Molten Salt Reactors and Associated Safeguards Challenges and Opportunities

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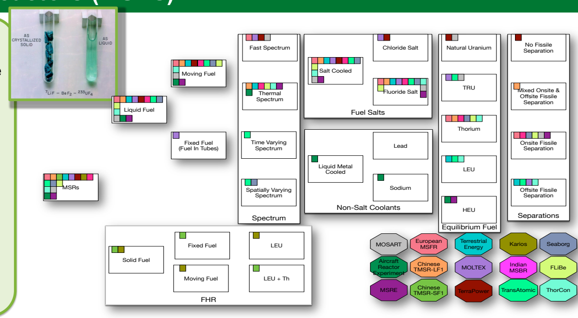
Introduction to Molten Salt Reactors (MSRs)

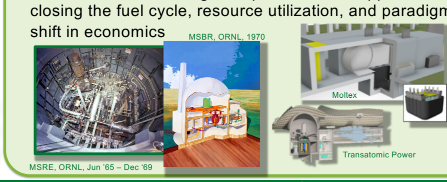
What are MSRs?

- Broad and diverse *class* of reactors that use liquid salt (Fl or Cl) either (a) as a coolant, with solid fuel, or (b) a *fuel dissolved in liquid salt* that also serves as the coolant
- In liquid-fueled MSRs, salt can be processed *online* or in *batches* to allow removal of fission products and for the introduction of fissile or fertile material during operation
- In many modern MSRs, there is *no active chemical separation* of fissile streams



Development: Historic & Current

- Early developments at ORNL from 1950s through mid-1970s; ARE, MSRE, MSBR, MSDR
- Developments stalled, but now renewed interest in MSRs worldwide. *Benefits*: high temperature heat application, closing the fuel cycle, resource utilization, and paradigm shift in economics



Unique Safeguards Challenges for MSRs

What are the Safeguards Challenges for MSRs?

- ***Continuously Flowing Material***
  - In and out of reactor core, and processing tanks or storage areas
- ***Continuously Changing Material***
  - Physical (solid and liquid)
  - Fissile/fertile material is continuously added during operations
  - Isotopics: depletion, fissile material, production & removal of fission products
- ***Demanding Measurement Environment***
  - High radiation, high dose, high temperature environments, no decay/cooling of fuel
- ***Accessibility***
  - All key components inside containment. Containment and infrastructure contaminated
- ***Large Variation in Reactor and Fuel Cycle Technology***
- ***Low Level of Design Maturity in Modern MSRs***

"…such reactors cannot be considered item facilities…"

"…more stringent nuclear material accountancy measures will likely be required to verify the quantities, locations and movements of the nuclear material…"

"…most of this instrumentation does not yet exist and a significant R&D effort can be expected…"

International Safeguards in the Design of Nuclear Reactors, IAEA, NP-T-2.9, August 2014

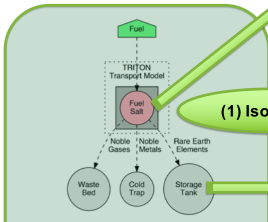
Solution and Path Forward

- Complete ***early assessments*** to inform on safeguards needs
- Opportunity to use true ***safeguards by design*** approach at the early stages of design
  - Requires truly ***multi-disciplinary approach***
    - Reactors, fuel cycle, modeling & simulation, *and* safeguards
  - ***Develop and deploy advanced modeling and simulation***, focused on the safeguards' needs and challenges

How Can Advanced Modeling and Simulation Be Applied to Inform on MSR Safeguards Needs?

Inventory (isotopics, mass, flow, location, signatures, dose) is key to early safeguards insights, but complex and unique to model

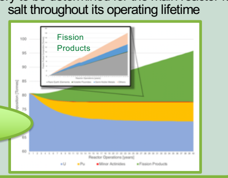
- ***Challenges and Needs***
  - (1) ***Isotopics:*** Ability to model continuous "feed and removal" not previously available in reactor physics / inventory tools
    - State-of-the-art tools developed by ORNL
  - (2) ***Detector Response:*** Ability to model detector responses and determine new correlations e.g., potential opportunity to use short-lived fission products
  - (3) ***Dose:*** Dose and activation predictions and assessments throughout the reactor system, both for the instruments and the inspectors



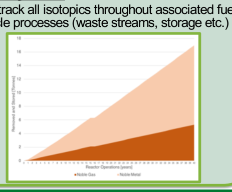
New MSR-specific capabilities have been developed, deployed, and validated for reactor, fuel cycle, and safeguards assessments

(1) Isotopics

"*Fuel Salt*": Advanced tools enable accurate inventory to be determined for the main reactor fuel salt throughout its operating lifetime



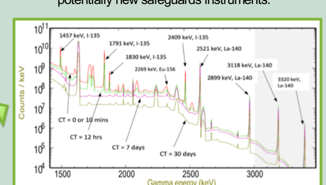
"*Storage Tank*": The new tools also calculate and track all isotopics throughout associated fuel cycle processes (waste streams, storage etc.)



(2) Detector Response

Inventory analysis from SCALE is coupled to GADRAS, simulating the gamma spectra of the salt, waste form etc as if it were measured by a detector.

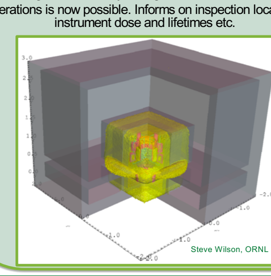
New correlations are derived to inform development of potentially new safeguards instruments.



(3) Dose and Activation

Irradiated fuel salt flows through core, reactor system, and through / into processing and storage tanks. Short-cooled (mins to hours) fuel salt, will emit a significant radiation field.

Therefore, measurements and potentially inspections must occur in high dose environments. Determining dose throughout the facility during normal and off-normal operations is now possible. Informs on inspection locations, instrument dose and lifetimes etc.



SUMMARY AND CONCLUSIONS

- Renewed and substantial private industry investment in ***diverse*** range of MSR technologies (*reactors, fuels, and fuel cycles*)
  - Unlikely one safeguards' solution or technology viable for all MSRs
- MSRs with fuel dissolved in salt results in potential need for ***paradigm shift in safeguards***
  - Flowing, and continuously changing fuel in a ***challenging measurement environment*** with limited accessibility
- ***Advanced modeling and simulation techniques*** for tracking nuclear material throughout the nuclear energy system provide ***fast, inexpensive early insight*** into MSR safeguards needs and ***enhances toolkit***
  - Accuracy, signatures to measure, locations, instrument lifetime
- Currently, MSR designs are ***relatively immature***, and therefore provides ***opportunity for safeguards-by-design***
- ORNL continues to work with its ***reactor, fuel cycle, and safeguards*** experts to develop MSR technologies