ORAUT-RPRT-0099 – Evaluation of EBR-II and BORAX-IV for ORAUT-OTIB-0054 Applicability

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I. Objective of ORAUT-RPRT-0099

Objective

- Today’s presentation deals with evaluation of the general applicability of ORAUT-OTIB-0054 in the determination of worker organ doses at the INL/ANL-W site in support of the NIOSH dose reconstruction project.
- The presentation summarizes the analyses in ORAUT-RPRT-0099 on the potential organ doses to workers at EBR-II and BORAX-IV, two high-priority ANL-W reactors. The objective was to determine if OTIB-0054 provides a bounding internal dose computational approach.

Objective (1 of 2)

- The evaluations described in RPRT-0099 were based on comparative analyses between the following analytical approaches:
- 1. Direct use of the OTIB-0054 Tool, with its built-in Mixtures of Fission and Activation Products (MFAP) source terms for the Advanced Test Reactor (ATR), Fast Flux Test Facility (FFTF), Hanford N-Reactor, and Training, Research, Isotopes, General Atomics (TRIGA) reactor; and
- 2. Reviewed and approved methods established for OTIB-0054, as implemented through use of spreadsheets, along with the BORAX-IV and EBR-II MFAP source terms, independently.

Objective (2 of 2)

- The analytical model and exposure pathway are the same in the two approaches. It's the source terms that are different, and hence the reason for the comparative analysis to evaluate the applicability of OTIB-0054 to the EBR-II and BORAX-IV.

II. Introduction

Introduction

- ORAUT-OTIB-0054 documents a methodology used in the assessment of claims by Energy Employees for compensation due to radiation-induced cancers.
- The methodology deals with the assignment of radionuclide-specific intakes of MFAPs for use in the dose reconstruction when air sampling or urinalysis data associated with worker exposures are available only as gross or total beta or gamma activities, i.e., when the assay method does not account for all of the MFAPs that may have been associated with the exposure.
- The assignment of radionuclide-specific intakes of MFAPs are based on the MFAP intensities relative to an indicator radionuclide in the gross beta or gross gamma urinalysis results (namely, ^{90}Sr or ^{137}Cs, respectively).

Introduction Cont’d

- In 2015/2016 SC&A carried out preliminary assessments as to whether the OTIB-0054 Tool would envelope, with sufficient accuracy, the conditions at the INL/ANL-W reactors as part of the of SEC-00219 and SEC-00224 ER reviews. The site was of primary interest because of the unique reactors built there by the AEC as prototypes, with various reactor configurations, fuel types and operating histories.

- OTIB-0054 is used for INL/ANL-W claims primarily because of gross bioassay methods (*in-vitro* and *in-vivo*) used by the site.

Rationale for Reactor Selection in Meeting the Objective of RPRT-0099

Rationale for Reactor Selection

- Fifty-two reactors were constructed at INL and ANL-W with many unique experiments, handling and processing of irradiated nuclear fuel, and disposal of radioactive waste. The reactors were categorized by SC&A/Saliant as high, medium and low priority based on the potential for underestimation of worker doses using the OTIB-0054 approach due to reactor design characteristics (i.e., fuel type, enrichment, cladding, etc.).

- Of these 52 reactors, EBR-II and BORAX-IV were selected as the first ones for evaluation of the applicability of OTIB-0054 at the INL/ANL-W Site.

Rationale for Selection of EBR-II

- EBR-II was an unmoderated sodium-cooled fast breeder reactor with a uranium/fissium* metal alloy fuel.   It was selected for the OTIB-0054 feasibility evaluation because its fuel type was significantly different than the mixed Pu/U oxide of the FFTF, the only sodium-cooled fast-neutron reactor evaluated for the OTIB-0054 development.

- EBR-II primarily operated in a steady state much like the reactors used in the development of OTIB-0054. In addition, experimental subassemblies were typically placed in the core for irradiation and testing of fuel samples and other reactor materials; hence, the availability of other fuel types for assessment of the OTIB-0054 applicability.

*fissium is a generic term for metal alloys used with uranium to create a fuel whose properties do not change with time

Rationale for Selection of BORAX-IV

- BORAX-IV was selected for the OTIB-0054 feasibility evaluation because its following features and operational history:

1. Atypical/different fuel design (93.65 wt% ThO_2 - 6.35 wt% UO_2),
2. Relatively short operating time, corresponding to about 0.5 day at power followed by 8.6 days downtime over a period of about 1 year, and
3. Very low burnup over its lifetime (about 1 GWd/MTHM*)

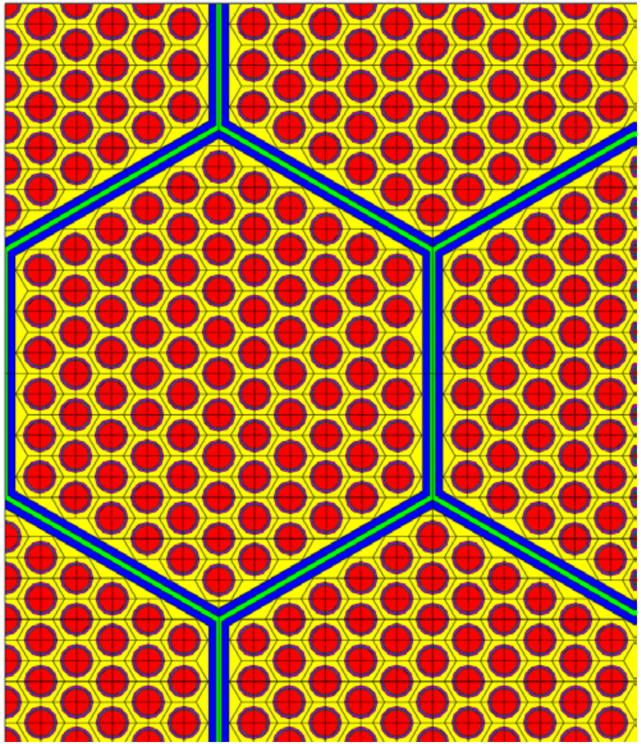
*MTHM is metric ton of heavy metal

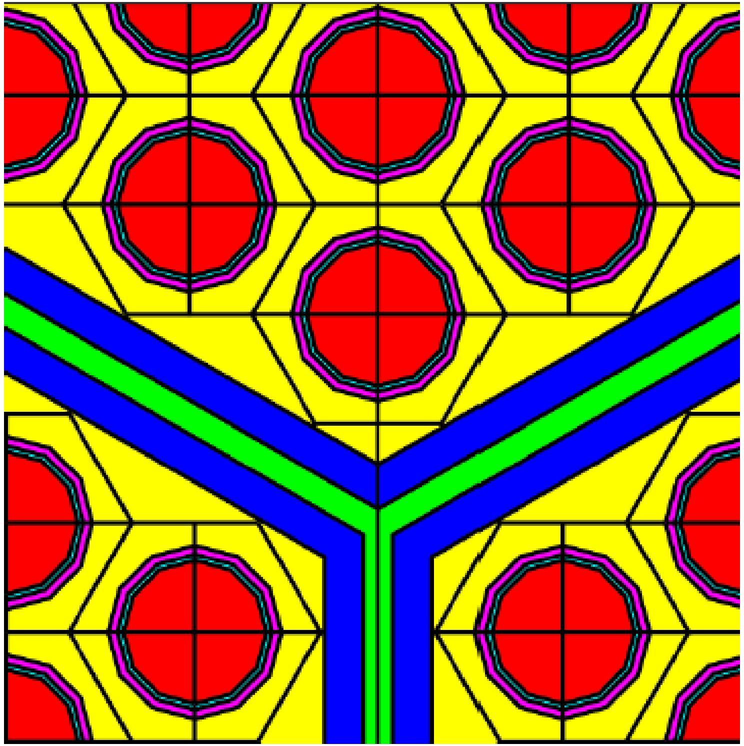
III. Reactor Modelling and Source-term Generation

Reactor Modeling and Source-Term Generation

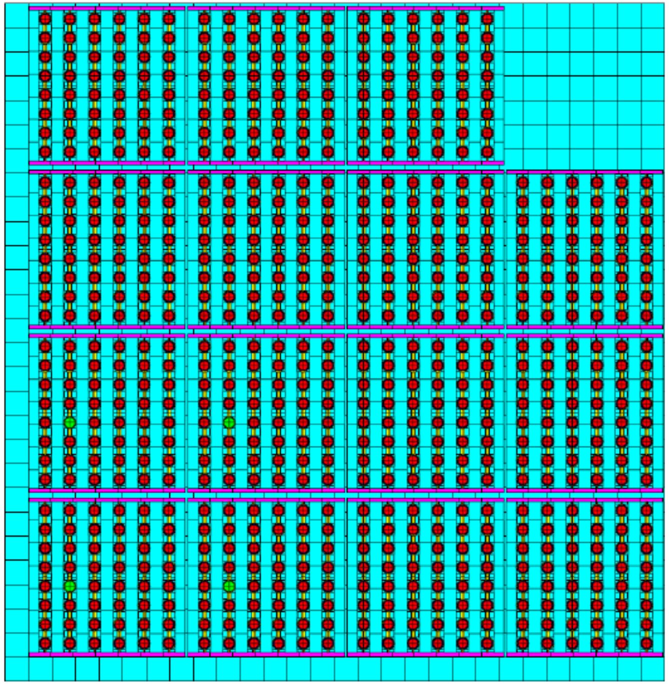
- The analytical tools employed in the source term generation include the TRITON and ORIGEN modules in SCALE 6.2.3.
- TRITON was used to model the nuclear reactor fuel lattices for reactor core simulation and for generation of radionuclide inventories (Ci/MTHM) as a function of burnup. The power histories were selected to be realistic, and for assemblies with highest burnups in the EBR-II core. For BORAX-IV, the lattice model was for one quarter of the core.
- The TRITON results at end of irradiation were then provided as input to ORIGEN for generation of radioactivity as a function of decay time, based on the same in-transit decay times to the various locations or processes as used in the OTIB-0054 model (namely, 10, 40, 180 and 365 days).
- Copies of the TRITON lattice models are presented in the following two slides.

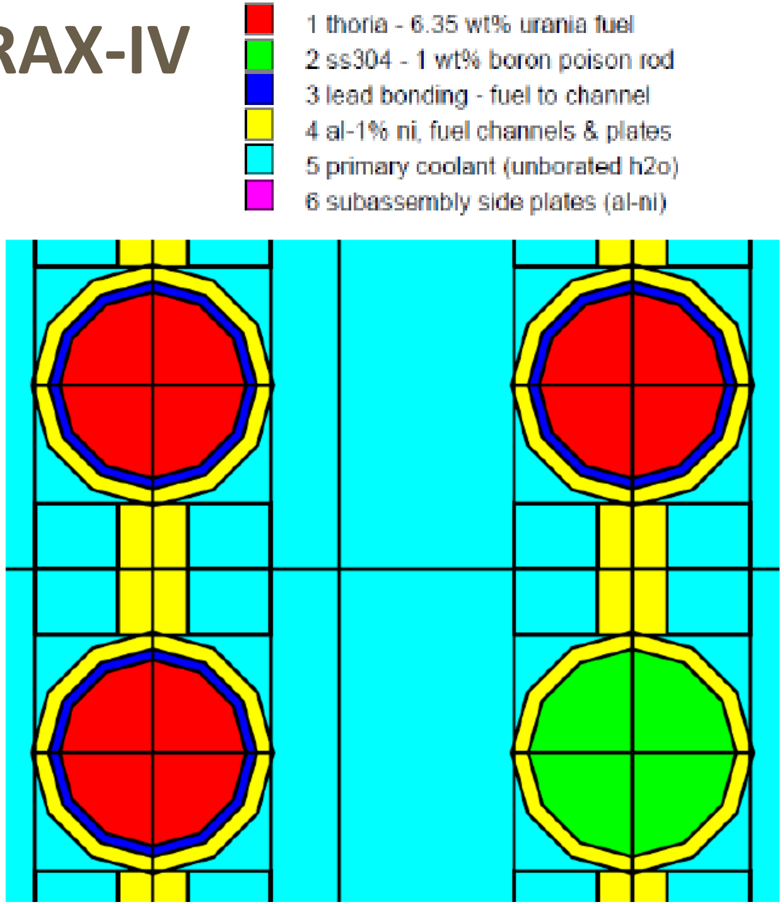
TRITON Lattice Model for EBR-II (the equivalent of 3 assemblies)





TRITON Lattice Model for BORAX-IV (quarter-core model)





Source Terms Generated for Comparative Analyses with OTIB-0054

- Summaries of the EBR-II and BORAX-IV parameters for generation of the MFAP source terms for the dose-comparative analyses with OTIB-0054 are presented in the following two slides. They reflect the differences in reactor design parameters (fuel type and enrichment) and operational histories (uptime, downtime, power level and burnup).
- It is noted that, for EBR-II, three sets of inventories were generated for three assembly types, a Mark-IA average assembly, a Mark-II peak-powered assembly, and an experimental assembly with peak burnup.
- Blanket assemblies in EBR-II were excluded from the analyses as they were considered as sealed sources that did not represent an internal exposure hazard.

EBR-II Source-Term Bases

Description	Modeled uptime and lifetime (days)	Uptime average power level (MWt/MTHM)	Burnup (at%)
Mark-IA average fuel assy. (U - 5 wt% fissium; U-235 enrichment 52.18 wt%)	116 and 149	129.0	1.77
Mark-II peak fuel assembly (U - 5 wt% fissium; U-235 enrichment 66.57 wt%)	347 and 480	168.4	6.64
Experimental assembly with peak burnup (UO_2 - 20 wt% PuO_2; U-235 enrichment 92.7 wt%)	564 and 1,211	75.04	7.90

BORAX-IV Source-Term Basis

Description	Modeled uptime and lifetime (days)	Core-average power level (MW(t)/MTHM)	Burnup (at%)
BORAX-IV core (93.65 wt% ThO_2 and 6.35 wt% UO_2; U-235 enrichment 93.2 wt%)	21 and 356	50.45	0.11

IV. Worker Organ Dose – Analytical Model for Comparative Analysis with OTIB-0054

Dose Model for Comparative Analyses (1 of 5)

- The comparative analyses documented in RPRT-0099 was between direct use of OTIB-0054 and spreadsheets implementing the reviewed and approved models established for OTIB-0054.
- The exposure pathway is inhalation of airborne MFAPs at an intake rate that would yield a predefined concentration in a 24-hr urine sample following 2- and 10-yr chronic exposures.
- Consideration is given to the committed dose to 28 organs.
- Noble gases and actinides are excluded from the analyses.
- Noble-gas and MFAP decay products are properly accounted for where needed, as is also decay and ingrowth in the urine sample between collection and counting.

Dose Model for Comparative Analyses (2 of 5)

- In both approaches the potential dose consequence evaluation is based on assumed gross beta and gross gamma measurements of urine samples. The evaluations consist of the following analyses (with minimal or full chemical separation, and with and without radioiodines):
  - Gross beta analysis of minimally-processed samples,
  - Gross beta analysis of chemically-processed samples, and
  - Gross gamma analysis of minimally-processed samples.
- The analytical model presented in the next few slides is for the "spreadsheet" approach. It consists of steps A through F, as follows:

Dose Model for Comparative Analyses (3 of 5)

A. As a first step, modified release fractions in DOE 1027 (not available for all MFAPs) are used as direct multipliers to convert the MFAP-specific activities determined by TRITON and ORIGEN (for 900+ radionuclides), at each of the four decay intervals, to renormalized compositions of the radioactivity inhaled by site workers. These are referred to as the NIFs (the Normalized Intake Fractions).

B. The analysis is then followed by estimation of bounding relative inhalation dose to any organ attributable to each MFAP. The MFAPs that contribute ≥ 1 % of the dose to any organ are then identified as dosimetrically important, and their contribution is renormalized to form the “Table D-1” MFAPs (about 30 MFAPs for EBR-II and 24 for BORAX-IV); they include the indicator radionuclides discussed in the next slide.

Dose Model for Comparative Analyses (4 of 5)

C. The "Table D-1" MFAPs are subsequently used in the quantification of the indicator radionuclide fractional contributions to urine sample gross beta and gross gamma measurements (^{90}Sr for the beta measurements and ^{137}Cs for the gamma measurements).

D. The indicator radionuclides are then assigned intake rates (pCi/d, based on IMBA) that would yield a corresponding 1 pCi activity in a 24-hour urine sample. This forms the basis to define the "Table D-1" MFAP intake rates based on their relative contributions to the urine measurements.

E. The "Table D-1" MFAPs are also used to define a subset of MFAPs that individually contribute ≥ 1 % to the CED. They constitute the "Table E-1" MFAPs, which are also renormalized.

Dose Model for Comparative Analyses (5 of 5)

F. The “Table E-1” MFAPs are then used to compute the doses to 28 organs which would result from the various assumed urine-sample measurements, for a total of 24 cases [4 decay times, 2 beta and 1 gamma measurements, and with or without radioiodines).

G. The final step in the spreadsheet analysis is the comparison of organ committed doses with corresponding results based on the OTIB-0054 methodology and the identical exposure scenario, with the exception of the MFAP composition.

V. Worker Organ Dose – Comparative Analysis with OTIB-0054

Organ Dose Comparative Analysis (1 of 2)

- The comparative analyses of interest is on organ doses computed through (a) direct use of OTIB-0054 and (b) spreadsheets implementing the models established for OTIB-0054 as described in the preceding slides.
- Summaries of the results for EBR-II and BORAX-IV are presented in the following slide in terms of organ dose ratios (OTIB/Spreadsheet), limited for presentation purposes to the slightly bounding 10-yr exposure interval and to organs with the smallest ratios (i.e., with the least bounding margin). Ratios > 1 imply that OTIB-0054 provides a bounding approach for these reactors.
- It is seen that all ratios are > 1. But this is a fortuitous result that cannot be readily extended to other reactors without further evaluation.

Organ Dose Comparative Analysis (2 of 2)

OTIB-0054 to Spreadsheet Dose Ratios (organ with smallest dose ratio)

Sample Description	OTIB/ BORAX-IV	OTIB-0054/EBR-II Assembly		
		Mark-IA	Mark-II	Experimental
Minimally-processed gross beta, with iodines	1.033 (bone surface)	1.019 (liver)	1.125 (bone surface)	1.370 (bone surface)
Minimally-processed gross beta, w/o iodines	1.033 (bone surface)	1.019 (liver)	1.125 (bone surface)	1.370 (bone surface)
Chemically processed gross beta, with iodines	1.637 (bone surface)	1.560 (bone surface)	1.720 (bone surface)	1.936 (bone surface)
Chemically processed gross beta, w/o iodines	1.637 (bone surface)	1.560 (bone surface)	1.720 (bone surface)	1.936 (bone surface)
Gross gamma, with iodines	1.046 (thym./esoph.)	1.001 (thym./esoph.)	1.278 (thymus/esoph.)	1.485 (testes)
Gross gamma, w/o iodines	1.067 (red bone mar.)	1.064 (liver)	1.369 (testes)	1.508 (testes)

VI. Conclusions

Conclusions (1 of 2)

- OTIB-0054 is the primary approach used for accounting exposures to unknown MFAPs when intakes and doses are assessed based on bioassay data. It is intended to provide a generic approach to account for exposures at all DOE and Atomic Weapons Employer sites, by encompassing a conservative and maximizing approach that encompasses uncertainties in dose estimates such that the approach represents an upper bound.
- Because INL/ANL-W has functioned as a reactor testing facility throughout its history, there was concern that OTIB-0054 might not provide a bounding approach and could potentially underestimate worker exposures to MFAPs for certain reactors that had unique operating conditions.

Conclusions (2 of 2)

- OTIB-0054 was determined to provide a bounding approach for the EBR-II and BORAX-IV analyzed cores, as described in today’s presentation.

- The evaluations of other “high priority” reactors at ANL-W and INL is on going.