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Preliminary Design of the HFIR Core and Pressure Vessel Assembly

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Abstract

A general description of the HFIR core and pressure vessel assembly is given.

Criteria and proposed designs for the target assembly, fuel element, control equipment, reflector, experimental facilities and pressure vessel are given in descriptive form. The operating conditions and other design data are given in tabular form.

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1. Introduction

One objective of the HFIR is to achieve an unperturbed thermal neutron flux of 5×10^{15} neutrons/cm^2-sec in a small target region. The results of optimization studies[1,2] indicate that this is practical with a cylindrical core geometry at a power level of 100 Mw. The basic core geometry considered is a vertical right cylinder composed of a light water target region, surrounded by concentric annular regions of fuel, control plates, and reflector, respectively. The dimensions of this core assembly are based on the results of preliminary studies reported by Cheverton.[2]

The preliminary designs of this core assembly and the reactor pressure vessel are given in this report.

2. Design Criteria, and Descriptions of Reactor Components and Reactor Vessel

2.1 General Description

The reactor core and pressure vessel assemblies are shown schematically in Figures 1 and 2, and in detail on ORNL drawing F-42099. The operating conditions and other design data are given in Table I.

The target array containing several hundred grams of Pu^{242} is at the axial center of the cores in the 5 1/16 in. diameter light water target region as shown in Figures 3 and 4.

The fuel annulus around the target region is composed of aluminum clad, fully enriched uranium plates and light water coolant channels. The uranium bearing portion of the fuel region is 20 in. high. The fuel plates, which are involute in shape, are arranged in two concentric rings, the outer ring being 17 1/8 in. OD. An isometric of the fuel element is shown in Figure 5.

The 0.8 in. thick annulus between the fuel and reflector regions contains two 1/4 in. thick concentric cylinders which are used as reactor control rods. The outer rod has a 24 in. high "black" region at the top for reactor shutdown, a 20 in. high "gray" (medium cross-section) region in the center for early cycle operations, and a 24 in. high "white" (low cross-section) region at the bottom for late cycle operation. The inner cylinder contains an 8 3/4 in. "black" region, a 20 in. "gray" region, and a 24 in. "white" region. The control rod regions are arranged such that withdrawing the cylinders in opposite directions as the cycle progresses will maintain symmetry about the horizontal midplane. Typical control rod positions are shown schematically in Figure 6. The inner control plate performs as a shim and regulating rod, while the outer plates perform both shim and safety functions. In order to provide multiplicity of safety rods, the outer control cylinder is split into quadrants. Each quadrant has its individual drive and release mechanism, which permits the "black" region to fall into the active region to provide emergency shutdown.

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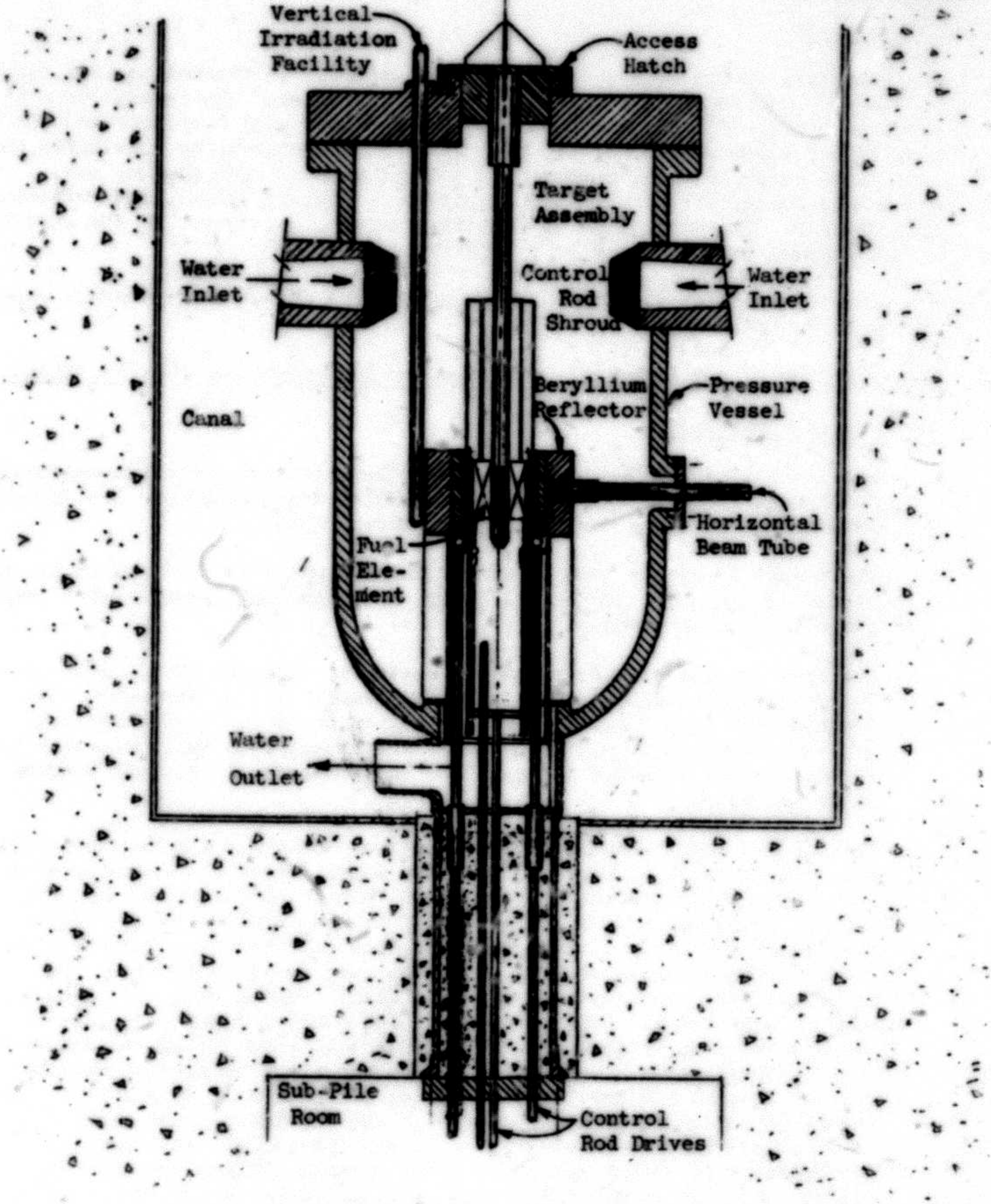

HFIR Reactor Assembly
Vertical Section

Figure 1.

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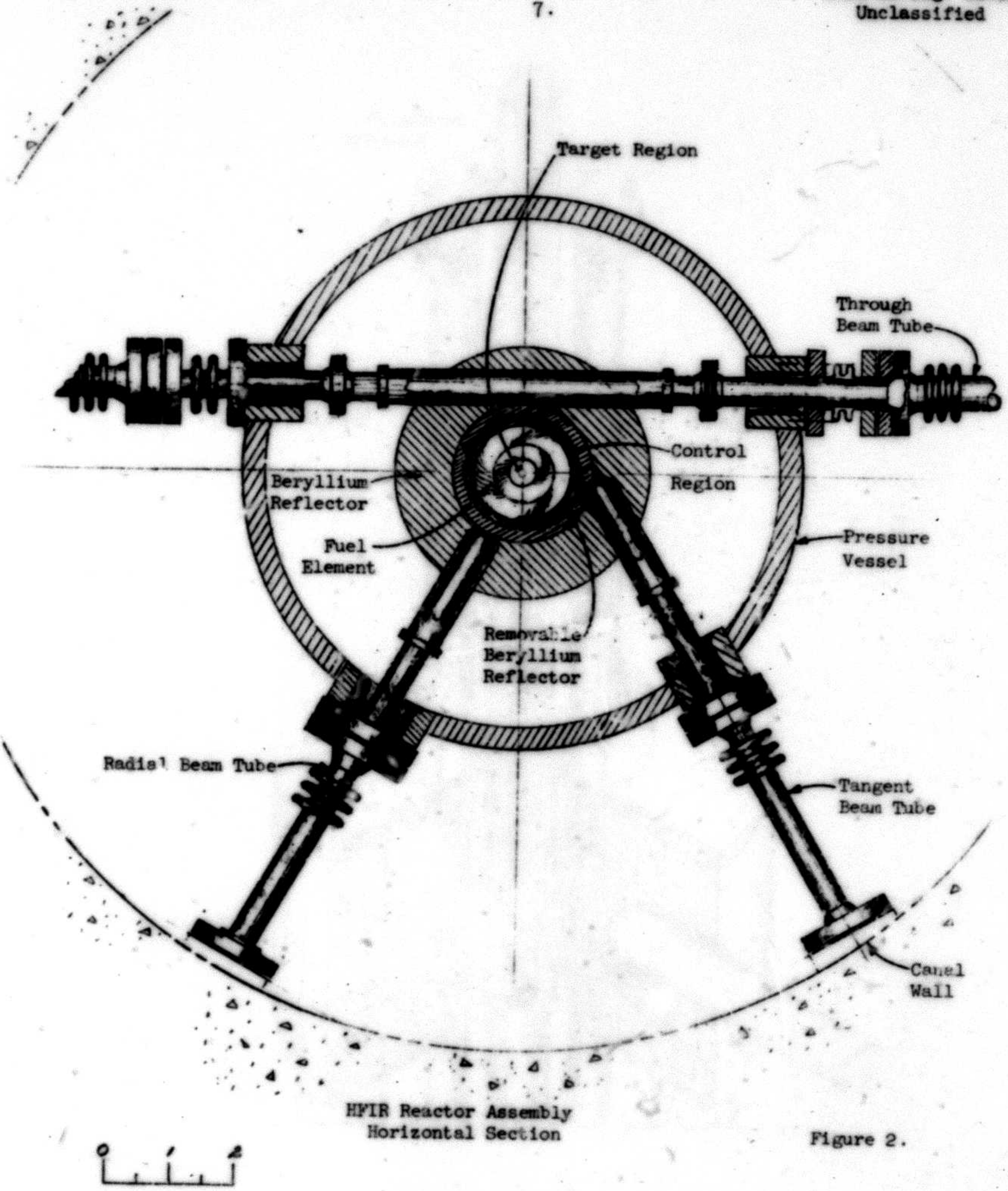

HFIR Reactor Assembly
Horizontal Section

Figure 2.

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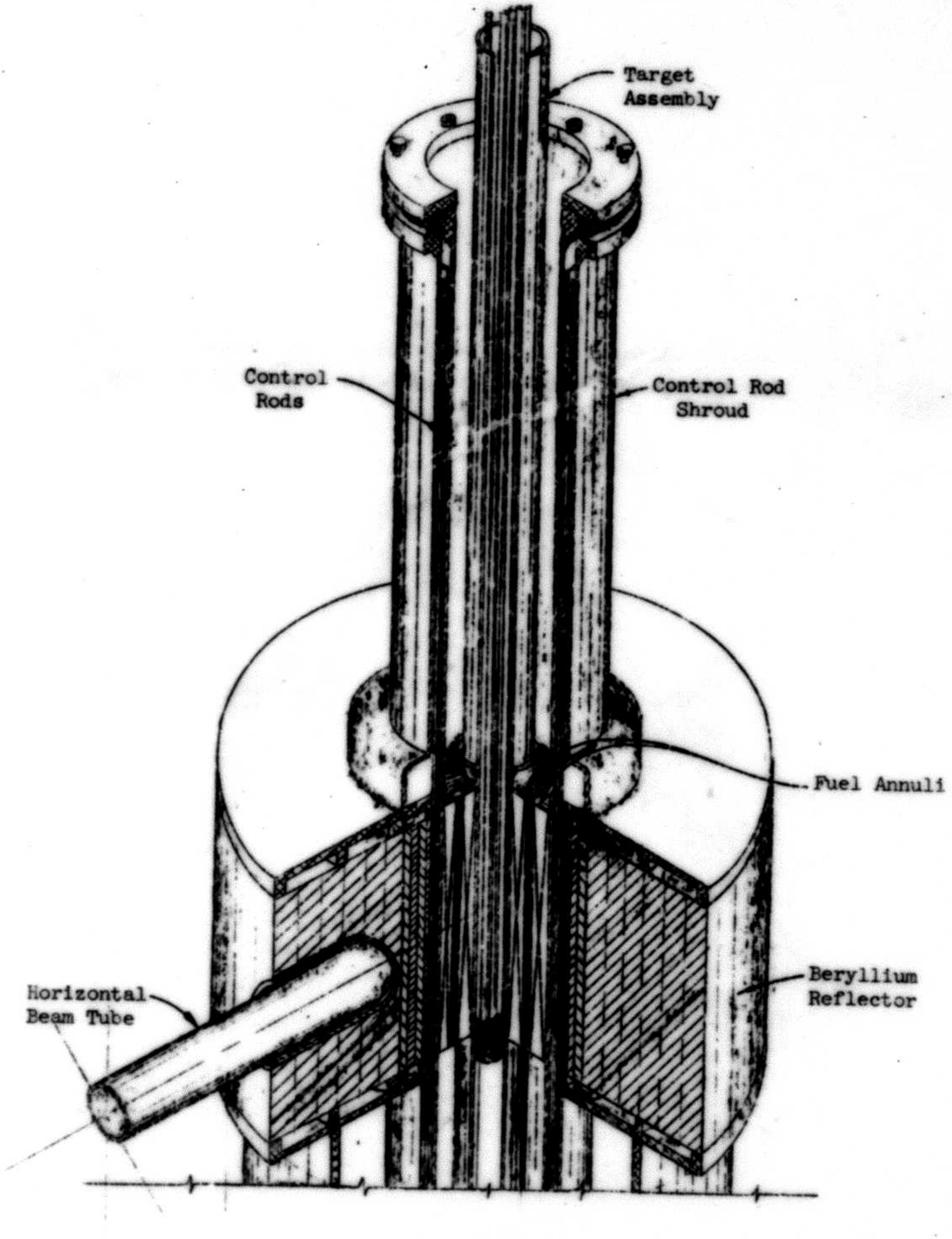
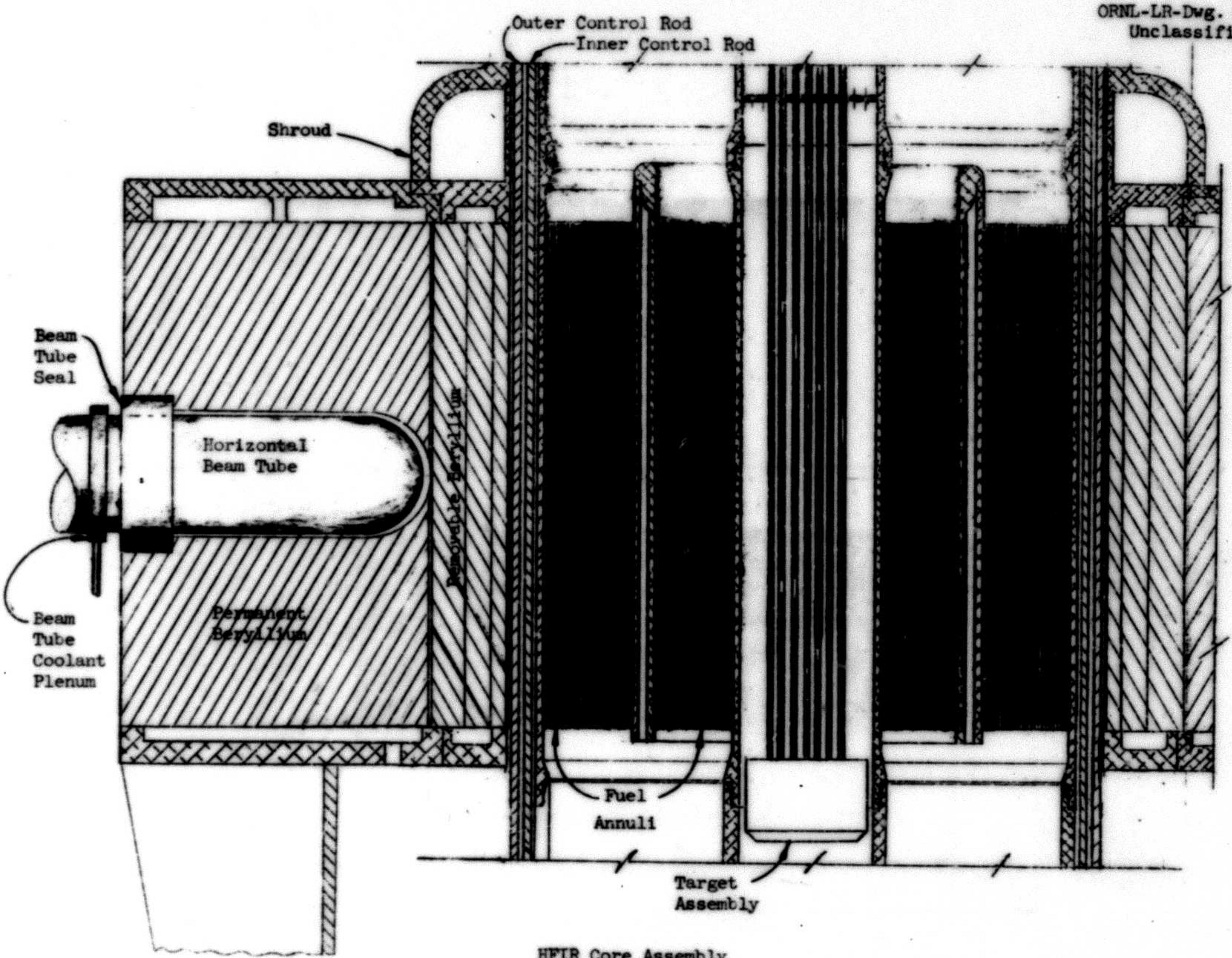


Isometric of HFIR
Core Components

Figure 3.



HFIR Core Assembly
Vertical Section

Figure 4.

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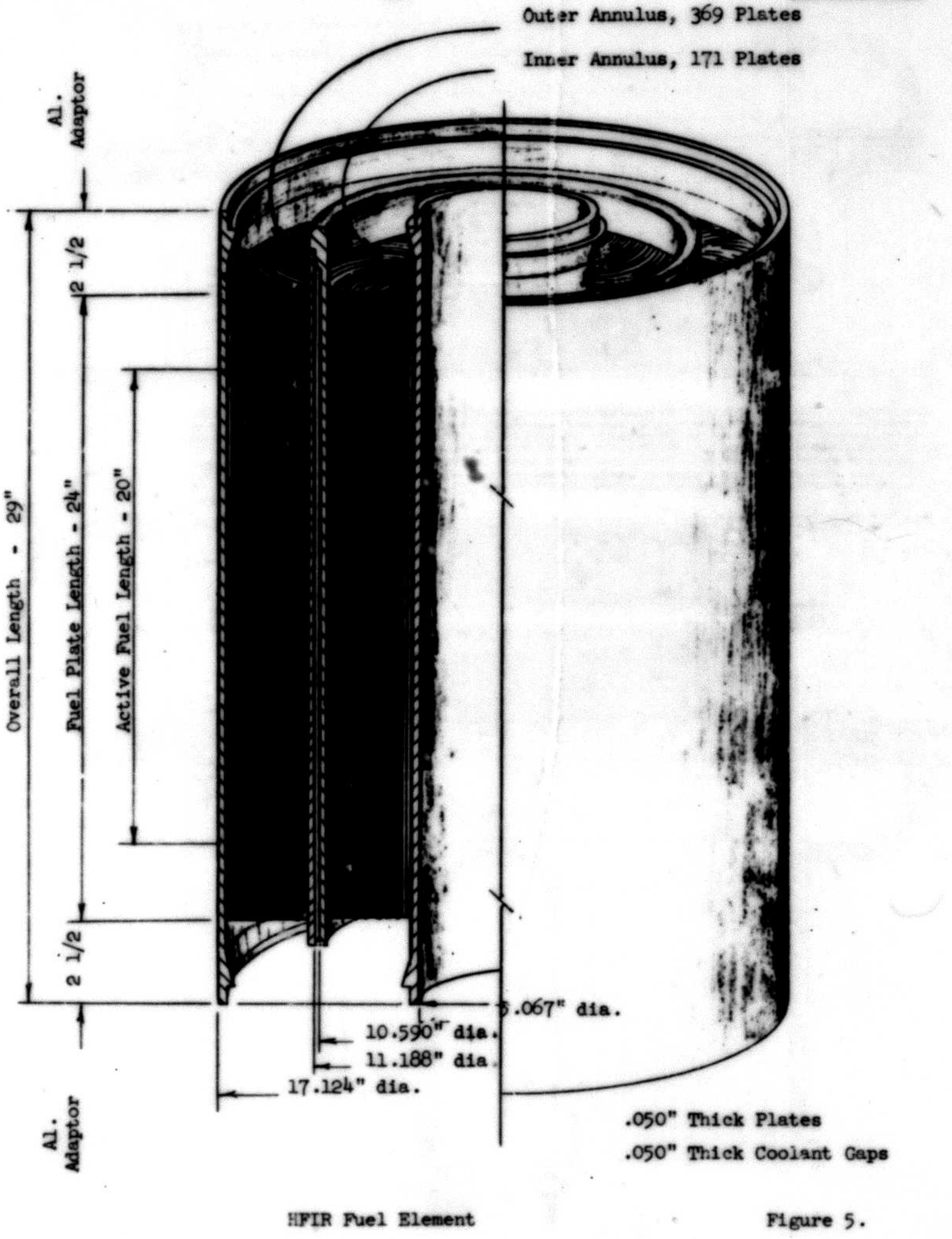
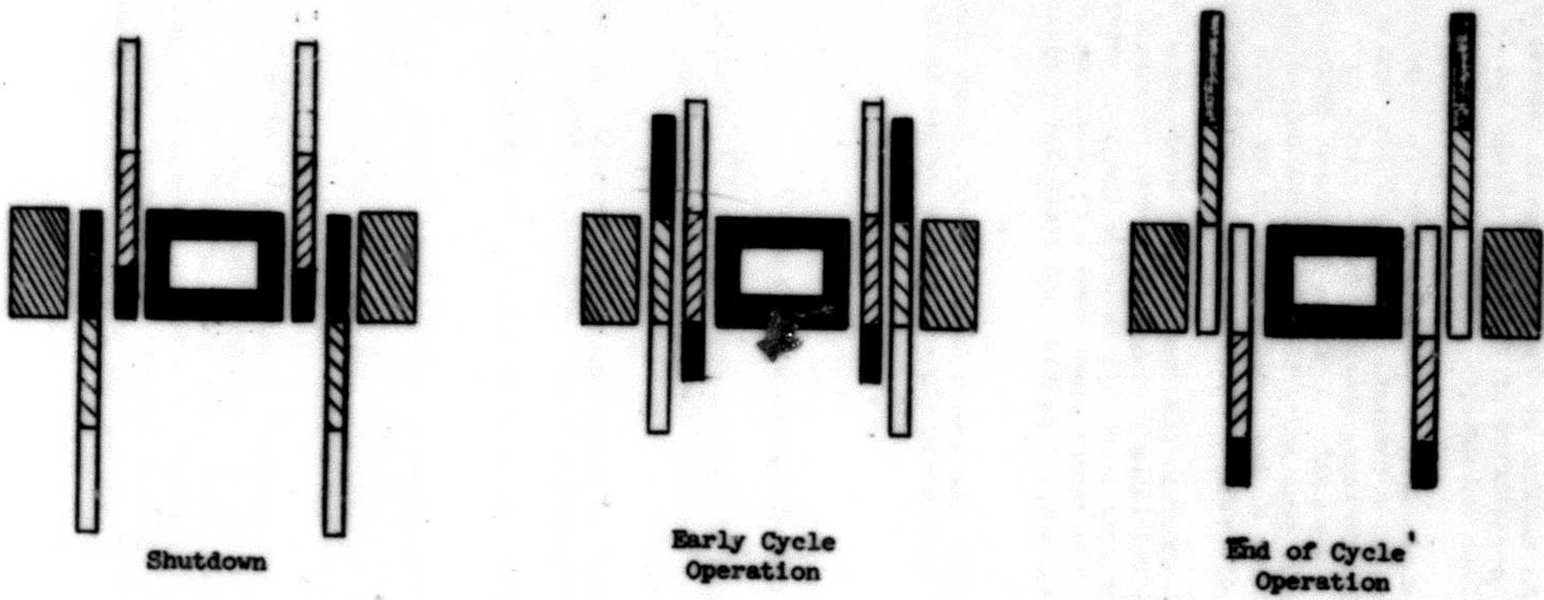


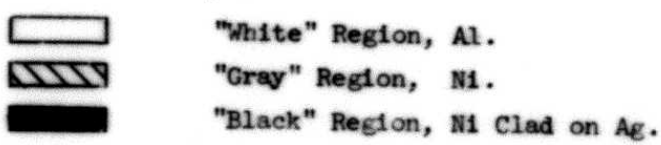
HFIR Fuel Element

Figure 5.



Typical HFIR Control Rod
Relative Orientations

Figure 6.



The beryllium reflector around the control region is 2 ft high and 1 ft thick. The inner 3.75 in. annulus of the beryllium is removable to permit replacement when necessitated by radiation damage and to provide access to the control plates and drives.

The reactor core is contained in a cylindrical pressure vessel which is 94 in. ID. The vessel has a removable flat upper head and a fixed hemispherical lower head. The core assembly is supported by a 4 ft high pedestal mounted on the lower head. A 30 in. ID vessel extension, attached to the lower head, penetrates the biological shielding below the reactor and permits location of the reactor control rod drive motors in the subpile room. The core support structure is shown in Figure 7.

The pressure vessel is located in the reactor pool where water above the fuel provides biological shielding during both normal operation and fuel replacement. The reactor core is 26 1/2 ft below the pool water level. A quick-opening hatch in the vessel upper head 9 ft above the core permits ready replacement of fuel, control plates, and removable beryllium as required.

Primary cooling water enters the vessel near the top, flows through the core regions in parallel and leaves through a side outlet in the lower vessel extension.

2.2 Target Array

The criteria for the target array are as follows:

1. The sample, containing an optimum loading of Pu^{242}, will be constructed in the form of clad rods, with the sample material length equal to the active fuel plate length.

2. A low cross-section material with good heat transfer and corrosion properties will be required for the container material.

3. Provisions for 6 extra rods will be made in the target holder for future use.

The target rods may be fabricated in the following manner: Pu^{242} in oxide form will be mixed with aluminum powder, made into pellets and packed into core length aluminum tubes. Special end caps are used to close the tubes, which after assembly become the target rods.

The results of optimization studies[2] (using for calculation purposes a homogenized target consisting of plutonium, the island water and the required aluminum) indicate that about 300 g of Pu^{242} is the desirable original charge. This will result in a target maximum heat generation rate of about 900 kw. To obtain adequate heat transfer area, 31 (3/8 in. OD) target rods on a 5/8 in. triangular pitch are used to contain the PuO_2-Al pellets.

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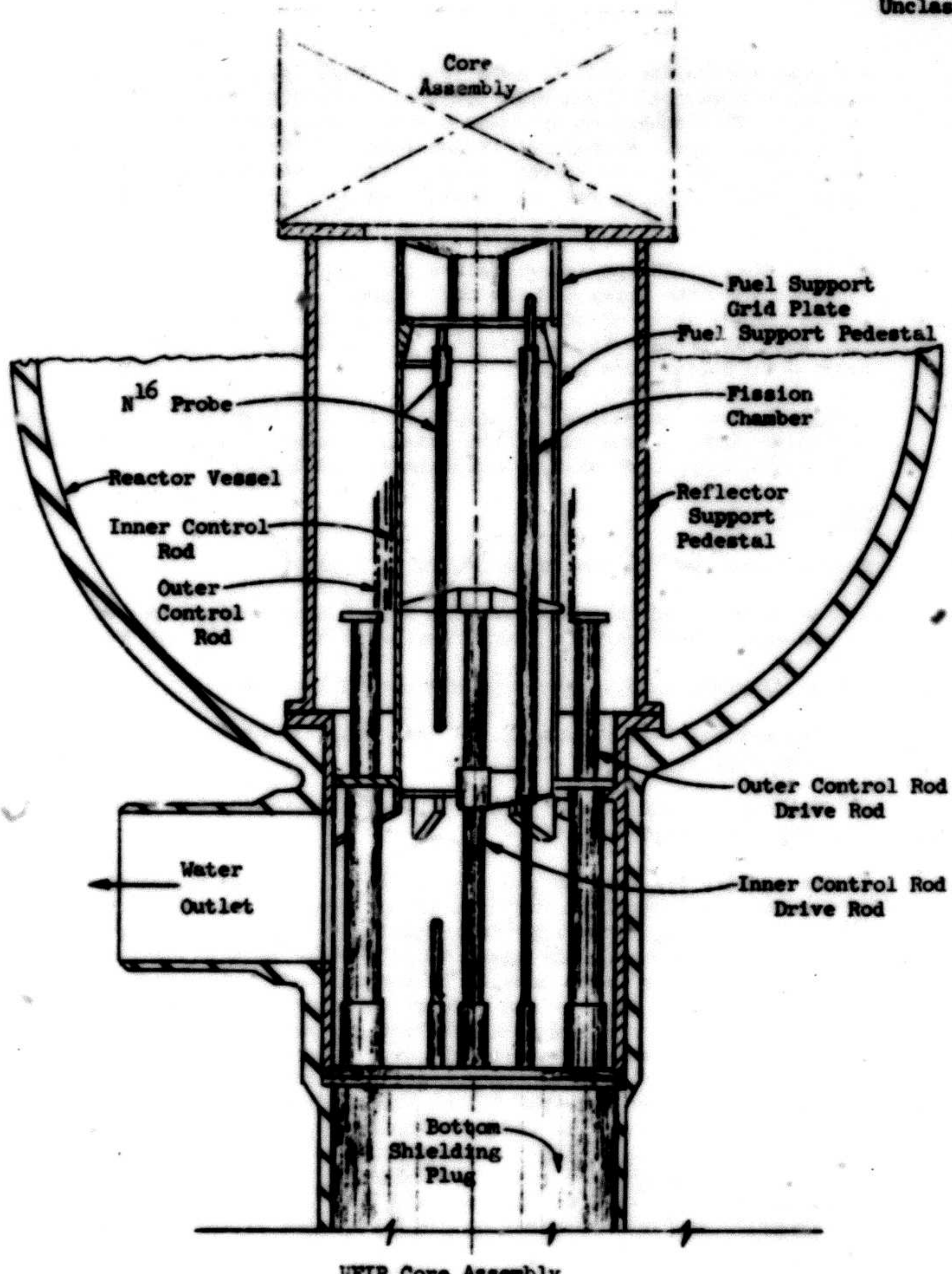

HFIR Core Assembly
Support Concept

Figure 7.

A target rod holder will be made from 37 (5/8 in.), very thin wall, aluminum, hexagonal tubes held together to form a large 4 3/8 in. hexagon. This honeycomb includes 6 extra tubes which can be used for special purposes. Either the target rods will be finned or the holder tubes will have 1/8 in. high, internal ridges which firmly hold the 3/8 in. target rods during operation. Design data for the target region are given in Table I.

A flow rate of 815 gpm is maintained through the target array, and 285 gpm flows between the array and the fuel element. This gives a water velocity in the target array of 50 fps which is more than that required for target cooling. The reason for overcooling the island is to make the reactor power coefficient more negative.

Provisions for installing thermocouples in the target rods and for getting the thermocouple leads out of the vessel through a target holder hole in the vessel upper head will be included in the design.

2.3 Fuel Element

The criteria for the fuel element are as follows:

1. An unperturbed thermal flux of 5×10^{15} neutrons/cm^2-sec in the island is desired at a total fission power level of 100 Mw.

2. An aluminum-clad, plate-type element will be used.

3. The maximum heat flux shall be less than 1/2 of the estimated burnout heat flux at similar conditions.

4. The fuel element loading should be sufficient for at least a 10-day operating lifetime.

In determining the physics and dimensions of the fuel element, the effect of a number of parameters was considered. These studies are reported elsewhere by Cheverton.[2] The fuel-annulus thickness and length were determined by considering the peak island thermal neutron flux as a function of the unit maximum power density in the fuel. The length selected was also influenced in part by the required pressure drop across the core. The results of the studies on the effect of power distribution on the flux and the ratio of maximum to average power density indicate the benefits of a radial grading of fuel concentration. For instance, the uranium concentration is lowest near the island where the thermal neutron flux is highest. The results also indicate the need to suppress the thermal neutron flux peaking at the fuel annulus ends. The peaking is reduced by a 2 in. extension at each end of the aluminum fuel cladding beyond the fuel region. The results also indicate that the use of burnable poison for power distribution control on the inner part of the fuel annulus is beneficial.

A metal-to-water ratio of 1.0 was selected on the basis of the nuclear, mechanical and thermodynamic studies.[15]

Only fuel plate configurations which give constant water gap thicknesses were considered. Involute plates fulfill this requirement and will be used in the first element.

The thickness of the fuel annulus appears to be too large to bridge with a single involute; therefore, two concentric annuli of involute fuel plates are used. A 0.3 in. water gap separates these two annuli.

The water coolant requirements for the aluminum clad plates were estimated using data correlations by Gambill and Bundy[3] for friction factors, film coefficients, and burnout heat fluxes. Using a method reported previously by Hilvety[4] and the correlations proposed by Gambill and Bundy, a study of the hot-spot and hot-channel factors has been made.[5] The results indicate that 50 mil thick fuel plates and 50 mil thick coolant channels permit operation with an adequate safety factor on heat transfer without resorting to impractical tolerances.

The results of studies by Lyon[6] and Chapman[7] on the effect of flow induced pressure differentials and other physical loads on the plates such as thermal distortion also indicate that reasonable tolerances on the manufacture of the element are satisfactory at the operating conditions.

The results of corrosion studies by Griess[8] indicate that the aluminum-clad fuel plates will be satisfactory for at least a 10-day fuel cycle. The thermal resistance of the aluminum oxide film formed during the corrosion experiments was determined by Griess.

The fuel element details are shown on ORNL drawings D-42100 through D-42111. The design data are given in Table I.

The water flow rate through the fuel element is 11,120 gpm. All but 220 gpm, which flows between the fuel annuli, is used for cooling the fuel plates. The nominal velocity in the fuel plate channels is 42 fps.

The results of calculations[5] indicate that the pressure drop through the fuel element at operating conditions is 74 psi and that the maximum fuel plate temperature at the water-oxide interface is [illegible]°F at a 100 Mw power level. The maximum hot-spot heat flux calculated is [illegible] x 10^6 Btu/hr-ft^2, which is less than one-half of the predicted minimum burnout heat flux for these conditions.[5]

2.4 Control Region

Criteria for the control region are based on nuclear considerations[2,9] and are summarized as follows:

1. The "black" region of the outer control rods should be worth about 24% in reactivity and should last as long as the "gray" region.

2. The "gray" region of each control rod should have the smallest possible cross section, consistent with reactivity control requirements, so as to prolong its life. The "gray" region must be worth about 13% in reactivity.

3. The "white" region should have as small a cross section as possible in order to extend the life of the fuel.

In addition to these nuclear criteria, the following general physical properties of the material are required:

1. The material combinations must be such that the permissible thermal stresses and deflections are not exceedrd.

2. The material must have good mechanical properties even after fast neutron doses up to 3×10^{22} nvt.

3. The material must be compatible with aluminum and beryllium from a corrosion standpoint at operating conditions.

Of course, beryllium would be the ideal material for the "white" region from a nuclear standpoint, but it is subject to radiation damage. Magnesium is questionable from a corrosion standpoint. Zirconium is undesirable from a heat generation point of view. Therefore, aluminum was selected as the "white" material. However, the neutron cross section of aluminum is such that control cylinders more than 1/4 in. thick would seriously shorten the life of the fuel. Further, the thickness of water in the control region must be kept at a minimum for the same reason. A 0.1 in. water channel between any two surfaces, at least one of which moves, was considered a minimum from a mechanical standpoint. And thus, the control region thickness was established as 0.8 in. (two 1/4 in. thick cylinders and three 0.1 in. thick water channels).

Having fixed the control cylinder thickness as 1/4 in., nickel was the only unclad material which met the criteria for the "gray" region.

For the "black" region silver clad with nickel (to protect the aluminum in the core against galvanic corrosion) was specified.[10]

A mechanical joint will be necessary between the aluminum and nickel sections of the control cylinders.

The "white" and "black" regions of the outer cylinder are 24 in. high and the "gray" region is 20 in. high. The inner cylinder has identical region heights except for the "black" region which is 8 3/4 in. high. The total travel of the cylinders is 44 inches for the outer cylinder and 28 3/4 inches for the inner cylinder.

The cylinders are accurately located and guided with bearings in the core structure to insure the required coolant gaps during operation.

A shroud above the core composed of an inner and outer cylinder adjacent to the control region, provides protection for the control cylinders in the up position. An orifice at the top of the shroud allows 800 gpm of cooling water to enter the control region for control plate cooling.

2.5 Control Drives

The control drive criteria are based primarily on safety considerations and are as follows:

1. The inner cylinder will be driven by a single drive.
2. The outer cylinder will be split in quadrants, each of which has its own individual drive and release mechanism for quick scram.
3. The drives should not interfere with the use of experimental facilities or with refueling operations.
4. Total stroke of each drive is 44 in.
5. Average scram acceleration necessary for first 6 in. of stroke of outer quadrants is 3 g even without the benefit of water flow.
6. The insertion and withdrawal speed is 5.75 in./min.
7. The run-down speed of the outer drives to pick up the quadrants after a scram is 48 in./min.
8. The release time required after a scram signal must be 10 milliseconds or less.
9. The position of any part of the control cylinders must be known within 0.02 in. during operation.

After an extensive study of all of the well known general types of control drives, it was concluded[11] that ORR type drives[12], utilizing mechanical drives and a subpile room for the drive location, was one of the most practical concepts for HFIR installation. The outer control cylinder quadrants will be driven from the bottom of the reactor with a lead screw drive and scrammed through a ball latch mechanism. The drive is basically the same as that used on the ORR[12] but has been redesigned for the HFIR operating conditions.

2.5.1 Inner Control Rod Drive

The inner cylinder is driven by a single drive rod connected to the bottom of the control plate by a hub and two webs. The drive rod runs through a seal in the bottom vessel flange and is connected to the drive located in the subpile room.

The drive for the inner control plate is essentially the same as those used for the outer control plate except for the omission of the scram device and fast rundown which is not required. The drive provides two separate and distinct motions. One motion is provided by the lead screw of the primary drive and is used for shimming over a 44 inch stroke. The other motion is provided by the input mechanism for the inner control plate regulating drive which moves the primary drive platform over a total stroke of about 3 inches for reactor regulation. When this 3 inch stroke is used up the reactor is shimmed to re-establish the 3 inch stroke for regulation.

Three separate control loops are to be used with the HFIR to provide a high degree of control system reliability. The servo outputs from the three control loops will be combined through the input mechanism for the inner control plate regulating drive into a single output to drive the inner control plate for reactor regulation. The servos will be constant speed motors which at steady state would not be running but can run either clockwise or counterclockwise as required to regulate the reactor. Should one servo operate erroneously, the remaining two servos will cancel this error and maintain control of the reactor.

For maintenance the inner control plate drive is uncoupled from the drive rod below the pressure vessel bottom flange and removed in the subpile room. The inner control plate and drive rod can be removed from the reactor by removing the core and core grid support and lifting them through the access flange in the top of the pressure vessel.

The drive rod seal in the pressure vessel bottom flange can be removed for maintenance by running the drive rod down into a seat built into the upper surface of the bottom flange. This keeps water from leaking out of the pressure vessel while the seal is removed.

2.5.2 Outer Control Rod Drives

The quadrants are driven by individual drive rods connected to the bottom of the control plates through a flange which is a part of the control plate. The drive rods run through a seal in the bottom vessel flange and are connected to the drives located in the subpile room.

The drive utilizes a lead screw to provide the linear motion for shimming. The shim speed is 5.75 inches per minute but provision has been made for the drive rod to move downward at a speed of 48 inches per minute to pick up the control plate after a scram. To insure that the high speed pickup operates only in a downward direction, two separate motors coupled through a differential are used for the shimming and fast pickup functions. The motors operate through a worm gear reducer and magnetic brake so that rotation of one will not rotate the other. A capacitor start-and-run motor is used with the shim drive. The fast pickup takes place after the control plate has seated in the dash pot. For this a single-shafted, air motor is used which will run in one direction only.

The control plates are coupled to the drive rods through a ball latch mechanism. The balls are built into the end of the drive rod and are forced to engage a groove in the control plate sleeve by a cylindrical cam actuated by an electromagnet incorporated in the drive mechanism located in the subpile room. De-energizing the electromagnet causes the control plates to scram. A coil spring is used between the control plate sleeve and drive rod to give the control plate a 3 g acceleration during the first 6 inches of scram.

Removal of the drives for maintenance is accomplished by uncoupling the drive rod from the drive mechanism in the subpile room. The control plates are removed through the top of the pressure vessel, after the removable reflector has been taken out, by disengaging the ball latch mechanism and loosening a bolt at the top of the drive rod.

2.5.3 Miscellaneous Equipment Associated with Control Plates and Drives

(A) Pressure Vessel Extension Shield Plug

The shield plug is a stainless steel sheathed concrete plug installed in the pressure vessel extension to give a low radiation level in the subpile room. The plug is suspended from the bottom of the pressure vessel. Longitudinal sleeves are provided in the plug for control drive rods and other items that penetrate the bottom flange of the pressure vessel.

(B) Shock Absorbers

Four shock absorbers are provided for the outer control plates. The dash pots are built into the top of the shield plug and can be removed through the top of the pressure vessel for maintenance. The shock absorber plunger is the bottom end of the control plate sleeve.

(C) Seat Switch

A seat switch is provided to determine that the control plate sleeve is seated in the dash pot after a scram. An actuating rod is used between the dash pot and the bottom flange of the pressure vessel. Seating of the control plate sleeve moves the actuating rod downward 1/4 in. A rod magnet is attached to the bottom of the actuating rod. Movement of this rod magnet operates a magnetic switch mounted to the pressure vessel flange.

(D) Clutch Switch

A clutch switch is incorporated in the ball latch mechanism to determine that the electromagnet has released its armature to scram the control plates.

(E) Position Indication

Position indication is provided through selsyns mounted to the drive platform in the subpile room. The selsyns are actuated through a pinion which meshes with the threads on the lead screw of the drive.

(F) Drive Rod Seals

"Palmetto" seals are built into the bottom flange of the pressure vessel for sealing the drive rod penetration through the pressure vessel. "Palmetto" seals are modified "O-Ring Seals" having a special backup ring arrangement to minimize extrusion between the push rod and seal housing. A double seal is provided with a lantern ring between seals for draining any leakage from the high pressure seal.

2.6 Beryllium Reflector

The four basic criteria governing the reflector design are as follows:

1. The inner portion of the reflector should be removable to provide for partial reflector replacement in case of severe radiation damage, and for access to the control plate drives.

2. The reflector water content must be held to the minimum practical value to avoid unnecessary loss of reactivity.

3. The reflector experimental facilities should be located as near as practical to the point of maximum thermal flux.

4. Thermal stresses in the Be should not exceed 12,000 psi at a power level of 125 Mw.

The design chosen as complying best with these criteria consists of a 3.75 in. thick reflector section consisting of four concentric cylinders with cooling water flowing through the annuli between cylinders, and an outer 8.25 inch thick permanent Be annulus with axial circular coolant channels. The inner 3 cylinders of the removable beryllium are removed from the reactor as a unit. The fourth cylinder (semi-permanent reflector) is attached to the permanent reflector and is removed only when necessary to replace it due to radiation damage. A layout of the current HFIR beryllium reflector and support structure design is shown on ORNL drawing F-42099, and the design data are summarized in Table 1.

2.6.1 Removable Reflector

All thermal stress calculations for the removable reflector are based on a flat slab geometry. Heat generation rates were obtained via the NIGHTMARE code.[13] The cylinders have all been designed to approximately the same stress level of 10,500 psi at 125 Mw.

In order to insure against possible jamming of the control plates in case of breakage of the inner beryllium cylinder, a 1/16 in. thick aluminum liner is provided at the removable reflector ID. The nominal thickness of the coolant annulus between cylinders has been set at 27 mils. Aluminum rivets provide spacing to insure a minimum coolant channel of 20 mils at the top and bottom of the assembly. Nominal clearance between the rivet face and next cylinder is 7 mils, with a ± 1 mil tolerance on both the cylinder inside radius and the rivet outside radius. These dimensions conform to the standard definition of a "free fit". A 1/16 in. thick water gap between the removable and semi-permanent reflectors provides for interference-free removal and replacement of the removable reflector.

The removable reflector assembly is held together by upper and lower aluminum grid plates which are fastened together by 8 aluminum bolts which penetrate the thickest beryllium cylinder. The top grid plate is held down by the lower flange of the control plate shroud which is bolted down to the permanent reflector upper grid plate. After the outer shroud is removed, the removable reflector assembly may be lifted out. The principal advantage of removing the removable reflector assembly as a unit is the ability to assemble and disassemble the removable reflector in the pool rather than in the reactor vessel.

The upper removable reflector grid plate also serves as an orifice plate to control coolant flow from the reactor supply through the removable reflector. About 40 psi pressure drop is required to obtain the necessary coolant velocity through the removable reflector. The upper grid plate thus absorbs about a 34 psi pressure drop. Cooling water for the aluminum bolts and for the annulus between the removable and semi-permanent reflector is supplied through the top grid plate from the control region.

Eight 1/2 in. diameter vertical irradiation facilities are provided in the thickest of the removable reflector beryllium cylinders. It is anticipated that access to these locations will be restricted to those times when the access hatch is open and the outer shroud is removed, thus these facilities will be utilized only for comparatively long term irradiations. These facilities are each provided with a removable beryllium plug which will be installed at all times when the facilities are not in use. An annulus around the beryllium plug, or irradiation sample, will provide cooling for this member, the water being supplied from the control plate region.

2.6.2 Permanent and Semi-permanent Reflector

For purposes of thermal stress calculations, the permanent reflector is assumed to consist of a large number of insulated cylindrical Be sections, one cylinder per coolant hole with the coolant hole located on the cylinder axis. All heat generated within a given cylindrical element[13] is assumed to be removed by the coolant flowing down the hole at the center of that element. The coolant holes are located on a series of circles which are concentric about the fuel element, with 80 holes per circle. Coolant hole circle radii are indicated in Table 1. In order to limit as much as possible the water content of the permanent reflector, it is necessary to utilize the smallest practical coolant hole diameter. After consultation with Machine Shop personnel,[14] it was concluded that the design should utilize 1/8 in. holes.

The 5/8 in. thick aluminum grid plate located at the top of the permanent beryllium serves several purposes: It acts as a tie-down point and locating device for the shroud and removable reflector, serves as a strainer to eliminate coolant hole plugging due to foreign materials in the coolant, acts as a tie-down plate for the permanent beryllium via bolts extending down into the support pedestal, and controls the coolant flow through the permanent reflector. The entire reflector assembly is supported from the bottom of the reactor pressure vessel via a 5/8 in. thick aluminum pedestal. A plenum chamber, located immediately below the permanent beryllium serves to support the permanent reflector and direct the coolant flow to the coolant outlet at the inside of the support pedestal.

In order to provide for access to the control plate drives without removal of the permanent reflector, it is necessary to provide for easy removal of 4 small sections of beryllium from the semi-permanent beryllium ring and from the ID of the permanent reflector. These are shown on TD-E-5873. These 4 removable pieces will be supported and located by the outer control plate shroud, and are located at the bottom by standoffs from the lower grid. These pieces also contain vertical irradiation facilities similar to those of the removable reflector. Aluminum bolts penetrating the entire length of these pieces hold the assemblies together in the same manner as the removable reflector is assembled. Cooling water for these pieces, the aluminum bolts, and the experimental facilities is provided from the control region. Coolant flowing through the holes in the removable blocks discharges directly into the low pressure coolant outlet region. These four pieces are thus in actuality a part of the removable reflector assembly.

In order to facilitate easy removal of the removable reflector section, most of the reflector experimental facilities have been located in the permanent reflector. Four types of facilities have been provided in the permanent reflector: horizontal beam holes, vertical 1 3/4 inch diameter facilities, vertical 3 inch diameter facilities, and inclined engineering facilities.

Three 5 1/2 inch diameter beam holes in the beryllium are provided. One of these is radial to the fuel element, one is tangential to the fuel element, and the third is a through hole penetrating the entire reactor assembly. Four-inch ID, internally cooled, aluminum beam tubes are installed in these holes. Cooling water flows from the reactor supply, through longitudinal 3/16 inch coolant holes in the center of the tube wall, into a plenum chamber, through a connecting pipe containing a flow control orifice, and into the reactor discharge at the bottom of the reflector support pedestal. Permanent reflector coolant flows around the beam tube in a 1/8 inch annulus. A labyrinth-type seal is provided between the beam tubes and beryllium reflector at the permanent beryllium outer surface to prevent short circuiting of the permanent reflector coolant and permit some relative motion between the beryllium and beam tube. The beam tubes are 5/8 inch thick and are designed for 1000 psi external pressure operation. Thermal and hydraulic expansions within the reactor assembly may result in as much as 1/16 inch radial and 1/8 inch axial differential movement between the beam tubes and beryllium reflector.

The 1 3/4 inch and 3 inch vertical irradiation facilities consist of holes drilled through the permanent beryllium reflector. These are provided with plugs to be inserted when the facilities are not in use. Access is provided through the upper permanent reflector grid plate. Cooling is accomplished by permanent reflector coolant flowing down a central, 1/8 inch diameter hole and through a 50 mil annulus around the plugs. If desired, any experiments in these locations could also be internally cooled by water drawn from the reactor supply above the upper grid plate and discharging into the reactor outlet at the bottom of the reflector assembly. Beryllium plugs will be provided for the 1 3/4 inch holes. Aluminum or beryllium plugs may be used in the 3 inch holes since there is very little reactivity effect resulting from the outermost parts of the permanent reflector region.

The engineering facilities consist of 4 slanting grooves in the OD of the permanent reflector. Permanent reflector coolant holes are bypassed around these grooves. Cooling of the facilities will be provided from the reactor supply and discharged into the reactor outlet at the bottom of the reflector support pedestal. Flanges are provided on the pedestal for this purpose.

2.7 Pressure Vessel

The criteria for the pressure vessel are given in ORNL Specification RD-8.8-1 and are summarized below:

1. The vessel is 94 in. ID and the design pressure is 1000 psi (the maximum cooling water temperature is 200°F).

2. The control drive rods will penetrate the vessel through an extension in the lower head.

3. The top of the vessel is a flat head which can be removed.

4. A quick opening, 28 in. ID hatch is located in the top head about 9 ft above the core.

5. Provision for about 20 penetrations each in the upper and lower vessel flanges and in the vessel wall must be made.

6. The interior and exterior surfaces of the vessel are to be stainless steel.

Details of the vessel requirements and experimental facility locations are shown on ORNL drawings TD-E-5595, TD-E-5607, TD-D-5613, and TD-E-5614.

2.7.1 Quick Opening Hatch

The functions of the quick opening hatch are: to provide access for replacement of the fuel element, removable reflector, control plates, and target assembly and associated instrumentation. To accomplish these functions the following conditions must be met: The design of the closure mechanism shall permit operation by means of a long handled tool manipulated by personnel standing on the pool bridge platform located 21'-5" above surface D.* The mechanism which releases the seal and clears the quick opening hatch so that it can be opened or closed shall require a maximum of 5 minutes to release and/or engage. All moving parts shall remain a part of the quick opening hatch when the hatch is removed. The quick opening hatch in the open position shall be free of the pressure vessel top head. The quick opening hatch when open shall provide a clear circular opening of 28 in. diameter. A target hole shall be provided in the center of the quick opening hatch cover. The target hole mechanical closure shall be designed such that upon release of the segmented holddown mechanism the quick opening hatch may be removed, leaving the target hole plug in position relative to the pressure vessel as shown on Dwg. TD-E-5595. The supplemental load for the target hole plug holddown mechanism which shall be added to the pressure load is provided in RD 8.8-1. All components except gaskets shall be designed for 20 years life during which opening and reclosure shall occur every 10 days. Gaskets for quick opening hatch and target mechanical closures shall be designed for 5 removals and replacements of the mechanical closures for the operating conditions given in Table 1 without replacing the gaskets. Gaskets shall be made from special radiation resistant rubber and shall not be located lower than Surface D.*

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* Surface D is the vessel flange surface located 9'-3" above the reactor midplane.

2.7.2 Top Head Mechanical Closure

The top head mechanical closure shall provide unimpeded access to the full internal diameter of the reactor pressure vessel cylinder. Design of this closure shall permit closing and replacement of the gasket by means of long handled tools manipulated by personnel standing on a platform located 21'-5" above surface D.* The design shall provide a means for retaining the studs in the vessel flange and preventing rotation of the studs when the top nut is removed. Guides shall be provided for putting the head in place. If threads are used in a position where they can be damaged by removing and replacing the head, they must be mechanically replaceable.

2.7.3 Pressure Vessel Top Head

The top head shall be a flat head having provisions for the quick opening hatch and other attachments as shown on Drawings TD-D-5613 and TD-E-5595. Lifting lugs shall be provided for lifting the head. The top head with its attachments shall be designed and located in elevation such that no portion of it will impede the lateral movement of the core above a plane located 2'-6" above Surface D.

2.7.4 Annulus Shield Plug

The annulus shield plug, shield plug wall, shield liner, pool floor liner, debris dam and pool mechanical closure are shown on Dwg. TD-E-5595. High-density concrete required for shielding shall conform to Specification RD-8.7-36.

A flexible-cord impregnated neoprene diaphragm in the pool mechanical closure shall be provided to seal the pool between the annulus shield liner and the annulus shield plug wall. This diaphragm must compensate for the relative thermal expansion of the annulus shield liner and the pressure vessel extension.

Anchor straps to provide a bond with the shield concrete shall be attached to the annulus shield liner flange which is to be in contact with the concrete.

The pool mechanical closure, debris dam, annulus shield liner, and annulus shield plug wall shall be designed to withstand 43 feet of hydrostatic head. The annulus shield liner, the pool floor liner, the annulus shield plug wall, pool debris dam and pool mechanical closure shall be fabricated from stainless steel or stainless-clad-carbon steel. If stainless-clad-carbon steel is used, the carbon

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*Surface D is the vessel flange surface located 9'-3" above the reactor midplane.

steel on the concrete side shall be painted with one coat of Amercoat No. 86 primer, in accordance with the manufacturer's instruction.

Installation and maintenance of the neoprene diaphragm can be performed by direct contact.

The debris dam gasket is used to keep debris from between the annulus shield liner and annulus shield plug wall.

2.7.5 Core Pedestal Support Surface

The core pedestal support surface serves as the support point for the reactor core and control rod drives. Tolerance and finish requirements are shown on Dwg. E-42136.

2.7.6 Pressure Vessel Support Assembly

The resultant of forces and moments acting upon the vessel through the nozzles shall be resisted by the pressure vessel suppor assembly. The vessel support shall be firmly anchored to the pool floor through anchor bolts. The support assembly shall be designed to limit the thermally and mechanically induced movements of the HB nozzles to the values shown in RD 8.8-1. The assembly shall permit access to the pool floor for cleaning from the pool bridge platform with offset-type tools.

2.7.7 Pressure Vessel Extension

The pressure vessel extension serves as the exit coolant flow passage and houses the extension shield plug through which the control rod drives are actuated. Dimensional requirements are shown on Dwg. TD-E-5595.

2.7.8 Water Nozzles and Screen Attachment Surfaces

A mounting surface shall be furnished on the inboard end of the coolant water inlet nozzles to provide for the attachment of a sediment screen in accordance with Dwg. TD-E-5595. The portion of the cooling water inlet and exit nozzles within 6 in. of the match lines shown on Dwg. TD-E-5595 shall be constructed of solid stainless steel.

2.8 Core Support Assembly

The criteria for the design of the core support assembly are as follows:

1. The support assembly must provide alignment, structural strength, and rigidity for the reactor core, control rods, and the vessel extension shield plug.

2. The interference with water flow should be small.

3. Eight reactor core bypass water nozzles must be provided for experimental use.

4. A water seal between the support assembly and the pressure vessel must be provided.

The proposed design is shown on ORNL drawing F-42099. The main support portion of the assembly is extra heavy for rigidity. The fuel support pedestal surface is as low as practical to permit the use of an extension on the control rods.

2.9 Reflector and Fuel Support Pedestals and Fuel Grid

The criteria for the design of the reflector and fuel support pedestals and the fuel grid are as follows:

1. They should not interfere with coolant water flow through core components and operation of the control rods.

2. The materials of construction must have a combination of density, thermal conductivity, and thermal expansion properties that will permit removal of the intense gamma heat from the materials without thermal expansion.

The proposed design is shown on ORNL drawing E-42135. The pedestals are two concentric cylinders. The inner pedestal supports the fuel grid on which the fuel element rests, and the outer pedestal supports the reflector. The inner diameter of the outer pedestal was fixed by control drive locations. The wall thickness for the outer pedestal was based on an external design pressure of 100 psi and for both pedestals an axial end load over the corresponding flow area equivalent to 100 psi. Aluminum is the material of construction in all cases.

2.10 Fission Chamber Thimbles and Drives

Three 3/4 inch aluminum pipe thimbles attached to the bottom flange of the pressure vessel near its center and running upward to a position 22 inches below the center of the core are provided for fission chambers. The thimbles have a 2 1/2 inch horizontal offset to decrease radiation streaming into the subpile room.

A preamplifier is located 4 feet 6 inches below and connected by flexible cable to each fission chamber. Movement of the assembly is accomplished by a rack and pinion drive which is mounted at the bottom of each thimble and provides 6 feet 8 inches of fission chamber travel.

2.11 N^{16} Probes

An N^{16} probe and two thermocouples are provided just below the core and on the radial centerline of each of the outer control plates to indicate any flux tilt in the reactor core. The probes and thermocouples will run through the bottom flange of the pressure vessel. The water is then routed through shielding to N^{16} analyzers in the subpile room. The thermocouple leads go to temperature indicators in the control room.

Table I

Nuclear and Heat Removal

Reactor Power Level, Mw	100
Neutron Fluxes, neutron/cm^2-sec	
Fast, fuel region, (max)	4.2×10^{15}
Thermal, island unperturbed (max)	5.5×10^{15}
" perturbed (avg)	2.4×10^{15}
reflector, beginning of cycle (max)	0.6×10^{15}
" , end of cycle (max)	1.2×10^{15}
Reactor Materials	
Fuel plate	U-Al, clad in Al
Fuel loading, kg of U^{235}	8.01
Target rod	PuO_2-Al, clad in Al
Target loading, g of Pu^{242}	300
Coolant	H_2O
Island moderator and reflector	H_2O
Side reflector	H_2O cooled Be
Heat Transfer and Coolant Data	
1. General	
System pressure, pump discharge, psi	1000
Total coolant flow rate, gpm	15,000
Pressure drop across vessel, psi	84
Temperature, °F	
Vessel inlet	120
Vessel outlet	167

2. Fuel Region

Geometry - two concentric cylindrical annuli, involute fuel plates

Fuel Region Dimensions

Inner annulus ID, in.	5.067
OD, in.	10.590
Outer annulus ID, in.	11.250
OD, in.	17.124
Radii of active fuel region, in.	
Inner annulus ID, (max.)	5.689
OD, (min.)	9.880
Outer annulus ID, (max.)	11.988
OD, (min.)	16.472
Height of active core, in.	20
Total fuel plate height, in.	24
Fuel plate thickness, in.	0.050
Coolant channel thickness, in.	0.050
Number of fuel plates	540
Total heat transfer area, ft^2	427
Volume of active core, liters	48.6
Design heat load, Mw	97.5
Power density, Mw/liter	
Maximum	3.73
Average	2.06
Heat flux, $Btu/hr\text{-}ft^2$	
Maximum	~~1.49~~ 1.53 $\times 10^6$
Average	0.8×10^6
Burnout (calculated)	~~3.45~~ 3.49 $\times 10^6$

Water flow rate, gpm	
Through fuel plate channels	10,900
Between fuel annuli	220
Nominal water velocity between plates, ft/sec	42
Pressure drop, psi	74
Temperature, °F	
Water inlet	120
Water outlet (nominal)	180
Fuel plate oxide surface (max)	~~[illegible]~~ 344
Fuel plate metal surface (max)	~~[illegible]~~ 576

3. **Target Region**

Geometry - 3/8 in. OD target rods spaced on triangular pattern

Target Region Dimensions	
Diameter of water island, in.	5.067
Rod diameter, in.	3/8
Height of active portion, in.	20
Total rod length, in.	29
Number of rods	31
Spacing between rod centers, in.	5/8
Design heat load, kw, (max)	900
Maximum heat generation rate, watts/gm target rod	435
Heat flux, Btu/hr-ft^2 (max)	0.84×10^6
Water flow rate, gpm	
Through hexagonal array	~ 815
Between array and island OD	~ 285

Nominal water velocity around rods, ft/sec	50
Pressure drop across sample array, psi	45
Temperature, °F	
Water inlet	120
Water outlet (from target array)	128
Rod oxide surface (max)	207
Rod metal surface (max)	312
Center of rod (assuming complete bonding)	390

4. Control Region

Geometry - Two concentric cylinders containing black, gray, and white regions. Axial plate movement. Inner cylinder solid, outer cylinder in 4 segments.

Control Region Dimensions

Overall ID, inches	17.124
OD, inches	18.748
Inner cylinder, ID, inches	17.332
OD, inches	17.832
Outer cylinder, ID, inches	18.040
OD, inches	18.540
Height, inches, black region, outer cylinder	24
" " , inner cylinder	8.75
gray region	20
white region	24
Coolant annuli thickness, inches (Typical of three)	0.104

Design heat load, Mw 3

Maximum heat generation rate, watts/gm plate	34
Heat flux, Btu/hr, ft^2 (max)	500,000
Water flow rate, gpm	800
Water velocity, ft/sec (nominal)	14.6
Pressure drop across control plates, psi	16
Temperatures, °F	
Water inlet	120
Water outlet (avg.)	145
Cylinder surface, (max)	220
(min)	120

5. Removable Beryllium Reflector

Geometry - concentric cylinders

Removable Be Dimensions

Overall ID, inches	18.748
Overall OD, inches	23.759
Height, inches	24.0

Nominal ID of individual cylinders, inches

Cyl. #	Material	
1	Al	18.748
2	Be	18.873
3	H_2O	19.626
4	Be	19.680
5	H_2O	21.486
6	Be	21.540
7	H_2O	23.759

Design heat load, Mw	~ 2
Maximum heat generation rate, watts/gm Be	31
Heat flux, Btu/hr, ft^2 (max)	~ 0.18 x 1(
Water flow rate, gpm	420
Coolant velocity, ft/sec	
In cylinders Nos. 3 and 5	20
In cylinder No. 7	12
Pressure drop across cylinders Nos. 3 and 5, psi	40
across cylinder No. 7	~ 10
Temperatures, °F	
Water inlet	120
Water outlet (nominal)	~ 154
Cylinder surface (max)	~ 180
Beryllium (max)	~ 260

6. Permanent and Semi-permanent Beryllium Reflector

Geometry - Two stacked Be annuli, with axial coolant holes divided between semi-permanent and permanent beryllium at inner circle of coolant holes.

Be Dimensions

ID, inches (semi-permanent reflector)	23.884
ID, inches (permanent reflector)	26.25
OD, inches	43.0
Height, inches	24.0
Coolant hole diameter, inches	0.125

Coolant hole spacing - Located on 6 concentric circles, 80 uniformly spaced holes per circle except where altered by experimental facilities.

Radii of coolant hole circles, inches

Circle No. 1	13.08

Circle No. 2	14.124
3	15.306
4	16.662
5	18.219
6	20.013
Design heat load, Mw	~ 1.7
Maximum heat generation rate, watts/gm Be	10.5
Heat flux, Btu/hr-ft^2, (max.)	~ 0.28 x 10^6
Water flow rate, through coolant holes, gpm	235
around experimental facilities, gpm	287
Coolant velocity, ft/sec	15
Temperatures, °F	
Water inlet	120
Water outlet (avg. from 1/8 " coolant holes)	~ 150
Be surface, (max.)	~ 210
Beryllium, (max.)	~ 270

References

1. J. A. Lane, et al, High Flux Isotope Reactor Preliminary Design Study, ORNL CF-59-2-65, March 20, 1959.

2. R. D. Cheverton, HFIR Preliminary Physics Report, ORNL-3006, October 4, 1960.

3. W. R. Gambill and R. D. Bundy, Recommended Correlations for Thermal Design for HFIR Core Composed of Plate-Type Elements without Spacers, Memo to J. R. McWherter, March 1, 1960.

4. N. Hilvety, Preliminary Hot Spot Analysis of the HFIR, ORNL CF-60-3-12.

5. N. Hilvety to J. R. McWherter, Personal Communication, January 24, 1961.

6. R. N. Lyon to T. G. Chapman, Personal Communication, Sept. 1960.

7. T. G. Chapman to J. R. McWherter, HFIR Fuel Element Design, Sept. 21, 1960.

8. J. C. Griess, et al, Effect of Heat Flux on the Corrosion of Aluminum by Water, Part I. Experimental Equipment and Preliminary Test Results, ORNL-2939.

9. R. D. Cheverton to C. E. Winters, HFIR Control-Plate Materials, Sept. 9, 1960.

10. R. D. Cheverton to C. E. Winters, HFIR Physics Progress Report for December-January, January 24, 1961.

11. L. C. Oakes to C. W. Collins, Personal Communication, April 1960.

12. T. E. Cole and J. P. Gill, The ORNL Research Reactor, General Description, ORNL-2240.

13. M. Tobias and D. R. Vondy to N. Hilvety, Personal Communication, July 7, 1960.

14. W. J. Barker to N. Hilvety, Personal Communication, Sept. 7, 1960.

15. C. E. Winters, HFIR Fuel Elements, Memo dated August 23, 1960.