Safety and Licensing Aspects of the Molten Salt Reactor

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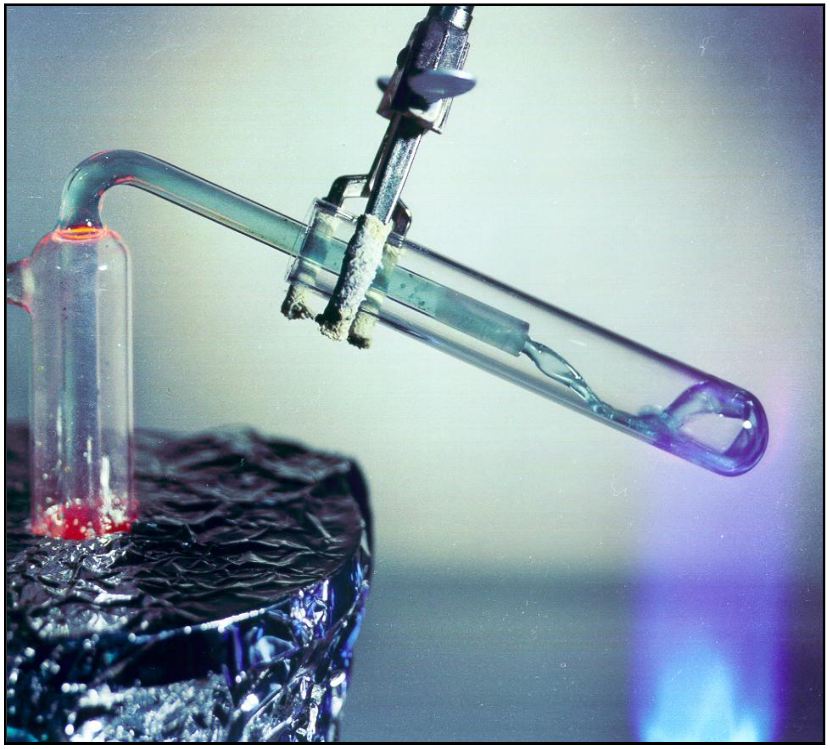
Molten Salt Reactor

Defining Characteristic: Fluid Fuel, Not Solid Fuel

Actinides and Fission Products Dissolved in a High-Temperature, Low-Pressure Molten-Fluoride-Salt Coolant



There is Renewed Interest in MSRs Because of Changing Goals and New Technologies (Since 1970)

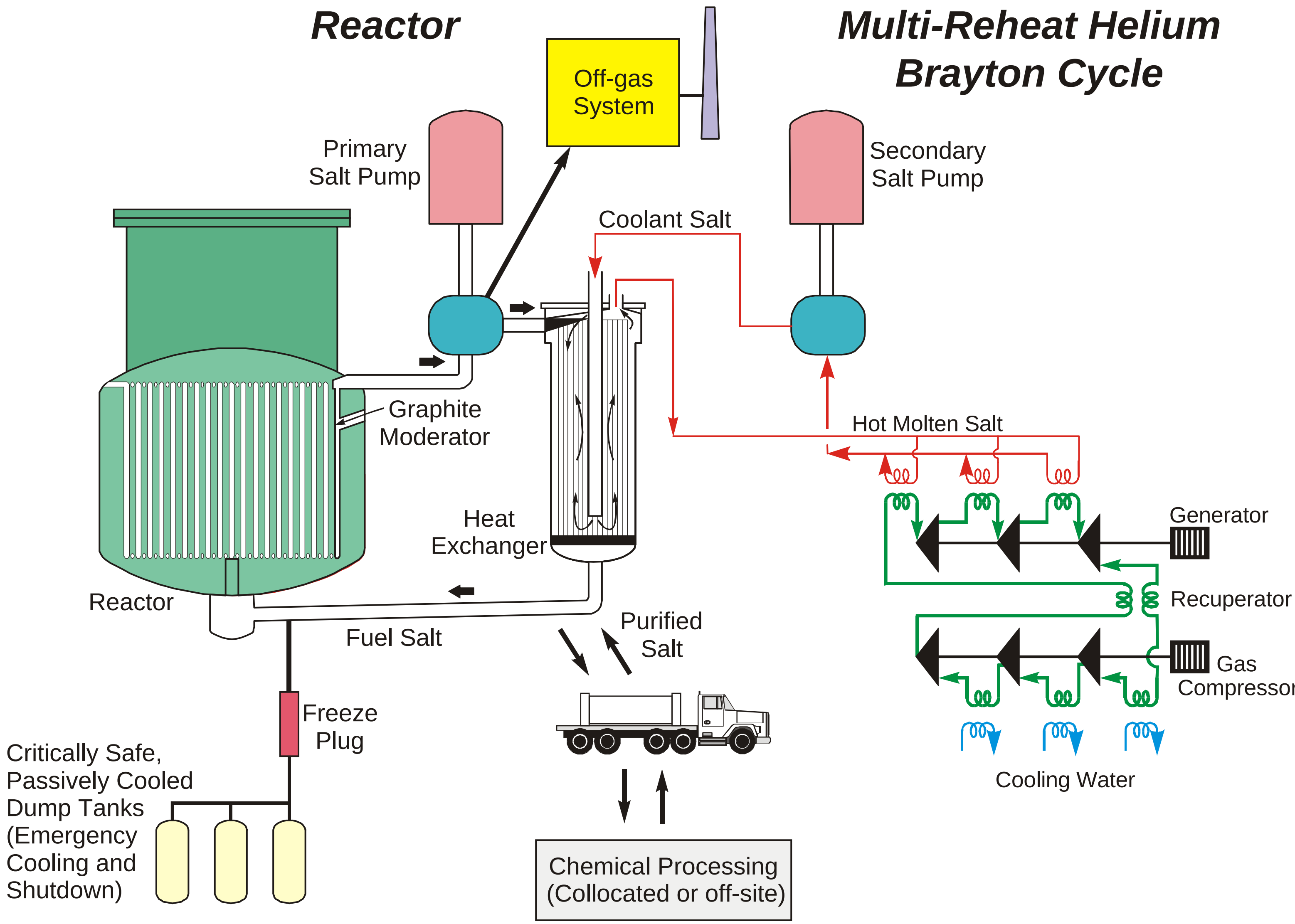
- MSR is one of six Generation IV concepts
  - Only liquid-fueled reactor selected
- Original basis for development (1950s-1960s)
  - Thorium-cycle breeder reactor ($^{232}Th + n \rightarrow {}^{233}U$)
  - Backup for the liquid-metal breeder reactor program
  - Program cancelled
    - Decision to develop only one type of breeder reactor
    - As a breeder reactor, MSR has a low breeding ratio, slightly above one
- Basis for renewed interest
  - Thorium-based MSR produces wastes with a very low actinide content (reduced waste management burden)
  - Breeder with low breeding ratio is acceptable
  - Unique capability to burn actinides
  - New technology (see ICAPP paper)

Molten Salt Reactor

Plant Design

Fuel Cycle

Molten Salt Reactor



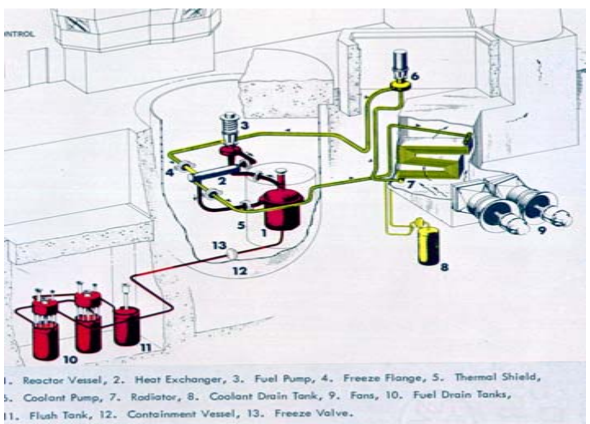
Molten Salt Reactors were Developed in the 1950s and 1960s

Molten Salt Reactors: Fuel Dissolved in Coolant

Aircraft Nuclear Propulsion Program

← ORNL Aircraft Reactor Experiment:
2.5 MW; 882ºC
Fuel Salt: Na/Zr/F

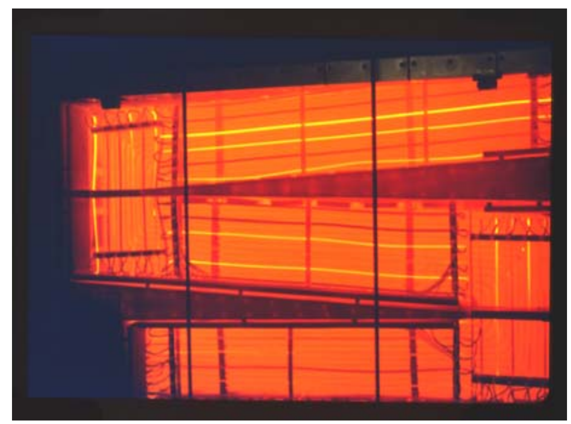
INEEL Shielded Aircraft Hanger→



Molten Salt Breeder Reactor Program

←ORNL Molten Salt Reactor Experiment
Power level: 8 MW(t)
Fuel Salt: ^{7}Li/Be/F
Clean Salt: Na/Be/F

Air-Cooled Heat Exchangers→



The Molten Salt Reactor Experiment Demonstrated the Concept

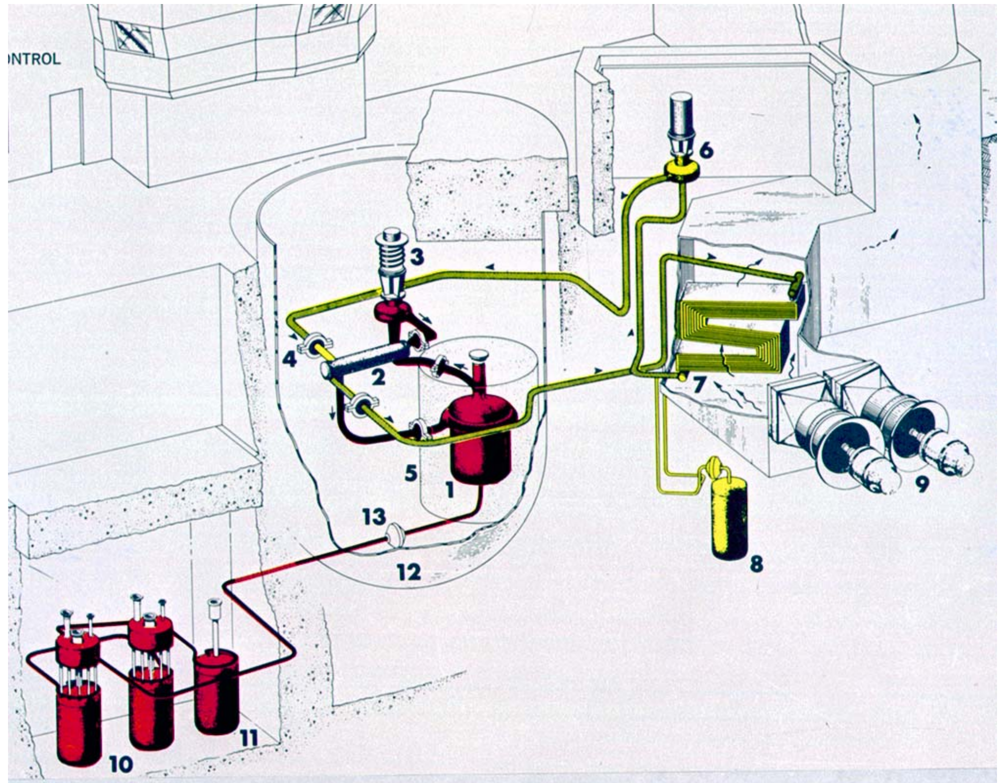
Hours critical	**17,655**
Circulating fuel loop time (hours)	**21,788**
Equiv. full power hrs w/ ^{235}U fuel	**9,005**
Equiv. full power hrs w/ ^{233}U fuel	**4,167**

1960s Goal: Breeder

- Base technology established

Today

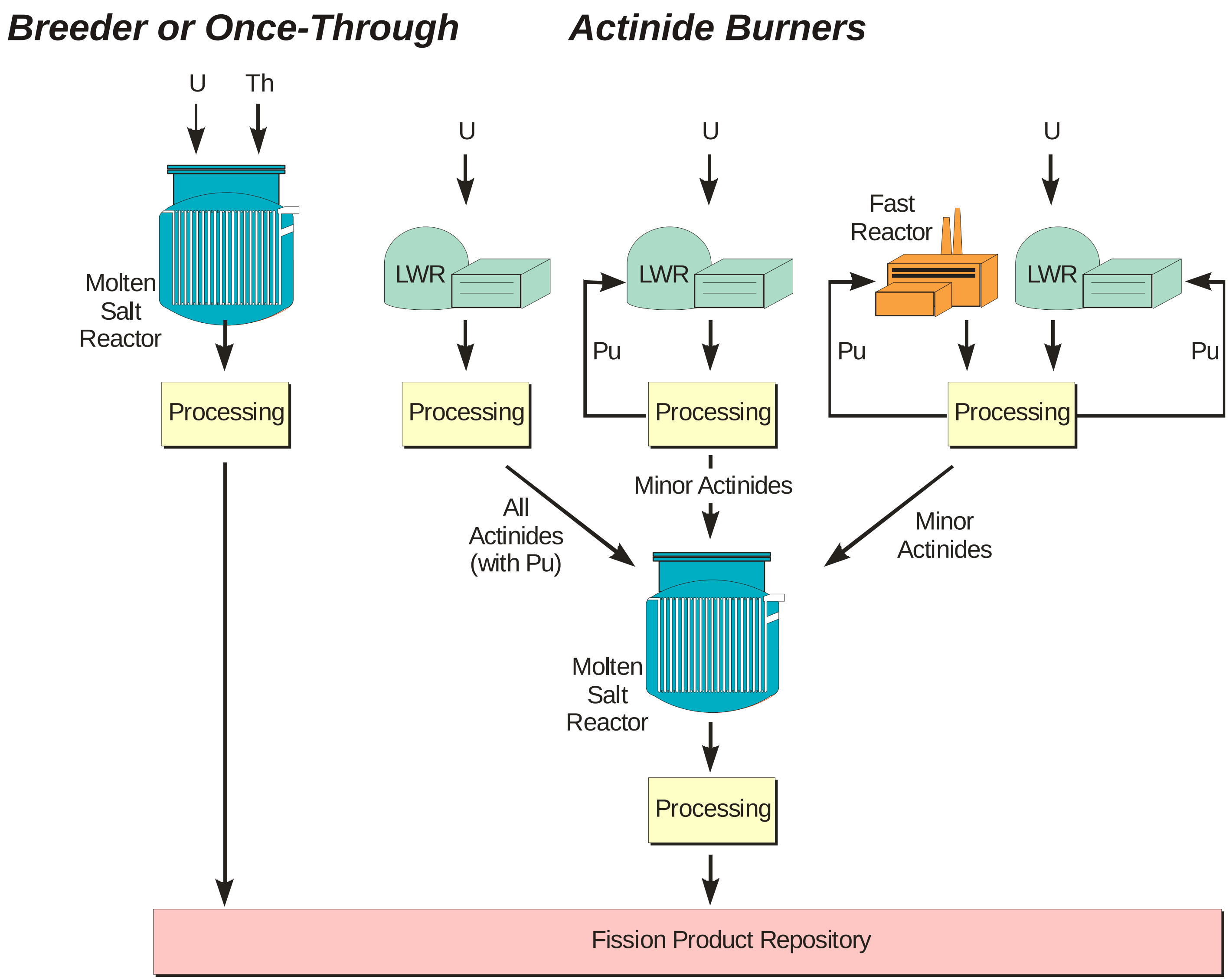
- Two options
  - Actinide burning
  - Breeder with breeding ratio of ~1
- New requirements
- New (since 1970) technology
  - Brayton cycle
  - Compact heat exchangers
  - Carbon-carbon composites



1. Reactor Vessel, 2. Heat Exchanger, 3. Fuel Pump, 4. Freeze Flange, 5. Thermal Shield, 6. Coolant Pump, 7. Radiator, 8. Coolant Drain Tank, 9. Fans, 10. Fuel Drain Tanks, 11. Flush Tank, 12. Containment Vessel, 13. Freeze Valve.

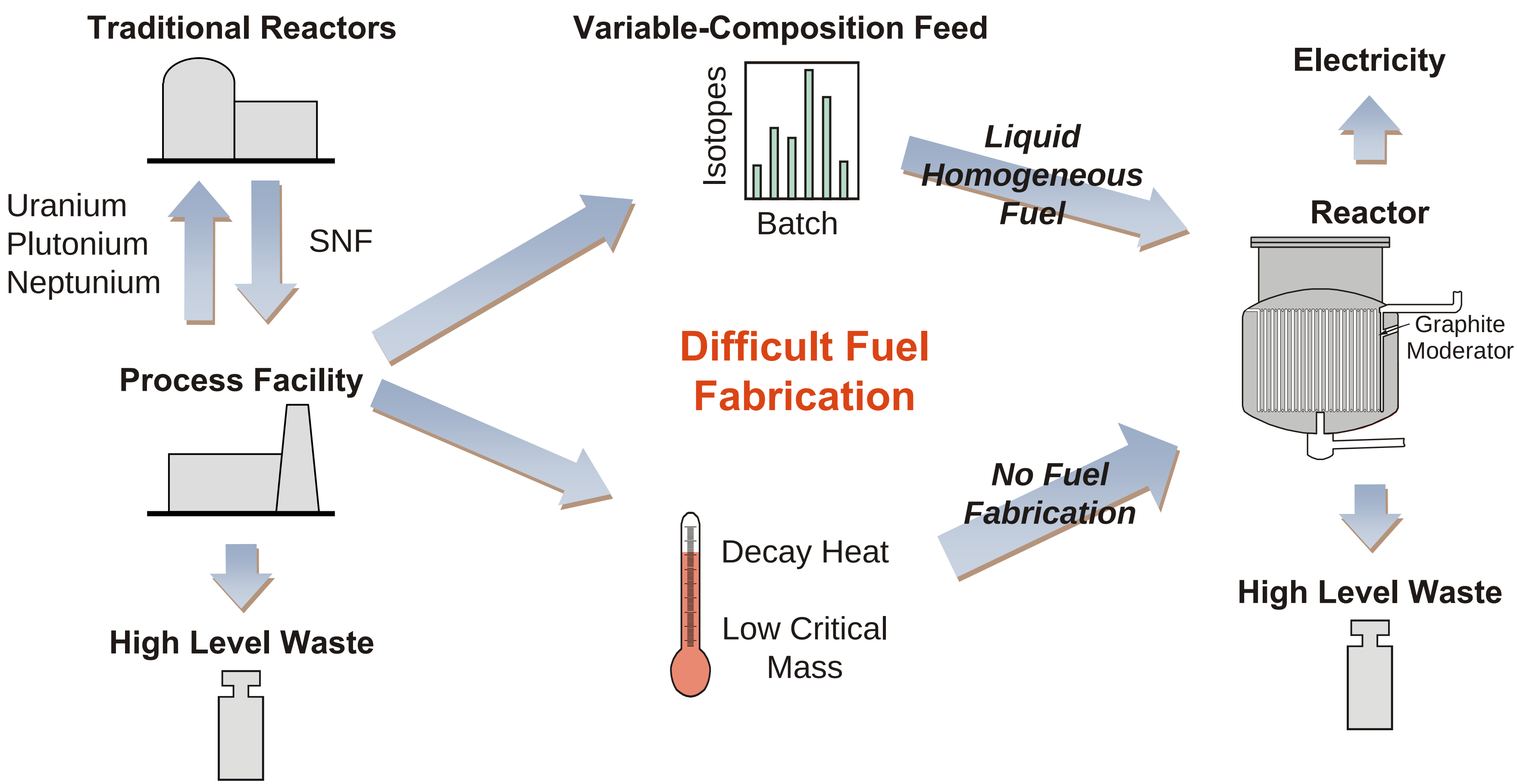
MSRE power = 8 MW(t)
Core volume <2 cubic meters

Molten Salt Reactor Fuel Cycles



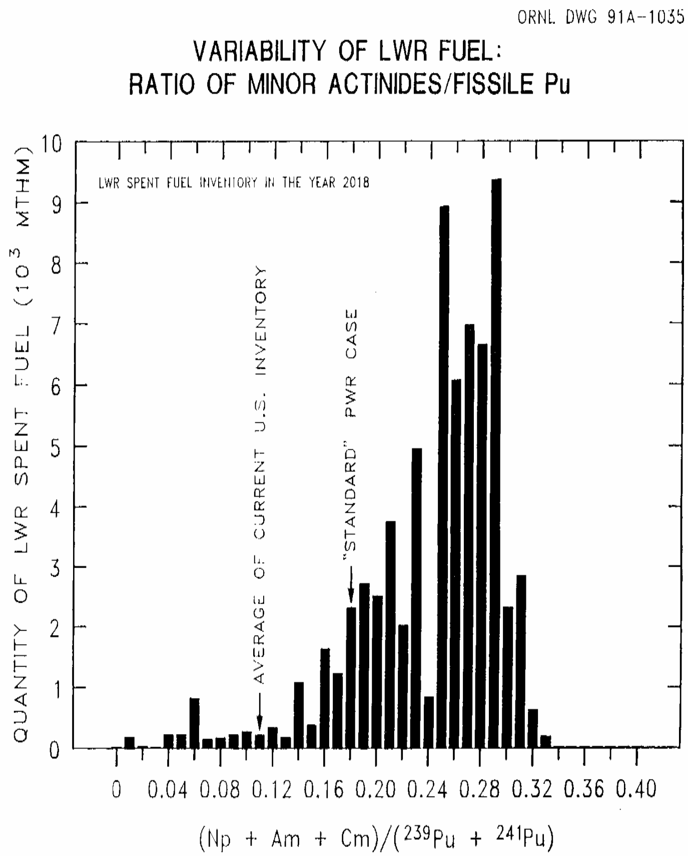
MSRs Avoid Several Solid-Fuel-Reactor Problems with Burning Actinides (High-Burnup Pu, Am, Cm)

Power Reactor Cycle | **Waste-Burning Problems Avoided by MSR** | **MSR Burner**



Variability of Np-Pu-Am-Cm Isotope Ratios in Spent LWR Fuel is Large

Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, Am-243, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, and Cm-248



- **Solid-fuel-reactor options**
  - **Licensed and operated with variations in isotopic ratios among fuel rods**
  - **Homogenization of 14 isotopes prior to fuel fabrication**
- **Molten salt reactor**
  - **Homogenous solution**

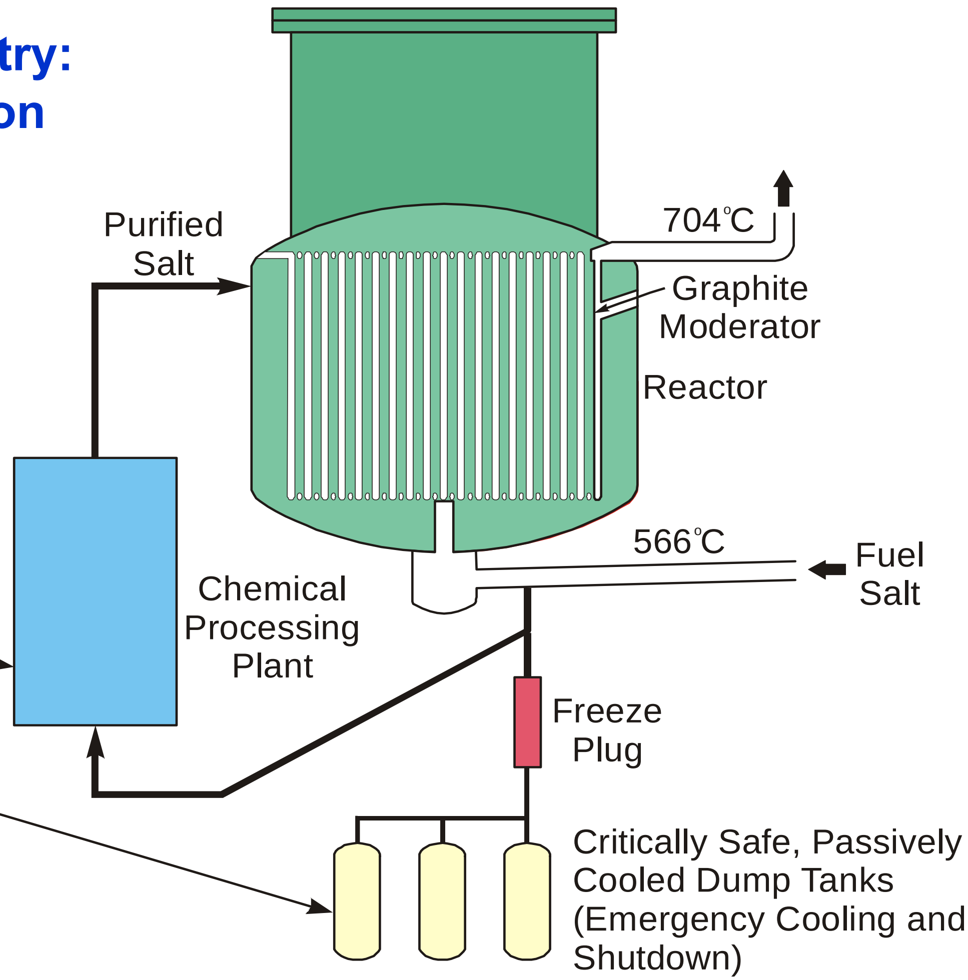
Critical Safety and Licensing Issues

- **Decay Heat Removal**
- **Source Term**
- **Neutronics**

MSRs Have a Different Decay Heat Approach: Dump Fuel Salt to Tanks

Safety Depends upon Chemistry: Keeping Actinides and Fission Products in Solution

- **Low pressure (molten salt boiling point ~1400°C)**
- **Low chemical reactivity**
- **Low accident source term with continuous removal of mobile fission products**
- **Passive cooling by dumping fuel to cooled tanks**



The Reactor Has a Small Accident Source Term but a Serious Off-Gas System

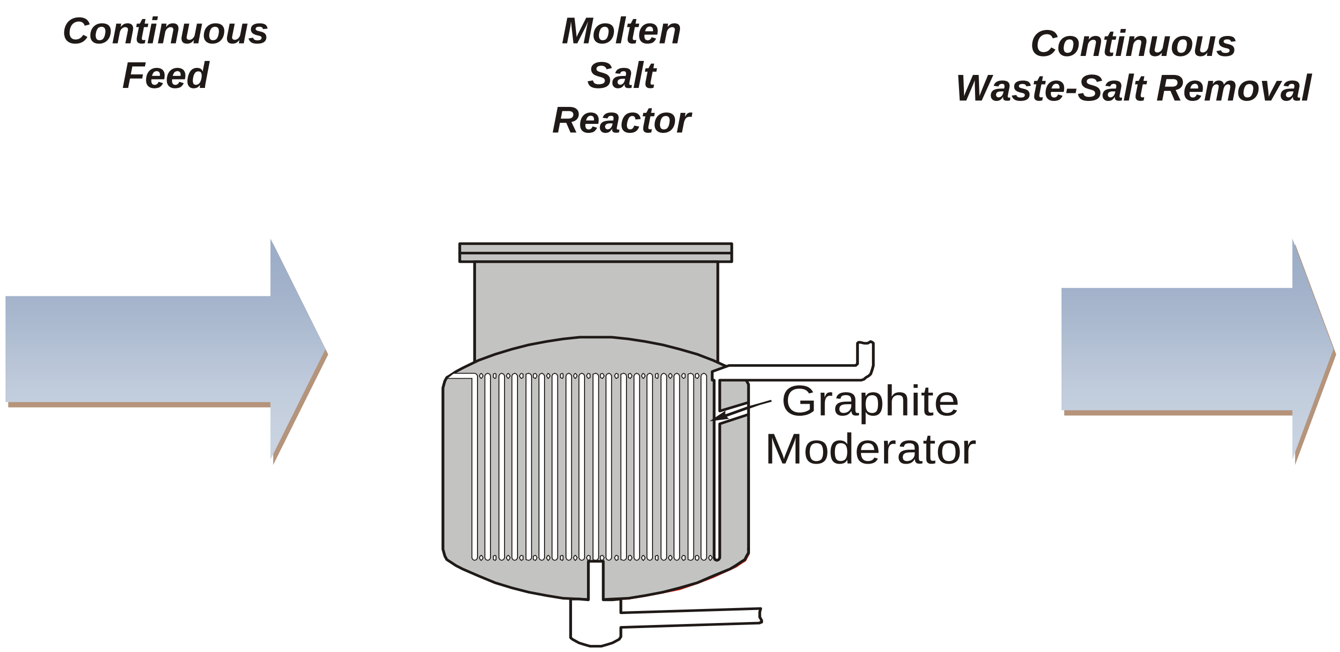
Reactor

- Reduced radionuclide source term
- Low pressure
- Off-gas system selectively removes volatile components
- Salt chemistry limits release of radionuclides under reactor accident conditions
  - Low iodine release potential
  - Low cesium release potential

Off-Gas System

- Significant radionuclide inventory
  - Xenon (with high decay heat)
  - Krypton
  - Other
- Critical safety system
- Minimize accident potential by approach to radionuclide storage
- Some of the safety issues of SNF processing plants

MSR Neutronics: Constant Core Composition (No Variable Burnup, No Time Dependence)



Conclusions

- **MSRs are GenIV concepts with potentially superior safety**
  - **Concept examined in detail in the 1970s**
  - **Significant research required (particularly for actinide burning)**
  - **Modern PRA techniques not yet applied**
- **Safety issues are significantly different**
  - **Potential for major *reactor* accidents reduced**
  - **Potential for *processing* accidents increased**
- **Will require performance-based (not prescriptive) licensing strategy**