

A Brief History of Molten Salt Reactors

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First a Couple of Quotes That Point to the Origins of the Molten Salt Reactor Concept

There were two people at the [Manhattan Project] metallurgical laboratory, Harold Urey, the isotope chemist, and Eugene Wigner, the designer of Hanford, both Nobel Prize winners who always argued that we ought to investigate whether chain reactors, engineering devices that produced energy from the chain reaction, ought to be basically mechanical engineering devices or chemical engineering devices. And Wigner and Urey insisted that we ought to be looking at chemical devices—that means devices in which the fuel elements were replaced by liquids.

The Proto-History of the Molten Salt System

Alvin M. Weinberg, *Former Director, Oak Ridge National Laboratory*

February 28, 1997

Two very different schools of reactor design have emerged since the first reactors were built. One approach, exemplified by solid fuel reactors, holds that a reactor is basically a mechanical plant; the ultimate rationalization is to be sought in simplifying the heat transfer machinery. The other approach, exemplified by liquid fuel reactors, holds that a reactor is basically a chemical plant; the ultimate rationalization is to be sought in simplifying the handling and reprocessing of fuel.

At the Oak Ridge National Laboratory we have chosen to explore the second approach to reactor development.

R.C. Briant & Alvin Weinberg, "Molten Fluorides as Power Reactor Fuels,"
Nuc. Sci. Eng, 2, 797-803 (1957).

History of the Development of The MSR

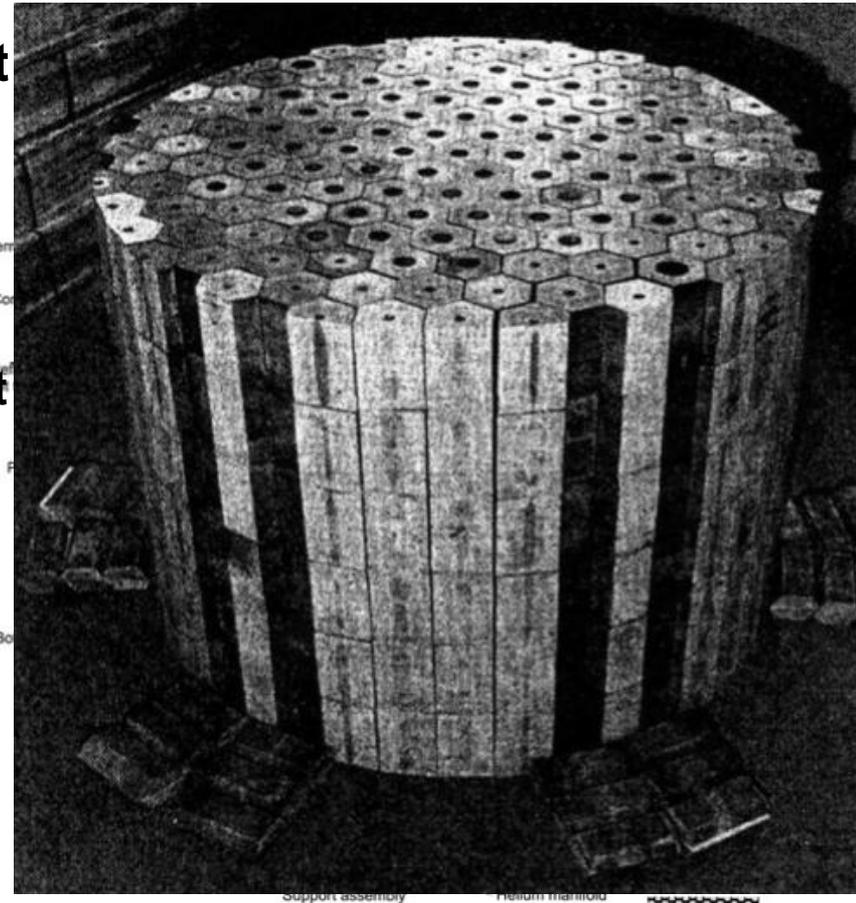
HISTORY: Molten Salt Reactor Technology Has 50-yr Development History at ORNL

- Originally proposed by Ed Bettis and Ray Briant of ORNL in late 1940's
- Aircraft Nuclear Propulsion Program (1946 – 1961)
 - Aircraft Reactor Experiment (1953 – 1954)
 - Aircraft Reactor Test (1954 – 1957)
- Experimental Molten Salt Fuel Power Reactor (1960)
- Molten Salt Reactor Experiment (1960 – 1969)
- Molten Salt Demonstration Reactor
- Molten Salt Breeder Experiment (1970 – 1976)
- Molten Salt Breeder Reactor (1970 – 1976)
- Denatured Molten Salt Reactor (1976-1980)
- Generation-IV MSR (Today)
- Liquid Salt Cooled Reactor (Today)

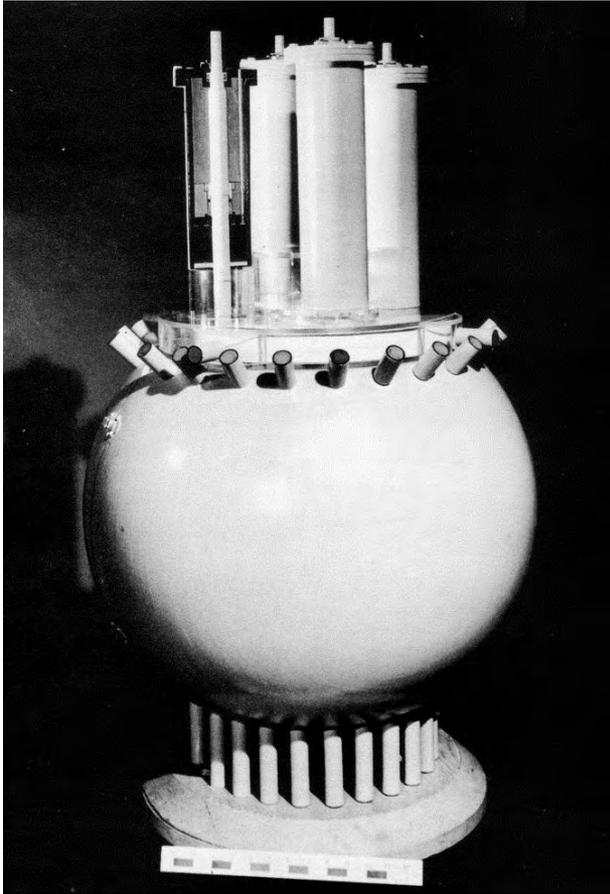
Molten Salt Reactors Were Among the First Successful Reactor Demonstrations

- Molten Salt Reactors were being developed at the same time as the AHR at ORNL and the Liquid-Metal Reactor at BNL
- The first MSR was developed to support the Aircraft Nuclear Propulsion program
 - Initial reactor the Air Craft Reactor Experiment provided initial technology push
 - Proposed to overcome issues with solid fueled reactors at high temperatures (e.g. positive reactivity coefficient from Xenon)
 - Very early demonstration of technology, operated for 100 MWh over nine days in November 1954
 - Considered successful, but did have issues with leaking radioactive gases
- ANP ended in 1961, but civilian program had already been launched.

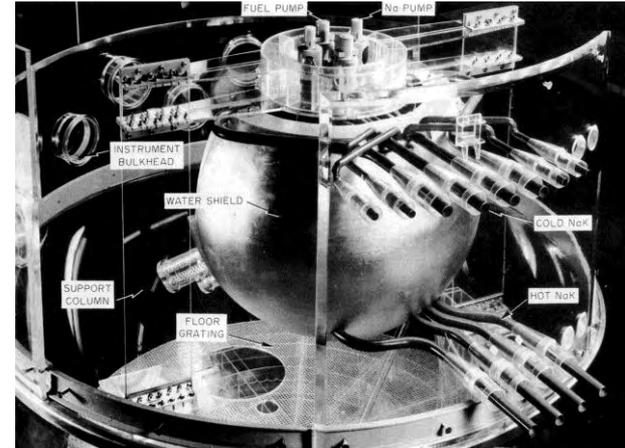
Aircraft Reactor Experiment



ART Facility Construction and Engineering Test Unit Fabrication Were Near Completion When ANP Program Was Cancelled In 1961



Full-Scale ART Model



Full-Scale ART Model



ART Building

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ORNL Matured Thorium-Fueled- MSR Through The Development of Three Distinct Concepts

Two-Fluid MSBR

- Fertile/Fissile salts separate
- Simpler salt processing
- More complex core design
- Modular Design
- Ultimately dropped by ORNL

Single Fluid MSBR

- **Mixes fissile/fertile into single salt**
- **Complex salt processing**
- **Simpler core design**
- **Reference MSBR concept at end of program**

Denatured MSR

- Developed in response to mid-70s proliferation concerns
- Once-through design (no processing)
- Keeps uranium in LEU form
- Requires LEU uranium support

Civilian Applications of MSR Were Also Being Developed: MSBR'58 Reactor Plant Isometric

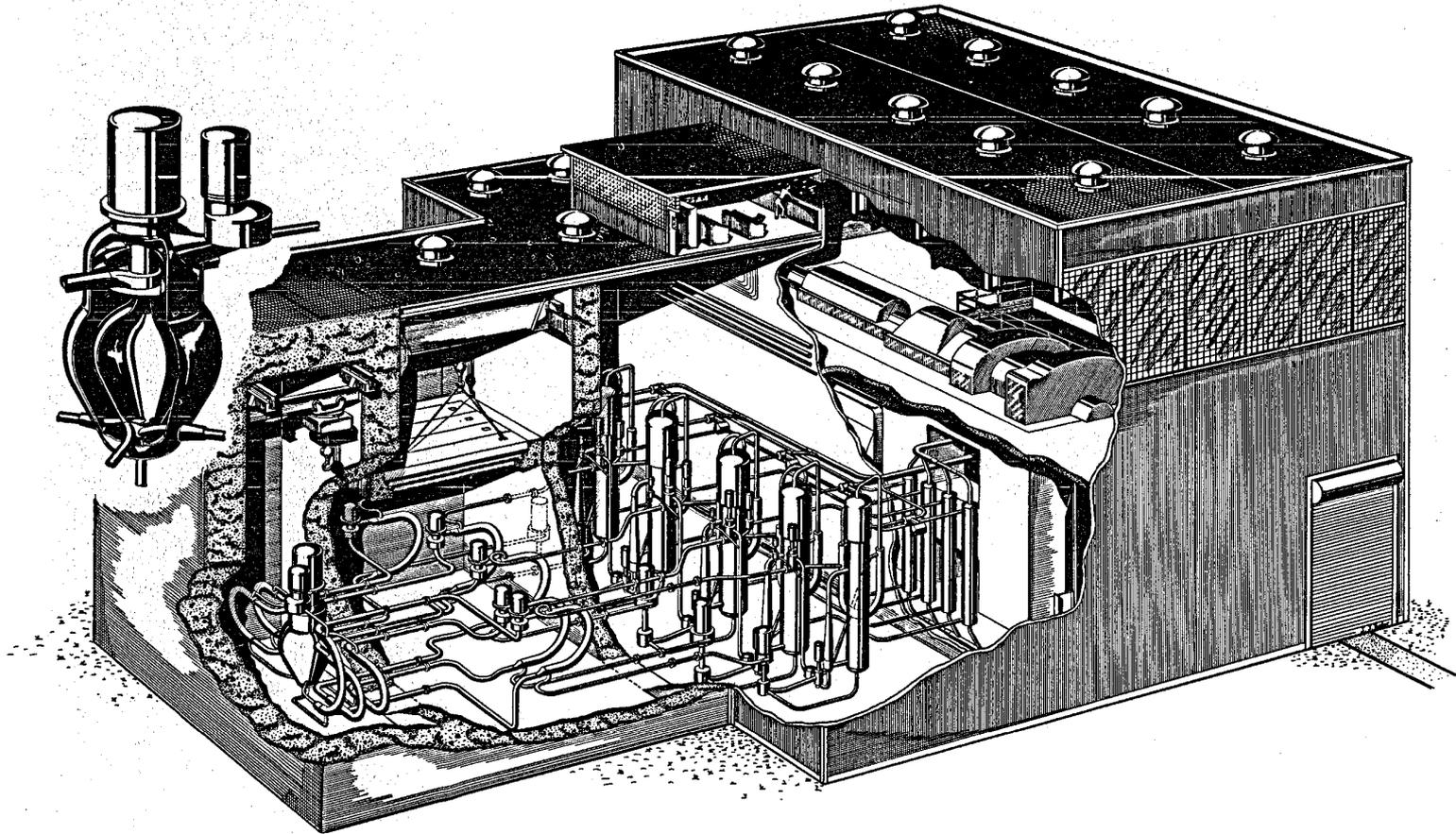
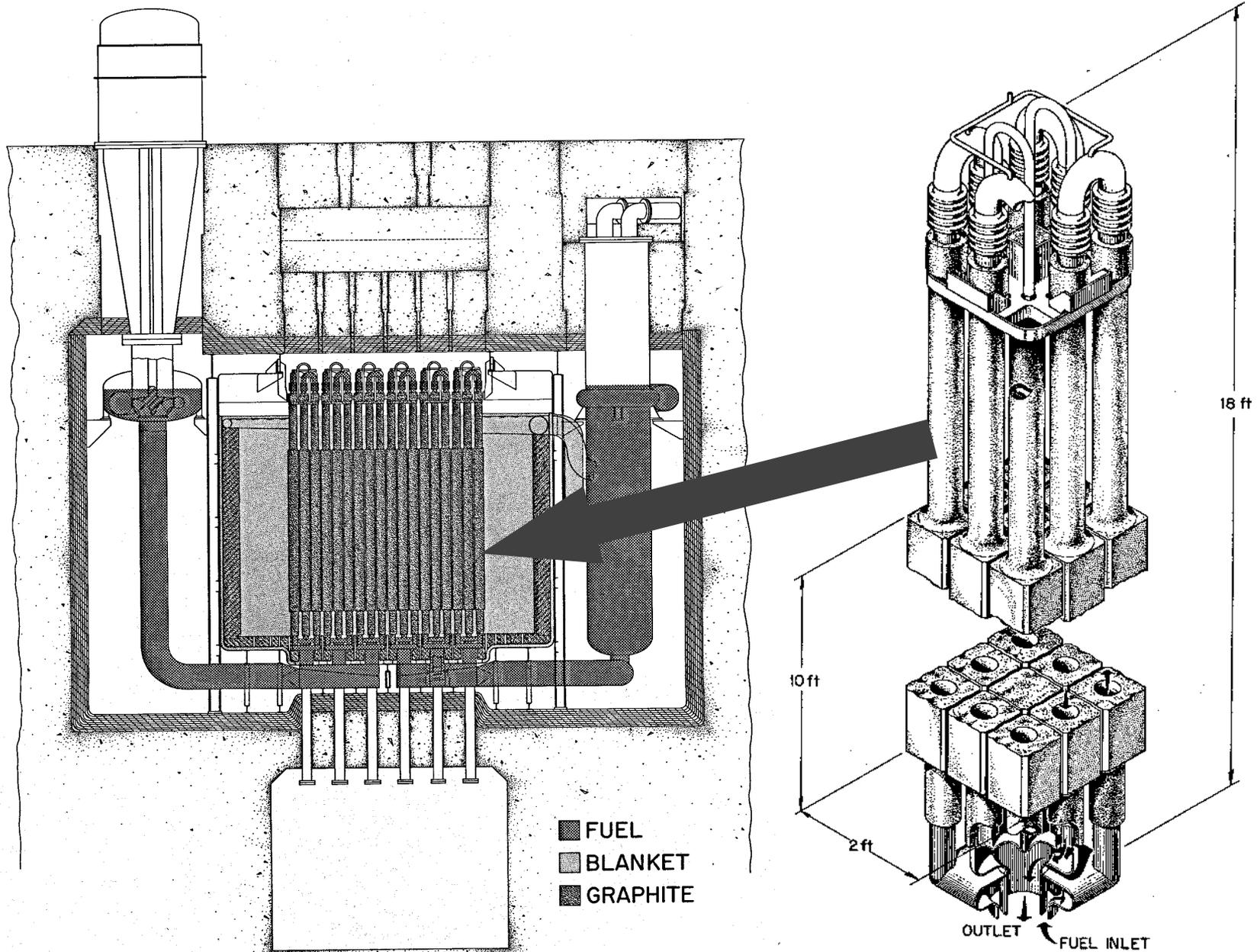
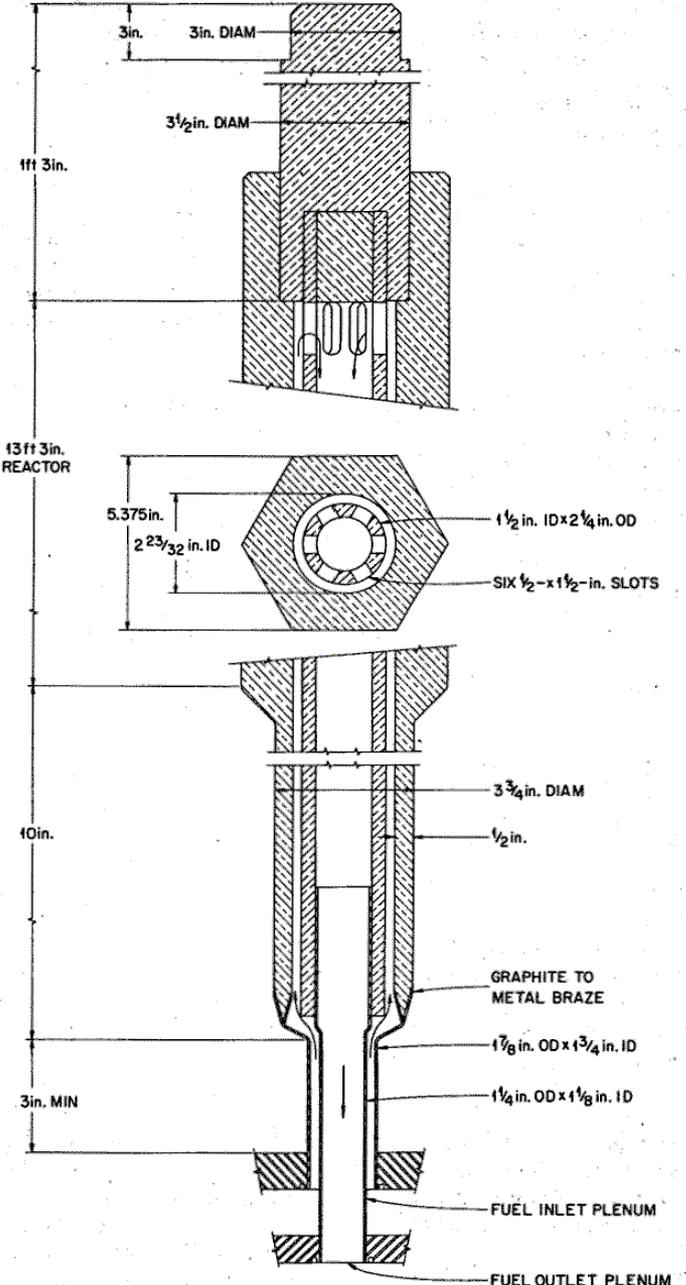
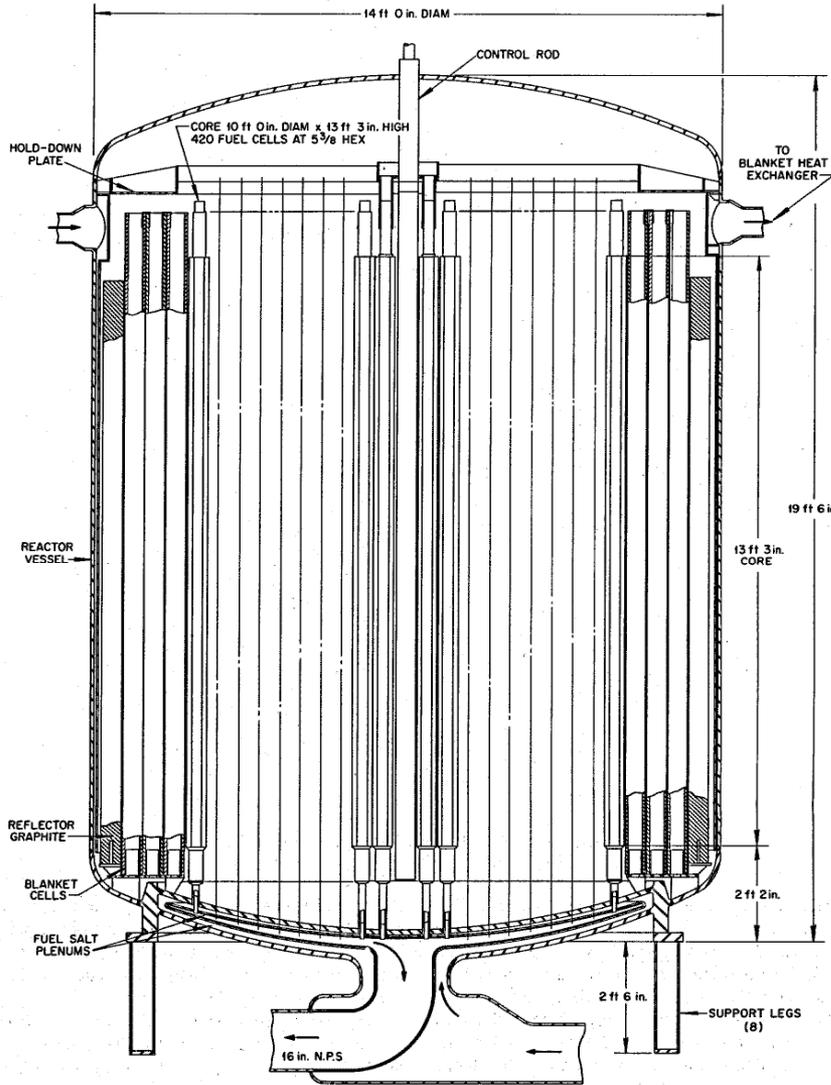


Fig. 1.1. Isometric View of Molten Salt Power Reactor Plant.

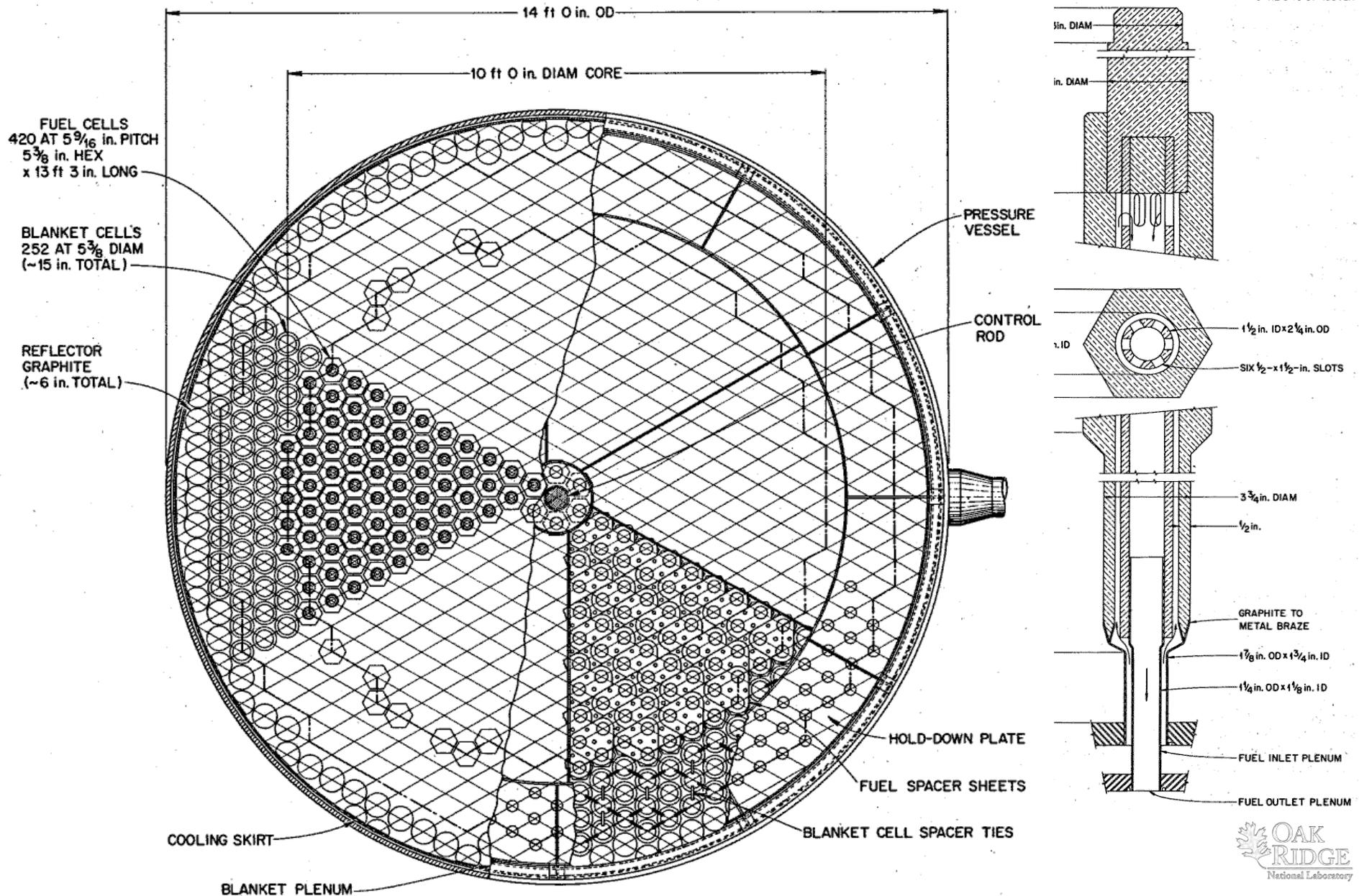
Two-Fluid 1000-MWe MSBR: July 1964



Two-Fluid 250-MWe MSBR: August 1967

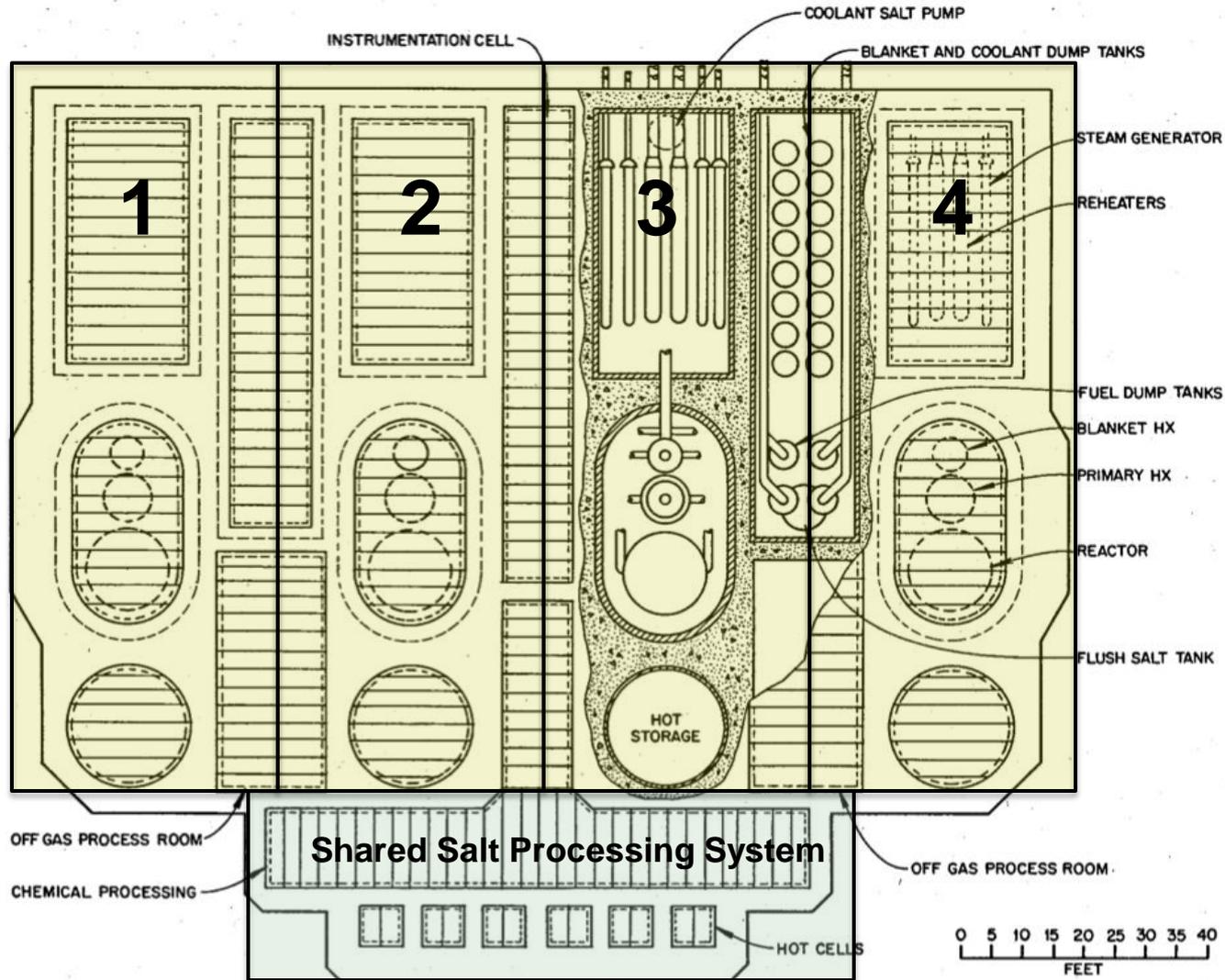


Two-Fluid 250-MWe MSBR: Core Design



An MSR-SMR: Plant Design with 4x250MWe Modules

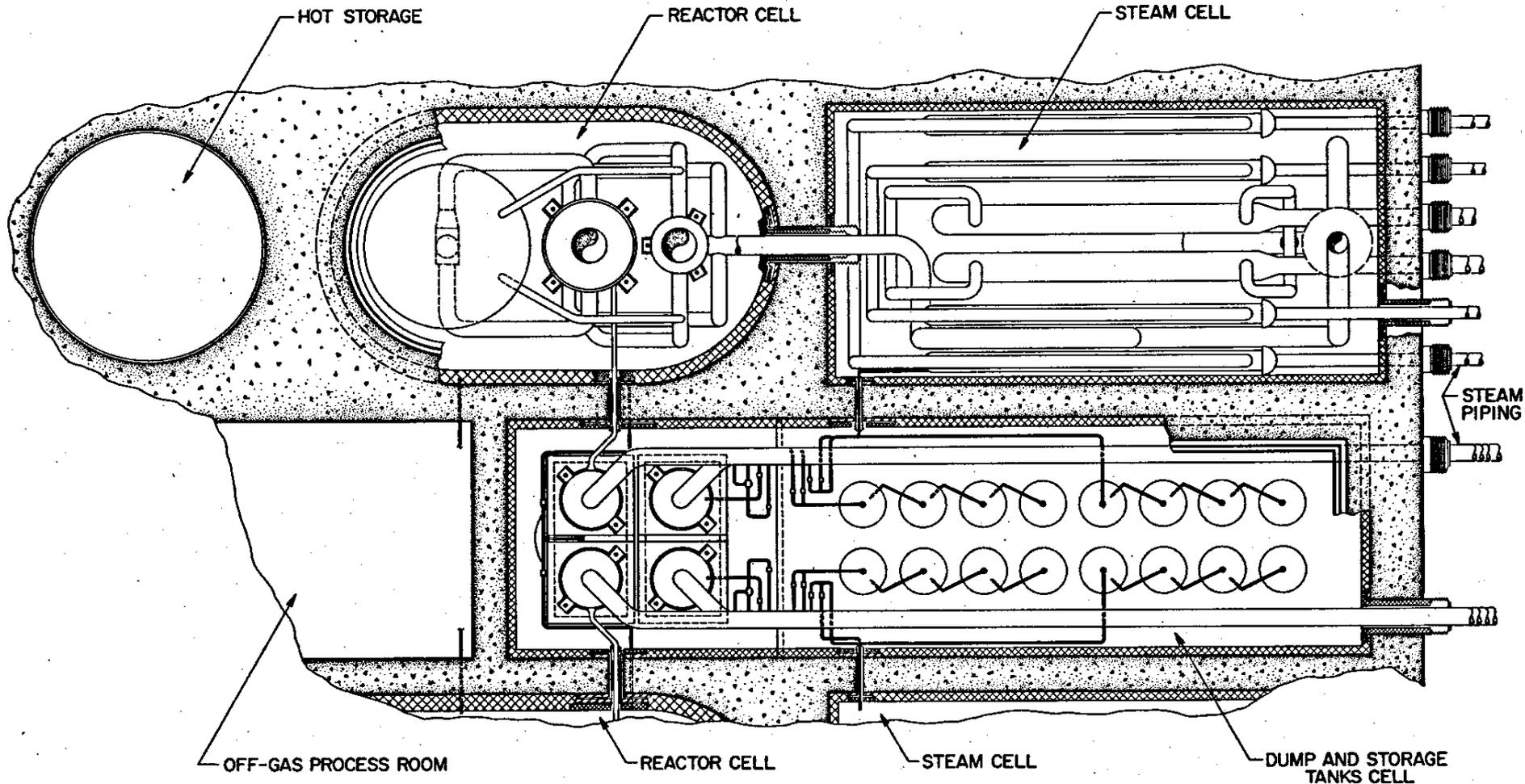
ORNL-DWG 68-28A



250-MWe MSBR Module Design Detail

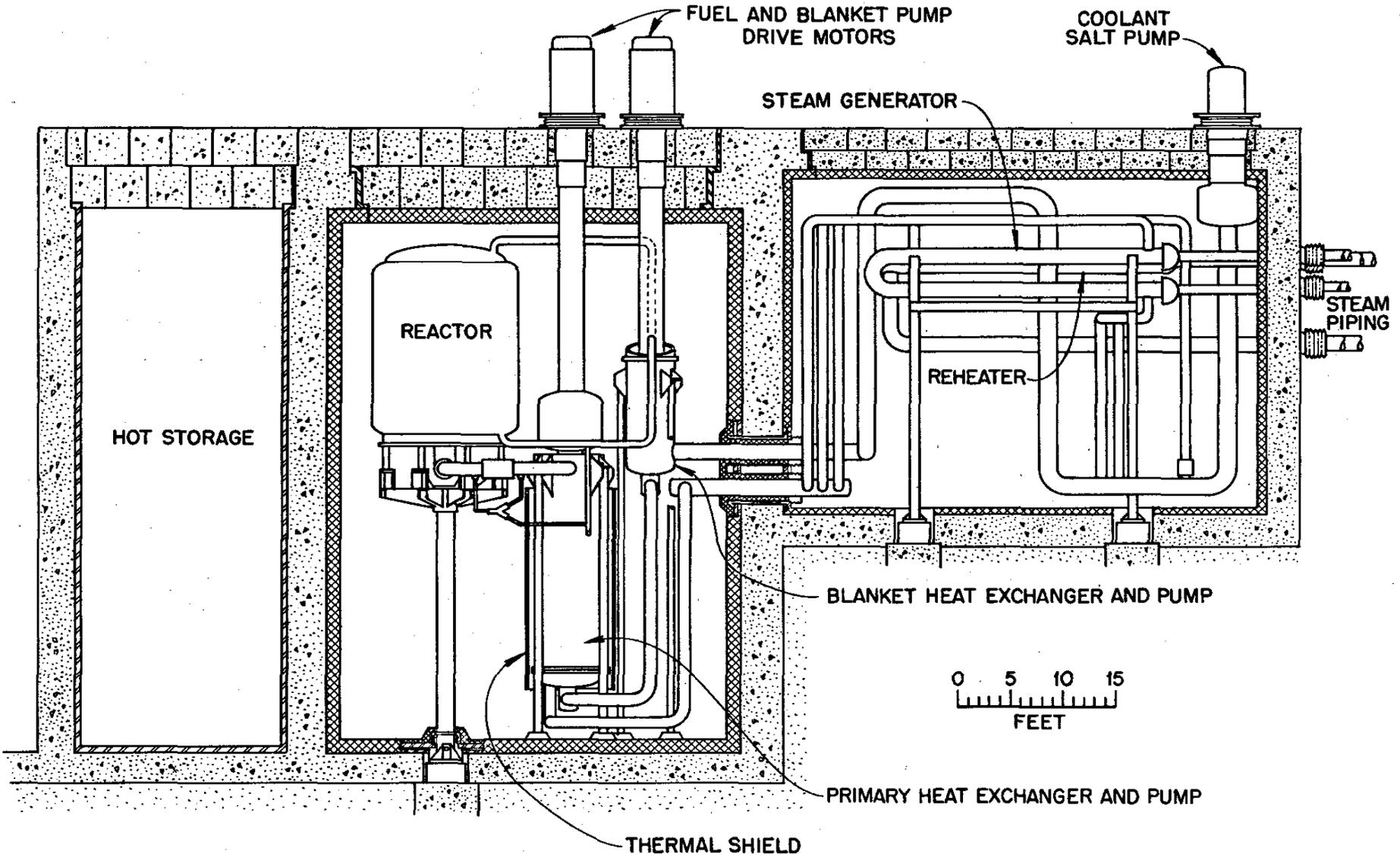
Plan View of Steam Generator and Drain Tank Cells

ORNL-DWG 68-30A

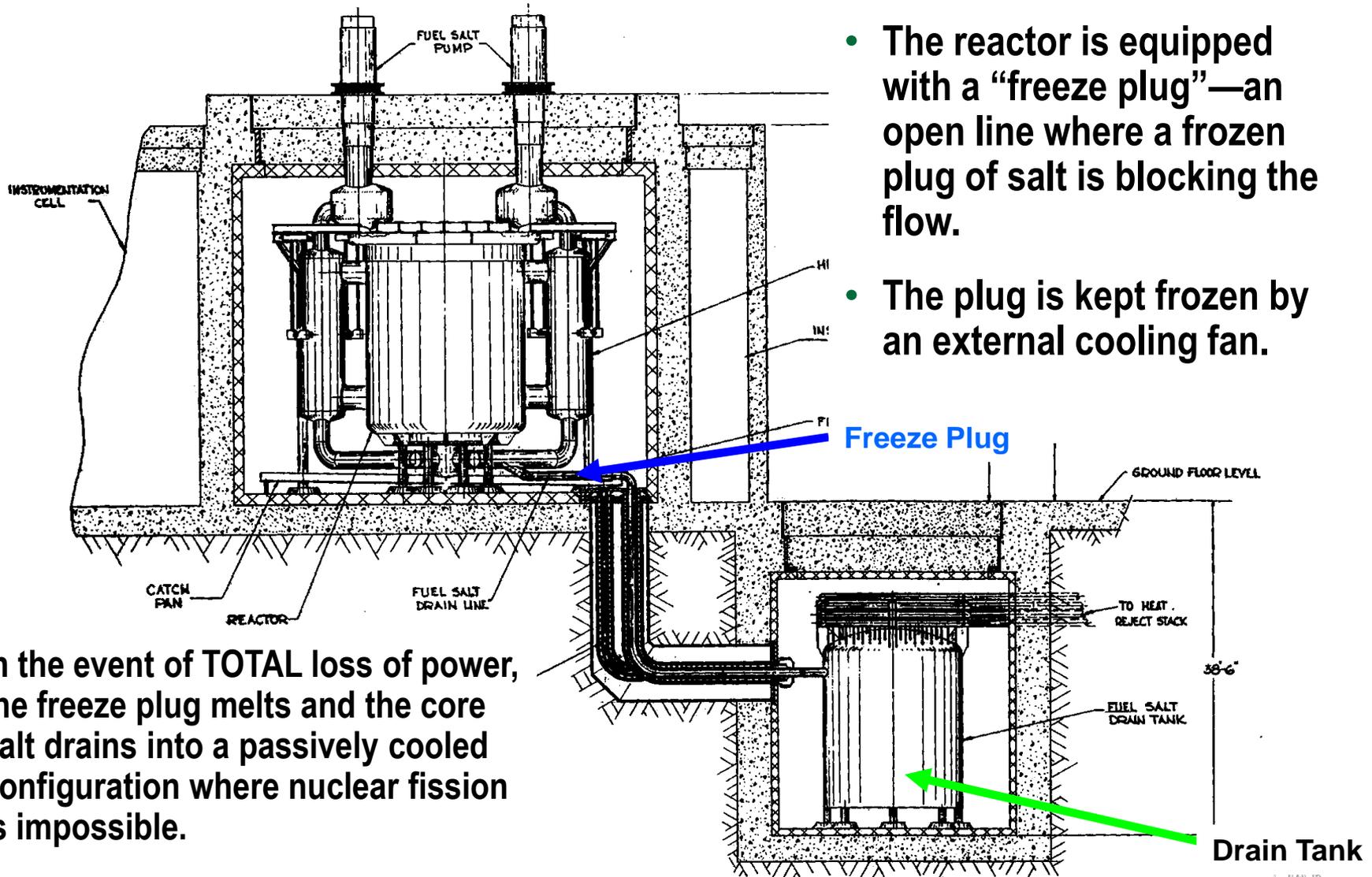


250-MWe MSBR Module: Sectional Elevation of Reactor Cell

ORNL-DWG 68-25A.



MSR passive safety: The freeze plug



“Plumbing” was a problem with the Two-Fluid Design

- **The two-fluid design required internal blankets, which created a “plumbing problem”**
- **Maintaining the coolant flow channels and returns resulted in a complex design**
 - **Note that graphite shrinks and swells during irradiation**
- **Developments in the late ‘60s provide a way to separate the thorium from fission products**
- **A new single fluid design was proposed and developed.**
- **This became the reference design for the MSBR**

By the way: MSR's can also be large: One-Fluid 1000-MWe MSBR (1972):

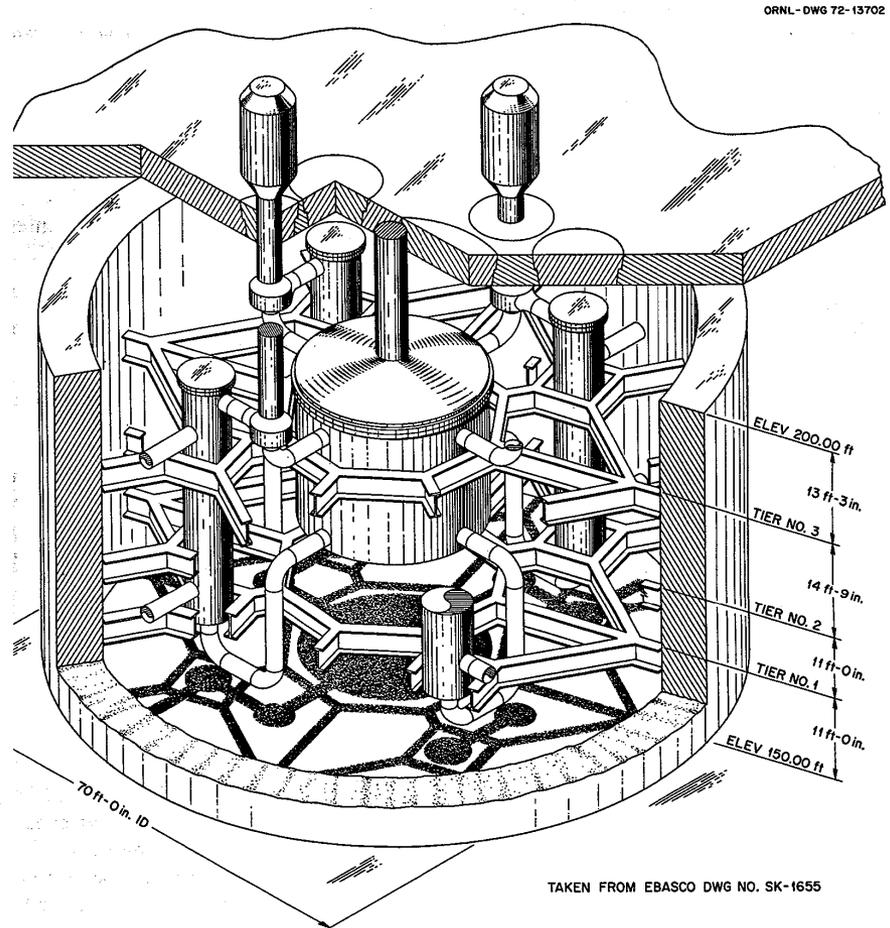
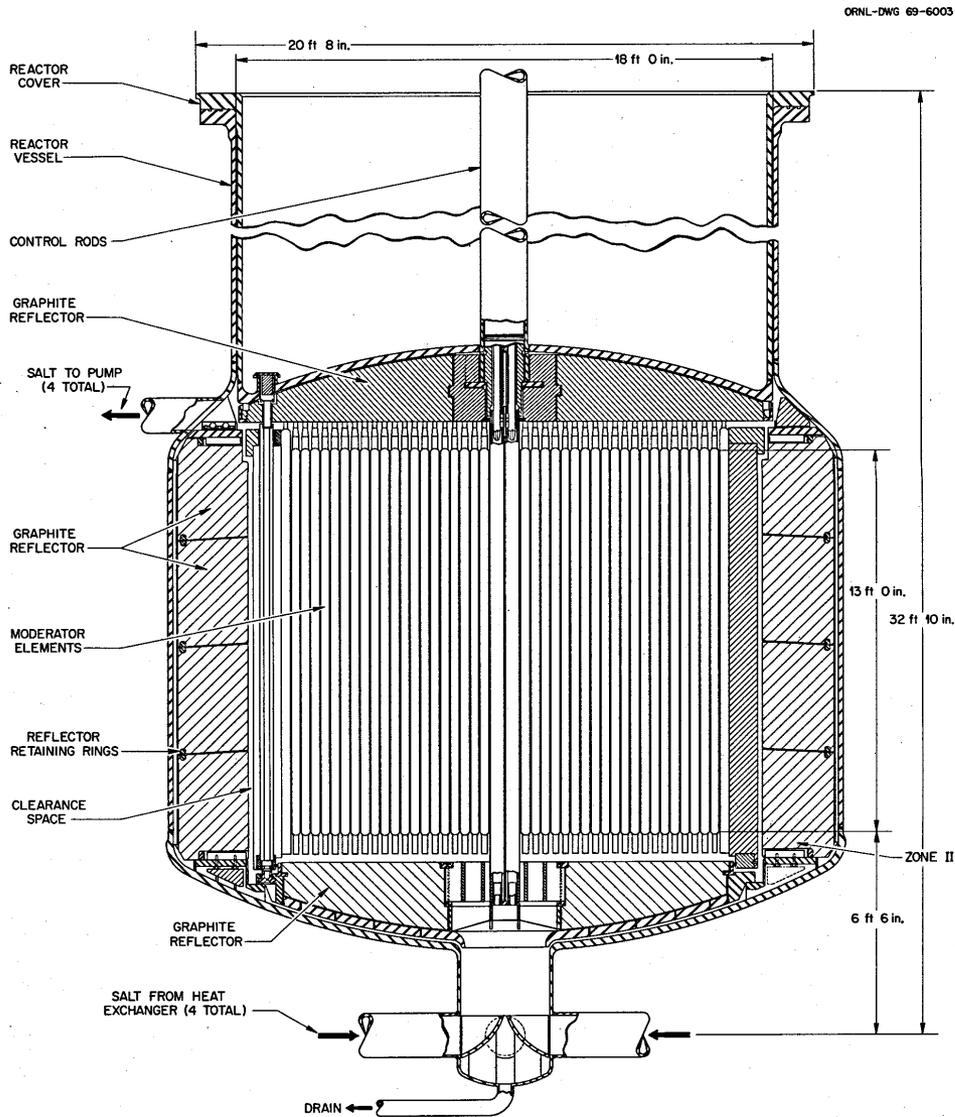


Fig. 1.3. Design study of MSBR cell.

The DMSR Was Developed to Address Proliferation Concerns of the 1970s

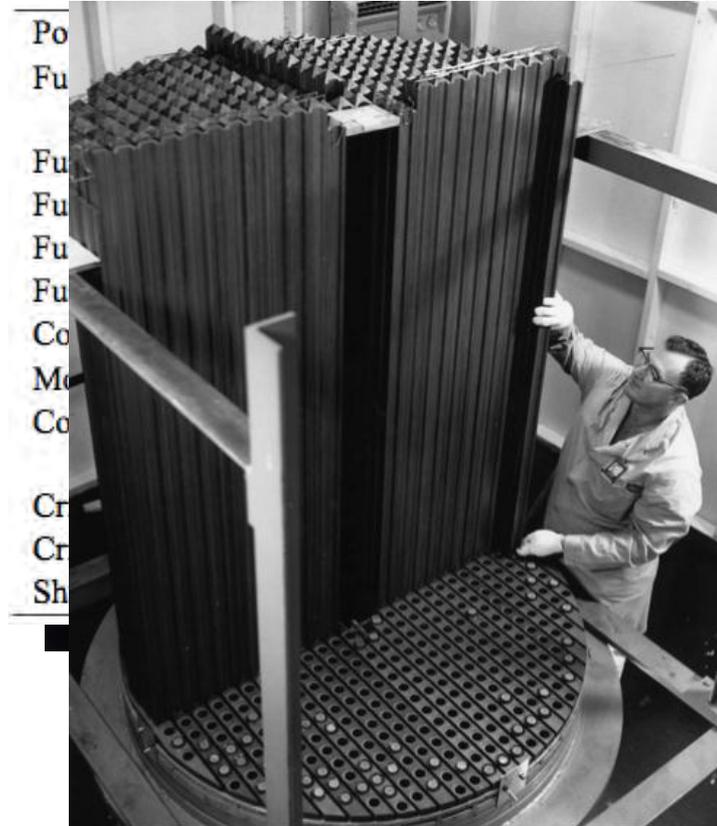
- Online processing is not performed (other than Kr, Xe gas removal and noble metal plate out)
- Enriched Uranium (19.75%) for startup and as feed material (to make up for limited processing)
- Operated as “once-through” system
- Lower reactor power density (no graphite replacement)
- Fueling
 - Thorium added only at initial loading
 - Enriched uranium added as required to maintain criticality
 - U-238 added as needed to maintain denatured state
 - $U-238 > (6 * U-233) + (4 * U-235)$

The Molten Salt Reactor Experiment

The Successful Operation of Two MSR at ORNL Provided “Proof of Principle”

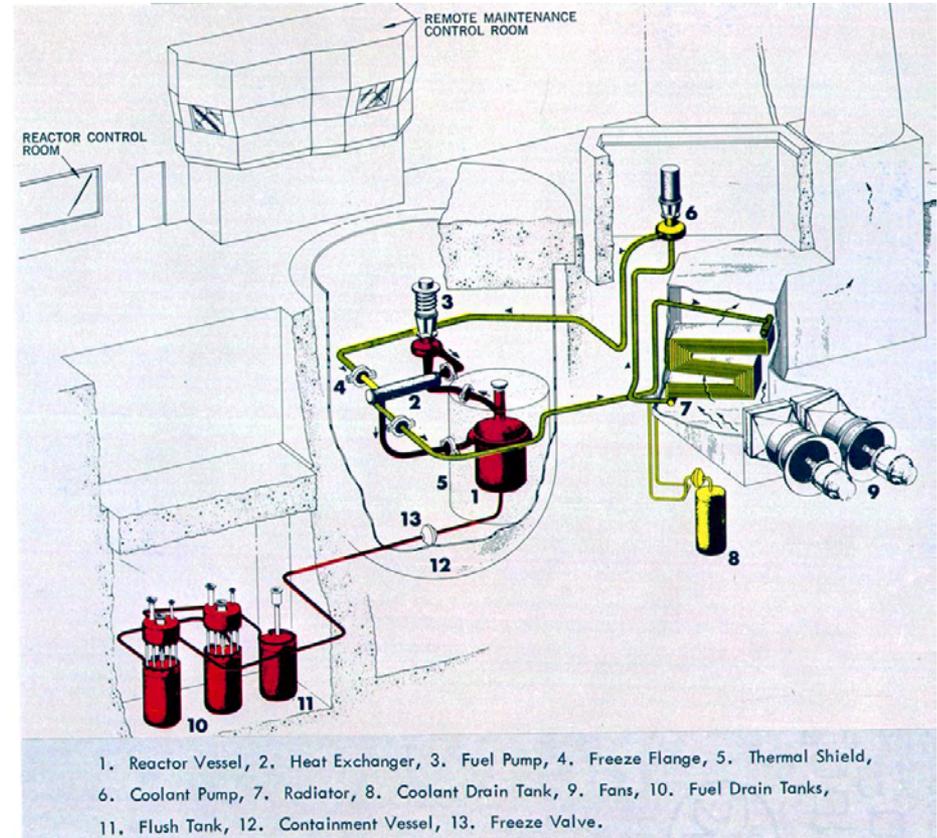
ORNL MSRE

- Two MSRs successfully operated
 - ARE (9 days of operation at high temperature)
 - Molten Salt Reactor Experiment (MSRE, 5 years of operation)
 - A third was essentially constructed, but not operated (Air Craft Reactor Test)
- MSRE highly successful experiment involving operation of a molten salt reactor with attributes that are similar to a power reactor
 - Established a “proof of principle” with good operating record
 - Operated on U-235 and U-233
 - Identified issues for R&D program (e.g. Tritium, Tellurium attack of INOR)
 - However, was not a complete demonstration (no thorium used in MSRE, no fission product removal, no power conversion system)
- ORNL proposed follow-on programs to lead to a commercial MSBR – Molten Salt Breeder Experiment and a Demonstration Reactor



Operating Experience: Molten Salt Reactor Experiment (MSRE) Was an Extremely Successful Demonstration

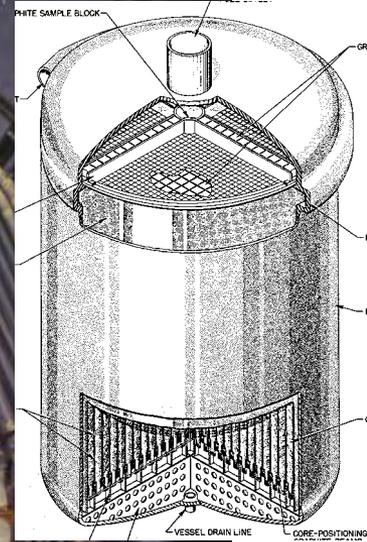
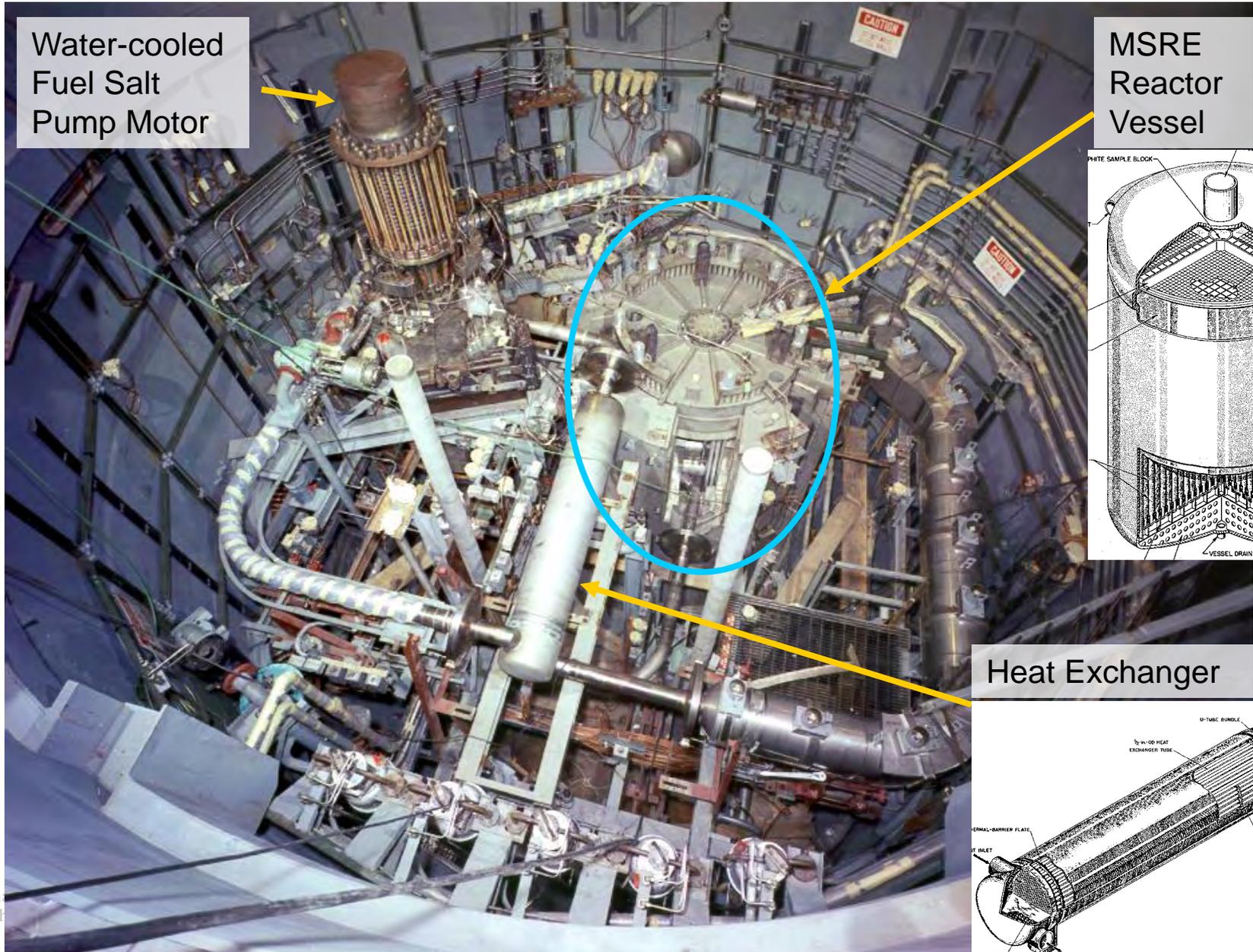
- Operated: 1965 – 1969 at ORNL
- Design features:
 - 8 MWt (original design was 10 MWt to facilitate construction on operating funds)
 - Single region core
 - Fuels
 - LiF-BeF₂- ZrF₄-UF₄
 - LiF-BeF₂- ZrF₄-UF₄-PuF₃
- Graphite moderated
- Hastelloy-N vessel and piping
- Achievements
 - First use of U-233 Fuel
 - First use of mixed U/Pu salt fuel
 - On-line refueling
 - >13,000 full power hours



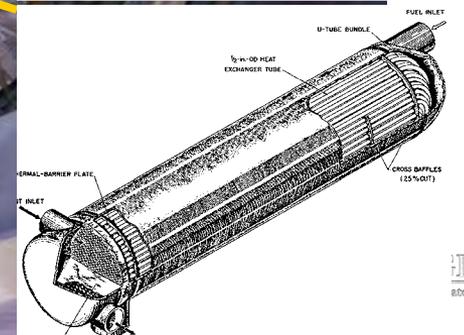
View inside the MSRE test cell

Water-cooled
Fuel Salt
Pump Motor

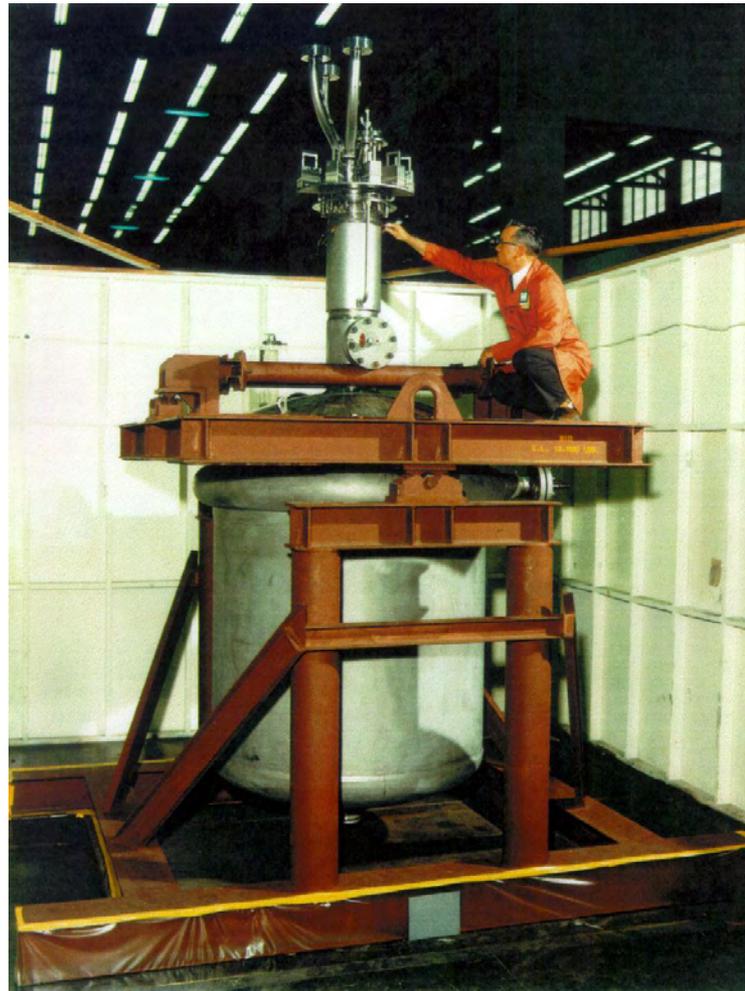
MSRE
Reactor
Vessel



Heat Exchanger



MSRE Graphite Moderator and Core Assembly



Summary/Conclusions

- **The development of the MSR was a key historical achievement of ORNL**
- **MSRs have been demonstrated at ORNL in the 1950s and 1960s and have shown good performance**
- **The MSR technology can scale from very small to large plant size**
- **MSRs have attractive features**
 - **Compact configuration**
 - **Passive safety/low-pressure system**
 - **Long-term operation through online fueling**
 - **Can support high efficiency electricity generation and/or high temperature heat applications.**
- **Advanced concepts can provide fast neutron spectrum**

For More Information

- R. C. Robertson, et al., *Two-Fluid Molten Salt Reactor Design Study*, ORNL-4528, August 1970.
- R. C. Robertson, et al., *Two-Fluid Molten Salt Reactor Design Study*, ORNL-4528, August 1970.
- R. C. Robertson, et al., *Conceptual Design Study of a Single-Fluid Molten-Salt Breeder Reactor*, Oak Ridge National Laboratory, ORNL-4541 (1971).
- H.G. MacPherson, “The Molten Salt Adventure,” *Nuc. Sci. Eng.*, 90, 374-380 (1985).
- A. M. Weinberg, *The First Nuclear Era*, AIP Press (1994)
- M.W. Rosenthal, *An Account of Oak Ridge National Laboratory’s Thirteen Reactors*, ORNL/TM-2009/181 (2009).
<http://info.ornl.gov/sites/publications/files/Pub20808.pdf>
- <http://www.energyfromthorium.com> - blog, discussion forum, and large collection of ORNL and other reports on MSR.
- Presentations from recent salt-cooled reactor workshop:
<http://www.ornl.gov/fhr>