Large Pool LMFBR Design
Volume 1: Reactor

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Final Report, August 1978

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ABSTRACT

The design effort reported herein, and performed by ARD in the period February-July 1978, and by S&W from mid-March to July, 1978 concentrates on those parts of the nuclear island unique to a commercial size pool type LMFBR. In particular, the work covers the reactor vessel, deck, rotating plugs, upper and lower internals, internal plenum separator system, IHX, pumps, cold traps, intermediate system layout, containment/confinement system, plot plan, and residual heat removal systems. Preliminary thermal, hydraulic, stress and system analyses are also presented.

The goals for this period of effort were:

- To refine the design status of components conceptually designed in a prior phase.
- To complete the conceptualization of the remainder of the nuclear island unique to the pool type system.
- To identify any conceptual feasibility problems of pool type LMFBRs.

Goals were met. No conceptual feasibility problems were identified.

VOLUME I

REACTOR DESIGN

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SECTION 1.0
INTRODUCTION

From August of 1977 through February of 1978, the Advanced Reactors Division (ARD) of Westinghouse Electric Corporation was actively engaged in the study and design of a large pool type liquid metal cooled fast breeder reactor which was identified by the acronym LPR (Large Pool Reactor). The effort in this time period was funded by corporate development and general research funds. On 24 February, 1978, Westinghouse and The Electric Power Research Institute (EPRI) entered into a contract extending through July, 1978, the objective of which was to continue design development of a large pool type LMFBR.

The design effort from August to December of 1977 resulted in the establishment of a conceptual design for a 1000 MW(e) pool type reactor. Design effort during that period was limited to the reactor vessel and its contents. The results of that effort were presented in a four volume interim report, "Westinghouse Large Pool Reactor", dated January, 1978. From January to July of 1978, the design effort was expanded to include the entire nuclear steam supply system (NSSS). On March 13, 1978, the Stone and Webster Engineering Corporation also entered into a contract with EPRI to work in concert with Westinghouse on the plant design for the LPR. The combined Westinghouse/Stone and Webster design efforts from January through June of 1978 are presented in this report.

1.1 EPRI GUIDELINES

EPRI established and issued design guidelines covering the design development of the pool type LMFBR. These guidelines were revised in part during the contract period, and the current guidelines are presented in Appendix L. Westinghouse has, in general, remained consistent with the guidelines. Three areas of the reactor design where the reference design differs from the guidelines are as follows:

- Mixed Mean Reactor Outlet Temperature - The guidelines specify a hot pool temperature of 875°F consistent with a saturated steam cycle. The LPR design is based on a hot pool temperature of 950°F consistent with the Benson superheated steam cycle. This difference in temperature has no effect on the configuration of the reactor.

- Core Inlet Plenum - The guidelines directed that the core support structure have two inlet plenums, and a method of changing the flow split between the blanket and fuel regions of the core. Conceptual designs of various two plena configurations and methods of adjusting the flow split have been defined, and are addressed in Appendix P. Although these concepts show that the use of a two plena core inlet is mechanically possible, the reference design shows only a single plenum. It is felt that effort should be placed on core design development and the questions of exit temperature difference amelioration before adopting the complications involved with two plena inlet designs.

- Vessel Temperature Control - The guidelines state that provisions should be made to allow the plant operator to control the vessel wall temperature within prescribed limits. The LPR approach to vessel temperature control uses a passive system including natural convection cooling by the reactor cavity cooling gas. There is nothing to be adjusted, therefore the design is self controlling and requires no attention from plant operators, other than assurance that reactor cavity cooling gas is constantly circulating.

1.2 WORK SCOPE

The scope of reactor design work performed in the period covered by this report was subdivided into four basic sub-tasks: the reactor deck, the reactor vessel, the reactor internals structures, and primary component designs. Building upon the work performed at ARD during the last half of 1977, the conceptual designs of the deck, vessel, and plenum separator system are developed in greater detail to establish reference designs for these components. In addition, the conceptual designs for the upper and lower internals structures, and for the primary pumps, IHXs, and cold traps are defined.

The structural configurations of the deck and rotating plugs are defined. The deck and plug cooling systems, shielding, and reflective insulation are defined. The method of supporting the deck and reactor are presented. The vessel shell and bottom head are defined and sized to accommodate expected seismic loadings. A totally passive method of establishing an acceptable thermal gradient in the vessel shell at its attachment to the deck is defined. The designs of the reactor internals structures including methods of construction, and fabricability considerations are evolved. Limited considerations of equipment maintenance procedures and reactor refueling methods were added to the original work scope to assure proper consideration of these operations in the overall design of the reactor.

1.3 RESULTING REFERENCE DESIGN

The reference reactor design which evolved from this effort is shown in Figure 1-1. It is a functionally integrated design arrangement of the various individual components and systems which are necessary for a pool type LMFBR. The evolution of these separate component designs has required thermal, hydraulic, and structural analyses of specific problems. However, time has not permitted the detailed systems analyses which are necessary to fully characterize the operational behavior of the reactor, and the structural acceptability of the design for all imposed operating conditions. Steady state operating temperatures are, for the most part, based on one dimensional evaluations and only two simple transient conditions have been studied.

As a result, the status of the LPR as of July 31, 1978 is that a reference integrated design configuration exists which requires extensive quantitative systems evaluations and analyses. The reference design includes certain features for which improved configurations have been identified, but have not been incorporated into the design arrangement. This report describes the reference reactor configuration and its basic functional operation. The supporting analyses for this design are presented in the appendices in Volume 3. The preferred alternate configurations are described in Appendix H. The basic characteristics and parameters of the LPR are given in Table 1-1.

LARGE POOL REACTOR

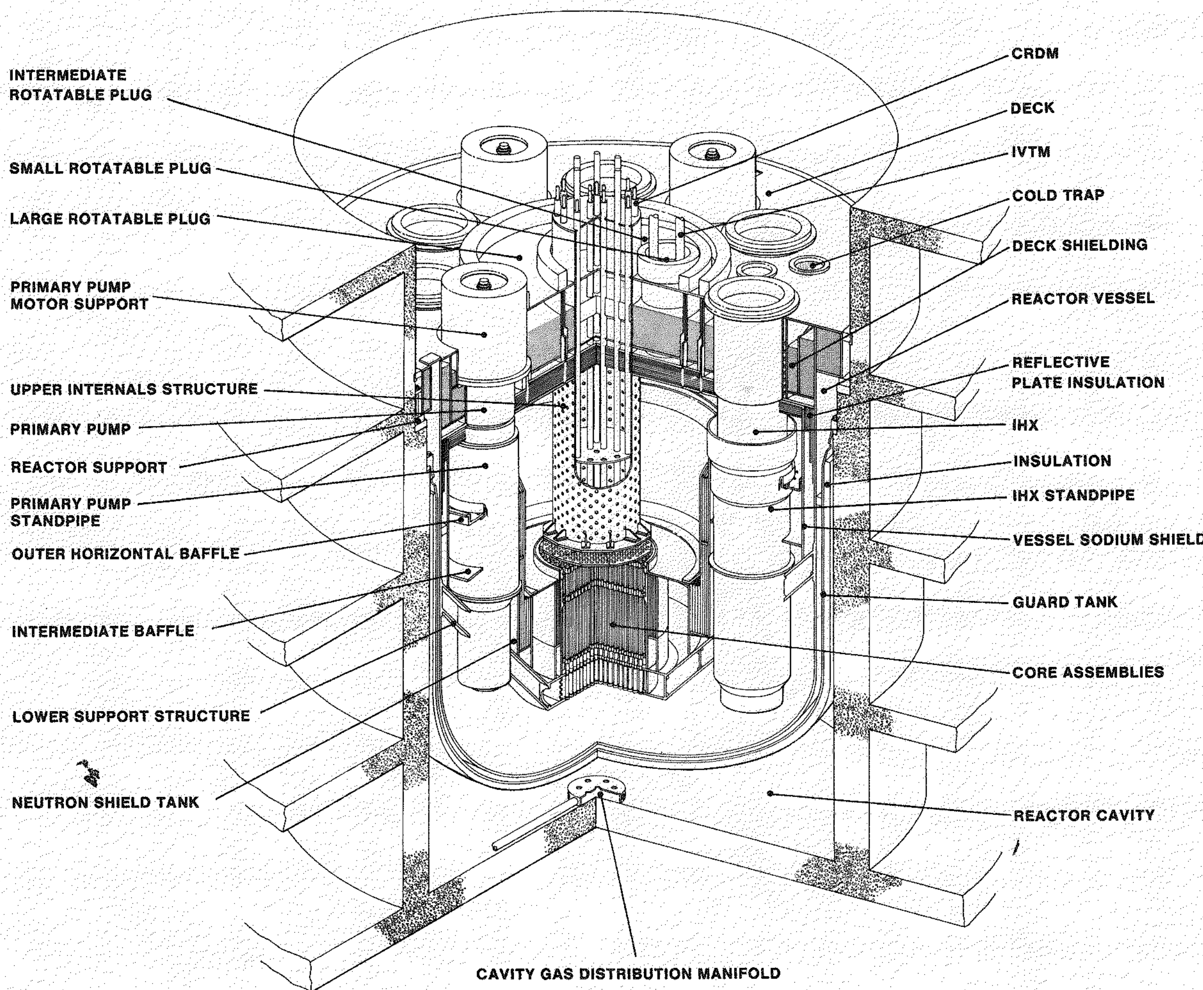


Figure 1-1. Large Pool Reactor

TABLE 1-1

LPR PRINCIPAL CHARACTERISTICS AND PARAMETERS

GENERAL DESIGN PARAMETERS

Plant Rating	1000 MW(e) Gross
Reactor outlet mixed mean design temperature (IHX inlet temperature)	950°F
Reactor ΔT (Core inlet to IHX inlet)	280°F
Steam conditions at turbine throttle	2215 psia, 850°F
Plant calendar life	40 years
Load Factor	80 percent
Core Design	
Core pattern	Bullseye
No. of fuel assemblies	360
No. of blanket assemblies	307
No. of radial shield assemblies	180
No. of control assemblies	24
Total removable core assemblies	871
Core barrel outside diameter	217.25 in.
Fuel assembly zone envelope dia.	153.10 in.
Core assembly, across flats	5.75 in.
Core assembly, length	181 in.
No. of rings of assemblies	18
Inter-assembly gaps	0.295 in.
Fixed shielding inside dia.	193.75 in.
Refueling	
Refueling method	Through fixed roof
Refueling temperature	595°F
Number of rotating plugs	3

TABLE 1-1 (Continued)

GENERAL DESIGN PARAMETERS (Continued)

In-Vessel Transfer Machine (IVTM)	
Type	Straight Pull
Location during reactor operation	In-Vessel
Number of IVTM	2 (1 + Spare)
In-vessel storage capacity	6
Primary Pumps	
No. of primary pumps	4
Pump type	Mechanical two stage, single suction
Pump envelope dia.	104 in.
Max. pump flow rate	26.5×10^6 lb/hr
Pump head	120 psid
Pump isolation	Locked Rotor
IHXs	
No. of IHXs	6
IHX active tube length	300 in.
IHX envelope dia. (at bundle)	122 in.
Primary side pressure drop	8 ft. of Na (3 psi)
IHX isolation	Slide valve at inlet
No. of intermediate loops	6
Cold traps	
No. of cold traps (NaK cooled)	2
Cold trap envelope dia.	60 in.
Location	In-vessel

TABLE 1-1 (Continued)

GENERAL DESIGN PARAMETERS (Continued)

Ex-vessel storage	
Ex-vessel storage mode	Under sodium
Ex-vessel storage capacity	1487 assemblies
N-1 operating capability (1 pump or 1 IHX down)	Yes
IHX to Core Thermal Center Spacing	10 feet
Hot Pool/Cold Pool Separation	Intermediate Sodium Plenum
Normal Operating Volumes	
Volume of Na in Hot Pool	51,856 ft^3
Volume of Na in Cold Pool	60,052 ft^3
Volume of Na in intermediate plenum	52,827 ft^3
Volume of cover gas	20,540 ft^3
Plugging meters	
No. of plugging meters	2
Type of plugging meter	NaK cooled
Plugging meter envelope diameter	24 inches
Location	In-Vessel
Sodium sampling stations	
No. of sodium sampling stations	2
Location	Within deck
Sampling pump	Submerged, Electromagnetic pump
Sampling station envelope size	60" x 60" x 60"
Residual Heat Removal (RHR)	
Number of systems	2
No. of units in each system	6
Location of active system	In intermediate loops
Max. core cladding temperature (with N-1 units operating)	1400^{o}F
Location of passive system	In IHX Shells

TABLE 1-1 (Continued)

GENERAL DESIGN PARAMETERS (Continued)

Flux thimbles	
No. of flux thimbles	8
Maximum Reactor cover gas pressure	5 in water
Flow control to fuel and blanket assemblies	Core assembly orifices
Control Rod Systems	2 Redundant systems (one system to be self-actuating)
Representative weights (estimated)	
IHX (each)	245 tons
Primary pump (each)	180 tons
UIS	75 tons
Mechanisms (total of 24)	33 tons
Vessel	720 tons
Lower support structure	700 tons
Core basket and fuel	750 tons
Neutron shield	600 tons
Plenum separator system components	560 tons
Mis. thimbles and refueling structures	150 tons
Sodium @ 600^{o}F	5000 tons
Deck and plugs	1550 tons
Deck shielding	2030 tons

REACTOR VESSEL

Type	Cylindrical with torospherical bottom
Vessel support	From deck
Vessel internal diameter	75 feet
Nominal operating temperature	670^{o}F
Maximum temperature (steady state)	790^{o}F

TABLE 1-1 (Continued)

DECK STRUCTURE	
Type of structure	Cold deck, radial beam with stressed skin
Deck support	From building structure
Cover gas retention barrier	Bottom plate
Type of insulation	Reflective plates
Type of shielding	Iron oxide pellets
Shielding thickness	6.5 feet
Method of cooling	Forced air circulation
Air flow rate	100,000 scfm
Provision for component replacement	Inerted cask with floor valve
Rotatable plugs	
No. of rotatable plugs	3
Large plug diameter	36 ft 8 in
Intermediate plug diameter	23 ft 8 in
Small plug diameter	7 ft 6 in
Components to be located, and/or supported by the deck	UIS Rotatable plugs Primary pumps IHXs Vessel Control rods Instrumentation Fuel transfer chute Cold traps

TABLE 1-1 (Continued)

DECK STRUCTURE (Continued)

Other penetrations to be provided:	
Flux thimbles	8
Sodium fill pipes (3 in.)	1
Cover gas pipes (3 in.)	8
Sodium level probes (6 in.)	5
Sodium sampling stations & plugging meters	4
IVTM nozzles (in small plug)	2
Maintenance port (in inter. plug)	1
Max. temperature of exposed surfaces of deck and deck-mounted equipment (for hands on maintenance)	$120^{o}F$
Nuclear radiation levels above roof (steady-state operation)	25 mr/hr

SECTION 2.0
REFERENCE REACTOR DESCRIPTION

2.1 GENERAL ARRANGEMENT

The Westinghouse Large Pool Reactor (LPR) shown in Figure 2-1 is a hot pool type LMFBR. The cylindrical reactor vessel is 75 ft in diameter with a torispherical bottom head, and is supported from a cold structural deck. The deck is 13-1/4 ft deep and supports six intermediate heat exchangers (IHX), four modular primary pumps, two in-pool cold traps, three rotatable plugs, and other auxiliary reactor equipment. The deck is simply supported from its periphery and uses radial keys to transmit lateral seismic forces back to the reactor building. The vessel is suspended within a guard tank which is independently supported from the wall of the reactor cavity. The guard tank is externally insulated, and the reactor cavity, between the guard tank insulation and the concrete walls, is cooled by the circulation of nitrogen gas. The cavity cooling gas also cools the top of the reactor vessel and aids in establishing an acceptable thermal gradient where the hot vessel is joined to the cold deck.

The only structural attachment to the reactor vessel is the double cone lower support structure (LSS) which is welded to the lower cylindrical wall of the vessel. The LSS supports the weight of the nuclear core, the neutron shield, the in-vessel fuel transfer station, and the plenum separator system components. It also provides lateral support to the bottoms of the IHXs and pumps. The bottom cone of this structure serves as a pressure boundary between the cold sodium pool below it, and the intermediate and hot sodium pools above the structure. The pressure differential across the cone is about 3 psi, and represents the pressure drop through the IHX tube bundles. The LSS also contains eight integral flow passages which interconnect the four primary pumps with the core, thus avoiding the need for any separate high pressure piping within the vessel.

No specific design effort has been expended on core design or fuel assembly design. A "bullseye" heterogeneous core arrangement was defined by the EPRI guidelines, and was used to size the core barrel and the upper internals structure. Similarly, no effort was spent on reactivity control system design, since standard existing designs should be applicable to any pool type LMFBR.

A unique feature of the LPR is the plenum separator system used to contain the various sodium regions within the pool, and to protect the vessel, IHXs, pumps, and major structures from high temperatures or thermal transients. Since the inception of LPR, the design has used an intermediate volume of sodium to effectively separate the hot and cold plena. The intermediate sodium plenum is established by the use of horizontal baffles and the neutron shield tank in a manner which promotes thermal stratification of the sodium between the hot and cold pools. In this way, the 280^{o}F steady state temperature difference between the pools is dissipated in the intermediate sodium rather than across a basic structural member. The neutron shield tank provides an annular plenum to radially separate the hot plenum from the intermediate plenum.

A basic component of the plenum separator system is the sodium shield; a cylindrical shell which extends from the LSS to within six inches of the bottom of the deck. This shield prevents sodium from contacting the vessel wall above the LSS, and thus, establishes a cover gas annulus between itself and the vessel. Reflective plate insulation is used within the upper part of this annulus adjacent to the deck structure to passively control the axial thermal gradient in the vessel shell. A total of eleven concentric plates of three different lengths are used to tailor the gradient to an acceptable shape.

The plenum separator system also uses standpipes to separate the primary pump from the hot plenum sodium, and the IHXs from the cold and intermediate sodium. These standpipes extend from the LSS through the various sodium plena. The pump standpipe extends above the hot pool free surface to exclude the inflow of hot sodium. The IHX standpipes terminate 2 ft 7 in

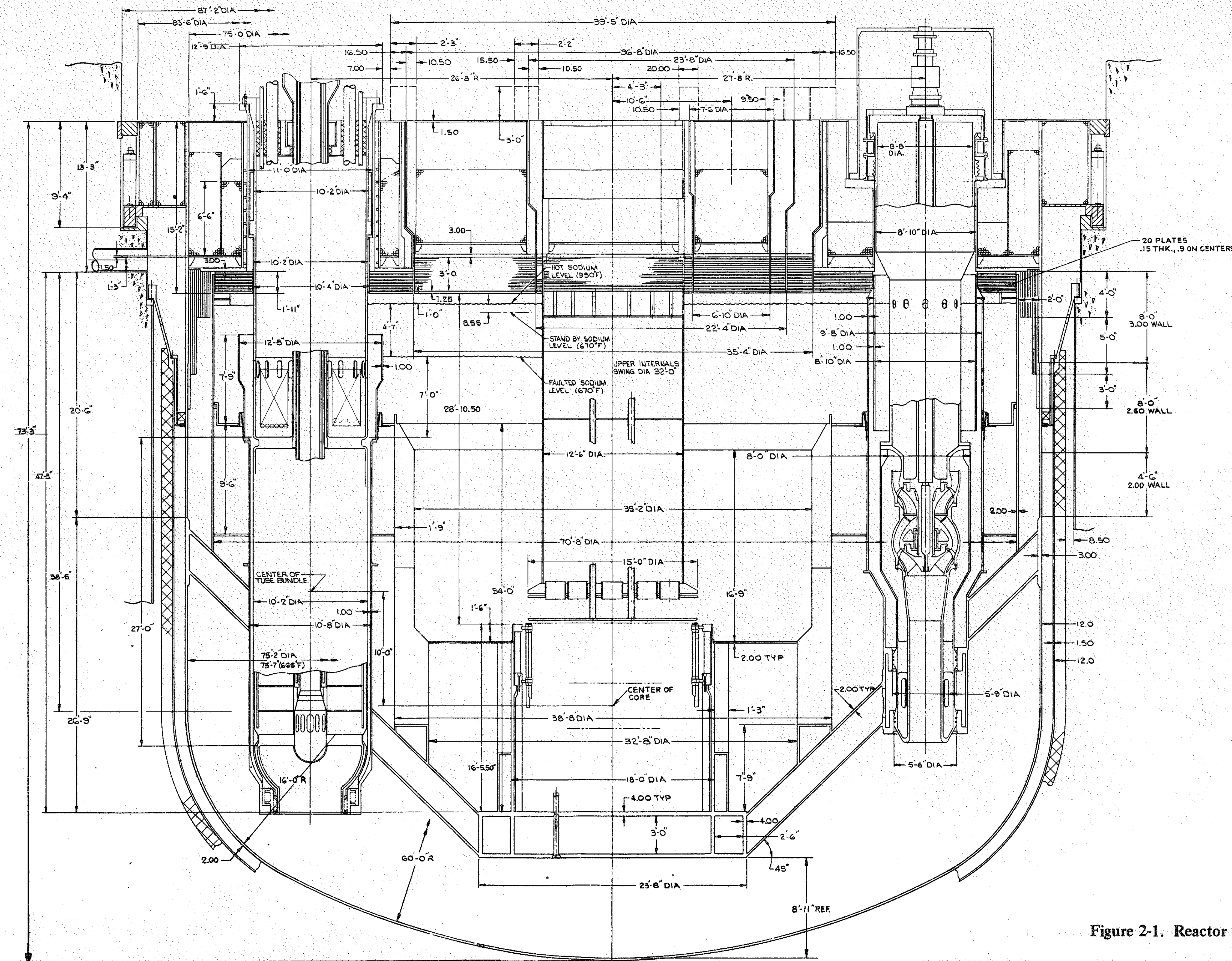


Figure 2-1. Reactor Longitudinal Section

below the maximum sodium level to permit a high level exit of sodium from the hot plenum as it flows into the IHXs. This high exit assures maximum displacement of the hot sodium from the reactor by cold sodium in the shortest possible time following a reactor scram.

Within the center of the hot pool is the upper internals structure (UIS). This structure serves to position the control rod guide tubes with respect to the core. It further provides secondary hold down to all fuel and blanket assemblies and supports thermocouple instrumentation over every assembly. The UIS is designed to permit maximum replacement of components without removal of the entire structure. In addition, the reactor plant design provides for possible replacement of the entire UIS. The UIS is rigidly attached to the intermediate plug in the deck and is not keyed to the core.

The six IHXs are equally spaced within the reactor and include heat removal coils for the passive residual heat removal (RHR-P) system. Each IHX is nominally 10 ft in diameter with a 25 ft active tube length. The IHXs are positioned axially to locate their thermal centers 10 ft above the thermal center of the core. This spacing promotes natural circulation of the sodium during complete loss of pumped circulation.

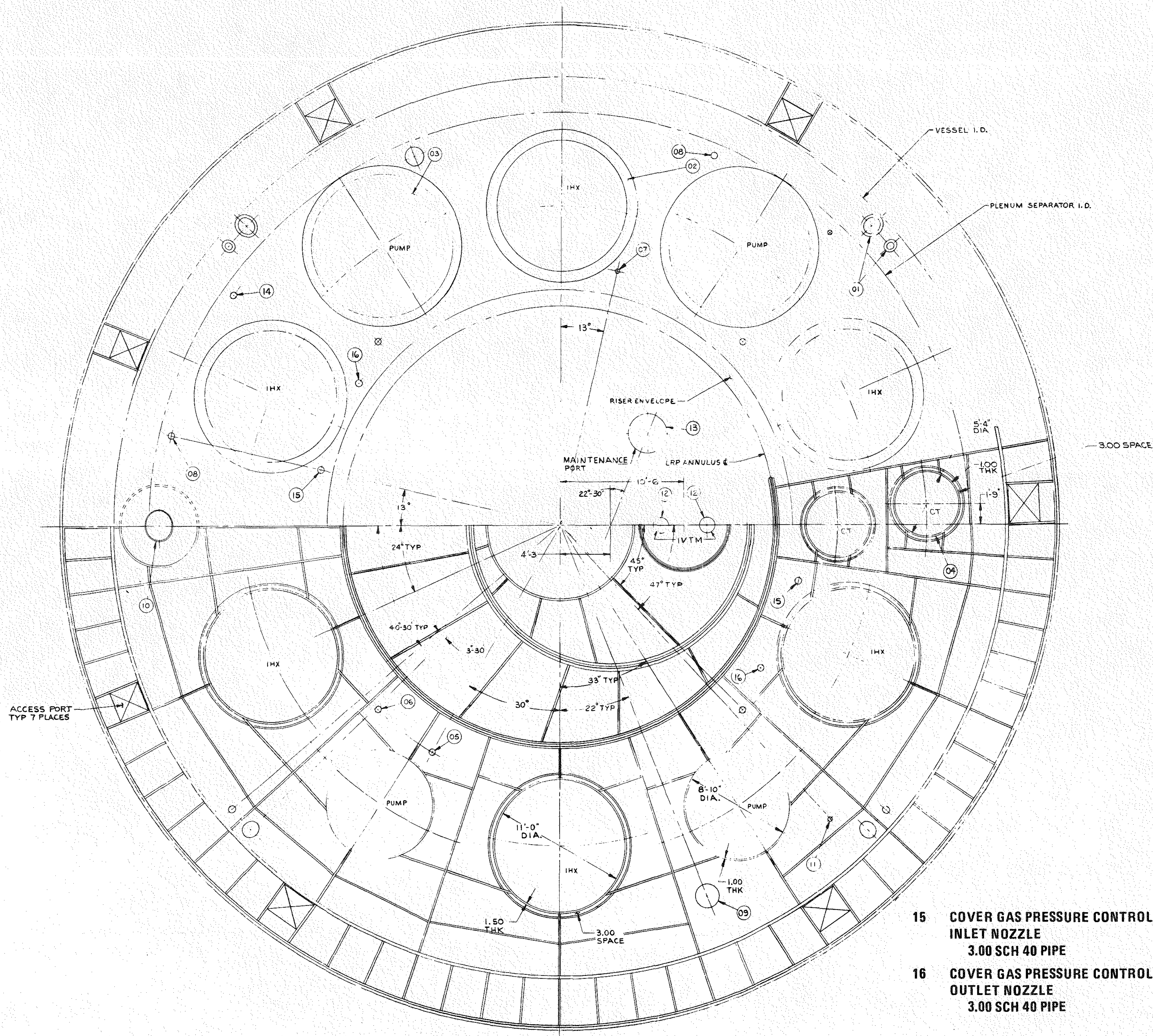
Primary sodium is on the tube side of the IHX bundle to obtain a lower pressure drop and more uniform flow distribution. Sodium from the hot pool enters each IHX through multiple holes in the shell above the RHR coils. It flows downward around the coils and flows through the tubes transfering heat to the secondary sodium on the shell side of the IHX. Cold sodium discharges from the bottoms of the tubes and enters the cold sodium plenum.

A sliding cylindrical valve is provided at the inlets to the IHX to manually isolate each IHX from the primary flow. In this way, any secondary loop can be isolated so that reactor operation can continue on an N-1 basis.

Each of the four primary pumps has a design flow rate of 26.5×10^6 lbs/hr. The two stage pumps are of modular design with concentric inlet and outlet chambers. These pumps plug into the LSS such that sodium is drawn from the cold plenum, and discharged into the integral flow distribution passages in the LSS at a pressure of about 120 psi. The sodium then passes through the core and is discharged into the hot plenum. The pumps do not have separate shut-off valves; however, the reactor can be operated with one pump stopped. In this case, the pump shaft is locked against reverse rotation, and the high reverse flow resistance of the impeller limits the reverse flow to an acceptable value.

The four pumps are symmetrically located between IHXs as shown in Figure 2-2. At one end of the primary axis of symmetry there are two in-pool cold traps. At the opposite end is the fuel transfer nozzle. All of these major reactor components are supported and positioned by the fixed structure of the reactor deck. The deck is basically a structural weldment with radial beams and stressed top and bottom plates. An open air cooling system is built into the deck to maintain the bottom plate at a temperature below 150^{o}F. This cooling system draws air from reactor containment, passes it through flow passages directly above the bottom plate, and discharges the heated air back into containment. The heat load from the deck is removed by separate chillers or by the containment air conditioning system. A series of 20 reflective plates are suspended below the deck to reduce the heat flux to the cooling system from the hot sodium pool. The deck also contains 78 in of shielding in the form of iron-oxide pellets. This shielding reduces the general radiation level above the deck to less than 25 mr/hr during steady state operations. It can also be removed to facilitate examination of the deck primary boundary as required.

The deck plan is shown in Figure 2-2, and has three rotatable plugs to accomodate refueling without incurring any possible interferences with reactor internal structures. The structural design of each plug is similar to that of the fixed deck. Each plug is actively cooled with self contained cooling systems. The numerous equipment penetrations in the plugs increase the conductive heat flux to the plugs. To compensate for this, a larger number of reflective insulation plates are used below the plugs as compared to that used for the fixed deck.



15 COVER GAS PRESSURE CONTROL SYS. INLET NOZZLE 2 REQD
3.00 SCH 40 PIPE

16 COVER GAS PRESSURE CONTROL SYS. OUTLET NOZZLE 2 REQD
3.00 SCH 40 PIPE

01 LOW LEVEL FLUX MONITOR
FLG DIA 11.00, TUBE DIA 6.00 4 REQD
FLG DIA 21.00, TUBE DIA 15.00 4 REQD

02 IHX 6 REQD
FLG DIA 12' - 9" (6.00 FLG)
HOLE IN ROOF, 11' - 0" DIA
RING O.D. 12' - 0"
IHX RAD 26' - 8"
IHX DIA 10' - 2"

03 PUMP 4 REQD
FLG DIA 13' - 3"
HOLE IN ROOF 8' - 10" DIA
PUMP RAD 27' - 8"
PUMP DIA 8' - 0"

04 COLD TRAP 2 REQD
FLG DIA 6' - 0"
HOLE IN ROOF 5' - 4" DIA
RING O.D. 5' - 8" DIA
COLD TRAP RAD. 23' - 6" – 31' - 0"

05 FILL LIQUID LEVEL MONITOR 1 REQD
6.00 PIPE
MONITOR RAD. 21' - 9"

06 PLANT PROTECTION SYS LIQUID LEVEL MONITOR 4 REQD
6.00 PIPE
SYS RAD. 21' - 9"

07 SODIUM FILL NOZZLE 1 REQD
3.00 SCH 40 PIPE
NOZZLE RAD. 21' - 9"

08 FAULTED LEVEL COVER GAS MAKEUP
3.00 SCH 40 PIPE 2 REQD
INLET RAD. 33' - 6"

09 SODIUM SAMPLING STATION 2 REQD
FLG DIA 2' - 0"
STATION RAD. 33' - 3"

10 FUEL, TRANSFER TUBE 1 REQD
2' - 8" PIPE
TUBE RAD. 34' - 8"

11 COVER GAS TREATMENT OUTLET NOZZLE
3.00 SCH 40 1 REQD
OUTLET RAD. 33' - 6"

12 IVTM 2 REQD
FLG DIA 2' - 3"
HOLE IN ROOF 1' - 3"
IVTM RAD. 4' - 11" WITH RESPECT TO SMALL ROTATING PLUG

13 MAINTENANCE PORT
FLG DIA 3' - 2"
PORT RAD. 8' - 3"

14 COVER GAS TREATMENT INLET NOZZLE
3.00 SCH 40 PIPE 1 REQD
INLET RAD. 33' - 6"

Figure 2-2. Plan View of Reactor Deck

2.2 NORMAL OPERATING CONDITIONS

The Westinghouse LPR design has essentially three distinct sodium plena: the hot pool which exists above the nuclear core, the cold pool which exists below the lower support structure, and the intermediate pool which separates the other two. Only the hot pool has a free sodium surface which is in contact with the cover gas. This arrangement was selected to prevent fluctuations in the hot and cold sodium levels when the primary pumps are turned on and off. The only change in sodium level occurs in the hot pool due to thermal expansion and contraction of the sodium, and this range of level change is less than one foot. At hot standby conditions, the total sodium volume of 165,000 ft^3 is at a design temperature of 670^{o}F*, and the sodium level is about 44 in below the bottom of the deck. When the reactor is brought to full power, the sodium in the hot plenum rises to within 35 in of the bottom of the deck.

The hot plenum, during normal reactor operations, is very turbulent and well mixed with a mean structural design temperature of 950^{o}F*. When the reactor is tripped, a number of different operating strategies are possible. A typical one is for the pumps to slow to pony motor speed. In this event, the mixing diminishes and stratification occurs with cold sodium entering the bottom of the plenum and displacing hot sodium out through the IHX inlets. This displacement action continues until the cold-to-hot interface rises to the tops of the IHX standpipes. At this level, the cold sodium can enter the IHX directly, thus the remaining volume of hot sodium above the inlet ports is removed only by entrainment. The pressure in the hot plenum is always equal to the cover gas pressure of about four inches of water, plus the static head of sodium.

The cold plenum during normal reactor operations is also very turbulent and well mixed with a mean temperature of 670^{o}F. The cold plenum acts to mix the discharges from the six IHXs and serves as a supply reservoir to feed the four main coolant pumps. When the reactor is tripped, the primary and

*Structural design temperatures used herein are higher than actual T/H design values.

secondary sodium systems continue to circulate and remove heat from the hot pool sodium as it passes through the IHX. The temperature of the cold plenum nominally will decrease; however, the amount of decrease is a function of the flow control provided by the primary and secondary pumps during coast down and standby operations, and the inlet temperature of the secondary sodium. The pressure in the cold plenum is equal to the pressure in the hot and intermediate plena including the static head, less 3 psi which represents the pressure drop through the primary side of the IHXs.

The intermediate plenum consists of that sodium which separates the hot and cold plena. This sodium is contained within two enclosed cells so that stratification of the sodium in each cell occurs and serves as a natural thermal separator of the hot and cold plena. The sodium temperature at the top of each cell nearly equals the 950^{o}F hot pool temperature during normal reactor operations, due to conduction across the horizontal baffles. The sodium temperature at the bottom of each cell is close to the 670^{o}F cold pool temperature. However, the radial boundaries of the intermediate plenum cells have differing thermal boundary conditions which give rise to thermal currents within each cell. There is no forced flow into or out of the intermediate plenum, thus the only circulation which occurs is that due to thermal gradients. The pressure in the intermediate plenum is the same as that of the hot plenum plus the static head.

During normal steady state conditions there is no forced circulation of sodium in the intermediate plenum. Low velocity thermal currents are present; however, there is no interchange of sodium between the intermediate and hot plena. During initial heat up, the intermediate sodium average temperature increases resulting in an expansion of the contained sodium. That sodium directly below the horizontal baffle is displaced into the hot plenum. Similarly, when the intermediate plenum sodium cools and contracts, sodium from the hot plenum is drawn into the intermediate plenum. No other mass transfers of sodium are expected to occur within the reactor.

2.2.1 FLOW PATH

The sodium flow path through the reactor during normal operations is shown in Figure 2-3. Sodium is drawn from the cold plenum into each pump inlet at a rate of 26.5 x 10^6 lbs/hr, passes through the two stage impellers where the pressure is increased by about 120 psi, and discharged to the lower pump housing. About 1.7 x 10^5 lbs/hr flow through the hydrostatic bearing for the pump shaft, and enter the upper pump housing. The main flow stream passes downward in the lower pump housing and discharges into the high pressure chamber of the pump receptacle at the bottom of the pump standpipe. The pump has two piston ring seals which close off the high pressure chamber from the cold sodium plenum at the bottom, and from the pump standpipe annulus at the top. The leakage at each seal is expected to be less than 2.5 x 10^3 lbs/hr. The sodium passes from each high pressure chamber to two flow ducts within the LSS, and the eight ducts empty into the annular flow dstribution chamber of the core support structure.

The leakage flows at the pump bearing and upper piston ring seal flow through the pump standpipe and exit into the hot pool. The flow rates are sufficiently low to permit the sodium temperature to increase to near the hot pool temperature before it leaves the standpipe.

The total flow from all four pumps is combined and distributed to the core assemblies by a system of orifices built into the core support structure. The core assemblies also have orifices to further tailor the flow distribution as a function of power output during life. As the sodium passes through the core, it is increased in temperature to a mixed mean average of 950^oF. It discharges from the tops of the core assemblies at various velocities and temperatures but at a pressure equal only to the static head of sodium above the core. The individual assembly discharges pass through the secondary holddown plate of the upper internals structure (UIS), past thermocouples which measure the individual discharge temperatures, and then into the hot pool. The major portion of the flow enters the hot plenum in the first four feet of the UIS length. The balance of the flow passes into the UIS and enters the hot plenum through holes distributed along the length of the UIS barrel.

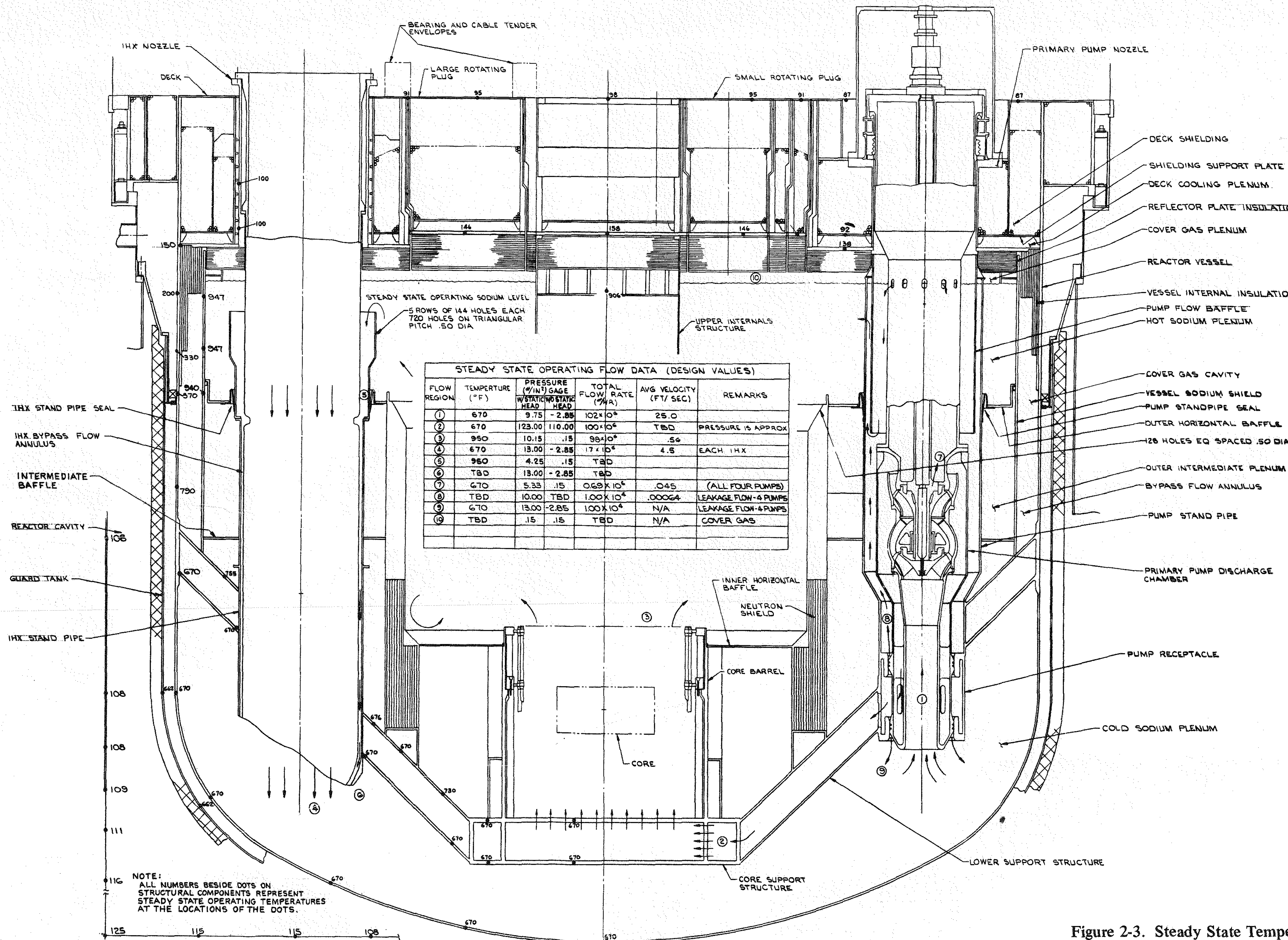
The sodium in the hot plenum is highly turbulent and well mixed by the time it reaches the top of the hot plenum. The sodium enters the tops of the IHX standpipes at a velocity of about 2 ft/sec. A small amount, estimated to be 3×10^3 lbs/hr, passes between the standpipe and the IHX and flows directly into the cold plenum. The driving force for this leakage is the 3 psi pressure drop which exists between the hot and cold plena. This leakage is limited by a bellows face seal at the bottom of each IHX, which mates with a ledge at the bottom of the IHX standpipe. The balance of the sodium enters the IHXs through numerous holes in the IHX shell above the upper tube sheet. It flows past the RHR coils, through the tube bundle where it gives up its heat to the secondary sodium, and into the cold plenum.

Although not shown in the LPR design, the bottom of each IHX standpipe has a nozzle or diffuser to direct the discharge sodium preferentially into the cold pool. The preferred configuration of this diffuser is the subject of an ongoing model flow test of the cold sodium plenum.

2.2.2 NORMAL TEMPERATURES

Design development of the LPR has not progressed to the point where structural thermal transient analyses have been conducted. Only steady state, average temperatures can be defined at this time; however, system transient analysis is in process and some limited qualitative thermal behavior can be addressed.

With the reactor shutdown, the hot standby average temperature of the sodium is 670°F. As the reactor is taken to power, the hot pool average temperature increases to 950°F and the cold pool temperature remains at 670°F. Heat transfers radially through the neutron shield tank and heats the intermediate sodium. Thermal conduction also occurs across the horizontal baffle and develops an upper layer of sodium whose temperature is close to that of the hot pool. Similarly, the LSS is the top boundary of the cold plenum and the bottom boundary of the intermediate plenum. Thus it maintains a heat sink temperature of about 670°F at the bottoms of the intermediate plenum cells. During steady state operation, stratification of



STEADY STATE OPERATING FLOW DATA (DESIGN VALUES)

FLOW REGION	TEMPERTURE (°F)	PRESSURE (#/IN²) GAGE W/STATIC HEAD	PRESSURE (#/IN²) GAGE W/O STATIC HEAD	TOTAL FLOW RATE (#/HR)	AVG VELOCITY (FT/SEC)	REMARKS
1	670	9.75	-2.85	102×10^6	25.0	
2	670	123.00	110.00	100×10^6	TBD	PRESSURE IS APPROX
3	950	10.15	.15	98×10^6	.56	
4	670	13.00	-2.85	17×10^6	4.5	EACH IHX
5	950	4.25	.15	TBD		
6	TBD	13.00	-2.85	TBD		
7	670	5.33	.15	0.69×10^6	.045	(ALL FOUR PUMPS)
8	TBD	10.00	TBD	1.00×10^4	.00064	LEAKAGE FLOW-4 PUMPS
9	670	13.00	-2.85	1.00×10^4	N/A	LEAKAGE FLOW-4 PUMPS
10	TBD	.15	.15	TBD	N/A	COVER GAS

Figure 2-3. Steady State Temperature Data

the sodium exists with some thermal convection mixing, resulting in a skewed cosine temperature distribution through the depth of the intermediate plenum. The average sodium temperature is higher than would be expected if a linear gradient existed.

Just above the hot plenum sodium, the cover gas has a temperature of about 935^{o}F. The deck and plug reflective insulation plates result in a reduction in cover gas temperature through the gas plenum down to about 200^{o}F directly beneath the deck bottom plate. The air cooling system of the deck reduces the bottom plate average temperature to 150^{o}F or less, and the shielding support plate temperature to about 100^{o}F. The axial thermal gradient through the shielding to the top plate of the deck is less than 10^{o}F.

The reactor vessel temperature below the LSS attachment is uniformly 670^{o}F. Above the LSS, the vessel is in contact with cover gas and is insulated from the hot pool by concentric reflector shields. Directly above the LSS the vessel wall is heated by the sodium in the intermediate plenum to a maximum temperature of about 790^{o}F. From this location to about two feet below the deck, the vessel wall has an essentially linear temperature gradient down to 150^{o}F.

When the reactor is tripped, it is assumed that the primary and secondary pumps are also tripped and coast down to pony motor speed. (Other options for pump control are under consideration and are described in Appendix E. This assumed method of operation is used only to indicate, in general, how the pool temperatures change during a transient.) With a pump coastdown time of 30 seconds, the volume of cold sodium which flows into the hot plenum during coastdown is about 50,000 gallons. The turbulence associated with pump coastdown should result in generalized mixing which lowers the hot pool mixed mean temperature by only about 30^{o}F. Under pony motor flow, the hot plenum sodium stratifies with cold sodium remaining at the bottom of the plenum and slowly displacing the hot sodium through the IHXs. The hot-to-cold sodium interface advances upward through the plenum and cools the inner shell of the neutron shield tank and the sodium shield above the outer horizontal baffle. The resulting changes in structural temperatures are relatively slow and are not expected to generate unacceptable thermal stresses. However, the bottom of the UIS, being directly above the core, does experience a sudden reduction in temperature following a reactor trip. This is a concern and is the subject of ongoing analyses.

2.3 DESCRIPTION

2.3.1 REACTOR VESSEL

2.3.1.1 FUNCTION

The function of the reactor vessel is to contain the reactor and its sodium and cover gas environment. The vessel of a pool type LMFBR is not truly a pressure vessel but a containment boundary which is subjected to a low cover gas pressure. For the LPR, the cover gas design pressure is 5 psig, and the steady state operating pressure is only 0.15 psig (four inches of water). The vessel does contain the liquid sodium to a depth of 70 ft 6 in, thus a hydrostatic pressure of about 26 psi exists at the bottom of the vessel. This hydrostatic pressure is a mechanical load on the vessel and is not to be confused with the pressure loads normally imposed on vessels.

LMFBR vessels are not directly addressed by the 1977 edition of the ASME Boiler and Pressure Vessel Code; however, the design of the reactor vessel is in accordance with the intent of the Code; and the design follows the applicable rules established by the Code.

2.3.1.2 DESCRIPTION

The reactor vessel is a cylindrical shell with a torispherical bottom head. It is supported from a structural deck which also serves as the top closure of the primary sodium containment boundary. The shell and bottom head are fabricated from stainless steel and the structural deck is fabricated from carbon steel. The vessel is attached to the deck with a bimetalic weld.

The top of the shell course has an internal diameter of 75 ft 0 in and a wall thickness of three inches for the first eight feet of length. The wall is reduced to a 2.5 in thickness for the second eight feet of length, and the balance of the shell and bottom head has a two inch wall thickness with one inch of added reinforcement where the reactor lower support structure (LSS) is attached. The bottom head has a 60 ft spherical radius and a knuckle radius of 16 ft. The overall internal depth of the vessel is 73 ft 3 in.

The vessel shell has no penetrations, and the only structural attachment to the vessel is the double cone lower support structure. Each cone is two inches thick and is attached to the vessel wall at a 45 degree angle using full penetration welds. In the circumferential band containing the attachment welds, the vessel shell is reinforced to a thickness of three inches. The actual attachment welds are made after the vessel is installed in the reactor cavity. Weld buildups are provided on the internal surface of the vessel to mate with each cone, thus the attachment welds are butt welds which can be radiographed to assure conformance to high quality.

That portion of the vessel above the upper cone of the LSS is exposed only to reactor cover gas. That portion of the vessel below the upper cone is exposed only to the cold sodium pool. The outside surface of the vessel is exposed to a nitrogen atmosphere. Representative steady state temperatures for the vessel are shown in Figure 2-3.

The major area of interest in the design of the vessel is the upper section of the cylindrical shell. The maximum steady state operating temperature of the vessel is about 800^{o}F thirteen feet below the bottom of the deck. The deck bottom plate to which the vessel is attached operates at about 150^{o}F. The method of controlling the transition from 800^{o}F to 150^{o}F along the vessel wall is one of the fundamental problems associated with pool type LMFBRs having a cold deck. In the LPR, an essentially linear gradient is obtained over a length of 11 ft with a two foot isothermal zone directly adjacent to the deck. This gradient is obtained passively by the use of vertical thermal reflector plates in the cover gas annulus which exists between the vessel wall and the sodium shield, and the use of the reactor cavity cooling gas as a natural convective heat sink. The vessel insulation is discussed in 2.3.1.4.

2.3.1.3 METHOD OF SUPPORT

The reactor vessel and its contents, excluding those components which are separately supported from the deck (i.e. IHXs, pumps, UIS, etc.), are supported from the deck structure through a full penetration bimetallic weld. This weld is located 7 in below the bottom of the deck and thus is within the 2 ft isothermal zone of the vessel thermal gradient. A stainless steel safe end is provided on the carbon steel shell which forms the vessel extension through the deck. This shell and safe end are 3 in thick to match the vessel thickness. This structure is annealed after depositing the safe end metal, and the weld prep is formed by manual chipping and grinding. The actual welding of the vessel to the safe end is done in the site factory where weld quality and full non-destructive examination can be assured.

During reactor operation, the bimetallic weld is subjected to an environment of dry argon gas on one side and dry nitrogen gas on the other. The normal temperature is 150^{o}F, and the only thermal cycling to be imposed is that associated with off normal operating conditions such as loss of deck cooling capability. The maximum number of such thermal cycles expected is less than 50 and the range of thermal cycling is less than 100^{o}F. Thus the operating conditions imposed on the bimetallic vessel support weld are extremely mild and do not result in any degradation of structural capability of the weld with lifetime.

2.3.1.4 INSULATION

Two different insulation systems are used to control the heat loss from the reactor vessel. The hot portion of the vessel is externally insulated by the guard tank and its insulation. This system is discussed in 2.3.11. The thermal gradient at the top of the vessel is established by internal insulation in the form of vertical reflective plates. These plates are concentric cyclinders, .15 in thick and spaced .75 in apart. The outermost shell is 12 ft long. The next three shells are 9 ft long, and the remaining seven shells are 4 ft long. By staggering the lengths and increasing the number of plates, it is possible to adjust the heat flux to the vessel shell and thus establish an acceptable thermal gradient. This system requires only natural convection cooling of the outside of the vessel wall. As a result, the only variable in the design which could result in a change in the gradient during the life of the reactor is the emissivity value assigned to the reflective plates. The design has been evaluated for the worst possible range of emissivities, and found to be acceptable for all values. (See Appendix C)

The eleven reflective plates are attached to and suspended from the bottom plate of the deck. Because of the logistics of construction, the plates must be installed in the cover gas annulus before the deck structure is welded to the vessel. The plate sections are then raised into position against the deck and welded in place. An access panel is provided in the sodium shield to facilitate final positioning of the reflective plates.

2.3.2 DECK

2.3.2.1 FUNCTION

The function of the deck is to provide a closure to the reactor vessel for containment of the reactor coolant, cover gas, fuel and other radioactive materials; and to prevent entry of air and other materials into the reactor vessel. The deck provides shielding to attenuate radiation from the core, sodium, and cover gas to acceptable levels within the head access area during normal reactor operations and during reactor shutdown. In addition, the deck provides support, containment and alignment for reactor related equipment such as pumps, control rod drive mechanisms and intermediate heat exchangers.

2.3.2.2 DESCRIPTION

The deck system, as shown in Figures 2-1, 2-4 and 2-5, consists of an outer stationary deck structure which supports three centrally located rotatable plugs.

STATIONARY DECK STRUCTURE

The stationary deck is an annular structure with an 87 ft 2 in outside diameter and a 36 ft 8 in inside diameter. The outer most ring girder is the support interface between the deck system and the containment building. The inner cylinder of the outermost ring girder (75 ft 0 in) is the support member for, and an extension of, the reactor vessel.

The annular structure between the vessel shell and the innermost diameter (36 ft 8 in) provides the penetrations for, and the support of, the following major equipment:

Number of Each	Description
1	Plug System
1	Fill Liquid Level Monitor
4	Plant Protection System Liquid Level Monitors
6	Intermediate Heat Exchangers
2	Cold Traps
4	Primary Pumps
4	Low Level Flux Monitor Tubes
4	Power Range Flux Monitor Tubes
1	Sodium Fill Nozzle
1	Cover Gas Treatment Inlet Nozzle
1	Cover Gas Treatment Outlet Nozzle
2	Sodium Purity Monitoring Systems
1	Fuel Transfer Tube
2	Cover Gas Emergency Inlet Nozzles

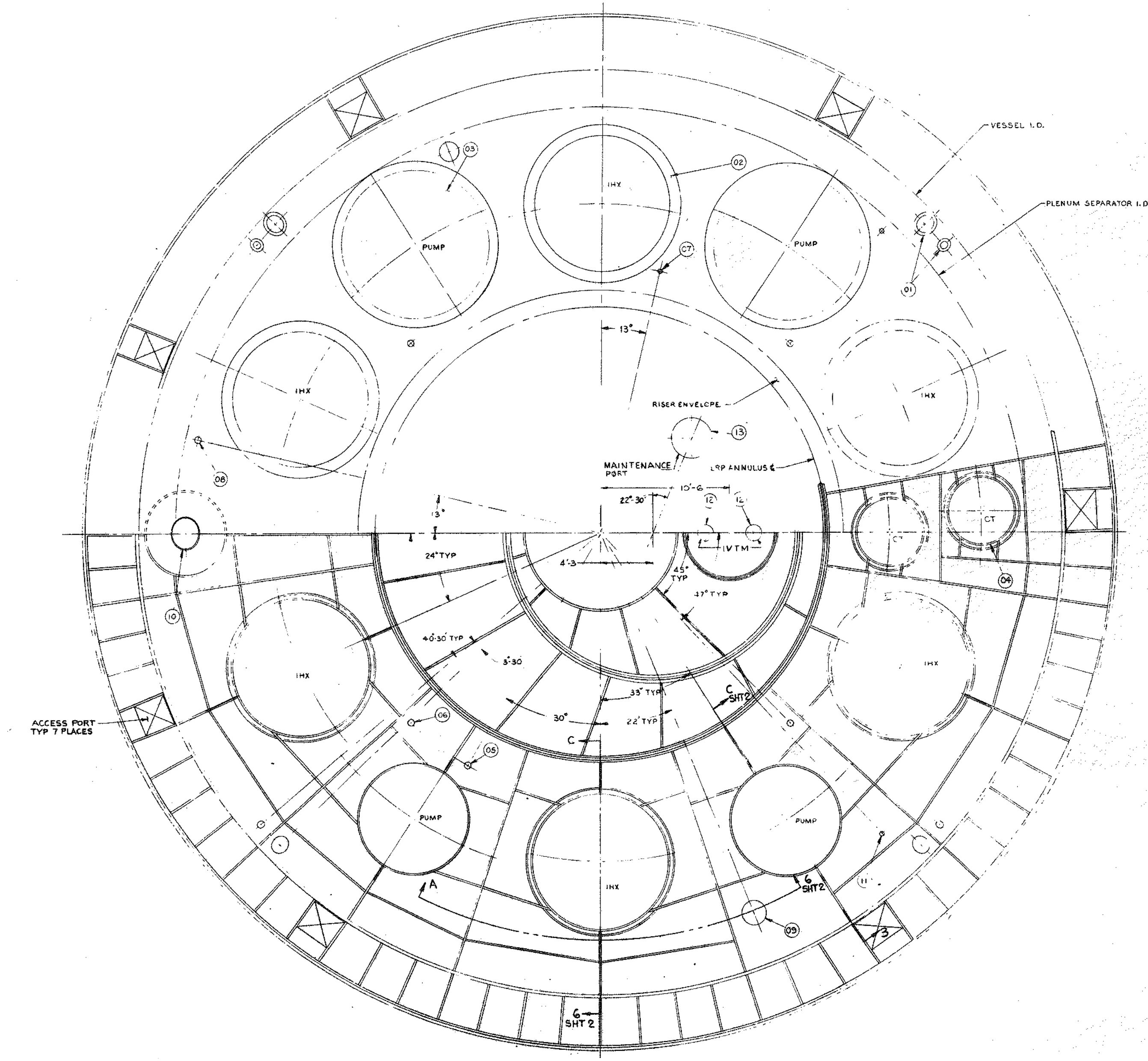
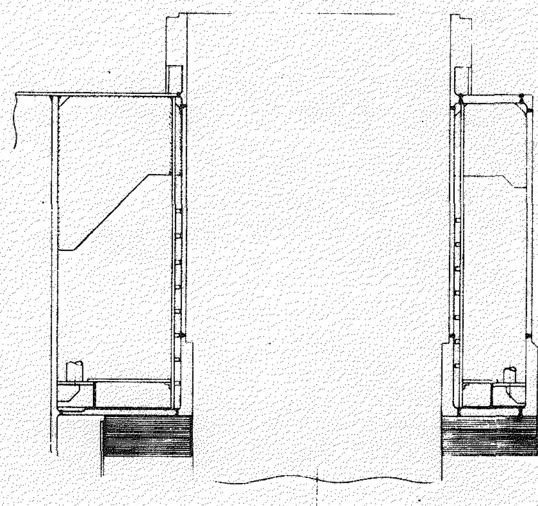
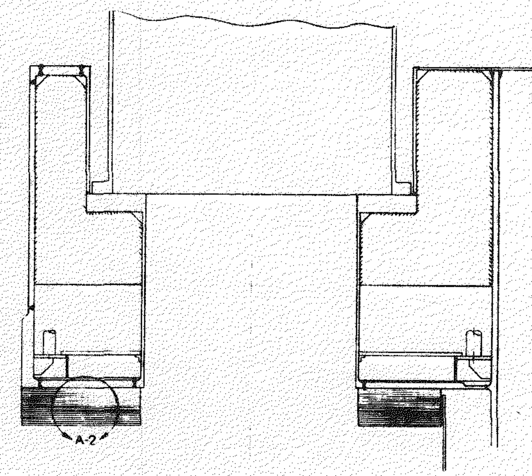


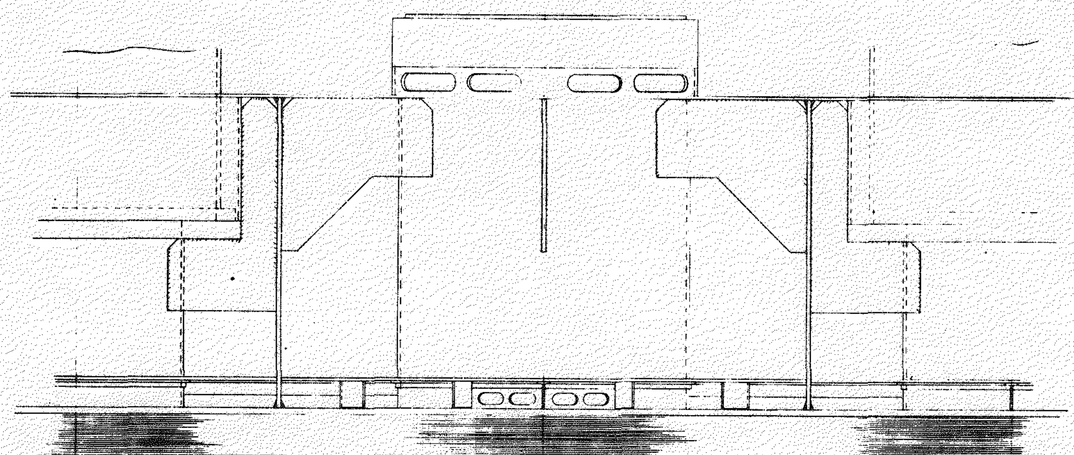
Figure 2-4. Deck Plan



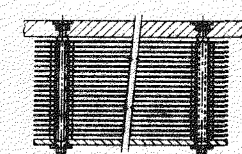
SECTION C-6



SECTION C-3



SECTION A-6



VIEW A-2

Figure 2-5. Deck Details

2	Faulted Level Cover Gas Make-up Lines
2	Cover Gas Pressure Control System Inlet Nozzles
2	Cover Gas Pressure Contol System Outlet Nozzles

The stationary deck structure is divided into twelve compartments. Deck material is structural carbon steel. Radial ribs extend from the innermost circular member of the stationary deck structure to the vessel cylinder, and form the vertical boundary of the twelve compartments. The bottom surface of the stationary deck structure, which forms the primary boundary, and the top surface which forms the working floor of the head access area, act to stabilize the radial ribs, and are major load carrying members of the stationary deck structure. This configuration is a monocoque structure in which the top, bottom and vertical cylindrical surfaces carry a major portion of the static and applied loads. All penetrations are circular in cross section and have approximate symmetry around the stationary deck. The penetrations, along with the deck bottom plate, form the primary boundary. The internal compartments of the deck structure therefore are isolated from and are not part of the primary boundary system. These compartments contain shielding in the form of iron ore pellets to reduce the radiation level on the top deck surface to acceptable levels. Deck shielding is addressed in Section 2.3.2.8.

Figure 2-5 depicts cross sections of the deck structure as specified in Figure 2-4. Sections C-6, and A-6 are taken through the IHX penetration. The inner cylindrical member supports the IHX, which passes through the deck structure and into the vessel. The IHX load is transmitted from the support cylinder to the deck structural members by means of vertical support plates which appear in Views D-6 and D-7 and B-6 and B-7. The IHX support cylinder is surrounded by a coolant plenum through which cooling air passes. The cooling air maintains the temperature of the cylindrical structure by removing heat supplied to it from the IHX. The cooling system is discussed in detail in 2.3.2.6.

The deck bottom plate is thermally protected by twenty thermal reflector plates shown in View A-2, Figure 2-5, which in combination with the cooling system maintain the bottom plate temperature below 150^{o}F during normal reactor operation.

Section C-3 of Figure 2-5 is taken through a coolant pump. The penetration is recessed into the deck structure to reduce the total length of the pump, which in turn reduces the unsupported pump shaft length.

Typical deck plate sizes appears in Table 2-1.

TABLE 2-1

DECK PLATE SIZES

Deck Plate Description	Thickness (inches)
Inner vertical circumferencial plate	2-5/8
Outer vertical circumferencial plate	1-1/2
Vessel wall extension	3
Radial ribs	1-1/2
Outer Diaphragms	5/8
Top and bottom plates (inner annulus)	4-1/4
Top and bottom plates (outer portion)	1-1/2
IHX nozzles	1-1/8
Pump nozzles	7/8
IHX and pump support brackets	1-1/2

The major portion of the stationary deck is fabricated from flat and rolled plate. Machined surfaces are required on the component support nozzles and on the innermost circular ring which interfaces with the rotatable plug system bearing and seals. Machining of these surfaces is performed after fabrication and assembly of the basic deck structure. Fabrication is addressed in Section 4.

2.3.2.3 METHOD OF SUPPORT

The arrangement for supporting the deck is, in reality the arrangement for supporting the total reactor since the deck supports the reactor vessel, rotatable plugs, and all items internal to the reactor vessel. The only exception is the guard tank assembly which is supported independently from the wall of the reactor cavity and not from the deck. This independent support is helpful in minimizing the possibility of common mode failure.

Figure 2-6 shows the conceptual design of the reactor support arrangement. The outer deck structure is made with a thick bottom ring that rests on a thick ledge plate embedded in the concrete structure of the reactor building. Downward loads of 2 g's or less are transmitted through the interface between these two plates. The interface is not machined after fabrication except locally to remove high spots. For good load distribution, shims can be inserted into the interface since the design allows for access from under the deck. Manways are provided at several locations around the periphery of the reactor vessel to serve as access paths. This feature is expected to reduce construction time and facilitate operations during refueling shutdowns. Maintenance and in-service inspectons required in the peripheral region of the reactor can therefore be done expeditiously and with only a minimal use of remote equipment.

The support ledge of the reactor building is located about 56 in above the bottom surface of the main deck structure. This location corresponds approximately with the neutral surface of bending of the main deck and is also above the elevated temperature region of the deck. Radial sliding at the main support interface, which is normally associated with temperature changes and bending in the deck, is therefore essentially eliminated. This is advantageous since it permits the use of either radial keys or large shear pins for transmitting lateral loads of up to 3.5 g's. Any temperature excursion in the deck can be accommodated by the keys.

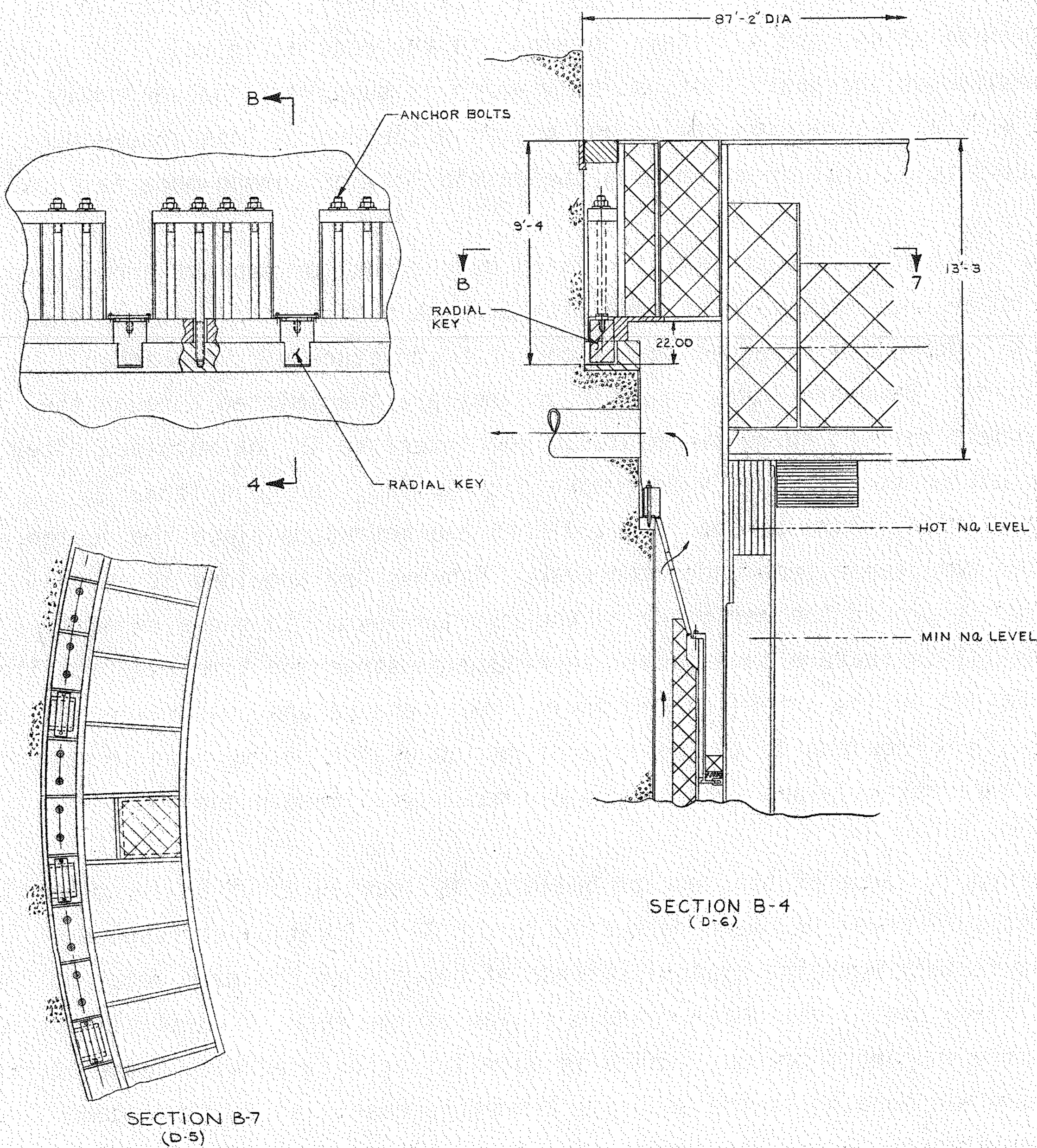


Figure 2-6. Large Pool Reactor Support

The design arrangement permits insertion and fitting of the radial keys after installation of the reactor vessel into the reactor cavity. No machining is required at installation except for the radial keys, which can be removed, machined and replaced individually.

Upward loads of one g or less are transmitted through four inch anchor bolts that are threaded into the ledge plate embedded in the concrete structure of the building. The bolts are made long to improve their energy absorption capability. Bolt inspecton is accomplished from above the deck after removal of the sealing blocks which circumscribe the deck. Embedment of the ledge plate is accomplished after it is positioned horizontally to provide a level surface for supporting the outer deck/reactor vessel weldment.

2.3.2.4 ROTATABLE PLUGS

The LPR has a three plug refueling system as shown in Figure 2-7. The three plug system was chosen over simpler two plug systems because of an interference between the fuel transfer chute and the swing of the upper internals structure. This problem is eliminated with the three plug design, because the third plug allows the fuel transfer station to be located further away from the reactor centerline than was the case for the two plug design. This in turn means that the fuel transfer chute can terminate at a point further away from the reactor centerline, where the interference with the upper internals structure swing does not occur.

The large rotatable plug has a major outside diameter of 36 ft 8 in and serves as the support for the intermediate rotatable plug. The intermediate plug has a major outside diameter of 23 ft 8 in and serves as a support for the upper internals structure, twenty-four control rod drive mechanisms, a maintenance port, core instrumentation bulkheads and the small rotatable plug. The small rotatable plug has a diameter of 7 ft 6 in, and serves as a support for two in-vessel fuel transfer machines.

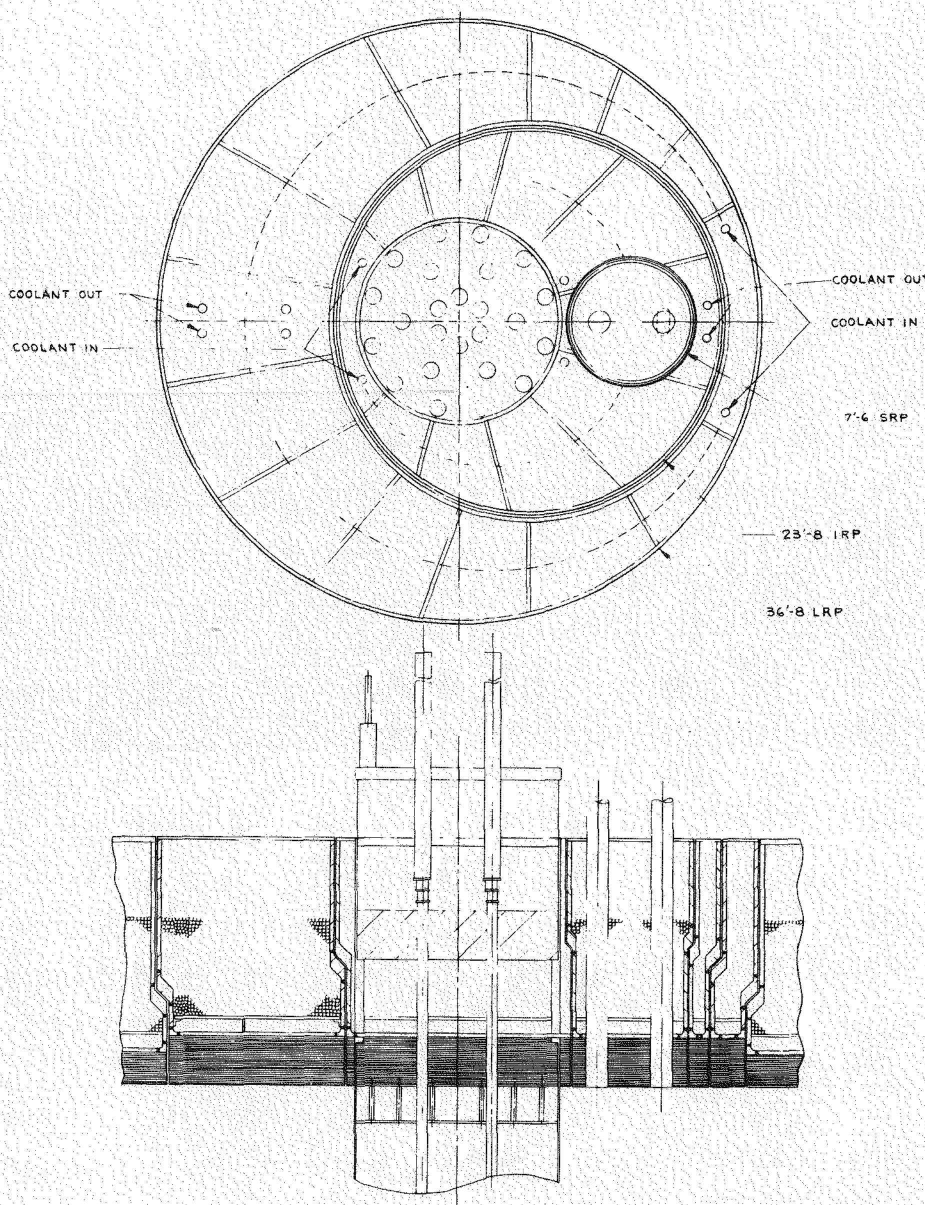


Figure 2-7. Three Rotatable Plug System

The structural configuration of the plugs is similar to that of the stationary deck. Construction is of an open grid work type with the primary boundary being the bottom surface of the plugs. Shielding is in the form of iron ore pellets, and is contained within the structure. The plug primary boundary is inspectable from the outside (top) and is accomplished by removing the shot shielding thus providing access to the primary boundary. The bottom surface of the plugs are thermally protected by thirty reflector plates and a cooling system similar to the system used on the stationary deck. This thermal protection system limits the bottom plate temperature to 150^{o}F. Cooling of the plugs is discussed in 2.3.2.6.

The major portions of the rotatable plugs are fabricated from flat and rolled plate. Machining is required after fabrication on the vertical circular surfaces of the plugs where they interface with each other and with the stationary deck. In addition, plug sealing surfaces and bearing mounting surfaces must also be machined.

2.3.2.5 INSULATION

The deck insulation is made up of a series of horizontal thermal baffle plates suspended from the deck and plug primary boundary plates. The thermal baffles are stainess steel, 0.15 in thick. They are vertically spaced on 0.90 in centers. This spacing is such that convective heat transfer between plates is virtually precluded; the spacing is not conducive to sodium bridging.

Twenty thermal baffle plates are used to insulate the fixed portion of the deck whereas thirty plates are used beneath the rotatable plugs. The twenty plate array reduces the heat flux to the deck to 210 Btu/hr-sq ft, exclusive of the heat flux from penetrations. This can be adequately handled by the active cooling system. The use of thirty plates under the rotatable plugs stems from a need to reduce the severity of the axial thermal gradient on the upper portion of the Upper Internals Structure (UIS) by extending the insulation over a greater length. Although this requirement only applies to the intermediate rotatable plug, a benefit is gained by using thirty plates to insulate all three plugs and the geometry of the deck and plugs is well suited to accommodate the difference in the number of plates used for the deck and the plugs.

Thirty plates reduce the heat flux to the plugs to 160 Btu/hr-sq ft which reduces the air cooling requirement from that of the fixed deck, and, since the plugs are thinner than the fixed portion of the deck, the thirty plates below the plugs do not extend below the line of the twenty plates used for the fixed deck. In fact, the lower boundary of the thermal baffles is uniform across the entire reactor.

The deck insulation system is designed to maintain the primary boundary at 150^{o}F using an active air cooling system which continuously functions during both reactor operation and refueling downtime.

2.3.2.6 DECK COOLING SYSTEM

The LPR deck is a "cold" design because it is judged that fewer structural, thermal, and distortion problems are encountered with a deck system that operates at near ambient temperatures, than with a deck system that operates nearer the temperature of the sodium pool (950^{o}F).

The cold deck is achieved:

- o by providing enough insulation between the sodium pool and the deck structure to reduce the heat flux to a practical minimum, and
- o by actively cooling the deck structure bottom plate, thereby removing the heat that passes from the sodium pool into the structure.

Active cooling is accomplished by passing air along, and parallel to, the deck bottom plate (primary boundary). The axial heat flux from the sodium pool into the deck structure is attenuated by means of thermal reflector plates.

Figure 2-8 depicts one of the twelve compartments in the stationary deck. The coolant flow path within each compartment is independent of each of the other compartments. Air is drawn into the deck compartment from the head access area by means of the piping shown in View C-4. The cooling air passes from the distribution manifold into a one foot high plenum directly above the lower deck plate. (The optimum plenum height is between three and twelve inches and will be specifically determined during subsequent design phases.) After passing through the cooling plenum, the coolant exits the compartment by means of a second manifold shown in View A-4.

An independent coolant path exists around each IHX penetration. Coolant enters around the top outside surface of the IHX nozzle, spirals around the nozzle, exits into the coolant plenum, flows across the plenum and mixes in the exit manifold with the previously mentioned coolant air. The exit coolant lines from each of the twelve deck compartments tie into a common manifold which extends around the periphery of the stationary deck. Fans connected to the common discharge manifold draw air through the deck cooling system and maintain a slight negative pressure on the coolant flow path with respect to the reactor system, preventing oxygen leakage into the sodium system in the event that a leak would develop in the bottom plate. Down stream of the fans, the air is cooled by means of component water or service water, and then discharged into the reactor containment building.

PLUG COOLING SYSTEM

The cooling system for the plugs is similar to that of the stationary deck. Thirty thermal reflector plates are installed beneath the plugs to reduce the axial heat load into the plugs as compared to the staionary deck which uses 20 plates.

As shown in Figure 2-7, air is drawn into the large and intermediate plugs from the containment building, passes into the cooling plenum and across the top surface of the bottom plate and exits the plugs through top mounted fans. The center island area containing the control rod drive mechanisms and the small rotatable plug are cooled in a similar manner, although the drawing does not show these cooling system details.

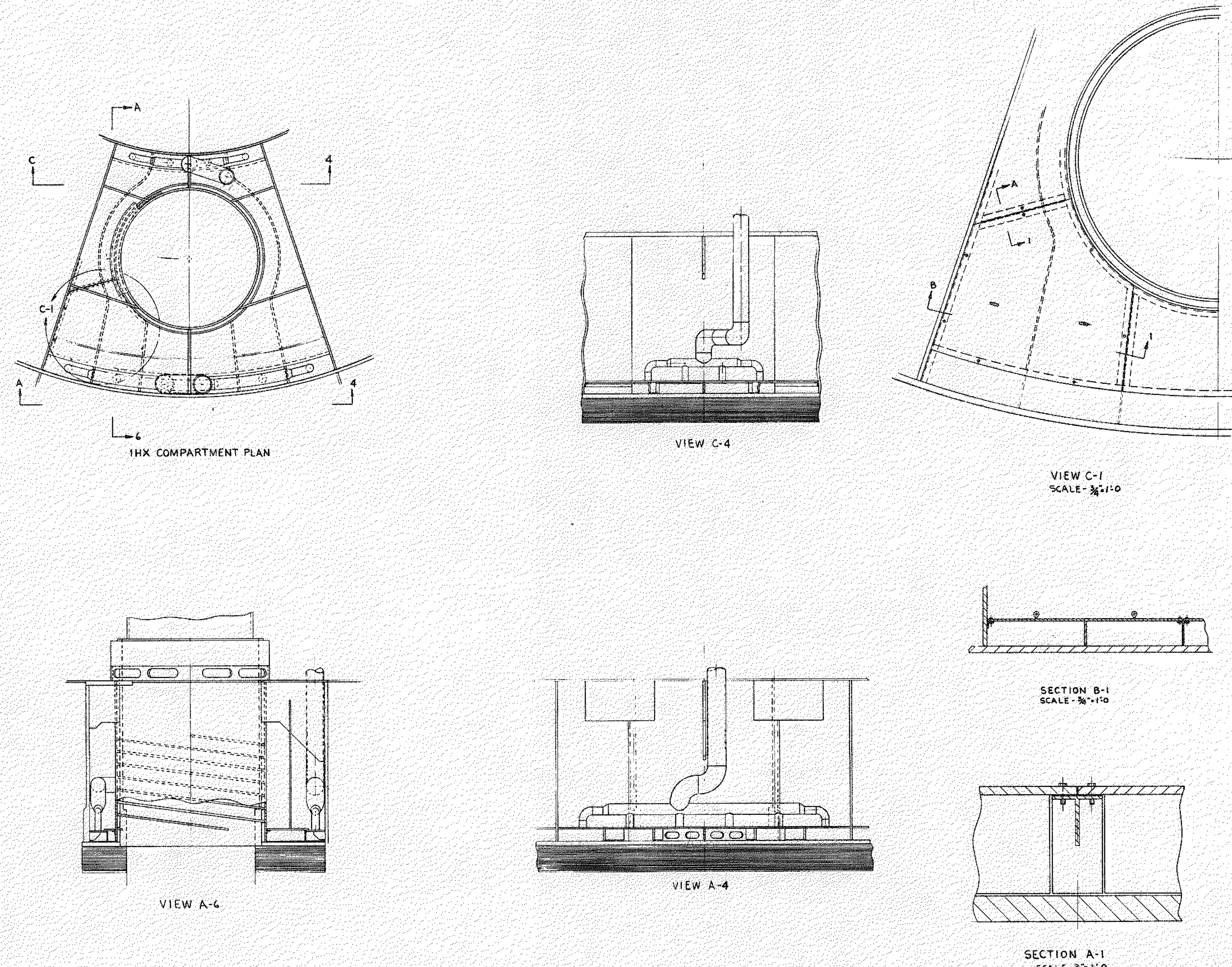


Figure 2-8. Deck Cooling Details

2.3.2.7 DECK AND PLUG THERMAL ANALYSIS SUMMARY

The thermal analysis performed for the deck system appears in Appendix B and in Section 3. This section presents significant results and conclusions of the analysis.

STATIONARY DECK

The stationary deck cooling system parameters appear in Table 2-2.

TABLE 2-2
STATIONARY DECK COOLING SYSTEM PARAMETERS

Parameter	Value
Primary Boundary Plate Design Temperature	$150^{o}F$
Deck Top Plate Design Temperature	$120^{o}F$
Total Stationary Deck Heat Load	800,000 BTU/hr
Design Flow Rate (Max.)	90,000 SCFM
Air Coolant Inlet Temperature	$85^{o}F$
Air Coolant Temperature Rise	$12^{o}F$
Maximum System Pressure Drop	27 inches H_2O
Total Fan Horsepower (70% effective)	546
System Uncertainty Factor (Reflected in Fan Horsepower)	2.0

Significant results and conclusions from the deck thermal analysis are:

- o Nuclear heating from actuated sodium gamma radiation, core neutrons, and cover gas radiation contribute less than 10% to the total deck heat load.
- o 20 thermal reflector plates are utilized beneath the primary boundary in the stationary deck. The resulting heat flux through the primary boundary is 210 BTU/hr-ft^2.

- The estimated heat flux radially outward from the IHX into the deck is 40 BTU/hr-ft^2.

- The optimum deck system cooling plenum height (above the primary boundary) is three inches. This results in flow velocities between 30 and 60 ft/sec. These velocities provide acceptable heat transfer coefficients yet do not result in prohibitive pressure drops through the system.

- In the event of loss of a cooling fan, standby fans are activated. In the event of loss of off-site power, emergency diesel generator power supplies the deck system cooling fans. In the event of loss of coolant flow, for whatever reason, the thermal inertia of the deck structure prevents rapid heatup. Preliminary analysis indicates that no serious structural damage occurs to the deck structure during a loss of cooling transient of up to 168 hours. However, as the design evolves the structural integrity of the deck will be verified.

ROTATABLE PLUGS

The rotatable plug cooling system parameters appear in Table 2-3.

TABLE 2-3

ROTATABLE PLUG COOLING SYSTEM PARAMETERS

Parameter	Value
Primary Boundary Plate Design Temperature	150^oF
Top Plate Design Temperature	120^oF
Total Rotatable Plug Heat Load	245,000 BTU/hr
Design Flow Rate (Max.)	16,000 SCFM
Air Coolant Inlet Temperature	85^oF
Air Coolant Temperature Rise	21^oF
Maximum System Pressure Drop	27 inches H_2O
Total Fan Horsepower (70% efficiency)	97
System Uncertainty Factor (Reflected in Fan Horsepower)	2.0

Significant results and conclusions from the rotatable plug thermal analysis are:

- o 30 thermal reflector plates are utilized beneath the primary boundary in the rotatable plugs. The resulting heat flux through the primary boundary is 175 BTU/hr-ft^2.
- o Active cooling is required for plug cooling. Passive cooling alone is inadequate to thermally protect the rotatable plug structure.
- o The optimum rotatable plug cooling plenum height (above the primary boundary) is three inches. This results in flow velocities between 30 and 60 ft/second. These velocities provide acceptable heat transfer coefficients yet do not result in prohibitive pressure drops through the system.

2.3.2.8 SHIELDING

The shielding requirement for the deck structure is to maintain the radiation level on the top surface to less than 25 mr/hr during operation. This requirement creates a rather unique problem for the pool reactor due to the amount of shielding required for an 87 ft diameter deck structure.

In addition, a potential requirement for primary boundary inspection means that access must be provided to the top surface of the deck bottom plate. The combined requirements dictate a shielding material that is inexpensive and is easily removable. Steel shot fulfills the removability requirement but is relatively expensive when compared to other shielding materials.

The shielding material chosen for the reference LPR design is iron ore shot, known as taconite. Preliminary cost estimates indicate that the cost of taconite is about one-tenth the cost of steel shot.

Physical properties of taconite are as follows:

Chemical Designation	Fe_2O_3
Pellet Size	3/8" to 5/8" diameter spheres

Chemical Composition	65% Iron
	94% Iron Oxide
	5% Silica
	1% Alumina
	<1% CaO and MgO
Density of taconite material	4.8 g/cc
Voids within pellets	22%
Packing Fraction	60%
Density of packed pellets	2.25 g/cc

Analyses were performed for both 3/8" diameter steel shot with a 52% packing fraction (PF) and for iron ore shot.

Key assumptions in the calculations include:

- Na^{24} activity level of 24 mCi/cm^3.
- Neutron flux level (and spectra) at the top of the sodium pool similar to CRBR ($\sim$35 n/cm^2-sec).
- Design dose rate above tank of <25 mrem/hr.
- Cover gas is not a major contributor to dose rate environment above the primary boundary elevation.

The last assumption requires that the rotatable plug design configurations consider effective bulk shielding or gas purges of plug annuli.

Na^{24} dose rate results, shown in Figure 2-9, are based on point kernal calculations. Neutron dose rate results are obtained from data derived from CRBR experiments conducted at ORNL. Correcting the experimental data to account for steel shot attenuation versus solid steel plate, yields an effective removal cross section of 0.02969 cm^{-1} for neutrons. (Value based on neutrons with energy of 24 keV or greater.)

Based on a steel shot bed thickness of 42 in, the resulting gamma dose, D_γ, is 5.5 mrem/hr, and applying an uncertainty factor of 1.5 yields D_γ = 8.3 mrem/hr. Neutron dose rate calcuations yield a dose rate of

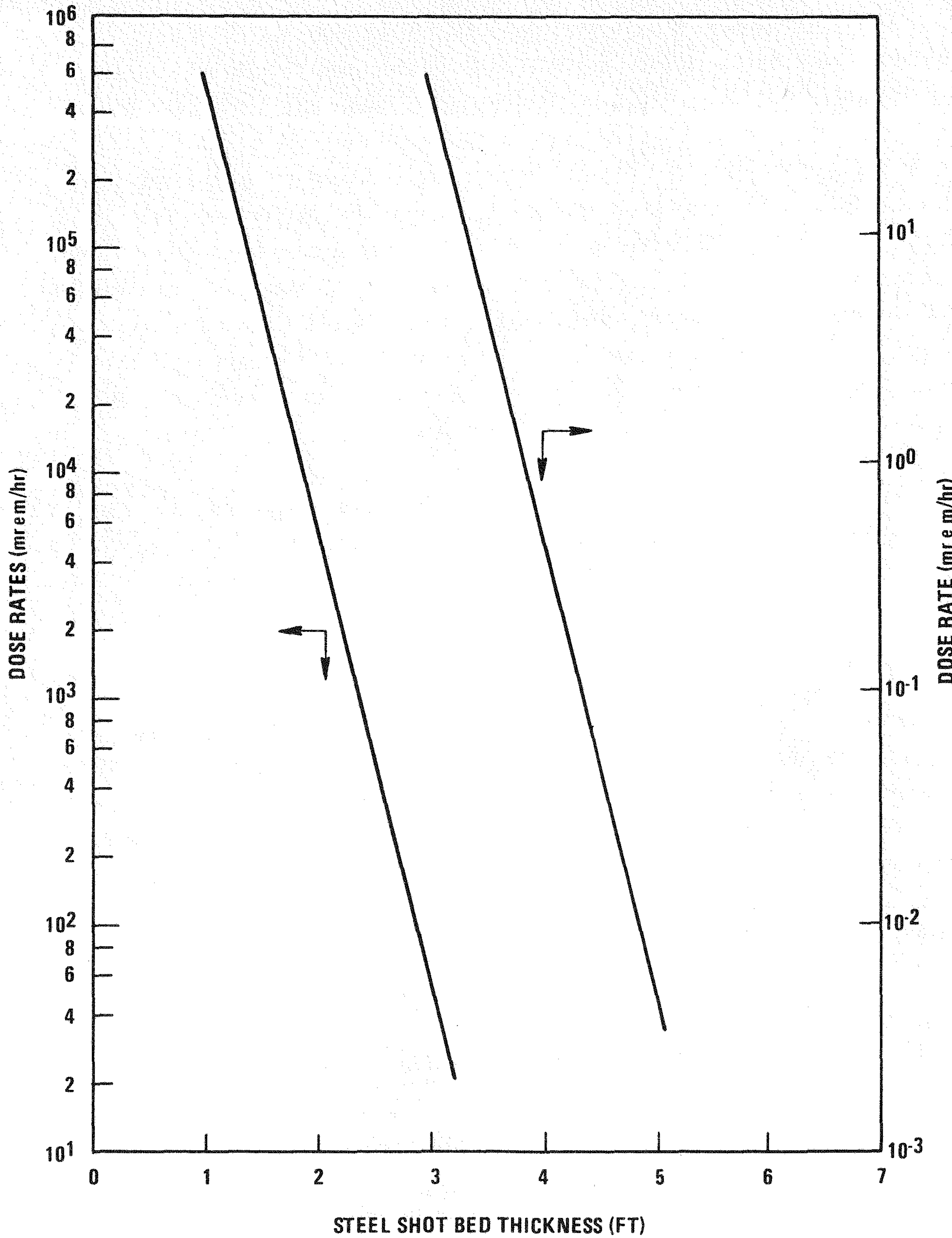


Figure 2-9. Na^{24} Dose Rates Versus Shot Thickness

2.3 mrem/hr, and applying an uncertainty factor of 3 yields D_n = 6.9 mrem/hr. The total dose rate above the 42 in shot bed thickness is then 15.2 mrem/hr.

Dose rates for the iron ore design concept are obtained by approximate modification of the steel shot results to account for differences in material densities. The ratio of steel to iron ore packed densities yields a factor of 1.8. This results in 78 in (1.85 x 42) of iron ore thickness to maintain the same gamma environment as the steel shot design. The iron ore neutron attentuation properties should be greater than a simple density correction would indicate. However, data is not currently available, and the density correction factor is applied to the neutron calculations.

In summary, a steel shot bed thickness of 42 in yields dose rates of $\leq$15.2 mrem/hr above the deck. The equivalent thickness of iron ore shot is calculated to be 78 in.

2.3.3 PLENUM SEPARATOR SYSTEM

The plenum separator system design selected for LPR is a passive system which requires no auxiliary sodium cooling. This design places the hot pool sodium in direct contact with the vessel sodium shield. The configuration represents a significant simplification to the total reactor system for the following reasons:

- No bypass flow is required.
- Orificing and distribution manifolds for the bypass flow are not required.
- The lower support structure is simplified.
- The possibility of gas entrainment or thermal striping as a result of discharging the bypass flow is eliminated.
- Thermal shielding of the reactor vessel is made less sensitive to the number of reflector shields that are used.

2.3.3.1 FUNCTION

The function of the plenum separator system is to isolate all of the various sodium regions which exist within the reactor in a manner which results in predictable thermal conditions in reactor structures during both steady state and transient operations.

The objectives of the plenum separator system are:

- To contain and minimize the volume of the hot pool.
- To establish separation between the hot and cold plena.
- To provide a safe and predictable stress regime in the reactor vessel wall at its attachment to the reactor deck structure.
- To protect the lower support structure from large thermal gradients.
- To isolate the IHX shell from the cold sodium and the primary pumps from the hot sodium.
- To keep the reactor vessel temperature as close to the cold pool sodium temperature as practical.

2.3.3.2 SYSTEM DESCRIPTION

The plenum separator system for LPR is shown in Figure 2-10, and consists of a number of individual structures which function as a system to separate the hot and cold plena of the pool type reactor. Some of these structures also serve to protect major parts of the reactor from the high temperature of the hot pool.

Working from the centerline of the reactor to the vessel wall, the plenum separator system includes the following structures:

- Inner horizontal baffle
- Neutron shield tank
- Outer horizontal baffle
- Intermediate baffle

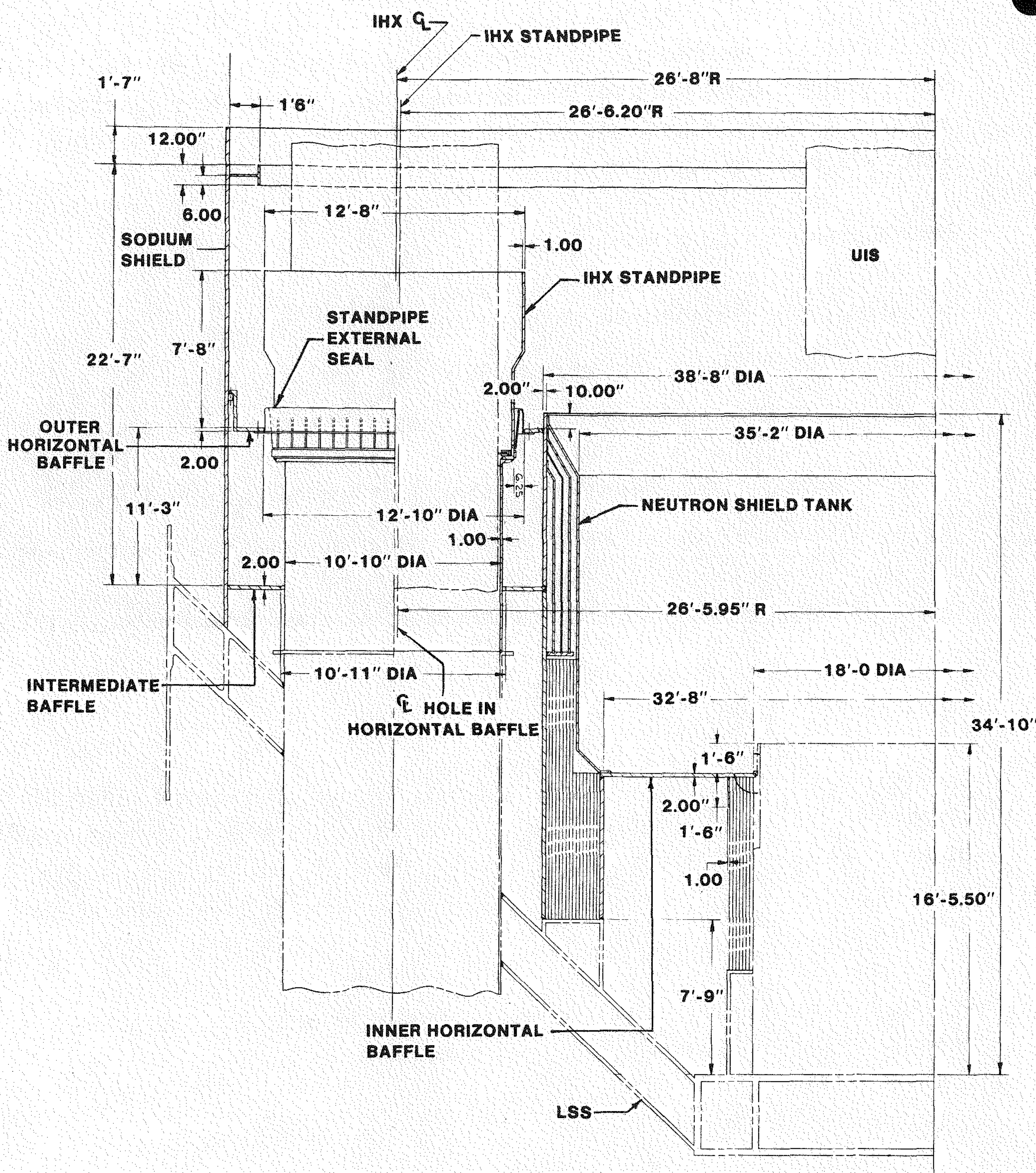


Figure 2-10. Plenum Separator System

- o IHX and pump stand pipes
- o Stand pipe external seals
- o Vessel sodium shield

Many of these structures interface with, and are supported by, the lower support structure (LSS). The LSS serves as a pressure boundry between the hot and cold plena, and is thus an integral part of the plenum separator system. Because of its more fundamental function, that of supporting the core, the description of the LSS is included separately in 2.3.5.

2.3.3.3 INNER HORIZONTAL BAFFLE

FUNCTION

The inner horizontal baffle shown in Figure 2-10 serves as the floor of the hot plenum, and extends from the upper portion of the core barrel to the inner wall of the neutron shield tank. Its function is to prevent the turbulent currents which exist in the hot pool from disturbing the stratified sodium below it which forms the inner intermediate plenum. During reactor startup, the sodium temperatures on both sides of the baffle are the same (670^{o}F), and the primary pumps are operating. Thus, the sodium in the hot plenum is turbulent, and the sodium in the intermediate plenum is quiescent. As the core power level is increased, the mixed mean temperature of the hot plenum increases from 670^{o}F to 950^{o}F. The upper surface of the horizontal baffle is heated by the hot pool sodium and transfers heat to the intermediate pool. The baffle is subjected to upward bowing due to the thermal gradient across it. During steady state operations, the intermediate plenum sodium below the baffle approaches hot pool temperature, and the baffle thermal gradient disappears. Because of the constant turbulence of the hot plenum, the baffle is not subject to radial differential thermal expansions during startup. If the reactor is tripped, cold sodium flows into the hot plenum, and being more dense, stratifies and settles on top of the horizontal baffle. The stratified cold sodium lowers the surface temperature, causing a downward bow due to the resulting thermal gradient. Subsequent heat transfer through the baffle, and thermal currents in the intermediate plenum slowly lowers the intermediate plenum temperature and the bowed baffle plate eventually returns to a level condition. The baffle plate must be designed to accommodate this reverse bending action incurred during each startup and scram of the reactor.

DESCRIPTION

The inner horizontal baffle is an annular plate having an OD of 35 ft 2 in, an ID of 18 ft 0 in, and a thickness of two inches. The OD has a built-in support configuration, being welded to the neutron shield tank. The ID has a simply supported configuration at its attachment to the core barrel. The baffle is a continuous ring with one penetration for access to the in-vessel fuel transfer station. This penetration requires a cover during reactor operations for continuity. The cover is removed for refueling using the in-vessel transfer machine (IVTM).

2.3.3.4 NEUTRON SHIELD TANK

FUNCTION

The neutron shield tank houses the outer neutron shield, and serves as a radial thermal barrier between various sodium plena. (A portion of the neutron shield is also located immediately outboard of the core barrel, within the inner intermediate plenum). The shield tank supports the inner edges of the outer horizontal baffle and intermediate baffle, and the outer edge of the inner horizontal baffle. The lower part of the tank separates the inner intermediate plenum, which is between the inner horizontal baffle and the lower support structure; and the cold intermediate plenum, between the intermediate baffle and the lower support structure. The middle part of the tank separates the hot outlet plenum from the cold intermediate plenum, and the top part of the tank separates the hot outlet plenum from the outer intermediate plenum. Because of these separations of various plena, each of which have distinct temperature profiles, various radial thermal gradients exist across the shield tank at every axial elevation. A desirable function of the shield tank is to maintain these radial gradients so that thermal convection currents in the intermediate plena are minimized. The radial thermal gradients also require that the inner and outer shells which form the tank be free to expand axially and radially independent of one another. The outer shell, and that portion of the inner shell below the inner horizontal baffle are in contact with stratified intermediate sodium; thus, they are not subject to rapid changes in temperature. These shells are used as structural support members. The inner shell above the horizontal baffle is a sodium boundary for the hot plenum, and thus is subject to all thermal transients which occur in this plenum. This shell need only support its own weight. It is rigidly attached to the inner horizontal baffle and has a sprung slip fit with the ID of the top of the outer shell.

DESCRIPTION

The neutron shield tank is an enclosed annular tank with an outside diameter of 38 ft 8 in, and an annular width of 21 in. The lower inner wall and the outer wall which support the horizontal baffles are straight walled cylinders with a nominal thickness of two inches. The upper inner wall, which is the only part of the tank in contact with the hot sodium plenum, is a one inch thick cylinder with conical transitions at each end. Both walls of the tank are supported by a pedestal, which is an integral part of the lower support structure.

The bottom portion of the tank houses the outer neutron shield elements and eight flux wells, and the upper portion of the tank contains three cylindrical baffles which isolate and control the thermal convection currents which exist due to the radial gradients across the tank. These cylindrical baffles are one-half to one inch thick, and are supported from a ledge attached to the outer shell above the neutron shield elements. The flux wells exit the neutron shield through the top conical section of the inner shell.

2.3.3.5 OUTER HORIZONTAL BAFFLE

FUNCTION

The functions of the outer horizontal baffle are the same as those described for the inner baffle, but in addition must support the flexible seals at the six IHXs and four pump penetrations.

DESCRIPTION

The outer baffle is an annular plate with 10 circular penetrations. The OD is 70 ft 8 in, the ID is 38 ft 8 in, and the thickness is two inches. The IHX penetration holes are 13 ft in diameter, and the pump penetration holes are 10 ft in diameter. Since the baffle expands radially with respect to the standpipes which pass through it, the centers for these holes are located at a smaller radial position than the standpipe centerlines at the lower support structure. This assures that the standpipes are centered in the baffle penetrations during normal reactor operating conditions, resulting in uniform minimal deflections of the seals. The baffle is built in at its inner edge and simply supported at the outer edge. In addition, the baffle receives some central support at each penetration in the form of a flange on each stand pipe which limits the downward deflection of the baffle.

2.3.3.6 INTERMEDIATE BAFFLE

FUNCTION

The function of the intermediate baffle is simply to separate the outer intermediate plenum into two axial zones: one with a rectangular elevation section having essentially stable boundary thermal conditions, and one with a triangular elevation section. The triangular shaped plenum has a variable thermal boundary along the conical surface of the LSS. As a result, greater thermal convection currents would be expected in this plenum, and the intermediate baffle prevents these currents from disturbing the stratification in the upper rectangular zone. This baffle is not subject to rapid thermal transients, and is not expected to have a thermal gradient across it greater than 20°F.

DESCRIPTION

The shape and size of the intermediate baffle is essentially the same as that of the outer horizontal baffle. However, this baffle is built-in at both edges and can be stiffened with ribs since thermal gradients are low. There are no seals between the intermediate baffle and the 10 standpipes.

2.3.3.7 IHX STANDPIPES

FUNCTION

Each IHX standpipe provides a pocket which extends the hot plenum through the intermediate plenum to the cold plenum. The IHXs are located in these pockets and extract the heat from the sodium as it flows from the hot plenum to the cold plenum. The bottom of the standpipe also provides lateral support to the bottom of the IHX during seismic events, however, the support still permits differential thermal expansion of the standpipe with respect to the IHX in the radial direction by bending the IHX. The bottom of the standpipe also provides a seal surface to mate with a bellows face seal attached to the IHX bottom head. This seal restricts sodium leakage between the outside of the IHX and the standpipe. The seal does not have to be absolute since heat is removed from the sodium in the standpipe through conduction both across the IHX shell to the secondary sodium, and across the standpipe to the intermediate plenum.

The standpipe is supported by the LSS, and extends to within 24 in of the hot operating sodium level. This provides a high exit for the hot sodium from the plenum and assures that most of the hot sodium is displaced from the plenum following a reactor trip. In addition to being open at the top, the upper part of the standpipe has a multiple number of small flow holes in the shell about three feet from the top end. These holes are below the faulted sodium level and assure continuity of flow through the IHXs in the unlikely event of a leak in the reactor vessel which could lower the sodium level to the faulted position.

DESCRIPTION

The IHX standpipes consist of three sections. The bottom section is an integral part of the LSS. The middle section is a cylinder with a top flange, and extends from just below the intermediate baffle to just below the horizontal baffle. The top section is a larger diameter cylinder which extends into the hot plenum. The ID of the smaller sections is 10 ft 8 in, and the ID of the top section is 12 ft 8 in. Nominally the wall thicknesses are one inch.

2.3.3.8 PUMP STANDPIPES

FUNCTION

Each pump standpipe provides a pocket of essentially cold sodium which extends through the intermediate and hot plena as shown in Figure 2-11. The primary pumps are located in these pockets and draw sodium from the cold plenum and discharge it to the LSS for distribution to the core. The bottom of each standpipe provides a receptacle to accept and mate with the two pump bottom seals. This receptacle also provides lateral support and position control to the bottom of the pump. Sodium leakage past the upper seal flows upward within the standpipe and outside of the pump housing. Sodium leakage through the labyrinth shaft seal flows upward within the upper pump tank, and then must flow downward outside the pump housing to eventually mix with the bottom seal leakage and then exit to the hot plenum. These leakage flow rates are expected to be low (about 400 gpm), thus the sodium has a high residence time within the standpipe. This permits the sodium to be heated by the intermediate and hot plena (through conduction across the standpipe wall) before being discharged to the hot plenum. An intermediate baffle is located between the top of the standpipe and the pump housing to increase

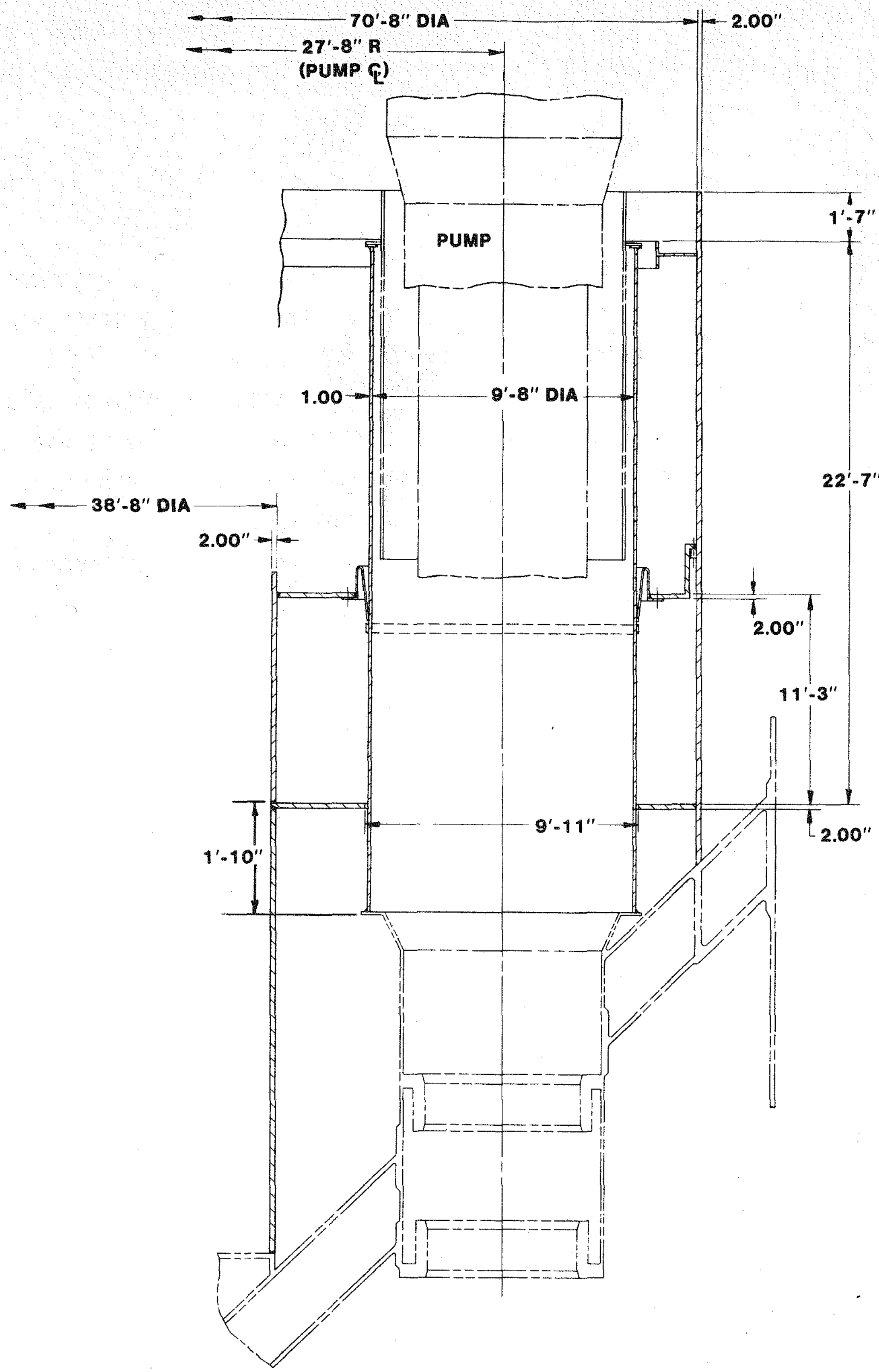


Figure 2-11. Pump Standpipe

the residency time of the pump over flow leakage. The final length and diameter of this baffle will be determined from future thermal and hydraulic analyses. The construction of the pump standpipes is similar to that used for the IHX standpipes.

DESCRIPTION

The pump standpipe consists of three sections. The pump receptacle section is an integral part of the LSS. The standpipe itself is a cylinder which extends 6 in above the maximum sodium level, and has an OD of 9 ft 10 in. The internal baffle is the third section. It is also a cylinder with an external flange which rests on the top of the standpipe. This flange and the upper extension of the baffle cylinder serve to keep hot plenum sodium from entering inside the standpipe. As stated above, the final dimensions of this cylinder are determined by thermal and hydraulic requirements which are not resolved; however, an interim diameter of 8 ft 10 in is established. Both cylinders of the standpipe have one inch walls.

2.3.3.9 STANDPIPE EXTERNAL SEALS

FUNCTION

The IHX and pump standpipes are supported and positioned by the LSS which is nominally at a temperature of 670°F. However, the standpipes also penetrate the outer horizontal baffle which is subject to the large temperature range of the hot plenum. As a result, differential radial thermal expansion of as much as one inch occurs at the penetration interface. The holes in the baffle are large enough to permit the radial motions to occur without deflecting the standpipes, but to assure that velocity currents in the hot plenum do not pass through this clearance space, a flexible seal is provided at each penetration. The seal, shown in Figure 2-12, is attached to the baffle and moves with it. Flexible fingers contact the standpipe and are deflected as the baffle plate expands and contracts. As the baffle bows in the axial direction due to thermal

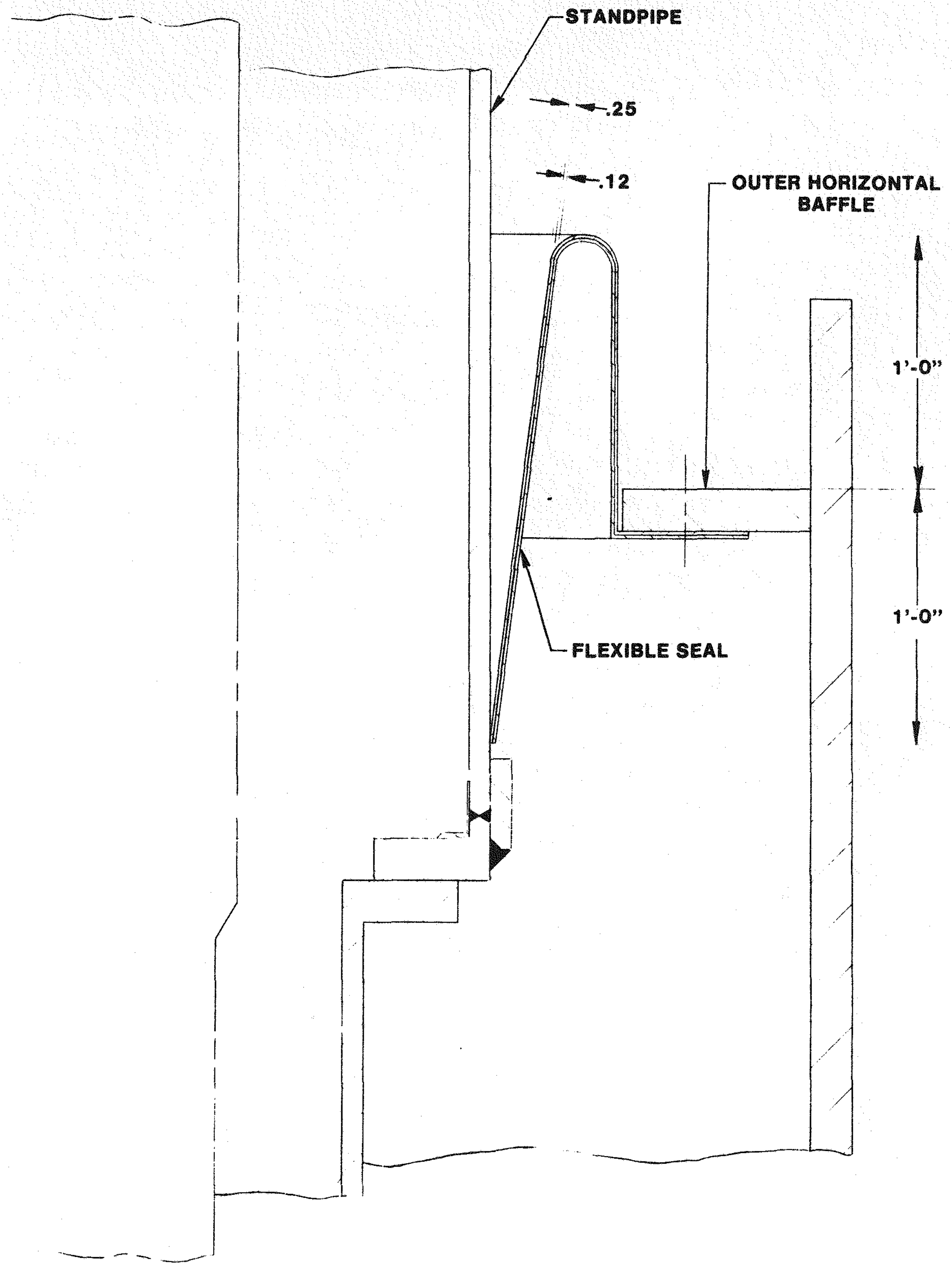


Figure 2-12. Standpipe External Seal

gradients across it, the seal slides with respect to the standpipe. Axial downward deflection of the baffle is limited by the seal fingers contacting a ring attached to each standpipe just below the horizontal baffle.

DESCRIPTION

Each standpipe seal consists of two thin sheets of inconel which are slit and formed and then nested together so that one sheet covers the slits in the other. Each sheet is .12 in thick, and the overall height of the seal is 2 ft. The seals are attached to the bottom side of the horizontal baffle and the flexible fingers extend downward. This arrangement assures that, in the unlikely event that an inner finger should separate from the seal, it would be retained in the stagnant intermediate plenum. Failure of an outer finger is much less likely to occur due to the larger bend radius on the upper seal layer.

2.3.3.10 VESSEL SODIUM SHIELD

FUNCTION

The sodium shield is a cylinder located 2 ft inside of the reactor vessel; it contains the sodium pool. The annular space between the sodium shield and the reactor vessel is filled with reactor cover gas. Reflective insulation is also provided in this space to control the heat flux from the sodium shield to the vessel wall. These reflective plates are a part of the vessel insulation and cooling system, and are discussed in 2.3.1.4. The shield supports the outer edge of the horizontal baffle from an internal ledge. The sodium shield is supported from the lower support structure cone and extends to within 6 in of the deck bottom plate. Twenty-four inches from the top of the shield is an internal tee flange which is welded to the shell at 20 distinct locations. This flange prevents sodium from sloshing behind the shield during seismic events, and also prevents amplified vibrations of the shield when in resonance with the primary pump forcing frequencies. This latter function is achieved by attaching the flange to the shield at 20 locations. This forces the shell to vibrate with 20 lobes, which is much greater than the normal 5 to 7 lobes at its fundamental frequency. Thus the natural frequency of the shield is artificially increased above the level of the primary forcing frequencies of the pumps. The internal flange which supports the horizontal baffle is also attached with intermittent welds to achieve the same purpose as the upper tee flange.

That portion of the shield top above the tee flange is at a lower temperature than the hot pool. Because of the cooling effect of the deck reflector plates, sodium aerosol and vapor in the cover gas is expected to condense on the inside of the shield and drip back into the main sodium pool. No direct circulation of cover gas from the sodium side to the vessel side of the shield is expected; thus, sodium transport and condensation in the gas space annulus is not expected to be a concern.

During normal reactor operation, the sodium shield above the horizontal baffle is at hot pool temperature. That part of the shield below the baffle is at the sodium temperature of the intermediate plenum, hot adjacent to the baffle and decreasing in temperature with distance from the baffle. Following a scram with stratification developing in the hot plenum, the shield temperature below the baffle will decrease very slowly; however, the shield above the baffle will be subjected to a rapid cooling from the baffle upward as the cold-to-hot sodium interface moves upward through the hot plenum. It is judged that the resulting thermal transient is acceptable, and no thermal protection is required on the upper portion of the shield.

DESCRIPTION

The sodium shield is 24 ft-10 in long, has an OD of 71 ft and is 2 in thick. The tee flange at the top has a web width of 17 in and a tee flange width of 12 in.

2.3.4 UPPER INTERNALS STRUCTURE

The Upper Internals Structure (UIS) is located between the reactor core and the reactor deck as shown in Figure 2-1.

2.3.4.1 FUNCTION

The functions of the UIS are:

- To provide guidance and positioning for the control rod drivelines.
- To provide seats for control rod scram arrest.
- To provide mixing, flow passage, and flow guidance for coolant exiting the core assemblies.
- To provide secondary holddown for all removable core assemblies that are not otherwise positioned vertically by two independent and diverse methods.
- To provide guidance, support, and positioning for in-vessel instrumentation.

2.3.4.2 DESCRIPTION

GENERAL

The overall arrangement of the Upper Internals Structure (UIS) is shown in Figure 2-13. It is bolted to and hangs from the underside of the intermediate rotatable plug and extends to within approximately 2 in of the top of the removable core components (i.e., fuel, blanket, control, and removable radial shield assemblies). Thus, it is located within the core outlet plenum and the major portion is in contact with sodium at an average temperature of 950^{o}F during normal reactor operation.

The UIS consists of groups of stainless steel components that are welded together; and groups of Inconel 718 components that are mechanically joined to each other and to the stainless steel components. Stainless steel is used for the principal structural components which consist of a support barrel and a support grid. Inconel 718 is used for components that are subjected to coolant with large temperature variations, primarily those located close to the core assemblies. The UIS is 180 in across at its widest point, 381.75 in in height from the rotating plug attachment point to

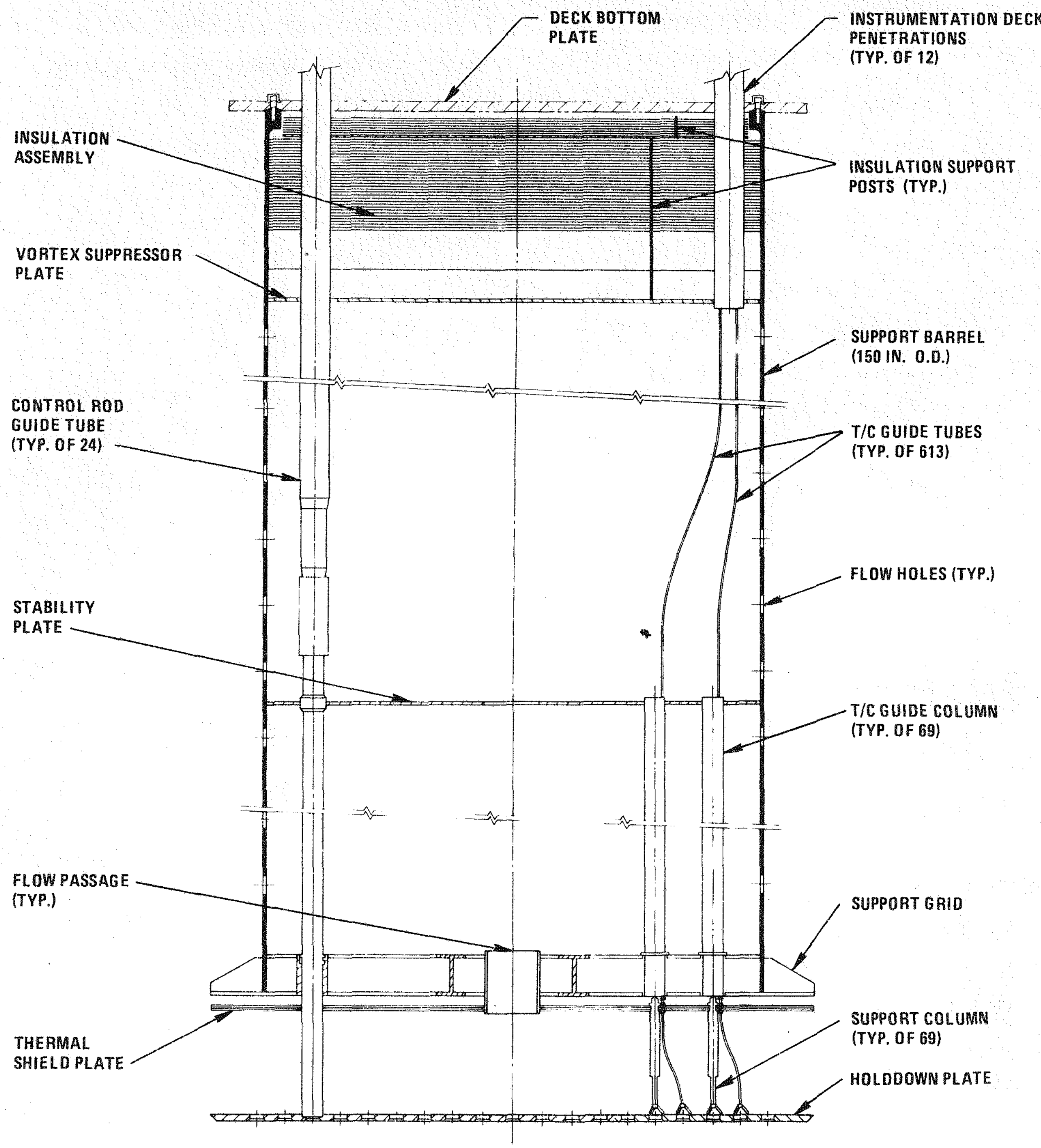


Figure 2-13. Upper Internals Structure Elevation

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the underside of the holddown plate, and weighs approximately 180,000 pounds. It is cantilevered from the intermediate rotatable plug and has no direct connection with the core support structure, i.e., no keys are provided. Further it is designed to move laterally during refueling operations without first being lifted. The components that comprise the UIS are:

- Support Barrel
- Support Grid
- Control Rod Guide Tubes
- Holddown Plate
- Instrumentation
- Thermal Shield Plate
- Flow Passages
- Stability Plate
- Vortex Suppressor Plate
- Insulation Assembly

These are described in the following paragraphs.

Support Barrel

The austenitic stainless steel support barrel extends from the underside of the intermediate rotatable plug to the support grid. It is 150 in in diameter, approximately 342 in long, and has a wall thickness of one inch. A flange at the top end accommodates bolts which connect the UIS to the intermediate rotating plug. The support barrel is welded to the vortex suppressor plate, the stability plate, and the support grid. Holes through the support barrel are provided over its length to permit that fraction of the coolant exiting the core, which flows upward past the support grid, to enter the hot plenum.

The support barrel is the principal component to provide stiffness to the UIS to resist effects of seismic events. The natural frequency of the UIS, treated as a cantilever, is an indication of the adequacy of a given design. For the design described herein, with a 1 in support barrel thickness, the natural frequency is between 9.0 and 11.9 Hz.

The support barrel diameter is controlled primarily by the control rod pattern, shown in Figure 2-14. It is desirable for the support barrel diameter to be as small as possible because of its direct influence on the diameters of the intermediate rotatable plug and the reactor deck. The 150 in O.D. selected encloses the control rod pattern, with adequate clearance, yet it is sufficiently large to provide significant bending stiffness.

Support Grid

One of the primary functional requirements of the UIS is to provide lateral positioning of the control rod guide tubes. This is accomplished by an I-beam type grid structure, made of stainless steel plates welded together. The grid structure, shown in Figure 2-14, consists of six intersecting beams whose basic dimensions are 12 in deep, 8 in wide, and 1.25 in thick (both web and flanges). At the 24 control rod locations, vertical pipes pass through or adjacent to the beams and are welded to them. These pipes serve as supports for the control rod guide tubes.

The support grid also provides location and support for the 69 thermocouple (T/C) guide columns. These T/C guide columns connect to ears integral with the support grid in all but six cases. For the remaining six cases, location and support is provided by auxiliary beams welded to the support grid. These T/C guide column locations are also shown in Figure 2-14.

The support grid is welded to the lower end of the support barrel, as shown in Figure 2-13. The support grid is 180 in across at its widest point. This is greater than the support barrel diameter so that secondary holddown and T/C coverage can be provided for all fuel, blanket, and control rod assemblies.

Control Rod Guide Tubes

A control rod guide tube for each of the 24 control rods extends from the holddown plate up into the intermediate rotatable plug as shown in Figure 2-13. The guide tubes provide guidance for the control rod drive shafts

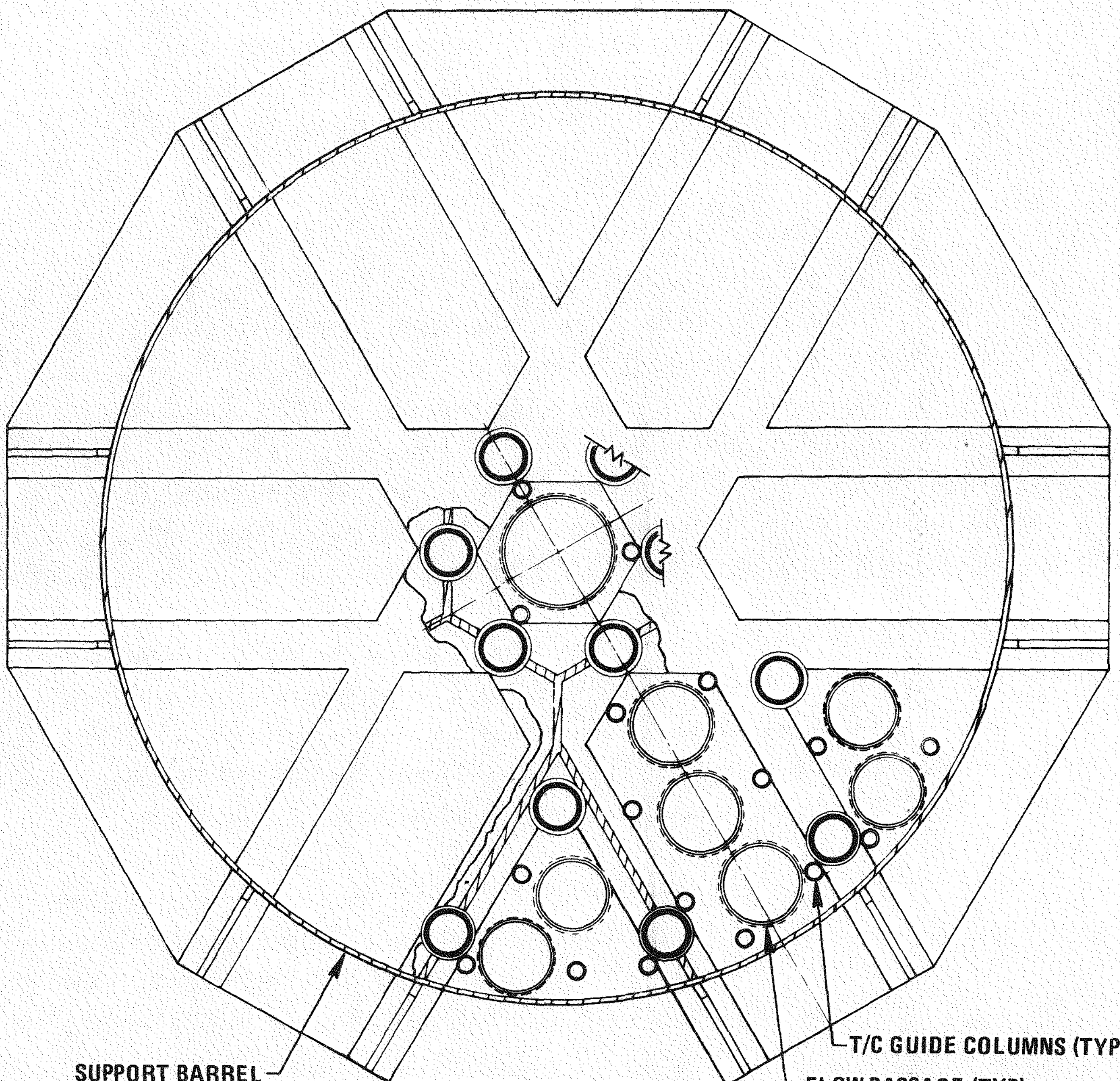

Figure 2-14. UIS Support Grid Plan

that connect the control rod absorbers in the reactor core to the control rod drive mechanisms on the intermediate rotatable plug. They also provide protection for the drive shafts against coolant cross flow and contain scram arrest stops.

The control rod guide tubes are made in two sections. The lower sections extend from the holddown plate to slip connections, located above the stability plate, with the upper guide tube sections. They are supported in the vertical direction by mechanical connections (eccentric locks) in the pipe sections provided in the support grid and in the lateral direction by the support grid and the stability plate. They extend part way through, but are not connected to, the holddown plate.

The lower sections of the control rod guide tubes are made of Inconel 718 to withstand the approximate $400^{o}F$ maximum temperature differences between the control rod and fuel exiting coolant. The mechanical connection to the support grid is provided primarily to enable replacement of a control rod guide tube, if necessary, but also because of the use of Inconel 718 and the need for a bimetal connection to the support grid. The clearances between the bottom of the guide tubes and the holddown plate are provided to permit relative thermal expansion (radial and axial) between these parts and to reduce the radial thermal gradients in the portions of the holddown plate between control rod and fuel assembly positions.

The upper sections of the control rod guide tubes are supported by the intermediate rotatable plug. The slip connections between the upper and lower sections are provided to accommodate relative thermal expansion between the plug and the UIS. A scram arrest is located in each upper section so that control rod scram loads are transmitted to the rotatable plug. The control rod guide tube upper sections are made of stainless steel with Inconel 718 inserts, or similar hard material, used at control rod drive line guidance points to reduce wear.

Holddown Plate

A holddown plate is located at the lower end of the UIS as shown in Figure 2-13. This plate provides secondary holddown for the fuel, blanket, and control rod assemblies to guard against these assemblies lifting if the primary holddown (hydraulic balance plus weight) were to fail. The holddown plate has a hole over each core assembly through which coolant flows. The holes over the control rod assemblies mate loosely with the control rod guide tubes, as described above. The plate is positioned from the support grid by support columns. Figure 2-15 shows a support column in greater detail as well as its mechanical connection to the holddown plate.

The holddown plate is made of Inconel 718 to withstand the thermal fatigue (striping) caused by the temperature differences of the coolant exiting from the various core assemblies. Because of limitations on the size of Inconel 718 plate obtainable, the holddown plate is made in seven pieces, as shown in Figure 2-16. Thermal expansion differences between the Inconel 718 holddown plate and the stainless steel support grid are accommodated by flexing of the Inconel 718 support columns. Dividing the holddown plate into seven pieces also helps to reduce the differential expansion (by reducing the length of each expanding component) and, therefore, the maximum deflection of the support columns.

The holddown plate is 2 in thick to provide sufficient strength to withstand the maximum hydraulic lift force, should the primary core assembly holddown fail. The periphery of the plate is chamfered to assure freedom from damaging interference with the core assemblies during lateral movement of the UIS when the intermediate plug is rotated.

Instrumentation

Figure 2-13 shows guide tubes leading from penetrations in the intermediate rotatable plug to positions over the exits of the core assemblies. These guide tubes are used to introduce thermocouples into the reactor for the

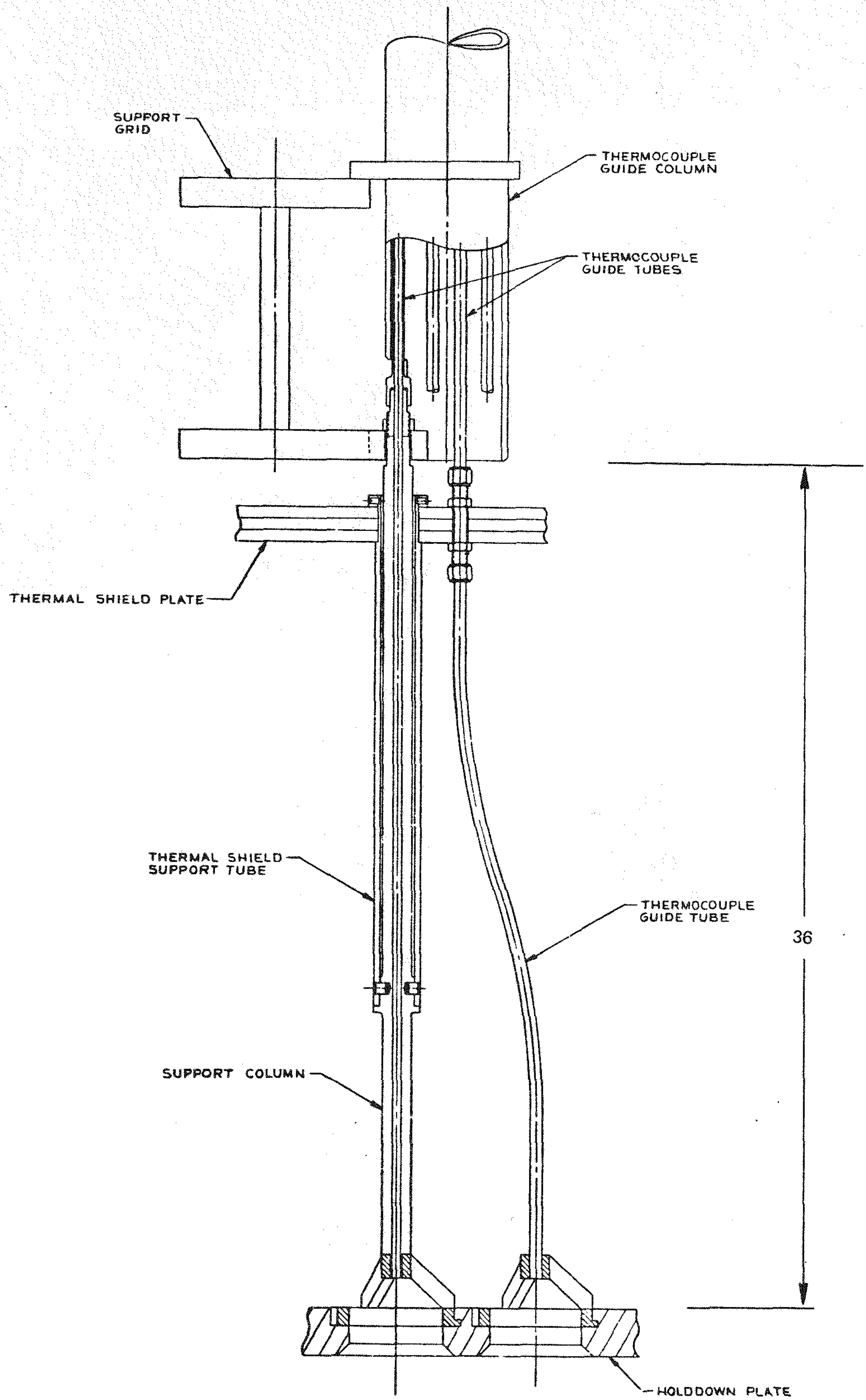

Figure 2-15. UIS Holddown Plate Support Elevation

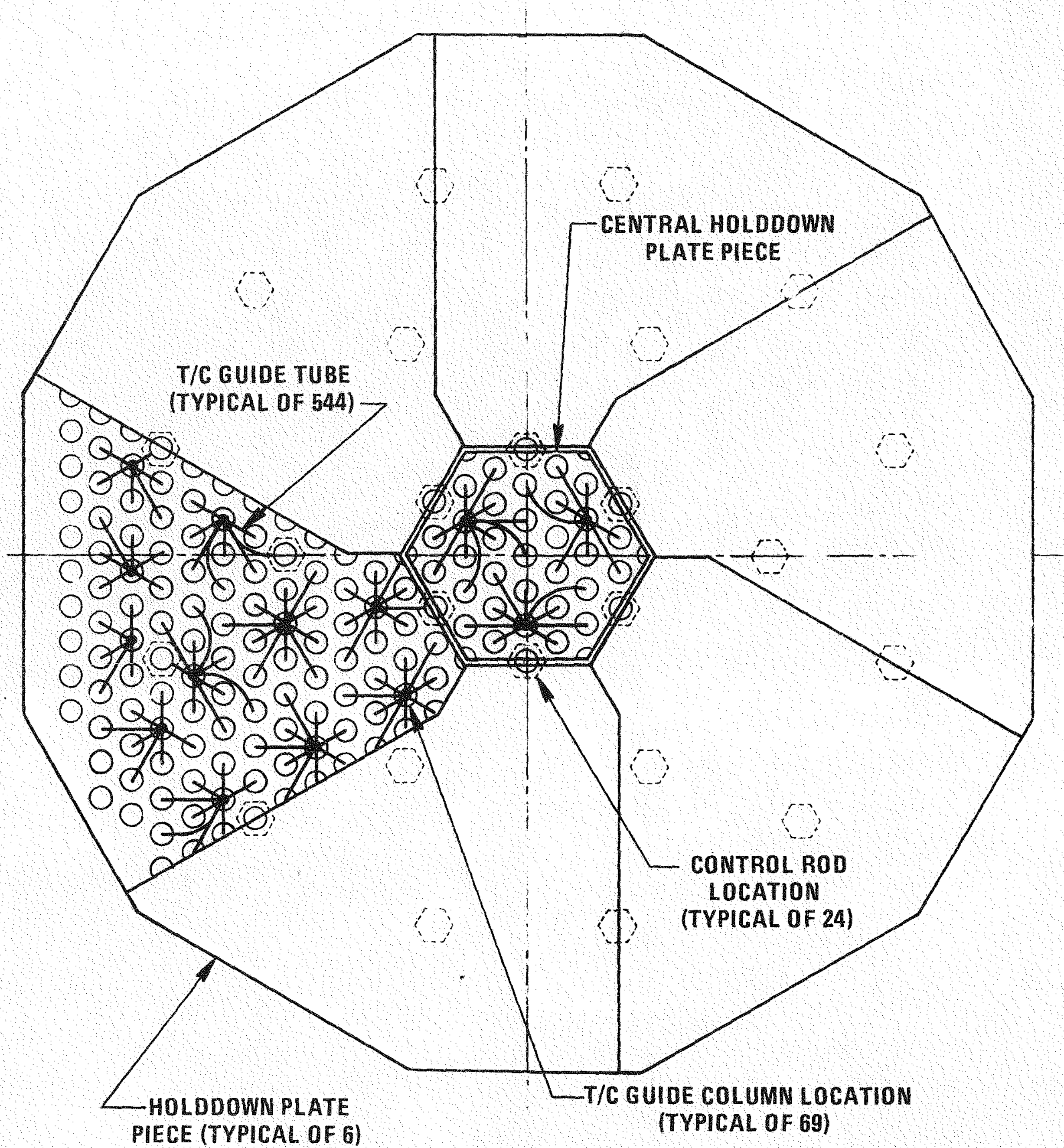

Figure 2-16. UIS Holddown Plate Plan

purpose of measuring the temperature of the coolant discharging from each fuel and control rod assembly and all but the outermost row of blanket assemblies. One thermocouple is provided for each of these 613 assemblies. These thermocouple guide tubes are gathered in groups of 6 to 11 in the space between the support grid and holddown plate and a group is run through each of the 69 T/C guide columns to the region above the stability plate. In the space between the stability plate and vortex suppressor plate, the T/C guide tubes are regathered in groups of approximately 51. Each of these groups is run through one of twelve penetrations through the UIS insulation plate assembly and the intermediate rotatable plug.

One T/C guide tube in each T/C guide column passes down through the center of the support column, as shown in Figure 2-15, so that the temperature of the coolant from the assembly directly below can be measured. The other T/C guide tubes are dispersed to positions over nearby assemblies, also as shown in Figure 2-15. These T/C guide tubes are positioned in the centers of the flow holes in the holddown plate by mechanical connections.

The lower ends of the T/C guide tubes are Inconel 718 in order to withstand thermal striping effects of the coolant. Stainless steel is used for the remainder of the T/C guide tubes if the bottom end of the T/C guide tubes are open to the coolant. If they are closed, to form dry wells, Inconel 718 is used throughout. This choice depends upon the T/C response time desired.

The T/C distribution pattern is shown in Figure 2-16. This pattern, along with the distance between the holddown plate and support grid, permits the T/C guide tubes to reach each core position with a minimum of bends and with a bend radius of at least 24 in. This is to enable insertion and replacement of the 0.250 in diameter sheathed T/C.

As shown in Figure 2-15, a short thermal shield support tube is located below the support grid to position the thermal shield plate from the support column. This tube is made of Inconel 718. Each T/C guide column that extends from the support grid to the stabilty plate is made of stainless steel. It is supported by the support grid.

Thermal Shield Plate and Flow Passages

As indicated herein, Inconel 718 is used for components that are subjected to coolant flow streams with large temperature differences to withstand the thermal fatigue effects caused by cyclic interaction of these coolant streams (thermal striping). By the time the coolant streams get above the support grid, sufficient mixing and temperature difference reductions occur so that stainless steel can be used. The stainless steel support grid, however, is protected from thermal striping by the combination of a thermal shield plate and flow passages as shown in Figure 2-13. The thermal shield plate is positioned off the support columns by the thermal shield support tubes, as shown in Figure 2-15.

The thermal shield plate is made in three layers of thin Inconel 718 plates. Each layer, in turn, consists of seven pieces, resembling the holddown plate pieces. These pieces and layers overlap to block flow through gaps between the pieces.

Short sections of Inconel 718 tubing penetrate and are supported by the thermal shield plate. These tubular pieces extend up past the support grid and form flow passages for the coolant as shown in Figure 2-13. Figure 2-14 shows the location of these 33 passages with respect to the support grid and support guide columns.

Stability Plate

The stability plate is located within the support barrel, approximately 210 in above the bottom of the UIS as shown in Figure 2-13. It consists of a flat stainless steel plate welded to the support barrel. Stability and positioning are provided by this plate for the control rod guide tubes and the T/C guide columns. The T/C guide columns are welded to the stability plate whereas the joint between the stability plate and the control rod guide tubes is mechanical because of the material difference and the replacability features of the control rod guide tubes. Flow holes are provided in the stability plate to permit sodium coolant to flow through on its way up and radially out of the UIS.

Vortex Suppressor Plate and Insulation Assembly

At the top end of the UIS is located a vortex suppressor plate and an insulation assembly. These components are shown in Figure 2-13. The vortex suppressor plate is located 60 in below the top of the UIS, and is about one foot below the normal sodium surface level. It consists of a flat stainless steel plate, stiffened by four parallel, welded-on, bars and is welded to the support barrel. The vortex suppressor plate is solid except for holes surrounding the control rod guide tubes (24) and the T/C penetrations (12) in the rotatable plug.

The insulation assembly consists of 39, 0.15 in thick and one, 0.5 in thick stainless steel plates spaced 0.75 in apart. These plates are located completely in the cover gas region above the sodium surface level. They provide insulation required to keep the temperature of the underside of the intermediate rotatable plug below 150^{o}F. The individual insulation plates are supported off the vortex suppressor plate by a group of support posts and spacers. Each of the lower 32 plates is made in 3 pieces so that they can be installed and still occupy the entire inside diameter of the support barrel, below the support barrel mounting flange. The top eight plates are each of smaller diameter and are each one piece. This top group of plates is positioned off the lower group, also by use of support posts and spacers, as shown in Figure 2-13. The one 0.5 in thick plate forms the transition between these two groups of plates.

2.3.4.3 ALIGNMENT

The required alignment of the UIS with respect to the reactor core depends upon the location of the UIS, core support structure, and core assemblies at installation, and the movement of these components during normal operation and seismic events. The UIS design helps to achieve alignment by use of a relatively stiff structure through the use of a barrel as the primary support member. As indicated above, the natural frequency of the UIS is between 9.0 and 11.9 Hz. For a safe shutdown earthquake (SSE), a maximum deflection of 0.65 in for the UIS is expected. When combined with a 0.67 in deflection of the core support structure under the same seismic event and a control rod assembly radial positioning tolerance of ±0.75 in relative to the core support structure (controlled by the core restraint system), the maximum possible UIS-to-control rod assembly misalignment becomes 2.07 in. With this maximum misalignment, the minimum clear passage through the control rod assembly handling socket and control rod guide tube is 2.53 in. Therefore, with the 1.04 in diameter connecting rod which passes across this interface, a minimum clearance for the connecting rod becomes 1.49 in. This clearance should be adequate to assure movement of the control rod at all times.

2.3.5 LOWER SUPPORT STRUCTURE

2.3.5.1 FUNCTION

The Function of the Lower Support Structure (LSS) is to position and support the reactor internal structures, excluding the upper internals structure. The LSS provides horizontal restraint and seismic support to the bottom of the primary pumps and horizontal seismic support to the bottom of the IHXs. The LSS, in conjunction with the primary pumps and IHXs, forms a thermal boundary between the cold plenum and the intermediate plena and a pressure boundary between the low and high pressure coolant. The LSS directs high pressure coolant from each primary pump discharge chamber to the core.

2.3.5.2 DESCRIPTION

The LSS includes a dual conical structure, four pump receptacles, six IHX standpipe supports and the core support structure. Core drop protection features are included in the design. The entire LSS is fabricated from stainless steel plate and forgings. Provisions for inservice inspection and monitoring are presented in Appendix R.

Dual Conical Structure

The dual conical structure provides a design that eliminates the need for piping between the primary pumps and the core. The conical box structure is supported from the wall of the reactor vessel as shown in Figure 2-17. The design provides four pump receptacles and eight internal ducts that direct coolant from the primary pumps to the inlet plenum distribution ring. The ducts are sized to contain the high pressure (120 psi) and to provide adequate passageways so that the maximum flow velocity does not exceed 25 ft/sec.

The structure consists of 2.0 in thick lower and upper cones separated by 2.0 in radial and longitudinal ribs as shown in Figure 2-18. A cylindrical shelf is included between the core support structure and the standpipes to support the large neutron shield.

The lower cone is fabricated from 36 formed segments welded together as shown in Figures 2-18. The cone is welded to the core support structure at the lower end and the reactor vessel at the upper end. The welds are all full penetration with welding performed from both sides of the cone.

The upper cone is fabricated from 120 formed segments and like the lower cone, the segments are welded together and fastened to the core support structure at the inner circumference, and to the reactor vessel at the outer circumference. Access holes are provided in the upper cone to facilitate full penetration welding from both sides. The access holes are closed and welded from the upper side only.

The two cones are stiffened and fastened together by 14 radial ribs and 98 longitudinal ribs. The ribs are joined by full penetration welds performed from both sides. Holes are provided in the ribs to provide access for welding.

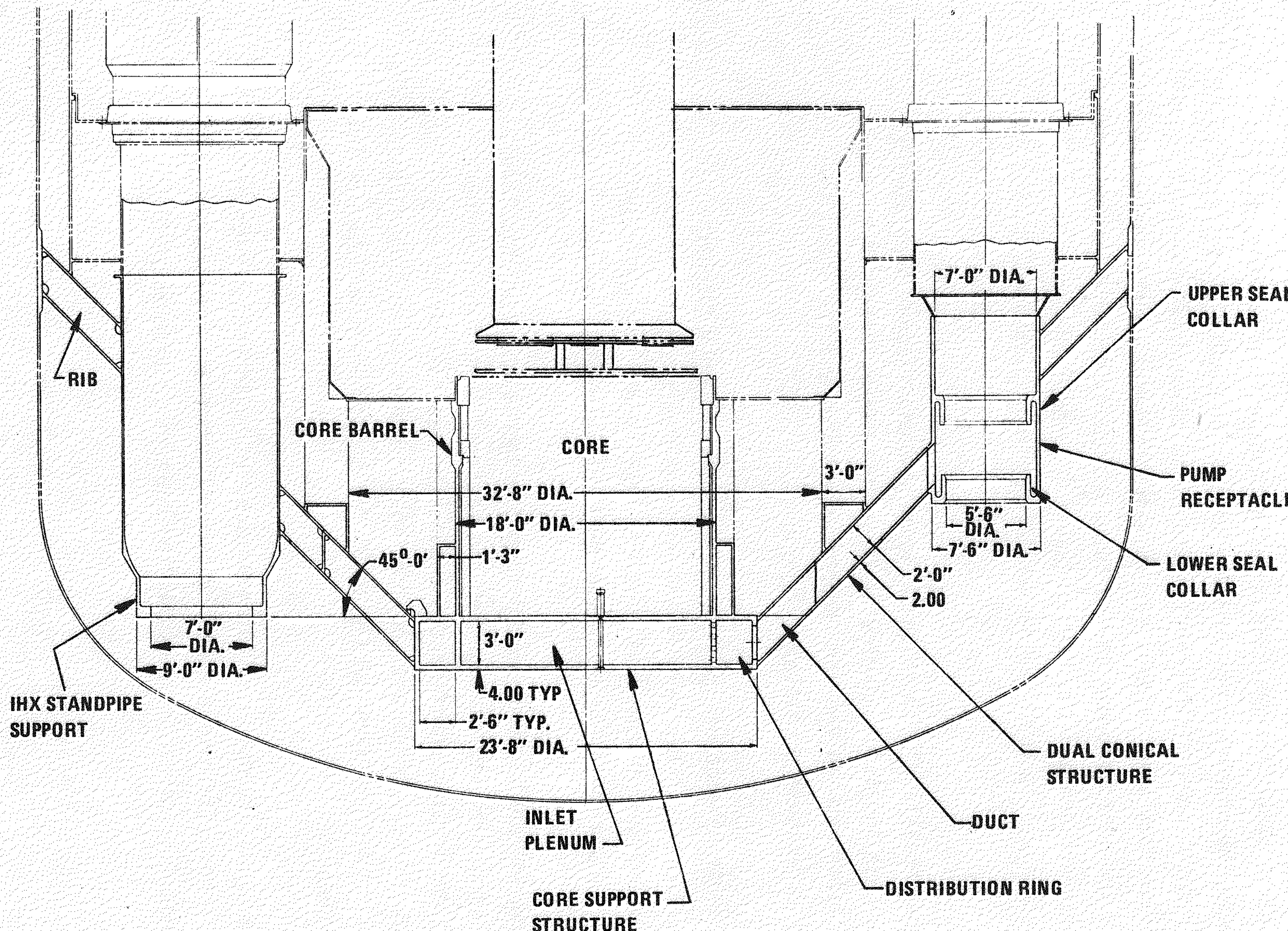

Figure 2-17. Lower Support Structure

Structural analysis performed on the conical structure/reactor vessel interface indicates that a concept with a dual conical structure extending all the way out to the reactor vessel is more desirable, from a stress standpoint, than a concept with a horizontal box structure between the conical structure and the vessel. The analytical results and conclusions are contained in A.3.2 of Appendix A. Due to the limited resources and time, no formal structural analysis was performed on the remainder of the LSS.

The fabricability of the dual conical structure was investigated. The results of the investigation indicate that the dual conical structure is complex, but it can be fabricated. A fabrication sequence is included in 4.6.7. It is planned in the future to further evaluate the fabricability of the dual conical structure with emphasis on making the weld joints more accessible and reducing the amount of steel in the structure.

Pump Receptacle

The four primary pump receptacles interface with the pumps and direct coolant flow to the LSS high pressure coolant ducts as shown in Figure 2-17. In addition to providing an enclosure for directing flow, the pump receptacle provides horizontal support for the bottom of the "simply supported" pump. Each receptacle is a hollow cylinder that includes a pump discharge annulus, upper and lower seal collars and a pump standpipe support. The lower seal collar interfaces with the bottom of the pump and forms part of the pressure boundary between the high pressure pump discharge and the cold plenum. The top seal collar forms part of the boundary between the high pressure pump discharge and the sodium coolant within the pump standpipe. The discharge annulus receives high pressure coolant from the pump discharge chamber and directs it to the ducts in the conical structure. The standpipe support extends above the upper seal collar and interfaces with and supports the pump standpipe in the plenum separator system. The standpipe support allows low temperature coolant that bypasses the upper seal collar to form an intermediate temperature zone between the pump discharge chamber and the coolant outside the standpipe.

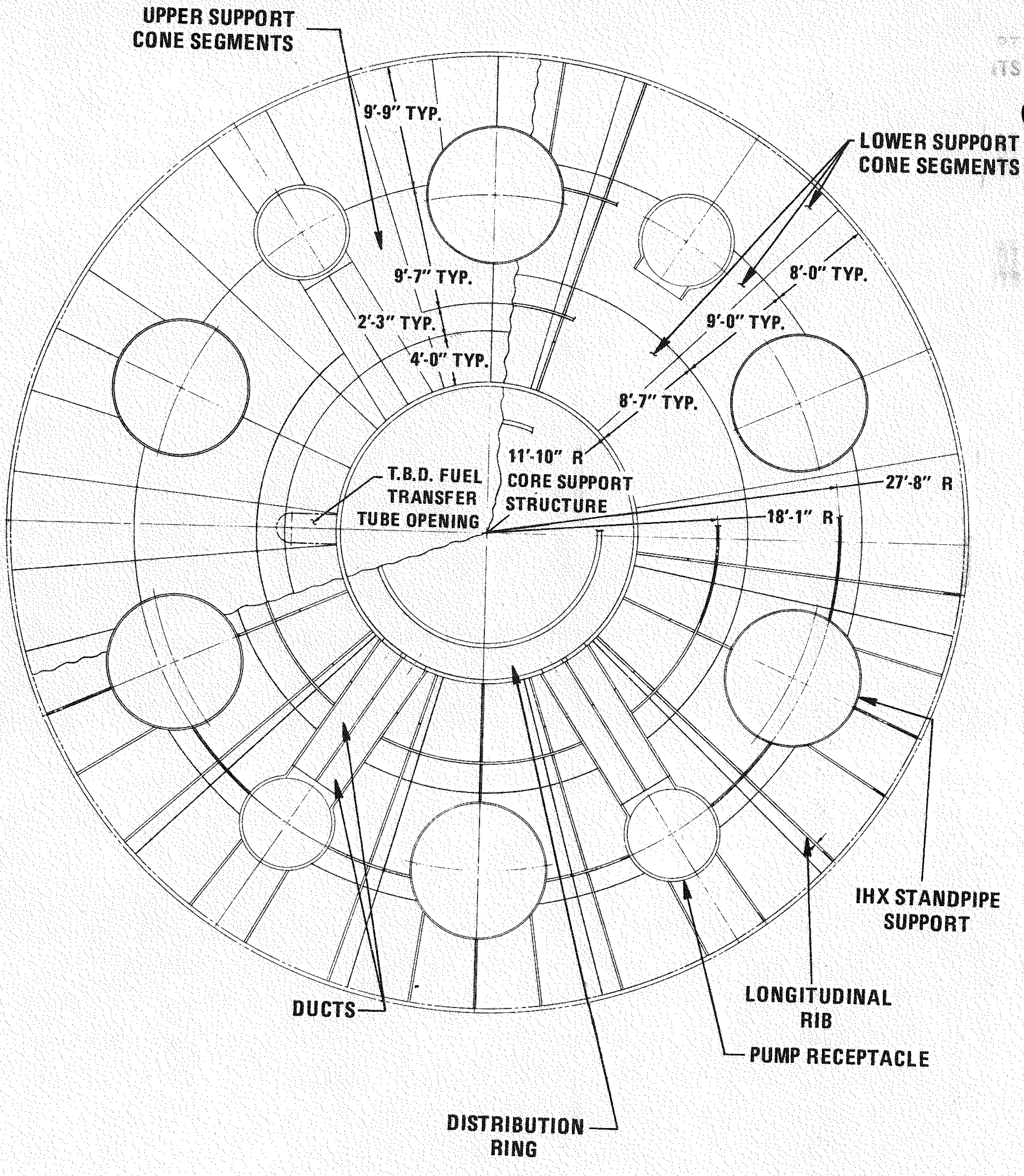

Figure 2-18. Lower Support Structure

IHX Standpipe Support

The six IHX standpipe supports are an integral part of the LSS. Each support is a hollow cylinder that is necked down at the lower end to facilitate sealing with the bottom of an IHX. The upper end has a flange that interfaces with and supports an IHX standpipe in the plenum separator system. The standpipe supports and standpipes, when combined with the IHXs, form a pressure and temperature boundary between the hot and cold sodium plena. An annulus is formed between the IHX housing and the standpipe to provide an intermediate temperature region between the tube bundle housing and the intermediate plenum.

The IHX standpipe support laterally restrains the bottom of the IHX during a seismic event. A seal is provided between the standpipe and the bottom of the IHX to prevent hot sodium coolant from bypassing the IHX and flowing into the cold plenum.

Core Support Structure

The core support structure (CSS) is a cylindrical structure that is welded to the center of the conical structure as shown in Figure 2-17. The CSS includes the coolant distribution ring, core inlet plenum and core barrel. A cylindrical shelf is included outside the core barrel to support the internal neutron shield. The coolant distribution ring is a rectangular cross section ring that receives coolant from the eight high pressure ducts and distributes the coolant to the core inlet plenum. The distribution ring is continuous and provides an intercommunicating passageway between the pumps so that if one pump should fail, the other pumps would provide adequate coolant to the core inlet plenum. The coolant flows from the distribution ring into the inlet plenum through holes in the inner wall of the distribution ring.

The core inlet plenum contains the removable inlet module assemblies shown in Figure 2-19. Each inlet module provides support, hydraulic hold-down and orificed flow to the individual core fuel, blanket, control rod and shield

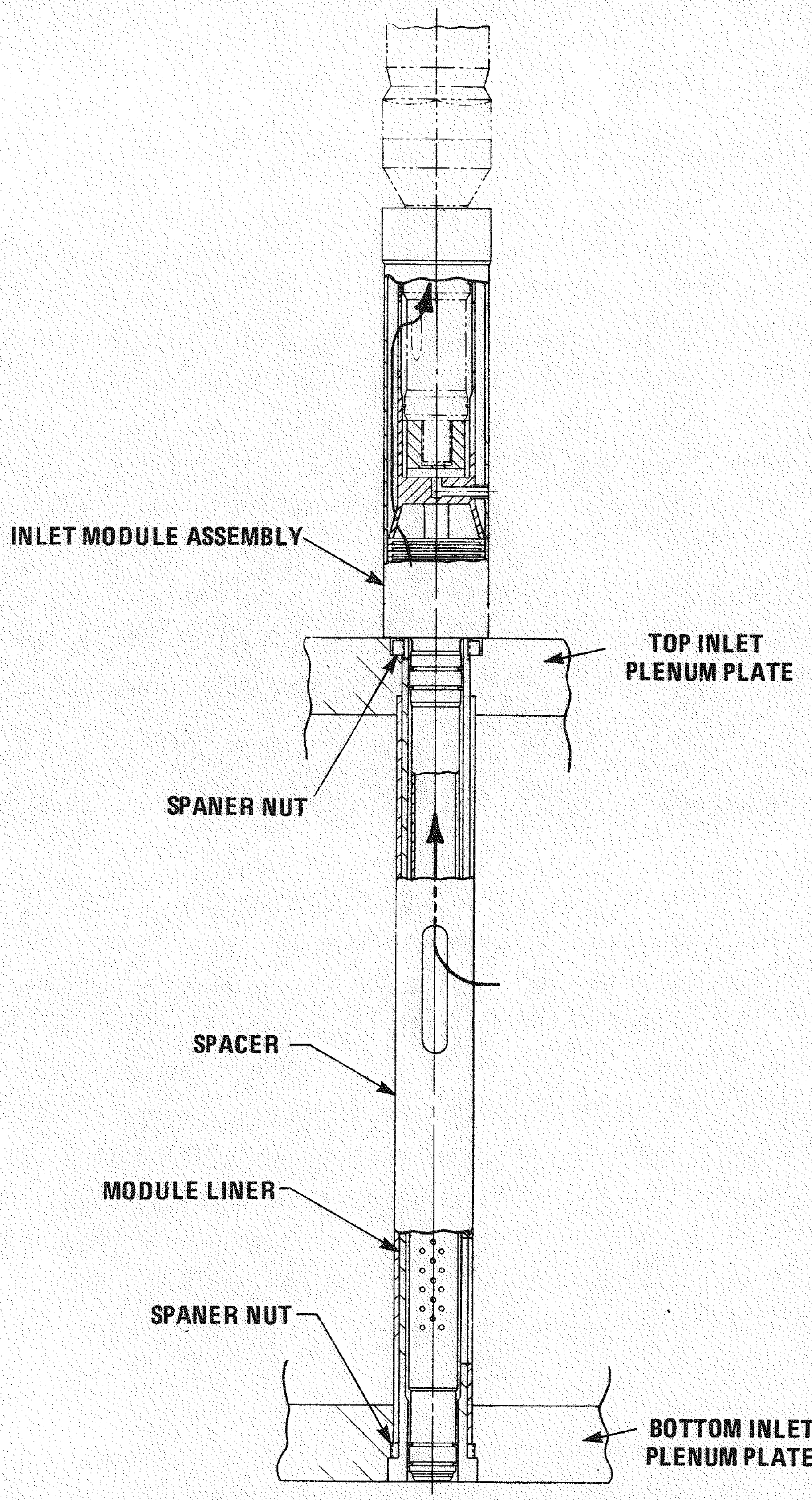

Figure 2-19. Removable Inlet Module

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assemblies. The inlet module seats on the top plate of the inlet plenum and fits down into a module liner. The module liners, in additon to providing a flow path to the inlet modules, tie the top and bottom inlet plenum plates together so that the plates have adequate strength to contain the high pressure coolant.

The core barrel is a cylinder above the core inlet plenum that supports the core restraint system. The core barrel, with its core restraint system, provides horizontal support for the core during refueling and reactor operations.

Core Drop Protection

Core drop protection is provided by a support arrangement between the core support structure and the conical structure and by the physical arrangement of the cone segments and reinforcing ribs within the conical structure. The support arrangement between the core support structure and the conical structure consists of an arrangement of load pads and lugs as shown in Figure 2-17. This arrangement is provided at 12 longitudinal rib locations at the conical-structure-to-core-support-structure interface. The load pads are welded to the upper cone segments over the longitudinal ribs. The 4.0 in thick lugs are welded to the top plate of the core support structure. A 0.03 in gap is provided between the lug and load pad surfaces during fabrication so that no load is supported by the lugs unless the core support structure to conical structure welds fail.

The physical arrangement of the cone segments and reinforcing ribs protect against a complete failure of the LSS due to crack propagation. This is accomplished by arranging the longitudinal weld joints in the conical structure so that they are not in the same plane. By placing the cone segment and rib weld joints in different planes and separating the cones with the ribs, it is difficult for a crack to propagate from one cone to the other. In the unlikely event that a crack should propagate within one cone, the ribs also act as tie plates or shear panels to prevent the LSS from failing completely. It should be emphasized that past experience indicates it is very unlikely that a failure would occur in welded stainless steel due to crack propagation.

2.3.6 INTERMEDIATE HEAT EXCHANGERS

Six Intermediate Heat Exchangers (IHX) are provided to transfer the reactor generated heat from the primary to the secondary heat transport systems. These units, which are hung from the reactor vessel deck into the primary sodium pool, also house the Passive Residual Heat Removal System (RHR-P) cooling coils.

2.3.6.1 FUNCTION

The function of the IHX units is to transfer heat from the primary pool to the intermediate loop while isolating the primary sodium from the secondary sodium, thereby preventing the transport of radioactive primary sodium and its associated corrosion and fission products out of the reactor containment building. Each unit transfers 428 megawatts thermal at the design conditions listed in Table 2-4. To insure sufficient effective heat transfer area throughout the service life, excess heat transfer area is provided to reasonably account for possible tube plugging, heat transfer surface fouling and other uncertainties that could effect heat transfer. Because of the effect it has on pool pressure levels and the resultant impact on the pool design, the IHX is designed for as low a primary side pressure drop as is reasonable. The design allowance for the primary pressure drop is 3 psi. The geometry, layout and location of the IHX within the pool are selected to promote natural circulation of both primary and secondary sodium in the normal flow direction, should all pumping power be lost. The IHX units also function to house the RHR-P cooling coils within the normal primary sodium coolant flow path in such a manner as to promote natural circulation cooling within the RHR-P. Each IHX is designed to be removable from the pool in order that maintenance can be performed when required.

TABLE 2-4

IHX THERMAL DESIGN CONDITIONS

Parameter	Value
Thermal Power, Mwt	428
Primary Inlet Temperature, ^{o}F	935
Primary Outlet Temperature, ^{o}F	665
Primary Sodium Flow Rate (Tube Side), Lbs/Hr	17.67×10^{6}
Intermediate Inlet Temperature, ^{o}F	606
Intermediate Outlet Temperature, ^{o}F	900
Secondary Sodium Flow Rate (Shell Side), Lbs/Hr	16.25×10^{6}

2.3.6.2 DESCRIPTION

The IHX (Figure 2-20) is a counterflow shell and tube type heat exchanger, which is designed for operation in the vertical position. The IHX employs a straight tube design with a central downcomer. The primary sodium flow is on the tube side, while the secondary sodium flow is on the shell side of the heat exchanger. The unit is supported from the reactor vessel deck by a hanging cylindrical support structure and is capable of being removed from the pool for purposes of maintenance or replacement. Each IHX is contained within a standpipe which connects the hot plenum of the pool with the cold plenum. The significant IHX design characteristics are found in Table 2-5.

The primary sodium leaving the hot plenum enters the annulus formed by the IHX standpipe and the support cylindrical structure and flows downward to an elevation above the upper tube sheet, makes a 90^{0} turn through openings provided in the support cylinder, and enters the plenum above the upper tube sheet. It again flows downward over the RHR-P cooling coils to the upper tube sheet, where it enters the tubes. The sodium then flows through the tubes to the lower tube sheet where the streams come together in the lower plenum. The primary sodium exits the IHX through the lower nozzle and enters the cold plenum region of the reactor.

The secondary sodium enters the central downcomer through the vertically oriented inlet nozzle. It flows downward through the downcomer, makes a 180^{0} turn through openings in the tube bundle shroud, and then flows upward through the bundle where the flow is distributed by support/flow plates. At the top of the bundle the sodium is collected in an annular flow space surrounding the central downcomer. The sodium then flows upward through the annular flow space, makes a 90^{0} turn at the top of the IHX and exits through the horizontally oriented secondary outlet nozzle. Both intermediate system coolant nozzles (inlet and outlet) are 26 in OD

The tube bundle consists of 5480 straight tubes, which have a 0.875 in OD and are located on a triangular pitch of 1.3125 in. The active tube length is 25 ft with a tube bundle length of 27 ft over the tube sheets. The

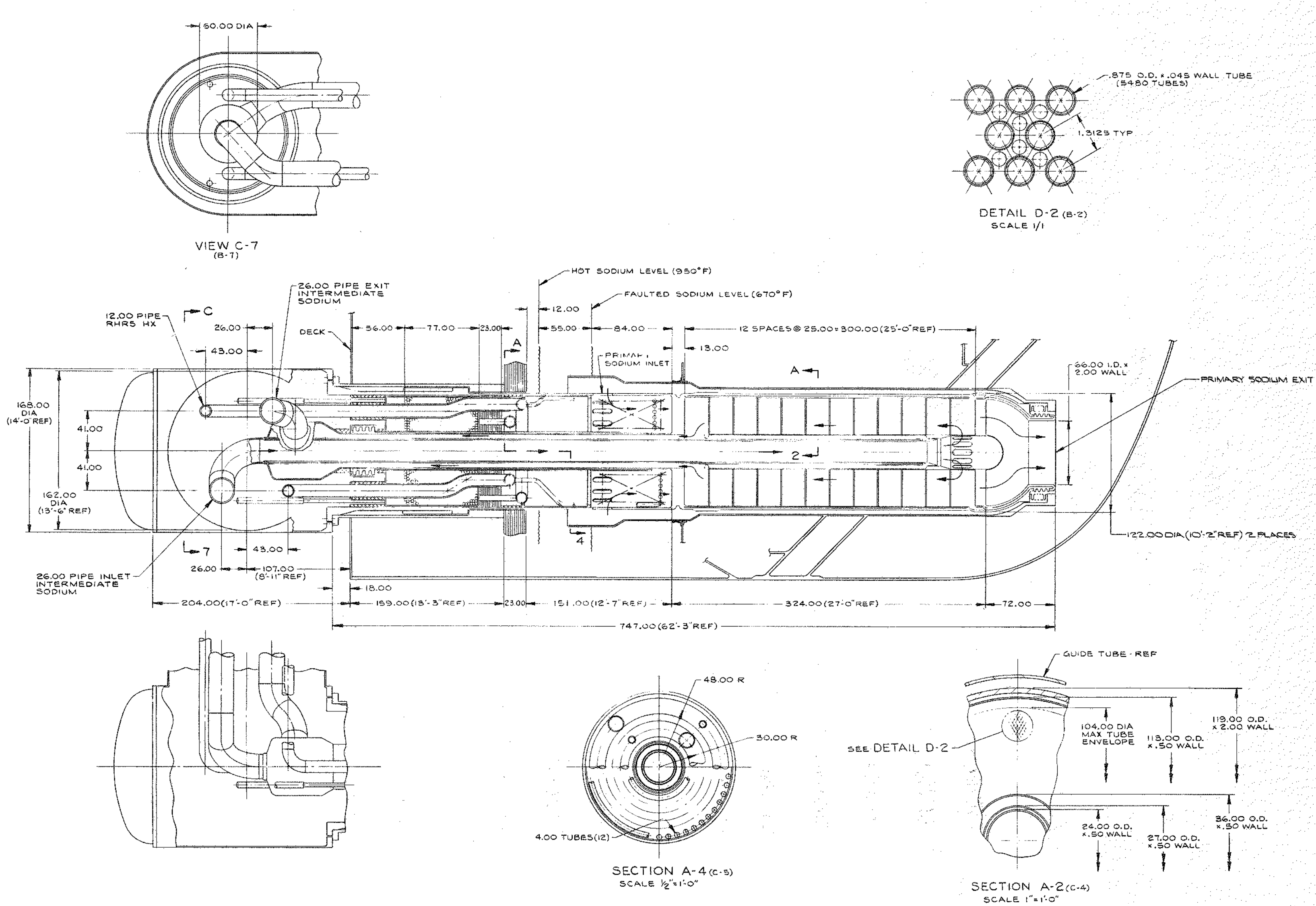

Figure 2-20. LPR Intermediate Heat Exchanger Conceptual Design

TABLE 2-5

IHX DESIGN CHARACTERISTICS

Parameter	Value
Thermal Rating, Mwt	428
LMTD, ^{o}F	45.5
Primary ΔP, psi	1.7
Secondary ΔP, psi	$\sim$20
Number of Tubes	5480
Tube OD, In.	0.875
Tube Wall Thickness, In.	0.045
Pitch, In.	1.3125
Tube Length, Ft.	25
Heat Transfer Surface Area, Ft^2	31,300
L/D	2.75
Overall Length, Ft.	$\sim$69
Approximate Dry Weight, Lb	490,000

bundle includes allowances in length and extra tubes for design uncertainties and potential losses in heat transfer area due to fouling and plugging of tubes. Support/flow plates are provided within the bundle for both tube support and to insure the flow distribution of the secondary sodium, which is required for the necessary thermal balance in a straight tube exchanger design. The upper tube sheet is fixed and is supported by the support cylinder, while the bottom tube sheet is free to move axially and is supported by the tubes. Differential expansion between the tubes and the shell is accommodated by a bellows located in the primary outlet nozzle region.

The tube bundle is surrounded by a shell which is protected by an outer bundle shroud. The shroud is fixed at the upper tube sheet and floats at the lower end of the bundle. The central downcomer is also protected by a liner. This assembly is provided with a piston ring type seal between it and the inner bundle shroud at its lower end. This seal minimizes bypass flow of the secondary sodium. The lower outlet plenum region is constructed of a hemispherical head fixed to the lower tubesheet with a vertical primary discharge nozzle at the bottom of the exchanger. Lateral restraints are provided at various locations between the concentric cylindrical structures described above to minimize vibrations within the unit.

The cylindrical support structure is hung from the reactor vessel deck by a flanged and bolted connection. This structure contains a shield plug where it penetrates the deck structure. The plug contains shielding material similar to the surrounding deck shielding arrangement. Attached to the bottom of the plug is a thermal barrier of reflective plate insulation, again similar to the surrounding deck insulation arrangement. The plug is stepped and is provided with localized shielding to prevent radiation streaming at penetration locations. Expansion bellows are provided between the secondary flow path structure and the shield plug to accommodate differential thermal expansion. To minimize the potential for sodium fire in containment, an inerted (nitrogen) housing surrounds the IHX flange and the secondary piping/nozzle connection region.

The IHX is designed to allow secondary side draining and venting. Drainage of secondary sodium can be accomplished by insertion of a drain tube down the central downcomer into the depressed region below the lower tubesheet. Vent/drain holes are provided where required within the bundle/shroud structures to allow drainage and prevent trapping of gas during filling. Primary draining occurs through the primary outlet nozzle upon removal of the IHX from the pool.

Integrally attached to the bottom plenum head of the IHX is a bellows face seal. This seal mates to a seal surface, which is integral with the lower end of the IHX standpipe, and restricts bypass leakage from the hot pool to the cold pool through the annular clearance between the IHX shell and the standpipe. Lateral restraints are also provided at the bottom plenum head to take seismic forces at this location. These loads are transmitted to the bottom of the IHX standpipe which provides the necessary support for the lateral seismic loads.

Each IHX is equipped with a valve, which permits isolation of the primary coolant circuit in any loop. The corresponding secondary loop can then be shut down for maintenance or other special operations. The reference valve concept employed is a sliding sleeve valve. The travel for this valve is approximately two feet. The valve is composed of a cylindrical sleeve that fits within the upper support cylinder. When actuated, the sleeve travels vertically downward to cover the primary flow opening in the support cylinder. In the reference concept the sleeve has piston ring type seals at the upper and lower ends to prevent bypass flow between the sleeve and the support cylinder. The valve is actuated by two electrically operated mechanisms, which are controlled to operate together. Remote operation capability is required as the region at the top of the IHX plug is normally inerted. Although a specific mechanism design has not yet been chosen, an electric motor capable of fine control with a ball/screw type drive is presently under consideration.

Each IHX houses a RHR-P cooling coil. The coil is located within the primary inlet plenum above the upper tube sheet. The elevation of the coil in this region is such that it is located below the faulted sodium level and therefore is always submerged in the primary coolant flow path under all possible conditions. The coil is composed of 12 - 4 in OD tubes coiled in a helical manner within the space between the secondary downcomer/exit annulus structure and the IHX support cylinder. The coiled tubes are connected to 12 in diameter coolant inlet and outlet headers. The headers, which are hung from the shield plug, are connected to inlet and outlet lines which penetrate the shield plug and which in turn are connected to the RHR-P coolant piping in the region above the plug. Coolant from the cold leg of the system enters the downcomer line and flows down to the inlet header, where it is distributed to the tubes. Flow is down through the tubes to the bottom of the coil, where it then rises as it is heated within the helically coiled tubes. Hot coolant is discharged from the tubes into the exit header and then flows up the outlet line to the RHR-P hot leg piping. Primary sodium flows downward over the coiled tubes in its normal flow path. The RHR-P coils are designed for natural circulation flow.

2.3.7 PRIMARY PUMPS

2.3.7.1 FUNCTION

The primary pump is the prime mover of sodium coolant in the pool. It takes its suction upward from the cold pool below the core support structure, and discharges the high pressure sodium downward and into the high pressure chambers located in the core support structure. This system feeds the high pressure sodium into the core inlet plenum. The pump is designed to deliver a flow of 26.5 x 10^6 lb/hr (approximately 61600 gpm) at a total dynamic head of 120 psi (approximately 334 ft).

2.3.7.2 DESCRIPTION

The LPR Primary Pump concept is shown in Figure 2-21. Westinghouse has selected a bottom suction, two stage primary pump which, both hydraulically

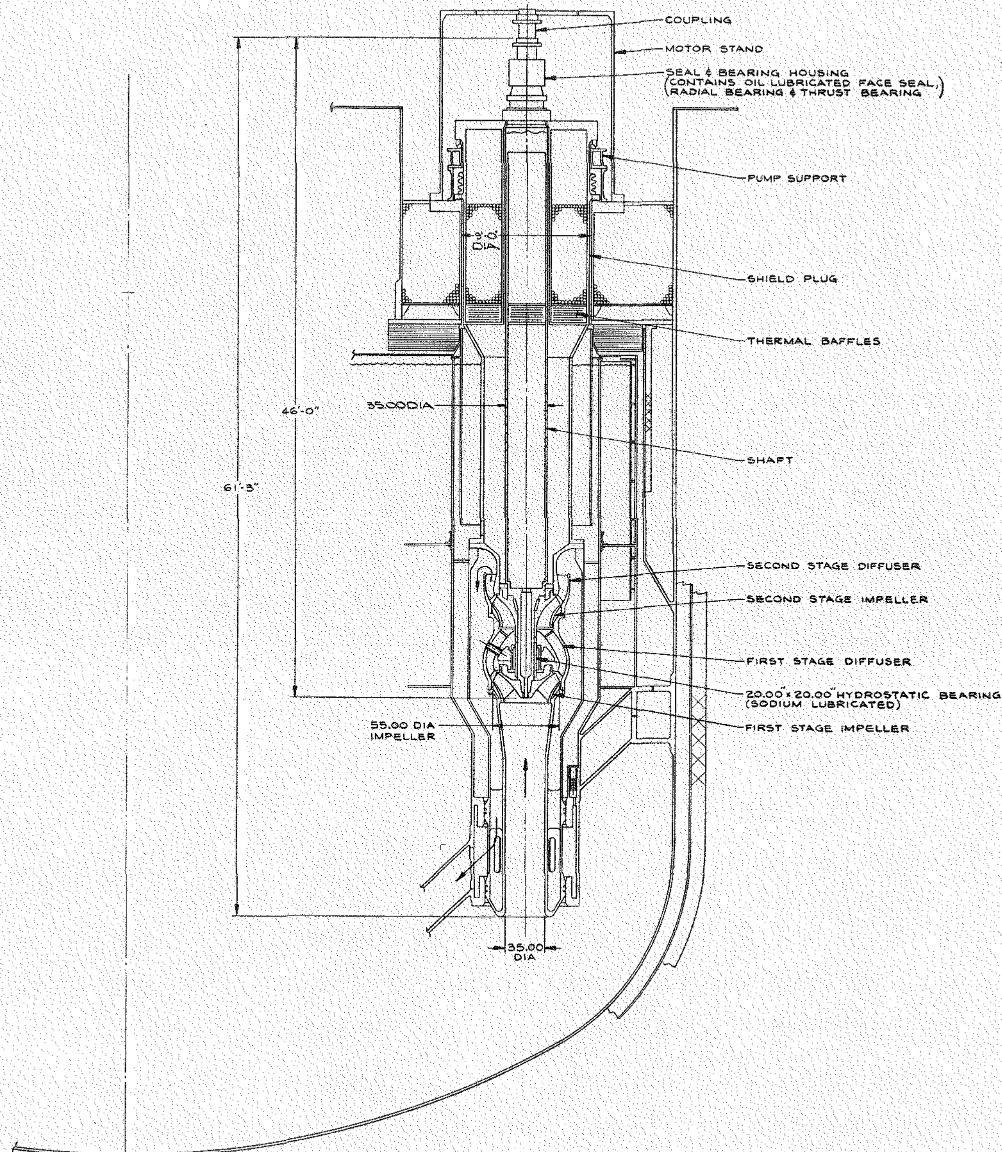

Figure 2-21. Large Pool Reactor Primary System Pump Concept

and mechanically, is similar to the two stage pump proposed by Westinghouse Electro-Mechanical Division in the Large Sodium Pump Development Program currently in progress for DOE.

The pump internal assembly, which is located in a pump standpipe penetrating the hot pool, has a central suction pipe and an annular discharge pipe which plugs into the lower support structure. The pump flange is supported in a well in the reactor deck. The suction pipe, which attaches directly to the static hydraulic assembly, takes sodium from the cold pool below the lower support structure and feeds it into the first stage impeller eye. The first stage impeller discharges into the first stage diffuser assembly, which converts the fluid velocity head to static pressure and feeds the fluid into the eye of the second stage impeller. The second stage impeller discharges into the second stage diffuser which discharges into the high pressure annulus. The first and second stage impellers each provide approximately half the head rise of the pump. The two impellers are located on a common shaft, which is supported by a sodium lubricated hydrostatic bearing located between the two impellers, and an oil lubricated radial and thrust bearing located above the pump flange.

The upper and lower impellers are stainless steel castings with an outside diameter of approximately 55 in. The basic design consists of six vanes, and the rotation is couterclockwise when viewed from the top. Each impeller is shrunk to the shaft at different shaft diameters, and is held in place by an impeller key and nut.

The pump first and second stage diffuser assemblies are designed with 12 vanes, and cast from stainless steel. The first stage diffuser is located between the first and second impeller, and the sodium lubricated bearing is mounted to the inner diameter of this component. The bearing is supplied with sodium at full second stage discharge pressure via feed tubes which bridge the inner and outer diffuser shrouds. The first stage diffuser bolts to the second stage diffuser, which is located above the second stage impeller. It incorporates a 180^{0} flow turning surface at the exit, and is bolted to the pump support cylinder. The upper end of the support cylinder consists of a thermal baffle region and a shield plug, and is welded to the pump flange.

The shaft is designed to have a lateral critical speed in excess of 125 percent of design speed. Additional design considerations include drive torque requirements, bearing loads, thermal shock, thermal convection, external pressure loads on the torqe tube, and dynamic balance. The shaft consists of three major parts (upper and lower end forgings, and the torque tube) which are welded together. Shaft design and manufacturing is based on the development of the FFTF primary pump shaft.

The shaft seal assembly consists of a gas buffered labyrinth seal and three oil lubricated face-type seals with a stationary carbon-graphite seal ring running against a steel runner, and a radial wiper seal to contain the lubricating and pressure retaining environment. This system is similar to that successfully demonstrated for the FFTF pumps. The basic function of the seal system is to retain pressure and circulate lubricant to remove heat which is conducted up from the sodium pool.

The oil lubricated radial and thrust bearings are located above the oil seal system.

With the motor support mounted to the deck, and a compliant support arrangement for the pump, various degrees of misalignment between the motor shaft and the pump shaft can exist (depending on the temperature difference between the core support structure and the deck). A study of the out-of-plumb effect of the pump shaft shows that the hydrostatic bearing performance on pony motor is limiting. Assuming a pony motor speed of 7 percent of design speed, calculations show up to $1/8^{0}$ out-of-plumb will allow acceptable hydrostatic bearing performance on pony motor at all operating conditions from shutoff to (N-1) loop runout flows.

The connection between the pump shaft and the drive motor shaft is provided by a commercially available gear type flexible coupling. Typically this coupling can accommodate total shaft misalignments (angular and lateral) of up to 1-1/2^{o}. This type of coupling is especially advantageous for operation on pony motor speed, since it produces very low side loads on the shaft as a result of misalignment.

ARD has chosen a 7000 horsepower Squirrel Cage Induction Motor for variable speed operation, and a design speed of 492 rpm. The motor is powered from a 3 phase, 60 hz, 13.8 KV power supply.

2.3.7.3 HYDRAULIC CHARACTERISTICS

There is some difference in the hydraulic design approach for primary pumps in a piped system as compared with a pool reactor. The piped primary system normally provides lower Net Suction Pressure Head (NPSH) than the pool pump, which results in a design with relatively high Suction Specific Speed. It is noted that some of the loop type primary pumps are operating with small amounts of cavitation on the inlet vanes. For the pool type reactors the NPSH for the pumps is usually higher.

Also it is required that no cavitation shall take place in the pump, since cavitation generates a noise signature which could be confusing with other noises in the pool. Accordingly, pool primary pump designs use a conservative suction specific speed. ARD has chosen a Suction Specific Speed of approximately 6500 for their primary pump, which yields a conservative pump design in terms of cavitation damage, and a low noise pump.

The hydraulic design point is a flowrate of 61600 gpm, a total dynamic head of 334 ft of sodium at a pump speed of 492 rpm. The hydraulics are designed to have a negative pump characteristic within the expected operating envelope of the pump, which extends from a conservatively high design resistance, to operating resistance with reverse flow leakage through a stopped pump (N-1 operation).

2.3.7.4 LOWER BEARING

The lower bearing is located between the impellers for the first and second stages of the pump. Support for the lower bearing is provided by the first stage diffuser casting. Considerable care has been exercised to assure a bearing support configuration that provides the necessary back-up stiffness required to ensure proper dynamics characteristics, and at the same time, be insensitive to differential thermal expansion between the bearing and the more massive bearing support.

The sodium bearing is a 20 by 20 in FFTF type hydrostatic bearing with four deep pockets. A standard radius to clearance ratio (R/C) of 500, yields a bearing with sufficient stiffness at both main motor and pony motor operations.

High pressure sodium from the outlet of the second stage diffuser enters the bearing feed supply reservoir through flow passages provided through the first stage diffuser. The supply reservoir is located in an annulus between the first stage diffuser and the bearing, and serves the purpose of attenuating the flow turbulence and allowing debris to settle out before sodium is fed to the bearing.

2.3.7.5 METHOD OF SUPPORT

The LPR plug-in pump concept requirés a compliant pump support to accomodate the thermal expansion difference between the deck and the core support structure, during heat-up, cooldown and thermal transients. The current reference concept is shown on Figure 2-21.

The support consists of a spherical seat at the upper support, which allows the pump to rotate in a vertical plane to take up radial differential expansion of 1.7 in which occurs between the cold 110^{o}F carbon steel deck, and the hot 670^{o}F stainless steel lower support structure. The lower lateral support is provided by plugging the pump nozzle into a receptacle in the lower support structure, and allowing sufficient clearance between the pump nozzle and the receptacle to prevent binding during the differential thermal movements. Piston rings are provided to seal the pump nozzle where it plugs into the lower support structure. A more detailed description and analysis of this reference support is provided in 2.3.8.1.

2.3.7.6 PUMP ISOLATION

An assessment has been made to determine the need for a valve in the primary pump. This assessment mainly includes hydraulic considerations, and the ability of the remaining pumps to operate when one pump is stopped. This situation can result in a substantial reverse flow through the stopped impeller, and the remaining pumps then operate on a lower impedance line. The amount of leakage through the stopped rotor is determined by the reverse flow impedance of a particular pump. A good correlation exists between the specific speed of a pump design and its stopped rotor reverse flow impedance. Table 2-6 below indicates this:

TABLE 2-6
LOCKED ROTOR FLOW IMPEDANCE

Specific Speed	ΔP at -100% flow
7500 (mixed flow)	230%
1800 (double suction)	70%

For the Westinghouse pump design, each impeller stage has a specific speed of 2630. It is therefore conservatively assumed that the reverse flow pressure drop is 100% of the design head at design flow.

Figure 2-22 shows the calculated design impedance curve, the (N-1) impedance curve with a valve, and the N-1 impedance curve with leakage through a stopped rotor. For the situation with a valve preventing reverse flow through the stopped rotor, the core flow is approximately 90 percent of design if the remaining pumps continued at design speed. For the situation without a valve, the core flow is 70 percent of design flow, with a leakage flow through the stopped pump of approximately 22 percent of total design flow for the primary system.

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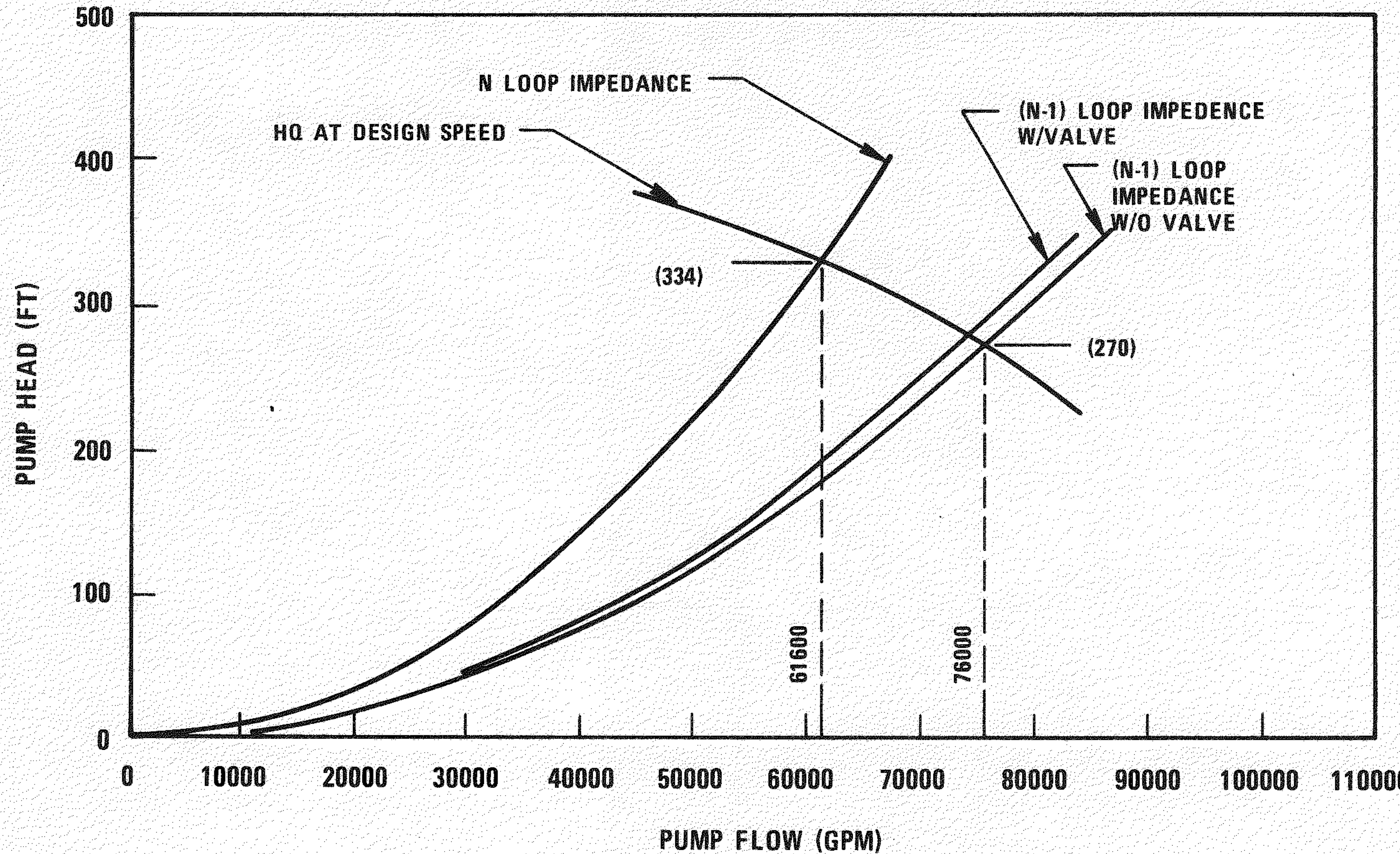

Figure 2-22. Primary System Impedance Curves

A reverse flow leakage through the stopped pump is short-circuiting the cold pool high and low pressure regions. In terms of total plant performance, only a slight loss in efficiency results from the increased pumping losses associated with this leakage. For operation on N-1 loops, the main difference is that of 90 percent verses 70 percent of full power capability, when comparing core flows with and without a valve in the pump. Also, the valve adds flexibility to the pool operation, especially in the area of single pump start-up. The decision of whether or not to incorporate a valve in the primary system pump has to be based on a tradeoff between the operational advantages and the cost of installing and maintaining the valve.

2.3.8 COMPONENT SUPPORTS

Component support studies have been limited to the two major components i.e., the primary coolant pumps and the intermediate heat exchangers (IHX). The main problem to be overcome in both cases is to provide adequate lateral and vertical support to resist seismic forces, and at the same time, provide sufficient flexibility to cater for differential thermal movements between the upper and lower supports. Differential thermal movement of the supports takes place in both the horizontal and vertical direction. The horizontal movement due to the difference in temperature between the deck and the lower support structure is the more difficult of the two thermal movements to accommodate. Support methods are described in the following sections.

2.3.8.1 PRIMARY PUMP SUPPORT

The basic concept selected for pump support, shown in Figure 2-23, provides a tight "pinned" support at the upper end and a loose simple support at the lower end. The purpose of this system of support is to provide adequate restraint to the pump under both operating and seismic conditions, to allow for axial and radial thermal differential movements, and to facilitate removal of the pump for maintenance.

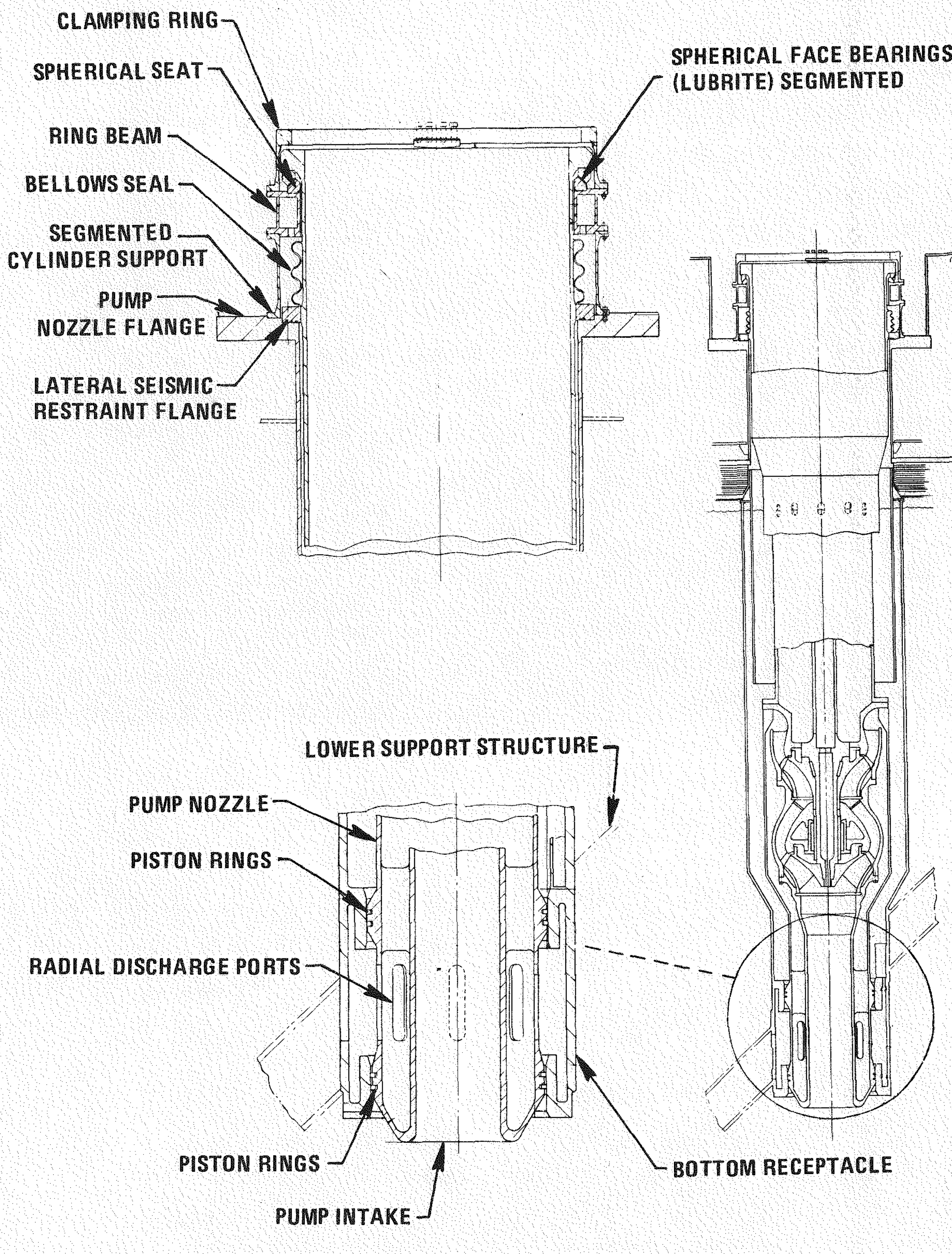

Figure 2-23. Pump Support

The above mentioned system of support is accomplished by providing a spherical seat at the upper pump support, which allows the pump to rotate in a vertical plane to take up radial differential expansion of 1.7 in which occurs between the "cold" 110^{o}F carbon steel deck and the "hot" 670^{o}F stainless steel lower support structure. Under certain transient conditions, the lower support structure may go as high as 800^{o}F, and the differential radial expansion is then 2.1 in. Therefore, 2.1 in is used as the design condition. This deflection does not account for deflections and/or rotations that can occur due to mechanical loads or thermal gradients. Response motions have not been defined but can be incorporated into the design if they are found to be significant. The lower lateral support is provided by plugging the pump nozzle into a suitable receptacle in the lower support structure and allowing sufficient clearance between the pump nozzle and the receptacle to prevent binding during the differential radial movement between the lower support structure and the deck. The pump can expand freely through the receptacle in the axial direction. The differential expansion is calculated to be 1.0 in. The design allows for over 3 in of axial movement. Piston rings are used to seal the pump nozzle to the lower support structure.

Scoping stress analysis has been carried out and the design concept is judged to be viable. Further design refinements are required to reduce stresses at some locations, but these are considered to be within the scope of the normal design evolution process. The scoping stress analysis report can be found in Appendix A.

<u>Upper Support</u>

The pump is supported by a spherical seat which allows movement as previously described. This bearing surface is lubricated using Lubrite, which is a pad of fibre impregnated with teflon, and fits between the metallic spherical seating faces. Lubrite is capable of taking bearing pressures up to 6,000 psi, with minimum friction occurring at bearing pressures between 2,000 and 4,000 psi. In this particular application, the bearing pressure is expected to be less than 1,000 psi. The spherical seating transmits the load from the pump, through a ringbeam, to a segmented cylindrical support, and into the flange of the pump nozzle which is a structural part of the deck. Lateral seismic restraint is provided by a flange bolted to the pump nozzle flange, and positioned so that it is in the same horizontal plane as the center of rotation of the spherical seat. There is no lateral movement of the pump casing at this plane when the pump casing moves to take up thermal expansion and, in doing so, rotates a small amount on its spherical seat. Thus, the flange providing lateral restraint is a close clearance fit around a circumferential load pad on the pump casing. This flange also serves to carry the O-ring seals and the bellows seal which seal the primary boundary. It is important from a stress point of view to limit the lateral movement of the bellows, and by mounting it as near to this plane of zero horizontal movement as possible, the stresses are kept to acceptable levels.

Downward seismic restraint is provided by the spherical seat. Upward seismic restraint is provided by a clamping ring secured to the ringbeam support, which provides a clamping restraint at points perpendicular to the radial centerline passing through the pumps and the reactor center. By clamping at these points, the pump is restrained against vertical motion, but is still free to move on its spherical seat to take up reactor differential expansion in the radial direction. Pump weight is approximately 75 tons. The object of this clamping load is to provide a force at the spherical seat such that a vertical 2 g seismic load does not cause separation at the seat. Differential expansion between the deck and the pump lower support causes a sliding motion on the spherical seat and between the clamp and the top of the pump. In examining the loads and stresses which result from this differential expansion, a coefficient of friction of 0.02 is used at the spherical Lubrite seat. The force due to friction that would be resisting motion at the clamp is of the order of 45,000 lb. The force resisting motion at the Lubrite spherical seat is 2. x 2120 lbs, which is small by comparison to the friction at the clamp. A force of 7450 lb (see Figure 2-24) is required on the pump at the pump lower support to cause the top support to function correctly and rotate on its

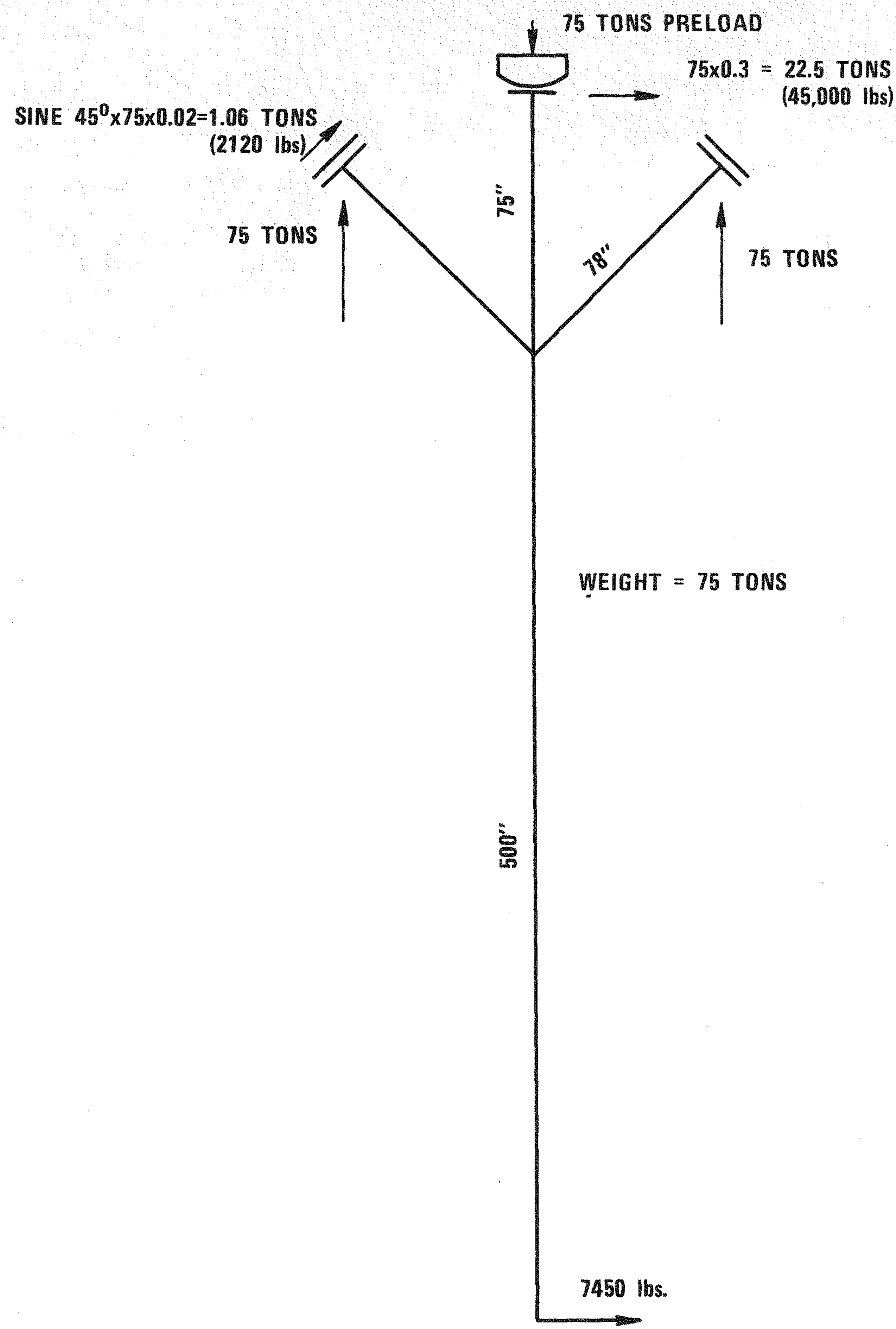

Figure 2-24. Pump Support - Force Diagram

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spherical seat overcoming the friction at the clamp. This loading condition induces a stress of only 250 psi in the pump casing and is therefore considered not to be a problem.

It is noted that when the radial differential motion takes place, there is a resultant vertical movement of the flange being clamped. This vertical motion adds slightly to the loads. However, the relative motion between clamp and flange is only 0.000079 in, which is so slight that the increase in frictional resistance to motion is negligible.

Lower Support

At the lower end, the pump nozzle is supported by plugging it into the lower support structure. This allows free axial expansion and provides simple support in the lateral direction. By allowing sufficient clearance between the pump nozzle and the receptacle in the lower support structure, the pump moves on its upper spherical support to take up the differences in thermal expansion between the deck and the lower support structure. To reduce leakage due to the clearance between the pump nozzle and the receptacle, piston rings are employed. The design allowable leakage past the piston rings is arbitrarily set at 6 gallons per minute per set of rings, or 12 gallons per minute per pump. These leakage rates are ten times greater than rates quoted by the manufacturer of similar rings which are used for the FFTF core basket. Typically one pump delivers approximately 62,000 gallons per minute at full flow, so it can be seen that the leakage represents a very small part of the pump flow and has little effect on core mixed mean outlet temperature or loss of pumping power. The piston rings are part of the pump nozzle and are therefore removable with the pump. To minimize the clearance necessary at the lower support receptacle and thus reduce the leakage and possible vibration, the nominal position of the bottom receptacle is off-set toward the reactor centerline by half the amount of the differential movement between the lower support structure and the deck. This has the effect of off-setting the pump centerline by 0^{o}-5' in the cold condition, going through the vertical to 0^{o}-3' at normal operating conditions, and to 0^{o}-5' at the maximum transient condition. This effect of reducing the clearances and minimizing the out of verticality is illustrated by comparing Figure 2-25-A with Figure 2-25-B. Discussions with the pump manufacturer have established that the pump will function satisfactorily with the shaft vertical within ± 8 minutes based on a pony motor speed of 7 percent. At faster shaft speeds, a larger tolerance on verticality is possible. LPR is considering a pony motor speed of 10 percent, thus the question of pump shaft verticality is not a problem.

Alternately, the pump shaft could be offset by 0^{o}-8' in the cold condition, see Figure 2-25-C to theoretically allow the pump centerline to be vertical during normal operating conditions.

Lateral load on the bottom of the pump due to the non-symmetric discharge of flow is expected to force the pump to its extreme limit of radial travel. This hydraulic effect is present in all the alternates illustrated in Figure 2-25-A, B and C, but is omitted from the figures for clarity. The hydraulic force varies from zero at zero pump speed to a maximum at full speed. Therefore at pony motor speed the effect is small and at normal operating speed, the force is sufficient to force the pump nozzle over until it contacts the side of the piston ring housing. It is concluded that at this stage in the design study the system illustrated in Figure 2-25-B is satisfactory and should be used. It is recognized that further refinements on pump verticality can be made, if necessary, as the design proceeds.

Wear of the piston rings and the receptacle in which they operate is not expected to be a problem. Material tests conducted for FFTF piston rings have established suitable material combinations for rings and mating cylinders that resist galling and wear in sodium at these temperatures. An alloy steel SA 453 (A 286) grade 660 piston ring in a stainless steel cylindrical receptacle is one possible combination for this purpose. To satisfy concerns in this respect, wear tests could be run simulating the flow conditions that would be anticipated to occur over the life of the plant. The receptacle providing the lower pump support could be made removable to facilitate recovery if a problem were incurred; however, the additional design complexity is not considered to be justified at this time.

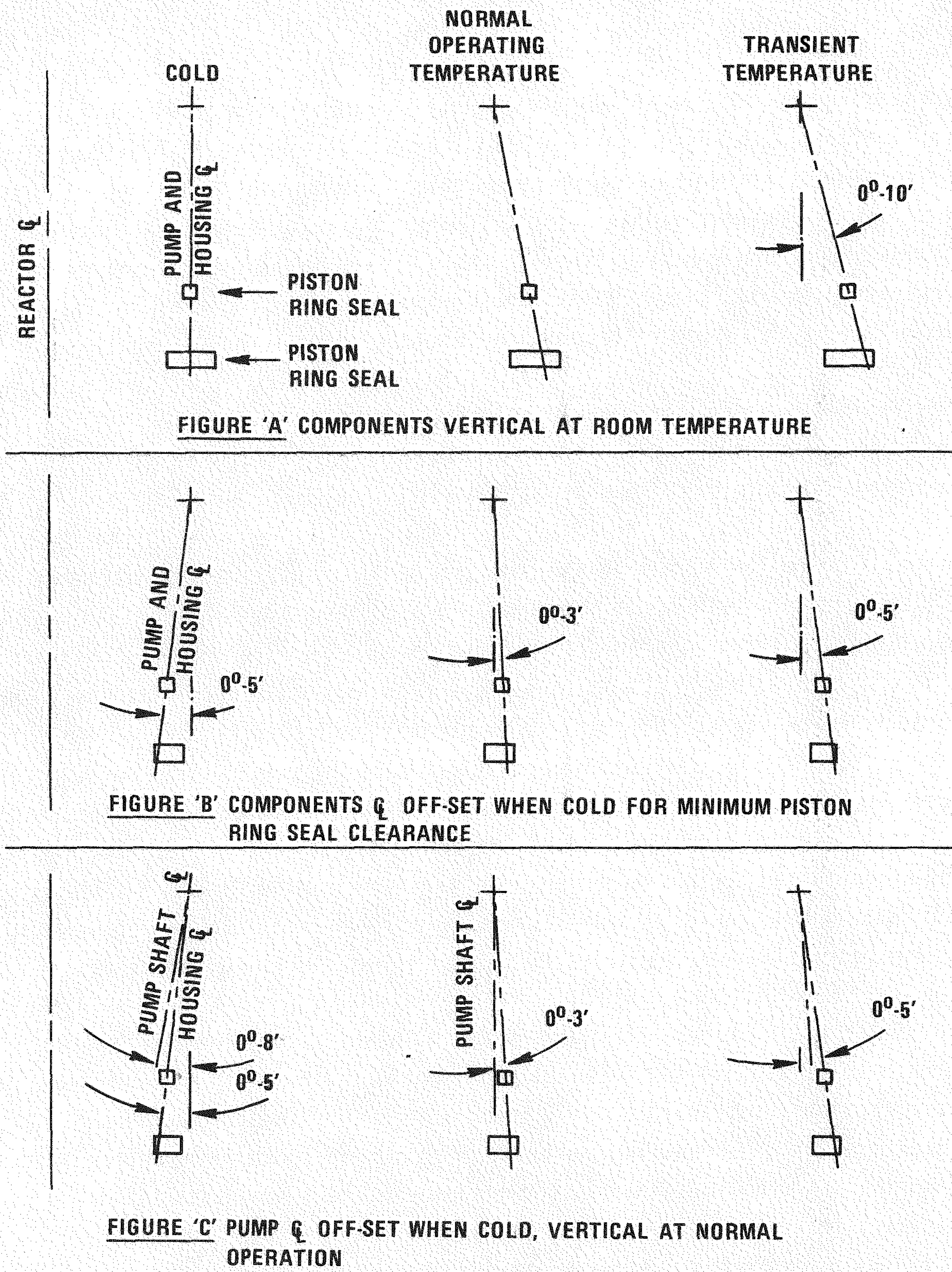

Figure 2-25. Pump Lower Support - Clearance

2.3.8.2 IHX SUPPORT

The method of IHX support selected for the reference design is shown in Figure 2-26, and employs a fixed support at the top, above the deck level; and a simple support at the lower end where the IHX interfaces with the IHX standpipe. Thermal expansion in the axial direction is catered for by allowing the IHX to slide through the lower support. The differential axial expansion is estimated to be 1.3 in.

Differential movement in the lateral direction results in flexure of the IHX and its supports which result in stresses being induced into the tube bundle, shell walls, support cylinders, flanges, and flange bolts. Stress analysis has to be done to verify that these stresses are within acceptable limits.

Upper Supports

The IHX upper support consists of a bolted flanged connection sealed with double O-ring seals. This provides rigid support of the IHX and a solid anchor point for the secondary sodium pipework. The load is carried from the IHX flange through the bolts to the IHX nozzle flange and into the deck structure.

Lower Support

The IHX lower support restrains the IHX in the lateral direction while allowing it to expand freely in the axial direction. Sealing of hot primary sodium from cold primary sodium, to reduce bypass flow around the heat exchanger, is accomplished by a bellows face seal.

The bottom of the IHX plugs into a receptacle at the bottom of the IHX standpipe. The load is taken from the lower support receptacle, through the bottom of the IHX standpipe and into the lower support structure (LSS). There is a limited amount of clearance where the IHX plugs into the support receptacle. Most of the lateral differential expansion of 2.1 in that takes

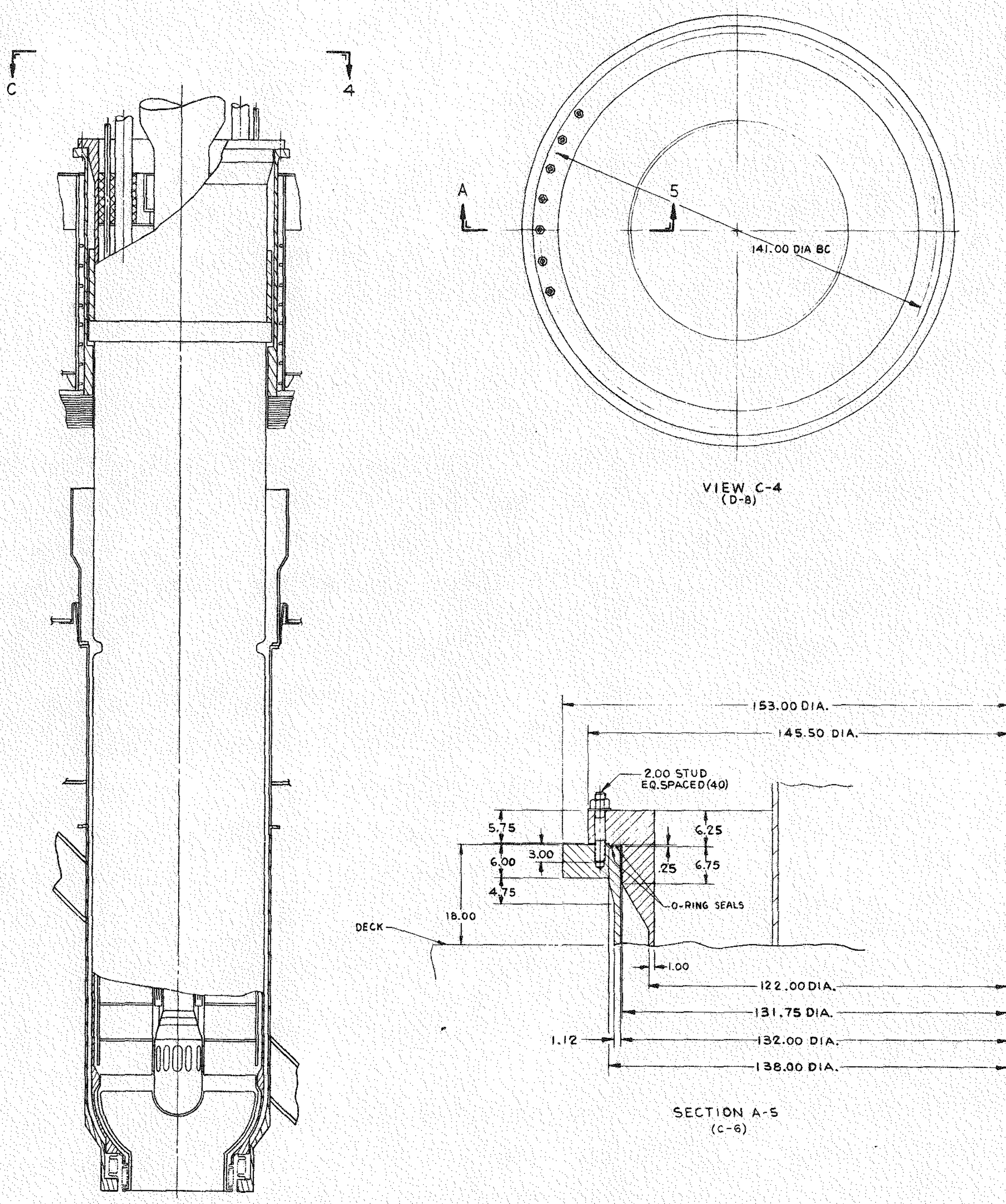

Figure 2-26. IHX Support

place between the upper support at deck level, and the lower support at LSS level, is taken up by flexing of the IHX and the supports. Stress analysis has to be done to verify that the stresses in the system are acceptable. If analysis should show that the stress situation is not acceptable, then a compliant, lower support can be designed. This compliant lower support could take the form of hydraulic dampers that would allow slow thermal movements with little resistance but would provide stiff restraint under fast seismic motion. The sodium operated hydraulic units would be removable with the IHX.

Differential radial expansion of the deck, at 110^{0}F and the lower support at 670^{0}F (800^{0}F transient) is taken by flexing of the IHX and its supports and is expected to induce stress into the shell of the heat exchanger and its supports. To minimize this stress, the IHX top support is off-set in the cold condition relative to the lower support. This causes the IHX centerline to go from out of vertical in one direction, through vertical, and out of vertical in the other direction as the system comes up to operating temperature. The radial differential expansion of 2.1 in results in a very small angle out of true vertical of approximately 0^{0}-5'.

2.3.9 NEUTRON SHIELD

2.3.9.1 FUNCTION

The function of the neutron shield between the core and the intermediate heat exchangers (IHXs) is to limit the activation of the secondary sodium. The secondary sodium activation is limited to meet a "hands-on" dose rate of less than 2 mr/hr at the steam generators. To meet this requirement, the activation of the secondary sodium in the IHXs must be kept to a source level less than 1.28×10^{-9} milli-curies per cc.

2.3.9.2 DESCRIPTION

The neutron shield thickness requirements are determined by extrapolating a one dimensional ANISN analysis of the surface dose rate of the IHX to the steam generators. The analytical results are based on a modified parfait core design for the beginning-of-life conditions. The neutron shield for the LPR evolved from the analytical results which indicate that the shield have an equivalent thickness of 18 in of stainless steel, and that it extend a minimum height of 120 in above the core midplane.

The neutron shielding between the core and the IHXs, as shown in Figure 2-10, consists of two separate cylindrical assemblies. The inner shield is located just outside of the core barrel and is supported by the core support structure. The outer shield is located inboard of the IHXs and is supported on the Lower Support Structure. The shielding is placed in two locations to maximize efficiency without obstructing motion of the upper internals during refueling. Each shield design has an average 50% volume fraction of stainless steel and 50% sodium coolant. The steel within the shields is cooled by natural convection.

The outer shield is 36 in thick at the bottom and 21 in thick at the top. The bottom region of the shield physically consists of a close packed array of tubes that are grouped and fastened together. The top region consists of three thin-walled cylinders that are fastened to the outer shell. The entire assembly is enclosed by inner and outer shells that perform part of the shielding function. The shells form the main structure of the shield and when welded to the horizontal baffles, form part of the boundary between the hot and intermediate sodium plena. A penetration is provided through the outer shield for the fuel transfer chute.

The inner shield is 16 in thick and is a tube design similar to the lower region of the outer shield. Windows are provided in the inner shield opposite the flux wells.

2.3.10 REACTOR AUXILIARIES

2.3.10.1 SODIUM PURIFICATION SYSTEM

FUNCTION

The function of the primary Sodium Purification System (SPS) is to remove those impurities, primarily oxygen and hydrogen, which enter the primary coolant boundary and become dissolved in the primary sodium during reactor operation or refueling.

The SPS is capable of maintaining the time weighted average oxygen concentration (with respect to corrosion potential) at $\leq$ 2 ppm when maximum reactor temperatures are greater than 800°F and $\leq$ 5 ppm at all other times. The system controls the overall concentration of all impurities to maintain the average plugging temperature below 300°F during reactor operation above 800°F, and below 350°F at all other times. Two independent SPS systems are provided, each of which can purify primary sodium at 100 gpm to meet these functional requirements.

To prevent an unnecessary load being placed on the impurity storage capacity of the regular system, a special portable purification system is used to handle the large amount of impurities which dissolve in the non-radioactive sodium when the system is initially filled, due to air and water vapor adsorbed on the reactor component surfaces.

The sodium purification system design study considered only cold trap concepts for impurity removal. The use of "getter" traps, which remove impurities by chemical reaction rather than by thermally induced precipitation, was not considered, although they may have advantages for pool reactor applications.

Location

The EPRI guidelines (Appendix L) require that the sodium purification system be located inside the reactor vessel and that no primary sodium be circulated outside of the vessel boundary. The intent of this guideline is to eliminate the chance of a radioactive sodium spill and consequent fire, concrete reaction, or release of radioactivity. In accordance with this guideline, the sodium purification system is installed inside the reactor vessel in the LPR reference design. A study was performed to compare the relative merits of the in-vessel location and the more conventional ex-vessel location for this system. On the basis of this study, which is described in Appendix H, the ex-vessel location is recommended as the preferred alternate for future plant designs.

Description

The design study concentrated on those aspects of the sodium purification system design which have the greatest impact on the overall reactor and plant conceptual design. In order of relative importance, those aspects are: (1), size of penetration through reactor deck; (2), above-deck provisions for routing cold trap cooling lines from the deck penetration to the containment wall; (3), in-vessel provisions for the cold trap equipment; and (4), arrangement and design of the cold trap system components themselves.

As shown in Figure 2-27, two reactor deck penetrations of approximately 5 ft diameter are provided for cold trap installation. A NaK cooling system is used to remove heat from the cold trap crystallizer. NaK was selected because its excellent heat transport properties allow the SPS to be made as compact as possible. To minimize the hazard of a NaK fire, the NaK pipes inside containment are enclosed in a steel guard pipe filled with inert gas. The guard pipe is provided with a removable cover to allow the cold trap to be removed for maintenance. The in-containment routing of the guard pipe and NaK lines and additional information on the design of the guard pipes is given in 3.1.3.1, Volume 2.

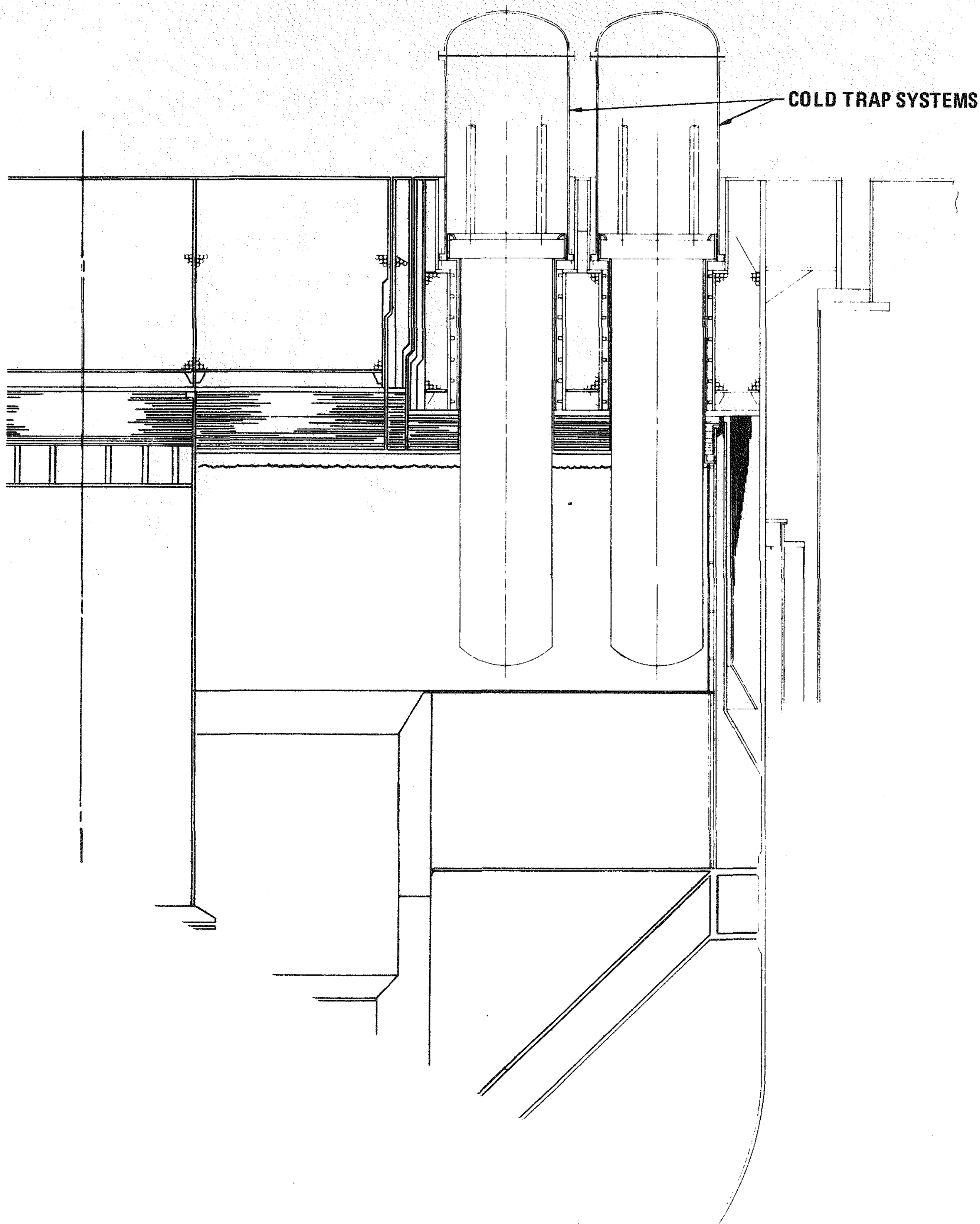

Figure 2-27. LPR In-Vessel Cold Traps

The design of the in-vessel portion of the SPS was carried out only to the schematic level necessary to define interfaces with other reactor components and to provide a basis for the in-vessel versus ex-vessel SPS design comparison described in Appendix H. The task of designing the in-vessel SPS includes both the design of the specialized individual system components (i.e., NaK cooled crystallizer tank, electromagnetic sodium pump, regenerative heat exchanger, temperature and pressure instrumentation, insulation, piping and internal structure) and the arrangement of these components into a compact package. This task would be most efficiently performed in a later stage of plant design by a vendor (such as the MSA Co.) who is experienced in the design and manufacture of such components and systems for commercial application. The remainder of this section describes the important features which ARD would have the vendor incorporate into the cold trap design.

As shown in Figure 2-27, the SPS is enclosed in a tank or thimble extending down through the deck into the hot pool to a level just above the upper horizontal baffle. The volume of that part of the thimble extending below the deck is about 300 ft^3. This volume accommodates a 1000 gallon crystallizer tank ($\sim$150 ft^3) with 150 ft^3 remaining for the EM pump, heat exchanger and other small components. With the size of these items being similar in size to those used in FFTF and CRBRP, the entire SPS can be packaged in this available space. If necessary, an additional 150 ft^3 of thimble volume can be provided by extending the thimble down to the intermediate horizontal baffle, although this complicates the design of the upper baffle and possibly interferes with the thermal stratification in the intermediate plenum.

Some of the more significant features which would be incorporated into the SPS are shown schematically in Figure 2-28 and discussed below:

Crystallizer

The crystallizer has an effective packing volume of $\sim$1000 gallons. The crystallizer internal design allows the impurities to deposit uniformly

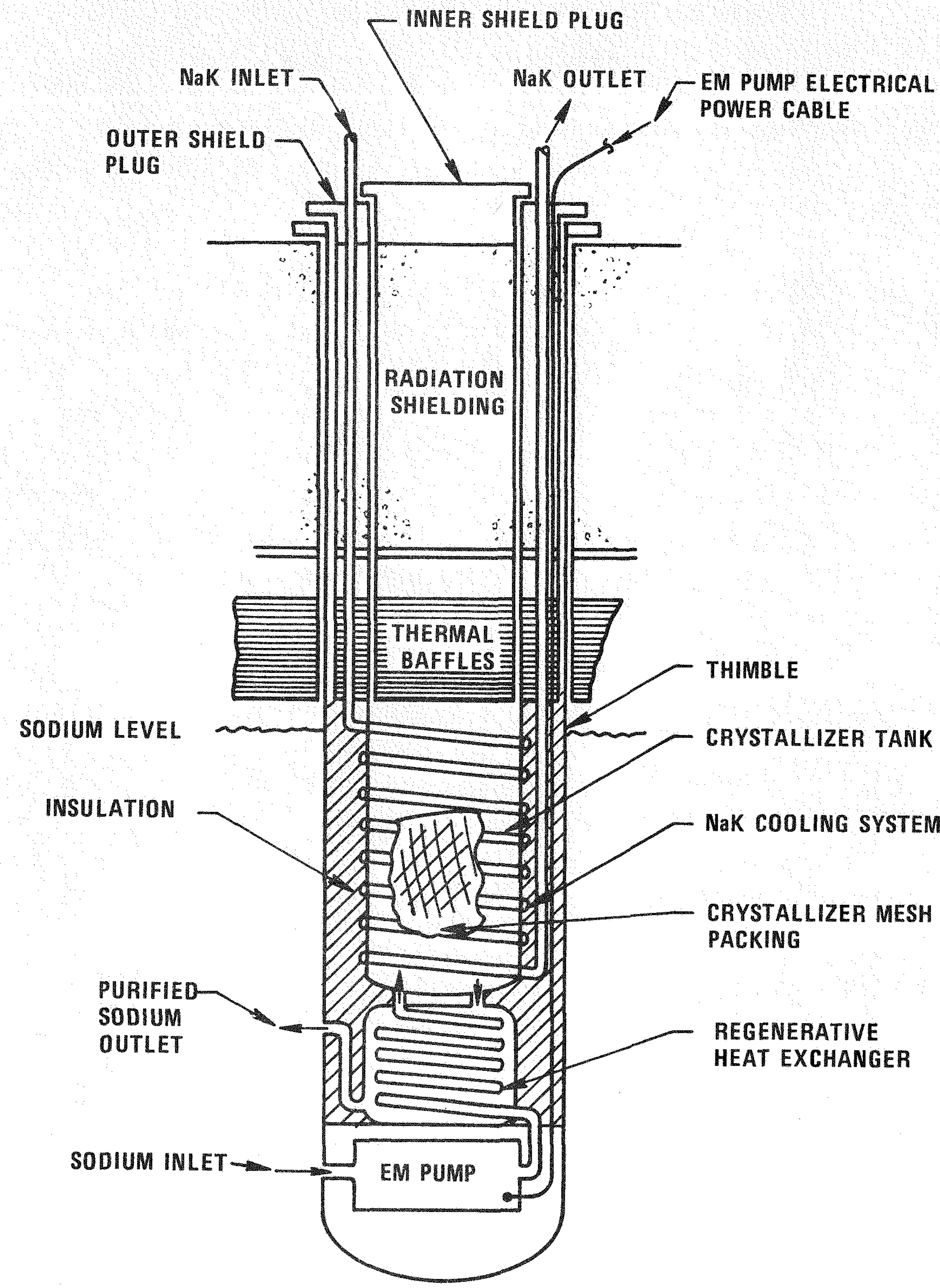

Figure 2-28. In-Vessel Primary Sodium Purification System Concept

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throughout the mesh packing so that plugging does not occur before the design impurity capacity is reached. The crystallizer packing and internal flow baffles where deposits are likely to accumulate are combined into one easily removable unit. The crystallizer tank is designed to allow the internals to be easily removed without disturbing the NaK cooling system or other SPS components.

It is conservatively predicted that a 1000 gallon crystallizer can accommodate all of the impurities entering the reactor during 10 years of normal operation, including refueling operations. If the in-vessel SPS had to accommodate a large amount of additional impurities introduced during unusual maintenance operations such as the removal and replacement of large components, the crystallizer replacement time would obviously be shortened. Alternatively, a portable ex-vessel cold trap system can be used during long term maintenance outages when the primary sodium activity level is relatively low.

Shield Plug

The SPS thimble has to have two concentric shield plugs. The NaK coolant pipes and the EM pump power cables run through the outer plug. Only the inner plug is removed to replace the crystallizer internals. Both plugs are removed to allow the entire PSPS to be removed for maintenance.

Electromagnetic Pump

An EM pump is used to force sodium through the SPS at 100 gpm. Since the pump must operate in a 950^{0}F environment, either a DC induction pump without coils or an induction pump with special high temperature coil insulation is required. Such pumps are not commercially available from domestic suppliers and a development program would be required to produce an acceptable component.

NaK Cooling System

The crystallizer tank is cooled by NaK circulated by an EM pump located outside of containment. The NaK is in turn cooled in a forced draft NaK-to-air heat exchanger also located outside of containment.

Instrumentation

Pressure sensors are placed at the sodium inlet and outlets of both the regenerative heat exchanger and the crystallizer tank to detect the onset of plugging in these components. A sodium flow meter and thermocouples at various locations throughout the system and in the crystallizer are also provided to monitor cold trap performance.

2.3.10.2 SODIUM PURITY MONITORING SYSTEM

Function

The functions of the primary Sodium Purity Monitoring System (SPMS) are to make various direct measurments of the impurity content of the primary sodium, to take samples of the sodium for laboratory analysis, and to expose test specimens to the sodium.

Location

The SPMS consists of the following equipment:

- Two independent, continuous reading plugging temperature indicators.
- On-line impurity measuring meters to continuously monitor the oxygen, hydrogen and carbon content of the primary sodium.
- Two multi-purpose samplers which can be used to: (a) provide a sample of sodium in an inerted, shielded cask for laboratory analysis; (b) equilibrate metal specimens in sodium at controlled temperatures between 400°F and 1400°F for impurity analysis; and (c) perform sodium filtration for extended periods of time to sample for particulates.

The EPRI design guidelines (Appendix L) require that the plugging meters and the sodium sampler be located in the reactor vessel. Because the guideline also requires that no primary sodium be circulated outside the vessel, the on-line purity meters must also be located inside the reactor vessel. In accordance with the guidelines, provision was made in the reference design for installing this equipment inside the reactor vessel. As was done with the Sodium Purification System, the relative merits of the in-vessel and the ex-vessel location for this system were compared (see Appendix H) and the ex-vessel location was selected as the perferred alternate for future plant design.

Plugging Temperature Indicator

The in-vessel plugging meter used in the LPR reference design is identical to the meter presently installed in PFR. The major features of this plugging meter are shown in Figure 2-29.

The plugging meter assembly is installed in a vertical thimble about 1.5 ft in diameter which penetrates the reactor deck and extends down about 4 ft into the hot pool. The plugging meter assembly, composed of a NaK cooled plugging orifice, a small sodium EM pump, an orifice flowmeter, connecting tubing, and temperature instrumentation, is positioned in the lower part of the thimble below the hot pool sodium level. Sodium is drawn into the meter through a port in the bottom of the thimble and discharged through a port in the side. NaK coolant lines carry the heat from the plugging orifice, up through the thimble shield plug, to a NaK-to-air cooler located on top of the thimble above the operating floor. The NaK is circulated by a small EM pump also located on top of the thimble. The entire plugging meter system is packaged into a compact module which can be removed as a unit for maintenance.

Impurity Meters

Although designs of impurity meters for installation in the reactor vessel were not developed in detail during the LPR design study, the general features and configuration were conceptualized as described here. The

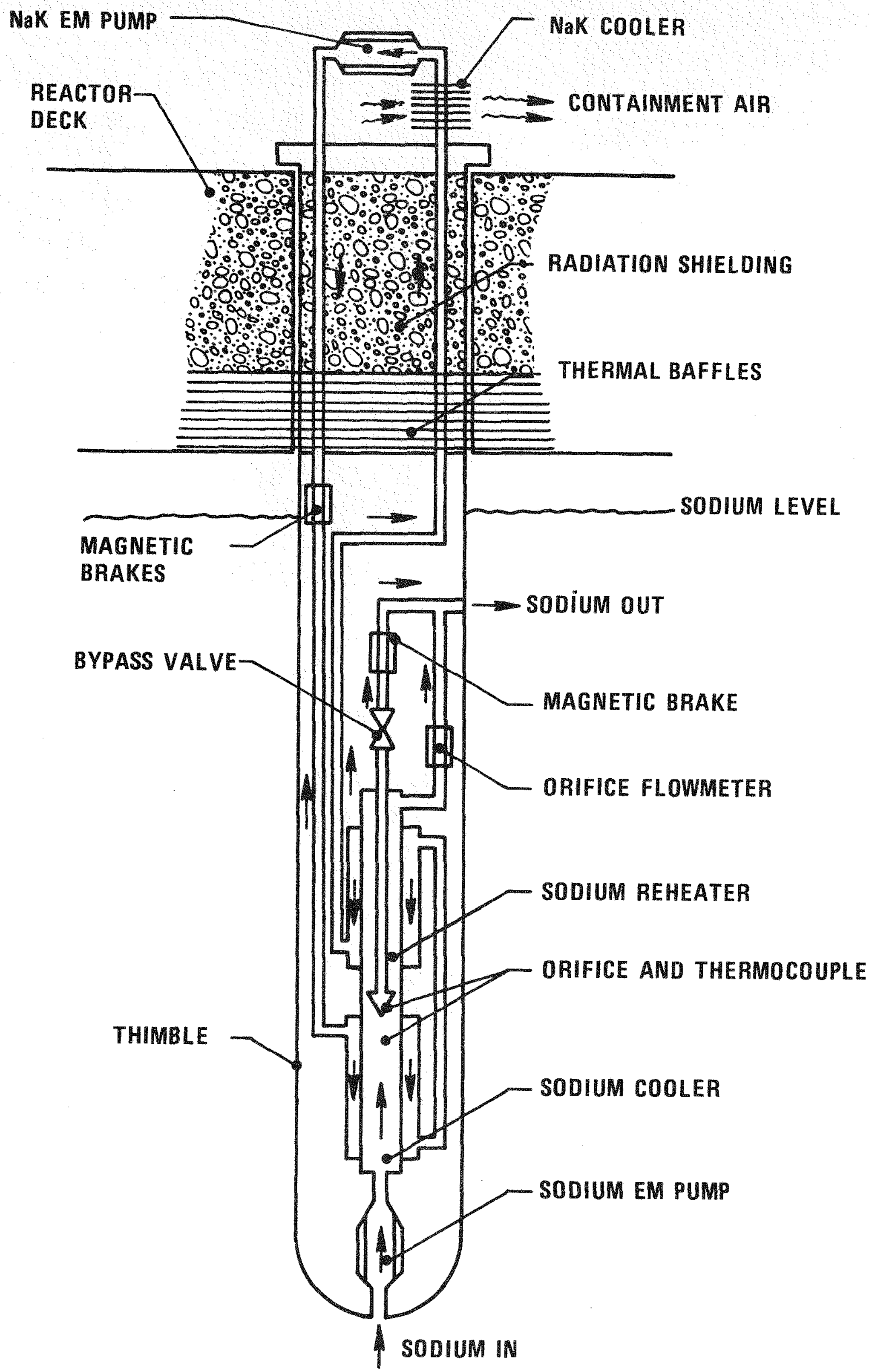

Figure 2-29. In-Vessel Plugging Meter Schematic

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in-vessel impurity measuring meters are of generally the same modularized thimble configuration as the PFR plugging meter. Each meter is installed in its own individual thimble or all three meters (oxygen, hydrogen and carbon) can be integrated into one thimble. The impurity sensing element which actually contacts the sodium is located in the bottom of the thimble immersed in the hot pool. A small EM pump is also located in the bottom of the thimble to circulate sodium through the sensing element. The part of the thimble situated in the reactor deck contains a shield plug consisting of thermal insulation and radiation shielding. Electrical wires for the EM pump, instrumenation leads and vacuum or gas lines are run from the bottom of the thimble, through the shield plug, up to the top of the thimble on the operating deck. The various supporting equipment for the impurity meters such as an ion pump, ion gage and mass spectrometer for the hydrogen detector, reference gas supply for the oxygen meter, and electronic voltmeter for the carbon meter, are located on the deck.

Sodium Sampling System

The sodium sampling system was not designed in detail and the following discussion describes the major features and configurations which would most likely be used if the design were carried further for the in-vessel location. The multi-purpose sodium sampler developed for CRBRP and shown in Figure 2-30 is used for sampling primary sodium in the LPR. The sampler is installed inside a small inert shielded cell located in the reactor deck structure. Although the cell was not designed, sufficient space is available for this cell in the reactor reference design. Sodium flow is supplied to the sampler by an EM pump located either in the cell or in a thimble extending down into the hot pool. Remote manipulators are provided in the cell to operate the multi-purpose sampler. Since access to the sampling cell is too restricted to allow manipulator operations to be viewed directly through a shielded window, TV cameras are used instead. The sampling cell is provided with an air lock to allow the sodium samples contained in an inerted shielded cask to be removed from the cell without contaminating the inert cell atmosphere.

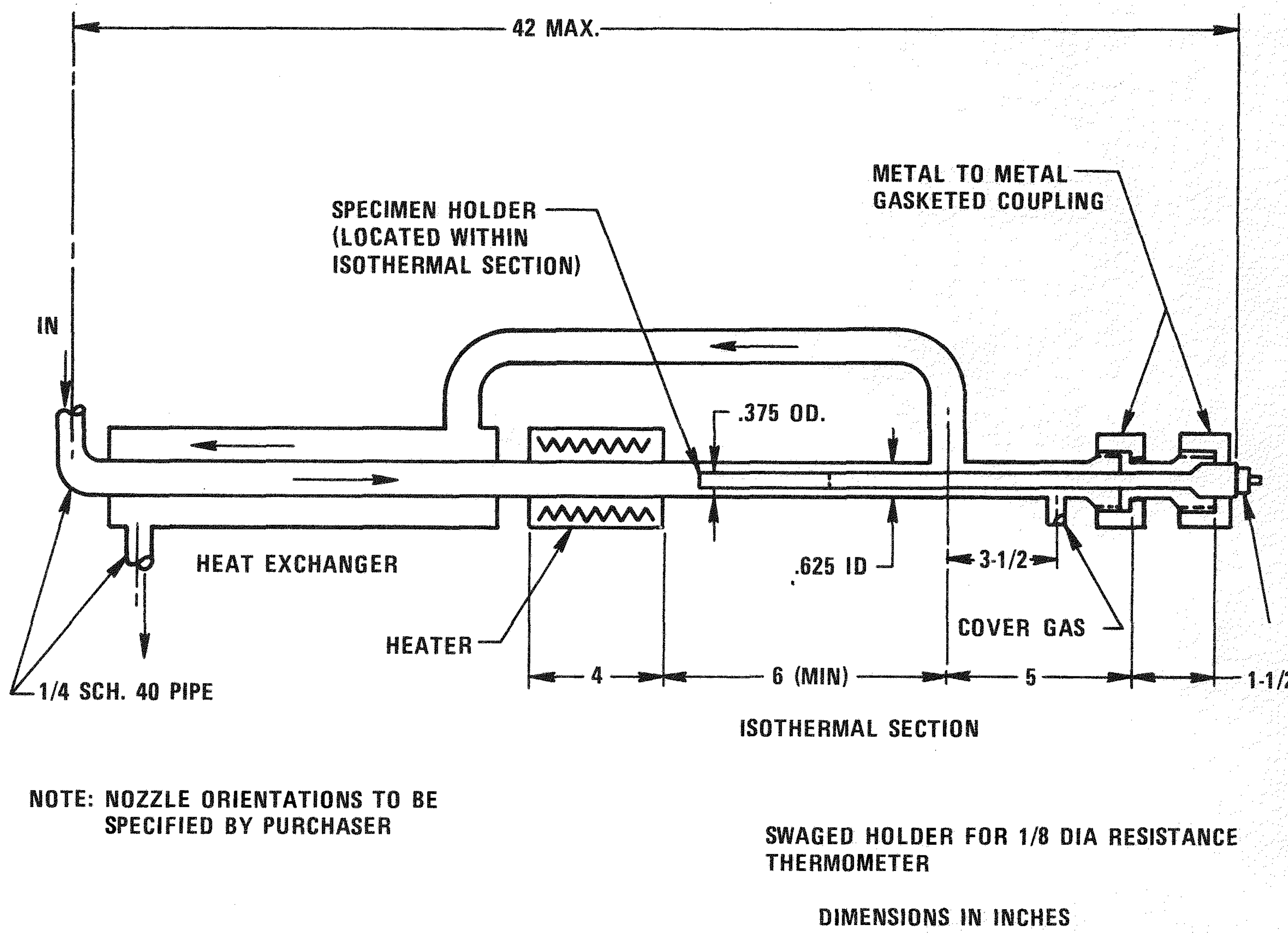

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Figure 2-30. Multipurpose Sampler for Sodium System

2.3.10.3 FLUX WELLS

Function

The LPR has eight flux wells which house neutron detectors to measure the operating and shutdown flux levels of the core. The flux wells provide two important functions. They protect the neutron detectors from direct contact with radioactive sodium, and they provide the guidance to position the detectors at the measurement locations. They also facilitate the installation and replacement of detectors. Separate wells in four locations around the core satisfy the PPS requirements for redundancy, diversity and separation.

Location

As indicated in Figure 2-2 the external termination of the flux wells (Item 01) are spaced approximately 90^{0} apart in four groups of two around the periphery of the stationary deck. The lower ends of the wells (not shown on the drawings) extend to the vicinity of the core barrel at the level of the core mid-plane. Locating the flux monitor wells is a compromise among diverse requirements. Ideally the wells should be vertical, to ease replacement of the monitors, straight, to ease deployment of the monitors and independent of neutron flux other than that generated by the core. The Upper Internals Structure swing and the rotatable plug sizes preclude vertical wells. This in turn results in either inclined straight wells or curved wells. Flux well location was chosen to minimize the effect of the fuel storage positions and the fuel transfer chute on monitor response.

Description

The flux wells are dry in that they are extensions of the reactor primary boundary and closed to the sodium pool. The wells extend from the operating deck to the flux measurement locations between the neutron shields.

Two wells are provided at each of four locations. One houses the power range compensated ion chamber and the other houses both the source range fission counter and the wide range fission chamber. The cables from the detectors are run up the wells and through a shield plug at the top to the deck.

2.3.10.4 SODIUM LEVEL PROBES

Function

The function of the sodium level probes is to provide: 1), outputs to the plant protection system in response to excessive loss of sodium during reactor operation; and, 2), outputs to the plant monitoring and surveillance system to aid in sodium pool fill and drain operations.

Location

The plant protection system liquid level monitors are spaced 90^{o} apart near the inside diameter of the stationary deck. The single fill liquid level monitor is similarly located and is near one of the plant protection system liquid level monitors. These locations are free from both in vessel interferences and interferences from deck mounted equipment and piping runs.

Description

Dry wells for the level probes extend from the deck into the sodium pool. These wells provide both protection from the sodium and facilitate the installation and removal of the probes. Four separate short wells provide for the plant protection measurements and one well for the long probe is used in the plant monitoring and surveillance system. The probes themselves are of the inductive type consisting of a wound coil probe similar to those qualified for FFTF and CRBRP. These sensors provide a reliable measurement and are capable of operating at high temperatures and within severe nuclear environments.

2.3.11 GUARD TANK

2.3.11.1 FUNCTION

The principal functions of the guard tank are listed below.

- Maintain a Safe Sodium Level - In the very unlikely event of a leak in the reactor vessel, the guard tank provides a secondary containment for the primary sodium. The tank prevents the level of the sodium in the reactor from falling below a safe level, namely the level required to provide primary sodium to the inlet of the IHXs. Except for sodium vapor, the guard tank also prevents sodium from contacting and reacting with the concrete wall of the reactor cavity.
- Provide Passageway for Remote Inspection Equipment - Weld joints in the reactor vessel and guard tank may require inspection during the lifetime of the plant in order to guarantee structural integrity. This inspection cannot be done manually because of temperature, radiation and access space limitations. Therefore a passage with controlled dimensions must be provided to facilitate movement of remote devices.
- Support Thermal Insulation - Thermal insulation is required between the reactor vessel and cavity wall in order to minimize heat loss from the reactor and to ease the problem of cooling the cavity wall. The guard tank is used to support this insulation so that the two can be assembled exterior to the reactor cavity and lowered into the cavity as a unit.

2.3.11.2 DESCRIPTION

The guard tank is a cylindrical, open top container having an inside diameter of 77 ft 6 in and a depth of 57 ft 8. The tank is made of stainless steel to provide high temperature strength and eliminate the need for stress relieving operations subsequent to fabrication. A conical section having a top flange is used for supporting the main part of the 1.5 in thick tank. The top flange is attached to a support ledge on the wall of the reactor cavity. The conical section is sufficiently long to permit the main part of the tank to operate hot while the top flange is at a temperature below 150^{o}F. The maximum temperature gradient for steady state conditions is 160^{o}F per axial foot.

The conical section of the tank has one circumferential row of holes to permit passage of the cavity coolant gas. There are no penetrations in the tank wall below the minimum or faulted sodium level to guarantee the sodium containment capability. Welding is used to close any cleanout hole left in the tank for removal of foreign objects following site construction. The tank is designed with sufficient rigidity to prevent contact with the reactor vessel when seismic accelerations are less than or equal to SSE values (.3g horizontal).

The annular region between the guard tank and reactor vessel is used as a passageway for remote inspection devices that examine welds in both containers. The guard tank is therefore shaped to match the shape of the reactor vessel at refueling temperatures. Under this condition the space between the reactor vessel and guard tank is 12 $\pm$ 4 in.

Thermal insulation is attached to the outside surface of the guard tank. An annular space exterior to the insulation is a necessary feature of the design. It is required for clearance while installing the insulated guard tank into the reactor cavity, and also for passage of cavity cooling gas during reactor operation and refueling.

Fabrication of the guard tank is done in a shop facility constructed at the plant site. Full penetration welds are used for joining various sections. Thermal insulation is attached to the outside surface of the tank prior to installation of the tank assembly into the reactor cavity. Grout used for supporting the assembly, is poured into position after the tank has been leveled properly on its support ledge.

A nitrogen dam is installed between the guard tank and reactor vessel at an elevation about 27 ft below the top of the deck. The purpose of the dam is to prevent hot nitrogen from leaving the region between the reactor vessel and guard tank. The dam does not have to be a seal but only an effective flow barrier to prevent undesirable convective currents. The dam is fabricated in sections and sized to fit the particular sector where it is to be installed. Each section is spring loaded to provide good contact against the reactor vessel and guard tank. Packing type thermal insulation is used to bridge the gaps between sections. All sections are removable primarily to provide access for in-service inspection equipment.

2.3.11.3 SUPPORT

The guard tank is supported by attachment of a top flange to a support ledge provided in the wall of the reactor cavity. Figure 2-31 shows the guard tank and its support features.

During fabrication, the top flange and cone weldment of the guard tank are match bored so that when the guard tank is centered on the support ledge, the tapped holes in the ledge ring line up with the stud clearance holes in the guard tank top flange. At installation, the grout dam ring is tack welded to the ledge ring after leveling and embedding the ledge ring in the concrete structure. Pilot studs are threaded into several of the tapped holes to guide the guard tank assembly properly into position on the support ledge ring. The hold down studs are then installed and used to pull down the guard tank top flange as required to level the guard tank and seat the grout dam ring. Non-shrink grout is then pumped into position and torque is applied to the anchor nuts after the grout has cured.

The grout provides a secure seat for supporting the guard tank. In addition, the structural arrangement is such that the grout is able to transmit both radial and lateral loads at rather low stress levels. For example, a 3.5g side load produces a compressive stress in the grout of 700 psi, or 10% of its ultimate strength.

The guard tank is anchored in position by a system of studs and nuts that are accessible from above. In-service inspection and any maintenance required can therefore be done relatively simply since manual access to this region is possible.

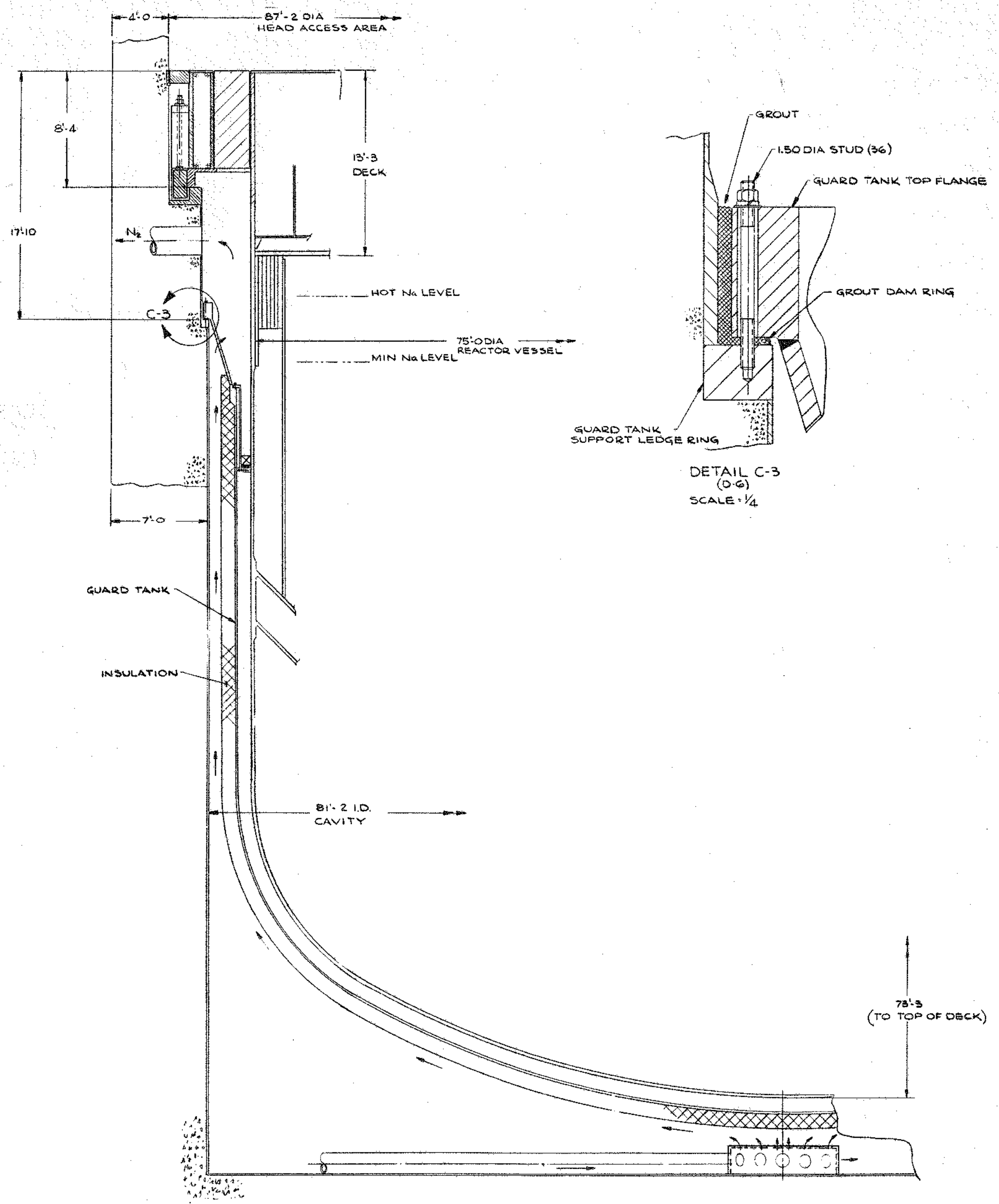

Figure 2-31. LPR Guard Tank and Peripheral Region

2.3.11.4 INSULATION

Thermal insulation is required outside the guard tank to minimize heat transfer to the wall of the reactor cavity. High temperature refractory fiber insulation capable of service up to 2300^{o}F is used. Having an installed conductivity factor of .04 Btu/hr-ft-^{o}F (at 400^{o}F), the insulation is a flexible blanket type made of alumina silica fibers. It has a density of 8 lbs/ft^3 and is made in lightweight sections that are 4' x 25' x 2" thick. The sections are installed directly on the outside surface of the guard tank over pins attached to the outside of the tank. The pins are located on 16 in centers and are no closer than 4 in to the edges of the blankets. A staggered joint construction is used for installation. A hexagonal mesh metal netting is used to help hold the blankets in place. The mesh is laced where it overlaps for secure containment of the insulation.

2.3.11.5 CAVITY COOLING SYSTEM

The operating temperature of the reactor vessel is sufficiently high that some cooling is required to prevent overheating of the reactor cavity wall. Overheating is defined as concrete temperatures greater than 150^{o}F. The cooling system chosen is designed to minimize the heat loss from the reactor vessel thereby increasing reactor efficiency and reducing the size and cost of the cooling system. The guard tank with its external insulation is used to reduce the heat transfer to the cavity wall and also to channel the cooling fluid against the surface of the wall.

The cavity cooling system is indicated on Figure 2-31. Nitrogen gas is forced into a distribution plenum located in the reactor cavity just below the reactor.

Entering the reactor cavity at 100^{o}F and at a slight positive pressure, the gas flows from the distribution plenum radially outward and upward along the inside surface of the cavity wall. The guard tank conical section contains many flow holes that permit the nitrogen to pass thru and enter the upper part of the reactor peripheral region before leaving through ducts that return the heated nitrogen to the cooling units and blowers. The nitrogen cooling system absorbs heat at the rate of about 100 kilowatts while cooling the cavity. Temperature control is provided by controlling blower speed to yield a nitrogen return bulk temperature of 110^{o}F. Standby cooler and blower units are used for providing the necessary redundancy in the system.

SECTION 3.0

TRANSIENT OPERATION CONSIDERATIONS

Preliminary transient analyses are presented for the vessel and deck. The complete loss of cooling air transient selected to analyze the deck represents the worst expected deck transient. Two transients are used to analyze the vessel. One causes flow stratification in the hot pool and the other one causes a rapid cooldown of the whole hot pool. Since the hot pool is the principal vessel heat source, these two transients cover the extremes in vessel boundary conditions.

3.1 VESSEL

The vessel temperature transients for the reference design are calculated for two plant transients. Both transients are reactor trips from full power. One has an exponential flow coastdown to seven percent pony motor flow, and the other one holds the flow constant at design flow. The coastdown transient results in flow stratification in the hot pool. It is caused by the fuel assembly cold jets, after flow coastdown, not having sufficient momentum force to overcome the bouyant force produced by the cold jet penetration into the hot pool. The momentum force of the jet is small at pony motor flow which corresponds to a small jet penetration into the hot pool. This results in the formation of a hot/cold pool interface which slowly rises to the hot pool surface. ANL, using model testing, Reference 1, demonstrated the existence of flow stratification during flow coastdown transients. The full flow transient results in complete mixing of the hot pool with a rapid decrease in temperature of the whole hot pool.

A two-dimensional TAP-A model of the vessel is used to calculate the transient temperatures. This model and the calculational results are described in Appendix C, Section C.3.

3.1.1 EXPONENTIAL FLOW COASTDOWN

The thermal boundaries to the vessel are the hot pool, intermediate plenum, reactor cavity, and deck. A discussion of these boundary conditions and transient results follows.

Vessel analysis requires the spatial temperature distribution in the whole hot pool. To define these temperatures, a simplified stratified flow model is used. Initially it assumes that the pool is completely hot at 950°F. At initiation of flow coastdown, cold flow enters the hot pool bottom at 670°F and forms a hot/cold fluid interface. Pony motor flow controls the interface rate of rise until it reaches the IHX inlet. Then the rate of rise is considerably slower because the sodium displacement mechanism above the IHX inlet changes from pony motor flow to entrainment of the hot pool by the cold flow. The hot/cold interface rise, as a function of time, is shown in Figure 3-1. The simplified stratified flow model results in a different transient IHX inlet temperature than the one given in Appendix E for a flow coastdown. The reason is the hot pool analytical models are different and the differences are to be resolved in the future.

The intermediate plenum controls the vessel temperature boundary below the horizontal baffle, and above the LSS. A VARR II transient calculation, described in Appendix C, Section C.4 defines the intermediate plenum transient temperature. Figure 3-2 shows the boundary temperature. The VARR II transient was only calculated for 800 seconds. After 800 seconds, it is assumed that the intermediate plenum temperature is constant. This assumption results in a steeper vessel axial temperature gradient by holding the intermediate temperature constant rather than decreasing it to its final steady state temperature of 670°F.

The reactor cavity nitrogen temperature is held at 100°F and the deck primary containment boundary plate temperature is held at 150°F. These cooling systems are not affected by the reactor shutdown transient.

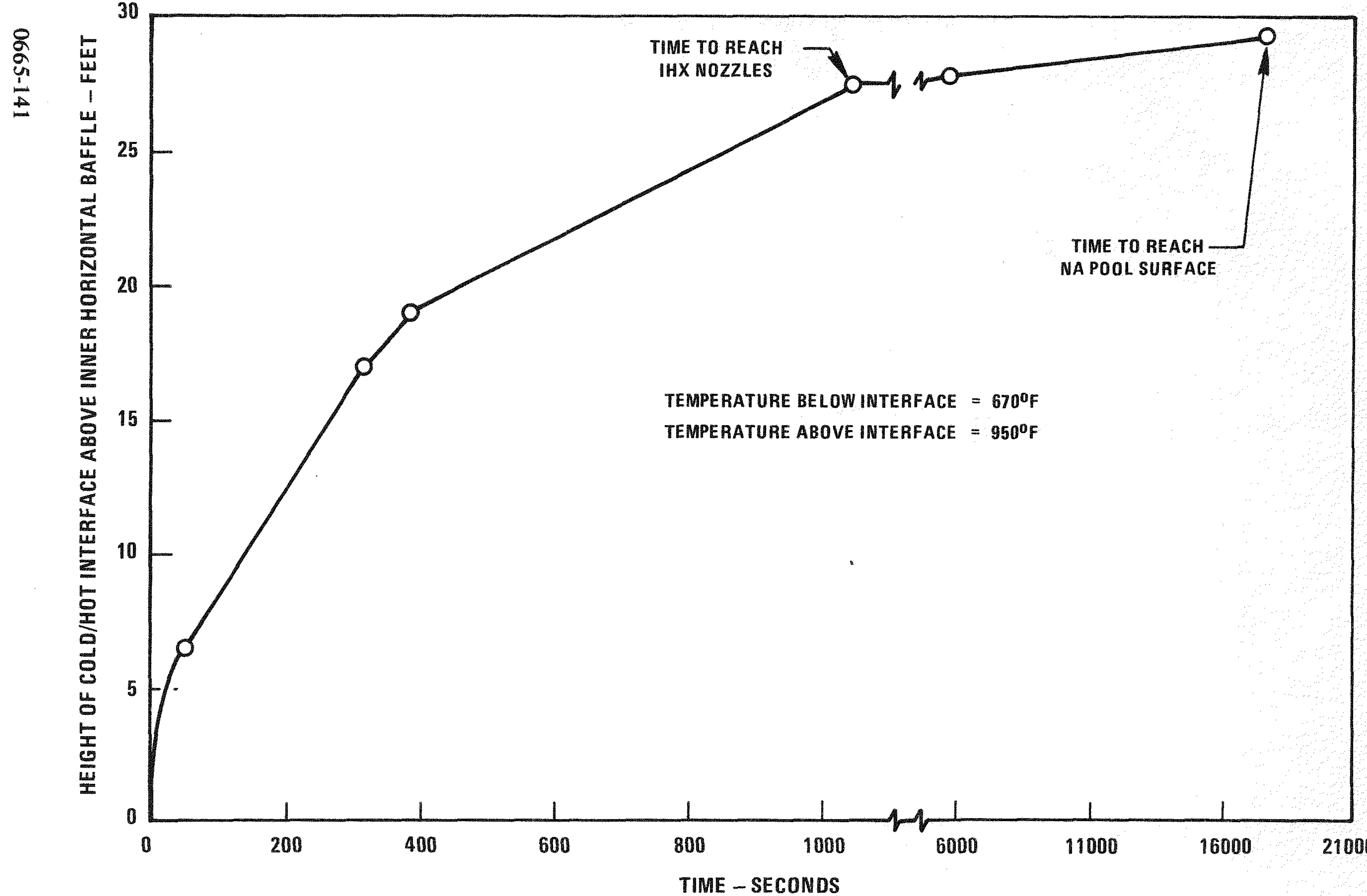

Figure 3-1. Hot Pool Cold/Hot Interface Rise History for a Pump Coastdown Transient

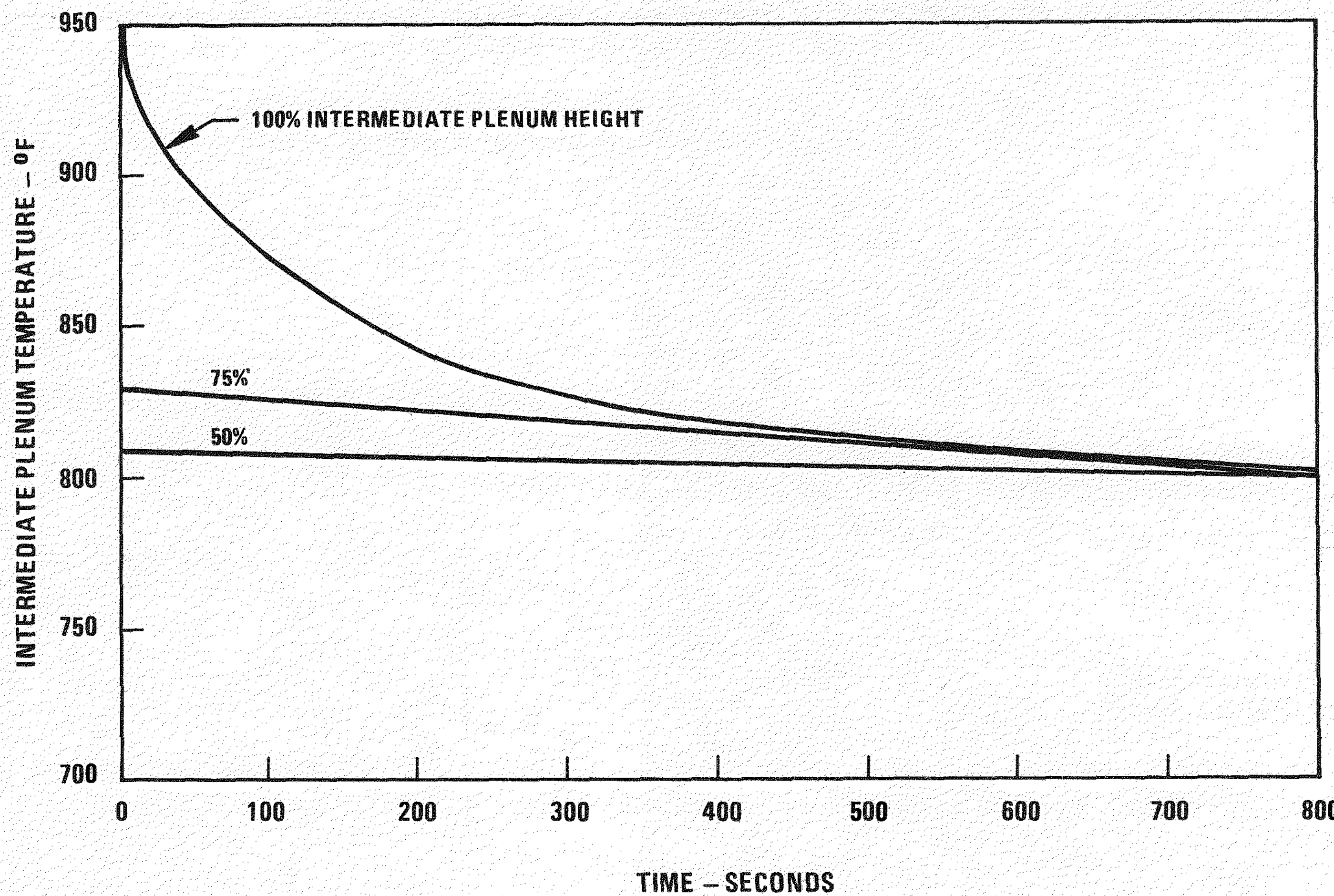

Figure 3-2. Intermediate Plenum Temperature for a Pump Coastdown Transient

These boundary conditions are used in the two-dimensional TAP-A vessel model which calculates the vessel transient axial temperature distribution as shown in Figure 3-3. The response of the vessel temperature to the transient is extremely small even after 20,000 seconds or 5.6 hours. During the transient, most of the in vessel temperature change occurs between 9 ft and 13 ft down from the roof. This length of the vessel has only one reflector plate or the smallest amount of insulation which accounts for the observed temperature change. From 13 feet and below, the intermediate plenum boundary temperature is held constant after 800 seconds because transient data beyond 800 seconds is not available. This temperature eventually decreases to 670^{o}F, the final equilibrium temperature of the cold and hot pools which bound the plenum. Thus, the final axial gradient should be close to the 20,000 second case except that the temperature below 13 feet should be 670^{o}F. The vessel axial temperature transient data indicates that the insulation of the reflector plates makes the vessel temperature insensitive to the stratified flow transient.

The vessel temperature is not calculated beyond 20 feet below the deck. Future modification of the TAP-A model is planned to include the whole vessel. It is expected that the temperature of the vessel bottom which encloses the cold pool does not decrease much during the transient. The vessel bottom temperature follows the cold pool temperature during a transient and the cold pool temperature gradually decreases 10^{o}F in 2000 seconds.

3.1.2 CONSTANT FLOW TRANSIENT

The temperature boundary conditions for the constant flow transient are the same as the flow coastdown transient except for the hot pool and intermediate plenum boundaries. Figure 3-4 show the hot pool temperature-time history. Since the flow is held constant, the hot pool is completely mixed and the temperature is uniform throughout the pool. The transient time duration at full flow is only 80 seconds, because that was the only full flow data available. The intermediate plenum temperature boundary condition was assumed constant during the short 80 second transient. This gives conservative results.

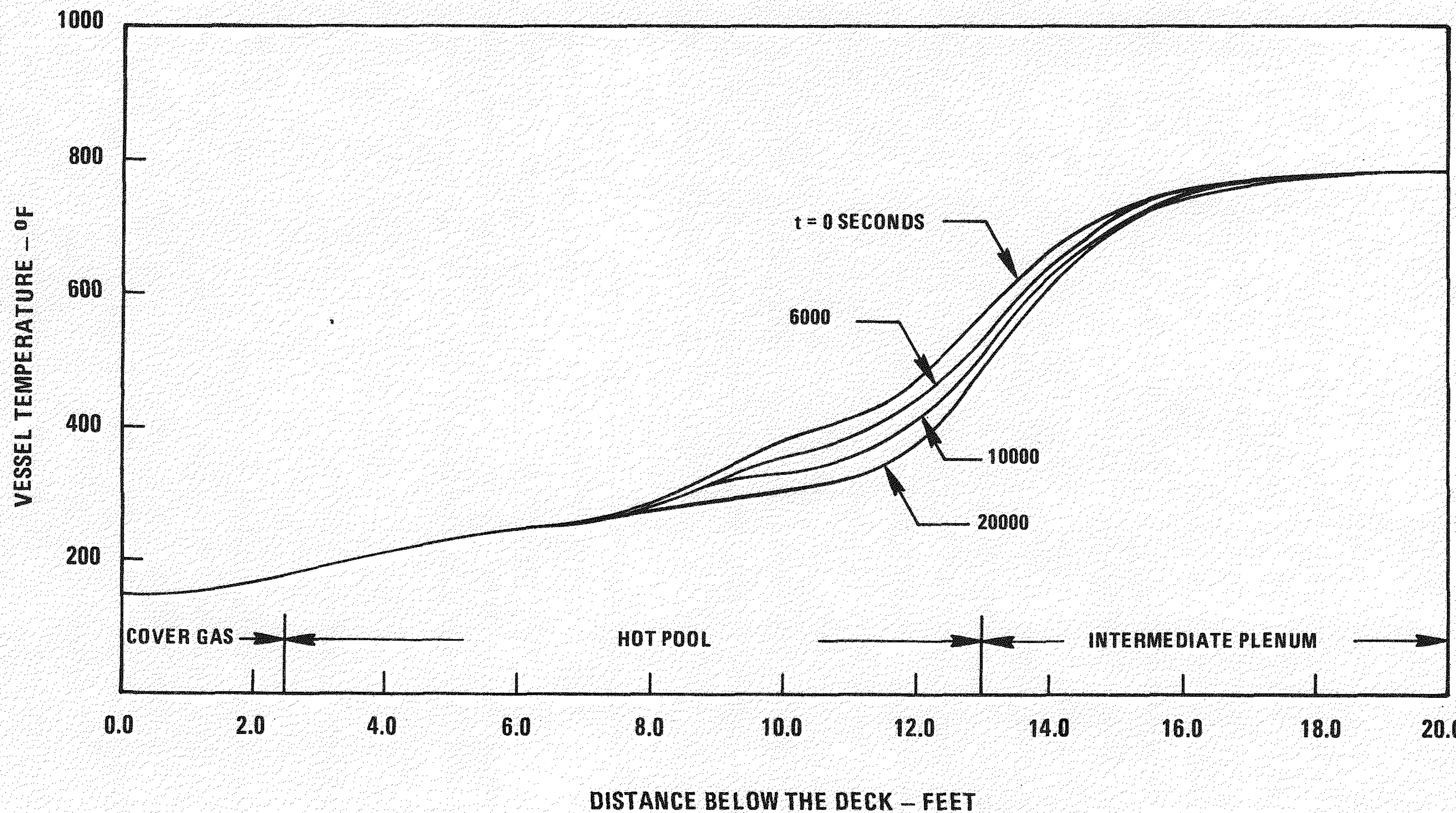

Figure 3-3. Vessel Axial Temperature Distribution for a Pump Coastdown Transient

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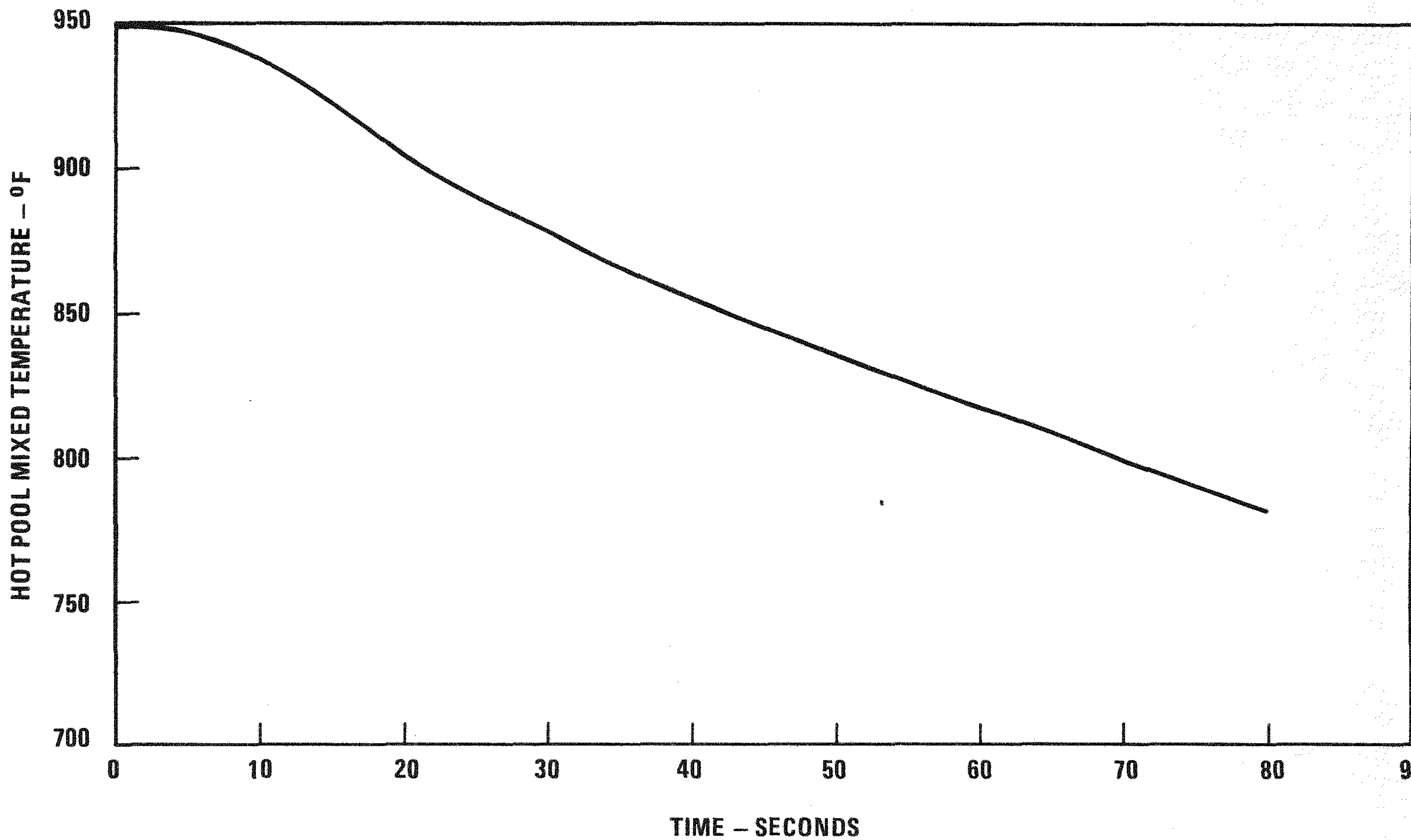

Figure 3-4. Hot Pool Transient Temperature for a Constant Design Flow Shutdown

The vessel temperature response to a constant flow transient is shown in Figure 3-5. The vessel temperature at the end of the transient is almost identical to that at the start of the transient, indicating that the reflector plates provide excellent insulation of the vessel from transient temperature changes in the hot pool and intermediate plenum. In the future the transient will be calculated for a longer time duration.

3.2 DECK

The expected worst case thermal transient affecting the deck structure is loss of coolant air flow to the gas plenum. The temperature of the deck structure must be determined during the transient, because the resultant thermal forces cause misalignment problems in the deck structure. The analysis, presented in subsequent sections, describes the thermal response of the deck for a loss of forced air cooling.

3.2.1 METHOD OF ANALYSIS

A 1-D ANSYS model of the deck is used to obtain temperature histories of the deck. A complete description of the modeling, assumptions, and boundary conditions is found in Appendix B, Section B.4.4.

The reactor, during the loss of deck air cooling flow, is assumed to be operating at steady state conditions which correspond to a hot pool temperature of $950^{o}F$. Following the loss of deck air cooling, the temperature transient in the deck is calculated for 180 hours. The 180 hour duration is considered to be conservative. In an actual loss of cooling flow event, it is believed that cooling flow is restored well before 180 hours. Two deck transients are calculated. One for a nominal reflector plate emissivity of 0.28 and the other for an end of life reflector plate emissivity of 0.80.

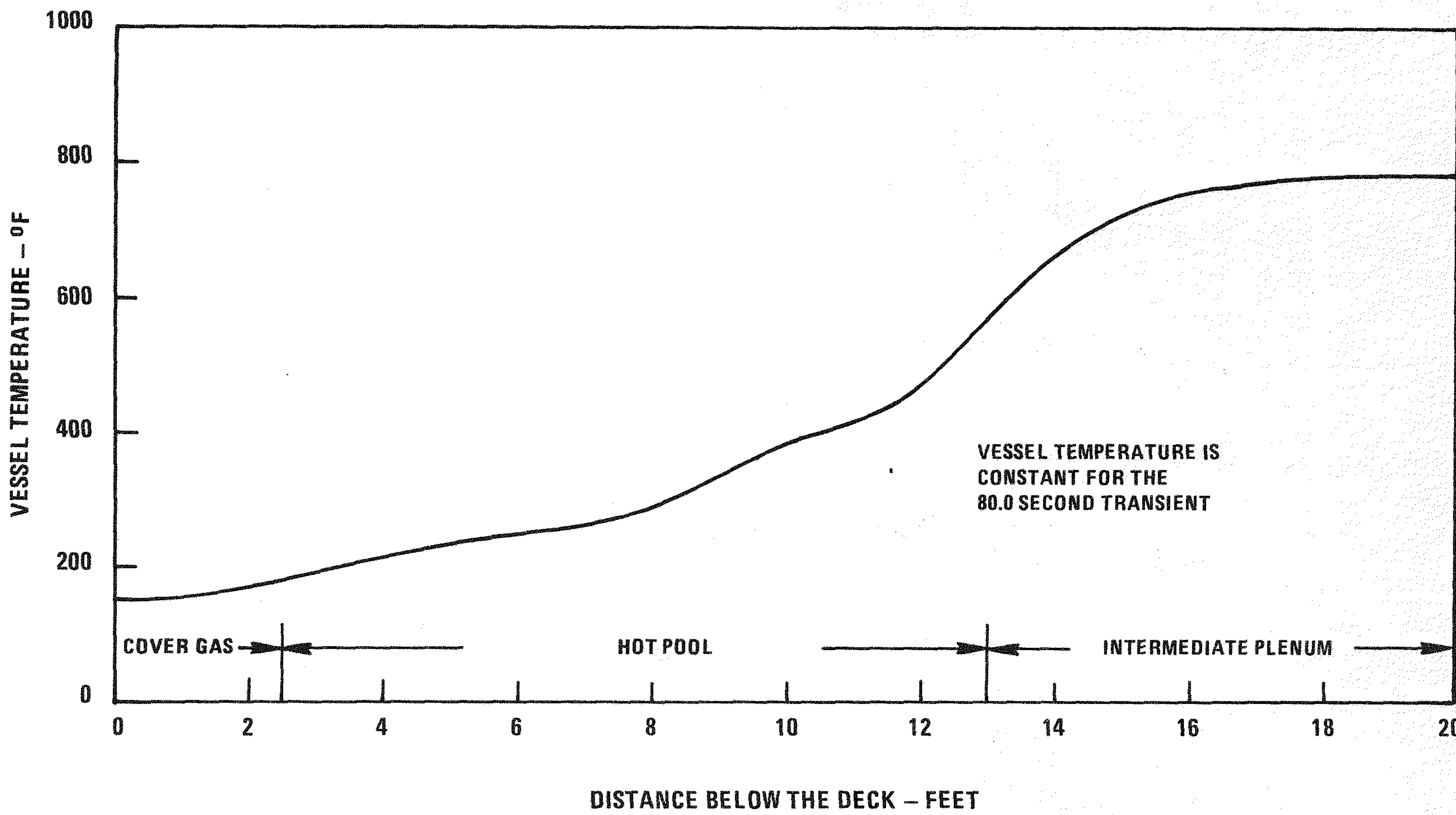

Figure 3-5. Vessel Axial Temperature Distribution for a Constant Flow Transient

3.2.2 RESULTS

Temperature histories at key locations are presented in 3-6 and 3-7. Shown are time/temperature plots of the primary sodium containment boundary plate, deck top plate and the top surface of the bioshielding. Also presented is a plot of the temperature difference between the primary boundary plate and the bioshield support plate. If this temperature difference is too large, adverse thermal stresses can occur. The maximum temperature differences at this location are 68^{o}F and 90^{o}F, corresponding to nominal and end of life emissivities, and occur at 57 and 68 hours, respectively. These should not cause any structural problems, based on a more conservative analysis done in the Interim Report (Reference 2) when a maximum ΔT of 110^{o}F was predicted, and the structure is shown to be adequate. Also, cooling to the deck should be restored long before the maximum temperature differences occur.

NOTE: Nominal Reflector Plate Emissivity = 0.28

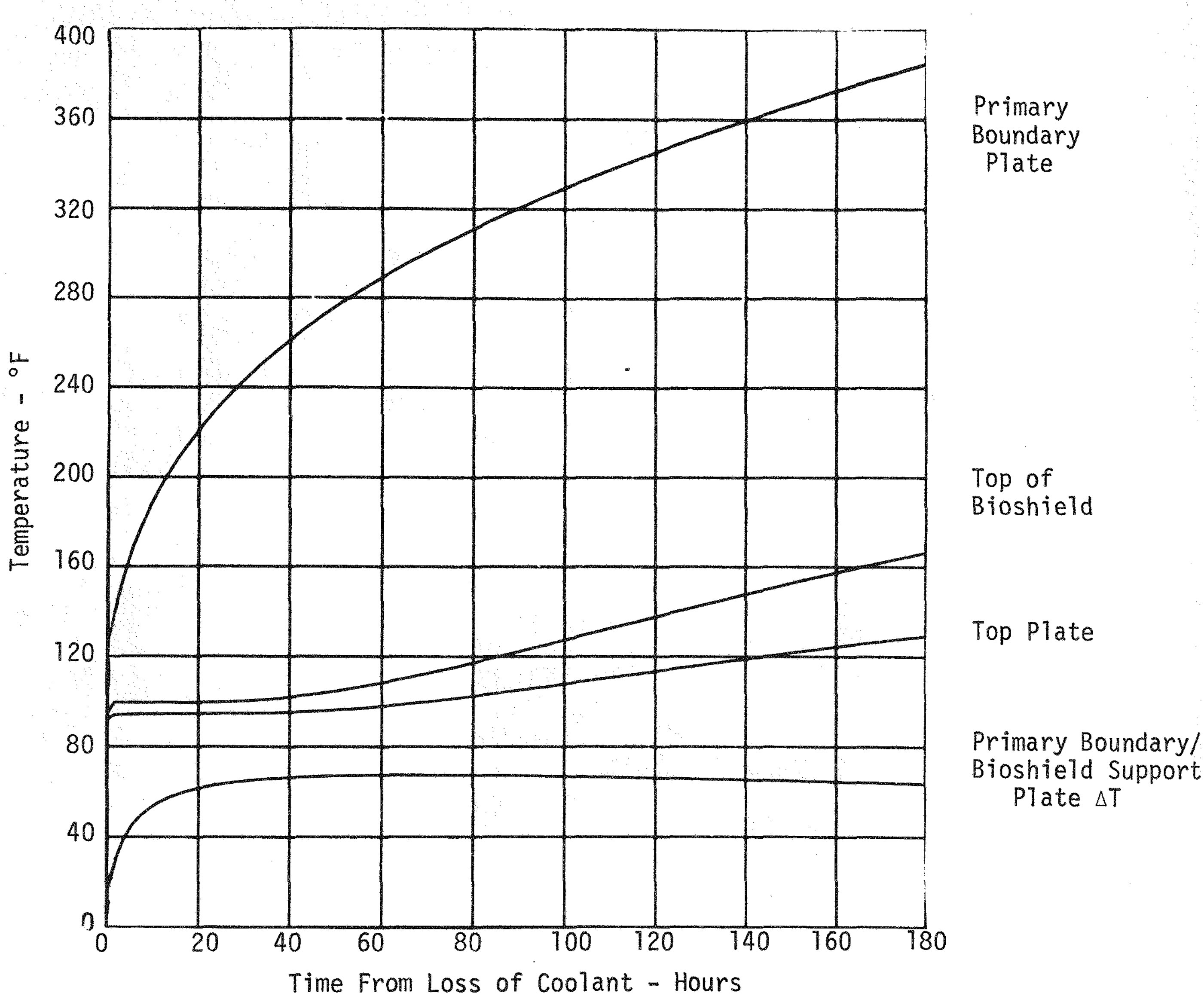

Figure 3-6. LPR Deck Temperature History During Loss of Coolant Transient - Nominal Reflector Plate Emissivity

NOTE: E.O.L. Emissivity = 0.8

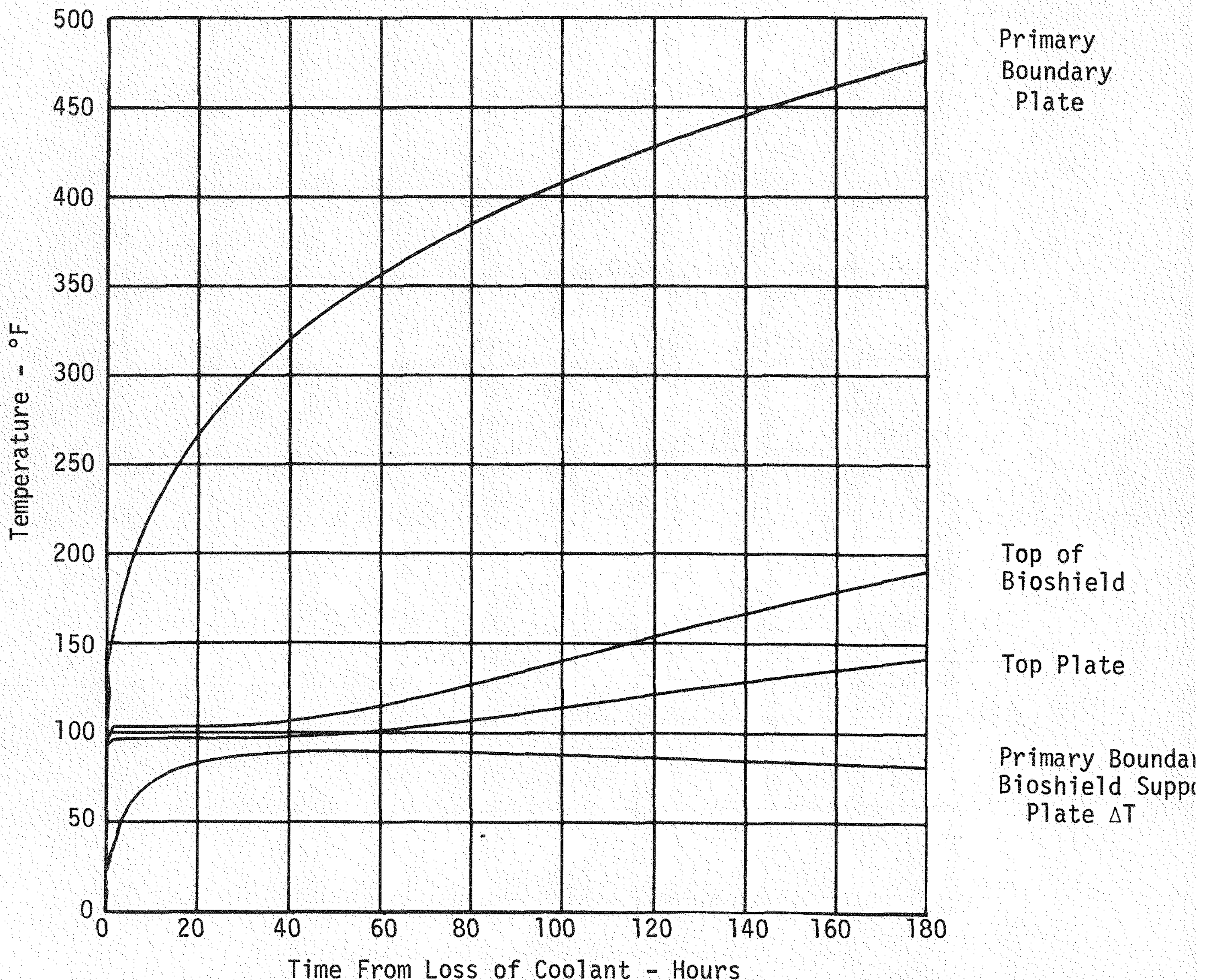

Figure 3-7. LPR Deck Temperature History During Loss of Coolant Transient - End of Life Reflector Plate Emissivity

SECTION 4.0

FABRICATION AND CONSTRUCTION

4.1 INTRODUCTION

The size of the large pool reactor components preclude shipment of the principal components in one piece unless the plant site is an off-shore location. Plant sites located on inland waterways limit the vertical ordinate of the shipping envelope to about 36 ft. Accordingly a structure of 36 ft maximum diameter and 1000 tons total weight (including shipping skid and lift beam) is considered as a limit for complete shop fabrication. Somewhat larger diameters, possibly up to 45 ft, can be accommodated with factory modifications or changes in processing. With this limitation, most of the major components of the LPR require a substantial amount of field fabrication. To accomplish this, a factory on the site is required similar to the one described in 4.3.

Although domestic experience on large pool reactor fabrication does not exist, recent fabrication of large LNG vessels, power shovels and off-shore drilling rigs provides a fabrication base which should enable large pool reactors to be constructed within a reasonable cost and schedule.

4.2 GENERAL FABRICATION

The following parts are fabricated by suppliers and shipped to the site factory for subsequent processing and assembly.

4.2.1 COMPONENT PARTS FOR WELDMENTS

- Formed plates for the bottom heads and knuckles on the guard tank and reactor vessel
- Formed plates for the cones on the guard tank, lower support structure and neutron shield.

- Formed plates for the cylindrical shells on the guard tank, deck, reactor vessel, lower support structure, sodium shield, neutron shield, outer horizontal baffle and curved ribs of the deck.
- Shaped and formed bar for the large rings required on the guard tank, guard tank support, reactor vessel support and vessel structural box flange.
- Shaped, trimmed and fit ribs for the deck and lower support structure.
- Shaped, trimmed and fit annular plate sections for the deck, lower support structure, vessel sodium shield, intermediate and outer horizontal baffles.
- Equipment standpipes and penetrations for the deck and lower support structure.

All of the components described above are prefabricated as accurately as possible, trial assembled, trimmed where necessary, matchmarked, appropriately braced and shipped to the site factory for assembly.

4.2.2 MAJOR SUBASSEMBLIES

To minimize the labor content of the fabrication in the site factory, maximum use is made of prefabricated component parts and subassemblies, particularly where the components have a complex configuration or require major post-weld machining. Several of the major components lend themselves to a sectored fabrication which has advantages. The fixed deck structure was examined for this method of fabrication based on the following criteria (see Figure 4-1).

- Fabricate and machine sectors to such an extent that only erection fitting to the reactor vessel remains. There can be four or more sectors.
- The outer portion of the shielding support plate should be fitted but not attached.
- The top covers should be fitted but not welded (unless manway openings are provided).
- Shielding shot is placed at erection.

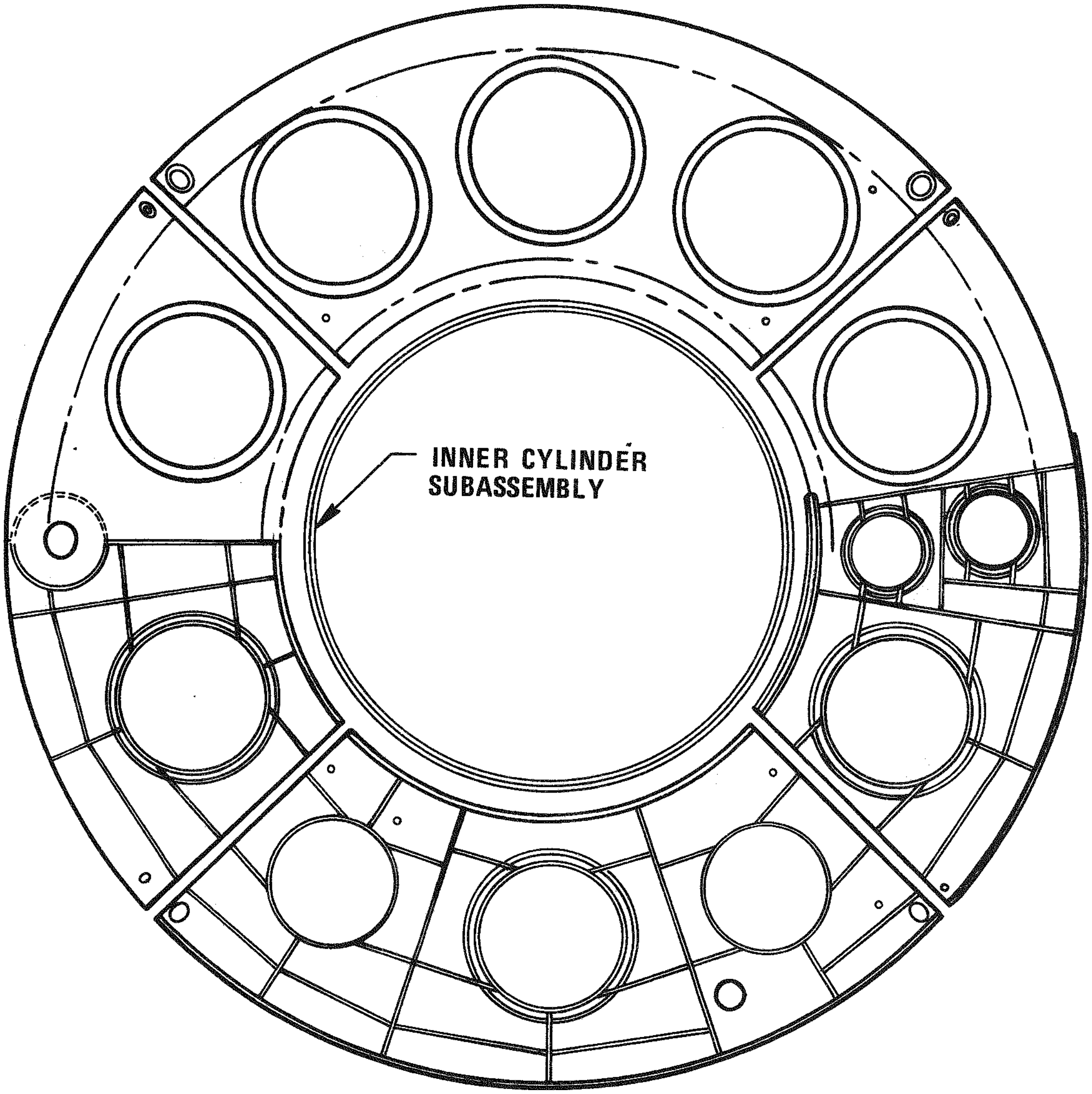

Figure 4-1 Fixed Deck Structure

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- Machining for attachment of insulation packages as well as fitting of insulation is done to the maximum extent possible.

- The vessel reflector plate insulation, adjacent to the weld of the deck bottom plate to the RV, must not be in place until the erection weld (sodium containment boundary) is completed and accepted.

The lower support structure (LSS) is another complex fabrication which lends itself to a sectional fabrication method (see Figure 4-2). The approach for this structure is to provide a minimum of two subassemblies, plus prefabricated components. These subassemblies are prefit and match marked. Portions of the cone top plate and the neutron shield pedestal must be installed in the site factory and these are supplied as prefit component parts for weldments.

The intermediate and outer horizontal baffles which are part of the plenum separator system are fabricated into two 160 degree subassemblies each containing three IHXs and two pumps and two 20 degree plates prior to installation in the vessel.

4.2.3 FINISHED ASSEMBLIES AND COMPONENTS

The following components will be completely fabricated off site and then shipped to the site for direct installation into the reactor vessel.

- Pumps, IHXs and cold traps
- Core Support Structure
- Inner Horizontal Baffle
- Large Rotatable Plug
- Intermediate Rotatable Plug
- Small Rotatable Plug
- Risers, bearings, gears, seals and drives for rotatable plugs
- Fuel transfer equipment
- Low level flux monitors

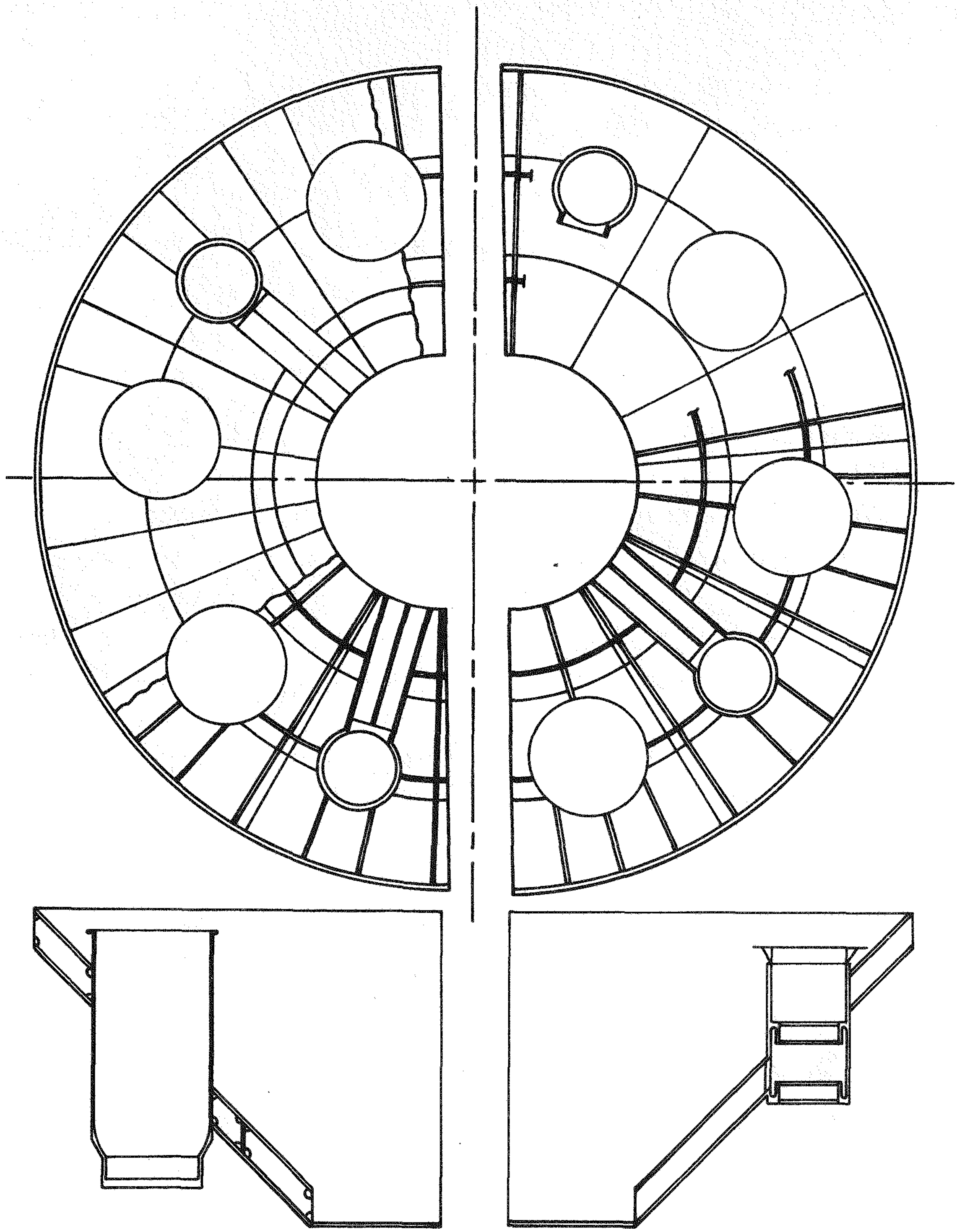

Figure 4-2 Lower Support Structure Sectors.

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- Radial shields and dummy core
- Upper internals structure
- IHX and pump standpipe seals and mounting hardware
- Reflective plate insulation modules
- Taconite shot
- Deck cooling piping assemblies

4.3 SITE FABRICATION FACILITIES

The on-site fabrication facilities play a vital role in the fabrication of the large pool components, especially those that exceed 36 ft in diameter. Volume 4 includes the Stone & Webster construction evaluation which identifies the salient characteristics of the site fabrication facilities. Reference 3 describes a concept for a site fabrication facility. References 1 and 2 describe a concept for fabrication and movement of large components. Some of the highlights of the proposed site fabrication facility are as follows:

- The floor space required to fabricate the major components at the plant site, as well as minimum major equipment, requires a factory approximately 130 ft x 330 ft with a crane lifting capacity of 200 tons and a hook height of 110 ft (see figure 4-3).
- The overall schedule for component fabrication in the factory is shown in Figure 4-4.

4.4 PACKAGING AND SHIPPING

4.4.1 SHIPPING CONTAINERS

The large rotating plug and some of the major subassemblies require a top loading shipping container similar to those described in Reference 1.

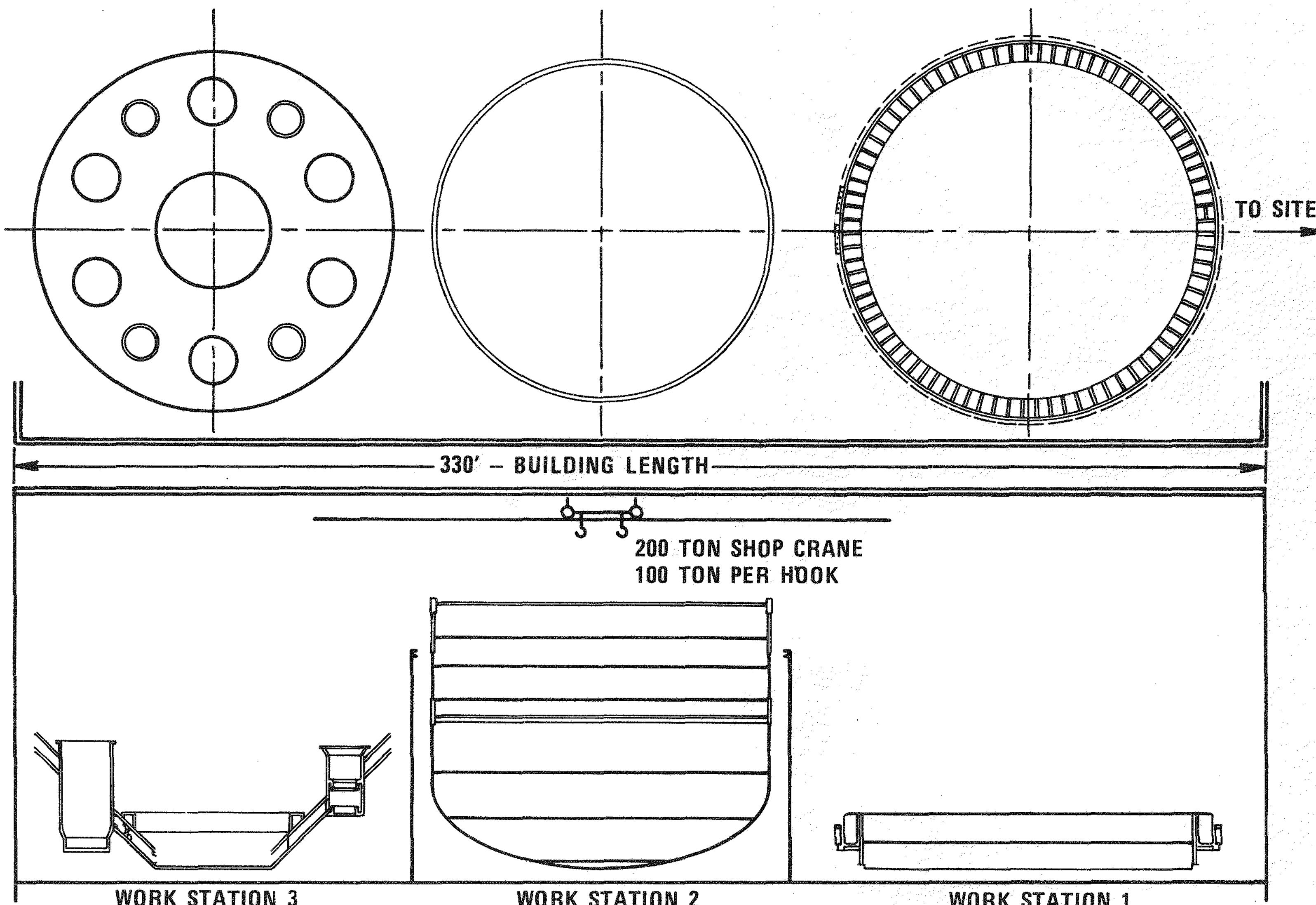

Figure 4-3 Field Fabrication Shop

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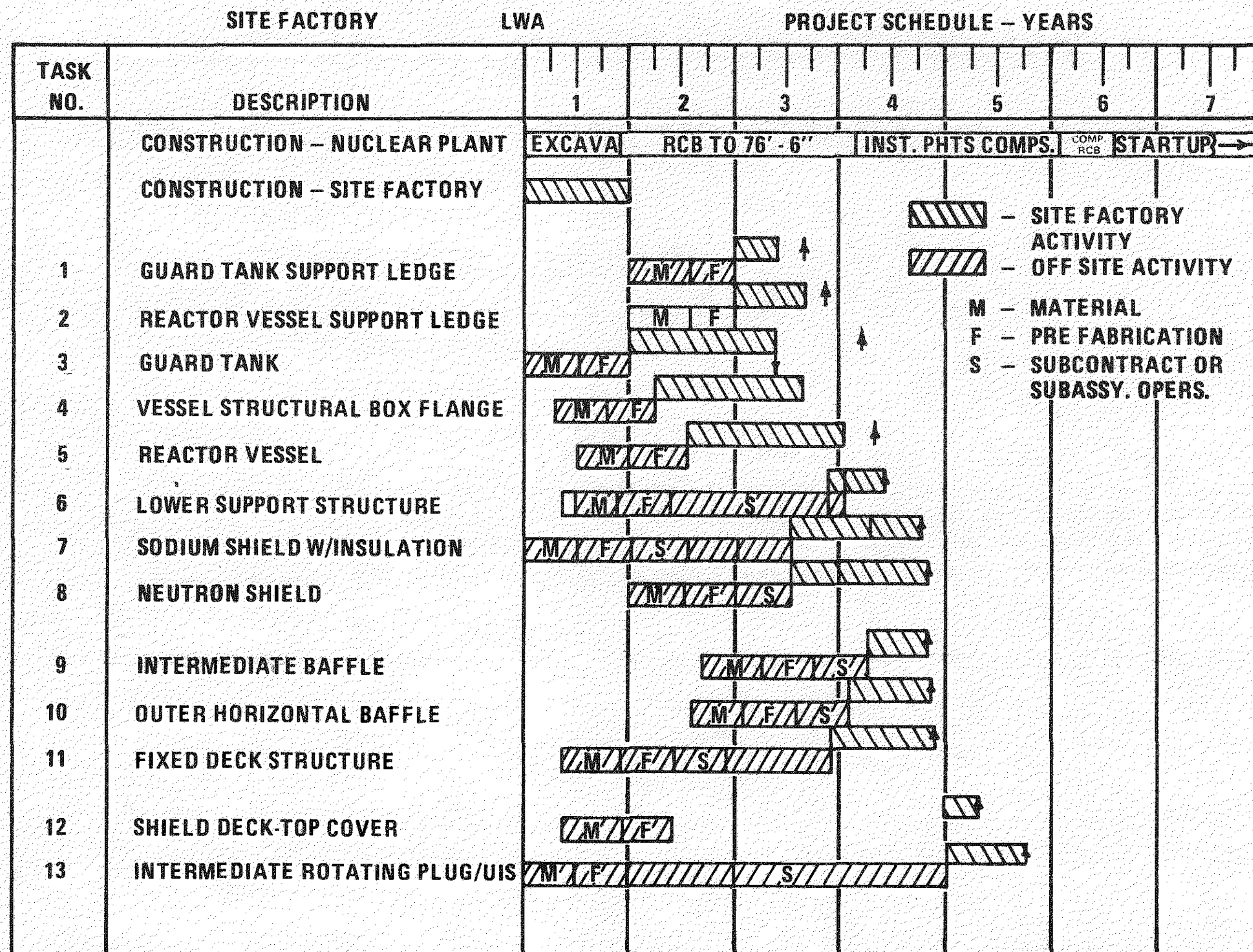

Figure 4-4. Site Factory Fabrication Schedule

4.4.2 ROUTE CLEARANCES AND SUITABLE BARGES

Reference 1 investigated shipping requirements with larger component envelopes and weights than anticipated in this study. A minimum number of barge shipments, with barges loaded to the maximum extent possible, are planned with the balance of materials and components shipped by rail or motor freight.

4.5 OFFLOADING AND MOVEMENT AT THE SITE

4.5.1 CRANES

Large capacity cranes are available to off-load large subassemblies and components from barges. These are required at all nuclear sites and it is concluded that adequate lifting arrangements can be provided including placement of large subassemblies and components on the site factory erection platens.

4.5.2 TRANSPORTERS

Movement of large components or subassemblies from the barge slip can be accomplished with existing transporters such as those described in Reference 2. Special tooling such as outriggers may be necessary to support the large components on the transporter decks.

4.6 COMPONENTS TO BE FABRICATED IN THE SITE FACTORY

Generally speaking, all components that exceed 36 ft in diameter will be fabricated on site either from component parts for weldments, or major subassemblies. These components are described in their general sequence of assembly, however, logistics will require some preassembly operations before final fabrication steps are taken.

4.6.1 GUARD TANK SUPPORT (Figure 4-5)

The guard tank support is made from 12 prefit segments supplied ready for weld assembly.

- The 12 ring segments are assembled on an erection platen and fit, welded into a subassembly, and inspected.
- The butt welds are post weld heat treated and inspected.
- The bolt pattern is laid out using the guard tank upper flange as a template.
- The 36 drilled and tapped holes are machined.
- The guard tank support on its erection platen is transported to the hoist area, and rigged to the installation crane for installation

4.6.2 REACTOR SUPPORT (Figure 4-5)

The reactor support is made from 36 prefit segments supplied ready for weld assembly.

- The 36 ring segments are assembled on an erection platen and fit, welded into a subassembly, and inspected.
- The butt welds are post weld heat treated and inspected.
- The keyways and bolt patterns are laid out using the vessel structural box flange support ring (Section 4.6.4) as a template and machined.
- The reactor support on its erection platen is transported to the hoist area, and rigged to the installation crane for installation.

4.6.3 GUARD TANK (Figure 4-6)

The guard tank is made from 118 prefit segments or parts supplied ready for weld assembly.

- The bottom head, made up of 6 pieces is fit, welded into a subassembly, and inspected.

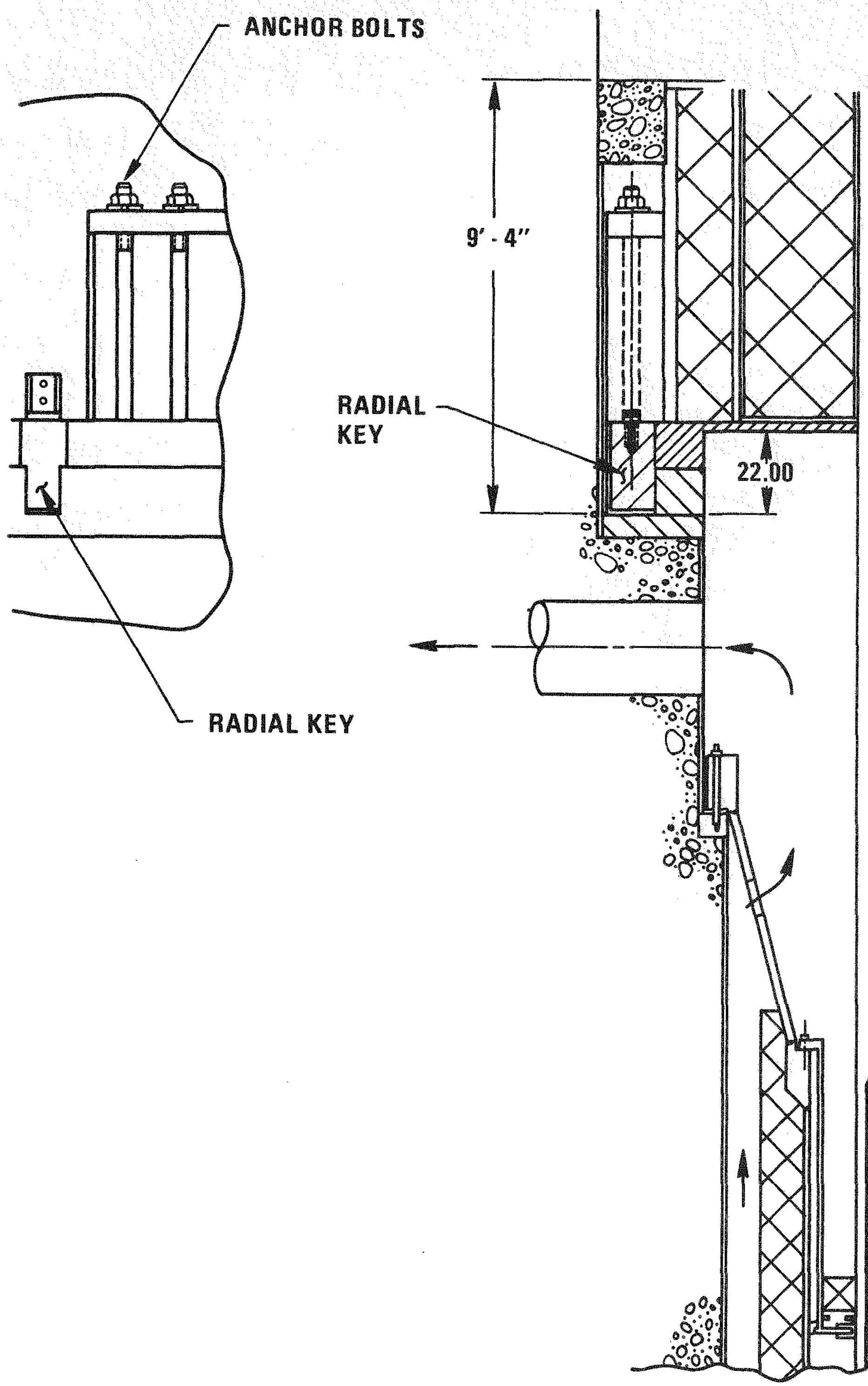

Figure 4-5.

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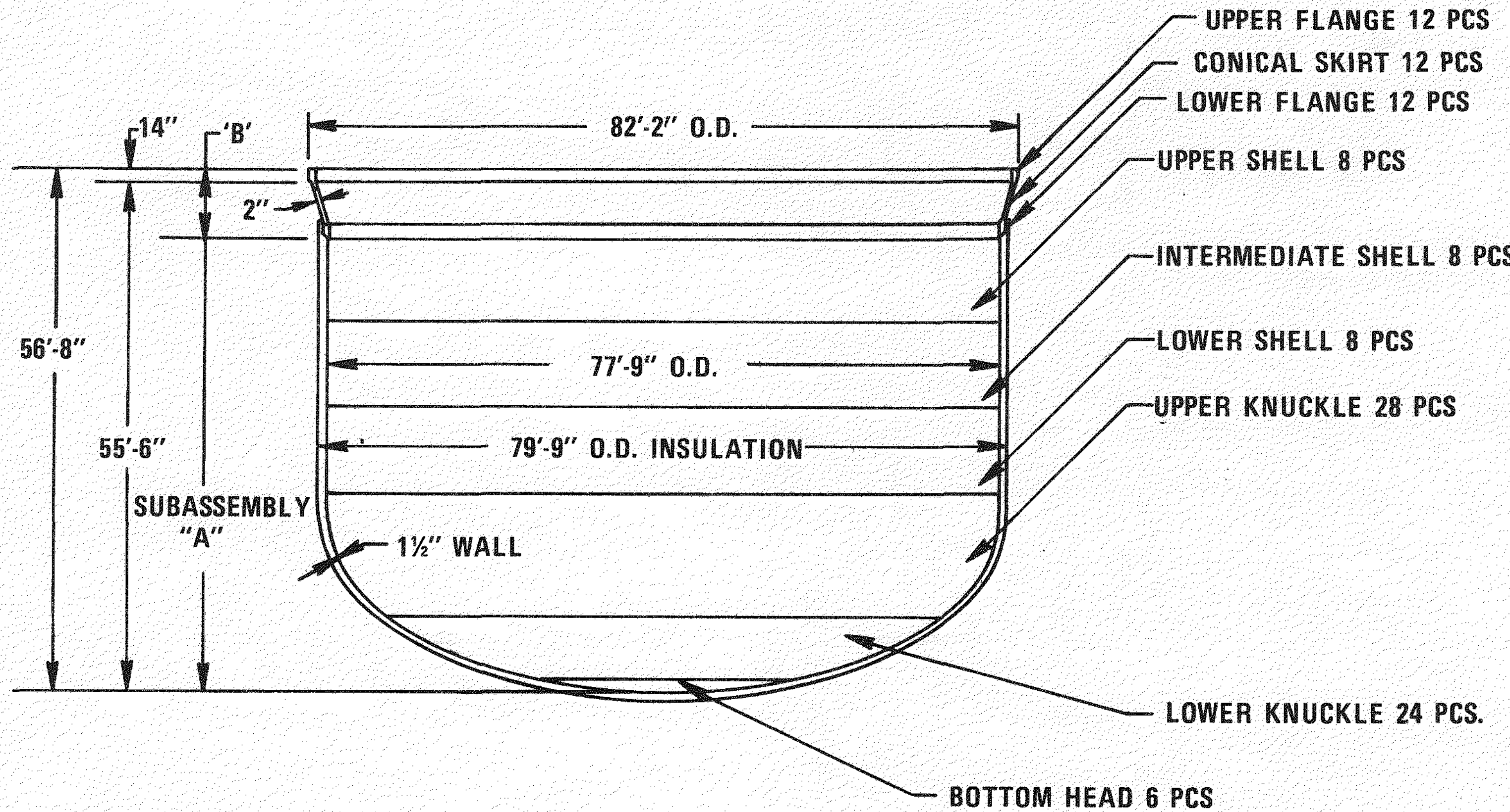

Figure 4-6. Guard Tank

- The lower knuckle, made up of 24 pieces, is fit, welded into a subassembly, inspected and joined to the bottom head.

- The upper knuckle, made up of 28 pieces, is fit, welded into a subassembly, inspected and joined to the lower knuckle.

- The lower shell course, made up of 8 pieces, is fit, welded into a subassembly, inspected and joined to the upper knuckle.

- The intermediate shell course, made up of 8 pieces, is fit, welded into a subassembly, inspected and joined to the lower shell course.

- The upper shell course, made up of 8 pieces, is fit, welded into a subassembly, inspected and joined to the intermediate shell course. A round up ring is installed. This completes subassembly "A".

- The lower flange, consisting of 12 pieces, is fit, welded into a subassembly and inspected. A round up ring is installed.

- The conical skirt, consisting of 12 pieces, is fit, welded into a subassembly, inspected and joined the the lower flange.

- The upper flange, consisting of 12 pieces, is fit, welded into a subassembly and inspected. A round up ring is installed and the subassembly joined to the conical skirt.

- The bolt pattern on the lower and upper flanges is laid out and drilled including the transfer drilling from the upper flange to the ledge ring. (see Figure 4-12). This completes subassembly "B".

- Subassembly "B" is fit, welded to subassembly "A" and inspected.

- The insulation is installed on the guard tank exterior surfaces.

- The guard tank is transported on its erection platen to the hoist area, and rigged to the installation crane for installation.

4.6.4 VESSEL STRUCTURAL BOX FLANGE (Figures 4-5, 4-7, 4-11)

The vessel structural box flange is made from 225 prefit segments or parts supplied ready for weld assembly.

- The bottom section of the vessel extension shell course, made up of 8 pieces, is fit, welded into a subassembly and inspected. The lower end is built up with a suitable weld filler for a bimetallic weld.

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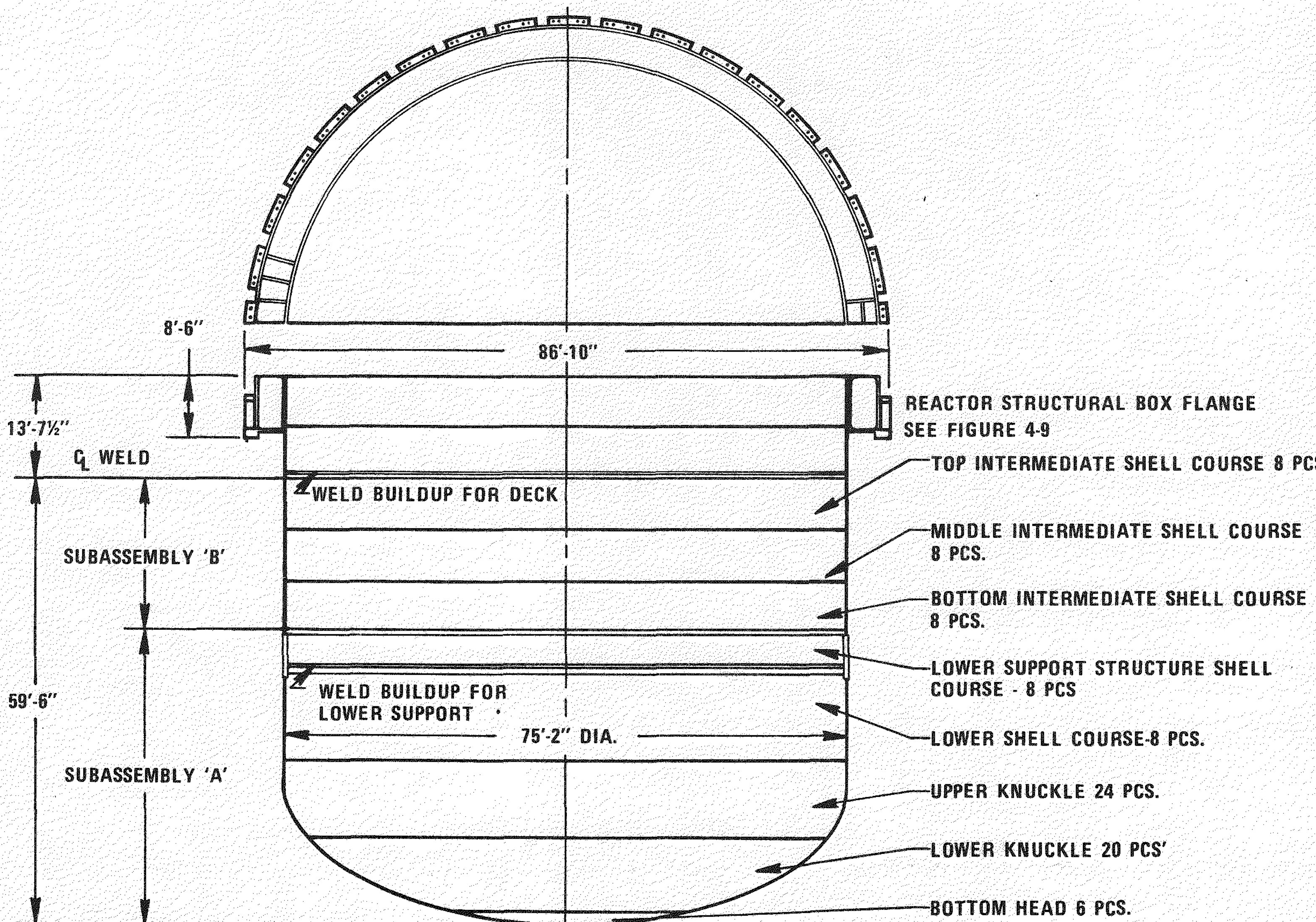

Figure 4-7. Reactor Vessel

- o The top section of the vessel extension shell course, made up of 8 pieces, is fit, welded into a subassembly, inspected, and joined to the bottom section. Round up rings are installed at the upper end of the top section and lower end of the bottom section. A weld buildup for the deck bottom plate is laid out, deposited and inspected. The annular plate location is laid out and the reactor vessel extension as-built diameter obtained with a Pi tape.
- o The annular plate, made up of 12 pieces, is fit, welded into a subassembly, inspected, trimmed on the inside diameter to suit the as-built vessel outside diameter, and joined to the reactor vessel.
- o The support ring, made up of 36 pieces, is fit, welded into a subassembly, inspected, trimmed on the inside diameter to suit the annular plate as-built outside diameter and joined to the annular plate. The bolt and keyway patterns are transferred to the reactor vessel support ring.
- o The outer cylinder, made up of 10 pieces, is fit, welded into a subassembly, inspected and joined to the support ring.
- o The bolting flange, made up of 36 pieces, is fit, welded to the outer cylinder and inspected.
- o The 108 gusset plates between the bolting flange and the support ring are fit, welded to the support ring, outer cylinder and bolting flanges and inspected.
- o The 80 radial ribs between the reactor vessel outer surface and outer cylinder inner surface are fit, welded and inspected.
- o The 7 access port standpipe assemblies adjacent to the reactor vessel outer surface are fit, welded and inspected.
- o The weldment is post weld heat treated in a temporary furnace erected on the erection platen and removed after completion of the heat treatment.

4.6.5 REACTOR VESSEL - STAINLESS STEEL SECTION (Figure 4-7)

The reactor vessel is made from 90 prefit component parts supplied ready for weld assembly.

- o The bottom dish, made up of 6 pieces, is fit and welded into a subassembly and inspected.
- o The lower knuckle, made up of 20 pieces, is fit, welded into a subassembly, inspected and joined to the lower knuckle.

- The upper knuckle, made up of 24 pieces, is fit and welded into a subassembly, inspected and joined to the lower knuckle.
- The lower shell course made up of 8 pieces is fit, welded and inspected and joined to the upper knuckle.
- The lower support structure shell course, made up of 8 pieces, is fit, welded and inspected into a subassembly and joined to the lower shell course. A round up ring is installed and a weld buildup for the core support cone is laid out, deposited, trimmed and inspected. This completes subassembly "A".
- The bottom intermediate shell course, made up of 8 pieces, is fit, welded into a subassembly, and inspected.
- The middle intermediate shell course, made up of 8 pieces, is fit, welded into a subassembly, inspected and joined to the bottom intermediate shell course.
- The top intermediate shell course, made up of 8 pieces, is fit, welded into a subassembly, inspected and joined to the middle intermediate shell course. Round up rings are installed at the upper end of the top shell course and lower end of the bottom shell course. This completes subassembly "B".
- Subassembly "B" is fit, welded to subassembly "A" and inspected.

4.6.6 REACTOR VESSEL (Figure 4-7)

The reactor vessel is made from major subassemblies fabricated in the site factory. Each of these components exceed the capacity of the factory crane and the assembly must be accomplished with the heavy lift equipment used for installation.

- The vessel structural box flange, described in 4.6.4 is moved from the site factory to the hoist area, rigged to the installation crane, and elevated.
- The stainless steel reactor vessel described in 4.6.5 is transported on its erection platen to a position directly under the elevated structural box flange.
- The structural box flange is lowered onto the stainless steel reactor vessel, aligned and tack welded. The rigging is detached from the structural box flange.
- The reactor vessel is returned to the site factory for the welding and inspection of the bi-metalic girth seam.

- The reactor vessel is transported on its erection platen to the hoist area, rigged to the installation crane for installation.

4.6.7 LOWER SUPPORT STRUCTURE (Figure 4-8)

The lower support structure is made from major subassemblies and prefit component parts ready for weld assembly.

- The lower support structure subassemblies depicted in Figure 4-2 are placed on an erection platen and the two long seams on the lower cone are fit, welded and inspected.
- The two interior upper cone plates are fit, welded and inspected.
- The outer neutron shield pedestal support cylinder subassembly is fit, welded and inspected.
- The inner neutron shield pedestal support cylinder subassembly is fit, welded and inspected.
- The neutron shield pedestal top plate subassembly is fit to the installed inner and outer cylinder, welded and inspected.
- The outside diameter of the cone lower plate and the thirty eight radial ribs are trimmed to suit the as-built inside diameter of the reactor vessel.
- The lower support structure is transported on its erection platen to the hoisting area, rigged to the installation crane for installation.

4.6.8 VESSEL SODIUM SHIELD (Figure 4-9)

The vessel sodium shield is made from 52 prefit component parts plus reflective insulation supplied ready for weld assembly.

LOWER SODIUM SHIELD SUBASSEMBLY

- The bottom shell course, made up of 8 pieces, is fit, welded into a subassembly and inspected.
- The upper shell course, made up of 8 pieces, is fit, welded into a subassembly and inspected.

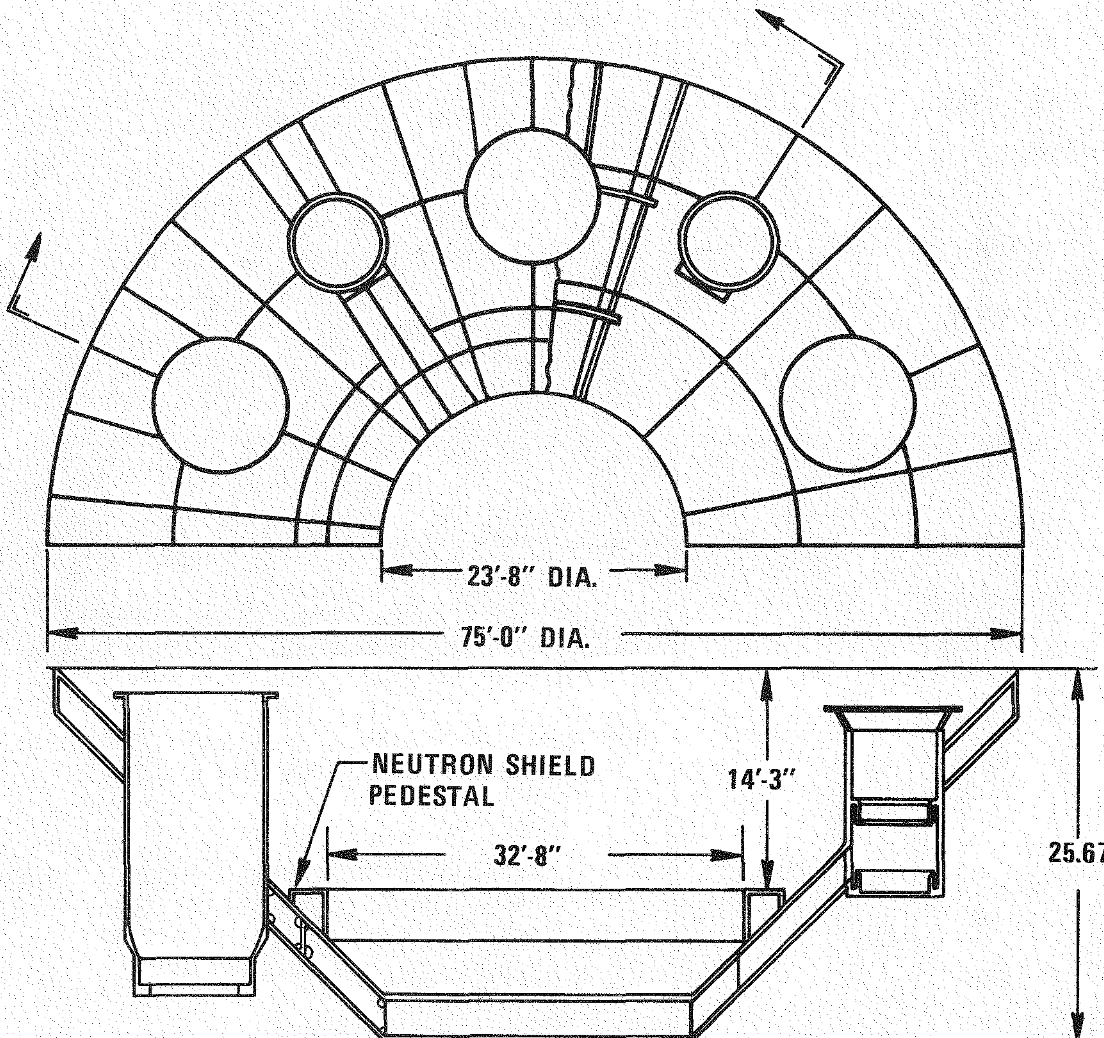

Figure 4-8. Lower Support Structure Supplied in Sections per Figure 4-2

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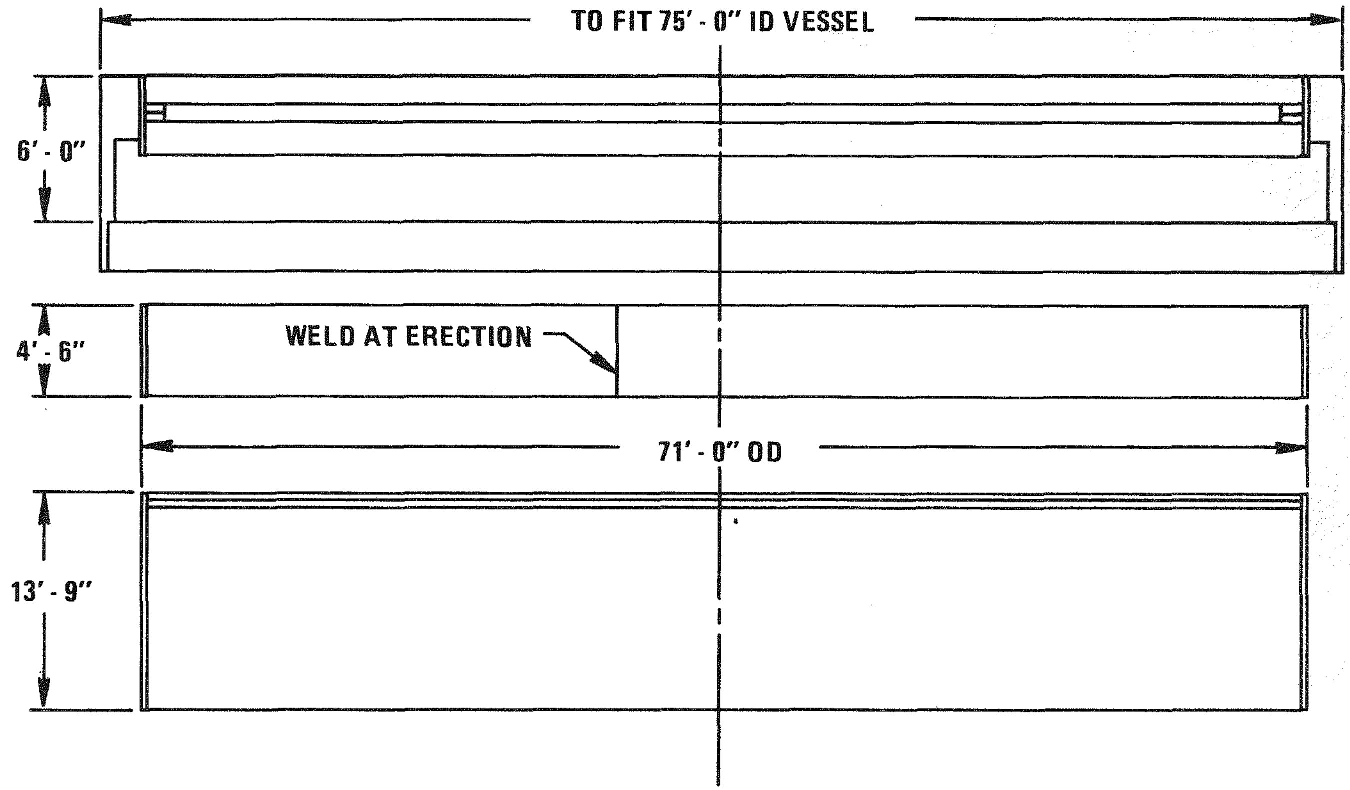

Figure 4-9. Sodium Shield Sub-Assemblies

- The outer horizontal baffle support ledge, made up of 8 pieces is fit, welded into a subassembly, inspected, properly located and joined to the upper shell.
- This completes the lower sodium shield subassembly which is joined to the lower support structure.
- The assembly is transported on its erection platen to the hoist area, rigged to the installation crane for installation.

UPPER SODIUM SHIELD SUBASSEMBLY

- The shell course, made up of 8 pieces, is fit, welded into a subassembly and inspected.
- The annular web plate, made up of 8 pieces, is fit, welded into a subassembly, inspected and properly located and joined to the shell course.
- The cylindrical flange, made up of 8 pieces, is fit, welded into a subassembly, inspected and joined to the web.
- The reflective insulation plates are installed on the outer periphery of the shell.
- The assembly is transported on its erection platen to the hoist, area, rigged to the installation crane and installed (temporarily placed on the upper end of the lower sodium shield subassembly).

INTERMEDIATE SODIUM SHIELD SUBASSEMBLY

- The intermediate sodium shield subassembly, made up of 8 pieces is fit, welded on all but one long seam and inspected.
- The ends are overlapped and the diameter reduced so that the subassembly can fit inside the upper sodium shield subassembly.
- This assembly is transported on its erection platen to the hoist area rigged to the installation crane and installed onto the outer horizontal baffle nested within the upper sodium shield subassembly.
- Once the fixed deck structure is welded to the vessel and the weld inspected and accepted, the upper subassembly is elevated into position and the intermediate subassembly fitted into place, welded and inspected. This requires two girth seams and one longitudinal seam.

4.6.9 NEUTRON SHIELD (Figure 4-10)

The neutron shield is made from 112 prefit component parts supplied ready for weld assembly.

OUTER WALL SUBASSEMBLY

Bottom Shell Subassembly

- The lower shell course, made up of 4 pieces, is fit, welded into a subassembly and inspected. The elliptical holes where the fuel transfer tube and low level flux monitors penetrate the shell are laid out, cut and trimmed.
- The upper shell course, made up of 4 pieces, is fit, welded into a subassembly, inspected and joined to the lower shell. A round up ring is installed.
- The subassembly is transported on its erection platen to the hoist area, rigged to the installation crane and installed.
- This subassembly is welded to the neutron shield pedestal on the lower support structure at its lower end and joined to the intermediate baffle at the upper end.

Top Shell Subassembly

- The lower shell course, made up of 4 pieces, is fit, welded into a subassembly and inspected.
- The upper shell course, made up of 4 pieces, is fit, welded into a subassembly, inspected and joined at the lower shell. A round up ring is installed.
- The subassembly is transported on its erection platen to the hoist area rigged to the installation crane and installed.
- This subassembly is welded to the intermediate baffle at its lower end. This completes the outer wall subassembly.

INNER WALL SUBASSEMBLY

Bottom Shell Subassembly

- The bottom shell course, is made up of 4 pieces, is fit, welded into a subassembly and inspected. The elliptical holes where the fuel transfer tube and low level flux monitors penetrate are laid out, cut and trimmed.

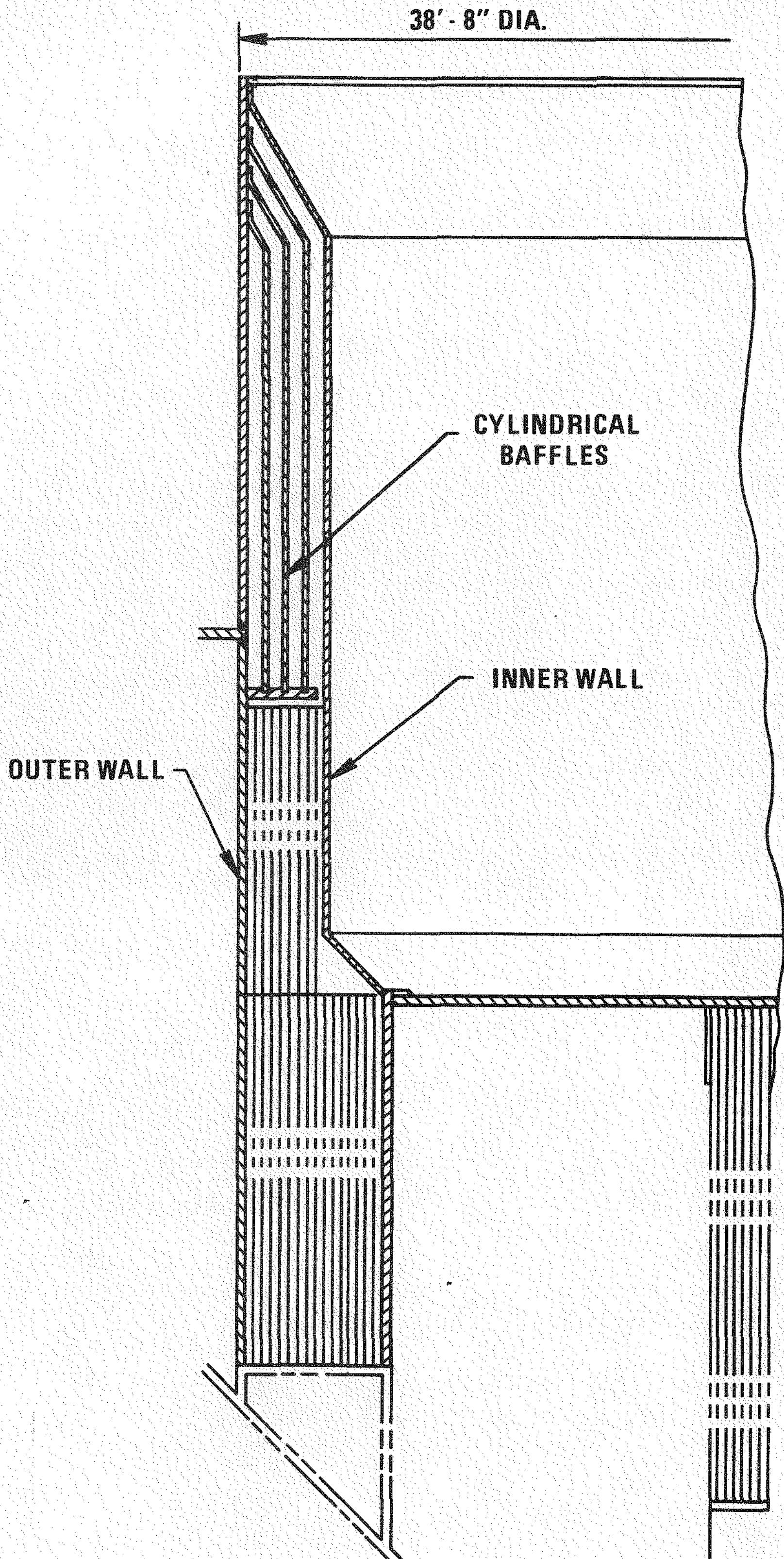

Figure 4-10. Neutron Shield

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- The subassembly is transported on its erection platen to the hoist area rigged to the installation crane and installed.
- This subassembly is welded to the neutron shield pedestal on the lower support structure at its lower end and joined to the inner horizontal baffle at the upper end.

Intermediate Shell Subassembly

- The flat ring, made up of 6 pieces, is fit, welded into a subassembly and inspected.
- The conical skirt, made up of 6 pieces, is fit, welded into a subassembly, inspected, trimmed and joined to the flat ring.
- The lower shell course, made up of 4 pieces, is fit welded and inspected into a subassembly and joined to the conical skirt.
- The upper shell course, made up of 4 pieces, is fit, welded into a subassembly, inspected and joined to the lower shell course.

Upper Subassembly

- The conical skirt, made up of 6 pieces, is fit, welded into a subassembly and inspected. One seam is left unwelded.
- The flange, made up of 4 pieces, is fit, welded into a subassembly and inspected. One seam is left unwelded. The flange is joined to the conical skirt to make a subassembly with one unwelded seam. The subassembly edges are overlapped and the diameter reduced so that the subassembly can be lowered through the large rotating plug opening.

Outer Interior Baffle Subassembly

- The baffle shell, made up of 4 pcs, is fit, welded into a subassembly and inspected. One seam is left unwelded.
- The conical skirt, made up of 6 pcs, is fit, welded into a subassembly and inspected. One seam is left unwelded. The skirt is joined to the shell to make a subassembly with an unwelded seam.

- The flange, made up of 4 pcs, is fit, welded into a subassembly, and inspected. One seam is left unwelded. The flange is joined to the conical skirt to make a subassembly with one unwelded seam. The subassembly edges are overlapped and the diameter reduced so that the subassembly can be lowered through the large rotating plug opening.

Middle Interior Baffle Subassembly

Inner Interior Baffle Subassembly

The number of pcs and fabrication sequence is identical to the outer interior baffle subassembly.

Interior Baffle Supports

The interior baffle supports are slotted to suit the as-built diameters of the shell sections of the interior baffles and trimmed to suit the as-built inside diameter of the outer wall.

4.6.10 PLENUM SEPARATOR SYSTEM COMPONENTS

The plenum separator system components are made from major subassemblies and prefit component parts ready for weld assembly.

INTERMEDIATE BAFFLE

- The two 160 degree subassemblies each containing three IHXs and two pumps, and two 20 degree plates which were prefabricated off site are trimmed on the outside diameter to suit the vessel sodium shield and on the inside to suit the neutron shield outer wall.
- The four subassemblies are then transported to the hoisting area for installation.
- This enables the intermediate baffle to be installed through the support ledge on the sodium shield for the upper baffle. The four radial seams that result are done in containment.

OUTER HORIZONTAL BAFFLE

- The two 160 degree subassemblies each containing three IHXs and two pumps, and two 20 degree plates which were prefabricated off site are fit-welded into a subassembly on an erection platen and inspected.

- The cylindrical skirt made up of 8 pcs is fit-welded into a subassembly inspected and joined to the baffle.
- The support ledge made up of 8 pcs is fit-welded into a flat ring subassembly, inspected, trimmed on the inside diameter to suit the as-built cylindrical skirt and joined to the skirt.
- The horizontal baffle assembly is trimmed on the outside diameter to suit the reactor vessel and on the inside to suit the neutron shield outer wall.
- The horizontal baffle is transported on the erection platen to the hoist area, rigged to the installation crane and installed in one piece.

4.6.11 FIXED DECK STRUCTURE (Figure 4-11)

The fixed deck structure is made from major subassemblies and prefit component parts ready for weld assembly.

- The fixed deck structure outer subassemblies depicted in Figure 4-1 are placed on the erection platen and the (4) long seams are fit, welded and inspected. The outside diameter is trimmed to the as-built inside diameter of the reactor vessel weld buildup.
- The fixed deck structure is transported on its erection platen to the hoisting area, and rigged to the installation crane for installation.

4.6.12 INTERMEDIATE PLUG/UPPER INTERNALS ASSEMBLY (Figure 4-12)

The intermediate plug/upper internals assembly is made from major components fabricated off site and delivered ready for final assembly.

- The upper internals assembly is centrally placed on jacks on an erection platen in a vertical supported position.
- Support columns are assembled to the top surface of the erection platen.
- The intermediate rotatable plug is hoisted by the crane over the upper internals assembly, aligned in azimuth and centralized and set to rest on the support columns.

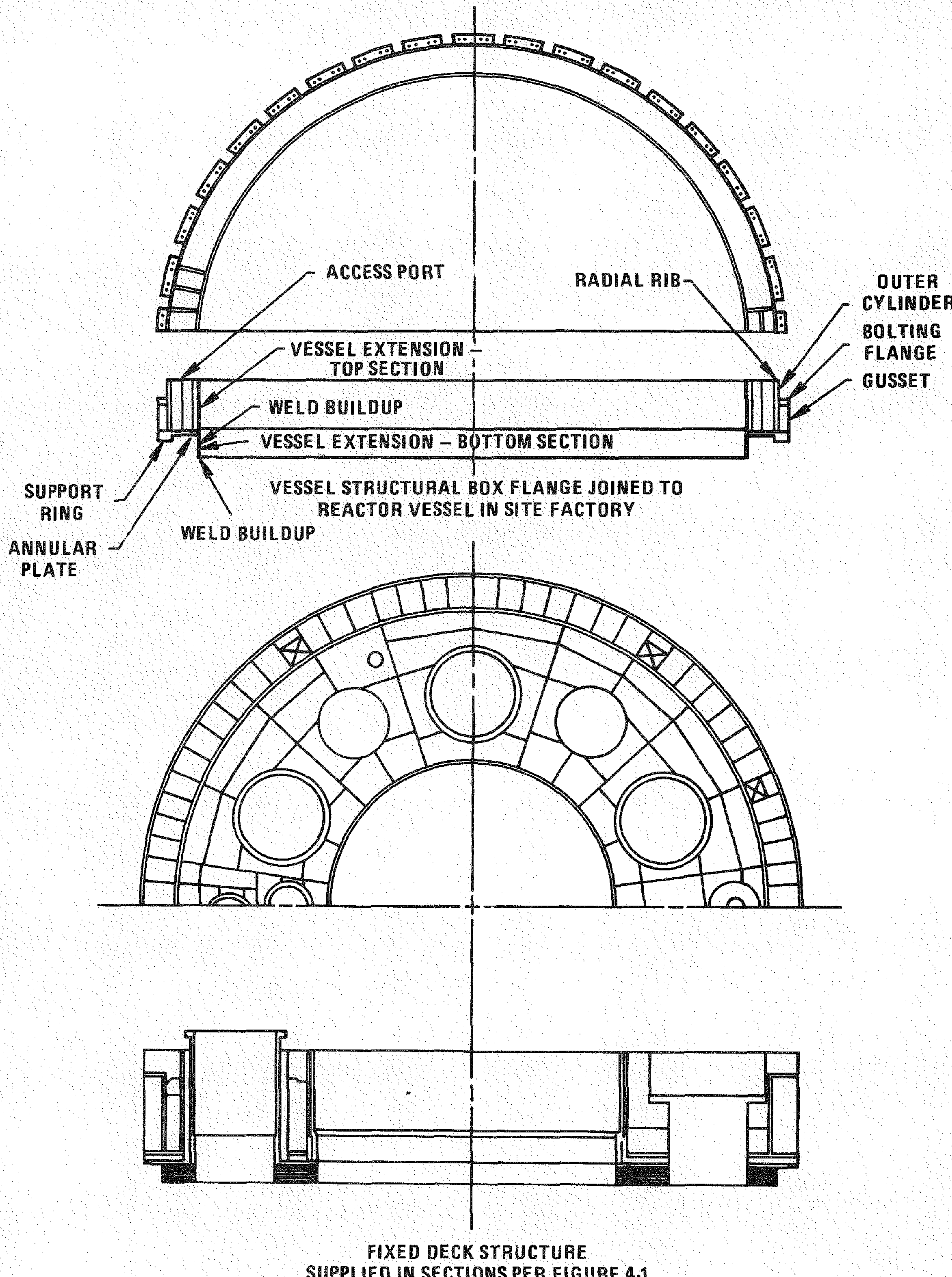

Figure 4-11. Outer and Inner Stationary Rings

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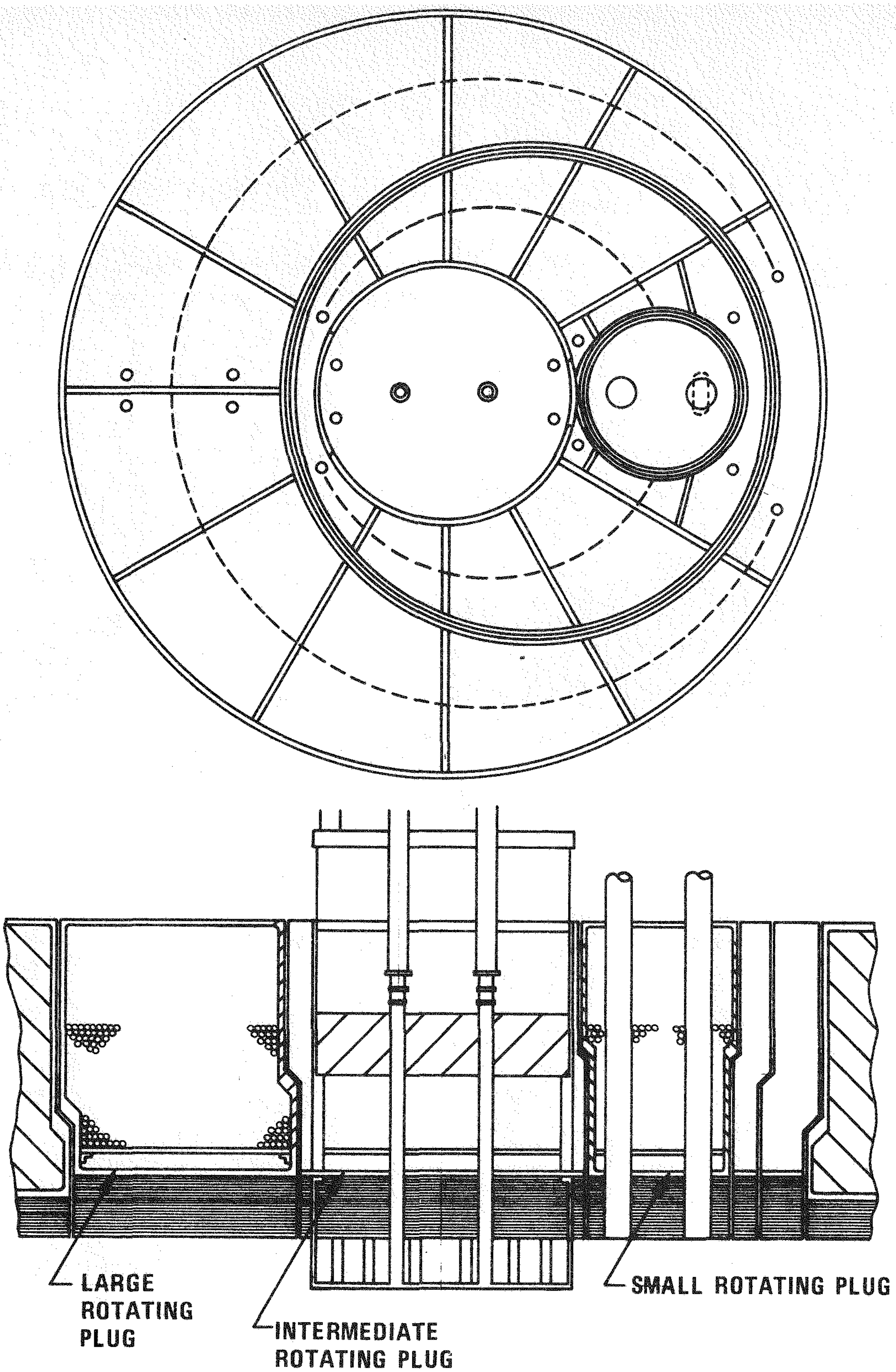

Figure 4-12.

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- o The upper internals assembly is jacked upward to seat against the intermediate rotatable plug and the mechanical attachment completed.
- o The CRDMs, instrumentation columns, and thermocouple guide tubes are installed..
- o The Intermediate Plug/Upper Internals assembly is transported on its erection platen to the hoisting area, rigged to the installation crane and installed.

4.7 POOL-TYPE LMFBR CONSTRUCTION SEQUENCE AND SCHEDULE

A pictorial representation of the critical path sequence is given in Figures 4-13 through 4-22.

The detailed schedule is specified in Section III of the Stone and Webster Construction Evaluation. The site factory must deliver the components to the hoist area to meet the schedule. To levelize the factory load, some of the components may have to be completed early and temporarily stored between the factory and the hoist area.

4.7.1 INSTALLATION CRANE

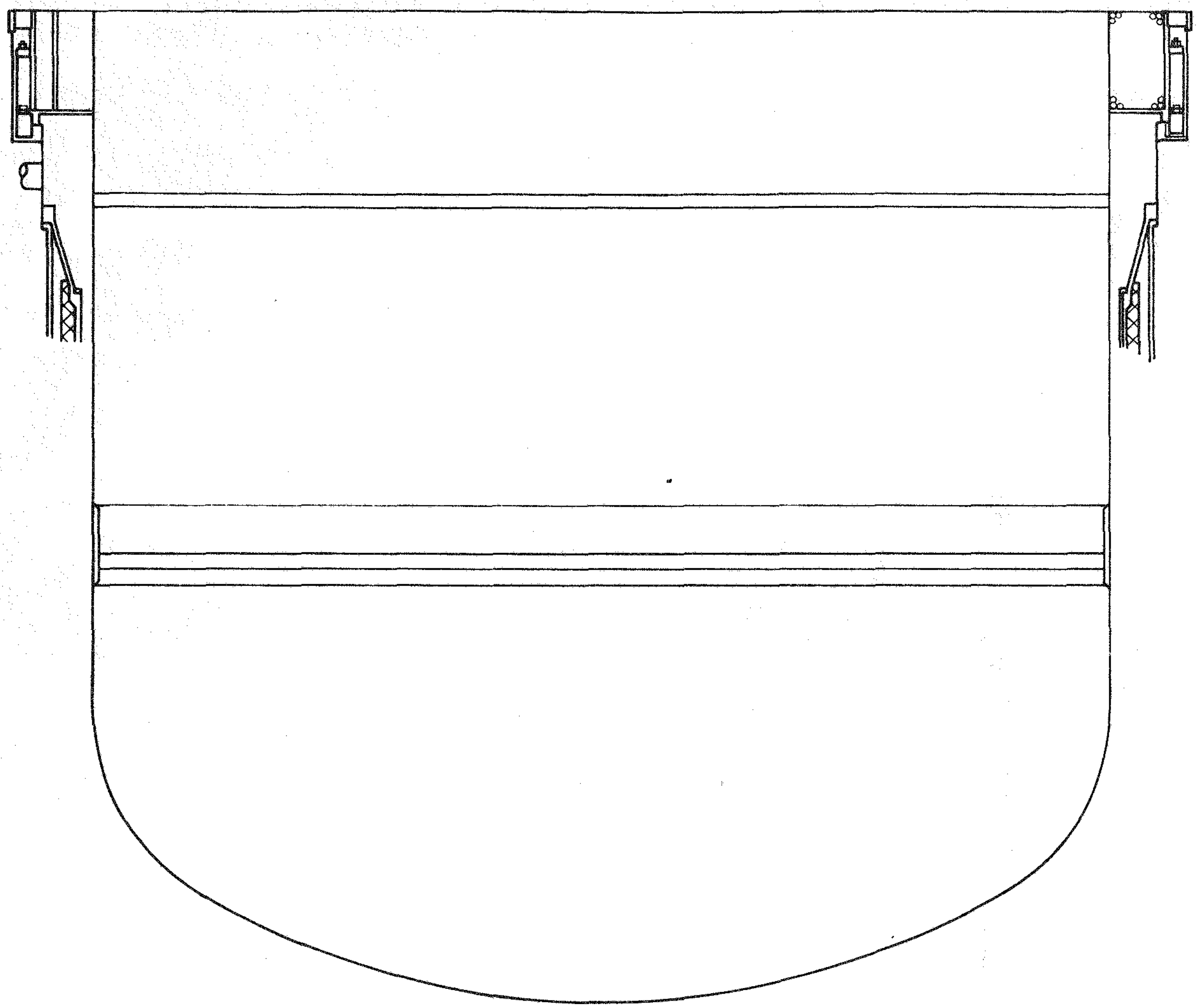
The installation crane is described in the Stone and Webster Construction Evaluation which is part of Volume 4.

4.7.2 PERSONNEL

Because of the extensive effort required to fabricate components in a site factory, proper selection of personnel is critical to the success of the program. Reference 1 describes this activity in some detail.

4.7.3 SPECIAL EQUIPMENT

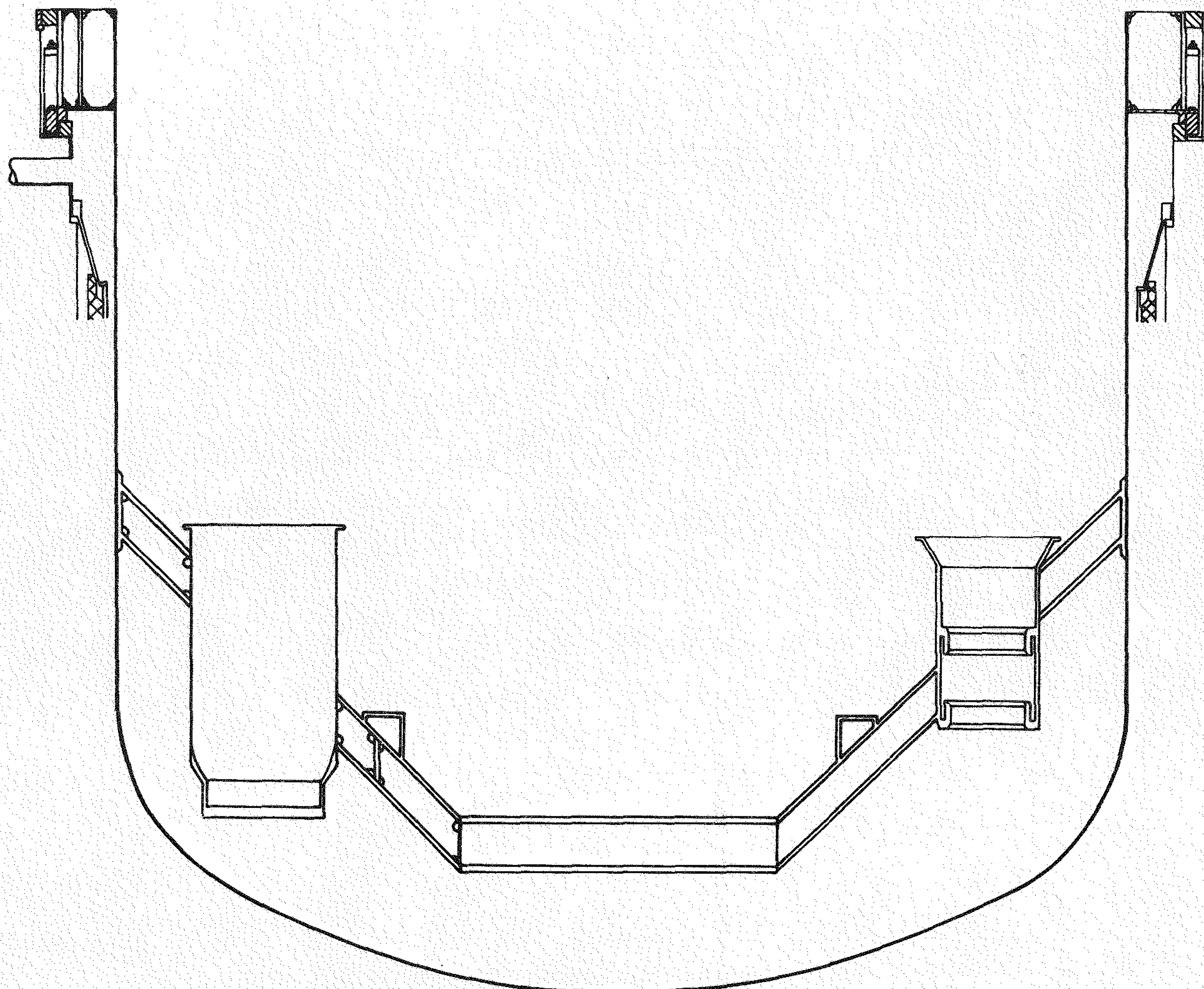
Extensive welding and some large machining is required. Maximum use of mechanized welding will be employed. Reference 1 specifies the equipment required.



1. INSTALL REACTOR VESSEL
   - INSTALL VESSEL AND ALIGN TO CAVITY CENTERLINE
   - SECURE VESSEL IN ALIGNED POSITION BY TACK WELDS OR TEMPORARY KEYS
   - FIT AND INSTALL RADIAL KEYS
   - INSTALL SHOT
   - INSTALL COVER PLATES & ACCESS PLUGS

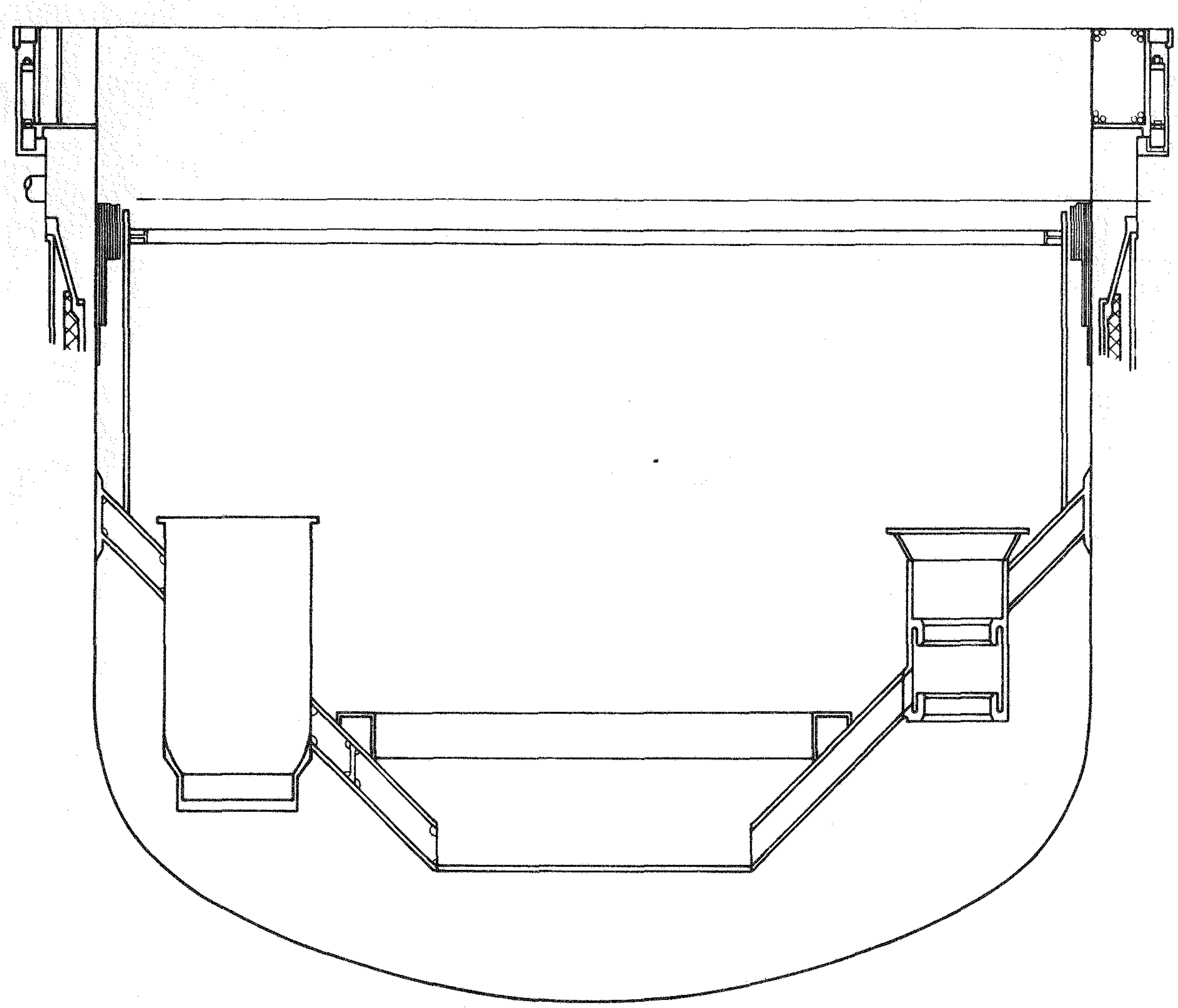
   } PARALLEL WITH SUBSEQUENT OPERATIONS

Figure 4-13. Construction Sequence



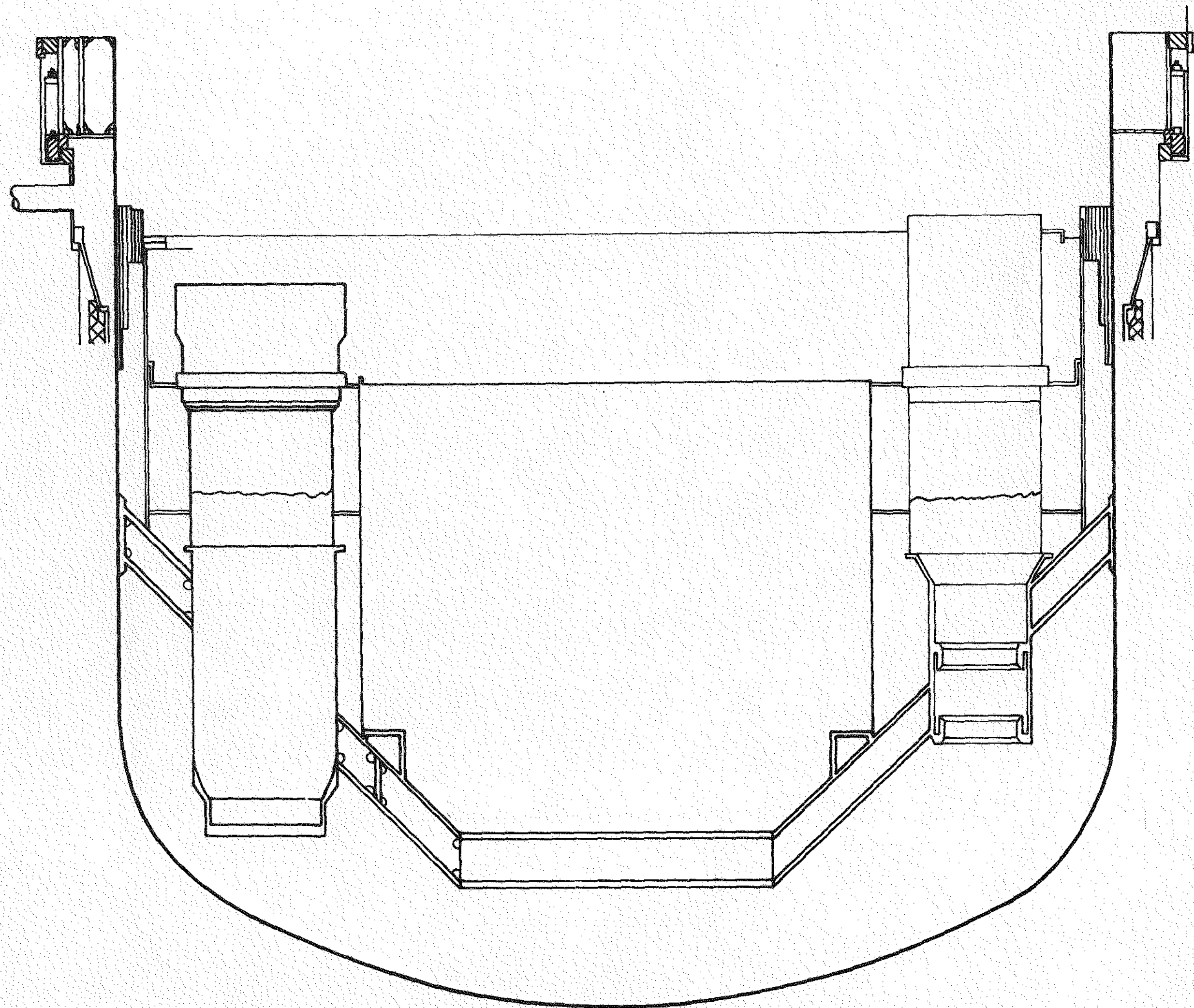
2. INSTALL LOWER SUPPORT STRUCTURE
- INSTALL TEMPORARY SUPPORT PADS
- FIT AND INSTALL LOWER SUPPORT
  - WELD LOWER CONE TO VESSEL - REMOVE SUPPORT PADS
  - WELD GUSSETS TO VESSEL
  - FIT, INSTALL AND WELD TOP CONE PLATES

Figure 4-14. Construction Sequence



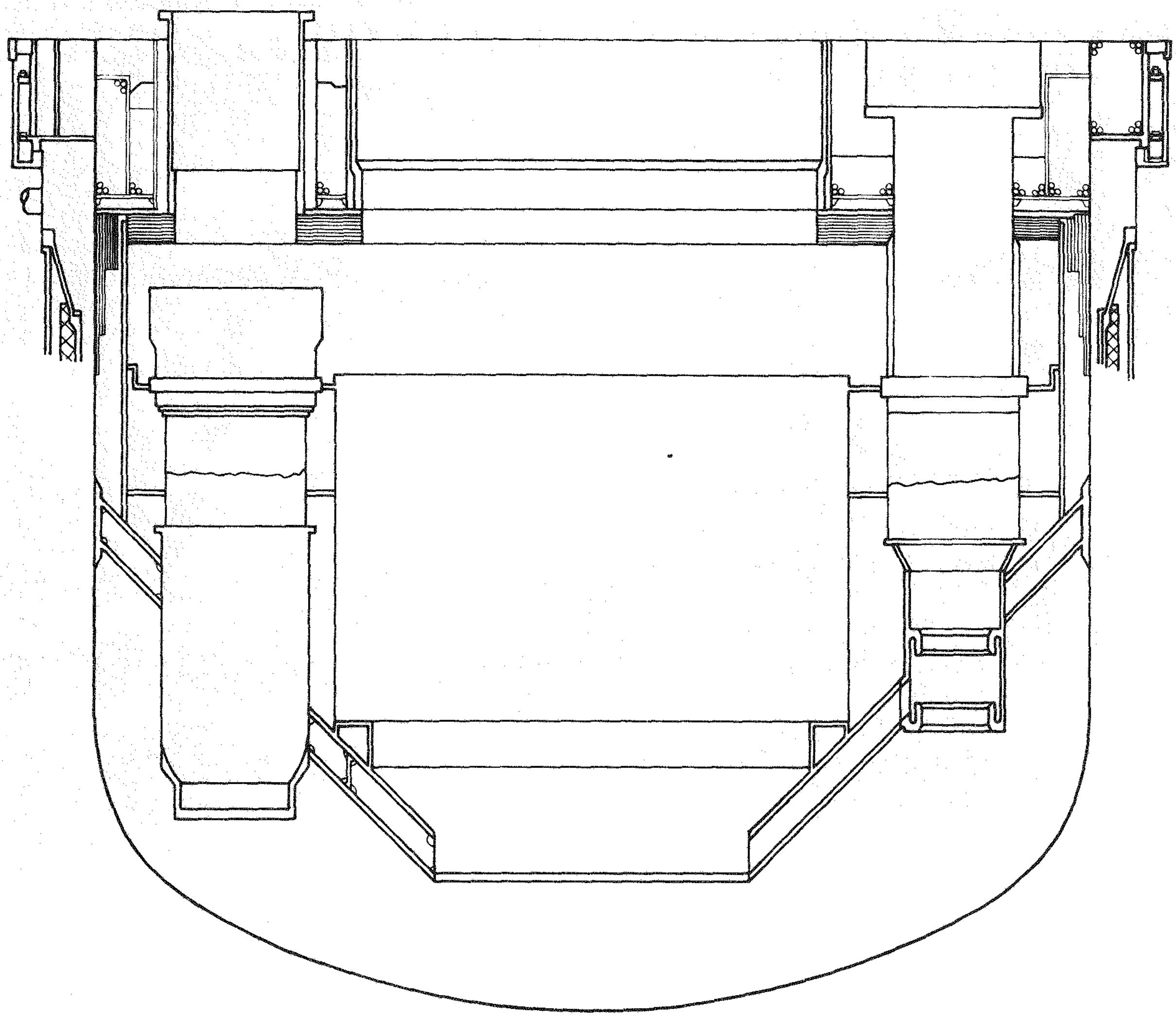
3. INSTALL VESSEL SODIUM SHIELD
- WELD LOWER SODIUM SHIELD SUB-ASSEMBLY TO LOWER SUPPORT CONE
- FIT BALANCE OF COMPONENTS FOR BUILD IN PLACE SEQUENCE (THIS IS NECESSARY TO PROVIDE ACCESS TO UNDERSIDE OF WELD JOINING DECK TO VESSEL I.D.)
- COMPLETE FABRICATION OF SODIUM SHIELD AFTER OPERATION 7 AS A PARALLEL OPERATION.

Figure 4-15. Construction Sequence



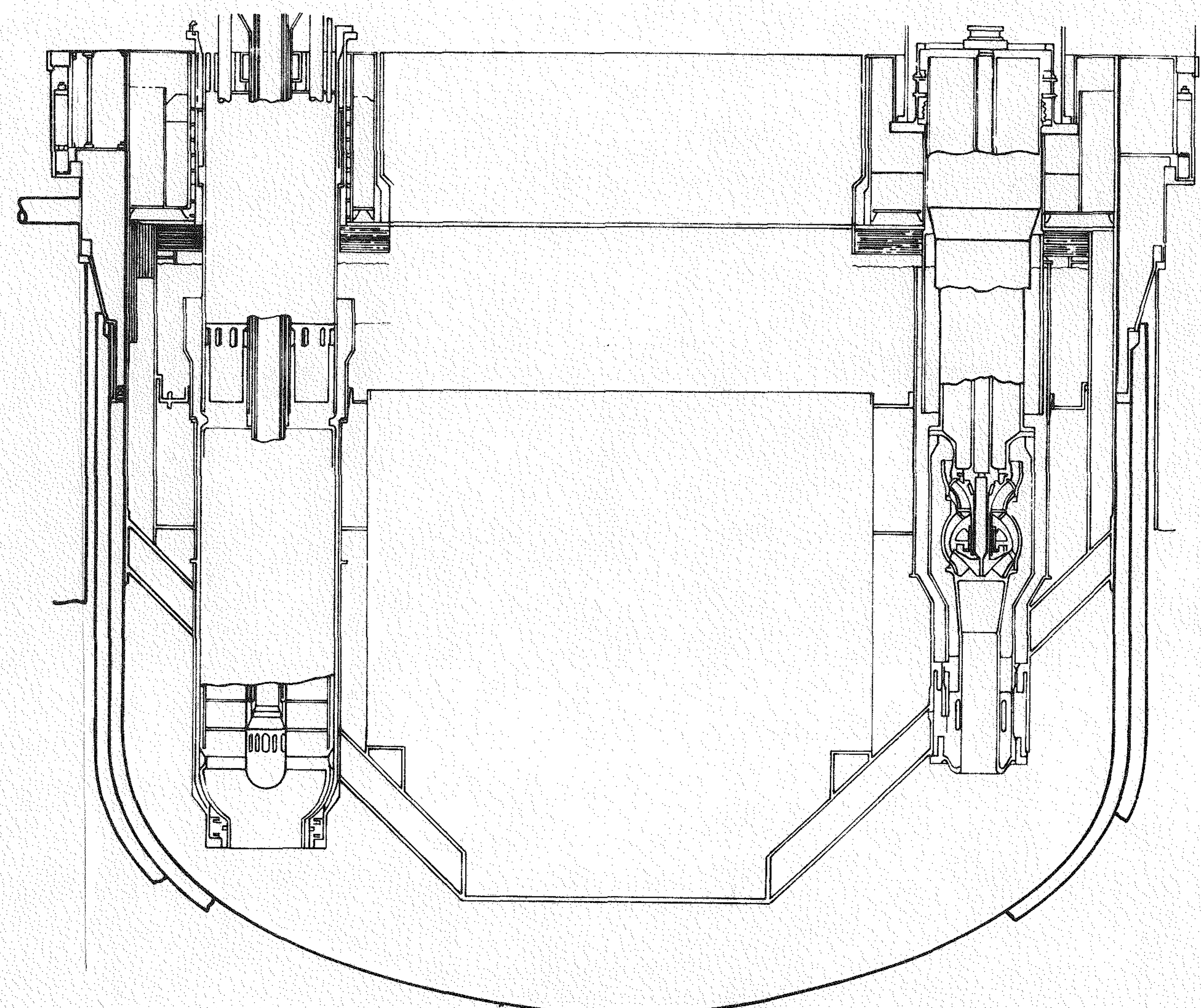
4. INSTALL NEUTRON SHIELD OUTER TANK/LOWER BAFFLE SUB-ASSEMBLY
5. INSTALL IHX AND PUMP INTERMEDIATE STAND PIPES.
6. INSTALL NEUTRON SHIELD OUTER TANK/UPPER BAFFLE SUB-ASSEMBLY WITH SEALS IN PLACE. INSTALL UPPER STANDPIPES

Figure 4-16. Construction Sequence



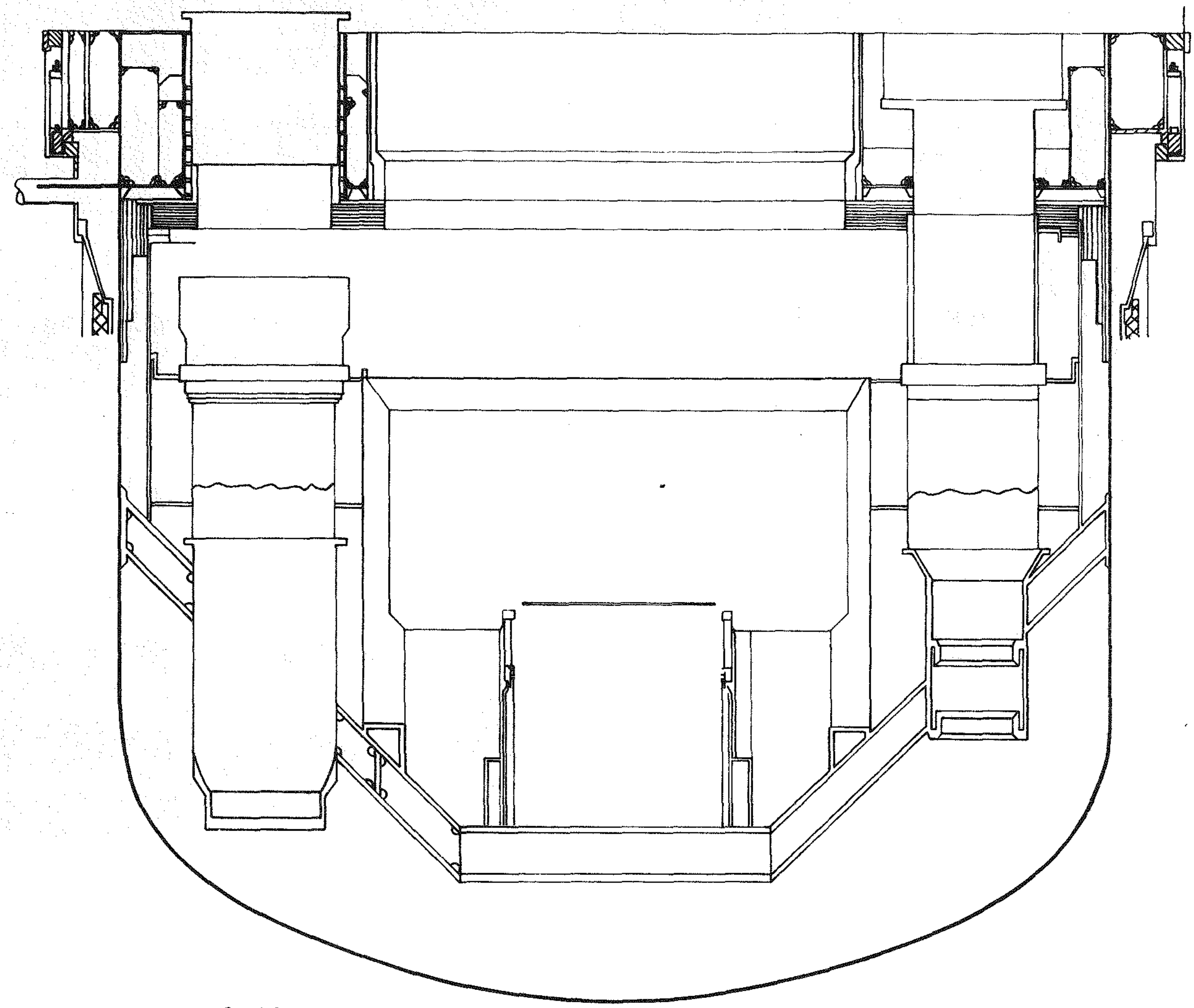
7. INSTALL FIXED DECK STRUCTURE
- FIT AND WELD FIXED DECK STRUCTURE TO 75' ID VESSEL
- FIT AND INSTALL OUTER SECTIONS OF SHOT SUPPORT PLATE
- INSTALL COOLING PIPING
- INSTALL SHOT
- INSTALL DECK TOP PLATE
- MACHINE STATIONARY RING EQUIPMENT MOUNTING SURFACES

Figure 4-17. Construction Sequence



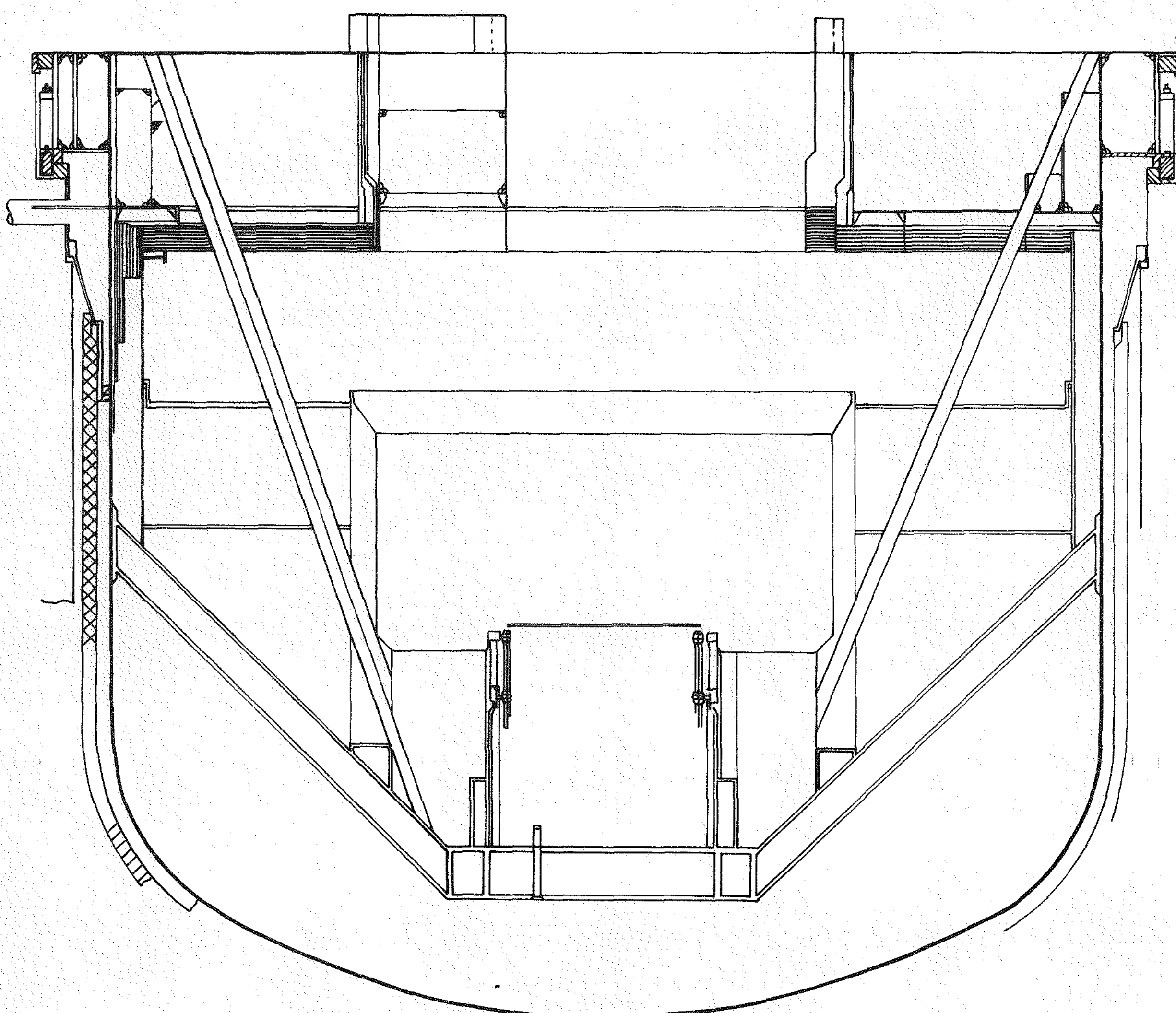
8. INSTALL PUMPS, IHX'S, AND COLD TRAPS IN PARALLEL MACHINE NEST FOR CORE SUPPORT STRUCTURE

Figure 4-18. Construction Sequence



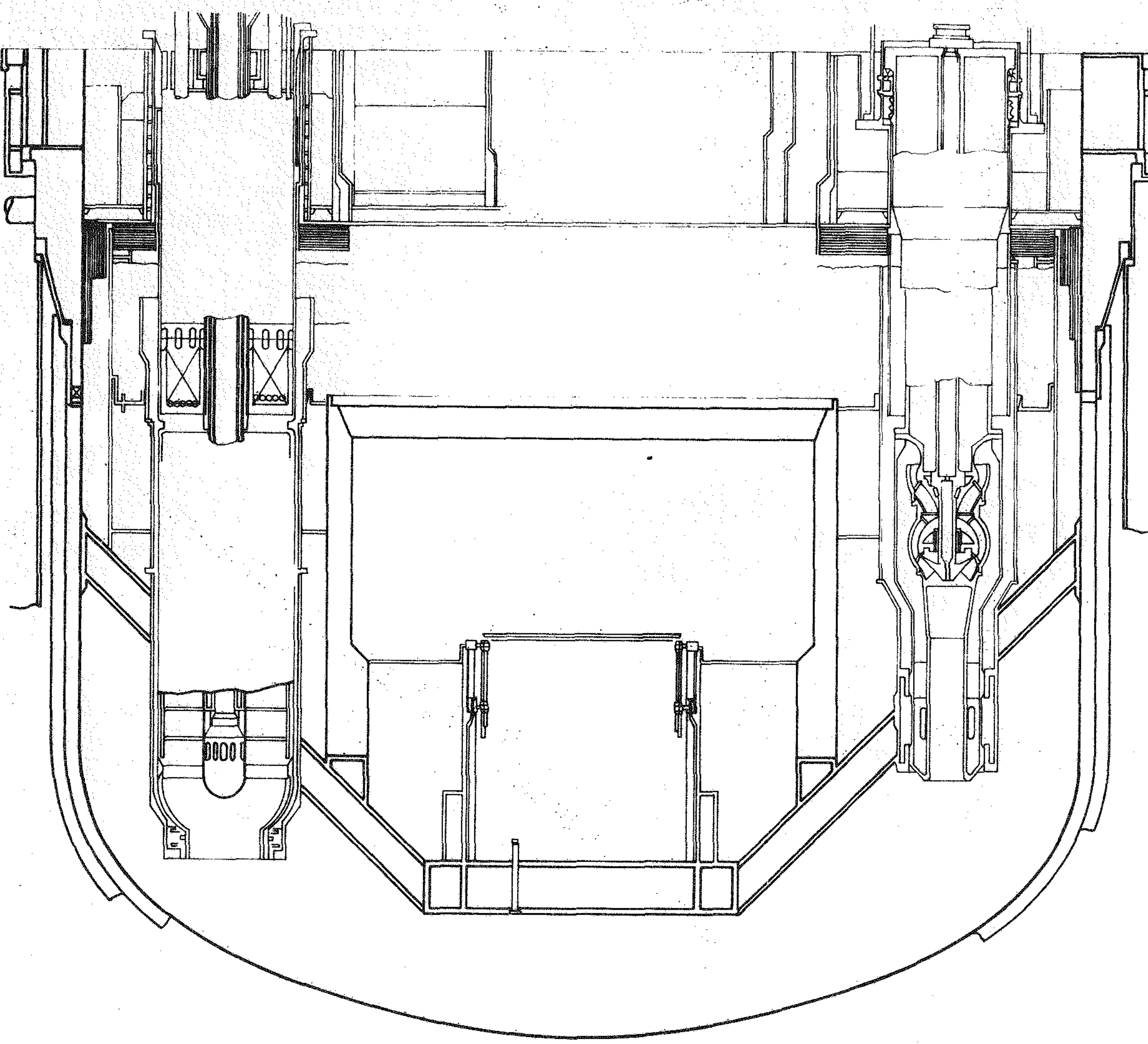
9. INSTALL CORE SUPPORT STRUCTURE
   - INSTALL SUPPORT PADS
   - FIT AND INSTALL CORE SUPPORT
     - WELD LOWER CONE TO CORE SUPPORT-REMOVE PADS
     - WELD GUSSETS TO CORE SUPPORT
     - FIT AND WELD FUEL TRSR. INTERFACING HARDWARE
     - FIT AND INSTALL TOP CONE PLATES
     - FIT AND WELD SECONDARY CORE SUPPORT
10. INSTALL BALANCE OF NEUTRON SHIELD AND INNER HORIZONTAL BAFFLE INCLUDING ANGULAR PENETRATIONS FOR FUEL TRANSFER AND LOW LEVEL FLUX MONITORS

Figure 4-19. Construction Sequence



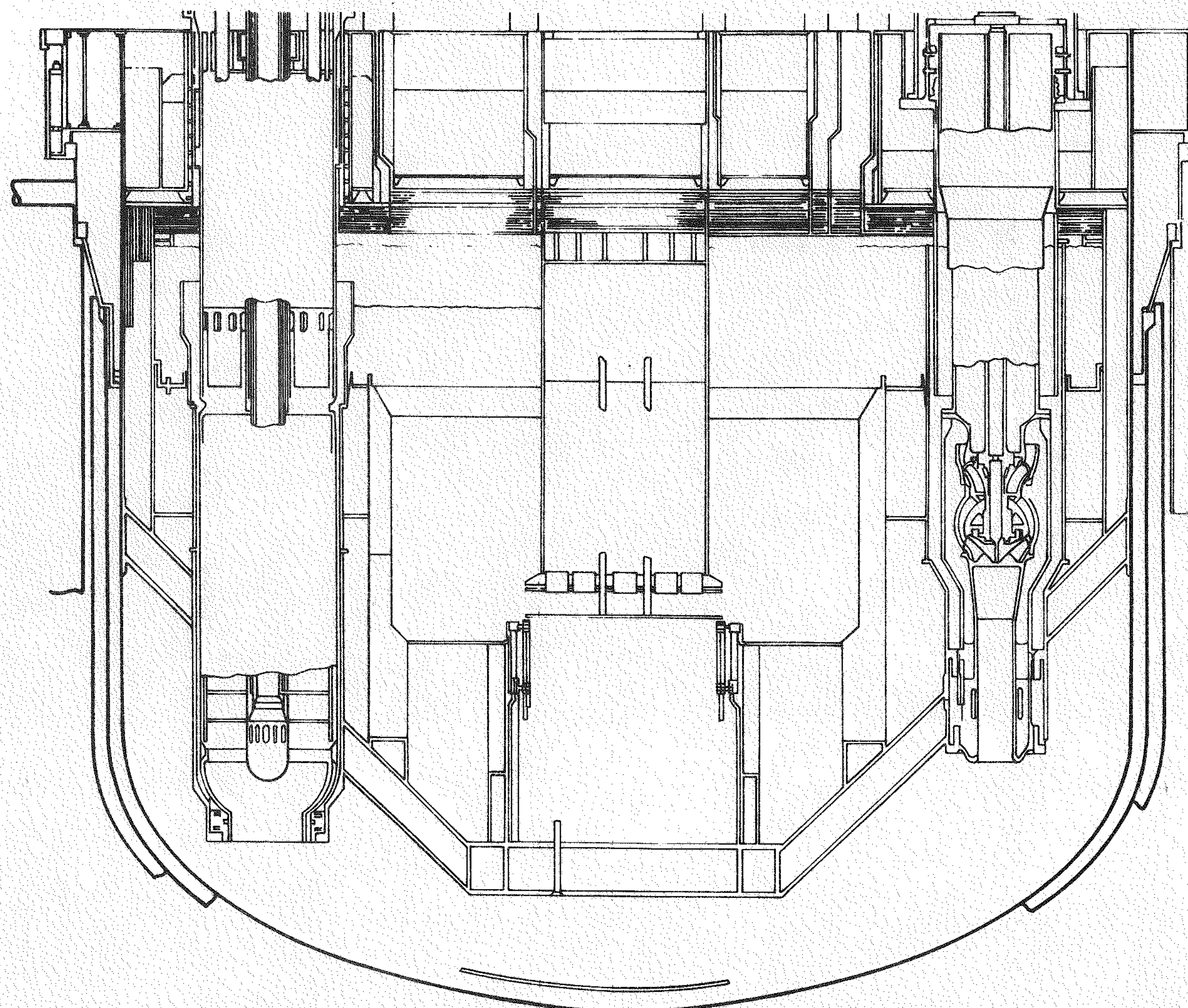
11. INSTALL LARGE ROTATING PLUG
IN PARALLEL, INSTALL FUEL TRANSFER EQPT
AND LOW LEVEL FLUX MONITORS

Figure 4-20. Construction Sequence



12. INSTALL RADIAL SHIELDS AND DUMMY CORE

Figure 4-21. Construction Sequence



13. INSTALL INTERMEDIATE ROTATING PLUG WITH UPPER INTERNALS ASSEMBLY, INSTALL SMALL ROTATING PLUG
14. TEST SEALS
15. GAS TEST SYSTEM
16. FUNCTIONAL TESTS
17. HEATUP
18. SODIUM FILL
19. HOT FUNCTIONAL

Figure 4-22. Construction Sequence

4.8 PROBLEM AREAS REQUIRING FURTHER WORK

- The box-like nature of the vessel structural box flange, lower support structure and fixed deck structure weldments will result in some welds with no access to the backside, or joints that cannot be welded unless access openings are provided. Further engineering evaluation and design alteration is required.
- The recess for the core support structure requires further design optimization or acceptance of a partial penetration weld where the top cone plate joins the core support structure.
- The fixed deck structure has several areas where the cylindrical members, radial ribs and penetration liners create weld joints with limited access. Further engineering evaluation and design alteration is required.
- Domestic sources of supply for the seals, bearings and gear train required for the 36 ft 8 in large rotatable plug must be developed or foreign sources utilized.
- The optimum configuration for all components used to make weldments must be worked out with a selected fabricator to minimize welding.
- The fitups of the lower support and fixed deck structure to the reactor vessel are critical and operations relating to these fitups should be given additional study.
- The configuration of the neutron shield should be altered to permit installation in one piece to reduce erection installation of the fuel handling tube and flux well penetrations.
- Alternate methods of fabrication should be evaluated to reduce the amount of welding done during erection.
- A tolerance study should be made to verify that probable as-built conditions such as annular gap variances which will result from the out of roundness of large cylindrical components and weld shrinkage and distortion are acceptable to the designer.

SECTION 5.0
CONCLUSIONS

The work performed by ARD in the period from February 1978 - July 1978 and the work performed by Stone and Webster in the period of mid-March through July, 1978 were extensions of the conceptual design of a Large Pool Reactor (LPR) previously evolved at ARD. This work has resulted in (1) certain simplifications within the reactor vessel, e.g., elimination of the use of bypass flow in the plenum separator region, (2) initial definition of the containment/confinement system, (3) initial definition of the building plot plan, (4) sizing and conceptual selection and design configurations for the pumps and IHXs, (5) preliminary analysis of certain reactor transients, (6) sizing and layout of the residual heat removal systems, and (7) initial T/H and stress analysis of selected components. The work performed in this period revealed no inherent or generic technical problems which would preclude the successful design and construction of an LPR within the U.S.

The continuing design effort has also reconfirmed the critical nature of the design of the reactor deck, the plenum separators and the reactor vessel. An important technical area concerns the hydraulics within the cold plenum, intermediate plenum and hot pool of the reactor. An understanding of the hydraulics in these regions is critical to plant performance as well as to the design of the reactor vessel, the plenum separators, and other pool components. Although continual analysis is necessary, it is believed that a proper understanding can only be obtained by proper hydraulic model tests.

Continued design optimization and structural analysis for seismic loads is also an important area. This is particularly true for the many large shells within the vessel, which are inherent in a pool type LMFBR.

To complete this report by the end of July, it was necessary to freeze the design on June 16, 1978. As a result, a number of design features were not fully evaluated, and a number of changes are known to be desirable. Alternate configurations require further evaluation to confirm their potential advantages over the present reference designs described herein.

For example, the seismic response spectrum used to size the reactor vessel was one which was defined during the PLBR Phase II studies of 1976-1977. During this current work effort, a new response spectrum has been defined applicable to the LPR size and configuration. A significant shift to lower frequencies is apparent in the new response spectrum. When this new data is incorporated into the design process, a thinner vessel wall thickness is expected to be allowable, and the stress levels of many other reactor components would be expected to decrease.

The design improvements made in the plenum separator configuration will permit a reduction in reactor vessel size. It is judged that the vessel inside diameter can be reduced from 75 ft without impacting other design features. Such a reduction in vessel size also permits a reduction in deck thickness while maintaining the same maximum static deflection.

The adoption of a three plug closure for the deck rather than a two plug arrangement came at the end of this work phase. The new configuration results in a smaller swing radius for the upper internals structure during refueling. As a result, the neutron shield tank can be reduced in diameter. Similarly, the fabrication and erection sequence developed for the reference design has identified areas where alternate designs could reduce the complexity of fabrication. The lower support structure, for example, no longer requires that both of the conical shells be continuous and form a sealed compartment.

The structural analysis of the UIS identifies a number of design changes, such as increasing the wall thickness, reducing the number of flow holes, etc., to bring the stress levels within allowable limits. There are four additional basic areas of the LPR design where alternate configurations could result in design improvements. These are discussed in detail in Appendix H. All of the above changes are cost effective and are expected to result in a more economical design.

It is therefore concluded that the next phase of pool design development should start by iterating on the reference design described herein to incorporate those design imporovements which were, of necessity, excluded because of time considerations, rather than for technical reasons. This revised design should then be subjected to extensive analytical review and analysis to confirm the design.

SECTION 6.0
REFERENCES

1. D. A. Howard and J. J. Lorenz, "CRBR Outlet Plenum Behavior During Transient Conditions," ANL-CT-76-49, Sept. 1976.

2. "Westinghouse Large Pool Reactor - Interim Report," Jan. 1978.

3. "ERDA-EPRI LMFBR Design Projects, Phase II Final Report, Volumes A, B1 and D1," Westinghouse Electric Corporation, Advanced Reactors Division, June 1977. Appendix W, "Partial Field Fabrication of the PLBR Spherical Reactor and Guard Vessels."

4. Iron Age, November 7, 1977, "First Huge Conch-Design LNG Tanks Built in United States."

5. Westinghouse Large Pool Reactor, Interim Report, Volume 3, January 1978. Appendix IV-D Site Fabrication Facilities.