MSRE Operation Highlights

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MSRE Operated Remarkably Successfully for a First of a Kind Reactor

- First criticality to conclusion of nuclear operation spanned 4.5 years
  - Salt operations began 9 months prior to criticality

Effective full power	Total	13,172 h
	^{235}U	9,005 h
	^{233}U	4,167 h
Fuel salt circulation time		21,788 h
Coolant salt circulation time		26,076 h
Availability during planned reliability testing period (final 15 months with ^{235}U)		86%
Availability during final runs	^{235}U	98.6%
	^{233}U	99.9%

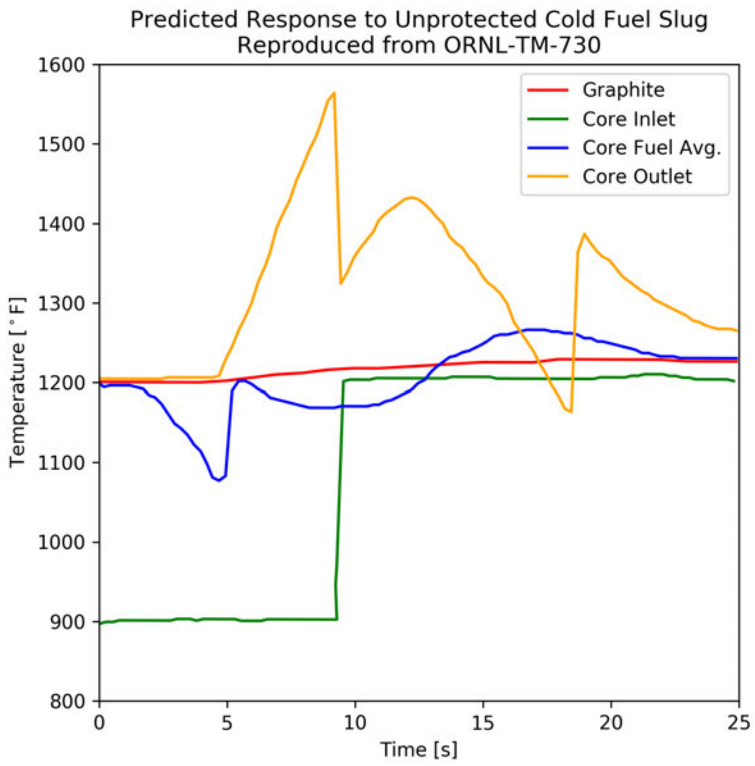
So far the Molten Salt Reactor Experiment has operated successfully and has earned a reputation for reliability.
USAEC Chairman
Glenn T. Seaborg

Source: ORNL-TM-3039

- Essentially no difficulties were encountered with the primary system during operation

MSRE Designers Employed Computational Models to Solve Coupled Neutron and Fuel Salt Transport Equations

- MURGATROYD code logic was developed and validated for Aqueous Homogeneous Reactor design
  - Extended to provide separate graphite heat capacity
  - Single point, single energy group, seven delayed neutron precursor groups
  - Employed for both design and safety calculations
  - Beta effective based upon the fraction of the time fuel in the core
- ZORCH code developed that includes axial spatial dependence in fuel and graphite temperature to more accurately represent transient responses
  - Shows that no damage would be anticipated even for unrealistic transients
  - Maximum fuel temperature anticipated ~850 °C (< 5 seconds) for unprotected cold slug addition
- Equipoise 3A code performed 2D, two group diffusion calculations for steady state power distribution and reactivity coefficients

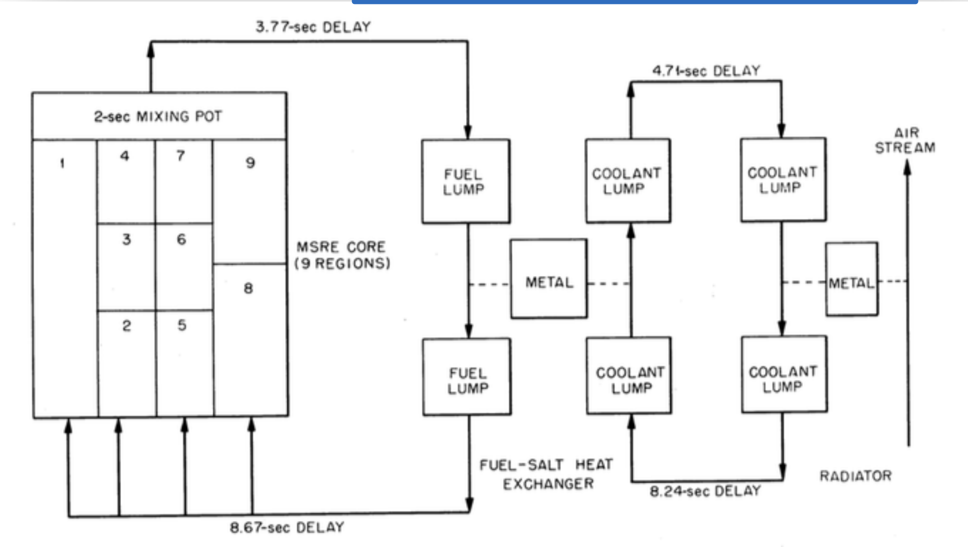


Temperature prediction for unprotected cold slug accident

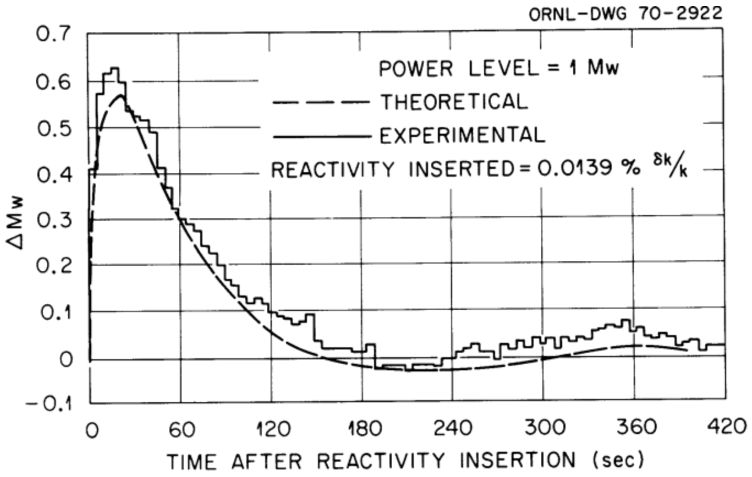
Dynamic Stability Tested at Low Power Before Full-Power Operations Began

- Dynamic plant model predicted stable operation – which was confirmed using low power testing
  - 44th - order system matrix with 4 time delays for heat convection and 6 time delays for precursor circulation
  - Solved with MATEXP Code
- Main conclusion – system has no operational stability problems and its dynamic characteristics were as predicted

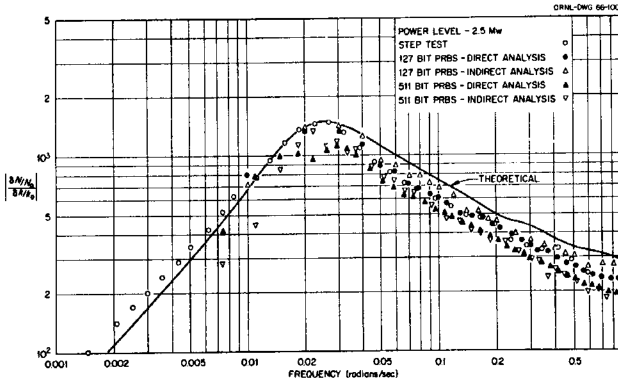
MSRE Reference Model

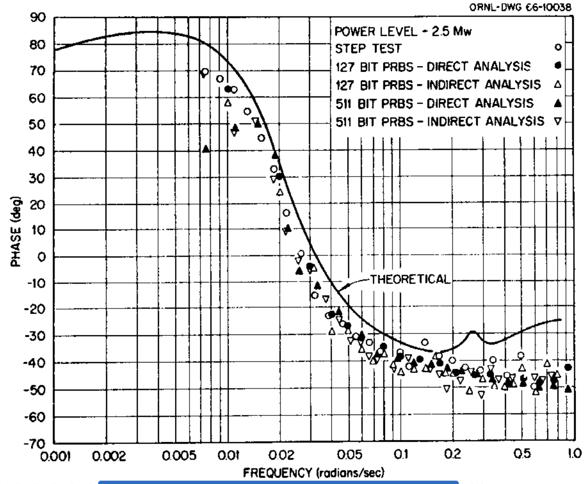


Source: Kerlin, Ball, and Steffy, Nuc. Tech. 10, 1971



Source: ORNL-TM-2997

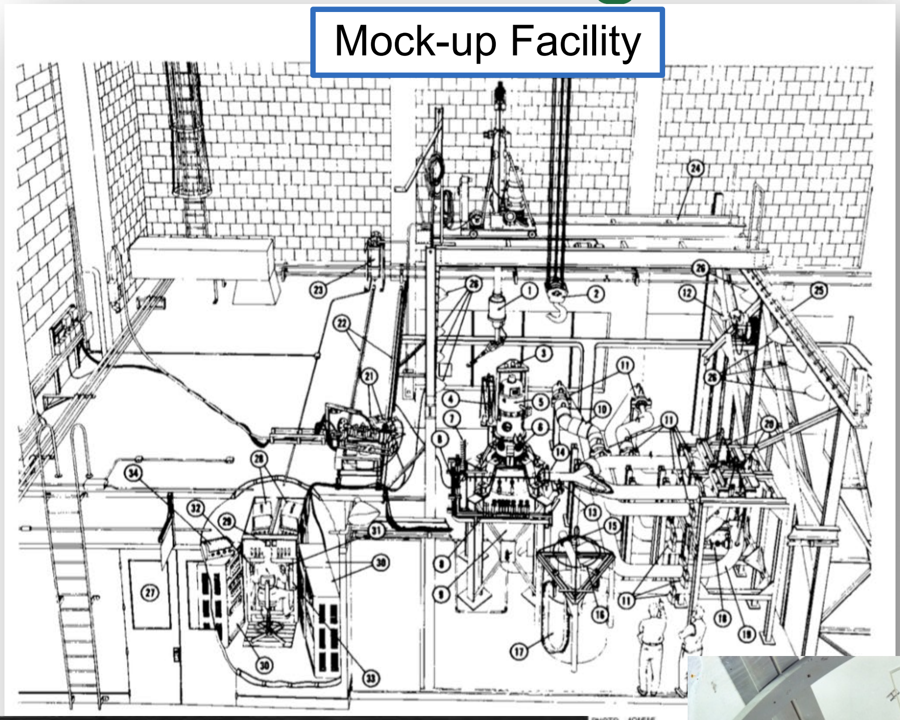




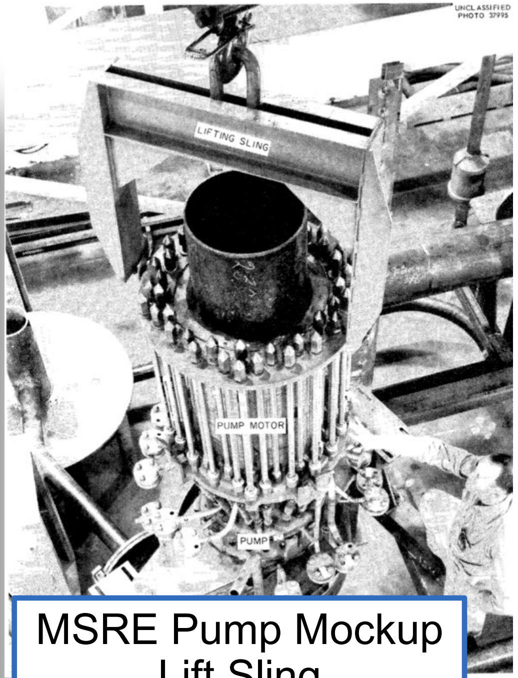
Source: ORNL-TM-1647

Extensive Remote Maintenance Planning and Demonstration

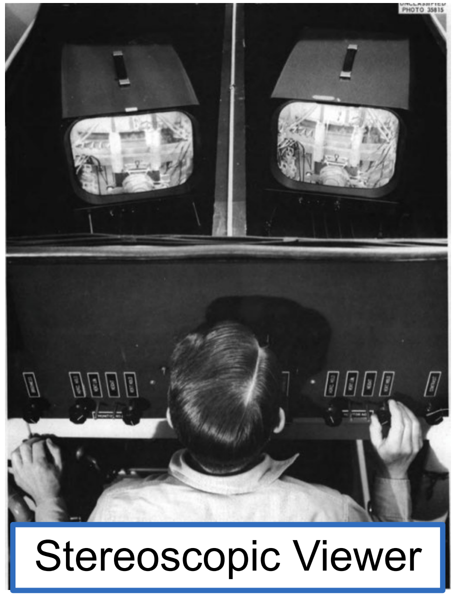
- Remote maintenance mock-up facility created
  - 650°C mock-up of 20 MWt MSR
  - Tools, techniques, and procedures for replacing all major components including heat exchangers, fuel pumps, reactor core vessel, pipe preheaters, and piping sections developed and demonstrated



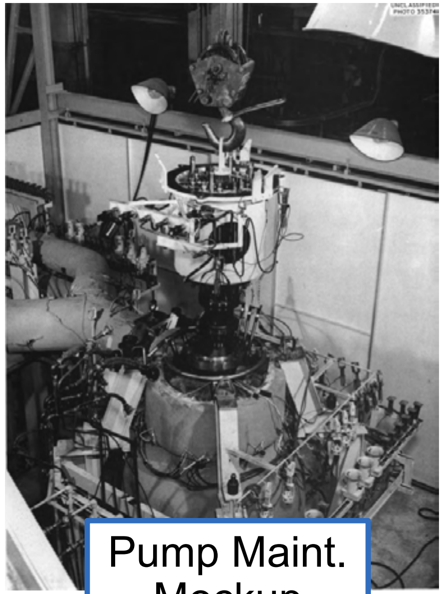
Mock-up Facility



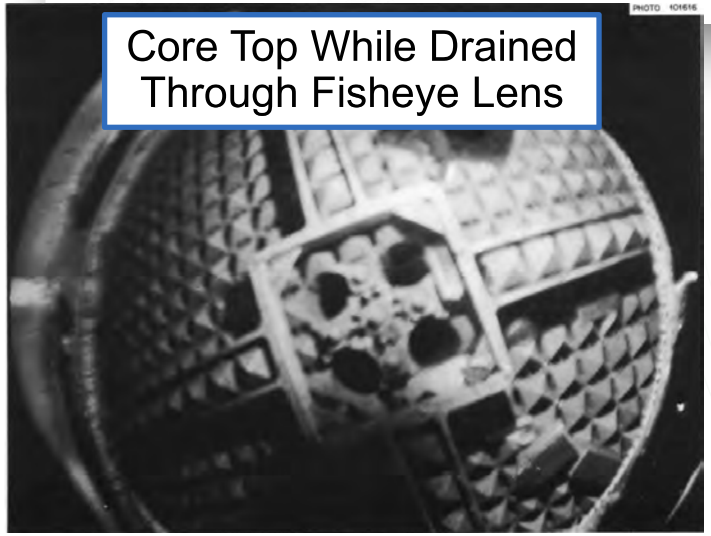
MSRE Pump Mockup Lift Sling



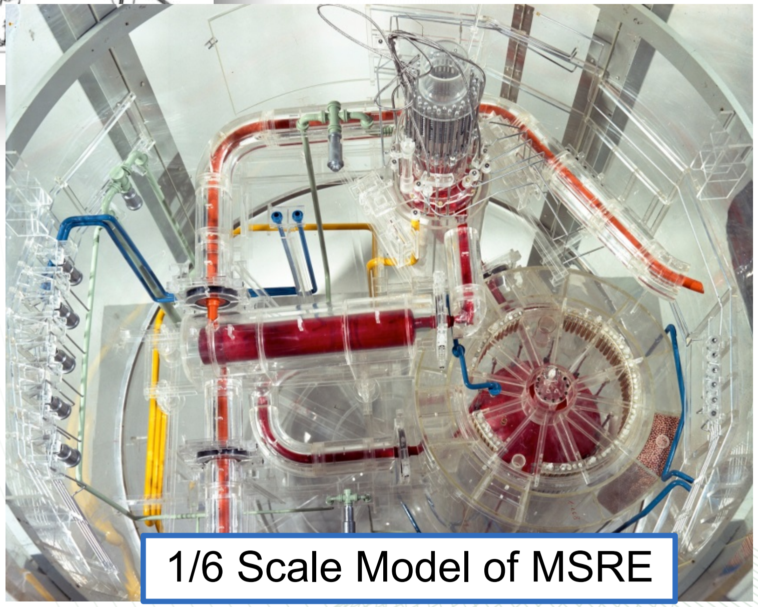
Stereoscopic Viewer



Pump Maint. Mockup



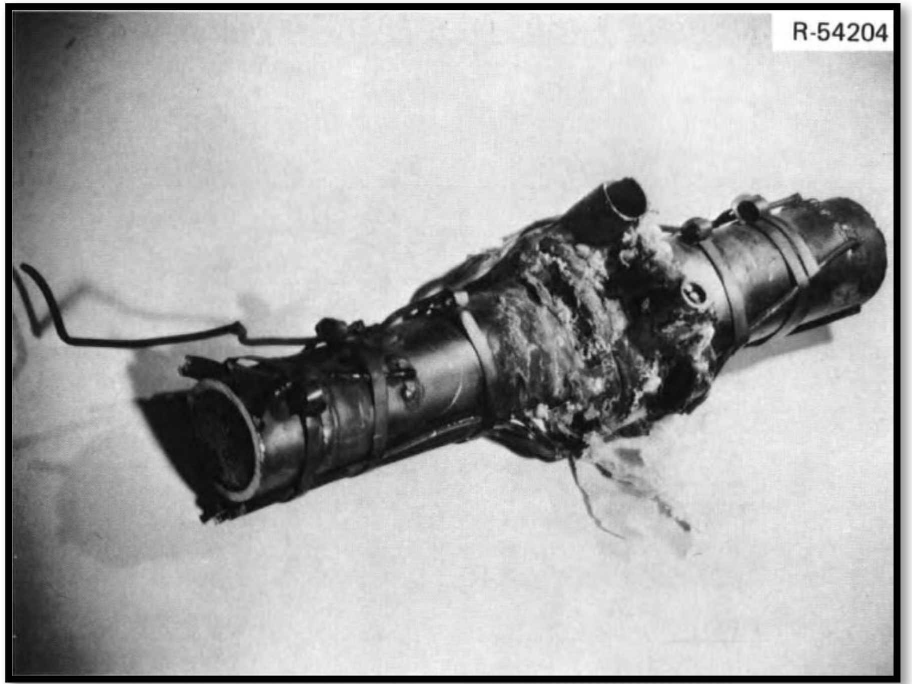
Core Top While Drained Through Fisheye Lens



1/6 Scale Model of MSRE

MSRE Did Encounter Issues During Operation

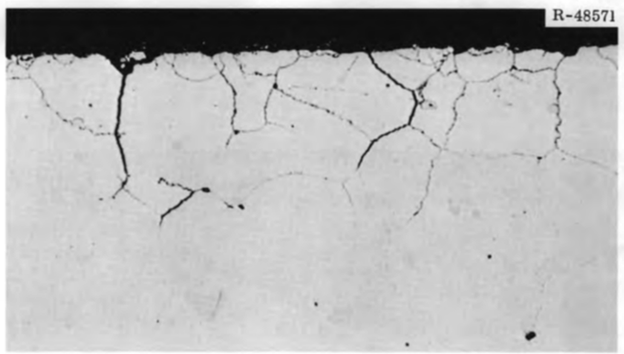
- Reactor vessel progressively embrittled due to neutron damage
  - Thick reflector recommended
- Drain tank isolation freeze valve cracked during its final cycle due to a field modification
  - Stiffening the air-cooling housing prevented pipe flexing
  - Xenon, iodine, krypton, and noble metals detected in reactor cell
- Pump-entrained gas caused sporadic (about 10 times/h) increases in reactor power (~5–10%) for a few seconds
  - Addressed by changing pump frequency
- Fuel-salt contacting materials
- Small, continuous leak of lubricating oil into fuel pump caused issues
- Control rod failed scram test due to snagging on thimble



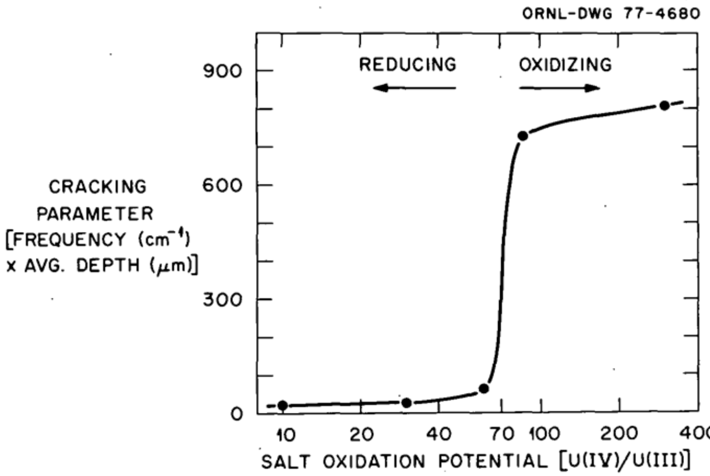
Bottom of cracked freeze valve

Salt-Wetted Alloy N Surfaces in MSRE Exhibited Tellurium-Assisted Surface Cracking

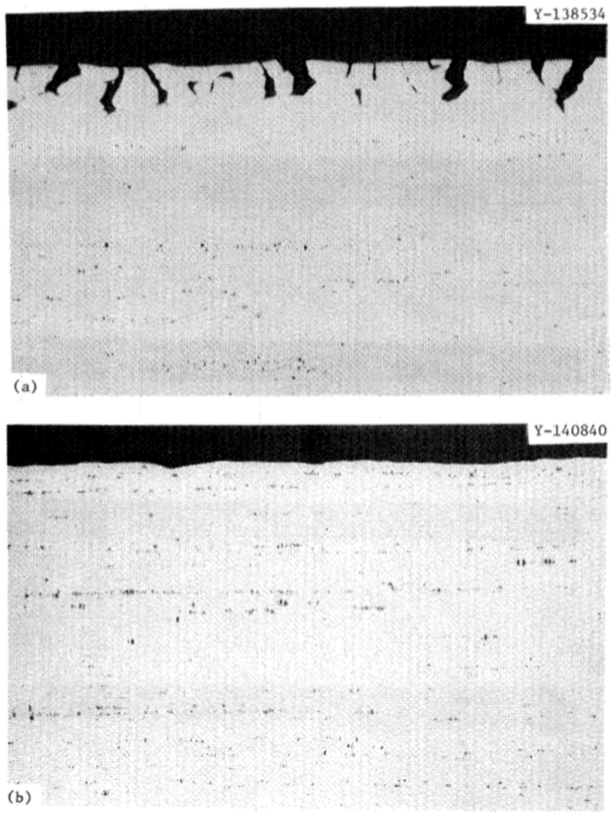
- Would be unacceptable for multi-decade lifetimes for thin-walled components
- Tensile testing of Alloy N surveillance specimens from the MSRE produced cracks in the grain boundaries connecting to the salt-exposed surfaces containing tellurium
- Intergranular embrittlement can be reduced by adding 1–2% niobium to Alloy N or by maintaining the salt in reducing conditions



Typical microstructure of Alloy N after exposure to MSRE core for 22,533 h at 650°C – 500x



Reducing condition improves performance



Alloy N exposed to MSRE fuel salt (500 h, 700°C) containing tellurium (a) oxidizing, (b) reducing – 100x

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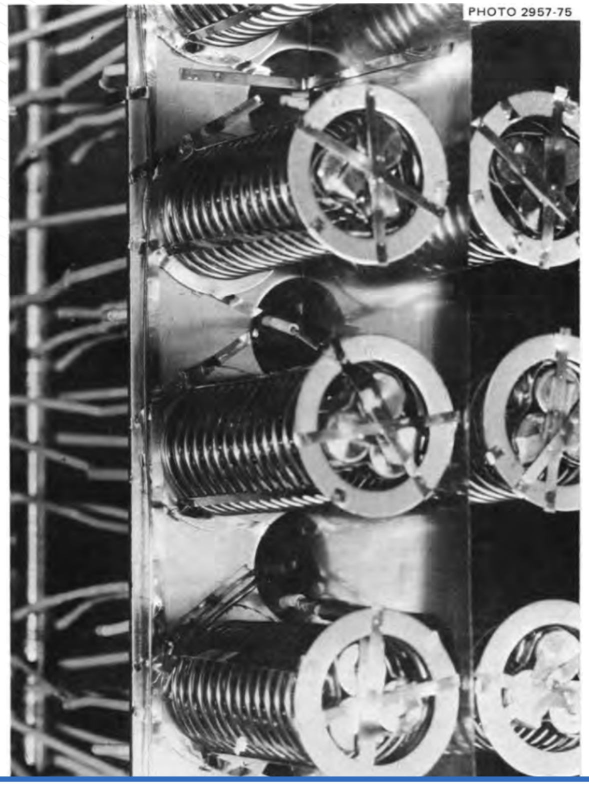
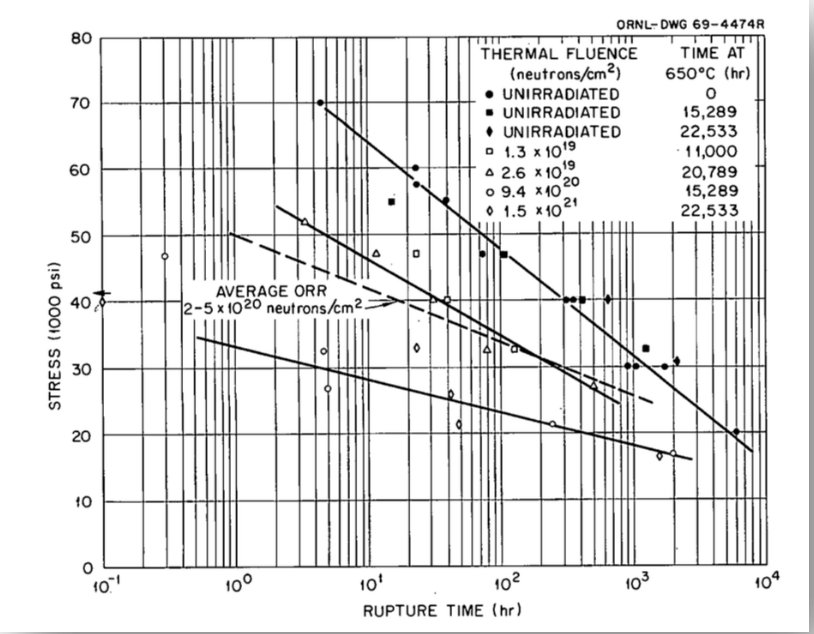
Niobium-Modified Alloy N Was Developed in Response to MSRE Embrittlement

All niobium-modified Alloy N specimens irradiated at 650°C had rupture lives in excess of those of standard unirradiated Alloy N

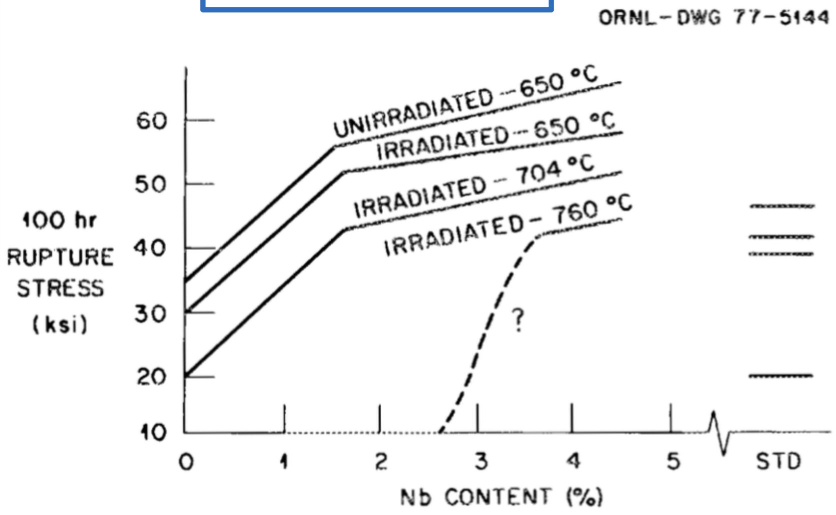


Cluster of modified Alloy N creep specimens prior to irradiation



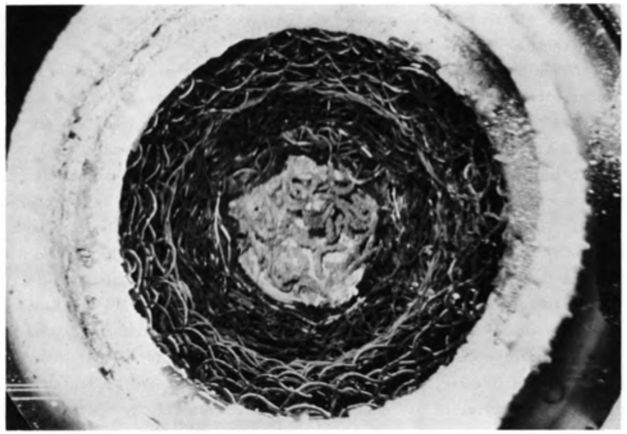
Stress rupture properties of MSRE surveillance specimens

Influence of Nb on stress rupture properties

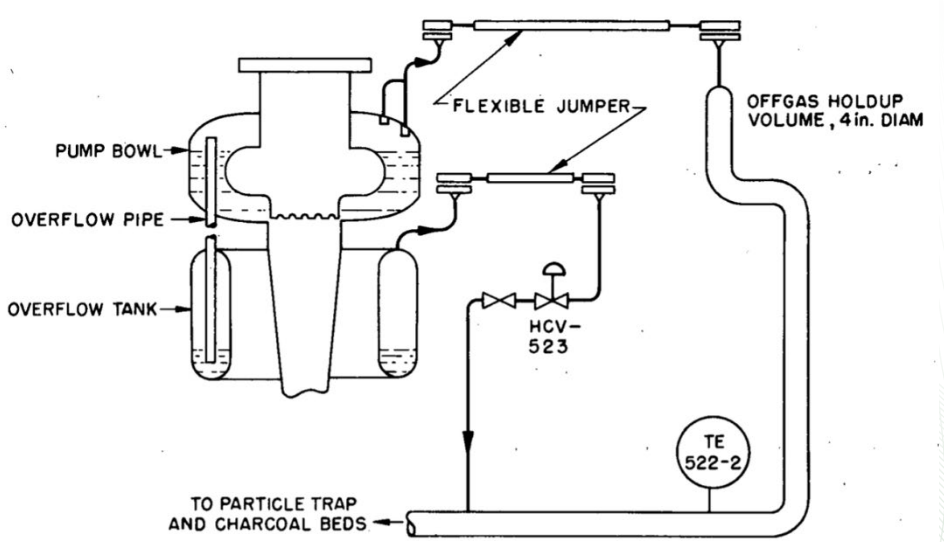


Offgas System Posed Challenges Due to Plugging Exacerbated by Oil Leak

- Lubricating oil leaking from pump seal caused issues with filters, check valves, and control valves
- Hydrocarbons tended to have gaseous fission products stick to them and in turn deposit on the particle filters thus clogging the system
- Problem was substantially reduced by employing a larger (15 versus 10 cm diameter), redesigned particle trap
- Key recommendation: Avoid use of hydrocarbon lubrication in all salt-connected systems



MSRE Mark 1 Offgas Particle Trap



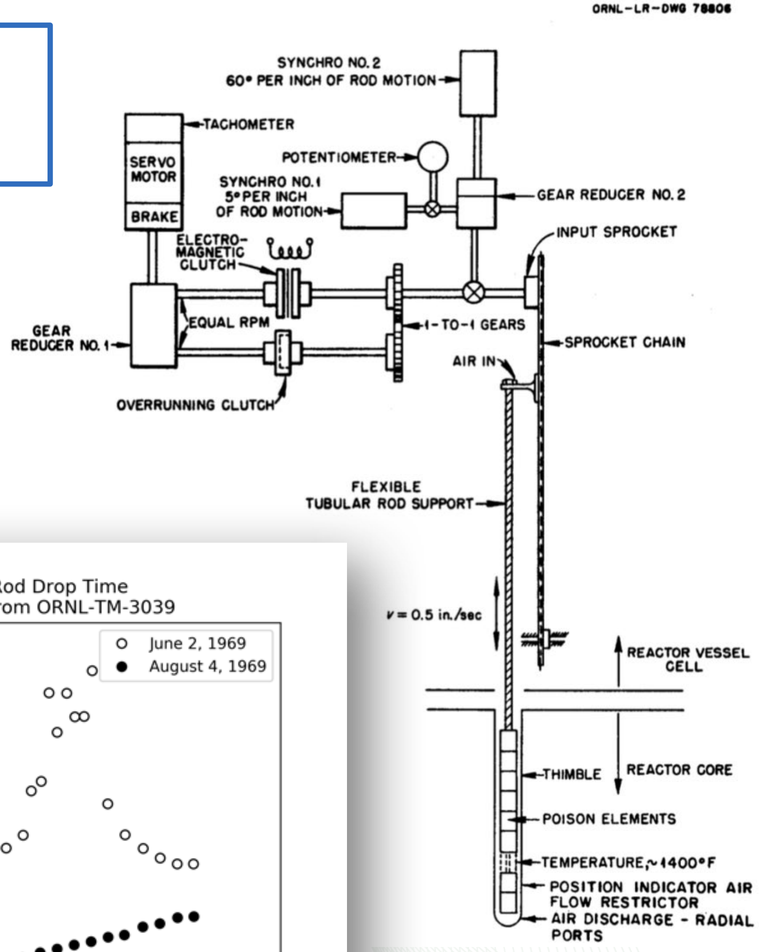
Offgas Piping Near Pump and Overflow Tank

Source: ORNL-TM-3039

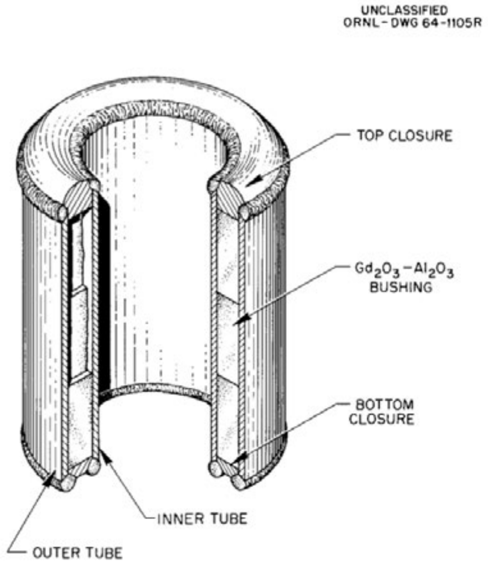
Absorber-Based Control System Performed Well

- Over 3000 scram tests performed with only one failure
  - Rod 3 stuck at 35 inches in channel
- Experimental ‘rod-jogger’ stuck control rod in out position during a *pseudo random binary sequence* test
  - Power level ramped up then decreased without intervention
- Mechanical wear was resulting in progressively longer drop times
  - Rods were used to shift power levels, to compensate for fission product buildup, and for fueled shutdown

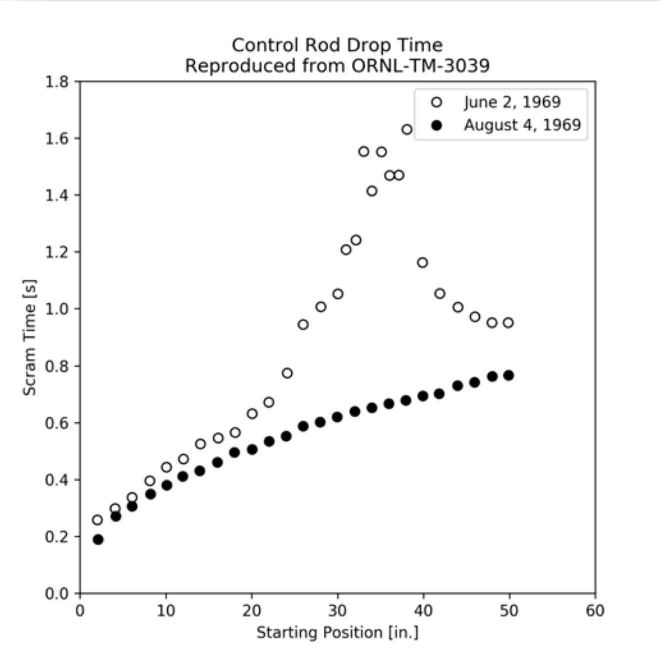
Absorber control schematic



Absorber element section



Stuck element and normal drop



Historic MSR Program Provided Substantial Experience to Support Future MSRs

- Very positive reactor operating experience
  - Computational models used to predict performance
  - Scale mockups and experiments critical to success
  - Adequate solutions to materials and operational challenges were demonstrated
- Extensive experimental base provides confidence that fluoride salt interactions and operations are adequately understood
  - Remaining issues for thermal spectrum fluoride salts are in system scale-up and modernization (i.e., automation for maintenance)