Draft

Advisory Board on Radiation and Worker Health
National Institute for Occupational Safety and Health

Review of ORAUT-RPT-0099 Evaluation of EBR-II and BORAX-IV for ORAUT-OTIB-0054 Applicability

Contract No. 75D30119C04183
Document No. SCA-TR-2021-SEC001, Revision 0

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January 15, 2021

SC&A, Inc. Technical Support for the Advisory Board on Radiation and Worker Health's Review of NIOSH Dose Reconstruction Program

Document title	Review of ORAUT-RPRT-0099 Evaluation of EBR-II and BORAX-IV for ORAUT-OTIB-0054 Applicability
Document number	SCA-TR-2021-SEC001
Revision number	0 (Draft)
Supersedes	N/A
Effective date	January 15, 2021
Task Manager	Stephen L. Ostrow, PhD [signature on file]
Project Manager	Gregory P. Beronja, PE [signature on file]
Document reviewer(s)	Rose Gogliotti, MS [signature on file]

Record of Revisions

Revision number	Effective date	Description of revision
0 (Draft)	1/15/2021	Initial issue

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Abbreviations and Acronyms

ABRWH	Advisory Board on Radiation and Worker Health
ANL	Argonne National Laboratory
ANL-W	Argonne National Laboratory-West
ATR	Advanced Test Reactor
BORAX	Boiling Water Reactor Experiment
CDC	Centers for Disease Control and Prevention
Ci/MTHM	curie per metric ton of heavy metal
DOE	U.S. Department of Energy
EBR	Experimental Breeder Reactor
FFTF	Fast Flux Test Facility
HEU	high enriched uranium
I	iodine
IMBA	Integrated Modules for Bioassay Analysis
INL	Idaho National Laboratory
LOFT	Loss of Fluid Test
MFAP	mixed fission and activation product
MORE	Mixed Oxide Reactor Experiment
MTR	Materials Test Reactor
MWe	megawatts electric
MWth	megawatts thermal
Na	sodium
NIOSH	National Institute for Occupational Safety and Health
O	oxygen
ORAUT	Oak Ridge Associated Universities Team
ORNL	Oak Ridge National Laboratory
PBF	Power Burst Facility
Pu	plutonium
RNSD	(ORNL) Reactor and Nuclear Systems Division
SEC	Special Exposure Cohort
SPERT	Special Power Excursion Reactor Test
SRDB	Site Research Database

TAN	Test Area North
Th	thorium
TRA	Test Reactor Area
U	uranium
WG	work group
wt%	weight percent

1 Introduction and Background

As part of the review of two National Institute for Occupational Safety and Health (NIOSH) Special Exposure Cohort (SEC) petition evaluation reports associated with Idaho National Laboratory (INL) and Argonne National Laboratory-West (ANL-W) facilities, for INL SEC-00219 (NIOSH, 2017) and ANL-W SEC-00224 (NIOSH, 2016a), SC&A identified the following potential issue: Does ORAUT-OTIB-0054, revision 04, "Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses" (hereafter "OTIB-0054") (NIOSH, 2015), adequately model the potential source terms of the reactors and yield claimant-favorable dose results? Though administratively separate until 2005 and with separate research programs, ANL-W is physically located on the INL site and shares many of the radiation protection issues and employs common radiation protection programs with INL. The two sites will be referred to collectively as "INL" in this report unless it is important to make a distinction.

Frequently, air sampling or urinalysis data on worker exposure to mixed fission and activation products (MFAPs) associated with nuclear reactors or nuclear fuel are available only in the form of gross beta or gross gamma activities unattributed to specific radionuclides. However, a radionuclide source mix, measured or assumed, is required to calculate internal doses. This limitation is particularly true for exposures during the early years of the U.S. nuclear program and especially so for the many INL reactors, which were experimental and often unique in design and operation. For those cases, as specified in the INL occupational internal dose technical basis document (NIOSH, 2010), OTIB-0054 provides generic guidance and a standard approach on how to assign radionuclide-specific intakes to exposed workers. Relating isotopic MFAP intensities to a strontium-90 indicator for gross beta data or a cesium-137 (Cs-137) indicator for gross gamma data allows, through a rather involved process, estimation of internal doses.

As the NIOSH literature frequently asserts, the methodology and claimant-favorable assumptions used in OTIB-0054 are expected to produce upper bound exposure results in most cases, but with a few reservations. For example, the assumed reactor, fuel, and operational combinations that underpin the OTIB-0054 methodology reflect situations where substantial burnup often occurred over protracted periods of time (hundreds of days) and the fuel maintained its integrity. However, the fuel at some of the INL operations (e.g., in the Test Area North (TAN) location) had very short burnup times and many operational cycles, and the reactors operated at enrichments and temperatures where the fuel was allowed to melt.

SC&A has concurred with NIOSH's assertions in its reviews of OTIB-0054 and its applications. All of the review findings related to these reviews have been resolved as part of the procedures review process. SC&A produced two reports in 2015 examining INL reactors in the Test Reactor Area (TRA) (SC&A, 2015a) and TAN (SC&A, 2015b) that discussed in detail possible limitations to the OTIB-0054 methodology. The TRA review effort examined the Materials Test Reactor (MTR), the Engineering Test Reactor, and the Advanced Test Reactor (ATR), and the TAN review considered the three Heat Transfer Reactor Experiments, which were part of the Aircraft Nuclear Propulsion Program. Subsequently, the November 10, 2015, meeting of the Advisory Board on Radiation and Worker Health (ABRWH) INL/ANL-W work group (WG) meeting directed SC&A to expand its OTIB-0054 applicability review to all the INL reactors beyond the six already examined.

SC&A examined the pertinent details of all 52 INL reactors (first considering the INL and ANL-W reactors separately and then, with the concurrence of the WG and NIOSH, merging them into one cohort). SC&A placed the reactors in "High," "Medium," and "Low" review priority categories after considering their designs and other physical characteristics (e.g., type of fuel and enrichment, cladding, coolant), operational histories (e.g., power level, steady state or pulsed, burnup history, within design limits or deliberately taken outside, length of operation, and incidents), and their potential for exposing personnel to internal radiation. Following discussions among SC&A, NIOSH (including its contractor, Oak Ridge Associated Universities Team (ORAUT)), and the WG, a list of several high-priority reactors emerged requiring further analyses to determine if the OTIB-0054 methodology to assign radionuclide-specific intakes of MFAPs is adequate as part of the process to determine internal doses when only gross alpha or gross beta measurements are available. NIOSH produced a report (referred to here as the "NIOSH report"), ORAUT-RPRT-0099, "Evaluation of EBR-II and BORAX-IV for ORAUT-OTIB-0054 Applicability," on May 8, 2020 (NIOSH, 2020). The NIOSH report analyzes two of the ANL-W reactors on the high-priority list: Experimental Breeder Reactor II (EBR-II) and Boiling Water Reactor Experiment IV (BORAX-IV), "to verify that OTIB-0054 does not underestimate the MFAP exposures" (p. 8). At its July 16, 2020, meeting, the WG tasked SC&A to review the NIOSH report and advise the WG of its assessment.

Table 1 summarizes the relevant important events that unfolded over a period of about 5 years pertaining to the applicability of OTIB-0054 to determine internal exposures from INL and ANL-W reactors. The process will continue because, as stated at the end of the conclusions section of the NIOSH report:

> The two reactors [EBR-II and BORAX-IV] were part of a group of six reactors that operated during the SEC evaluation periods for INL and ANL-W that were classified as high-priority reactors deemed to require further evaluation. Corresponding analyses for the other high-priority reactors on the INL/ANL-W site are currently in progress and will be reported separately. [NIOSH, 2020, pp. 18–19]

Table 1. Events pertaining to the reactor analysis issue

Date	Event	Notes
9/28/2015	SC&A issued "NIOSH SEC-00219 Test Reactor Area Modeling," SCA-SEC-2015-0074-C, rev. 0, September 28, 2015 (SC&A, 2015a)	
9/28/2015	SC&A issued "Review of NIOSH Strategy for Reconstructing Internal Doses to Workers at Test Area North," SCA-TR-2015-SEC0074A, rev. 0, September 28, 2015 (SC&A, 2015b)	
11/10/2015	WG meeting	SC&A directed to screen INL reactors other than the 6 already addressed in (SC&A, 2015a) and (SC&A, 2015b)
3/2/2016	SC&A issued "INL SEC-00219 Reactor Prioritization for Evaluation of ORAUT-OTIB-0054 Applicability," SCA-TR-2016-SEC002, Rev. 0, March 2, 2016 (SC&A, 2016a)	

Date	Event	Notes
5/24–25/ 2016	ABRWH meeting	SC&A directed to screen the ANL-W reactors as well as the INL ones
6/10/2016	SC&A issued "INL SEC-00219 Reactor Prioritization for Evaluation of ORAUT-OTIB-0054 Applicability," SCA-TR-2016-SEC002, rev. 1, June 10, 2016 (SC&A, 2016b)	
7/13/2016	SC&A issued "Argonne National Laboratory-West SEC-00224 Reactor Prioritization for Evaluation of ORAUT-OTIB-0054 Applicability," SCA-TR-2016-SEC010, rev. 0, July 13, 2016 (SC&A, 2016c)	
7/28/2016	NIOSH issued "NIOSH Proposal for INL and ANL-W Reactor Prioritization for OTIB-0054 Evaluation," July 28, 2016. (NIOSH, 2016b)	
12/8/2016	SC&A issued "INL SEC-00219 and ANL-W SEC-00224: SC&A Response to NIOSH Reactor Analysis Plan and Consolidation of all Reactor Modeling Comments," SCA-TR-2016-SEC012, rev. 0, December 8, 2016 (SC&A, 2016d)	
5/16/2017	WG meeting	NIOSH directed to perform reactor characterization studies for the following reactors categorized as High Priority: LOFT, MORE, PBF, SPERT I–IV (most bounding case), BORAX I–V (BORAX-IV selected), EBR-I (most bounding case, probably Mark-IV Pu core), EBR-II, MTR (Phoenix Pu core)
5/8/2020	NIOSH issued "Evaluation of EBR-II and BORAX-IV for ORAUT-OTIB-0054 Applicability," ORAUT-RPRT-0099, rev. 00, May 8, 2020 (NIOSH, 2020)	Partial fulfillment of WG direction at the 5/16/2017 meeting
7/16/2020	WG Meeting	SC&A directed to review NIOSH EBR-II/BORAX-IV report (NIOSH, 2020)

2 NIOSH Report ORAUT-RPRT-0099

2.1 Overview

NIOSH issued ORAUT-RPRT-0099, revision 0 (NIOSH, 2020), on May 8, 2020, in partial fulfillment of the directions received from the WG at its May 16, 2017, meeting to determine whether OTIB-0054 adequately determines (i.e., does not materially underestimate) the MFAP exposures at the two reactors under consideration. Section 2.0 of the NIOSH report describes the methodology employed: using two different approaches to calculate organ doses, then comparing the results. Using the same exposure scenario, but with different source terms, the first approach directly used the OTIB-0054 Tool with its built-in MFAP source terms for its four archetypical reactors (ATR, Fast Flux Test Facility (FFTF), Hanford-N Reactor, and a TRIGA reactor) and associated representative reactor operating scenarios, for a total of nine generic cases. The second approach used "reviewed and approved methods established for OTIB-0054, as implemented through use of spreadsheets, along with the BORAX-IV or EBR-II MFAP source term" (NIOSH, 2020, p. 8). In all cases considered in the NIOSH report, three different types of urine samples and measurements were considered: (1) gross beta analysis of minimally processed urinalysis samples with and without radioiodines, (2) gross beta analysis of chemically processed samples with and without radioiodines, and (3) gross gamma analysis of minimally processed samples with and without radioiodines.

Determination of exposures using OTIB-0054 is multi-stepped and quite complex; the procedure is summarized in the NIOSH report. This SC&A report will only briefly present the methodologies used and refers the reader to the NIOSH report (NIOSH, 2020), OTIB-0054 (NIOSH, 2015), related files about the code (NIOSH, 2013), and files pertaining to the analysis performed in the NIOSH report (NIOSH, 2019a, 2019b, 2019c). NIOSH's (2013) "calculations roadmap" presents the steps followed in an OTIB-0054 analysis; this is from 2013 and the latest version of OTIB-0054 (rev. 04) is from 2015, but the general methodology followed is unchanged. NIOSH (2019a), NIOSH (2019b), and NIOSH (2019c) are file folders, each containing many other file folders and individual files, some of which are discussed individually in this report. NIOSH (2019a) contains files pertaining to OTIB-0054 evaluation for INL reactors. NIOSH (2019b) contains files related specifically to EBR-II. NIOSH (2019c) contains files related specifically to BORAX-IV. As stated in the NIOSH report (p. 9):

> Because of the computationally complex nature of the evaluations for EBR-II and BORAX-IV, only essential information and data are provided in this report. . . . All of the detailed development work supporting this summary report can be found in the Site Research Database (SRDB).

Section 5.0 of the NIOSH report presents an overview the EBR-II and BORAX-IV reactors. A good source of background information on the reactors in addition to that found in the NIOSH (2019b, 2019c) compilations can be found in the U.S. Department of Energy's (DOE's) history of INL (DOE, 2000).

The EBR-II, built by Argonne National Laboratory, operated from 1961 to 1994 and was similar to, but a large scale up from, the EBR-I. The EBR-II continued fast neutron breeder reactor development at ANL-W, including onsite reprocessing of spent fuel into new fuel pins, demonstrating both breeding of new fuel and the feasibility of a closed fuel cycle. The unmoderated core (unmoderated because the reactor relied on a fast neutron spectrum), with 67 percent enriched uranium-235 (U-235) fuel (high enriched uranium (HEU)), sat in a tank of 90,000 gallons of liquid sodium (Na) primary coolant, had a closed-loop Na secondary coolant system, and produced steam in a tertiary system. The entire liquid metal fast breeder reactor system was placed in a large containment building for safety. The pool design combined with the use of metallic alloy fuel rendered the reactor passively safe (i.e., it could shut down safely during an incident without relying on active mechanical systems). The maximum power level was 62.5 megawatts thermal (MWth), and the EBR-II could supply 20 megawatts electric (MWe) of electric power to INL facilities.

More reactor and system details can be found in, for example, ORAUT's (2019a) report, "Radionuclide Source-Term Generation for the EBR-II Nuclear Reactor and Potential Dose Consequence Evaluation Based on the OTIB-0054 Methodology," which is one of the documents included in the NIOSH (2019b) EBR-II compilation. The EBR-II was placed in the High category with respect to assessing OTIB-0054 applicability because the only archetypical reactor in OTIB-0054 that was sodium cooled, the FFTF, used mixed uranium and plutonium oxide fuel while EBR-II used only HEU metal alloy fuel.

The BORAX series of reactor experiments, located at ANL-W, tested the feasibility and safety and explored the operating parameters of direct steam production in a light-water reactor. Previously, the consensus among nuclear engineers had been that steam boiling in a reactor could lead to potentially dangerous operational instabilities. BORAX-IV was a modification of BORAX-III and operated from 1956 to 1958 at a maximum power level of 20 MWth (and 2.5 MWe) and 300 pounds per square inch gauge primary coolant pressure. It tested uranium (U-233 and U-235) and thorium ceramic fuel plates (to allow higher temperature operations than with uranium fuel plates), some of which purposefully contained defects to determine reactor behavior with compromised fuel. The tests released some short-lived radionuclides to the atmosphere. Operating at full power with many fuel elements having cladding defects, it released approximately 4,565 curies of short-lived radionuclides to the atmosphere in March 1958. More reactor and system details can be found in, for example, ORAUT's (2019b) report, "Radionuclide Source-Term Generation for the BORAX-IV Nuclear Reactor and Potential Dose Consequence Evaluation Based on the OTIB-0054 Methodology," which is one of the documents included in the NIOSH (2019c) BORAX-IV compilation. BORAX-IV was placed in the High category with respect to assessing OTIB-0054 applicability because its fuel consisted of a mixture of uranium and thorium oxides, which is outside the range of fuels found in OTIB-0054, and because it operated for only relatively short campaigns resulting in low fuel burnup.

2.2 Reactor modeling

The NIOSH report describes the reactor modeling process in section 6.0, first source term generation, then decay time considerations, and finally exposure comparison protocols. Again, as noted previously about the implementation of OTIB-0054, the reactor modeling and source term generation process is quite complex and will only be touched on briefly in the following discussion. Source terms were generated using the TRITON and ORIGEN code modules contained in the SCALE Code System, whose development into a very sophisticated and comprehensive reactor lattice analysis modular system began in 1969 by Oak Ridge National Laboratory to assist the U.S. Nuclear Regulatory Commission. There is a large library of literature on SCALE, its modules, its use, results, and comparison and validation of its component systems. Two primary references are Oak Ridge National Laboratory (ORNL) (2020) and ORNL (2018). As stated in the abstract section of ORNL (2018, p. v):

> The SCALE Code System is a widely-used modeling and simulation suite for nuclear safety analysis and design that is developed, maintained, tested, and managed by the Reactor and Nuclear Systems Division (RNSD) of Oak Ridge National Laboratory (ORNL). SCALE provides a comprehensive, verified and validated, user-friendly tool set for criticality safety, reactor and lattice physics, radiation shielding, spent fuel and radioactive source term characterization, and sensitivity and uncertainty analysis.

TRITON is used to model portions of nuclear reactor fuel lattices and generate cross-section sets as a function of burnup that are then used by ORIGEN, a general purpose, point depletion and decay code. ORIGEN uses a matrix-exponential method to calculate time-dependent radionuclide concentrations and activities, taking into account production, depletion, and decay of the radionuclides for a user-specified fuel configuration, composition, and properties and reactor operational scenario (e.g., power levels as a function of time). The output of ORIGEN can be used as input to a radiation shielding program, a criticality analysis, or a lattice physics simulation of reactor core behavior. Data in OTIB-0054 rely on ORIGEN as part of the process of generating fission and activation product inventories for the four archetypical reactors and nine cases. The NIOSH report used ORIGEN to generate radioisotope inventories after the conclusion of the fuel irradiation period for the reactors at the same time intervals (10 days, 40 days, 180 days, and 1 year) as in OTIB-0054. The decay times were chosen to conceptually correspond to different stages in the fuel cycle.

As outlined in Section 2.1 of this report, NIOSH assessed OTIB-0054 applicability to EBR-II and BORAX-IV reactors by comparing doses calculated with two different approaches: the first directly used OTIB-0054 with its built-in source terms for the archetypical FFTF, ATR, and TRIGA reactors, and the second used source terms generated specifically for EBR-II and BORAX-IV based on available operational and physical information from the literature. Operational and exposure scenarios were the same, as were the assumed gross beta and gross gamma measurements (urine samples for 2-year and 10-year chronic exposure periods), in each approach.

Section 7.0 of the NIOSH report provides details about the source term development for the two reactors. NIOSH describes the approach as follows:

> TRITON was used for generation of the radionuclide concentrations (Ci/MTHM) as a function of burnup [for almost 1,700 radionuclides]. The radionuclide concentrations at the end-of-fuel burnup were then decayed through the use of ORIGEN. . . . The radionuclides with initial inventories less than 1×10^{-6} Ci/MTHM were excluded because they contribute 0% to the total potential dose . . . . The remaining 900+ radionuclides with initial inventories greater than 1×10^{-6} Ci/MTHM were then converted to total assembly or core curies and provided as input to ORIGEN for postirradiation decay. Subsequently, the decay-corrected inventories (with decay times equal to 10, 40, 180 and 365 days) were subjected

> to computerized screening based on their dose contributions to any of 27 organs in the database. Those radionuclides contributing more than 1% of the dose to any organ, at any postirradiation decay, were then selected for further processing. This process led to the elimination of all but no more than 30 of the initial 900+ radionuclides for each evaluation. [NIOSH, 2020, p. 13]

Tables 7-1 and 7-2 of the NIOSH report summarize respectively the EBR-II and BORAX-IV source term parameters (i.e., subassemblies or cores modeled, modeled uptimes and lifetimes, uptime average power level, and burnup) used for evaluation against OTIB-0054 built-in models and refer respectively to tables in NIOSH (2019b) and NIOSH (2019c) for full source term tabulations. U-235 enrichments for the EBR-II varied from 52.18 to 92.7 wt% in three different cases and the BORAX-IV core was assumed to have a fuel composition of 93.65 weight percent (wt%) ThO_2 and 6.35 wt% UO_2, with a U-235 enrichment of 93.2 wt% in a single case. The U-235 is fissile (can fission with thermal neutrons), while the thorium-232 (Th-232) is fertile (can breed more fuel by absorbing a neutron and transforming to U-233, which is fissile). NIOSH judged these cases to be the most likely to not to be adequately modeled by the OTIB-0054 methodology. NIOSH (2019b) and NIOSH (2019c), respectively, provide the details of the selection. The three EBR-II subassemblies considered are summarized in section 1.1 of ORAUT (2019a): Mark-IA driver fuel subassembly (U-fissium fuel)[1] surrounded by subassemblies of the same design, Mark-II subassembly (U-fissium fuel), surrounded by subassemblies of the same design, and an experimental subassembly (UO_2 – 20 wt% PuO_2 fuel) adjacent to Mark-IA subassemblies, irradiated to end-of-life conditions that lead to cladding defect.

Section 8.0 of the NIOSH report details how the study determined intake fractions and dosimetrically important radionuclides following standard OTIB-0054 procedures (NIOSH, 2015, section 6.0), noting that:

> Dosimetrically significant radionuclides, both in terms of quantity and total activity, differ based on reactor design and operation. Reactor design parameters such as the type of fuel, enrichment, cladding, moderator, and coolant are key factors in the source term generated under power. Operational parameters such as length of operation, steady-state or periodic operation, and operation of reactor within or outside of design criteria are also central factors. [NIOSH, 2020, p. 15]

Tables 10-1 and 10-2 of the NIOSH report summarize in a convenient form the internal dose comparison results for the 2- and 10-year chronic exposure intervals for each reactor and organ considered that have the smallest dose ratios: doses calculated using the OTIB-0054 Tool to doses calculated using reactor-specific source terms. Perfect agreement of the two methods—that is, a ratio of 1.000—is interpreted to mean that use of the generic OTIB-0054 data produces results equivalent to EBR-II- and BORAX-IV-specific analyses. Ratios greater than 1.000 imply that the generic OTIB-0054 evaluation is more claimant favorable, and ratios less than 1.000 imply that it is less claimant favorable. This is irrespective of the many conservatisms and claimant-favorable assumptions and methods built into the OTIB-0054 approach in general.

[1] ORAUT (2019a) defines "fissium" as a "Mixture of fission product metals that are not removed by melt-refining processes, specifically molybdenum, ruthenium, rhodium, palladium, zirconium and niobium, which are apportioned in the mixture according to their yield in the fission process."

Table 10-1 for the EBR-II reactor shows all dose ratios are greater than 1.000, ranging from a low of 1.001 for 2-year and 10-year chronic exposures to the thymus and esophagus for a Mark-IA subassembly for a gross gamma sample with radioiodines, to a high of 1.936 for 10-year chronic exposure to the bone surface for an experimental subassembly for a chemically processed gross beta sample with radionuclides or without radioiodines.

Table 10-2 for the BORAX-V reactor shows similar results, that all dose ratios are greater than 1.000, with a low of 1.031 for 2-year chronic exposure to the bone surface for a minimally processed gross beta sample with and without radioiodines to a high of 1.637 for 10-year chronic exposure to the bone surface for a chemically processed gross beta sample with and without radioiodines.

Tables 10-1 and 10-2 show only the smallest ratios out of the larger calculated sets shown in ORAUT (2019a) and ORAUT (2019b). Therefore, taken together, these tables demonstrate that for the chosen cases for the two reactors, the generic OTIB-0054 approach is at least as claimant favorable as the reactor-specific approach.

3 SC&A Evaluation

SC&A reviewed OTIB-0054 as part of the procedures review process, and all findings have been resolved. OTIB-0054 uses claimant-favorable assumptions and generally produces claimant-favorable internal dosimetry results. However, the two experimental reactors considered here, EBR-II and BORAX-IV, have physical and operational characteristics that place them outside the space in which OTIB-0054, with its archetypical cases, was designed to operate. EBR-II was liquid metal cooled and used HEU metal fuel, while the only OTIB-0054 reactor that was also liquid metal cooled, FFTF, used mixed uranium and plutonium oxide fuel. BORAX-IV fuel consisted of uranium and plutonium oxides, and the reactor was operated for short campaigns with low fuel burnup.

In assessing the EBR-II and BORAX-IV results, SC&A first carefully went over RPRT-0099 (NIOSH, 2020) and its voluminous backup material, particularly the documents found in the three folder compilations (NIOSH, 2019a, 2019b, 2019c) pertaining to the OTIB-0054 Tool, and EBR-II, and BORAX-IV respectively, to assure that the overall evaluation plan makes sense and is implemented correctly. SC&A believes that the approach the NIOSH report takes in comparing the standard OTIB-0054 implementation results to EBR-II- and BORAX-IV-specific implementation results, by only varying the cross section sets and looking at ratios of calculated doses, is well conceived and valid.

The NIOSH report relies on a wealth of EBR-II and BORAX-IV reactor material that appears in the reference documents. SC&A reviewed the references and determined that the report accurately extracted pertinent information about the reactors' physical and operational parameters to use in the analyses. SC&A, which is familiar with the theory and implementation of the SCALE modules and OTIB-0054 modeling, also delved into the details of their applications and believes that NIOSH used them correctly and appropriately. However, SC&A did not run any cases itself and relied on the assumption that NIOSH did so correctly.

The dose ratios in tables 10-1 and 10-2 of RPRT-0099 for EBR-II and BORAX-IV respectively represent the "worst case" 2- and 10-year chronic exposures to different organs (i.e., the smallest ratios). In all cases, the ratios are greater than 1.000, implying that the OTIB-0054 Tool calculations (the standard implementation) are more claimant favorable than the EBR-II- and BORAX-IV-specific implementations. The results in both tables assume gross beta and gross gamma urinalysis, for minimally or chemically processed gross beta samples and minimally processed gross beta samples, with and without radioiodines.

For EBR-II (table 10-1), the ratios range from an almost identical 1.001 for gross gamma sampling with radioiodines for 2-year and 10-year chronic exposures to the thymus and esophagus for Mark-IA subassemblies to a high of 1.936 for chemically processed gross beta sample with and without radioiodines for 10-year chronic exposure to the bone surface for the Experimental subassembly. The modeling considered Mark-IA, Mark-II, and experimental subassemblies.

For BORAX-IV (table 10-2), the ratios range from a low of 1.031 for minimally processed gross beta sample with and without radioiodines for 2-year exposures to the bone surface, to 1.637 for chemically processed gross beta sample with and without radioiodines for 10-year exposure to the bone surface. In all cases, the modeling specified a ThO_2-UO_2 fuel composition.

SC&A examined the two underlying ORAUT reports from which the NIOSH report summarizes information: ORAUT (2019a) for EBR-II and ORAUT (2019b) for BORAX-IV.

EBR-II: The last row of table 10-1 of RPRT-0099 refers to the appropriate ratio results tables of ORAUT (2019a) for the six exposure and subassembly cases considered: 2-year and 10-year chronic exposures for Mark-IA, Mark-II, and Experimental subassemblies. All ratios are >1.000. However, it should be noted that while all ratios are claimant favorable, some that appear in the ORAUT (2019a) report are quite a bit greater. All the large ratios appear for both 2-year and 10-year chronic exposures with gross gamma samples, chemical processing, and with or without iodine-131 (I-131). The organ dose ratios range from 6 to 7 for the Mark-IA subassembly (ORAUT, 2019a, table 2-23), from 7 to 9 for the Mark-II subassembly (ORAUT, 2019a, table 3-22), and from 6 to 7 for the Experimental subassembly (ORAUT, 2019a, table 4-21).

BORAX-IV: The last row of table 10-2 of RPRT-0099 refers to the appropriate ratio results tables of ORAUT (2019b) for the two exposure cases considered: 2-year and 10-year chronic exposures for the modelled ThO_2-UO_2 fuel core. All ratios are >1.000, but, as in the EBR-II case, some organ dose ratios shown in ORAUT (2019b) are in the range of 7 to 9 for both 2-year and 10-year chronic exposures with gross beta samples, chemical processing, and with or without I-131.

SC&A Conclusion: SC&A concurs with NIOSH's conclusion that, at least for these two reactors, the standard OTIB-0054 approach can be used to determine claimant-favorable internal doses when only gross gamma or gross beta data are available. However, as discussed in the preceding two paragraphs, under certain circumstances, it appears that the standard OTIB-0054 approach may substantially overestimate the reactor-specific organ doses. Consequently, SC&A recommends that NIOSH follow up its analyses with a discussion of why and under what conditions this might happen and whether the potential overestimation can result in unrealistically high dose assignments.

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