OAK RIDGE
National Laboratory

November 5, 2025

Off-Gas for Molten Salt Reactors

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Oak Ridge National Laboratory

U.S. DEPARTMENT of ENERGY

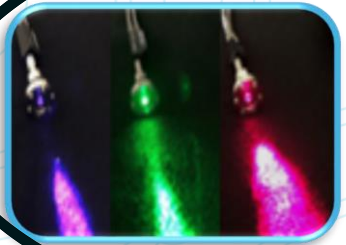
ORNL IS MANAGED BY UT-BATTELLE LLC
FOR THE US DEPARTMENT OF ENERGY

Molten Salt Reactor
PROGRAM

The DOE-NE MSR campaign off-gas program serves as the hub to address technology challenges for MSRs to enter the commercial market.

SALT CHEMISTRY

Thermophysical and Thermochemical Properties of Molten Salts –
Experimental and Computational



TECHNOLOGY DEVELOPMENT

Off-Gas Management
Radionuclide Release
Monitoring, Sensors & Instrumentation
LSTL & FASTR

NATIONAL AND INTERNATIONAL MSR SAFETY

Guidance on reasonable approaches to demonstrating safe and economic commercial prototype molten salt reactors.

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

1) MSRs can provide a substantial portion of the energy needed for the U.S. to have energy security, energy independence.
2) There is a need for an abundant energy for the foreseeable future for data centers, desalination, process heat, hydrogen production...

SALT IRRADIATION

Fuel salt irradiation and post irradiation examination capabilities NRAD, ATR

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MODELING & SIMULATION

NEAMS Tools & MELCOR utilized for
- Species Tracking
- Accident Scenario
- Mechanistic Source Term...

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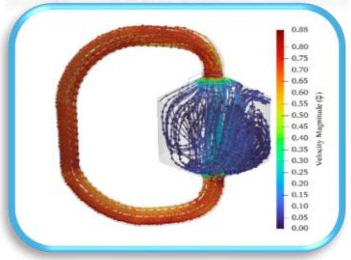
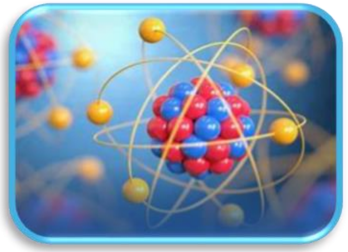


MSR RADIOISOTOPES

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



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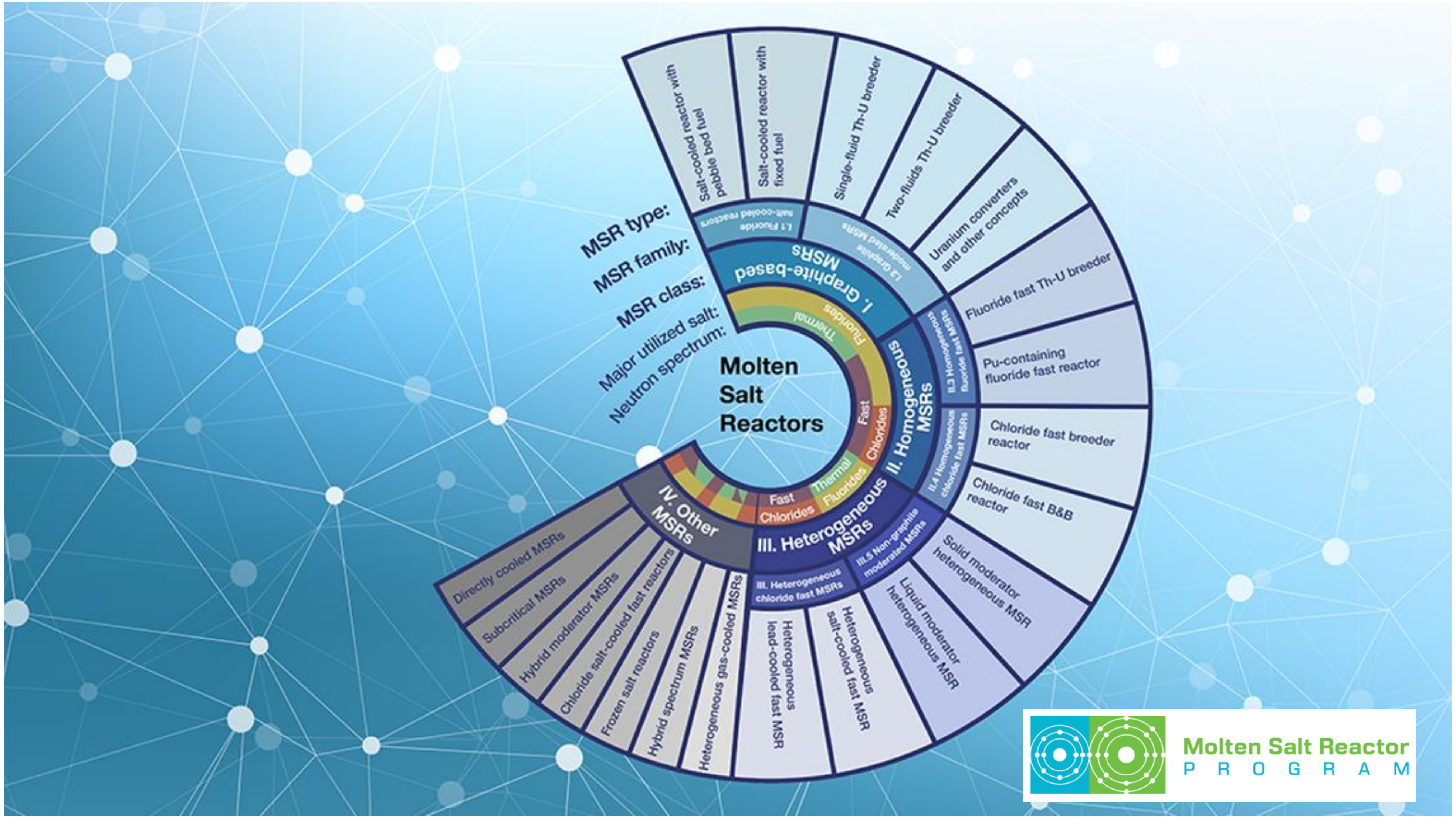
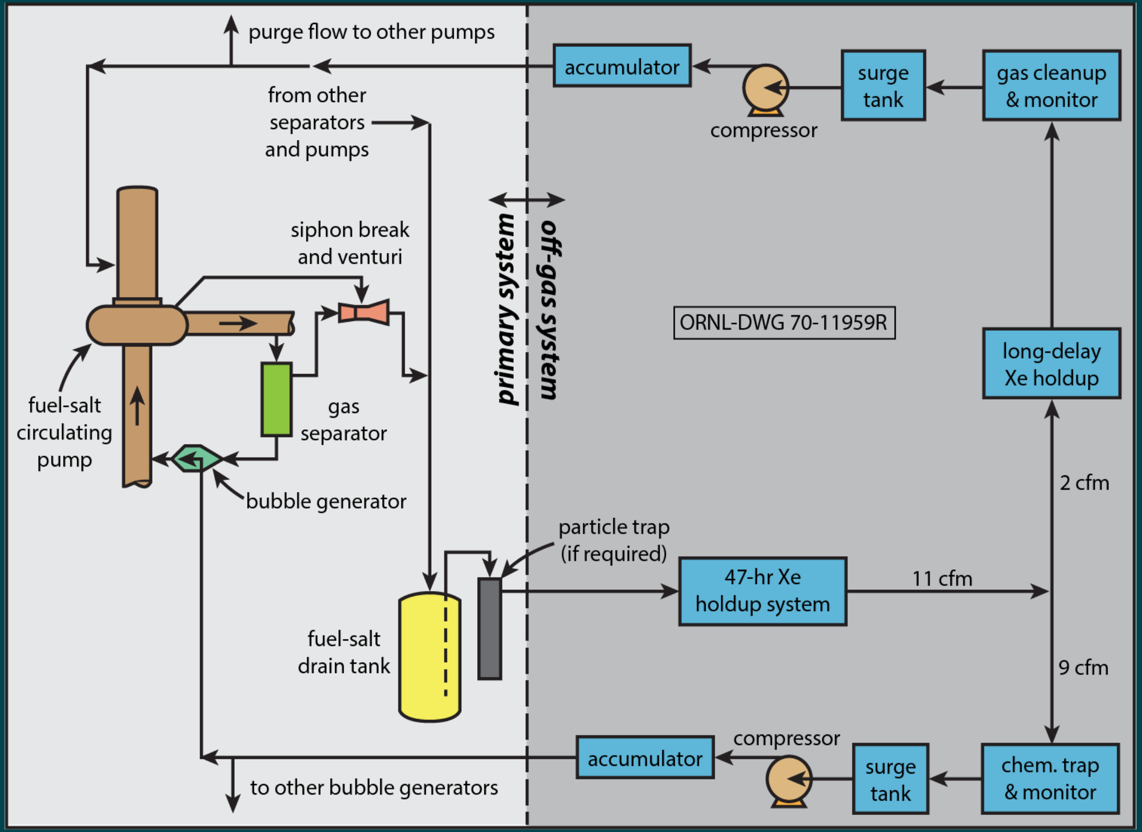
How does off-gas fit into the taxonomic descriptions of MSRs?



The off-gas serves as the pressure boundary, required for safety and licensing. Its role will be determined by the configuration of the reactor and associated processes (in-on-at-off).



Liquid fueled versus liquid cooled

Salt circulation and definition of pressure boundary

Salt composition: chloride versus fluoride

Reactor materials: graphite

For each type of reactor, must assess off-gas requirements.

- Define the requirements (temperature/pressure/flow rate) of the complete off-gas system, including auxiliary units, & needed redundancy
- Define loading – He, trace impurities, particulates, vapor pressures of salt species (ICl, IFx, T), daughter production, revolatilization
- Assess decay heat handling
- Share commonalities where possible

MSR Off-Gas	Advanced Fuel Cycle Off-Gas	Pyroprocess Off-Gas
No cooling	Cooled fuel > 5 years	Cooled fuel > 5 years
Continuous operation over several years	Batch process	Batch process
Low carrier gas flow rate (He)	Carrier gas will be air/H2O/NO2	Inert gas (Ar) – stagnant?
Salt aerosols, volatile FP, acidic gases, noble metal particles, H-3	Kr-85, I-129, C-14, H-3 in gas phase	Low FP load in gas phase

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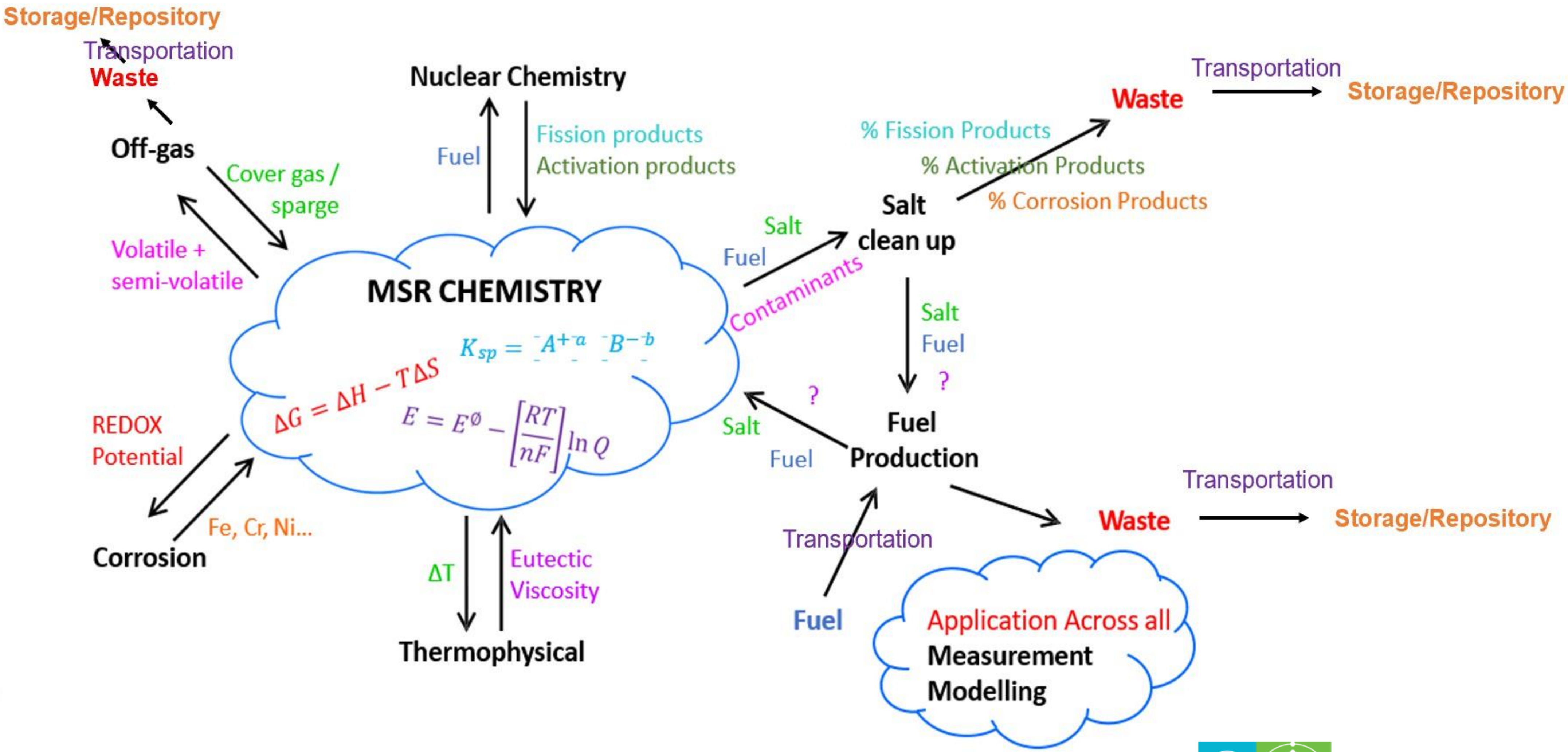
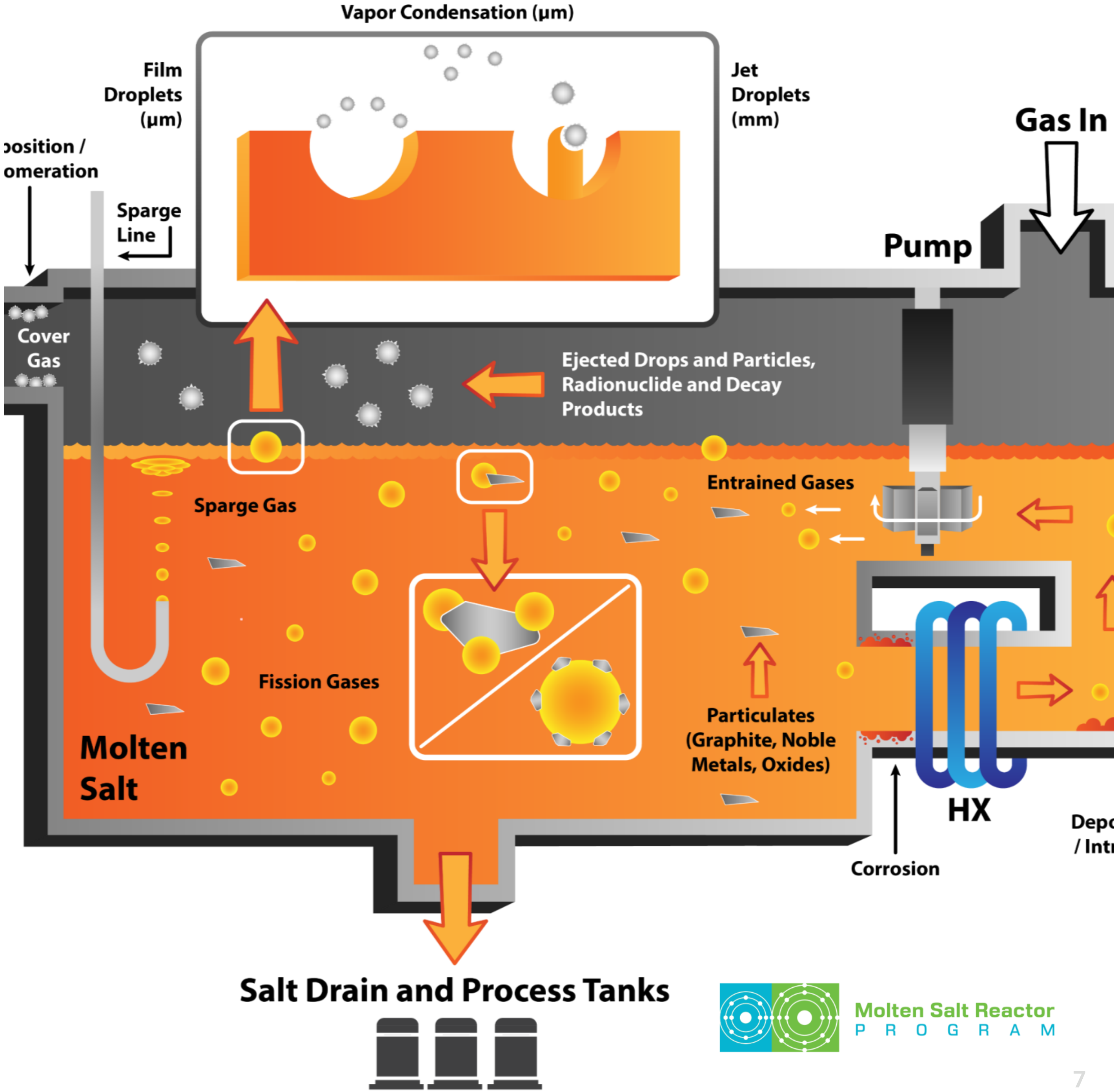
The chemistry of fission and activation products will determine how they are transported into the off-gas.



Mechanisms that transport radionuclides into the cover gas include vaporization, aerosol formation, and gas sparging.

The reactor design will affect the degree to which such mechanisms play a major role in radionuclide transport.



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The disposition of radionuclides in an MSR off-gas has its own terminology, depending on the requirements of the MSR design.

Confinement

Containment

Capture

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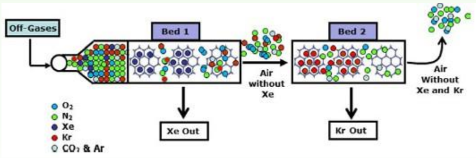
Online tracking of radionuclides is needed to demonstrate the success of off-gas systems.

Component Testing

Large Scale Test Loop

Xe/Kr separation in MOF

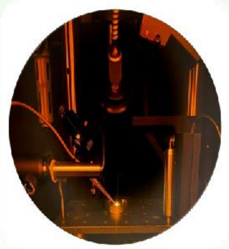


Radionuclide Identification/Speciation

Raman Spectroscopy

405 nm 532 nm 671nm

Laser Induced Breakdown Spectroscopy



Gas/Liquid Interface

Bubble Measurement

Source Term Modeling

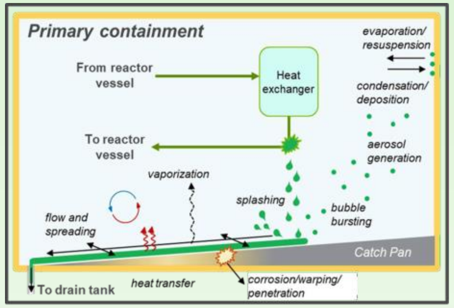
Bulk Gas	Gas Film	Liquid Film	Bulk Liquid
p_i pressure	p_i^*	c_i^*	c_i concentration

$$c_i^* = p_i H$$

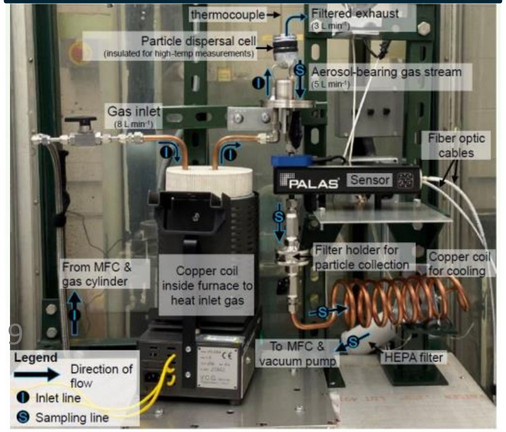
$$p_i^* = c_i / H$$

Spill Test

Engineering Scale Salt Accident Analysis Facility

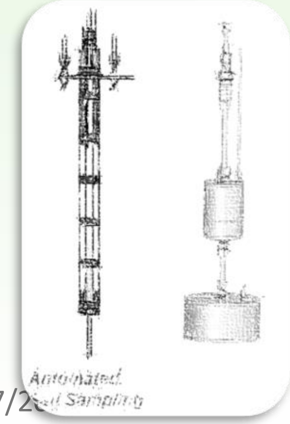


Salt Aerosol Concentration and Size Measurements



Sensors/Salt Chemistry

Salt Composition
Redox
Salt Level



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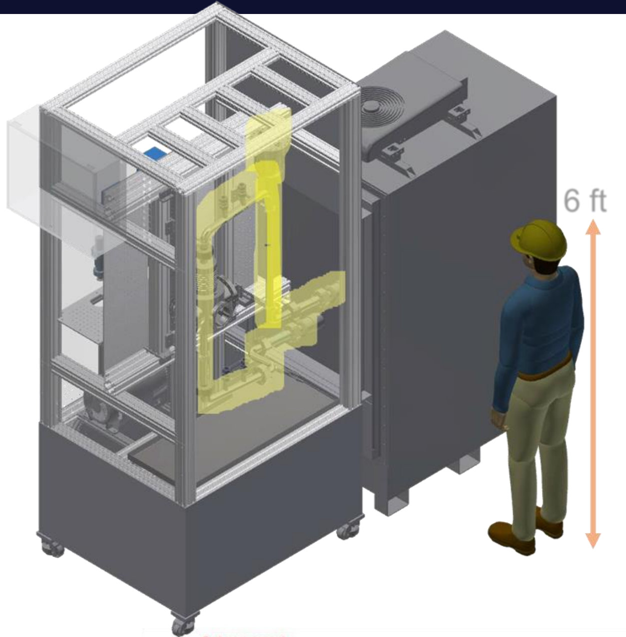
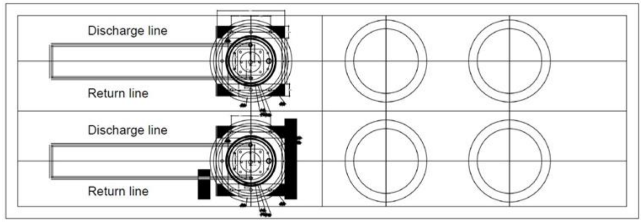
Large-scale salt loops at DOE labs support sensor testing

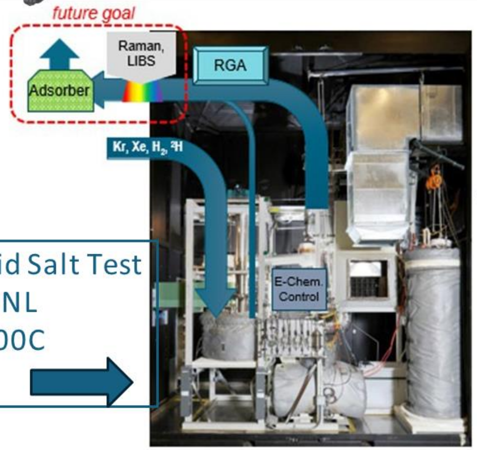
FASTR -Facility to Alleviate Salt Technology Risks – ORNL
NaCl-KCl-MgCl2
725C
154L

MSTTE – Molten Salt Tritium Transport at INL
FY 2025 Deuterium- FLiNaK salt



Actinide Salt Loop at ANL





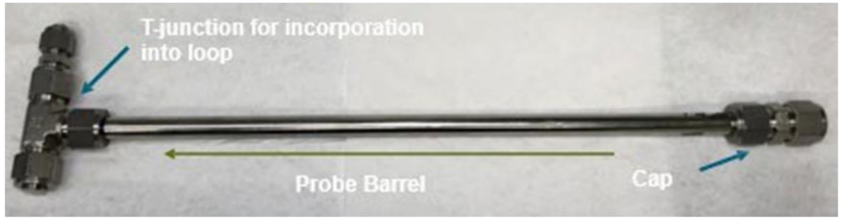
LSTL - Liquid Salt Test Loop at ORNL
FLiNaK – 700C
80L

Probe materials have been tested in LSTL

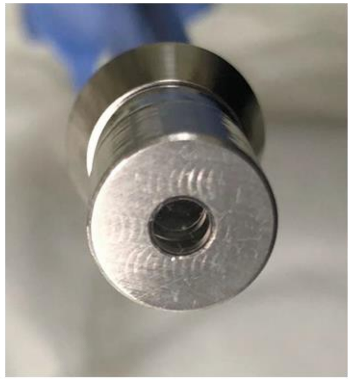
Before incorporation into salt loop

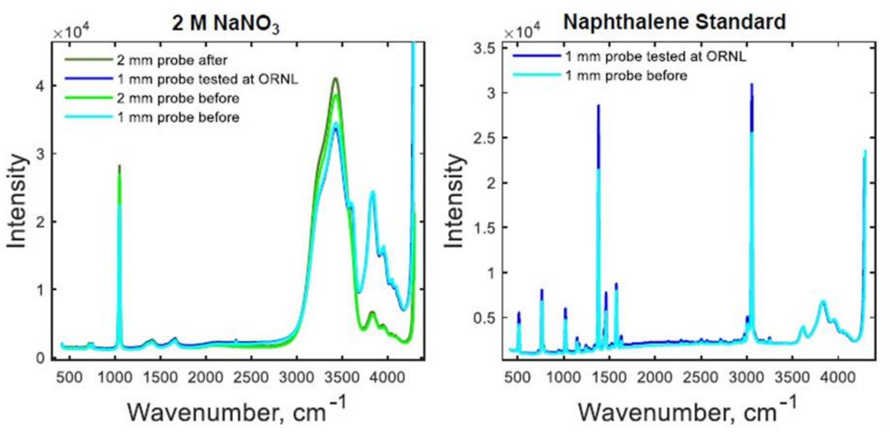
Salt loop testing

- Probe barrel swaged into loop
- **Visually, probe appears in excellent condition after exposure in LSTL**
- **Raman data suggests comparable signal after incorporation into loop**
- **Minimal materials degradation/impacts to performance**

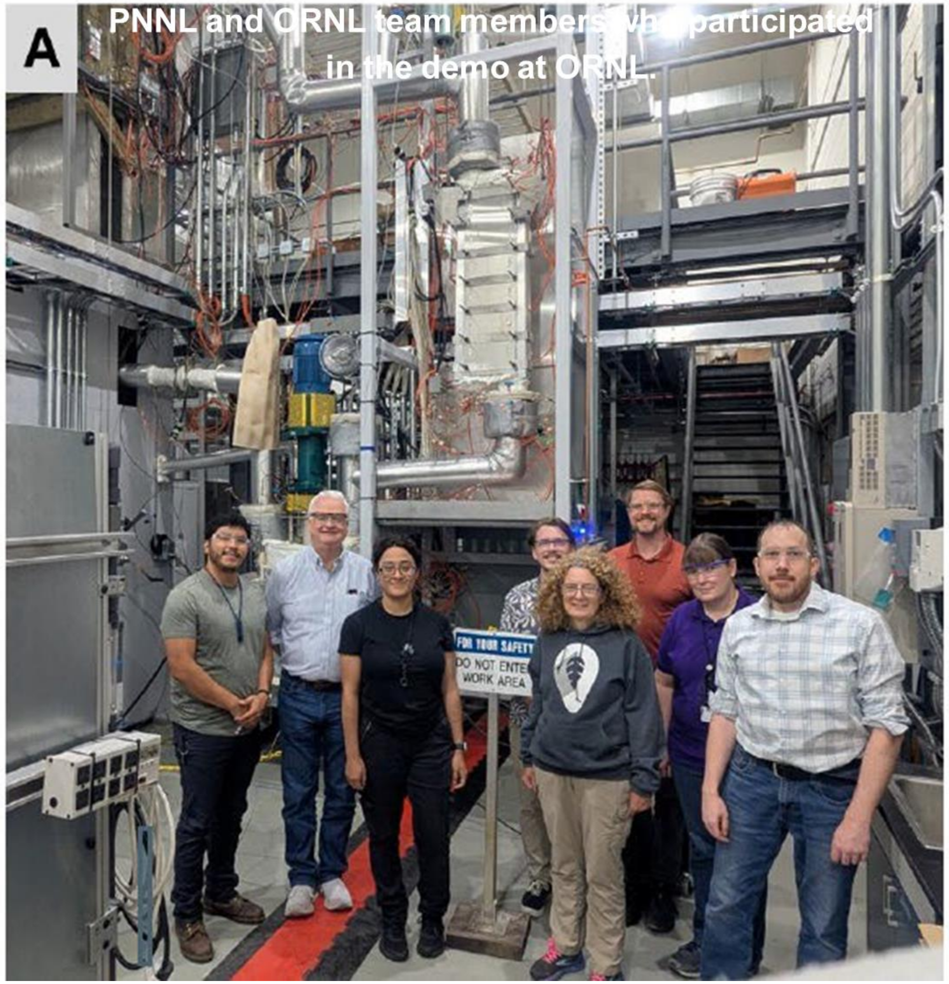


After incorporation into salt loop

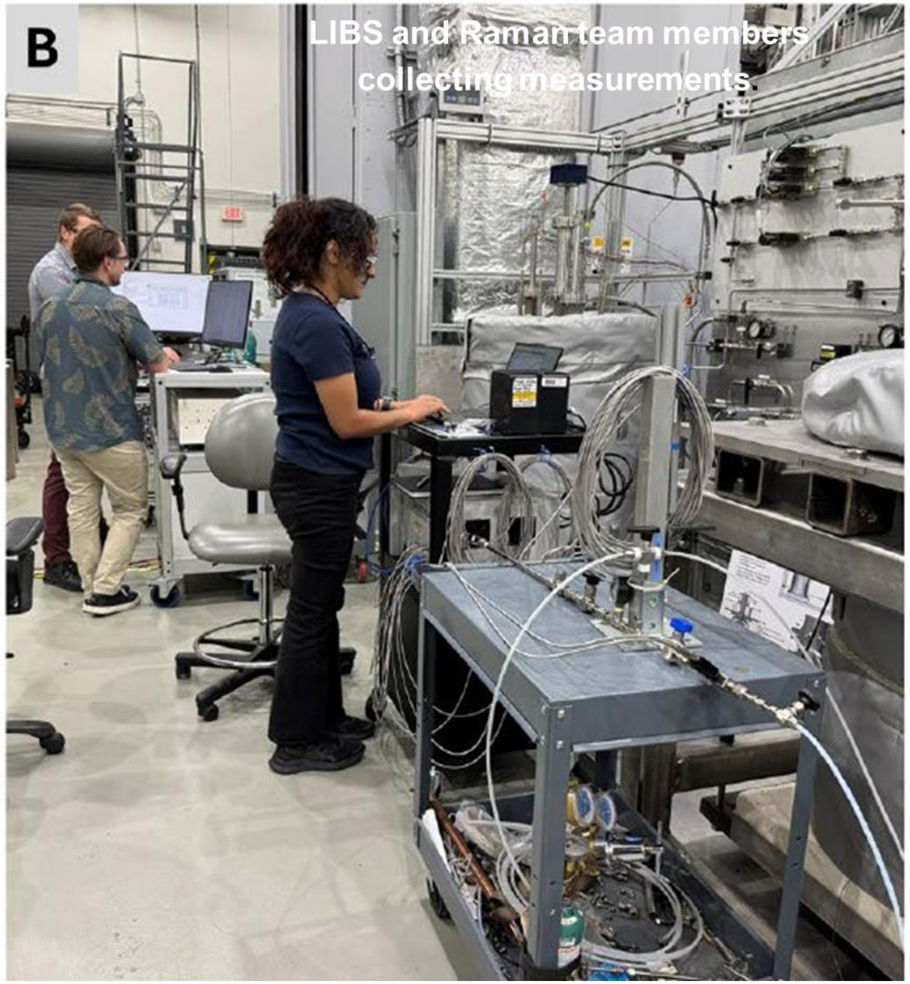




Tandem use of Raman, LIBS, and redox probes, flow sensors demonstrated in FASTR

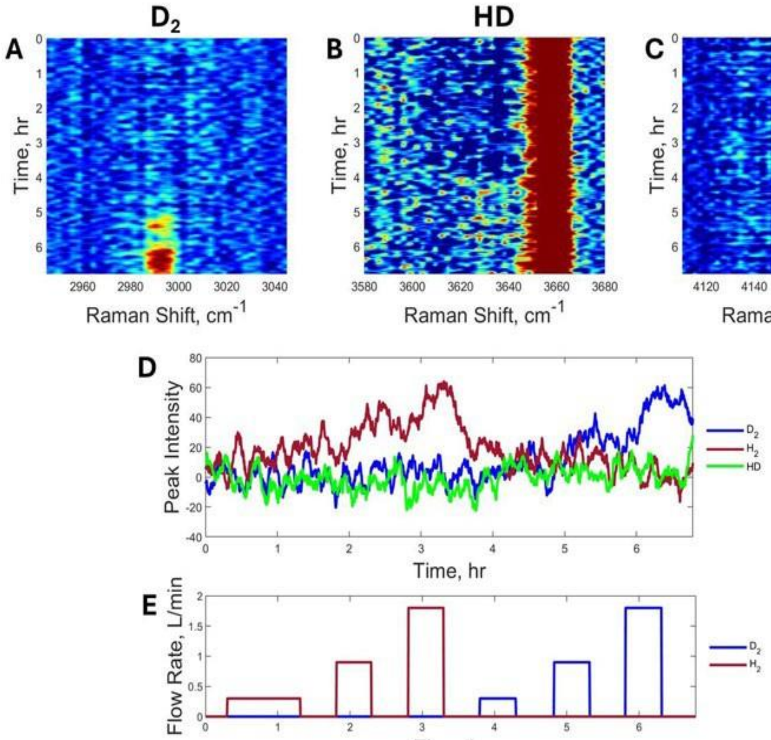


A PNNL and ORNL team members who participated in the demo at ORNL.



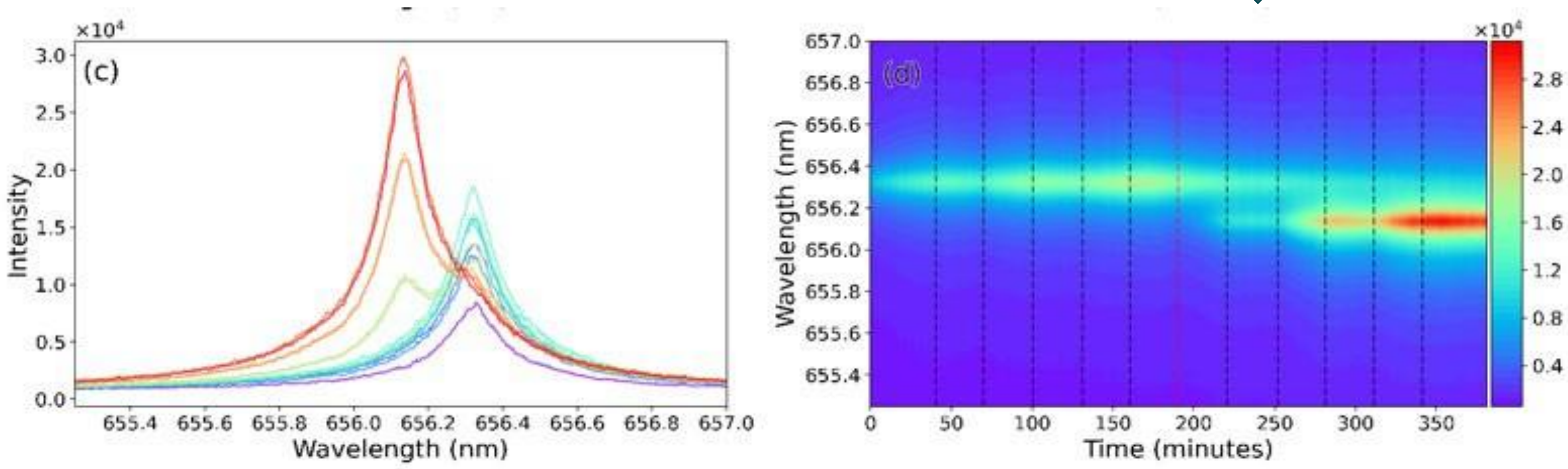
B LIBS and Raman team members collecting measurements.

Detection of hydrogen isotopes by Raman, LIBS, and RGA on FASTR Salt Loop

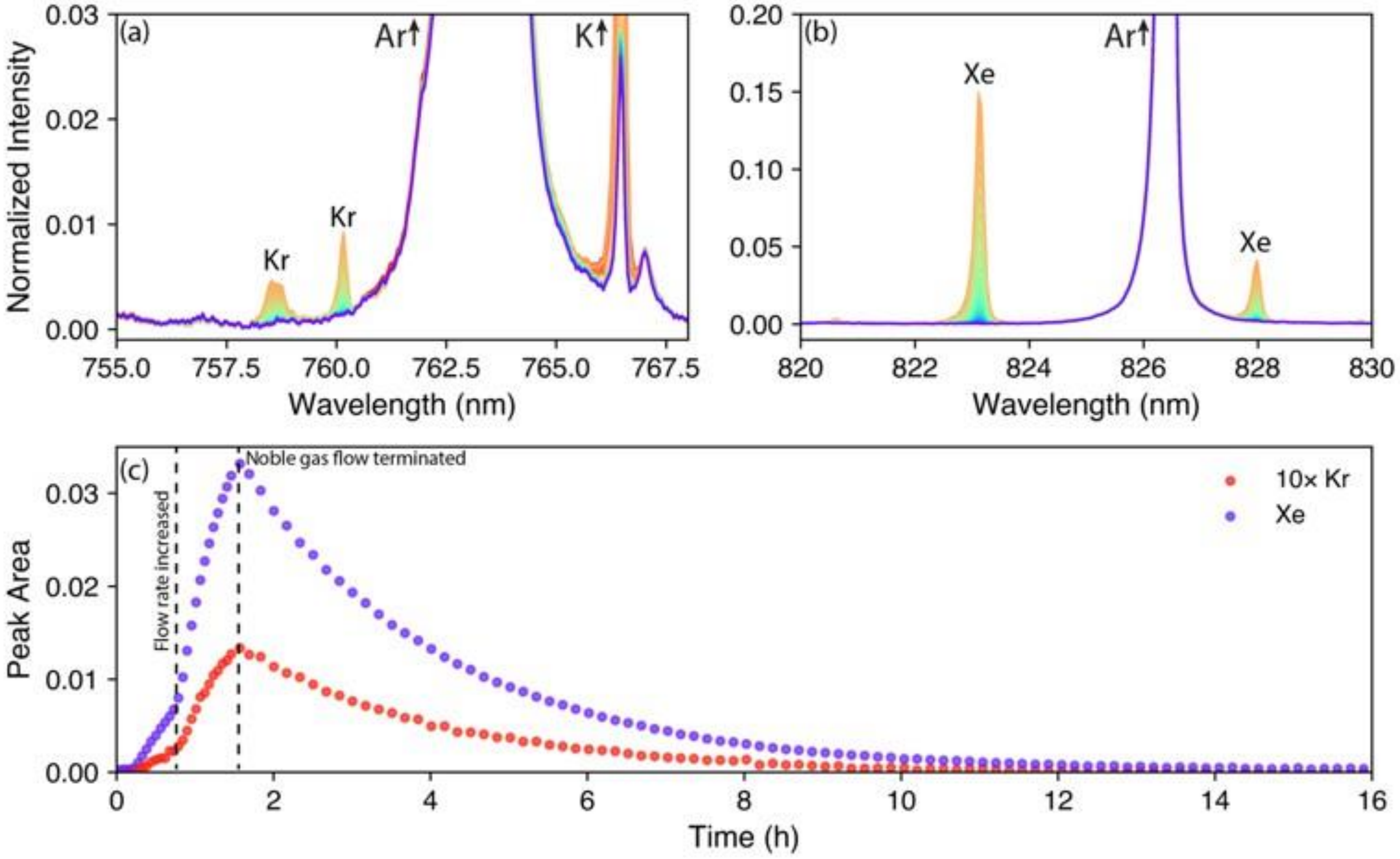


Heat maps for Raman signal. Spectral signatures for H2, D2, and HD
Felmy et al., PNNL-38277 (Sept 2025)

Spectral shift from H to D by LIBS
Andrews et al. ORNL/TM-2025/4115 (Sept 2025)

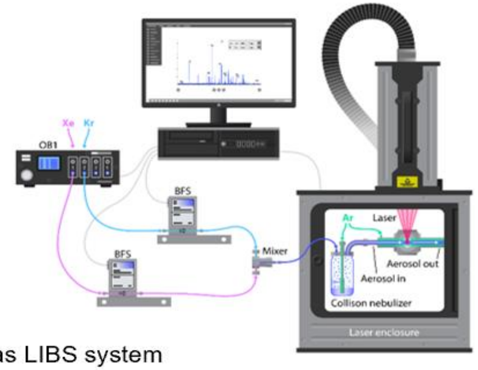


Time evolution of (a) Kr and (b) Xe was recorded on the Ar-swept FASTR storage tank

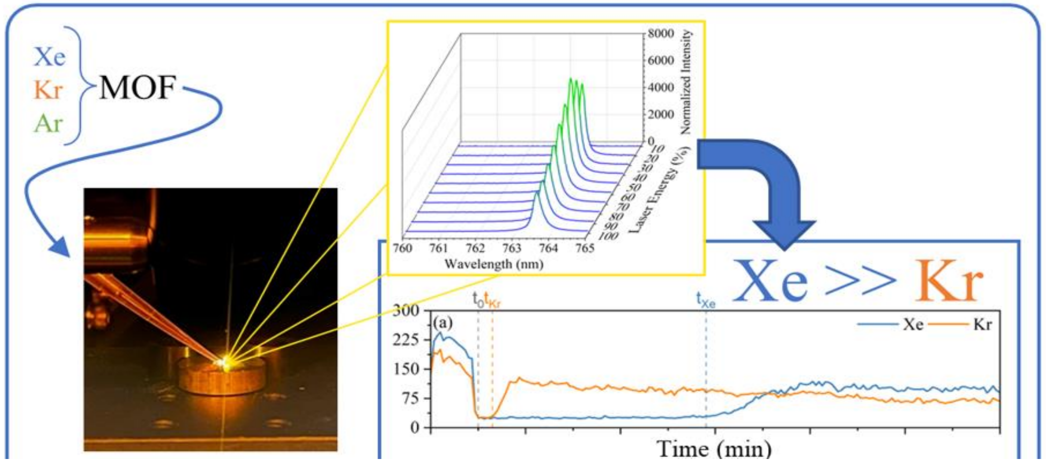


Monitoring Xe and Kr capture on MOFs using LIBS

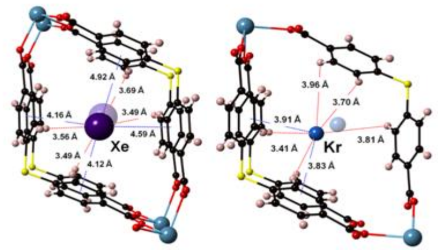
Laser induced breakdown spectroscopy of aerosols and noble gases



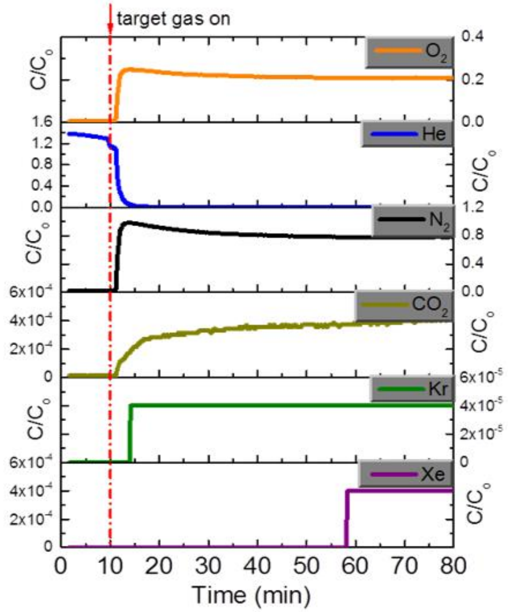
Aerosol/Gas LIBS system



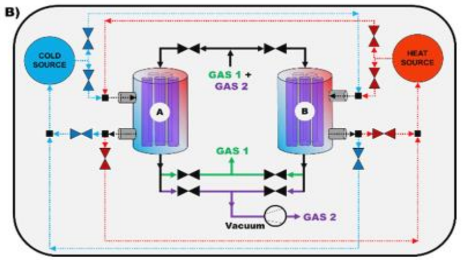
Metal organic framework for Xe and Kr capture



The PNNL patented MOF technology can be used to separate the noble gases from their surroundings.

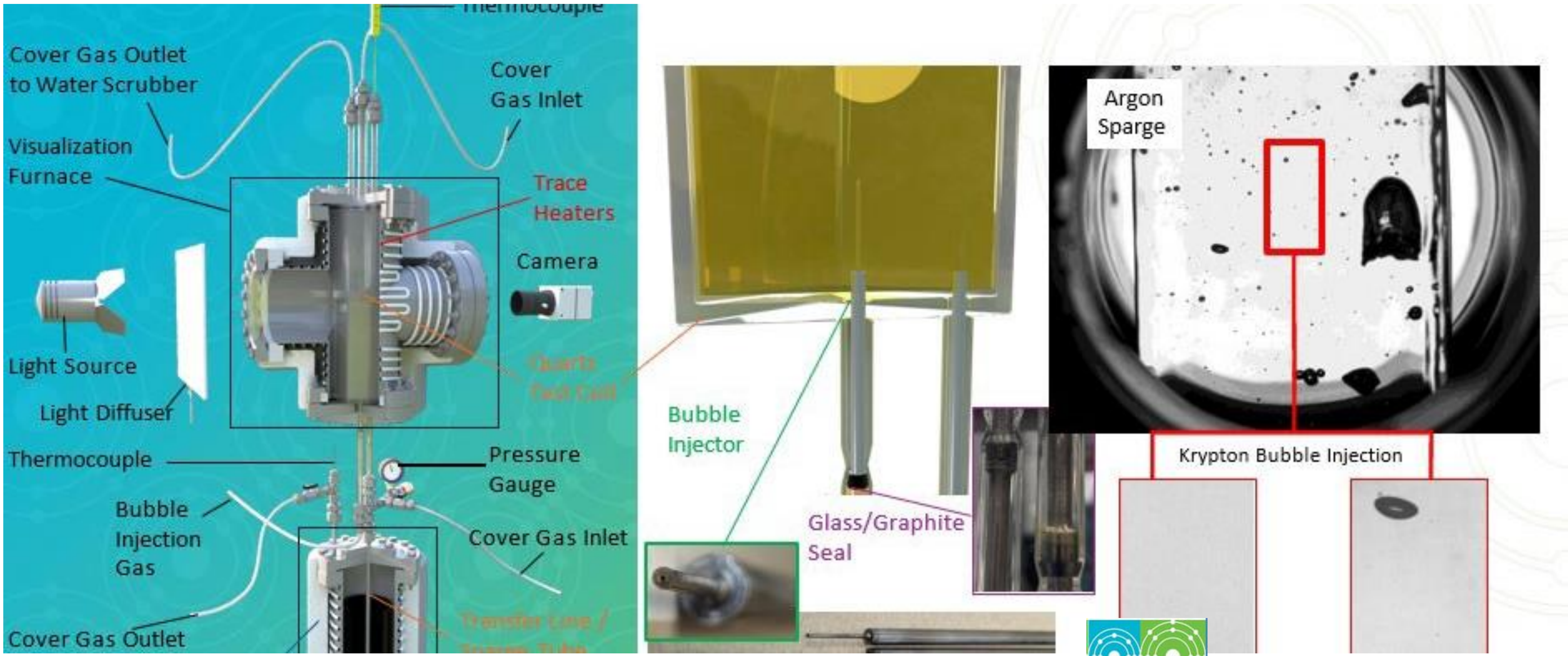


Wet gas (RH 48%)



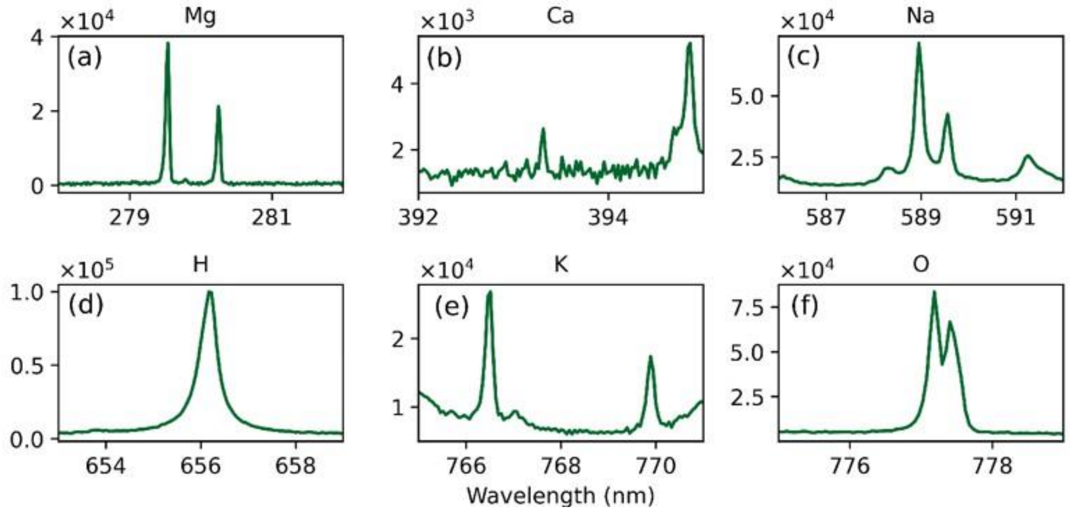
Off-gas adsorption and desorption system

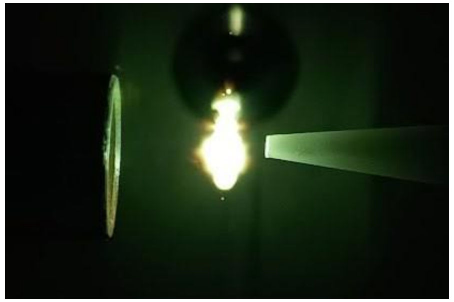
MSR gas and particle transport visualization



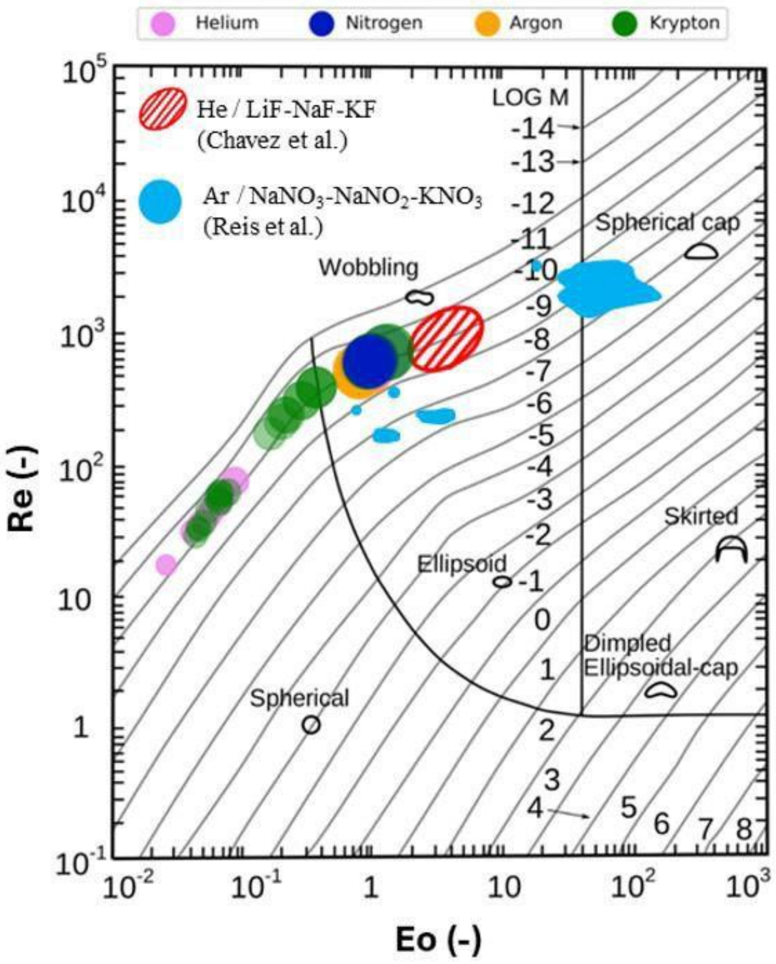
Aerosols are a major pathway for radionuclide transport from MSRs

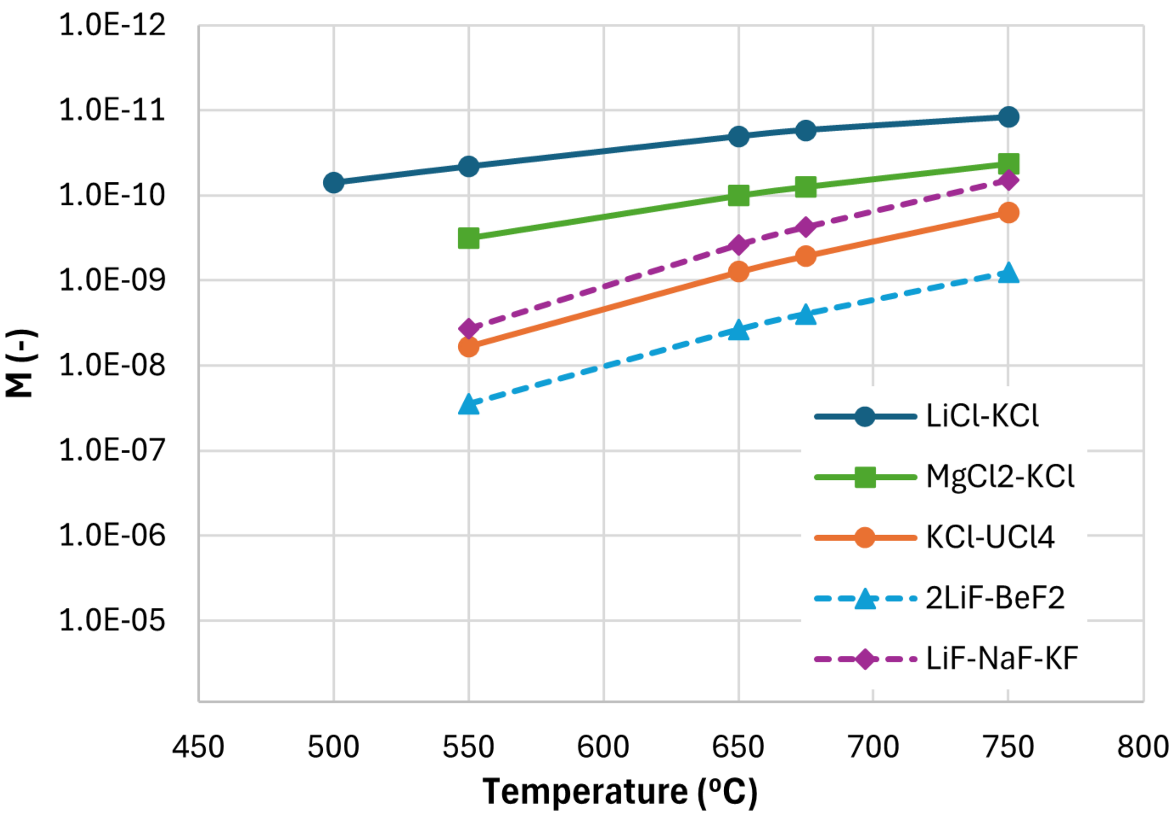
- LIBS plasma identified salt aerosols in Ar generated in FASTR under pumped flow
- Indicative of salt composition
- Andrews et al., ORNL/TM-2025/4115 (Sept 2025)





Bubble behavior is inadequately described by existing correlations





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D. Orea, K. Robb, J. McFarlane, "*Comparative Study Between Experimental Measurements and Model Predictions of Bubble Rise Velocity in Molten LiCl-KCl*", Nuclear Engineering and Design (2025)

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Modelers use data from small and large-scale experiments for model development and code validation

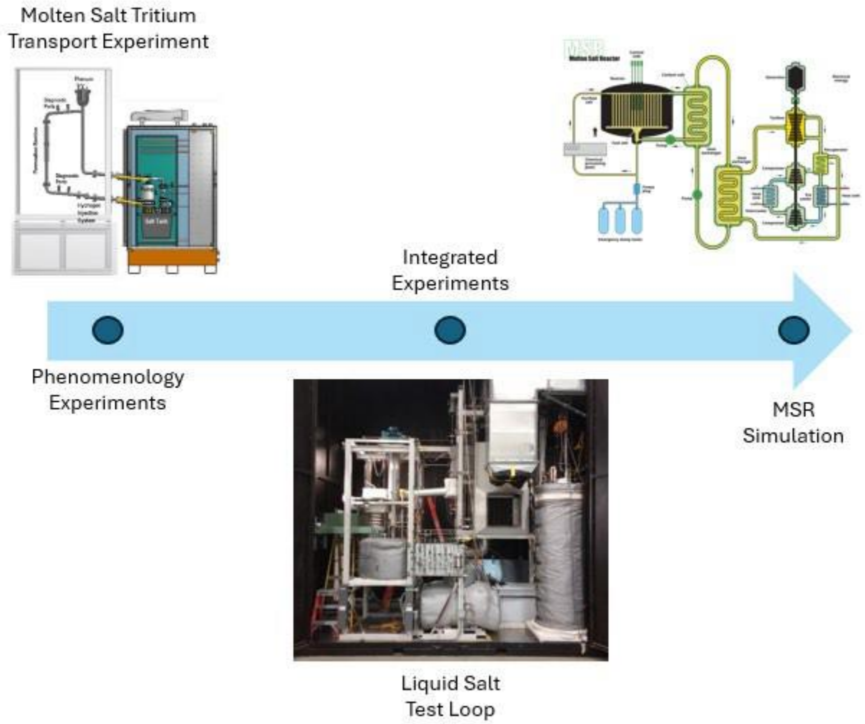
Molten Salt Reactor PROGRAM

NEAMS Nuclear Energy Advanced Modeling and Simulation

MELCOR: nuclear accident simulation code at SNL

Significant strides within the last few years to increase model accuracy for molten salt reactors (MSRs). It is the primary code developed for the

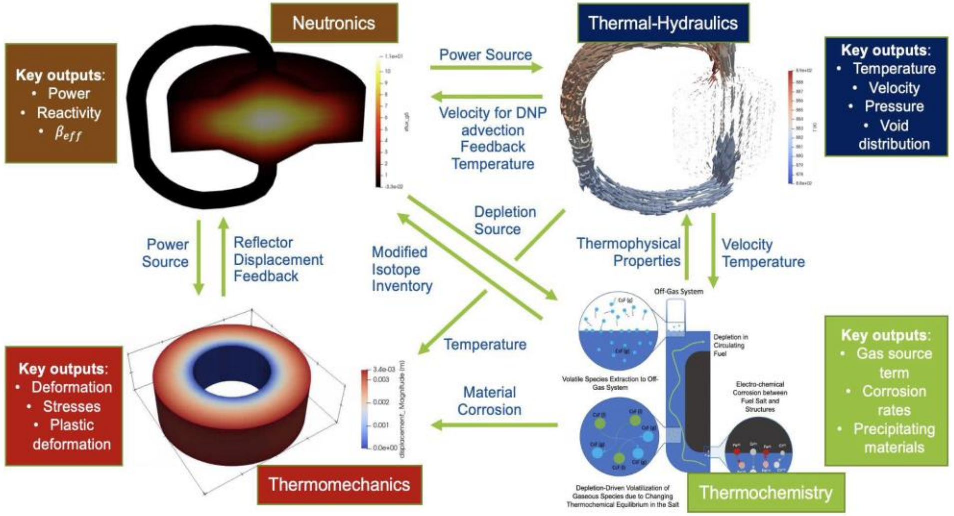
- Assessment and evaluation of safety for a broad range of reactor concepts, notably including MSRs.
- MSR model development has been focusing on improving chemistry and fission product transport mechanisms
- Working with MSR campaign to fill knowledge gaps



NEAMS Tools at INL, SAM at ORNL, MSTDB

Coupling between:

- Neutronics, Thermal-Hydraulics, Thermomechanics and Thermochemistry (speciation, mass accountancy, and corrosion)
- Species tracking in MSRs – volatility, bubble behavior, and aerosol generation



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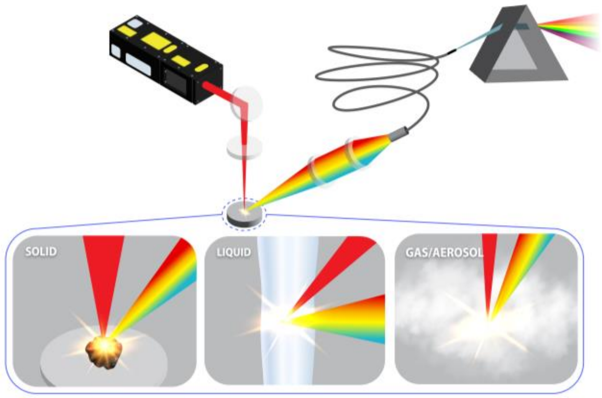
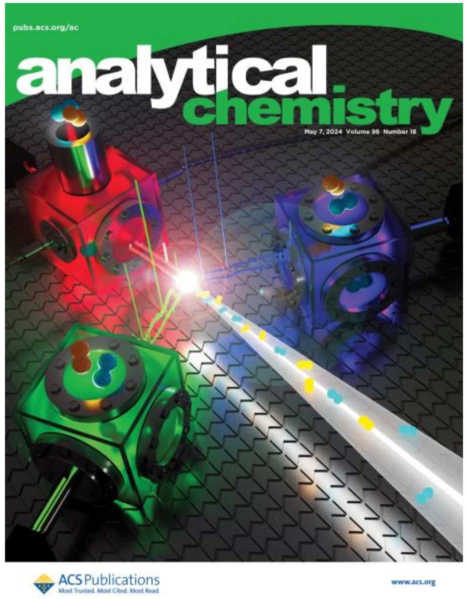
In the US, the goal is to demo an integrated off-gas system in 5 years.

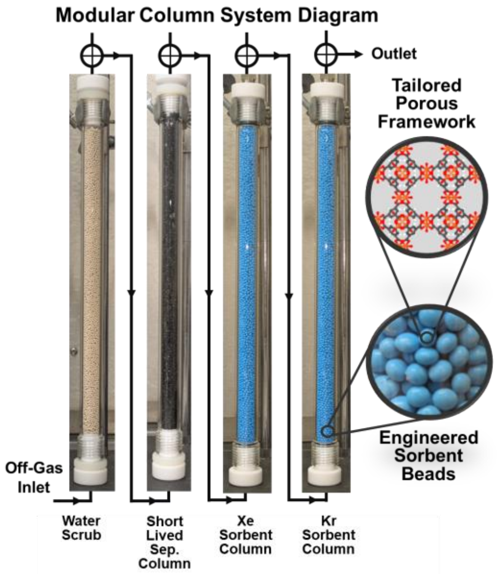
FY 26	FY 27	FY 28	FY29	FY 30	
Roadmap and start design	start building the integrated off gas system	Start cold test Analize cold test results	modify design if necessary and start building system for hot test	Start hot test – Analyze result	Off gas system ready for testing in MSRR and MCRE



Radionuclide sensors



& transport, vapor pressures, chemistry



Capture technologies

Testing in large loops

Deployment in MSRs

MSR Campaign Website:

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

The breadth of the MSR design space presents a substantial challenge to the completeness and broad applicability of any technology development planning activity. Dozens of design concepts are currently in some state of development, nearly all have been introduced in the past decade, and it is not currently possible to reasonably evaluate which designs will eventually be successful. Nevertheless, MSRs have common characteristics and many technology development issues are broadly applicable to most MSRs

MSR Annual Campaign Review

- April 22-24, 2025
- April 16-18, 2024
- May 2-4, 2023
- April 26-27, 2022
- June 17, 2021

MSR Course

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An Overview of the Molten Salt Thermal Properties Database□Thermophysical, Version 2.1.1 (MSTDB-TP v.2.1.1)	Link	ORNL/TM-2023/2955	2023	25
FY23 Progress Report on Viscosity and Thermal Conductivity Measurements of Molten Salts	Link	ORNL/TM-2023/3048	2023	31
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Thank you
Teresa Krynicki, INL

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