CONCEPTUAL DESIGN OF REACTOR ASSEMBLY OF PROTOTYPE FAST BREEDER REACTOR

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Abstract

The conceptual design of Reactor Assembly of 500 MWe Prototype Fast Breeder Reactor (as selected in 1985) was reviewed with the aim of 'simplification of design', 'Compactness of the reactor assembly' and 'ease in construction'.

The reduction in size has been possible by incorporating concentric core arrangement, adoption of elastomer seals for Rotatable plugs, fuel handling with one transfer arm type mechanism, incorporation of mechanical sealing arrangement for IHX at the penetration in Inner vessel redan and reduction in number of components. The erection of the components has been made easier by adopting 'hanging' support for roof slab with associated changes in the safety vessel design. This paper presents the conceptual design of the reactor assembly components.

1.0 INTRODUCTION

After successful construction, commissioning and operation of Fast Breeder Test Reactor (40 MWt, 13 MWe), design of a 500 MWe Prototype Fast Breeder Reactor (PFBR) is in progress in India. Pool type layout is chosen for the Primary sodium circuit as it accommodates most of the active components in one single vessel, eliminates the high pressure active sodium piping, provides better containment for radioactivity and reduces the exposure of operating personnel to radioactivity. The concepts chosen for the various components of Reactor Assembly (fig. 1) in order to have simplification of design, compactness and ease of construction are presented in this paper. The main characteristics of PFBR are given in Table I and the major dimensions of Reactor Assembly components are listed in Table II.

2.0 CONCEPTS CHOSEN FOR MAJOR COMPONENTS

2.1 Main vessel

Main vessel contains the primary sodium and supports the core, grid plate, core support structure and inner vessel. It also serves as a boundary against release of radioactivity under operating & accident conditions and absorbs the energy released during Core Disruptive Accident (CDA). It is a cylindrical vessel with no penetrations (fig.2) and hence provides maximum reliability against sodium leaks. Bottom cover is of special shape arrived from buckling considerations. The

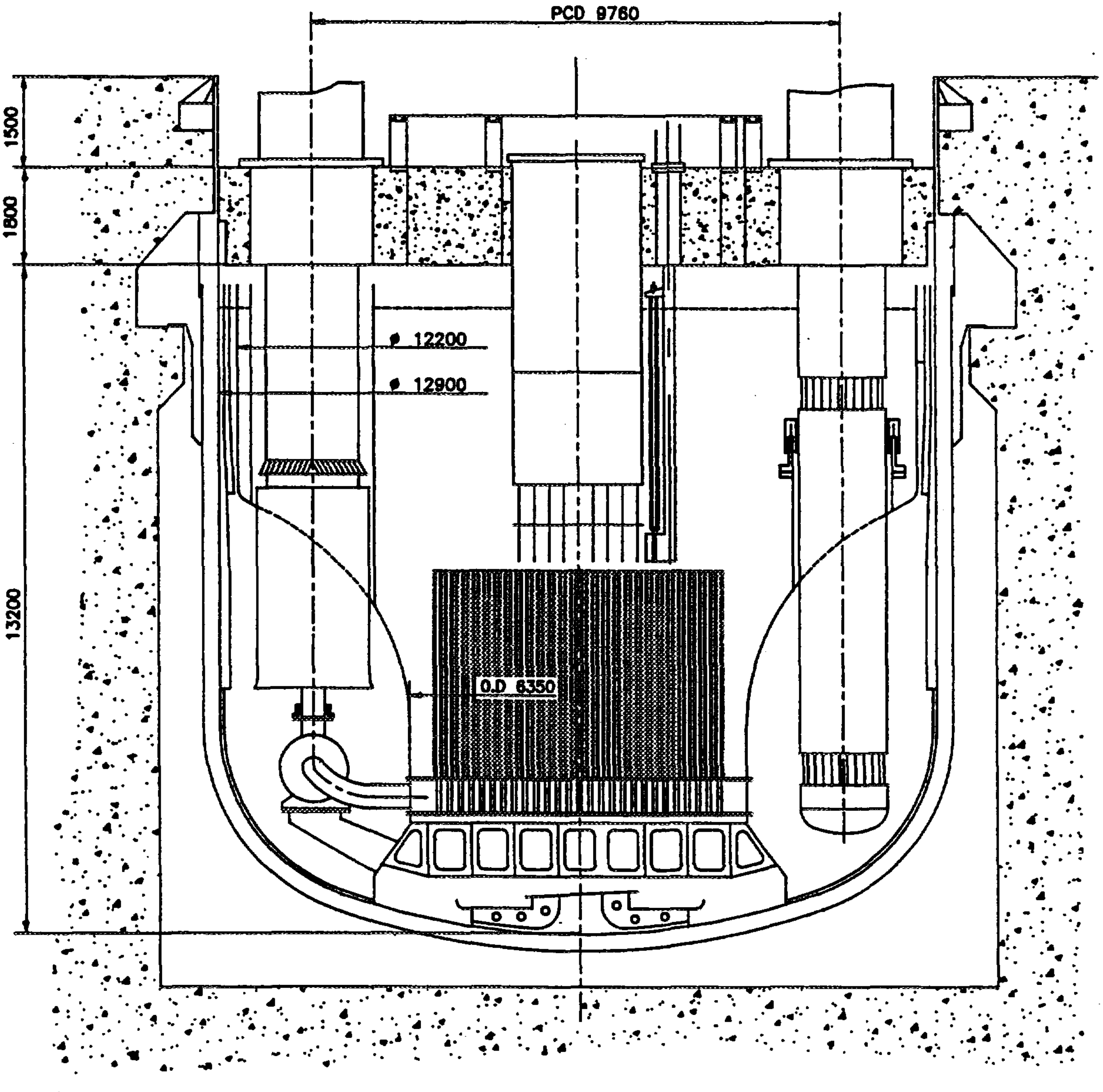


FIG. 1. Reactor assembly.

TABLE : I PFBR – MAIN CHARACTERISTICS

REACTOR POWER	1250 MWt / 500 MWe
PRIMARY CIRCUIT	POOL TYPE
ACTIVE CORE DIA / Ht	2 m / 1 m
FUEL	UO_2 – PuO_2
PRIMARY INLET TEMP	670 K (397°C)
OUTLET TEMP	820 K (547°C)
SECONDARY INLET TEMP	628 K (355°C)
OUTLET TEMP	798 K (525°C)
PRIMARY Na FLOW	8.5 m^3/s
NO. OF PRIMARY PUMPS	2
NO. OF IHX	4
NO. OF SECONDARY LOOPS	2

TABLE: II SIZE OF REACTOR ASSEMBLY COMPONENTS

COMPONENT	SIZE (m)	
	DIA	Ht
MAIN VESSEL	12.9	13.2
SAFETY VESSEL	13.53	13.52
INNER VESSEL	12.2	9.1
ROOF SLAB	12.9	1.8
LARGE ROTATABLE PLUG	6.93	1.8
SMALL ROTATABLE PLUG	4.68	1.8
INTERMEDIATE HEAT EXCHANGER	2.52	15.63
SODIUM PUMP	2.2	14.3

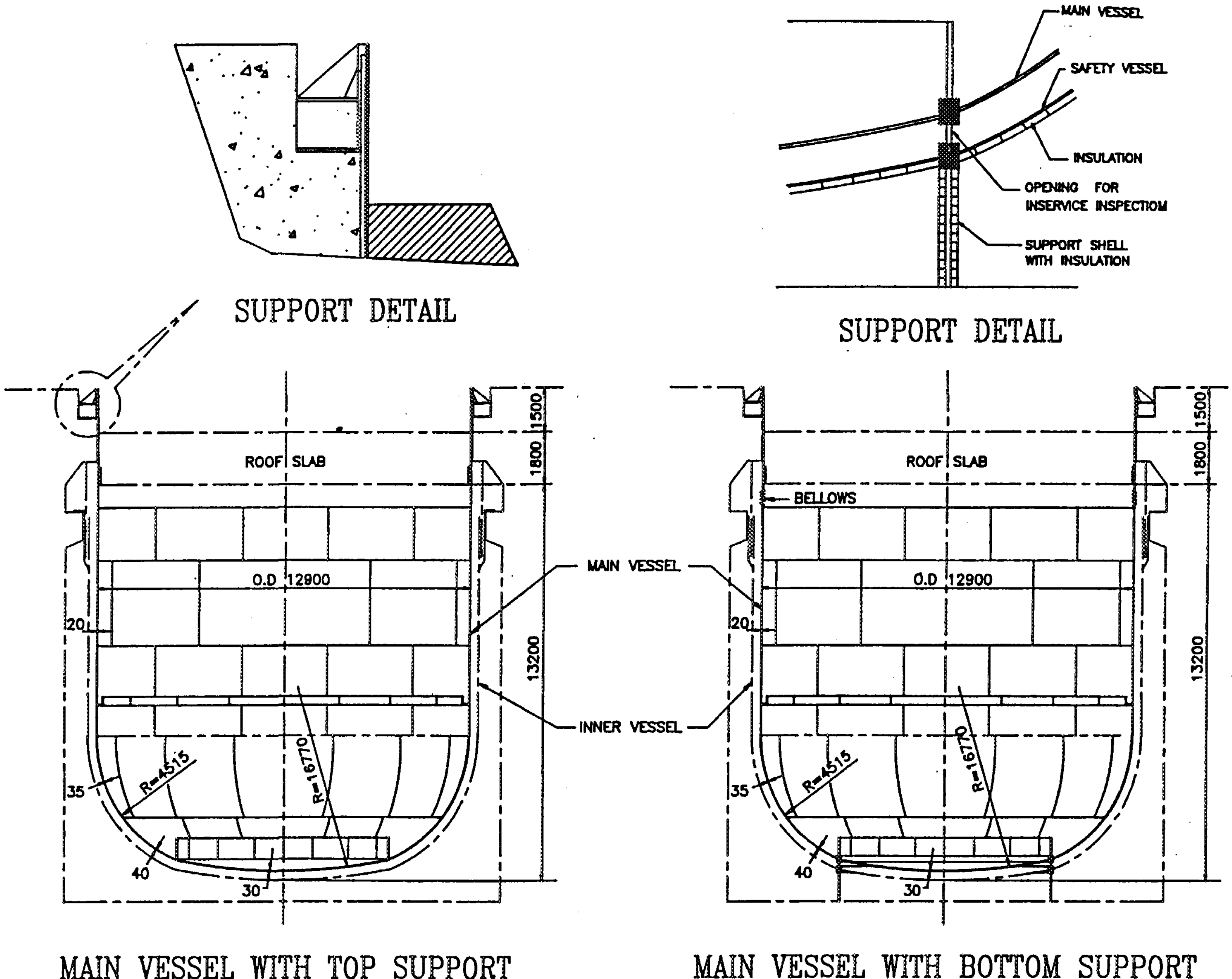

MAIN VESSEL
SAFETY VESSEL
INSULATION
OPENING FOR INSERVICE INSPECTIOM
SUPPORT SHELL WITH INSULATION
SUPPORT DETAIL
SUPPORT DETAIL
ROOF SLAB
O.D 12900
20
35
R=4515
R=16770
40
30
1500
1800
13200
MAIN VESSEL
INNER VESSEL
BELLOWS
MAIN VESSEL WITH TOP SUPPORT
MAIN VESSEL WITH BOTTOM SUPPORT

FIG. 2

main vessel is suspended by a cylindrical shell supported on the reactor vault. This arrangement simplifies the erection of reactor assembly components, eliminates the risk of buckling of the support shell under seismic conditions and permits free dilation of main vessel in radial and axial directions, thus minimising thermal stresses.

Supporting the main vessel at the top also eliminates the need for large diameter bellows, which has to be designed for higher pressure due to CDA conditions, if the vessel was supported at the bottom (fig.2). In order to enhance the structural integrity and to minimise the effects of age hardening, the temperature of the upper portions are maintained below 723 K (450 ^{0}C) by cooling with cold sodium. This also reduces the axial temperature gradient in the vessel and the damage to the shell because of thermal cycling due to changes of sodium level in the cold pool.

2.2 Cooling circuit for Main Vessel

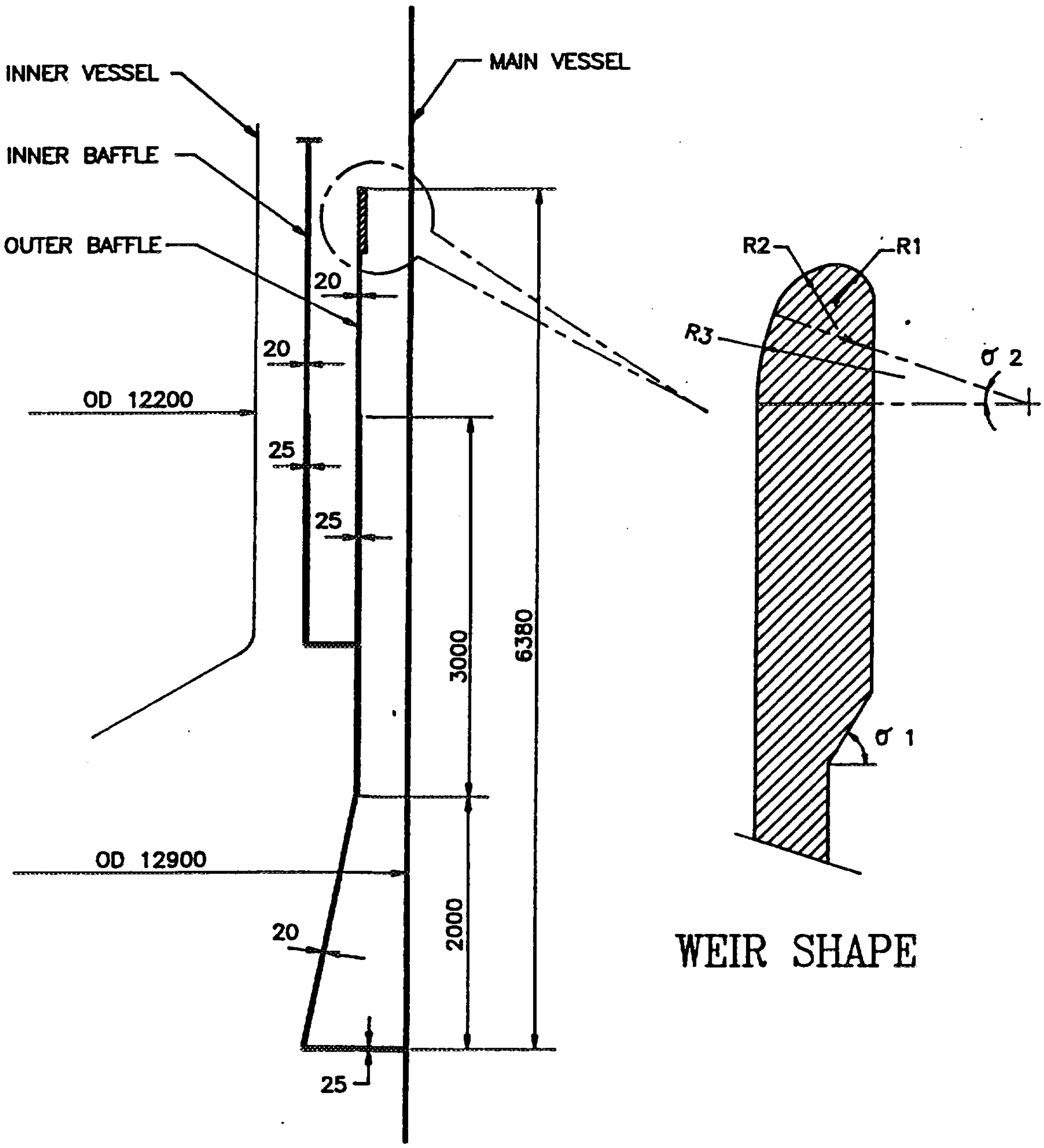
The cooling circuit consists of cooling pipes and thermal baffles (fig.3). The cooling pipes are spaced suitably to provide uniform flow distribution along the circumference of the vessel. The cooling pipes are bound together by a circular ring to avoid flow induced vibrations (fig.4). This arrangement eliminates the need for support brackets on the main vessel which are undesirable from the thermal inertia consideration. The thermal baffle has a weir arrangement at the free end to reduce the energy of free fall of sodium so that level oscillations due to fluid structure interaction are minimised and gas entrainment risk in the sodium pool is reduced.

2.3 Core Support Structure

The core support structure (CSS) is a box structure with orthogonal stiffeners. This arrangement results in effective use of structural material for supporting the core loads. It is supported on the main vessel through a cylindrical shell of sufficient length, to avoid transmission of rotations to main vessel due to its deflection. Supporting CSS from the cylindrical portion of main vessel is not considered as it results in increased main vessel height.

2.4 Grid Plate

A single grid plate is used to support and locate the core and shielding subassemblies. This simplifies the supporting of grid plate on the CSS, keeps the grid plate nozzle to pipe connection on the cold pool side which can be of welded construction and avoids penetration of these pipes through the CSS shell which requires bellows for sealing. A fully bolted construction is adopted to simplify manufacture of this large diameter component. The bolted construction offers ease of erection of components and reduces the time involved. The grid plate has four inlet pipes, with a pair of nozzles connected to each of the two primary sodium pumps through a spherical header.



WEIR SHAPE

THERMAL BAFFLE

FIG. 3.

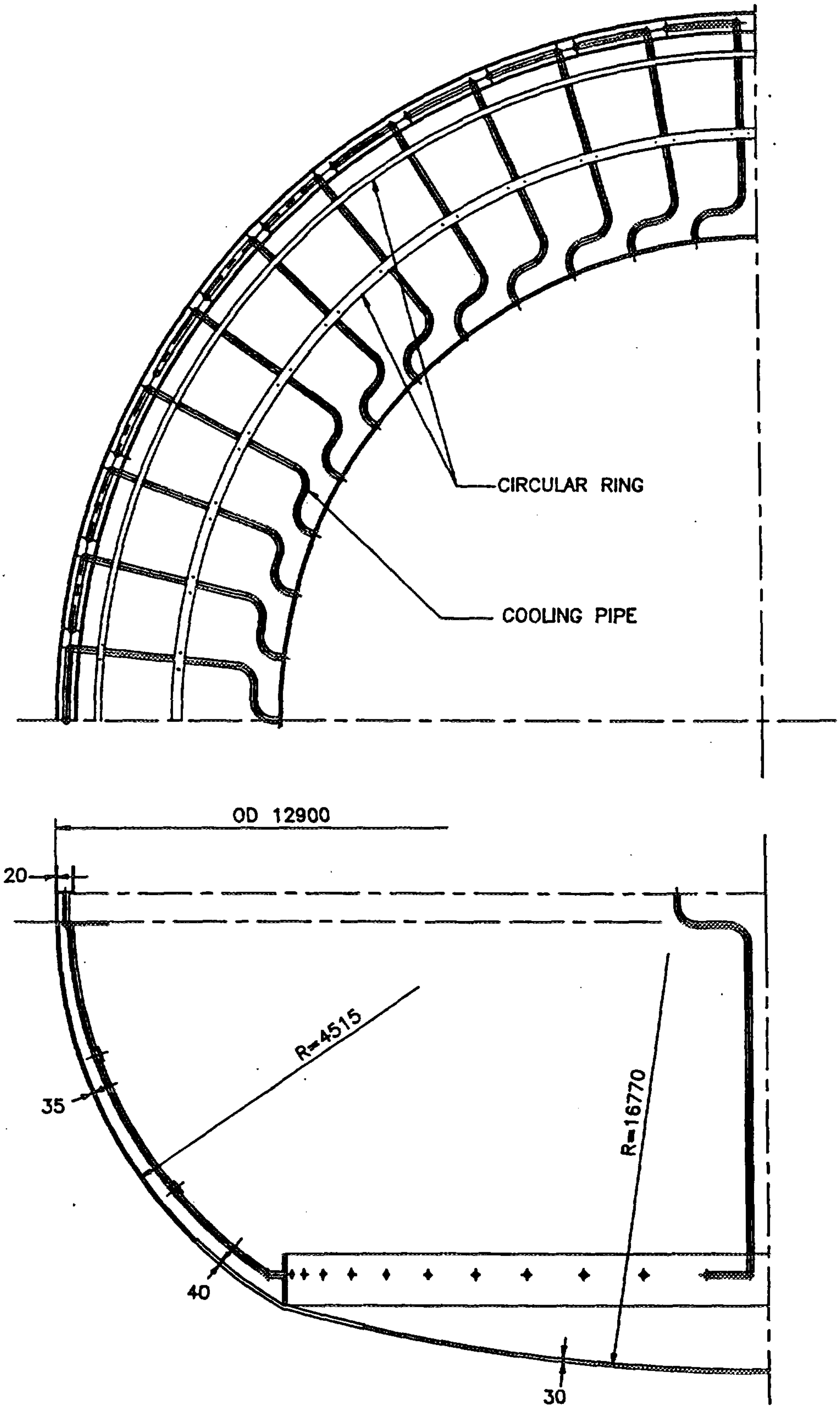


FIG. 4. Main vessel cooling pipes.

The sleeves provided for shielding subassemblies at the periphery of grid plate have no provision for radial entry of coolant and they assist in uniform distribution of coolant flow towards central regions of grid plate. However, provision for axial entry of sodium at the bottom of shielding subassemblies is made. The leakage flow from the bottom of grid plate is utilised for the purpose of cooling shielding subassemblies and main vessel.

2.5 Core Catcher

Though the probability of occurance of fuel melt down is very remote, it is foreseen that local melting of fuel pins in subassembly can occur due to flow blockage and the effect will propagate to the surrounding six subassemblies causing fuel pins to melt in them.

Hence, in accordance with defence in depth philosophy and to take care of the residual risk of fuel pin melt down in seven subassemblies, a provision of core catcher below CSS is envisaged. The details of core catcher and core subassemblies are presented in another paper.

2.6 In-Vessel Transfer Position

The invessel transfer position (IVTP) is located as close to the core centre as possible to reduce the diameter of Large Rotatable Plug (LRP) and hence the diameter of the main vessel . In order to achieve this, shielding assemblies containing boron carbide enriched in Boron-10 are used in the vicinity of IVTP. The tilter for handling of subassemblies in IVTP is guided by a special sleeve arrangement in grid plate and is supported on the CSS.

2.7 Inner Vessel

The inner vessel which seperates the sodium into hot pool and cold pool, is fixed on the grid plate by a flange at its lower end. The lower shell surrounds the core, which is concentrically located and the upper shell surrounds the IHX and primary sodium pumps, the stand pipes of which penetrate redan portion of vessel. The location and shape of redan from upper shell to the lower shell is arrived at based on the thermal hydraulics and structural considerations. A single vessel with torroidal shaped redan has been selected.

To minimise the leakage of sodium from hot pool to cold pool at the penetration of IHX in the vessel, a mechanical seal with 'piston rings' is used. This seal is very compact and results in minimum diameter of the upper shell. The alternative type of sealing, argon pocket seal, results in larger diameter of the upper shell, has the risk of introduction of argon gas along with sodium into the core inadvertantly and hence has been avoided.

2.8 Roof Slab

Roof slab along with rotatable plugs and control plug provides thermal and biological shielding in the upper axial direction of the reactor. It also supports to the components such as primary sodium pumps, intermediate heat exchangers and rotatable plugs and provides a leak tight enclosure for the cover gas. Since thick plates (600 - 800 mm) are not available, a box structure made of 30 mm thick carbon steel plates (to avoid PWHT) is used as roof slab. Concrete of density 3.5 g/cc is used as the shielding material as it is cost effective. For cooling , air is chosen as the medium as it does away with the need to have a large supply of nitrogen and associated safety problems. The bottom plate of roof slab is cooled by air jets from an inlet plenum, thus making it possible to maintain uniform temperature. The ensuing hot air is then used to heat the top plate to reduce the temperature difference between the plates (fig. 5). This reduces the bowing of roof slab due to differential temperature. The temperature of the top plate is maintained between 373 K (100^{o} C) to 383K (110^{o}C) to avoid deposition of sodium in the annulus between the shells at various component locations. The vertical shells in roof slab at Pump and IHX penetrations are also cooled to control the circumferential temperature difference in them within acceptable limits.

The ex-vessel transfer of core subassemblies is done through a primary ramp for which a penetration is provided in roof slab. The penetration is cooled by forced circulation of air in the jacket surrounding it, so that in case the fuel transfer pot gets stuck in the vicinity of the penetration, cooling can be provided to avoid undue rise in temperature. The heat removal capacity of the ramp cooling circuit is 5 KW.

2.9 Rotatable Plugs

The rotatable plugs are used to position the invessel transfer machine over the core subassembly to be handled inside the main vessel. The diameter of the main vessel is controlled by diameter of LRP and hence it is desirable to keep it minimum. The combination of two rotatable plugs and one transfer arm machine which results in reasonable diameter of LRP has been chosen (fig. 6). The structural, shielding and cooling aspects of rotatable plugs are same as those of roof slab. During fuel handling, when the plugs are being rotated, they are cooled by air from reactor hall using blowers located on them temporarily.

2.10 Support Arrangement for Rotatable Plugs

To avoid cold spots on the support structure where sodium aerosols could form deposits, the support flanges for LRP and Small Rotatable Plug (SRP) are located at roof slab top elevation (fig.7). During reactor operation, sealing is provided by 'O' rings which are disengaged prior to rotation of the plugs. In order to reduce the flange width of the support arrangement,

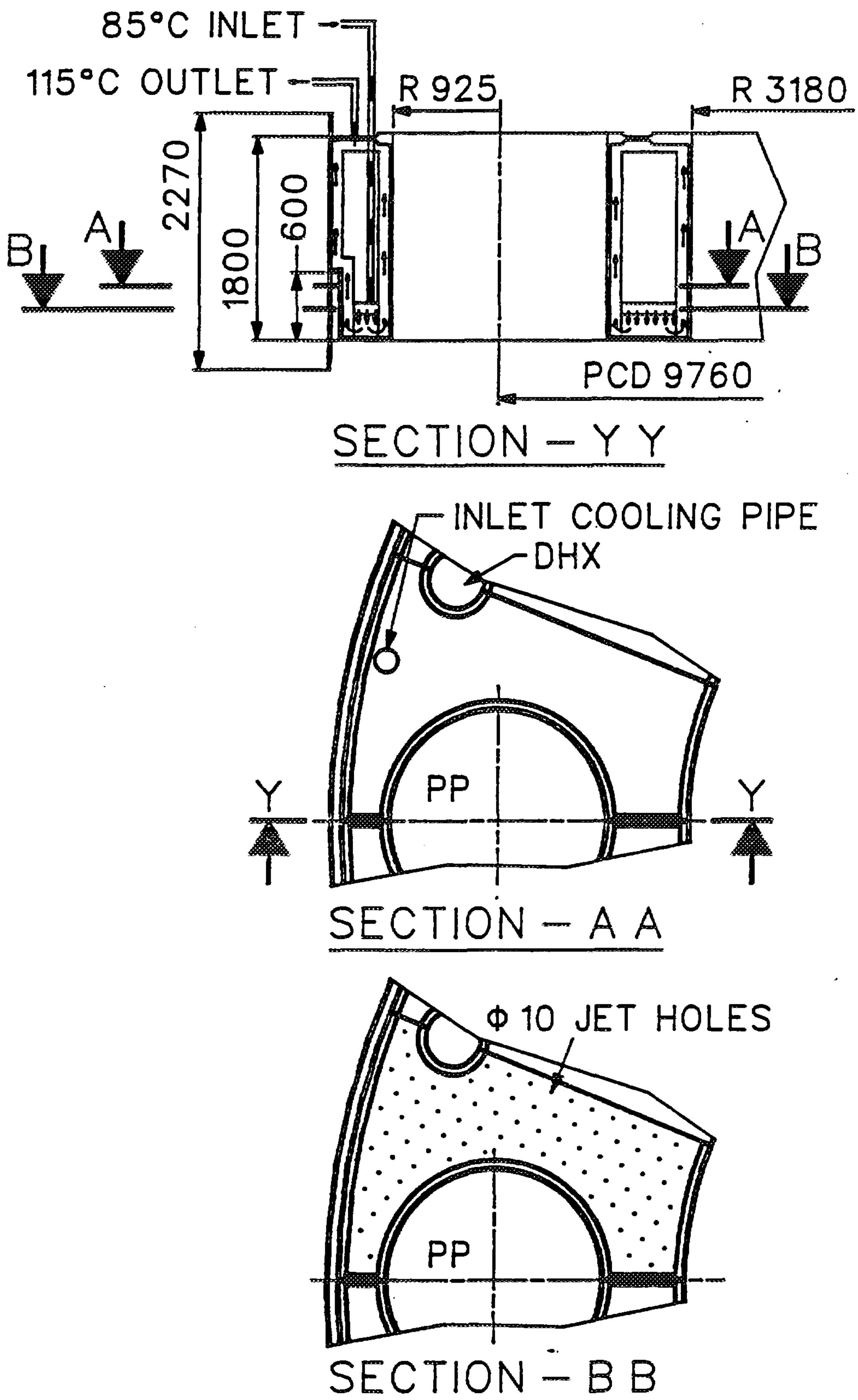


FIG. 5. Roof slab cooling system.

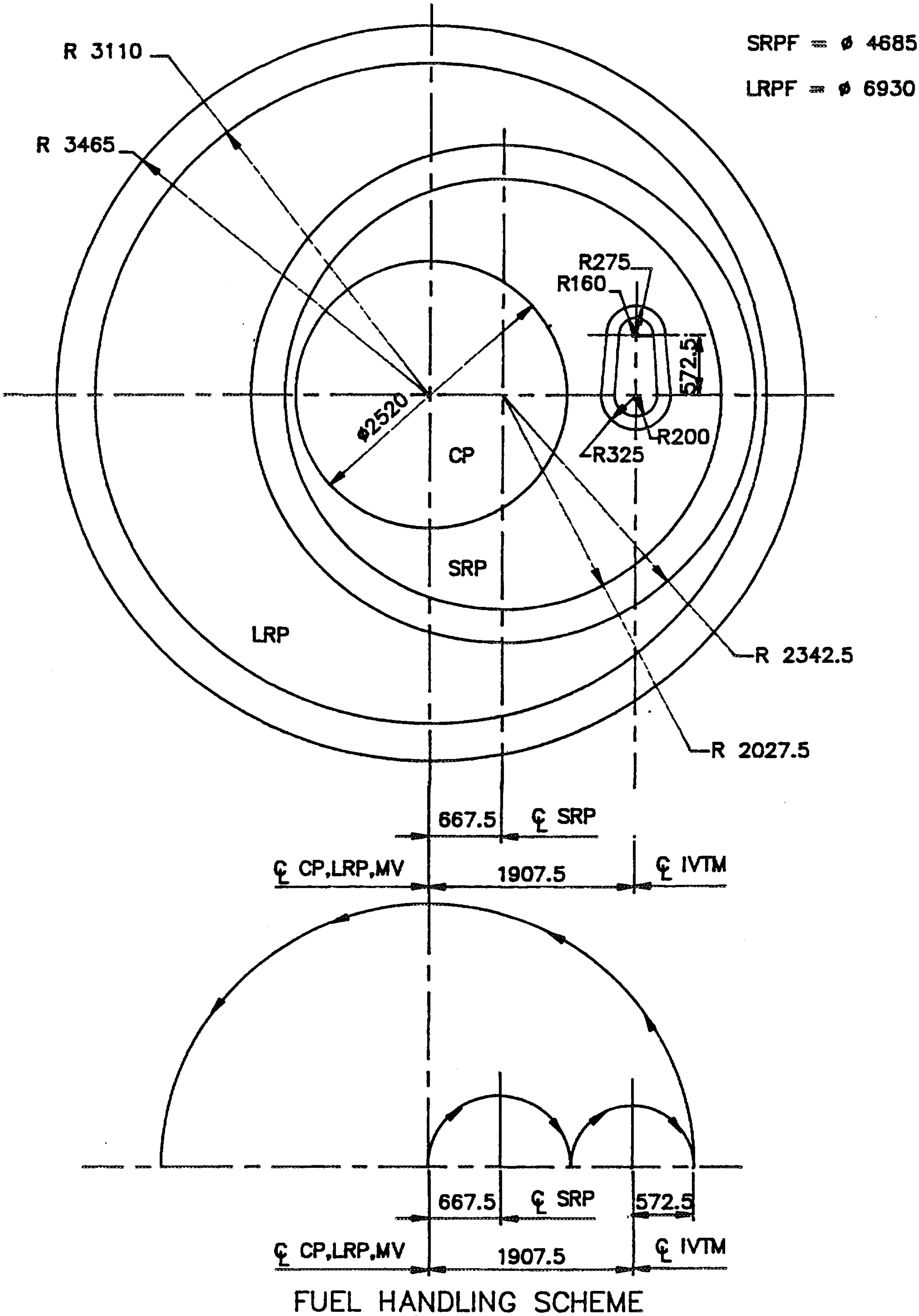


FIG. 6. Size of rotatable plugs for handling scheme with 1 transfer arm.

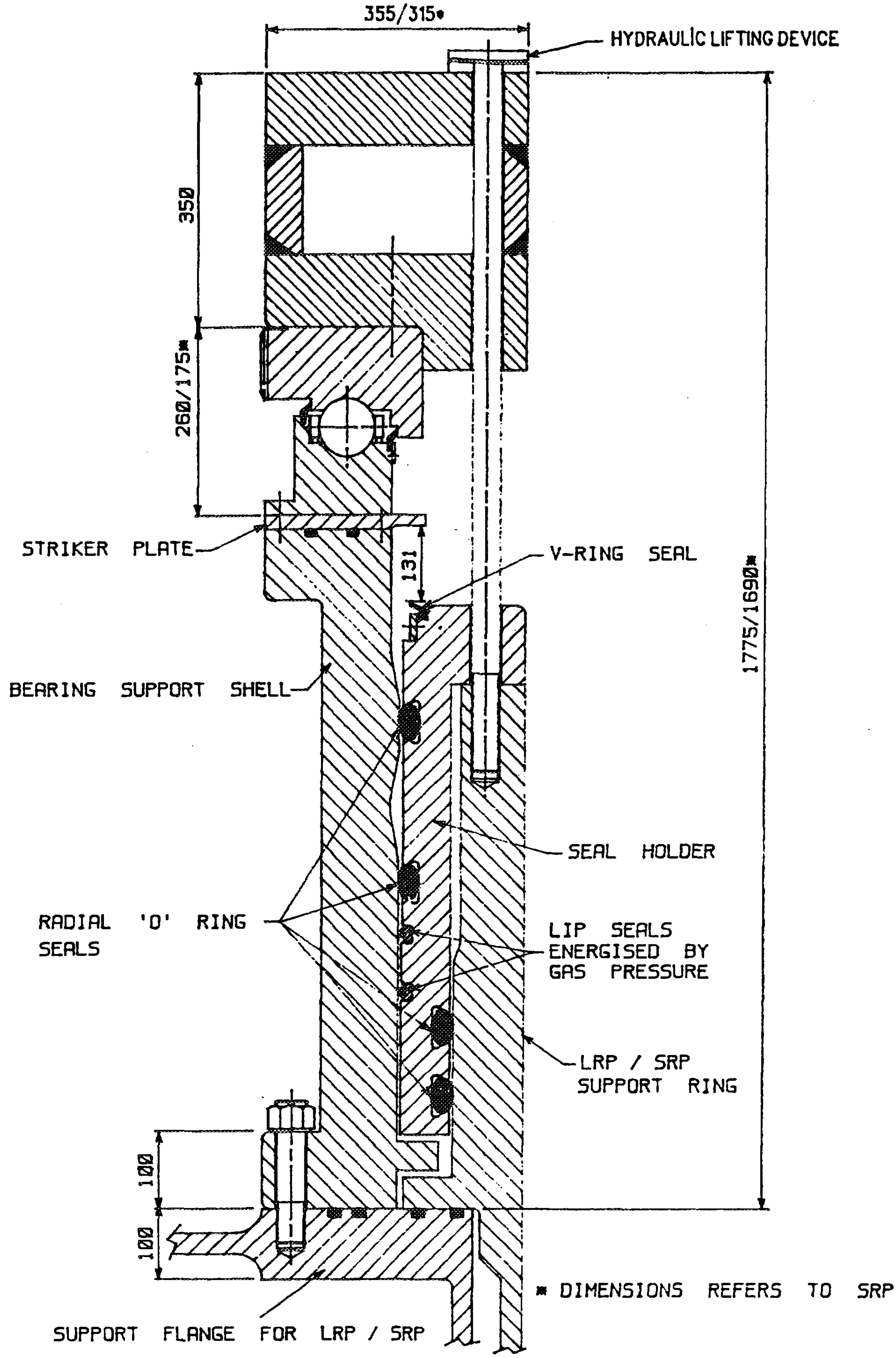


FIG. 7. Sealing arrangement for rotatable plugs (under normal operation).

elastomer seals (V ring seal and lip seals) are chosen for sealing during fuel handling conditions. A seal holder is provided which can be lifted separately to enable easy replacement of the seals. Liquid metal seal has not been used as it requires costly machining, increases the construction time, results in larger flange width and also requires auxiliaries.

2.11 Control Plug

Control plug provides support for the control rod drive mechanisms, thermocouple tubes housing the thermocouples which monitor the outlet temperature of fuel subassemblies and failed fuel identification modules. A separate control plug is provided on SRP to facilitate easy replacement if required. Though integration of control plug with SRP results in smaller diameter of LRP, a separate control plug is selected in order to have the above advantage.

2.12 Intermediate Heat Exchangers

In order to reduce the capital cost and construction time of the reactor, 2 loop concept with 2 IHX per loop has been chosen. The IHX tube size and the diameter of IHX have been optimised to have savings in overall cost of the component.

2.13 Primary Sodium Pumps

There are 2 primary sodium pumps and they are of top suction, single impeller type. The removable part diameter of the pump is kept minimum by integrating the pump intake skirt with the stand pipe of the inner vessel. The outlet from the pump is connected to a spherical header which distributes the flow through two pipes to the grid plate.

2.14 Safety Vessel

A safety vessel surrounds the main vesel, so that in the unlikely event of sodium leaking from main vessel, the sodium level in hot pool does not fall below IHX inlet windows and a path for natural convection cooling is available. The safety vessel is supported directly on reactor vault. This arrangement also helps to reduce the outer diameter of roof slab. The nominal gap between the vessels is 300 mm from considerations of in-service inspection. An anti- convection barrier is fixed in the gap between the vessels at an elevation close to bottom of roof slab in order to minimise convection currents .

Thermal insulation in the form of panels of thickness 100 mm are fixed on the outer surface of safety vessel so that the area of thermal insulation is minimum, the vault remains cool and intervention for maintenance is easy. The insulation is sized based on temperature of the safety

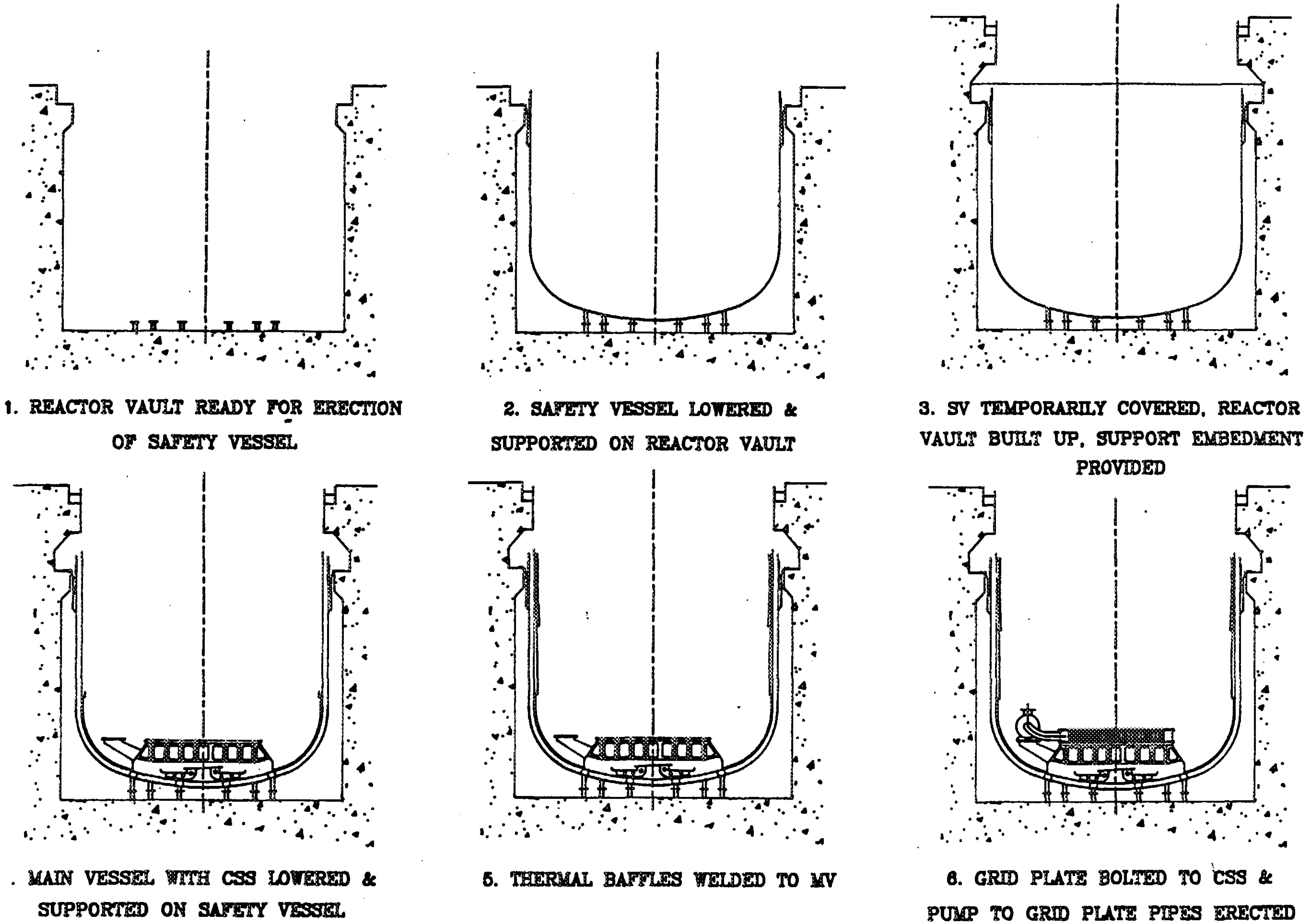
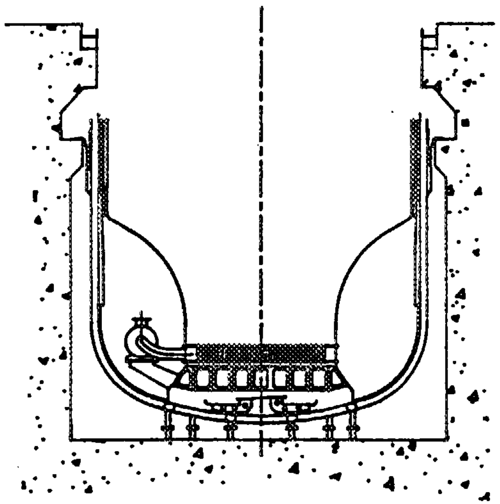
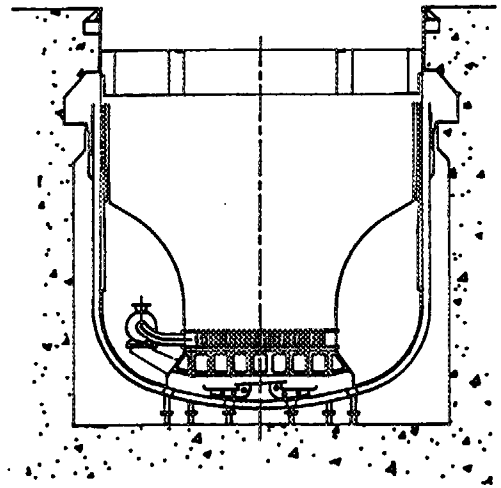


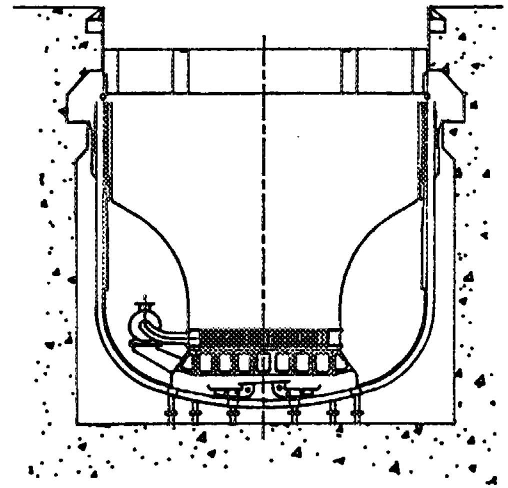
FIG. 8a. Erection sequence for reactor assembly components.



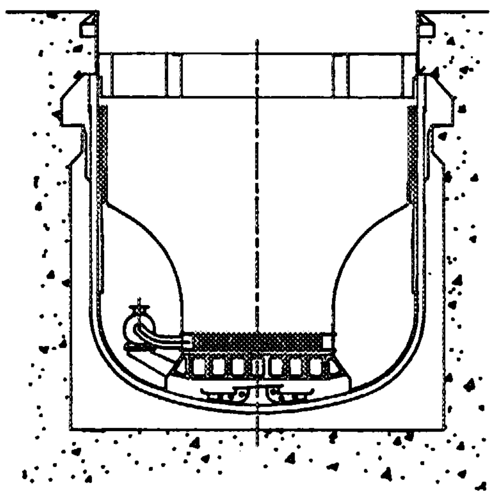
7. INNER VESSEL LOWERED & BOLTED TO GRID PLATE



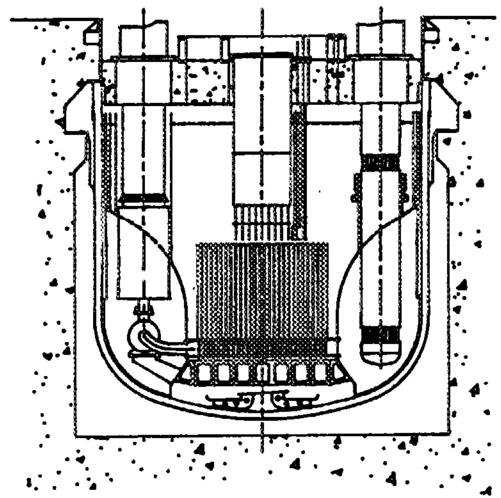
8. ROOF SLAB LOWERED & WELDED ON TO ITS SUPPORT



9. MV ALIGNED & WELDED TO ROOF SLAB



10. COMPLETION OF TOP PORTION OF SAFETY VESSEL



11. OTHER REACTOR ASSEMBLY COMPONENTS ERECTED

FIG. 8b. Erection sequence for reactor assembly components.

vessel under DHR conditions and heat removal capacity of reactor vault cooling system which uses air as the cooling medium.

3.0 ERECTION OF REACTOR ASSEMBLY COMPONENTS

Considerable simplification has been made in erection of Reactor Assembly components.

The erection sequence foreseen is as follows (fig.8).The reactor vault with lining is made ready for erection of safety vessel. Safety vessel with thermal insulation mounted on its outer surface is erected in the vault using screw jacks to support it at its bottom. The upper part of the reactor vault which supports roof slab is then cast. Collapsible spacer pads are fixed on the inner surface of safety vessel and main vessel with CSS is lowered and supported on it. The grid plate is lowered and is bolted on to CSS. The grid plate inlet pipes are erected. The inner vessel is lowered and is bolted to grid plate. The roof slab is then lowered on to the reactor vault and is welded to the embedded support structure. The combination of main vessel, inner vessel etc. is aligned to roof slab and the main vessel is welded to it. The collapsible spacer pads are removed from the space between main and safety vessels. The supporting screw jacks for safety vessel are also removed. The upper portion of safety vessel is assembled in-situ. After these operations, LRP, SRP, control plug, primary sodium pumps, IHXs , decay heat exchangers etc. are erected.

The concrete supporting structure for the Inclined Fuel Transfer Mechanism (IFTM-exvessel fuel transfer machine) is cast and IFTM is installed.

4.0 CONCLUSION

The conceptual design of reactor assembly components has been reviewed and considerable simplifications have been made in design of CSS, grid plate, inlet pipes to grid plate, primary sodium pumps, roof slab, and support structure for rotatable plugs. The resulting reactor assembly is more compact in size and offers considerable ease in erection of components.