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GENERAL DESCRIPTION OF ADVANCED HEAVY WATER REACTOR

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Abstract

Advanced Heavy Water Reactor is a boiling light water cooled, heavy water moderated and vertical pressure tube type reactor with its design optimised for utilisation of thorium for power generation. The core consists of $(Th\text{-}U^{233})O_2$ and $(Th\text{-}Pu)O_2$ fuel with a discharge burn up of 20,000 MWd/Te. This reactor incorporates several features to simplify the design, which eliminate certain systems and components. AHWR design is also optimised for easy replaceability of coolant channels, facilitation of in-service inspection and maintenance and ease of erection. The AHWR design also incorporates several passive systems for performing safety-related functions in the event of an accident. In case of LOCA, emergency coolant is injected through 4 accumulators of 260 m^3 capacity directly into the core. Gravity driven water pool of capacity 6000 m^3 serves to cool the core for 3 days without operator's intervention. Core submergence, passive containment isolation and passive containment cooling are the added features in AHWR. The paper describes the various process systems, core and fuel design, primary components and safety concepts of AHWR. Plant layout and technical data are also presented. The conceptual design of the reactor has been completed, and the detailed design and development is scheduled for completion in the year 2002.

1. INTRODUCTION

The Advanced Heavy Water Reactor (AHWR) is a 235 MWe heavy water moderated, boiling light water cooled, vertical pressure tube type reactor with its design optimised for utilisation of thorium for power generation. The conceptual design and the design feasibility studies for this reactor have been completed and at present the reactor is in the detailed design stage. The reactor design has a number of passive features described subsequently in this paper. The overall design philosophy includes achievement of simplification to the maximum extent.

While the detailed economics of operation of AHWR are yet to be worked out, pending finalisation of plant design, the reactor incorporates several features to simplify the design and to eliminate certain systems and components, likely to make AHWR economically competitive with other available options for power generation. Some important elements in the AHWR design, having bearing on its improved economics, are as follows:

- Elimination of high pressure heavy water coolant thereby leading to reductions in heavy water inventory, heavy water leaks, and exposure of personnel to tritium.
- Replacement of complex and long delivery items like steam generator by steam drum of simple construction.
- Minimising dependence on active systems like primary coolant pumps (due to natural circulation of light water coolant), thus enabling usage of conventional equipment for performing duties of much less safety importance.
- Shop fabrication of major components of the reactor, such as coolant channels, to reduce construction cost and time.

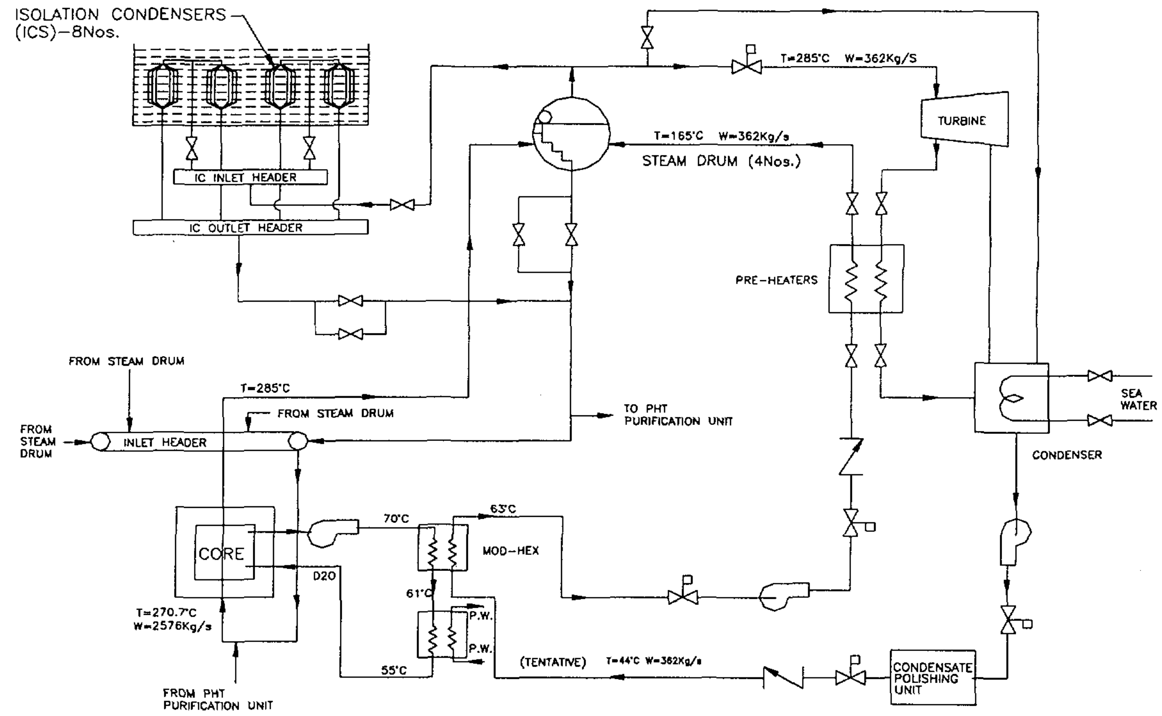

FIG. 1. Simplified PHT system flow sheet.

2. DESCRIPTION OF THE NUCLEAR SYSTEMS

2.1 Primary Heat Transport System

The Primary Heat Transport (PHT) System is shown in Fig. 1. This system is designed to cool fuel assemblies by boiling light water, which flows through the coolant channels by natural circulation.

The steam-water mixture from each coolant channel is led through 125 mm NB tail pipes to four steam drums, which are located with an elevation difference of 39 m with respect to inlet feeder (coolant channel bottom). The steam at a pressure of 70 kg/cm^2 is separated from steam-water mixture in steam drums. The steam is led to the turbine by two 400 mm NB pipes. The steam from the turbine is condensed and after purification of the condensate and preheating, it is pumped back to steam drums at a temperature of 165°C. The feedwater is mixed with the water separated from steam-water mixture at 285°C in steam drums. The water level in the steam drum is a function of reactor power and is maintained at a set level during power operation.

A nearly uniform exit quality of steam in all the channels is maintained by providing orifices at the bottom of the reactor coolant channels.

2.2 Core Decay Heat Removal System

The reactor core decay heat removal through Isolation Condensers (ICs) is a passive safety feature for the removal of the core decay heat during normal reactor shut down. The system is designed to remove the core decay heat for a period of three days without operators' intervention.

The core decay heat removal system is designed for the removal of heat at 3% of full reactor power, with steam temperature of 150°C, and has capability for the removal of decay heat of 6% of full power for a duration of a few seconds, when the steam temperature is 285°C. The IC consists of vertical tubes, joined at both ends to cylindrical headers and is submerged in the Gravity Driven Water Pool (GDWP). The steam from coolant channels enters IC tubes from top end through steam drums and is condensed due to surrounding cool water of GDWP. The condensate returns by gravity to the PHT system through a outlet header of ICs.

The system is designed for 4 x 50% capacity. Eight ICs (out of which four operate at a time) are located in eight compartments of GDWP. The capacity of GDWP (for cooling) is based on the requirements of 2 m of water level above the ICs.

2.3 Active Shut Down Cooling System

An active shutdown cooling system is provided to lower the temperature of PHT system from 150°C to 60°C during long shut down of the reactor for maintenance. The system consists of four loops out of which two operate at a time. This system is designed to take care of the eventuality of non-availability of ICs for removal of the reactor core decay heat.

2.4 Moderator System

The moderator system is designed as a full tank concept for normal operation. However, the level control system is incorporated to change heavy water level in the top reflector region for reactor power adjustments. Helium is used as a cover gas in AHWR.

2.5 Emergency Core Cooling System

The Emergency Core Cooling System (ECCS) is designed to remove the core heat by passive means in case of a postulated Loss of Coolant Accident (LOCA). In the event of rupture/breakage in the primary coolant pressure boundary, the cooling is achieved initially by a large flow of borated light water from advanced accumulators and later cooling of the core is achieved through the GDWP. The inventory of GDWP is adequate to cool the reactor core for a period of three days without operators' intervention.

The ECCS consists of four accumulators of total capacity of 260 m^3 and a gravity driven water pool of capacity 6000 m^3, both connected to the ECC header. The ECC header is connected to individual coolant channels above the tail pipe. The ECC coolant enters the core through eight perforated water tubes arranged in the fuel cluster so as to ensure wetting of fuel pins by spray action. The coolant, after coming out of rupture pipe gets accumulated in the reactor cavity along with PHT coolant and is re-circulated through heat exchangers to ensure long term core cooling.

2.6 Reactor Core and Fuel Design

2.6.1 Design Objectives

The reactor physics parameters are finalised to meet the following important design objectives:

- Power in Thorium fuel: 75% , approximately.
- Slightly negative void coefficient of reactivity.
- Discharge burn up: Minimum target of 20,000 MWd/Te
- Initial plutonium inventory: As low as possible.
- Self sustaining in U^{233}.
- Thermal power: 750 MW.

2.6.2 Fuel Cluster Design

The reactor core has 424 coolant channels. In 340 channels, the fuel cluster consists of 44 $(Th\text{-}U^{233})O_2$ and 8 $(Th\text{-}Pu)O_2$ pins, called Thoria and MOX fuel pins, respectively. The fuel clusters in the remaining 84 channels have all Thoria pins. To generate lower power fraction in MOX fuel, the plutonium content in MOX is kept low at 4.5 % (typically) and these pins are located at the outermost circle of the fuel cluster. Since the MOX fuel accumulates burn up faster than the Thoria pins, they need replacement from reactivity considerations, so as to allow Thoria pins to reach the designed burn up of 20,000 MWd/Te. The fuel reconstitution frequency is estimated to be two times in its life. The power flattening is achieved by loading fresh MOX fuel clusters in the outer most radial zone and the reconstituted MOX fuel clusters in middle & inner zones. The maximum. channel power is 2.3 MW.

2.6.3 Moderator and Reflector

The reactor core is contained in a calandria having heterogeneous mixture of heavy water as moderator and pyrocarbon material as scatterer. Heavy water is provided as reflector in the radial direction with thickness of 300 mm. Heavy water is also reflector in the axial direction with thickness of 750 mm at bottom location and 600 mm thick at top location. This arrangement, evolved after detailed analysis of a number of cases, meets the requirements of satisfactory k-effective value and negative void coefficient of reactivity.

2.6.4 2.6.4 Shut Down System

AHWR is provided with two independent fast acting shut down systems namely primary and secondary shut down systems. The primary shut down system (PSS) consists of absorber rods having boron carbide as neutron absorbing material. Boron carbide is filled in an annulus of thickness 1.5 mm, formed by stainless steel shells. The secondary shut down system consists of a liquid poison injection system in which lithium pentaborate solution with boron content of 20 g/litre will be injected in the poison tubes.

2.6.5 Reactor Fuel Design

2.6.5.1 Design Objectives

The fuel assembly of AHWR is designed to provide :

- Continuous full power operation.
- Low pressure drop of the coolant.
- Stable neutronic/thermal hydraulic coupling during all stages of reactor operations.
- On-power fuelling operation.
- Reconstitution of fuel clusters
- Spray on fuel pins from ECC system during LOCA.

2.6.5.2 Description

The fuel assembly consists of components like fuel cluster and shield plug. The fuel cluster of length 4200 mm is suspended inside the pressure tube of coolant channel from top by a hanger assembly and has features to enable the separation of the shield plug from the spent fuel inside the fuelling machine and also joining of the same shield plug with new fuel.

The fuel pins are arranged in a square lattice pitch of 13.7 mm in the cluster. The fuel pin of 11.2 mm OD consists of Zircaloy clad tube of thickness 0.6 mm. In addition to fuel pins, the fuel cluster has eight perforated Zircaloy tubes (called water tubes) which are arranged at outer periphery, for spraying emergency core cooling water directly on the fuel pins, during LOCA. The fuel pins are held between top and bottom tie plates with the help of eight fuel pins, called tie rods. The remaining fuel pins (44 nos.) are resting on the bottom tie plate and are free to expand axially at top. The inter-element spacing of 2.5 mm between fuel pins is maintained with the help of six Zircaloy spacers.

2.7 Fuel Handling and Transport System

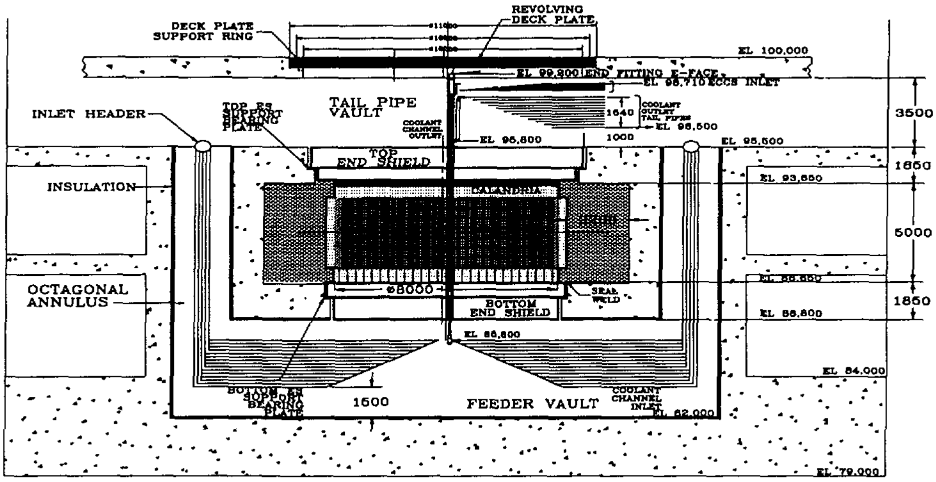

FIG. 2. AHWR reactor component layout.

2.7.1 Design Philosophy

The AHWR is designed to have on-power fuel handling feature to increase the capacity factor of the reactor by maintaining the designed reactivity in the core and optimising the fuel burn up. The fuelling frequency is estimated to be six assemblies in a month.

The fuelling machine has the following major components:

- A fuelling machine head for handling the fuel clusters by means of ram drives and snout drive for coupling and making pressure tight joint with the coolant channel.
- A carriage for movement of the machine on rails, laid between reactor block and storage block.
- Shielding to limit the surface dose rate below 0.6 mr/hr, by using lead, steel and paraffin wax as shielding materials, so as to make the machine and reactor top approachable during fuelling operations.
- A cooling system to remove the decay heat from the fuel clusters.
- A control and an electrical system for remote operation of the machine from the control room in auto and manual mode.

2.8 Primary Components

The primary components of reactor pile block structure consist of equipment and components contained in the reactor cavity. These include calandria with vertical coolant channels, end shields at top and bottom, concrete vault filled with light water, tail pipe vault at top and feeder vault at bottom. Figure 2 shows the layout of AHWR reactor components

2.8.1 Design Bases

The following are the major bases for the design of AHWR pile block components and structures:

- Easy replaceability of coolant channels.
- Heterogeneous moderator and reflector system having heavy water and pyrocarbon material.
- Features to facilitate in -service inspection and maintenance.
- Ease of erection.

- Adequate shielding to enable accessibility to areas outside the pile block during reactor operation.
- Provision for direct emergency core cooling.
- On-power refuelling.

2.8.2 Calandria

The calandria is a vertical cylindrical shell structure having a sub-shell at each end, connected by flexible annular plate. Both the sub shells are in-situ welded to tube sheets of end shields. Vertical calandria tubes are arranged in a square lattice pitch and rolled to lattice tubes of end shields. Nozzles and penetrations are provided in the shell and sub-shell regions of calandria for circulation and level control of heavy water moderator and circulation of helium (cover gas). Vertical penetrations are provided for primary and secondary shut down systems, and reactivity mechanisms. The calandria is provided with over-pressure relief devices to mitigate pressure rise in an accident.

2.8.3 Coolant Channel

The coolant channel accommodates fuel assembly, maintains thermal insulation between hot pressure tube and cold calandria tube and provides interface for coupling to primary heat transport system at both ends. It also facilitates injection of light water directly into the fuel clusters from emergency core cooling system in case of LOCA and provides interface to facilitate on-power fuelling operations.

The design provisions are made to take care of:

- Thermal expansions.
- Creep/growth related dimensional changes.

The coolant channel consists of a pressure tube, end fittings at top and bottom ends. The coolant channels are supported on top end shield. The top end fitting has a provision for connection to outlet tail pipe and ECCS injection pipe. It also has suitable features to enable engagement of the fuelling machine. The bottom end fitting is connected to the inlet header, which is located above the core, through individual feeder pipe. Calandria tubes, concentrically located outside the pressure tubes in the calandria region, are rolled to lattice tubes of end shields.

2.8.4 End Shields

End shields are provided at top and bottom ends of the calandria and are in-situ welded to calandria sub-shells. The end shields are designed to achieve a dose rate less than 0.6 mr/hr, in the tail pipe vault and the feeder vault, after one hour of reactor shut down, to allow access of personnel in these areas. The shielding materials are arranged in different layers like steel, water and mixture of water & carbon steel balls. The top end shield supports coolant channels and other vertical penetrations. The top end shield is provided with a composite tube sheet at the bottom end for circulation of heavy water, to remove the heat generated in the composite tube sheet of end shield. Both the end shields have recirculation-cooling system using light water so as to maintain a temperature of 55°C from thermal stress considerations. The end shields are supported through bearing plates on the concrete structure of the reactor block.

2.8.5 Deck Plate

The deck plate provides shielding above tail pipe vault to limit the dose rate below 0.6 m/hr, during full power operation, so as to make the reactor top accessible for on-power fuelling and other operations. The deck plate serves as a platform for removal of fuel assemblies and supports the shielding skirt of the fuelling machine. The deck plate consists of inner and outer revolving floors that are supported on special bearings to facilitate alignment to any lattice position by selecting a proper combination of rotation of revolving floors. The inner revolving floor has a central opening of 600 mm diameter which is normally closed by a shielding plug and a flapper mechanism. During fuelling operations, the shielding plug is removed and the flapper is opened after lowering of shielding skirt of the fuelling machine. The shielding skirt also makes a leak tight joint with the inner revolving floor.

2.8.6 Reactor Vault

The calandria is surrounded by a heavy density concrete vault, filled with light water, to provide thermal and biological shielding against neutrons and gamma rays. The thickness of water shield and concrete are arrived on the basis that the dose rate in adjacent rooms is less than 0.6 m/hr during reactor operation and in the annulus after one hour of reactor shut down. The vault cooling system is designed to remove the heat generated in vault water due to attenuation of gamma rays and due to transfer of heat from calandria. The inlet and outlet piping of calandria vault are provided with inverted 'Us' to prevent draining of the vault in case of a pipe break/rupture.

3. DESCRIPTION OF TURBINE GENERATOR PLANT SYSTEM

3.1 Steam and Feedwater System

3.1.1 Design Requirements

The steam and feedwater system is a closed loop system designed to meet the following design requirements:

- Generation of 99.9% dry steam in steam drums for operation of the turbine.
- Condensation of steam in the condenser which is exhausted from the turbine in operation mode or in by-pass mode.
- Purification of full flow of condensate and pump back to steam drums through pre-heaters and feed water pumps, which are conventionally available equipment.
- Acts as a heat sink for the reactor under emergency conditions.

3.1.2 Steam Drum and Steam System

The system has four steam drums, constructed from carbon steel and lined with stainless steel of overall size 3600 mm diameter x 10,000 mm length. Each steam drum is connected to 106 tail pipes coming from the reactor coolant channels, which carry steam-water mixture. The water level in each steam drum is controlled by a water level regulator by comparison with set point level and flow of feed water with respect to steam flow rate.

The steam from each steam drum is tapped from top location by a 300 mm NB pipe. The outlet pipes from two steam drums are connected to a 400 mm NB pipe and two of these pipes (from four steam drums) are connected to steam chest of the turbine. The pressure relief system (consisting of four safety valves and four relief valves) is installed on 400 mm NB pipe lines within the primary containment of the reactor to protect against over pressure in case of rupture of the pipe line.

4. INSTRUMENTATION & CONTROL SYSTEMS

4.1 Design Concepts

The function of the instrumentation and control system is to monitor and control various plant parameters like neutronic, thermal hydraulic, and process parameters reliably, using principles of redundancy, diversity, testability and maintainability. The above is achieved by having triplicated channels, using principle of 2 out of 3 logic and fail safe criteria for the safety systems. The system is also provided with a feature of on-power testing of channels. The instrumentation for control and protection system is independent and separate. An extensive operator information system is provided to have features like display, alarm, record, retrieval of the plant parameters etc. The details of this system are being worked out.

4.2 Reactor Protection System

The shutdown system designed for fast transients consists of two completely independent and redundant devices. The fast acting primary shut down system consists of mechanical shut off rods and secondary shut down system to inject liquid poison into the tubes.

4.3 Reactivity Control

The reactivity is controlled by the following methods:

- Refuelling to take care of reactivity loss due to fuel depletion.
- Addition of poison into the moderator to control long term excess positive reactivity by addition of boron.
- Moderator level control in top reflector region to effect power changes.
- Adjuster rods for Xenon override operations.

5. ELECTRICAL SYSTEMS

The salient features of the electrical system are as follows.

- Minimum two independent off-site power sources of 220 kV for start-up through one Start-up Transformer (SUT).
- Two independent power supply sources for normal power operation
  - From grid through Start-up Transformer (SUT).
  - From main generator through Unit Transformer (UT).
- Automatic transfer of station auxiliaries to other source in case of failure of one source.
- Three Class 1E emergency diesel generators, one feeding to each of the two independent bus section and one stand-by to either of the bus section to provide on-site stand-by power for Class 1E equipment.
- Three independent Class 1E 240V AC system with a stand-by and automatic switching and battery back up for reactor protection channel.
- Three independent 2 x 100%, 48 V DC system with battery back-up for reactor protection channel.
- AC voltage levels of 6.6 kV and 415 V.
- DC voltage levels of 220 V and 48 V.

6. SAFETY CONCEPTS

6.1 Safety Requirements and Design Philosophy

Prevention of accidents is the basic design philosophy in AHWR. All proven measures of current safety concepts assuring reliable operation are incorporated in the design to prevent accidents. These include the following:

- Systems and components designed with conservative margins.
- Use of the redundancy concept for operating systems to increase the reliability.

- Preventive maintenance.
- In-service inspection.
- Large water reservoir in GDWP.
- Incorporation of passive safety features.
- Negative void coefficient of reactivity.

6.2 Safety Systems

6.2.1 Passive Safety Features

The Advanced Heavy Water Reactor (AHWR) is being designed with incorporation of many passive systems/elements to facilitate the fulfilment of safety functions e.g. reactor operation, reactor shutdown, residual heat removal, emergency core cooling, confinement of radioactivity etc. For removal of heat from the reactor core under operating as well as accident conditions, heat removal paths and systems are shown in Figure 3. These systems are described in the following paragraphs.

6.2.2 Natural Circulation of Primary Coolant

During normal reactor operation, full reactor power is removed by natural circulation caused by thermosyphoning phenomenon. Primary circulation pumps are eliminated and the necessary flow rate is achieved by locating the steam drums at a suitable height above the centre of the core, taking the advantage of reactor building height. By eliminating nuclear grade primary circulating pumps, their prime movers, associated valves, instrumentation, power supply and control system, the plant is made simpler, less expensive, easier to maintain as compared to options involving forced circulation in the primary coolant circuit. The above factors also lead to considerable enhancement of system safety and reliability since pump related transients have been removed.

6.2.3 Core Decay Heat Removal

During normal reactor shut down core decay heat is removed by Isolation Condensers (ICs) which are submerged in Gravity Driven Water Pool (GDWP), located above the steam drum. The steam, led to the ICs by means of natural circulation, condenses inside the IC pipes and heats up the

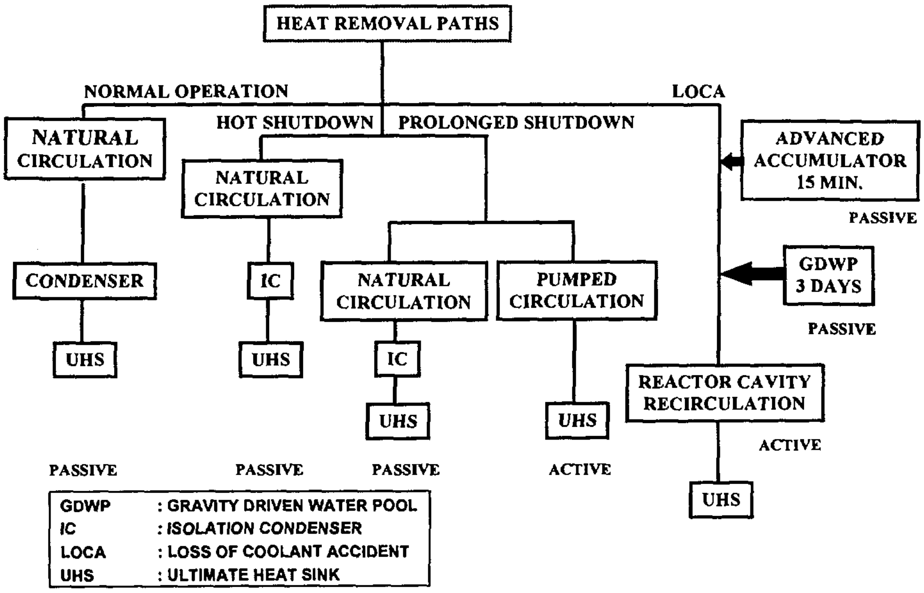

FIG. 3. Heat removal paths of AHWR..

surrounding pool water. The condensate returns by gravity to the core. The water inventory in GDWP is adequate to cool the core for more than 3 days without any operator intervention and without boiling of GDWP water. A GDWP cooling system is also provided. An Active Shut Down Cooling System (ASDCS) is also provided to remove the core decay heat in case the ICs are not available.

6.2.4 Shutdown Systems

Two completely independent and redundant fast acting devices (mechanical shut off rods and liquid poison injection) are provided to shutdown the reactor. These devices are actuated by active systems. In case of failure of these devices to act, the reactor will be shutdown due to negative void coefficient of reactivity.

6.2.5 Emergency Core Cooling

During Loss-Of-Coolant-Accident (LOCA) emergency coolant injection is provided by passive means to keep the core flooded so as to prevent overheating of the fuel.

The Emergency Core Cooling System (ECCS) is designed to fulfil the following two objectives:

1. To provide large amount of cold borated water directly into the core in the early stage of Loss-of-Coolant Accident (LOCA) and then a relatively small amount of cold borated water for a longer time to quench the core. This objective is achieved through ECCS accumulator.
2. To provide water through Gravity Driven Water Pool (GDWP) to cool the core for more than 3 days.

Long-term core cooling is achieved by active means by pumping water from reactor cavity to the core through heat exchangers.

6.2.6 Core Submergence

After Loss Of Coolant Accident (LOCA), the water from the PHT system, advanced accumulators and the GDWP, after cooling the core, will be guided and get collected in the space around the core called reactor cavity. Thus the core will be submerged under water. If GDWP fails during any postulated scenario, its inventory will get collected in the reactor cavity and will provide heat sink to the core.

6.2.7 Failure of ECCS during LOCA

The reactor core of AHWR contains huge inventory of heavy water moderator and surrounding vault water. Although the possibility of failure of ECCS is very rare but if ECCS is not available during LOCA due to any reason, the fuel temperature will start rising and ballooning of pressure tubes will occur. Due to ballooning the pressure tubes will come in contact with calandria tubes and heat will be transferred to the moderator and then from moderator to vault water.

6.2.8 Passive Containment Isolation

To protect the population at large from exposure to radioactivity, the containment must be isolated following an accident. To achieve this, passive containment isolation, in addition to the closing of the normal inlet and outlet ventilation dampers, has been provided in AHWR. The reactor building air supply and exhaust ducts are shaped in the form of U bends of sufficient height. In the event of LOCA, the containment gets pressurised. This pressure acts on GDWP inventory and pours water by swift establishment of a siphon, into the ventilation duct U bends. Water in U bends acts as seal between the containment and the external environment, providing the necessary isolation between the two. Drain connections provided to the U bends permit the re-establishment of containment ventilation manually when desired.

6.2.9 Passive Containment Cooling

Passive containment coolers (PCCs) are utilised to achieve post-accident primary containment cooling in a passive manner, and to limit the post-accident primary containment pressure. A set of PCCs are located below the GDWP and are connected to the GDWP inventory. During LOCA, the mixture of hot air and steam is directed to flow over the PCCs. Steam condenses and hot air cools down at the PCC tube surface and hence provides long term containment cooling after the accident.

6.3 Severe Accidents

The primary objective followed in the development of AHWR is to enhance the level of safety to such an extent that the probability of occurrence of a severe accident becomes negligibly low, on account of the presence of safety features as already described. This will be confirmed by a PSA. In this context, it may be noted that the core submergence, discussed earlier, and presence of a large pool of water below the reactor, following an accident, will serve as effective barriers to escalation of any severe accident scenario.

7. PLANT LAYOUT

7.1 General Arrangement of the Reactor Building

The reactor building of AHWR is a cylindrical concrete structure. This consists of two coaxial cylindrical shells closed at top by dome structures. The inner structure, called primary containment, accommodates high enthalpy systems like reactor core, primary coolant systems, fuelling machine etc. The primary containment has a diameter of 44 m and a height of 72 m, and it is constructed from pre-stressed concrete. A large pool of water, called the Gravity Driven Water Pool (GDWP), is located near the top of the primary containment. This pool is designed to perform several passive safety functions. The outer structure having a diameter of 58 m and a height of 74.5 m is constructed with reinforced concrete and is called secondary containment. Both these structures are supported on a concrete raft. AHWR reactor building elevation is shown in Figure 4.

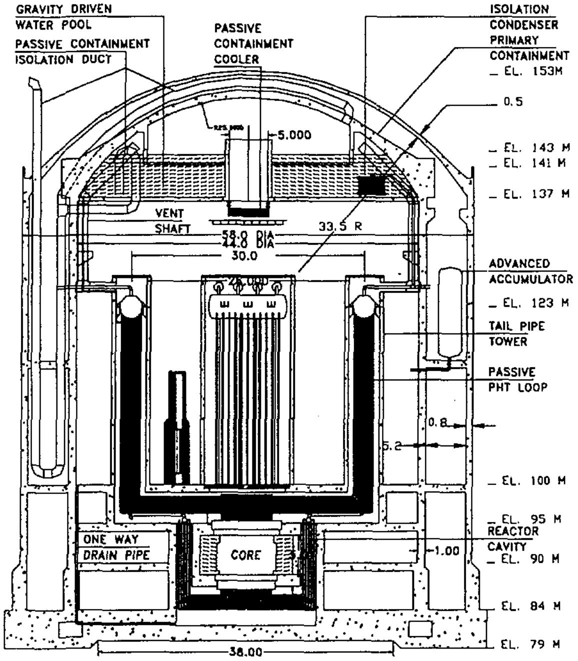

FIG. 4. AHWR reactor building elevation.

7.2 Criterion for Design of Layout

The layout of reactor building is carried out to meet the following objectives:

- Minimisation of primary containment volume.
- Effective utilisation of space in the annulus between primary and secondary containments.
- Unrestricted entry to reactor top for on- power fuel handling and transfer operations.
- Adequate shielding against radiation and preventing spread of radioactive contamination during normal and accidental conditions.
- Provision of a large water inventory at a suitable height, capable of supporting a number of passive systems.
- Submergence of reactor core under water before exhaustion of inventory of emergency core cooling system.
- Easy access to maximum number of equipment for operation and maintenance during normal and accidental situations.
- Fire prevention and control.

8. TECHNICAL DATA (As per format given in IAEA-TECDOC-968)

General Plant Data

Power plant output, gross	245	MWe
Power plant output, net	235	MWe
Reactor thermal output	750	MWt
Power plant efficiency	33	%
Cooling water temperature	30	°C

Nuclear Steam Supply System

Number of coolant loops	4	
Primary circuit volume	307	m^3
Steam flow rate at nominal conditions	362	kg/s
Feedwater flow rate at nominal conditions	362	kg/s

Reactor coolant system (Calculation being updated)

Primary coolant flow rate	2576	kg/s
Reactor operating pressure	7	MPa
Steam temperature/pressure	285/7	°C/MPa
Feedwater temperature	165	°C
Core coolant inlet temperature	270.7	°C
Core coolant outlet temperature	285	°C
Mean temperature rise across core	14.3	°C

Reactor Core

Active core height	3.5	m
Equivalent core diameter	7.6	m
Heat transfer surface in the core	2740	m^2
Total fuel inventory	49	t HM[#]
Average linear heat rate	9.6	kW/m
Average fuel power density	15.3	kW/kg HM
Average core power density (volumetric)	84	kW/l
Thermal heat flux, F_q (average)	274	kW/m^2
Enthalpy rise, F_H (average)	291	kJ/kg

Fuel material		$(Th\text{-}Pu)O_2 + (Th\text{-}U^{233})O_2$	
Fuel assembly total length		4027	mm
Rod array			
Number of fuel assemblies		424	
Number of fuel rods/assembly		52	
Number of control rod guide tubes		36	
Number of spacers		7	
Enrichment (range) of first core, average			Wt%
Enrichment of reload fuel at equilibrium core			
Plutonium		4.5 Wt%	
Uranium-233		Self sustaining	
Operating cycle length (fuel cycle length)			months
Average discharge burnup of fuel		20 000	MWd/t HM
Cladding tube material		Zircaloy	
Cladding tube wall thickness		0.6	mm
Outer diameter of fuel rods		11.2	mm
Fuel channel/box; material		Zr-2.5 wt% Nb	
Overall weight of assembly, including box		200	kg
Heavy metal weight/assembly		114.6	kg
Active length of fuel rods		3500	mm
Burnable absorber, strategy/material			
Number of control rods (assemblies) (RRC)		36	
Number of grey control rods (assemblies) (GRC)			
Number of water displacer rods (assemblies) (WDR)			
Absorber rods per control assembly			
Absorber material :	RRC		
	GRC		
	WDR		
Drive mechanism	RRC		
	GRC		
	WDR		
Positioning rate [or steps/s]			mm/s
Soluble neutron absorber			

[#] HM = Heavy Metal

Reactor pressure vessel

Calandria

Inner diameter	8600	mm
Wall thickness	≈ 50	mm
Total height, inside	5000	mm
Base material	SS 304L	
Transport weight (empty)	55	t

Coolant channel

Total height of coolant channel	13400-- 15700	mm
Inner diameter of pressure tube	120	mm
Wall thickness of pressure tube	4	mm
Base material	Zr-2.5 wt% Nb	
Design pressure/temperature	8.5/300	MPa/°C
Transport weight (without fuel and water)	0.5	t

Reactor recirculation pump

(AHWR is Natural circulation system)	Not Applicable	
Type	-	
Number	-	
Design pressure/temperature	-	MPa/°C
Design mass flow rate (at operating conditions)	-	kg/s
Pump head	-	MPa
Rated power of pump motor (nominal flow rate)	-	kW
Pump casing material	-	
Pump speed (at rated conditions)	-	rpm
Pump inertia	-	kg m^2

Primary Containment

Type		Pressure suppression	
Overall form (spherical/cylindrical)		Cylindrical	
Dimensions (diameter/height)		44/72	m
Free air volume	V_1 volume	9724	m^3
	V_2 volume	53240	m^3
Design pressure/temperature		359/156	kPa/°C
Design leakage rate			vol%/day
Is secondary containment provided?		Yes	

Reactor auxiliary systems

Reactor water cleanup,	capacity	33	kg/s
	filter type	Mixed bed	
Residual heat removal,	at high pressure	22.5	MW
	at low pressure (150°C)	22.5	MW
Coolant injection,	at high pressure	1322	kg/s
	at low pressure	49	kg/s

Power supply systems

Main transformer,	rated voltage		kV
	rated capacity		MVA
Plant transformers,	rated voltage		kV
	rated capacity		MVA
Start-up transformers,	rated voltage		kV
	rated capacity		MVA
Medium voltage busbars (6 kV or 10 kV)			
Number of low voltage busbar systems			
Standby diesel generating units :	number		
	rated power		
Number of diesel-backed busbar systems			
Voltage level of these			V AC
Number of DC distributions			
Voltage level of these			V DC
Number of battery-backed busbar systems			
Voltage level of these			V AC

Turbine Plant

Number of turbines per reactor	1	
Type of turbine(s)	Horizontal, impulse reaction	
Number of turbine sections per unit (e.g. HP/LP/LP)	1 HP/1 LP	
Turbine speed	3000	rpm
Overall length of turbine unit		m
Overall width of turbine unit		m
HP inlet pressure/temperature	6.8/284	MPa/°C

Generator

Type	Static exciter, stator and rotor core hydrogen cooled and stator windings water cooled.	
Rated power	275	MVA
Active power	245	MWe
Voltage	16.5	kV
Frequency	50	Hz
Total generator mass, including exciter	240	t
Overall length of generator	11	m

Condenser

Type	Surface condenser	
Number of tubes	21193 (18 BWG) 413 (16 BWG)	
Heat transfer area	21 020	m^2
Cooling water flow rate	17	m^3/s
Cooling water temperature	30	°C
Condenser pressure	8.4	kPa

Condensate pumps

Number	2	operating
	1	stand by
Flow rate	212	kg/s
Pump head		MPa
Temperature	42.8	°C
Pump speed	1500	rpm

Condensate clean-up system

Full flow/part flow	1440	m^3/h
Ion Exchanger type	Mixed bed	

Feedwater pumps

Number	2	operating
	1	stand by
Flow rate	260	kg/s
Pump head		MPa
Feed pump power		MW
Feedwater temperature (final)	165	°C
Pump speed	3000	rpm

Condensate and feedwater heaters

Number of heating stages,	low pressure	1
	high pressure	2

9. PROJECT STATUS AND PLANNED SCHEDULE

The conceptual design of AHWR was completed in December, 1997. On the basis of first level analytical studies and experimental work, the feasibility of the design concept was established and a Feasibility Report was issued.

Detailed design of nuclear systems of AHWR is in progress. It is planned to develop design details for nuclear systems, conduct supportive analysis and experimental developments, prepare detailed specifications for non-nuclear systems and issue Detailed Project Report in the year 2002.