INL/CON-24-81796-Revision-0

Lessons Learned During UCl3-NaCl Fuel Salt Capsule Irradiation

November 2024

Changing the World's Energy Future

Toni Y Karlsson, Morgan Tess Kropp

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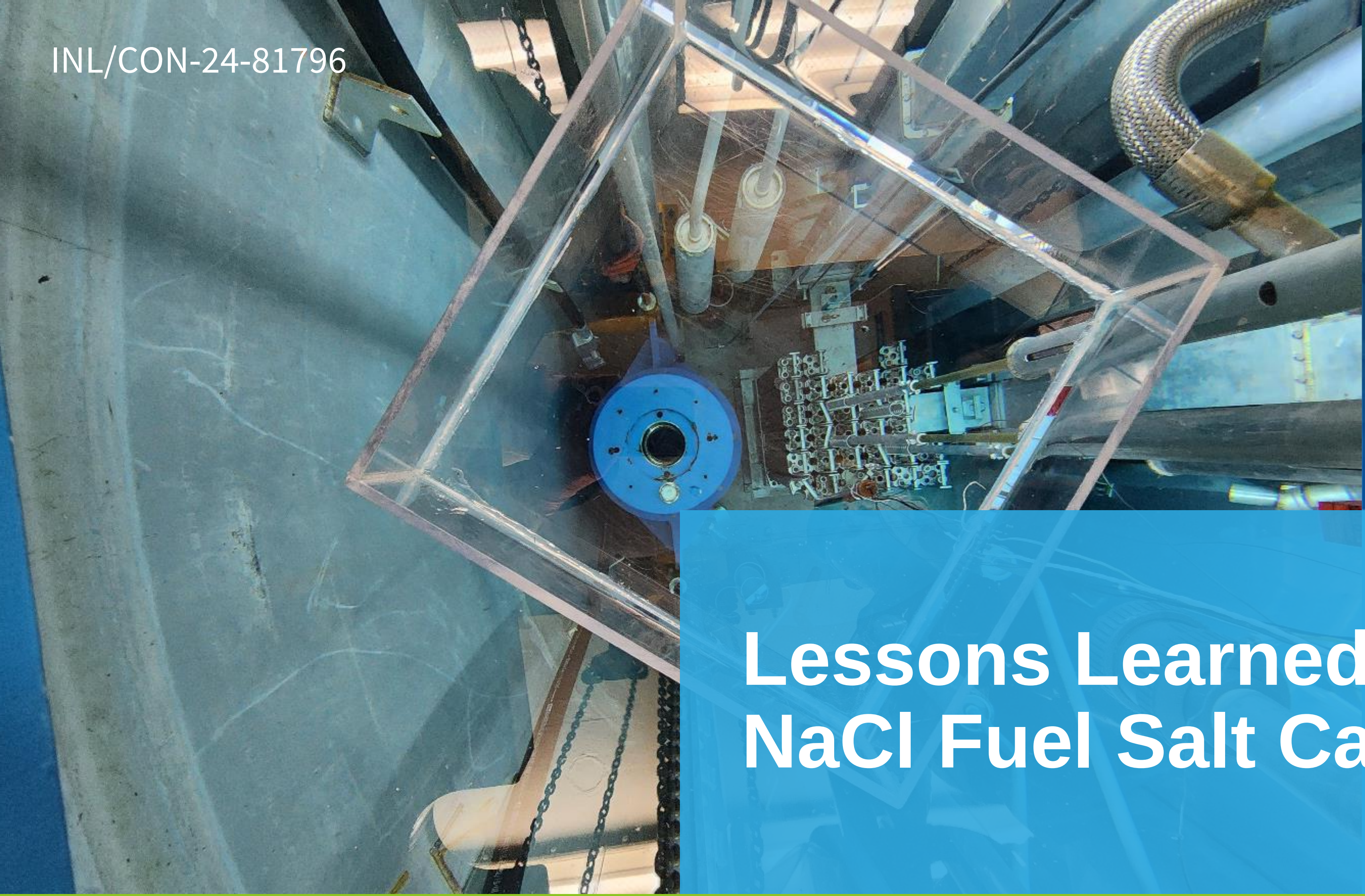

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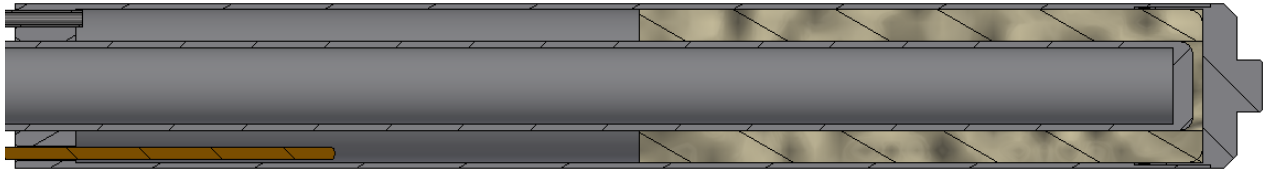
Pyrochemical Science, Research Scientists

Lessons Learned During UCl_3-NaCl Fuel Salt Capsule Irradiation

Outline

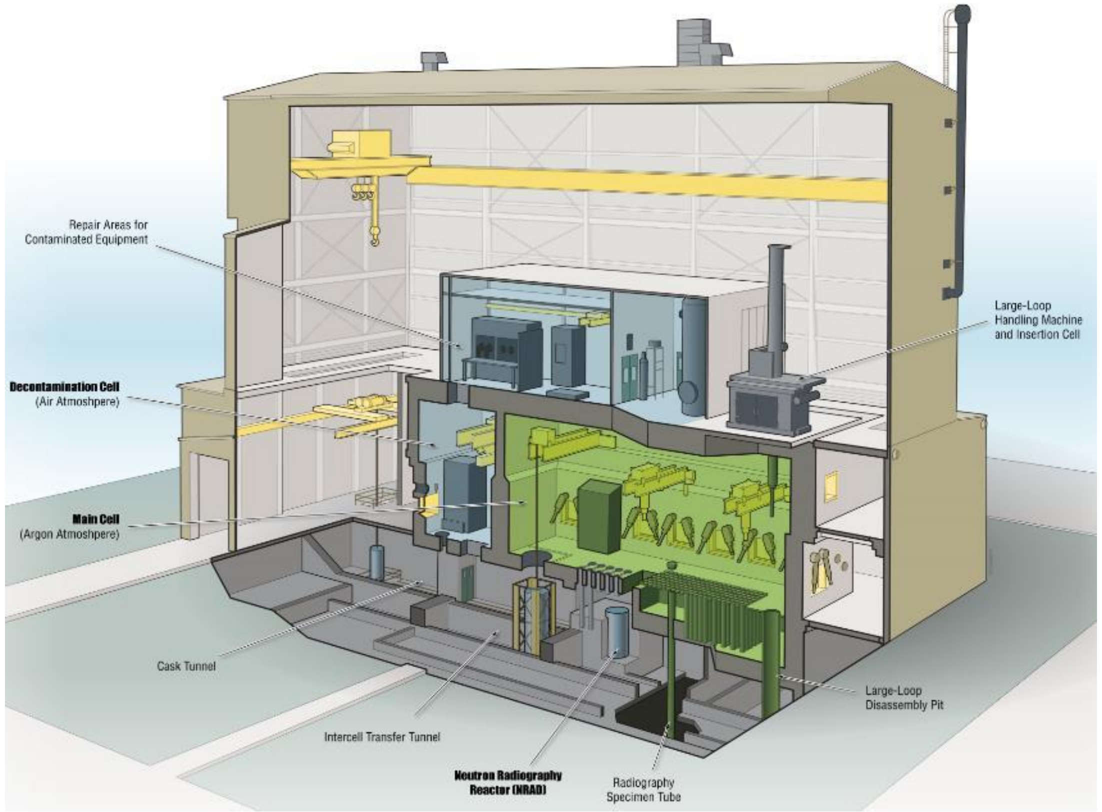
- Overview
- Irradiation facility
- Vehicle Design
- Timeline
- Lessons Learned
- Summary
- Acknowledgements

Overview



- Salt: ~41g of $0.33UCl_3$-$0.67NaCl$ (93wt% ^{235}U)
- Capsule material: Inconel-625
- Other structural material: SS-316
- Plenum gas: Ar
- Outer can: 15He/85Ar mixture
- Predicted fuel performance under irradiation
  - Fission Heat = 20 W/cm^3
  - Neutron Flux = 3.5×10^{12} n/cm^2-s
  - Gamma Flux = 1.4×10^{13} γ/cm^2-s
  - Salt Temperature = 525-900°C

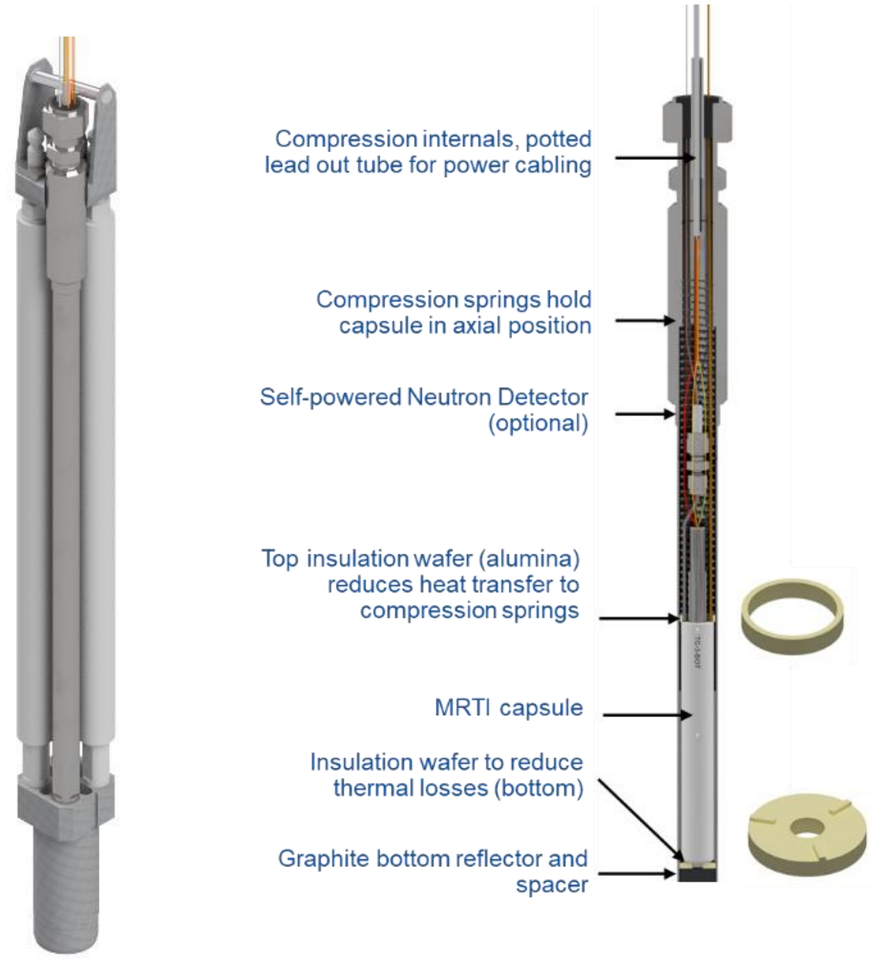
Irradiation Facility



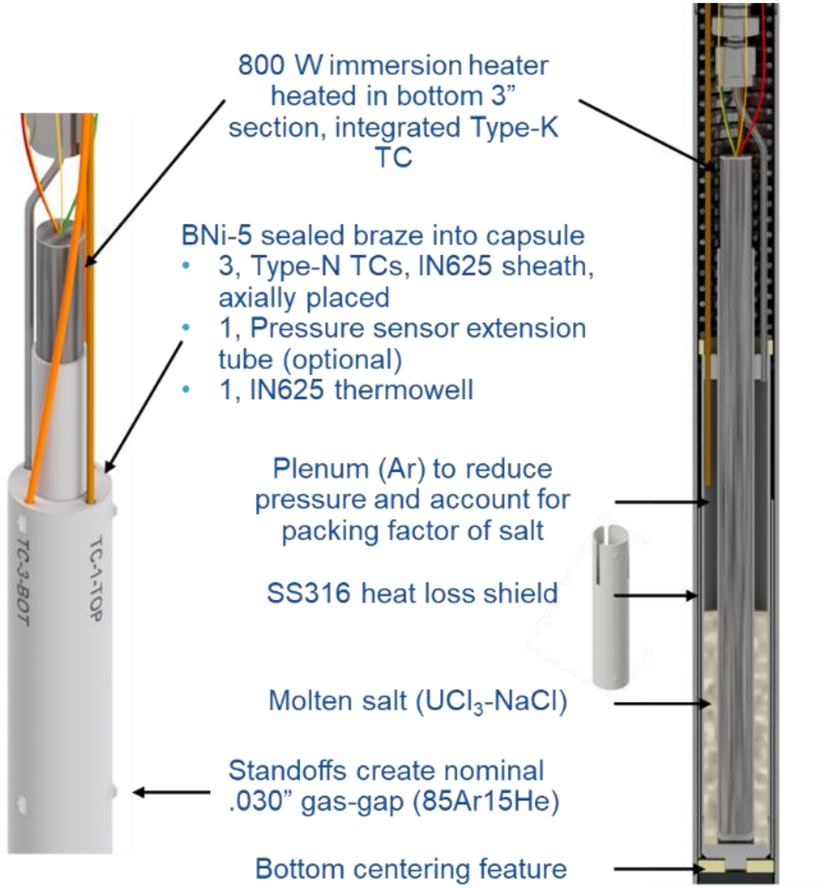
- Neutron RADiography (NRAD) Reactor
- 250 kW TRIGA-fuel MTR-grid pool reactor
  - Typically used for neutron radiography PIE
  - Pool reactor (no pressure)
  - Only TRIGA that handles HEU
  - No experiment traffic/schedule, irradiate by request
- Immediate access to HFEF for quicker turnaround PIE

Capsule Design

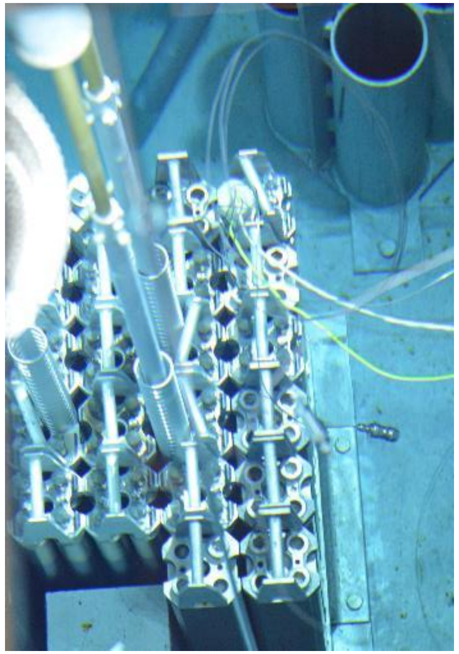
Outer Can/Cluster

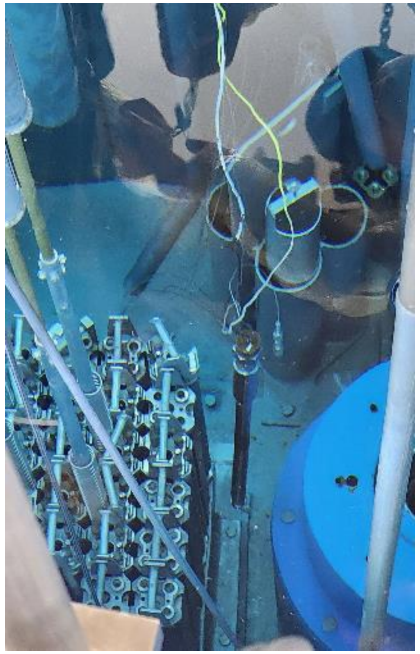


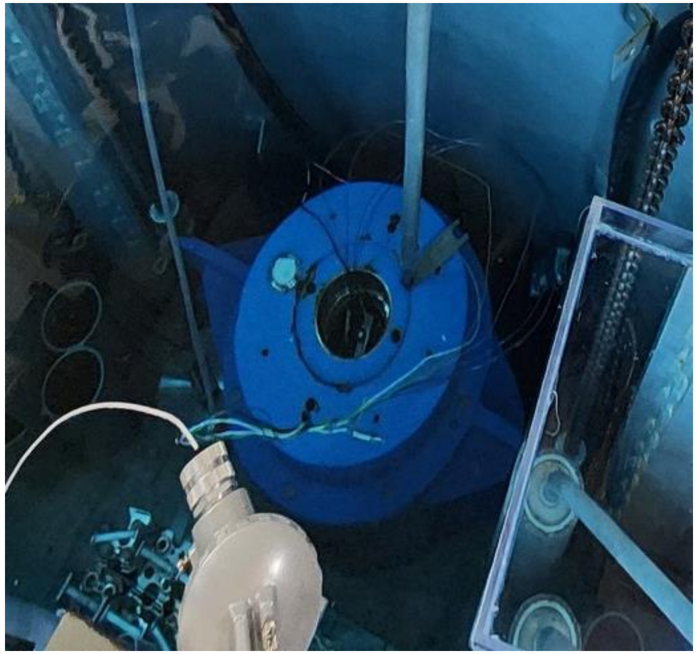
Inner Capsule



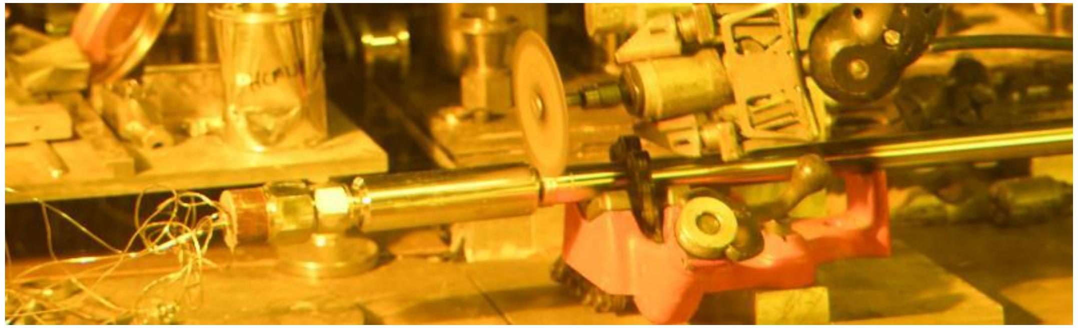
Placement and Removal from NRAD

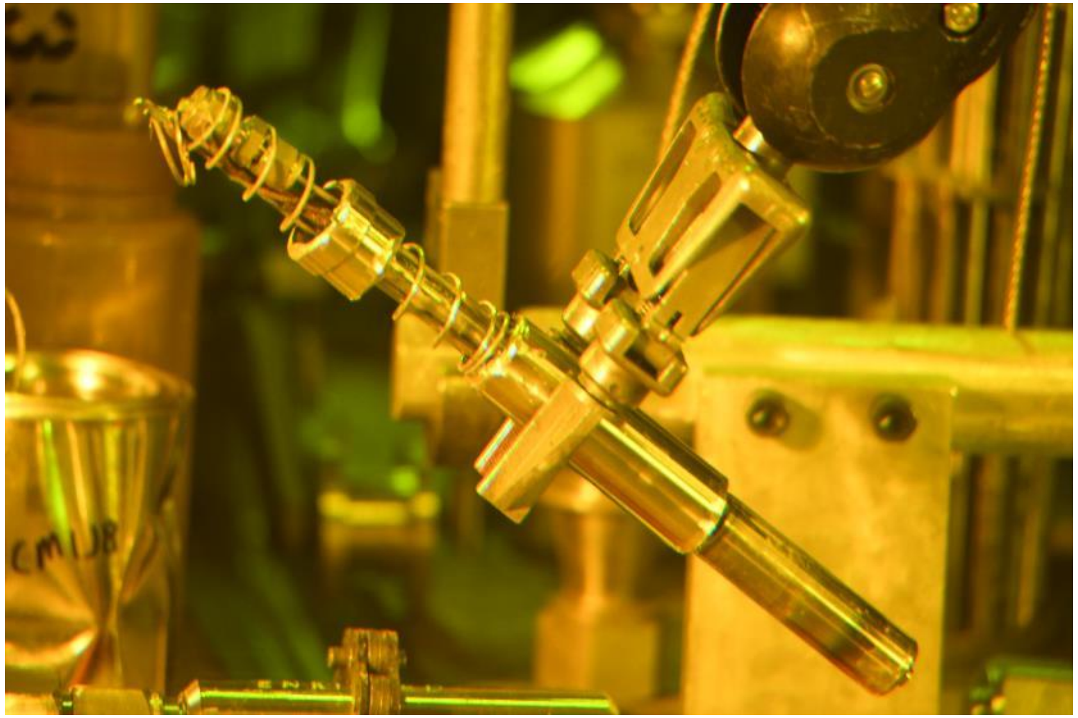






Timeline



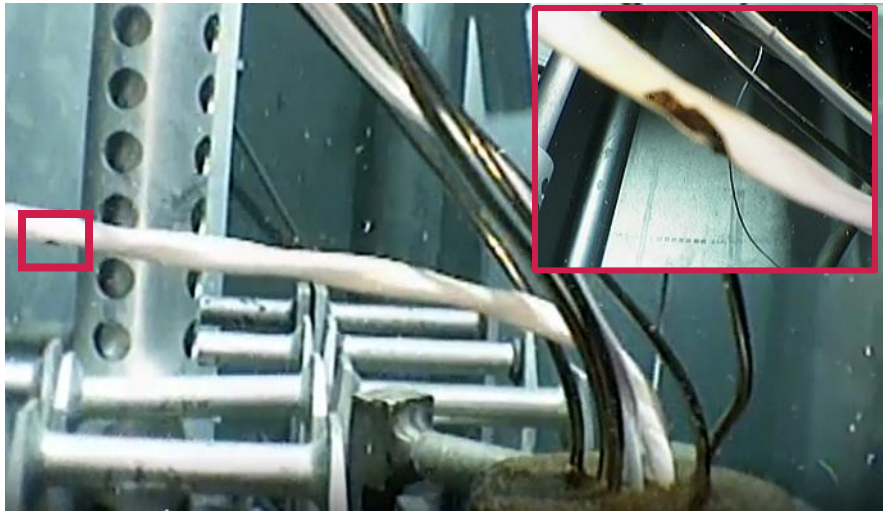


- Capsule design and fabrication: 2020-2022
- Fuel loaded into capsule: April 2023
- Capsule placed into NRAD core: August 21st 2023
- Irradiation complete: June 4th 2024
  - 390 hr
  - 0.196 GWd/MTU
- Transfer to Ar cell: June 25th 2025
- Capsule disassembly: July 9th 2025
- “Rapid” PIE performed
  - Radiography
  - PGS

Timeline – Lessons Learned

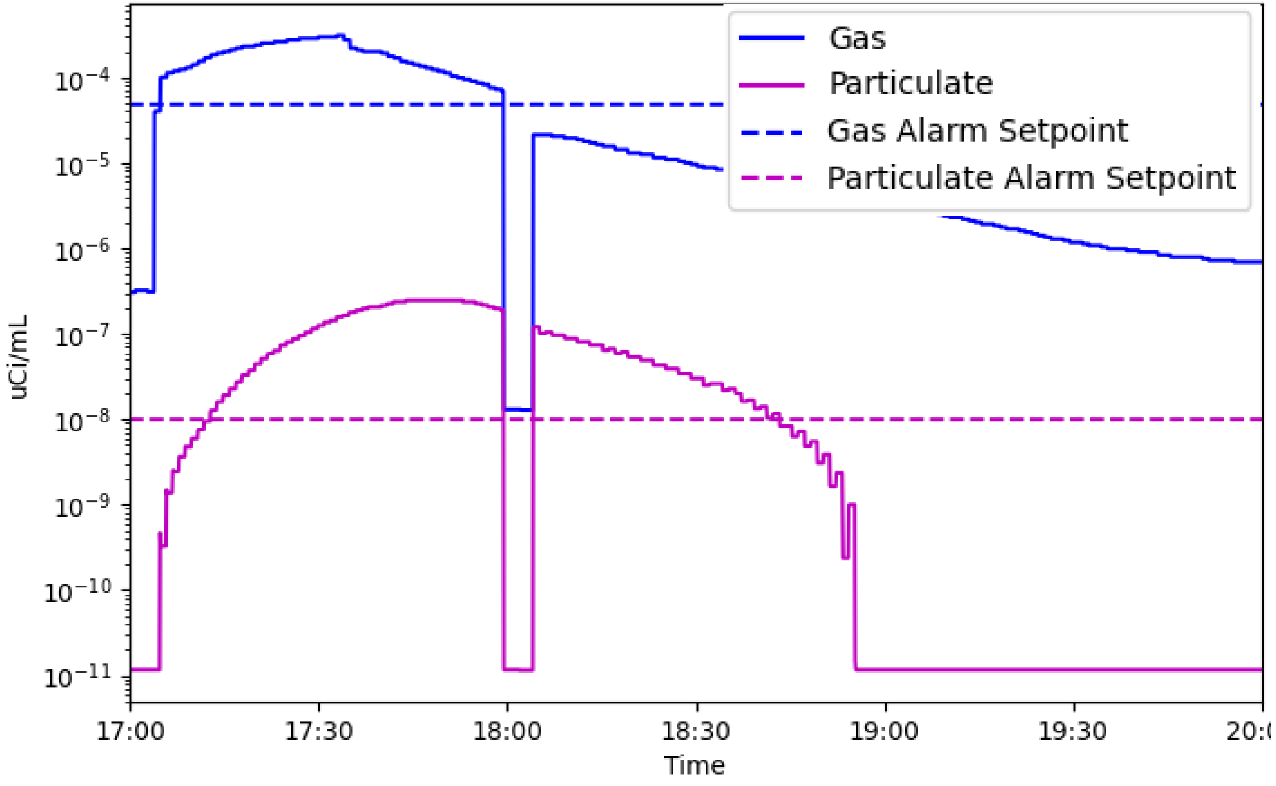
- Capsule design and fabrication: 2020-2022
  - New thermal paste used on heater
- Fuel loaded into capsule: April 2023
  - Ar/He gas loading for heat transfer
- Capsule placed into NRAD core: August 21st 2023
  - Furnace failure
- Irradiation complete: June 4th 2024
  - Ar-40 decay time
  - 36-hour operations
  - Cut tubing
  - CAMS
  - Contamination
- Transfer to Ar cell: June 25th 2025
  - Tolerances too tight
  - Breach of capsule

Lessons Learned - Materials



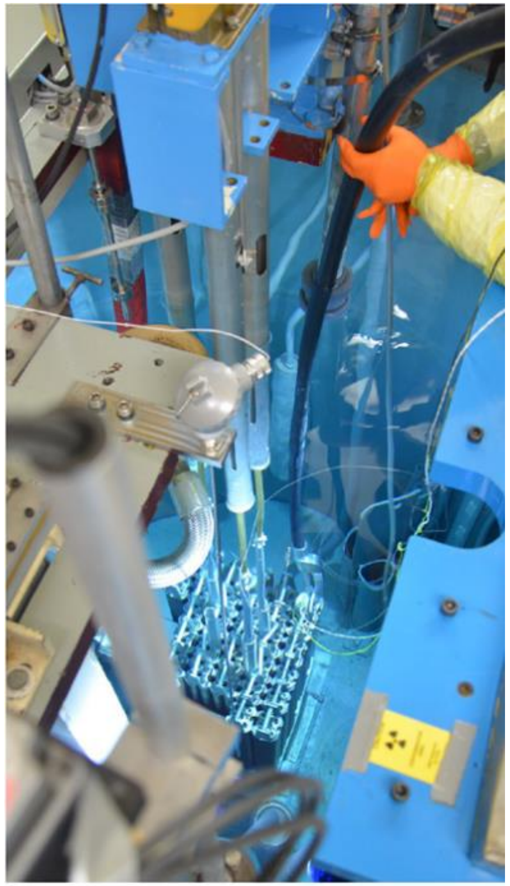
- Heater
  - Cables used PTFE (Teflon) insulation – waterproof and high temperature resistance, but not radiation resistant
  - Radiation resistant cables were not available for heater unit
  - Assumed that gamma dose would be low due to the peripheral positioning and that heater would be adequate
  - Insulation flaked off due to embrittlement and possible water flow erosion
  - Exposed wires caused heater to short and fail

Lesson Learned - Design



- Contamination Event
  - On Monday evening into Tuesday morning, we performed the final irradiation on MRTI.
  - The team then proceeded to recover the capsule from the NRAD reactor. The capsule was placed in the transfer cask and we were preparing to cut the leads, which included a gas-filled tube containing Ar/He mix (used for heat transfer).
  - As the tube was cut (according to procedure) several gas bubbles were seen.
  - Shortly thereafter, the continuous air monitors (CAMS) alarmed in the room.

Lesson Learned – Design Cont.



Cut: 4-TC’s, Ar/He fill line, heater power lines

- Personnel immediately evacuated the area.
- RadCon performed nasal swabs, sputum samples, and contamination surveys
  - No ALPHA contamination
  - CAM filter readings were also taken with inconclusive results (primarily Ar-41 although there were indications of other isotopes).

Lesson Learned – Design Cont.

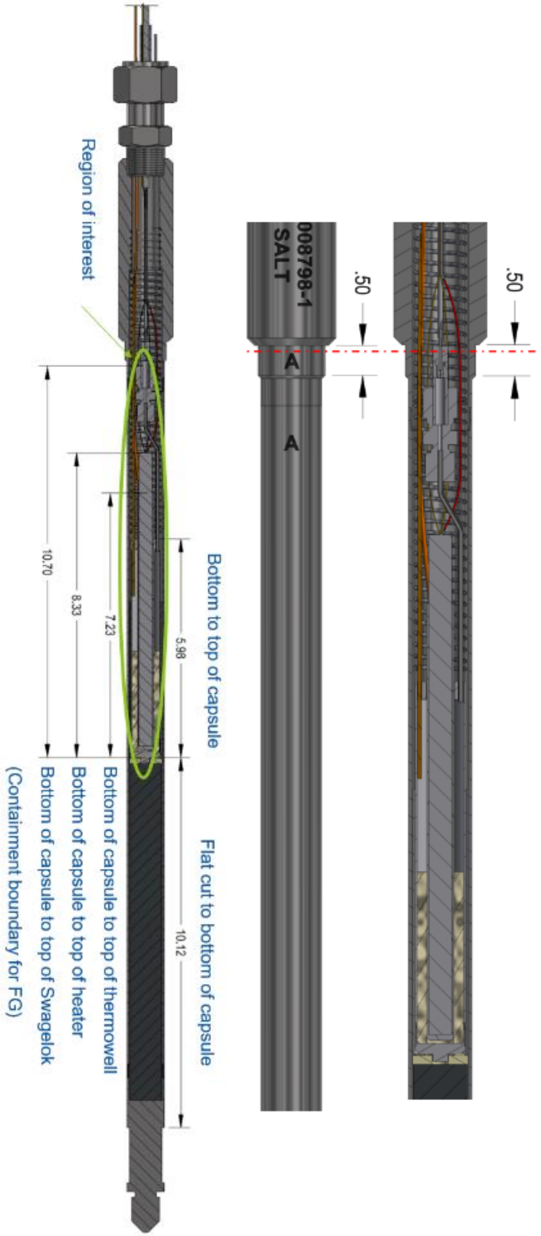
- 7 personnel were exposed to potential airborne activity.
- Initial direct scans of all entrants (5 Ops and 2 HPTs) were taken.
- The highest contamination levels measured were 35,000 dpm/scan beta/gamma with no detectable alpha.
- 7 of 7 whole body counts have been completed with no detectable dose above background.
- Analytical Laboratory performed gamma spec with no detectable isotopes after a 4-hour run, suggesting only short-lived isotopes were present.
- An overnight gamma scan yielded the same results.

Lesson Learned – Design Cont.

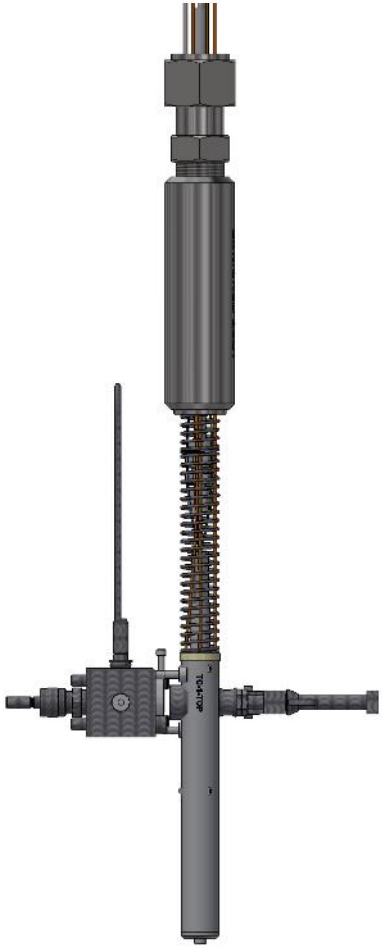
- Based on the information, it is postulated that the contributing cause to this event is an activated component of a heat transfer compound which contains sodium silicate as well as some other proprietary contents.

- **Personnel Fatigue**: some of the operators involved in the activity were on nights and the work had carried over into dayshift resulting in their work hours approaching the 24hr mark at the time of the event.
- **Failure to recognize the hazard**: During pre-planning meetings and during the pre-job brief, operators and experiment engineers did not recognize the gas as a hazard and were more concerned with water entering the capsule because of moderator limitations in HFEF hotcell
- **Time Pressure**: One of the objectives in the MRTI experiment was capturing iodine gas. In order to get a representative sample prior to decay, the experiment needed to be expedited to the HFEF hotcell. This resulted in changes to the procedure to remove the previously incorporated wait time.
- **Experience**: NRAD personnel have limited experience with irradiated capsules.

Lesson Learned – Tools/Design

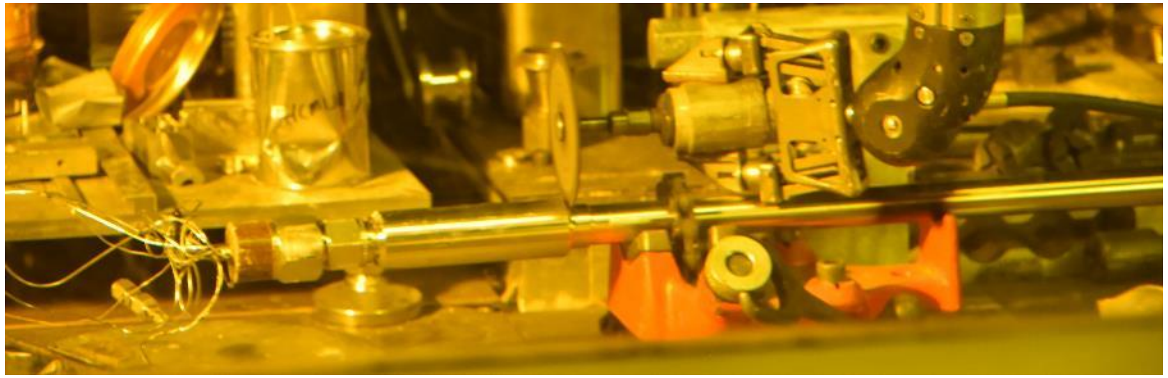


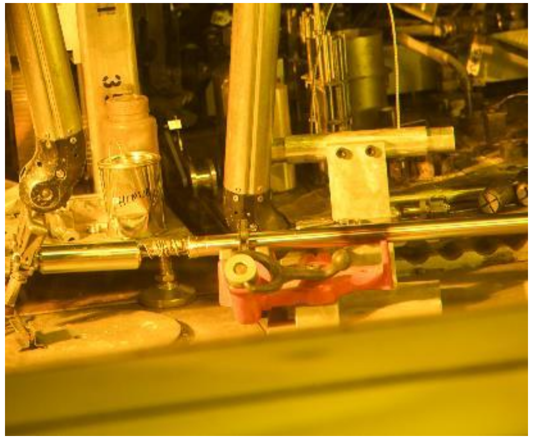
Cable bail hanging support for GASR

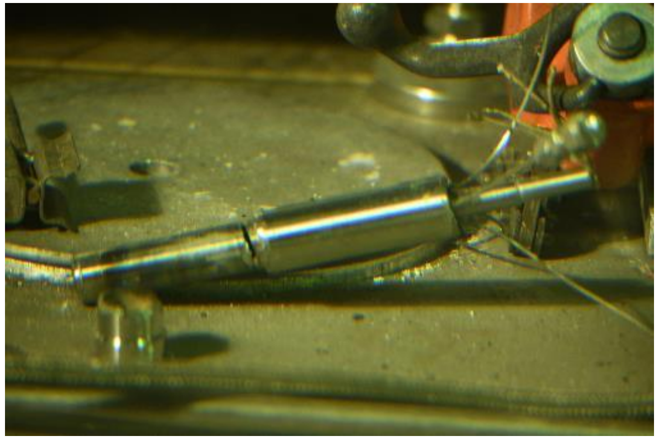


- Once MRTI assembly was transferred into the hotcell, disassembly was required to remove the capsule
- The first cut successfully opened the outer can revealing the spring, immersion heaters, and tubing
- However, the outer sleeve became stuck due to too tight tolerances, most likely due to the “stand-offs”

Lesson Learned – Tools/Design Cont.

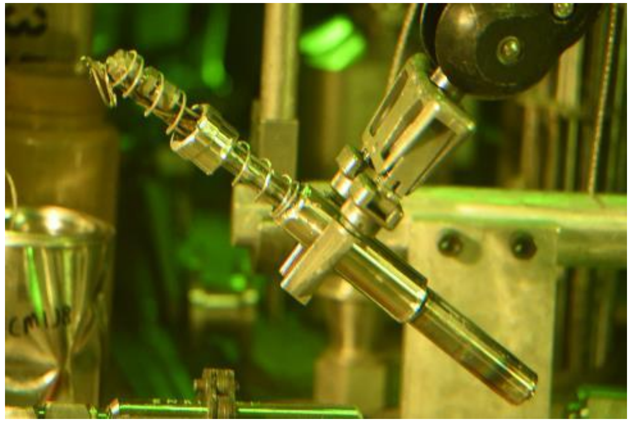


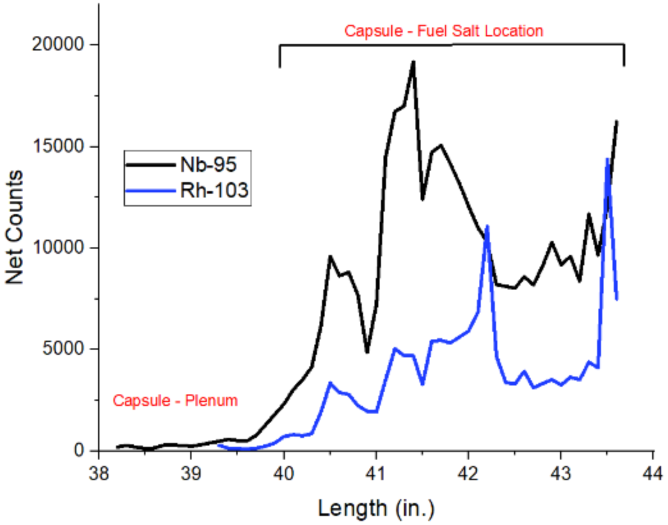


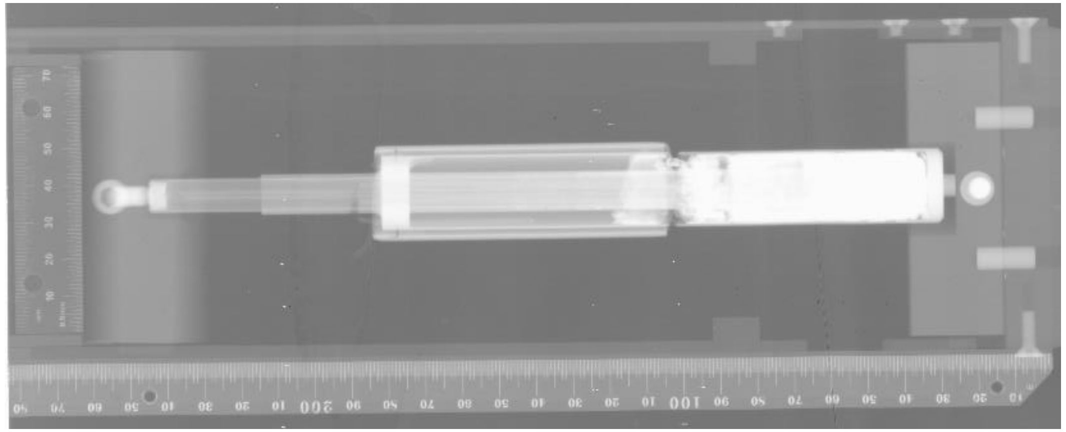


- Made unplanned cuts due to outer can being stuck
- Paused and came up with best option cut plan to remove outer can for plenum gas retrieval with GASR
- Tool available was “peanut grinder”
- Inconel capsule wall was very thin
- During cut, the capsule was breached, gas sample lost to hot cell

Summary







- We did many things wrong
  - Fatigue
  - Project turnover
  - Excessive paperwork
  - Focused on wrong things
  - Design did not consider PIE
  - Hot cell tools
- However, we will regroup, redesign, and try again.
- PIE will continue on this capsule
- Feedback is welcome!

Acknowledgements

- Big thanks to
  - Abdalla Abou Jaoude
  - Stephen Warmann
  - Evan Lovel
  - Mike Ruddell and entire NRAD crew
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  - Calvin Downey
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  - Hot cell operators
  - Many others!
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  - INL LDRD office
  - Molten Salt Reactor Campaign

Idaho National Laboratory

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MFC Immediate Lessons Learned
Inadvertent gas release from MRTI experiment

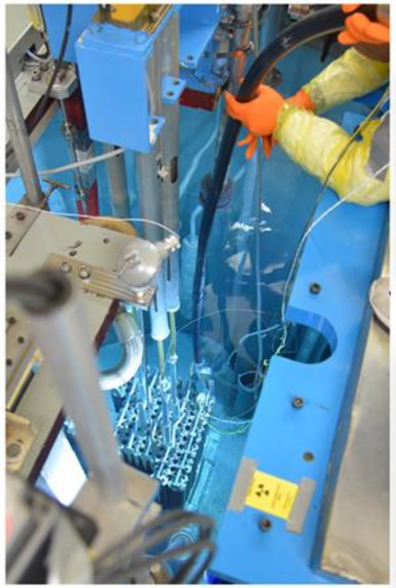
Summary

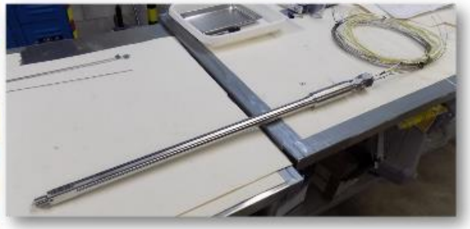
While loading the Molten-salt Reactor Temperature-controlled Irradiation (MRTI) capsule into the Neutron Radiography Reactor (NRAD) Cask, operators cut leads coming off the MRTI sample per NRAD-LI-0001. At the time of the event, the NRAD cask was located under water in the NRAD reactor tank.

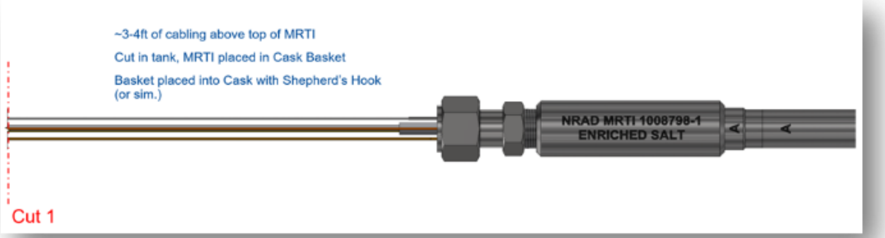
One of the cut leads was a purge gas line for the outer container of the experiment that contained an isolated volume of argon / helium (85/15) mix gas.

Short lived activated gases came out of the purge gas line and into the space of the NRAD reactor room. The NRAD Gaseous CAM alarm was received, and all personnel (5 Operators, 2 Health Physics Technicians (HPT)) evacuated through the HFEF cask tunnel and into the 008 area.

See CO 2024-1118.







Fact-Finding/Critique Results

- Purge gas was not recognized as a hazard and was not mitigated.
- Not all material contained in the outer container was analyzed in the Experiment Safety Analysis (ESA).
- Primary focus was on water getting into the sample, a moderator concern vs. activated gasses coming out.
- Some time pressure existed to get the sample transferred after reactor operations to preserve short-lived fission product data.
- Imprecise terminology in the controlling procedure prevented Radiological Controls (RadCon) staff from recognizing that the outer capsule would release activated gasses.
- Some operators had been working for the previous 24 hours prior to the event.

Actions

- All personnel evacuated the area, whole body surveys and internal monitoring was performed. No additional dose was assigned. All individuals were subsequently released by RadCon.
- The affected area was isolated and posted per RadCon requirements.
- The irradiation experiment process will be reviewed and improved.

Lessons Learned

- All potential hazards associated with work evolutions need to be considered during the planning and execution phases.
- Operations and Engineering need to involve RadCon in the planning and validation of work involving radiological hazards
- System response and potential hazards need to be understood prior to completing a critical step or irreversible action