Molten Salt Reactor
PROGRAM

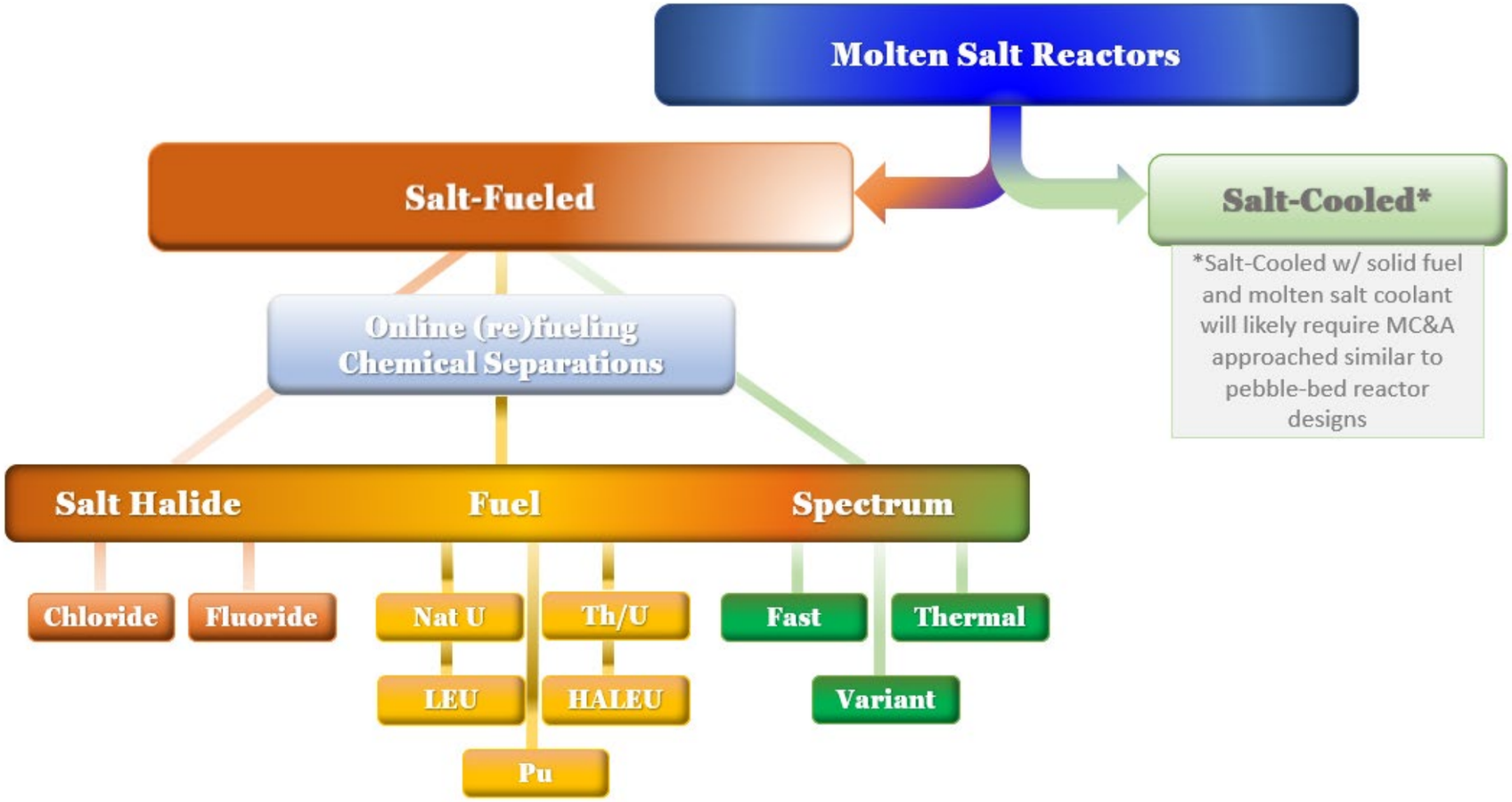
Advanced Reactor Technology - Molten Salt Reactor Program Overview

Janelle Eddins, Federal Manager; Patricia Paviet, National Technical Director

Argonne NATIONAL LABORATORY
Idaho National Laboratory
Lawrence Livermore 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

PNNL-SA-222197

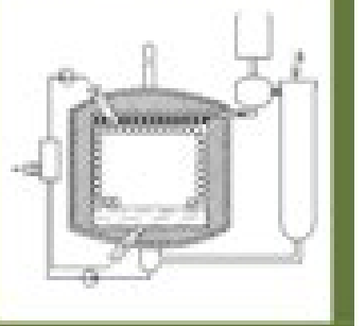
MSRs are a Class of Reactors in which a Molten Salt performs a Significant Function in Core



- Liquid- and solid-fueled variants
- Chloride-, fluoride-, and mixed halide-based fuel salts
- Salt and liquid-metal coolants
- Thermal, fast, time-variant, and spatially-variant neutron spectra
- Wide range of power scales
- Intensive, minimal, or inherent fuel processing
- Multiple different primary system configurations
- Nearly all fuel cycles

Molten Salt Reactor Concept(s) … so many

Fluoride salt cooled reactors



Kairos Power,
Hermes 1 &2 FHR
AGR-FHR

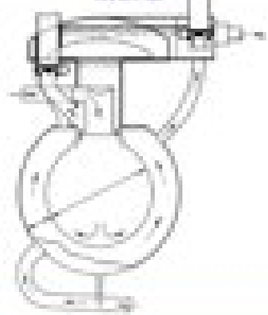
Graphite moderated

MSRs

Terrestrial Energy, iMSR
SINAP, TMSR-LF1
Flibe Energy, LFTR and LFLEUR
ThorCon, ThorCon-500
Thorium Tech Solution, FUJI
Saltfoss Energy, CMSR
Fissionaire, TS-MSBR

Homogeneous fluoride fast

MSRs



Euratom, MSFR
Kurchatov Institute, MOSART
Bhabha Atomic Research Center, IMSBR
Bochvar Institute (VNIIINM), FMSR

Homogeneous chloride fast

MSRs

Exodys Energy MCSFR
CEA, ARAMIS
Euratom MSFR (Cl version)
STELLARIA, Stellarium, CURIO, HOPE
Flibe Energy, SCIFR
KAERI and Samsung Heavy Industries
CorePower

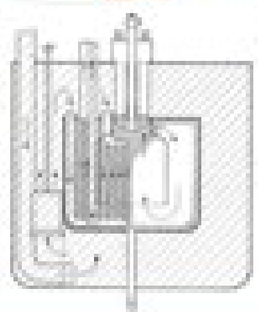
Non-graphite moderated

MSRs

Copenhagen Atomics
Alpha Tech, ARC Reactor

Heterogeneous chloride fast

MSRs



MOLTEX, SSR-W
Thorizon, Thorizon One

Deployment Status

☒ Operated in the past ☒ Operating today ☐ Operating at commercial scale

- The first MSR was the Aircraft Reactor Experiment Reactor, US, 1954
- One MSR is currently operating in China: TMSR-LF1
- More than 15 MSR designs are under development globally. Two are under construction in the U.S.: Hermes and MSR-1 (MSRR)

*TRISO fuel

Courtesy NRC, Greg Oberson and Raj Iyengar

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Accelerating Advanced Reactor Demonstration and Deployment in the U.S.

U.S. DEPARTMENT of ENERGY

Selected for Reactor Pilot Program
Aalo, Antares, Atomic Alchemy, Deep Fission, Last Energy, Oklo, Natura Resources, Radiant, Terrestrial Energy, and Valar Atomics

Fuel Line Pilot Project Selection
Standard Nuclear, Oklo Inc., Terrestrial Energy Inc., TRISO-X Inc., Valar Atomics Inc.

REACTOR AND CRITICAL EXPERIMENT (RACE) FACILITY
NRIC | TEST BED

Aalo-X
Aalo | MICRO

SMR-300
HOLTEC | SMR

MSR-100
Natura Resources | SMR

ANTARES-R1
Antares | TEST REACTOR

DOME
NRIC | TEST BED

LOTUS
NRIC | TEST BED

HERMES
Kairos | TEST REACTOR

KALEIDOS*
Radiant | TEST REACTOR

2026

2027

2028

2029

2030

IMSR
Terrestrial Energy USA

HERMES 2
Kairos | SMR

AURORA
Oklo | SMR

Xe-100
X-energy & Dow | SMR

NATRIUM
TerraPower

Aalo CRITICAL ASSEMBLY*
Aalo | EXPERIMENT

MARVEL
DOE | TEST REACTOR

MCRE
Southern Co.

PROJECT PELE
DoW & BWXT | MICRO

MARK-0*

NEXT MSRR
Natura Resources & Abilene Christian University | TEST REACTOR

*July 4th, 2026

Molten Salt Reactor PROGRAM

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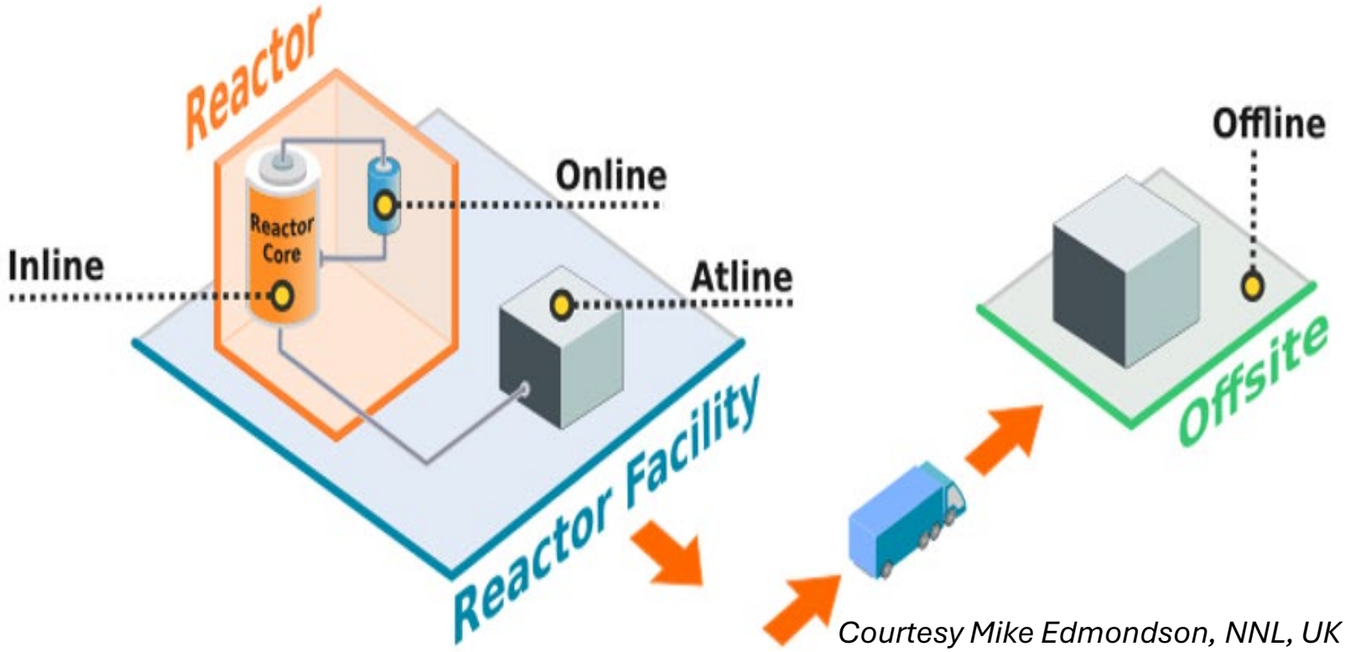
Office of Nuclear Energy

MSR Operation – In Operando

Complexity of Nuclear Processes
Require Understanding
Composition/Phase
States/Thermophysical Properties

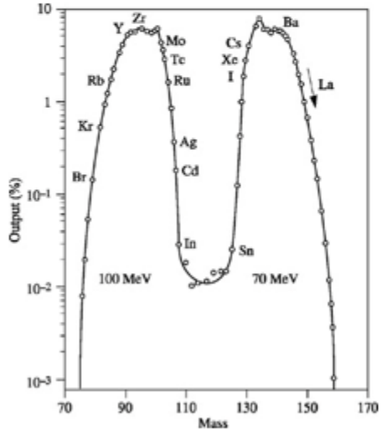


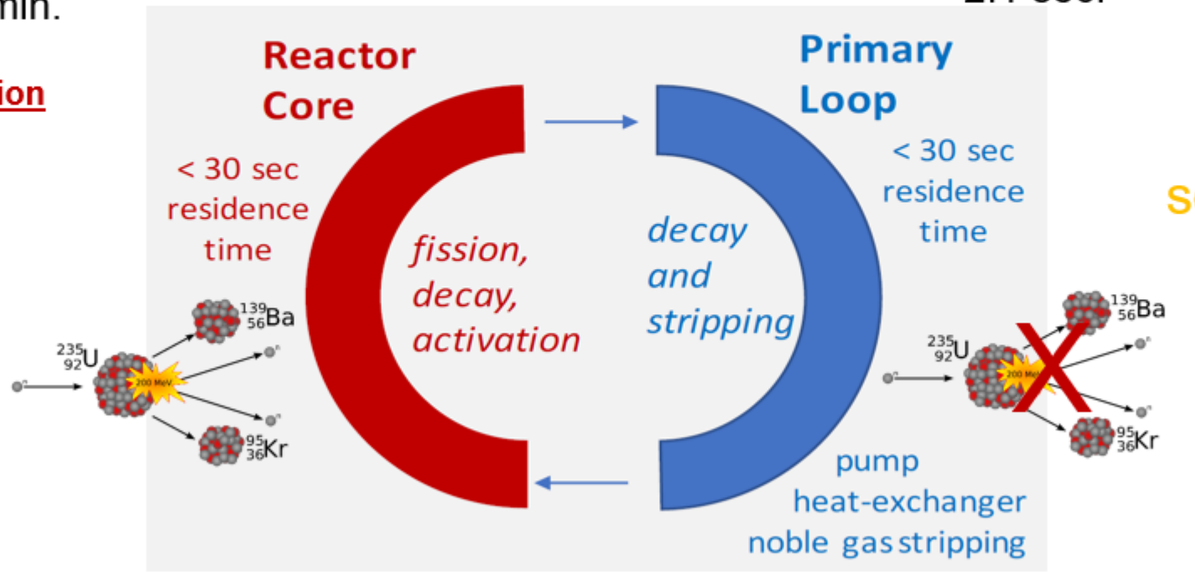
Courtesy Mike Edmondson, NNL, UK

$^{135}I \longrightarrow ^{137}Xe \longrightarrow ^{137}Cs$
25 sec. 4 min.

$^{99}Zr \longrightarrow ^{99}Nb \longrightarrow ^{99}Mo \longrightarrow ^{99}Tc$
2.1 sec. 15 sec. 2.75 days

Fission product distribution





soluble
sometimes soluble
insoluble
gaseous

$^{131,132}Cd \longrightarrow ^{131}In \longrightarrow ^{131}Sn \longrightarrow ^{131}Sb \longrightarrow ^{131}Te \longrightarrow ^{131}I \longrightarrow ^{131}Xe$
<1 sec <1 sec 1 min. 23 min. 25 min. 8 days

Courtesy Prof. Ted Besmann, USC/ORNL

U.S. DEPARTMENT of ENERGY
Office of Nuclear Energy

Stakeholder Engagement Priorities (GAIN)

600 18th Street North
Birmingham, AL 35203

August 25, 2020

Ms. Christine King
Director, DOE Gateway for Accelerated Innovation in Nuclear -GAIN-
Idaho National Laboratory
Idaho Falls, ID 83415

Subject: Needs related to the development and demonstration of Molten Salt Reactor Technology

Molten Salt Properties

One of the most significant challenges facing the industry is the lack of a broadly accepted, NQA1 qualified set of data characterizing various unirradiated and irradiated molten salts. Thermochemical and thermophysical properties of the salts (with and without fuel, pre- and post-irradiation, and across a wide temperature range) are necessary not only for technology developers but also for the regulatory body. Currently, a knowledge gap exists in available data and an understanding of the thermophysical, chemical, and materials properties relating to irradiated multi-component molten salt systems and reactor construction materials. Collection of historical data and establishment of new data is necessary for the design and construction of demonstration reactors, as well as licensing of future commercial MSR designs.

Ongoing experimental work occurring under the MSR National Campaign and summarized in a soon-to-be established Salt Property Database is a starting point for addressing these needs; however, this effort has not been focused on the priority needs of the industry and existing salt property characterization infrastructure within the national lab complex is insufficient to meet the needs of industry. These capabilities need to be significantly expanded in the near-term to enable demonstration of commercially competitive MSR designs.

MSRs introduce a new set of material related challenges associated with salt in contact with structural materials. In particular, the following phenomena need to be further investigated: development of tertiary creep, defect annihilation, chromium depletion mechanism, and cracking due to inward migration of fission product in alloys in contact with chlorine-based molten fuel salts. Graphite salt interaction is also an area of interest for several of the members, in particular: salt infiltration, chemical interaction with salt and fission product, irradiation stability, manufacturing process, and silicon carbide coating (effect in tritium penetration).

Progress in modern instrumentation, maintenance, and robotics for nuclear environments has been slow due to gaps in radiation-hardened electronics technology and research. Due to the harsh neutron and gamma radiation doses coupled with the elevated temperature environment, research and development for new electronics and electronic materials is essential for enabling new monitoring, control, and maintenance techniques.

Program Mission Statement

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

High Priority R&D

Chemistry Challenges

- Gaps in thermophysical and thermochemical properties of molten salts, Actinide fluoride and chloride bearing mixtures. ASTM Standard Methods Development. Synthesis of molten salts and fuel molten salts. Chemical and physical state of elements.

Monitoring and Chemistry Control of Molten Salts, with potential Online Salt Clean-up

- Fuel Salt Processing: The online processing of liquid fuel salts to extract fission products and manage the chemistry of the salt mixture is one of the most promising aspects of MSRs. However, this area needs further investigation and demonstration to ensure reliability and efficiency. MSR operations in operando (solubility, particulates, plating out…)

Safety Demonstration and Regulation

- Novel Designs and Fuel Cycles: MSRs employ innovative designs and fuel cycles, necessitating thorough safety demonstrations and regulatory approval. Developing safety cases and regulatory frameworks for MSRs is a key condition for its success.

Off-Gas Management

- Compliance with US and International regulatory requirements. Online monitoring tools development, Understanding the complex MSR gas and particle transport phenomena, and predicting off-gas & aerosol transport for accident analysis, demonstration of an integrated off-gas system .

Molten Salt Reactor PROGRAM

U.S. DEPARTMENT of ENERGY
Office of Nuclear Energy

DOE - Office of Nuclear Energy supports seven national laboratories to efficiently and effectively addressing, in partnership with other stakeholders, the technology challenges for MSRs to enter the commercial market.

SALT and FUEL SALT CHEMISTRY

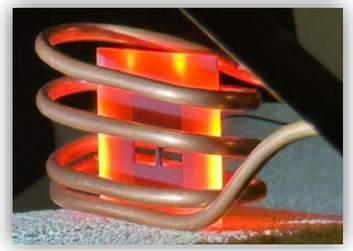
Thermophysical and Thermochemical Properties of Molten Salts – Experimental and Computational
Salt purification and synthesis
UF3, UF4, UCl3, PuCl3, AmCl3 Databases
ASTM Standard Method Development

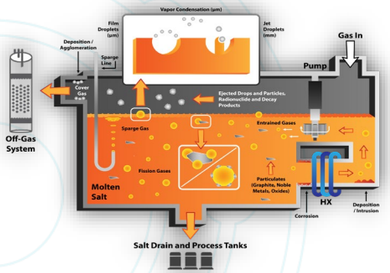
MODELING & SIMULATION FOR MSR SAFETY

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

MATERIALS

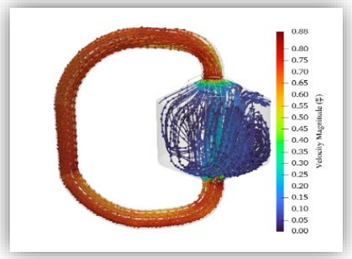
Development of materials surveillance technology
Graphite/Salt Interaction
Corrosion studies (SS316H, Alloy 709, Alloy 625, Haynes 244) in F and Cl salts
Under AMMT and GCR programs





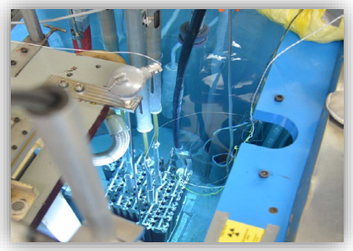
TECHNOLOGY DEVELOPMENT

Off-Gas Integrated System
Salt Chemistry Monitoring Tools
Radionuclide Release Monitoring
MSR Gas and Particles Transport Phenomena



SALT IRRADIATION

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



ENGINEERING SCALE FACILITY

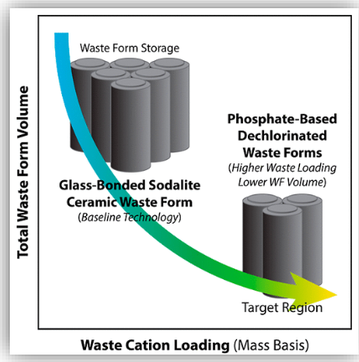
LSTL- FLiNaK loop - ORNL
FASTR –NaCl/ MgCl2/ KCl loop-ORNL
MSTTE – Molten Salt Tritium Transport Experiment - INL
SAAF- Salt Accident Analysis Facility - ANL
ASL – Actinide Salt Loop - ANL
ClESF – Chlorine Enrichment & Separation Facility - PNNL

MSR RADIOISOTOPES

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

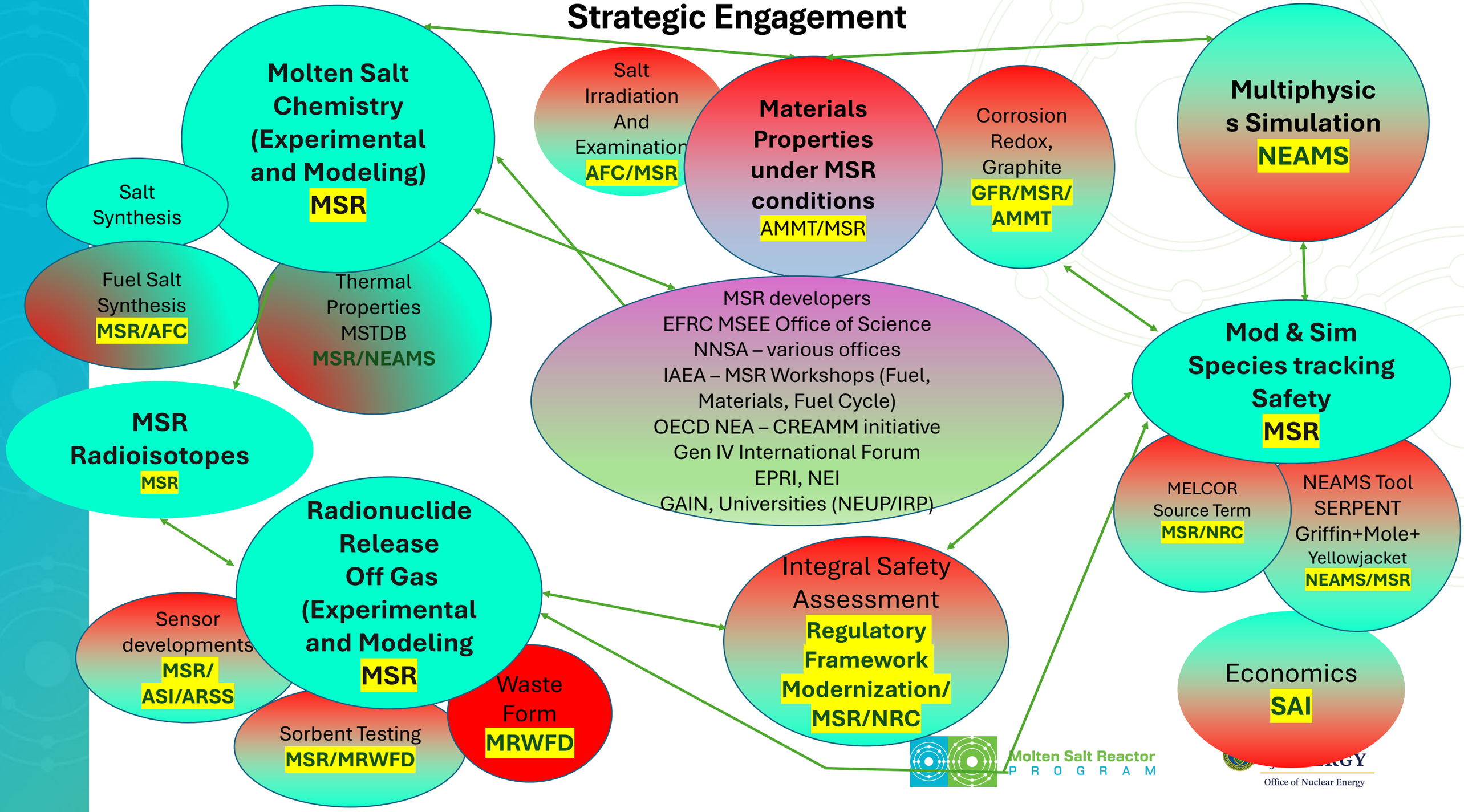
WASTE FORM DEVELOPMENT

Off-gas waste-form development (Iodine)
Dehalogenation process for chloride and fluoride salt waste treatment
Under MRFWD Program



Argonne NATIONAL LABORATORY · INL Idaho National Laboratory · Lawrence Livermore National Laboratory · Los Alamos NATIONAL LABORATORY · OAK RIDGE National Laboratory · Pacific Northwest NATIONAL LABORATORY · Sandia National Laboratories

Strategic Engagement



Molten Salt Thermal Properties Database – Updating the Roadmap

NEAMS
NUCLEAR ENERGY ADVANCED MODELING & SIMULATION PROGRAM

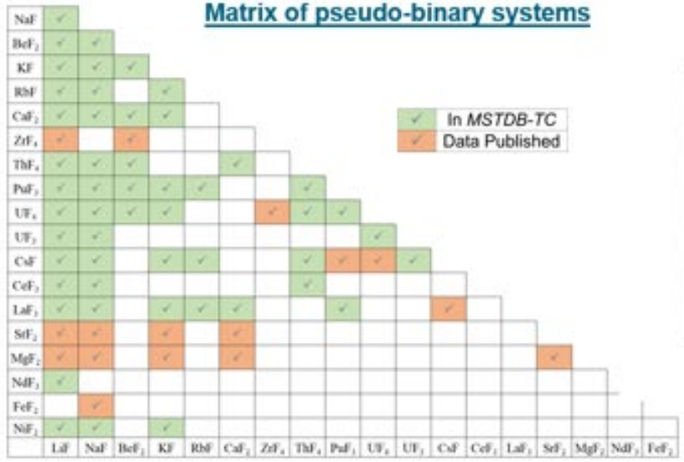
UNIVERSITY OF SOUTH CAROLINA

MSTDB-TC Fluoride Systems Content: Be-Ca-Ce-Cs-K-La-Li-Na-Ni-Nd-Pu-Rb-Th-U-F

Pseudo-ternary and higher order systems

- BeF2-LiF-NaF
- BeF2-LiF-PuF3
- BeF2-LiF-ThF4
- BeF2-LiF-UF4
- BeF2-NaF-PuF3
- BeF2-NaF-ThF4
- BeF2-NaF-UF4
- BeF2-ThF4-UF4
- CaF2-KF-NaF
- CaF2-LaF3-LiF
- CaF2-LaF3-NaF
- CaF2-LiF-KF
- CaF2-LiF-ThF4
- CeF3-LiF-ThF4
- CsF-LaF3-LiF
- CsF-LiF-KF
- CsF-LiF-PuF3
- LaF3-LiF-NaF
- LiF-KF-NaF
- LiF-KF-RbF
- LiF-NaF-CeF3
- LiF-NaF-PuF3
- LiF-NaF-RbF
- LiF-NaF-ThF4
- LiF-NaF-UF4
- LiF-PuF3-ThF4
- LiF-PuF3-UF4
- LiF-ThF4-CaF2
- LiF-NaF-BeF2-ThF4-PuF3-UF4
- LiF-NaF-BeF2-KF-PuF3-UF4
- LiF-NaF-KF-

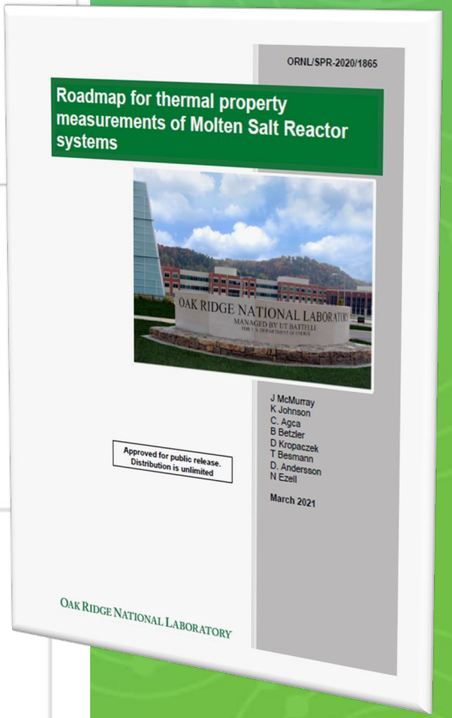
Matrix of pseudo-binary systems



MSDTB- TP for Fluoride Salts

KF	B					
LiF	A, B, D	A, B, C, D				
NaF	A, B	A, B, C	A, B, C, D			
ThF4		A, B	A, B, D	A, B		
UF3						
UF4		A, B	A, B	A, B		
ZrF4			A	A, B, D		
	BeF2	KF	LiF	NaF	ThF4	UF3	UF4

Key
A: Density
B: Viscosity
C: Thermal conductivity
D: Heat capacity



MSTDB-TC Chloride Systems Content: Al-Ca-Ce-Cs-Fe-K-Li-Mg-Na-Ni-Pu-Rb-U-Cl

Pseudo-ternary and higher order systems

- CeCl3-KCl-LiCl
- CeCl3-KCl-MgCl2
- CeCl3-KCl-NaCl
- CeCl3-LiCl-MgCl2
- KCl-LiCl-UCl3
- LiCl-NaCl-MgCl2-KCl-PuCl3-UCl3
- LiCl-NaCl-MgCl2-KCl-CeCl3

Matrix of pseudo-binary systems

MSDTB- TP for Chloride Salts

KCl	A, B								
LiCl	A	A, B, D							
MgCl2		A, B, D	A, B						
NaCl	A, B	A, B, D	A, D	A, B					
PuCl3									
ThCl4		A			A				
UCl3		A, B	A		A, B				
UCl4		A, B	A	A	A, B				
ZrCl4		A							
	AlCl3	KCl	LiCl	MgCl2	NaCl	PuCl3	ThCl4	UCl3	UCl4

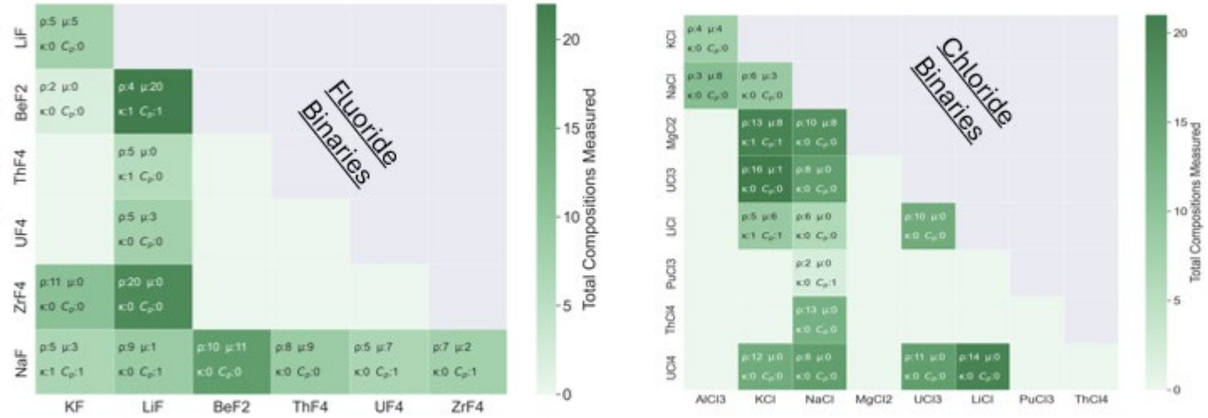
Key
A: Density
B: Viscosity
C: Thermal conductivity
D: Heat capacity

Molten Salt Reactor PROGRAM

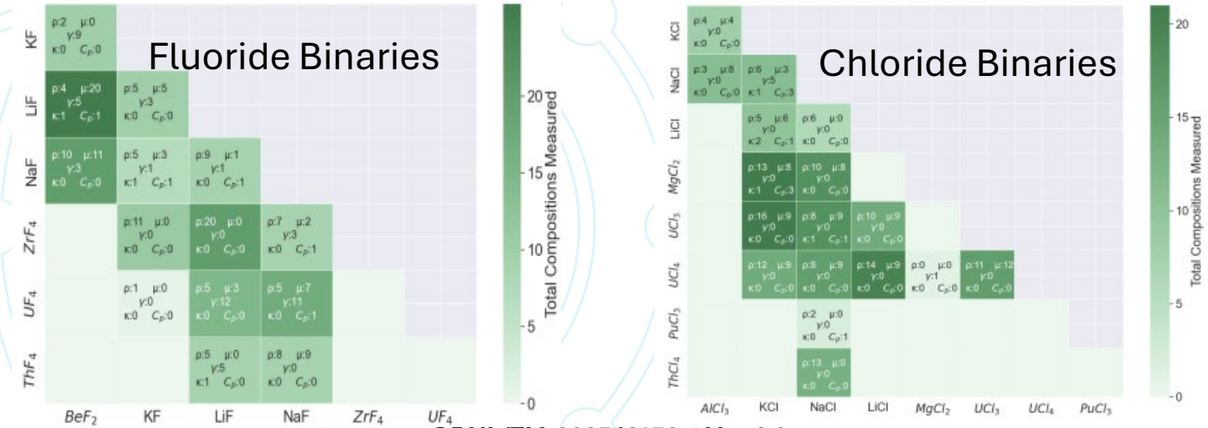
Molten Salt Thermal Properties Data Bases

Thermophysical Properties - managed by ORNL

- It contains empirical relations for the following properties:
  - **Melting and boiling points; Density; Viscosity; Heat Capacity; Thermal Conductivity**
- Each property entry in the database includes a margin of experimental error
  - This list is constantly expanding. The data is based on the outputs of 180+ independent experimental studies in literature.

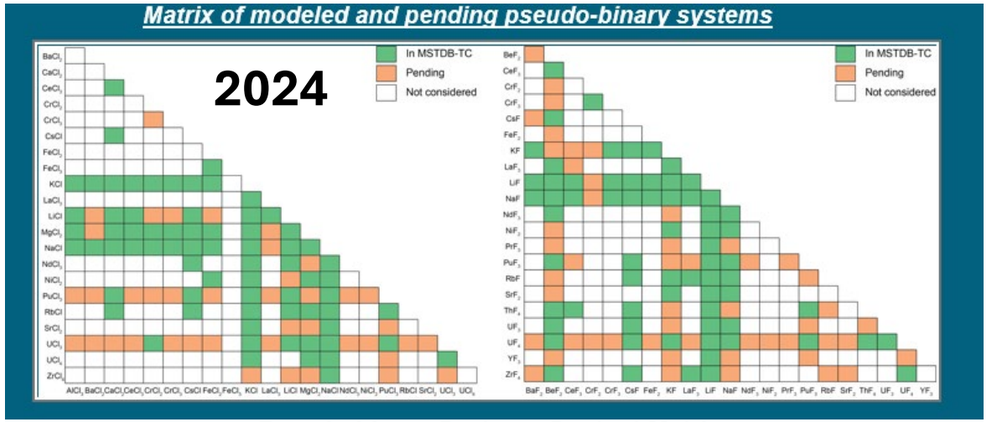


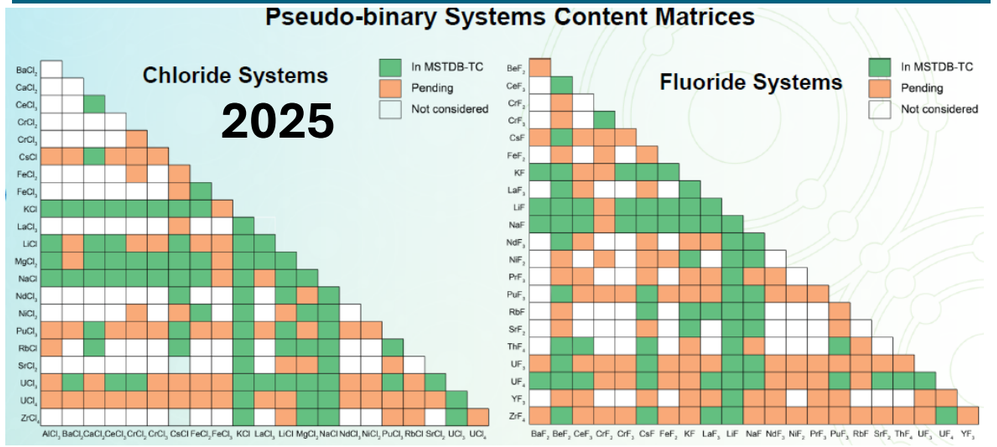
ORNL/TM-2024/3575 **Ver 3.1**



ORNL/TM-2025/4159 - Ver 4.0

Thermochemical Properties managed by U. of South Carolina

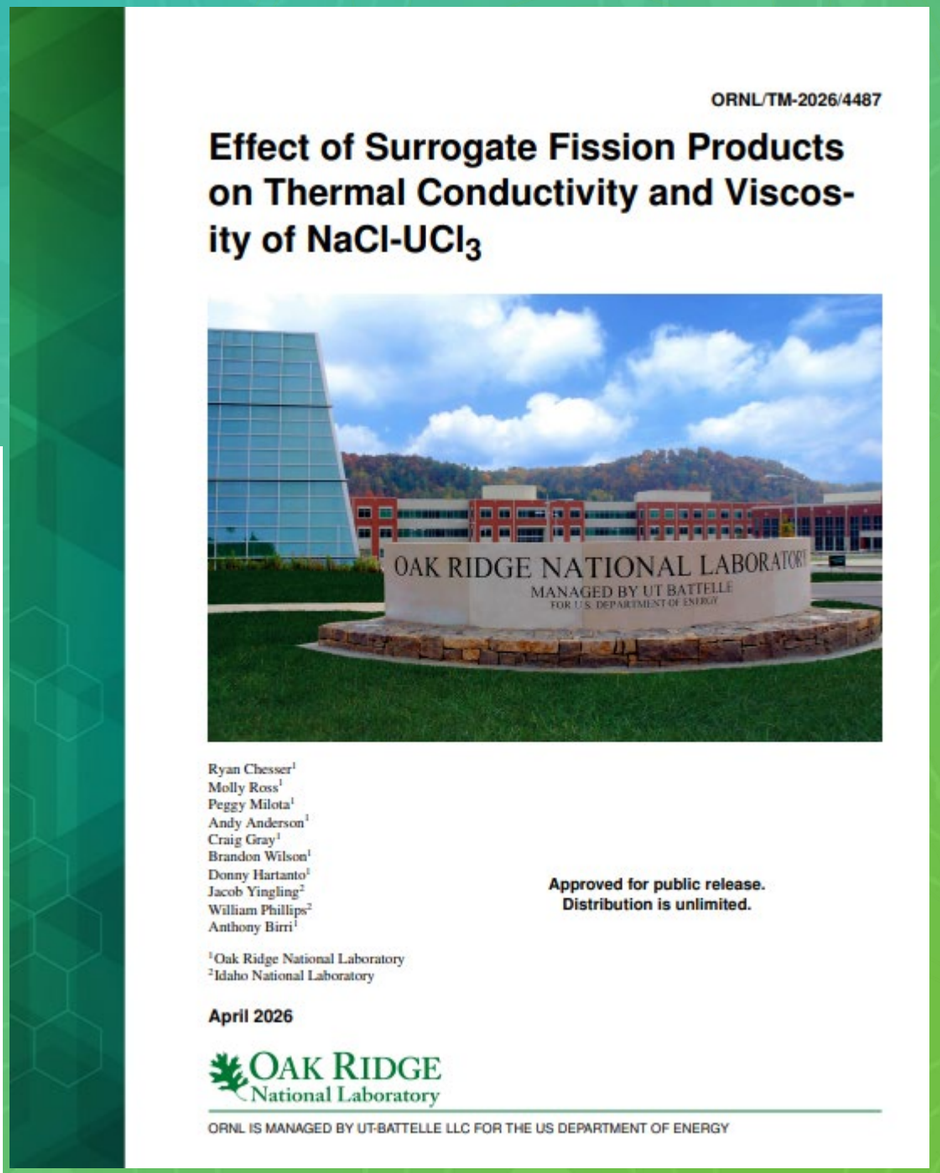




Recent release of the Molten Salt Thermal Properties Database-Thermochemical - Ver. 4.0

Effect of surrogate fission products on thermal conductivity and viscosity of $NaCl-UCl_3$

Viscosity and thermal conductivity measurements were performed on $NaCl-UCl_3$ (63-37 mol %) with and without 2.21 mol % surrogate FP additions to determine the impact of burnup on these thermophysical properties during the lifetime of an operating MSR. The selected quantity of surrogate FPs was determined by using ORIGEN to determine the extent to which the uranium would burn up and quantify the content of salt-seeking FPs. Results indicated that the addition of approximately 2.21 mol % surrogate FPs caused a consistent and statistically significant increase in viscosity of roughly 10% across the measured temperature range. In contrast, while thermal conductivity values were marginally higher with the addition of surrogate FPs, the change remained within the experimental uncertainty margin and was not considered statistically significant. These results will ideally provide a bounded understanding of how these properties will evolve over the course of operation in a MSR fueled with $NaCl-UCl_3$, and may justify simplifications in modeling and licensing efforts. While efforts were made to account for salt-seeking fission product species in the surrogate fission product blend tested here, effects of dissolved fission gas species such as xenon and krypton, as well as time-dependent radiation-induced effects were not considered and may cause additional changes in thermophysical properties. Namely, these results suggest that thermal conductivity of the fuel will not have any statistically significant changes over a significant operational period; this may allow for the assumption of temporal independence of this property, making thermal hydraulic modeling less cumbersome.



ORNL/TM-2026/4487

Effect of Surrogate Fission Products on Thermal Conductivity and Viscosity of $NaCl-UCl_3$

Ryan Chesser[1]
Molly Ross[1]
Peggy Milota[1]
Andy Anderson[1]
Craig Gray[1]
Brandon Wilson[1]
Donny Hartanto[2]
Jacob Yingling[2]
William Phillips[2]
Anthony Birri[1]

[1]Oak Ridge National Laboratory
[2]Idaho National Laboratory

April 2026

OAK RIDGE National Laboratory

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

Integrated Off-Gas Management

Relevant Regulatory Drivers for U.S. Off-gas Treatment

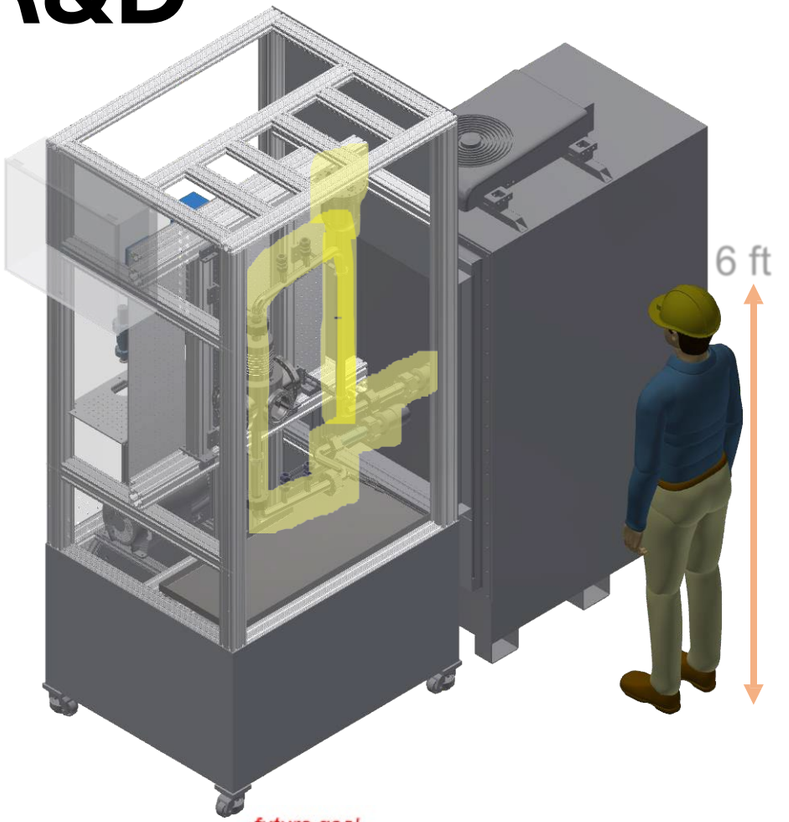
- **Volatile off-gas components have wide range of half-lives and disposal requirements:**
  - ^{3}H 12.31y
  - ^{14}C 5715 y
  - Xe Stable and very short half-life < 30 days
  - ^{85}Kr 10.76 y
  - ^{129}I 1.57×10^{7} y
- **Regulations**
  - Standards for normal operation (40 CFR 190) (Applies to Fuel Cycle Facilities)
    - *25 mrem/y whole body*
    - *75 mrem/y thyroid*
    - *50 000 Ci/GWy ^{85}Kr - (1.85×10^{15} Bq / GWy)*
    - *5 mCi/GWy ^{129}I - (1.85×10^{8} Bq / GWy)*
    - *0.5 mCi/GWy ^{239}Pu and other alpha-emitters*
  - 40 CFR 61 (Applies to facilities operated by DOE).
    - *Limits equivalent dose to the public to 10 mrem/y.*
- **NRC**
  - Standards for protection from ionizing radiation (10 CFR 20) (Applies to NRC Licensed Facilities)
    - Applies to facilities licensed by NRC.
    - Total equivalent dose not to exceed 0.1 rem/y.
    - Provides a table of air concentration limits for each radionuclide.

Jubin, Paviet, Bresee, Atalante 2016

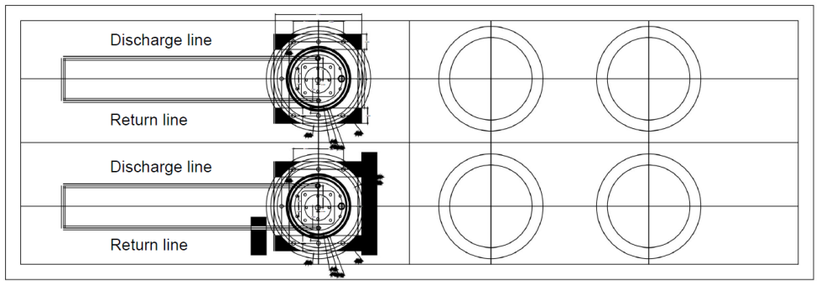
Salt Loops supporting MSR R&D

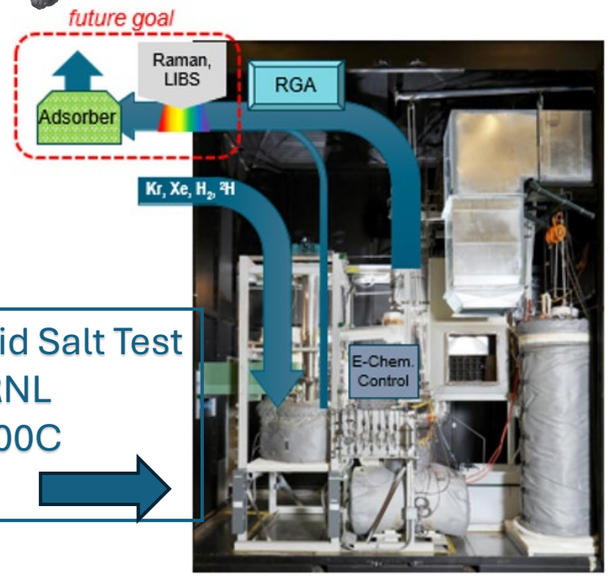
FASTR -Facility to Alleviate Salt Technology Risks – ORNL
NaCl-KCl-MgCl2
725C
154L

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



Actinide Salt Loop at ANL





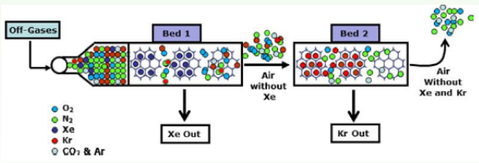
LSTL - Liquid Salt Test Loop at ORNL
FLiNaK – 700C
80L

Technology Development and Demonstration
Multi-faceted approach to investigation of technologies for MSR off-gas systems

Component Testing

Large Scale Test Loop

Xe/Kr separation in MOF

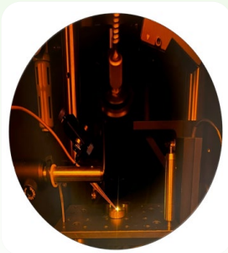


Radionuclide Identification/Speciation

Raman Spectroscopy

405 nm 532 nm 671nm

Laser Induced Breakdown Spectroscopy



Gas/Liquid Interface

Bubble Measurement

Source Term Modeling

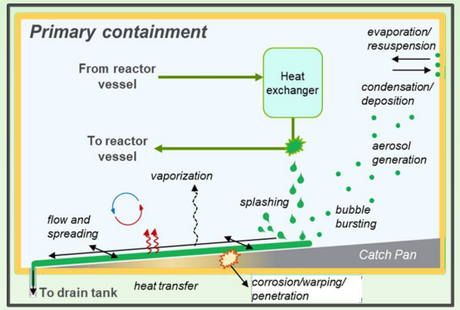
Bulk Gas	Gas Film	Liquid Film	Bulk Liquid
p_i pressure	p_i^*	c_i^*	c_i concentration

$$c_i^* = p_i H$$

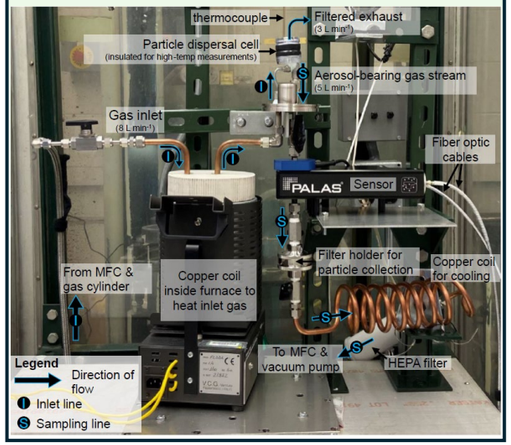
$$p_i^* = c_i / H$$

Spill Test

Engineering Scale Salt Accident Analysis Facility

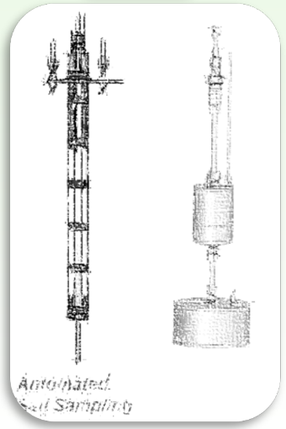


Salt Aerosol Concentration and Size Measurements



Sensors/Salt Chemistry

Salt Composition
Redox
Salt Level



Argonne NATIONAL LABORATORY · INL Idaho National Laboratory · Los Alamos NATIONAL LABORATORY · OAK RIDGE National Laboratory · Pacific Northwest NATIONAL LABORATORY

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Gas Phase Analysis

Multiple applications

Off-gas treatment

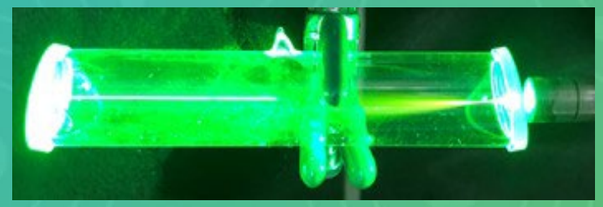
Supporting system development and demonstrations

Laying foundation for tools that enable cost effective and near-term deployment of technology

Fluorination

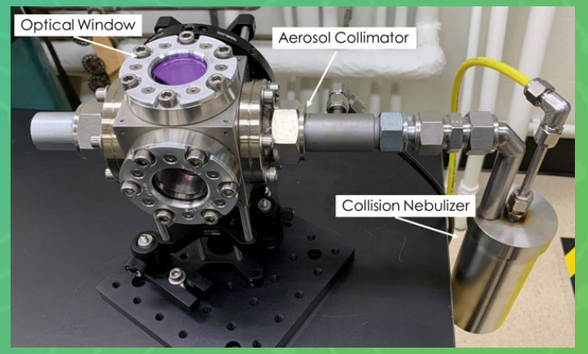
And more

Molecular



PNNL team
Heather Felmy,
Sam Bryan,
Paulina Guerrero-Almaraz

Atomic



ORNL team
Hunter Andrews,
Zechariah Kitzhaber

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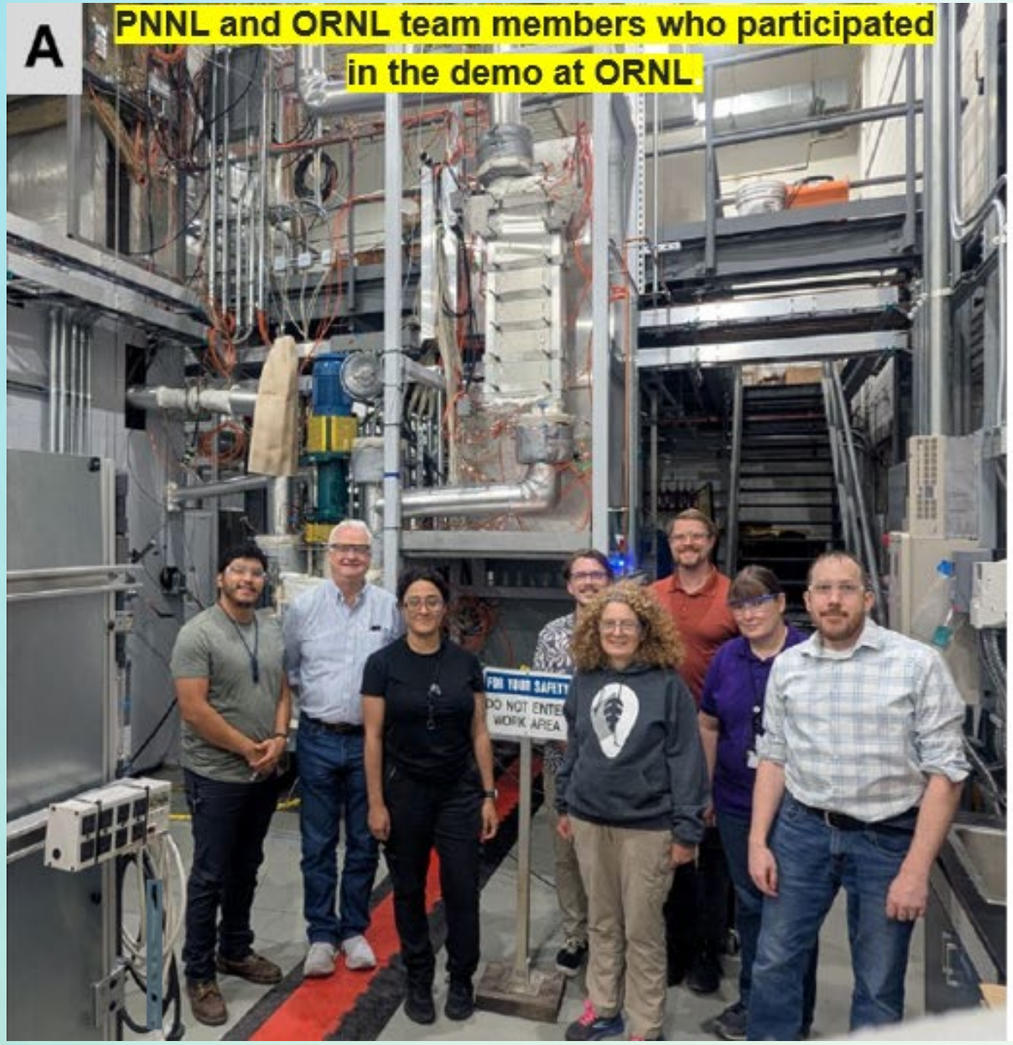
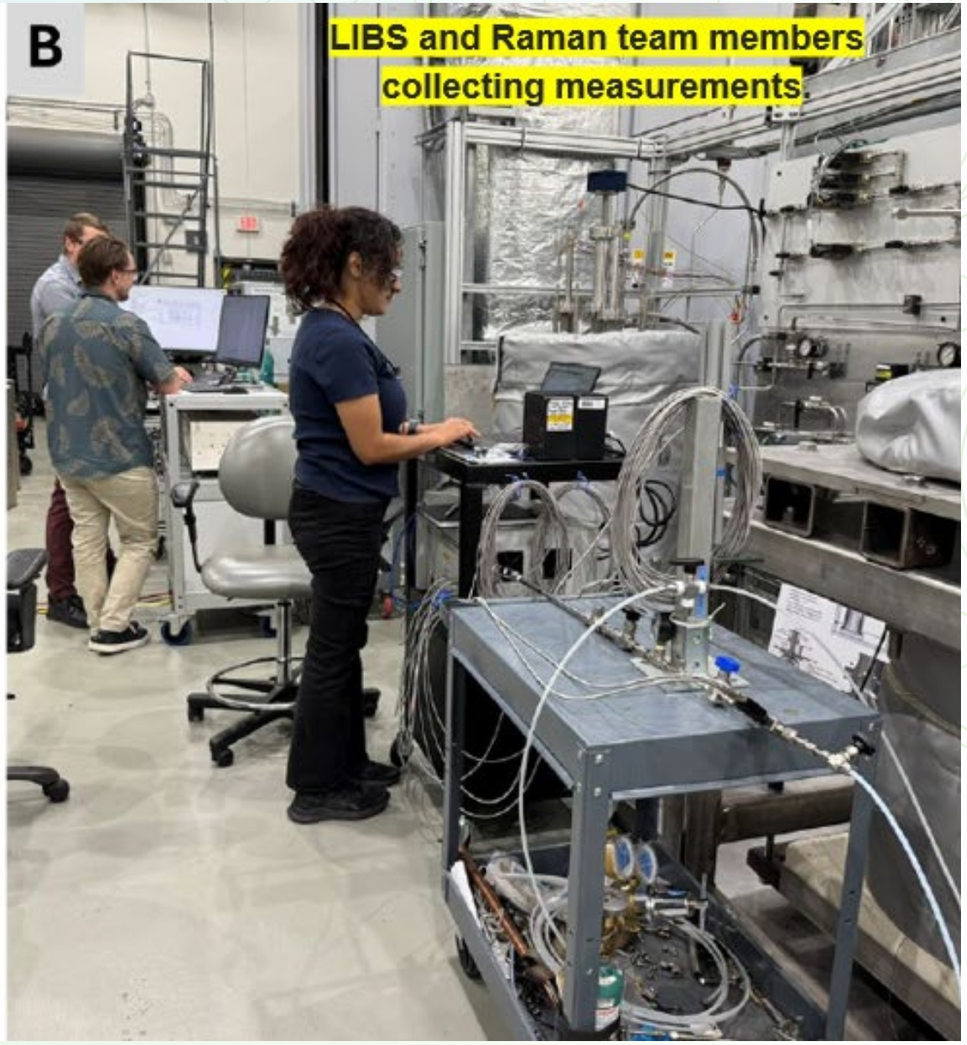
Tandem use of Raman, LIBS, and redox probes, flow sensors demonstrated in FASTR – August 2025





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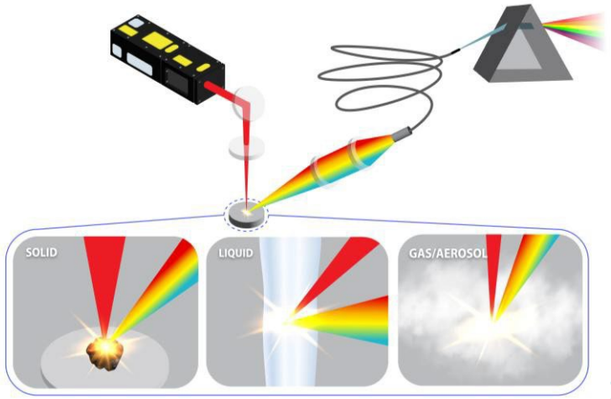
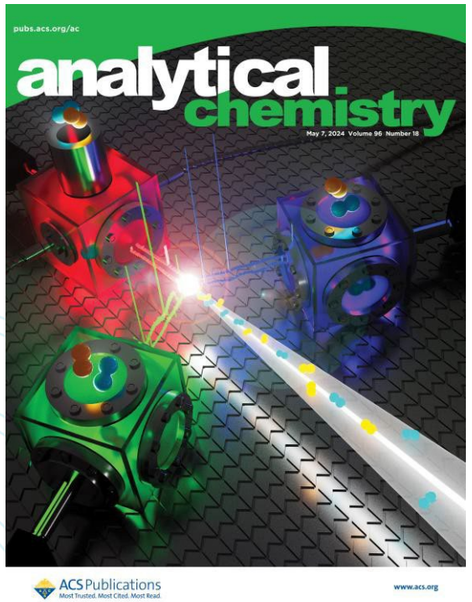
Heather Felmy et al, PNNL-38277, SEP 2025; Andrews et al., Hunter Andrews et al, ORNL/TM-2025/4115

Objective: Demonstration of an integrated off-gas system in 5 years.

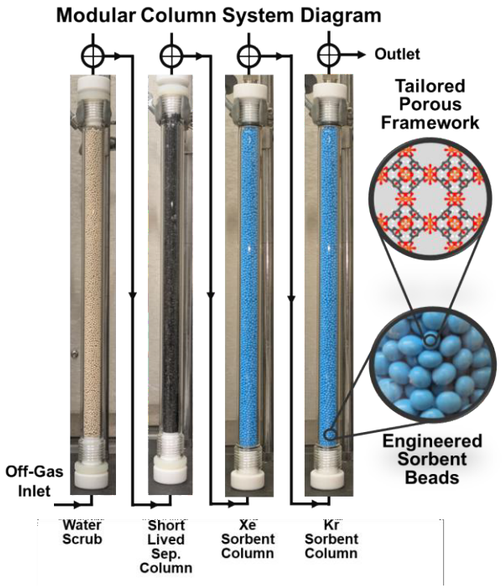
FY 26	FY 27	FY 28	FY29	FY 30	
Roadmap and start design	start building the integrated off gas system	Start cold test Analize cold test results	modify design if necessary and start building system for hot test	Start hot test – Analyze result	Off gas system ready for testing in MSRR and MCRE



Radionuclide sensors



& transport, vapor pressures, chemistry



Capture technologies

Testing in large loops

Deployment in MSRs

Panel Session on Thursday 23 April at 11:05 am MT

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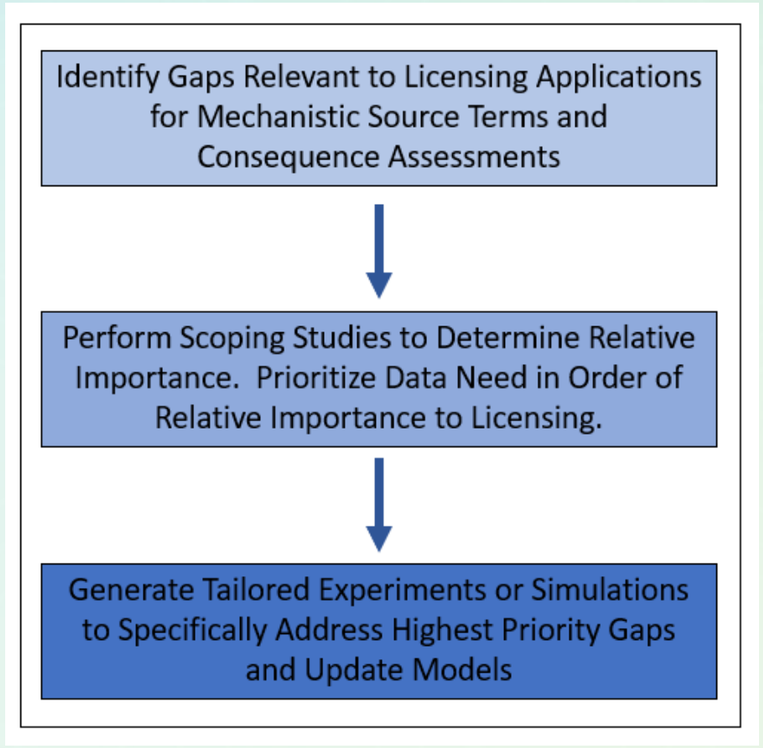
Safety of Molten Salt Reactor

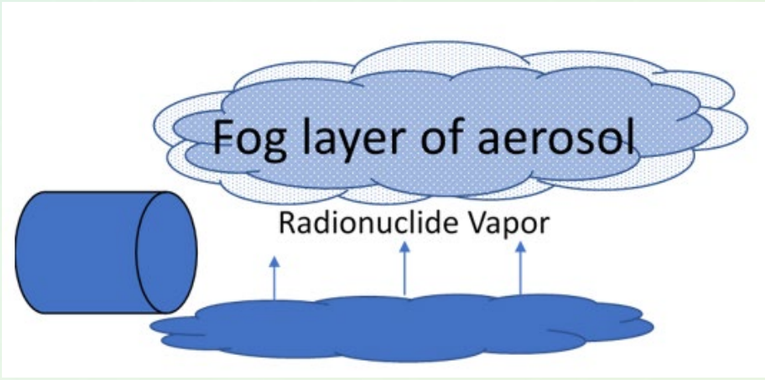
Data needs of Importance for Mechanistic Source Term Modeling

MELCOR simulations of postulated accident scenarios for MSRs will require experimental validation using datasets generated at a relevant scale. For MELCOR to best inform MSR accident experiments, it is recommended that initial scoping studies be performed on the identified gaps to best inform the relative importance of each item, with priority assigned based on relevance to licensing applications.

Based on the assessment of relative importance and relevance to licensing, tailored experiments and simulations should be developed to specifically address the highest priority data gaps

Data Needs	Status
Spill geometry, volume, salt temperature, and salt composition	Vendor-dependent but some nominal values needed
Substrate properties: thickness and extent, temperature, thermal conductivity, heat capacity, and density	Vendor-dependent but some nominal values needed
Salt physical properties (thermal conductivity, heat capacity, density, viscosity and surface tension)	Available for pure salts at operating temperatures. Need to verify extrapolations to higher temperatures. Contaminant effects due to air and water vapor exposure are unavailable and may be estimated.
Vapor pressure with temperature and salt composition, and vapor diffusivity in atmosphere	Estimated from thermodynamic database if available.





Courtesy Lucas Albright Matt Christian, and David Luxat

Pathway to generating experimental data for MELCOR development and validation

- MELCOR simulations of postulated accident scenarios for MSRs will require experimental validation using datasets generated at a relevant scale

Salt spill scenario

Interaction with stakeholders
(model developers and MSR vendors)

Conduct individual process tests at laboratory scale	Conduct integrated process tests at laboratory scale	Design engineering-scale tests for integrated processes	Conduct-engineering-scale tests
• Identify and develop measurement techniques • Develop methods to simulate processes • Quantify dispersal behavior of spilled molten salt to fill data gaps in process models	• Apply coupled methods and measurement techniques • Measure processes simultaneously to fill data gaps on coupled processes in multi-physics codes	• Identify initial conditions of the spill and test variables • Design test apparatus • Identify safety considerations and design limitations	• Use representative fluoride and chloride salt compositions • Test geometries that facilitate model development • Adopt a modular design approach for maintenance and design flexibility

Courtesy Sara Thomas, ANL and David Luxat/Matt Christian, SNL

The Roadmaps…

MSR Overall Roadmap Short- and Long-term R&D

	FY 26 – FY 30	FY 30 – FY 40
SALT CHEMISTRY And THERMAL PROPERTIES	Update of the MSR Thermal properties Roadmap Focus on density, viscosity, heat capacity and thermal conductivity ASTM Standard Test Method for Measurement of Viscosity of a Molten Salt using a Rotational Viscometer Round robin experiment	Continue to develop capabilities and complete database for the determination of the thermal properties of molten salts – Emissivity, Vapor Pressure, Surface Tension Impact of impurities on thermal properties ASTM Standard Test Method for heat capacity and density of Molten Salt.
INTEGRATED OFF GAS MANAGEMENT	Develop and demonstrate an integrated off gas management system at engineering scale Produce sorbents at engineering scale	Work with MSR developer(s) to Implement the system into an MSR Sorbent production – Commercial scale
SENSOR INSTRUMENTATION. MAINTENANCE	Composition/Species: Raman (off gas), LIBS (off gas), electrochemistry Flow, Pressure, Salt Level In-situ chemistry control (redox control)	Composition/Species: Raman (Salt,) LIBS, (Salt) Salt Sampling Filtration/Collection of insoluble species
SAFETY	Salt Accident Analysis Facility (SAAF) Develop and validate source term and accident progression models (MELCOR) for MSR safety and licensing MSTTE – Tritium Transport (Experimental and Modeling) Evaluation Model development Tools (NEAMS) for safety analyses	Operational challenges presented by MSR – Develop predictive modeling capabilities to support operations of any MSR Continue experiments and safety demonstration tests In-depth studies on the evolution of fuel salt chemistry as a function of burnup, as well as on radionuclide retention under both normal and accident conditions.
ISOTOPES	Chlorine -37 – Engineering Scale Recovery of enriched Cl-37 – Lab scale	Chlorine-37 – Pilot Scale (Enrichment and Recovery) Tritium Recovery for fusion application Xe-133 recovery for medical application

Reports from the ART MSR Program

Nathaniel Hoyt and Nora Shaheen, M3AT-25AN0702031 - Installation of Molten Salt Flow Loop with Chemistry Monitoring and Control System

Sara Thomas, M3AT-25AN0702041-Complete system component integration plan and preliminary designs for engineering scale test facility

Sara Thomas, M3AT-25AN0702042-Complete initial construction activities for automated salt transfer device

Sara Thomas, M3AT-25AN0702043-Complete demonstration of aerosol sensor sensitivity to aerosol formation mechanism

Heather Felmy, M3AT-25PN0702061-Complete demonstration of flow cell design on representative gas stream

Praveen Thallapally, M3AT-25PN0702071-Scale up and fabricate MOF engineered particles to support FY'25 irradiation experiments

Melissa Rose, M3AT-25AN0705011-Quantify the precision and bias in molten salt property measurements of molten salts

Melissa Rose, M4AT-25AN0705012-Complete quality assessment of unary chloride property data in MSTDB-TP.

Melissa Rose, M3AT-25AN0705014-Measure effect of corrosion products and oxides on thermal properties of FLiNaK salt

Marisa Monreal, M3AT-25LA0705037-Complete Measurements for Development of the NaCl-MgCl2-UCl3 phase diagram```

Marisa Monreal, M3AT-25LA0705036-Complete phase transition experiments of LiF-NaF-KF-UF4 mixture

Tony Birri, M2AT-25OR0705041-Complete thermal property measurements on multiple actinide fluoride mixtures

Tony Birri, M3AT-25OR0705042-Complete measurement of viscosity and thermal conductivity of NaCl-UCl3 + FPs

Reports from the ART MSR Program (Cont.)

Kyle Makovsky, M3AT-25PN0705052-Complete the determination of the effects of corrosion products and water content on thermophysical properties for the MgCl2-KCl binary salt system.
Kyle Makovsky, M2AT-25PN0705051-Complete the measurements of volatility, heat capacity, phase mapping, and evolved gas analysis of various coolant/fuel salts.
Kyle Makovsky, M3AT-25PN0705053-Develop a Mitigation Strategy for Fluid Inclusions
Manh Thuong Nguyen, M3AT-25PN0705062-Complete computational investigation of thermophysical (density, specific heat, and viscosity) and structural properties of NaCl-PuCl3-AmCl3 molten salts.
Vanda Glezakou, M3AT-25OR0705071-Complete computational assessment of viscosity and thermal conductivity of Uranium chloride/fluoride salts
Toni Karlsson, M2AT-25IN0705081-Complete PIE of Irradiated Salt
Toni Karlsson, M3AT-25IN0705082-Initiate corrosion analysis of capsule
Toni Karlsson, M3AT-25IN0705083-Complete preliminary design of new capsule
Ted Besmann and Juliano Schorne-Pinto, M3AT-25OR0705092-Optimize thermochemical models of Ba, Sr, and I in MgCl2 and Sm, Pr, Gd in LiF, NaF, KF, NaCl, KCl.
Bruce McNamara, M2AT-25PN0705101-Complete High Purity 37Cl Separations by Thermal Diffusion Isotope Separations.
Hunter Andrews, M2RD-25OR0602014-Complete mobile LIBS analysis of the off-gas from small and large sparging salt vessel.
Daniel Orea, M3RD-25OR0602018-Complete bubble visualization tests in molten salt systems
Mauricio Tano, M3RD-25IN0602021-Complete Initial Engineering Framework for Species Tracking in MSRs involving Fuel Salt and Structures
Matt Christian, M3RD-25SN0602032-Complete Deposition Modeling of Metals and Safeguard Materials in MSRs

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Spectrochimica Acta Part B: Atomic Spectroscopy

Volume 230, August 2025, 107237

Real-time monitoring of trace noble gases using laser-induced breakdown spectroscopy—An investigation of the impact of bulk gas on plasma properties and sensitivity ☆

Hunter B. Andrews [a], Zechariah B. Kitzhaber [a], Joanna McFarlane [b]

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Nuclear Engineering and Design

Volume 445, 15 December 2025, 114495

Advancing molten salt reactor technologies: Prioritizing standardisation needs and bridging gaps ☆

A. Jenet [a b], P. Souček [c], K.-F. Nilsson [d], A. Caverzan [d], E. Capelli [e], P. Paviet [f], M. Rose [g], D. Holcomb [h], A. Smith [i], J. Křepel [j], F. Taucer [a], O. Beneš [c]

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Separation and Purification Technology

Volume 363, Part 1, 14 August 2025, 132050

Recent advances in the capture of halogen gas by porous adsorbents: A review

Sun Hae Ra Shin [a], Ambalavanan Jayaraman [b], Praveen K. Thallapally [a]

International Journal of Thermophysics (2026) 47:80
https://doi.org/10.1007/s10765-026-03748-0

Molten Halide Salt Surface Tension: Methods and Correlations

Ryan Chesser[1] · Nicholas Termini[1] · Anthony Birri[1]

Received: 2 March 2026 / Accepted: 24 March 2026

Abstract

This paper reviews various methods for studying surface tension and their applicability to fluoride and chloride molten salt systems, including a comparison of benefits and drawbacks. Such a comparison aids in experiment design based on desired factors such as scale, accuracy, and repeatability. A detailed review is presented for existing literature data regarding the surface tension of molten fluoride and chloride salts. These reference data were compiled and analyzed to determine cross-validated correlation equations for several alkali and alkaline earth fluoride and chloride salts as functions of temperature. These correlations are necessary for reliable multiphysics modeling approaches as well as accurate design and analysis of multiphase molten salt phe-

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ARTICLE | August 5, 2025

Sparge Sampling of Molten Salts for Online Monitoring via Laser-Induced Breakdown Spectroscopy

Zechariah B. Kitzhaber, Daniel Orea, Joanna McFarlane, Benjamin T. Manard, and Hunter B. Andrews*

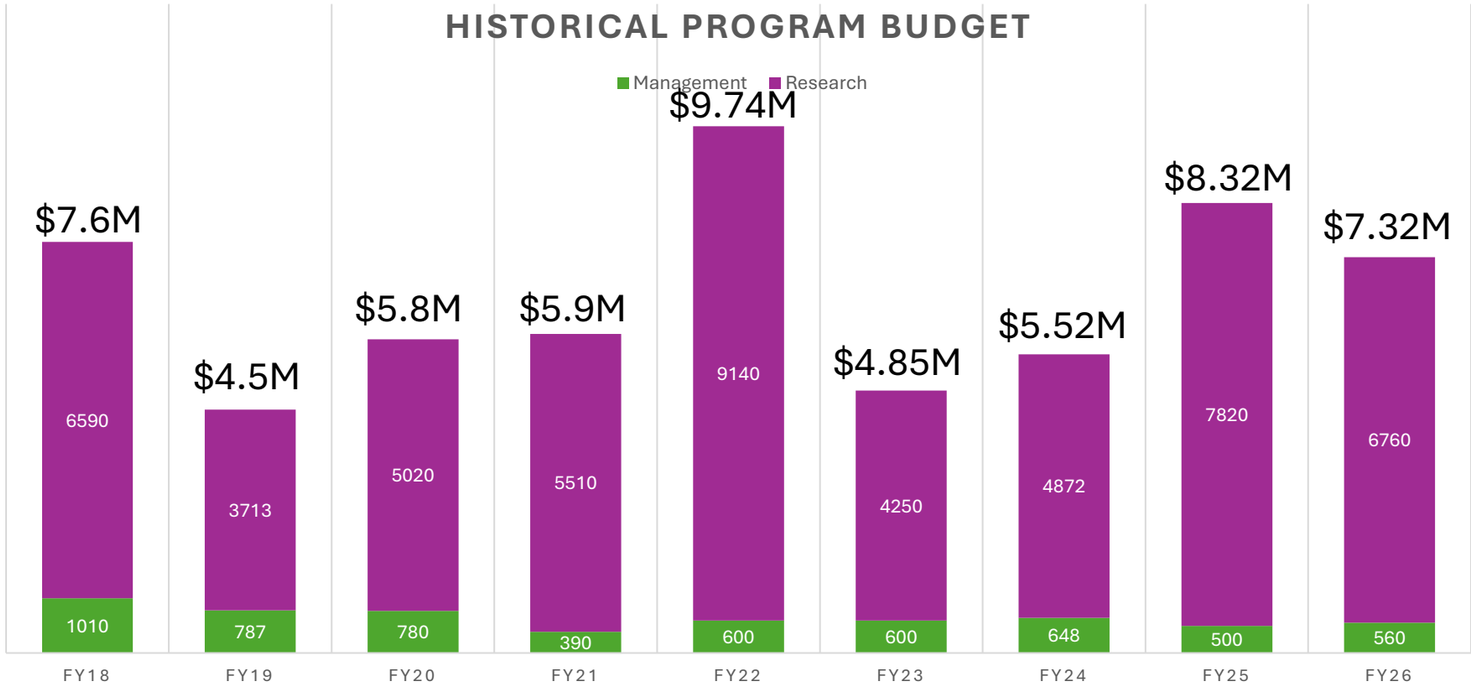
lump to Expand

28

Recent Papers

- *Round Robin Measurements of Molten Salt Properties for LiF-NaF-KF (FLiNaK) and NaCl-KCl Mixtures*, Troy Munro, et al. J. Chem. Eng. Data, https://doi.org/10.1021/acs.jced.5c00421
- *Irradiation of an enriched uranium (NaCl-UCl3) fuel salt capsule, summary of nondestructive post-irradiation examinations, and solidification modeling,* Toni Karlsson, et al., Nuclear Engineering and Design, Volume 448, 2026, 114680, ISSN 0029-5493, https://doi.org/10.1016/j.nucengdes.2025.114680
- *Thermodynamic Properties of $ZrCl_4$ with LiCl, NaCl, KCl, CsCl, $MgCl_2$, and UCl_3 for Molten Salt Reactor Applications*, Jack A. Wilson, et al., Journal of Molecular Liquids 437 (2025) 128578 https://doi.org/10.1016/j.molliq.2025.128578
- *Thermodynamic Assessment of the Na, K, Cs, Mg | Cl, I Reciprocal System,* Clara M. Dixon, et al., J. Chem. Thermo. (2025)
- https://doi.org/10.1016/j.jct.2025.107548
- *Purification of Uranium Tetrafluoride Using Ammonium Bifluoride,* Kyle R. Foster, et al., Journal of Fluorine Chemistry 285–286 (2025) 110449 https://doi.org/10.1016/j.jfluchem.2025.110449
- *Coordination-driven mixing behavior of corrosion and fission products in NaCl-UCl_3 molten salt*, Gaoxue Wang, et al., Journal of Nuclear Materials 615 (2025) 155949 https://doi.org/10.1016/j.jnucmat.2025.155949

- Seven National Laboratories
- Experimental Capabilities
  - Various salt loops
  - New equipment to measure thermal properties of molten salt
- Development of three roadmaps –
  - Chemistry
  - Integrated off-gas management
  - Short- and Long -Term needs
- Education and Training, Retention



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Summary

- The ART Molten Salt Reactor continues to successfully leverage national laboratory expertise and infrastructure to support MSR development and deployment by filling out the gaps identified by MSR developers
  - Thermophysical and thermochemical properties of molten salt (experimental and modeling using AIMD) + Databases with annual workshop in June
  - Off gas integrated management system
  - Sensors/Instrumentation development
  - Various molten salt loops
  - NEAMS Tools and MELCOR supporting safety and licensing
- We are very engaged with MSR developers (nationally and internationally)
- We are very engaged with academia, other DOE Offices, regulators
- We are engaged via NEUP research proposals with professors and students, SULI program (Undergrad program from office of science…) – Important to maintain the expertise, successful succession plan, good knowledge management and transfer.
- Extraordinary dedicated team (ANL, INL, LANL, LLNL, ORNL, PNNL, SNL) who is passionate about molten salt reactor systems which have infinite options.


Clean. Reliable. Nuclear.
ENERGY
NUCLEAR ENERGY

Resources

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Euromost 2026 – 1st European Conference on MSR– 26-29 May 2026, Baden-Baden, Germany

https://joint-research-centre.ec.europa.eu/events/molten-salt-reactor-technology-euromost-2026-05-26_en

IAEA MSR Structural Materials Workshop, 20-24 July 2026), Vienna, Austria (Hybrid)

https://intouchplus.iaea.org referencing **event EVT2504152**

ACS Fall Meeting – Symposium on MSR 23-27 August 2026, Chicago, IL

https://www.acs.org/events/fall.html

MSR Annual Workshop , 27-29 October 2026, Knoxville, TN

MSR Program 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

Contacts

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Molten Salt Reactor Reports

CHEMISTRY

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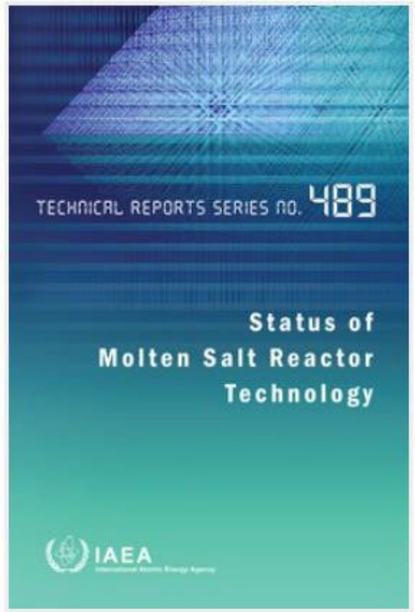
Synthesis and Thermophysical Property Determination of NaCl-PuCl3 Salts	Link	INL/RPT-22-69181	2022	34
Engineering-Scale Batch Purification of Ternary MgCl2-KCl-NaCl Salt Using Thermal and Magnesium Contact Treatment	Link	ORNL/TM-2022/2554	2022	31
An Overview of the Molten Salt Thermal Properties Database□Thermophysical, 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
Experimental Plan for Synthesis of an Americium- and Plutonium-Containing Salt	Link	INL/RPT-24-80052	2024	18

« ‹ 1 2 3 ›

Thank you
Teresa Krynicki, INL

MSR Taxonomy from the IAEA TRS No. 489

Status of Molten Salt Reactor Technology



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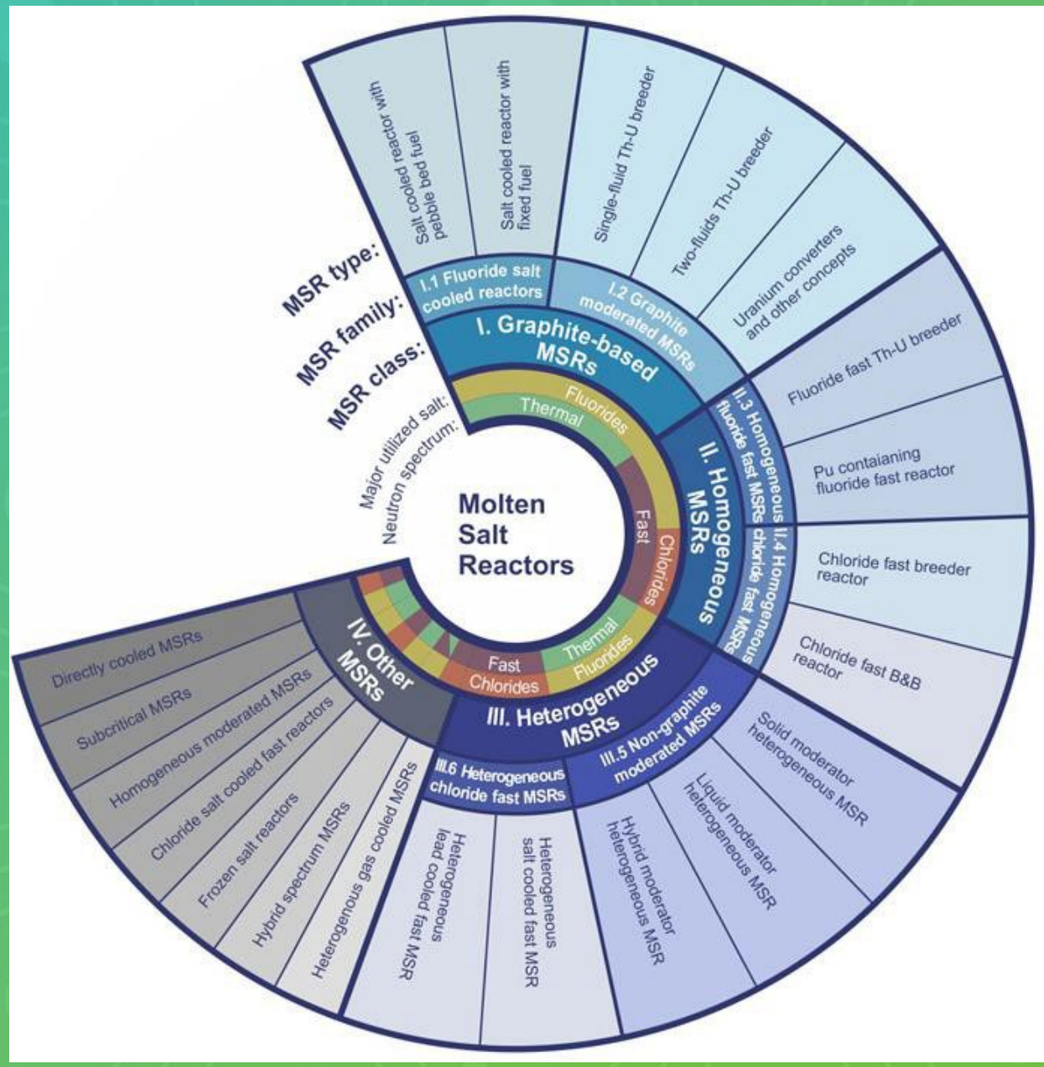

https://www.iaea.org/publications/14998/status-of-molten-salt-reactor-technology

Thank You

Patricia.Paviet@pnnl.gov

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