U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Molten Salt Reactor PROGRAM

Molten Salts Thermophysical Properties Determination and Salt Irradiation Experiment at INL

Dr. Toni Karlsson and Dr. Abdalla Abou-Jaoude

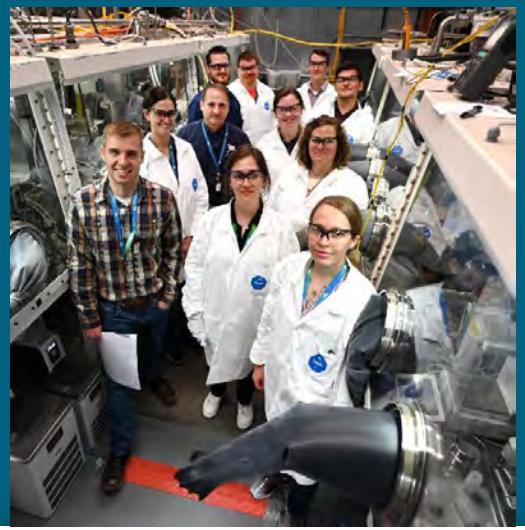
INL/CON-24-77550

INL Idaho National Laboratory

Annual MSR Campaign Review Meeting 16-18 April 2024

Overview

- FY24 Work Packages and Milestones
- WP1 – Thermal Properties
- WP2 – Capsule Irradiation & PIE
- Next Steps
- Conferences, Articles
- Team



Thermal Properties (AT-24IN070502 - Thermochemical and Thermophysical Properties Database Development – INL)

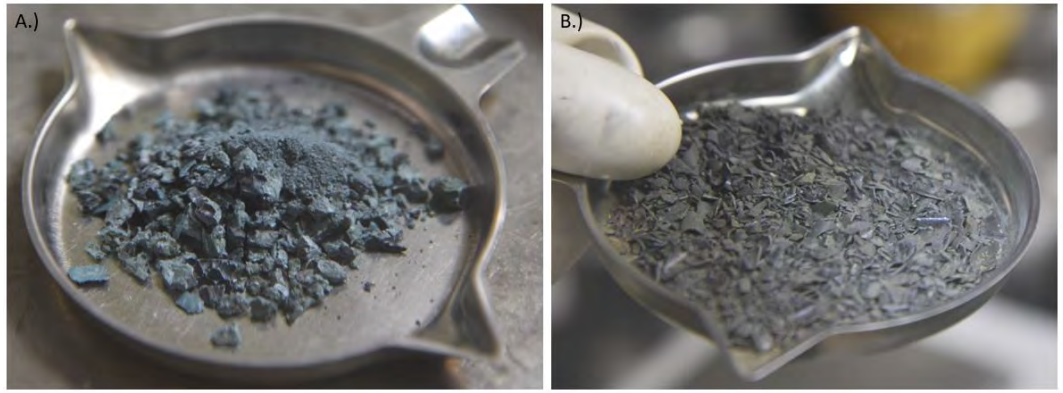
Milestone Number	Milestone Title	Due Date	Status
M3AT-24IN0705021	Complete Chemical/Isotopic Analysis of Fuel Conditioning Facility Flowloop (FCF) Salt	2/15/2024	Complete
M4AT-24IN0705022	Complete Experiment Plan for Actinide (Pu/Am) Salt Synthesis	8/15/2024	On track
M2	*Complete synthesis of plutonium/americium (Pu/Am) metal to chloride and initiate characterization of the salt*	*2/27/2025*	*Pending Funding*

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

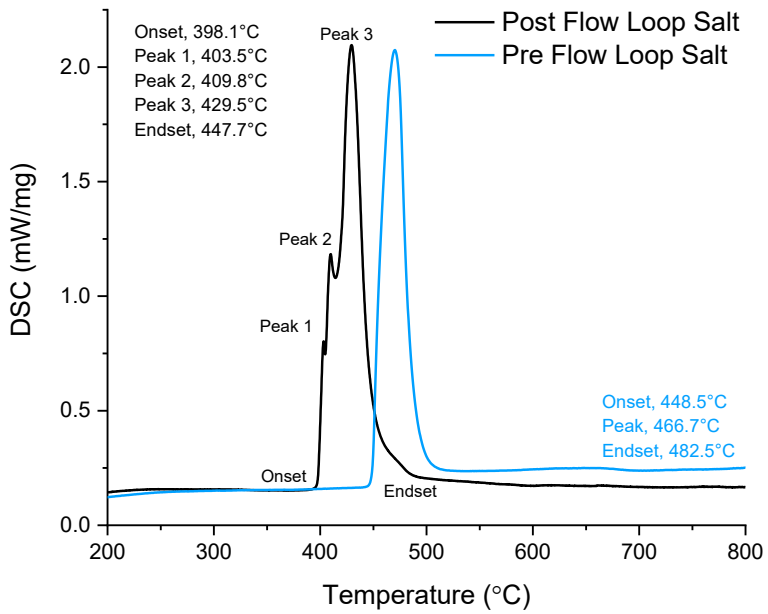
Milestone Number	Milestone Title	Due Date	Status
M3AT-24IN0705081	Complete Fuel Salt Irradiations in NRAD	8/18/2024	On track
M2	*Draft journal article, "Off-Gas and Initial Post Irradiation Examination Measurements from Enriched Uranium Trichloride – Sodium Chloride Eutectic (UCl_3-NaCl) Salt" (working title)*	*1/23/2025*	*Pending Funding*

Status WP1: Natural Convection Flow Loop Salt Study

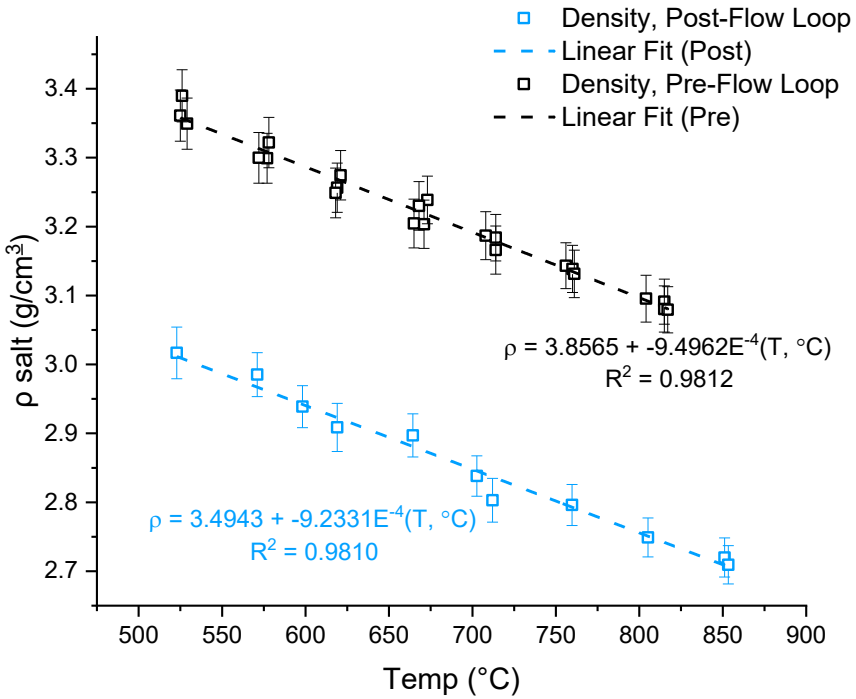
- Flow loop material of construction was analyzed (TerraPower)
- Salt was retrieved and characterized by the MSR Campaign
- Post flow loop salt highlights
  - No corrosion products were detected in the salt by ICP-OES (Cr, Fe, Mn, Ni, Zn, etc.)
  - $NaCl\text{-}PuCl_3$ seems to be relatively inert to material tested, hypothesized due to stable +3 valence state as opposed to +3/+4 valence of U in chloride salt
  - The primary salt was “contaminated” with rinse salt resulting in a change in solidus/liquidus temperature and density
    - $10MgCl_2–60NaCl–26PuCl_3$ (mol%)



Images of flow loop salt. A.) Pre-flow loop operation and B.) post-flow loop operation.



Melting Temperature



Density

OSTI Report: INL/RPT-23-74483-Rev000

Status WP1: Salt Synthesis and Properties

- 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.

Increase surface area of Pu/Am-metal

$$2Pu/Am + 3H_2 = 2PuH_3/AmH_3$$

$$2PuH_3 \rightarrow 2Pu + 3H_2$$

Supply chlorinating agent

$$Pu/Am_{(s)} + 3NH_4Cl_{(s)} + NaCl_{(s)} \rightarrow Pu/AmCl_{3\,(s)} + NaCl_{(s)} + 3NH_{3\,(g)} + 1.5H_{2\,(g)}$$

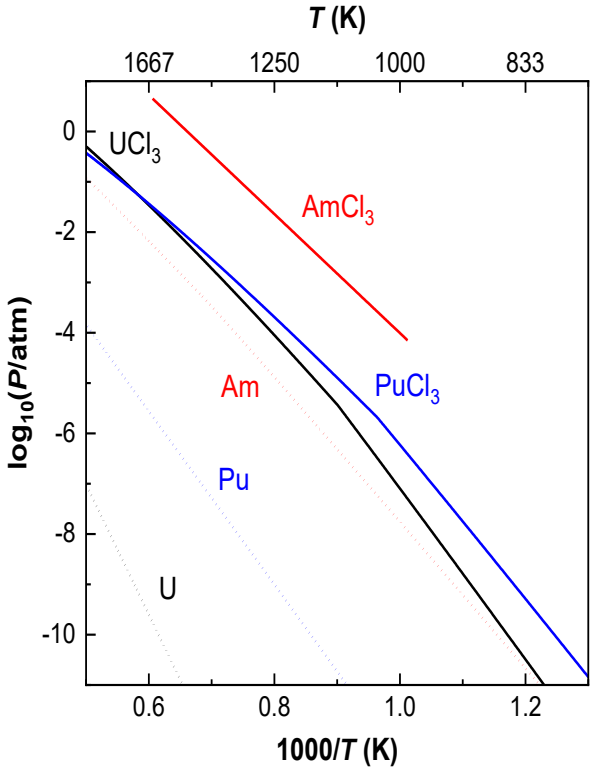
Pu/Am metal alloy

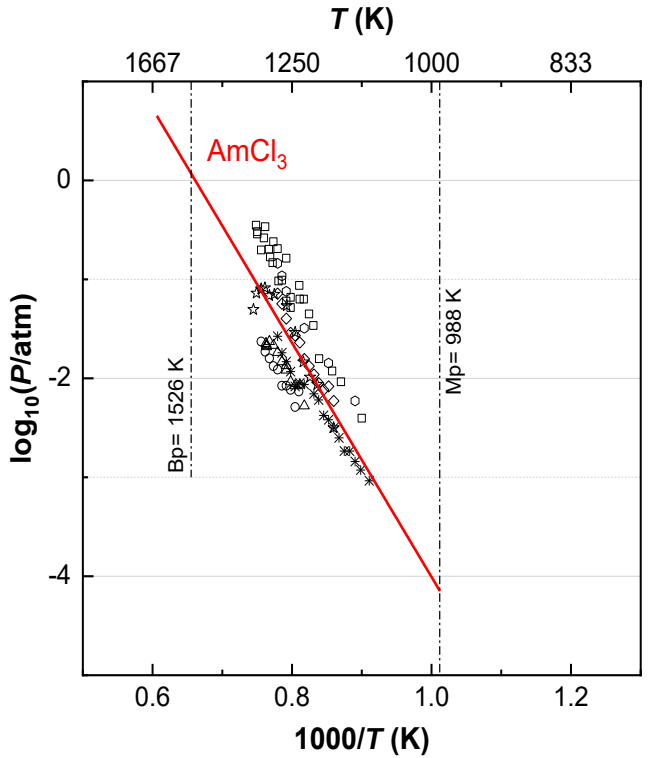
Pu-metal (top), NaCl-36 mol% PuCl3 salt (bottom)

Status WP1: Salt Synthesis and Properties

- Some MSR concepts propose combining aqueous recycling to recover U/Pu to then burn in a LWR as an oxide/MOX fuel (U, Pu)O_2
- In this scenario the minor actinides such as, Am will be “burned” in an MSR to reduce the footprint of a geological repository
- $AmCl_3$ has low boiling point, 1253°C
  - **Must take precautions and consider vapor pressure of $AmCl_3$ during synthesis**
  - Very interesting salt!
    - Experiments to selectively volatilize $AmCl_3$ from bulk salt (not funded)
    - Study pure $AmCl_3$ salt (not funded)
- Should be able to safely handle $AmCl_3$ (no mass loss) for T < 775°C (partial pressure below 100 Pa)

$AmCl_3$ is 166 times more volatile than $PuCl_3$ at 1000 K, with a partial pressure of 7 Pa at its melting point (715°C/988 K). Behavior of the ternary mixture ($PuCl_3$-$AmCl_3$-NaCl) is not well understood.

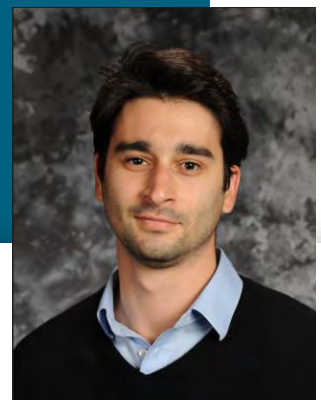




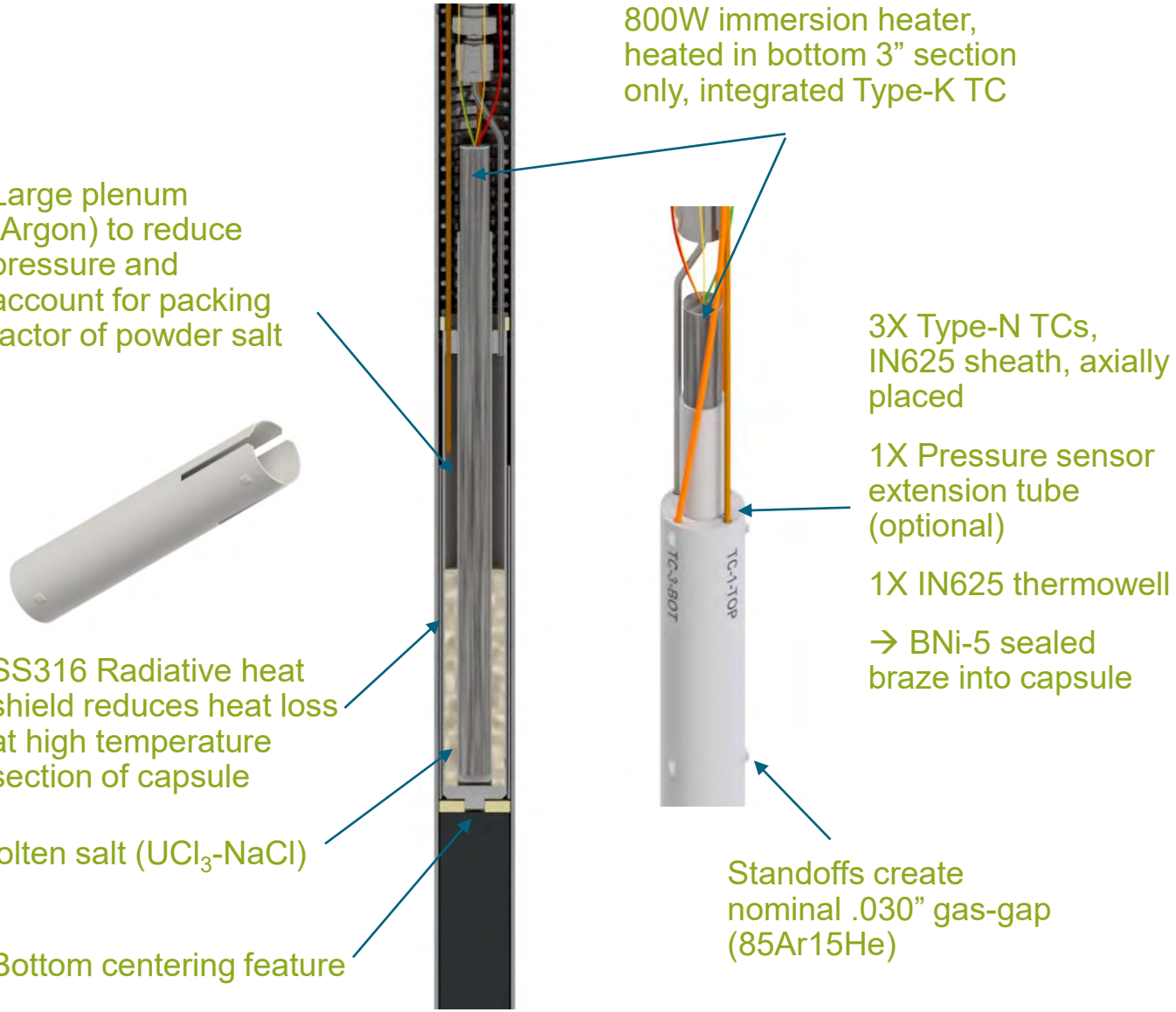
Graphs provided by Dr. Juliano Schorne Pinto (Univ. of South Carolina). Thank you Juliano!!!

Status WP2: Salt Irradiation

- Irradiate molten fissile material-bearing chloride salt with salt-facing materials relevant to MSR development
- Salt sample: 0.66UCl_3-NaCl (93wt% ^{235}U), 40g, 13 cm^3
- Why NRAD?
  - TRIGA-fuel MTR-grid pool reactor for neutron radiography PIE
  - Experiment in core
  - Pool type, no pressure
- Predicted 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`-s
  - Salt Temperature = 525-900°C



Dr. Abou-Jaoude
Abdalla.AbouJaoude@inl.gov



Executing Research in Three Primary Areas

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

Capsule Irradiation Experiment Overview & Goals

Mission Statement

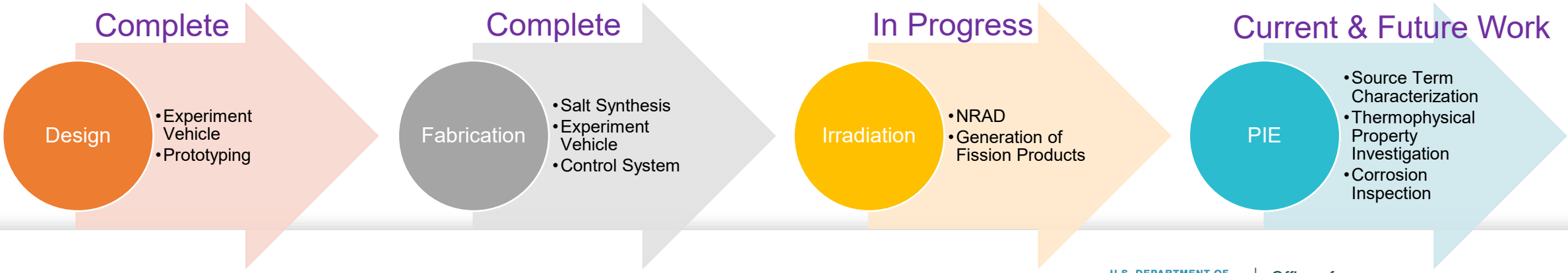
Establishment of a domestic neutron irradiation capability for fissile material-bearing salts for Molten Salt Reactor (MSR) R&D.

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

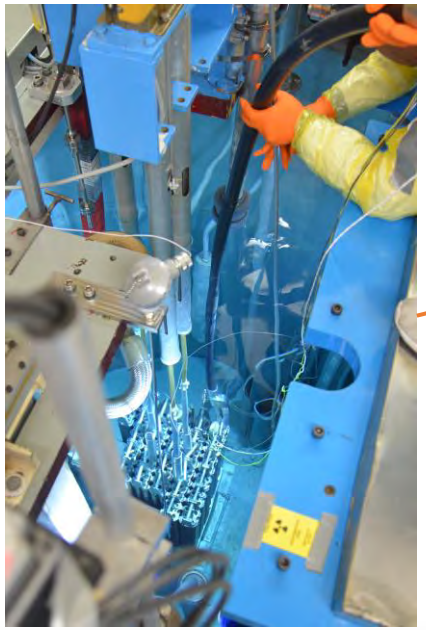


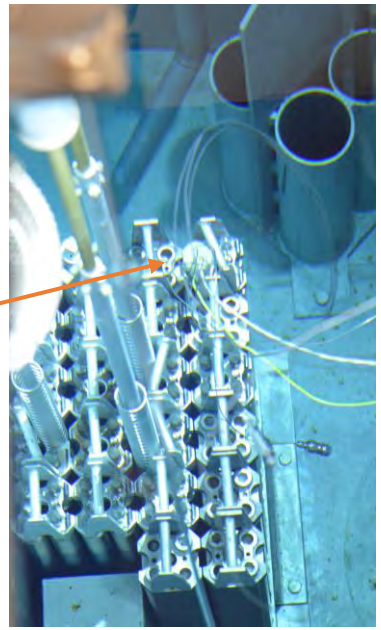
Status WP2: Salt Irradiation

- Placed in the NRAD reactor in August 2023
- Will remove capsule on June 4th
  - Expected Burnup = ~0.2MWd/kgHM
- Cask transfer to HFEF main cell on June 5th
- "Rapid" PIE to begin June 6th ***(pending funding)***
  - PGS
  - Radiography
  - Off-gas analysis (PNNL collaboration)
  - PGS
  - Salt Extraction
  - Elemental/isotopic/impurity analysis

UCl_3-NaCl salt synthesis performed by Dr. William Phillips (INL)

MRTI Inner Capsule





Insertion of experiment in NRAD core on 08/21/2023

Richard Cox (PNNL)
Off-Gas Analysis

FY24 Next Steps

Shawn Reddish, transuranic glovebox operator making salt samples

- **Am/Pu Salt Synthesis**
  - Draft experimental plan
  - Hydride/dihydride of Pu/Am metal (FMF) – *Pending Funding*
  - Synthesis of Pu/$AmCl_3$-NaCl salt (FMF) – *Pending Funding*
  - Prepare sample for transfer (FMF to ARL) – *Pending Funding*
  - Stability, melting temperature, Cp, and enthalpy determination (FFGB)
  - Density (FMF)
- **Capsule Irradiation**
  - Wrap-up irradiation, June 4th (NRAD)
  - Cask transfer fuel assembly with capsule to decon cell (HFEF)
  - "Rapid" PIE *(Pending Funding)*
    - PGS-1 (HFEF)
    - Radiography (HFEF)
    - Collect gas sample (HFEF to PNNL)
    - PGS-2 (HFEF)
  - Write article

Synthesized by Dr. William Phillips!

Pu/Am metal alloy (left), Irradiation capsule (middle), UCl_3-NaCl salt before irradiation (right)

Importance

Through the MSR Campaign, utilize competences and capabilities to allow collaborations between national lab and universities (PNNL, INL, U of SC).

Experimental and computational researcher, working together to solve common problems. “Speak the same language”

Novel research helping to advance our understanding and predictions of MSR fuels.

- **Conferences/Presentation**
  - **2024 TMS**
    - Discussion on the Lessons Learned, Tips, and Tricks When Measuring Thermal Properties of Molten Salts (Presentation)
    - Irradiation of Enriched Uranium Bearing Chloride Salt (Presentation)
  - **ORNL MSR Workshop**
    - Thermal Properties and Related Activities at INL
  - **Plutonium Futures**
    - Experimental Investigations on the NaCl-$PuCl_3$ Eutectic Salt System
- **Papers**
  - **Thermophysical Properties of NaCl-UCl_3-$PuCl_3$ Molten Salts: A Combined Computational and Experimental Study,** Manuscript in process (Manh Nguyen, PNNL leading)
  - **Corrosion in a Natural Convection Flow Loop Containing NaCl-$PuCl_3$ Salt,** Manuscript in process
  - **A Comparative Study and Determination of Thermophysical Property for LiCl-KCl Eutectic,** Manuscript in process
  - **Off-Gas and Initial Post Irradiation Examination Measurements from Enriched Uranium Trichloride – Sodium Chloride Eutectic (UCl_3-NaCl) Salt**

Teammates

- Teamwork makes the dream work!
  - Brought together by the MSR Campaign
    - INL, PNNL, U. of South Carolina
- Goal: Work as a united, cross-disciplinary team, to collect first-of-a-kind data needed for model validation, database development, and MSR deployment


Abdalla Abou-Jaoude


Toni Karlsson


Richard Cox


Juliano Schorne Pinto


Manh Nguyen


Steve Warmann


Morgan Kropp


Scott Middlemas


Nick Erfurth


Michael Karlsson


Robin Roper


Michael Woods

Thank you

Your email Address

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