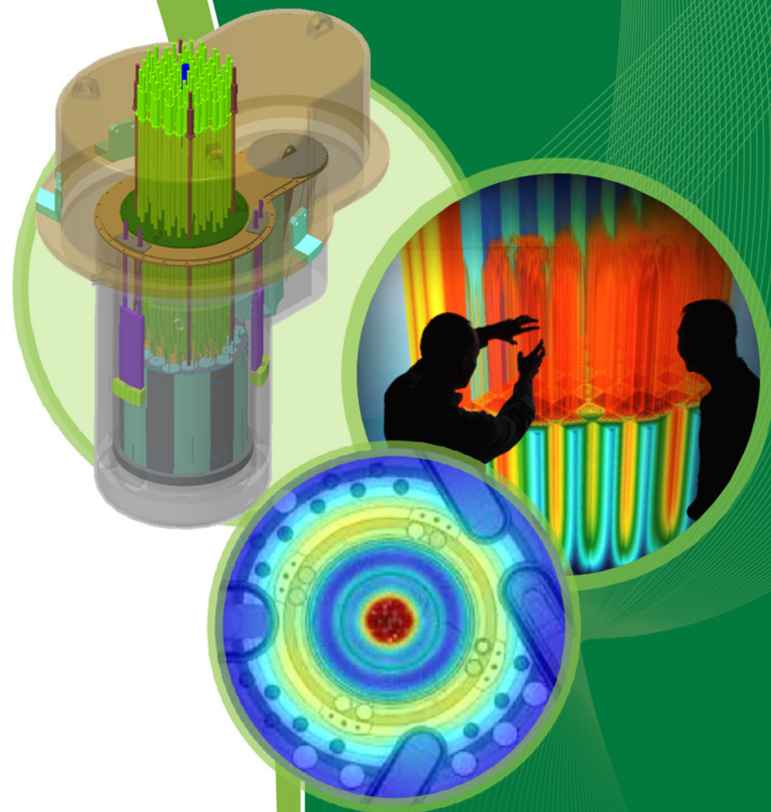
Module 11: Regulatory Issues and Challenges



Presentation on Molten Salt Reactor Technology by:

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Fluid-Fueled Molten Salt Reactors Provide Unique Challenges to Regulation

- Aspects of MSRs not present in traditional nuclear systems
  - Potentially highly corrosive behavior (requires careful redox control)
    - Compatibility of salts with reactor materials (at high temperatures and radiation conditions)
  - High melting point
  - High boiling point (low pressure)
  - Large volumetric heat capacity
  - Significant quantities of fuel outside the reactor core
    - Heat exchanger, various tanks, pumps, possible associated fuel processing, possible continuous addition/removal of fuel
  - Distributed delayed neutrons (mobile fuel)
  - Noble gas fission products evolve out of the salt into cover gas; noble metal fission products plate out onto surfaces; fuel salt retains most other fission products, but not all

Fluid-Fueled Molten Salt Reactors Provide Unique Challenges to Regulation (cont.)

- Aspects of MSRs not present in traditional nuclear systems
  - Salt vapor deposition in cover gas lines
  - Potential for larger volumes of high activity components (filters and replaced components)
  - Fuel composition continuously changing
  - Fuel performs cooling function
  - Strong prompt negative reactivity feedback with increasing temperature for most designs
  - Tritium production (lithium fuel salts)
  - Presence of bubbles (fission product gasses) passing through the core
  - Beryllium hazard for Be-based salts

Regulatory Issues/Challenges of Molten Salt Reactors

- MSR safety analysis/licensing strategy or framework needs to be developed
  - Principal design criteria are needed
  - Major phenomena have not been identified or ranked
  - Accident sequences and initiating events have not been identified
  - Qualified safety analysis tools are not yet available
    - Identification of safety analysis codes (applicability of LWR tools?)
    - Operational experience does not exist
    - Nonprototypic (scaled) separate and integral effects tests need to be used
      - Quality data and benchmarks need to be developed
    - Need for test and prototype reactors (MSRE may be used for similar designs)
  - Mechanistic source term needs to be developed
  - Tritium control criteria will be necessary (particularly in lithium salt systems)
  - Be control for Be-based salts will be necessary
  - Fuel qualification process needs to be defined

Regulatory Issues/Challenges of Molten Salt Reactors (cont.)

- Systems, structures, and components (SSCs) must be carefully chosen
  - High temperature tolerant
  - Radiation damage resistant
    - Interior shielding/reflection common design element
  - Corrosion resistant
    - Fuel salt-wetted SSCs may need to be clad to assure salt compatibility in addition to high temperature and high radiation tolerance
  - Replaceable using remote tooling
  - Leak-tight gaskets and valves remain unproven
  - Instruments will require long leads to signal processing due to high radiation and temperatures
  - Tritium retention
  - Some materials may be difficult to obtain (isotopic separation, alloys)
  - Materials need to be qualified for nuclear use

Means of Obtaining Principal Design Criteria based on Advanced Reactor Design Criteria (ARDC)

- ARDC 1–5 Overall Requirements
  - No change required
- ARDC 10 First fission product barrier is not the cladding but the reactor vessel and associated piping, gaskets and seals, heat exchangers, pumps, and valves as well as any tanks or clean up systems than contain fuel
  - Definition of a Specified Acceptable Fuel Design Limit (SAFDL) or Specified Acceptable Radiological Release Design Limit (SARRDL) is the challenge
  - Any or all of these systems may contain fuel during normal operation
  - AOOs affecting these components or systems may be different for each system and are not necessarily related to core events
  - How will on-site reprocessing systems, if any, be addressed?
- ARDC 11–13 and 17–19 Generally applicable
- ARDC 14 and 15 Reactor Coolant Boundary and Coolant System Design
  - Definition of reactor coolant boundary and coolant system is the challenge
- ARDC 16 Containment
  - Likely the containment will be leak tight, could have multiple containments

Means of Obtaining Principal Design Criteria based on ARDC (cont.)

- ARDC 17 Electrical Power
  - Current designs employ passive shutdown and heat removal systems which do not require off-site or on-site electrical power
- ARDC 21–25 Protection System Functions, Reliability, Testability, Independence, Failure Modes, Separation, and Reactivity Control Malfunctions
  - May require rethinking how these are applied across the spectrum of MSR designs
    - For example: MSRs, such as those with drain tanks, may not have a scram system using neutronic poisons (MSRE); as a result of draining the core, the shutdown, residual heat removal, and emergency core cooling functions are transferred to systems outside the reactor core
- ARDC 26 and 27
  - Reactivity control system may be only used to control temperature and not for shutting the reactor down
    - For example: In the MSRE, control rods were used to control the temperature, but shutdown was achieved by draining the salt from the reactor core region
- ARDC 28 and 29   Generally applicable

Means of Obtaining Principal Design Criteria based on ARDC (cont.)

- ARDC 30–33 Coolant Boundary Quality, Fracture Prevention, Inspection, Coolant Inventory Maintenance
  - Definition of coolant boundary will have impact on these ARDC
  - Inspection may be very difficult (radiation and thermal environment)
  - Inventory maintenance may need to be defined (drain tanks)
- ARDC 34–37 RHR and ECC Inspection and Testing
  - RHR is required of all systems that may possibly contain fuel or fission products – multiple RHR systems (designs may differ based on the function and/or system)
  - Definition of a postulated accident will determine which are ECC and which are RHR
  - Inspection and testing may be difficult (radiation and thermal environment) and/or require draining and flushing the fuel salt
  - RHR systems may be shared or independent (heat sink)

Means of Obtaining Principal Design Criteria based on ARDC (cont.)

- ARDC 38, 39, 40, 41, 42, 43 Containment Heat Removal, Inspection and Testing and Containment Atmosphere Cleanup, Inspection and Testing
  - Applicable, but there may be multiple containments (e.g., for distributed source terms)
  - Inspection and testing may be difficult (radiation and thermal environment) and possibly require draining and flushing the fuel salt
- ARDC 44–46 Structural/Equipment Cooling, Inspection and Testing
  - Multiple structures requiring cooling
  - Inspection and maintenance may be difficult (radiation and thermal environment)

Means of Obtaining Principal Design Criteria based on ARDC (cont.)

- ARDC 50–53 Containment Design, Fracture Prevention, Leakage Testing, Testing and Inspection
  - Applicable but may be multiple containments of differing design
  - Inspection and testing may be difficult (radiation and thermal environment)
- ARDC 54–57 Containment Penetrations and Isolation
  - Will be design dependent; it may be necessary in designs using drain tanks to not have isolation except for multiple parallel freeze plugs
  - Testing and inspection may be difficult (radiation and thermal environment)

Means of Obtaining Principal Design Criteria based on ARDC (cont.)

- ARDC 60–63 Fuel Storage and Handling and Radioactivity Control
  - These ARDC probably take on more importance for a MSR
    - Fuel storage systems may be directly connected to the reactor
    - Much different from conventional used fuel pool or dry cask storage
    - Inaccessibility compared to current LWR (affects inspection and testing)
    - May store fuel temporarily that will be reused in the reactor, processed, or used in subsequent reactors
    - Fuel forms will be different from those in any other reactors
    - Doses likely to be higher because there is no hold-up time
    - Design criteria of other systems related to fission product storage, handling, and control required (e.g., like "other systems" in ARDC 61)
  - ARDC 64 Monitoring Radioactive Releases
    - Applicable to MSRs

Potential Additional (70 Series) MSR-Specific Design Criteria

- Intermediate Coolant System
- Fuel Salt and Cover Gas Purity Control
- Salt Receiving, Storage, and Processing Systems
- Salt Leakage Detection
- Salt Heating Systems
- Salt/Water/Organics Reaction Prevention Mitigation
- Fuel Salt System Interfaces
- Cover Gas Inventory Maintenance

Significant Changes Required to NUREG-0800

The SRP applies to LWRs as do some referenced regulations (e.g.,10 CFR 50.34(h) and 10 CFR 52.47(a)(9)). An assessment as to the applicability of NUREG-0800 to MSRs provides a useful framework and scope of regulatory challenges

- Chapter 4
  - Fuel, Nuclear, and T/H sections generally will need major revisions
  - Control Rods – revisions may be major or minor depending on the MSR design
  - Structural Materials and Rod Drives – minor revisions
- Chapter 5
  - Major changes to sections associated with the reactor cooling systems
  - Sections dealing with balance of plant – minor revisions
- Chapter 6
  - The corrosive nature of the salt will require special attention to compatibility with such systems as drain tanks and freeze valves, RHR, and other systems designed to protect the reactor during postulated accidents
  - Containment systems will be unique and require major revisions

Significant Changes Required to NUREG-0800 (cont.)

- Chapters 7 and 8 are generally technology neutral. Note that some MSRs may not have a rapid acting shutdown system so some revisions may be needed.
- Chapter 9 Auxiliary Systems will be significantly different for a MSR, especially the fuel handling and storage. Major revisions will be needed.
- Chapter 15 This chapter will require major revisions as most transients and accidents will be significantly different. Responses to initiating events will be different and there may be new events that will have to be analyzed.
- Other programmatic chapters will likely require minor revisions as the designs mature

Fuel Qualification Needs to be Defined

- Fuel Qualification – Traditional
  - For heterogeneous reactors the fuel/cladding system is the principal barrier to release of fission products
  - Extensive effort has been placed by the industry and NRC on assuring that the behavior of the fuel is well understood under all perceived operational conditions (including AOOs and postulated accidents) ⟺ fuel qualification
    - Heterogeneous fuel performance is substantially impacted by radiation and temperature history
    - Liquid fuel has no history effects (accumulated stress, creep, swelling, etc.) beyond changes to chemical composition
  - Includes extensive irradiation and hot cell examinations

Fuel Qualification Needs to be Defined (cont.)

- Fuel Qualification – MSRs
  - No equivalent to the traditional fuel qualification process
  - MSRE indicates that fluoride salt compounds are insensitive to irradiation damage
  - Chloride salts need irradiation data
  - Major concern will be changing chemical behavior during dwell time in the reactor and in storage
  - **Issue:** There are no regulatory precedents for what are the controlling parameters that need to be addressed in the MSR fuel qualification

Fuel Qualification Needs to be Defined (cont.)

- Fuel Qualification – MSRs
  - Properties are generally known for pure fuel salts at beginning of life
  - Properties are not well known for salts containing corrosion products, fission products and minor actinides as a result of irradiation (outside of MSRE)
  - Need fuel performance modeling with data benchmarks (does not require irradiated materials)
  - NRC must be involved to assure that information generated is adequate and complete
  - Appropriate quality assurance must be applied

Fuel Qualification Needs to be Defined (cont.)

- Fuel Qualification – MSRs
  - Need for basic information to be generated to assure that all parameters associated with fuel salts that can affect safety or operations are understood (impurity limitations/cliff edge effects) – Simultaneous Fuel Performance Specification
    - Radionuclide retention (source term)
    - Container attack (fission makes fuel salt more oxidizing)
    - Progressive degradation of heat removal capabilities and restoration via chemistry control system
      - Density
      - Boiling point
      - Melting point
      - Viscosity
      - Thermal conductivity
      - Heat transfer properties
    - Fissile material plate-out
    - Solubility (fuel, actinides, fission products)

Qualification of MSR Fuel May Be Less Expensive and Time Consuming than Current Heterogeneous Fuel

- No irradiation
- No hot cell examination
- Can be accomplished without radioactive isotopes. May require natural U and surrogate for Pu (chemical behavior not dependent on isotopic composition)
  - Only chemically insignificant quantities of trans-plutonium elements anticipated
- Small samples (special effects tests) / no geometric requirements

MSRs Will Require a Significant Change in Current Regulations and Guidance

- Revision of ARDC
- Adaption of the Standard Review Plan
- System descriptions and functions will need to be revised
  - Allocation of safety functions will need to be revisited
- Accident sequences and initiators will be unique
- Categorization/classification of equipment
- Fuel qualification
- Mechanistic source terms
- Which regulations apply where? 10 CFR 50, 10 CFR 70, or combinations of both
  - MSR-specific safeguards regulations will also need to be established
- Others will be identified as the MSR designs progress