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

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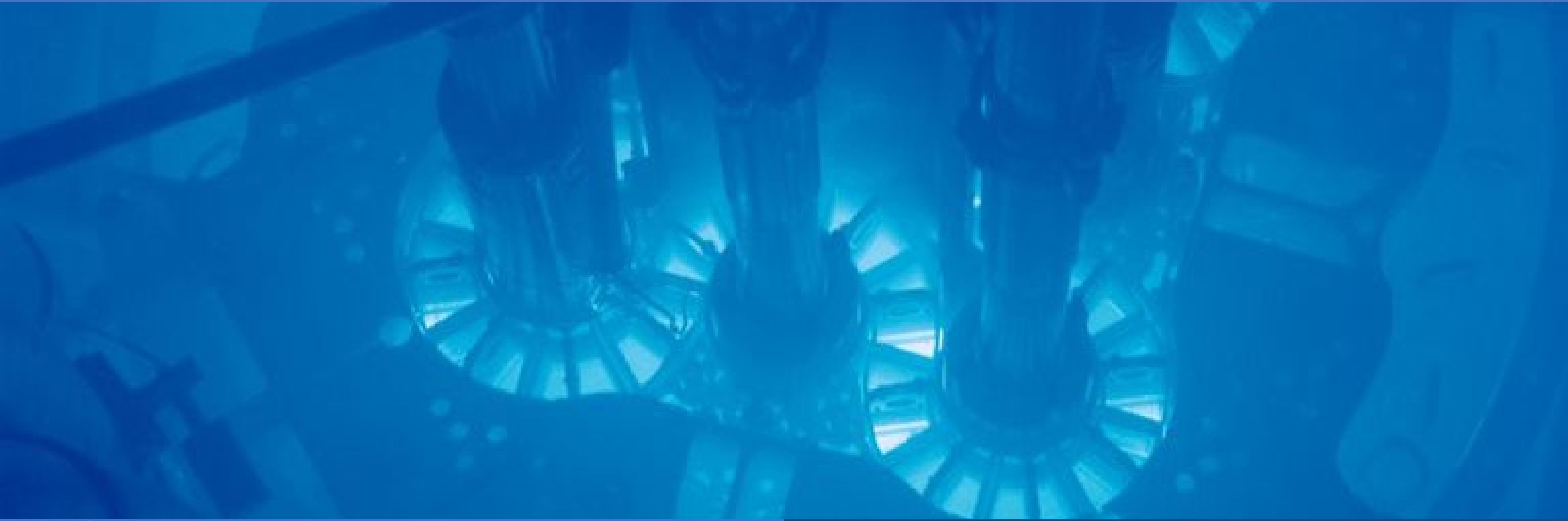


Molten Salt Reactor Campaign

ORNL MSR Workshop

October 12 & 13, 2021

Dr. Patricia Paviet

National Technical Director

Program Goal and Objectives

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

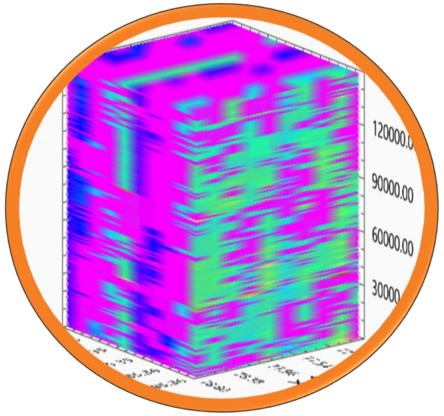
1) a substantial portion of the energy needed for the US to achieve net zero carbon emissions by 2050 and
2) abundant energy worldwide for the foreseeable future.

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

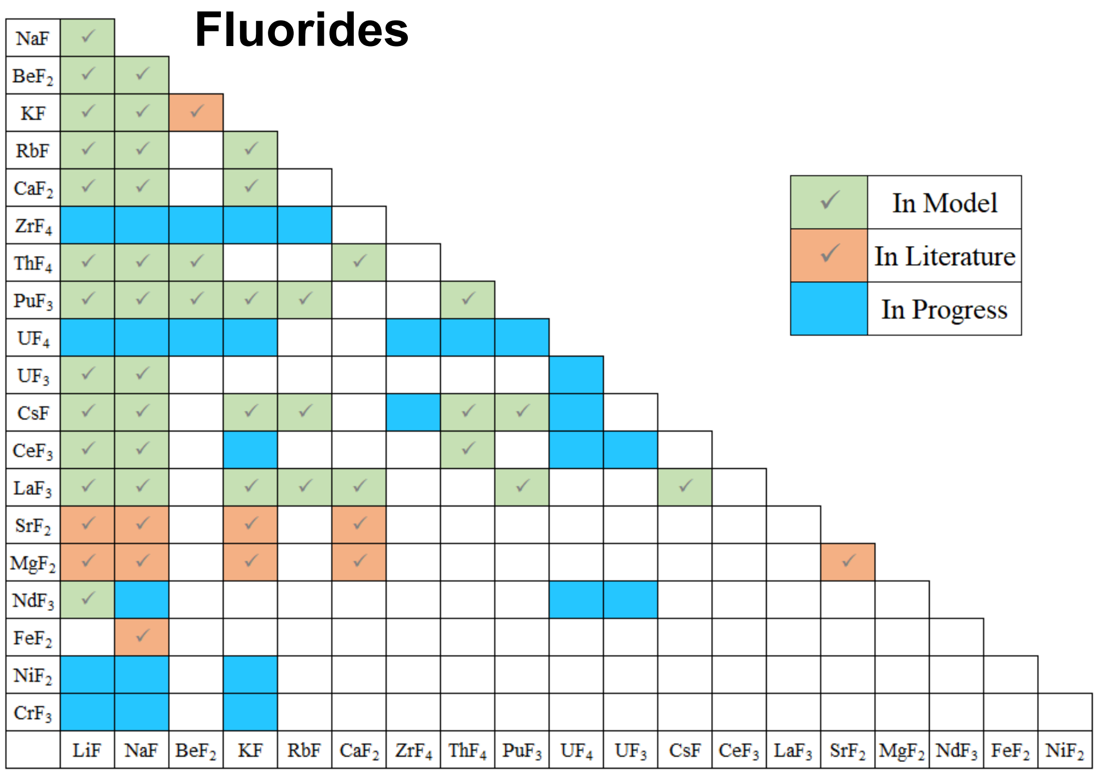
Technology Development and Demonstration
Radionuclide Release Monitoring, Sensors & Instrumentation, Liquid Salt Test Loop

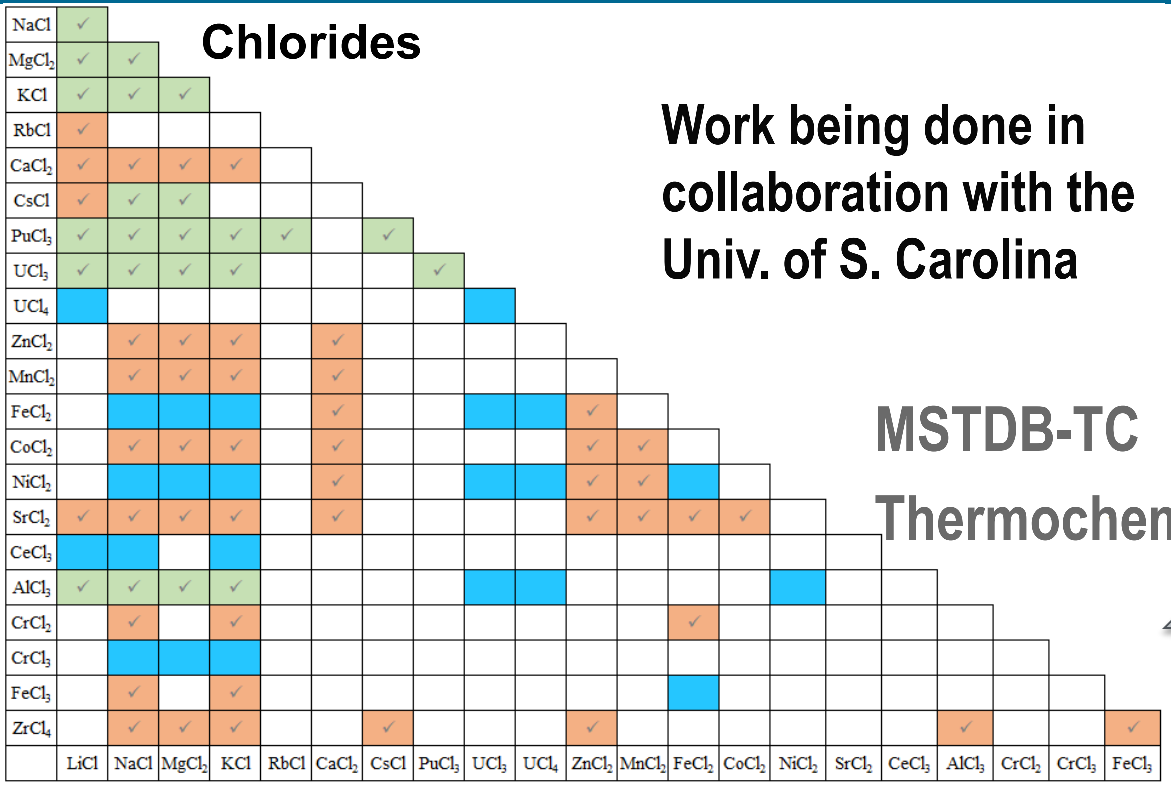
Materials
First to Market: Gaps in Codes and Standards for 316H
Near Term Deployment: Use corrosion resistant clad on ASME qualified base metal,
Long-Term Solution: Develop and qualify next generation structural materials for MSR
Salt/Graphite Interaction



Modeling
Integral molten salt reactor response to support radionuclide sensor technology development; Integral system analysis to characterize the magnitude and composition of radionuclide transport from a molten salt to different regions of an operating MSR plant.

Salt Chemistry - Property measurements relevant to industry needs → support development of MSTDB (Molten Salt Thermal Properties Database) – ORNL, ANL, INL, PNNL, LANL





Work being done in collaboration with the Univ. of S. Carolina

MSTDB-TC
Thermochemical

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**

Properties modeled
A: Density
B: Viscosity
C: Thermal conductivity
D: Heat capacity

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**

MSTDB-TP
Thermophysical

Liquid Salt Test Loop and Sensors Development/Demonstration in support of MSR monitoring

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

INL– Tritium transport

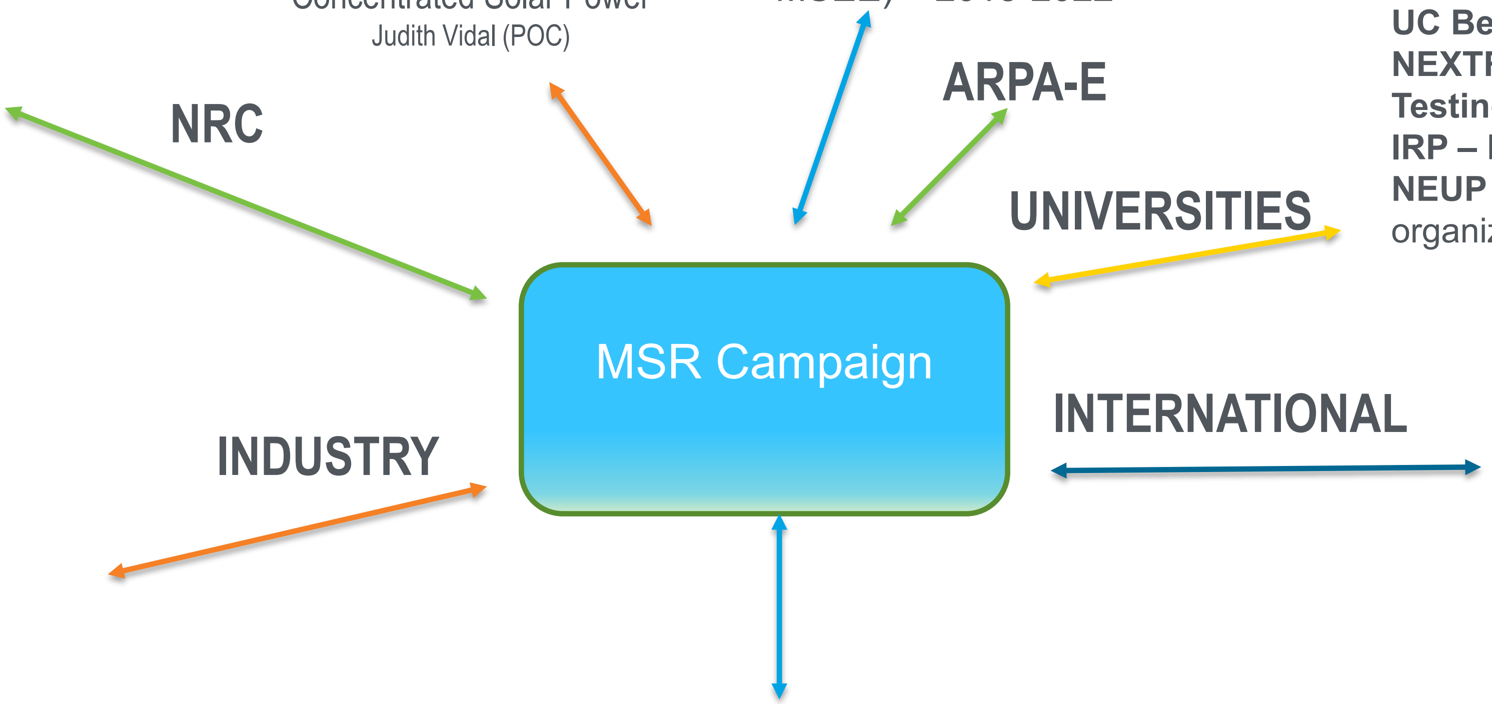
US MSR Community = the four Pillars: Government, Industry, National Labs, Universities – Recipe for Success

Nuclear Regulatory Commission is developing a technology-neutral, performance-based, risk-informed regulatory framework

EERE/NREL
Chloride Salt – Concentrated Solar Power
Judith Vidal (POC)

EFRC
Molten Salts in Extreme Environments (MSEE) – 2018-2022

University of South Carolina (Prof. Ted Besmann)
UC Berkeley (Prof. Raluca Scarlat)
NEXTRA - Nuclear Energy eXperimental Testing Research Alliance (Prof. Tony Hill)
IRP – MIT (Prof. Charles Forsberg)
NEUP – NEUP review (28-30 JUN 2021) organized by NE-43



MSR TWG
EPRI
NEI
Campaign Review Meetings
Conferences/MSR workshops

Gen IV International Forum
IAEA
NEA/OECD

Department of Energy (DOE)-Office of Nuclear Energy (NE) activities focus remains on enabling MSR industry and building supporting infrastructure

Nuclear Energy Advanced Modeling and Simulation (NEAMS) tool development; AMMT, ART, FC, ASI, ARS…Nuclear Energy University Program (NEUP) (20% of budget); Small business opportunities; Gateway for Accelerated Innovation in Nuclear (GAIN) vouchers; Direct industry awards.

Fiscal Year 2022 Consolidated Innovative Nuclear Research

PROGRAM DIRECTED: NUCLEAR ENERGY ADVANCED MODELING AND SIMULATION

IRP-NEAMS-1: COMBINED EXPERIMENTAL-MODELING ASSESSMENTS OF IMPURITIES/FISSION PRODUCTS IN MOLTEN SALTS AND FUNDAMENTAL CORROSION MECHANISMS OF RELEVANT STRUCTURAL ALLOYS
(FEDERAL POC – BRIAN ROBINSON & TECHNICAL POC – CHRIS STANEK)
(ELIGIBLE TO LEAD: UNIVERSITIES ONLY)
(UP TO 3 YEARS AND $3,000,000)

During operation of a Molten Salt Reactor (MSR) impurities are present in the salt and furthermore fission products are formed thus affecting the thermophysical properties, corrosion kinetics of structural materials, as well as reactor

PROGRAM DIRECTED: NUCLEAR ENERGY ADVANCED MODELING AND SIMULATION

operations. Proposal are sought to study the impact of halide salt impurities on reactor performance based on experimental and computational methods.

There are several specific topics of interest. First, proposals are sought that address the impact of low impurity concentration on burnup calculations. Specific examples include the impact of low concentrations of impurities on temperature, spectrum and cross-section uncertainties, and reactor operation. Experiments aimed at the identification of specific isotopes are expected be a useful complement to the modeling research. A second topic of interest is salt property alteration with impurity concentrations to ultimately provide recommendations for the allowable concentrations for oxygen, hydroxide, etc. to ensure sound MSR operation, with a focus on heat transfer and containment corrosion. For example, oxide/hydroxide impurities accelerate corrosion rates of halide salt melts in contact with stainless steel and nickel-based alloys. These recommendations generated through the R&D performed should include allowable impurity concentration of the fresh salt melt as well as allowable impurity/fission product concentration during MSR operation.

Vital to the development of impurity limits and guidelines is a better understanding of corrosion mechanisms of austenitic stainless steels, ferritic/martensitic stainless steel, and nickel-based alloys in fluoride and chloride salt melts at 650° C to 750° C. It is currently believed that the corrosion of stainless steel and nickel-based alloys in contact with halide salt melts is derived by the leaching of chromium from the alloy matrix and the formation of stable chromium fluoride or chromium chlorides at the salt-containment interface. The depletion of chromium may weaken the steel structure to further enhance corrosion rates. Overall, corrosion rates of stainless steel and nickel-based alloys could be, as a simplified approach, derived by chromium-self diffusion from the alloy matrices to the surface and the ultimate formation of stable chromium halides. However, overall chromium self-diffusion is a result of matrix and grain-boundary diffusion and their specific ratio is dependent on temperature as well as on microstructure (e.g., phases, precipitates, grain sizes, texture, defects). The proposal should therefore address these and any additional factors to derive an approach for modeling chromium diffusion, and subsequently corrosion of austenitic stainless steels (e.g., Alloy 316H and Alloy 709), ferritic/martensitic stainless steels (e.g., HT9, T91) and nickel-based alloys (e.g., Hastelloy N and Haynes 244). This research will provide a fundamental theoretical and experimental basis for enhancing the current knowledge on corrosion of austenitic stainless steels (fcc) vs. ferritic/martensitic stainless steel (bcc), vs. the more expensive nickel-based alloys in contact with halide salt melts at temperatures applicable to MSR operation.

Proposals are sought that employ integrated experiments and modeling/simulation to address the above problems. Proposals should rely on NEAMS software or at a minimum provide a clear path for model developed in to NEAMS codes.

Since this research is aimed at the deployment of MSR technology, industry partnership is required.

FY21 CINR Awards funded MSR relevant Projects

- **Design and intelligent optimization of the thermal storage and energy distribution for the TerraPower Molten Chloride Fast Reactor in an integrated energy system**, PI: Prof. Brown, University of Tennessee, Co-PI Dr. Kathryn Huff, University of Illinois, Dr. Jamie Coble, University of Tenessee, Dr. Greenwood, ORNL and Mr. Walter TerraPower. NEUP CT-2

- **Total Mass Accounting in Advanced Liquid-Fueled Reactors, PI:** Dr. L. Raymond Cao, The Ohio State University, Co-PI: Dr. Praneeth Kandlakunta – The Ohio State University; Dr. Shelly Li – University of Utah, NEUP CT-4

- **High-Efficiency Electrochemical Test Facility for Corrosion and Hydrodynamic Analysis in Molten Salts, PI: Prof.** Devin Rappleye, Brigham Young University , NEUP General Scientific Infrastructure

- **Real-Time *In Situ* Characterization of Molecular and Complex Ionic Species in Forced-Flow Molten Salt Loops and a Molten Salt Research Reactor, PI:** Kim Pamplin, Ph.D., Abilene Christian University, Co-PI Timothy Head, University of Illinois Urbana-Champaign; Jessie Dowdy, Aaron Robison, and Rusty Towell - Abilene Christian University NEUP General Scientific Infrastructure

- **High-Temperature Molten Salt Irradiation and Examination Facility for the Penn State Breazeale Reactor** , PI: Prof. Amanda Johnsen –Pennsylvania State University , Co-Pi from Pennsylvania State University, NEUP Research Reactor Upgrades Infrastructure Support

The projects would be integrated with the campaign if the campaign had either significant input into the project selections or adequate funding. The efforts are largely separate and not strongly related. However, I am encouraging the PIs to reach out to me and keep me informed.

Conclusion

- Despite a small FY 2022 budget, the MSR campaign is recognized for supporting the MSR community with an increase collaboration with other DOE NE programs such as NEAMS.
- The 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.
- MSR concepts are on a fast track, and we need to continue this momentum
  - MSR Advanced Reactor Demonstration Projects

    Kairos Power

    - Hermes test reactor - reduced scale FHR pebble bed test reactor
      - East Tennessee Technology Park (adjacent to ORNL)
      - License Application End 2021 – Construction start 2023 – Operation 2026

    Southern Company Services

    - Molten Chloride Reactor Experiment – fast spectrum
      - Integrated effects test facility anticipated to be operational in 2022
      - Provide data to support development of TerraPower’s molten chloride fast reactor

Questions?

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