Review of ORAUT-RPRT-0099: Evaluation of EBR-II and BORAX-IV for ORAUT-OTIB-054 Applicability

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Issue background

- SC&A reviewed INL SEC-00219 and ANL-W SEC-00224 and identified a potential issue:
  - Does ORAUT-OTIB-0054, "Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses," adequately model the source terms of the INL site reactors and yield claimant-favorable dose results when actual mixtures of activation and fission products (MFAPs) are not available and only gross beta and gross gamma measurements are available?
- NIOSH asserts that the methodology and claimant-favorable assumptions of OTIB-0054 are expected to produce upper bound exposure results in most cases.
- Note: Argonne National Laboratory-West (ANL-W) is physically located within the overall Idaho National Laboratory (INL) site; the combined site is now referred to as "INL."

Reactor modeling history (1 of 2)

- SC&A made two evaluations in 2015 to determine whether OTIB-0054 produced acceptable results for six INL site reactors that operated during the SEC evaluation periods:
  - HTRE-1, HTRE-2, and HTRE-3 used in the Aircraft Nuclear Propulsion program, located in Test Area North
  - Materials Testing Reactor, Engineering Testing Reactor, and Advanced Test Reactor, located in the Test Reactor Area
- Following subsequent discussions, the INL/ANL-W work group (WG) at its November 2015 meeting directed SC&A to create a prioritized list to examine OTIB-0054 applicability for the remaining reactors.

Reactor modeling history (2 of 2)

- INL had 52 different reactors at various times: 34 at INL, 12 at ANL-W, 4 at Naval Research Facility, and 2 never operated.
- SC&A considered all the applicable INL reactors not already analyzed and, in a 2016 report, “INL SEC-00219 Reactor Prioritization for Evaluation of ORAUT-OTIB-0054 Applicability,” placed them in “High,” “Medium,” and “Low” review categories considering the reactor designs and operating characteristics.
- After WG discussions, NIOSH analyzed two high-priority reactors, EBR-II (Experimental Breeder Reactor-II) and BORAX-IV (Boiling Water Reactor Experiment-IV) in ORAUT-RPRT-0099 to determine if the OTIB-0054 methodology to assign radionuclide-specific intakes of MFAPs is adequate to determine internal doses.

NIOSH report and SC&A response

- NIOSH produced ORAUT-RPRT-0099, “Evaluation of EBR-II and BORAX-IV for ORAUT-0054 Applicability,” May 8, 2020.
- SC&A commented on ORAUT-RPRT-0099 in “Review of ORAUT-RPRT-0099, Evaluation of EBR-II and BORAX-IV for ORAUT-OTIB-0054 Applicability,” January 15, 2021.

EBR-II description

- Built by ANL as a scale-up from EBR-I and operated from 1961 to 1994
- Liquid metal fast breeder reactor, with passively safe design
- Unmoderated core with 67% enriched U-235, sitting in a tank of liquid sodium primary coolant, and cooled by a closed-loop liquid sodium secondary circuit
- Maximum power level of 62.5 MWth and 20 MWe
- Onsite reprocessing of spent fuel into new fuel pins
- EBR-II placed in High category because the only sodium-cooled fast reactor in the OTIB-0054 default library is the Fast Flux Test Facility (FFTF) at the Hanford site, which used mixed uranium and plutonium oxide fuel while EBR-II used only high enriched metal alloy fuel

BORAX-IV description

- 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
- BORAX-IV operated from 1956 to 1958 at a maximum power of 20 MWth and 2.5 MWe and at 300 pounds per square inch primary water coolant pressure
- Tested U-233, U-235, and thorium oxide ceramic fuel plates; some of the experiments intentionally caused fuel failure
- BORAX-IV was placed in the High category for 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 short campaigns resulting in low fuel burnup

OTIB-0054 reactor modeling overview

- OTIB-0054's complex reactor physics modeling process consists of cross section and source term generation, decay time specifications, physical and operational reactor specifications, and dose calculations.
- OTIB-0054 source terms were generated using the TRITON and ORIGEN modules in the SCALE code system.
  - TRITON, a reactor physics module for transport, depletion, and sensitivity analyses, generated radionuclide concentrations as a function of burnup.
  - ORIGEN, a general-purpose point depletion and decay module, generated fission and activation product inventories for OTIB-0054's library of 4 reactors and 9 cases.

RPRT-0099 reactor modeling

- RPRT-0099 used ORIGEN to generate radioisotope inventories for the two INL reactors at 10 days, 40 days, 180 days, and 1 year to conceptually correspond to different stages in the fuel cycle.
- RPRT-0099 assessed OTIB-0054 applicability to EBR-II and BORAX-IV reactors by comparing doses calculated with two approaches:
  1. OTIB-0054 with its built-in source term and other data for its archetypical FFTF, Advanced Test Reactor, and TRIGA reactors
  2. Source terms and other data generated specifically for EBR-II and BORAX-IV based on available operational and physical information
- 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 exposures).

ORAUT-RPRT-0099 dose comparisons

- RPRT-0099 compares doses calculated using the generic OTIB-0054 library to those calculated using reactor-specific data by looking at ratios of the two methods for worst case 2- and 10-year chronic exposures to different organs:
  - Ratios greater than 1.000 imply that the generic OTIB-0054 evaluation is more claimant favorable.
  - Ratios less that 1.000 imply that the generic approach is less favorable.
- **Results:** All dose ratios are greater than 1.000 for EBR-II and BORAX-IV reactors, which indicates that the generic OTIB-0054 approach is more claimant favorable than the reactor-specific approach, the degree ranging up to about a factor of 9.

SC&A evaluation summary

- 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 doses.
- However, experimental reactors EBR-II and BORAX-V have physical and operational characteristics that place them outside the space in which OTIB-0054, with its archetypical cases, was intended to operate.
  - EBR-II was liquid metal cooled and used highly enriched uranium metal fuel.
  - BORAX-IV fuel consisted of uranium and plutonium oxides, and the reactor was operated for short campaigns with low fuel burnup.
- SC&A reviewed RPRT-0099 and relevant data.
  - Although it did not conduct its own independent SCALE or OTIB-0054 modeling, SC&A assumes that NIOSH performed the analyses correctly.

SC&A conclusions and recommendations

- SC&A concurs with NIOSH's assertion 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, it appears that under certain circumstances, the standard OTIB-0054 approach may overestimate the reactor-specific organ doses up to a factor of 9 (details are in SC&A's review of RPRT-0099).
- SC&A recommends that NIOSH follow up its analysis with a discussion of why and under what conditions significant overestimation might happen and whether this can result in unrealistically high dose assignments.

Future reactor analyses

- 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 and that SC&A, NIOSH, and the WG classified as high-priority reactors needing further evaluation.
- NIOSH stated in RPRT-0099 that it is currently conducting corresponding analyses for the other high-priority reactors on the INL/ANL-W site and will report on them separately.

Questions?