MSR Campaign Review – April 2025
INL/MIS-25-84399

Molten Salt Reactor
PROGRAM

Initial Investigations of an Irradiated Chloride Fuel Salt: $NaCl\text{-}UCl_3$

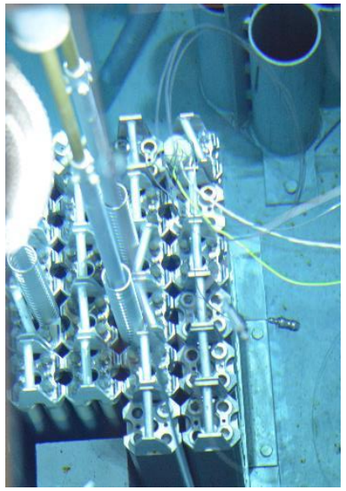
Initial results, future work, and next irradiation

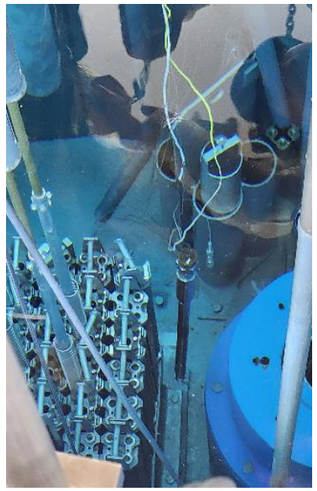
Presented by **Toni Karlsson** on behalf of the Irradiation Team

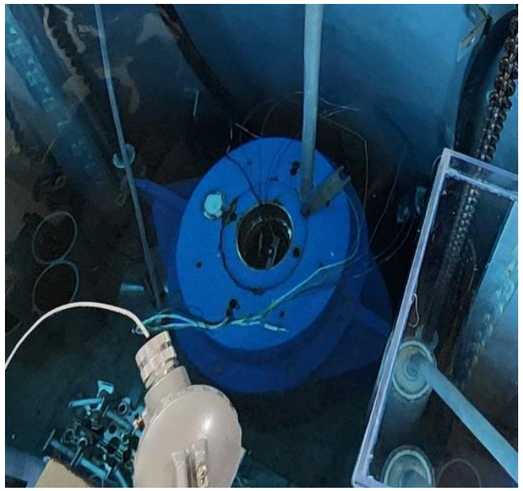
Argonne NATIONAL LABORATORY
INL Idaho National Laboratory
Los Alamos NATIONAL LABORATORY
OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY
Sandia National Laboratories
U.S. DEPARTMENT of ENERGY
Office of Nuclear Energy

Outline

- Am/Pu Salt Synthesis
- MRTI Irradiation experiment
  - Overview
  - Irradiation
  - PIE
- ATR Irradiation
  - Overview
  - Preliminary Design
  - Accomplishments
- Am/Pu Synthesis
- Milestones







MRTI = Molten-salt Reactor Temperature-controlled Irradiation

PIE = Post Irradiation Examination

ATR = Advanced Test Reactor

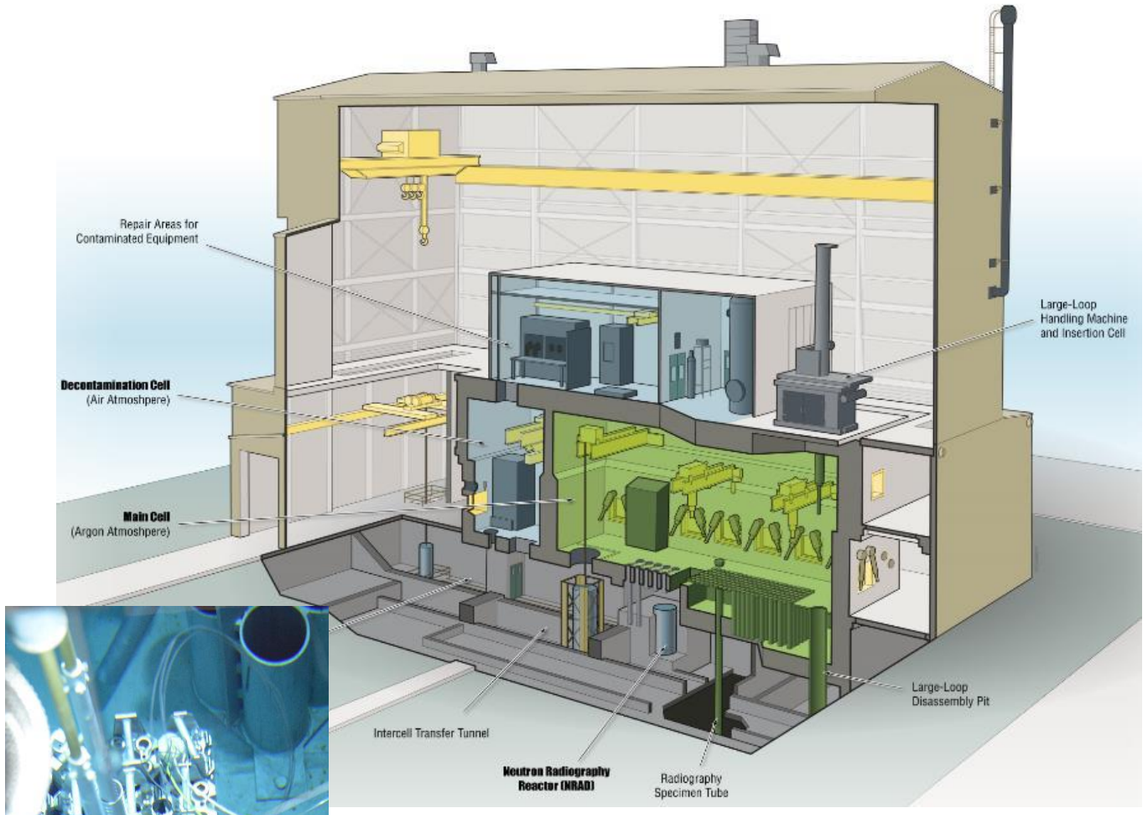
MRTI - Overview

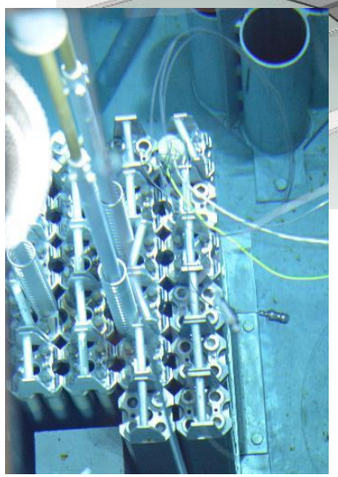
- Salt: ~41g of 33UCl_3-67NaCl (93% ^{235}U)
- Capsule material: Inconel-625
- Other structural material: SS-316
- Plenum gas: Ar
- Outer can gas: 15He/85Ar
- Predicted fuel performance under irradiation
  - Fission Heat = 20 W/cm^3
  - Neutron Flux = 3.5x10^{12} n/cm^2-s
  - Gamma Flux = 1.4x10^{13} γ/cm^2-s
  - Salt Temperature = 525-900°C

SS = Stainless Steel

MRTI - Overview

- 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





NRAD = Neutron RADiography
TRIGA = Training, Research, Isotope, General Atomics
MTR = Materials Test Reactor
HEU = Highly Enriched Uranium
HFEF = Hot Fuel Examination Facility

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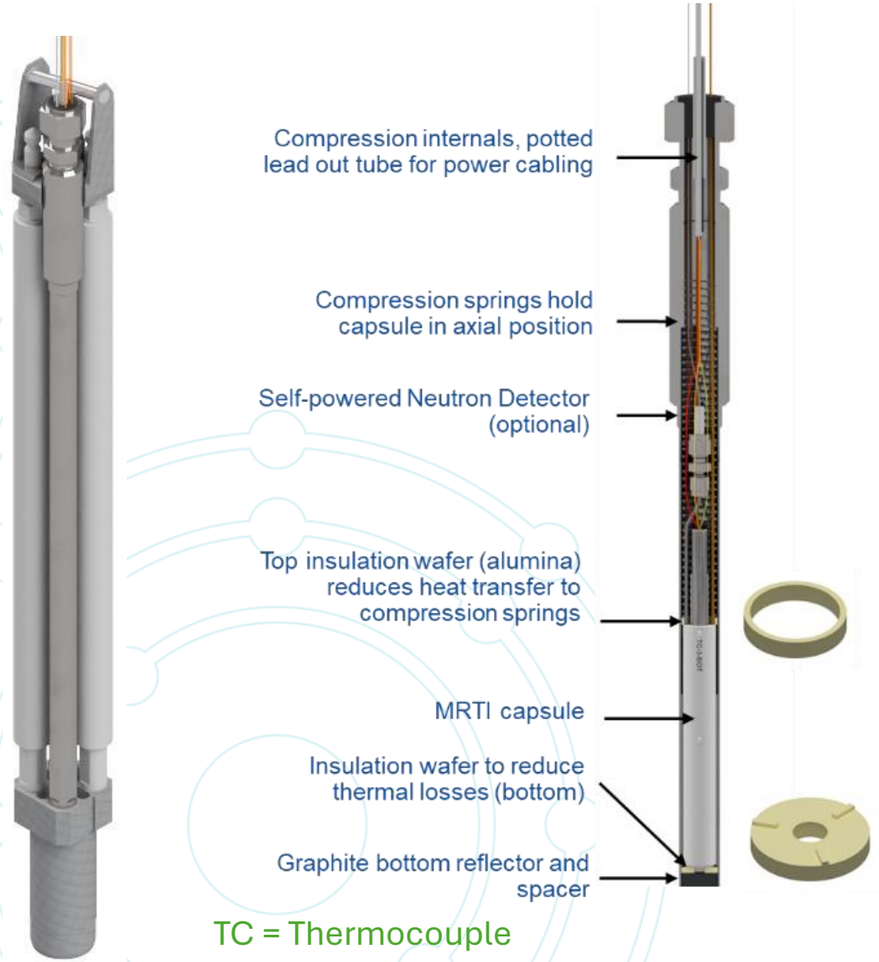
MRTI – Overview

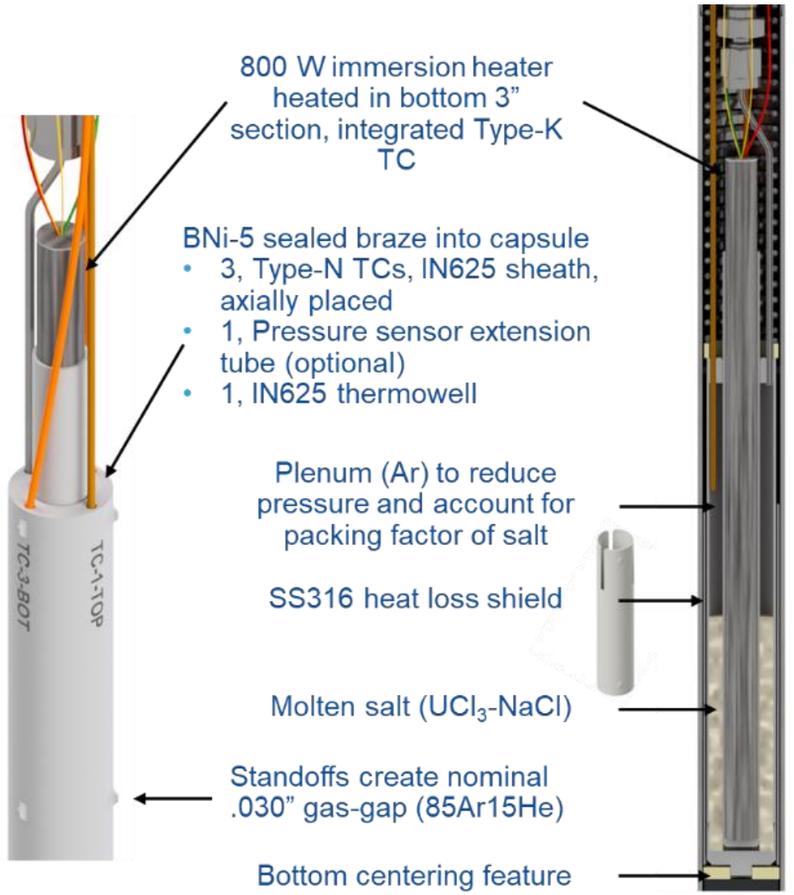
Outer Can/Cluster



TC = Thermocouple

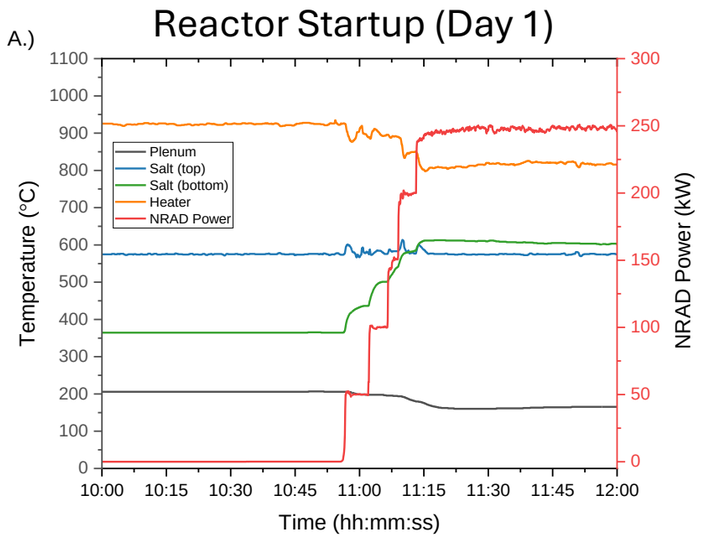
IN625 = Inconel 625

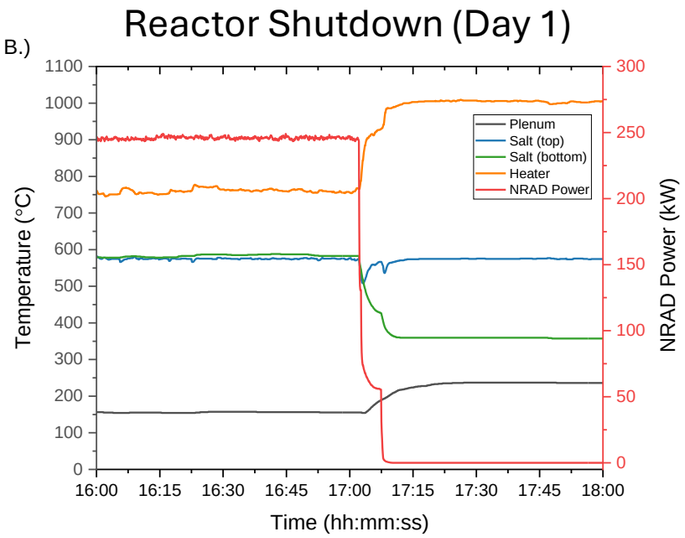
Inner Capsule

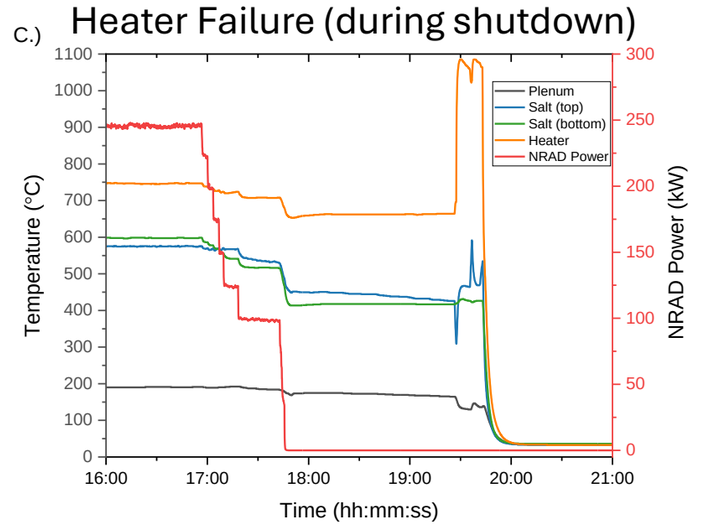


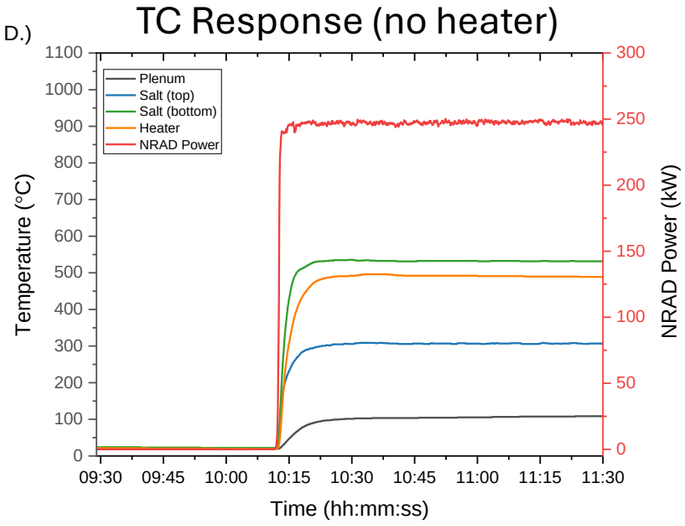
MRTI - Irradiation

- Irradiation started on August 21st 2023
- Final irradiation on June 3rd 2024
  - 390 hr of irradiation
  - 0.20 GWd/MTU burnup
- Transferred into HFEF main cell on June 25th 2024
- Disassembled in July 2024







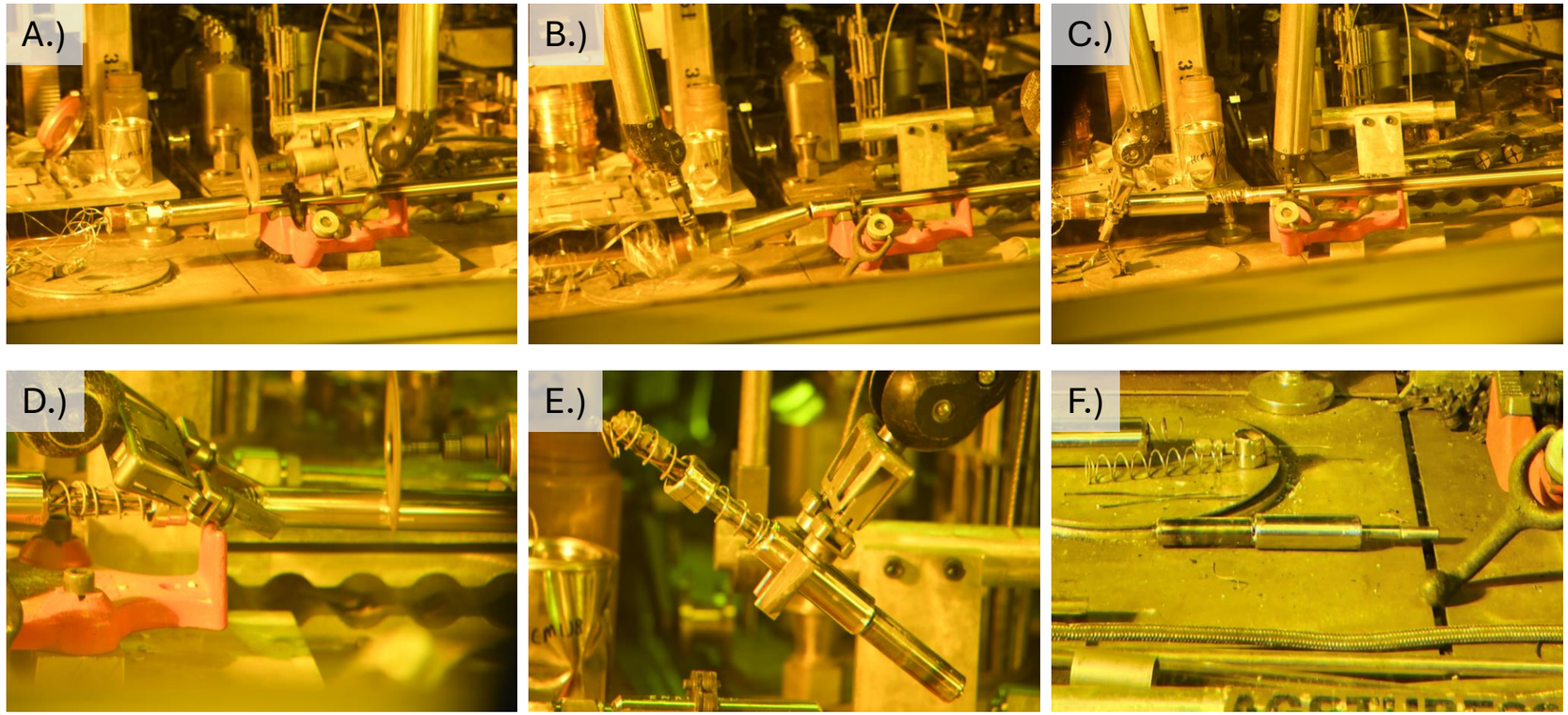


GWd = Gigawatt days

MTU = Metric Ton of Uranium

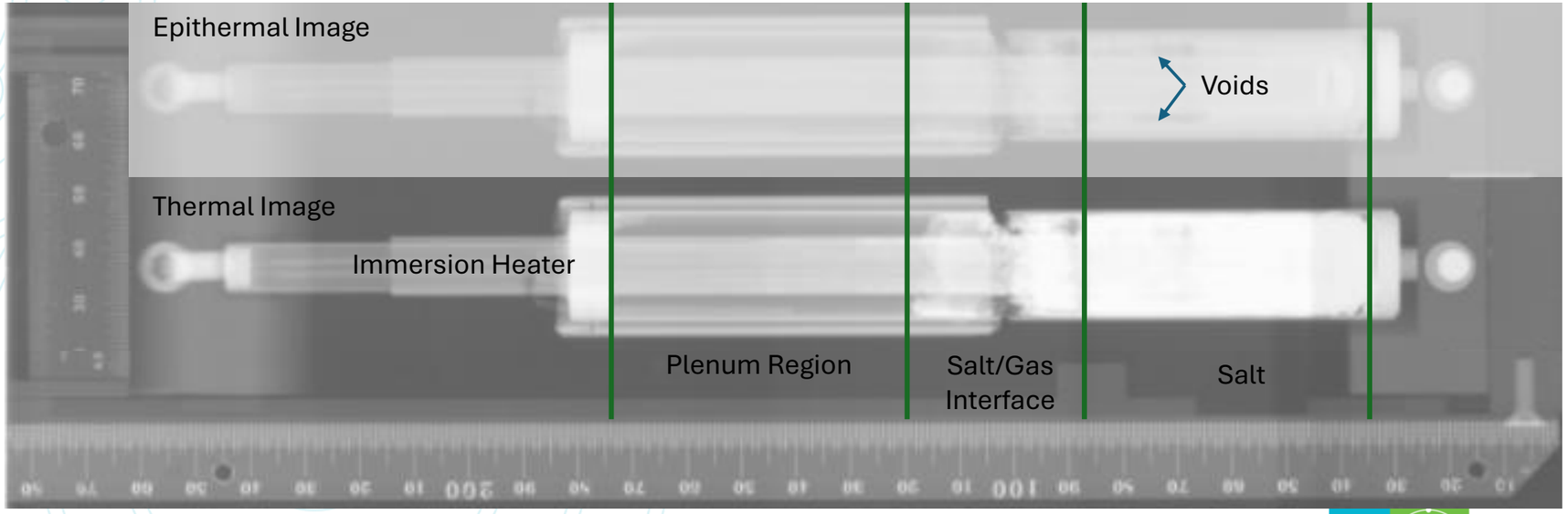
MRTI – PIE

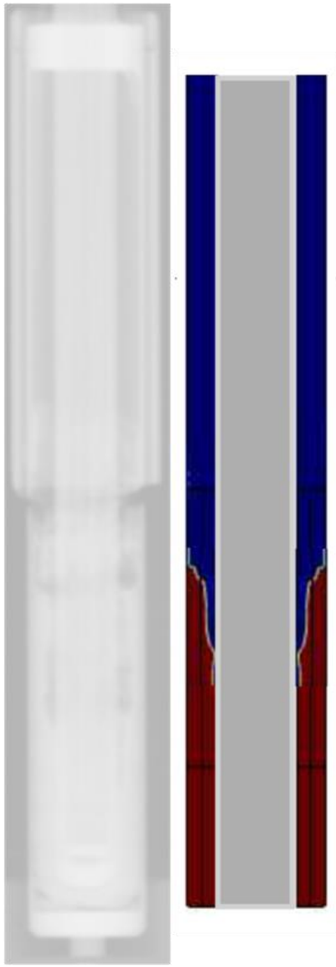
- Remotely disassembled in Ar hot cell
- Die grinder used to remove capsule from outer can
- Capsule was breached during the process, unable to collect off-gas sample
- Immersion heater “stuck” in place



MRTI - PIE

- Neutron radiograph imaging
  - 5 angles: 0, 45, 90, 120, 240
  - Thermal and epithermal imaging
    - Epithermal neutrons have higher energy, can penetrate further into the sample than thermal neutrons
    - Solidification modeling using CFD

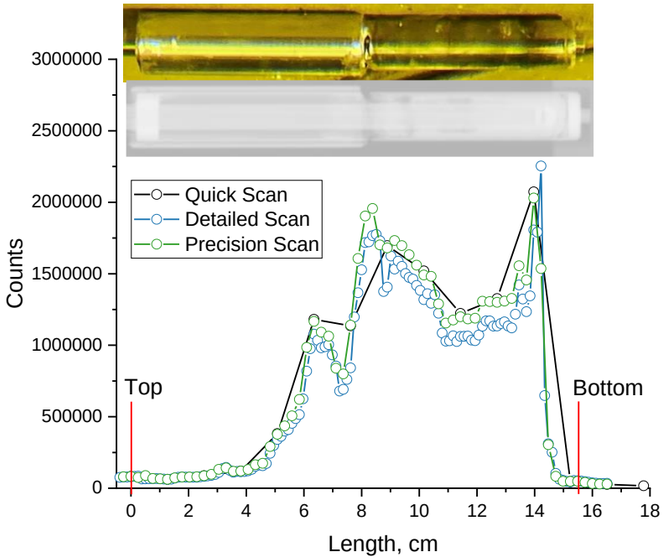


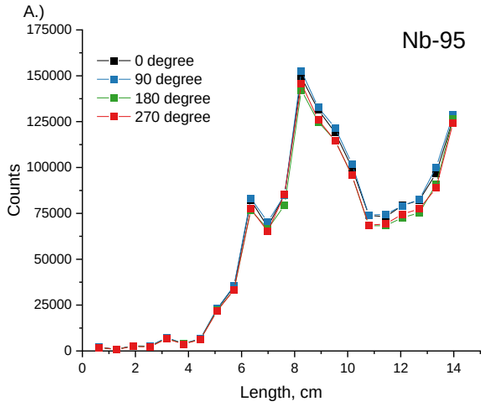


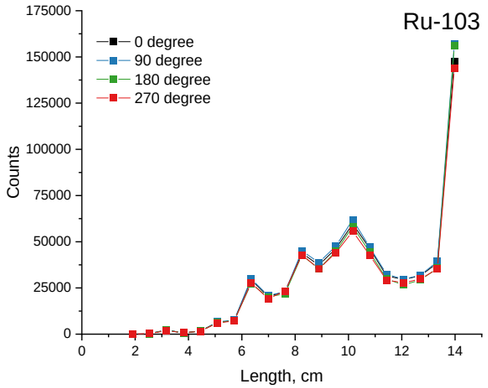
CFD = Computational Fluid Dynamics

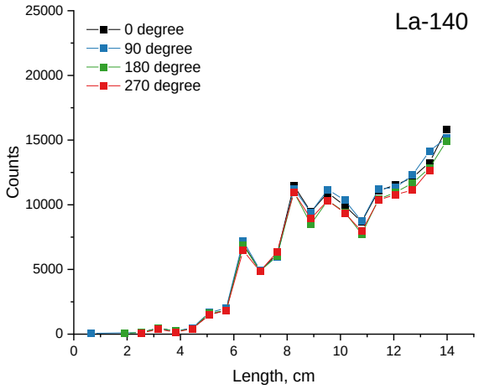
MRTI - PIE

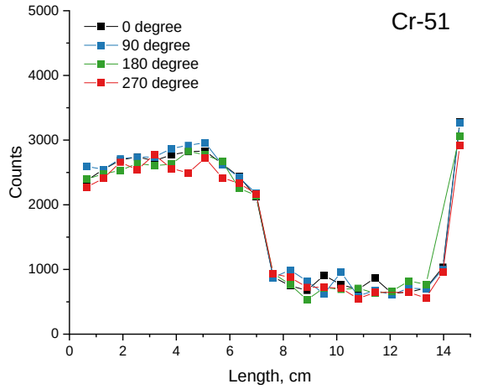
- PGS the length of the capsule
  - Useful energy range ~150eV – 1600keV
  - Background, quick, detailed scans (4 angles)
- Expected FP (ORIGEN 2 software):
  - Nb^{95}, Zr^{95}, Y^{91}, Ce^{141}, Sr^{89}, Ru^{103}, Pr^{144}, Ce^{144}, Pr^{143}, La^{140}, Ba^{140}, S^{35}, Nd^{147}, Ru^{106}, and Rh^{106}
- Activated material of construction
  - Cr^{51}, Co^{60}, etc. (low counts)











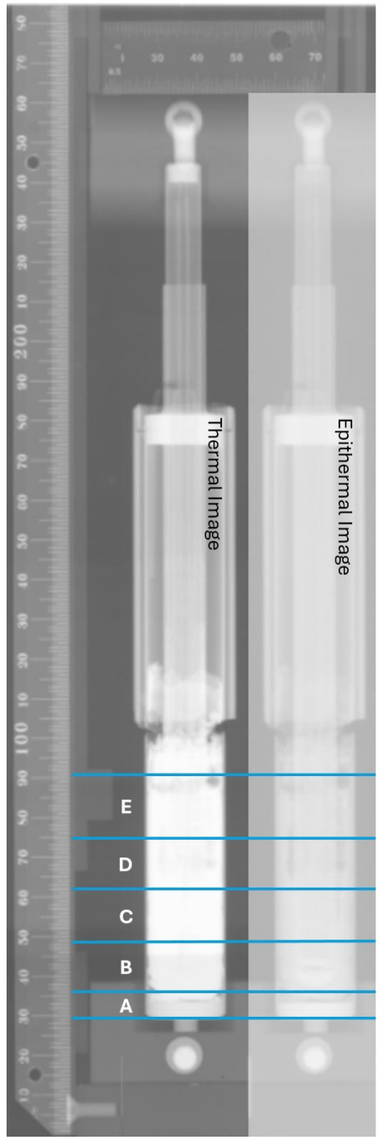
PGS = Precision Gamma Scan

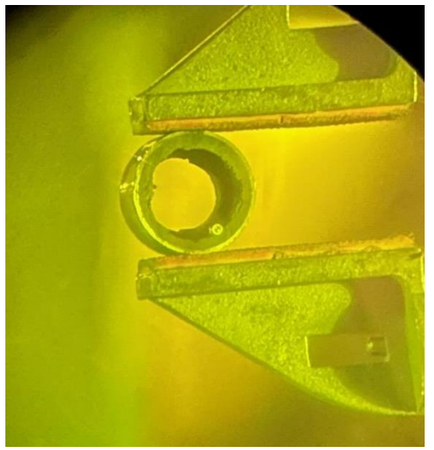
keV = kilo- electron volts

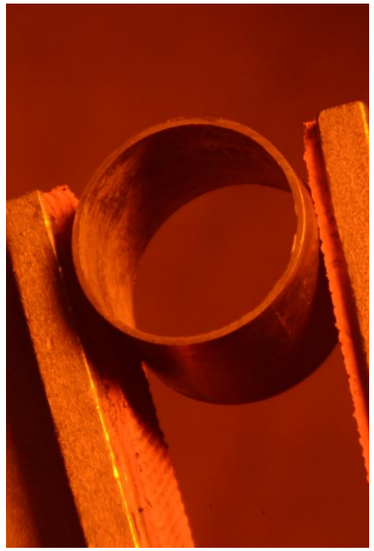
FP = Fission Product

MRTI - PIE

- MRTI sectioning
  - Low speed saw
  - Analysis of Segment E
    - SEM (material of construction)
    - Elemental/isotopic (salt)
  - Salt melted out of segment
  - All other segments/salt are stored in individual capsule in HFEF
  - Two slices extracted from Segment E
    - Radial - mounted in epoxy
    - Planar - mounted on SEM ‘sticky dot’



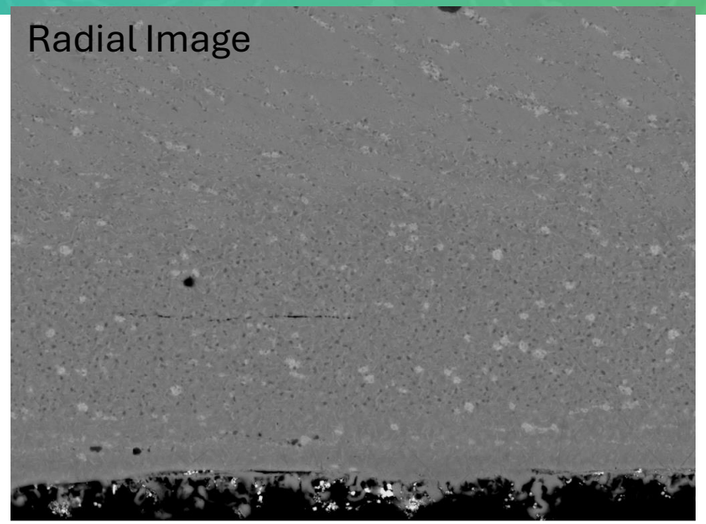


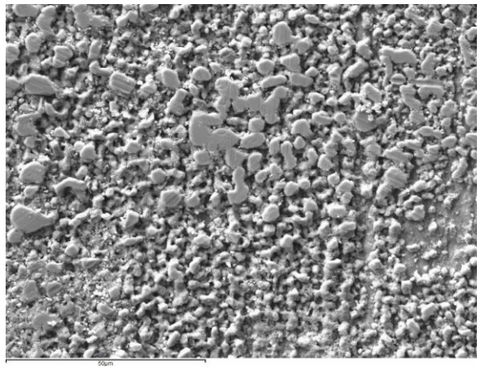


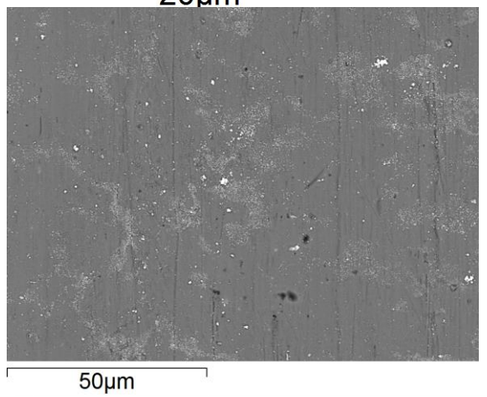
SEM = Scanning Electron Microscope

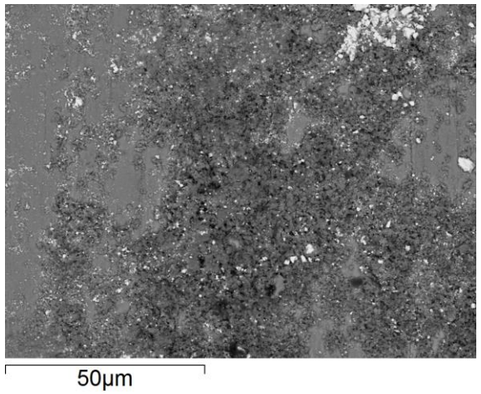
MRTI - PIE (preliminary data)

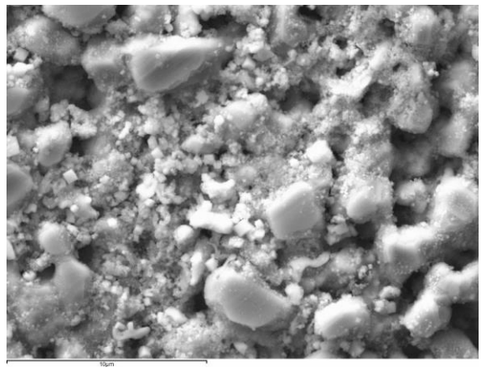
- Radial sample shows several features
  - Corrosion deposit layer
  - Fe rich layer
  - Cr rich layer
  - Bulk Inconel-625
- Planar sample shows
  - One spot showed corrosion of Inconel-625
  - Observed deposits on surface
- Elemental mapping ongoing

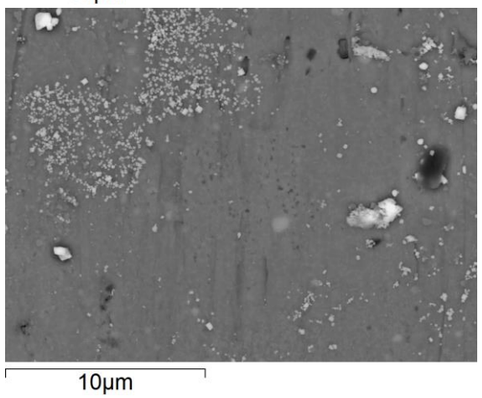


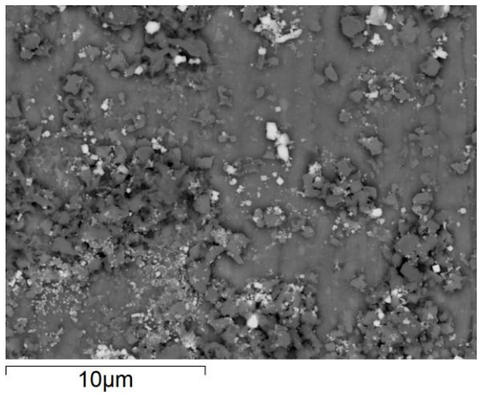






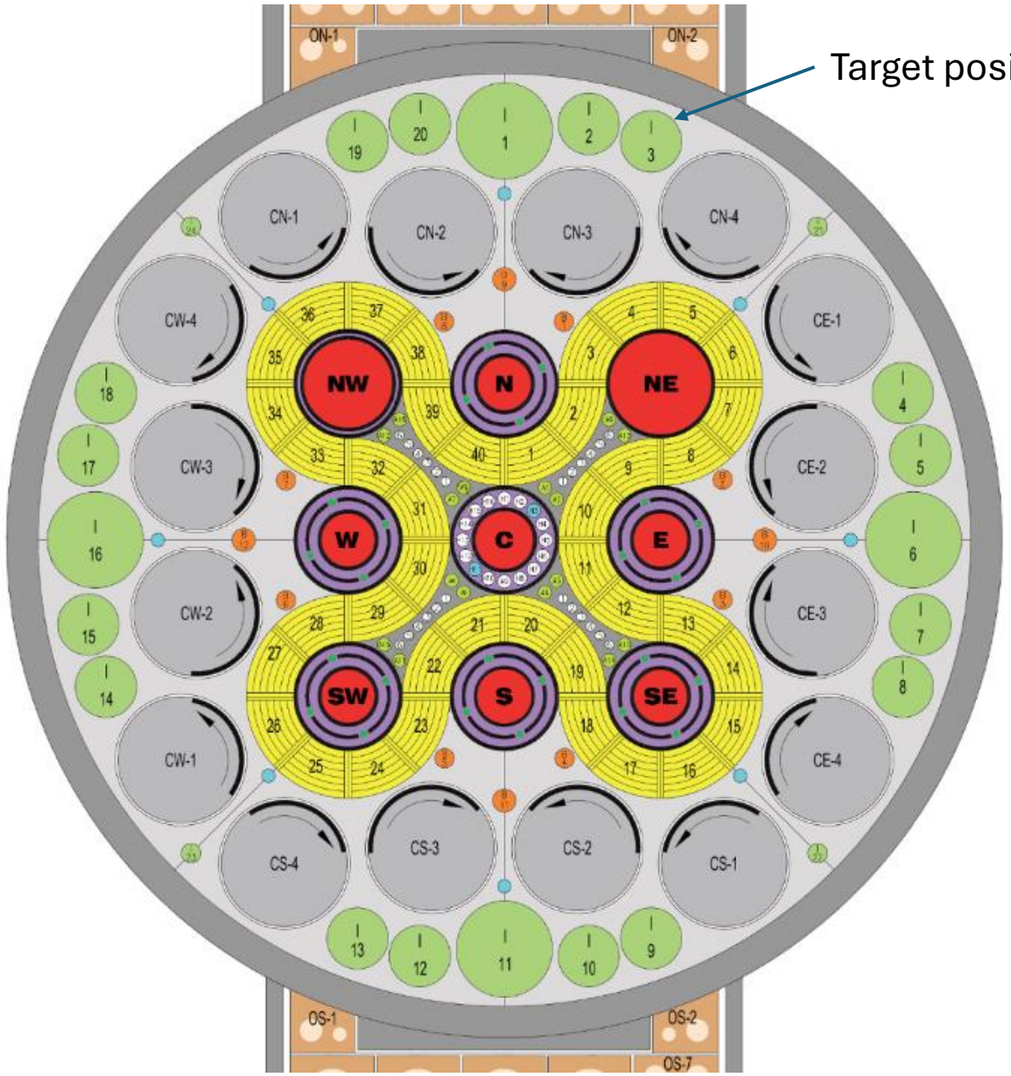






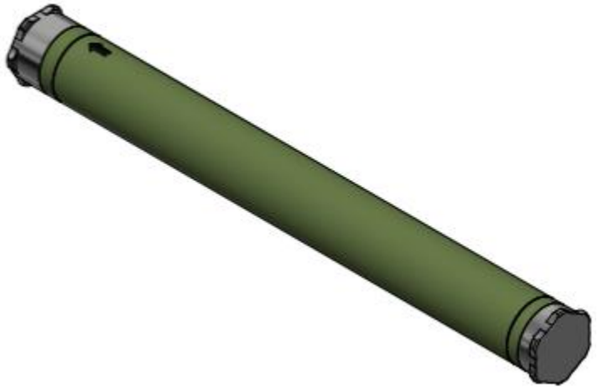
ATR - Overview

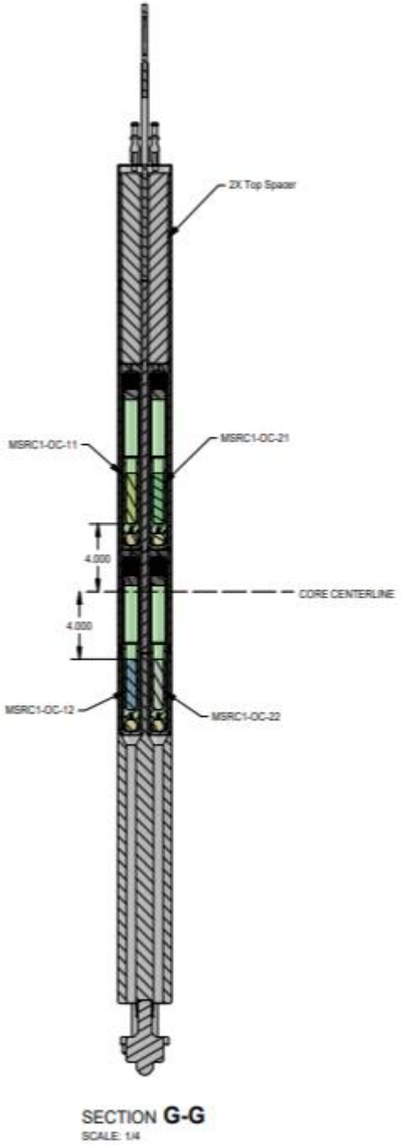
- Purpose
  - Gain understanding of fuel salt chemistry having a minimum of 2 GWd/MTU burnup to provide insights on fuel performance, pre- and post-irradiation
    - Design a standardized salt irradiation capsule (no lead outs)
    - Out-of-pile off gas analysis
    - Effect of chemical/thermal properties
    - Partitioning of FPs
    - Out-of-pile corrosion test for comparison (proposed)
    - Need to work with modeling community to determine “high-value” data for validation

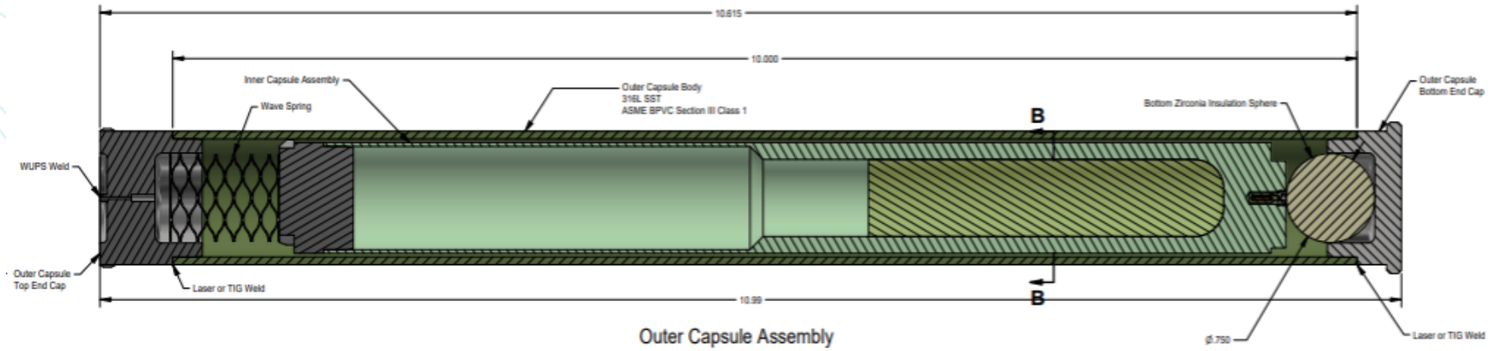


ATR – Conceptual Design (preliminary)

- Targeting Medium I position (I-3)
  - Neutron variance during cycle (drum rotation)
  - Neutron flux
  - Size
- 4 capsule configuration, double stacked
- 316H in contact with salt
- Passive sensors
  - Melt wires
  - Fluence monitors
  - 600 – 900°C







Outer Capsule Assembly

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ATR Irradiation Team

Matt Arrowood
Experimental Manger

Calvin Downey
Lead Design Engineer

Daniel Chapman
Thermal Analysis

Frederick “Rick” Gleicher
Neutronic Analysis

Many other team members and we will continue to grow!

Daniel Sluder
ATR Experiment Engineer

Ryan Sandbek
Structural Analyst

Bryon Mowlds
Quality Assurance

Toni Karlsson
Technical Lead

Steven Warmann
PIE Experiment Manager

ATR - Irradiation

- Assembly, irradiation, and PIE approved through the IWA process (INL specific)
- Assembled the design and analysis team
- Drafted the F&OR for MSR-C1
- Held Experiment Design Kickoff Meeting
- Developed conceptual capsule design with passive flux and thermal wires
- Developed conceptual design for irradiation vehicle/basket
- Identified the preferred ATR irradiation position (I-3)
- Neutronic models being developed to inform on enrichment, thermal design, and geometry
- Thermal models being developed
  - Thank you, Tony Birri and Julian Schorne-Pinto!

IWA = Irradiation Work Acceptance

F&OR = Functional and Operation Requirements

Am/Pu Salt Synthesis

- Material has been identified and inspected
- Pu/Am alloy contains approximately 20wt% Am
  - Old sample, need to verify starting material composition and isotopic
  - Perform hydride/dihydride reaction, NH_4Cl to chlorinate
  - Can be mixed with desired salts UCl_3/UCl_4, NaCl, $MgCl_2$, etc.
  - Will be characterized to determine elemental/isotopic analysis, density, and MP
- Delays in synthesis due to H/dH furnace being broken
  - Attempts to repair have been delayed due to facility upgrades to support MCRE
  - Facility agreed to prioritize furnace restart activities in April

H/dH = hydride/dihydride

MCRE = Molten Chloride Reactor Experiment

MP = Melting Point

Milestones

Thermal Properties (AT-25IN070502 - Thermophysical Property of Actinides- INL)

Milestone Number	Milestone Title	Due Date	Status
M2AT-25IN0705021	Complete Synthesis of Plutonium/Americium (Pu/Am) Metal to Chloride and Initiate Characterization of the Salt	2/27/2025	Missed 07/30/2025
M3AT-25IN0705022	Complete Initial Thermal Property Measurements of $PuCl_3$-$AmCl_3$-NaCl Salt	9/25/2025	On track
M4AT-25IN0707021	Complete Thermophysical Property Measurements of CEA Provided Salt at INL	08/15/2025	Missed?

Salt Irradiation and PIE (AT-24IN070508 - Irradiation of Salt – INL)

Milestone Number	Milestone Title	Due Date	Status
M2AT-25IN0705081	Complete initial PIE of Irradiated Salt	10/01/2024	Complete
M3AT-25IN0705082	Initiate corrosion analysis of capsule	06/05/2025	On track
M3AT-25IN0705083	Complete preliminary design of new capsule	08/25/2025	On track

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  - Abdalla Abou Jaoude
  - Stephen Warmann
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  - Mike Ruddell and entire NRAD crew
  - Steven Papas
  - Calvin Downey
  - William Philips
  - Hot cell operators
  - Tammy Trowbridge
  - Austin Poole
  - David Zirker
  - Irradiation Team
- Support
  - INL LDRD office
  - Molten Salt Reactor Campaign

Manuscript in process: Irradiation of an Enriched Uranium (NaCl-UCl_3) Fuel Salt Capsule, Summary of Nondestructive Post Irradiation Examinations, and Solidification Modeling

Toni Karlsson[1*], Abdalla Abou-Jaoude[1], Ramiro Oscar Freile[1*], Morgan Kropp[1], Steve Warmann[1], Evan Lovel[1], Brian Kajganich[1], Marc Babcock[1], Katie Hawkins[1], Calvin Downey[1], Mauricio Tano Retamales[1], William Phillips[1], Glen Papaioannou[1], Chuting Tsai[1], Michael Ruddell[1], Reed Eichele[1], Steven Pappas[1], Charles Pierce Jones III[1], Richard M. Cox[2], and Patricia Paviet[2]

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Thank you

Toni.Karlsson@inl.gov