ORNL Research and Demonstration Reactors

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OAK RIDGE NATIONAL LABORATORY
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ORNL Has Designed And Operated Several Research And Demonstration Reactors

- In addition to the Oak Ridge Graphite Reactor (first operating reactor in the world), ORNL has designed many research reactors and small demonstration reactors
  - Army Package Reactor
  - Aircraft Reactor Experiment
  - Low Intensity Test Reactor (LITR)
  - Bulk Shielding Reactor (BSR)
  - Oak Ridge Research Reactor (ORR)
  - Homogeneous Reactor Experiment (HRE 1 and 2)
  - Molten Salt Reactor Experiment (MSRE)
  - Experimental Gas-Cooled Reactor (EGCR)
  - Tower Shield Reactor (TSR)
  - Health Physics Research Reactor (HPRR)
  - High Flux Isotope Reactor (HFIR)

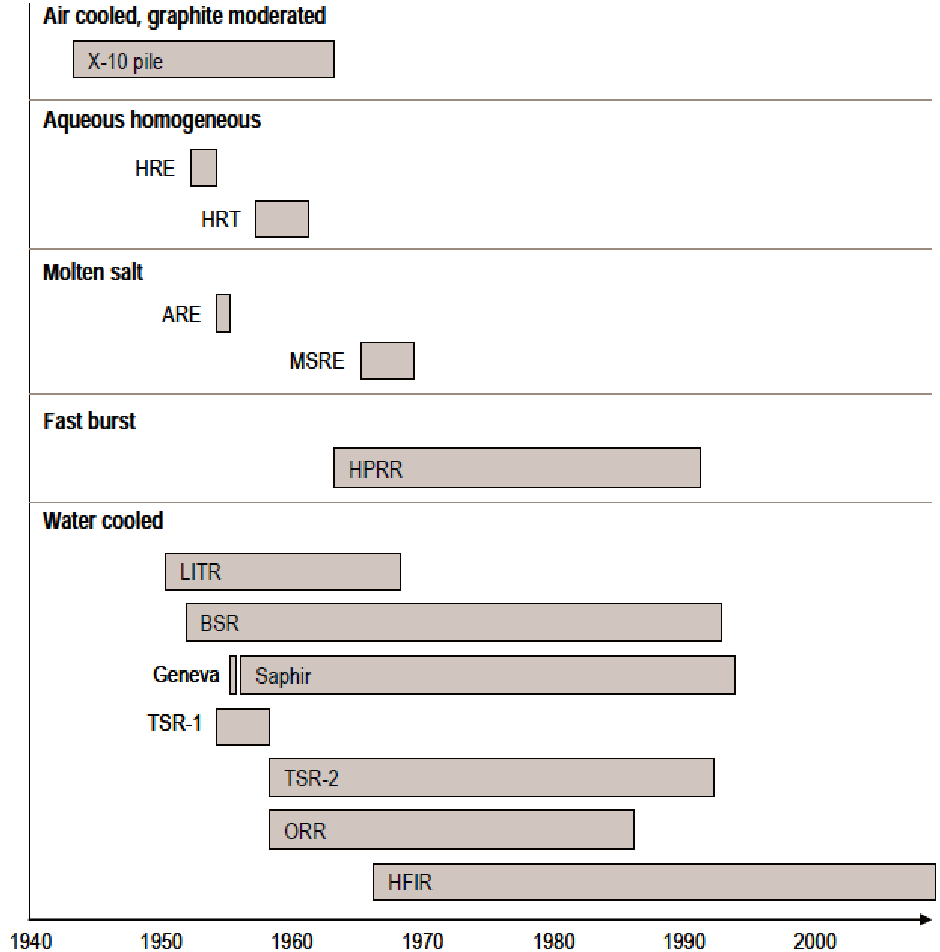
ORNL Has Designed And Operated Several Research And Demonstration Reactors (Continued)

- This lecture will emphasize the seven highlighted reactors.

- Historical significance
  - Represent a common type of research reactor found around the world
  - Have unique characteristics that might be challenging to an IAEA inspector

- In the late 1980s, five of these reactors were in operation at the same time at ORNL
  - ORR, BSR, HPRR, TSR, and HFIR
  - Today only one (HFIR) remains in operation

ORNL's Reactors from Criticality to Shutdown



Brief Overview Of The Reactors That Will Not Be Discussed In Detail

- Army Package Reactor (1953–1957)
  - 10 MW(t)–2 MW(e)
  - PWR using stainless steel cladding
  - HEU (UO$_2$ Powder dispersed in SS plates)
  - Used standardized components, first reactor with a pressure containment structure
  - Built at Fort Belvoir, Virginia by the American Locomotive Co.
  - Similar Reactors were used at other remote bases including Antarctica and one was use on floating ships to provide backup power to Panama Canal
  - ORNL provided technical assistance to B&W in the design of a 69MWt PWR to propel the N.S. Savannah (300,000 miles without refueling 8 years in operation)
  - Represents a historical example of a Small Modular Reactor (SMR) concept that is gaining renewed interest today

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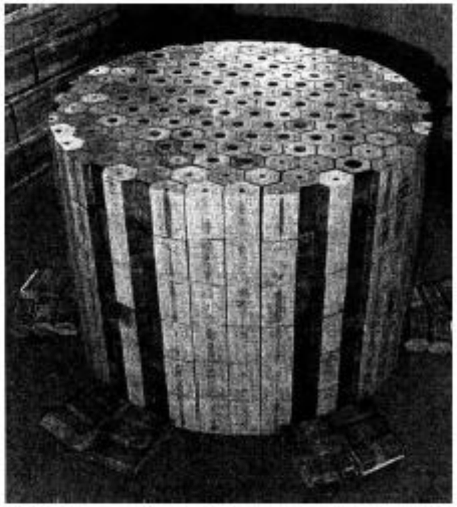
Brief Overview Of The Reactors That Will Not Be Discussed In Detail (Continued)

- Aircraft Reactor Experiment (1954)
  - 2.5 MW 1000 hour of operation
  - Fuel/coolant molten salt (NaF-ZrF_4-UF_4)
  - 93% enriched uranium as fuel
  - BeO moderated
  - Sodium secondary coolant
  - Peak temperature 880°C
  - 46 cm diameter core



Brief Overview Of The Reactors That Will Not Be Discussed In Detail (Continued)

- GCRE (1957–1966)
  - This reactor was to be built as a prototype for a gas-cooled power reactor
  - Joint venture between ORNL and the Tennessee Valley Authority
  - Canceled by the Atomic Energy Commission (AEC). Terminated in 1966 with fuel in the core but never started. AEC focused on LWR

Brief Overview Of The Reactors That Will Not Be Discussed In Detail (Continued)

- **TSR (1953–2001)**
  - Spun off of the need to provide better shielding for the Aircraft Nuclear Propulsion Project
  - 1 MW LWR 93 % enriched U/Al fueled spherical reactor in spherical vessel suspended between twin towers nearly 200 ft (60 m) in the air
  - Tested shield designs for candidate materials ranging from the aircraft reactors, space reactors, tanks, and fast breeder reactors

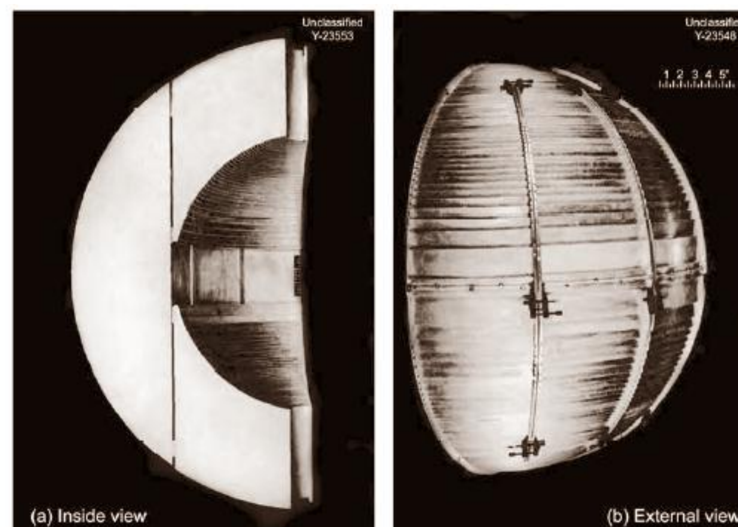


Fig. 42. TSR-II core.

Brief Overview Of The Reactors That Will Not Be Discussed In Detail (Continued)

- **HPRR (1962–1987)**
  - 93% enriched U/Mo, cylinder 20 cm in diameter and 20 cm high, bare fast reactor
  - Pulse reactor used to study health physics, dosimetry, biochemical research, and instrumentation development
  - Helped scientists estimate solar radiation doses to Apollo astronauts

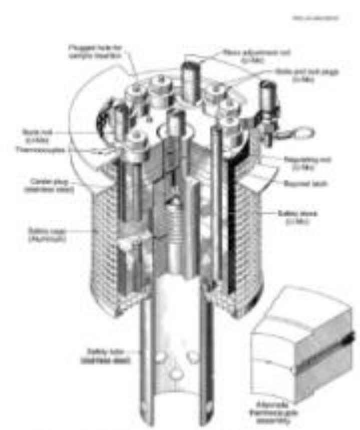


Fig. 29. The HPRR core. (ORNL-LR-DWG 65074A)

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Oak Ridge Graphite Reactor (X-10 Reactor

- The reason ORNL was created was as a result of the Chicago Pile (CP-1) which went critical December 2, 1942
- OGR originally designed as a pilot plant for Pu production along with the separations facility adjacent to the reactor
- OGR was designed and constructed in 9 months and went critical Nov. 4, 1943.
  - Shutdown Nov. 4 1963
- Produced 326 g of Pu in 3 years

Fig. 1. Final layer of the Chicago Pile. The sign identifies the 19th layer of graphite; portions of layer 18, which contained slugs of uranium oxide, are also visible. (Courtesy of Argonne National Laboratory)

Fig. 8. The Graphite Reactor in 1947. (DOE Oak Ridge Operations Photo 3537)

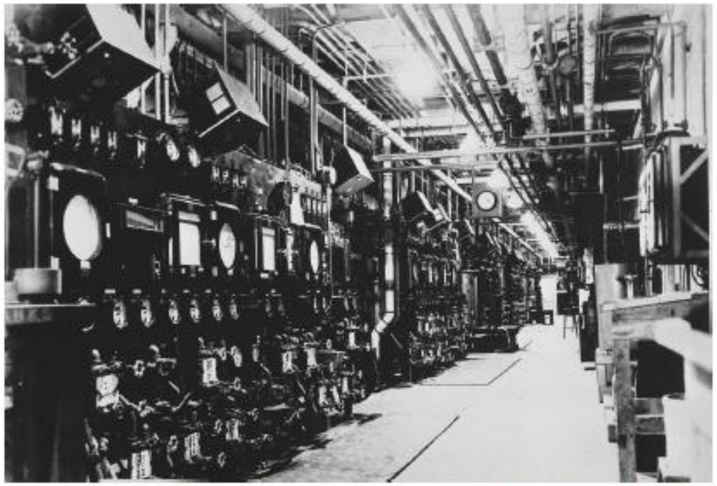
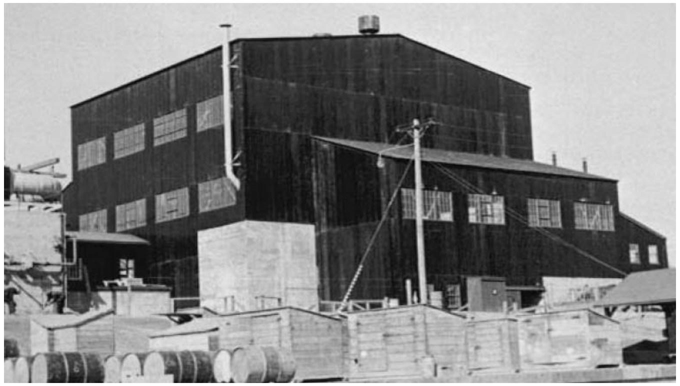


Fig. 7. Operations area of the chemical separations pilot plant. (ORNL History Photo 185)

Oak Ridge Graphite Reactor (X -10 Reactor)

- 3.4 MW(t) graphite moderated U(natural) metal fuel
  - 44,000 1 in. × 4 in. (2.54 cm × 10.2 cm) Al clad uranium slugs
- Air cooled
- 24 X 24 ft (7.3 m × 7.3 m) graphite containing 1248 fuel channels
- Avg.Thermal Flux 5×10^{11} n/cm^2/s
- Fast flux 5×10^{11} n/cm^2/s



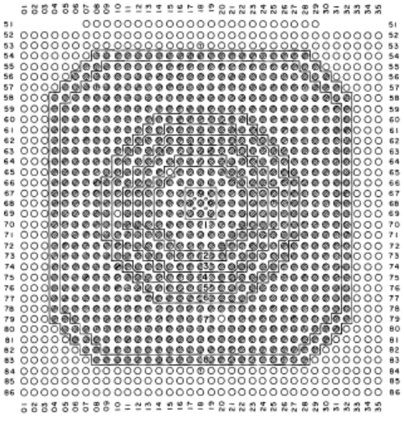


FIG. 2.2 OGR FUEL LOADING PATTERN

Fig. 4. Graphite Reactor fuel slug.

Oak Ridge Graphite Reactor (X-10 Reactor)

- 3 safety channels located on top of core contained Cd
  - Gravity insertion
- 2 shim rods
- 2 regulating rods
- Employed mechanical and pneumatic drives (diverse and redundant)
- Rods entered from the side of reactor

Gear Driven Regulating Rods OGR

Hydraulic Driven Regulating Rods OGR

Sand Tanks Used to Back Up Hydraulic-Driven Regulating Rods OGR

Oak Ridge Graphite Reactor (X-10 Reactor)

- Fresh Fuel was loaded from front face of reactor using push rods
- Spent Fuel was pushed out back of reactor fell into containers located in spent fuel canal
- Spent fuel transported by underground canal to reprocessing plant next door

OGR (cont.)

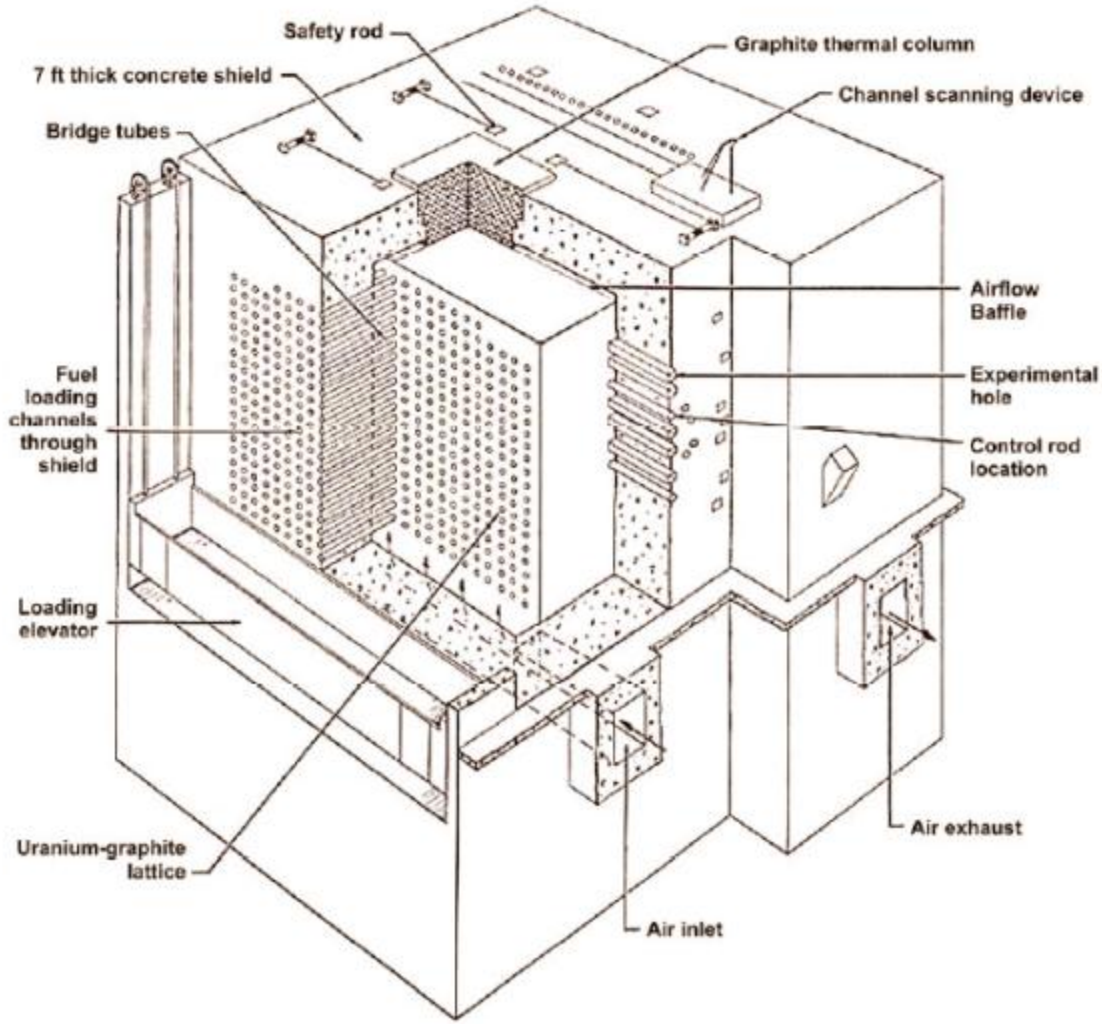
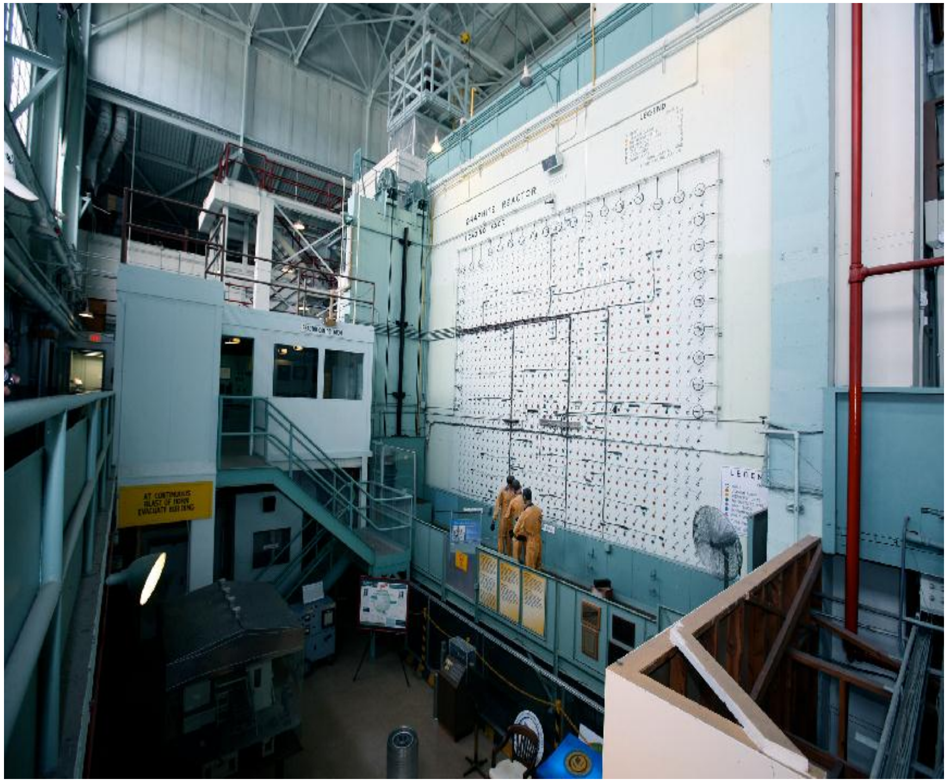


Fig. 5. Cutaway view of the Graphite Reactor.

Oak Ridge Graphite Reactor Refueling operation



Oak Ridge Graphite Reactor (X-10 Reactor)

- After the WW II ended, reactor became a research reactor
- Experiments were conducted in and around the reactor
  - First medical isotopes produced
  - Irradiated many isotopes for use world wide
  - Materials irradiation
  - Fuel performance
  - Water Moderation experiments (precursor to PWRs)
  - Biological effects irradiation measurements- animal irradiations (dosimetry)
  - Reactor physics experiments
  - Radiation detection
  - Neutron scattering (Clifford Shull won Nobel Prize-1994)

Oak Ridge Graphite Reactor (X-10 Reactor)

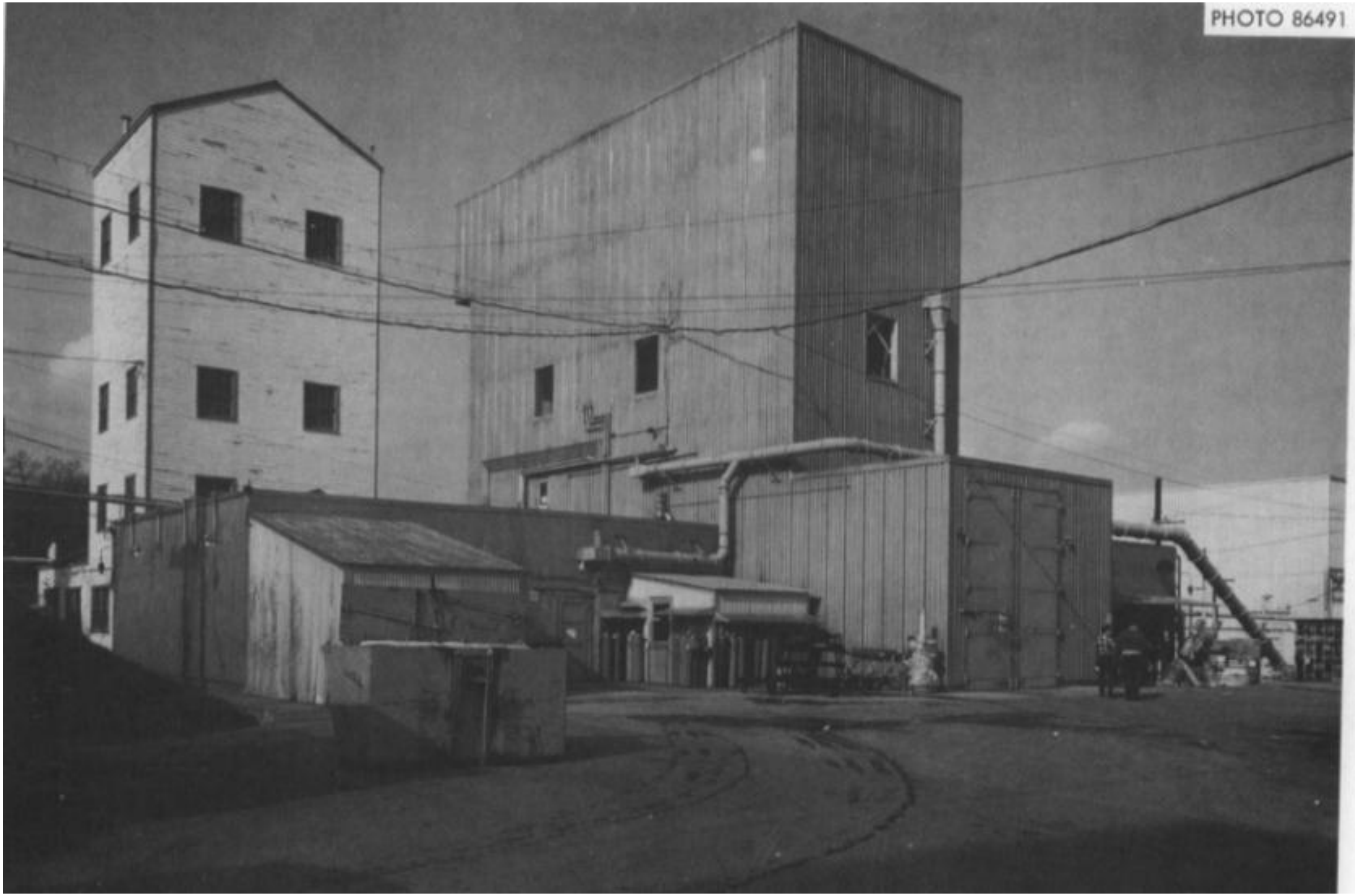
- Safeguard Issues
  - Graphite is readily available (nuclear grade is most common)
  - Natural U fuel
  - Use of industrial materials
  - Simple to construct, operate
    - Used for research
    - Used to produce Pu
  - Rapidly constructed
  - First production reactors were graphite moderated

Low Intensity Test Reactor Building 3005 (Next to OGR)

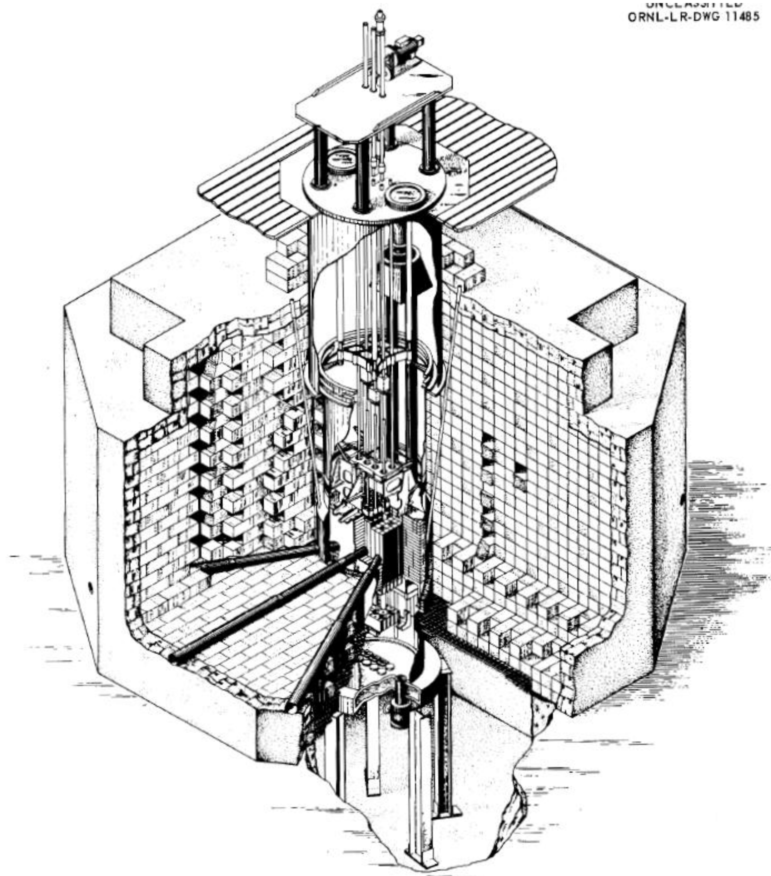
- 3 MW water-cooled/moderated (downward flow)
- Be reflected
- MTR fuel elements (U/Al) (enriched U)
- Thermal flux 2×10^{13} n/cm^2/s
- 1948 hydraulic test facility for Materials Test Reactor (MTR)
- 1950 critical mock-up for MTR
- 1951 500 kW training reactor for MTR operators (low-intensity training reactor)

Low Intensity Test Reactor (Continued)

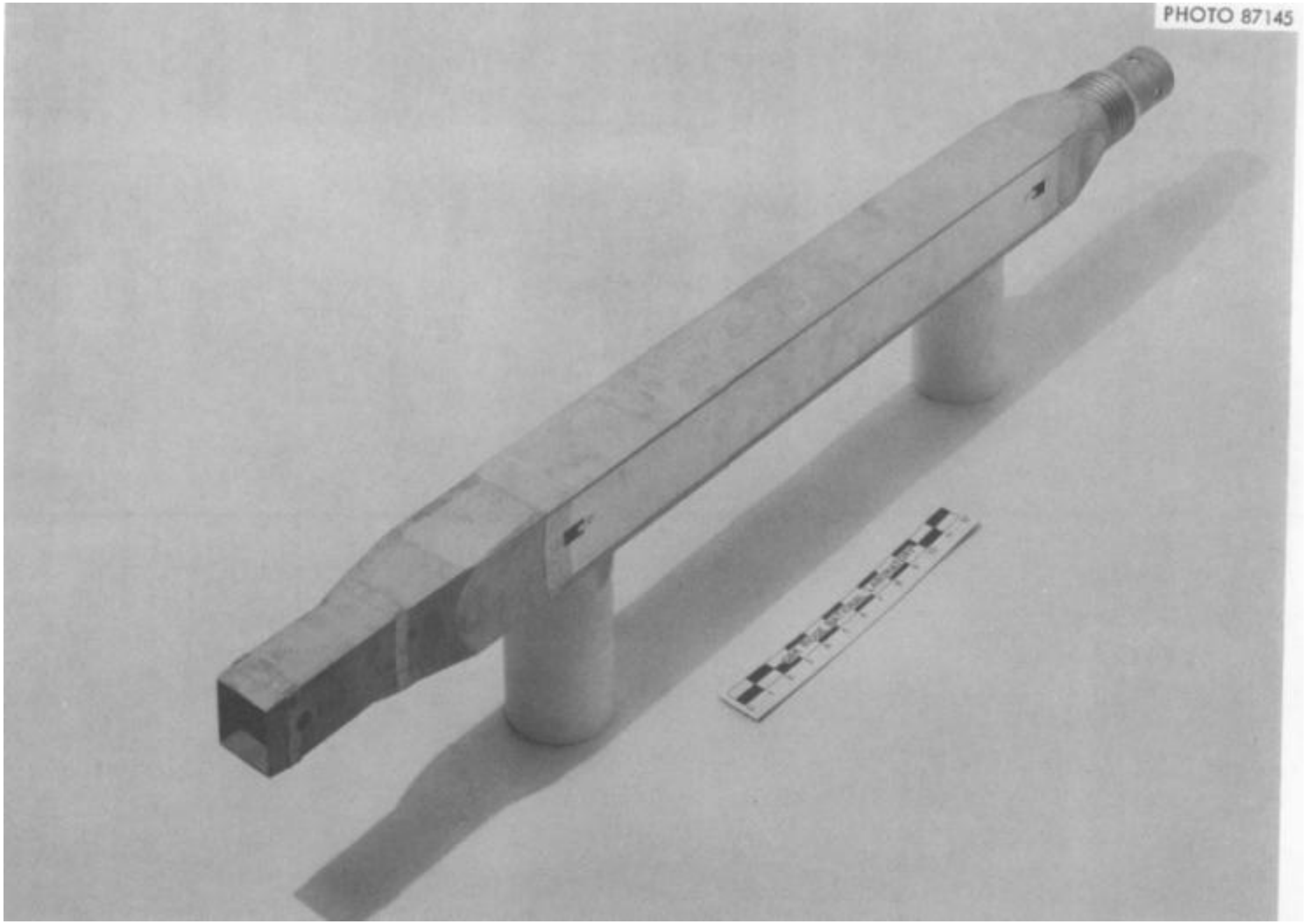
- 1951 converted to experimental reactor
  - (Low Intensity Test Reactor)
- 1951 power raised to 1 MW, 1952 power raised to 1.5 MW, and 3 MW in 1953
- Control
  - One regulating rod
  - Three shim/safety
  - Enter from the top of vessel
- Flexible core loading to allow for in-core experiments (array of 5 × 9)
- First demonstrated the feasibility of a boiling-water reactor
  - Led to development of BORAX reactors at INL and later to BWRs



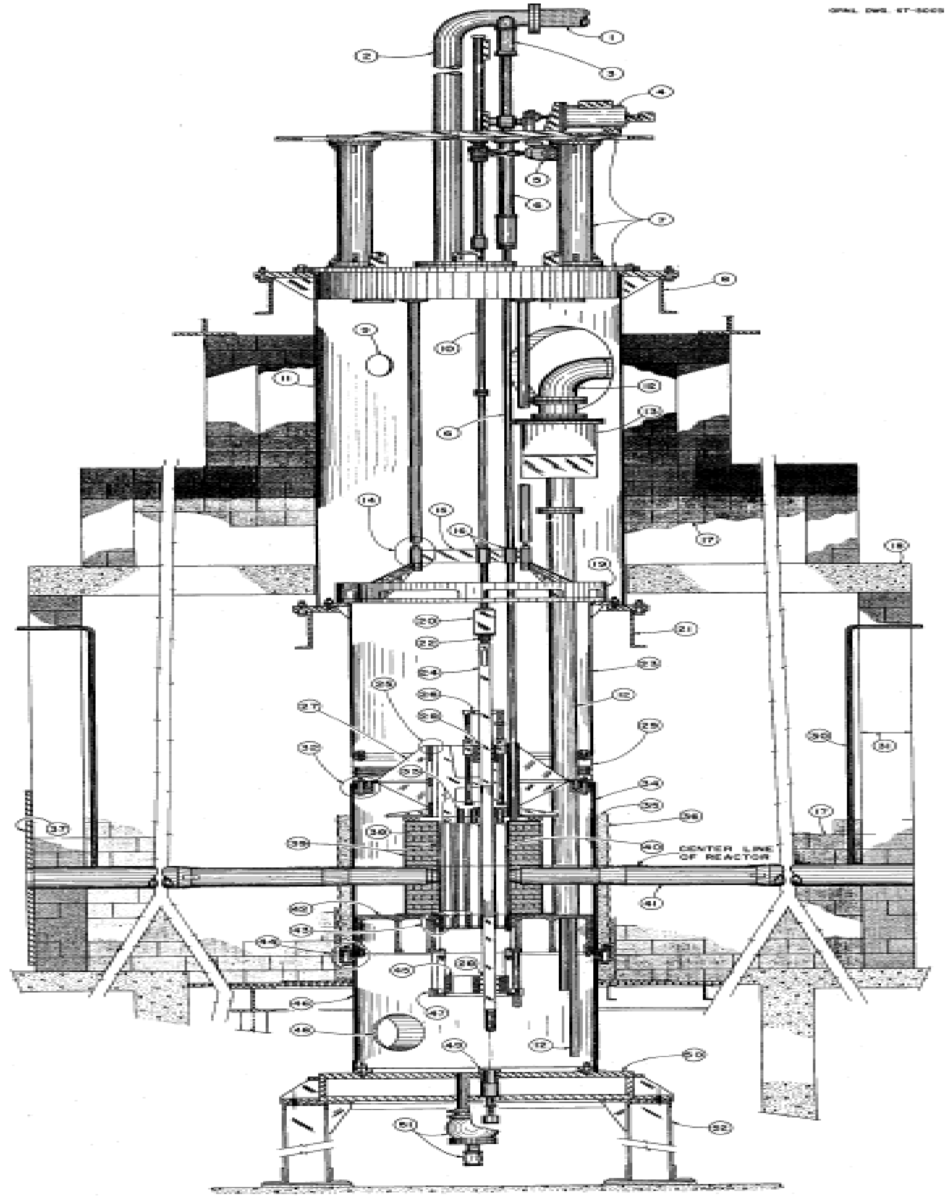
South Side of the LITR Building



Low-Intensity Test Reactor



LITR Fuel Element



Vertical Cross Section of the LITR

Legend for Figure No. 5.2.4

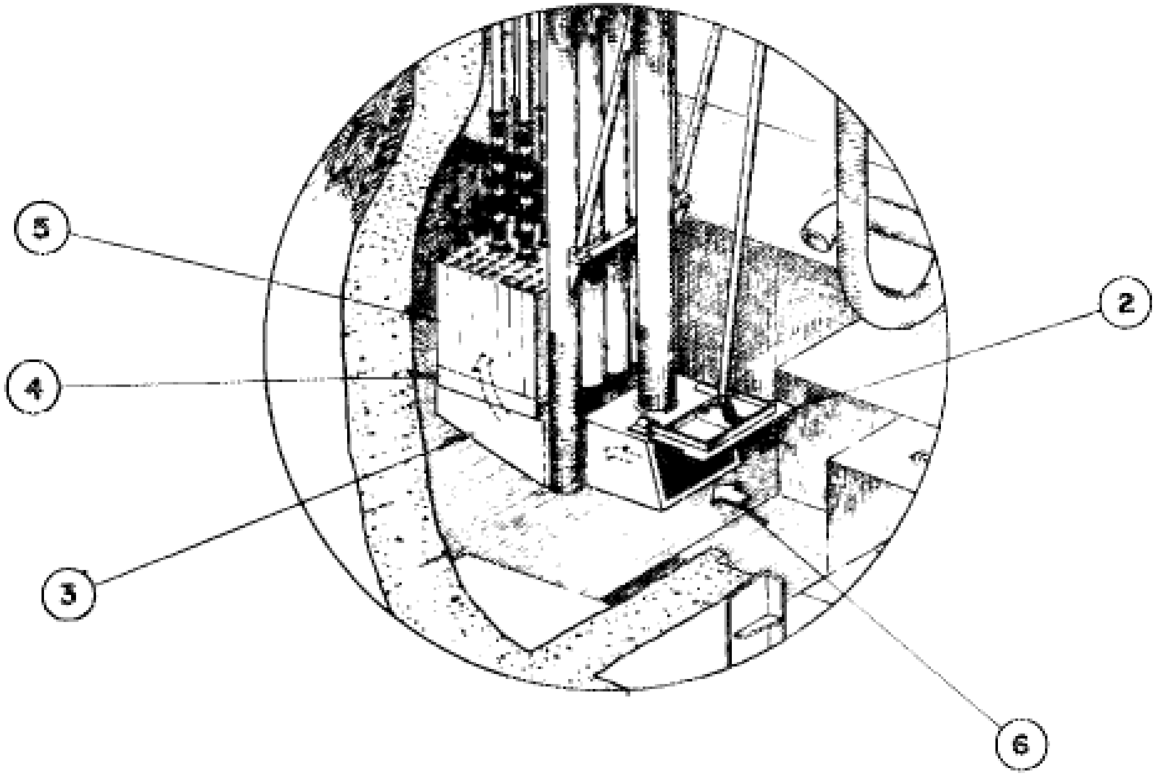
1. Flexible Rubber Line
2. Overpressure Relief Line
3. Regulating Rod Upper Shock Absorber
4. DC Motor for Regulating Rod
5. Shim Rod Drive Motor
6. Regulating Rod Drive Shaft
7. Top Plug Assembly
8. Upper Support for Reactor Tank
9. Primary Water Inlet Opening
10. Shim Rod Drive Shaft
11. "A" Section of Tank
12. Primary Water Exit Line
13. Exit Water Line Expansion Joint and Transition Piece (Fig. 6.7.2)
14. "Spider" Positioning Mechanism (Fig. 5.3.9)
15. Guide Bearing Grid, "Spider"
16. Guide Bearing
17. Dry Stacked Concrete Block Shield
18. Precast Concrete Slabs
19. Guide Ring for "Spider"
20. Electromagnet
21. Support for Reactor Tank
22. Shim Rod Armature
23. "B" Section of Tank
24. Shim Rod
25. Locking Device for Upper Grid Assembly (Fig. 5.3.13)
26. Lifting Device for Upper Grid Assembly
27. Upper Grid Support
28. Shim Rod Guide Bearing
29. "C" Section of Tank
30. Ventilation System for Beam Holes and Dry Stacked Shield (Fig. 9.2.2)
31. Mortared Concrete Block Shield
32. Figure 5.3.5
33. Removable Beryllium Reflector Pieces
34. "D" Section of Tank
35. River Sand
36. Plastic Impregnated with B_4C
37. Shielding, Steel Plate
38. Permanent Beryllium Reflector
39. Box for Permanent Reflector
40. Fuel
41. Beam-Hole Liner
42. Lower Fuel Grid Support
43. Side Skirt Plate and Fuel Grid Locking Device (Figs. 5.3.11 and 5.3.12)
44. Figure 5.3.7
45. Lower Guide Grid (Fig. 5.3.14)
46. "E" Section of Tank
47. Lower Guide Grid Cradle (Fig. 5.3.14)
48. Sealed Opening
49. Shim Rod Shock Absorber and Seat Switch Assembly (Fig. 5.3.8)
50. "F" Section of Tank
51. Reactor Tank Drain Valves
52. Lower Support for Reactor Tank

Bulk Shielding Reactor (BSR) Building 3010 Next to LITR (1950–1987)

- 2 MW water-cooled forced circulation
- MTR aluminum cladding plate type (square)
- HEU fuel
- First swimming pool design
- Reactor suspended from bridge could be moved within the pool
- Experiments could be moved up to reactor face
  - D_2O tank could also be used on face of reactor
- Designed to do shielding experiments as part of Air Craft Nuclear Propulsion Program
- Critical mockup (pool critical assembly) added to one end of pool, used same fuel as BSR
- Served as model for Geneva reactor
  - Assembled in BSR pool, disassembled and set up at first conference for Peaceful Uses of Atomic Energy, Geneva, Switzerland (1955)
  - Modified to use 20% enriched fuel sold to Swiss government; increased power to 10 MW and operated for many years
- Operated remotely from Oak Ridge Research Reactor control room
- Cost $250,000

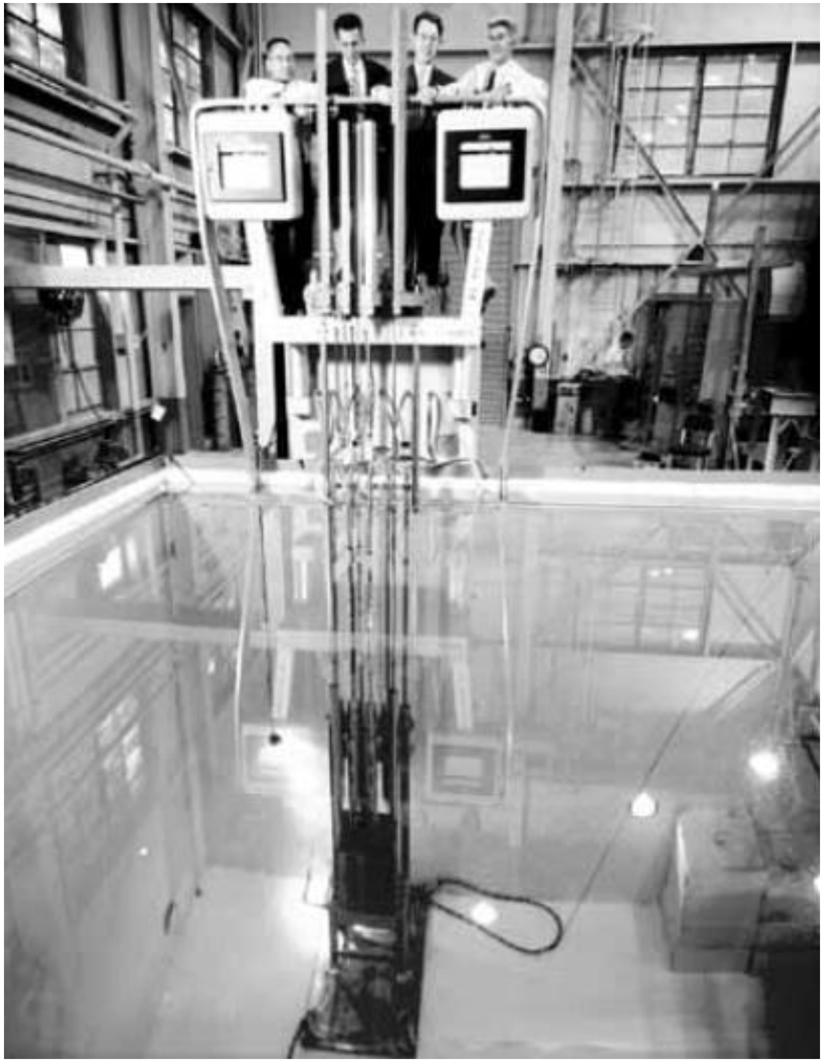
BSR Reactor Characteristics

- Four control/safety rods contained in specially designed fuel assembly
- Entered from top of reactor
- Natural circulation at low power levels
- Forced circulation at 2 MW (downward)
  - Pumped water from decay tank below core into pool causing pool water to flow downward through core (1200 gpm)
- Proliferation issues
  - Movement of materials adjacent to reactor interface
  - D_2O tanks
  - Ease of reactor configuration changes and access to reactor core
  - In-pile experiment locations



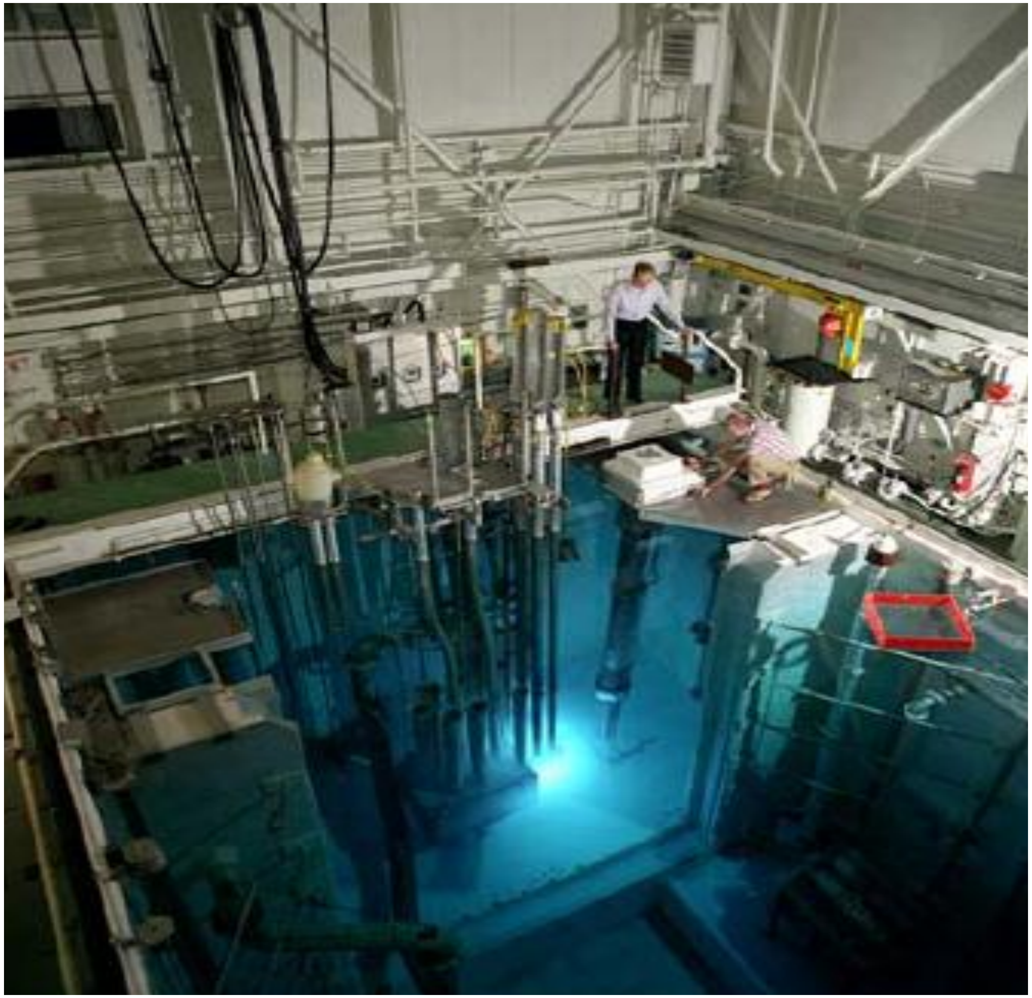
Restricted Isometric View of the BSR Showing the Flow Path for Natural-Convection Cooling During Mode-1 Operation

BSR Building



Geneva Reactor in BSR Pool

Leo Holland Explaining the Geneva Reactor to President Eisenhower



BSR Side View

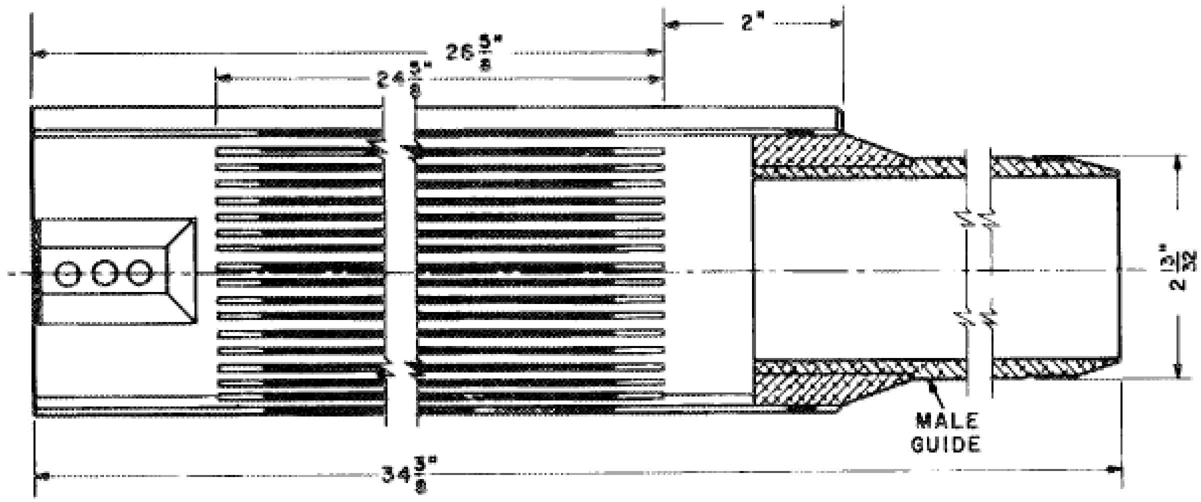
BSR Top View

BSR—Moving Experiments

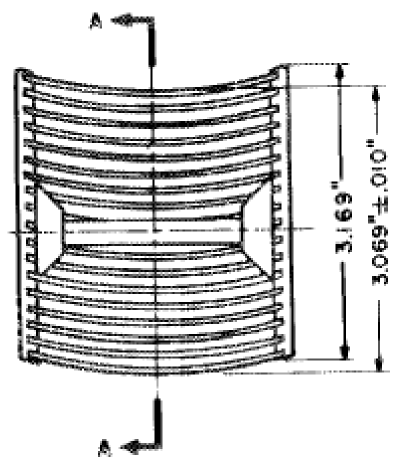
BSR Fuel Description

Table 4.1. Selected reference dimensions for standard BSR fuel elements

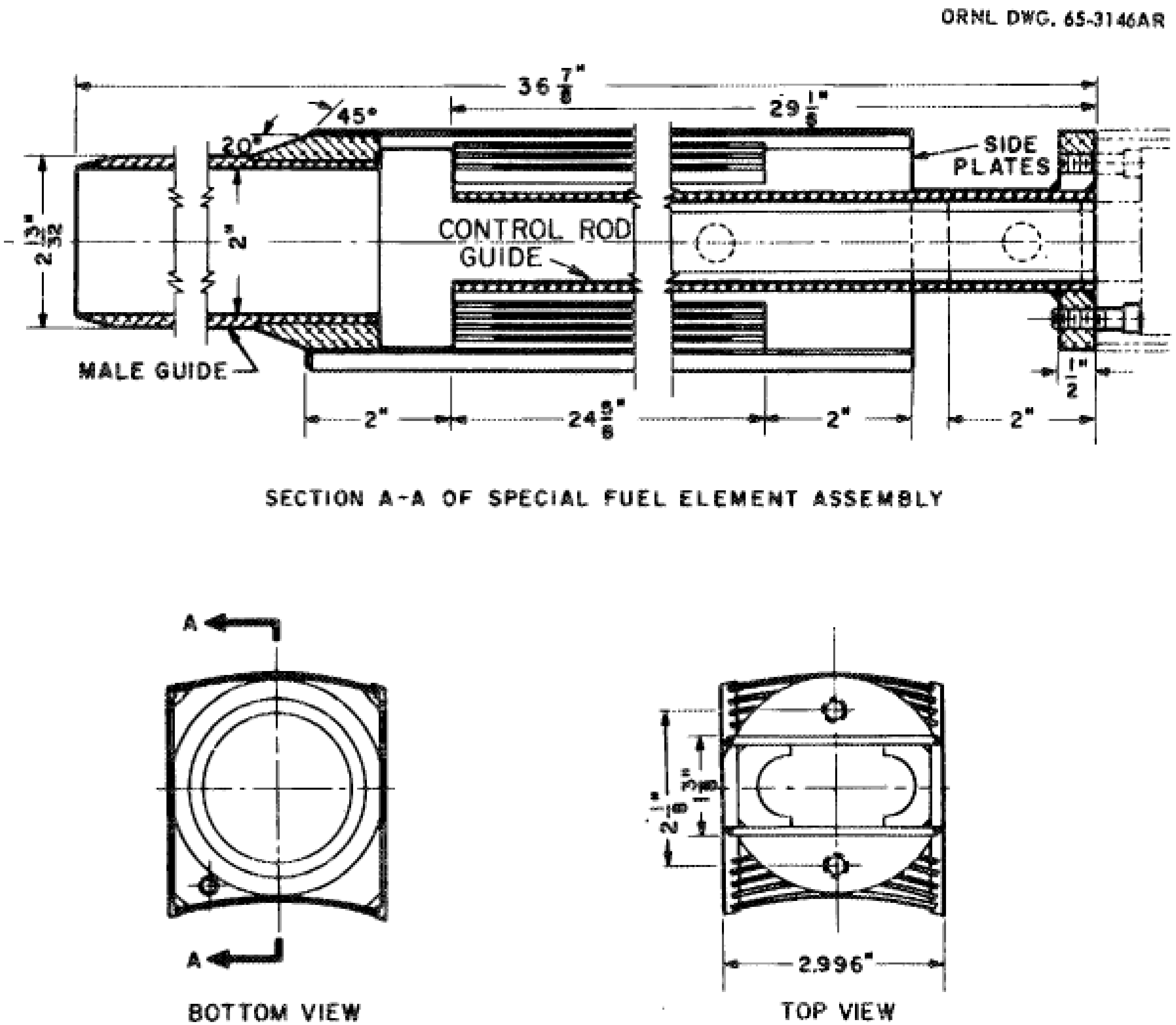
Unit	Nominal dimension (in.)
Element Assembly	
Length	34 3/8
Width (through side plates)	2.996
Width (through outside fuel plates)	3.069
Plate spacing	0.117
Inside Fuel Plates	
Thickness (overall)	0.060
Length (overall)	24 5/8
Clad thickness	0.020
Core (alloy) thickness	0.020
Core (alloy) length	23 5/8
Width (before bending)	2.845
Outside Fuel Plates	
Thickness (overall)	0.060
Length (overall)	28 5/8
Clad thickness	0.020
Core (alloy) thickness	0.020
Core (alloy) length	23 5/8
Width (before bending)	2.845



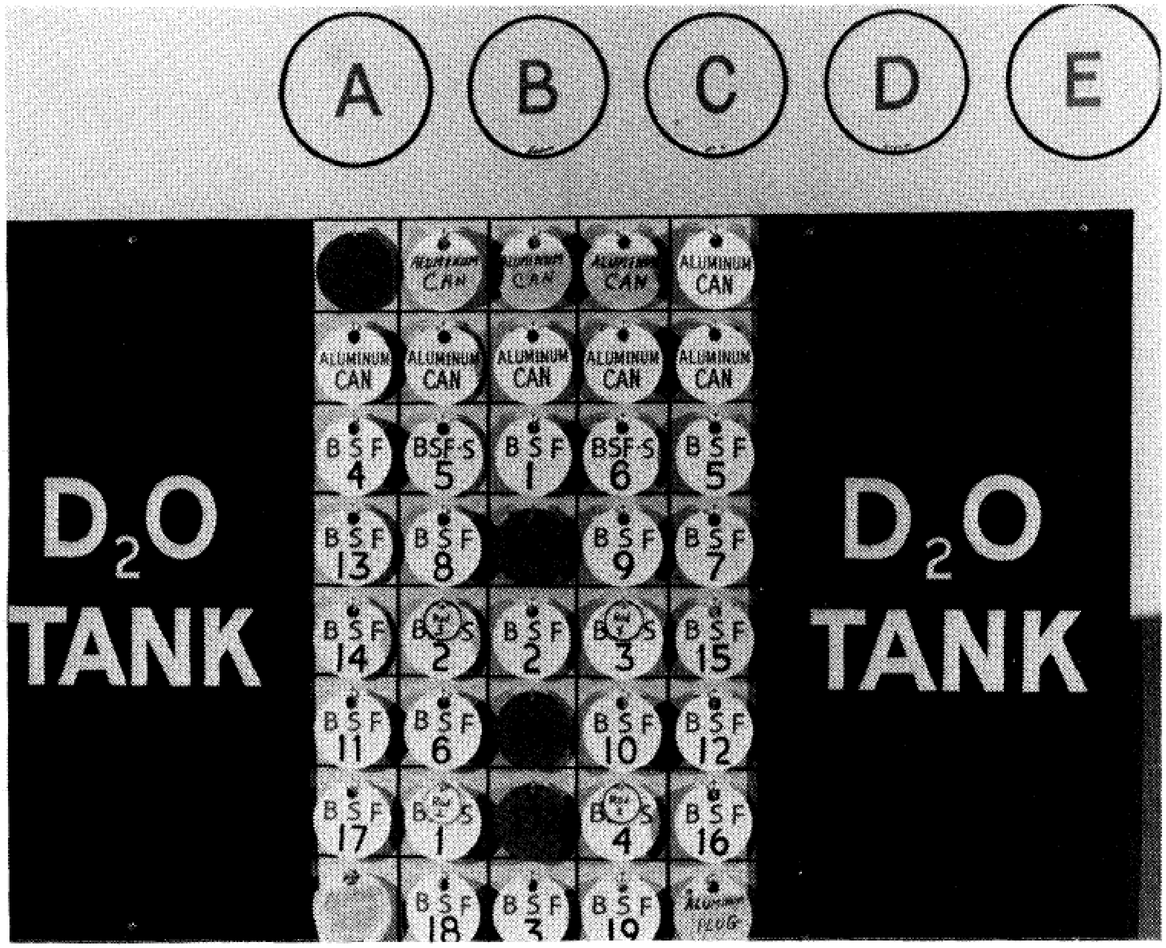
SECTION A-A OF FUEL ELEMENT ASSEMBLY



Standard BSR Fuel Element

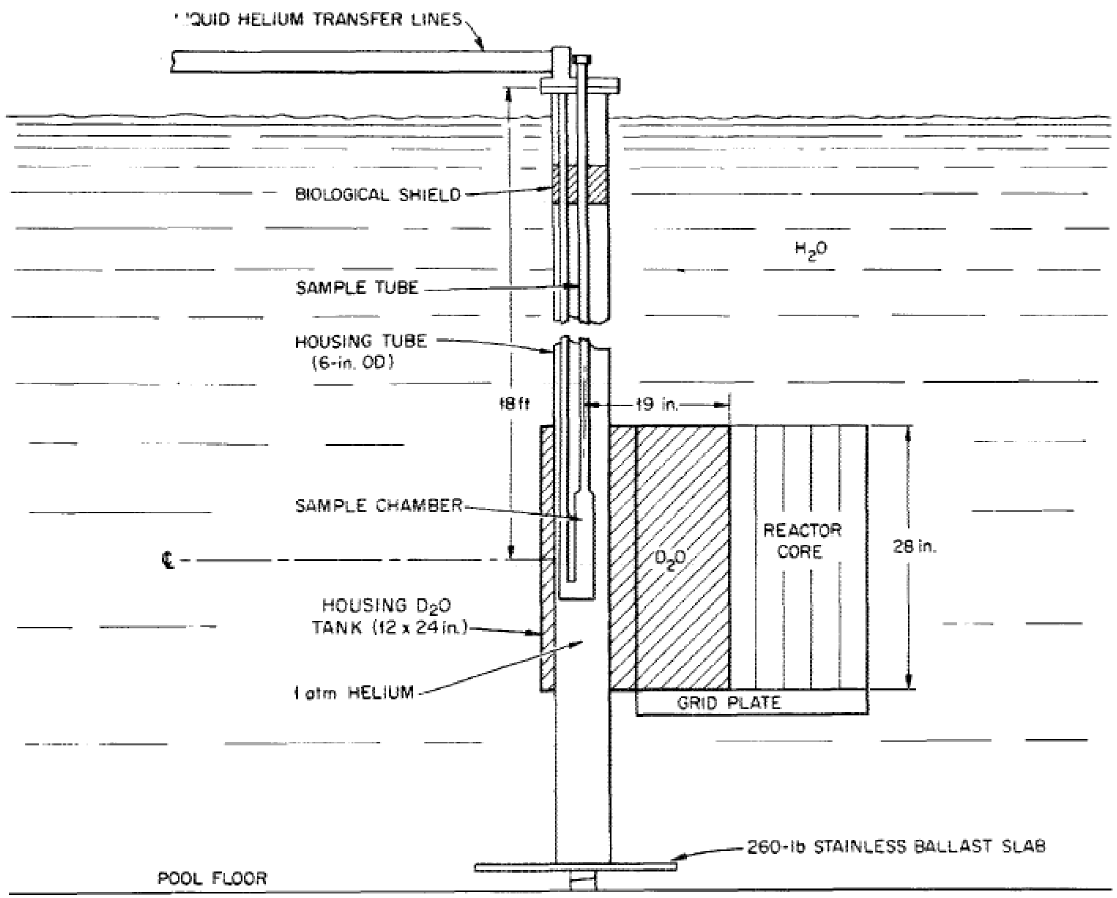


Special Fuel Element for Control Rod



BSR Core Configuration Board

Helium Cryostat



The Liquid Helium Cryostat

Oak Ridge Research Reactor Building 3042 (Adjacent to BSR) 1957–1987

- 20 MW tank reactor in swimming pool (21 ft × 10 ft × 28 ft deep)
  - 150,000 gallons of water
- Enriched uranium, aluminum cladding, plate-type fuel element
  - 9 × 7 fuel array
  - 6 horizontal beams
- Combined features of the MTR and BSR
- Light-water cooled and moderated (12,000 gal/min downward flow through core)
- Be reflected
- Contained in an aluminum tank 5 ft in diameter and 15 ft in height
- Control system operates from bottom of core (no interference with access to top of reactor)
- Thermal flux of 1.3×10^{14} n/cm^2/s
- Employed auto start up (<300 kW)
  - Employed movable control elements (top half poison bottom half fuel) (4 elements)
  - Disengaged from drive (scram) gravity accelerated into the core

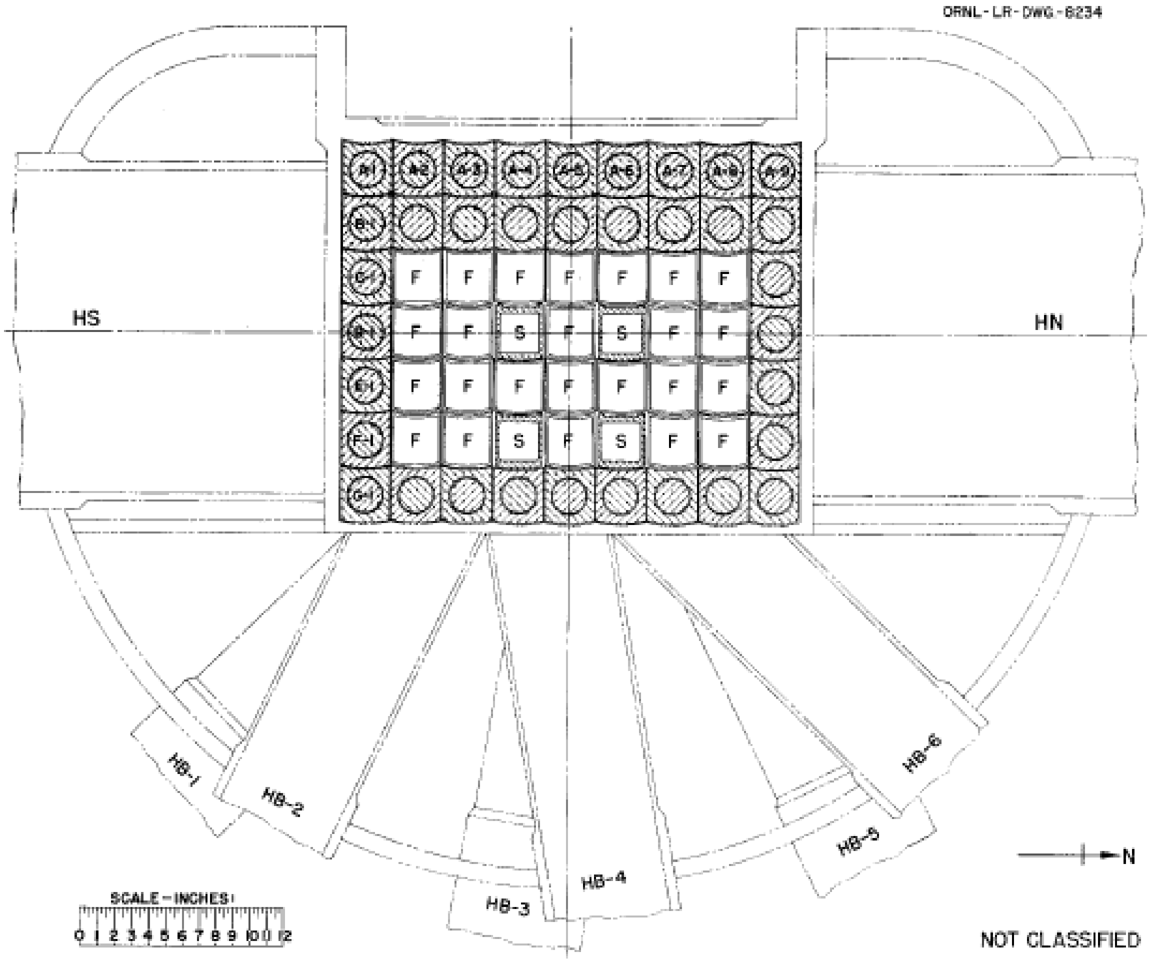
Versatile Design Allowed A Wide Variety Of Experiments

- Beam tubes (neutron scattering)
- In-core loops
- Multiple rabbit tubes
- Isotope production
- Fuel testing
- Materials irradiation
- Large access space in pool to one face of reactor
  - Thermal column
  - Irradiation of large equipment
- Building (108 ft × 80 ft × 71 ft) lots of space for experiment around pool
- Over pool hot cell

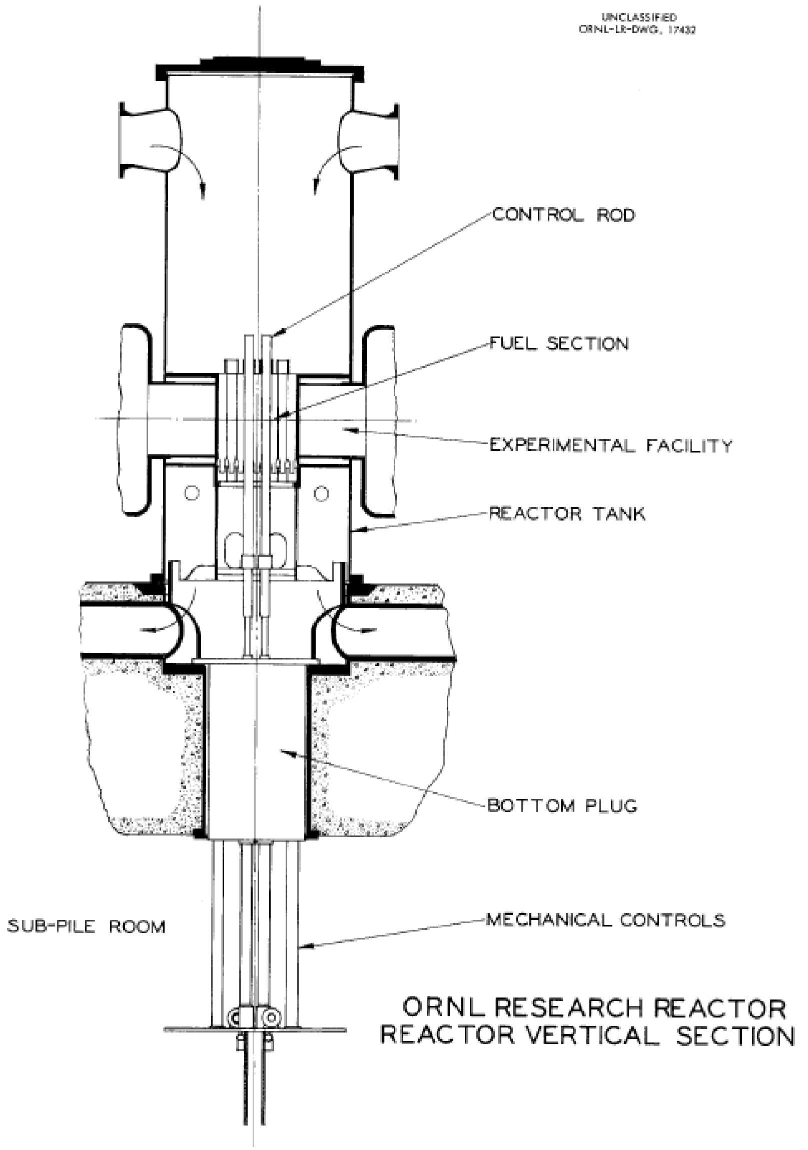
In-Core Loops

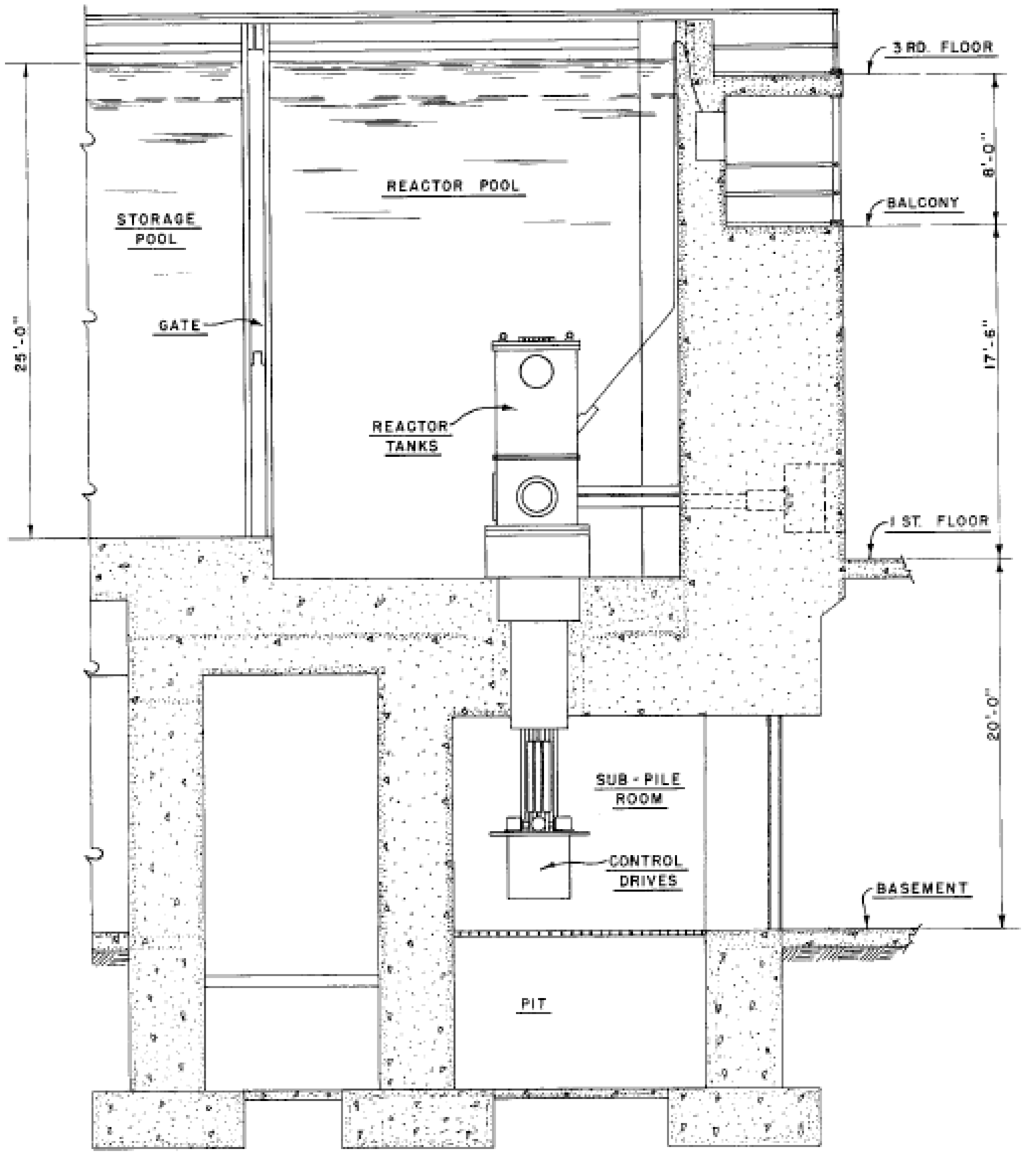
- HTGR spherical fuel testing
- Flowing helium loop for fuel testing
- Pressurized-water loop for testing in support of first nuclear commercial nuclear ship—Savannah
- Testing of solution fuel for HRE

Plan View Of ORR



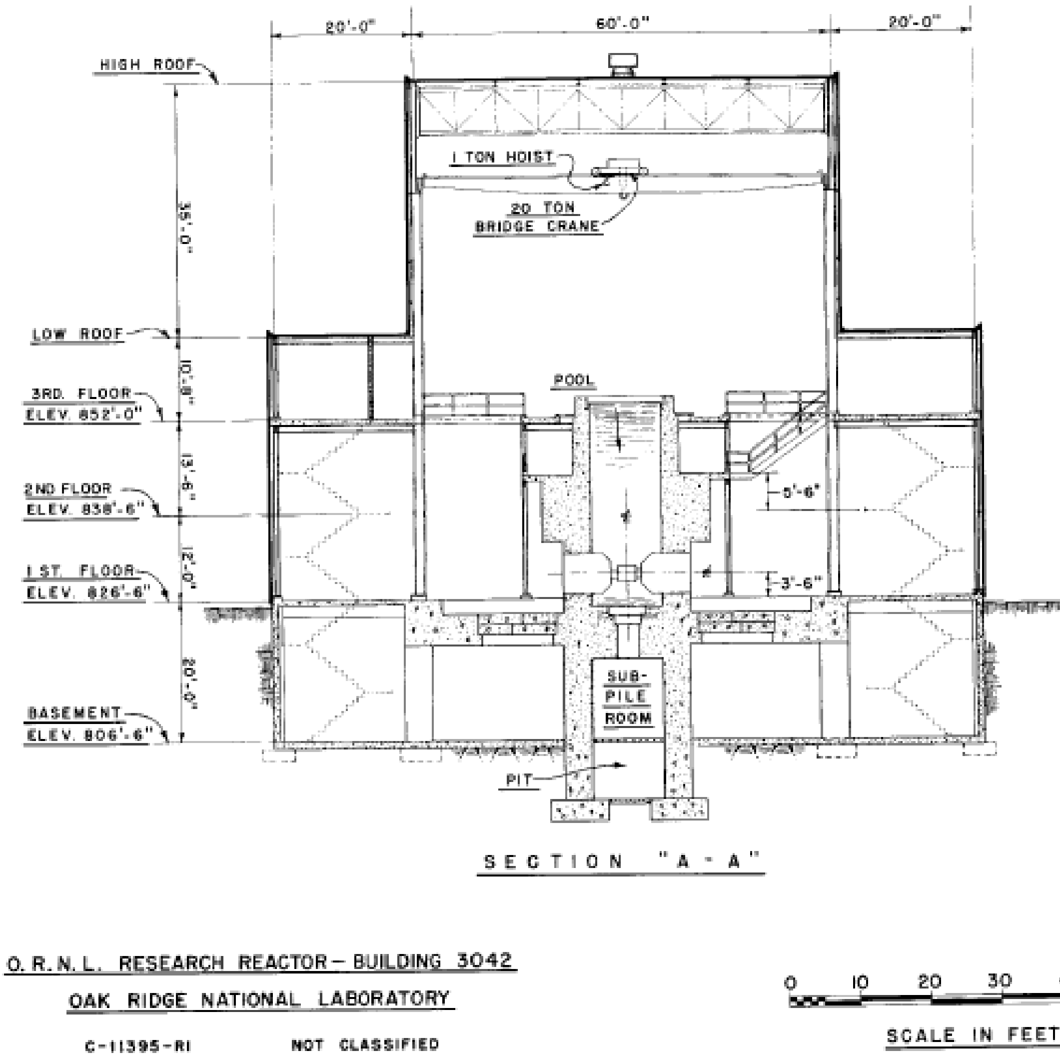
Vertical Section Through Core

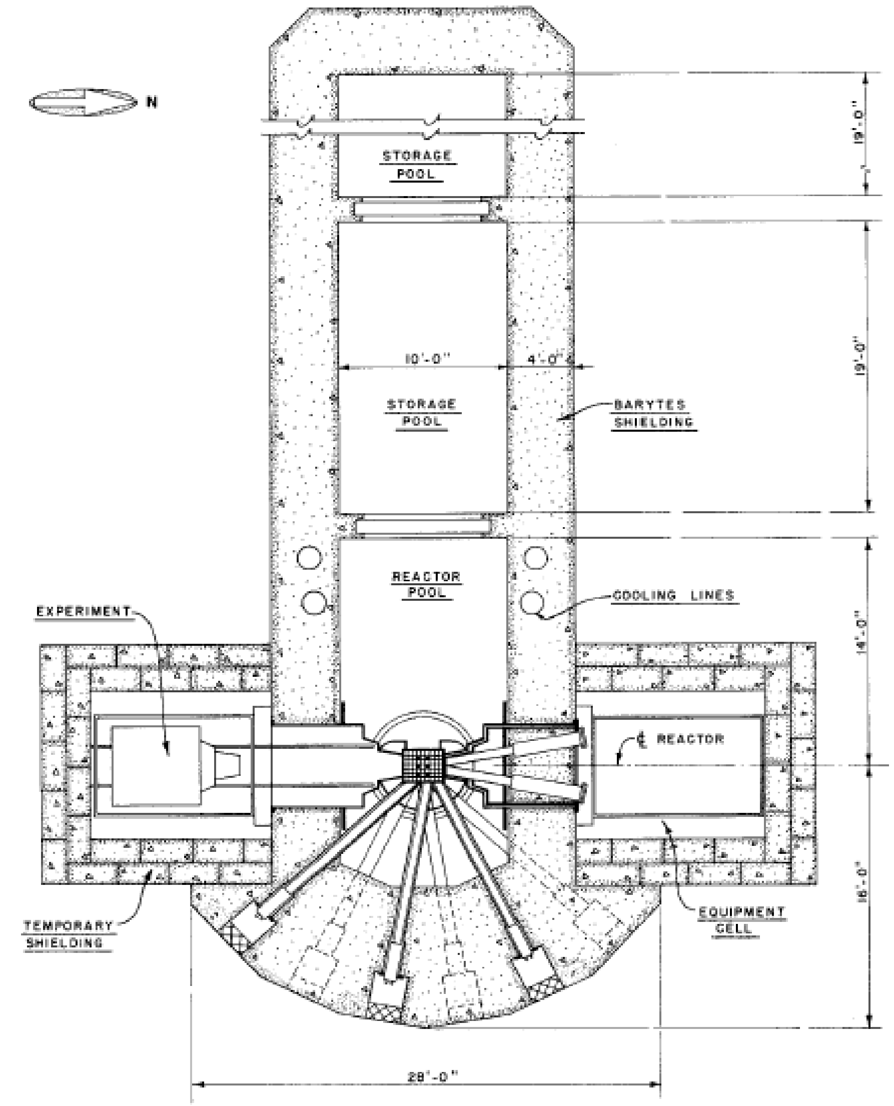




REACTOR STRUCTURE —VERTICAL SECTION

End View Of ORR Building





REACTOR AND POOL STRUCTURE
HORIZONTAL SECTION

0 5 10 15 20
SCALE IN FEET

REACTOR AND POOL STRUCTURE
HORIZONTAL SECTION
O. R. N. L. RESEARCH REACTOR BUILDING 3042
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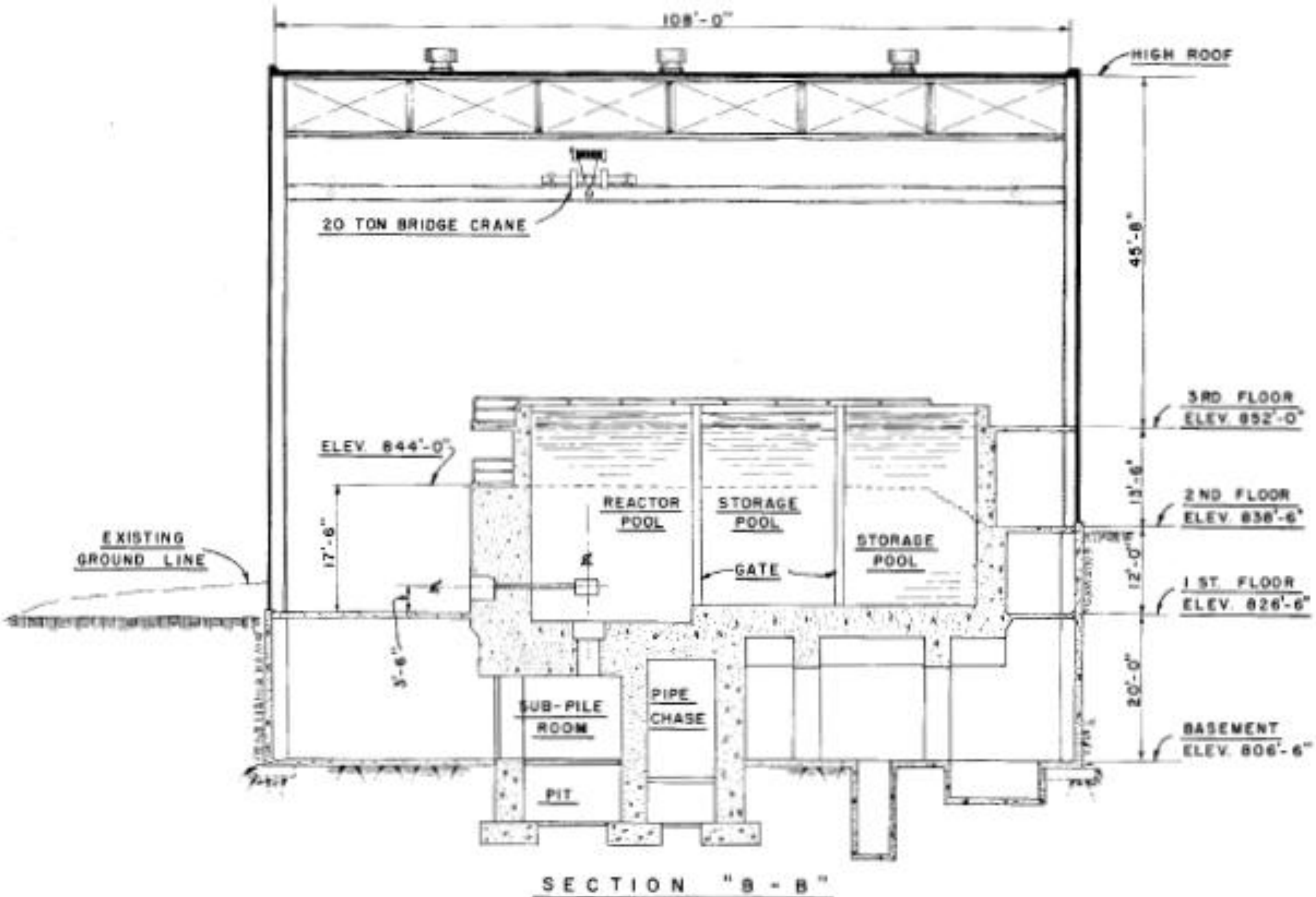

O. R. N. L. RESEARCH REACTOR – BUILDING 3042

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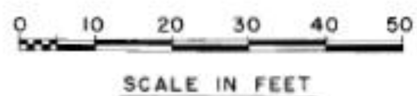
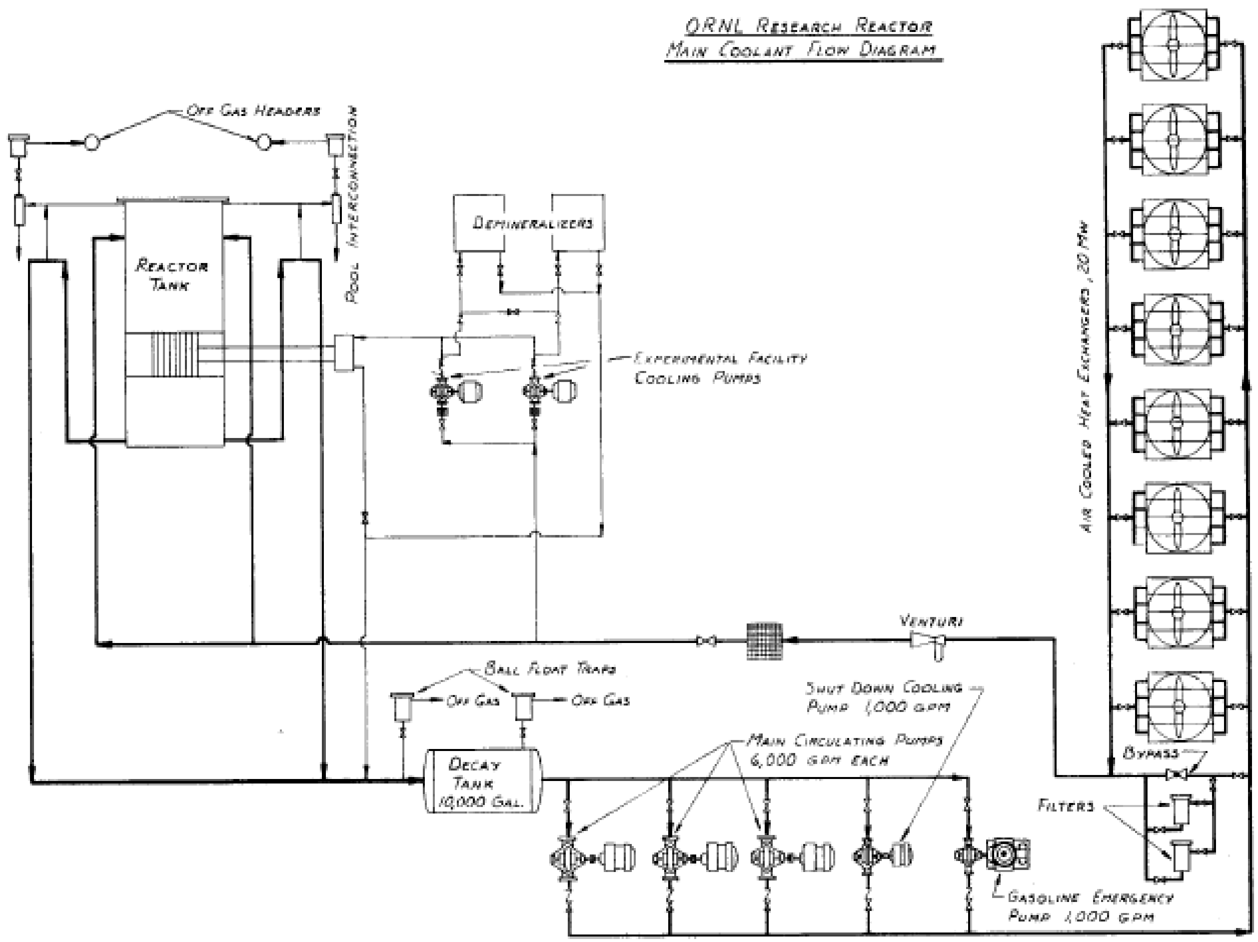
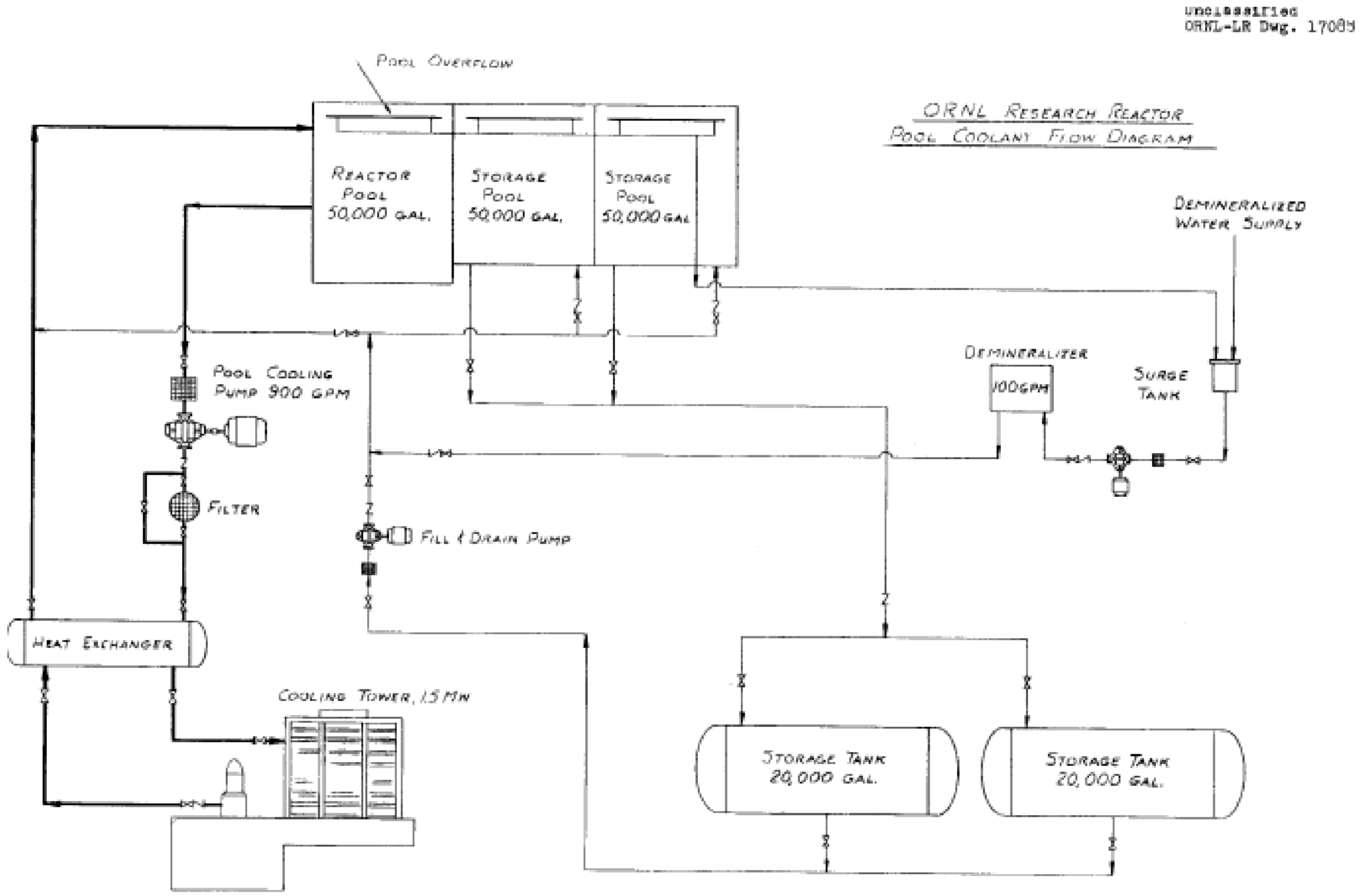
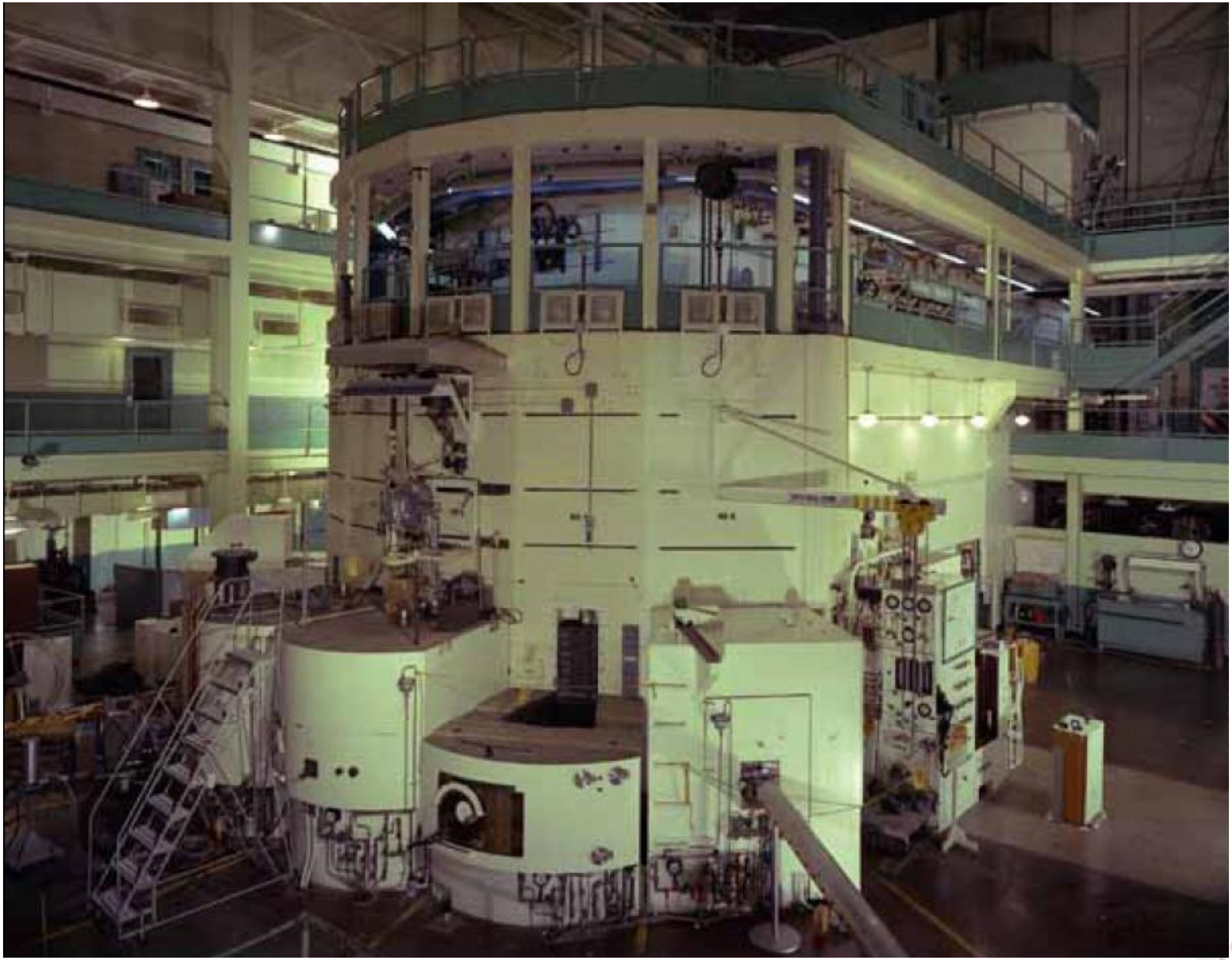


Primary Cooling



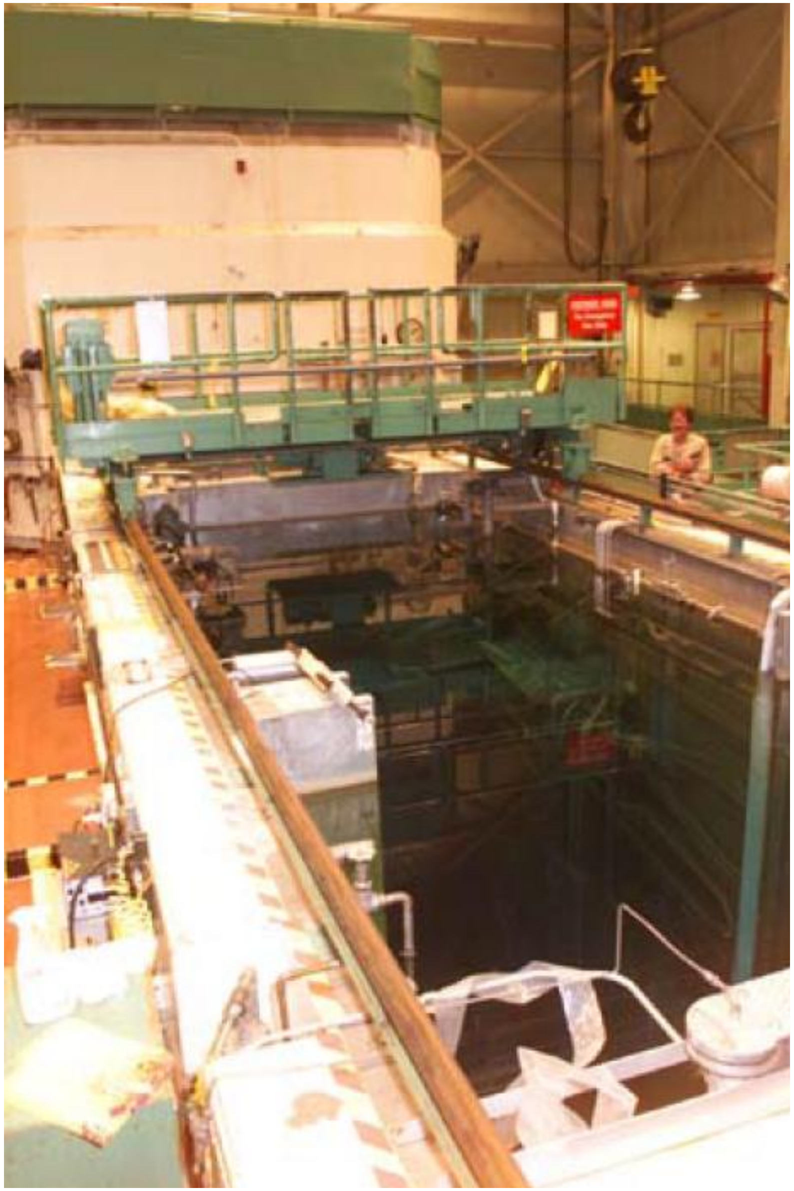
Pool Cooling





Top View Of Tank—ORR

ORR Pool



ORR Hot Cell At One End Of Pool

Issues Of Importance To Inspection Associated With ORR

- Large power
- Very versatile
  - Rearrange fuel in almost any configuration
  - Closed loops in core
  - Changeable fuel
    - First reactor to run on LEU silicide fuel (1987)
    - Led to conversion of many aluminum-fueled research reactors from HEU to LEU
- Access to fuel face in pool

Homogeneous Reactor Experiment HRE (1952–1954)

- Combined fuel, moderator, and coolant in a single solution
  - HEU uranyl sulfate (uranium dissolved in sulfuric acid)
  - On-line reprocessing
  - No refueling shutdown
  - Excellent load following

- 1 MW(t) [150 kW(e)]

HRE Design Characteristics

- Spherical 50 liter Tank 347 SS
- D_2O reflected (10-in.-thick reflector tank)
- Fuel density 30 g U/l
- Power density 20 kW/l
- Design outlet temperature 250°C at 1000 psia
- Flow rate of 100 gpm fuel
- Flow of 30 gpm of D_2O

Advantages Of Homogeneous Reactor

The principal advantages of homogeneous systems may be considered to be the following:

(a) Neutron losses may be kept low since structural materials can be largely eliminated from the reactor.

(b) Continuous processing becomes possible with consequently lower neutron losses to fission product poisons.

(c) Lower initial and operating cost, as a result of the simplicity of design, chemical handling, refueling, and few intricate parts.

(d) A minimum amount of fuel is required for a given power level.

(e) There is no deteriorating radiation damage to hard-to-replace structural material or moderator material, i.e., no "Wigner" disease.

(f) It is possible to produce power and RW products simultaneously with Pu production with a low hold-up of fuel.

Disadvantages Of Homogeneous Reactor

(a) The possibility of sudden reactivity changes due to density fluctuations caused either by bubble formation or temperature changes may create difficult control problems.

(b) The fuel solution is very corrosive to most materials of construction.

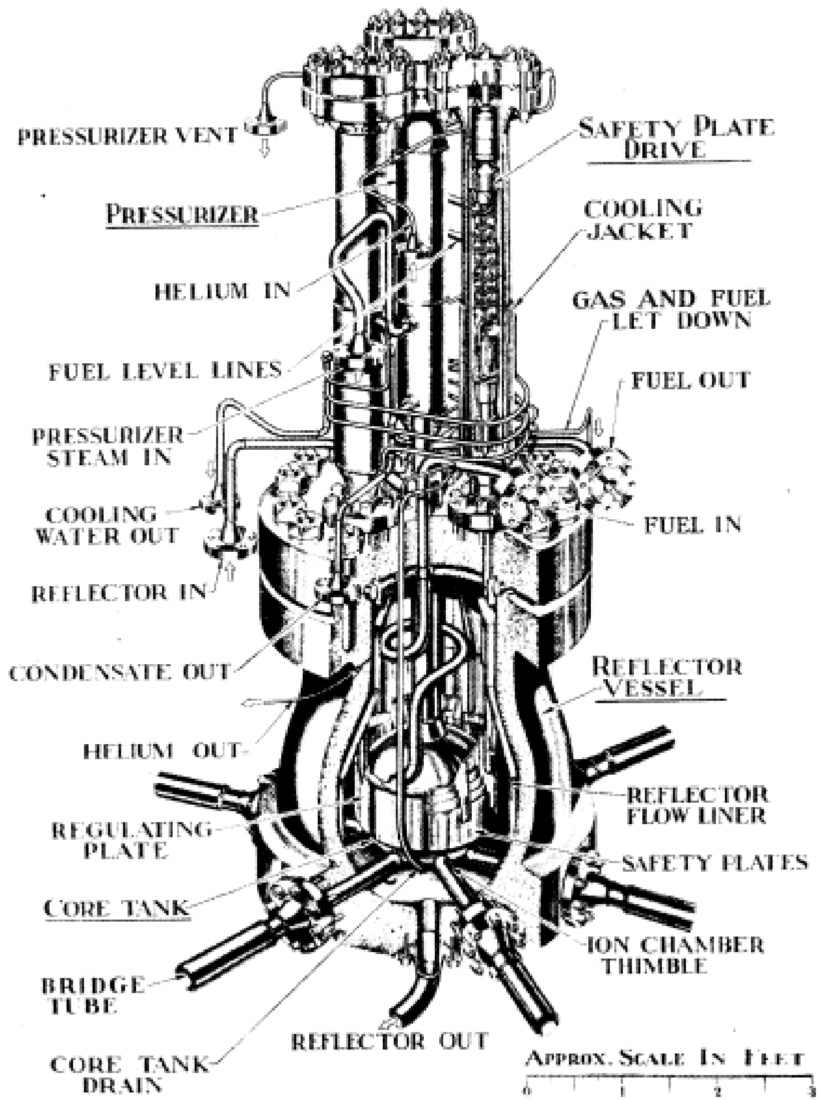
(c) There will be a loss of some delayed neutrons in the external circuit which conceivably can narrow the margin for safe control.

Safety

- Fuel and/or D_2O can be dumped from core to critically safe dump tank below reactor
- Negative void/density/temperature coefficient
- ^{10}B plates in vapor space above core
- Similar plate in moderator surrounding the core
- Adjustment of reflector fluid
- Adjustment of fuel density
- Disassociation gases (oxygen and hydrogen from water being exposed to radiation) recombined using a burner or catalytic converter

HRE Building (Melton Valley Road Near HFIR)

HRE Layout



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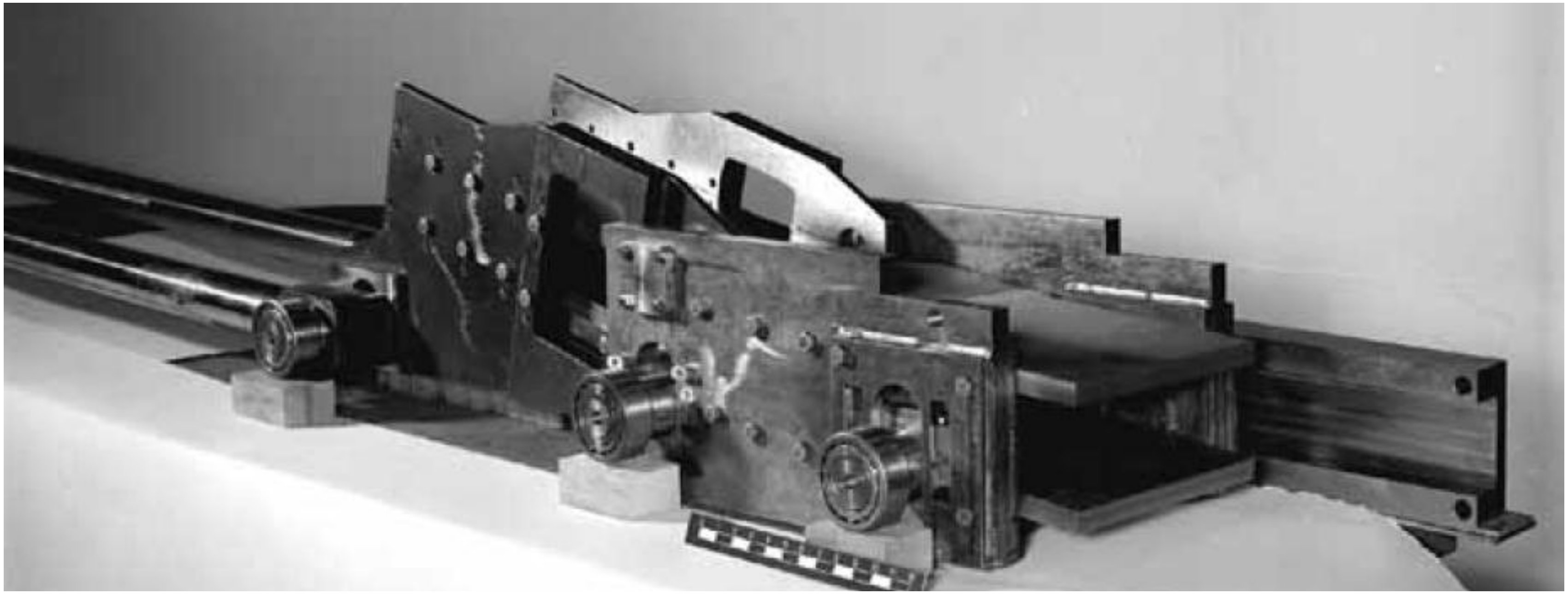
HRE Flame Recombiner



HRE-2 (1957–1961) or HRT

- Power level 5 MW(t)
- Zircalloy-2 core tank 32-in. diamete
- 10 gm U/l uranyl sulfate
- Design temperature 300°C at 2000
- D_2O reflected
- 17 kW/l power density
- Flow rate 400 gpm
- No active safety control
  - Variable solution concentration
  - Negative temperature coefficient
  - Dump tank for fuel and reflector
- Occupied same building as HRE-1

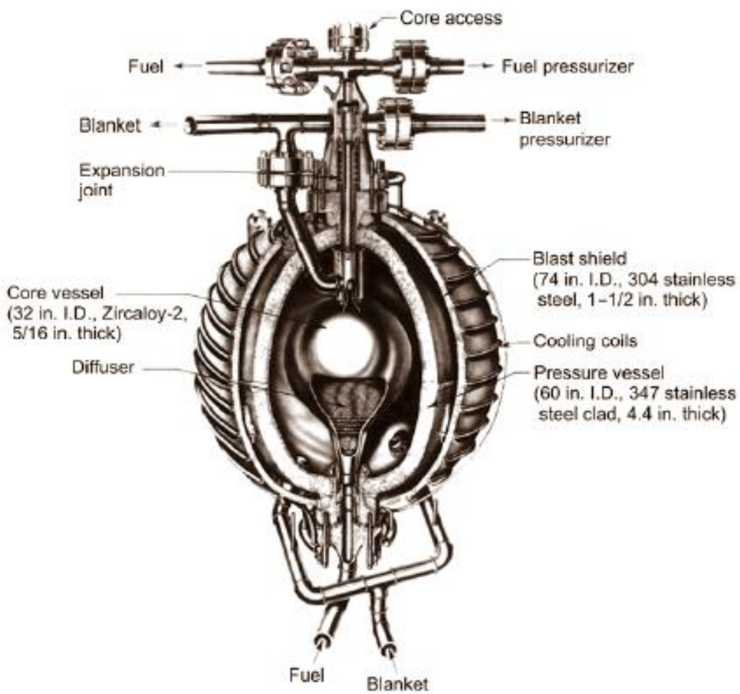


Fig. 14. HRT core and pressure vessels. (ORNL Photo 23459)

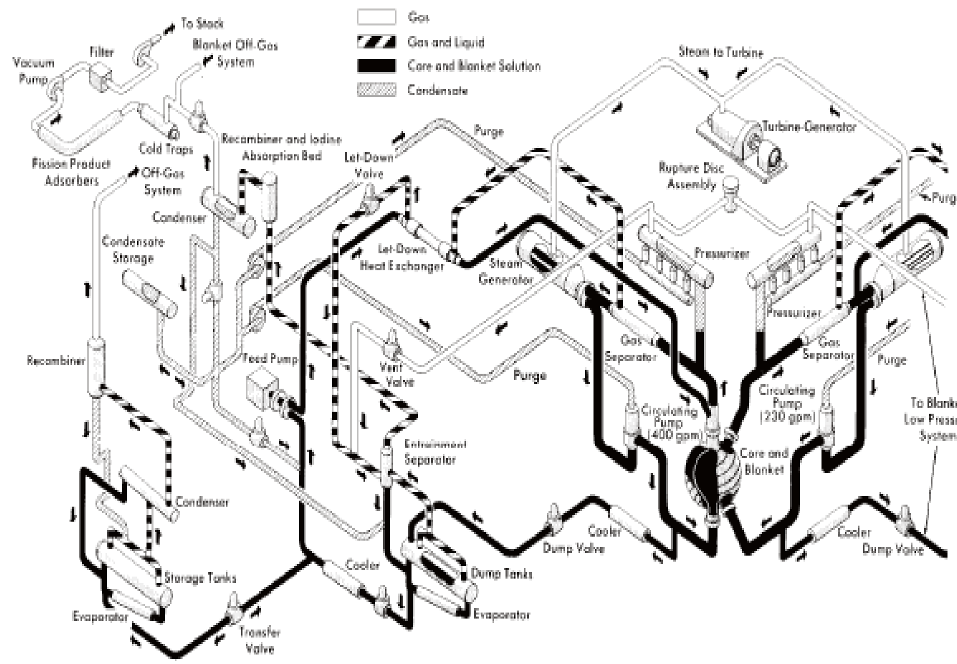


Fig. 15. Schematic flow diagram for the HRT.

Inspection And Proliferation Concerns (HRE)

- On-line reprocessing
- Hot chemistry lab needed to analyze results of sampling
- Accessibility limited
- Sampling technique clearly different than in heterogeneous reactors
- Can breed Th/^{233}U or U/^{239}Pu in core or reflector/blanket

Molten Salt Reactor Experiment Melton Valley Road Next To HFIR (1964)

- Spin-off of aircraft nuclear propulsion program
- 10 MW(t) single region core
- Graphite moderated
- HEU UF_4 dissolved in Be F_2 – Li^7F – ZrF_4 salt
  - Be F_2 low melting point
  - Li^7F salt good fluid flow properties
  - ZrF_4 protects against UO_2 precipitation
- 1200°F–1265°F fuel temperature
  - Liquidus temperature 840°F
- Density 130 lb/ft^3
- Heat capacity 0.48 Btu/lb-°F
- Thermal conductivity 3.2 Btu/h

MSRE Design Description

- Reactor vessel 5-ft diameter by 8-ft high Hastelloy-N (high nickel molybdenum alloy)
- Graphite structure with in tank is 55-in. diameter by 67-in. high surrounded by "core can"
- Graphite is assembly of vertical bars 2-in. square by 67-in. long
- Fuel flows in 0.4-in. by 1.2-in. channels in grooves inside of graphite bars (1140 channels) at 850 gpm
- Core volume is 90 ft^3
  - Fuel 20 ft^3
  - Graphite 70 ft^3
- Coolant fuel flow pattern
  - Inlet salt 1175°F enters top of vessel
  - Flows downward in annulus between core can and reactor vessel
  - Upward through graphite matrix
- Three poison rods 1-in. diameter gadolinium oxide clad in Inconel
- Helium cover gas
- Dump valve into two critically safe drain tanks under reactor vessel

MSRE Fuel Reprocessing

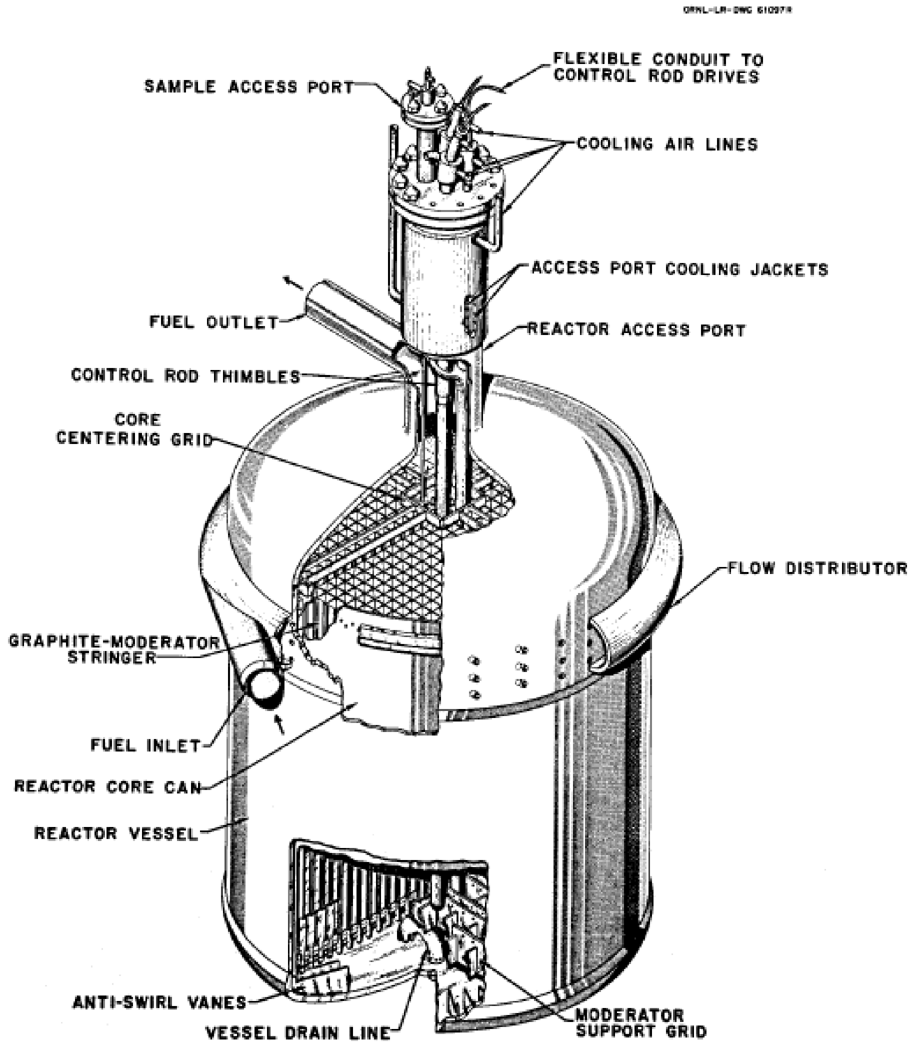
- Uranium removed by treating with fluorine gas resulting in creation of UF_6, volatilization

- Usually done in batch process adjacent to reactor

MSRE Building

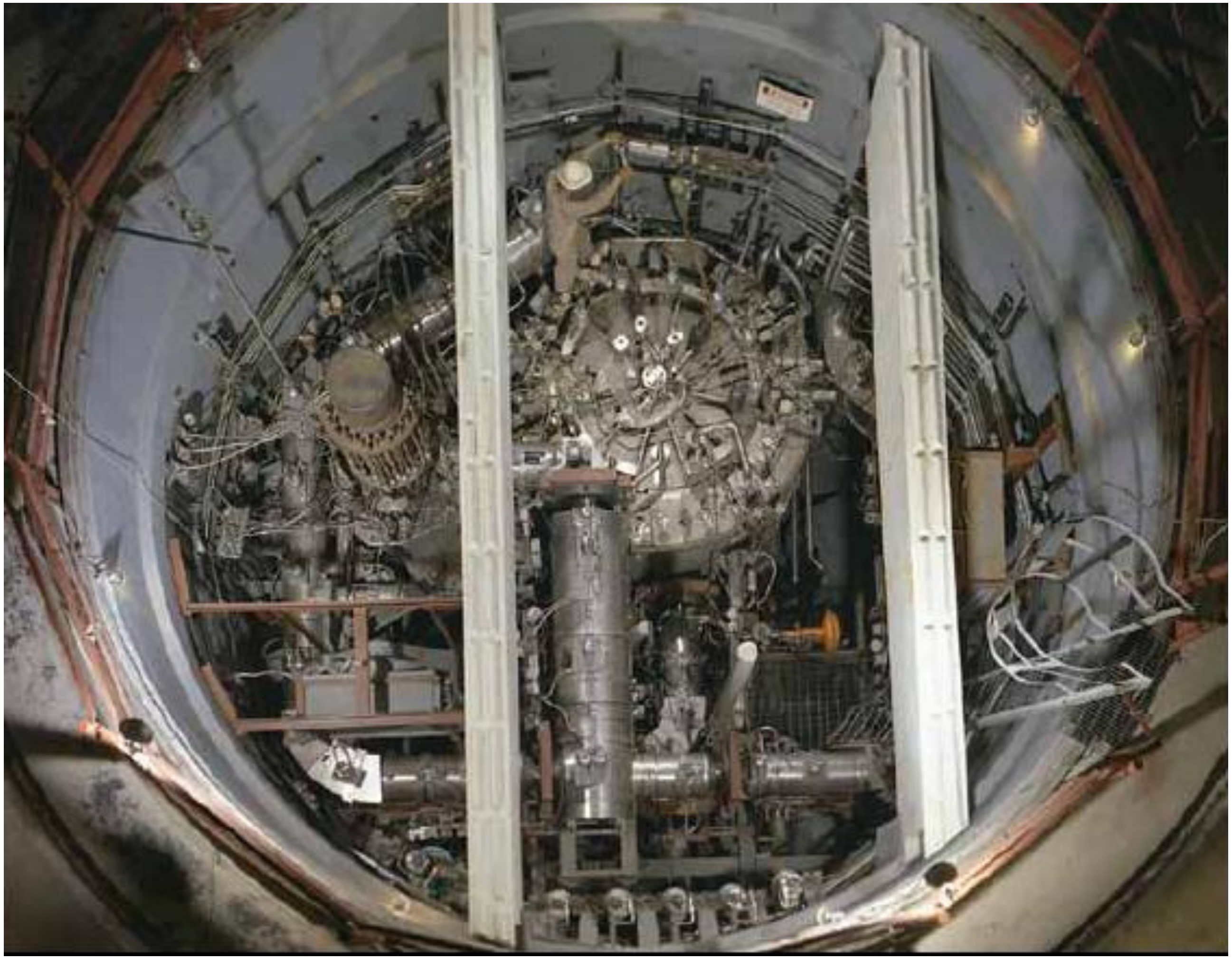
Molten Salt Reactor Experiment Vessel

MSRE Reactor Vessel

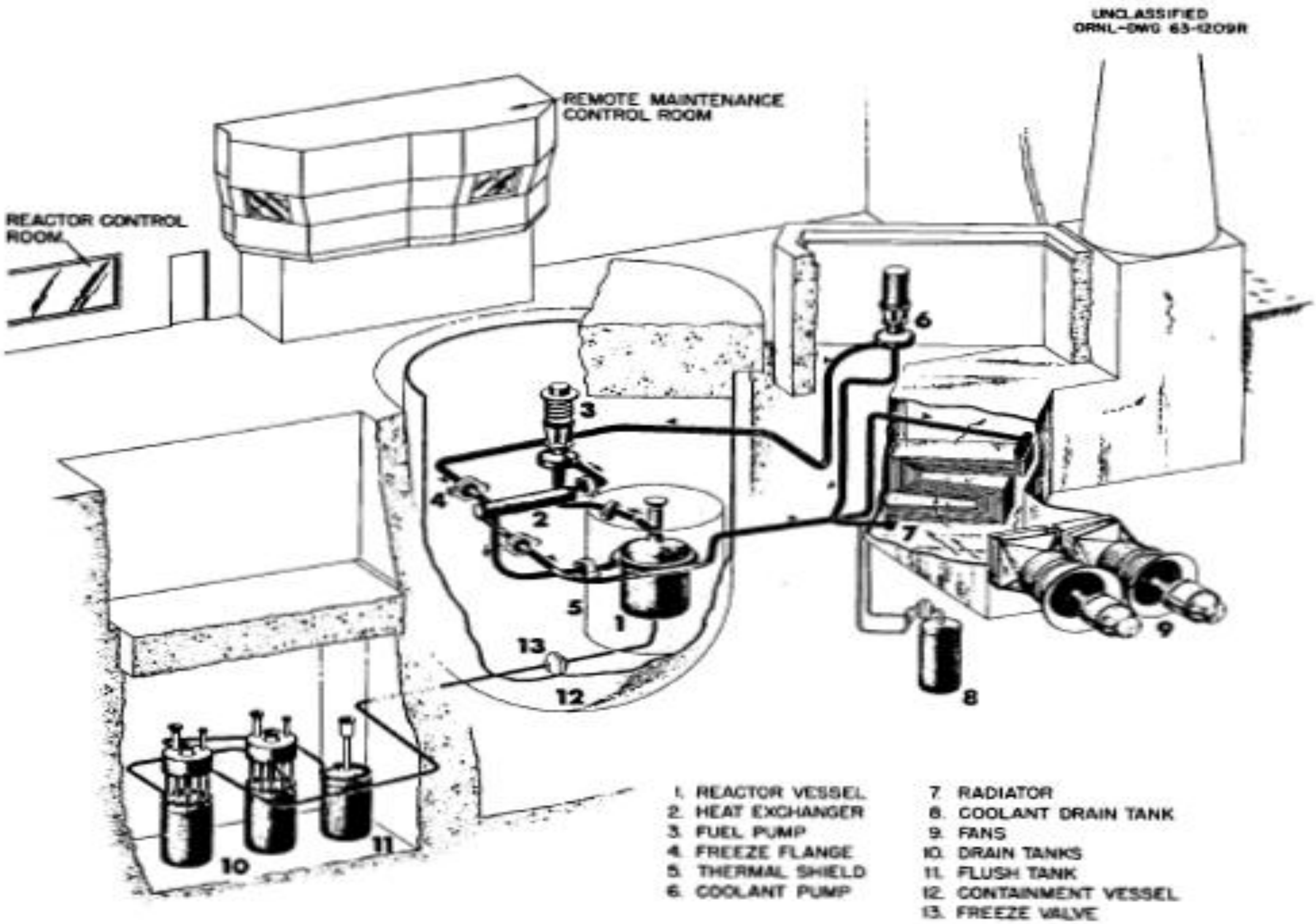


Reactor Vessel

MSRE Top View

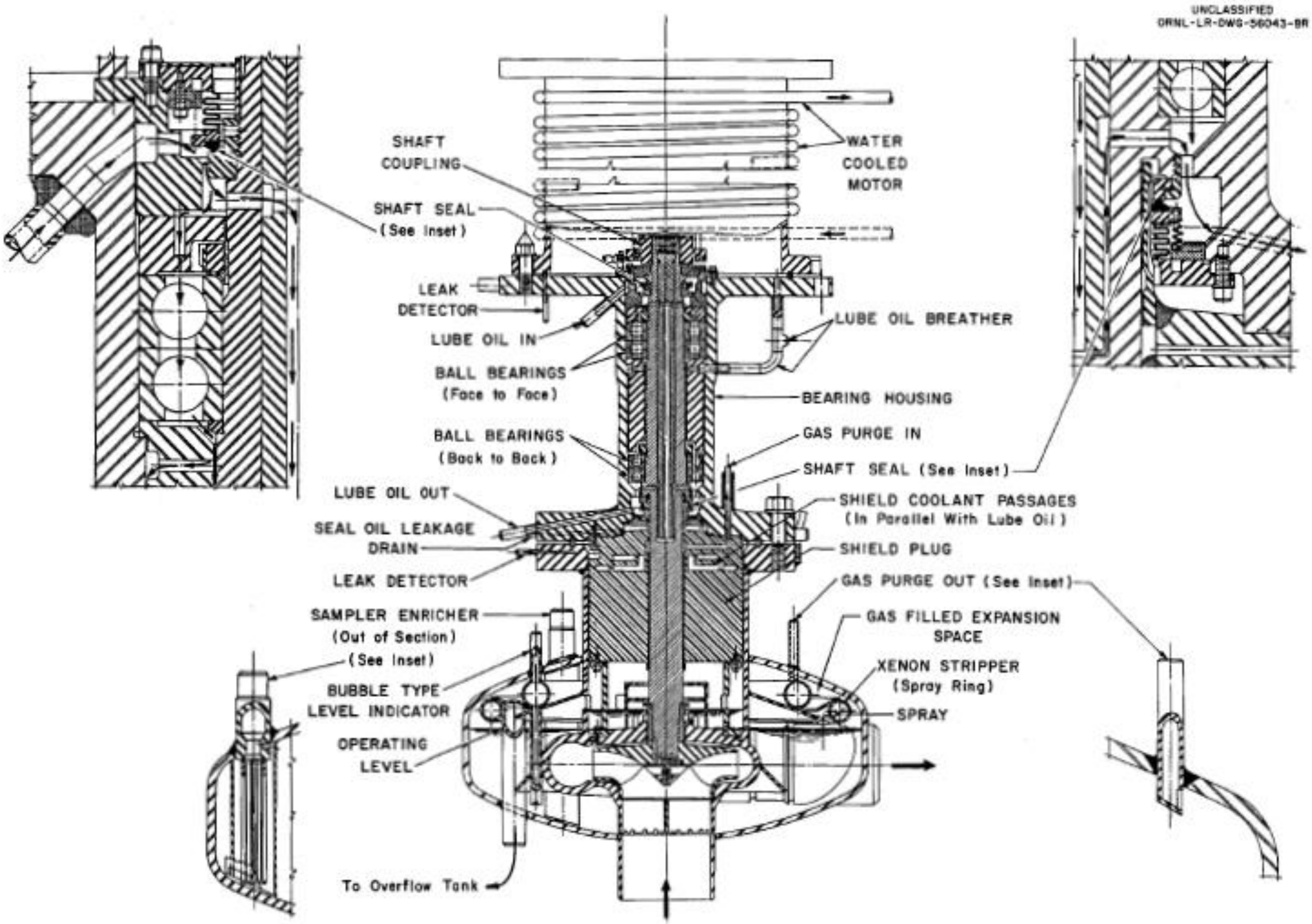


MSRE Flow Diagram



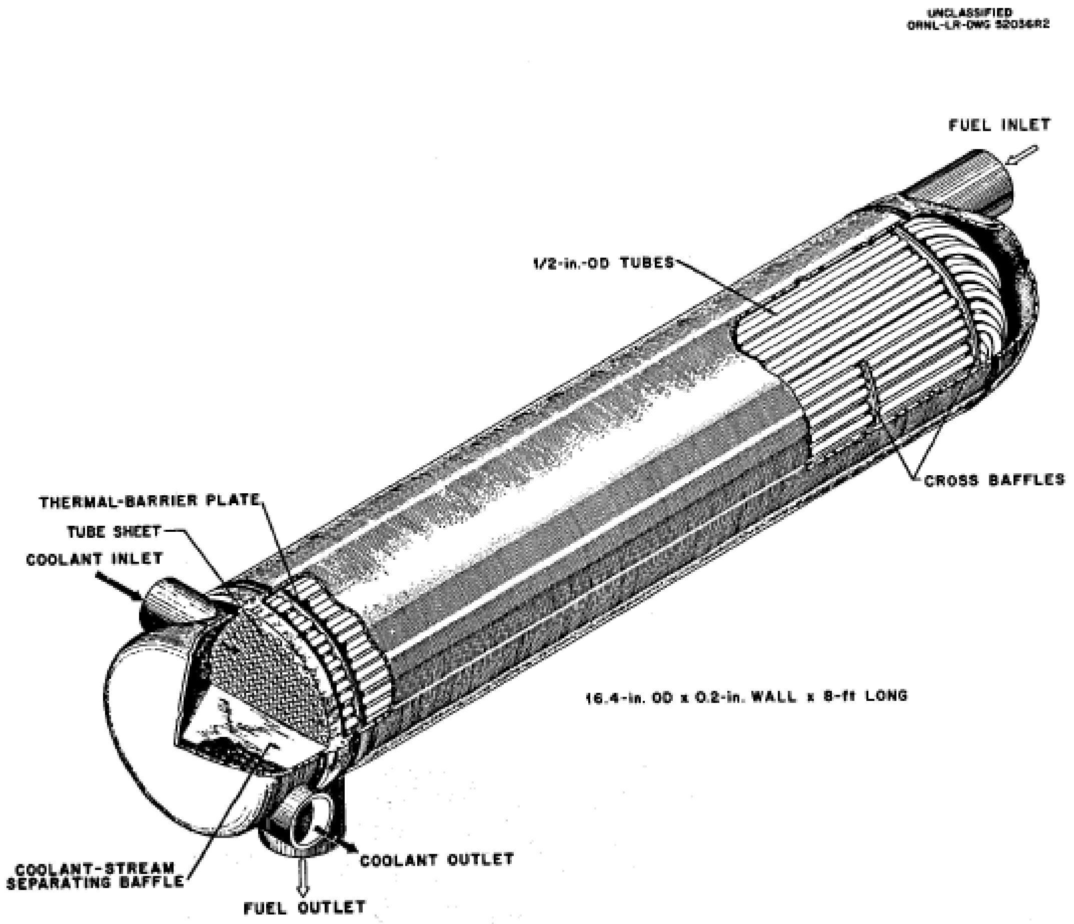
MSRE Flow Diagram

MSRE Fuel Pump (Centrifugal Sump Type) 1160 rpm



MSRE Fuel Pump

MSRE Heat Exchanger Tube Shell 163 Tube 0.5-in. OD, 16-in. Diameter, And 8-ft Long



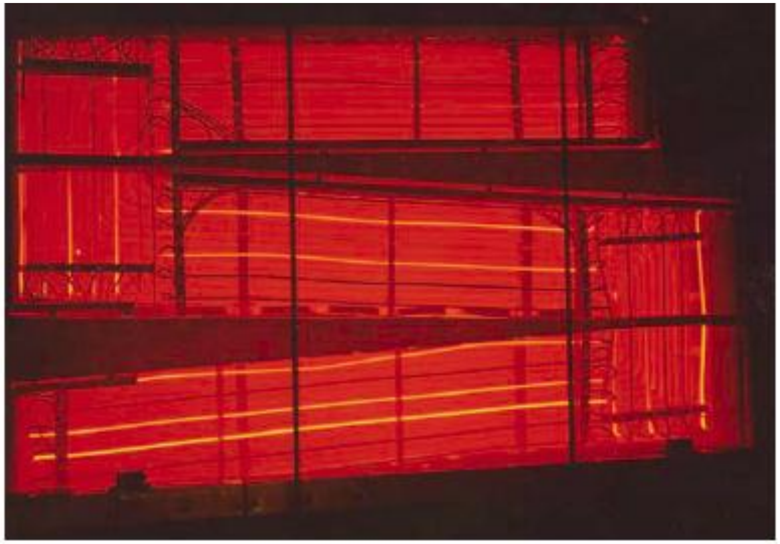


Fig. 26. MSRE air-cooled radiator with its door open.

Primary Heat Exchanger

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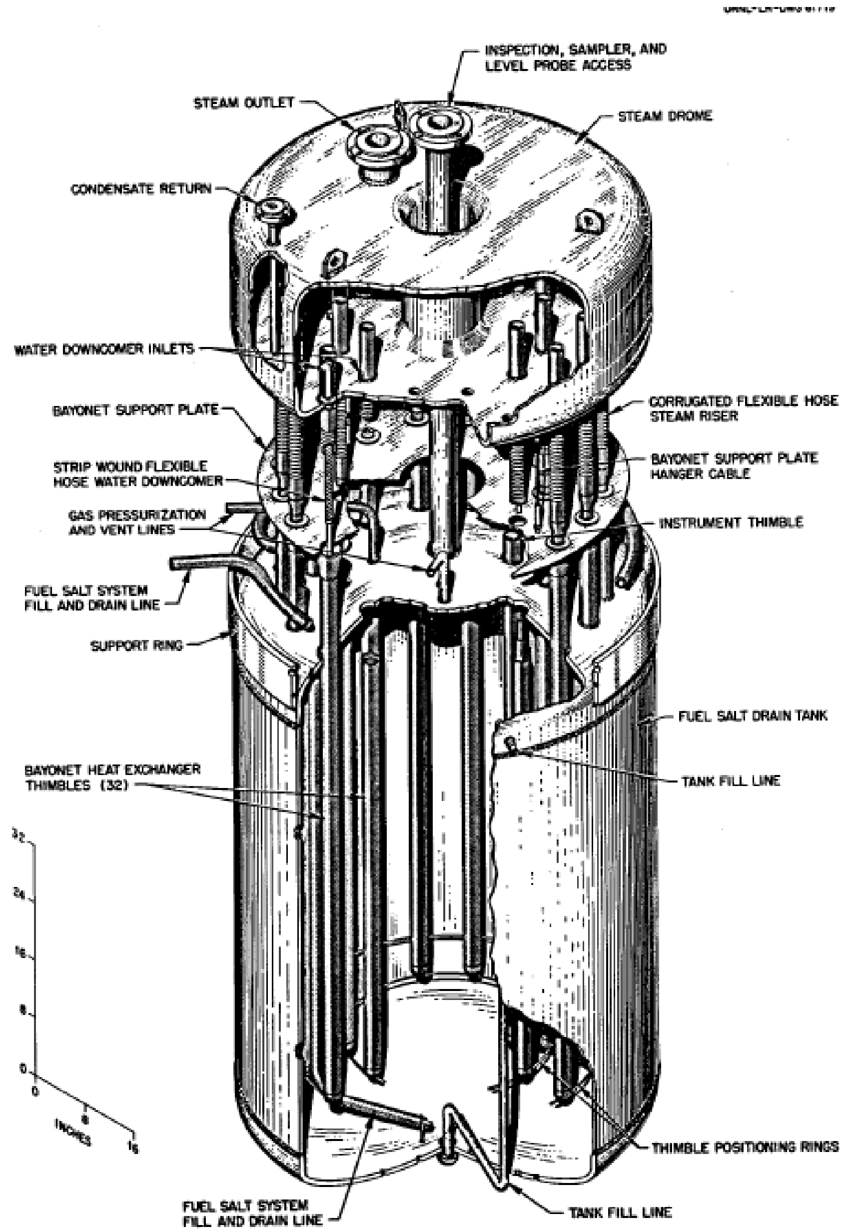
MSRE Drain Tank



MSRE Core/Can

Fig. 23. Graphite core of the MSRE.

MSRE Pumps

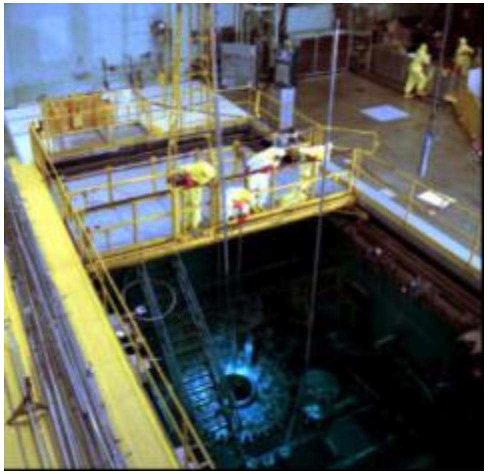
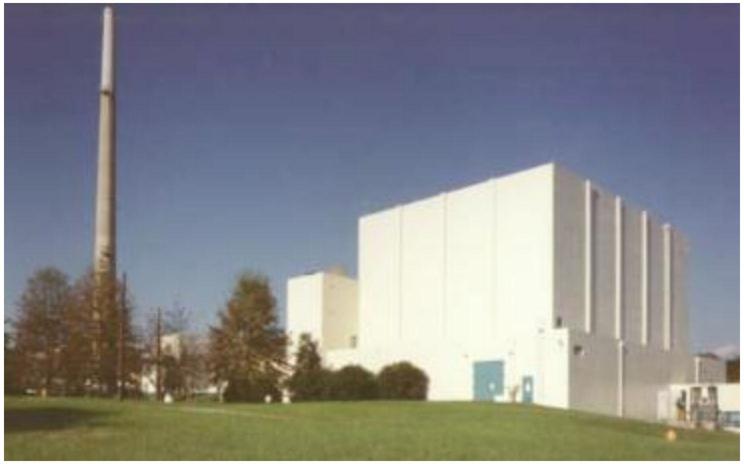
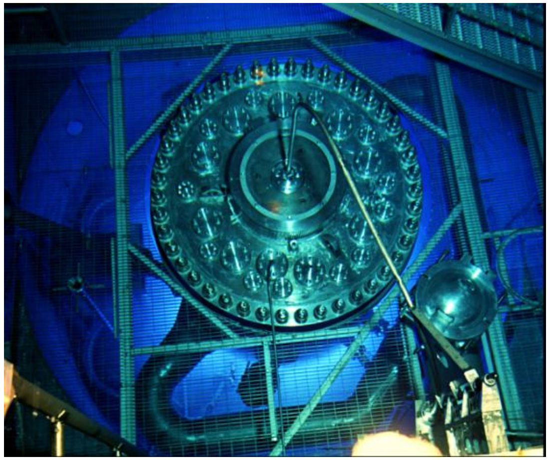
Molten Salt Is Transparent

Inspection and Proliferation Issues Associated With MSR

- High temperatures make access to reactor and processing loop difficult even during shutdown
  - Special equipment required for monitoring
- Fluid fuel allows variation in concentration, isotopes and fuels
  - MSRE converted from a ^{235}U core to Th/^{233}U core without design changes in system
- Inventory of materials would require hot (thermal and radioactive) chemistry sampling
- Processing (extraction of fuel) uses chemical processes and occurs at temperatures not found in aqueous reprocessing or electroprocessing (LMR metal fuel)
- Ease in removing fuel from salt with online reprocessing
- On-line or batch processing means no fuel necessarily is transported to or from the site or stored on site. Makes visual observation difficult
- Ability to breed both Th/^{233}U and U/^{239}Pu using molten blankets around the core

High Flux Isotope Reactor

- 85 MWt [100 MW(t) original design] flux trap reactor
- Critical in 1965, currently operating
- 93% enriched Cermet fuel (U_3O_8-Al) plates Al cladding (9.3Kg U^{235})
- Water cooled, water moderated, Be reflected
- Pressurized light water reactor design with pressure vessel sitting in bottom of a pool

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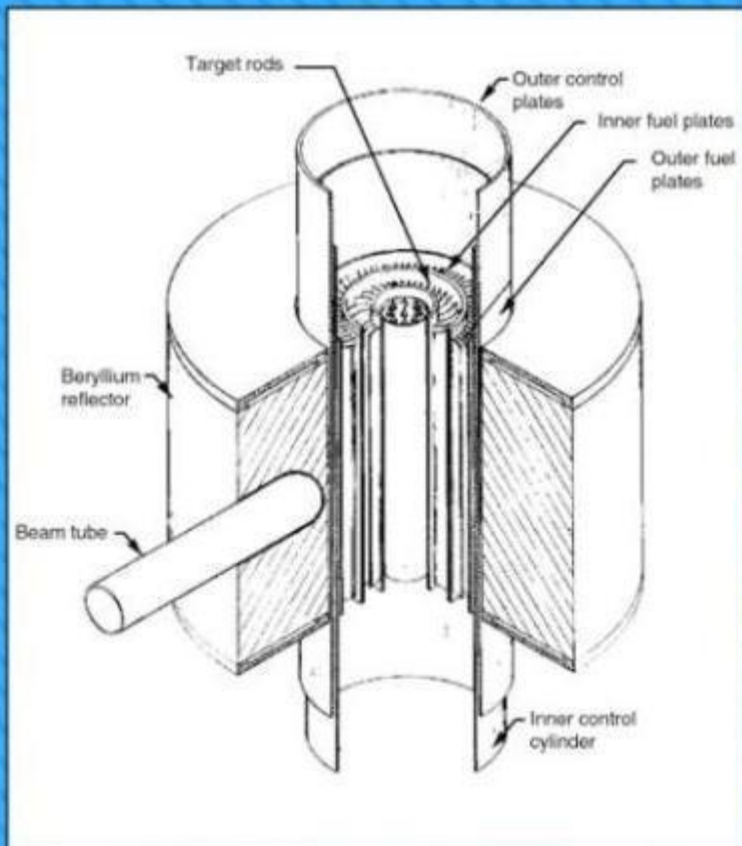
ORNL-DWG 95M-10449

HFIR Was Designed to Produce the High Flux Needed for Transplutonium Isotope Production



- Compact core — high power density
- Flux trap design
- World's highest thermal flux (2.5×10^{15} N/cm$^2 \cdot$ s)
- Beam intensities among world's highest
- Concentric cylinders
  - Target
  - Fuel
  - Control elements
  - Reflector

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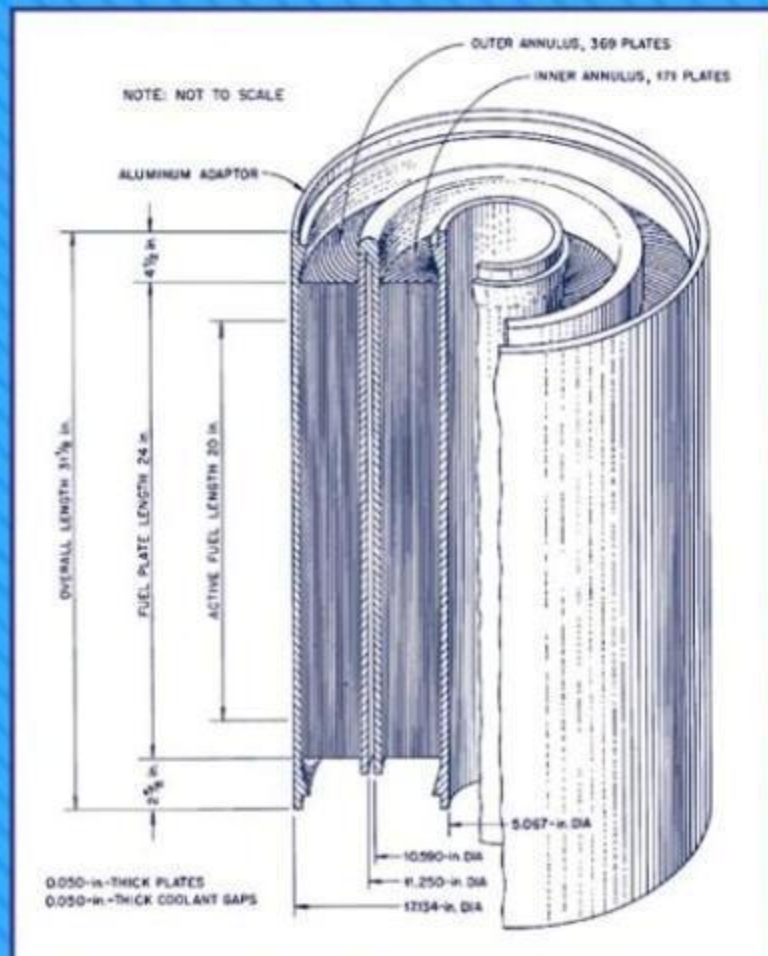
ORNL-DWG 95M-10452

HFIR Fuel Element



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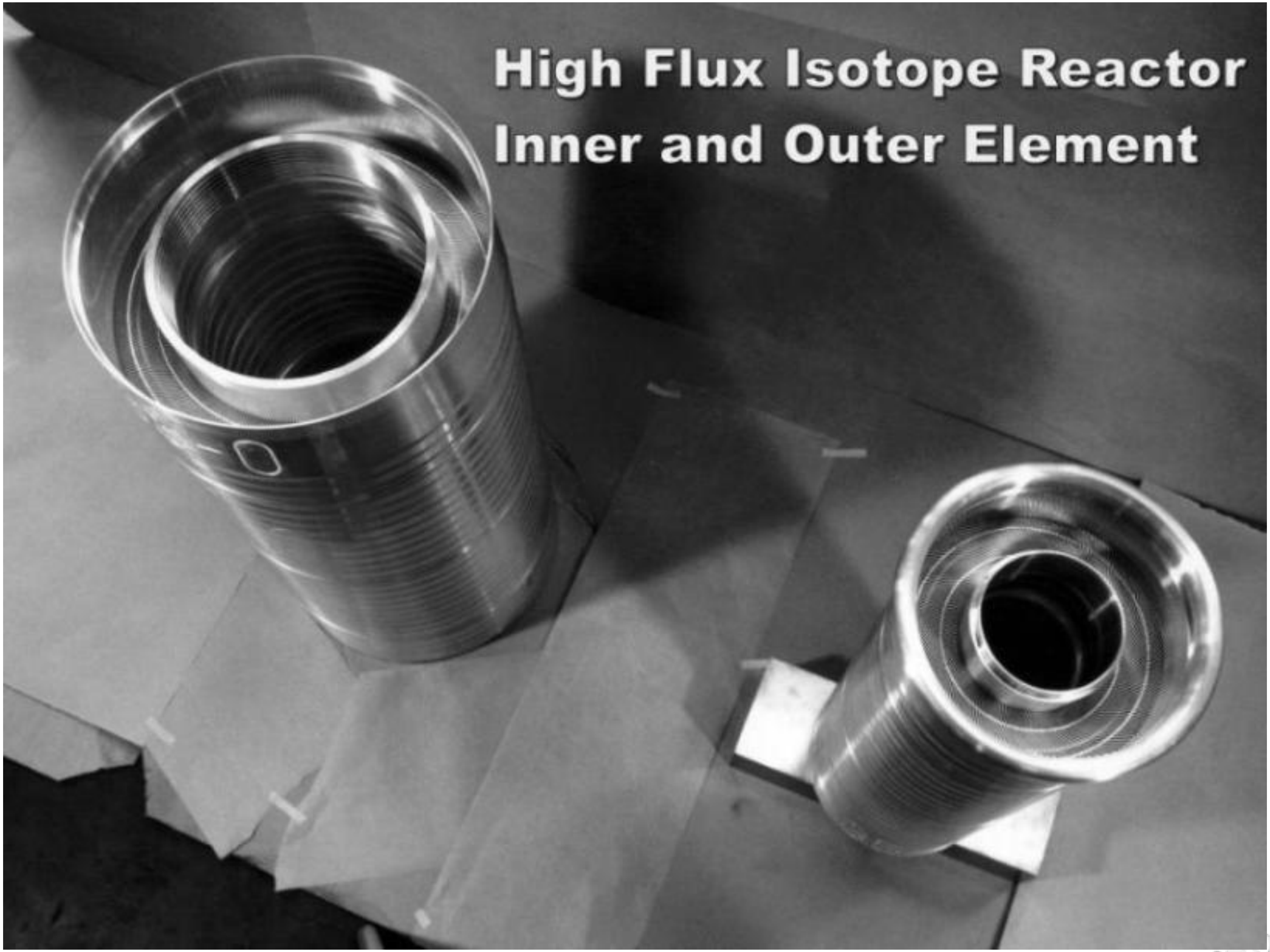
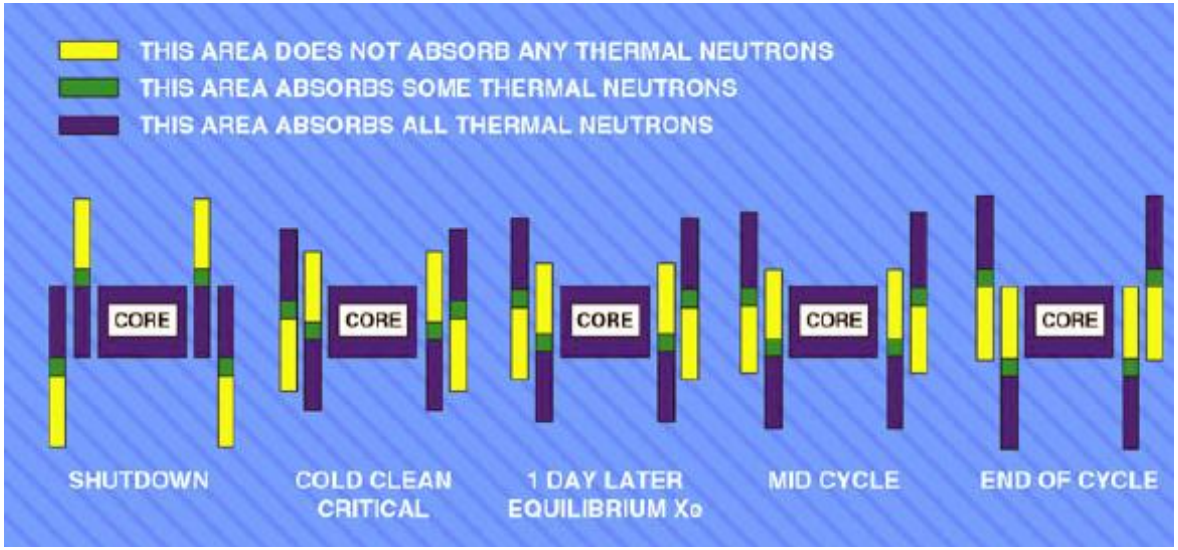

High Flux Isotope Reactor
Inner and Outer Element

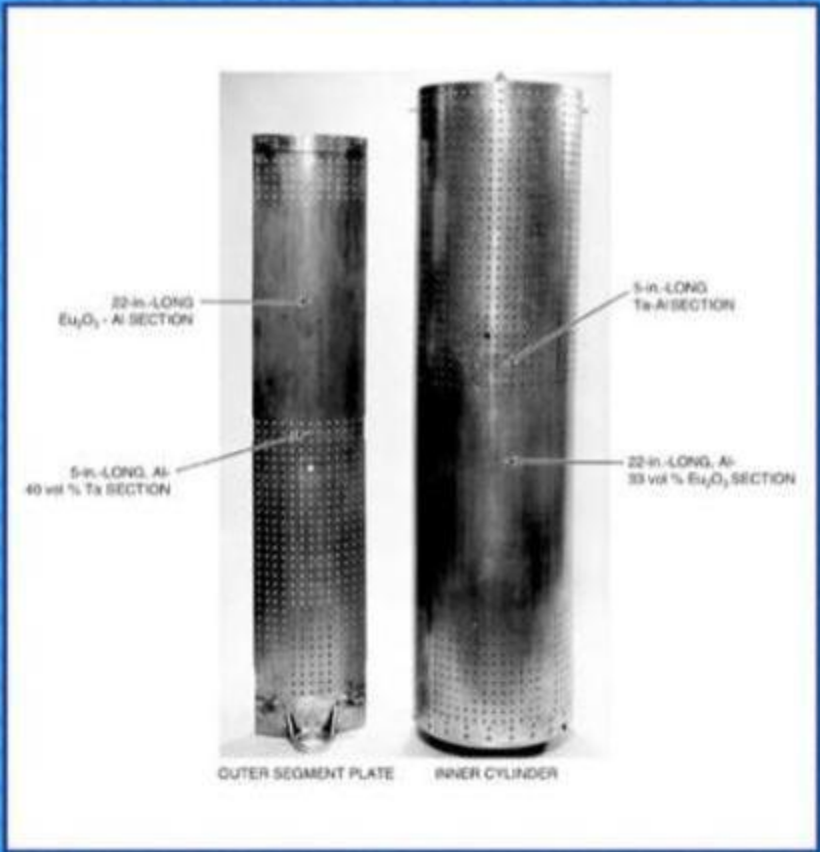
High Flux Isotope Reactor

- Control and Safety System
  - 4 Independent quarter cylindrical sections with Eu_2O_3 as the poison
  - 1 cylinder containing Eu_2O_3 for control
  - Safety plates drop in from top of core
  - Control cylinder enters from the bottom



ORNL-DWG 95M-10453

Control Plate and Cylinder



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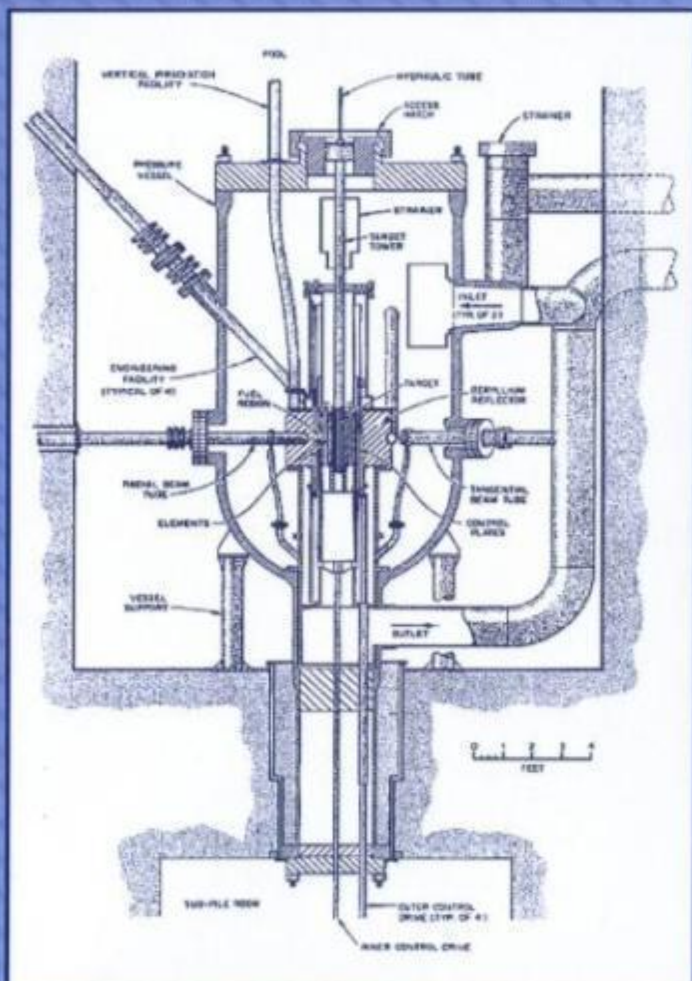
ORNL-DWG 95M-10451

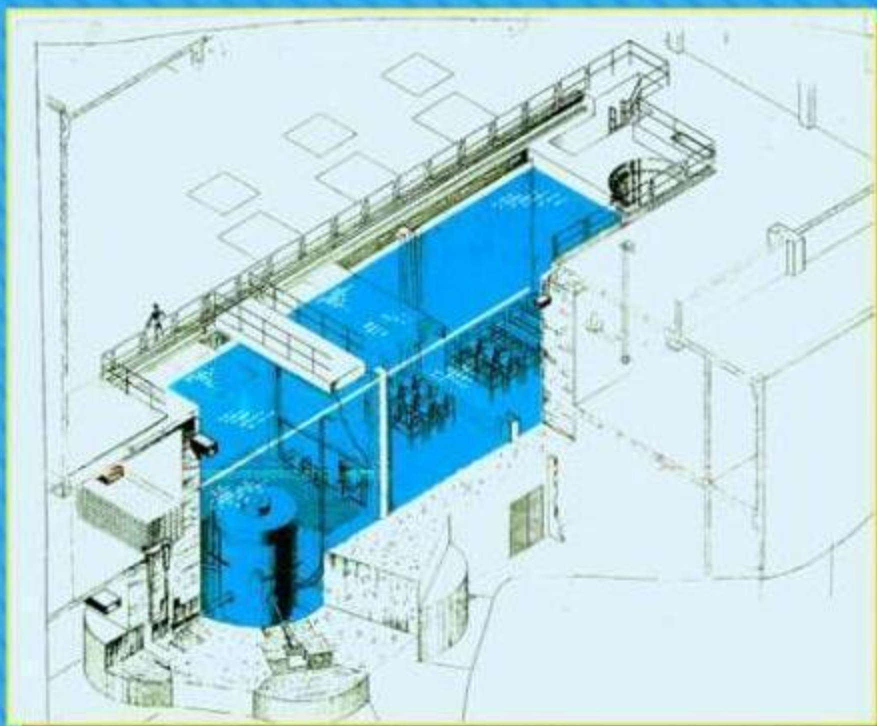
Reactor Characteristics
Vertical Cross Section of HFIR



- Power level: 100 MW (85 MW)
- Light water moderated and cooled
- Beryllium reflected
  - I.D. =18.9"; O.D. = 43.0"; Ht = 2.0'
- Fuel: AL clad U_3O_8 plates
  - 9.4 Kg ^{235}U
  - I.D. ~ 5"; O.D. = 17-1/8"
  - active fuel length = 20"
- Control
  - concentric cylinders of EuO
- Pressure vessel
  - carbon steel with stainless clad
  - 94" I.D. x 2-7/8" thick
- Coolant flow: 16,000 GPM
- Inlet pressure: 468 PSIG;
  Temp: 120°F
- Outlet pressure: 358 PSIG
  Temp: 156°F
- Fuel cycle:
  - 21 days (100-MW operations)
  - 26 days (85-MW operations)
  - 7 days outage

ORNL DWG 95M-10456

The Pressure Vessel is Located in a Pool of Water



- Reactor pool
  - 18' W * 20' L * 36' D
- Storage pool
  - 18' W * 41' L * 20' D
- All handling of irradiated components is done under water

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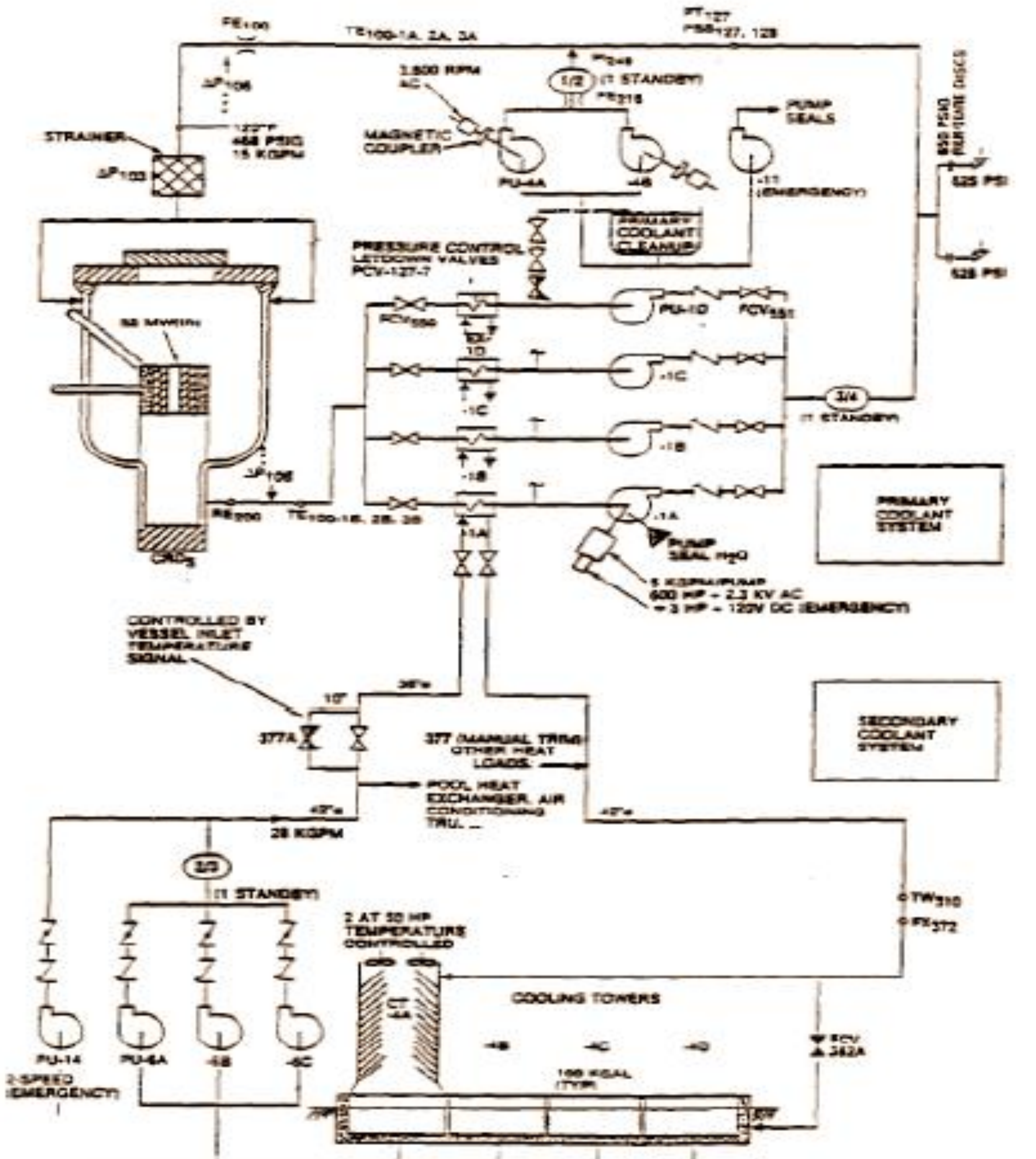
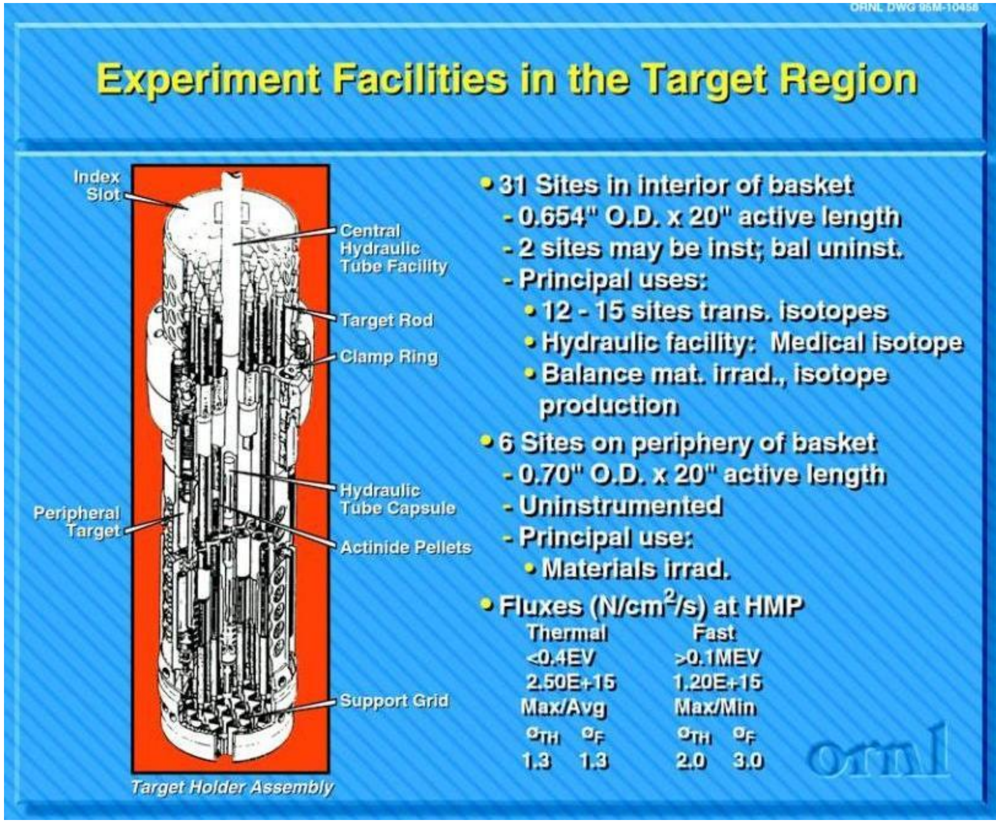
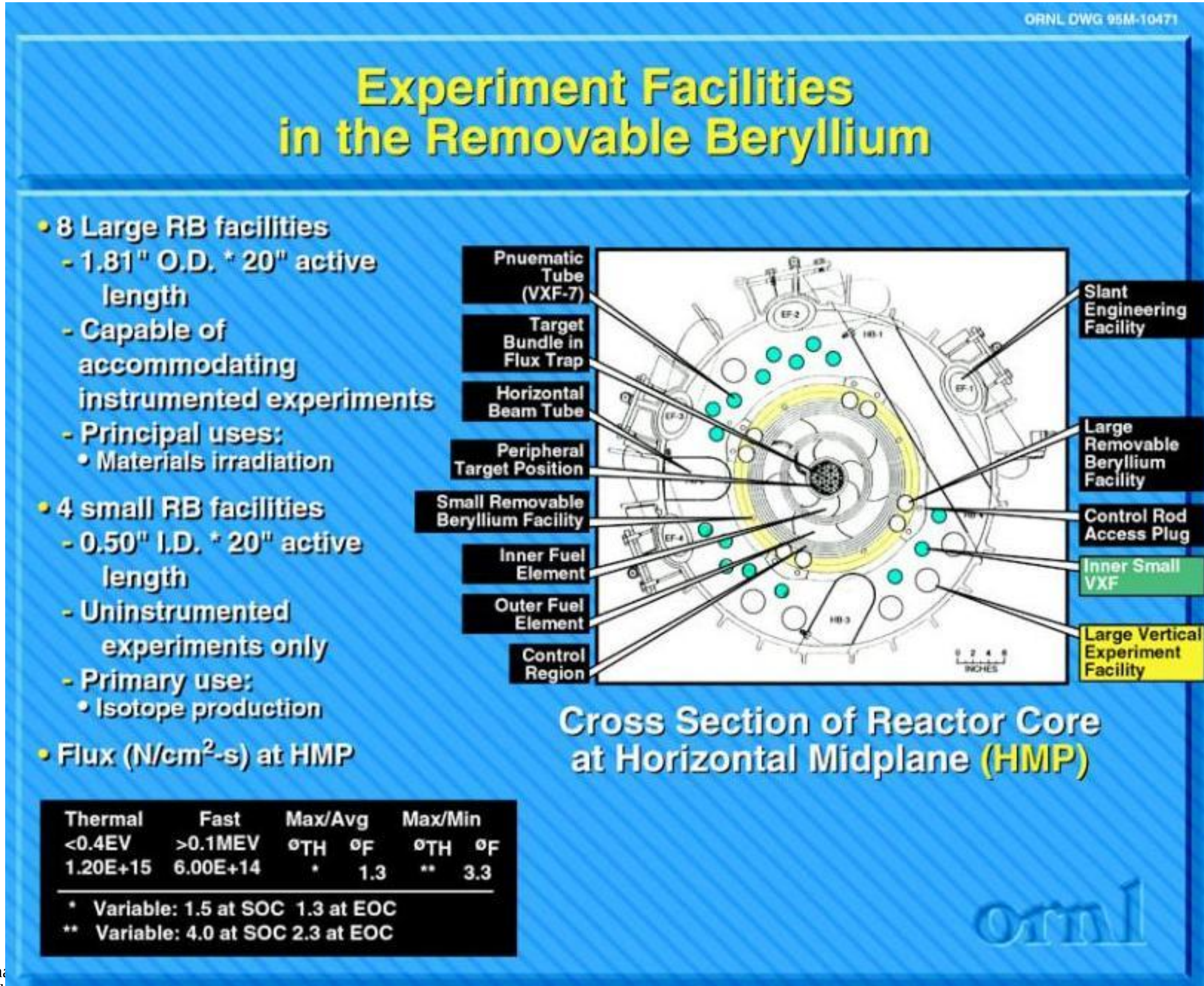
High Flux Isotope Reactor Cooling System



HFIR Experimental Capabilities

- Trans-plutonium isotope production
- Medical isotope production
- Materials Irradiation
- Neutron Activation Analysis
- Neutron Scattering
  - 3 thermal neutron beams
  - 1 cold neutron beam




ORNL DWG 95M-10471
Experiment Facilities
in the Removable Beryllium
• 8 Large RB facilities
- 1.81" O.D. * 20" active length
- Capable of accommodating instrumented experiments
- Principal uses:
• Materials irradiation
• 4 small RB facilities
- 0.50" I.D. * 20" active length
- Uninstrumented experiments only
- Primary use:
• Isotope production
• Flux (N/cm2-s) at HMP
Thermal <0.4EV 1.20E+15
Fast >0.1MEV 6.00E+14
Max/Avg ØTH * ØF 1.3
Max/Min ØTH ** ØF 3.3
* Variable: 1.5 at SOC 1.3 at EOC
** Variable: 4.0 at SOC 2.3 at EOC
Pnuematic Tube (VXF-7)
Target Bundle in Flux Trap
Horizontal Beam Tube
Peripheral Target Position
Small Removable Beryllium Facility
Inner Fuel Element
Outer Fuel Element
Control Region
Slant Engineering Facility
Large Removable Beryllium Facility
Control Rod Access Plug
Inner Small VXF
Large Vertical Experiment Facility
INCHES
Cross Section of Reactor Core at Horizontal Midplane (HMP)
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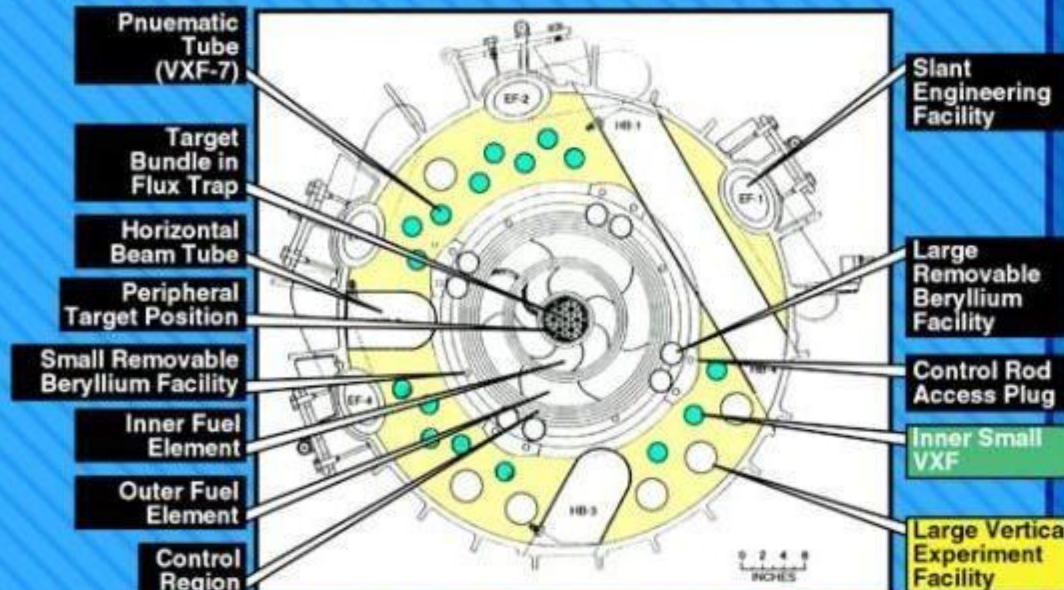
ORNL DWG 95M-10496R

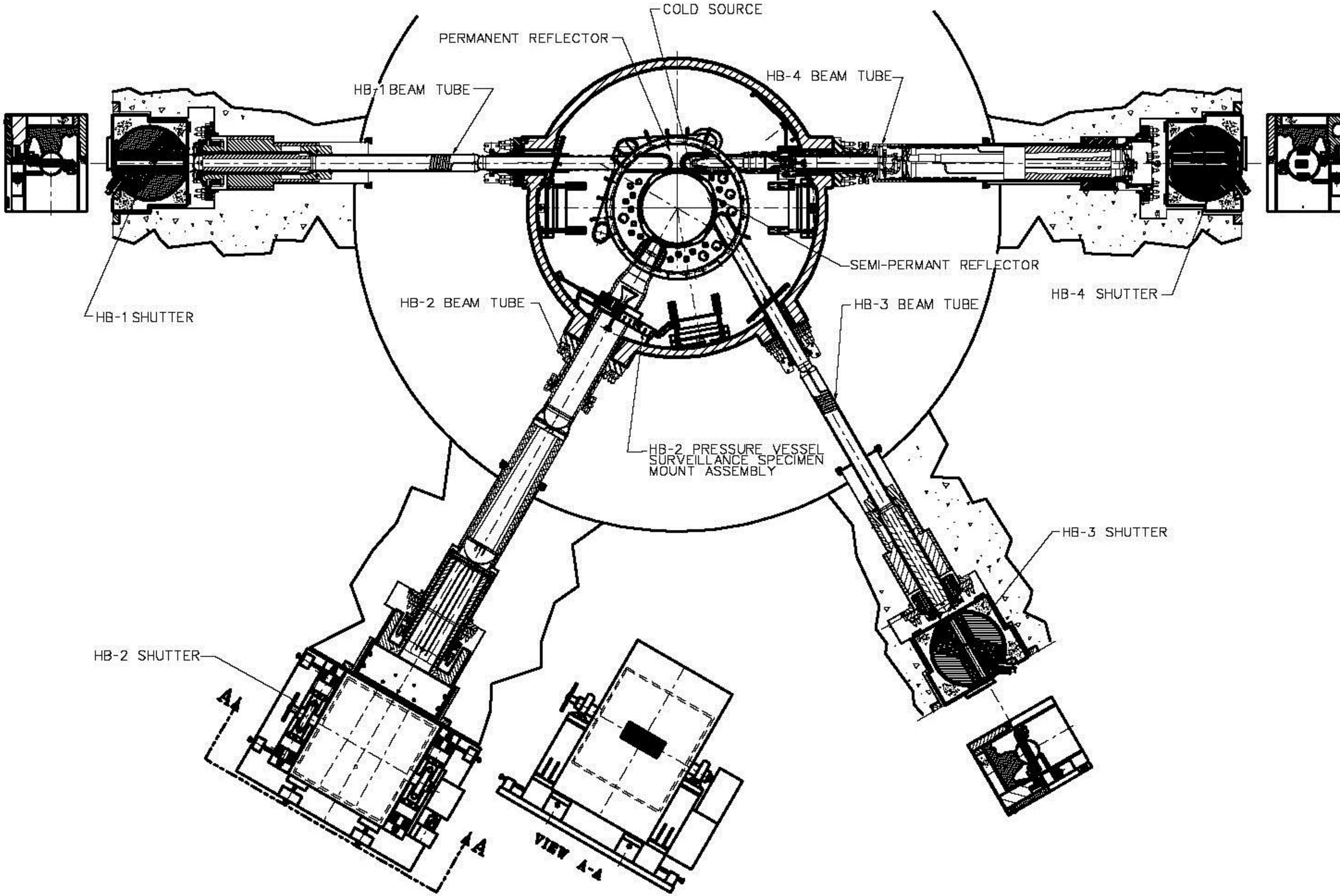
Experiment Facilities in the Permanent Beryllium

- 16 small vertical experiment (VXR) facilities
  - 1.58" I.D. * 20" active length
  - 11 sites at 15.34"R : Inner Small VXF
  - 5 sites at 17.36"R : Outer Small VXF
  - Capable of performing inst. irrad.
  - Principal uses:
    - Isotope production
    - Neutron act. analyses
    - Materials irradiation
- Six large vertical experiment facilities
  - 2.834" I.D. * 20" active length
  - Capable of performing inst. irrad.
  - Primary use:
    - Isotope production
- Flux (N/cm^2-s) at HMP



Cross Section of Reactor Core at Horizontal Midplane (HMP)

	Thermal <.4EV	Fast >.1MEV	Max/Avg ϕ_{TH}	Max/Avg ϕ_F	Max/Min ϕ_{TH}	Max/Min ϕ_F
ISVXF	7.50E+14	5.10E+13	1.3	1.3	2.2	2.7
OSVSF	5.10E+14	1.80E+13	1.3	1.3	2.1	2.7
LVXF	4.30E+14	1.20E+13	1.3	1.3	2.0	2.7


COLD SOURCE
PERMANENT REFLECTOR
HB-4 BEAM TUBE
HB-1 BEAM TUBE
SEMI-PERMANT REFLECTOR
HB-4 SHUTTER
HB-2 BEAM TUBE
HB-3 BEAM TUBE
HB-1 SHUTTER
HB-2 PRESSURE VESSEL
SURVEILLANCE SPECIMEN
MOUNT ASSEMBLY
HB-3 SHUTTER
HB-2 SHUTTER
A
A
VIEW A-A

Safeguards Issues Related to High Flux Reactors

- Most use highly enriched U
- Frequently refueled (1 month to 6 months) because of high burnup
- Reflectors may be decoupled from core neutronics
  - Excess neutrons in the reflector implies that except for strong absorbers, materials in the reflector do not affect the core neutronics or fuel cycle
  - Implies that the inspectors need to be aware as to how materials used in experiments are tracked.

ORNL Has Long And Colorful History Of Examining A Variety Of Reactor Designs

- Reactors had different coolants (water, gas, fuel solution, molten salt)
- A variety of fuels—aluminum-based, homogeneous, molten salt solutions, uranium slugs
  - HEU
  - LEU
  - Natural uranium
  - Plutonium
  - ^{233}U and ^{235}U
  - Thorium
- Wide range of power 1 MW–100 MW
- Variety of shapes—swimming pools, pressure vessels, hanging spheres, graphite matrixes, tanks, bare/pulsed
- Experiments—isotopes, actinide production, materials irradiation effects, fuels, neutron scattering, neutron activation, shielding, reactor physics
  - Some leading to Nobel Prize
  - Others leading to large-scale use of nuclear energy, medical treatment and diagnostics, safer reactors, better instrumentation, new and better materials