Safety, Safeguards, and Security Context for MSRs

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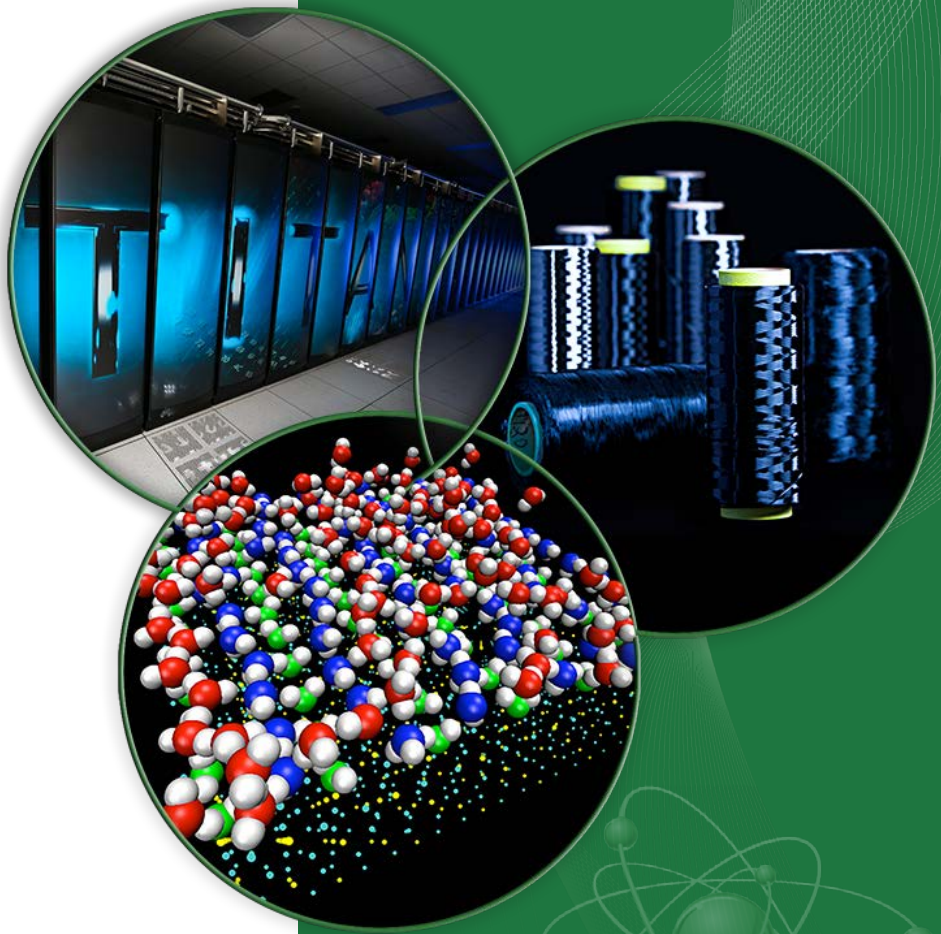

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The Wide Variation of MSR Designs Impacts Security, Safeguards, and Safety Approaches

- MSR designs vary from denatured to breeders
- MSRs can have neutron spectrums ranging from thermal to fast
- MSRs can have varying fuel cycles may even change over lifetime of the reactor
  - U/Pu
  - Th/U
  - LWR recycle fuel
  - Actinide burning
  - Different salts
- MSRs can have on line or batch reprocessing or no fuel processing
- MSR may have fuel present in piping, storage tanks, heat exchangers and salt cleanup systems outside reactor vessel.
- FHR will have safeguards and security issues similar to gas reactors

Current Safeguard Approaches May Not be Applicable for MSRs

- Accountability currently is based on physical units
  - May still work for FHR (solid fuel) but complicated by the small size but large number of TRISO fuel kernels
  - MSR liquid-fueled reactors require the development of new methods
    - Homogeneous mixture of fuel, coolant, fission products, actinides
    - Continuous variation of isotopic concentrations in the fuel salt
    - High melting temperature
    - On line reprocessing possible
    - Unique refueling schemes
    - Liquid fuel requires one type process for safeguards likely that frozen fuel will require another
    - Fuel outside the vessel
    - Difficult to introduce safeguards after the design of a MSR is completed

Security Issues Related to MSR

- Subject to the same threats as current reactors
  - Theft
  - Sabotage
- Some liquid-fueled MSRs may have inherent/passive mechanisms that make them less vulnerable to sabotage/theft
  - Inherent shut down (fuel expansion)
  - Dump valves to empty the reactor vessel into subcritical passively cooled underground storage tanks
  - High operating temperature/liquid fuel
- Fuel outside reactor vessel in some designs may provide sabotage/theft vulnerabilities.

It is Important that MSRs Consider Safeguards and Security Early in the Design

- Difficulty/expensive to retrofit the design
  - Retrofits may interfere with operations, maintenance radiation protection or safety aspects of the design
- Safeguards
  - Designers/researchers need to work with the regulators to develop methods that make it easier to implement safeguards in the design
    - monitoring - challenging in a MSR (temperature, tritium, high radiation)
    - remote sampling capability (counting and visual accountability won't work)
    - reduce quantities of fuel outside the vessel
    - accessibility for inspections
- Design security into the MSRs
  - Perform vulnerability studies early and as necessary as the design progresses

FHRs Safety Design Approaches Overlap with Several Other Reactor Concepts

- Fuel–mHTGR
- Passive residual heat removal–mHTGR/SFR
- Low pressure–SFR
- Intermediate cooling loop–SFR
- High melting point coolant–SFR
- High boiling point coolant–SFR
- Containment–SFR

Safety Framework of MSRs May Require New Approaches

- Fuel design limits are not meaningful in liquid-fueled systems
  - Many regulatory requirements use fuel design limits as acceptance criteria–what is the alternative and still meet the safety requirement?
- Defense in depth-fission product barriers (clad, vessel, containment)
  - Does lack of cladding reduce DID?
  - Credit for solubility/chemistry of fission products in salt
- Significant tritium production/high temperatures in thermal spectrum reactors
  - Leakage
  - Removal
  - Disposal/storage

Safety Framework of MSRs May Require New Approaches (continued)

- Fuel and fission products outside the vessel
  - Fission product barriers (heat exchangers, storage tanks, salt treatment)
  - Delayed neutron fraction impact
    - Control issues
    - Neutron production in cooling system or cleanup system
  - Subcritical dump tanks
    - Decay heat removal
    - Criticality
- Shielding/Radiation protection
- High melting temperature of fuel introduces heating requirements to prevent freezing
  - Electrical power (long term SBO)
- Waste handling, used fuel handling, and storage

Safety Framework of MSRs May Require New Approaches (continued)

- Chemistry of salts
  - Corrosion control (redox)
  - Materials compatibility
  - Precipitation
  - Cleanup
- Reactivity control
  - Reactivity coefficients
  - Shutdown and control requirements
  - Power distribution/isotopic content of fuel
- Cover gas containment/treatment/disposal
- I&C

Safety Framework of MSRs May Require New Approaches (continued)

- Decay heat removal
  - Core
  - Ex-vessel salt treatment
  - Ex-vessel heat exchangers
  - Storage (dump tanks)
- Containment–leak tight (performance requirement)
- Fuel handling
- Operations and Maintenance
  - Tritium impact (thermal spectrum)
- Source Term

Must Have Early Interaction with the Regulators and Support Organizations (SDO)

- Development of Design Requirements, Regulations, Policy
  - On going joint NRC/DOE initiative- a beginning
  - Follow on work - regulatory gap analysis
    - RG 1.206 and NUREG 800
  - Advanced Reactor Policy Statements
  - Risk Informed Performance Based Approaches
- Safety analysis codes being used (adapt current or are new ones needed?)
- Experiment validation use of special effects, test and demonstration/prototype reactors
  - Modeling and Simulation ?
- Standards
  - FHR safety design requirement ANS 20.1
  - MSR safety design requirement ANS 20.x (organizational meeting at ANS winter meeting)
  - ANS 30.1 Risk Informed Design Criteria for Advanced Reactors
  - ASME codes Section 5 high temperature materials, use of ceramics

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Conclusion

- MSR safeguards and safety will present new challenges for the designer and regulator
  - Safeguards approaches may require a major shift from current practices
  - Designer/Safeguard experts need to get involved early in order address the challenges
- MSR safety approach requires early interaction with the regulator.
  - May require new policies and certainly a modification to regulations/requirements - risk informed performance based approaches
  - Use of simulation and modeling, separate effects testing, test and demonstration/prototype reactors