# INL/ANL-W Reactor Prioritization & Other Reactor-Related Issues

INL/ANL-W WG Meeting

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May 16, 2017

# Introduction

- This presentation summarizes SC&A report: *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 (12/8/2016) to inform the INL/ANL-W Work Group in providing guidance to NIOSH with respect to:
  - Prioritizing new reactor and irradiated fuel characterization studies.
  - Addressing specific SC&A concerns related to modeling Test Area North (TAN) and Test Reactor Area (TRA) operations.

# Background

- A primary tool NIOSH uses for internal dose reconstruction is ORAUT-OTIB-0054, *Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gamma Analysis*.
- SC&A performed preliminary assessments in 2015 and 2016 of whether the OTIB envelopes, with sufficient accuracy, the important conditions of the INL and ANL-W reactors, and prioritized the reactors into High, Medium, and Low categories for further detailed investigations.
- NIOSH responded (7/28/16) with a plan for additional reactor evaluations.
- SC&A's latest report, *INL SEC-00219 and ANL-W SEC-00224: SC&A Response to NIOSH Reactor Analysis Plan and Consolidation of all Reactor Modeling Comments* (12/8/16), addresses the NIOSH report, consolidates all SC&A comments related to reactor evaluation prioritization, and adds an appendix on workforce and exposure potential.

# INL/ANL-W

- Operations at the INL and ANL-W sites involving radioactive materials were very complex, and many unique nuclear reactors and experiments were built and tested, with different fuel types, blankets, reflectors, moderators, coolants, operating scenarios, and burnups.
- There were a total of 52 reactors at the INL site.

**INL Site Reactors**

| Location | Number |
|---|---|
| INL | 34 |
| ANL-W | 12 |
| NRF (Naval Research Facility) | 4 |
| Never Operated | 2 |

# ORAUT-OTIB-0054

- NIOSH uses OTIB-0054 to determine internal doses when only gross beta or gross gamma measurements are available by assigning fission and activation product intakes for different radioisotopes that are directly tied to an indicator radionuclide (strontium-90 [Sr-90] or cesium-137 [Cs-137]).
- The OTIB generated 9 different representative cases based on four reactors, which are intended to envelope the range of reactor and nuclear fuel types and operating scenarios.

| Reactor Type | Reactor |
|---|---|
| High Flux Reactors | Advanced Test Reactor (ATR) |
| Na-Cooled Fast Reactors | Fast Flux Test Facility (FFTF) |
| Pu Production Reactors | Hanford N-Reactor |
| Research Reactors | TRIGA with Stainless Steel Cladding |

# SC&A Priority Rankings

- SC&A assigned priority rankings to each applicable reactor for further, detailed analyses, considering the factors below, which are likely to indicate if the radionuclide mixtures in OTIB-0054 might result in an under or unrealistic estimate of internal doses.
  - Fuel type, enrichment, and cladding
  - Moderator and reflector
  - Coolant
  - Operational mode and whether it was inside or outside design limits
  - Length of operation/overall burnup
  - Number (approx.) of potentially exposed workers (Appendix A)
  - Incidents or other factors with potential to contribute to the risk of unintended/unprotected exposures

# SC&A Priority Rankings

- SC&A categorized seven INL and seven ANL-W reactors in the High Priority category for further studies:
  - INL: LOFT (Loss of Fluid Test Facility); OMRE (Organic Moderated Reactor Experiment); PBF (Power Burst Facility); SPERT-I, -II, -III, -IV (Special Power Excursion Reactor Test)
  - ANL-W: BORAX-I, -II, -III, -IV, -V (Boiling Water Reactor Experiment); EBR-1, -II (Experimental Breeder Reactor)

# NIOSH Response

NIOSH proposed (7/28/16):

- Merging the INL and ANL-W high priority category reactors for detailed evaluation of OTIB-0054 applicability using the ORIGEN isotope generation and depletion code.
- Eliminating several reactors from the high priority category: LOFT, BORAX-I, -II, -III, -V. Reasons are given in the report.
- Modeling the most extreme experiment from all four of the SPERT reactor tests as a “bounding case.”
- Modeling the most bounding case of the last two EBR-I cores.

# NIOSH Response

**Summary: Reactors that NIOSH Proposes to Evaluate**

| | |
|---|---|
| OMRE | Organic Moderated Reactor Experiment |
| PBF | Power Burst Facility |
| SPERT I-IV | Special Power Excursion Reactor Tests |
| BORAX-IV | Boiling Water Reactor Experiments |
| EBR-I (Core 4) | Experimental Breeder Reactor-I |
| EBR-II | Experimental Breeder Reactor-II |

# SC&A Response to NIOSH

| No.[a] | NIOSH Recommendation[b] | SC&A Response |
|---|---|---|
| 1 | NIOSH proposes merging the INL and ANL-W high priority category reactors for evaluation of OTIB-0054 applicability. NIOSH also proposes that after the evaluation of the high priority category reactors is completed, any concerns regarding the medium and low priority category reactors can then be addressed. | **SC&A concurs**. Whether a reactor is classified as an INL reactor or an ANL-W reactor is immaterial to the reactor modeling work. Treating them together and generating a single report would reduce repetition in NIOSH's report-writing and the Board's and SC&A's reviewing efforts. |
| 2 | NIOSH proposes that the LOFT be removed from consideration for evaluation of OTIB-0054 applicability at this time because nuclear operations did not commence until December 1978. | SC&A recognizes that the first five LOFT experiments were non-nuclear, thermal-hydraulic experiments and that the potential for radiation exposure did not occur until December 1978, which is after the INL SEC-00219 period. **SC&A believes** that, given the facility's size, long operating history, beyond-design-basis operating scenarios, and potential to have exposed a significant number of personnel, the LOFT reactor merits a more detailed examination with respect to whether it can be adequately modelled by OTIB-0054. Such an examination could be conducted as a site profile exercise. |
| 3 | NIOSH agrees that the OMRE should be evaluated for OTIB-0054 applicability due to its unique moderator and coolant. | **SC&A agrees** with NIOSH's characterization with respect to OTIB-0054 and notes (Section A.5) that, based on the limited data available (only for the last year of operation), there appears to be a significant potential for exposure of hundreds of regular workers and visitors. |

# SC&A Response to NIOSH (cont.)

| No.[a] | NIOSH Recommendation[b] | SC&A Response |
|---|---|---|
| 4 | NIOSH agrees that the PBF should be evaluated for OTIB-0054 applicability due to the use of ceramic fuel. | **SC&A agrees** with NIOSH's characterization with respect to OTIB-0054 and notes (Section A.3) that, based on the limited data available (only for the first few years of operation), there appears to be a potential for exposure of typically less than 100 regular workers and visitors per month. |
| 5 | NIOSH proposes that a model for the most extreme experiment from all of the SPERT, in terms of possible departures from OTIB-0054, be used to represent the "bounding" case to cover all four SPERT reactors. | **SC&A disagrees** with NIOSH's recommendation. Although the four SPERT reactors were all part of the same series of reactor experiments that subjected the reactor systems to large reactivity excursions, as seen in the summaries of Table 1, they differed significantly from each other and should be examined separately, perhaps by choosing the "worst case" scenario for each reactor. NIOSH should justify in its report its choice, perhaps by performing some preliminary calculations to determine the "bounding case" |

# SC&A Response to NIOSH (cont.)

| No.[a] | NIOSH Recommendation[b] | SC&A Response |
|---|---|---|
| 6 | BORAX Nos. I, II, and III all ceased operations before the end of the approved SEC period for ANL-W. NIOSH proposes BORAX Nos. I–III be removed from consideration for evaluation of OTIB-0054 applicability as their operating years are covered by the SEC period when bioassay data are known to be incomplete and an infeasibility to reconstruct doses has already been established. NIOSH agrees that BORAX-IV should be evaluated for OTIB-0054 applicability due to the use of uranium-thorium oxide fuel. NIOSH proposes that BORAX-V be removed from consideration for evaluation of OTIB-0054 applicability because its primary function was to evaluate steam superheating with essentially the same configuration as BORAX-IV. | **SC&A concurs** with NIOSH's assessment about OTIB-0054 and notes (Appendix A) that individual documentation concerning the workforce at the BORAX-IV experiment in 1958 could not be located and, therefore, is not discussed further. |

# SC&A Response to NIOSH (cont.)

| No.[a] | NIOSH Recommendation[b] | SC&A Response |
|---|---|---|
| 7 | NIOSH proposes that the most bounding of the last two EBR-I cores be used. While it is initially believed the plutonium core would be bounding, some preliminary modeling would need to be performed on all four cores to confirm this. | **SC&A concurs** with NIOSH about OTIB-0054 and expects that the resulting NIOSH report will make a compelling case for which core is bounding. In addition, SC&A notes (Section A.1) that several hundred workers and visitors were present during the period of operation for the MARK IV core. |
| 8 | NIOSH agrees that EBR-II should be evaluated for OTIB-0054 applicability. | **SC&A concurs** with NIOSH about OTIB-0054 and notes (Section A.2) that hundreds of workers and visitors could have been exposed each year; in some years, the average worker penetrating doses were greater than 100 mrem. |

<u>Notes</u>:

The above table is taken from: *INL SEC-00219 and ANL-W SEC-00224: SC&A Response to NIOSH Reactor Analysis Plan and Consolidation of all Reactor Modeling Comments,*12/8/16. “Bolding” added here.

(a) Numbering added here from bulleted list in NIOSH 7/28/16 report.

(b) Recommendations copied from the NIOSH 7/28/16 Conclusions section.

# SC&A Response to NIOSH

- Appendix A of the 12/8/16 SC&A report examines exposure potential:
  - Prioritized reactor sites generally employed 100s of monitored workers, except for the PBF, which appears to have assigned only about 30 workers during most of its badging cycles.
  - Penetrating doses at the prioritized reactor sites were significant, with some monthly badging cycles averaging 100s of mrem.
  - While external exposures do not necessarily imply internal exposure potential, the magnitude of these external doses is indicative of the source terms being considered.
  - Coupled with the extensive internal dosimetry program at INL for fission products, an adequate characterization of the mix of source term contaminants appears warranted.

# SC&A Response to NIOSH

- SC&A issued targeted reports on 9/28/15 examining the applicability of OTIB-0054 to reactors in the INL **TAN** and **TRA** facilities. Comments from these two reports are collected in the SC&A 12/8/16 report for completeness.

# Test Area North (TAN)

- SC&A examined the applicability of OTIB-0054 and Tables 5-22 and 5-23 (Actinide to Sr-90 and Actinide to Cs-137 Ratios, respectively) of the INL Internal Dosimetry TBD to the performance of internal dose reconstruction for facilities that handled and stored spent and irradiated fuel at TAN.
- The spent and irradiated fuel from the **Heat Transfer Reactor Experiment (HTRE)** tests was of particular interest because the reactor, fuel, and operational combinations that underpin the OTIB-0054 methodology reflect situations in which burnup often occurred over protracted periods of time (hundreds of days) and the fuel maintained its integrity. In contrast, the fuel at HTRE had very short burnup times and the reactors operated at high temperatures, allowing the fuel to melt.
- In addition, HTRE employed highly enriched uranium, as opposed to the enrichment levels of the uranium in the fuel used to derive the mix of fission and activation products provided as default mixes in OTIB-0054 and TBD Tables 5-22 and 5-23.

# Test Area North (TAN)

- To explore these potential concerns, SC&A performed ORIGEN-ARP runs, where the isotopic mixtures of fission and activation products were compared at different lengths of continuous operation at 20 MW (low power) and at 200 MW (high power): 20 hours and 200 days for both power levels, and an additional 20 day-run for the high-power case.
- These scenarios were intended to provide a general representation of the operating conditions of the HTRE tests (e.g., HTRE-1 was operated at 20 MW for 150.8 hours).

# Test Area North (TAN)

- The 200-day cases are indicative of the long burnup times used to derive the relative mixes of radionuclides in Tables 7-3a through 7-3i (the nine characteristic reactor cases) of OTIB-0054, while the shorter burnup times (20 days and 20 hours) are typical of many of the TAN experiments.
- SC&A analyses assumed a fuel cool-down period of 10 days, and then multiplied the relative amounts of fission products produced by selected organ dose conversion factors (DCFs), which yielded a relative "index of harm" for each fission product. SC&A then summed the indices of harm for the fission products for each of the burnup durations.

# Test Area North (TAN)

- In summary, the results of these investigations revealed the following for **fission products**:
  - For the high power level (200 MW), the indices of harm for the 20-day burnup and the 20-hour burnup were about the same as, slightly higher than, or slightly lower than (i.e., claimant favorable), the 200-day burnup for all organs of concern, except for the thyroid, for which the relative index of harm was substantively higher (i.e., 8.29).
  - For the low power level (20 MW), the derived indices of harm for the 20-hour burnup compared to the 200-day burnup for all organs of concern were not claimant favorable.

# Test Area North (TAN)

- For **actinide activation products,** for all cases analyzed, the ratios of the inventories of all actinide activation products to the inventories of Cs-137 and Sr-90 were grossly overestimated compared to the ratios in Tables 5-22 and 5-23 of the TBD. SC&A's scoping analyses stopped at this point.
- **SC&A recommends** that NIOSH continue these types of investigations to better understand the applicability and limitations of OTIB-0054 and TBD Tables 5-22 and 5-23 applied to reconstructing internal doses to TAN workers involved in irradiated and spent fuel operations, where the power levels and burnup durations were significantly different from those upon which the isotopic mixes were derived in OTIB-0054 and TBD Tables 5-22 and 5-23.

# Test Reactor Area (TRA)

- Another 9/28/15 SC&A report examined the three TRA reactors and their operations to determine if they are adequately enveloped by OTIB-0054: Materials Test Reactor (MTR; 1952–1970), Engineering Test Reactor (ETR; 1957–1981), and ATR (1967–present).
- All are material testing reactors with similar designs, but with size, power level, and capabilities increasing from the first to the last; the maximum power level was MTR - 40 MW; ETR - 175 MW; and ATR - 250 MW.
- Their high-flux capability allows for the accelerated simulation of long-term irradiation of reactor materials. Each is a pressurized, light-water-moderated, beryllium-reflected reactor, primarily using highly enriched uranium fuel arranged in an unusual curved plate configuration. The primary reactivity control mechanism consists of rotating beryllium cylinders with hafnium shells.

# Test Reactor Area (TRA)

- SC&A found that OTIB-0054 adequately envelopes the three TRA reactors (the OTIB explicitly models the ATR) for uranium fuel operations, but noted that the **MTR also ran for a period with plutonium (Pu) fuel**; in 1958 it became the first reactor run with a Pu-239 core. The MTR-Phoenix experiment was a demonstration project for a potential high-power, compact reactor to convert the fertile Pu-240 to the fissile Pu-241 through neutron capture.

# Test Reactor Area (TRA)

- **It is not clear** which, if any, of the nine OTIB-0054 representative reactor cases would adequately envelope the MTR with plutonium fuel. Although the MTR plutonium fuel operations used fuel plates physically similar to those used in the uranium fuel, and the rest of the reactor configuration was not significantly modified, the nuclear properties of plutonium differ from those of uranium, and the fission product abundance distribution and core neutron spectrum (and, hence, activation product yield) would be different. The issue of whether OTIB-0054 adequately envelopes the MTR when fueled with plutonium merits further investigation and discussion by NIOSH.