PFBR PSAR

Prototype
Fast Breeder Reactor

Preliminary
Safety Analysis Report

Chapter 1
GENERAL DESCRIPTION OF PLANT

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1. GENERAL DESCRIPTION OF PLANT

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Chapter 1

General Description of Plant

1.1 INTRODUCTION

Prototype Fast Breeder Reactor (PFBR), is a 500 MWe unit designed by Indira Gandhi Centre for Atomic Research, Kalpakkam. It is a sodium cooled, mixed oxide (MOX) fuelled, pool type fast reactor. The core thermal power is 1253 MW and the gross electrical output is 500 MWe. The reactor is located at Kalpakkam, 500 m south of Madras Atomic Power Station (MAPS). Kalpakkam is 60 km south of Chennai on the coast of Bay of Bengal.

1.2 PLANT DESCRIPTION

1.2.1 SITE CHARACTERISTICS

Suitability of the site, has been verified based on the following considerations:

- Land availability
- Proximity to load centre
- Access to site by road and rail
- Geological, seismological, meteorological and hydrological conditions
- Waste disposal
- Availability of condenser cooling water
- Availability of good infrastructure

1.2.2 PLANT LAYOUT

The plant layout has been developed on the basis of a single unit (fig. 1.1). The layout has been made taking into consideration safety requirements, distance for flow of energy, constructability, maintainability, security and economics. The reactor containment building (RCB) is rectangular in shape. The RCB, fuel building (FB) and two steam generator buildings (SGB) are connected and laid on a common base raft from safety considerations. In addition, control building, two electrical buildings and radwaste building are also laid on the common raft and connected to form a nuclear island consisting of eight buildings to reduce the magnitude of structural response under seismic loads and length of cables. The finished floor levels of all safety related buildings are 0.8 m above the design basis flood level. A service building is provided to cater to the needs of plant services. The turbine building is located such that the missile trajectory is outside the safety related buildings and the stack. Four diesel generators provided for Class III emergency power requirements are housed in two separate safety related diesel generator buildings. The stack, 100 m tall, is located close to the radwaste building. There is single point entry in the radiation zones. The switchyard is oriented to suit the power evacuation scheme, based on 220 kV transmission system.

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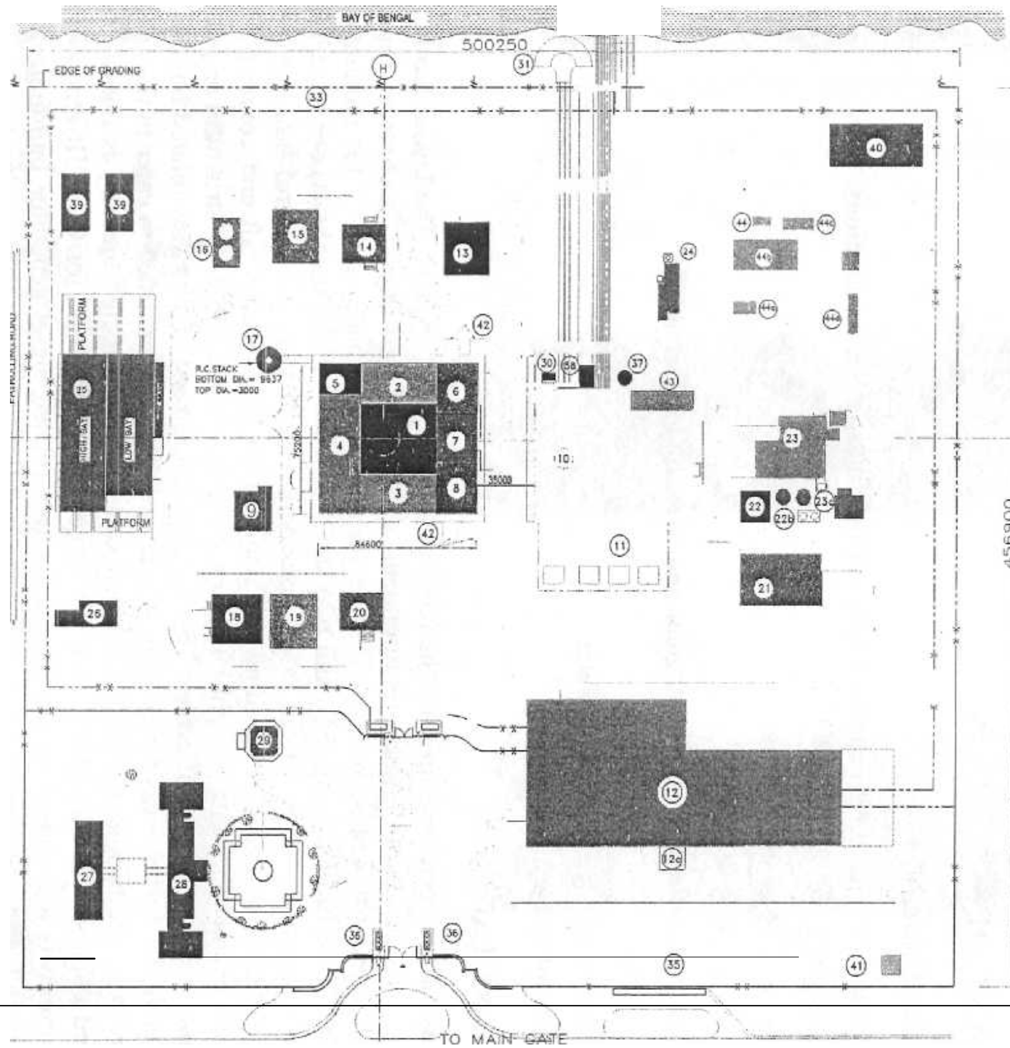

NOTE: ALL DIMENSIONS ARE IN 'mm' ONLY

LEGEND:

1. REACTOR CONTAINMENT BUILDING
2. STEAM GENERATOR BUILDING-1
3. STEAM GENERATOR BUILDING-2
4. FUEL BUILDING
5. RAD WASTE BUILDING
6. ELECTRICAL BUiLDINS-1
7. CONTROL BUILDING
8. ELECTRICAL BUILDING-2
9. SERVICE BUILDING
10. TURBINE BUILDING
11. TRANSFORMER YARD
12. 220 kv INDOOR SWITCH YARD
13. LIQUID N2 STORAGE
14. DIESEL GENERATOR BUILDING-1
15. FUEL OIL STORAGE-1
16. HORTON SPHERES
17. STACK
16, SERVICE WATER PUMP HOUSE
19. FUEL OIL STORAGE-2
20. DIESEL GENERATOR BUILDING-2
21. RAW WATER AND FI RE WATER PUMP HOUSE
22. PACKAGE BOILER! FUEL OIL STORAGE TANK
21 DM. PLANT
24. CHLORINE BUILDING
25. SITE ASSEMBLY SHOP
26. CONSTRUCTION POWER STATION
27. TRAINING CENTRE/ FUTURE EXTN.
23. ADMINISTRATIVE BUILDING
29. CANTEEN
30. EMERGENCY TURBINE OIL TANK,
31. CONOENSER COOLING WATER OUTFALL
32. CONDENSER COOLING WATER INTAKE JETTY.
33. SECURITY FENCE.
34. SEA WATER PUMP HOUSE.
35. BUS STAND,
36. SECURITY.
37. CONDENSATE STORAGE TANK,
38. SEA WATER FILTERS
39. STORE,
40. OPEN SCRAPYARD
41. SPACE FOR SEWAGE LIFT STATION
42. TRANSFORMER AREA FOR CONVERTERS.
43. OFFICE ROOM
44 EFFLUENT TREATMENT PLANT
   a) OIL WATER SEPARATOR
   b) CENTRAL MONITORING BASIN
   cj SLUOGE POND
   d) COLLECTION SUMP & PUMP ROOM
   e) ELECTRICAL CONTROL BLDG.

Fig. 1.1 : PLANT LAYOUT

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1.2.3 NUCLEAR STEAM SUPPLY SYSTEM

1.2.3.1 REACTOR CORE

The active core, in which most of the heat is generated by controlled fission, consists of 181 fuel subassemblies (FSA) of which 85 with 21 % PuO_2 content are in the inner enrichment zone and 96 subassemblies with 28 % PuO, content are in the outer enrichment zone (fig. 1.2). There are 2 rows of radial blanket subassemblies. 12 absorber rods viz., 9 control and safety rods (CSR) and 3 diverse safety rods (DSR) are arranged in two rings. Enriched boron carbide is used as absorber material. The details of core are as indicated in table 1.1

Table 1.1 : Core Subassembly Data

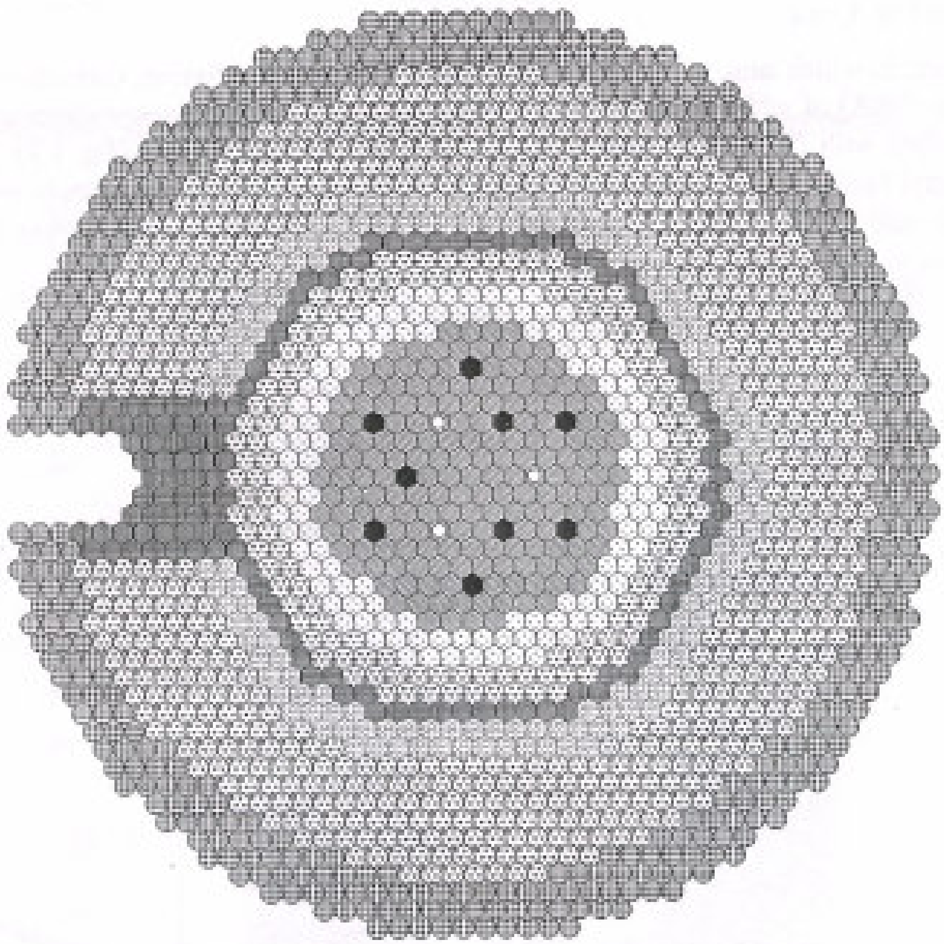
Type of Subassembly	*No*
Fuel Inner	85
Fuel Outer	96
Control and safety rod	9
Diverse safety rod	3
Blanket	120
Steel Reflector	138
B_4C Shielding (Inner)	125
Internal Storage	156
Steel shielding	609
B_4C Shielding (Outer)	417
Total	1758

Each FSA (fig. 1.3) consists of 217 helium bonded pins of 6.6 mm diameter. Each pin has 1000 mm column of MOX, 300 mm each of upper and lower depleted UO., blanket columns and fission gas plena. Maximum linear pin power of 450 W/cm has been fixed based on hot spot analysis with adequate margin for fuel melting. The initial peak fuel bum-up is 100 GWd/t and is targeted to be increased to 200 GWd/t in the long run.

Radial core shielding is provided by SS SA and B_4C SA. This together with the top axial shielding provided within the SA limits the secondary sodium activity thereby enabling controlled access to SGB.

1.2.3.2 REACTOR ASSEMBLY

The reactor assembly consists of grid plate, core support structure, inner vessel, main vessel, thermal baffles, safety vessel, thermal insulation, roof slab, rotatable plugs, control plug and absorber rod drive mechanisms (fig. 1.4). A single grid plate is used to support all the core subassemblies (CSA) and to distribute coolant to the CSA. The grid plate has four sodium inlet pipes i.e. two from each of the primary sodium pumps. The core support structure supports the



SYMBOL	TYPE OF SUBASSEMBLY
	FUEL (INNER)
	FUEL (OUTER)
	CONTROL AND SAFETY ROD
	DIVERSE SAFETY ROD
	BLANKET
	STEEL REFLECTOR
	B_4C SHIELDING (INNER)
	STORAGE LOCATION
	STEEL SHIELDING
	B_4C SHIELDING (OUTER)
	TOTAL SUBASSEMBLIES

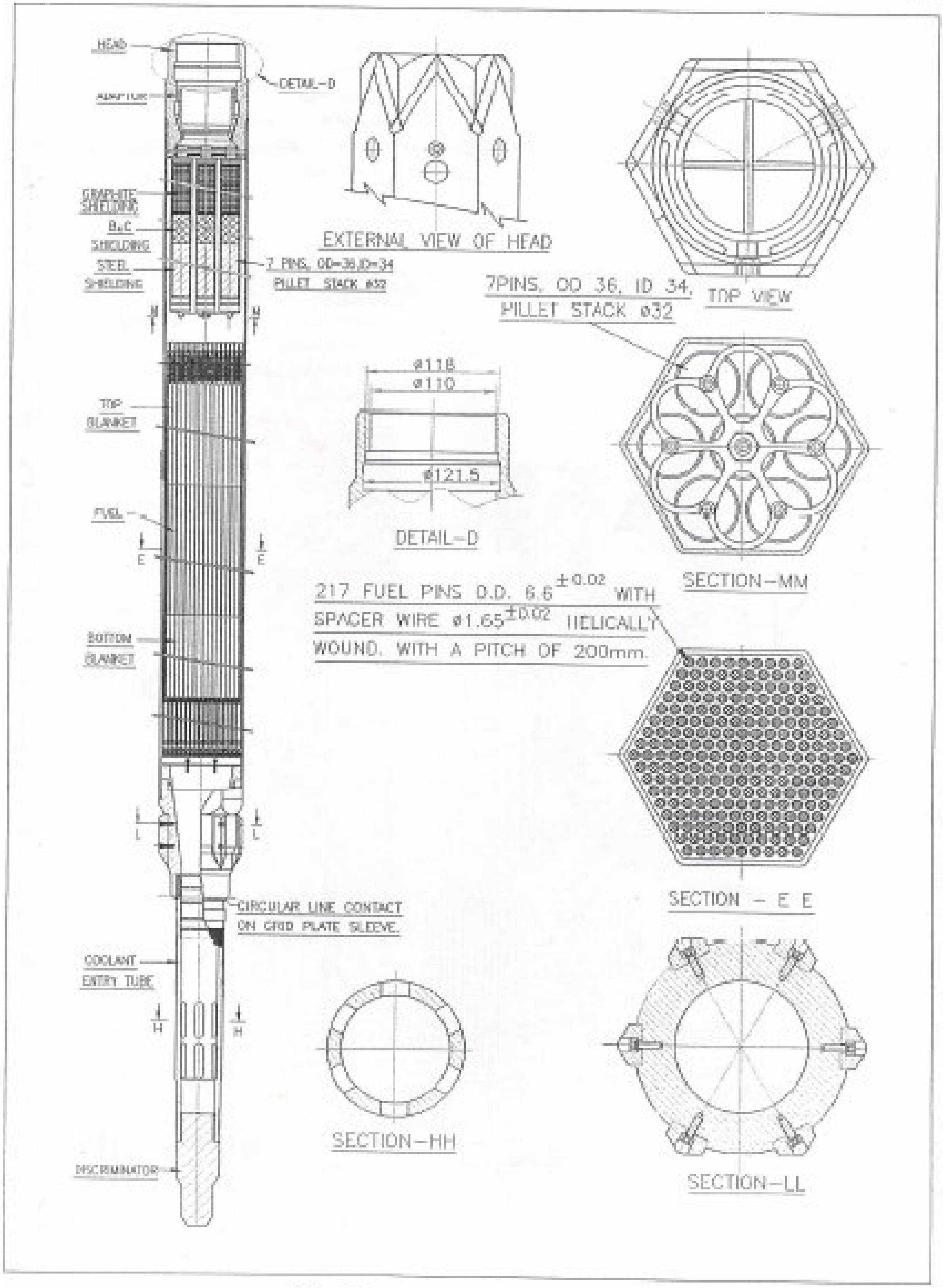


Fig. 1.3 : FUEL SUBASSEMBLY

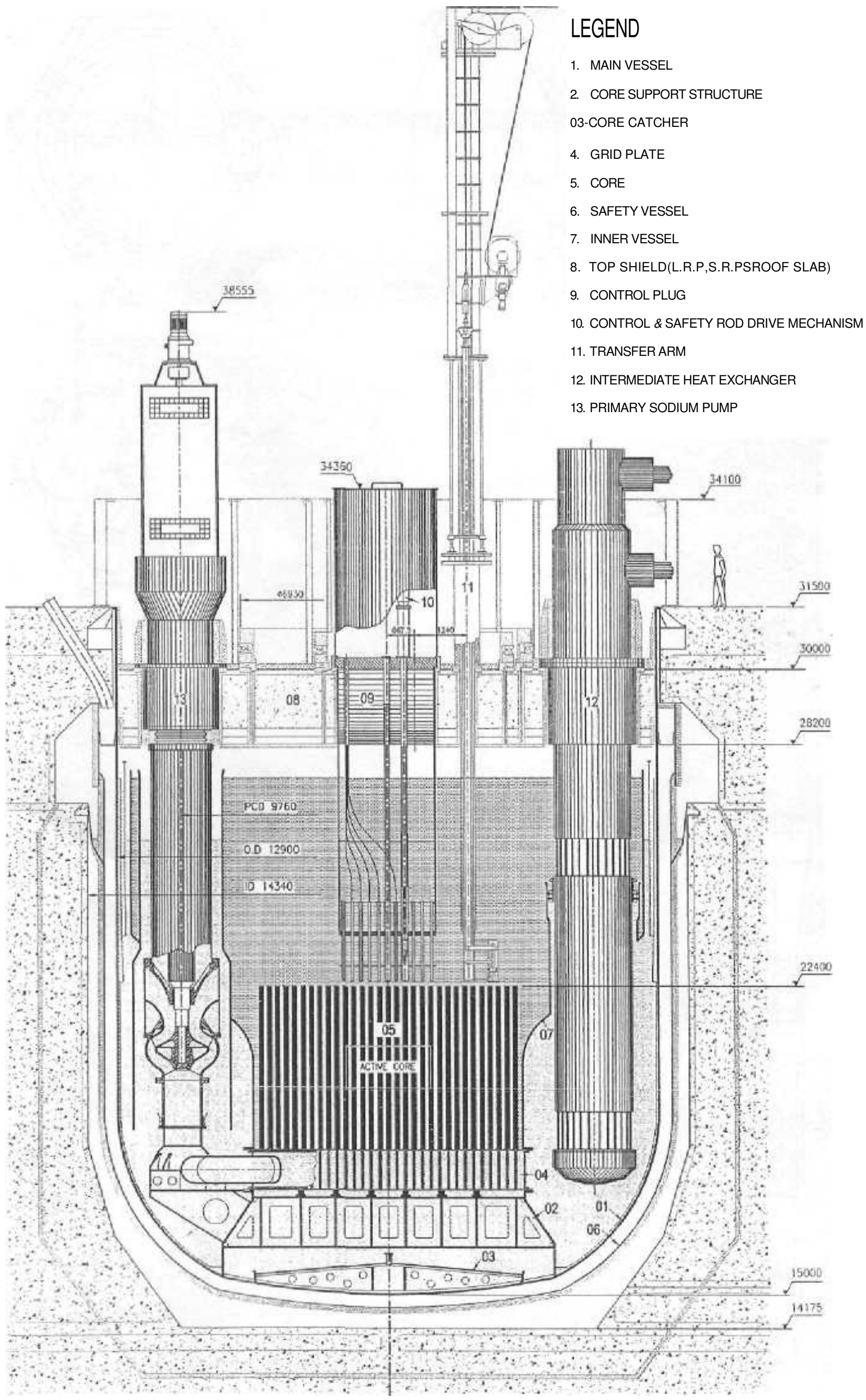


Fig. 1.4: REACTOR ASSEMBLY

grid plate and inner vessel. The main vessel diameter (12.9 m) has been optimised considering the fuel handling scheme and the layout of the components on the roof slab. The height of the main vessel is fixed such that the active portion (fuel) of the FSA is submerged in sodium during refuelling. The main vessel has no penetration and the bottom closure shape is specially designed to enhance its buckling resistance. It is top supported by welding to the outer shell of the roof slab and is free to expand downwards. To enhance its structural integrity, it is cooled by cold sodium to keep the maximum temperature during normal operation < 723 K. About 6 % of the total primary sodium flow is used for cooling the main vessel. The total weight of primary sodium is 1150 t. Safety vessel is provided to collect the leaking sodium in the remote event of any sodium leakage from the main vessel. The intervessel space between the main vessel and the safety vessel is filled with nitrogen. The gap is 300 mm to permit robotic visual and ultrasonic inspection of the vessels and to keep the sodium level to about 250 mm minimum above the bottom of inlet windows of IHX which ensures continued cooling of the core in case of a main vessel leak. An inner vessel separates the hot and cold pools of sodium. To minimise sodium leakage from hot pool to cold pool at the IHX penetration, a mechanical seal is used. Roof slab supports the large rotatable plug, primary sodium pumps, IHX and heat exchangers of the decay heat removal system. The roof slab is a box structure made of 30 mm thick carbon steel plates. It provides thermal and biological shielding in the top axial direction. Heavy density concrete is used as the shielding material. Air is used for cooling the roof slab. A warm roof slab concept (T > 383 K) has been chosen to avoid deposition of sodium in the annular gaps. Rotatable plugs (LRP & SRP) enable access to all CSA, which require handling. A replaceable separate control plug supports twelve absorber rod drive mechanisms, thermocouples for measurement of sodium outlet temperature of each FSA and three failed fuel location modules for sodium sampling. The control plug also houses six tubes inside which neutron detectors are located for monitoring neutron flux. A central canal plug is provided at the centre of control plug to enable installation of experimental subassemblies in the core.

The reactor shutdown system consists of 9 control and safety rod drive mechanisms (CSRDM) and 3 diverse safety rod drive mechanisms (DSRDM). CSRDM are used to control the reactor power manually and to start-up/shutdown of the reactor. They have an electromagnet in argon space, which can be de-energised to drop the control and safety rod (CSR), and an oil dash pot to decelerate the CSRDM towards the end of its travel. DSRDM are used only to scram the reactor. DSRDM has electromagnet in sodium, which is de-energised to drop diverse safety rod (DSR). A dash pot in sodium decelerates the DSR towards the end of its travel.

A core catcher is provided below the core support structure to prevent the core debris reaching the main vessel and to cool them by natural convection of sodium. It is designed for the case of melt down of seven subassemblies following a hypothetical total instantaneous blockage of a single fuel subassembly.

1.2.3.3 Main Heat Transport System

The Primary sodium circuit is contained within the main vessel and removes heat from the core and delivers it to the secondary sodium circuit in IHX (fig. 1.5). The primary circuit consists of the reactor core, the hot pool at the core outlet, four IHX, the cold pool, two primary pumps, the primary pipes and the grid plate. Primary sodium flows from the hot pool on the shell side of the IHX, through IHX to the pumps, and from the pump discharge to the grid plate. IHX is a vertically oriented, shell and straight tube heat exchanger. Secondary sodium enters through a

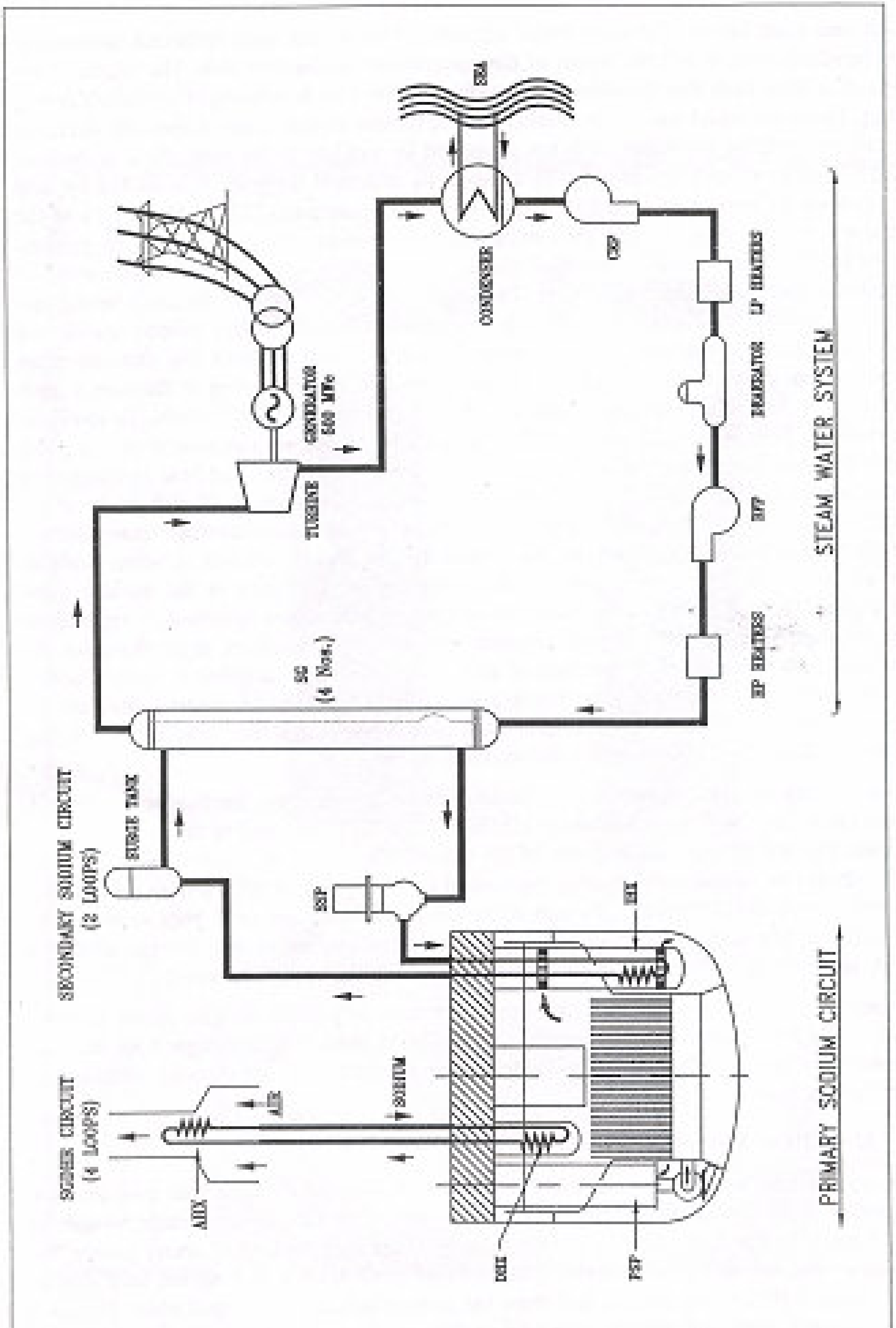


Fig. 1.5 : MAIN HEAT TRANSPORT SYSTEM

central down comer in the IHX, rises from the lower plenum through the tube bundle and exits through an annular flow riser. The primary pump is a vertical, single stage, single suction, free surface centrifugal pump. An auxiliary pony motor provides capability for decay heat removal.

There are two secondary loops. The main components of each secondary loop are the tube side of the two IHX, surge tank, the shell side of the four steam generators (SG), the secondary pump, connecting piping and the isolation valves of the SG. The SG is a once through integrated, vertical, counter current shell and tube heat exchanger with provision of expansion bend in each tube with sodium flow from top to bottom. Each SG is provided with tube leak detection system. Rupture discs are provided at the inlet and outlet of each SG to limit the pressure in the IHX from large sodium water reaction. The secondary pump is a vertical, single stage, single suction centrifugal pump. Sodium purity is maintained in the primary and secondary circuits by cold traps. All sodium piping inside the RCB is provided with nitrogen inerted guard piping to ensure that no sodium from primary sodium purification, secondary and safety grade decay heat removal (SGDHR) circuits can enter the containment volume in the event of a leak. Continuous leak monitoring of the inter-pipe annulus is provided by sodium leak detectors.

In case of off-site power failure or non-availability of steam-water system, the decay heat is removed by SGDHR circuit consisting of four identical loops. Each of these loops consist of one sodium/sodium heat exchanger (DHX) immersed in the hot pool, one sodium/air heat exchanger (AHX) located at elevated level, associated sodium piping, tanks, and air dampers. The intermediate sodium and air flow are by natural circulation. Each loop can remove 8 MW when hot pool temperature is 803 K. Diversity is provided for DHX, AHX and dampers.

1.2.3.4 COMPONENT HANDLING SYSTEMS

The core subassemblies (fuel, absorber, blanket, reflector and shielding SA) are handled with reactor in shutdown condition at a sodium temperature of 473 K. Refuelling is done after 185 effective full power days (efpd). The handling system is divided into two parts i.e. in-vessel handling and ex-vessel handling. In-vessel handling is done with the help of two rotatable plugs and a transfer arm. For ex-vessel handling, an inclined rotatable shield leg machine called inclined fuel transfer machine (IFTM) is used (fig. 1.6). Handling of fresh SA consists of receipt from transport flask, visual inspection to check for any apparent damage, checking of serial number and core zone to which they are to be loaded, flow test for any gross blockage of flow path and storage in fresh SA storage bay. They are then transferred to the reactor using fresh SA transfer chamber cell transfer machine and IFTM after preheating to 473 K.

The spent fuel subassemblies are stored inside the main vessel for one campaign (8 months) and then shifted to spent subassembly storage bay (SSSB) located in FB, which is a demineralised water filled pool. It has capacity to store 710 CSA. Sodium sticking to CSA is washed in fuel transfer cell before lowering them into the pool water. Special handling is done using leak tight shielded flasks. One flask is used to handle large components like primary pump and IHX and another for slender components like ARDM. There is a separate flask for handling DHX. A decontamination facility is provided inside RCB for removal of sodium and radioactive corrosion and fission products from primary components before taking them for maintenance. A process using a mixture of nitrogen, carbondioxide and water vapour is employed for sodium removal prior to decontamination of components.

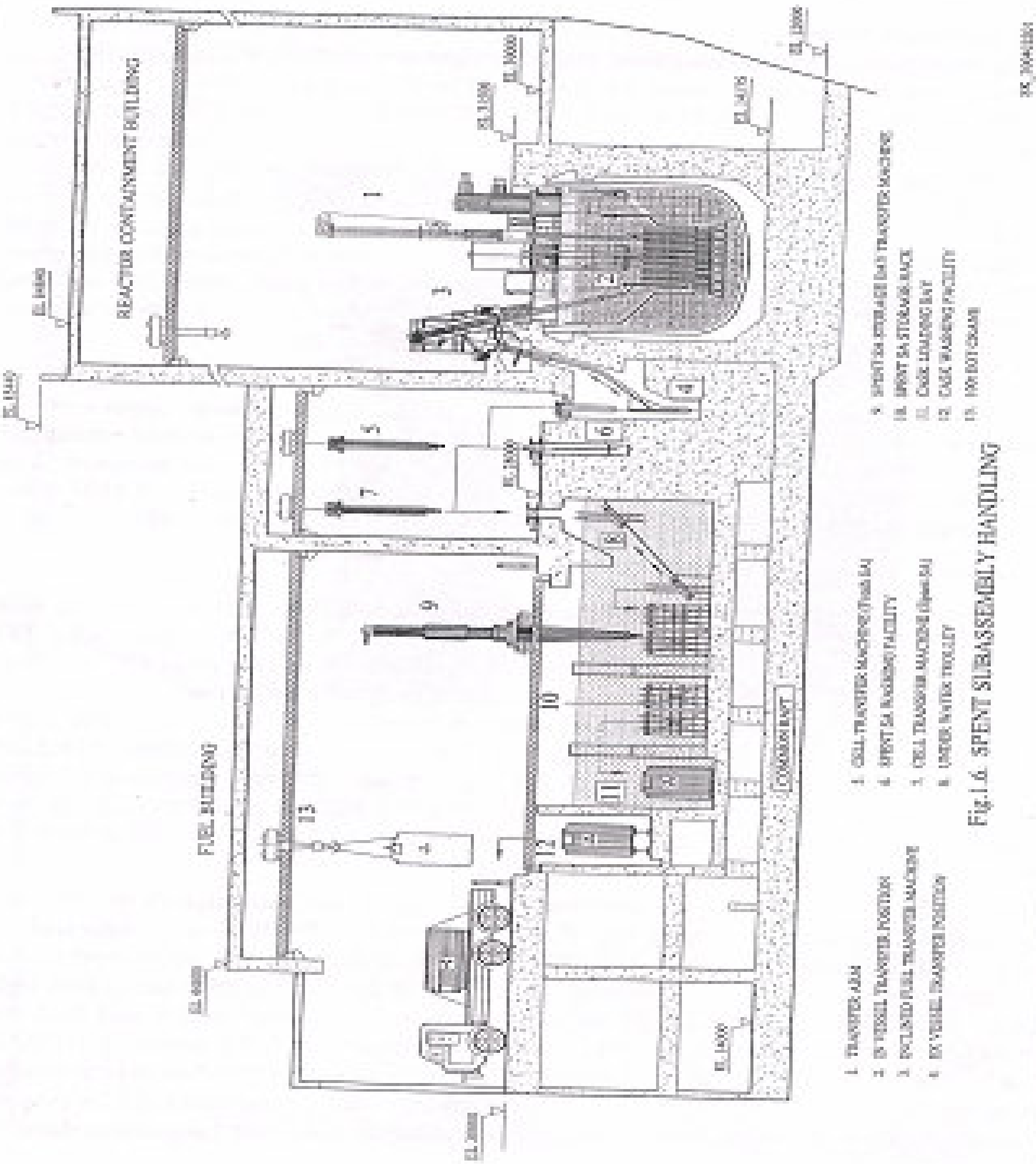


Fig. 1.6 : SPENT SUBASSEMBLY HANDLING

1.2.4 BALANCE OF PLANT

1.2.4.1 STEAM-WATER SYSTEM

The steam-water system adopts the standard turbine that is used in fossil fired thermal power stations of the same rating. The turbine is of tandem compound design with separate HP, IP and LP cylinders. The steam cycle employs regenerative feed water heating based on steam bled from the turbine. There are 6 stages of feed water heating, five in surface type feed water heaters and the sixth in a direct contact heater, deaerator. The system is designed to heat the condensate from 320 K to 508 K.

A steam separator is provided at the common outlet of 8 SG to take care of two-phase flow during start-up and shut down of the plant. Reheating of HP exhaust steam is done using live steam from the SG in 2 vertical steam to steam reheaters. The condensate from the condenser hot well is delivered to the deaerator using 3x50% condensate extraction pumps, through 3 low pressure heaters, gland steam condenser and a full flow on-line condensate polishing unit. The feed water from the deaerator storage tanks is supplied to the SG using 2x50% turbine driven feed water pumps and 1x50% motor driven feed water pump through a double train of 2 high pressure heaters. A turbine bypass of 60% capacity is provided to facilitate bypassing the main steam and restart of the unit after a minor turbine fault.

At nominal power, a flow of 1805 t/h at a pressure of 16.7 MPa and temperature of 763 K, is delivered to the single flow HP turbine. After expansion in HP cylinder, steam exhausts to a steam-steam reheater wherein the HP turbine exhaust steam is reheated before admission to a double flow IP turbine. Subsequently, steam enters the double flow LP turbine and exhausts to a steam surface condenser cooled by seawater.

To remove the heat rejected from the steam cycle in the condenser, a once-through condenser cooling water system is employed using sea water. The total heat rejected in the condenser is 755 MWt. 2x50% concrete volute pumps are provided for condenser cooling.

1.2.4.2 ELECTRICAL POWER SYSTEMS

Electrical power system is a source of power for the reactor coolant pumps and other auxiliaries during normal conditions, and for the protection system and engineered safety systems during normal and accident conditions. Both off-site and on-site electrical power supply systems are provided. 220 kV is the transmission voltage. The plant is connected to the Tamil Nadu/Southem Regional Grid to transmit the power generated and these connections also provide off-site power supply to the station. A 220 kV substation with five numbers of transmission lines and double circuit ties to MAPS 220 kV bus is provided (fig. 1.7). An indoor switchyard is provided to increase the reliability of the electrical equipment against the saline atmosphere. The switching scheme selected for the extra high voltage (EHV) substation is double main bus scheme with double circuit breakers in the feeder of the generator transformer (GT) and a single circuit breaker in the transmission line connections. Additionally a bus coupler linking the two main bus is also provided to facilitate power flow through the 220 kV bus on generator trip.

The generator is directly coupled to the turbine. The electric power from the terminals of the generator flows to the GT and two unit auxiliary transformers through isolated phase bus ducts. The generator circuit breaker is located between the generator and the GT. The GT steps-up the generator voltage of 21 kV to 220 kV, which is connected to the grid through 220 kV substation.

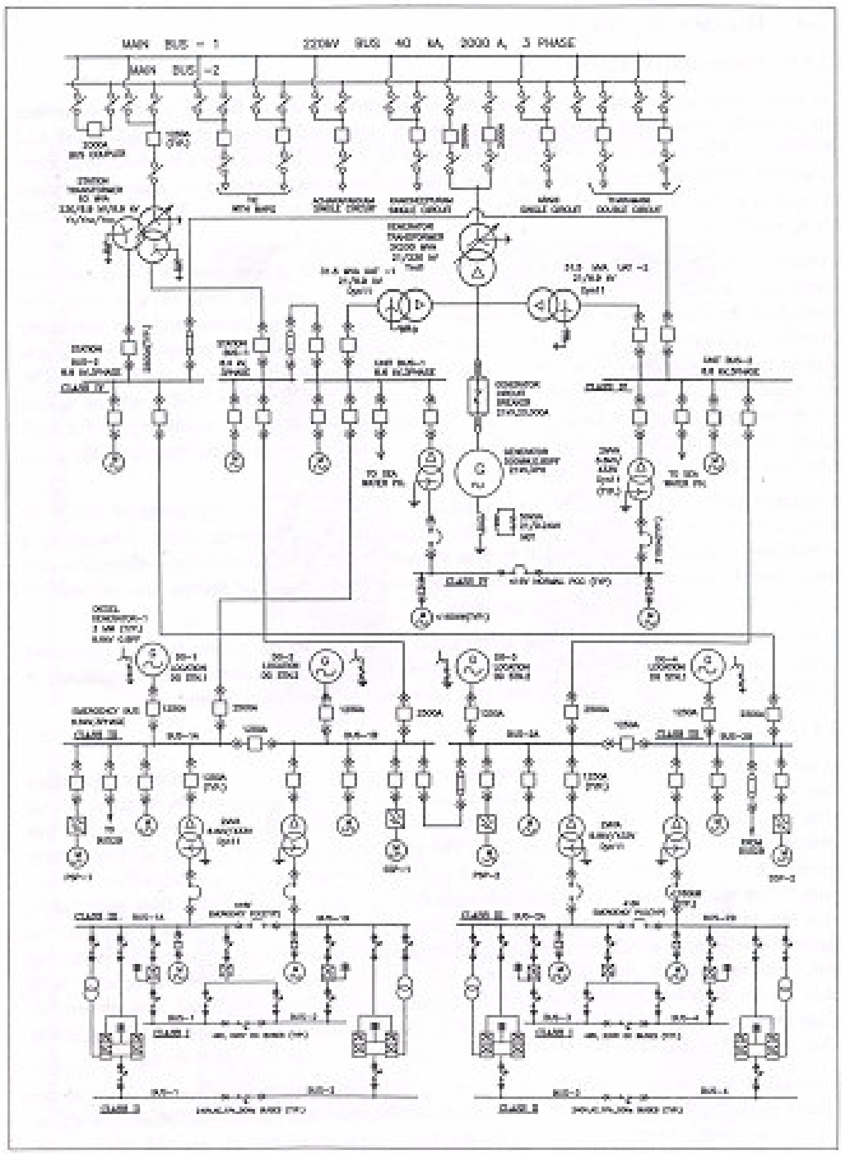


Fig. 1.7 : SCHEMATIC DIAGRAM OF ELECTRICAL POWER SYSTEMS

Fig. 1.7 : SCHEMATIC DIAGRAM OF ELECTRICAL POWER SYSTEMS

Class IV is the main source of power to all the station electrical loads. The Class IV normal AC power supply system derives its power from different sources of supply as mentioned below;

- From the grid through a 220 kV/ 6.9 kV/ 6.9 kV station transformer.
- From the grid through a 220 kV/ 21 kV GT and two numbers of 21 kV/ 6.9 kV unit auxiliary transformers with the generator circuit breaker kept in open position.
- From the terminals of the TG through the two numbers of 21 kV/ 6.9 kV unit auxiliary transformers when the generator circuit breaker is closed during power generation.

The AC supply voltages (Class III and IV) selected for the station auxiliary loads are :

High voltage *6.6* kV, 3 Ph, 50 Hz Medium voltage 415 V, 3 Ph, 50 Hz

Safety related loads, which can withstand power supply interruption of the order of few minutes, are fed from Class III bus. The Class III 6.6 kV busses are normally supplied from the Class FV busses. Standby emergency diesel generators (DG) are provided as on-site sources of AC power to feed the Class III supply system. There are 4 DG sets, each rated to supply 50% of the total emergency power supply demand with a rating of 3MW. DG take 10 s to start. Major loads connected to the Class III bus include main drive system and pony motors supply system of primary sodium pumps, reactor assembly top shield cooling system blowers, water chiller compressors, ventilation system emergency fans/blowers, AHU, instrumentation & control power supplies, TG emergency auxiliary drives.

Class 11-240 V, AC, 1 Ph, 50Hz UPS supply is provided for computers, distributed digital control equipment and other hardware requiring no break AC supply.

Class 1-48 V DC safety systems power supply is used for neutron flux monitoring system, core temperature monitoring system and the pneumatically operated dampers of SGDHR. There is another Class I 48 V DC safety and safety related system which supplies control room panel requirements, process related 48 V DC loads etc. SGDHR motor operated dampers, Class III power supply switchgear control & protection, input supply to CSRDM/DSRDM off-line inverters, DC emergency lighting and high power solenoids are the major loads for Class I - 220 V DC safety and safety related systems power supply. The DC load of the TG plant and Class IV switchgear control power requirements are met by Class I - 220 V DC general power supply system.

For power supplies to CSRDM & DSRDM motors, 415 V, 3 Ph, 50 Hz is used. Two independent off-line dedicated inverter systems having input from the Class I - 220V DC safety and safety related system power supply along with the 415V emergency feeders are provided to supply these motors.

Variable speed AC drives are provided for the two primary and two secondary sodium pumps. The supply to these drive systems for normal operation is fed from the Class FV normal AC power supply through Class III bus. However, when the normal AC power supply fails, the flywheels provide for all the four sodium pumps, the energy requirements for the flow coast down. An AC pony motor is additionally provided for each of the primary sodium pumps to continue the forced convection core cooling during the period of off-site power failure as well as station black out condition for 4 h.

Mineral insulated stainless steel sheathed heating elements with expanded cold output are used for preheating the sodium systems. The primary sodium side is initially preheated through nitrogen gas system which is electrically heated. SG preheating is by hot water in the tubes together with electrical heaters on the shell side.

1.2.4.3 AUXILIARY SYSTEMS

Nitrogen Supply System

This system supplies nitrogen to (1) liquid nitrogen plant required for cover gas purification system, (2) provide inert atmosphere in components and cells housing sodium equipment and (3) mitigate the consequences of sodium leak (fire). Nitrogen is produced in-house by a pressure swing adsorption (PSA) type plant and stored in two horton spheres. The PSA type plant is sized for producing 30 Nm^3 at 0.5 MPa and stored in two horton spheres of 3,600 Nm^3 at 1.6 MPa after booster compression. Impurity levels in nitrogen are limited to $H_2 < 10$ vpm, $O_2 < 10$ vpm and dew point to less than 213 K.

Argon Supply System

This system consists of a bank of cylinders supplying argon to RCB, SGB and FB. Argon is employed as a cover gas over sodium free levels in all the components and also for providing inert atmosphere in various handling facilities. Argon is supplied at 0.9 MPa from six banks of 40 cylinders each. The impurity levels in argon are limited to $O_2 < 5$ vpm, $H_2 < 10$ vpm, $N_2 < 100$ vpm, $H_2O < 5$ vpm and $CH_4 < 10$ vpm.

Service Water System

This system is an intermediate closed loop DM water system for cooling various plant equipment such as TG auxiliaries, DG, spent fuel cooling system heat exchangers (HX) and dissipates the heat to sea water/raw water. The system has three sub-systems (1) Normal service water system (NSWS) which cools all non-safety equipment with normal power supply (2) Emergency service water system (ESWS) which cools non-safety equipment like chillers and air compressors during Class IV power failure, (3) Safety related service water system (SSWS) which cool all safety related equipment (DG, spent fuel cooling HX, top shield cooling HX and biological shield cooling HX). NSWS rejects heat to seawater, and ESWS and SSWS reject heat to raw water and then to air through a cooling tower. The total heat rejected is 25 MW.

Biological Shield Cooling System

This is a closed loop DM water system provided for cooling the reactor vault concrete. The cooling is accomplished by circulating water through 2x100% coils embedded in the lateral and bottom of the vault. The system rejects the heat to SSWS in a HX. The heat removal capacity of the system is 250 kW.

Fire Water System

This is the main fire suppression system in all plant areas - indoor and outdoor, except reactor containment and steam generator buildings. The system provides a pressurised ring main. External hydrants are provided around buildings at regular intervals. Internal hydrants are provided at all elevations in all buildings except RCB and SGB. Sprinklers and high velocity sprays are provided to protect cable galleries, transformers, oil tanks and DG sets. Both electrical and diesel engine driven firewater pumps are provided to assure fire water supply at all credible situations.

Sodium Fire Protection System

All sodium pipelines inside RCB are provided with guard pipe and the inter-space is inerted with nitrogen. The primary cold traps are provided with nitrogen inerted guard vessel. Small pipelines of primary sodium purification circuits are housed in nitrogen inerted steel cabin. In case of a sodium leak, the sodium is contained in the guard pipe/guard vessel/steel cabin and there is no sodium fire as they are nitrogen inerted. The primary argon buffer tank (which is also used for fill and drain of sodium) is single walled and housed in steel lined concrete cell and flooded with nitrogen in case of sodium leak. Nitrogen injection provision has been made in case of sodium leak in AHX.

All sodium pipelines, components and tanks housed in SGB-1 & 2 are single walled and provided with leak collection trays beneath them to collect any sodium leak. To suppress the sodium fire, dry chemical powder (DCP) is applied over the leaked sodium. The quantity of DCP stored is 3 times the quantity of sodium likely to catch fire.

1.2.5 CONTAINMENT

The containment is designed to provide a leak tight boundary that contains the release of radioactive core fission products and fuel, and withstands the pressure resulting from burning of sodium in air through potential leak paths in case of core disruptive accident (CDA) so that dose limits for design basis accident (DBA) are not exceeded. The leak tightness has been specified as 0.1 V% /h. The design pressure of the containment following CDA is 25 kPa. Single containment, rectangular, non-vented and reinforced concrete construction are the main design features of the containment. During normal operation, the containment is kept under small negative pressure (500 Pa below atmospheric). All ventilation ducts opening to the containment atmosphere are automatically isolated by dampers closing in 60 s in the event of CDA.

1.2.6 INSTRUMENTATION AND CONTROL (I&C)

The important functions of I&C system are to monitor various parameters in order to guide the operator in all the states of the reactor, control certain parameters within limits and initiate automatic safety actions on critical parameters crossing set limits. A three level control scheme is adopted viz. field, local control centre and control room. Safety and safety related systems are monitored and operated from control room and they are designed in fail safe mode. Two diverse hardwired logic systems are provided for systems connected with reactor safety. Microprocessor based distributed digital control system is used for non-safety related systems. Neutron detectors are provided above the core at the bottom of control plug to monitor the flux and provide signals for safety action on parameters - neutron power, period and reactivity. Neutron monitoring is triplicated to permit 2/3 logic. Failed fuel detection is done by monitoring of cover gas fission product activity and delayed neutrons in the primary coolant. Three selector valves that sequentially select sodium samples from FSA outlets are provided for location of failed fuel subassembly. 2 chromel-alumel thermocouples are provided at the outlet of each FSA to monitor the temperature of sodium. Flow delivered by sodium pump is measured using bypass type electromagnetic flow meter and safety action is taken on power to flow ratio. These provisions ensure that there are at least two diverse safety parameters to shut down the reactor safely for each design basis event. 10 SCRAM parameters from core monitoring systems and heat transport systems are connected to plant protection system to automatically shutdown the reactor in case of any abnormal event.

The reactor is designed to operate as a base load station and the power is controlled manually. The squirrel cage induction motors of PSP and SSP are fed from current source inverters. The voltage and frequency of the power supply to the motors are varied to change the pump speed and the sodium flow by solid state variable frequency drive, which has a better efficiency and speed regulation of ±l rpm. Automatic control loops have been provided to maintain constant steam temperature and pressure at the inlet to the turbine over the power range of 20-100 % P . A separate backup control room is provided for the unlikely situation of non-availability of main control room to enable shut down of the reactor, to maintain it in a prolonged sub-critical state and to ensure core cooling.

Sodium leak results in fire and smoke formation affecting visibility. For early detection of sodium leaks, wire type leak detectors for single walled pipes, spark plug leak detectors/mutual induction type detectors for double walled pipes and vessels and sodium ionization detectors in closed cells and cabins have been provided. Mutual inductance type level probes are used for continuous as well as discrete sodium level measurements in the reactor pool and other sodium tanks. For SG tube leak detection, one 'Hydrogen in sodium' detector (HLD) is provided at the outlet of each SG module and an additional HLD is provided in the common header which collects cold sodium leaving the four SG modules in each secondary loop. Two 'Hydrogen in Argon' detectors are installed in the cover gas space of surge tank for detection of leak during low temperature operation. Acoustic leak detectors are installed at various locations on the outer shell of SG which provide additional information.

1.2.7 RADIOACTIVE WASTE MANAGEMENT

The radioactive waste management system collects and temporarily stores the liquid and solid wastes generated in the plant and periodically transfers it to Centralised Waste Management Facility (CWMF) located 1 km from the plant for safe storage/disposal. The gaseous waste is handled in the plant itself.

Liquid wastes generated while washing CSA (60 m^3) and decontamination of sodium wetted components (250 m^3) are collected in storage tanks and pumped to CWMF. Category I potentially active detergent waste (Activity level (A) < 3.7×10^4 Bq/m^3; 38 m^3/d) and Category II active non-chemical waste effluents ($3.7 \times 10^4 < A < 3.7 \times 10^7$; 30 m^3/d) are discharged to the sea under supervision of CWMF after dilution with the condenser cooling water. The gaseous effluents are collected, stored, if necessary and released through the stack. The primary source of radioactive gaseous waste is the release from reactor cover gas. A cover gas purification system (CGPS) having activated charcoal bed at cryogenic temperature is provided to adsorb the gaseous fission products released by failed fuel pins (gas leakers) in the core. The estimated total annual airborne radioactivity release to the environment with CGPS in operation is less than 34 TBq. The solid radioactive waste system provides means for collecting and storing temporarily the solid wastes which consists of mainly discarded active components, spent fuel cooling circuit resin cartridges and filters, cotton wastes and rags, prior to transportation to CWMF.

1.3 TECHNICAL DATA

Important technical data is summarised in table 1.2.

Table 1.2 : Technical Data

1. GENERAL		
Reactor thermal power	MWt	1250
Electrical output (gross/net)	MWe	500/470
Fuel		PuO_2 -UO_2
Coolant		Sodium
Concept of Primary Na circuit		Pool
No. of primary sodium pumps		2
No. of Intermediate Heat Exchangers		4
Reactor coolant inlet temp	K(°C)	670 (397)
Reactor coolant outlet temp	K(°C)	820 (547)
No. of secondary loops		2
Steam temp, at HP turbine inlet	K(°C)	763 (490)
Steam pressure at HP turbine inlet	MPa	16.7
Gross thermal efficiency	%	40
Plant life	y	40
2. CORE		
2.1 GENERAL		
Type of core		Homogeneous
Active core height	m	1
Core pressure drop	m of Na	60
Equivalent core diameter	mm	1970
Active core volume	1	2857
No. of enrichment zones		2
Pu enrichment Zone I/Zone II	wt %	20.7/27.7
Fuel inventory in active core (PuO_2-UO_2)	t	9.15
Max. fuel bumup	GWd/t	100 (initially)
Max. radiation damage	dpa	85
Max. fuel residence time	d	560
Refuelling interval	efpd	185
Total Na flow through core	t/s	6.8
Blanket material		Depleted UO_2
Absorber material		B_4C enriched in B-10

Table 1.2 : Technical Data—*contd.*

	Clad and Wrapper material		20% CW D9
	Plutonium inventory	t	2.02
	Blanket inventory (axial/radial)	t	6.0/15.7
	Breeding ratio		1.04
	Reactivity worth of CSR/DSR System	pem	10541/4153
2.2	FUEL SUBASSEMBLY		217
	No. of pins in SA		
	Pin OD x thk x length	mm	6.6/0.45/2580
	Hexcan width across flats x thickness	mm	131.3 x 3.2
	Fuel smeared density	%	83
	Max. linear heat rating	W/cm	450
	Subassembly length	mm	4500
	Max coolant flow	kg/s	**36**
2.3	CONTROL AND SAFETY ROD SUBASSEMBLY		19
	No. of pins in each SA		
	Pin OD x thk	mm	22.4 x 0.5
	Absorber material length	mm	1110
	Quantity of B_4C in each rod	kg	11.8
	Pellet density	%	90
	B-10 enrichment	%	65
	Pin max. linear power	W/cm	750
2.4	DIVERSE SAFETY ROD SUBASSEMBLY		19
	No. of pins in each SA		
	Pin OD x thk Absorber	mm	21.2 x 0.5
	material length Quantity of	mm	1010
	B_4C in each rod Pellet density	kg	10.3
	B-10 enrichment	%	90
3.	REACTOR ASSEMBLY	%	67
3.1	MAIN VESSEL		
	Material		
	OD (Cylindncal Shell) x lit.		SS 316 LN
	Thickness (cylindrical shell)	**m**	12.9 x 12.9
	Mass	mm	25
		t	135

Table 1.2 : Technical Data—*contd.*

3.2	SAFETY VESSEL		
	Material		SS 316 LN
	O.D (Cylindrical Shell) x ht	m	13.54 x 12.87
	Thickness (cylindrical shell)	mm	15
	Mass	t	110.6
3.3	CORE SUPPORT STRUCTURE		
	Material		SS 316 LN
	Height	mm	1600
	Thickness	mm	30
	Mass	t	44.8
3.4	GRID PLATE		
	Material		SS 316 LN
	Diameter	m	6.8
	Mass	t	80
3.5	INNER VESSEL		
	Material		SS 316 LN
	O.D of upper cylindrical shell	m	12.2
	I.D of lower cylindrical shell	m	6.32
	Height	m	9.11
	Thickness (upper & lower shells)	mm	15/20
	Mass	t	61
3.6	ROOF SLAB		
	Material, structural/shielding		CS (A48P2)/concrete
	Diameter x height	m	12.9 x 1.8
	Thickness	mm	30
	Mass, structural material/shielding material		210/270
	Support		
	Type		Suspended
	Material		CS (A48P2)
	Dia x height	mm	13520 x 1500
	Thickness	mm	30
	Mass	t	21

Table 1.2 : Technical Data—*contd.*

3.7 ROTATABLE PLUGS (**LRP** & **SRP**)		
No. of plugs		2
Material, structural/shielding		CS (A48P2)/concret
Shell Diameter (LRP/SRP)	m	6.36 / 4.22
. Height	m	1.8
Thickness (LRP/SRP)	mm	30/20
Mass (LRP/SRP) :		
i. Structural steel	t	50.5 / 32.3
ii. Shielding material	**t**	60.5 / 32.0
Seals		Inflatable
Bearings		Single large diamete ball
3.8 CONTROL PLUG		
Material, structural		SS 316 LN
Material, shielding		SS plates
Overall diameter x height		2.52 x 7.76
Mass	t	54
3.9 FAILED FUEL LOCATION MODULE		
No. of modules		3
Scanning cycle time	min	24
Detection technique		DND
3.10 CSRDM		
Number		
Free fall time including response time of electromagnets	s	< 1
Travel speed Dropping	mm/s	2
mechanism Mass (each)	Deenergising electromagnets	
3.11 DSRDM	t	1.2
Number		
Free fall time including response time of electromagnets		3
Travel speed Dropping	s	< 1
mechanism Mass (each)	mm/s	4
	Deenergising electromagnets	
	t	0.8

Table 1.2 : Technical Data—*contd.*

4. COMPONENT HANDLING

4.1 CORE COMPONENT HANDLING

4.1.1 General

Reactor state during fuel handling		shut down
Fuel handling temperature In-vessel	K (°C)	473 (200)
handling	Two rotatable plugs with one transfer arm	
Ex-vessel handling	Rotatable shielded leg with single transfer pot	
Temporary storage of spent fuel		In-vessel
Number of in-vessel storage locations		156
Cooling mode during handling		Natural convection

4.1.2 InVessel Transfer Machine (IVTM)

Type of mechanism		Transfer arm
Orientation during handling		SA auto-orientation
Maximum pull	kN	15
Hoist speed	mm/s	40
Material of construction		SS 304 LN
Max. decay power per fuel SA	kW	90
Min. cooling time after shutdown	h	18
Diameter of handling canal	mm	320
Mass	t	25

4.1.3 Inclined Fuel Transfer Machine (IFTM)

Number of transfer positions (in-vessel/ex-vessel)		1 / 1
Number of transfer pots		1
Atmosphere inside the mechanism		Argon gas SS
Material of construction		304 LN
Maximum decay power of spent fuel SA	kW	5

4.1.4 Fuel Storage **(Outside)**

Total fresh fuel storage positions		56 711
Total number of spent fuel storage positions		Water pool
Type of storage for spent fuel		DM water
Coolant for spent fuel storage		

Table 1.2 : Technical Data—*contd,*

5. PRIMARY SODIUM CIRCUIT

5.1	GENERAL		
	Temperature rise across core	**K**	150
	IHX inlet temperature	K(°C)	817(544)
	IHX outlet temperature	K(°C)	667(394)
	Sodium pressure at inlet to grid plate	MPa	0.63 (max)
	Flow through grid plate	t/s	7
	Inventory of sodium	t	1150
	Sodium purification		Ex-Vessel
5.2	PRIMARY SODIUM PUMP		
	Type of pump	Centrifugal, top suction	free surface, single stage.
	Material of construction		SS 304 LN
	Flow per pump	Cu m/s	4.13 (net)
	Head developed	mlc	75
	Nominal speed	rpm	590
	Nominal shaft power consumption	MW	3.2
	Mass of pump without motor & flywheel	t	60
5.3	**IHX**		
	No. of IHX per secondary loop		2 in parallel
	Rating/IHX	MWt	314.7
	Material of construction		SS 316 LN
	Primary sodium side		shell
	Sodium flow rate per IHX (Primary/secondary)	t/s	1.649/1.45
	Tube diameter x thickness	mm	19 x 0.8
	No. of tubes		3600
	Size, flange dia x height	m	2.52 x 18
	Mass per IHX	t	43

6. SECONDARY SODIUM CIRCUIT

6.1	GENERAL		
	No. of loops		2
	System capacity per loop	VlWt	626.5
	No. of steam generators per loop		4
	No. of pumps per loop		1
	Inventory of Na per loop	i	205

Table 1.2 : Technical Data—*contd.*

6.2 SECONDARY SODIUM PUMP

Type of pump		Centrifugal, free surface, single bottom suction
Material of construction		SS 304 LN
Location		cold - leg
Flow	Cu m/s	3.34
Head developed	mlc	65
Nominal speed	rpm	960
Nominal shaft power consumption	MW	2.33
Mass per pump without motor and flywheel	t	15

6.3 STEAM GENERATOR

Concept		Integrated Once through with steam reheat
Type		Counter-current, vertical, shell and tube type heat exchanger with expansion bend in each tube
Shell side fluid		Sodium
Tube side fluid		Feed water - Steam
No. of SG per loop		4
Material		Mod 9Cr-lMo(Gr 91)
Thermal power per SG	MWt	158
Na inlet/outlet temp	K (°C)	798(525)/628(355)
Water inlet/steam outlet temp	K (°C)	508(235)/766(493)
Tube OD x WT	mm	17.2 x 2.3
No. of tubes		547
Sodium flow rate	kg/s	725
Feed water flow rate	kg/s	70.3
Nominal sodium side pressure	MPa	0.78
Steam pressure at SG outlet	MPa	17.2
Overall height	m	26
Weight of module	t	33

7. STEAM-WATER CIRCUIT

Concept		Modified Rankine cycle with regenerative feed heating
No. of cylinders in Turbine		3 (1 - Single flow HP, 1 - Dual flow IP, 1 - Dual flow LP)

Table 1.2 : Technical Data—*contd.*

No. of feedwater Heaters		6 (3 LP heaters, 1 Deaerator, 2 x 50 % HP heaters)
No. of Condensate Extraction Pumps		3 x 50%
No. of Boiler Feed Pumps		2 x 50% turbine driven, 1 x 50% motor driven
Type of Condenser Cooling		Once through using sea water
Heat removed in condenser	MWt	755
Condenser tube material		Titanium
No. of CCW pumps and type		2 x 50% concrete volute
Flow per pump	cu.m/s	9.44

8. SAFETY GRADE DECAY HEAT REMOVAL CIRCUIT

8.1 GENERAL

No. of loops		4
Coolant		Sodium
Type of circuit		Passive (natural circulation)
Heat sink		Air

8.2 SODIUM/SODIUM HEAT EXCHANGER (DHX)

Location		Hot pool sodium
No. of DHX		4 (2 designs)
Rating per unit	MWt	8
Material		SS 316 LN
Straight tube design DHX		
Size, Flange dia x overall Height	mm	830 x 11350
Shell diameter	mm	520
Mass per heat exchanger	t	3.6

8.3 SODIUM/AIR HEAT EXCHANGER (AHX)

Location		Steam generator building
Rating per unit	MWt	8
No. of Heat-Exchangers		4 (2 designs)
Material		Mod 9Cr-lMo (Gr.91)
Serpentine design AHX		
Size, Length x Width x Height'		5.45 x 5.15 x 4.6
"Mass per AHX (including casing)		20

Table 1.2 : Technical Data—*contd.*

9. REACTOR CONTAINMENT BUILDING		
Shape		Rectangular
Size	m	42.1 x 40.1 x 54.8 m height above FFL
Pressure during normal operation	Pa	-500 (below atmosphere)
Design pressure during DBA	kPa V	25
Leak rate under DBA	% /h	0.1
10. STEAM GENERATOR BUILDING		
Shape		Rectangular
Size	m	41 x 19.6 x 30 m height above FFL
11. FUEL BUILDING		
Shape		Rectangular
Size	m	60 x 20 x 14.8/32 m height above FFL
12. BOP AUXILIARY SYSTEMS		
Service water heat load	MW	23.5
DM plant capacity	Cu m/h	2 x 48
Package boiler capacity	Cu m/h	35
Compressed air plant capacity	Nm-Vh	4 x 1000
Nitrogen plant capacity	Nm^3/h	30
13. ELECTRICAL POWER SYSTEM		
13.1 GENERATOR		
Rated output	MVA/MW	588/500
Rated terminal voltage	kv	21
Rated frequency	Hz	50
Power factor		0.85
Synchronous speed	rpm	3000

Table 1.2 : Technical Data—*contd.*

13.2 TRANSFORMERS	Rating (MVA)	Voltage rating (kV)
i) Main transformer (3, 1 Ph units)	3 x	21 / 235
ii) Station transformer	63	220 / 6.9
iii) Unit transformer (2 units)	31.5	21 / 6.9
iv) Auxiliary Transformers - Class IV	10x2	6.6/0.433
	2 x 1.6	6.6 / 0.433
- Class III	4 x 2	*6.6 1* 0.433
	2 x 1	*6.6 1* 0.433
13.3 POWER SUPPLY For	kV/V	6.6 & 415
station loads Diesei		
generator	No x MW	4 x 2.4
Instrumentation & control backup DC	-	Battery & DG
supply	V	48 / 220
Single phase AC supply 48 V DC.	V	240
battery (2 systems) 220 V DC battery	No x Ah	4 x 600, 4 x 200
(2 systems) 240 V AC UPS battery	No x Ah	2 x 1500, 4 x 300
	No x Ah	4 x 750