of where processing was occurring. This includes supervisory staff, engineers, individuals who were not normally in contact with the radiological materials but who worked routinely in the production areas, etc. Doses will be applied as a lognormal distribution.

Low – This category is for individuals exposed to ambient air in the environment outside of the uranium production areas who may have been incidentally exposed. This includes office workers or non-uranium workers who are documented to have been in a different location from the uranium work. These intakes allow for incidental exposures and will be applied as a constant. The rationale for this value is provided below.

As discussed above, uranium bioassay data is available for 48 workers who were involved in uranium production in 1944 and 1945. The supervisor listed six of those workers as Group 4 workers perceived to only have only incidental occasional exposure to uranium. The distribution of the bioassay results for the four groups are consistent with those rankings, with some overlapping of the range of results. Of the six workers in the Group 4 category, four workers had a bioassay result of <3 µg/L, one worker had a result of 7 µg/L, and one worker had a result of 9 µg/L.

The Group 4 workers presumably would have been exposed to both ambient air outside of the production facilities and occasional incidental exposure to uranium work areas; therefore, the highest result from that group of workers should provide a bounding estimate for workers in other (non-uranium) facilities or locations. An intake rate derived from this value will be used for the Low category of intakes and be applied as a constant.

5.3 Intake Calculations

Intakes are provided for the High, Medium, and Low exposure categories.

High

The High intake category is the 95th percentile of the intake distribution and is applied as a constant value in the Interactive RadioEpidemiological Program (IREP). Per ORAUT-OTIB-0060, the GSD was rounded up to 3.0. The calculation of the 95th percentile intakes are derived from the 50th percentile (GM) intakes given above with the GSD rounded up to 3.0, according to the equation:

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$$95th\ Percentile = (GM) * (GSD^{1.645})$$

where GSD = 3.0

The 95th percentile intake rates are then:

- Type F: 526.9 pCi/day
- Type M: 2160 pCi /day
- Type S: 42,240 pCi /day

Medium

The medium intake category are the 50th percentile intake values above in Section 5.1 and are applied as a lognormal distribution with the GSD rounded up to 3.

- Type F: 86.46 pCi/day
- Type M: 354.5 pCi /day
- Type S: 6932 pCi /day

Low

The low intake category is based on an excretion rate of 9 µg/L with the parameters discussed in Section 5.1. Those values were input into IMBA to determine the following intake rates:

- Type F: 31.52 pCi/day
- Type M: 129.2 pCi /day
- Type S: 2525 pCi /day

5.4 Assignment of Internal Exposures

The intakes were derived from bioassay taken during the uranium production. Uranium production activities in both Annex 1 and Annex 2 ended in 1945. Production work in the Chemistry Building had ended in 1943. There were continuing activities in all three buildings after 1945.

Records of decontamination activities for the Chemistry Building are currently unavailable, although records for later years indicated the building had been remodeled.

After 1945 Annex 1 continued to operate producing thorium for a few years. No decontamination information is available. The facility was demolished in 1953, although there are currently no available radiological monitoring data from the demolition work.

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The use of Annex 2 after 1945 is not clear and it is not known if or when the facility was decontaminated. However, Annex 2 was sold by the Atomic Energy Commission to ISC in 1953 and used as a Plumbing Shop until it was razed in 1972.

To allow for potential intakes of uranium after the end of 1945, the production era intake rates are to be applied through 1953 for the Chemistry Building, Annex 1 and Annex 2. Additionally, that intake rate is also applied for the 1972 demolition of Annex 2.

Workers at the uranium production facilities could have been exposed to uranium with solubility types of F, M, and S. Dose reconstructors will select the material type that provides the highest dose. These calculated intake rates presume that the period of the bioassay results included normal uranium production operations, including blowout and fire events.

Tables 2, 3, and 4 show the inhalation intakes for the three categories of exposure. All intakes are calendar day intake rates.

Table 2: 95th Percentile Intakes (For Employees with High Exposure Potential)

Nuclide	Solubility	Intake Type	Intake Rate (pCi/day) 1942-1953, 1972	Distribution
U-234	F	Inhalation	526.9	Constant
U-234	M	Inhalation	2160	Constant
U-234	S	Inhalation	42,240	Constant

Table 3: 50th Percentile Intakes (For Employees with Medium Exposure Potential)

Nuclide	Solubility	Intake Type	Intake Rate (pCi/day) 1942-1953, 1972	Distribution	GSD
U-234	F	Inhalation	86.46	Lognormal	3.0
U-234	M	Inhalation	354.5	Lognormal	3.0
U-234	S	Inhalation	6,932	Lognormal	3.0

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Table 4: Low Intakes (For Employees with only Incidental Exposure Potential)				
Nuclide	**Solubility**	**Intake Type**	**Intake Rate (pCi/day) 1942-1953, 1972**	**Distribution**
U-234	F	Inhalation	31.52	Constant
U-234	M	Inhalation	129.2	Constant
U-234	S	Inhalation	2,525	Constant

5.5 Residual Radioactivity Period Environmental Uranium Exposure

After 1953, the internal exposure potential to uranium was reduced and continued to be reduced throughout the operation of the site. The median (50^{th} percentile) intake rates derived above were used to estimate surface contamination levels based on a 30-day suspension as discussed in Battelle-TBD-6000, Section 3.4.2 (Battelle 2011). The contamination levels were multiplied by a re-suspension factor of 1×10^{-5}/m and a breathing rate of 9.6 m^3/d to determine the following inhalation intake rates:

- Type F: 1.681 pCi/day
- Type M: 6.891 pCi /day
- Type S: 134.8 pCi /day

These intake rates are applicable for 1954. For subsequent years, a gradual reduction of the contaminants is presumed in accordance with depletion factors provided in ORAUT-OTIB-0070, *Dose Reconstruction During Residual Radioactivity Periods at Atomic Weapons Employer Facilities* (ORAUT 2012b). A depletion rate of 0.00067 per day was used to determine annual depletion factors, as presented in ORAUT-OTIB-0070, Table 4-2.

Table 5 below presents the inhalation intake rates from residual radioactivity. The intakes will be assigned using a lognormal distribution and a GSD of 3.0. Annex 2 was demolished in 1972, and the radiological status of the facility at that time is not clear; therefore, the operational intake rates (from the 1942-1953 period) will be assigned for Annex 2 work that year.

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Table 5: Uranium Inhalation Intakes from Residual Contamination				
Annual Reduction Factors		**Intakes (pCi/day)[1] Lognormal Distribution; GSD = 3**		
Year	**Factor**	**F**	**M**	**S**
1954	1.00E+00	1.68	6.89	134.8
1955	7.83E-01	1.32	5.40	105.5
1956	6.13E-01	1.03	4.22	82.61
1957	4.80E-01	0.81	3.31	64.68
1958	3.76E-01	0.63	2.59	50.67
1959	2.94E-01	0.49	2.03	39.62
1960	2.31E-01	0.39	1.59	31.13
1961	1.81E-01	0.30	1.25	24.39
1962	1.41E-01	0.24	0.97	19.00
1963	1.11E-01	0.19	0.76	14.96
1964	8.67E-02	0.15	0.60	11.68
1965	6.79E-02	0.11	0.47	9.15
1966	5.32E-02	0.089	0.37	7.17
1967	4.16E-02	0.070	0.29	5.61
1968	3.26E-02	0.055	0.22	4.39
1969	2.55E-02	0.043	0.18	3.44
1970	2.00E-02	0.034	0.14	2.70
1971	1.56E-02	0.026	0.11	2.10
1972[2]	1.23E-02	0.021	0.085	1.66
1973	9.60E-03	0.016	0.066	1.29
1974	7.51E-03	0.013	0.052	1.01
1975	5.88E-03	0.010	0.041	0.79
1976	4.61E-03	0.0077	0.032	0.62
1977	3.61E-03	0.0061	0.025	0.49
1978	2.83E-03	0.0048	0.020	0.38
1979	2.21E-03	0.0037	0.015	0.30
1980	1.73E-03	0.0029	0.012	0.23
1981	1.36E-03	0.0023	0.0094	0.18
1982	1.06E-03	0.0018	0.0073	0.14
1983-end	8.32E-04	0.0014	0.0057	0.11

[1]Intake rates are normalized to calendar days.
[2]For 1972, use Tables 2, 3, and 4 for workers potentially exposed to demolition of Annex 2.

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Ingestion intakes during the residual period are estimated from the derived surface contamination levels using the methods specified in OCAS-TIB-009 (DCAS 2004). The annual ingestion rates were then determined by multiplying the initial intake rate by the annual reduction factors shown in Table 5 above. Ingestion intakes are provided in Table 6.

Table 6: Uranium Ingestion Intakes from Residual Contamination				
Annual Reduction Factors		**Intakes (pCi/day)[1] Lognormal Distribution; GSD = 3**		
Year	**Factor**	**F**	**M**	**S**
1954	1.00E+00	3.5E-02	1.4E-01	2.8E+00
1955	7.83E-01	2.7E-02	1.1E-01	2.2E+00
1956	6.13E-01	2.1E-02	8.8E-02	1.7E+00
1957	4.80E-01	1.7E-02	6.9E-02	1.3E+00
1958	3.76E-01	1.3E-02	5.4E-02	1.1E+00
1959	2.94E-01	1.0E-02	4.2E-02	8.3E-01
1960	2.31E-01	8.1E-03	3.3E-02	6.5E-01
1961	1.81E-01	6.3E-03	2.6E-02	5.1E-01
1962	1.41E-01	4.9E-03	2.0E-02	4.0E-01
1963	1.11E-01	3.9E-03	1.6E-02	3.1E-01
1964	8.67E-02	3.0E-03	1.2E-02	2.4E-01
1965	6.79E-02	2.4E-03	9.7E-03	1.9E-01
1966	5.32E-02	1.9E-03	7.6E-03	1.5E-01
1967	4.16E-02	1.5E-03	6.0E-03	1.2E-01
1968	3.26E-02	1.1E-03	4.7E-03	9.2E-02
1969	2.55E-02	8.9E-04	3.7E-03	7.2E-02
1970	2.00E-02	7.0E-04	2.9E-03	5.6E-02
1971	1.56E-02	5.5E-04	2.2E-03	4.4E-02
1972[2]	1.23E-02	4.3E-04	1.8E-03	3.5E-02
1973	9.60E-03	3.4E-04	1.4E-03	2.7E-02
1974	7.51E-03	2.6E-04	1.1E-03	2.1E-02
1975	5.88E-03	2.1E-04	8.4E-04	1.7E-02
1976	4.61E-03	1.6E-04	6.6E-04	1.3E-02
1977	3.61E-03	1.3E-04	5.2E-04	1.0E-02
1978	2.83E-03	9.9E-05	4.1E-04	7.9E-03
1979	2.21E-03	7.7E-05	3.2E-04	6.2E-03

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Table 6: Uranium Ingestion Intakes from Residual Contamination				
Annual Reduction Factors		**Intakes (pCi/day)[1] Lognormal Distribution; GSD = 3**		
Year	**Factor**	**F**	**M**	**S**
1980	1.73E-03	6.1E-05	2.5E-04	4.9E-03
1981	1.36E-03	4.8E-05	2.0E-04	3.8E-03
1982	1.06E-03	3.7E-05	1.5E-04	3.0E-03
1983-end	8.32E-04	2.9E-05	1.2E-04	2.3E-03

[1]Intake rates are normalized to calendar days.

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