History of the ORNL Molten Salt Program

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Director, Consortium for Advanced Simulation of Light Water Reactors

Workshop on Molten Salt Reactor Technologies – Commemorating the 50th Anniversary of the Startup of the MSRE

Oak Ridge National Laboratory
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Presentation Objective

- Provide a high-level presentation on the progression of the development of the MSR concept over multiple decades (1940s – 1970s)
- Details are necessarily omitted:
  - Salt, materials, processing research was carried out throughout the multi-decade program
  - Will not be discussed
- Dates provided generally from quarterly reports so information represents the state of the art at the time (not necessarily when it was developed)

1940's

Early Reactor Development of 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. <u>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.</u>

The Proto-History of the Molten Salt System
Alvin M. Weinberg, *Former Director, Oak Ridge National Laboratory*
February 28, 1997

Eugene Wigner

Harold Urey

1946 Nuclear Energy for Propulsion of Aircraft (NEPA) Project Started followed by 1951 Aircraft Nuclear Propulsion Program

- 1946 – 1961
- $1B Investment
- Pioneering work
  - ZrH fuels
  - Molten salt fuels
  - Liquid metal heat transfer
  - Light-weight metals
  - Advanced I&C
  - High temperature corrosion resistant materials

- **1947 – Feasibility study for molten salt for ANP begun on "the initiative of V.P Calkins, Kermit Anderson, and E.S. Bettis"**
- **1949 – ORNL Selected as lead of AEC activities on ANP program with Alvin Weinberg as Director**

1950's

ANP Reactor Development
Aircraft Reactor Experiment
Early Civilian Reactor Concept

1950-1952 MSRs Emerge As Primary Technology for ANP

- **November 1949** - “No preferred reactor type, coolant mechanism, or shielding material for the nuclear airplane has yet been definitely chosen by any agency”
- **August 1950** - “During the past quarter studies have been initiated to ascertain whether uranium-bearing fused salt mixtures were of possible value in this connection.”
- **December 1951** – “The search for a nonoxidative high-temperature fluid other than sodium which would be suitable as a reactor coolant has lead to the proposed use of fused fluoride salts containing uranium. “
- **March 1952**- “Studies of the performance and design of the circulating-fuel air- craft reactor are sufficiently encouraging that the first Aircraft Reactor Experiment (ARE) to be constructed by the Oak Ridge National Laboratory will be of this type.”

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1953 ORNL Aircraft Power Plant

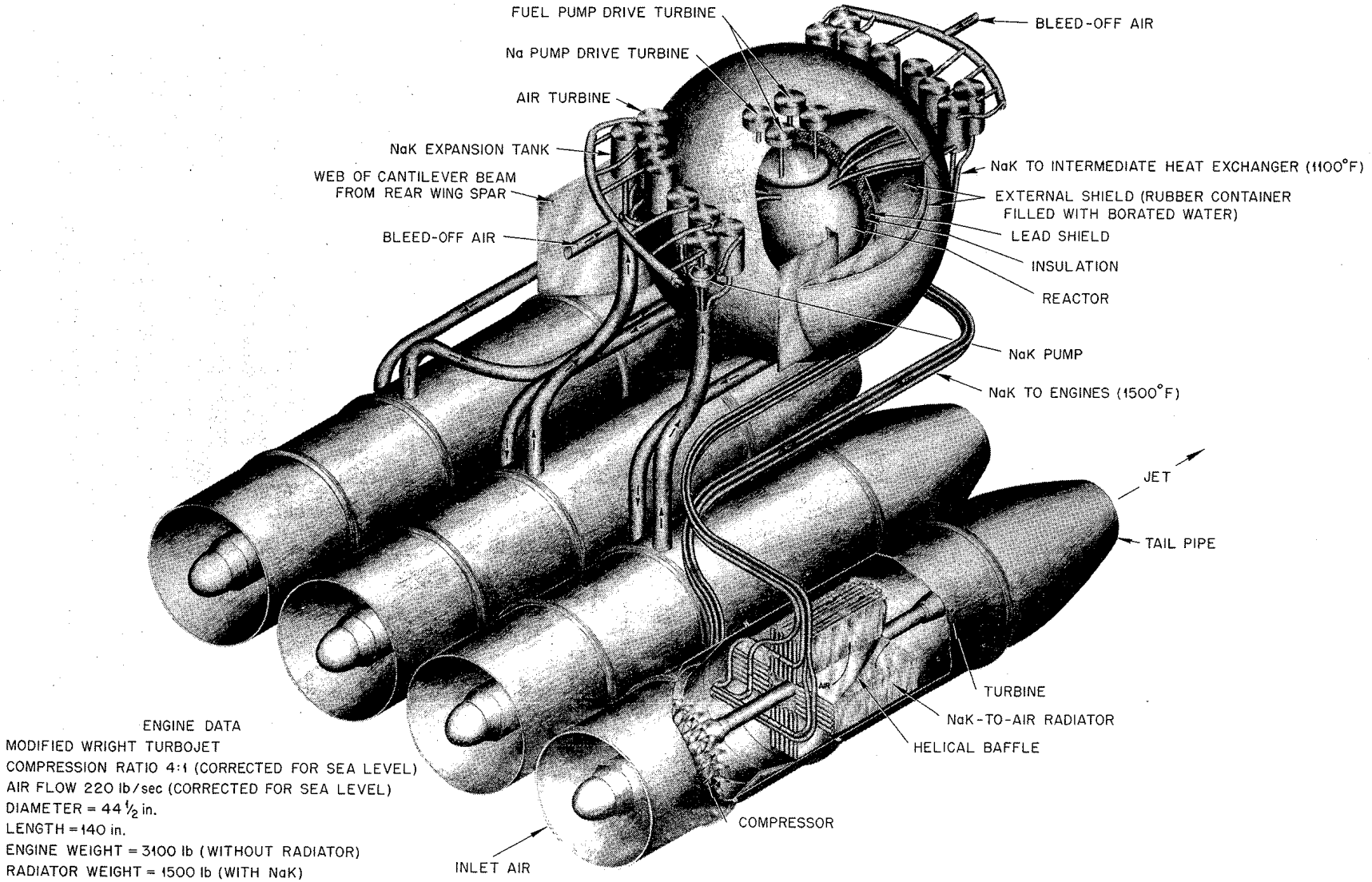
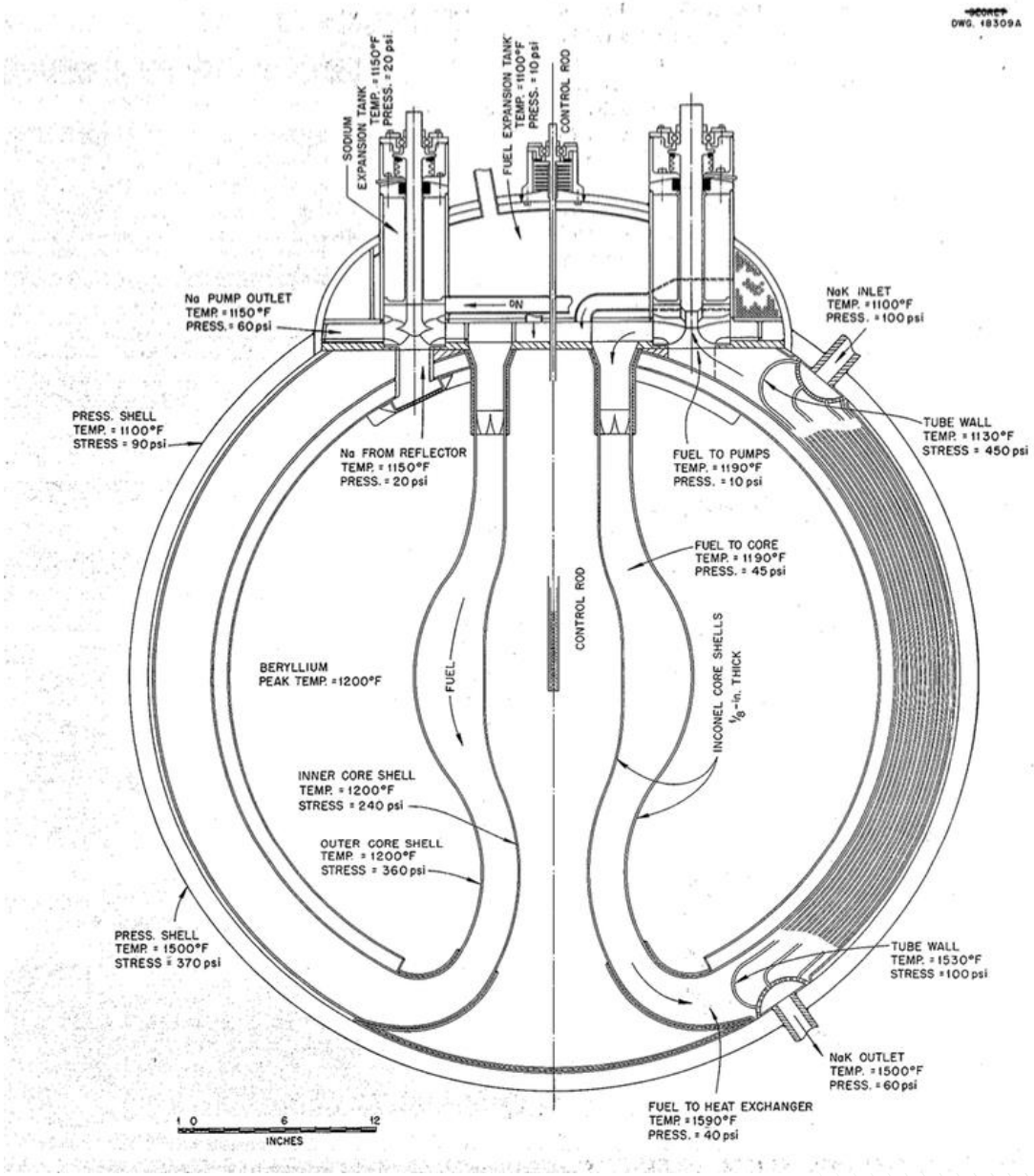


Fig. 4.33. Aircraft Power Plant (200 Megawatt).

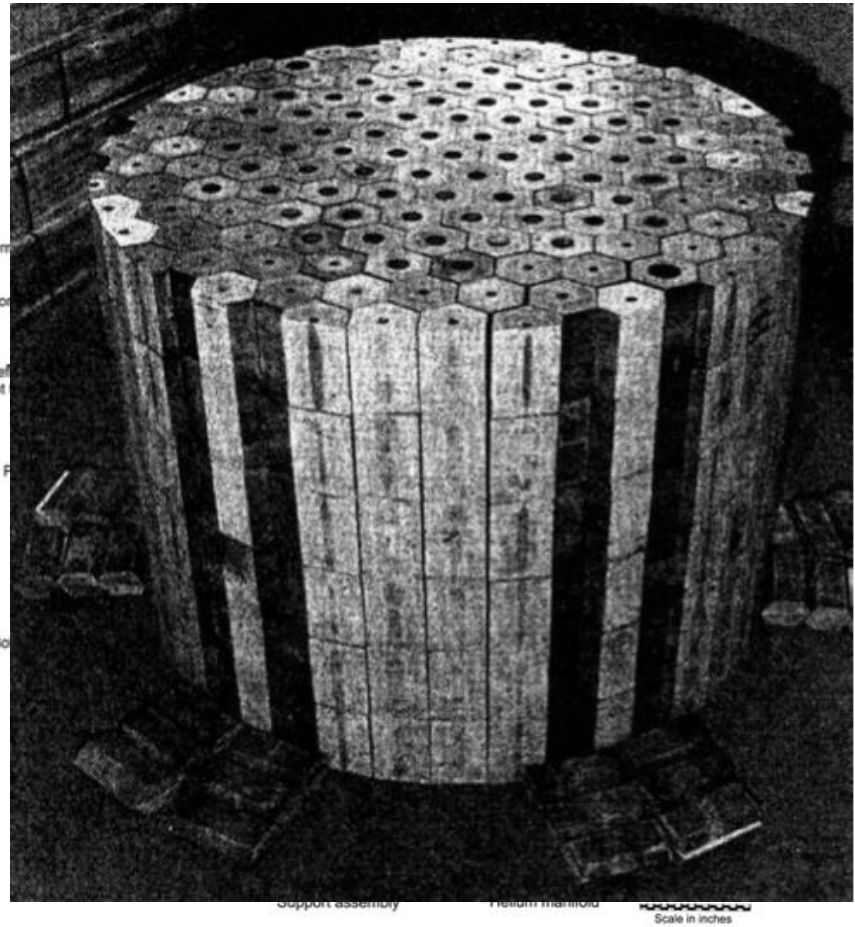
1953 Cross Section of ANP Reactor



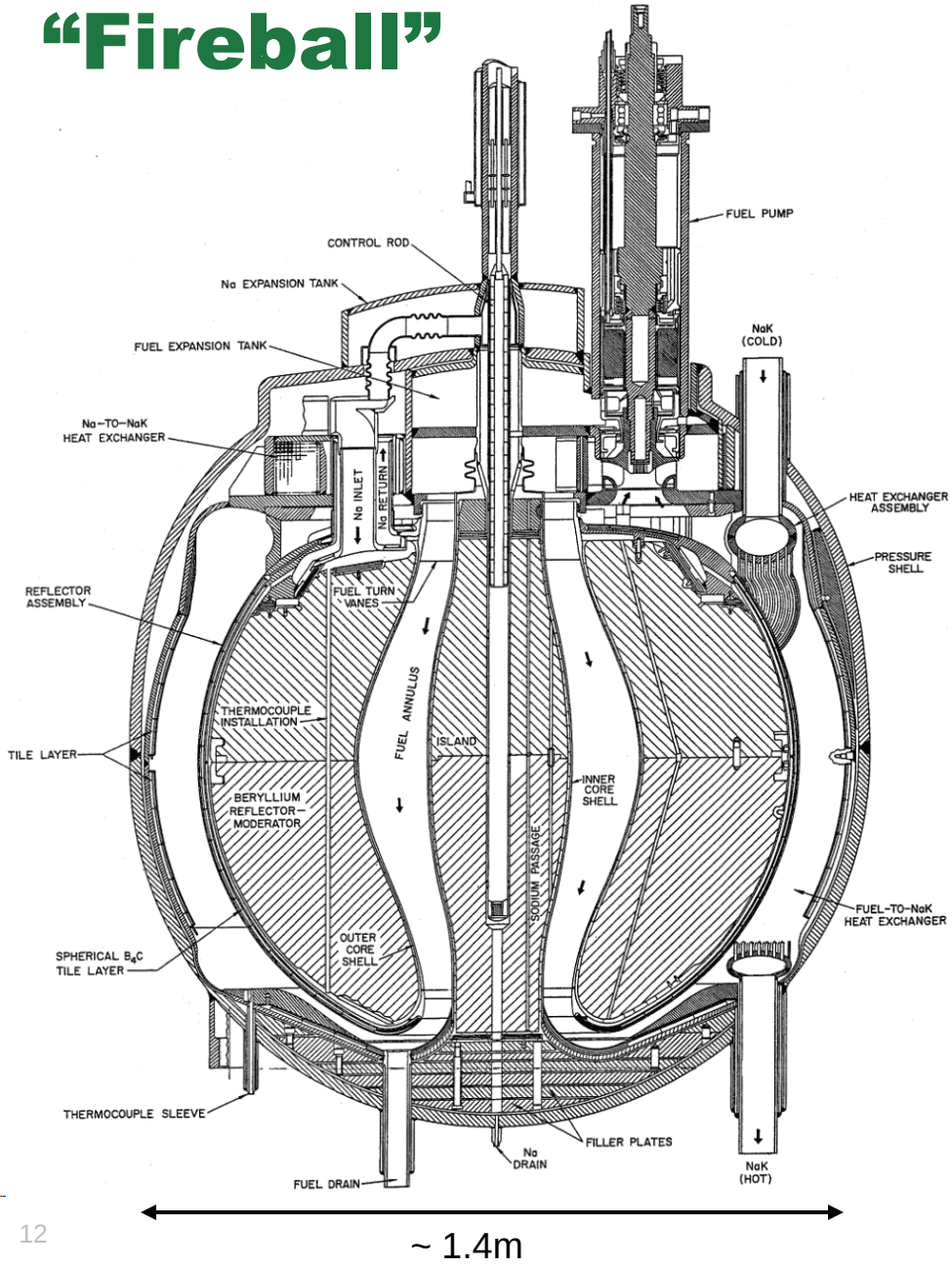
1954 Aircraft Reactor Experiment (ARE) Successful

- In order to test the liquid-fluoride reactor concept, a solid-core, sodium-cooled reactor was hastily converted into a proof-of-concept liquid-fluoride reactor.
- The Aircraft Reactor Experiment ran for 100 hours at 860 °C
  - Operated from 11/03/54 to 11/12/54
  - Liquid-fluoride salt circulated through beryllium reflector in Inconel tubes
  - $^{235}UF_4$ dissolved in $NaF\text{-}ZrF_4$
  - Produced 2.5 MW of thermal power
  - Gaseous fission products were removed naturally through pumping action
  - Very stable operation due to high negative reactivity coefficient
  - Demonstrated load-following operation without control rods

Aircraft Reactor Experiment



1956 Aircraft Reactor Test (ART) "Fireball"

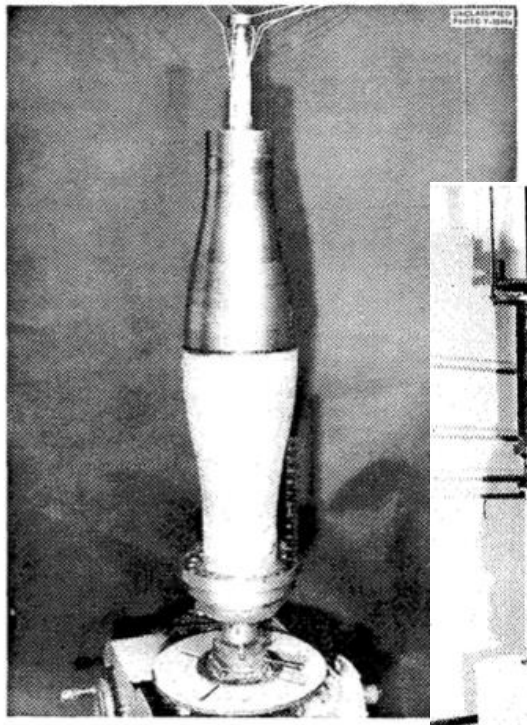


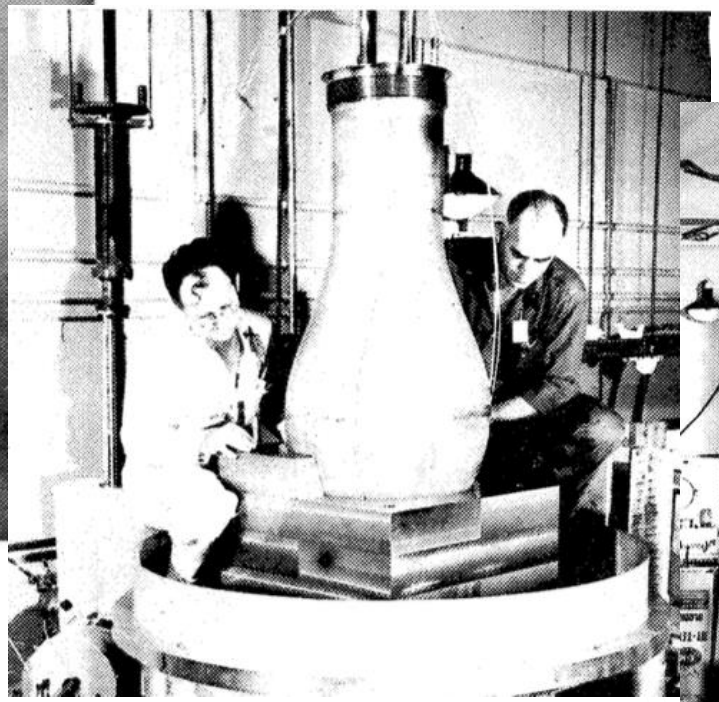
The "Fireball", or Aircraft Reactor Test, was the culmination of the ANP effort at ORNL.

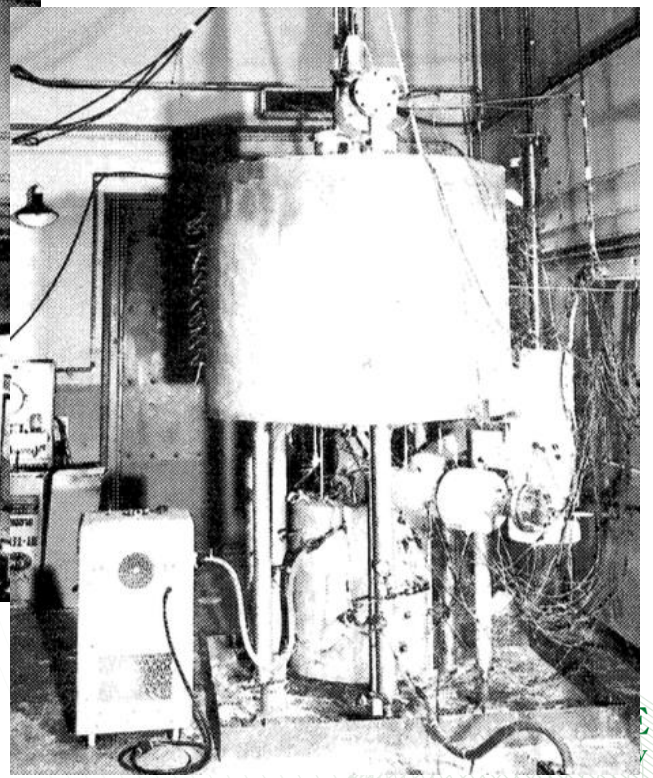
- Same configuration/size as ANP Reactor
- $^{235}UF_4$ dissolved in $NaF\text{-}ZrF_4$
- Designed to produce 60 MW of thermal power
- Core power density was 1.3 MW/L
- NaK used to transport heat to jet engines at 1150 K
- 1500 hours (63 days) design life
- 500 hours (21 days) at max power
- The "Fireball" pressure shell was only 1.4 meters in diameter
  - Contained core, reflector, and primary heat exchanger inside

1956 Low Power, Electrically Heated, High Temperature Critical Experiment operates at 1200 °F

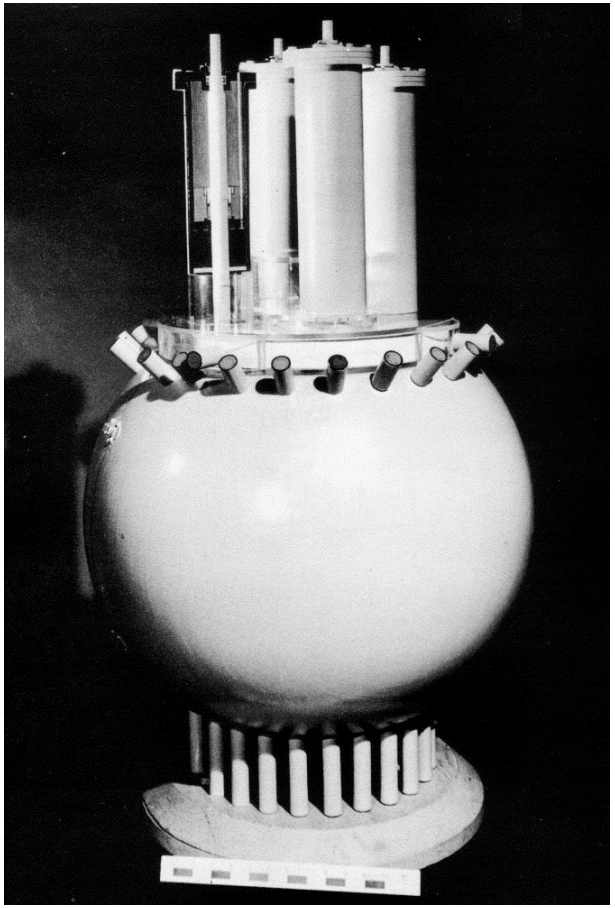
The mockup differed from the ART principally in that the fuel was not circulated and there was no sodium in the reflector-moderator regions.



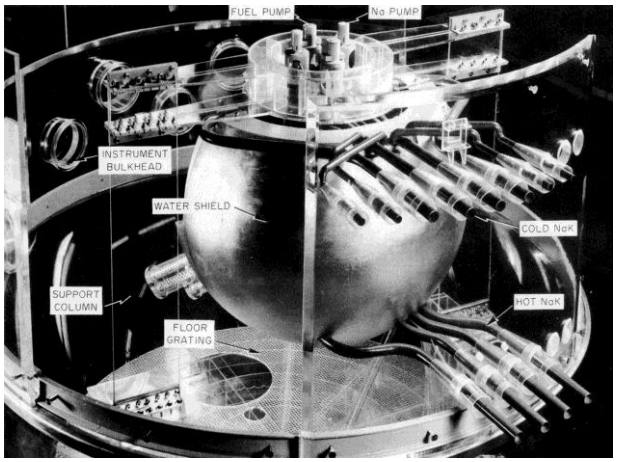




1961 ART Facility Construction and Engineering Test Unit Fabrication Were Near Completion When ANP Program Was Cancelled



Full-Scale ART Model



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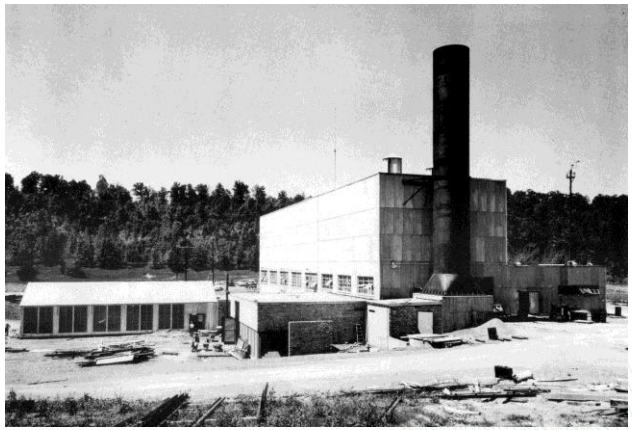
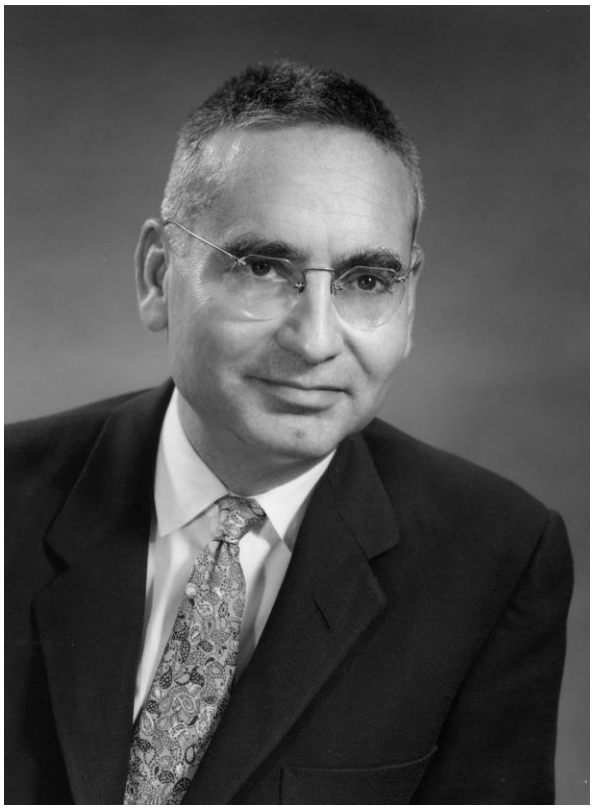


ART Building



Alvin Weinberg

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).

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1958 Civilian Molten Salt Power Reactor Program Initiated

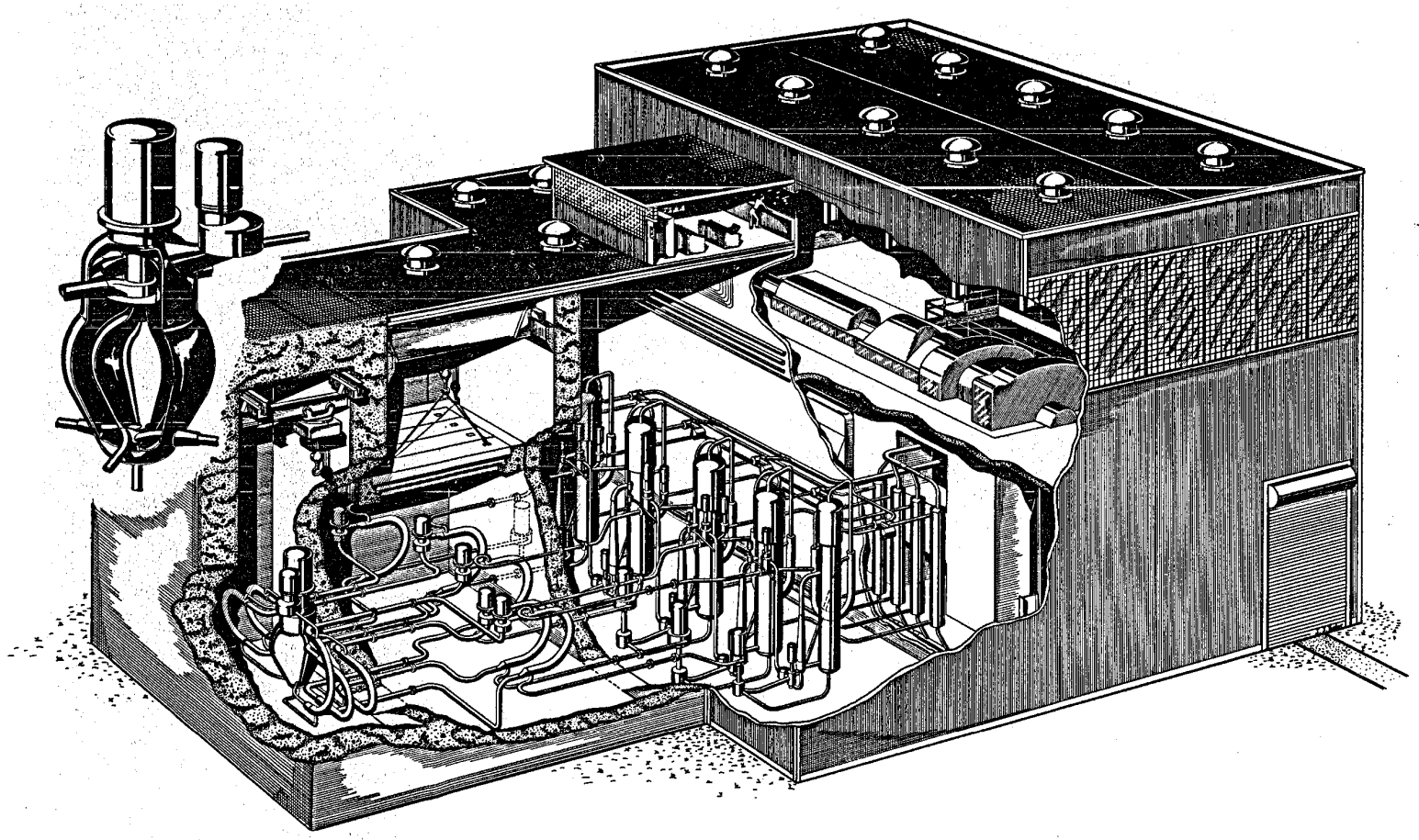
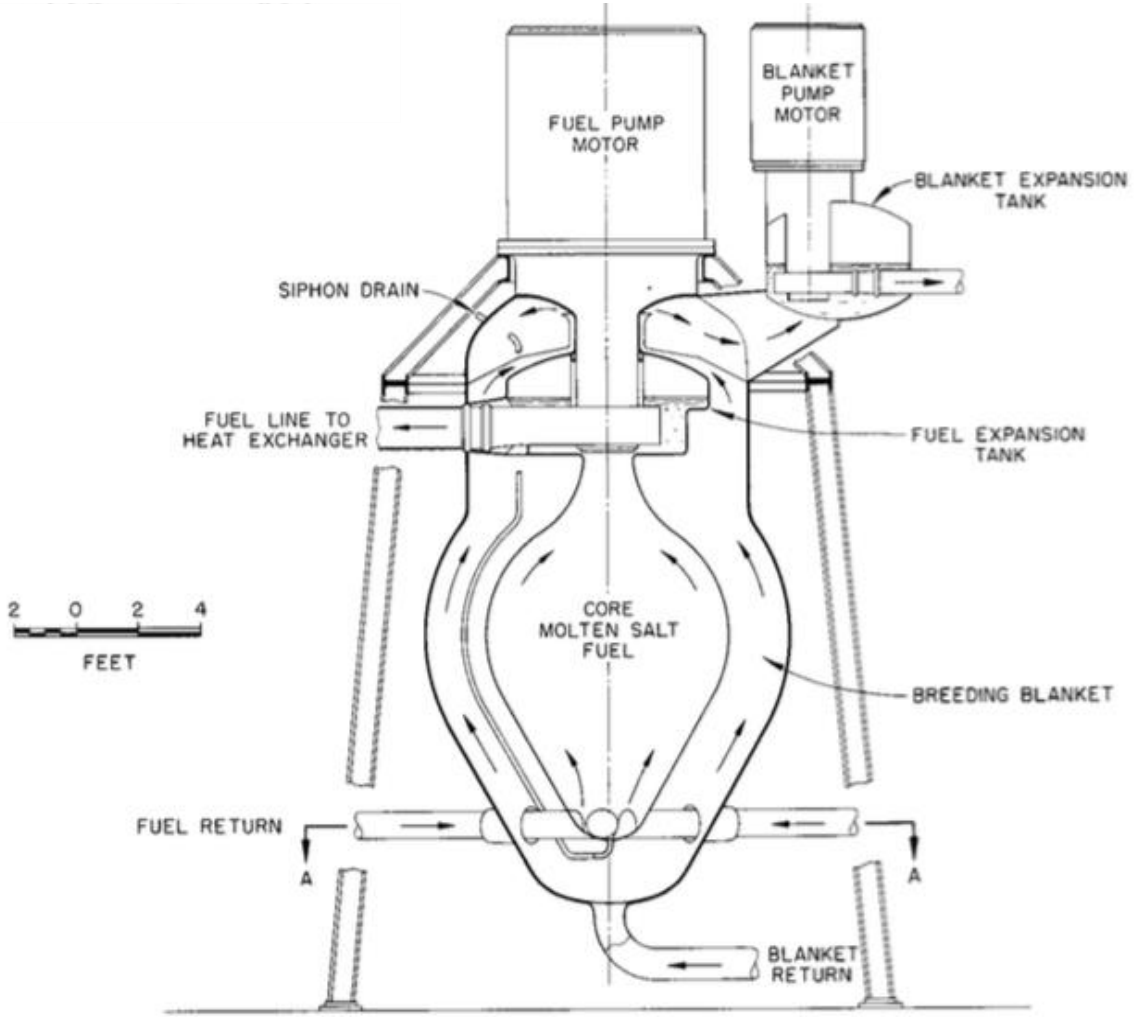


Fig. 1.1. Isometric View of Molten Salt Power Reactor Plant.

1958 Initial Civilian MSR Designs Heavily Leveraged ANP concept



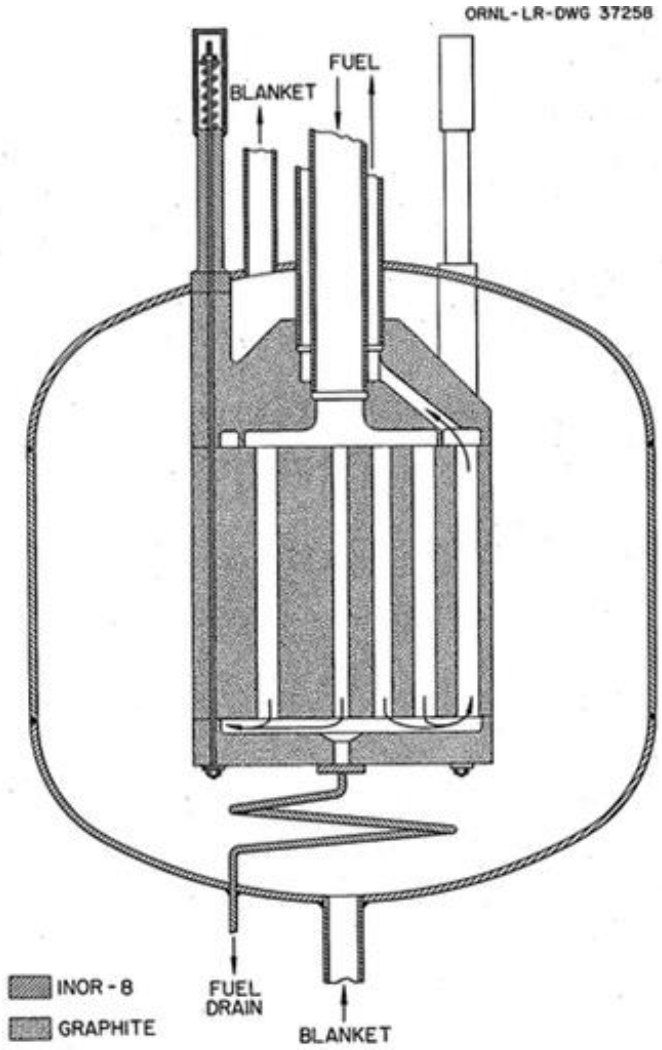
- U^{235}/U^{233}
- U/Th Fuel Cycle
- Two Region/batch processing
- 640 MWt/260 Mwe
- 1210 °F Exit Temperature

1959 Fluid Fuel Reactor Task Force and Down Selection

- In 1959 the three fluid-fueled reactor concepts were being developed were reviewed by an AEC expert task force
  - Aqueous Homogenous Reactor (ORNL)
  - Liquid Metal Fuel Reactor (BNL)
  - Molten Salt Reactor (ORNL)
- This task force ultimately resulted in the down selection to the MSR as the primary fluid-fueled reactor concept (TID-8507):

  The molten salt reactor has the highest probability of achieving technical feasibility. This is largely due to the use of a solution fuel (as contrasted to a slurry fuel in the LMFR and the AHR), and the availability of a suitable container material (INOR-8)

1959 Design began to resemble what we now recognize as MSRs

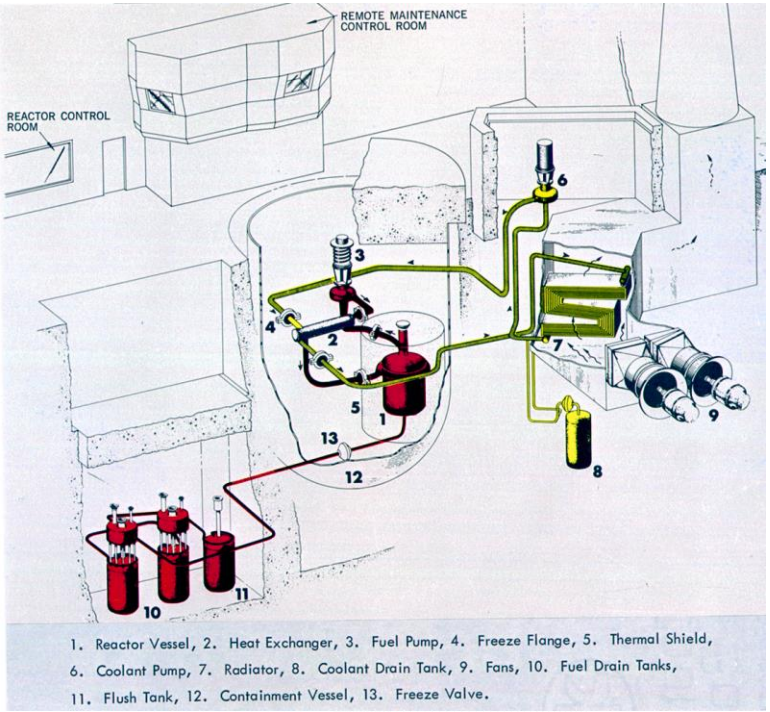


1960's

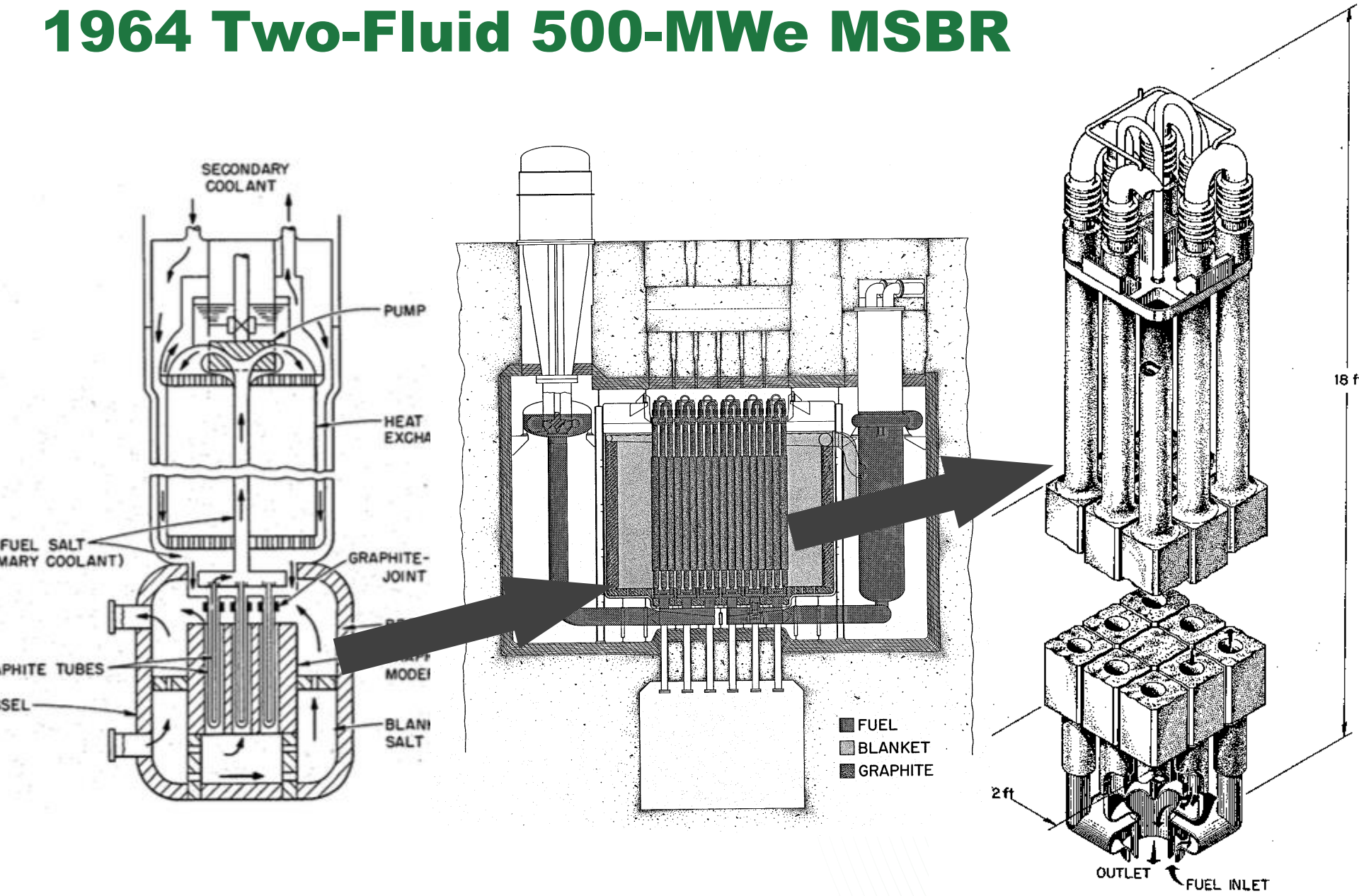
Designing the MSRE
MSBR Development
MSRE Operations

1960-1964 Primary Focus of Reactor Design was on MSRE

- 1960 – MSRE design begins
- 1961 – Orders of special materials placed
- 1961-1963 – Modifications to ART building (7503)
- Design, procurement, construction of MSRE 90% complete on January 31, 1964

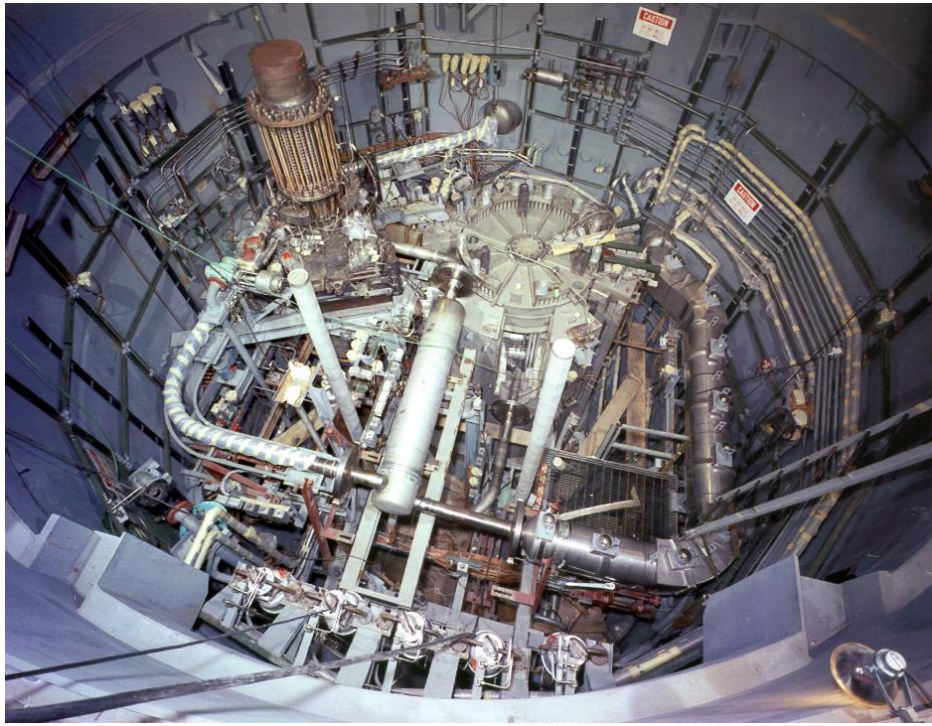


1964 Two-Fluid 500-MWe MSBR

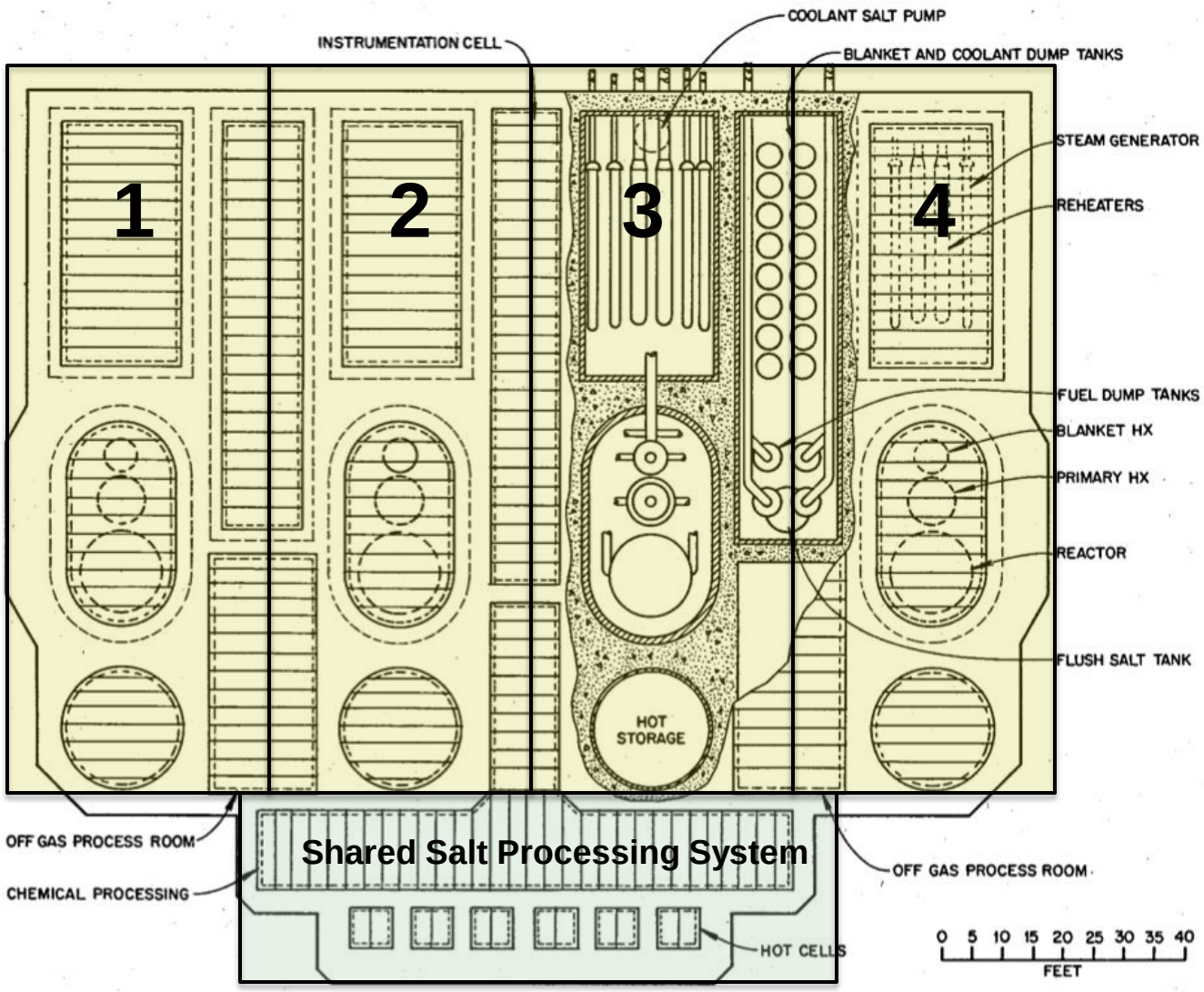


1965 – 1969 Operating Experience: Molten Salt Reactor Experiment (MSRE) Was an Extremely Successful Demonstration

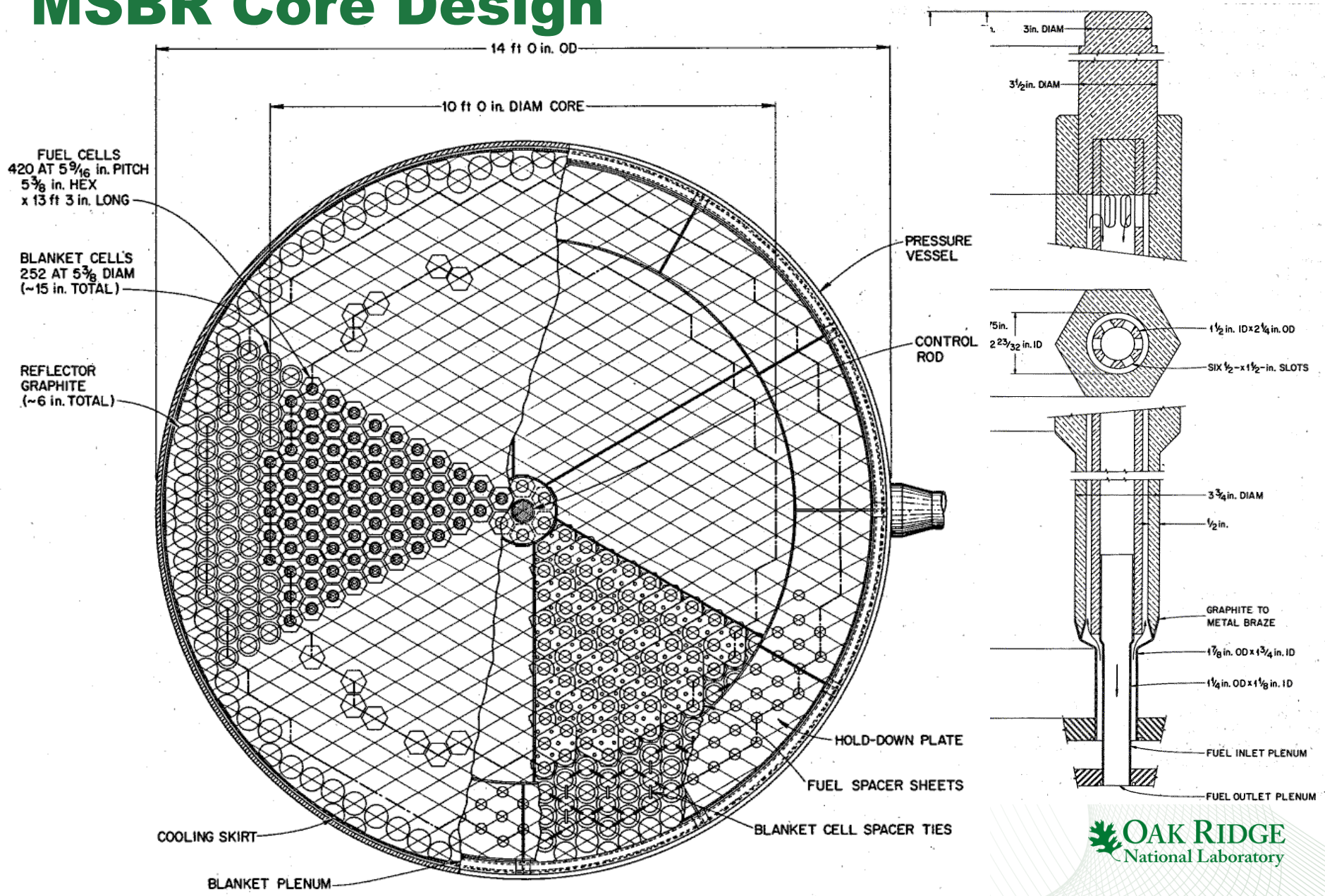
- 1965 (June) First Criticality
- 1966 (Dec) First Full Power Operation
- 1968 (Oct) First Operation on U-233
- 1969 (Dec) Shutdown
- Design features:
  - 8 MWt
  - Single region core
- Graphite moderated
- Alloy N vessel and piping
- Achievements
  - First use of U-233 Fuel
  - First use of mixed U/Pu salt fuel
  - On-line refueling
  - >13,000 full power hours



1966 - 1967 Focus on Two-Fluid Modular Plant Design with 4x250MWe Modules



1966-1968 Modular Two-Fluid 250-MWe MSBR Core Design



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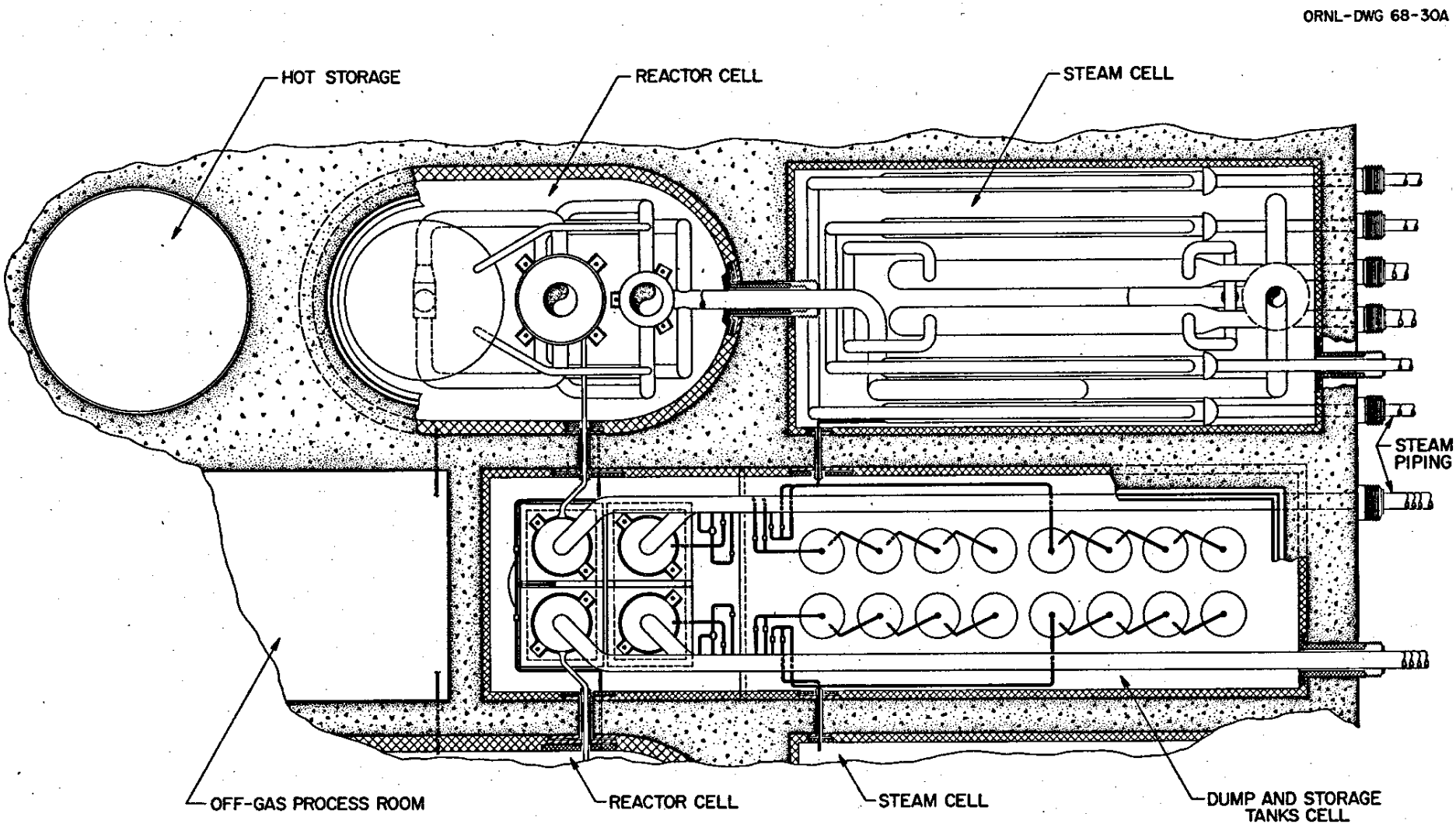
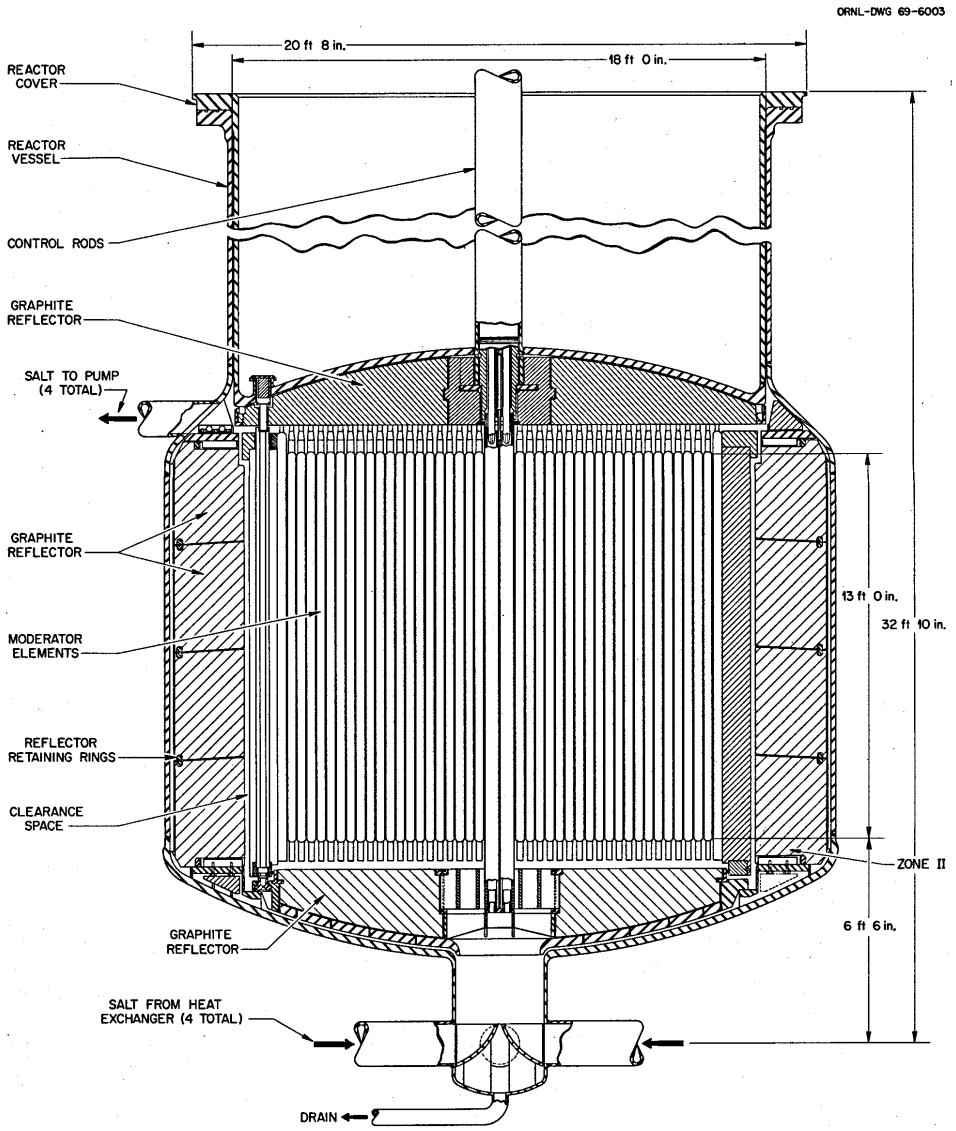
1966-1968 250-MWe MSBR Module Design
Plan View of Steam Generator and Drain Tank Cells



1968 MSBR Development Changes Focus on Single Fluid Design

- Concerns over mechanical failure of graphite cells separating fuel from fertile salt.
- Two developments enabled consideration of single fluid system:
  - Development of liquid bismuth reductive metal extraction of protactinium and rare-earths from thorium/uranium salts
  - Analysis showing large single fluid core designs with zoning can reduce leakage to allow breeding
- Single fluid simplifies system and becomes reference design
- Single fluid MSBR resembles scale up of MSRE

1970 Reference Single Fluid Design



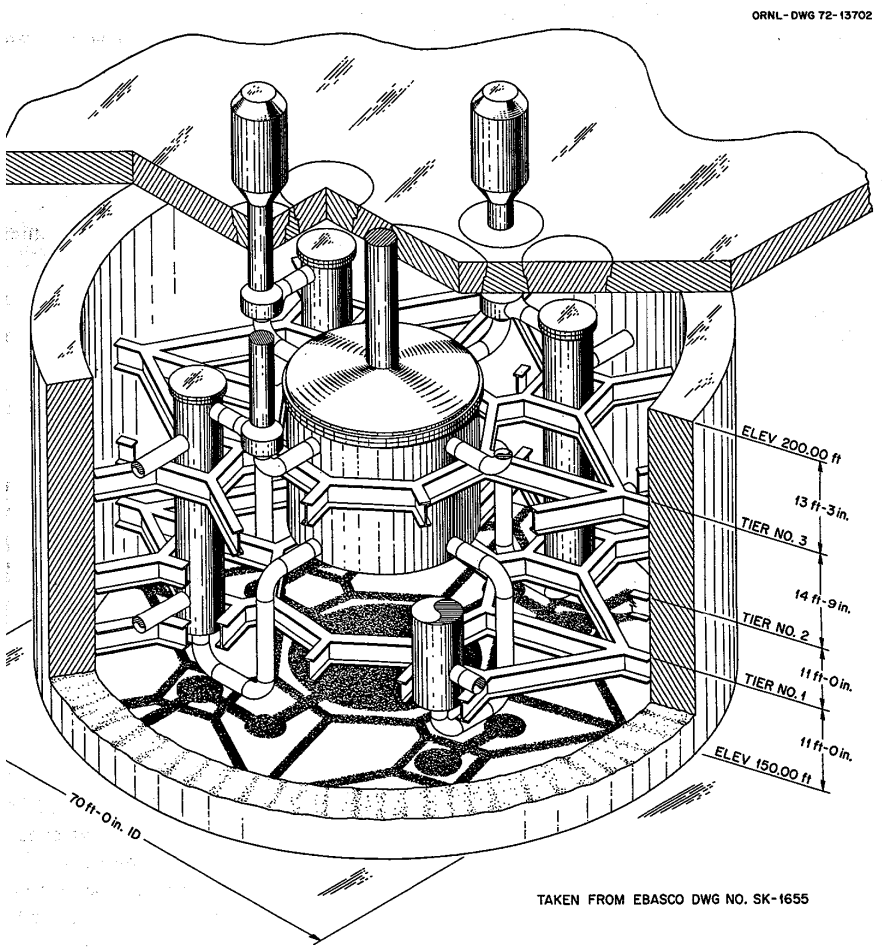


Fig. 1.3. Design study of MSBR cell.

1970’s

Molten Salt Breeder Experiment
Molten Salt Demonstration Reactor
Program Shutdown

MSR Program Stops, Restarts… and stops

- Early 1970s – Design studies on next step
  - Molten Salt Breeder Experiment (100 MWt)
  - Molten Salt Demonstration Reactor (300 MWe)
- September 1972 – Wash-1222 Evaluation of Molten Salt Breeder Reactor Program
- January 1973 – Program terminated due to “budgetary Reasons”
- January 1974 – Program reinstated to focus on technology development (tritium management, alloy development to address tellurium cracking)
- February 1976 – Program terminated for “budgetary reasons)

Why Did U.S. Discontinue Research and Development on Molten Salt Reactors?

- *Political and technical support too thin geographically (ORNL only stakeholder)*
- *LMFBR program got early start, had major federal funding, and many stakeholders.*
- *When MSBR program progressed to need for substantial increase in funds, AEC could not justify the diversion of funding from the LMFBR program*

  -- H. G. MacPherson (1985)

Another perspective….

Our problem is not that our idea is a poor one – rather it is different from the main line, and has too chemical a flavor to be fully appreciated by non-chemists.

-- Alvin Weinberg