INL/CON-24-81817-Revision-0

National Laboratory Developments, Idaho National Laboratory MSR Workshop 2024

November 2024

Toni Y Karlsson

Changing the World's Energy Future

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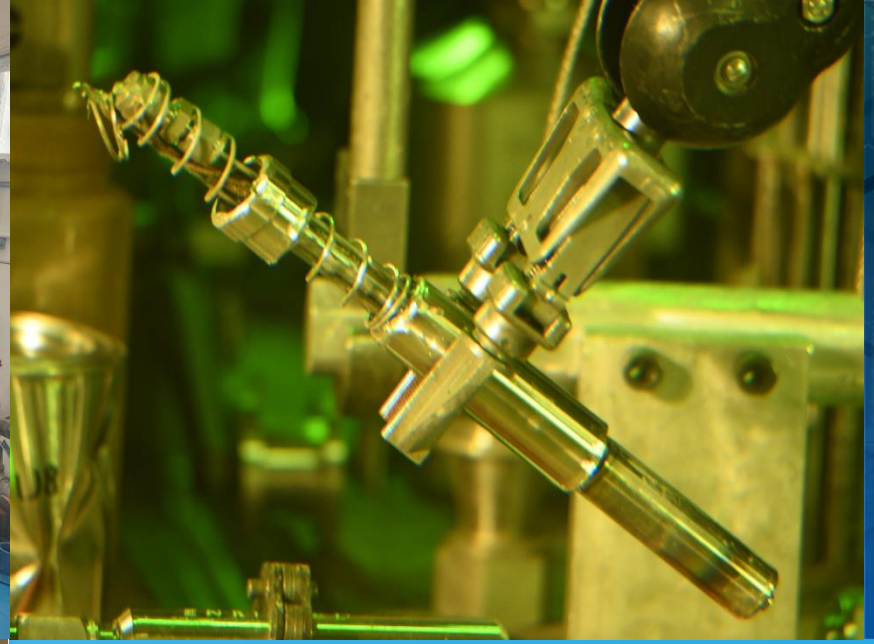
http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517



November 5, 2024

Toni Karlsson
Research Scientist

National Laboratory Developments

Idaho National Laboratory – MSR Workshop 2024

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Idaho National Laboratory

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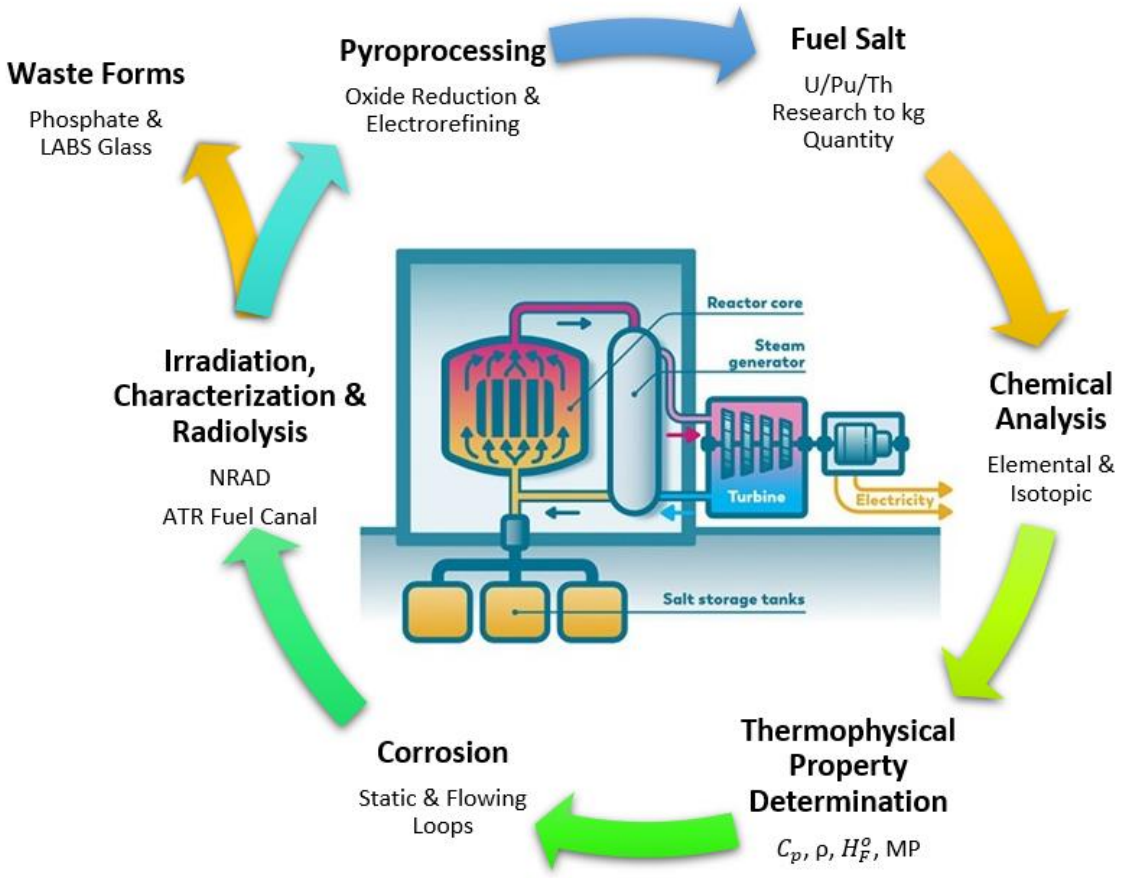
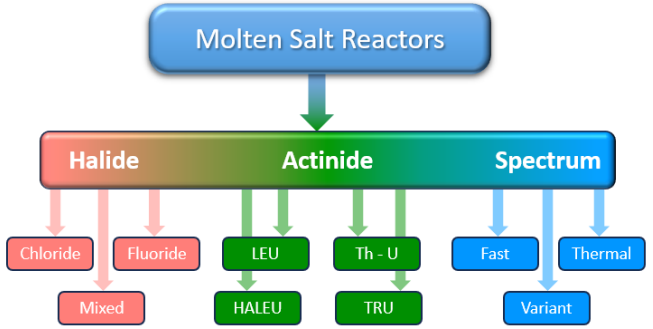
Introduction

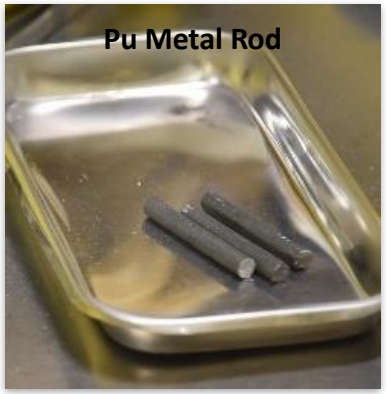


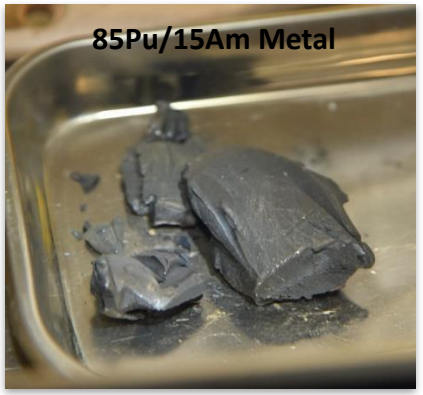
- General Outline
  - Capabilities
  - Infrastructure
  - Collaborations
- MSR research has expanded rapidly in the last 5 years
  - Covering the entire fuel cycle
  - Variety of fuel composition
  - Many reactor designs



Capability - Salt Synthesis

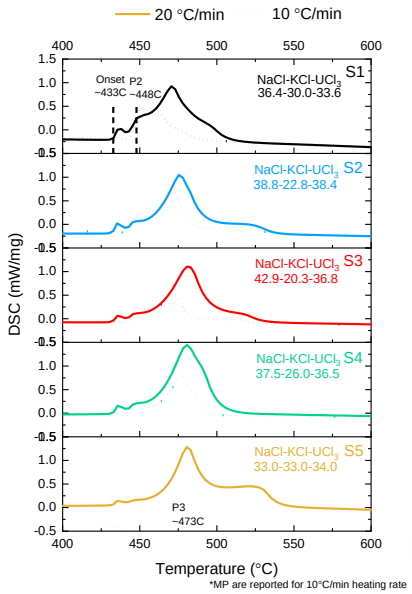
- INL has unique inventory of salts and starting material for MSR fuel salt research
- Accommodate a large variety of MSR fuel concepts
- Salt synthesis, irradiation, and analysis facilities on same campus
  - Facilities setup for high temperature synthesis of novel salts
  - Developing capabilities for new fluorinating and chlorinating pathways
  - Lab to engineering scale synthesis
  - Collaborating with National Science User Facility (NSUF) to build “salt library”

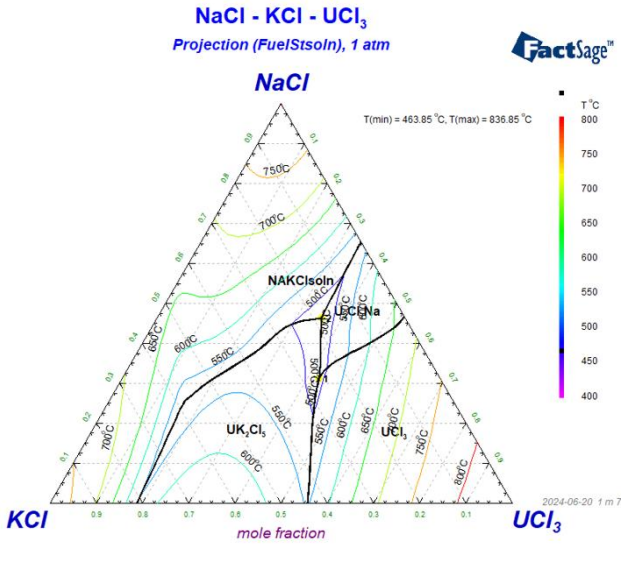


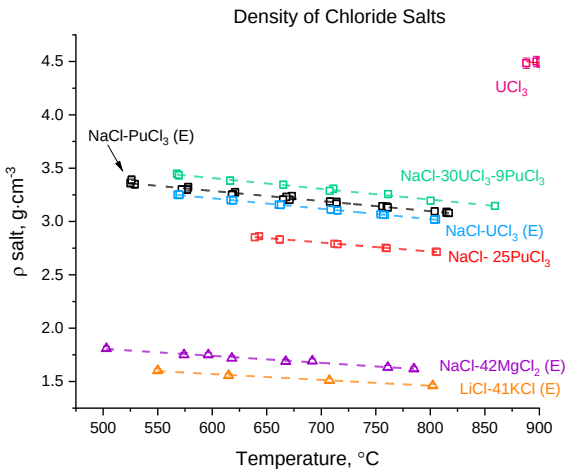


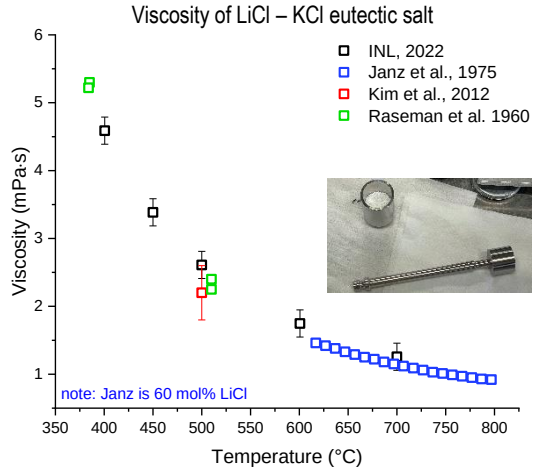
Capability - Salt Property Measurements

- Generate data sets needed by stakeholders to design and license MSRs
- Method validation and benchmarking
  - Participate in multi-lab thermal property validation, fuel performance
  - Experimental data used for model development and validation
- Next steps
  - Continue to expand capabilities, i.e. salt standards, sensors, other properties
  - Investigation of irradiated and “fresh” fuel salts
  - Expand collaborations with other labs and campaigns

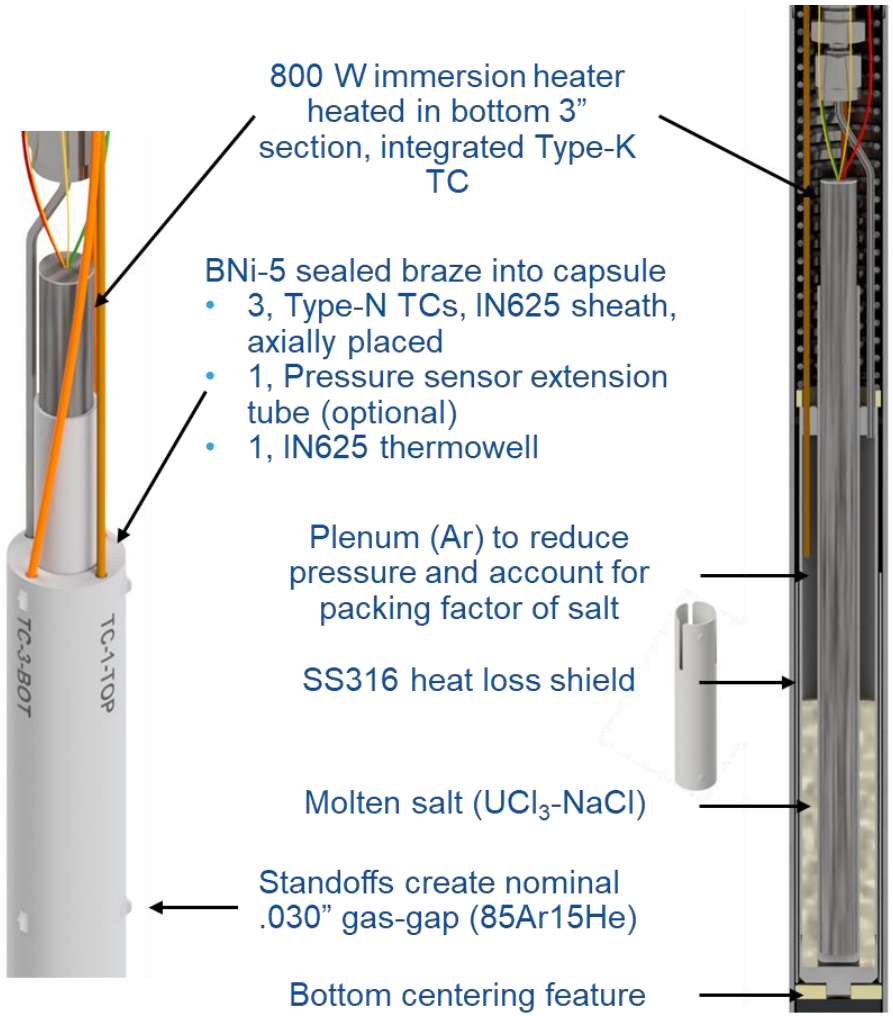








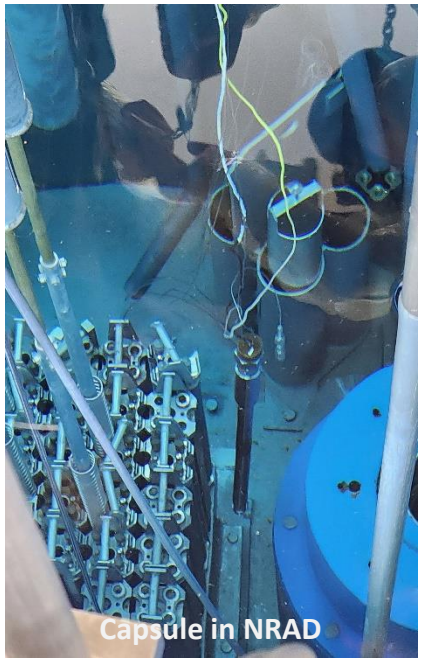
Capability - Fuel Salt Irradiation

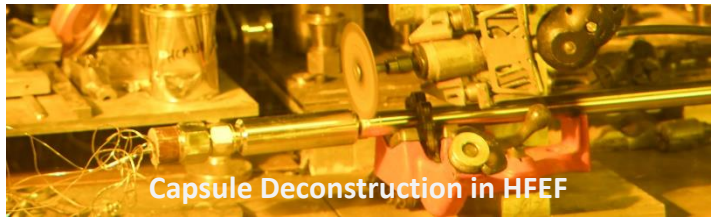


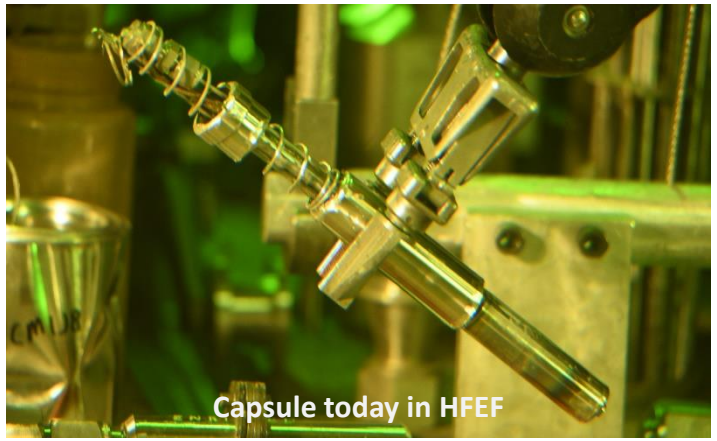
Fuel Salt Capsule Design

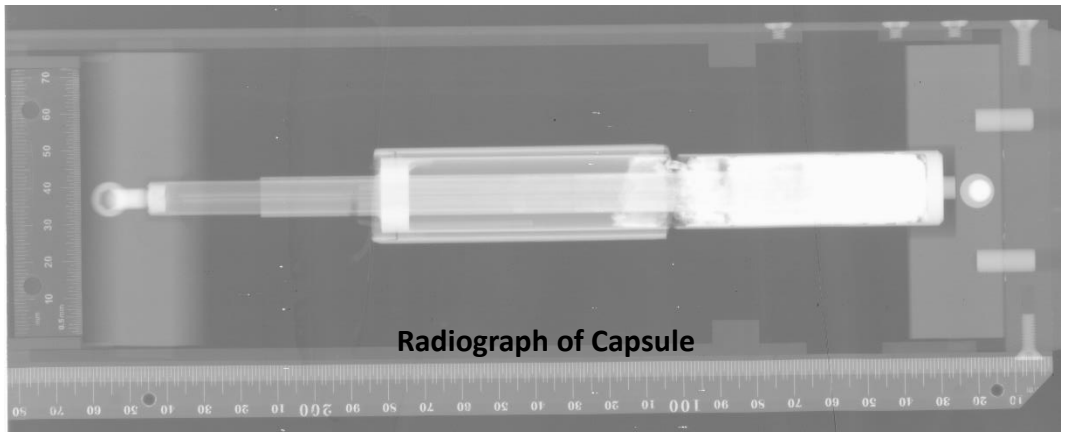
- Irradiation on fuel bearing salt were complete in June 2024
  - UCl_3-NaCl, 93% U^{235}
  - Inconel-625 capsule
  - 390 hours, 0.196 GWd/MTU
- Neutron RADiography (NRAD) Reactor
  - Fission power density of 20 W/cm^3
  - Flux 3.5x10^{12} **n**/cm^2-s, 1.4x10^{13} γ/cm^2-s
  - Salt temperatures above 525°C
  - Outer experiment wall temperature below 100°C
- Research focus areas
  - Radioactive source term quantification
  - Thermophysical property evolution
  - Salt-facing materials corrosion

Capability - Fuel Salt Irradiation


Capsule in NRAD

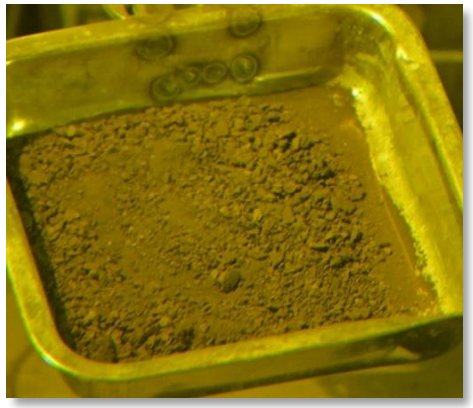

Capsule Deconstruction in HFEF


Capsule today in HFEF

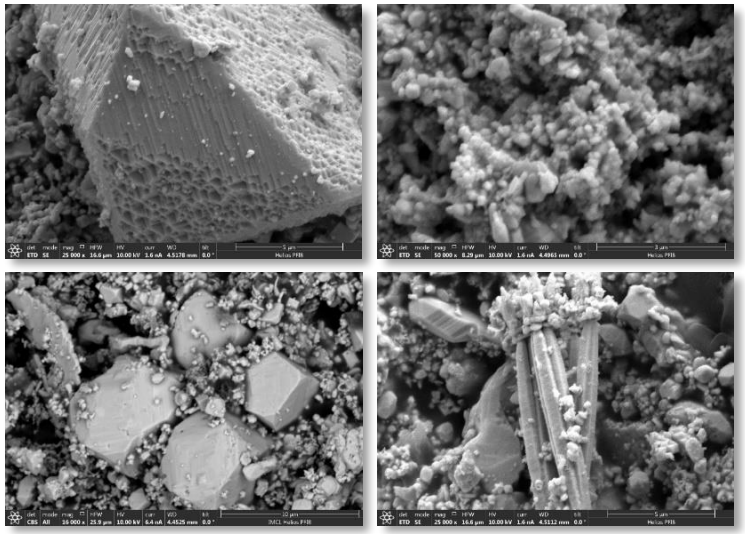

Radiograph of Capsule

- Post Irradiation Examination
  - Gas analysis
  - Precision Gamma Scanning (PGS)
  - Radiography
  - Elemental/isotopic analysis (salt)
  - Corrosion analysis (capsule)
- Next Steps
  - Retrieve salt and section capsule
  - Utilize lessons learned to design new capsule
  - Planning for next irradiations
    - Ternary UCl_3-NaCl-$MgCl_2$
    - Binary UCl_3-NaCl
    - Ternary UF_4-NaF-KF
    - Pu-bearing salt
  - Develop roadmap for higher burnup irradiations

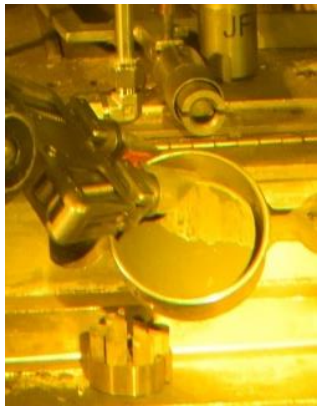
Capability – Fuel Cycle Development



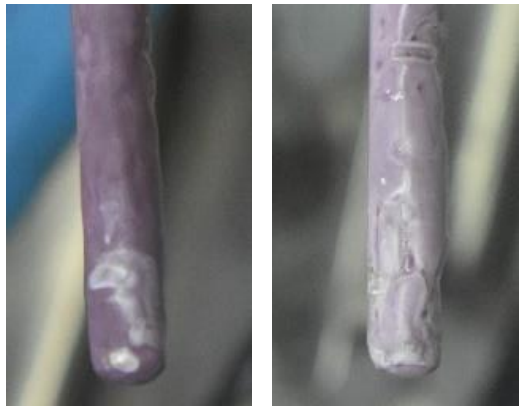
Particles Formed in Salt



Micrographs of Particles



Voloxidation Setup and Fuel

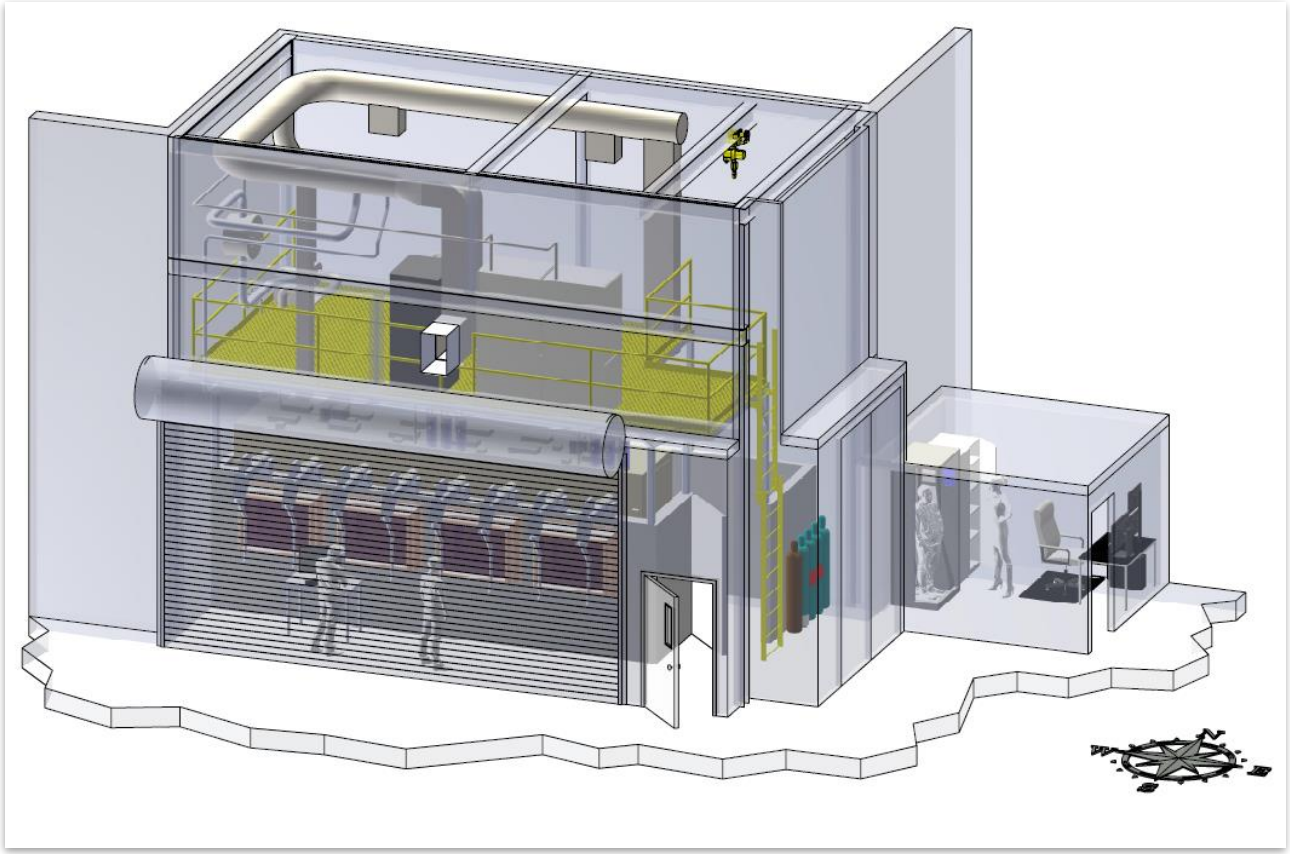


Uranium Depletion in Salt

- INL has been demonstrating pyrochemical molten salt technologies for decades
  - Metal fuel (EBR-II processing)
  - Oxide Fuel (JFCS)
- Example of research activities
  - Particle formation and morphology
  - Voloxidation of spent nuclear fuel (SNF)
  - Methods for managing actinide and FP inventory
  - Development of fluoride fuel cycle
  - Representative sampling and analysis
  - Waste forms – Talk by Morgan Kropp on Wednesday

Infrastructure - MSTEC

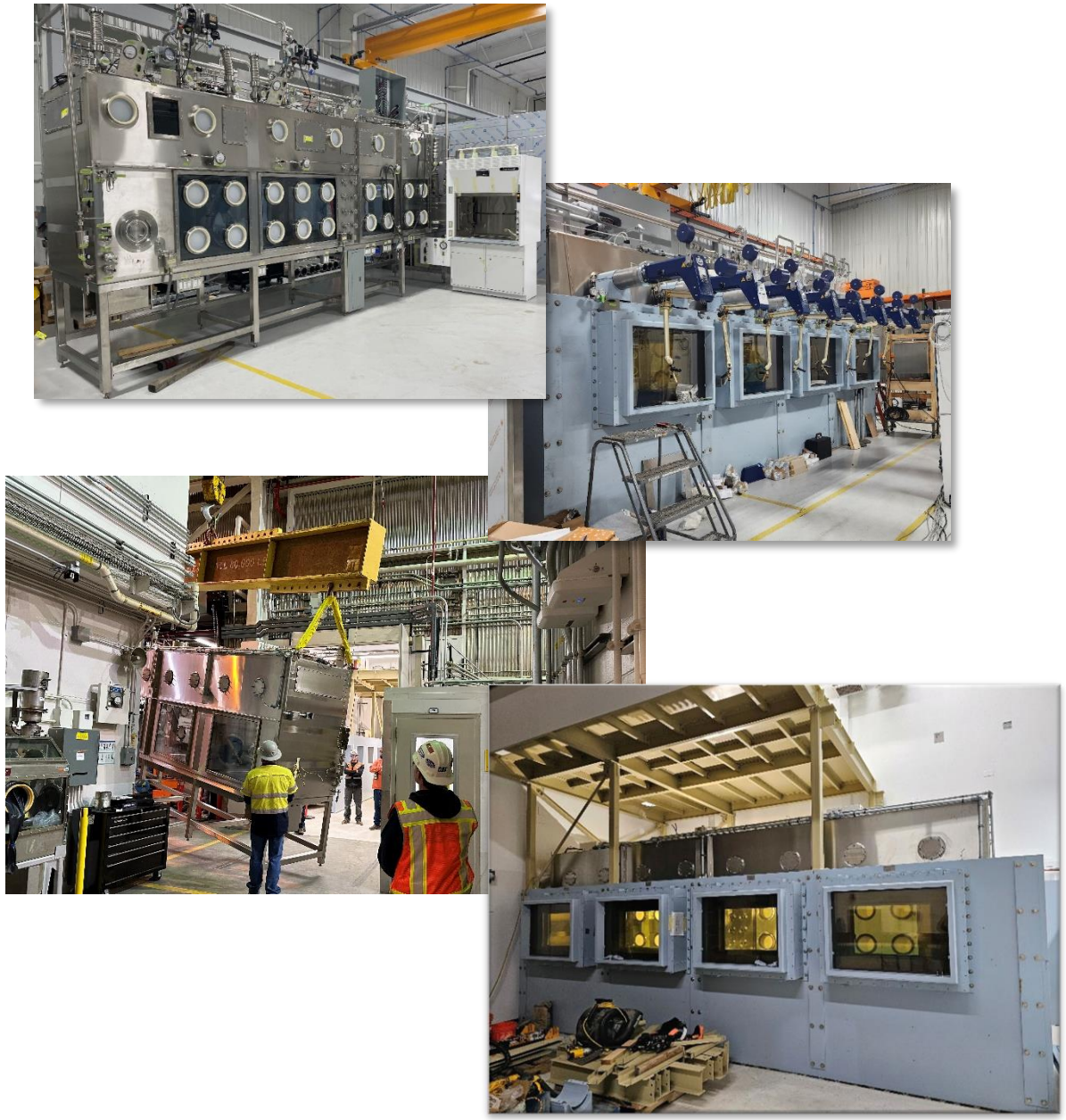
- Molten Salt Thermophysical Examination Capability (MSTEC)
- Located at the Materials and Fuels Complex (MFC)
  - Analytical lab, hot cells, and irradiation facilities on same campus
- Instrumentation
  - Includes universal furnace (electrochemistry, salt synthesis), DSC, STA, rheometer, pycnometer, and densitometer
- Compatible Materials
  - Chloride/fluoride salts, fresh fuel and irradiated fuel salts, pyrophoric material (U, Pu metal), gases (H_2, HCl, Cl_2, HF, F_2, NF_3), Be salts



Shielded glovebox with an agon atmosphere, housing characterization equipment for studying properties and chemistry of high temperature liquids not limited to but focusing on TRU and irradiated fuel salts

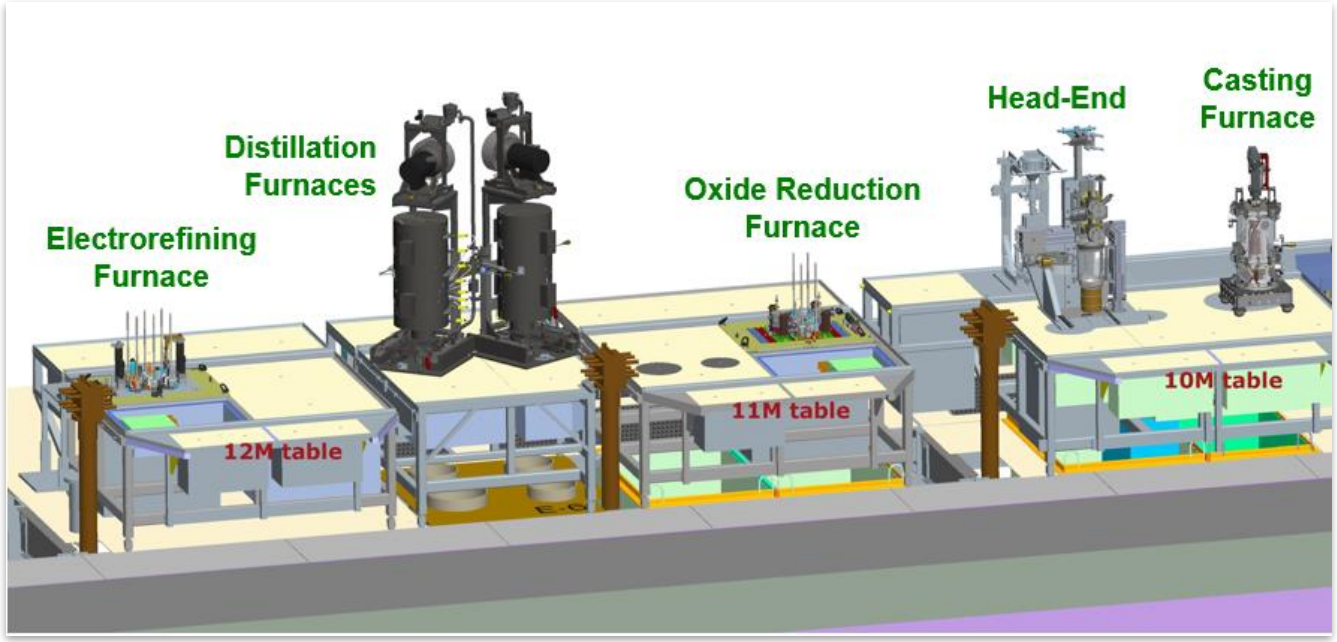
Infrastructure - MSTEC

- Shielded glovebox with an inert argon atmosphere
  - 6.5m (length), 1.2m (width), 1.8m (height)
  - Partition wall to separate “clean” from “dirty” side
  - Connected to a fume hood with small and large transfer chamber
  - TRU glove box with 8’’ glove ports
  - Steel shielding with manipulators and leaded glass
  - Cask and French Can connection for transferring irradiated samples
  - Shieled storage compartments
- Progress
  - FY25 – Commission and readiness assessment



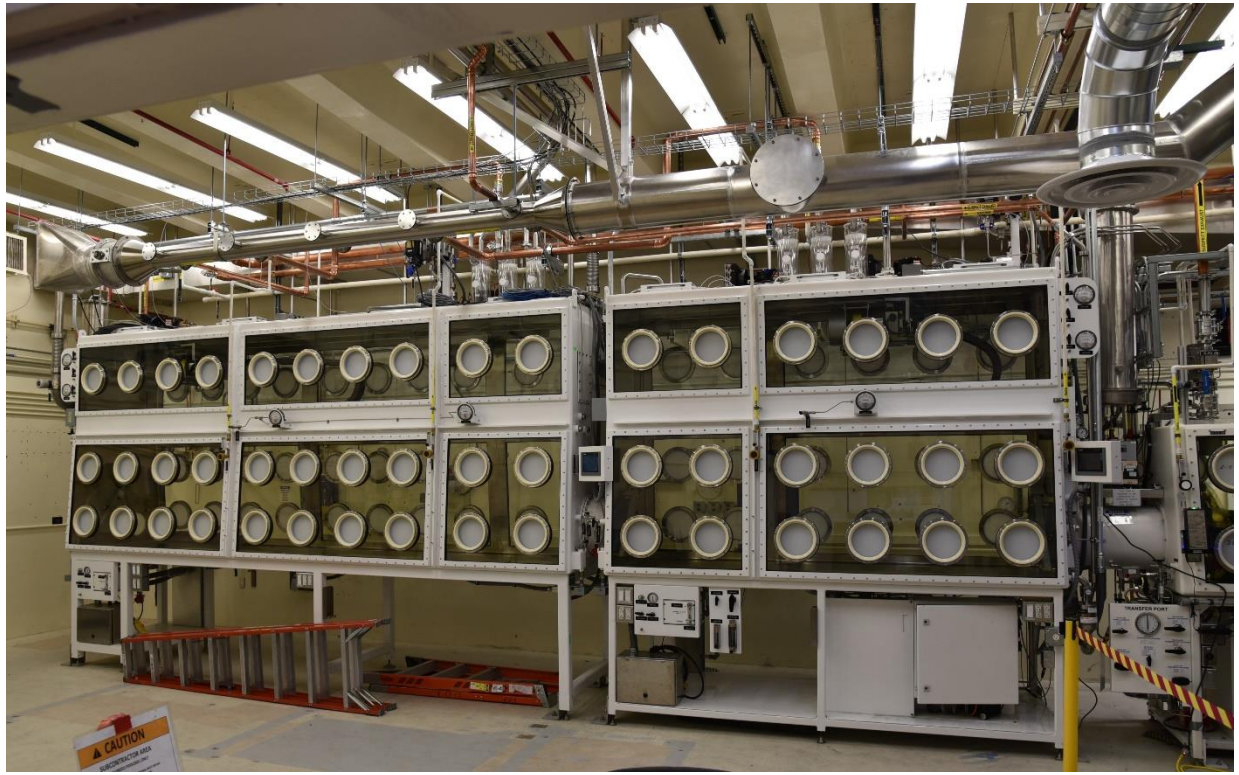
Infrastructure - SPYRE

- Scalable PYrochemical REcycling (SPYRE) Testbed
  - Located in the Hot Fuel Examination Facility (HFEF) main hot cell
  - Equipment used to study develop kg-scale pyrochemical flowsheets using SNF
- Major equipment includes:
  - Head-End: Fuel decladding and sampling
  - Oxide Reduction: Electrochemical reduction of oxide fuel to metal in molten salt
  - Vacuum Distillation: removal of salt from fuel or baskets
  - Electrorefiner: Collection of purified U and U/TRU products
  - Casting Furnace: Fabrication of recycled fuel for further irradiation



Multi-Function Glovebox (MFG)

- It is a combination of two gloveboxes
  - Fuel Characterization Glovebox (FCG) for fuel stock preparation and characterization
  - Fuel Manufacturing Glovebox (FMG) for fuel manufacturing and synthesis
- Design Features
  - Class A, transuranic gloveboxes with shielded (leaded) windows
  - 18 kgs U-235 equivalent (~ 9 kgs Pu)
  - 96 gloves total
  - 3, 22inch floor feed though on the FMG for wells and furnaces
- Will first be used for the Molten Chloride Reactor Experiment (MCRE) fuel salt synthesis
- Open for other projects as needed!



Collaborations

- Science & Technology Development
  - Th, U, Pu, and minor actinide high temperature chemistry
  - Irradiated material testing
  - Separation and purification technologies
  - Online monitoring and sensor development
- Work Force Development
  - Engage and mentor early career researchers
  - Rotational assignments, sponsored PhD students (educate future workforce)
  - Enhance domestic and international collaborations
- Infrastructure
  - Expand current capabilities and adapt to new and emerging demands
- What can we improve on? Feedback is welcome!

Acknowledgements

- Big thanks to
  - Abdalla Abou Jaoude
  - Stephen Warmann
  - Morgan Kropp
  - Mike Ruddell and entire NRAD crew
  - Steven Papas
  - Calvin Downey
  - William Philips
  - Cameron Howard
  - Scott Middlemas
  - Nick Erfurth
  - Juliano Schorne-Pinto
  - Manh Nguyen
  - Richard Cox
  - HFEF, FCF, FMF, ARL operators
  - Many others!

Idaho National Laboratory

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