Molten Salt Reactor Experience
Applicable to LS-VHTR Refueling

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Molten Salt Technology was Developed to Support Large Programs (1950–1970)

Molten Salt Reactors: Fuel Dissolved in Coolant

Aircraft Nuclear Propulsion Program

← ORNL Aircraft Reactor Experiment: 2.5 MW; 882°C
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 Billion-Dollar (1950s) Aircraft Nuclear Reactor Propulsion Program Developed Molten Salt Systems for Reactor Applications

Molten Salt Reactor (Fuel Dissolved in Coolant) for Jet Bomber

INEEL Shielded Aircraft Hangar

← Hot Cell

External Views →

ORNL Nuclear Reactor

← Aircraft Reactor
Experiment: First Molten Salt Reactor; 2.5 MW; 882°C
Fuel Salt: Na/Zr Fluoride

Goal: 60 MW(t); 873°C; Diameter: 56 in. →
Aircraft Reactor Experiment (ARE) Successfully Demonstrated Molten Salt Reactor Technology in 1954

- Fuel: NaF-ZrF₄-UF₄ (53-41-6) (mol %)
- Intermediate sodium heat transfer loop
- Operated >100 MWh [2.5 MW(t)] for 2 months
- Maximum fuel temperature: 882°C; Material: Inconel

Core Vol.: 1.37 ft³
Loop Vol.: 3.60 ft³
Pump Vol.: 1.70 ft³
Molten Salt Breeder Reactor Program
(Electricity and Breeding)

- Follow-on program to the Aircraft Nuclear Propulsion Program
- Parallel to sodium-cooled fast reactor program
- Included clean secondary salt heat-transport loops
The Molten Salt Reactor Experiment (MSRE)

U-235 fuel operation
- Critical: June 1, 1965
- Full power: May 23, 1966
- End operation: March 26, 1968

U-233 fuel operation
- Critical: October 2, 1968
- Full power: January 28, 1969
- Reactor shutdown: December 12, 1969

MSRE power = 8 MW(t)
Core volume <2 m³

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

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MSRE Graphite Moderator Core

- MSRs have graphite cores
  - No fuel (Fuel in salt)
- Graphite replacement required
  - Radiation damage implies occasional replacement
  - Not done in the MSRE
  - Graphite replacement studies done for commercial MSRs
- Similarities to LS-VHTR refueling with graphite-matrix fuel
MSRE Pumps

Overhung motors and extended shafts used for remote maintenance

MSRE used the pump-bowl to purge out Xe/Kr by sparging

Advanced materials and coatings for bearings under development at the end of the MSBR program
Pump Development was Successful

Table 8.3. Characteristics and operation time for ORNL salt and liquid metal pumps

<table>
<thead>
<tr>
<th>Model</th>
<th>Fluid</th>
<th>Head (ft)</th>
<th>Flow (gpm)</th>
<th>Speed (rpm)</th>
<th>Temperature (°F)</th>
<th>Number built</th>
<th>Total hours</th>
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<tbody>
<tr>
<td>LFB</td>
<td>Na, NaK, and molten salt</td>
<td>92</td>
<td>5</td>
<td>6000</td>
<td>1100–1400</td>
<td>46</td>
<td>466,000b</td>
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<td>DANA</td>
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<td>300</td>
<td>150</td>
<td>3750</td>
<td>1000–1500</td>
<td>10</td>
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<td>DAC</td>
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<td>60</td>
<td>1450</td>
<td>1000–1400</td>
<td>3</td>
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<tr>
<td>In-Pile Loop</td>
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<td>1</td>
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<td>8</td>
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<tr>
<td>MF</td>
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<td>50</td>
<td>700</td>
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<td>21,500</td>
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<tr>
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<td>1500</td>
<td>3500</td>
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<td>MSRE fuel salt pump</td>
<td>Molten salt</td>
<td>50</td>
<td>1200</td>
<td>1175</td>
<td>1000–1225</td>
<td>2e</td>
<td>31,600</td>
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<td>Helium</td>
<td></td>
<td></td>
<td></td>
<td>100–1200</td>
<td></td>
<td>6,000</td>
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<td>800</td>
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<td>1000–1225</td>
<td>2</td>
<td>24,600</td>
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<tr>
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<td>Helium</td>
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<tr>
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<td>30</td>
<td>6500</td>
<td>850–1400</td>
<td>1</td>
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</table>

Preliminary designs were developed for the 20,000-gal/min., 300-ft.-head MSBR pumps. More recent development of large sodium pumps may be applicable to new designs.

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Multiple Test Loops Supported the MSR Programs

ORNL Coolant Salt Technology Facility

- Secondary loop testing (1970s)
- Pump: 850 gal/min.
- Piping: 5-in. Sch. 40
- Material: Hastelloy N
- Temperature: 450–600°C (other loops to 900°C)
- Run time: 9300 h
MSRE Salt Filtration Systems

Inconel-600 fiber-metal material filtration ("felt-metal")
rated at 98% efficiency for 10-micron particles
Status of Salt Technology at the End of the ORNL MSR Program

- Two test reactors
- Massive data base of salt properties
- 750,000 hours of pump loop test data
- ~1,000,000 hours of corrosion test data including natural circulation loops
- Significant experience in remote maintenance
- Preliminary design of 1000-MW(e) molten salt reactor
- Start of development of industrial-scale pumps, valves, bearings, and heat exchangers
- Formation of Molten Salt Group of companies
LS-VHTR Refueling Conditions are Milder Than in a MSR

- Lower temperatures
- Lower radiation levels
  - MSR has fission products and actinides in the salt!
- Less corrosive salt environment
- Small concentrations of fission gases in gas spaces
Conclusions

- MSRs were designed for and maintained using remote operations
- Large experience base with hot operations
- LS-VHTR refueling conditions are milder than those seen in MSRE operations and maintenance
  - Lower temperatures
  - Much lower radiation levels
  - Clean salt
- Mechanical refueling operations in salt are viable