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Molten-salt Research Temperature-controlled Irradiation (MRTI) Experiment Overview

Neutron Radiography (NRAD) Reactor

Molten Salt Reactor PROGRAM

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy

INL Idaho National Laboratory

Overview

- MRTI overview
- Why NRAD was chosen?
- Capsule/Experiment Design
- Installation
- Irradiation Overview
- Removal & Transfer to The Hot Fuels Examination Facility (HFEF)
- Post Irradiation Examination (PIE)
- Future Plans
- Questions?

Molten-salt Research Temperature-controlled Irradiation (MRTI) Experiment Overview & Goals

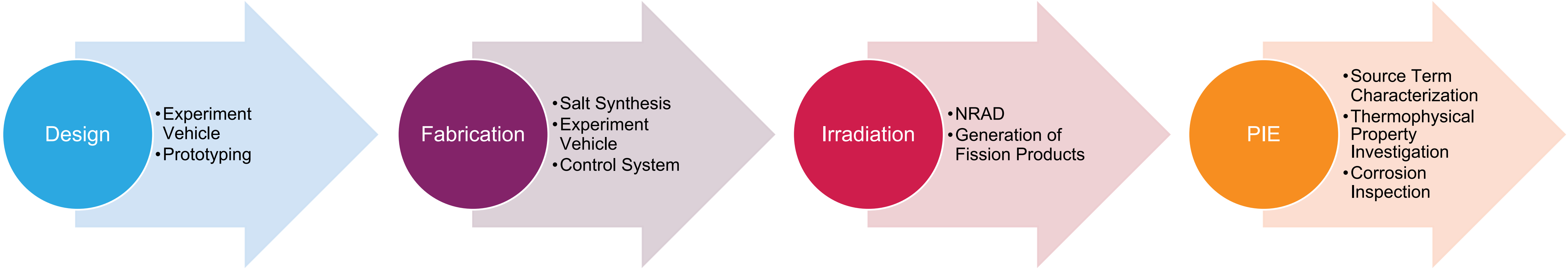
Establishment of a domestic neutron irradiation capability for fissile material-bearing salts at INL for Molten Salt Reactor (MSR) R&D.

Executing Research in Three Primary Areas

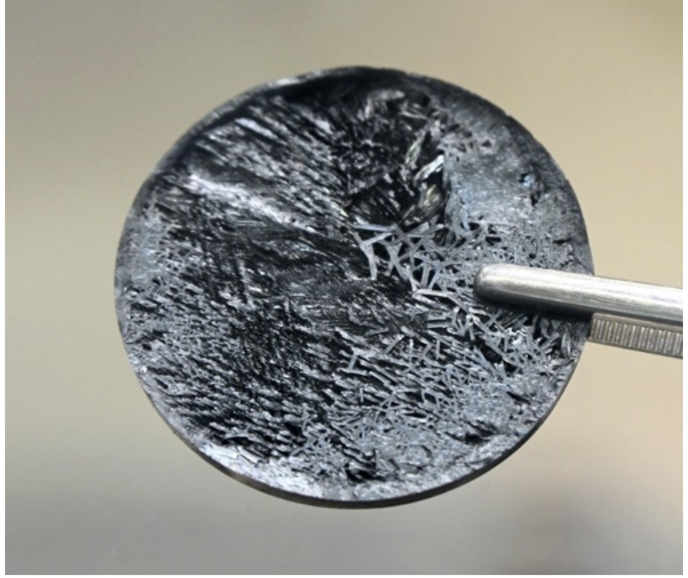
1. Radioactive Source Term Quantification
2. Thermophysical Property Evolution
3. Salt-facing Materials Corrosion

Mission Realization

Utilize the Neutron Radiography Reactor (NRAD) to irradiate molten fissile material-bearing chloride salt with salt-facing materials relevant to MSR development



First Use-Case: UCl_3-NaCl



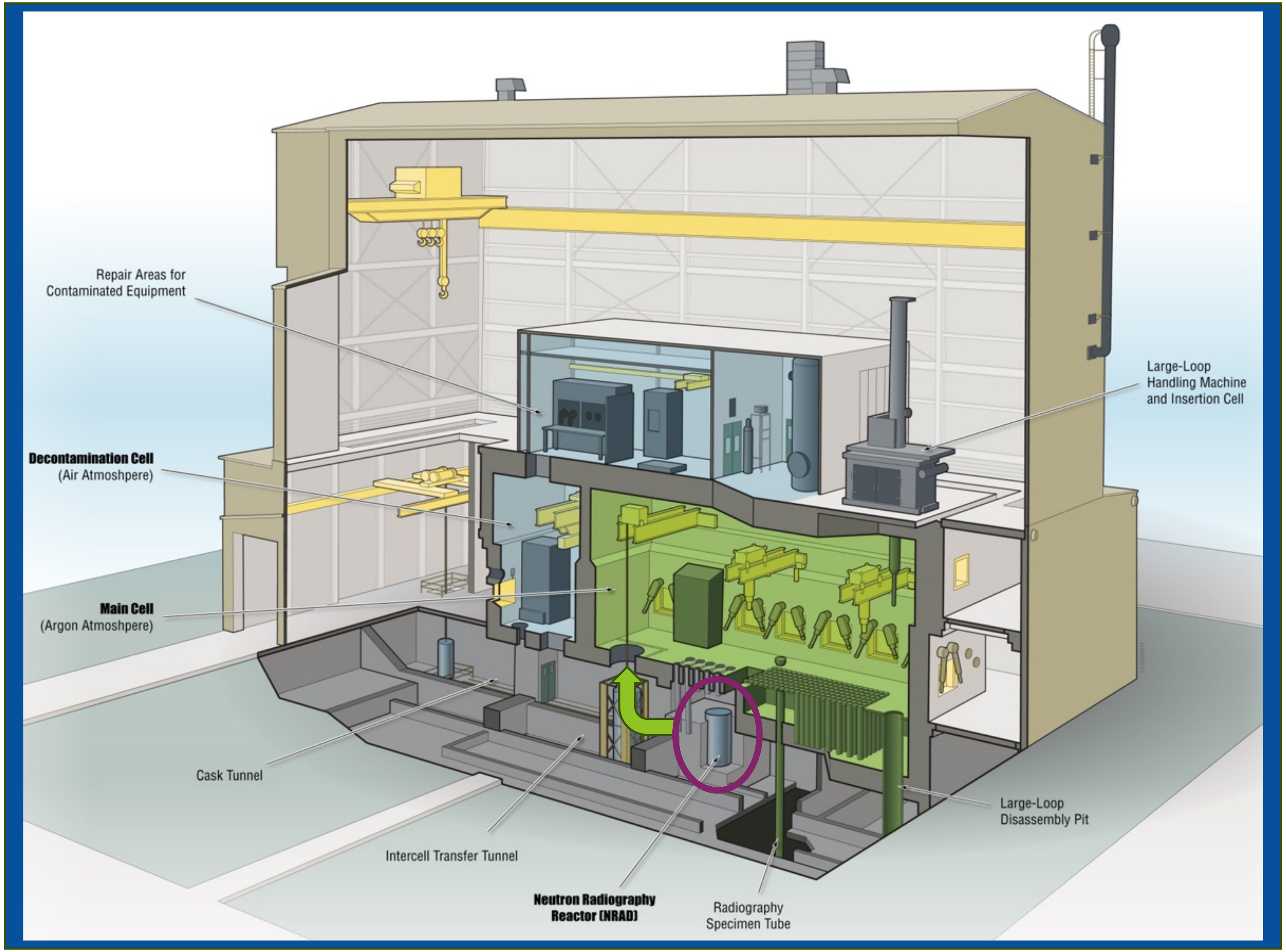
Sample of HEU-bearing salt

- Chloride salt selected as limited irradiation data
- Synthesized world's first sample of HEU (93wt% ^{235}U) bearing UCl_3-NaCl eutectic
- Salt-facing wall material: IN-625
- Other structural material: SS-316
- He/Ar mixture for experiment: 15/85

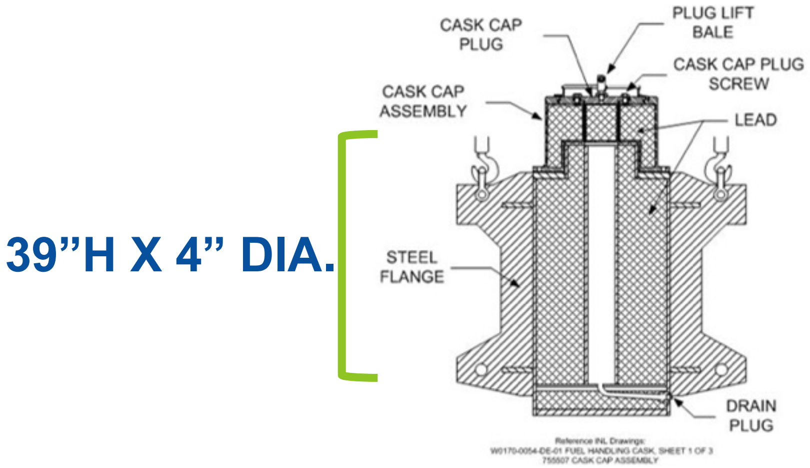
Predicted performance under irradiation:

- 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

Why NRAD?



- Variable power, max 250 kW
- Only TRIGA that handles HEU
- No experiment traffic/schedule, irradiate by request
- Immediate access to HFEF for quick turnaround PIE



Neutron Radiography (NRAD) Reactor

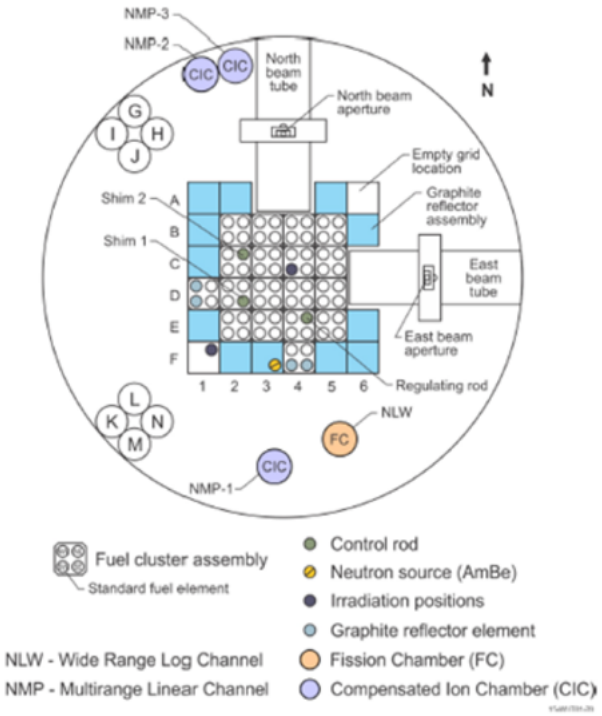


Figure 1. Sixty-four-element core and tank layout.

- 250 kW TRIGA-fuel MTR-grid pool reactor for neutron radiography PIE
- NRAD 4-pin fuel cluster
- F1 and C4 position available for experiments
- $2.1\times10^{12}\ \frac{n}{cm^2-s}$ in F1 Position
- $5.2\times10^{12}\ \frac{n}{cm^2-s}$ in C4 Position

MRTI Inner Capsule Mechanical Design

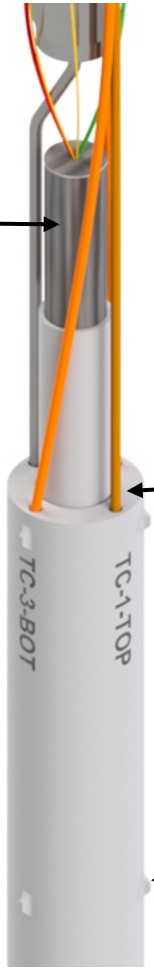
800 W immersion heater
heated in bottom 3” section only
integrated Type-K TC

Large plenum (Argon) to reduce pressure and account for packing factor of powder salt

SS 316 Radiative heat shield reduces heat loss at high temperature section of capsule

Molten salt (UCl_3-NaCl)

Bottom centering feature



3X Type-N TCs, IN625 sheath, axially placed

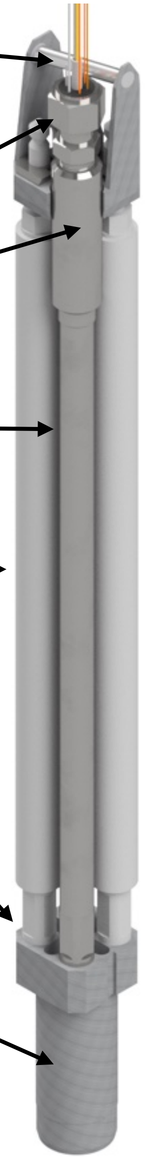
1X Pressure sensor extension tube (optional)

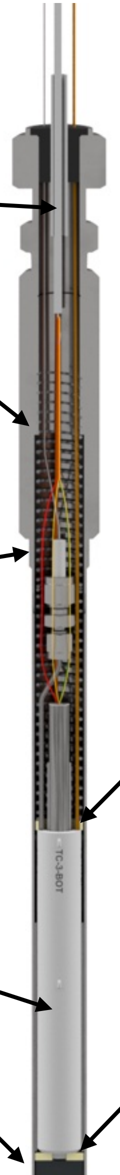
1X IN625 thermowell

→ BNi-5 sealed braze into capsule

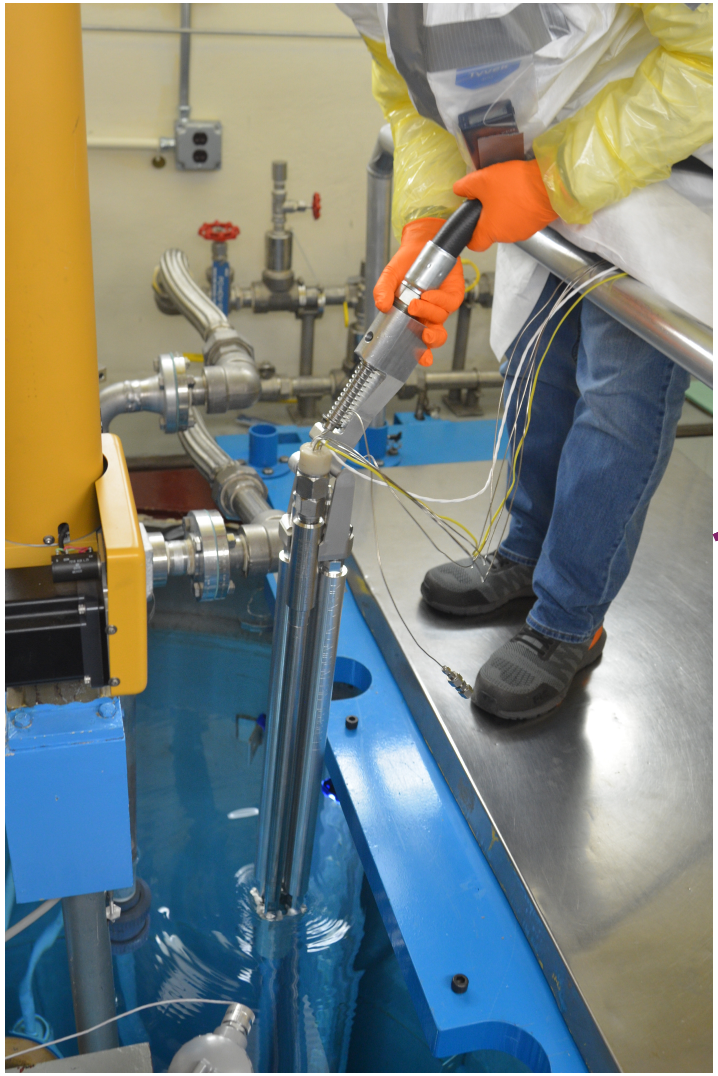
Standoffs create nominal .030” gas-gap (85Ar15He)

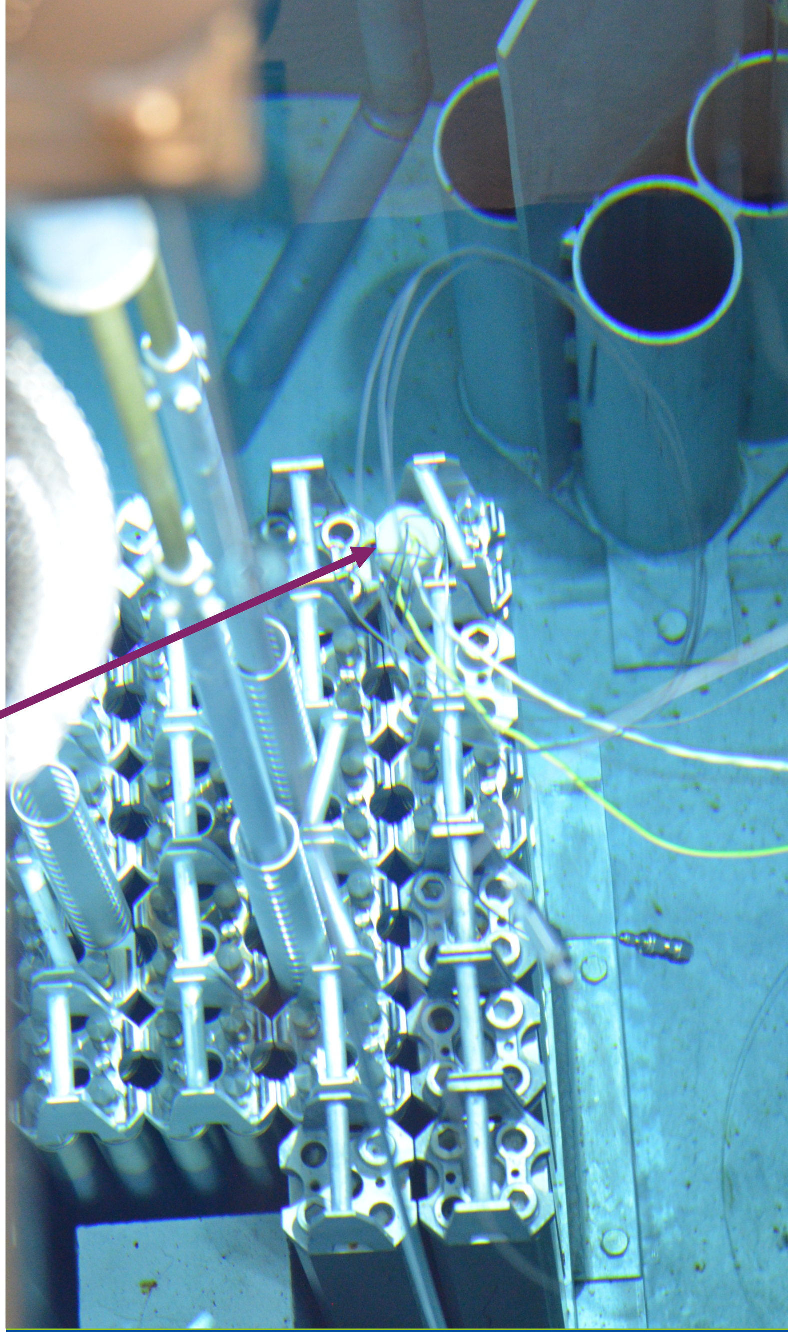
MRTI Outer Can and Cluster Mechanical Design





Insertion in the NRAD Reactor

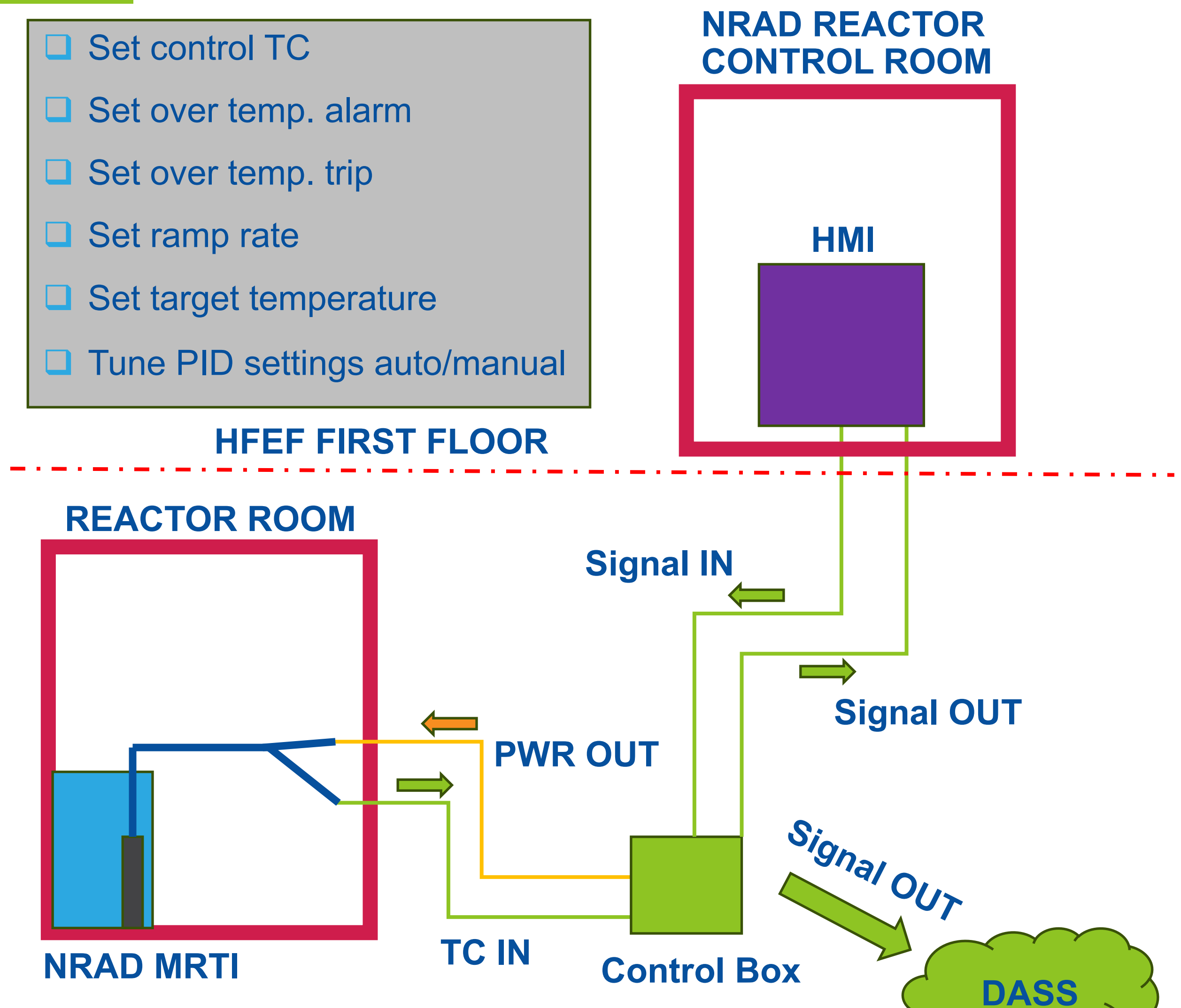




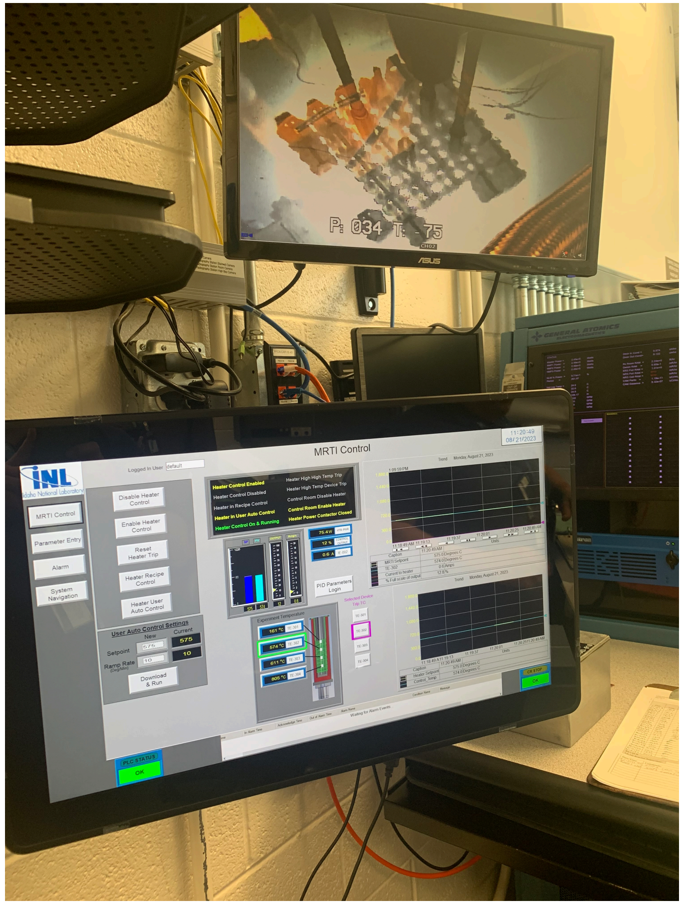
Insertion of Experiment in NRAD core on 8/17/2023

MRTI Heater Control System and Data Acquisition

- ❑ Set control TC
- ❑ Set over temp. alarm
- ❑ Set over temp. trip
- ❑ Set ramp rate
- ❑ Set target temperature
- ❑ Tune PID settings auto/manual

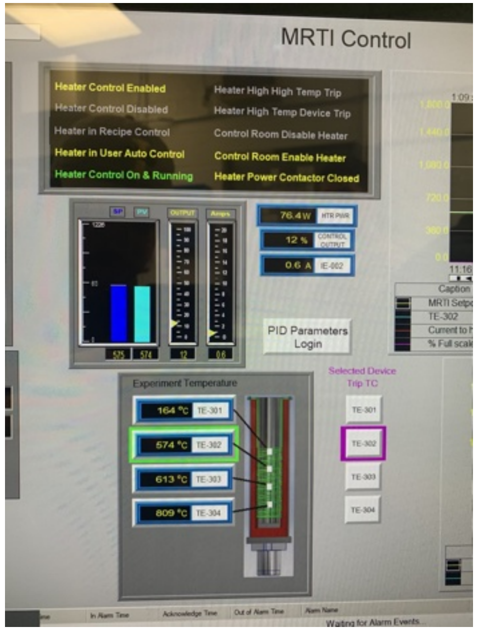


Supports multiple Type-K and Type-N TC connections and up to three heater outputs

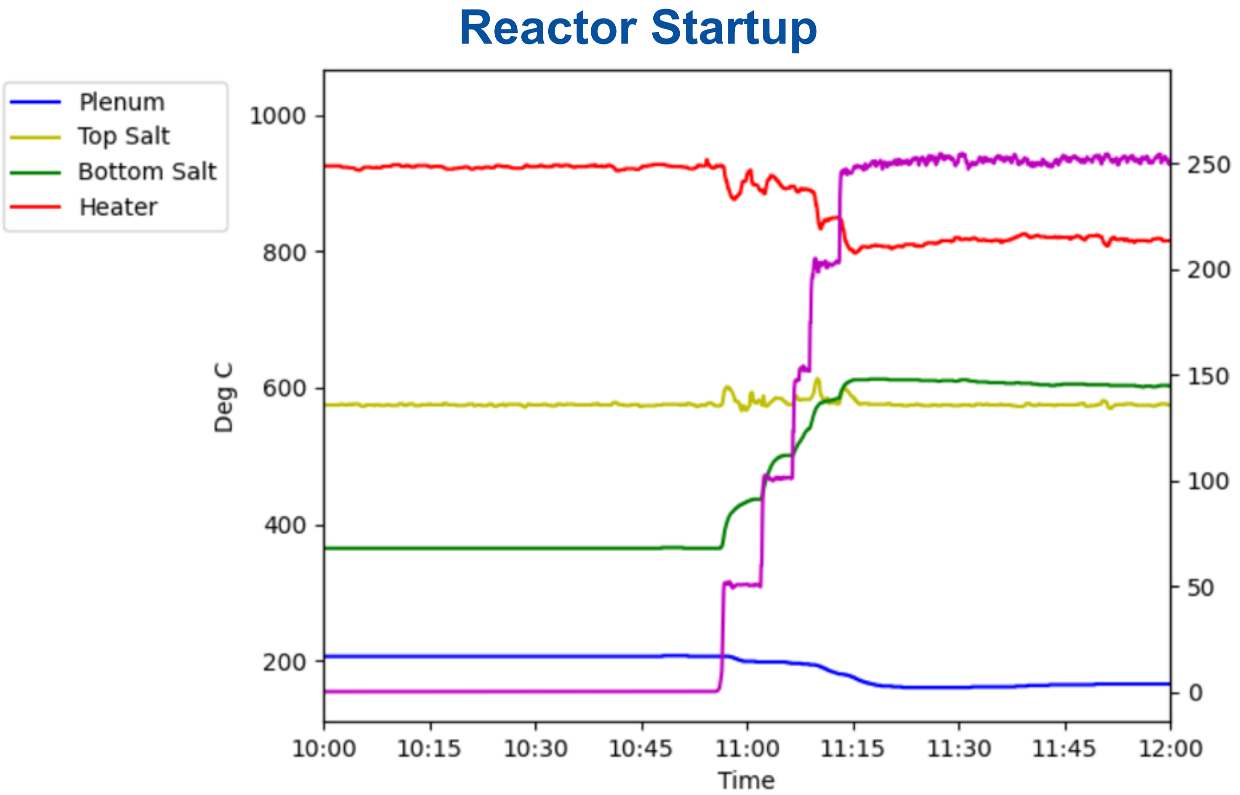


REACTOR ON

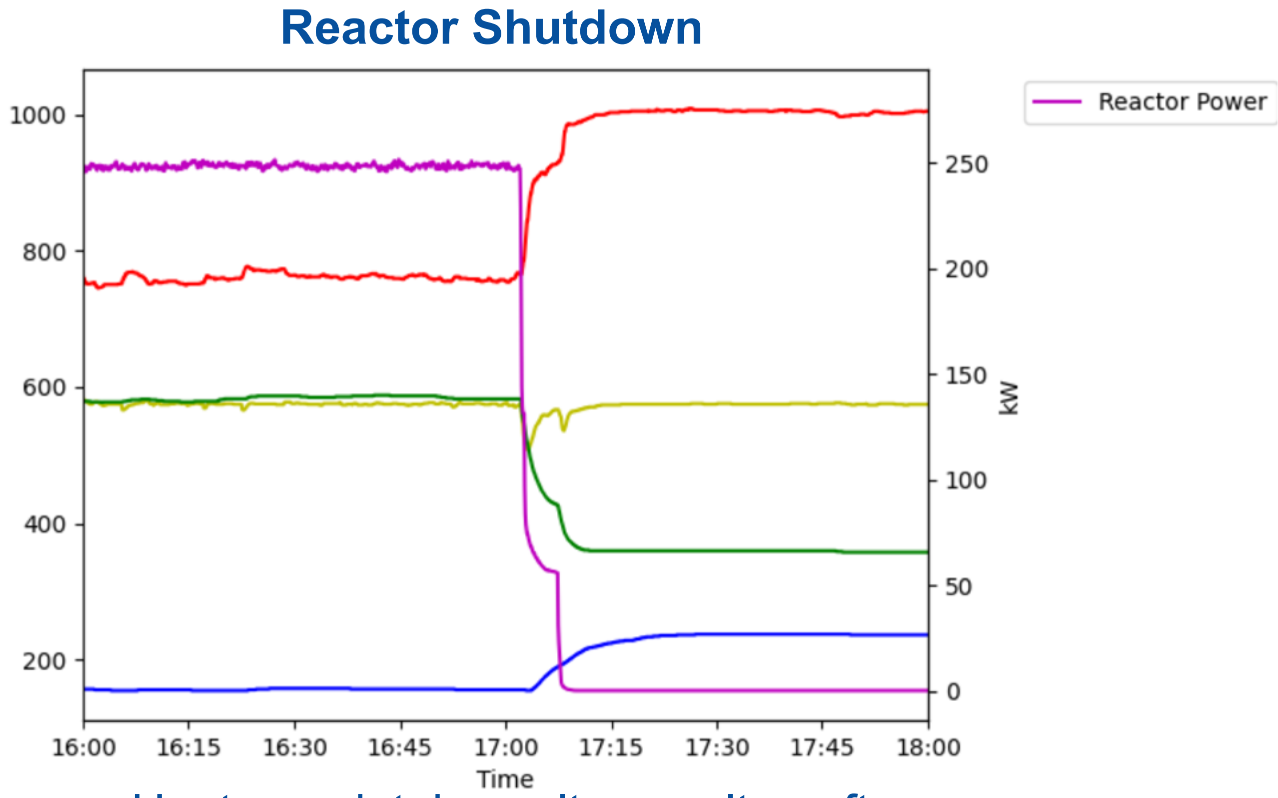
MRTI HMI



MRTI First Irradiation – 8/21/2023



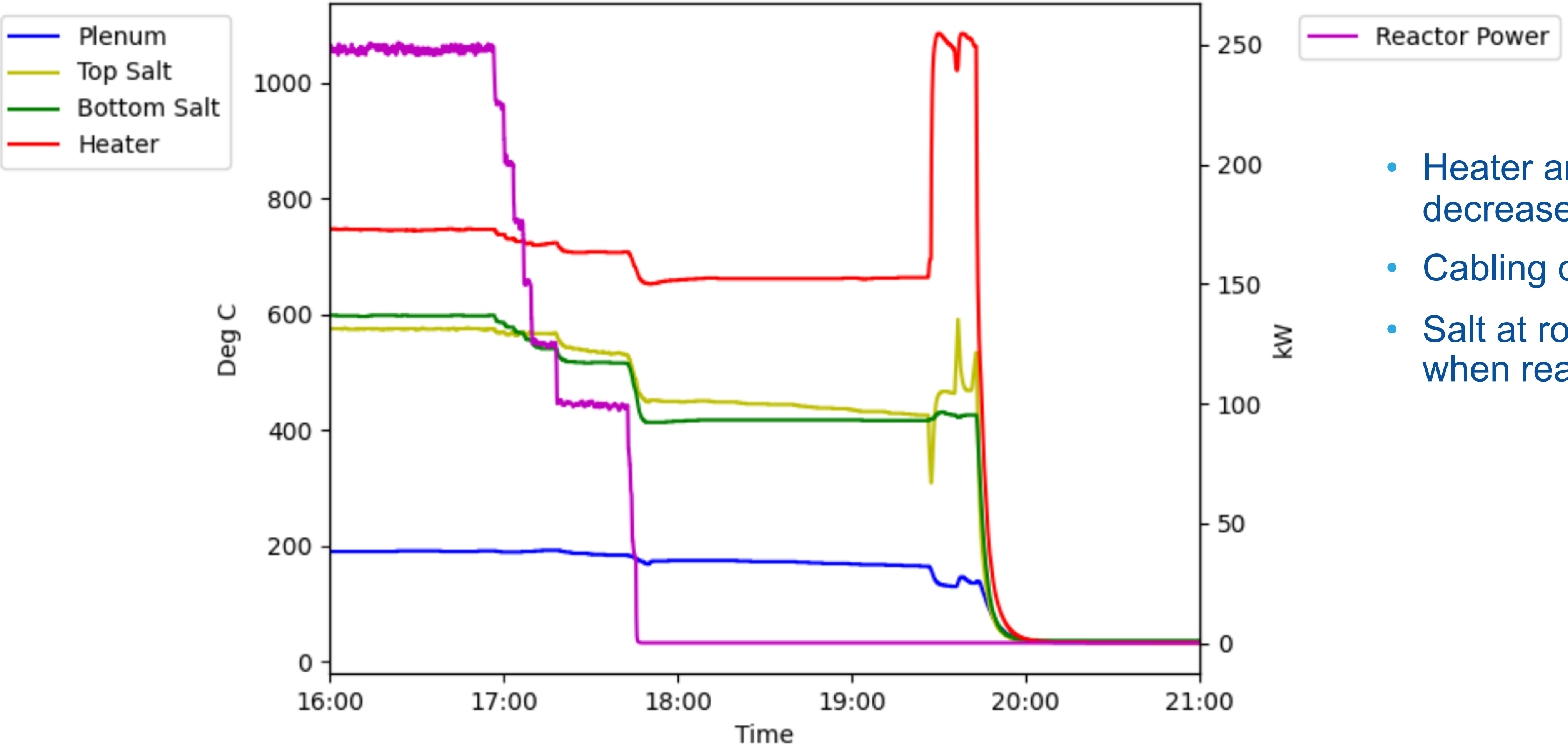
- 50kW steps for startup
- 575-600°C temperature
- Heater temperature decreased



- Heater maintains salt as molten after shutdown
- Heater temperature increases

First Fueled Chloride Irradiation in History!

Heater Failure – 9/5/2023



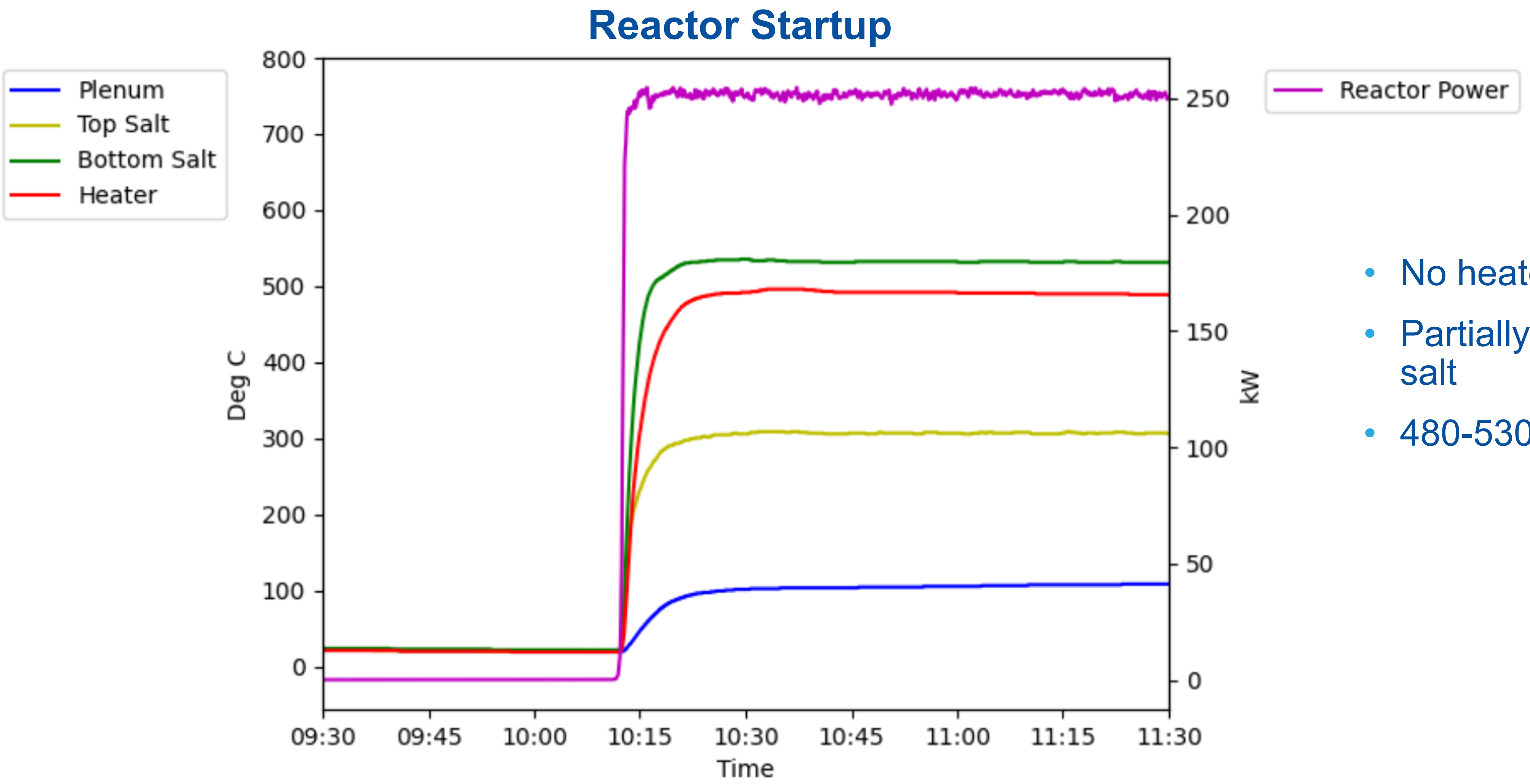
- Heater and salt temperatures decreases after shutdown
- Cabling degradation
- Salt at room temperature when reactor is shutdown

MRTI Heater Failure

In-Tank Camera

- Heater cables used PTFE (Teflon) insulation – waterproof and high temperature resistant, 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.

Post Heater Failure Irradiation – 9/19/2023

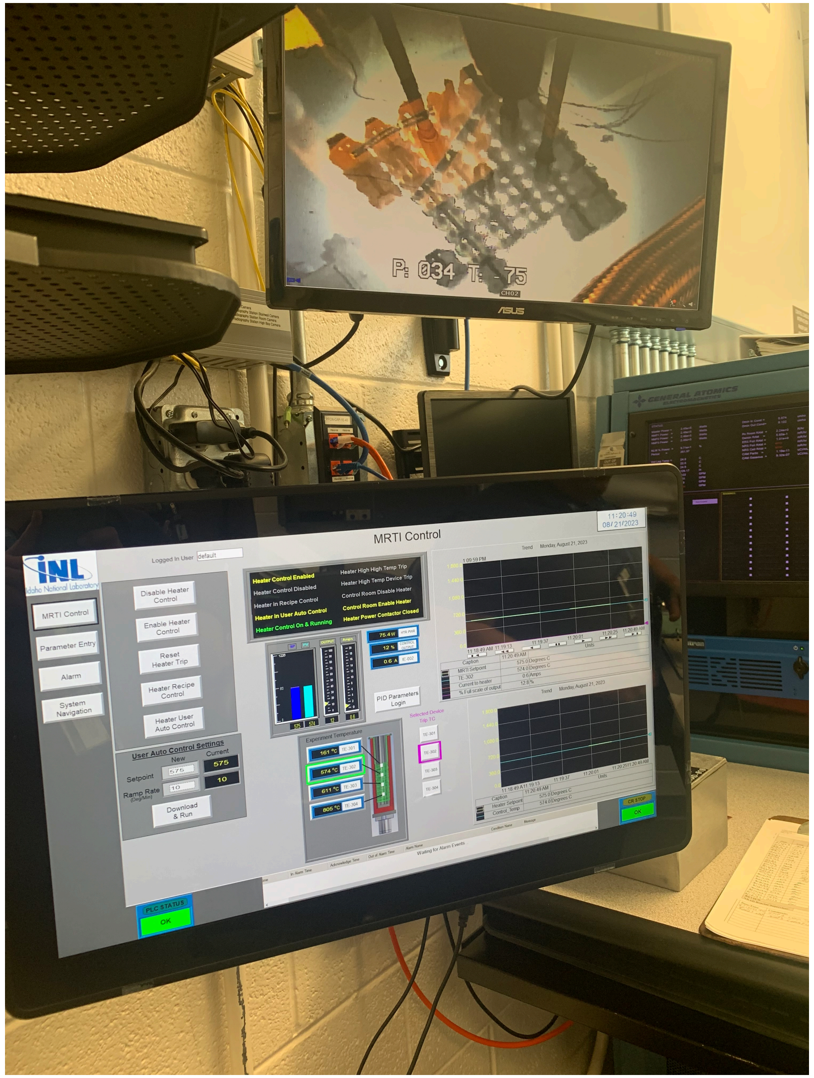


- No heater
- Partially molten salt
- 480-530°C

Irradiation Summary

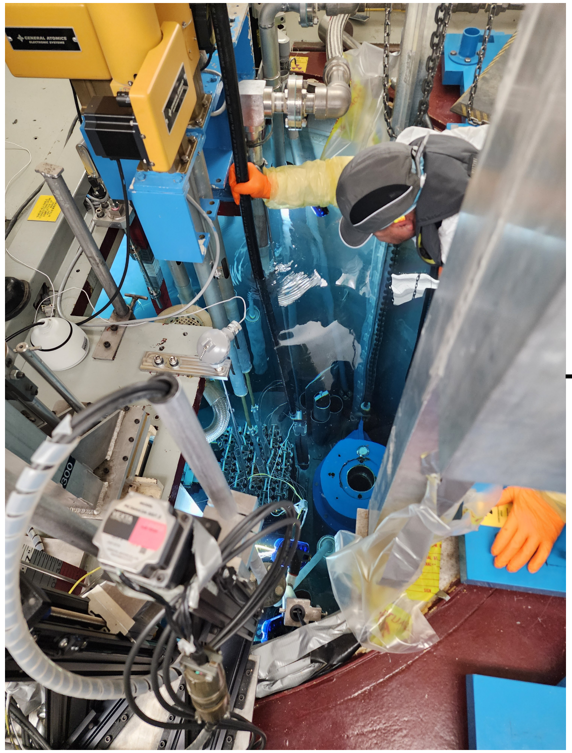
- First irradiation – 8/21/2023
- Final irradiation – 6/3/2024
- Number of reactor runs – 54
- Total run time – 390 hours
- Burnup – 92 MWH

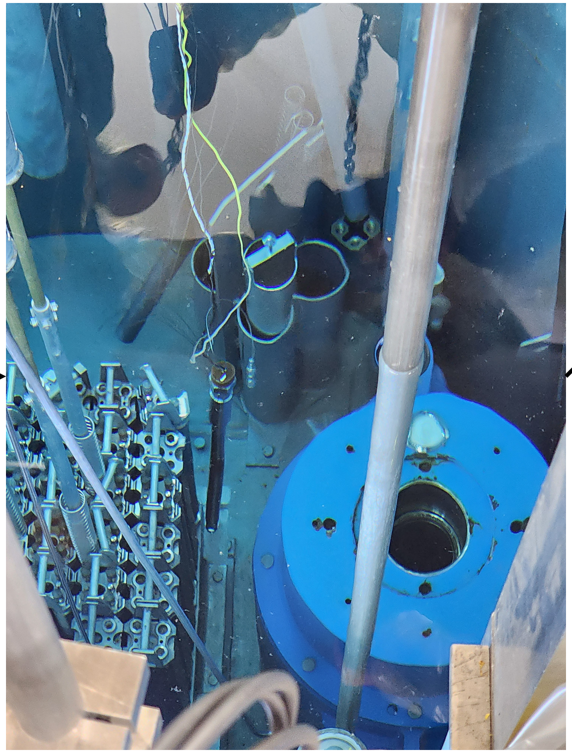
- Final six irradiations were overnight to build up short lived fission products prior to experiment transfer



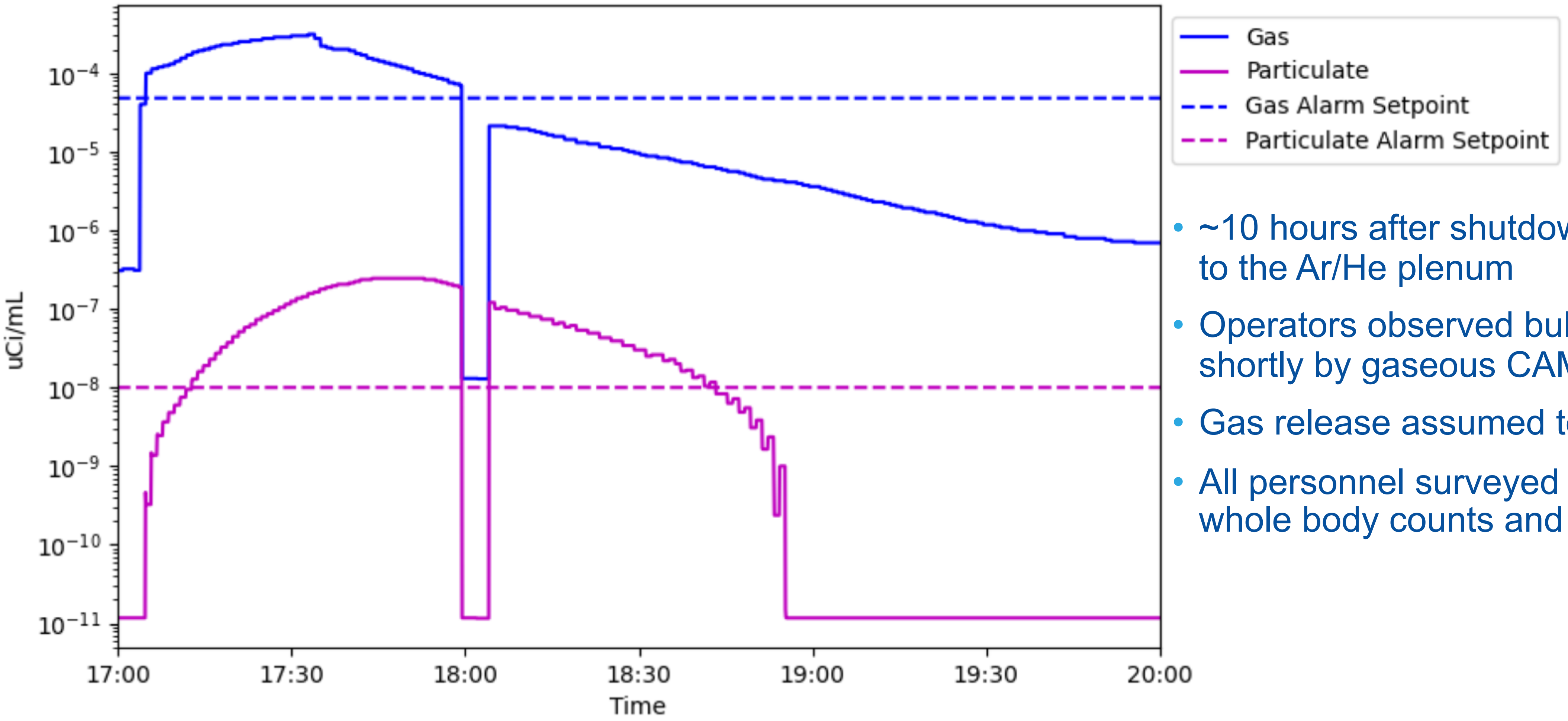
Removal Process

- Rotate cluster to allow access to MRTI
- Removal of MRTI
- Loading MRTI/basket into cask
- Cutting lines and creating bale



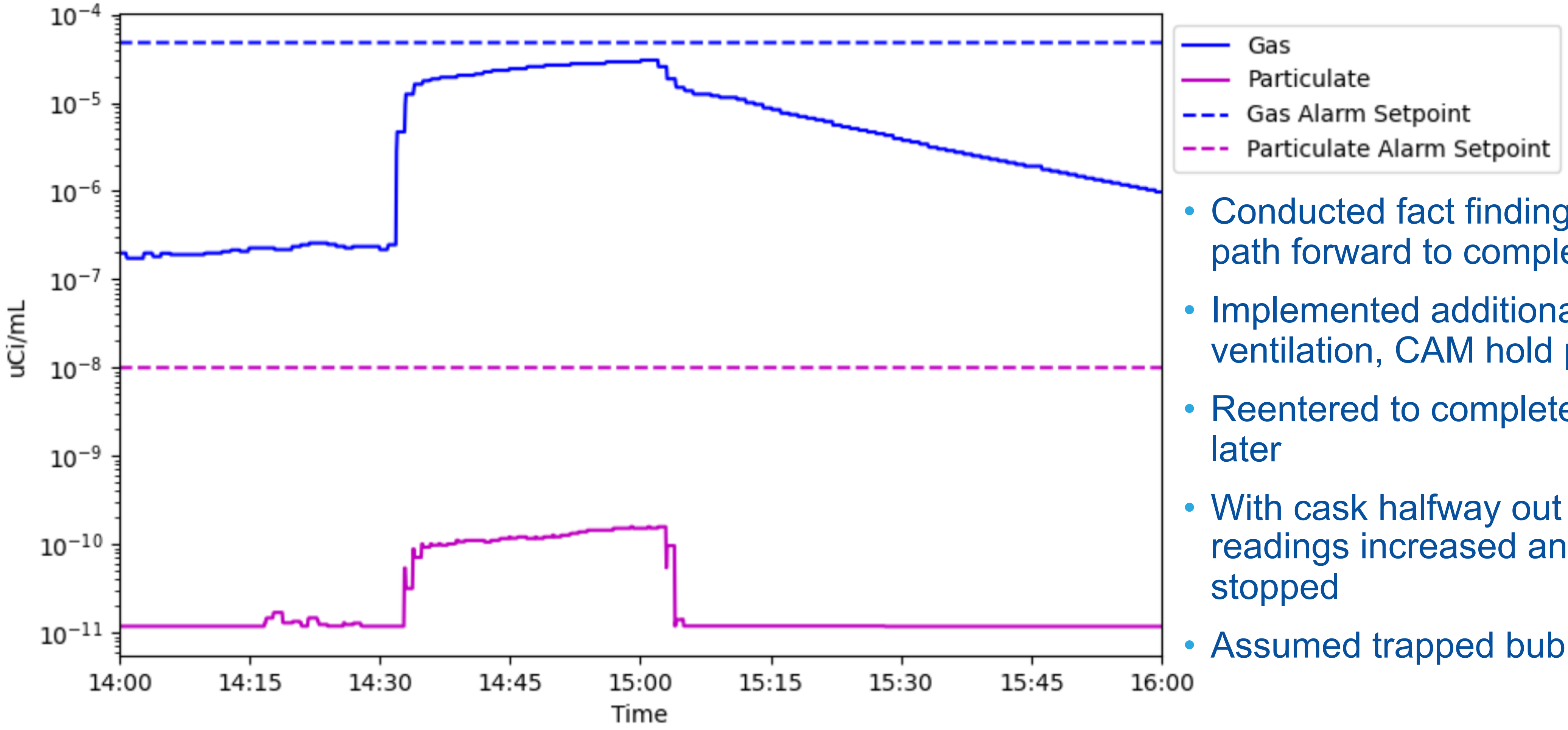


Gas Release Event – 6/4/2024



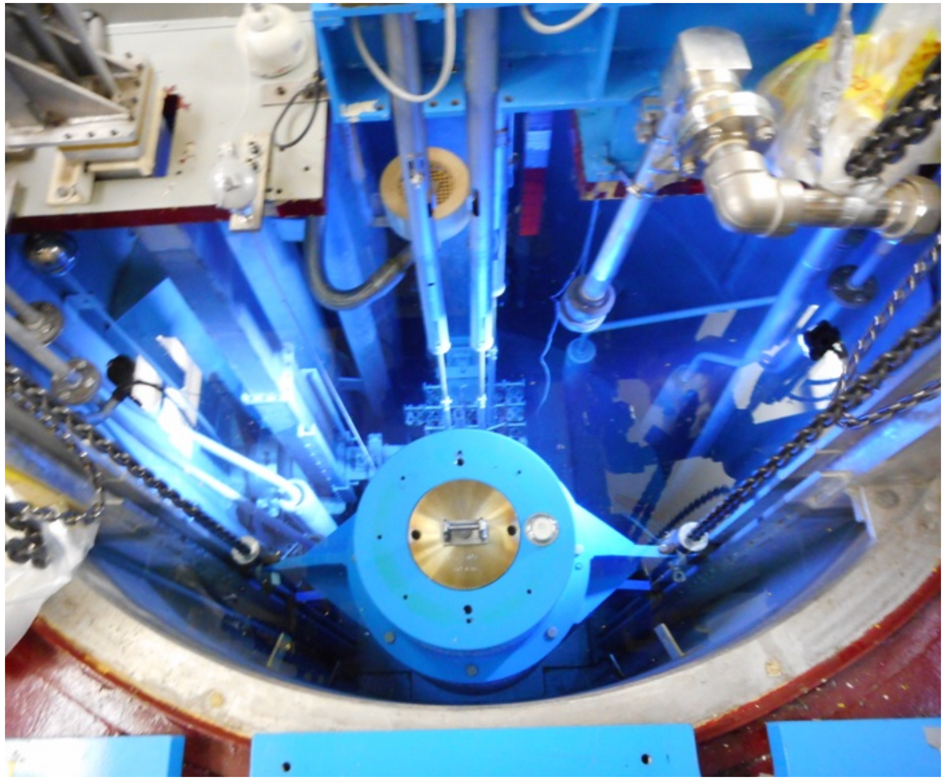
- ~10 hours after shutdown, cut gas lines to the Ar/He plenum
- Operators observed bubbles followed shortly by gaseous CAM alarm
- Gas release assumed to be Ar-41
- All personnel surveyed out and passed whole body counts and bioassays.

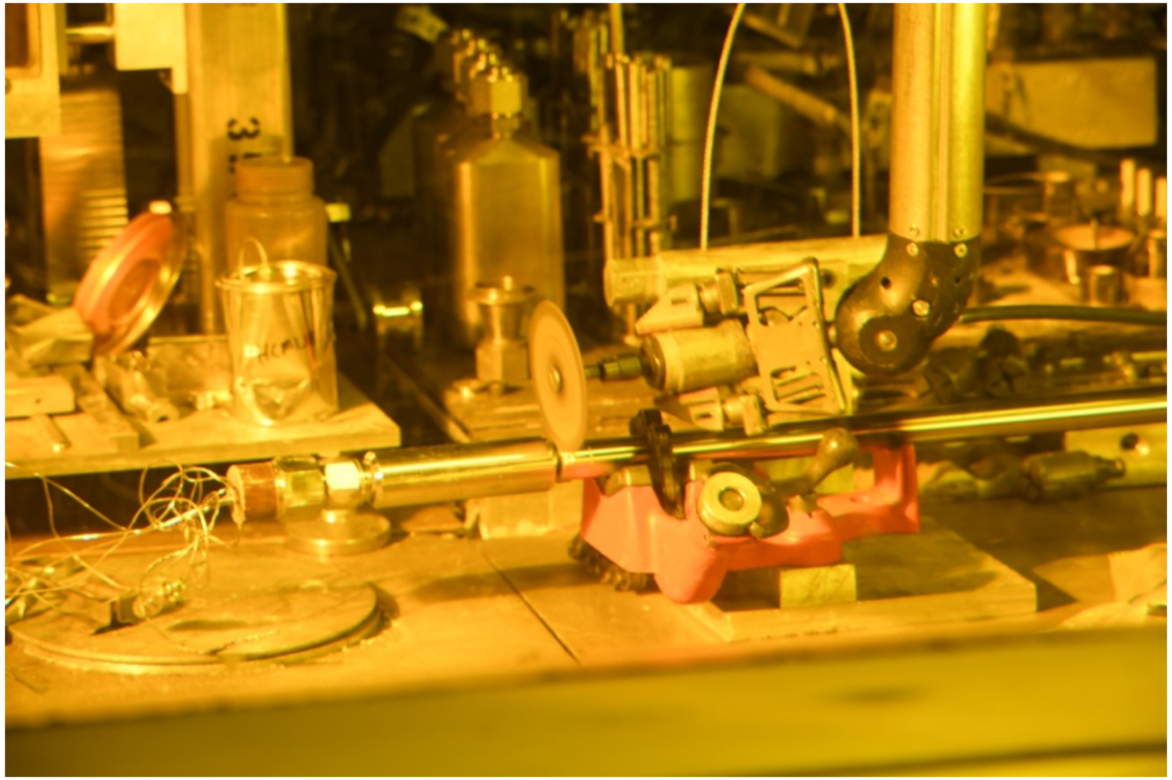
Re-entry – 6/18/2024



- Conducted fact finding and decided upon path forward to complete transfer
- Implemented additional controls (directed ventilation, CAM hold points)
- Reentered to complete transfer 14 days later
- With cask halfway out of water, CAM readings increased and transfer was stopped
- Assumed trapped bubble of Ar-37 released

Re-entry – 6/19/2024



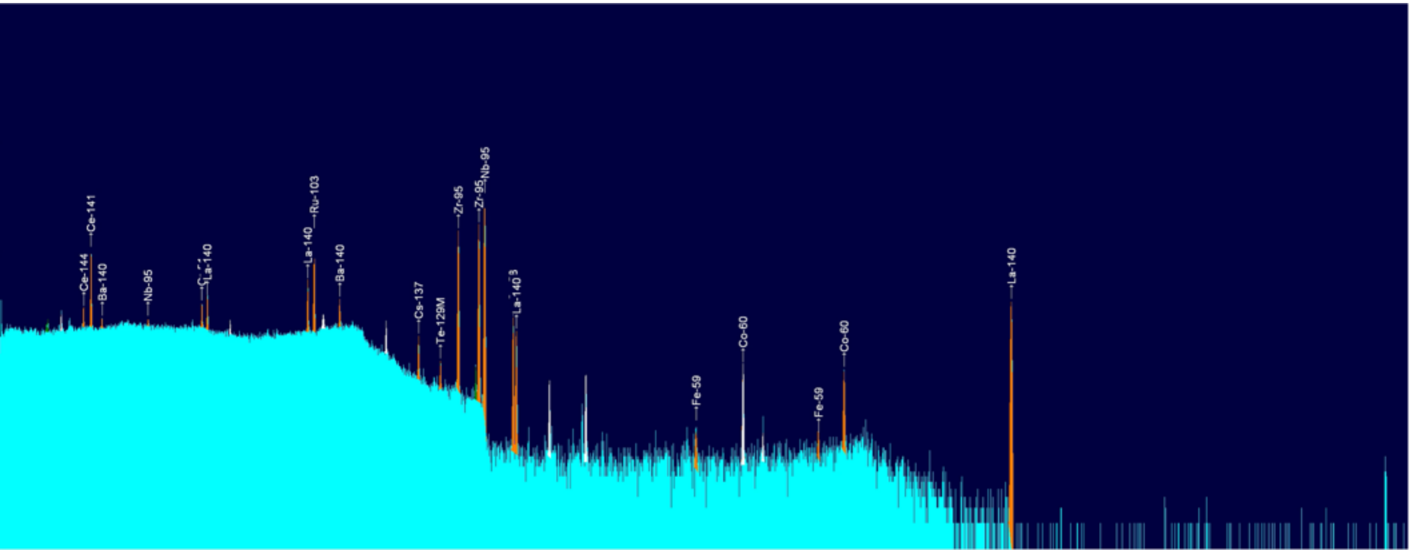


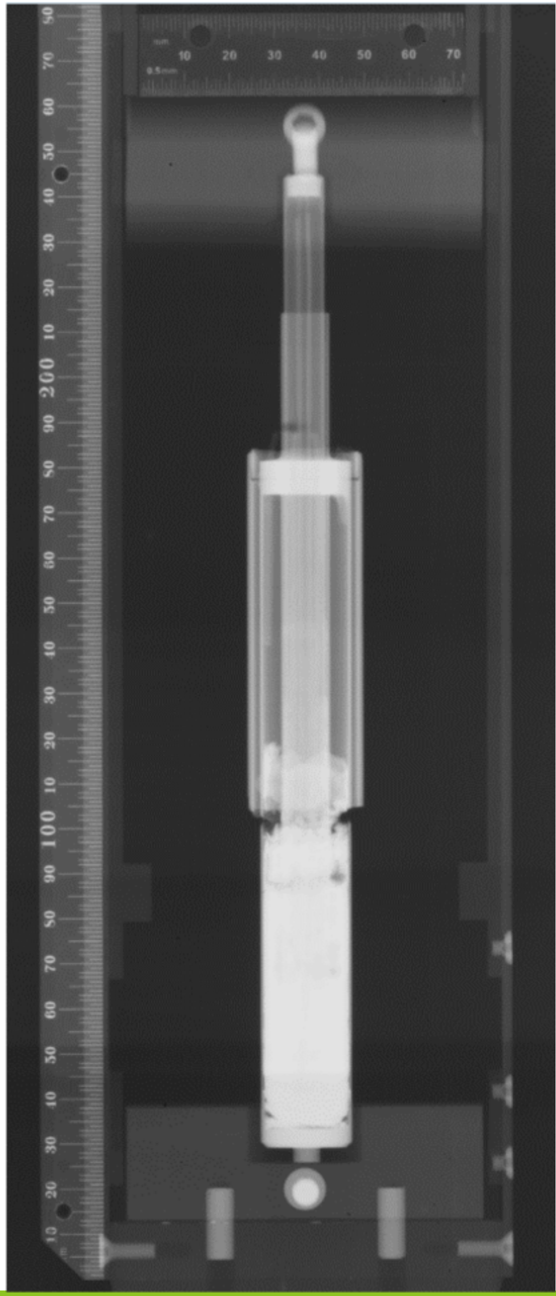
- Updated Radiation Work Permit
- Implemented additional PPE requirements

- Re-entered following day to remove cask from reactor tank to cask cart
- Transfer completed to HFEF successfully

In-cell Disassembly

- Disassembly in HFEF main cell
- Planned single cut to separate outer SS sleeve from inner salt capsule
  - Tight tolerances and possible thermal swelling caused binding and resulted in subsequent cuts being required
- Transferred capsule for neutron radiography and precision gamma scanning





Future Plans

- Continued PIE
- Future MRTI iterations with alternate fuel salts
  - Modified experiment design
  - Robust transfer plan
- Continued molten salt interest from:
  - DOE Molten Salt Reactor Campaign
  - Seaborg Technologies
  - Korean Atomic Energy Research Institute (KAERI)

Acknowledgements

Molten Salt Reactor
PROGRAM

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  - NRAD Operators
  - HFEF Operators
  - Radcon Personnel

Idaho National Laboratory

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