# Module 12: MSR Development and R&D Issues


**Presentation on Molten Salt Reactor Technology by:**
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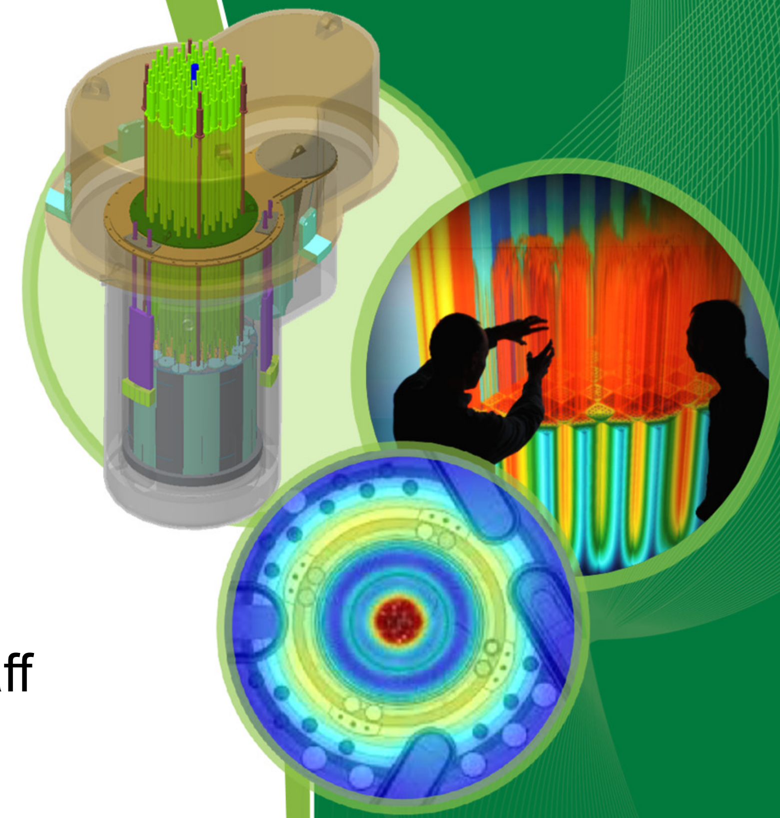


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# Previewing MSR Development and R&D Issues

- Status: MSR technology today
- Public–private partnership emerging to develop MSRs
- R&D areas identified by MSR Technical Working Group via GAIN interactions
- DOE-NE MSR R&D related activities and Roadmap
- Key MSR Technology Development Issues
  - Reactor Technology
  - Modeling and Simulation
  - Licensing
  - Fuel Qualification
  - Materials (previous presentation)
  - Fuel Cycle (previous presentation)
  - Safeguards (previous presentation)



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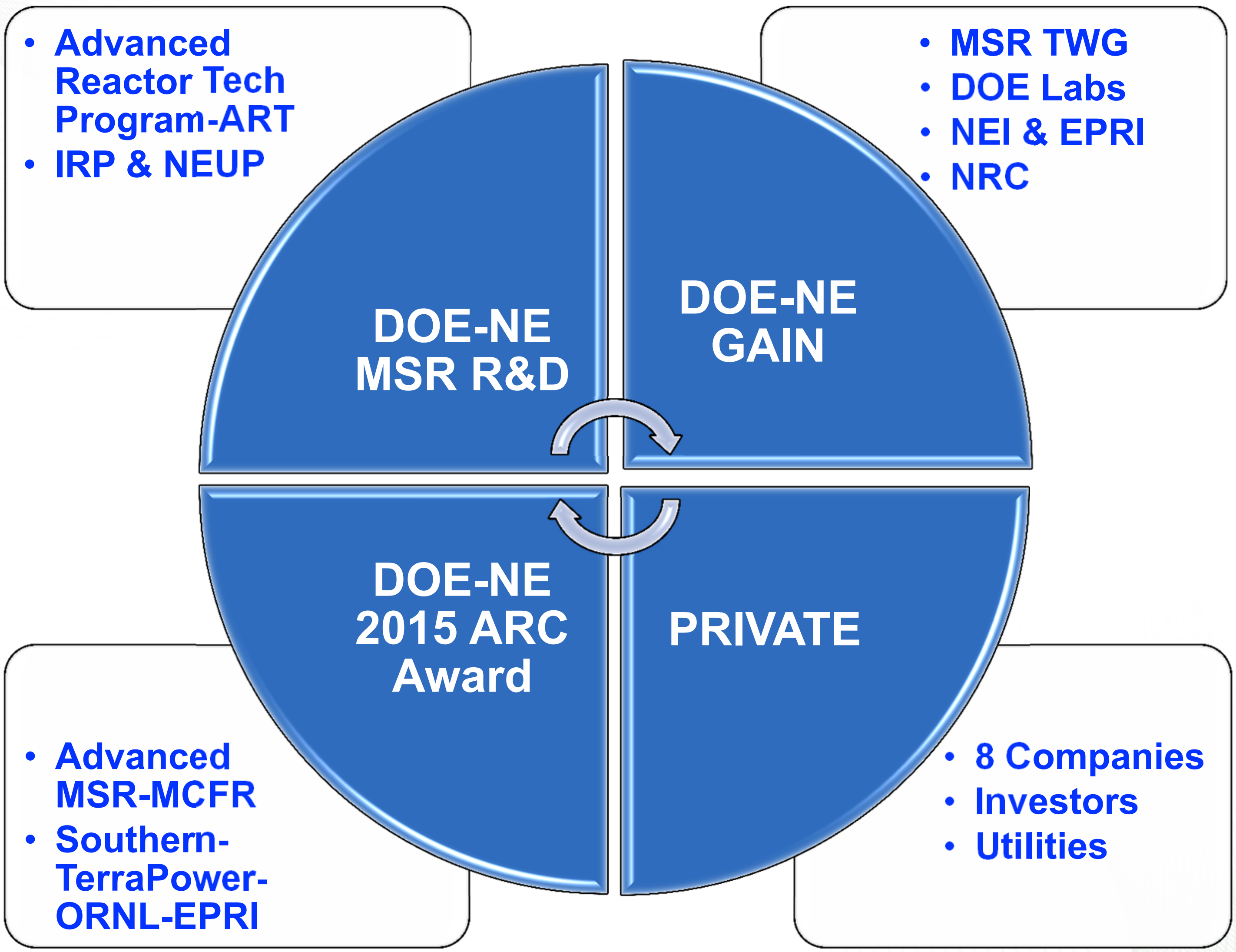
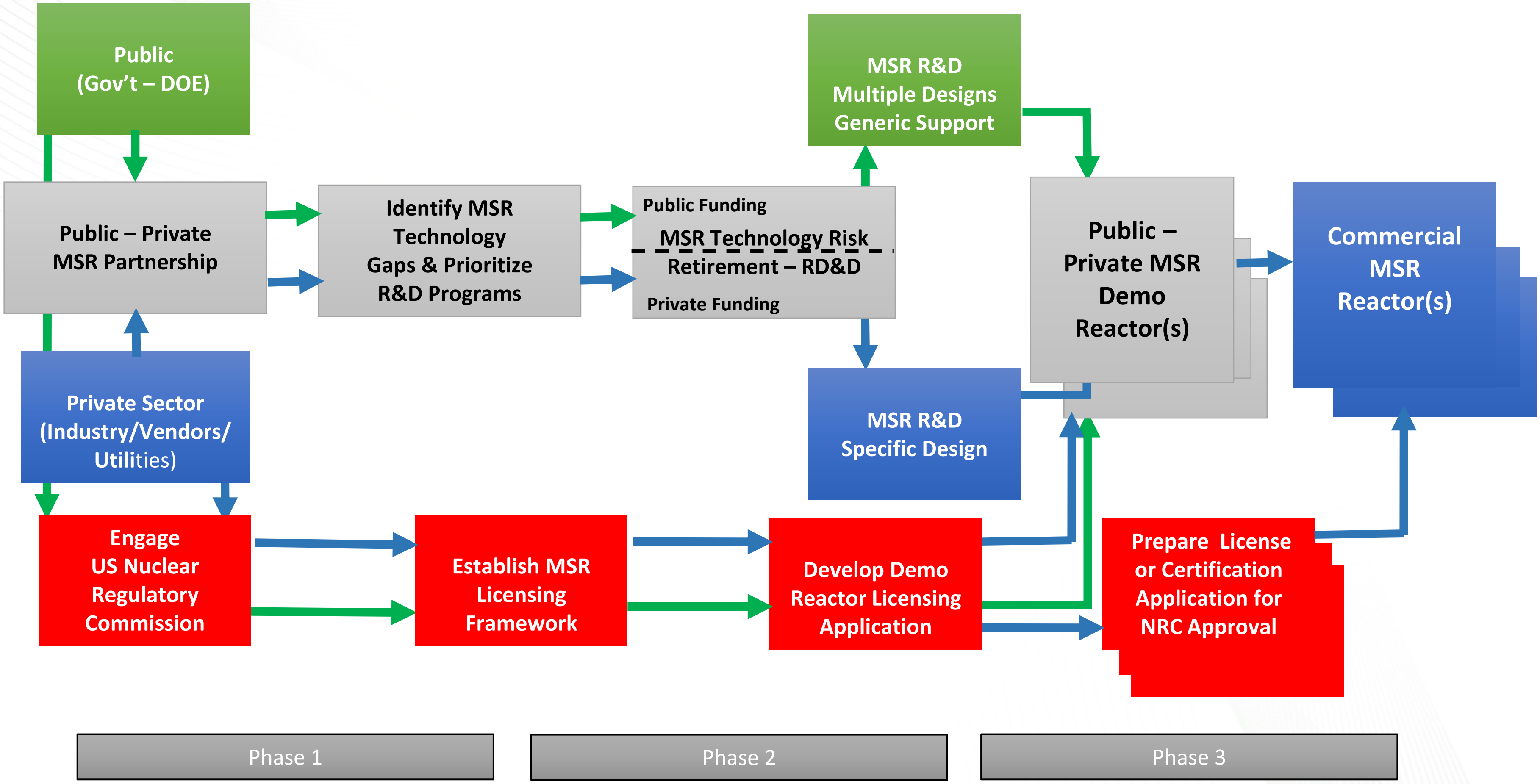
# Challenges for Successful Development and Commercial Deployment of MSRs

- 50 years since US operated an MSR
- Lower TRL vs other advanced reactors
- Sustained RD&D effort required
- Different reactor technology
- Need for test and experimental facilities
- Need for mod-sim capabilities
- Different safeguards approach
- Commercial supply chain
- Demonstrated economic performance

# New R&D Paradigm: Private R&D and Government–Private Partnership Evolving to Develop MSRs



# Successful Deployment for MSRs Likely Is Public–Private Partnership



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# MSR Technical Working Group Identified R&D Needs from MSR Companies

**Separate effects test program highlighted in December 2016 letter to GAIN Director – provided to DOE-NE**

- Base Technology
  - Salt synthesis and purification
  - Physical properties and static corrosion studies
- Modeling and simulation
  - Gap analysis
  - Tool selection, development, and integration
  - Verification and validation
- Vendor development
  - Pump, valve, and heat exchanger development
- Irradiation studies
  - Material coupon studies and PIE
  - Salt capsule testing (variety of salts and materials – corrosion studies)
  - In-core salt flow loops (one fluoride and one chloride)
- Flow loops
  - Small-scale forced convection (250–500 kW) – multiple materials and salts
  - Medium-scale forced convection (2–3 MW) – fluoride and chloride loops

**Additional Topics Identified March 2017**

- Licensing
- Safeguards and nonproliferation
- I&C
- Balance of plant
- Salt chemistry
  - Properties and characterization
  - Corrosion and fission products
- Modeling and simulation support
  - Design
  - NRC evaluations

# DOE and NRC Visions for Advanced Non-LWRs Align for Readiness to Deploy

## DOE Vision for Advanced Reactors*

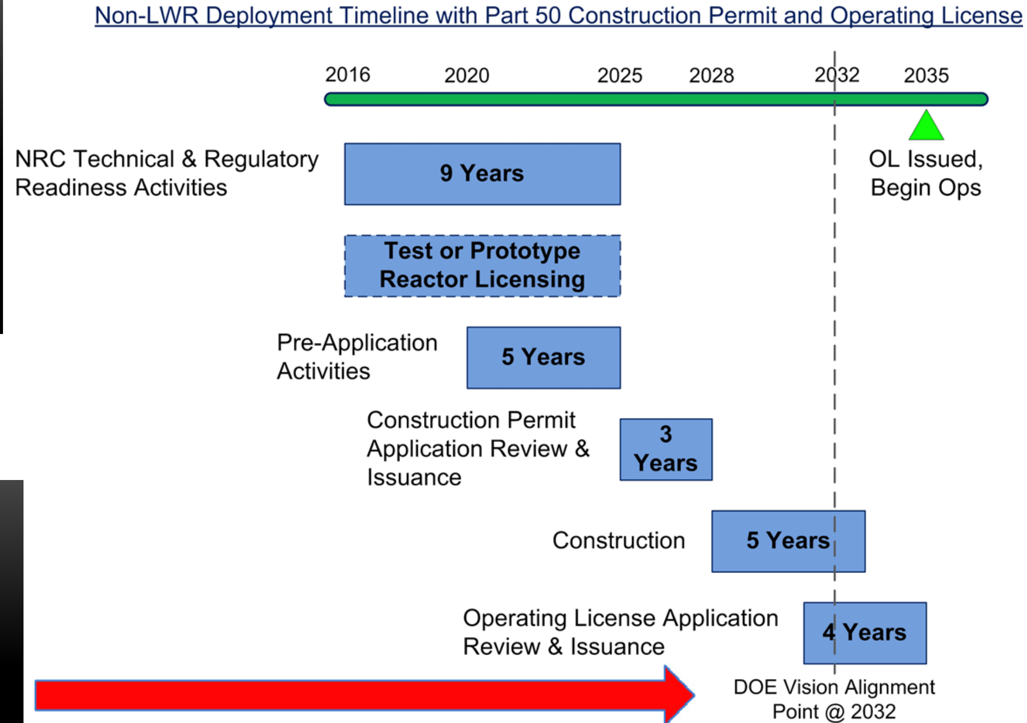
***By 2050, advanced reactors will provide a significant and growing component of the nuclear energy mix both domestically and globally, due to their advantages in terms of improved safety, cost, performance, sustainability, and reduced proliferation risks.***

## DOE Goal for Deploying Advanced Reactors*

***By the early 2030s, at least two non-light water advanced reactor concepts have reached technical maturity, demonstrated safety and economic benefits, and completed licensing reviews by the U.S. Nuclear Regulatory Commission (NRC) sufficient to allow construction to go forward.***

* DOE report : *Vision and Strategy for Development and Deployment of Advanced Reactors* - 2017

## NRC Strategic Goal for Non-LWRs*

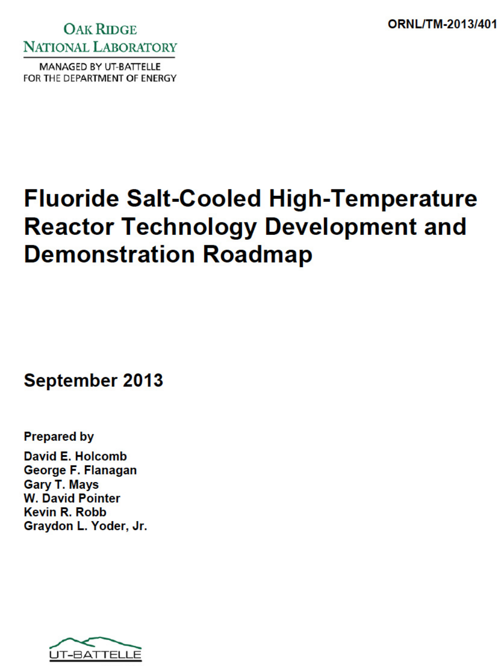



**Similar timeline for Part 52**

** Source: Jennifer Uhle, DOE-NRC Workshop on Advanced Non-LWRs, June 2016*.

# DOE-NE R&D Initiatives Shaping MSR R&D Plan

- National Technical Director for MSRs in ART program named
- April 10–12 Molten Salt Chemistry workshop at ORNL
  - Objective: Identify potential science-based, technology-driven research opportunities to facilitate and accelerate MSR technologies development
  - DOE-NE lead: Stephen Kung ORNL lead: David Williams
- Providing MSR developers access to MSR historical documents (~210 to date) via GAIN
- DOE MSR Roadmap => starting point for defining R&D activities is underway
  - MSR Strategic Plan (2017)
  - FHR Roadmap (2013)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ORNL/TM-2013/401

**Fluoride Salt-Cooled High-Temperature Reactor Technology Development and Demonstration Roadmap**

**September 2013**

Prepared by
David E. Holcomb
George F. Flanagan
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# Seven Strategic Objectives Identified to Support MSR Goal

1. Establish the technical and safety basis for liquid-fueled MSRs by retiring the technical risks associated with MSR performance, safety, and licensing.
2. Identify and establish the physical R&D infrastructure (loops, test stands, etc.) needed to support the development of MSRs.
3. Demonstrate the technology viability, component and system reliability, and safety of MSRs by constructing and operating appropriate test and/or demonstration reactors to support the ultimate deployment and licensing of MSRs.
4. Establish the technologies to enable a commercial MSR fuel cycle.
5. Incorporate modern modeling and simulation (mod-sim) capabilities into the development of tools and methods to support the design, operations, and licensing of MSRs.
6. Enable the NRC to achieve a well-defined and timely pathway for licensing by providing the information needed to formulate a licensing framework and basis for MSRs.
7. Support and enable private sector development and deployment of MSRs by key stakeholders via public-private partnerships.

# Fuel Qualification for Heterogeneous Fueled vs Homogeneous Reactors

- For heterogeneous reactors the fuel/cladding system is the principal barrier to the release of fission products
- Extensive effort has been placed by the industry and regulator (NRC) on assuring that the behavior of the fuel is well understood under all perceived operational conditions ⟺ fuel qualification
- Introduction of a new solid fuel type can take as much as hundreds of millions of dollars and up to 25 years for qualification
  - Requires extensive irradiation and hot cell examinations
- MSRs have no equivalent to the traditional fuel qualification process

**There are no regulatory precedents for defining the controlling parameters**

# Designers/Applicants Will Need to Determine the Safety Implications of Fuel Salt Changes and Make Their Case with NRC

- Not all possible chemical compositions need to be explored
- Designers/Applicants will need to determine which parameters are important to the safety case and degree of variability allowed
- This might be considered to be a chemical version of the Specified Acceptable Fuel Design Limits (SAFDL) as described GDC 10 in Appendix A  of 10CFR50
- Cladding  as a principal fission product barrier is included in current heterogeneous fuel qualification program
  - For MSRs the reactor vessel and associated piping is covered by ASME standards
  - Thus, only the fuel itself may need to be considered in the MSR qualification process – to be determined

# A Possible Approach for MSR Fuel Qualification to Start the Discussion

- In submitting an application, the applicant has assumed certain properties of fuel/coolant that are then used in the safety analysis in order to meet the regulatory requirements
- This set of data forms the basis for the determination of the parameters impacting the safety case
- Sensitivity studies can be used to determine the limiting values for these properties that, if exceeded, could result in a plant exceeding the safety envelope
  - Not only thermal hydraulic properties need be considered but other properties such as
    - Solubility of fission products in the salt which might impact the source term
    - Plate-out of radioactive material or solubility limits assumed for the fuel



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# A Possible Approach for MSR Fuel Qualification to Start the Discussion (cont.)

- Once the important parameters are identified, experimental measurements and data can be developed to indicate the impact of salt composition on the important parameters
- Major drawback is the variability of salts being proposed by various designers
- Chloride salts need irradiation data to confirm their stability in the reactor environments

# NRC Will Likely Need to Define a Process to Establish Regulatory Requirements Before DOE or Industry Can Initiate Needed R&D

- IF the NRC agrees that the process is basically a chemical issue then fuel qualification of MSRs may be shortened compared to the current heterogeneous fuels
  - No irradiation
  - No hot cell examination
  - Special effects testing/ not related to geometry or configuration
  - As a result - should be less expensive and less time consuming
- Informal discussions with NRO and RES have been started (March 2017)

# Insights on Mod-Sim (M&S) and V&V Efforts Moving Forward for MSRs

- Per IAP, NRC's plan is to use existing codes where possible, minimizing development costs
- Any new codes will need adequate V&V and benchmarking
  - Experiments (separate effects testing and integral effects testing) along with scaling will be required
  - Lack of operational data will likely require more V&V than currently required for LWRs
  - Industrially developed codes may be used in lieu of NRC-developed confirmatory codes, if NRC is allowed to follow or participate in the development of the code
- Conclusion: There is no indication that M&S codes will reduce the need for experiments in the current strategic plan action plans (next 5 years)

# MSR R&D Areas Recommended by ORNL to DOE-NE for Near Term—Potential Value to All/Most MSR Developers

- Determine what the equivalent of a fuel qualification program looks like for a liquid-fueled reactor
- Develop a code-qualified base structural alloy and coating (chemical compatibility) for both fluoride and chloride systems
- Develop salt chemistry capability to perform thermal and physical property evaluations and measurements (plans underway)
- Perform chloride salt capsule testing and loop testing
- Address need for developing modern salt components (pumps and valves) needed for loops and scaling up to commercial scale

# MSR R&D Areas Recommended by ORNL to DOE-NE for Near Term—Potential Value to All/Most MSR Developers (cont.)

- Demonstrate passive decay heat removal systems and validate models => confirm for NRC
- Plan and conduct zero power critical experiments – develop international benchmark
- Identify and develop safeguards approach and I&C needed for safeguards measurements
- Identify how automation effectively impacts maintenance for MSRs – high temperature and radiation areas
- Develop point designs for both fluoride and chloride MSRs to focus development of safety analysis tools and experiments



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