

Molten Salt Reactor Panel

NEAMS Review Meeting

Theme: This panel will focus on how NEAMS modeling and simulation capabilities can materially reduce technical, regulatory, and deployment risks for MSRs over the next 5–10 years.

Moderator: Dr. Mauricio Tano, Idaho National Laboratory



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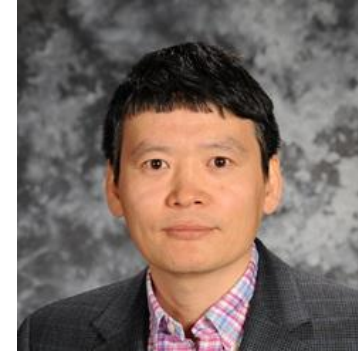
Panelists



Dr. Ting Fei
Argonne National Laboratory
Multiphysics Applications



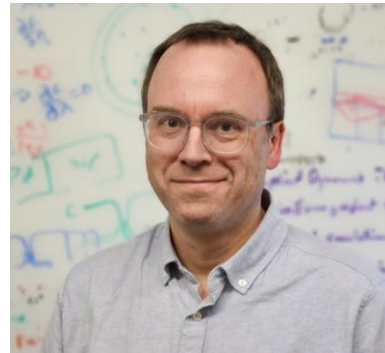
Mr. Travis Mui
Argonne National Laboratory
Thermal Fluids



Dr. Yaqi Wang
Idaho National Laboratory
Reactor Physics



Dr. Tony Birri
Oak Ridge National Laboratory
Structural Materials & Chemistry



Dr. Daniel Schwen
Idaho National Laboratory
Structural Materials & Chemistry



Dr. Patricia Paviet
Pacific Northwest National Laboratory
NTD – Advanced Reactor Technology MSRs

Plan

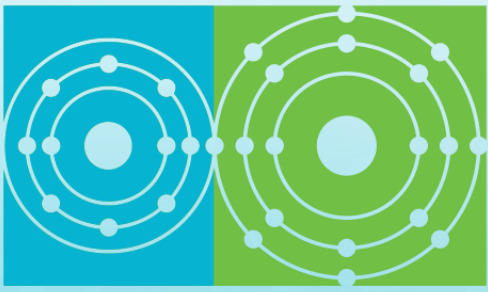
1. Introduction on MSR Landscape & DOE Program Perspective - Dr. Patricia Paviet
2. NEAMS Technical Area Accomplishments & Near-Term Direction - NEAMS MSR Panelists
3. Cross-Cutting Challenges & Paths Forward – NEAMS MSR Panelists
4. DOE Perspective: Gaps & Partnership Opportunities - Dr. Patricia Paviet
5. NEAMS Success Stories & Exciting Capabilities – NEAMS MSR Panelists
6. Value & Impact Assessment from DOE Stakeholders - Dr. Patricia Paviet & Dr. Toni Karlsson
7. Open Q&A



1) Introduction on MSR Landscape & DOE Program Perspective

Dr. Patricia Paviet

- **Guiding Question:** From a DOE MSR program perspective, can you set the stage for MSR technology development, deployment timelines, and where modeling and simulation is most critical?
- Suggested points:
 1. Diversity of MSR concepts (fuel salt vs coolant salt, spectrum, materials challenges).
 2. Rough deployment and demonstration timelines (context for NEAMS impact).
 3. DOE priorities in fuels, materials, licensing readiness.
 4. Where M&S is already influencing decisions and where it must improve.



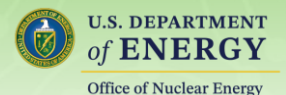
Molten Salt Reactor
P R O G R A M

Research on Molten Salt and Molten Salt Reactor Supported by DOE-NE

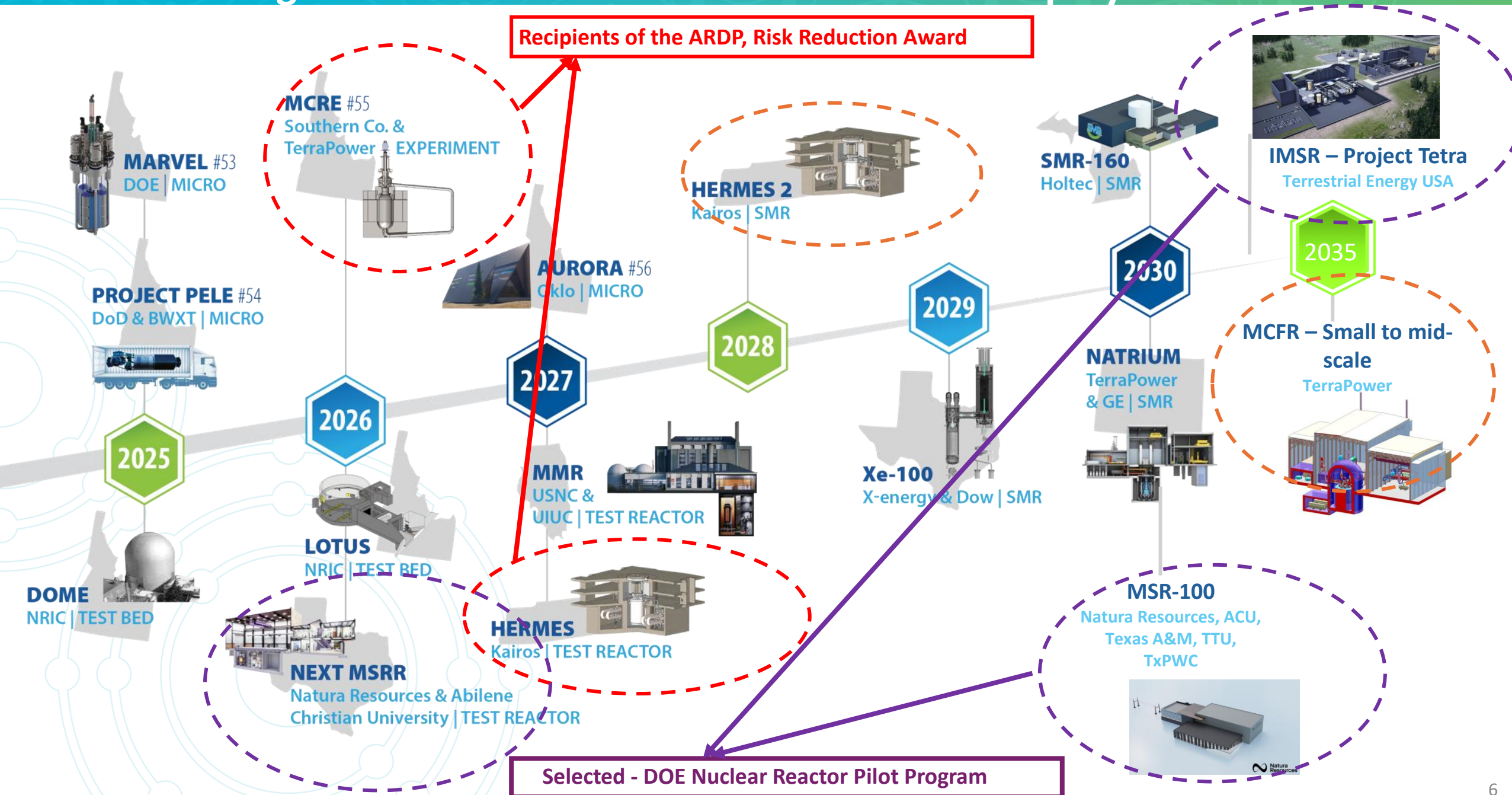
Dr. Patricia Paviet, National Technical Director, ART MSR Program

PNNL-SA-219953

NEAMS Annual Program review 10-12 February 2026



Accelerating Advanced Reactors Demonstration & Deployment in the U.S.



VISION - The ART-MSR program serves as the hub for efficiently and effectively addressing, in partnership with other stakeholders, the technology challenges for MSR to enter the commercial market.

SALT and FUEL SALT CHEMISTRY

Thermophysical and Thermochemical Properties of Molten Salts –
Experimental and Computational
Salt purification and synthesis

Mission:

Develop the technological foundations to enable MSRs for safe and economical operations while maintaining a high level of proliferation resistance.

SALT IRRADIATION

Fuel salt irradiation and post irradiation examination capabilities
NRAD, ATR, HFIR
Under AFC Campaign

TECHNOLOGY DEVELOPMENT

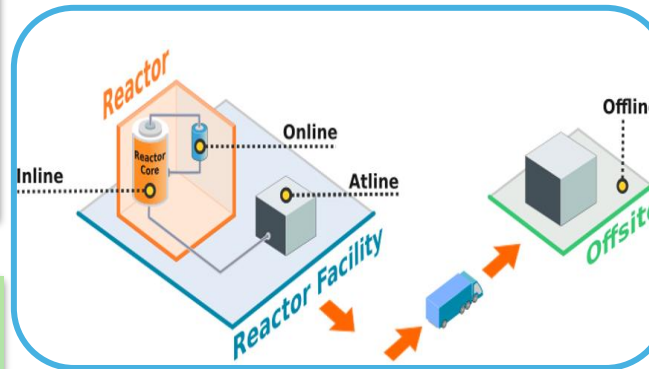
Off-Gas Integrated System
Salt Chemistry Monitoring Tools
Radionuclide Release Monitoring,
Sensors & Instrumentation
Bubbles Behavior

MODELING & SIMULATION

NEAMS Tools & MELCOR used for
Species Tracking
MSR Safety
Accident Scenario
Mechanistic Source Term....

ENGINEERING SCALE FACILITY

LSTL- FLiNaK loop - ORNL
FASTR –NaCl/ MgCl₂/ KCl loop-ORNL
MSTTE – Molten Salt Tritium - INL
Transport Experiment
SAAF- Salt Accident Analysis Facility - ANL
ASL – Actinide Salt Loop - ANL
CIESF – Chlorine Enrichment & Separation Facility - PNNL



MSR OPERATIONS

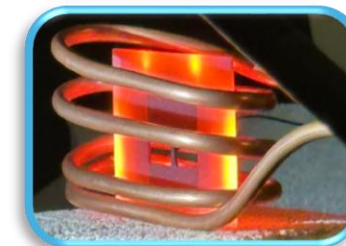
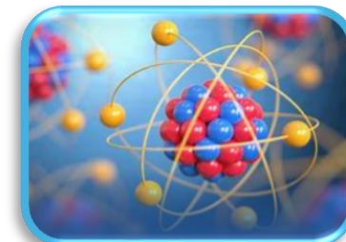
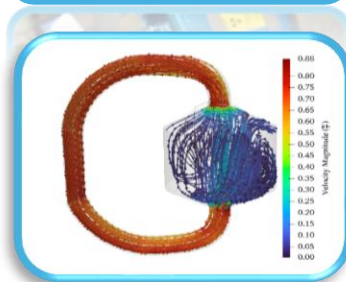
MSR Unique Characteristic =
Ability to Process Fuel during
Operations
Neutron Poisons Removal
Medical Radioisotopes Production
Behavior of Insoluble Particulates

MSR RADIOISOTOPES

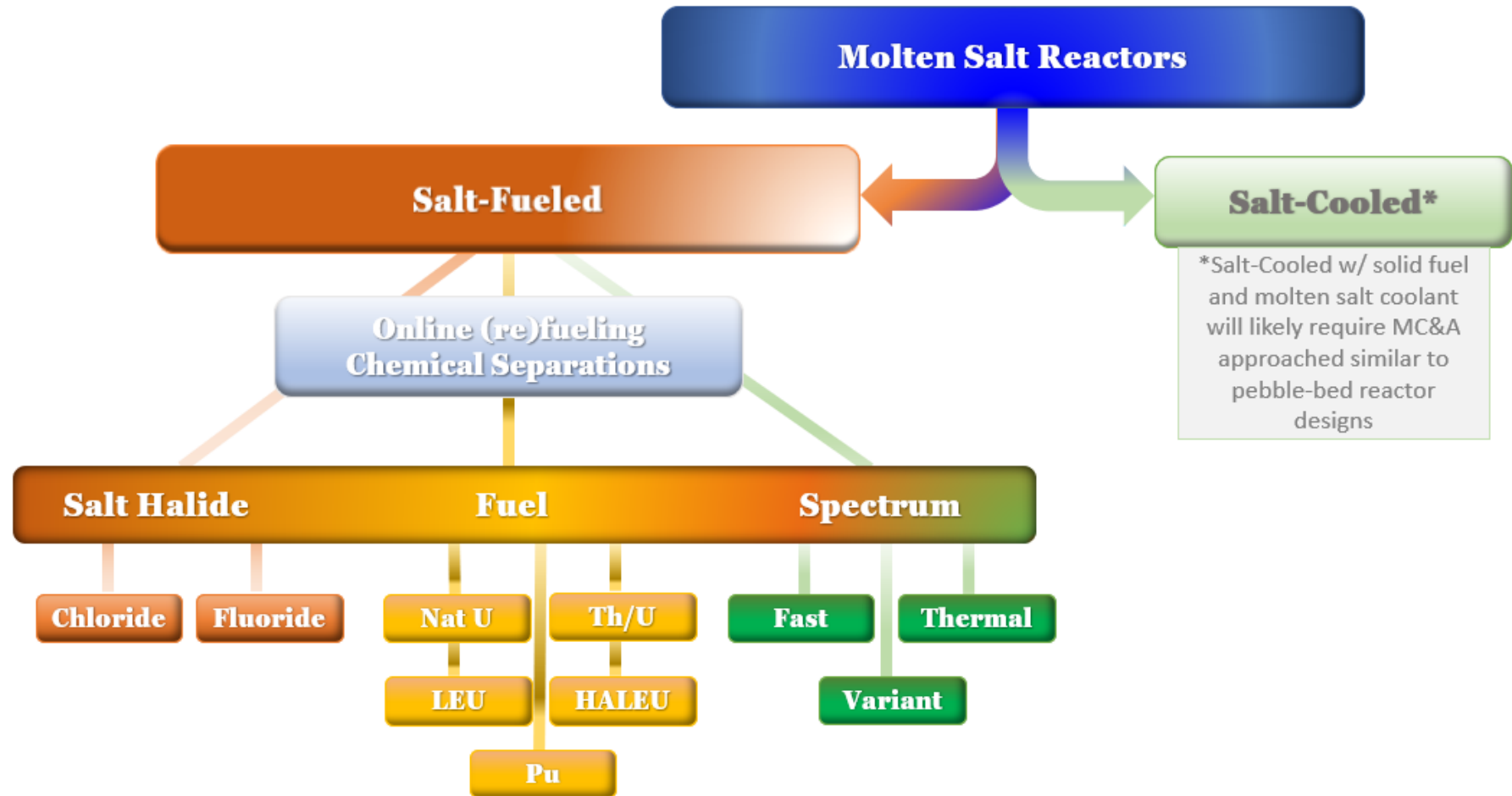
Developing new Technologies to
separate Radioisotopes of Interest to
the MSR Community.

MATERIALS

Development of materials
surveillance technology
Graphite/Salt Interaction
Corrosion studies in F and Cl salts
Under AMMT Campaign



MSRs....so many concepts



Category: Classes:

Molten Salt Reactors

I. Graphite based MSR

II. Homogeneous MSR

III. Heterogeneous MSR

IV. Other MSR

Families:

I. 1. Fluoride salt cooled reactors

I. 2. Graphite moderated MSR

II. 3. Homogeneous fluoride fast MSR

II. 4. Homogeneous chloride fast MSR

III. 5. Non-graphite moderated MSR

III. 6. Heterogeneous chloride fast MSR

Types:

Salt cooled reactor with pebble bed fuel

Salt cooled reactor with fixed fuel

Single-fluid Th-U breeder

Two-fluid Th-U breeder

Uranium converters and other concepts

Fluoride fast Th-U breeder

Pu containing fluoride fast reactor

Chloride fast breeder reactor

Chloride fast breed & burn reactor

Solid moderator heterogeneous MSR

Liquid moderator heterogeneous MSR

Heterogeneous salt cooled fast MSR

Heterogeneous lead cooled fast MSR

Directly cooled MSR

Subcritical MSR

Hybrid moderator MSR

Chloride salt cooled fast reactor

Frozen salt MSR

Hybrid spectrum MSR

Heterogeneous gas cooled MSR



Molten Salt Reactor
PROGRAM



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**ART-MSR Program Review in Albuquerque, NM, hosted by SNL
21-24 April 2026**

**Euromost 2026, 1st European Workshop on MSR 26-29 May 2026,
Baden-Baden, Germany**

IAEA MSR Structural Materials Workshop, Vienna, Austria, 20-24 JUL 2026

12th Annual MSR Workshop, Knoxville, TN, 27-29 OCT 2026

GIF WEBINARS : <https://www.gen-4.org/resources/webinars>

- Webinar #9 <https://www.gen-4.org/resources/webinars/education-and-training-series-9-molten-salt-reactors-msr>
- Webinar #8 <https://www.gen-4.org/resources/webinars/education-and-training-series-8-fluoride-salt-cooled-high-temperature-reactors>
- Webinar #35 <https://www.gen-4.org/resources/webinars/education-and-training-series-35-czech-experimental-program-msr-technology>
- Webinar #42 <https://www.gen-4.org/resources/webinars/education-and-training-series-42-comparison-16-reactors-neutronic-performance>
- Webinar #44 <https://www.gen-4.org/resources/webinars/education-and-training-series-44-molten-salt-reactor-safety-evaluation-us>
- Webinar #73 <https://www.gen-4.org/resources/webinars/education-and-training-series-73-molten-salt-reactors-taxonomy-and-fuel-cycle>
- Webinar #88 <https://www.gen-4.org/resources/webinars/education-and-training-series-88-multiphysics-depletion-chemical-analyses-molten>
- Webinar #97 <https://www.gen-4.org/resources/webinars/education-and-training-series-97-overview-and-update-msr-activities-within-gif>
- Webinar #107 <https://www.gen-4.org/resources/webinars/education-and-training-series-107-overview-nuclear-energy-advanced-modeling-and>

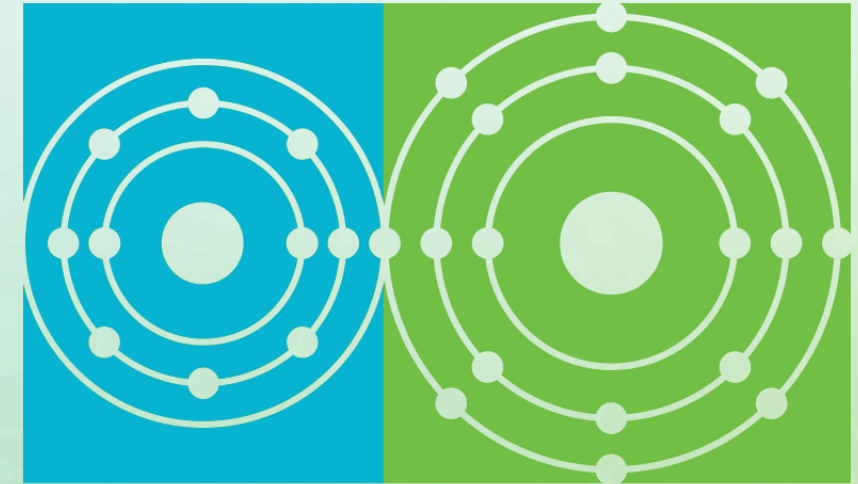


**Molten Salt Reactor
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Thank You



Molten Salt Reactor
P R O G R A M

Patricia.Paviet@pnnl.gov

<https://gain.inl.gov/doe-molten-salt-reactor-program/>

2) NEAMS Technical Areas Accomplishments & Near-Term Direction

NEAMS Panelists

- **Guiding Question:** What are your most impactful recent accomplishments for MSRs, and where are you headed next to support credible modeling and simulation for MSR design, analysis, and licensing?
- Panelists are encouraged to clearly state:
 1. What problem this capability solves?
 2. Who benefits (designer, experimenter, regulator, program manager)?
 3. Why it matters now?

Multiphysics Applications Highlights

Tingzhou Fei, ANL

FY25-26 Contributors:

ANL: Tingzhou Fei (WPM), Jun Fang, Shayan Shahbazi

INL: Mauricio Tano(WPM), Ramiro Freile, Rodrigo de Oliveira, Samuel Walker, Parikshit Bajpai, Olin Calvin, Chaitanya Bhave

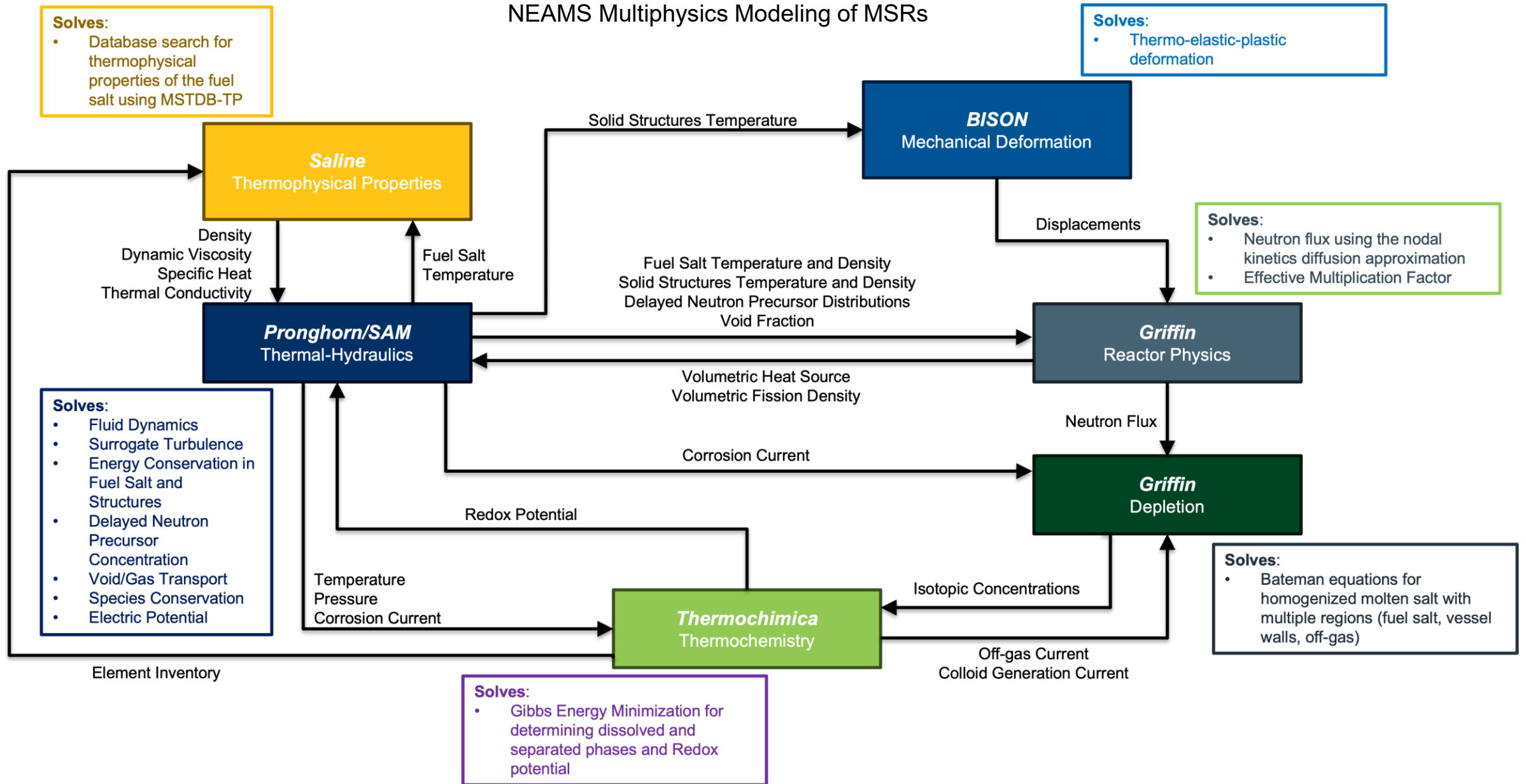
ORNL: Donny Hartanto, Eva Davidson (WPM)



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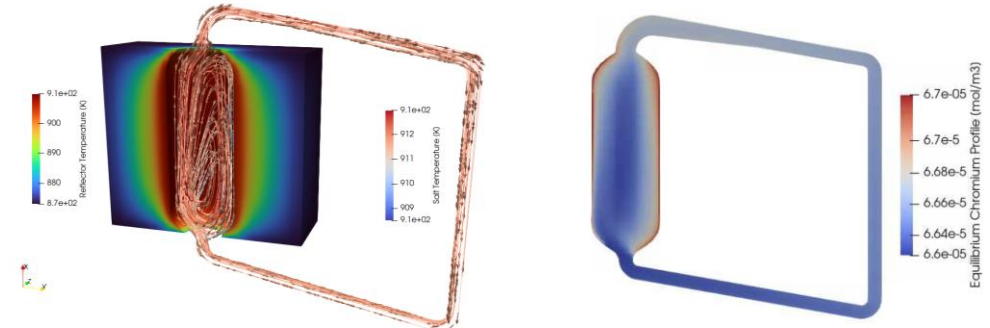
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NEAMS Multiphysics Modeling of MSRs



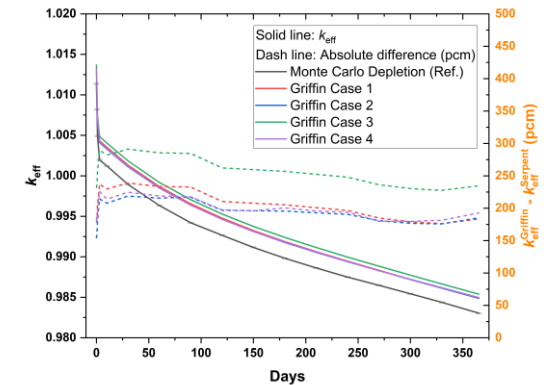
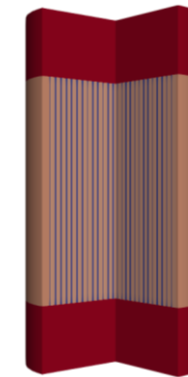
MSR Multiphysics Analysis and Demonstration

- Demonstrated steady state MSR analysis including neutronics, thermal hydraulics, species transport, and chemistry
 - Demonstrated depletion for both thermal (MSRE) and fast (Lotus) MSR with **Griffin**
 - Demonstrated cross section generation with **OpenMC** and **SHIFT** for depletion
 - Developed **MOSCATO/NeK** model for noble metal deposition calculation in MSRE heat exchanger
- Steady state and transient modeling of LOTUS-MSR
 - Verified **Griffin/Pronghorn** with high-fidelity results under steady state.
 - Demonstrated corrosion and species transport calculation
 - Demonstrated unprotected and protected LOFA transient analysis

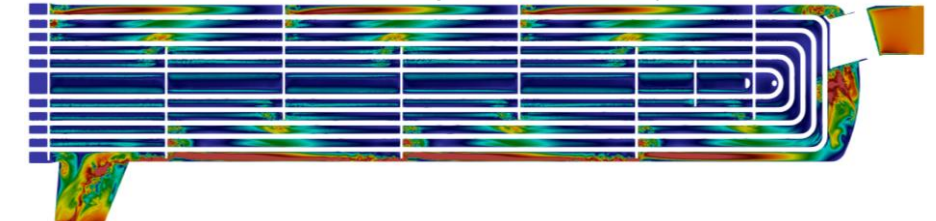


LOTUS MSR Multiphysics Demonstration

MSRE
Microscopic
Depletion

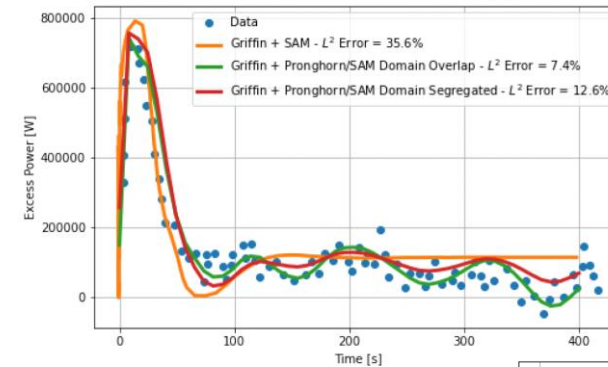


MSRE Heat Exchanger CFD Analysis



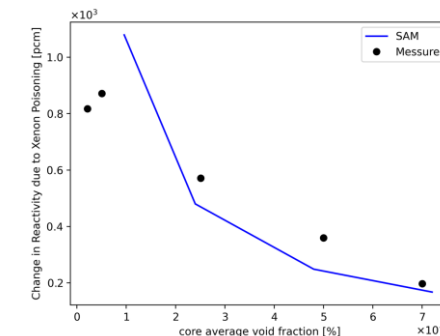
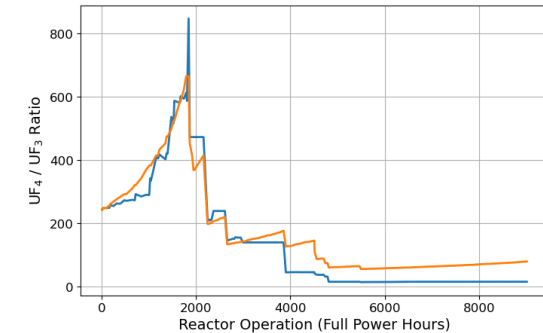
MSR Multiphysics Validation

- MSRE transient (pump startup/coastdown, reactivity insertion, and natural circulation) validation with **Griffin/Pronghorn/SAM**
- MSRE redox potential calculation validation of **Griffin/Pronghorn/Thermochemica**
- MSRE steady state Xenon transport validation of **Griffin/SAM**
- Conducted single-physics validation in support of multiphysics coupling
 - Validated **SAM** drift flux two-phase flow modeling using TAMU Molten Salt Flow Loop.
 - Verified **Thermochemica** integration in MOOSE by reproducing phase diagram for NaCl- UCl_3 .
- *FY26 work will focus on the transient demonstration of the multiphysics coupling and uncertainty quantification.*
 - *Neutronics, thermal hydraulics, species transport, chemistry*



MSRE Transient Validation

MSRE Redox Validation



MSRE Xe Transport Validation

Chemistry and Corrosion Technical Area

Daniel Schwen

Idaho National Laboratory

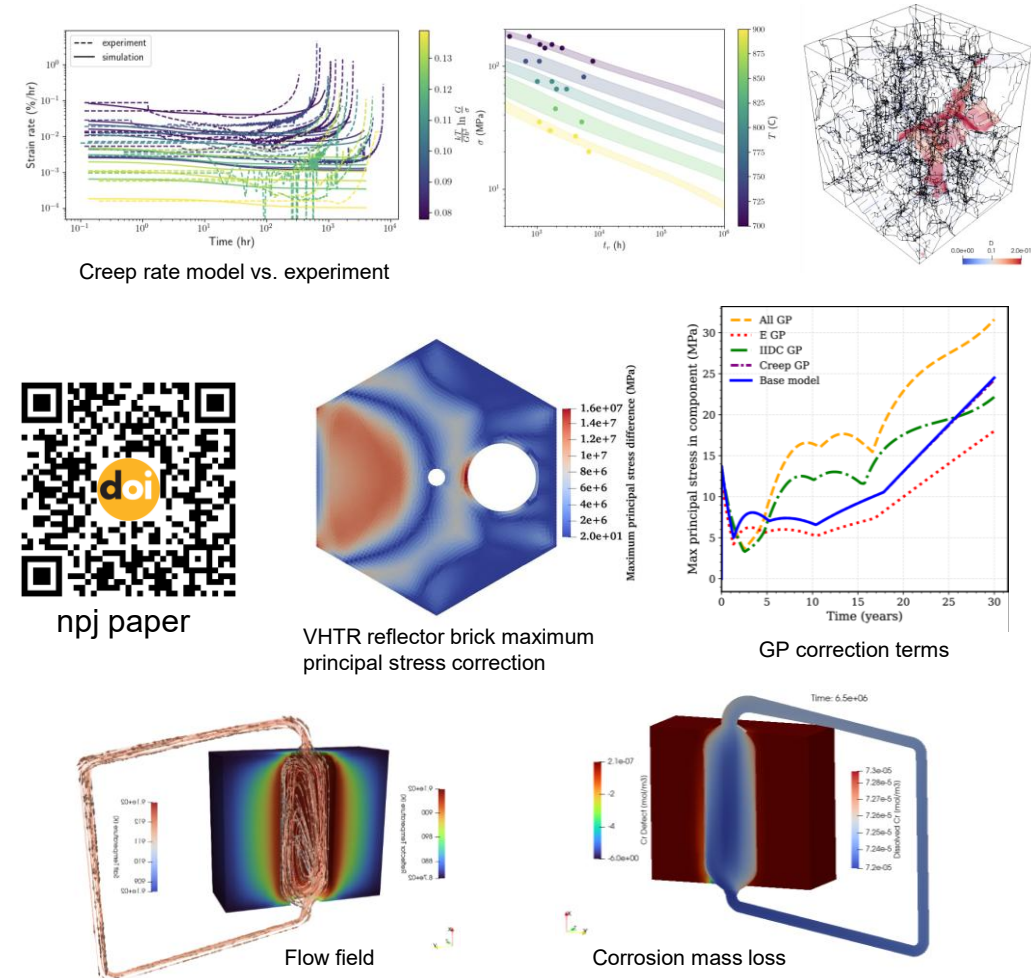


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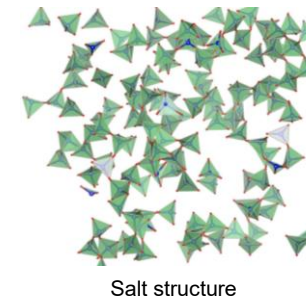
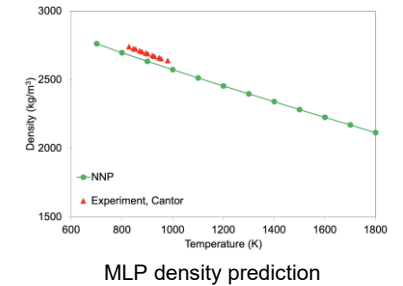
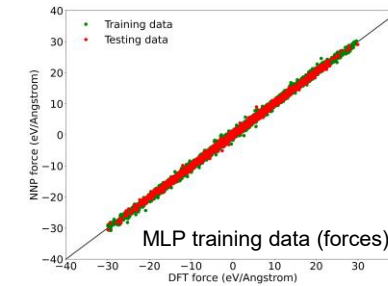
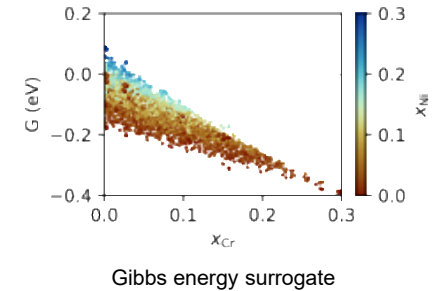
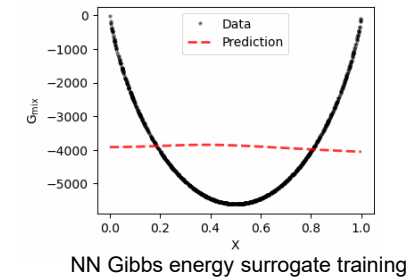
Chemistry and Corrosion – 1/2

- **ANL** Alloy 709 development and qualification
 - physics-based creep/thermal aging model accelerating long-term property prediction
 - MOOSE solid mechanics, CZM
 - Ongoing: NEML2-MOOSE GPU improvements.
- **INL** Bayesian calibration of irradiated graphite property models under high temperatures
 - FY'25: Bayesian calibration framework with explicit model-form discrepancy, reducing predictive errors by up to **65%** across multiple grades
 - FY'26: Additional graphite properties and grades (NBG-25 & ETU-10), forward uncertainty quantification at the component scale
- **INL** Electrochemistry for Corrosion and Plating
 - FY'25: PNP-based electrochemistry and mass-transfer model in MOOSE
 - FY'26: Loop and integral reactor validation framework for corrosion modeling, verifying coupling of corrosion and depletion for studying long-term reactor operation



Chemistry and Corrosion – 2/2

- **INL Accelerate Thermochemistry** solves
 - *Thermochimica* parallelization, kd-tree based results caching
 - PF corrosion with NN free energy surrogates trained on MSTDB-TC
 - *Thermochimica* testing and bug fixes
- **INL Thermophysical Properties**
 - FY'25: MLP for ternary fuel bearing FLiBe salts, predicted thermophysical properties over wide temperature and composition ranges can be well described by simple, analytical equations
 - FY'26: develop MLP for LiF-BeF₂-UF₄ salts, predict thermophysical properties where experimental data is lacking
- **LANL Thermophysical Properties**
 - FY25: AIMD thermophysical properties of LiF-BeF₂-UF₄
 - FY26: AIMD of NaF-ZrF₄-UF₄ molten salts. Currently validating the computational protocols by comparing to available experimental data.



Structural Materials and Chemistry

Tony Birri, ORNL

Oak Ridge National Laboratory



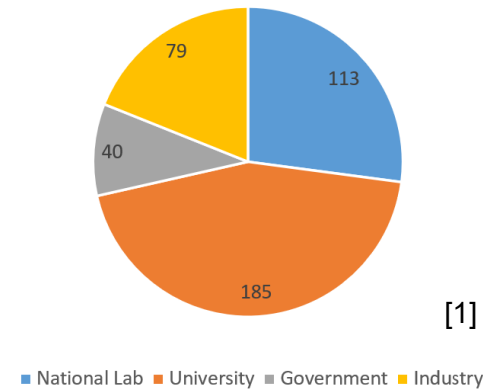
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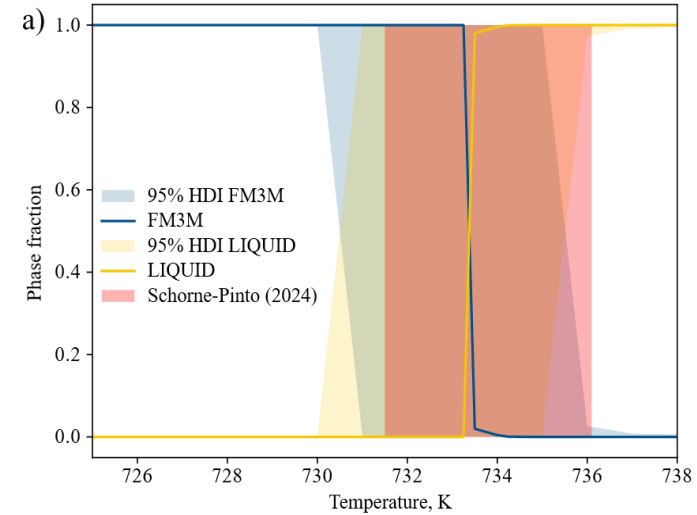
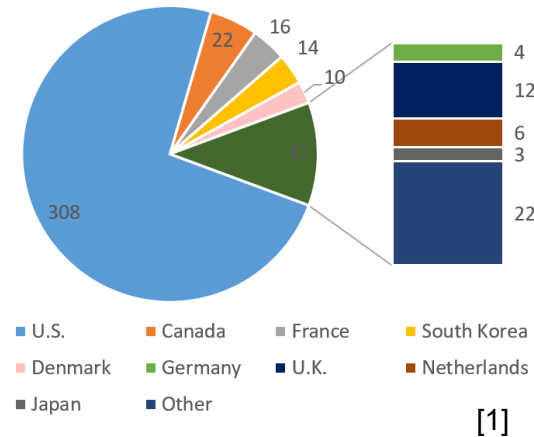
Structural Materials and Chemistry-- Accomplishments

- Molten Salt Thermal Properties Database (MSTDB, soon to be MSD) has had several improvements (collaborative with MSR program)
- MSTDB-TC uncertainty propagation capabilities implemented and applied
 - Thermodynamic calculation uncertainty is important for defining operating conditions for MSRs
- MSTDB-TP expanded to include surface tension, developed thermal conductivity prediction model
 - Expanded property characterization capabilities reduces burden on developer efforts; broad database supports all developers
- Look Ahead: MD integration into TP, expanded UQ efforts for TC

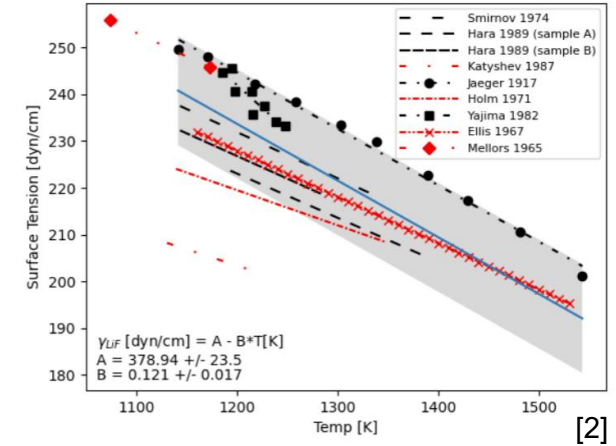
MSTDB Subscribers by Institution Type



MSTDB Subscribers by Country

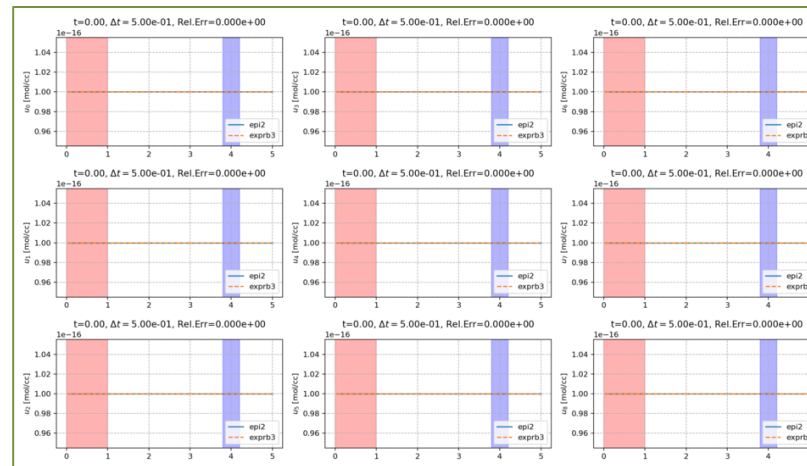
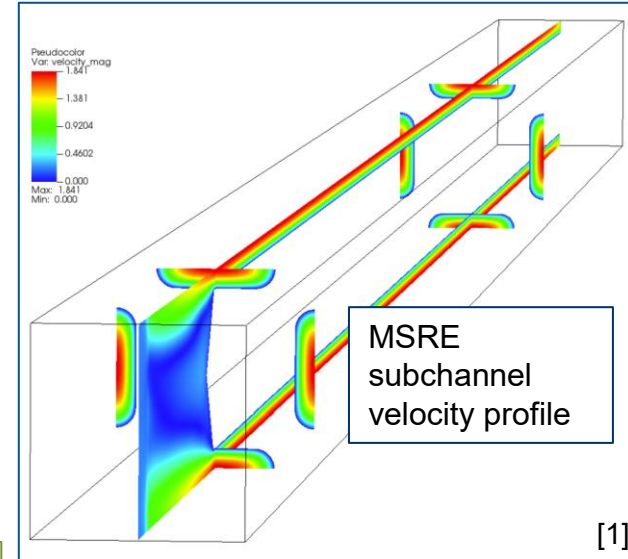
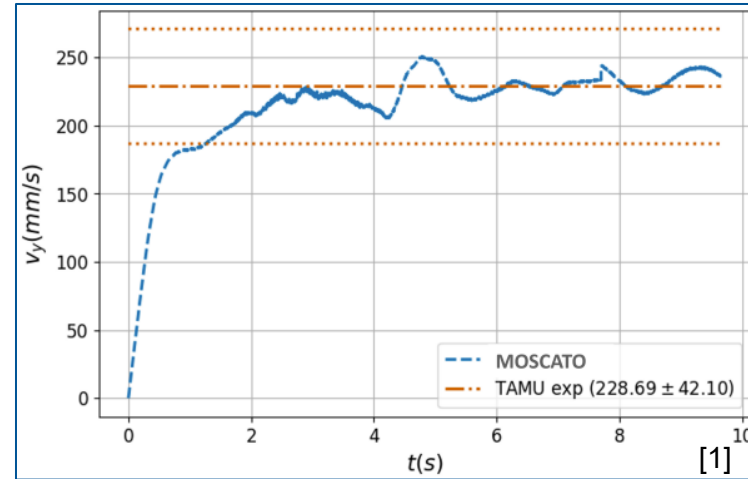


LiF Surface Tension Correlation with 2σ Uncertainty Band



Structural Materials and Chemistry-- Accomplishments

- Several improvements to Molten Salt Chemistry and Transport (MOSCATO)
 - Enhanced capabilities for bubbles transport (Level-Set methods for single-bubble, solver for bubbly flow)
 - Geometry-specific mass transfer correlation for MSRE subchannel
- Mole has had further integration efforts with MOOSE, improved species transport capabilities
 - Migrated Henry's gas constant and mass transfer Aux. kernels from Mole to MOOSE
 - Building a next generation transient multi-species transport capability with exponential integrators and matrix-free methods



$$\frac{\partial u}{\partial t} = \underbrace{Lu}_{\text{Decay, Trans.}} - \underbrace{\left(\frac{1}{A} \right) (\nabla(Avu) + D \nabla \cdot (A \nabla u))}_{\text{Adv., Diffusion}} \pm \underbrace{S(u, t)}_{\text{liq} \rightarrow \text{vap.}}$$

RX Pipe Gas Rem.

Thermal Hydraulics Developments for Molten Salt Reactors

**Mauricio Tano, Ramiro Freile, Victor Coppo Leite, David Reger, Mengnan Li,
Joshua Hansel, Guillaume Giudicelli, Lise Charlot, Mustafa K. Jaradat**
Idaho National Laboratory

**Travis Mui, Daniel O'Grady, Thanh Hua, Andrés Nicolás Fierro López, Ling Zou, Rui Hu,
Nadish Saini, Dillon Shaver, Ananias Tomboulides, Aleksandr Obabko, Elia Merzari**
Argonne National Laboratory

Robert Salko
Oak Ridge National Laboratory



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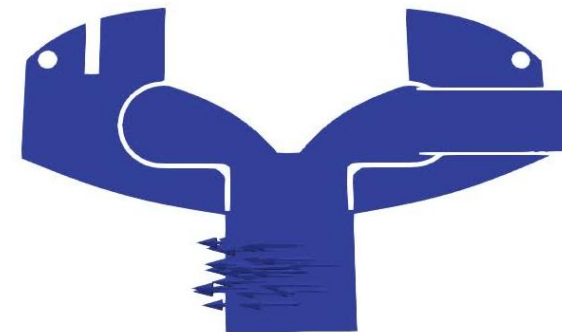
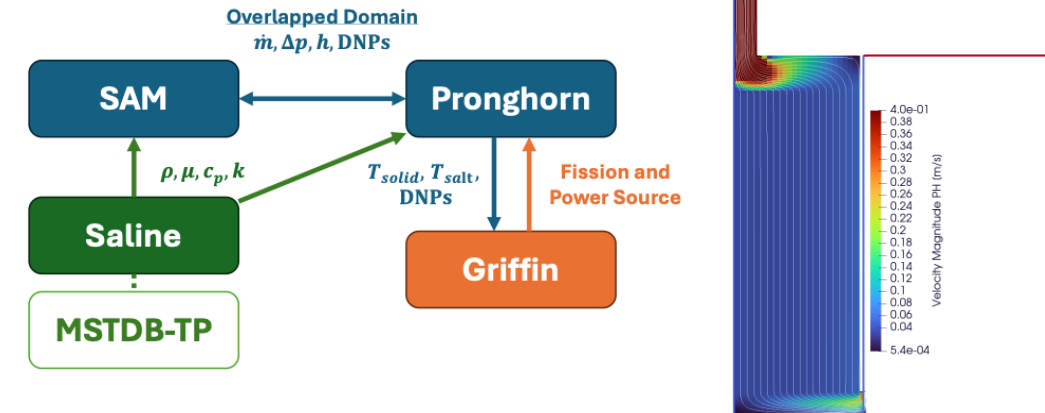
Thermal Hydraulics Area: FY25 Developments

FY25 Report
on OSTI

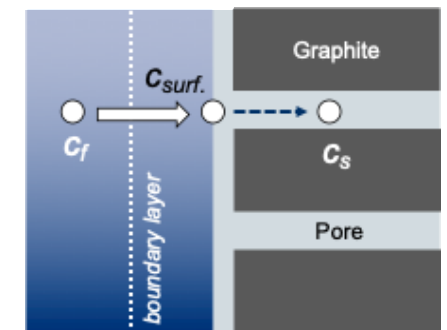


- **Multi-scale SAM-Pronghorn-Saline Integration, V&V, and MSRE Demonstration**
- **SAM (System scale)**
 - Noble gas transport model to consider migration in graphite, off-gas removal, and point kinetics reactivity feedback
 - Multi-scale/multi-phase mass transfer closures adopted from MOSCATO/NekRS
- **Pronghorn (Engineering scale)**
 - Improved corrosion/plating models by enhanced RANS to capture buoyancy effects and re-laminarization
 - Improved two-phase Euler-Euler flow modeling
- **NekRS/Nek5000 (Lower length scale)**
 - Completed a novel implementation of the level-set method for high fidelity two-phase flow simulation
 - Implemented models for radiation heat transfer for FHRs

Integrated multi-scale
demonstration of MSRE



Two-phase MSRE pump priming
simulation in Pronghorn



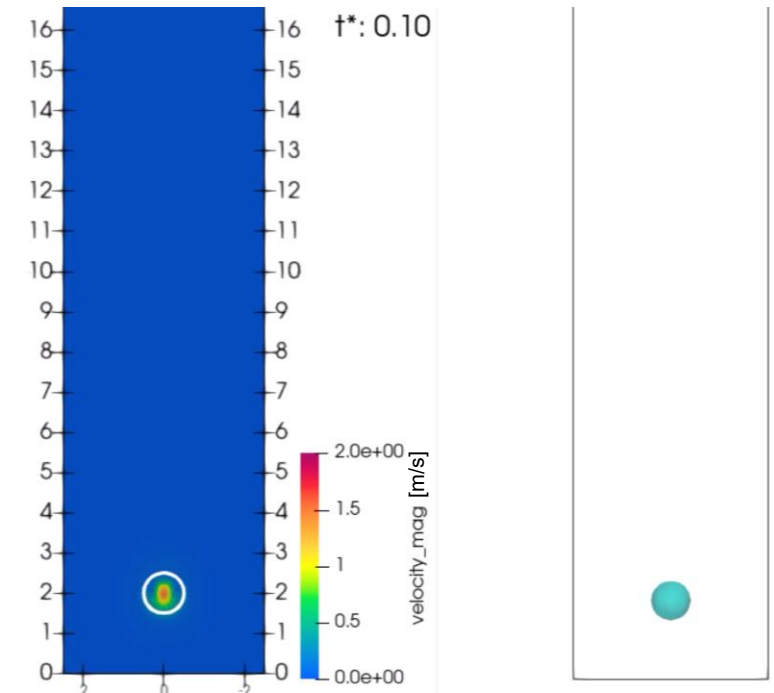
Noble gas migration in
graphite in SAM

1. "Integrated Molten Salt Reactor Modeling Capabilities in NEAMS Thermal Hydraulics Tools", ANL/NSE-25/71 / INL-RPT-25-88160, 2025.
2. "Spectrally Stabilized Interface Capturing Formulation and Implementation in Nek5000/NekRS", ANL/NSE-25/51, 2025.



Thermal Hydraulics Area: Looking Ahead

- **Advancing the NEAMS TH tools with more validation and novel MSR modeling capabilities on top of what we currently have:**
 - Framework for general species transport (i.e. DNPs, FPs, noble metals)
 - Two-phase flow modeling (i.e. noble gas, bubble transport)
 - Specific phenomena: redox corrosion, tritium transport, fluid solidification, ...
- **Multi-scale SAM-Pronghorn-Saline**
 - Development for modeling and validation of salt spill phenomena
- **SAM** (*System scale*)
 - System-level noble metal transport and deposition
 - User-friendly input syntax improvement for species/gas transport modeling
- **Pronghorn** (*Engineering scale*)
 - Improve radiation heat transfer and solidification/melting for salt spill accidents
 - Deploy aerosol transport modeling for higher fidelity radionuclide tracking in spills
 - Continued validation of two-phase Euler-Euler model
- **NekRS/Nek5000** (*Lower length scale*)
 - Development of interfacial species transport for chemistry
 - Performing validation simulations of the MSRE heat exchanger



Novel high fidelity level-set method in Nek5000 used to model a Helium bubble rising in FLiNaK

Reactor Physics

Yaqi Wang
Idaho National Laboratory



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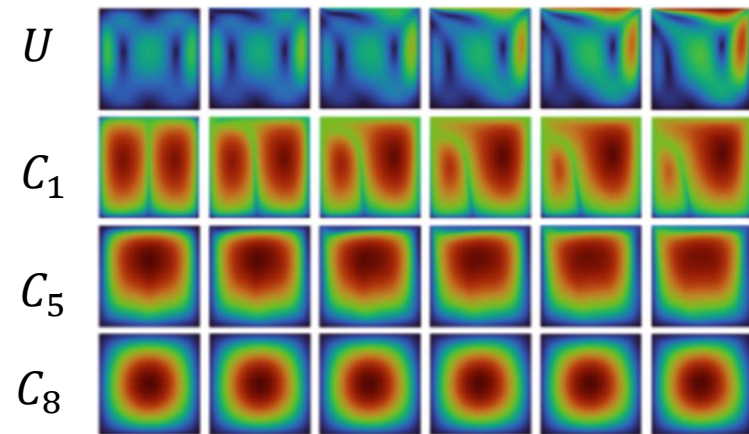
NEAMS Reactor Physics – MSR (Molten Salt Reactor)

Technical Area Overview

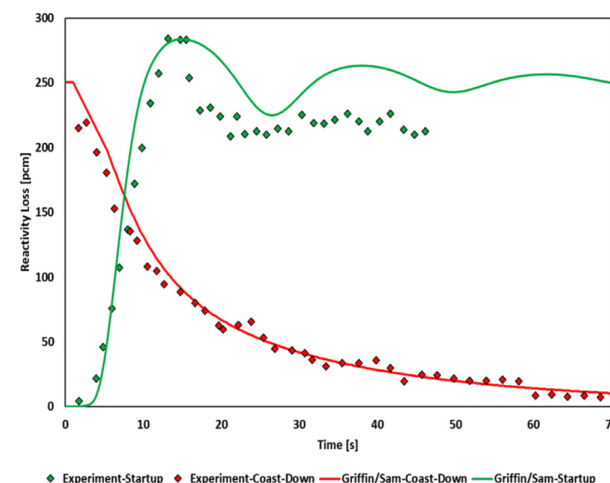
- ❖ **Goal:** Develop and deploy codes for modeling **neutral particle transport** and **nuclide depletion/decay**
- **Griffin:** non-LWR MOOSE-based reactor physics code focusing on transients and multiphysics modeling
- **Shift:** LWR and non-LWR Monte Carlo (MC) reactor physics code (ORIGEN depletion)

MSR Capabilities

- Steady/transient multiphysics coupling neutronics and fluid dynamics with delayed neutron precursor transport: Griffin-Pronghorn for CNRS MSR benchmark and Griffin-SAM for MSRE experiment.
- Depletion considering isotopes with short, intermediate, long half-lives, insoluble species, species in the off-gas with Griffin-Pronghorn coupling.



*Mustafa K Jaradat, et. al.. Verification of Griffin-Pronghorn-coupled multiphysics code system against CNRS molten salt reactor benchmark. *Nuclear Science and Engineering*, v198, 2024.



Comparison calculated reactivity losses by Griffin/SAM and measured values data during pump start-up and coast down tests.

*Mustafa K. Jaradat, et. al, Thermal Spectrum Molten Salt-Fueled Reactor Reference Plant Model, INL/RPT-23-72875, 2023

NEAMS Reactor Physics – FY25 Updates and Look Ahead

FY25 Griffin Updates

- Experimental branch hosting MSR depletion capability has been refactored and merged into the Griffin main branch.
- A new material for external region number densities tracking is added in Griffin.
- Deployed improved method for scattering matrix generation in Shift for trace nuclides.

FY26 and Beyond

1. Evaluate PKE (point-kinetics equation) parameters including beta-effective for MSR considering the delayed neutron precursor transport and enable IQS (improved quasi-static) method for accelerating transient calculations.
2. Use Griffin SSAPI (self-shielding API) to generate cross sections on the fly for thermal-spectrum MSR.
3. Enable online refueling, FP production, removal, replacement, and gases transmutation.

3) Cross-Cutting Challenges & Paths Forward

NEAMS Panelists

- **Theme:** What challenges must NEAMS tools overcome to substantially accelerate MSR deployment over the next 5 and 10 years?
- Guiding points:
 1. Data availability and quality (salt properties, corrosion, irradiation).
 2. Verification, validation, and credibility for licensing use.
 3. Multiphysics coupling challenges unique to MSRs.
 4. Computational scalability and turnaround time.
 5. Dependencies on experiments, facilities, or other DOE programs.

4) DOE Perspective: Gaps & Partnership Opportunities

Dr. Patricia Paviet

- **Guiding Questions:**
 - From the ART MSR perspective, are there gaps in the current M&S ecosystem that NEAMS should be prioritizing?
 - Where do you see opportunities for stronger partnership?

5) NEAMS Success Stories & Exciting Capabilities

NEAMS Panelists

- **Guiding Question:** Which NEAMS capability are you personally most excited about, and how do you see it being used by MSR stakeholders in the near future?
- Concrete examples are encouraged to highlight cases where NEAMS tools:
 - Enabled a design/licensing decision
 - Informed experiments
 - Provided critical insights

6) Value & Impact Assessment from DOE Stakeholders

Dr. Patricia Paviet & Dr. Toni Karlsson

- Guiding Questions:
 1. What NEAMS capabilities stood out as particularly impactful?
 2. What changes in direction or emphasis would increase value?
 3. What opportunities for tighter integration with fuels and materials programs exist?

7) Open Q&A

- Guiding Themes:
 1. Biggest modeling gap for MSR deployment?
 2. What defines credible MSR modeling?
 3. Key missing multiphysics coupling?
 4. Most critical data need?
 5. Main barrier to tool adoption?
 6. Where should NEAMS focus next?



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