MSRE Design Features

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Session 3 – Deep Dive on MSRE Design, Operations, and Authorization

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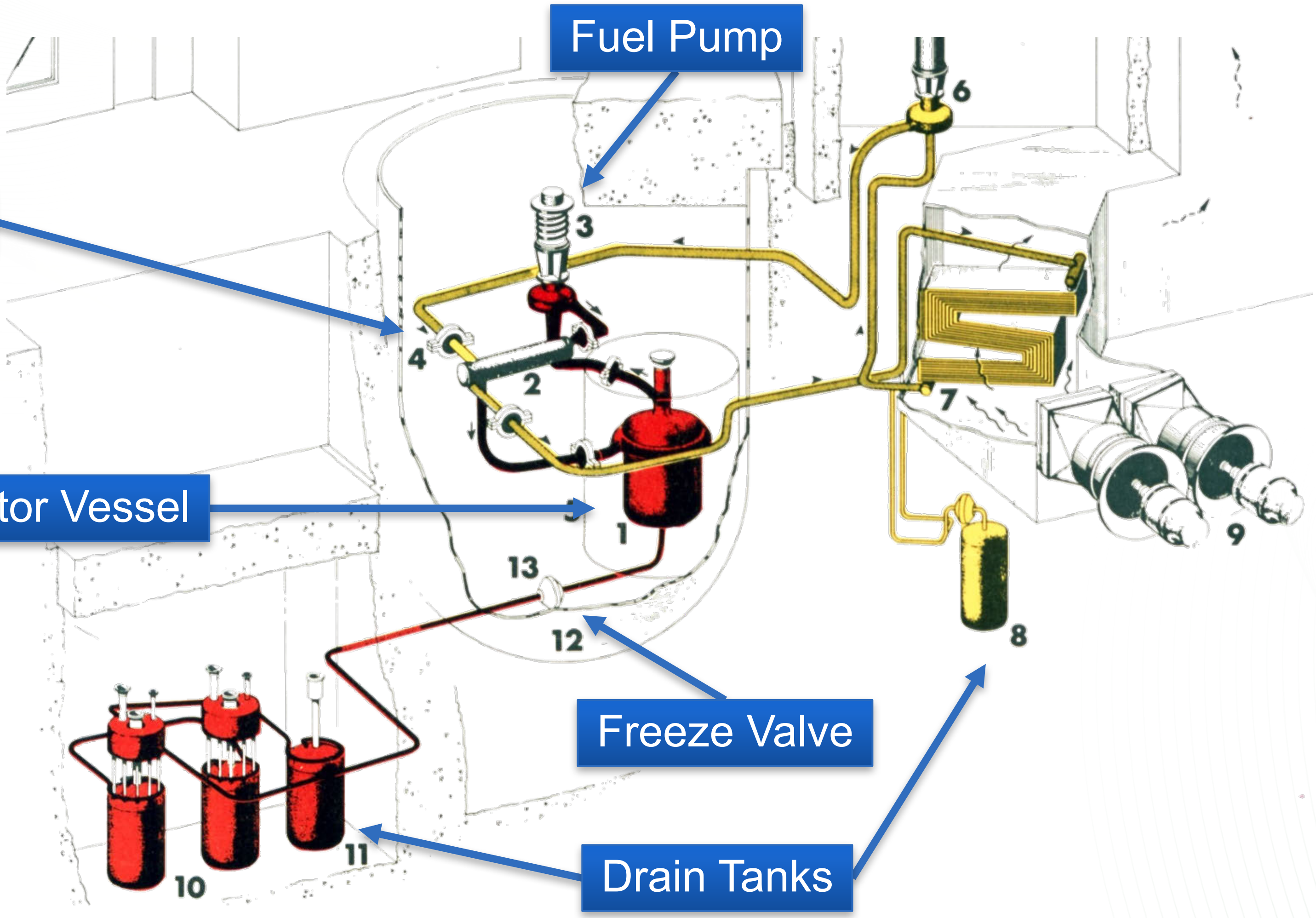
The 8 MWt MSR Experiment (MSRE) Reactor



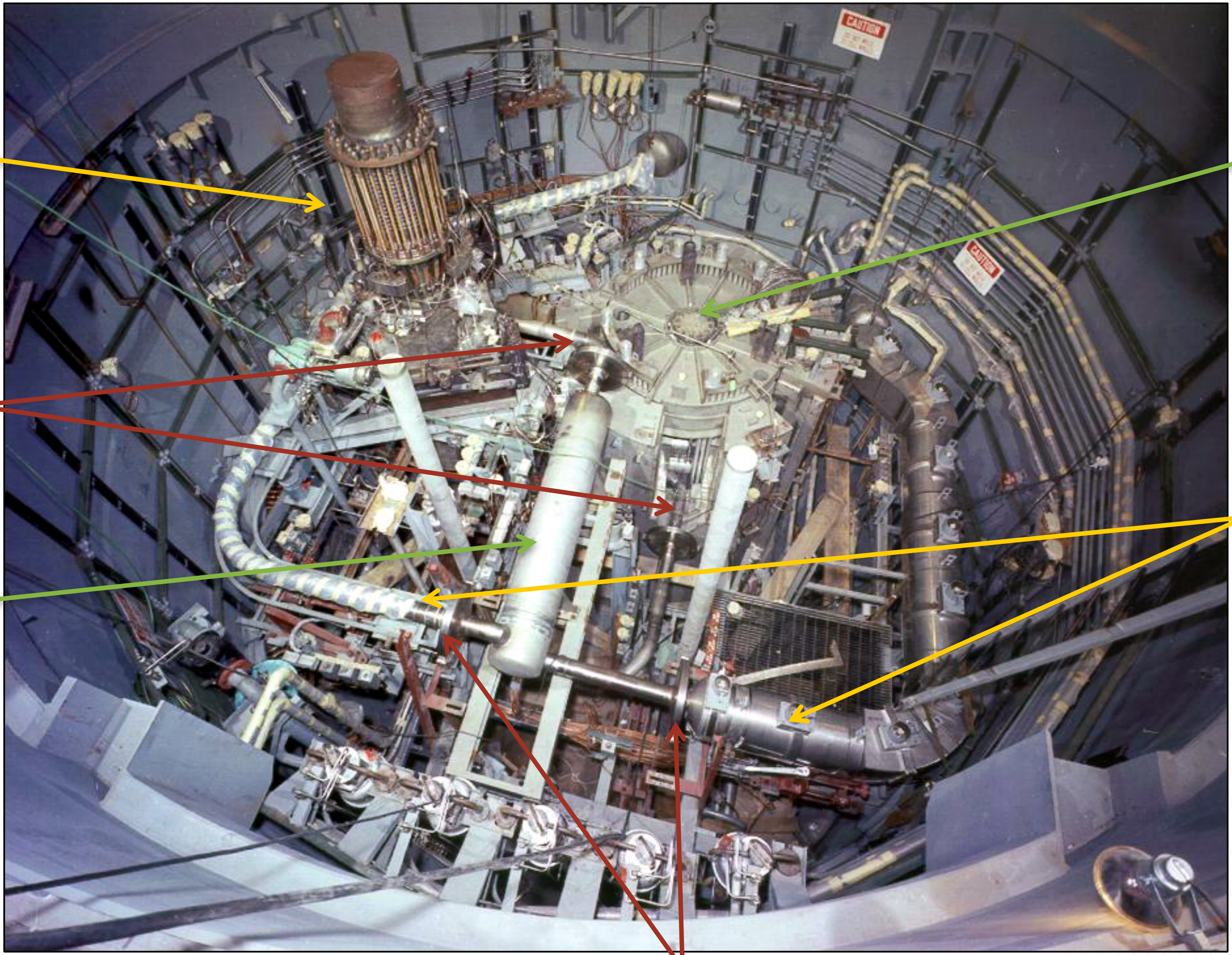
1. Reactor Vessel, 2. Heat Exchanger, 3. Fuel Pump, 4. Freeze Flange, 5. Thermal Shield, 6. Coolant Pump, 7. Radiator, 8. Coolant Drain Tank, 9. Fans, 10. Fuel Drain Tanks, 11. Flush Tank, 12. Containment Vessel, 13. Freeze Valve.

- Red – fuel salt flow
- Yellow – coolant salt flow
- No power conversion – heat dissipated to atmosphere
- Major system components shown

Source: ORNL-TM-728

OAK RIDGE National Laboratory

MSRE Reactor Cavity from Above



Source: ORNL-TM-728

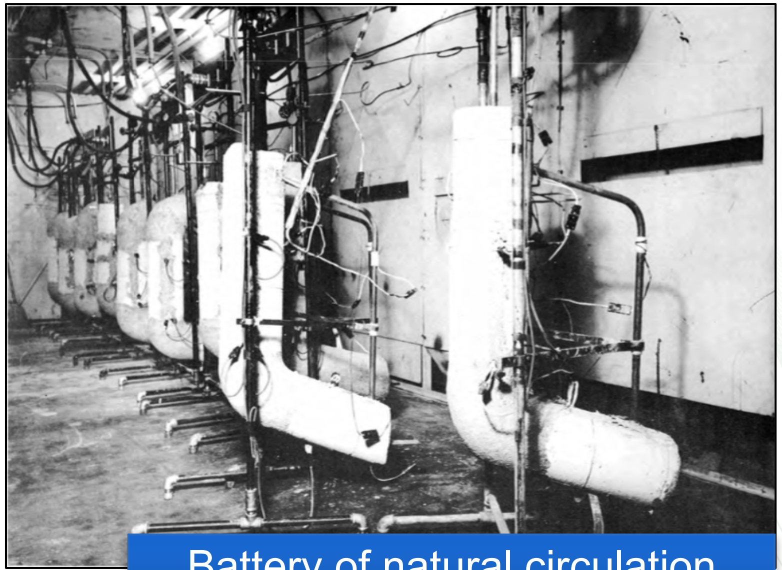
ORNL Photo 66372

Extensive Testing Enabled the Success of the MSRE

- Numerous experimental facilities employed over several years leading up to the MSRE
- Facilities studied salt behavior, material development, corrosion, radiation effects, etc.
- Molten Salt Reactor Experiment (1960 – 1969)
  - 8 MWt
  - Alloy N vessel/piping
  - Single Region Core, Graphite moderated (thermal)
  - >13,000 full power hours

  Operation:
  - 1965 (June) First Criticality
  - 1966 (Dec) First Full Power Operation
  - 1968 (Oct) First Operation on U-233
  - 1969 (Dec) Shutdown

ORR In-Pile Fuel Salt Loop



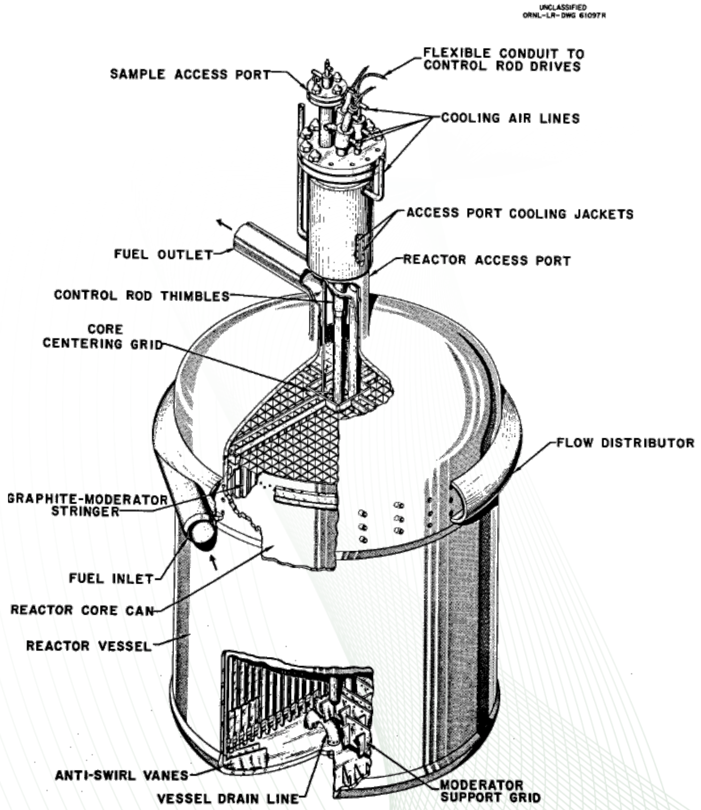
Battery of natural circulation loops as of 1957

Design Requirements Drove the Unique Design Features

Purpose: "To demonstrate that the desirable features of the molten-salt concept could be embodied in a *practical reactor* that could be constructed and maintained without undue difficulty and one that could be operated *safely and reliably*"

R. C. Robertson
MSRE Design and Operations Report

- Traditional fuel management, radiation damage accounting, etc. not applicable
  - Required special considerations for remote maintenance (distributed source terms, i.e., fuel salt loop, off-gas, tritium)
- High temperatures (core outlet 704°C) and low pressure (pump outlet 55 psig)
  - Salt also freezes at relatively high temperatures requiring attention to potential salt pooling and trace heating
  - The heat exchanger and all piping are pitched downward at 3° with the horizontal to promote drainage of the salt.
- Salt Properties:
  - $LiF-BeF_2-ZrF_4-UF_4$ – Low cross section for parasitic absorption
  - Favorable thermal/radiation stability, good thermophysical properties, and no violent chemical reaction with air/water
  - Not primarily dependent upon fast acting control rods (negative temperature coefficient and low excess reactivity)
  - Requires careful chemistry control to prevent corrosion
- High power density and low fuel inventory
  - Required fuel salt processing/chemistry control and online fueling



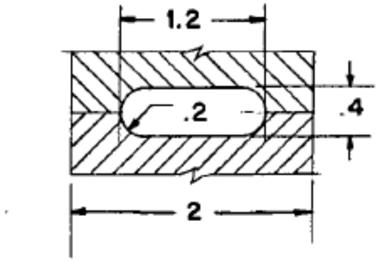
MSRE Vessel Design

The MSRE Vessel and Graphite Moderator

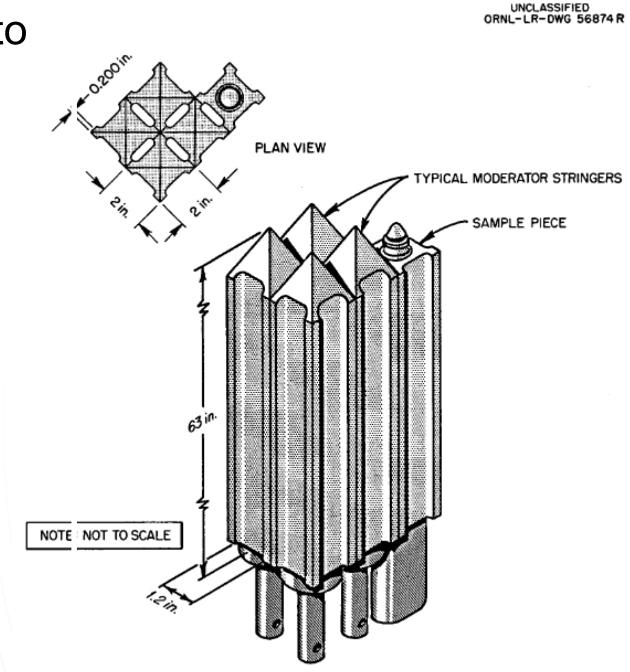
MSRE Vessel: 5 ft diameter, 8 ft tall
(20 ft^3 fuel salt and 70 ft^3 graphite)

MSRE Graphite Moderator
55 in. diameter, 64 in. tall

- The reactor core is formed of 617 2-in.×2-in. graphite stringers
  - 513 full and 104 fractional-sized blocks at the periphery
  - Upper stringer surfaces are tapered to prevent salt pooling
- Stringers are mounted in a vertical, close-packed array
  - Half-channel salt flow passages are machined in the four faces of each stringer
  - Total of 1140 fuel passages
- Graphite stringers float in salt
  - Stringer lower end in 1 in. dowels
  - Use of retainer rings to limit radial mobility (i.e., floating and thermal expansion)



TYPICAL FUEL PASSAGE



Typical Stringer Arrangement

Source: ORNL-TM-728

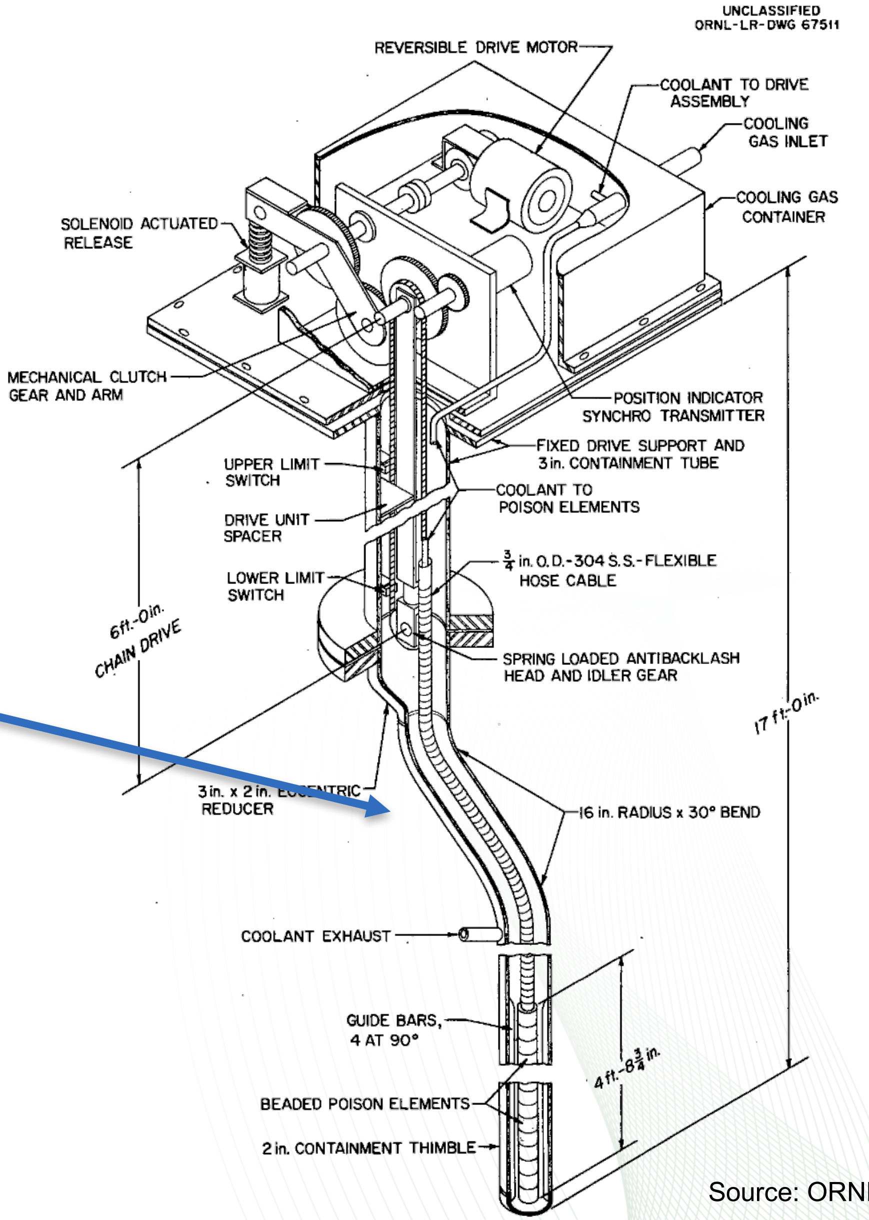
Oak Ridge National Laboratory

MSRE Reactivity Control System… not a Safety System

- 3 control rods provide adjustment for reactivity
  - Control flux at low power and dampen temperature swings at power, not required for fast-acting, nuclear safety purposes
  - Power level determined by coolant loop ΔT (via radiator blower) and flow.
  - Complete reactor shutdown accomplished by draining fuel salt
- Curved "dog-leg" guide tubes eliminate straight line of sight for radiation to control rod drive hardware through the tube
- Control rod guide tube separates control elements from direct contact with salt and go through bored graphite stringers

MSRE Control Elements
Gd_2O_3-30%Al_2O_3 bushings on flexible stainless steel hose

Source: ORNL-4123

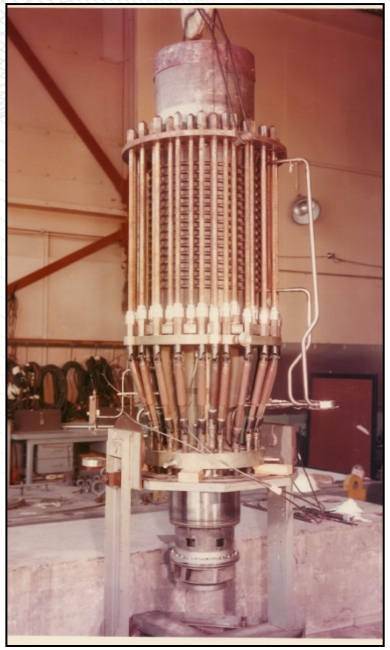


Source: ORNL-TM-728

MSRE Control Rod and Drive Assembly

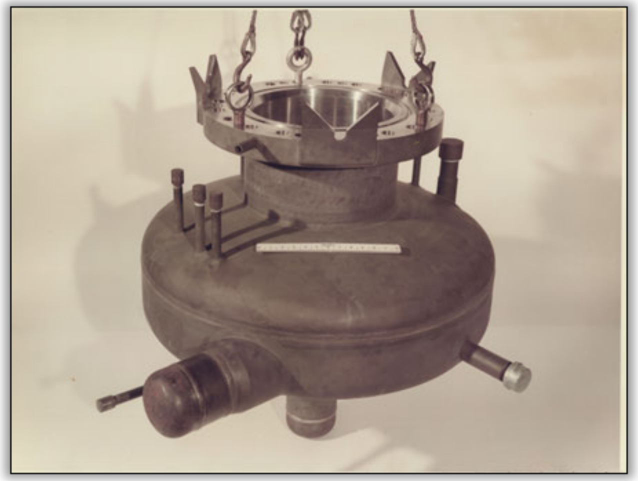
OAK RIDGE National Laboratory

The MSRE Pump Bowl Is Multi-Purpose

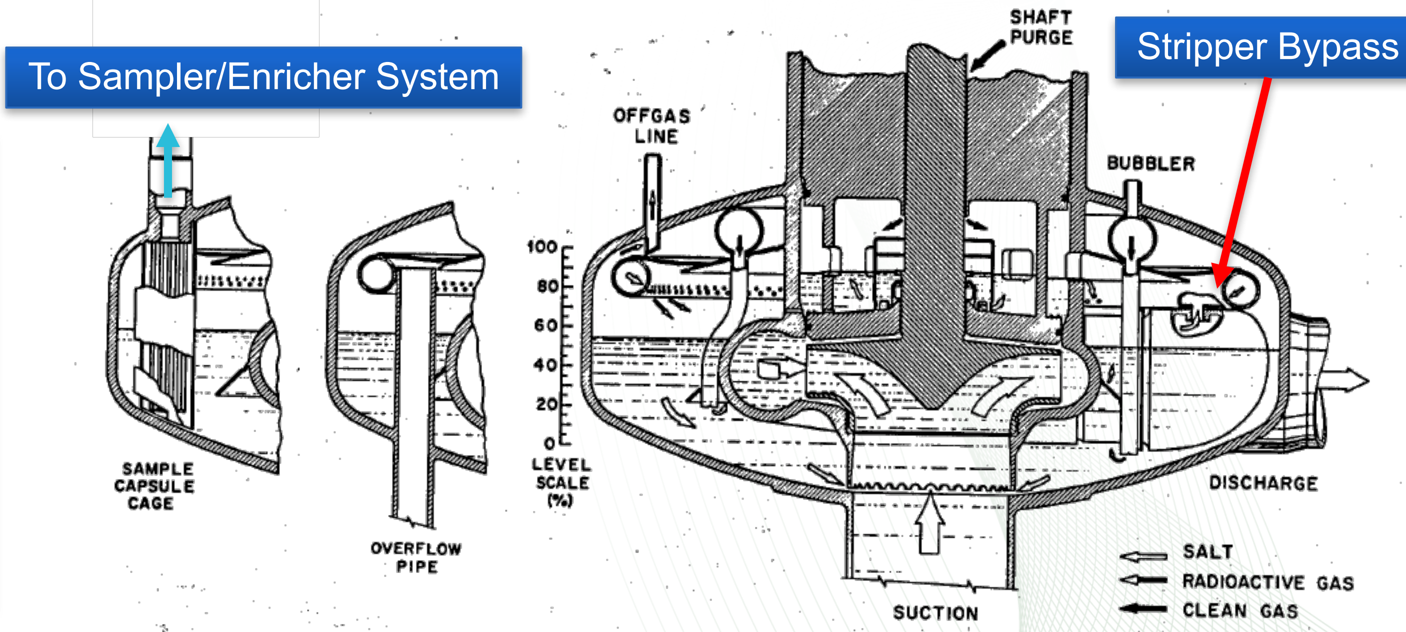


MSRE Pump with extended bolts

- Centrifugal sump-type pump with an overhung impeller and bolt extensions for remote maintenance
- Helium flows through the gas space in the bowl to sweep xenon and krypton to the off-gas disposal system
  - Protects seal from fission gases, salt mist, and tritium
  - Salt “stripper” bypass flow (~ 60 gpm) sprayed onto salt surface to improve release of fission product gasses
  - Off-gas system includes charcoal beds/holdup volume
- Sampling and fuel addition are possible through the bowl
  - Sample/Enricher system has “dog-leg” section



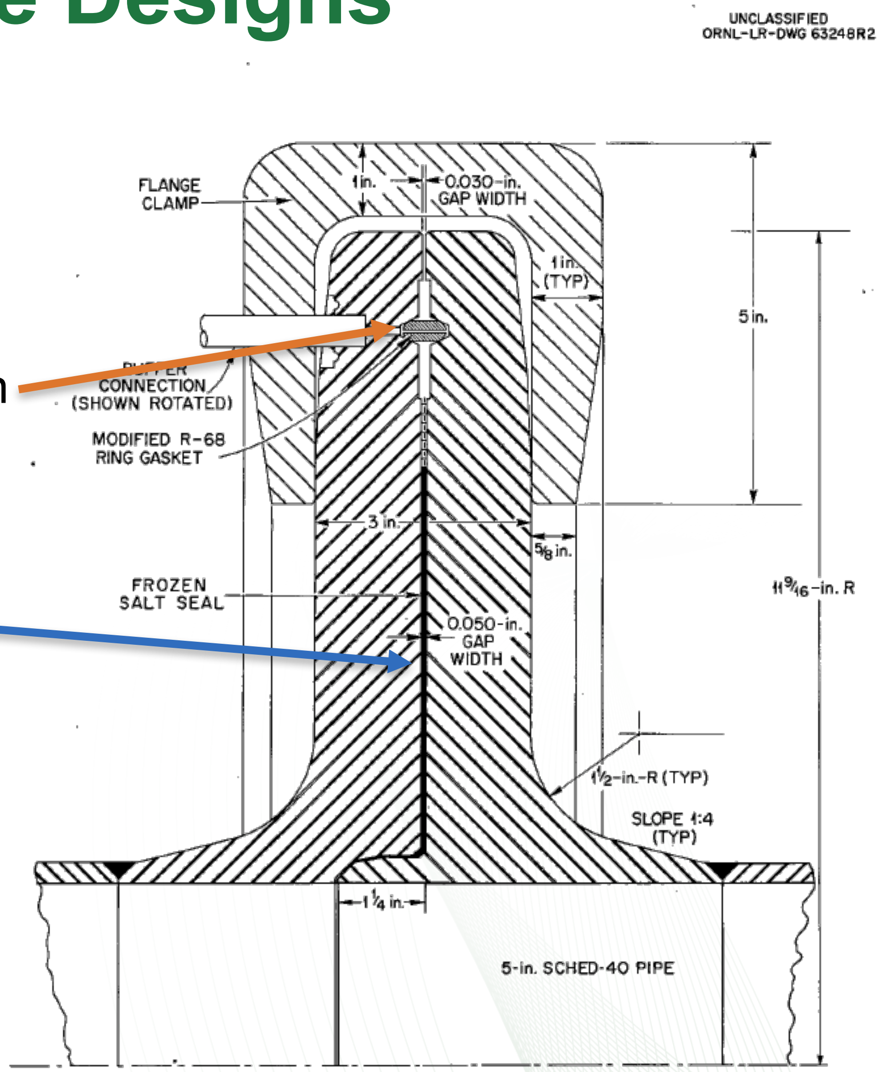
MSRE Pump Bowl



Source:
ORNL-TM-3039
ORNL-TM-728

Piping Required Special Freeze Flange Designs

- Freeze flange (Alloy-N) type
  - Create tight seal which prevents salt contact with ring-joint gasket
- Access hole at sight of gasket for helium buffer gas and leak detection
  - Two holes in nickel gasket to enable buffer gas to access both sides
- Alloy-N salt screen
  - Located in the 0.050 in. gap
  - Improves salt solidification (passively cooled)
  - Provides a convenient intact cake for salt removal during maintenance
- Clamps hydraulically seal flange
  - Affords a more constant gasket loading during thermal cycling than bolting
- Male end of clamp installed facing “uphill”
  - Limits salt pooling

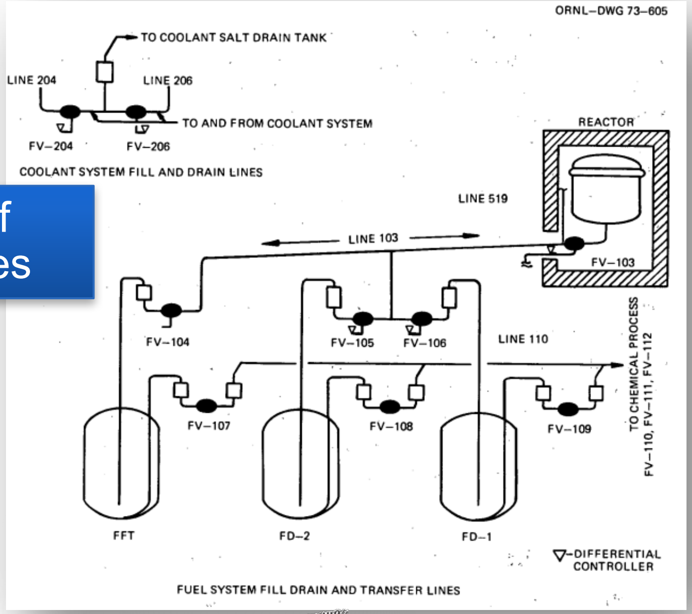


Freeze Flange and Clamp

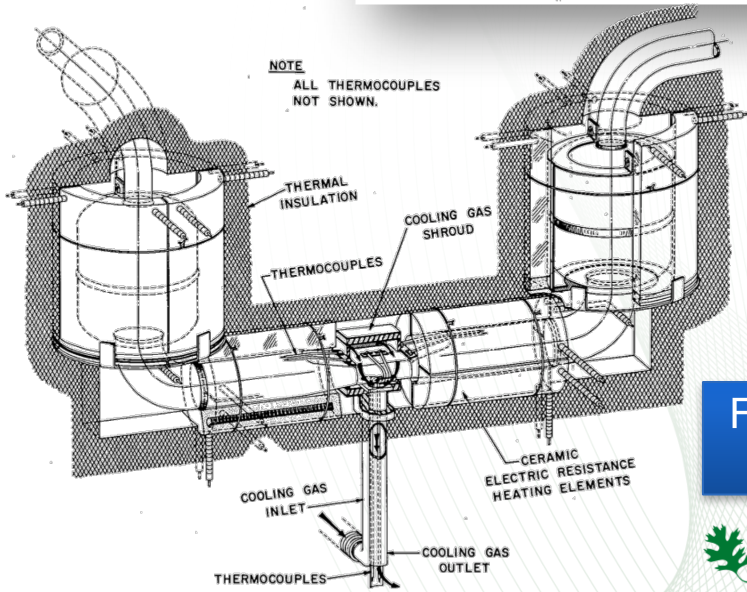
Source: ORNL-TM-728

MSRE Freeze Valves Control Flow to the Drain Tanks

- Flow of salt in the drain, fill, and processing systems is controlled by freezing or thawing a short plug of salt
  - 12 freeze valves located throughout the plant
- Freeze valves preferred since reliable mechanical closure valve unavailable
  - Development began in 1960
  - 1.5 in. pipe flattened for a length of ~ 2 in.
  - Installed with flat surfaces horizontal (avoid air pockets)
  - Operations not hampered by “slow” response and lack of “off-on” functionality
- Three operational modes
  - Deep frozen: heaters adjusted to maintain 200–260°C without cooling air
  - Thawed: heaters adjusted to maintain 650°C without cooling air (active: ~1-2 min., passive: ~10 min.)
  - Frozen: Heaters remained in thawed condition but cooling gas flow adjusted to hold just frozen to allow for rapid thaw
- Draining a small amount of fuel salt shuts down the reactor
  - Complete fuel salt drain in approximately 30 minutes



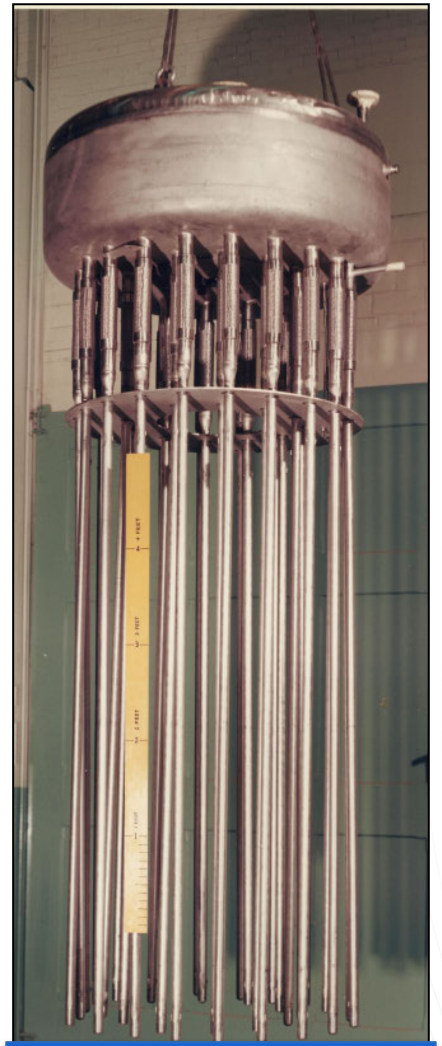
Location of freeze valves



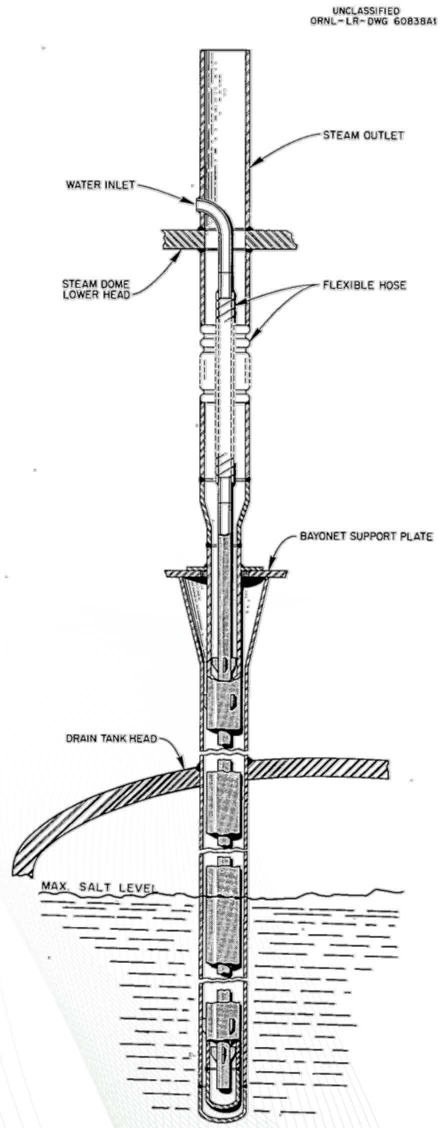
Freeze valve schematic

MSRE Drain Tanks Provide Passive Safety

- Five tanks are provided for safe storage of the salt mixtures
  - Two fuel-salt drain tanks
    - One tank can hold entire fuel salt inventory in non-critical state
  - One flush-salt tank
    - No fissile material
    - Used to wash fuel circulating system
  - One coolant-salt tank
  - One for storage and reprocessing
- Decay heat removed by boiling water in bayonet tubes in the fuel-salt drain tanks
  - Passively cooled fuel salt
  - Steam condensed in an air-cooled condenser and gravity fed back to drain tanks



Array of bayonets for fuel drain tanks



Bayonet tube schematic

Source: ORNL-TM-728

A Few Takeaways…

The MSRE…

- … was an all-encompassing, mature research project with extensive testing and documentation
- … successfully demonstrated numerous technologies and techniques for high-temperature molten salt applications
  - The topics covered in this presentation only scratch the surface of the various design features and facilities that went into the MSRE
- … technologies are foundational to modern MSR designs
- … demonstrated that MSRs are indeed *practical* to be constructed and able to be operated *safely and reliably*

Thank you