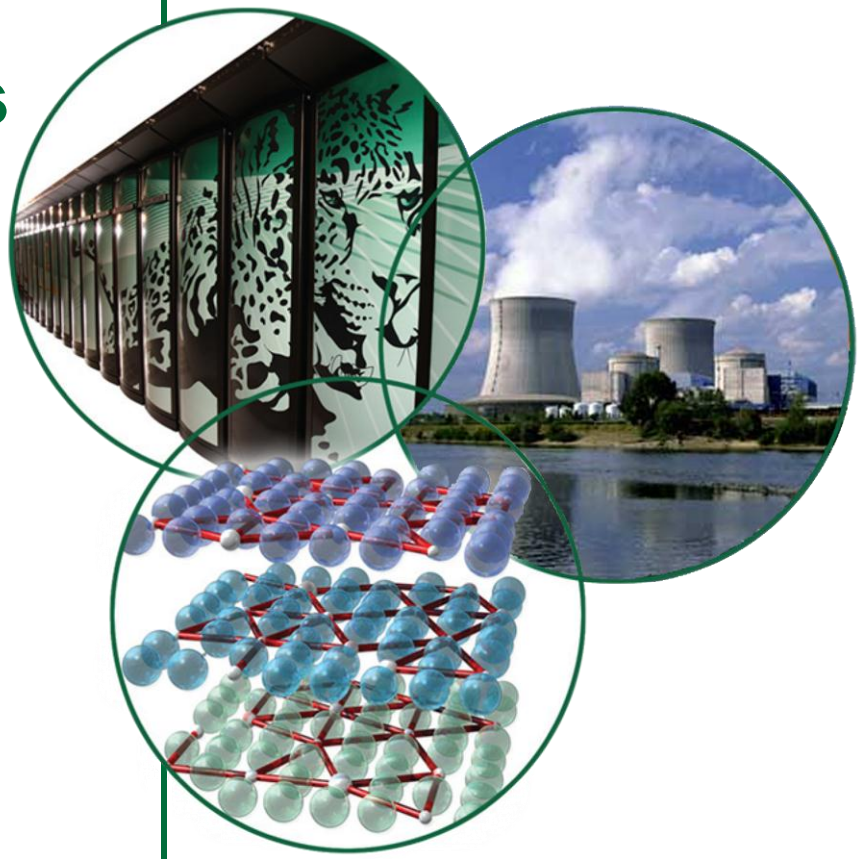
Safety-Related Design Aspects of Molten-Salt Reactors and Related Licensing Implications



Presented to:

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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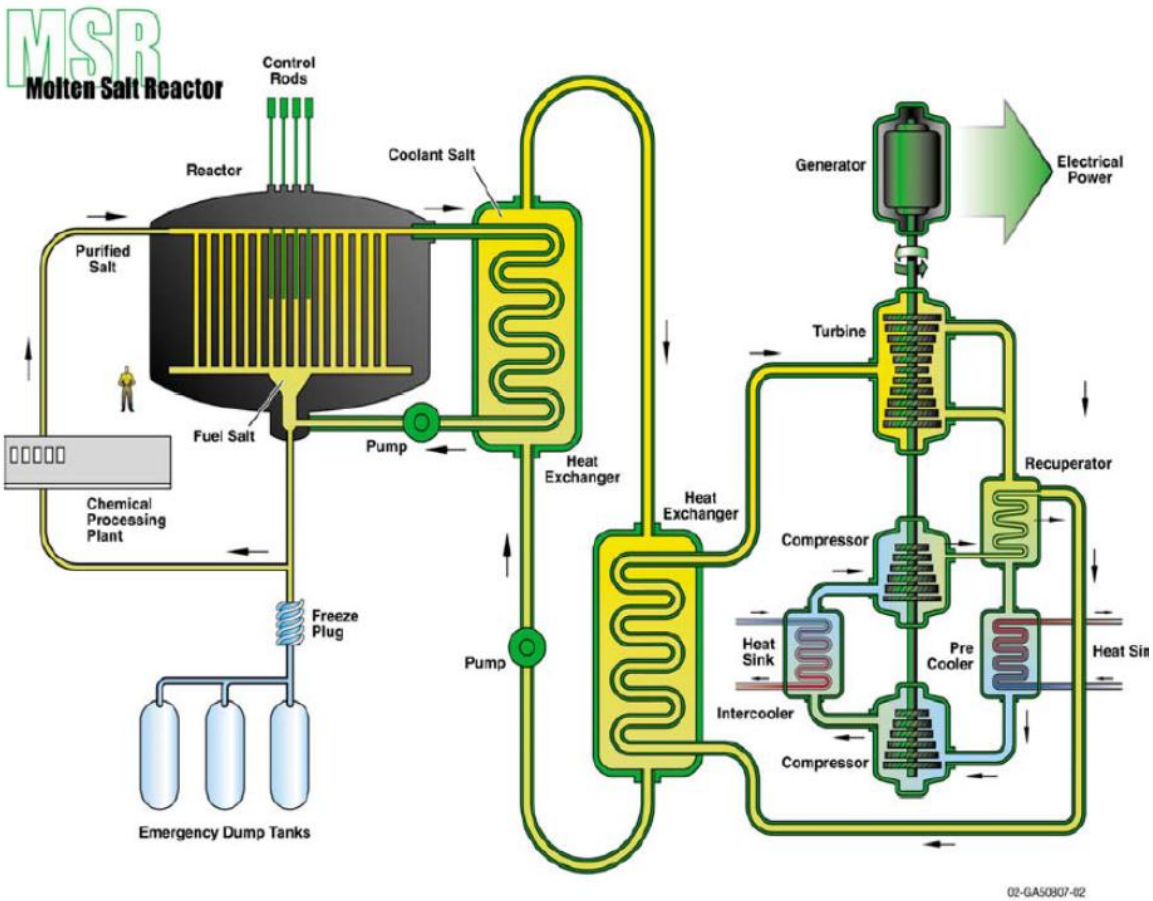
MSRs Are "Fluid-Fueled" Reactors With Fissile Material Mixed in Carrier Salt



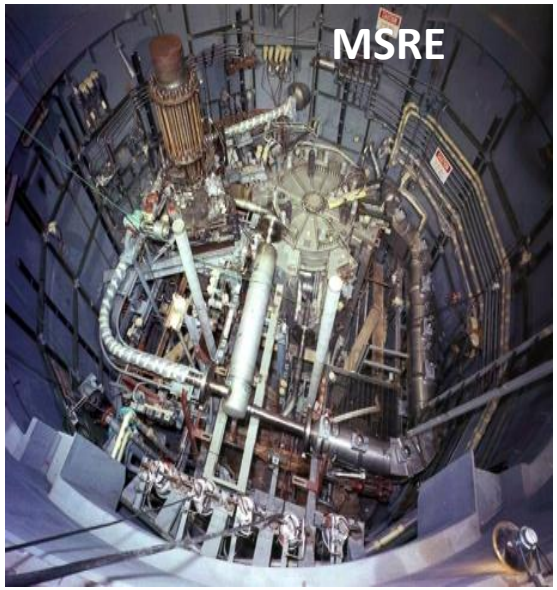
Differences Between Fluid-Fueled and Solid-Fueled Reactors Are Basis for Unique Safety Features

- On-line fuel processing to remove gases and volatile fission products
- External (to the core) cooling
- Minimal excess reactivity
- Core drain to passively cooled subcritical configuration

Developing Safety Basis for Licensing Focuses On Same Requirements for all Rx's

Design Safety Objectives:

- Control and containment of fission products
- Maintain reactivity control => heat generation
- Remove decay heat



MSR Safety Basis:

- Inherent design of fluid-fueled reactors
- Key characteristics in using salts as coolant
- Passive safety attributes
- Directly related operating experience from MSRE and technology development efforts for MSBR

Inherent Characteristics of Coolant Salts That Provide Attractive Safety Features

- Low pressure operation at high temperatures(boiling point for salt at ~1400 C)
- Low chemical reactivity (does not react with water and air)
- Retention of fission products and actinides (solubility)
- Negative reactivity coefficients (as temperature increases expanded fuel is “pushed out” of core)
- Compatible with suitable structural provided chemistry control maintained materials – non-corrosive
- Salt can function as passively safe “drain valve” under accident conditions

Safety Implications of Engineered Safety Design Features Based on Fluid-Fueled Reactor and Use of Salt as Coolant

MSR Engineered Safety Design	Safety Implication
On-line line fuel processing - continuous removal of fission products	• Reduces need for excess reactivity • Removes source for reactivity transients • Reduces source term • Reduces driving force (decay heat) - accident
Chemically stable salt	• Eliminates energetic reactions • No fire or explosion hazards
Negative temperature coefficient – temperature control	• Reduces criticality transients • Ease of control of operations
External cooling – fluid fueled	• Precludes fuel-coolant rearrangement to reduce likelihood of increased reactivity
Molten salt fuel-coolant mixture	• Meltdown is of no concern – normal state • Breach of vessel, pipe, etc., => will freeze and be confined
Salt freeze valves (sections of pipe actively cooled) - elevated temperature heats salt to drain fuel salt by gravity into dump tanks	• Passive safety - maintain fuel-coolant subcritical • Passive cooling => decay heat removal

Safety Issues for MSRs Are Both Operational and Accident Related

- Operational Related
  - More intensive operations and manipulations with highly radioactive materials (refueling, maintenance, etc.) => spills and contamination
  - Core is directly adjacent to vessel wall embrittling nickel-based alloys
  - On-line fuel reprocessing (interactions/interfaces with reactor)
  - Tritium production and sequestration (Li-based salts)
  - Accumulation of fission products in primary system, off-gas systems, and dump tanks
- Accident Related
  - Power fluctuation: gases and volatiles forming bubbles that may collapse once in the core => increased reactivity
  - Power fluctuation: “cold slug” where “cooled fuel” outside core w/little or no circulation then enters core => increased reactivity

Safety Analysis Methodology and Licensing Strategy Need to Be Developed

- Safety
  - Fuel qualification
  - Engineering or materials approach to avoid reactor vessel embrittlement
  - High temperature materials => codes and standards
  - Coolant salt thermal performance
  - Accident analysis codes
- Licensing
  - Most countries' licensing requirements based on
    - LWRs
    - Solid-fueled reactors
  - Demonstration of MSR technology – test reactor, prototype reactor ??
  - Identification of AOO's, DBA's and BDBA's*
  - MSR and fuel processing operations
  - Risk-informed approach using probabilistic risk assessment

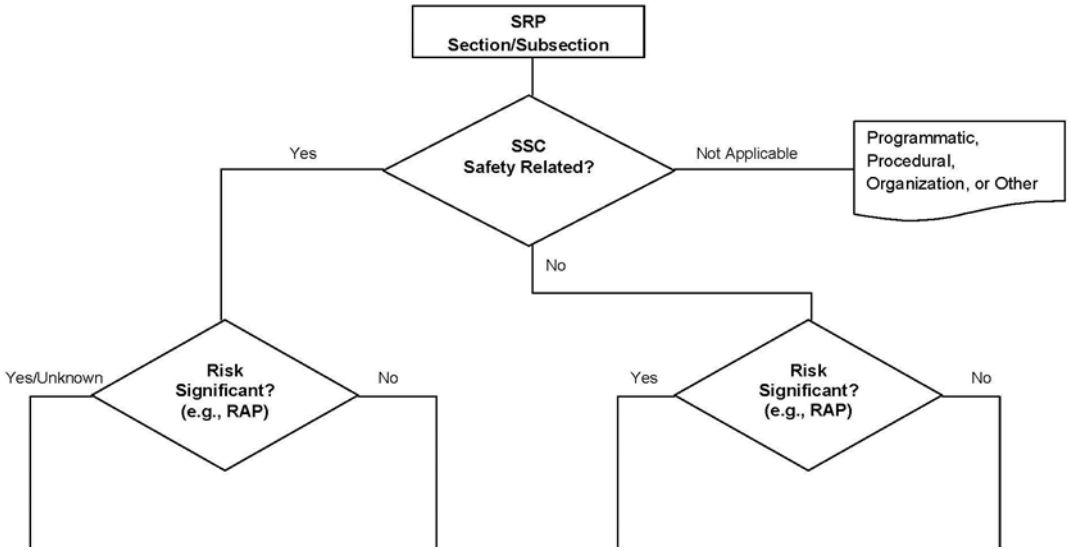
*AOO – Anticipated Operational Occurrence DBA – Design Basis Accident BDBA – Beyond Design basis Accident

Licensing Experience With Other Non-LWR Reactor Types Provide Insights for MSRs

- PRISM – liquid metal cooled reactor – limited safety evaluation report from U.S. NRC
- Toshiba 4S – pre-application submittals
- Gas-cooled reactors
  - PBMR pre-application submittals
  - DOE's Next Generation Nuclear Plant developed a licensing strategy (2008)
- U.S. NRC has recently developed review approach for homogenous aqueous reactor

U.S. NRC Has Developed More Risk-Informed Licensing Framework for Small Modular Reactors (iPWRs) - May Be Extended to Advanced Reactors

- Takes a graded approach for review of systems, structures, and components (SSCs)
- Detailed classification and review for safety-related and risk-significant SSCs
- Progressively less detailed review for non-safety & not risk-significant
- Incorporates and credits performance based program requirements
- Achieve improved efficiencies in reviews
- Design-specific standard review plan documents



SECY-11-0024, *Use of Risk Insights to Enhance the Safety Focus of Small Modular Reactor Reviews,* May 11, 2011