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

DOE-NE
Molten Salt Reactor Activities

Dr. Patricia Paviet
National Technical Director

MSR Annual workshop - 11-12 October 2022

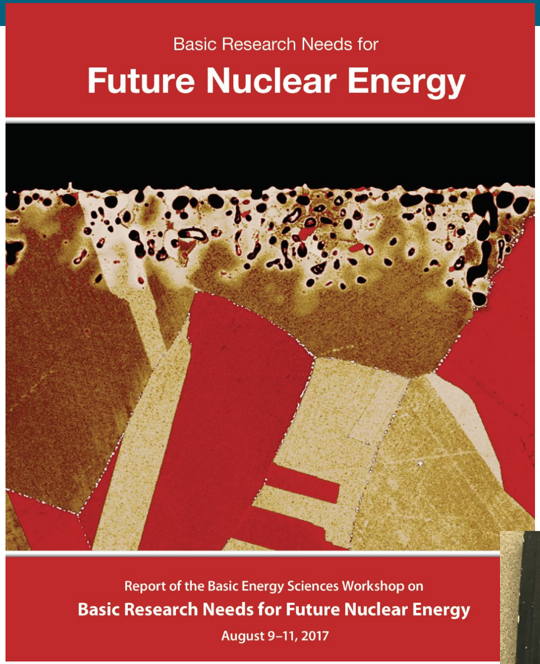
PNNL-SA-178183

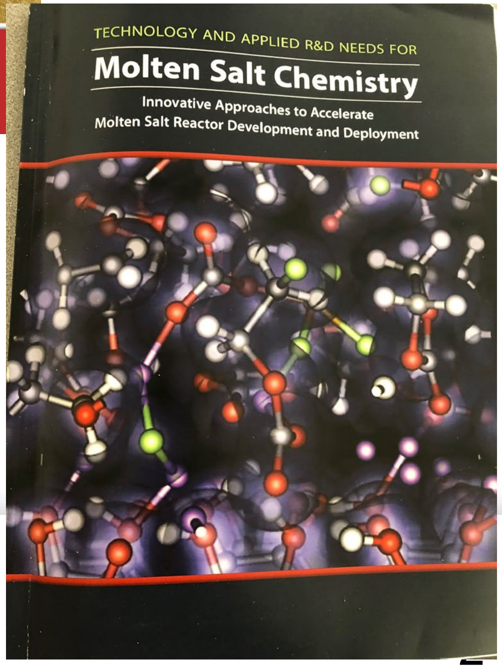
Pacific Northwest National Laboratory | INL Idaho National Laboratory | Oak Ridge National Laboratory | Argonne National Laboratory | Los Alamos National Laboratory | Sandia National Laboratories | Molten Salt Reactor PROGRAM

2017 – Two DOE Workshops have paved the way….

Enabling the Design of Revolutionary Molten Salt Reactors

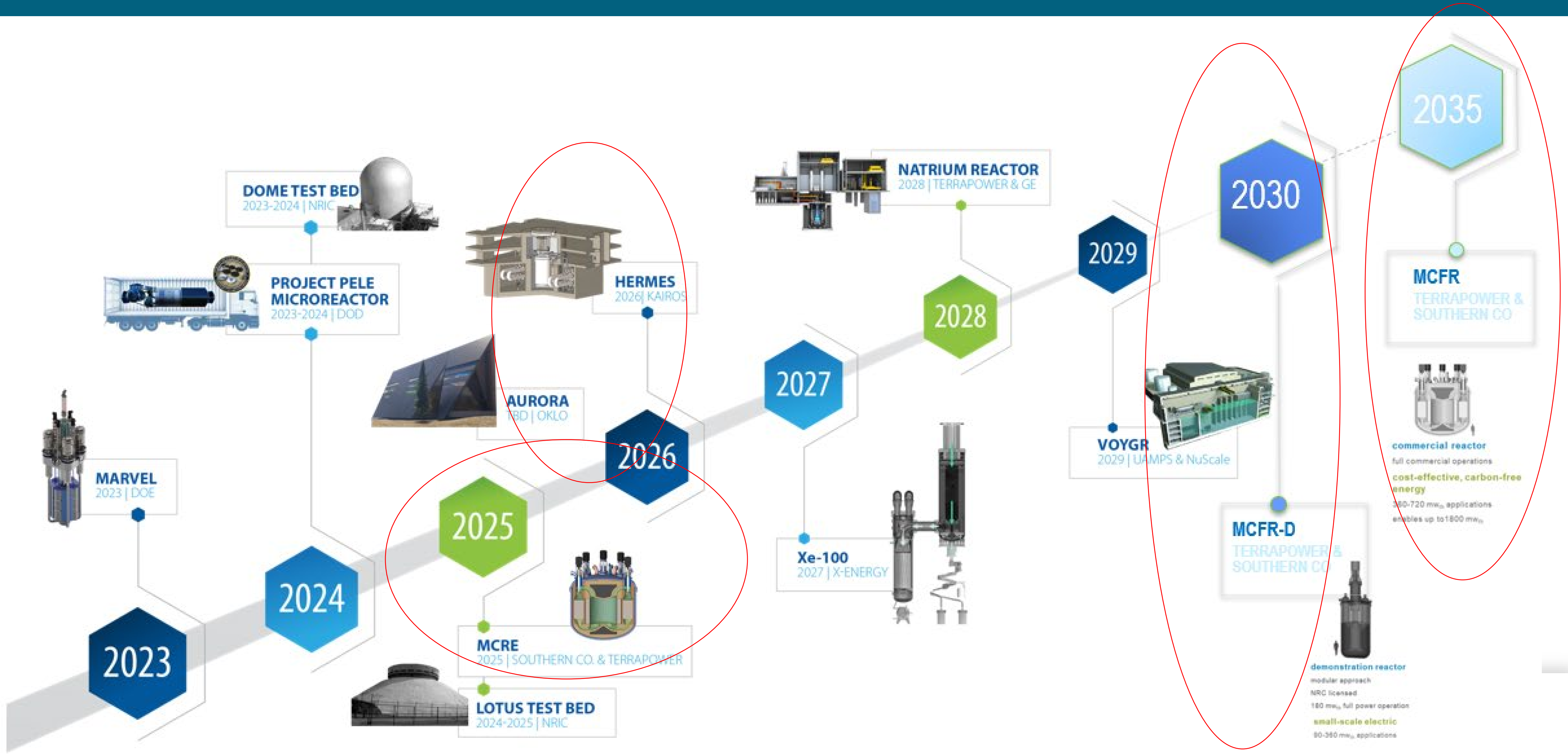
- Understanding and controlling chemistry and properties during operation
- Sensors to monitor salt conditions
- Proliferation risk
- Chemical processing and materials recovery
- Corrosion resistant materials





"How can we characterize and predict the structure, dynamics, and energetics of molten salts-including an evolving chemical composition across length and time scales?"
- Basic Research Needs for Future of Nuclear Energy (2017)

Five Years later in 2022 …
Accelerating Advanced Reactor Demonstration & Deployment



Adapted From Dr. Shannon Bragg-Sitton, INL – GIF webinar presented on 19 April 2022 “ Role of Nuclear Energy in decreasing CO_2 Emission”

MSR Program Goals and Objectives

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 US to achieve net zero carbon emissions by 2050 and
2) There is a need for an abundant energy worldwide for the foreseeable future.

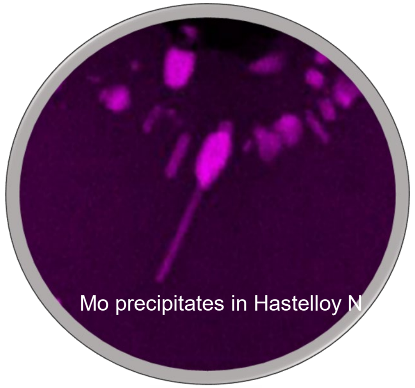
Vision: The DOE-NE MSR campaign serves as the hub for efficiently and effectively addressing, in partnership with other stakeholders, the technology challenges for MSRs to enter the commercial market.

Salt Chemistry

Determination of the Thermophysical and Thermochemical Properties of Molten Salts – Experimentally and Computationally

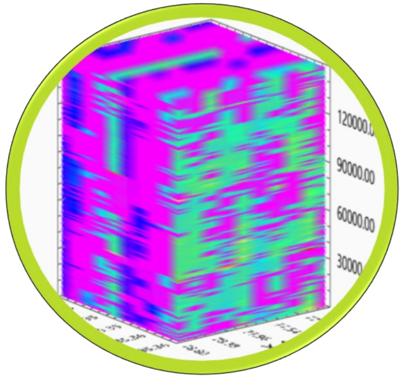
Technology Development and Demonstration – Radionuclide Release

Radionuclide Release Monitoring, Sensors & Instrumentation, Liquid Salt Test Loop, ACU (first university-based molten salt research reactor) and MCRE



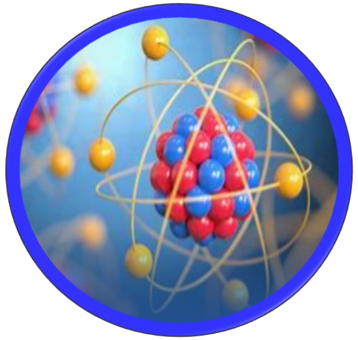
Advanced Materials

Development of materials surveillance technology Gaphite/Salt Interaction and support graphite code and standards activities De-risk the transition from 316H to higher performance alloy 709



Modeling

Integral system analysis to characterize the magnitude and composition of radionuclide transport from a molten salt to different regions of an operating MSR plant.



MSR Radioisotopes

Developing new technologies to separate radioisotopes of interest to the MSR community

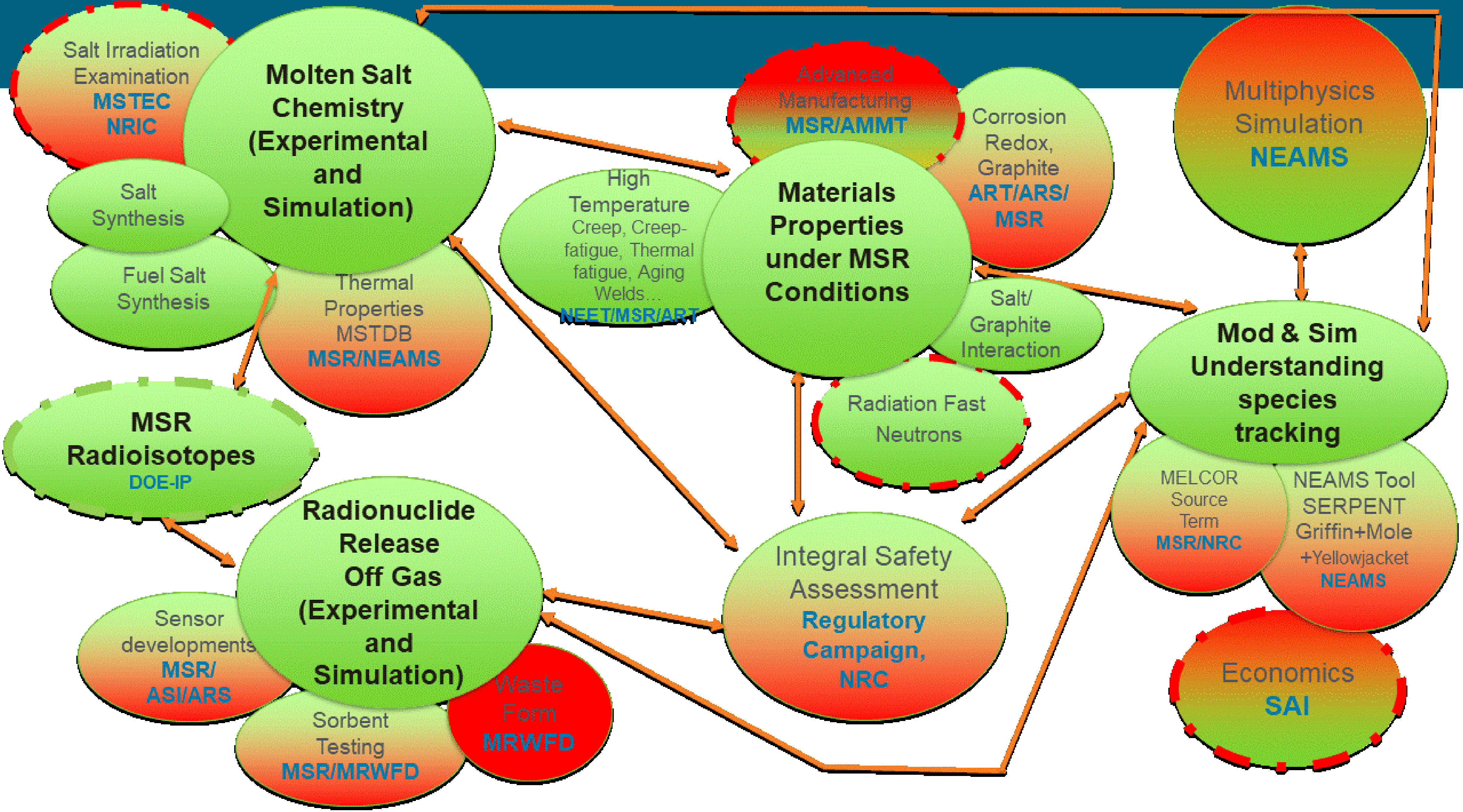
International Activities

GEN IV International Forum
Expertise | Collaboration | Excellence

IAEA
International Atomic Energy Agency

NEA
NUCLEAR ENERGY AGENCY

Strategic Organizations Engagement



Thermophysical Properties of Molten Salts

Property	
Phase Transition Temperatures	D S Ca
Heat Capacity	DSC M te
Solubility of FPs	S
Vapor Pressure	Tra
Density / Volume Expansion Coefficients	H
Viscosity	Rota
Thermal Conductivity/ Diffusivity	La /
Emissivity	P
Surface Tension	H
Enthalpy of Fusion	
Melting Point	DSC / Thermomechanical Analysis

Heat Capacity (J/g·K)
Cp

Enthalpy
ΔH

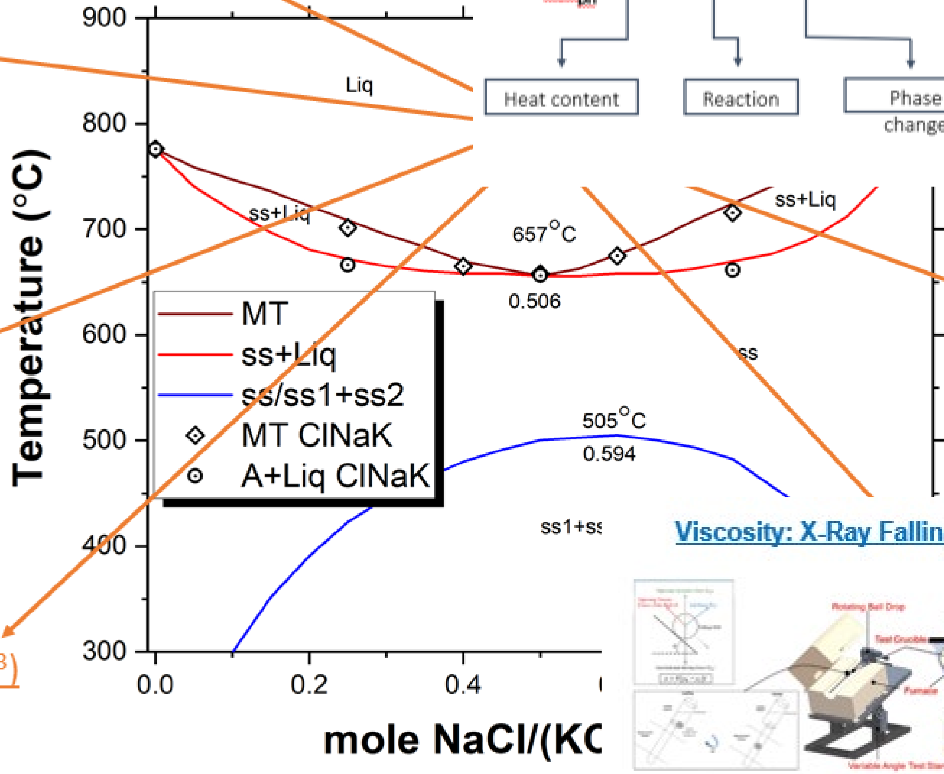
Diffusivity (m²/s)
α

Melting Point (K)
m.p.

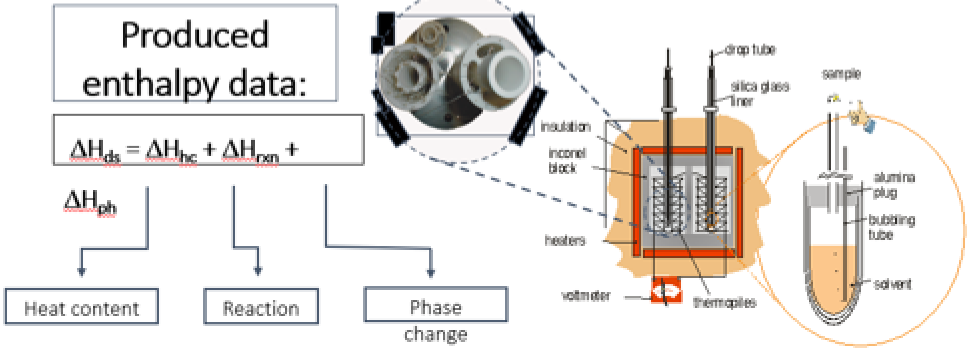
Density (g/cm³)
ρ

Viscosity (P
η

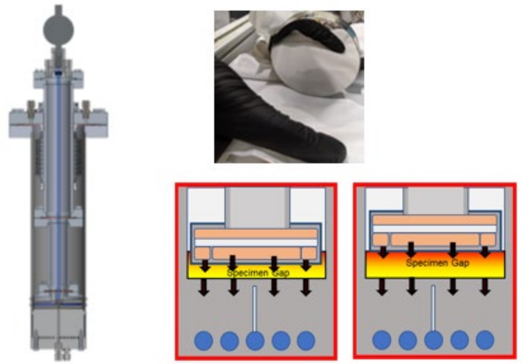
por Pressure (Pa)
p*



Twin Calvet Drop Calorimetry



Thermal Conductivity System



Viscosity: X-Ray Falling Ball

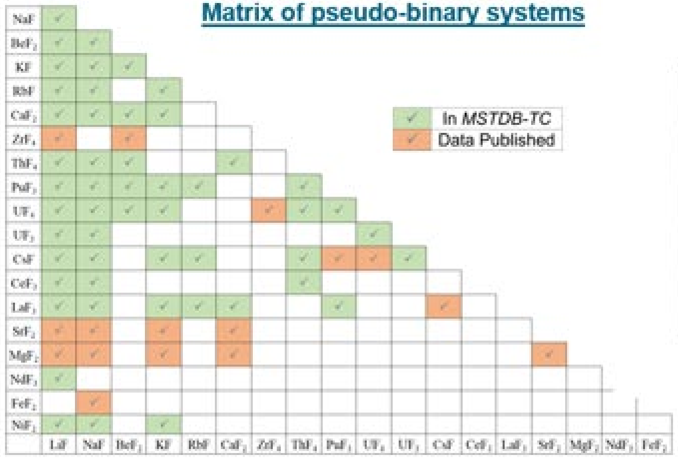
Molten Salt Thermal Properties Database

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-

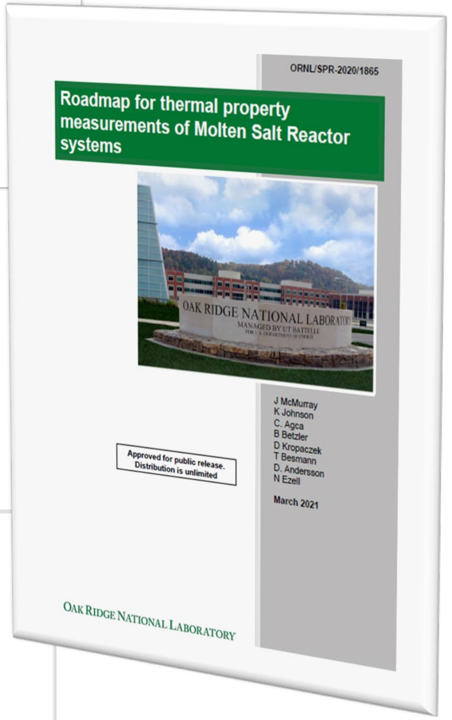
Matrix of pseudo-binary systems



MSDTB- TP for Fluoride Salts

	BeF2	KF	LiF	NaF	ThF4	UF3	UF4
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			

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

	AlCl3	KCl	LiCl	MgCl2	NaCl	PuCl3	ThCl4	UCl3	UCl4
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							

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

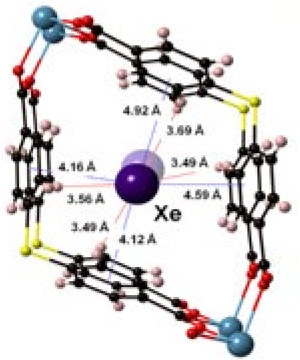
Technology Development and Demonstration

Multi-faceted approach to investigation of technologies for MSR off-gas systems

Component testing

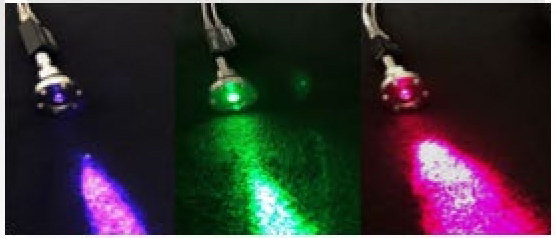
- Large Scale Test Loop

- Xe/Kr separation in MOF



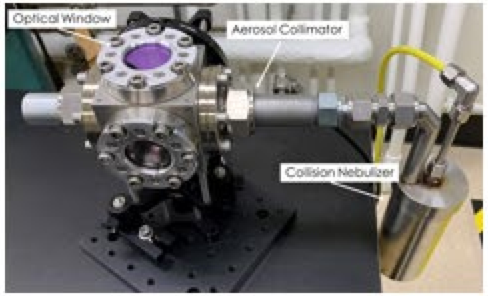
Radionuclide identification/speciation

Raman



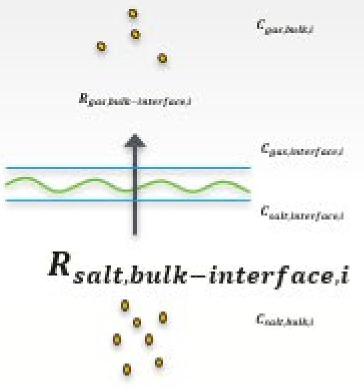
405 nm 532 nm 671

LIBS



Source term modeling

- Gas-liquid interface
- Provides source term to off-gas

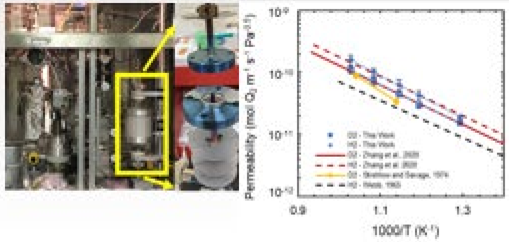


Removal Rate

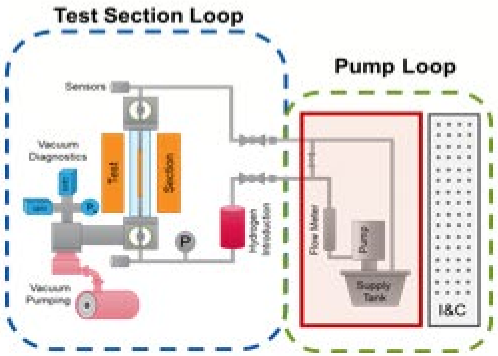
$$\frac{d(m_i)}{dt} = kA(C_{gas,interface,i} - C_{gas,bulk,i})$$

Tritium permeation

- Hydrogen isotope permeability in Hastelloy N



- Tritium transport salt loop



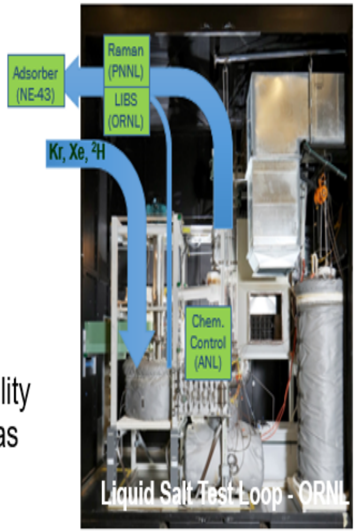
Liquid Salt Test Loop (LSTL) for Sensors Testing

Testing - STEP 1 LSTL

Existing & operable salt test facility is unique in the U.S. for technology development and demonstration with relevant powers, temperatures, and flowrates

PNNL/ORNL Xenon Radionuclide Release and Monitoring using Laser Induced Breakdown Spectroscopy

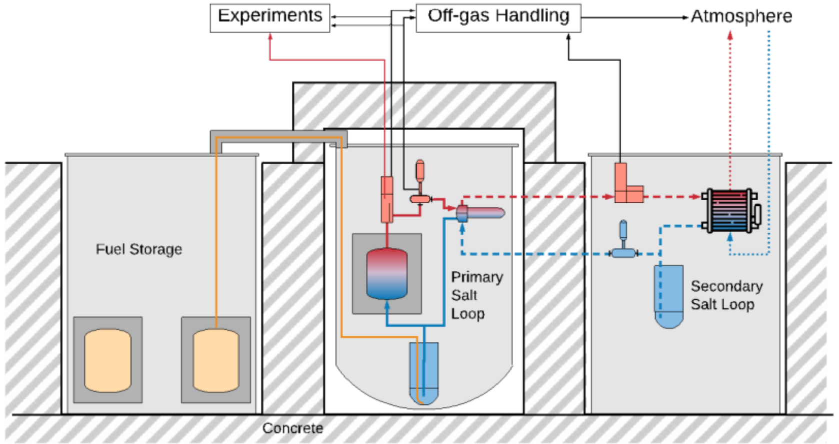
ORNL– Salt loop and capability for testing sensors and off-gas components



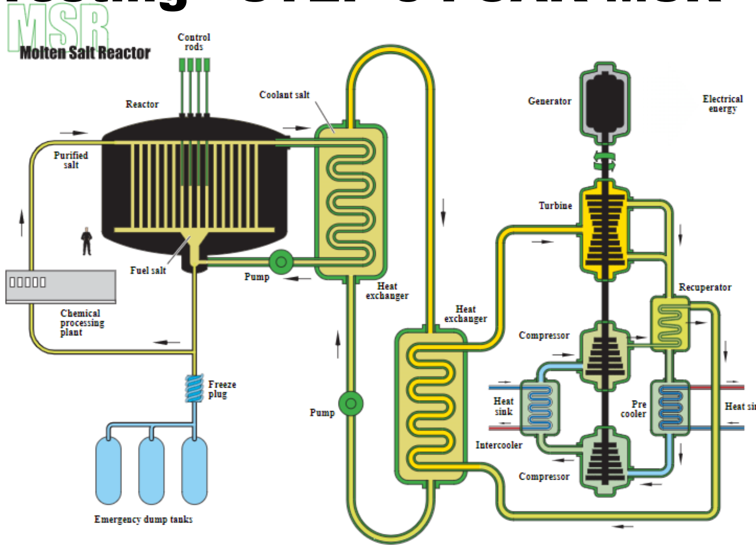
ANL - Distributed salt chemistry monitoring and control

PNNL– Raman and FTIR sensor development for iodine species and tritium

Testing - STEP 2 MSRR



Testing - STEP 3 FOAK MSR

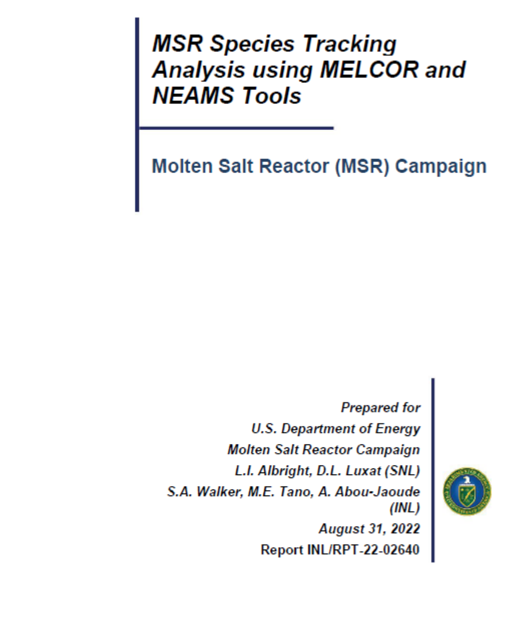


Modeling and Simulation

MSR SPECIES TRACKING ANALYSIS USING MELCOR AND NEAMS TOOLS

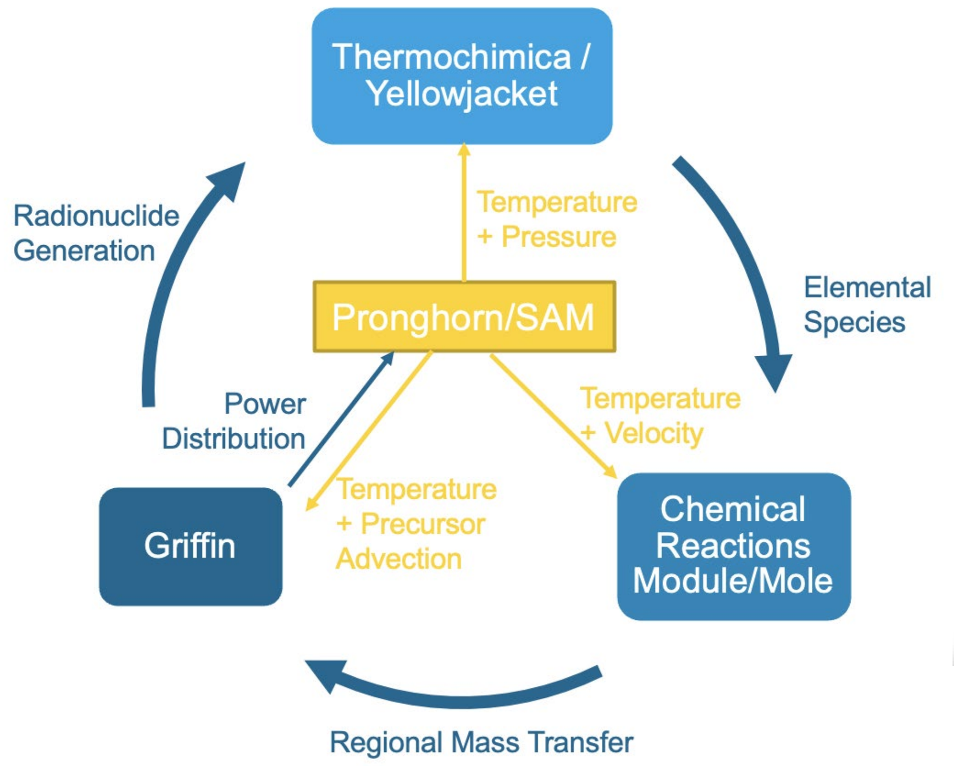
- NEAMS toolkit used to accurately resolve multiphysics analysis in MSRs for gaseous speciation and corrosion of structural materials due to thermochemical changes in the fuel-salt.

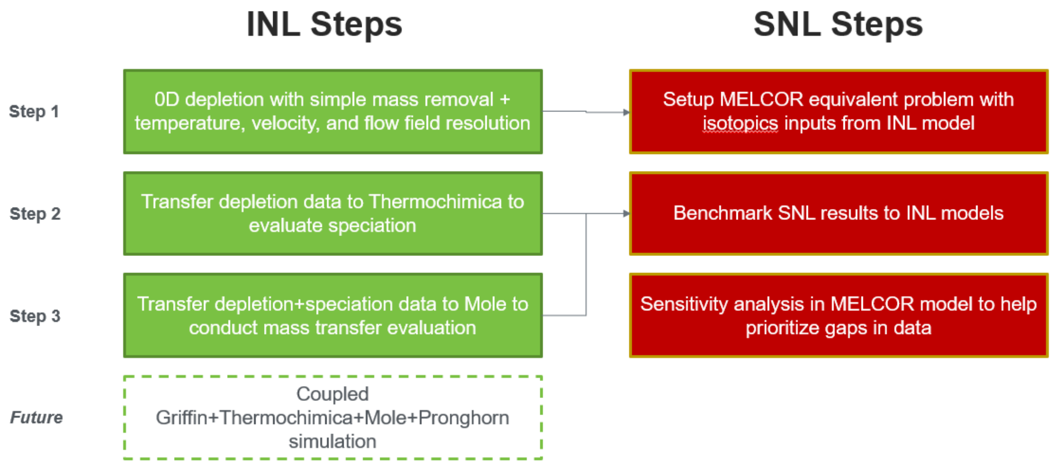
- Support MSR campaign missions through MELCOR modeling and analysis
- Identify and collaboratively resolve MSR mechanistic source term knowledge gaps
- Develop engineering level models for mechanistic source term capability gaps


MSR Species Tracking Analysis using MELCOR and NEAMS Tools

Molten Salt Reactor (MSR) Campaign

Prepared for
U.S. Department of Energy
Molten Salt Reactor Campaign
L.I. Albright, D.L. Luxat (SNL)
S.A. Walker, M.E. Tano, A. Abou-Jaoude (INL)
August 31, 2022
Report INL/RPT-22-02640





Advanced Materials

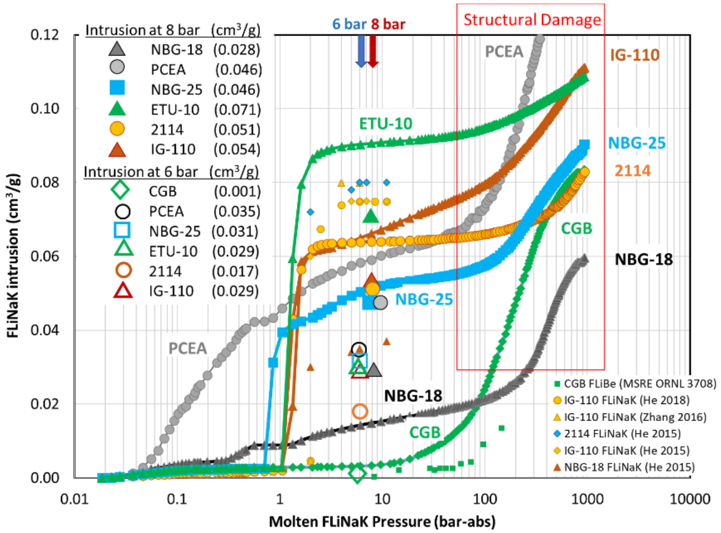
Salt and Materials Interaction

Supporting MSR development by studying 316H flowing salt compatibility at high temperature (off-normal)

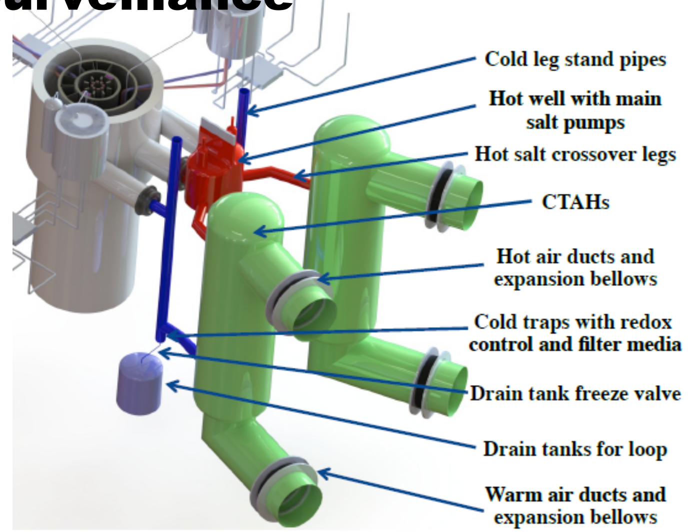
2021 ORNL FLiBe TCL

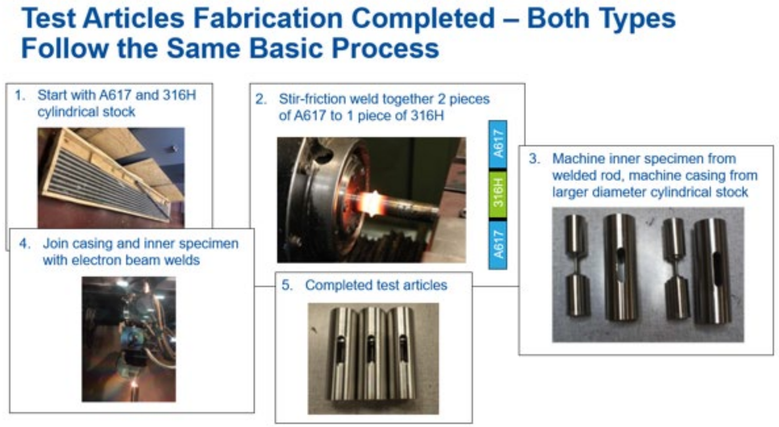
Graphite-Salt Study

Study of salt intrusion in graphite and chemical interactions that may affect graphite's structural or physical properties



Development of Test Articles for Surrogate Materials Surveillance





FY22 IRP Awards funded MSR Relevant Projects

Two IRPs - MRWFD and NEAMS

Reduction, Mitigation, and Disposal Strategies for the Graphite Waste of High Temperature Reactors	State University of New York, Stony Brook	$3,000,000
Bridging the gap between experiments and modeling to improve design of molten salt reactors	University of California, Berkeley	$2,998,545

IRP NSUF - Integrated Effects of Irradiation and Flibe Salt on Fuel Pebble and Structural Graphite Materials for Molten Salt Reactors

PI: Gabriel Meric, Chong Chen, Kevin Chan, Kairos Power; Collaborators: Gordon Kohse (MIT-NRL), Lin-Wen Hu (MIT-NRL), David Carpenter (MIT-NRL) - The project's scope is to investigate the neutron irradiation response of F-Li-Be (Flibe) molten salt/graphite and Flibe/fuel carbon matrix systems with a focus on irradiation-affected salt infiltration and its potential effect on graphite/carbon matrix microstructure under irradiation

- **Four NEUPs**

A Molten Salt Community Framework for Predictive Modeling of Critical Characteristics, PI: Zi-Kui Liu – Pennsylvania State University (PSU), **NEUP FC1.2**

Understanding the Interfacial Structure of the Molten Chloride Salts by in-situ Electrocapillarity and Resonant Soft X-ray Scattering (RSoXS), PI: Feifei Shi-The Pennsylvania State University, **Nuclear Material Accountancy During Disposal and Reprocessing of Molten Salt Reactor Fuel Salts**, PI: Stephen Raiman - Texas A&M University, **NEUP FC-3**

Optical Basicity Determination of Molten Fluoride Salts and its Influence on Structural Material Corrosion, PI: Yafei Wang, University of Wisconsin-Madison, **NEUP**

FY22 SciDAC Award

Los Alamos National Laboratory to lead study of molten-salt nuclear reactor materials

$9.25 million DOE nuclear energy research program aims to improve safety and efficiency of sustainable nuclear energy

https://nrl.mit.edu/announcements/2022/CINR-FY22-awards

https://neup.inl.gov/SitePages/FY22_IRP_Awards.aspx

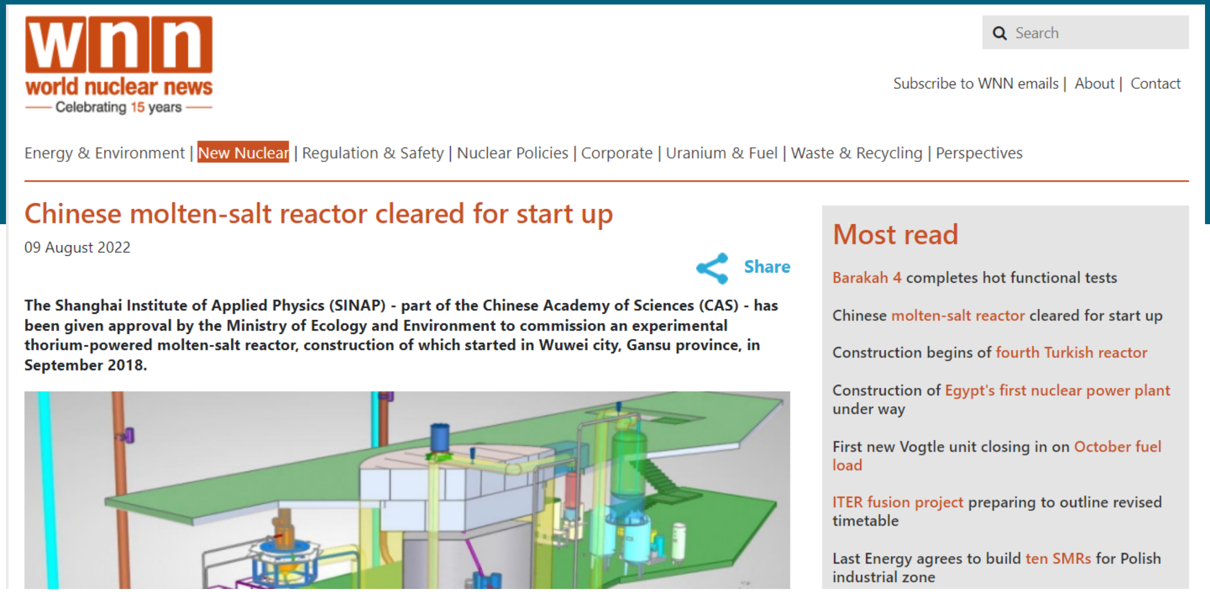
Conclusion

Reduced Budget Impacts the MSR program:

- Minimum scope of work activities
- Some research on stand-by or survival mode
- Potential loss of workforce and decrease visibility in the national and international arena
- Could delay the development and deployment of MSRs in the U.S.
- Loss of influence and presence in MSR international community

Several programs in DOE- NE are working on MSRs and leveraging from each other: ARS, NEAMS, MRWFD

Without any additional support and commitment, the US is not competing in international deployment.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Chinese molten-salt reactor cleared for start up

09 August 2022

Share

The Shanghai Institute of Applied Physics (SINAP) - part of the Chinese Academy of Sciences (CAS) - has been given approval by the Ministry of Ecology and Environment to commission an experimental thorium-powered molten-salt reactor, construction of which started in Wuwei city, Gansu province, in September 2018.

Most read

Barakah 4 completes hot functional tests

Chinese molten-salt reactor cleared for start up

Construction begins of fourth Turkish reactor

Construction of Egypt's first nuclear power plant under way

First new Vogtle unit closing in on October fuel load

ITER fusion project preparing to outline revised timetable

Last Energy agrees to build ten SMRs for Polish industrial zone

https://www.world-nuclear-news.org/Articles/Chinese-molten-salt-reactor-cleared-for-start-up

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GIF Webinar Series
2016–2023
EDUCATION AND TRAINING WORKING GROUP

GEN IV International Forum
Expertise | Collaboration | Excellence
EDUCATION AND TRAINING WORKING GROUP

Wednesday, January 2025, 8:30 am EST

Molten Salt Reactor Fuel Cycle and Thermodynamics Simulation

https://www.gen-4.org/gif/jcms/c_84279/webinars

Your Presenter:
Dr. Jiri Krepel
Paul Scherrer Institute
Switzerland

Thank you

International Conference on Topical Issues in Nuclear Installation Safety: Strengthening Safety of Evolutionary and Innovative Reactor Designs
18–21 October 2022, Vienna, Austria

Molten Salt Thermal Properties Working Group

Databases Training/Workshop
University of South Carolina, November 9th, 2022

Fuel and Materials for Molten Salt Reactors: I

Technical Session | Sponsored by MSTD
Monday, November 14, 2022 | 1:00–2:45PM MST

2022 ANS Winter Meeting

Fuel and Materials for Molten Salt Reactors: II

Technical Session | Sponsored by MSTD
Monday, November 14, 2022 | 3:15–5:00PM MST

Research by U.S. DOE NEUP Sponsored Students - - Molten Salts

Technical Session | Sponsored by ETWDD
Tuesday, November 15, 2022 | 3:15–5:00PM MST

Itinerary

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509-372-5983