Summer Internship

on

Overview on Various Systems at Nuclear Power Stations

at

Kakrapar Atomic Power Station (KAPS)

Submitted in partial fulfillment of the requirements for the award of a degree of

BACHELOR OF TECHNOLOGY
IN
MECHATRONICS ENGINEERING

Submitted by:

Vaibhav Thakur

0201MT211059

JABALPUR ENGINEERING COLLEGE

JABALPUR 482001

Year: 2023-24

Acknowledgments

I would like to express my sincere gratitude and appreciation to the management and staff of the Kakrapar Nuclear Power Plant for providing me with the invaluable opportunity to complete my internship. Firstly, I would like to thank my reference Mr. K.C. Sharma and Samuel Parmar who gave me this opportunity to witness the processes involved in the nuclear power plant. I would also like to thank them for their guidance and support throughout my training period.

I would also like to express my appreciation to Mr. Sulesh Patel and the employees of the Kakrapar Nuclear Power Plant who generously shared their time and expertise with me during my internship. Their willingness to answer my questions and provide insights into their respective roles and responsibilities has broadened my perspective and enhanced myunderstanding of the nuclear industry.

Finally, I would like to thank Dr. Agya Miashra Head of Department, Mechatronics Department, JEC for promoting me for this training and all the professors who guided me in taking up the opportunity.

Abstract

This internship report provides an overview of my experience and learning during my internship at the Kakrapar Atomic Power Plant. The internship focused on gaining practical knowledge about the turbines, other auxiliary and waste management systems employed in nuclear power generation.

The report begins by introducing the Kakrapar Atomic Power Station, its significance in the nuclear energy sector, and its commitment to safety and sustainability. It highlights the objectives and scope of the internship, emphasizing the specific areas of focus.

The report then delves into the theoretical and practical aspects of the various components and processes involved in power generation at the Kakrapar Atomic Power Station. It gives the details about the Reactor, Turbines, Governing system, Cooling Systems, Condensate systems, Safety, and Waste management systems incorporated at the power plant.

The internship report concludes by summarizing the knowledge and skills gained during the internship and their potential applications in the field of nuclear energy. It reflects on the personal and professional growth achieved through this internship and expresses gratitude to all individuals and organizations that contributed to the successful completion of the internship.

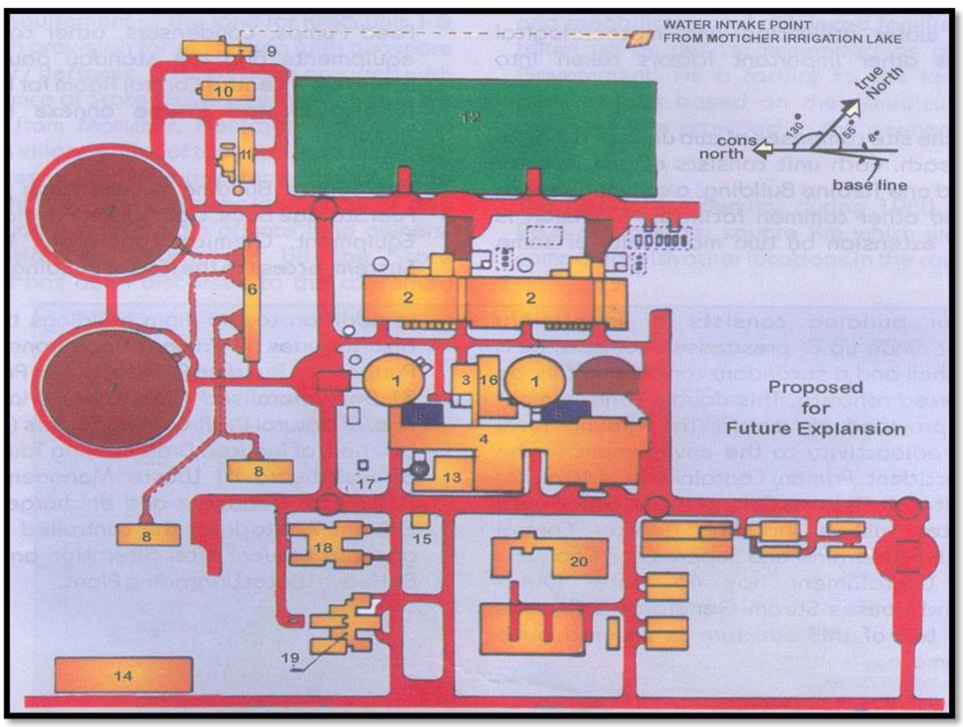
Table of Contents

Chapter 1: Introduction

Kakrapar atomic power station (KAPS**),** a unit of Nuclear Power Corporation of India Ltd. is located in Mandvi Taluka of the district of Surat in the state of Gujarat. The station is 29 km downstream of the Ukai dam on the Tapti River and falls in the region of Kakrapar's left bank canal (KLBC). NPCIL is a wholly owned undertaking of the Government of India under the administrative control of the Department of Atomic Energy. The mission is to produce nuclear power technology in a self-reliant manner which is an environmentally benign and economically viable source of electrical energy to meet the growing electricity needs of the country.

KAPS is a twin unit module of 220 MWe each of pressurized heavy water reactors (PHWRs). The reactors use natural Uranium available in India, as fuel and heavy water produced in the country as moderator and coolant. The first unit attained criticality in 1993 while the second unit achieved criticality in 1995. Situated in western India in the state of Gujarat near the famous industrial town, Surat, this station has operated very well over the past years and has enabled the Nuclear Power Corporation of India Ltd. to achieve an attractive operational surplus.

1.2.1 DETAILS OF THE PLANT LAYOUT

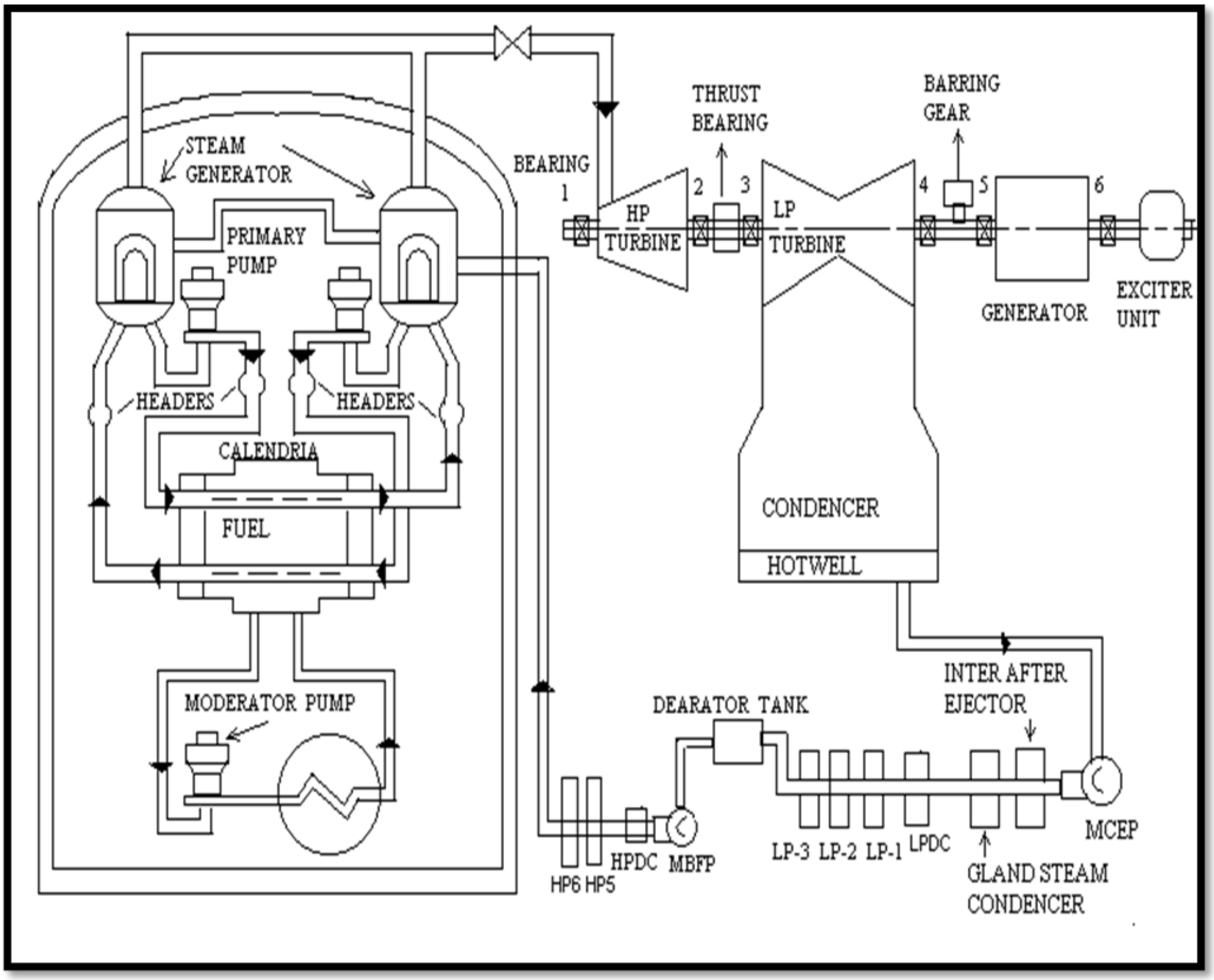


1. Reactor Building-1&2.
2. Turbine Building-1&2
3. Purification Building.
4. Service Building
5. Reactor Auxiliary Building.
6. CW Pump House.
7. Natural Draft Cooling Tower-1&2.
8. Induced Draft Cooling Tower-1&2.
9. Raw Water Pump House.
10. Pretreatment Plant.
11. Demineralizer Plant.
12. 220 KV Switchyard.
13. Waste Management Plant
14. Solid Waste Burial Ground.
15. Central Alarm Station.
16. D_2O upgrading Plant.
17. Stack.
18. Canteen Building.
19. Administrative Building.
20. Warehouse.

1.2.2 TECHNICAL DATA

Type of Reactor	**PHWR**
Output	2x220 MW at 220 KV
Type of fuel	Natural Uranium
No fuel bundles	3672 bundle
Primary coolant	Heavy water
O/L header pressure & Temp.	87 kg/cm^2 at 293^{0}C
Moderator	Heavy water
Calandria End shield material	S 304 L
Coolant tubes	ZR-2 for K-1 & ZR+N_B for K2
Calandria tubes	Zr-2
End fittings	SS 403
Coolant channels	306 Nos. of SS
Steam Generator	4 nos. with INCOLOY-800 tubes.
Steam condition	250°C at 40 kg/cm^2 1340 T/hr
Condenser vacuum	690 mm of Hg

1.2.3 GENERAL LAYOUT OF THE PLANT



Chapter 2: Details of the Training

2.1 CLASSIFICATION OF POWER:

Each load within the station has been classified according to the degree of reliability for its supply. There are four classes of power within the station.

(1) Class-I Power:

The Class-I power system supplies all the loads that require a 250V DC power supply which should be uninterrupted.

(2) Class-II Power:

The Class-II Power system supplies all the loads which must be fed from an A.C., source which should be uninterruptible.

(3) Class-III Power:

The Class-III system covers all loads which may be interrupted for a short period during an outage or disturbance of the system.

(4) Class-IV Power:

Class IV powers the station service system to cover all other loads which may be interrupted during an outage or disturbance without endangering the plant.

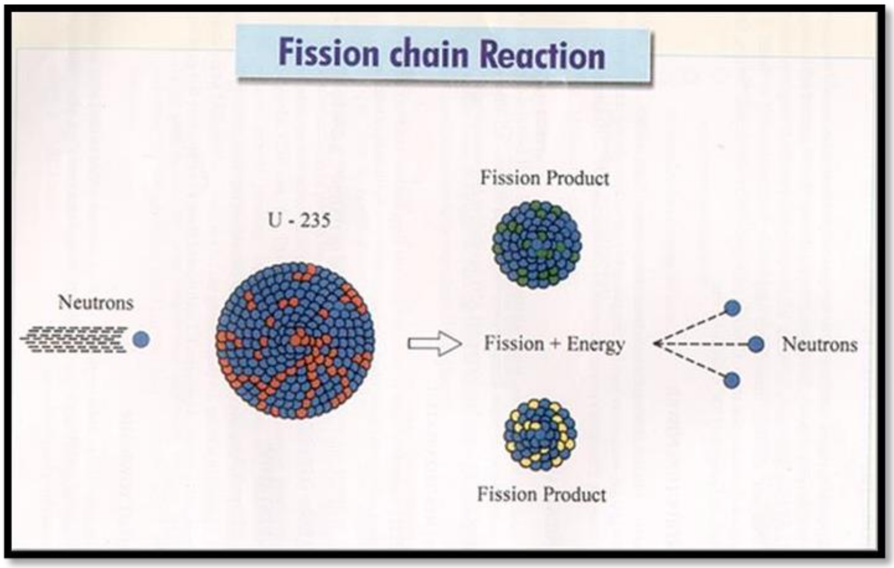
2.1 NUCLEAR REACTOR

The Reactor Core serves as the containment structure where a self-sustained and regulated chain reaction takes place, leading to the fission of Uranium atoms and the generation of heat energy. It encompasses the arranged configuration of nuclear fuel, moderator, coolant, and control rods, all working together to facilitate the controlled production of nuclear reactions and the desired rate of heat energy release.

2.1.1 **PRINCIPLE**

When a heavy nucleus is split up into smaller nuclei, a small amount of mass is converted into energy. The amount of energy produced is given by Einstein's mass-energy relation $E=mc^2$. This breaking up of a nucleus into two or more smaller nuclei is called Nuclear Fission.

In Natural Uranium, two types of isotopes U-238 and U-235 are available in the ratio 139:1. It is the less abundant U-235 isotope that fissions and produces energy which is the fuel for the reactor. When a U-235 atom is struck by a slow neutron, it will split into two or more fragments.



Splitting is accompanied by the release of a tremendous amount of energy in the form of heat, kinetic energy of the fission products, and two or three fast neutrons. These fast neutrons, which eject out of the split atom at high speed, are made to slow down so that they have a high probability to hit other U-235 atoms which in turn releases more energy and further sets the neutrons. The slowing down of neutrons is achieved by the moderator which is Heavy water. Attainment of self-sustained splitting of Uranium atoms is called "Chain Reaction".

$${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{38}Sr^{90} + {}_{54}Xe^{144} + 2\,{}_{0}n^{1} + \text{ENERGY (Heat \& Radiation)}$$

2.1.2 MAJOR COMPONENTS

1. Reactor Building:

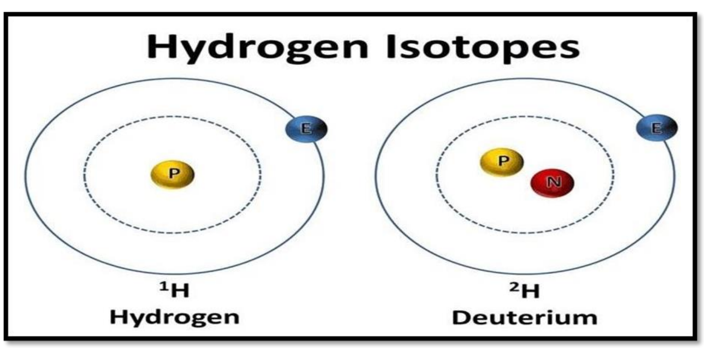
The reactor building, with a diameter of approximately 46m and a height of 72m, is designed to withstand an internal pressure of 1.25 kg/cm^2. The reactor itself comprises various components, including:

1. An integral calandria and end shields
2. Connections for the moderator
3. Connections for the helium cover gas
4. Coolant tube assemblies and coolant feeder pipes
5. Primary and secondary shut-off rods and reactivity control rods

Within the reactor, the fuel is housed in coolant tubes, which are supported by 306 calandria tubes and end shields. The calandria vessel contains heavy water, serving as both a moderator and reflector. The calandria is submerged in a pool of demineralized water, replacing the air in the calandria vault. This improvement offers better radiation shielding and more efficient removal of heat transferred to the vault through a single water-based system. The water in the pool is continuously cooled and circulated.

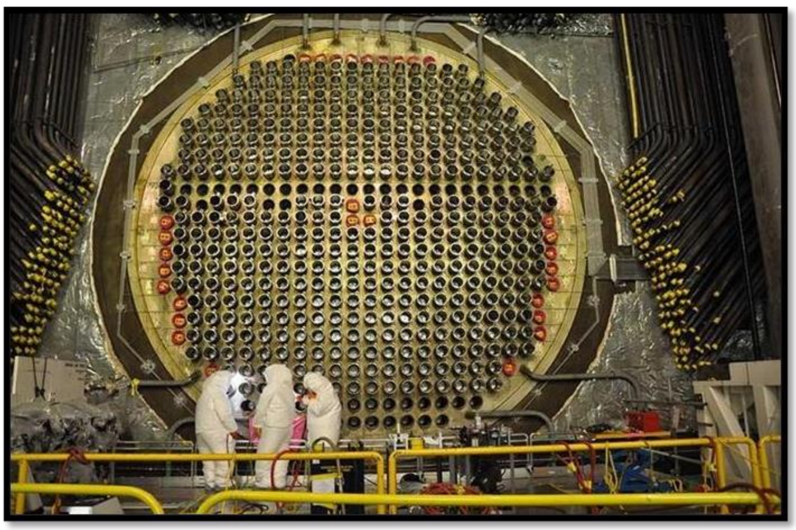
2. Heavy water and its usage:

Heavy water, weighing approximately 140 tons, serves the dual purpose of moderator and coolant within the reactor. The coolant carries the heat energy from the reactor to a vertical, integrated U-tube shell-type heat exchanger, which acts as a boiler generating steam to drive a turbine generator. While heavy water (D_2,O) shares similar chemical properties with ordinary water(H_2O), There are slight differences in their physical properties.



3. Calandria:

The reactor vessel or Calandria is the main component of the reactor where the heat is produced for power generation. This contains the Fuel, the Coolant Channel, and the Moderator. Calandria, integral to the End shields is a horizontal cylindrical shell of 6m diameter, 5m long containing 306 horizontal tubes housed in the Calandria Vault. These tubes inside the calandria are called calandria tubes. Calandria tubes house the pressure tube which contains the fuel of the reactor in the form of bundles. The fuel bundle is 0.5m long. Each fuel bundle consists of 19 pencils which are arranged in a symmetric circular pattern. The fuel is in the form of Uranium pellets. Each pencil contains 24 Uranium pellets. The annular space between the pressure tube and the calandria tube is filled with CO_2.

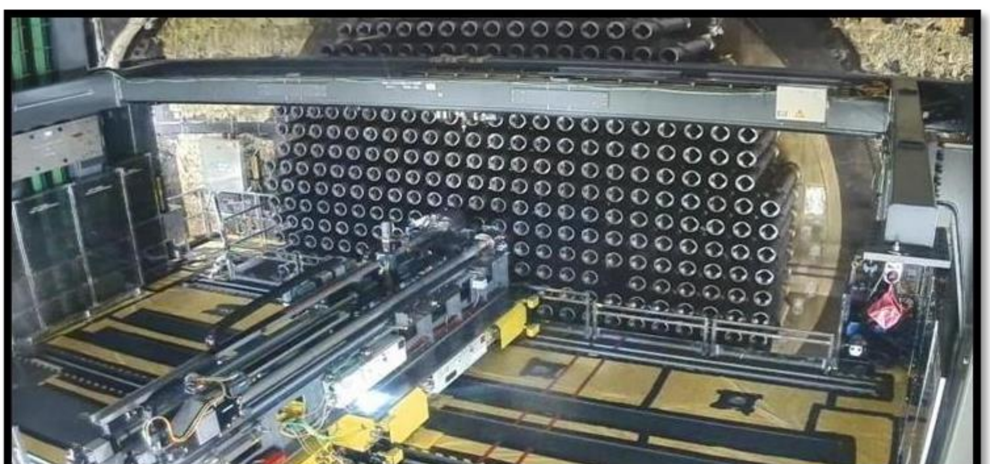


The coolant channels are inside these calandria tubes. Calandria vault in turn is filled with Light water. This is continuously circulated to remove heat. The Calandria tubes are made of Zircaloy and the coolant tubes are made from Zirconium 2.5% Niobium alloy.

4. Fuel:

All 306 coolant channels within the calandria are identical in nature. The fuel is in the form of pellets created from Sintered Natural Uranium Oxide, encased in Zircaloy Sheath, and shaped into cylindrical elements measuring 49.5cm in length and 802 cm in diameter. Each fuel bundle assembly comprises 19 such cylindrical elements. A total of twelve assemblies are housed within a single coolant channel, with fuel being supplied and discharged from both ends of the reactor. The adjacent fuel channels are arranged to receive fuel from opposite directions.

The refueling process for the reactor involves the insertion of approximately one channel, consisting of 12 fuel bundles, per day. This is made possible through an online power refueling system, which is a distinctive feature of PHWRs. The refueling operation is carried out automatically and remotely using a microprocessor-based computer system.



2.2 STEAM GENERATORS

The main purpose of steam generators and the feed water system is to transfer the heat produced in the reactor to the turbine generator to generate electricity. The Primary Heat Transport system circulates high-pressure coolant (Heavy Water) through the fuel in the coolant channels to extract the heat generated by fission. The coolant, which enters the reactor at a temperature of 249℃, absorbs heat from the fuel and exits at 293℃. The Heavy Water then moves to the steam generator, where it transfers its heat to the Feedwater (Light Water) and generates steam at a pressure of 44 kg/cm^2 and a temperature of 250℃. Safety valves are installed in the steam generator to prevent overpressure and release the steam into the atmosphere. The steam generator functions as a Heat Exchanger, with Heavy Water flowing inside the tubes and Feeding water into the shell. Various separators are employed to ensure that only superheated steam with a moisture content of 0.25% passes through to the turbine, preventing the passage of excess moisture.

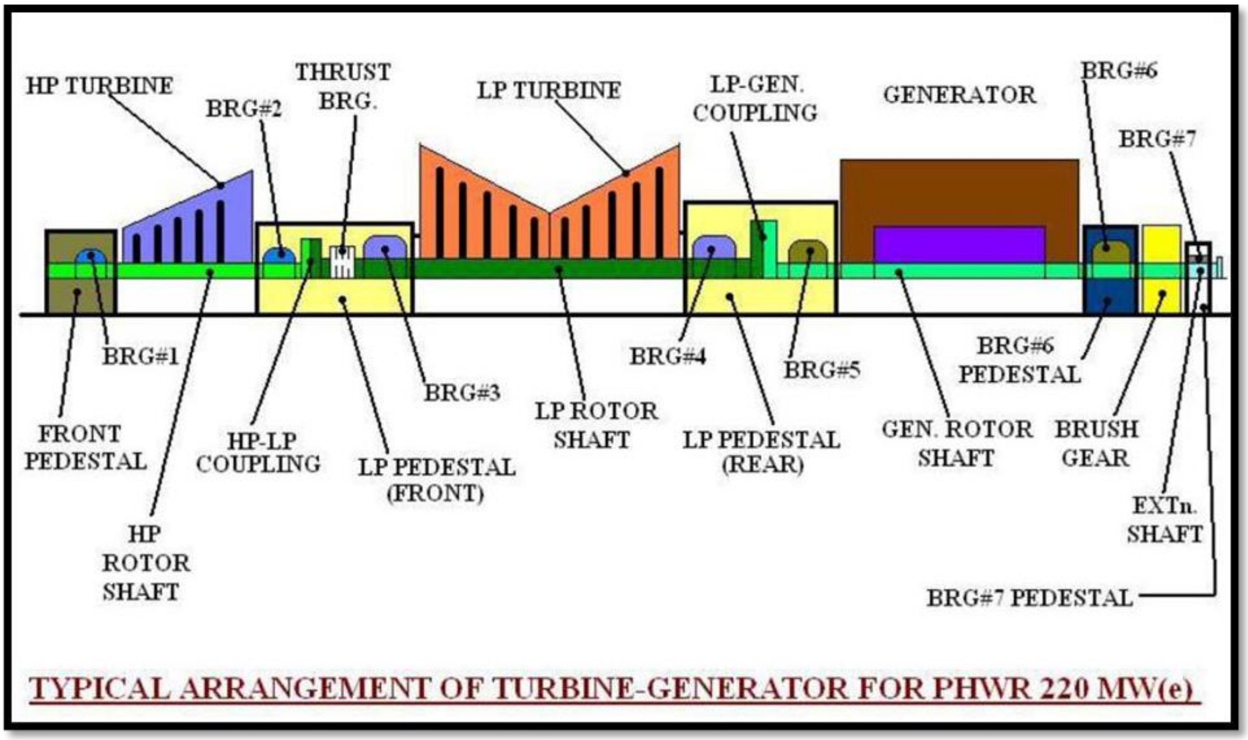
2.3 TURBINE AND IT'S AUXILIARY SYSTEMS

The turbine is designed as a Tandem compound impulse-reaction turbine, operating on a single axis and utilizing low-pressure wet steam supplied from a heavy-water moderated and heavy water-cooled reactor fueled with uranium dioxide. The system operated at a pressure of 39.7kg/cm^2 and a temperature of 250.3°C, with a wetness level of 0.26% at the stop valve.

To facilitate steam expansion, the turbine is configured with two cylinders:

(1) A high-pressure single-flow (H.P.) cylinder
(2) A double flow low pressure (L.P.) cylinder

Following expansion in the H.P. cylinder, the steam is discharged to a separator-cum-reheater unit consisting of two separators. In this unit, moisture is removed from the steam, and the steam is reheated to 233°C before entering the double-flow L.P. cylinder.



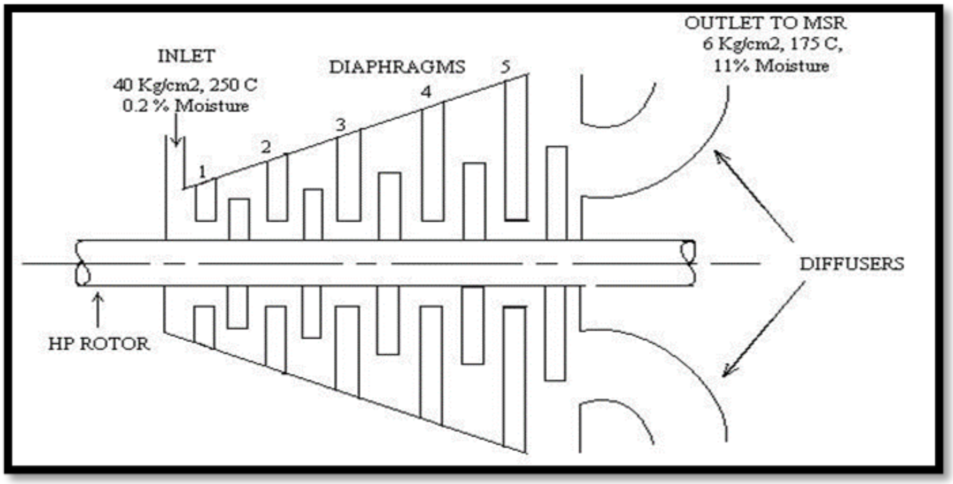
The turbine has a maximum continuous rating (MCR) of 236 MW and an economical continuous rating (ECR) of 227.5 MW at the generator terminal speed of 3000 rpm. To enhance efficiency, steam is extracted from appropriate stages of expansion to enable 6-stage regenerative feed heating, resulting in a final feed water temperature of 170.7°C.

Steam is supplied to the turbine through two Combined Isolating and Emergency Stop valves (CIES valves) located within two integrated chests. The steam then passes through governor valves positioned on either side of the machine’s centerline. Each governor valve comprises a steam strainer and two throttle valves housed in separate chests. During initial runs, temporary strainers with 3.2mm holes are installed in the CIES valves. For regular turbine operation, permanent strainers with 5mm holes are used. The CIES valve chests and the connection between the governor wall chest and the bottom halves of the H.P. cylinder are linked by loop pipes that offer flexibility to accommodate thermal expansion without excessive force or movement.

2.3.1 H.P. TURBINE

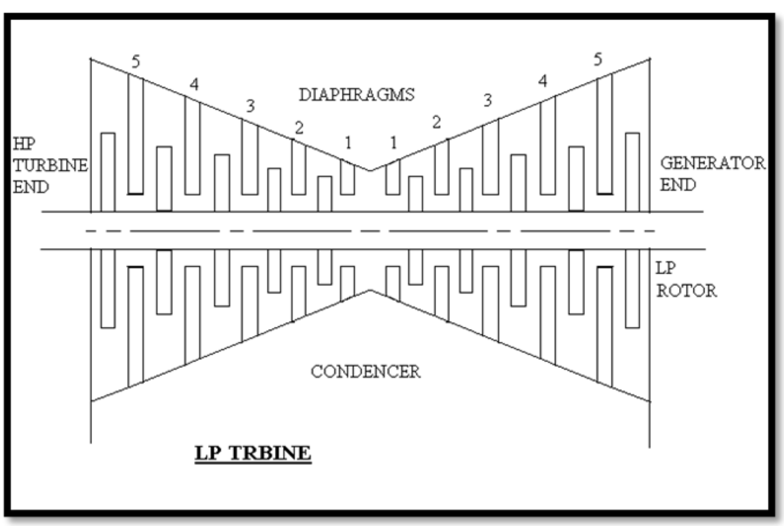
The HP cylinder consists of five stages. Steam is released from the HP cylinder for steam reheating before stage 4, and for feed heating before stage 5, through the cylinder's exhaust. The resulting exhaust steam is directed into two parallel separators-cum-reheater units located on either side of the machine's center line. In these units, bled steam and live steam are utilized as the heating medium to remove a significant portion of the moisture in the two stages of the reheater section.

The steam from the reheaters passes through two interceptor steam chests, each housing an interceptor emergency valve & an interceptor governor valve before entering the LP cylinder, from where it finally exhausts to the condenser.



2.3.2 L.P. TURBINE

Each flow of the LP cylinders consists of five stages, and steam is extracted from stages 2, 3, 4, and 5 for feed heating to the deaerator. These extracted steam flows are combined and directed into a shared exhaust chamber, which is securely attached to a firmly supported condenser through welding.



The turbine consists of two rotors, the LP rotor and the HP rotor, which are firmly connected to create a single shaft. Each rotor is supported by two main bearings. The thrust bearing is located in the pedestal between the HP and LP cylinder. When observing the machine from the front pedestal towards the generator end, the rotor rotates in a clockwise direction.

To ensure proper functioning, an oil system is in place. It supplies low-pressure oil for lubricating the bearings and high-pressure oil for the turbine control gear and generator shaft sealing system. Within the oil system, a high-pressure jacking oil system is integrated to allow the entire rotor assembly, including the generator rotor, to float in the bearing during the starting and shutdown phases when the barring gear is engaged.

The barring gear is positioned at the rear and pedestal between the turbine and generator. It is a single-speed, automatically engaging mechanism. Its purpose is to slowly rotate the rotor system during startup and shutdown, aiding in achieving uniform heating and cooling of the machine.

2.3.4 MOISTURE SEPARATOR CUM REHEATER

As the steam expands in the HP turbine, its moisture content gradually increases due to the saturated condition of the steam coming from the steam generator, At full load, the moisture content inside the HP cylinder can rise to 11%. However, if the steam continues to expand in the LP turbine without any intervention, several issues can arise.

(1) Excessive moisture content in the steam.
(2) Lowering of individual stage efficiency in the turbine.
(3) Erosion and corrosion of turbine blades.

To address these concerns, steps are taken to improve the steam quality before it enters the LP turbine. This is accomplished through a process involving moisture separation and reheating of the steam. A wire mesh-type separator pad is employed, along with two stages of reheating in MSR.

In the first stage, bleed steam is extracted from the HP turbine, and the 3rd stage is utilized to heat the steam. Subsequently, the steam passes through a live steam reheater, where live steam is extracted from the main steam line before the CIES valve is used for reheating. This arrangement is chosen for its ability to maximize efficiency within the existing turbine cycle.

To prevent over-pressurization of the reheater shells, safety measures are implemented. Three relief valves, each with a capacity of 50577 kg/hr are installed on the left-hand side of the hot reheat line. Additionally, two bursting diaphragms are provided on each shell. The relief valves are set to open at 6 kg/cm^2 and in the event of their failure, the bursting diaphragms will best at 7.05 kg/cm^2. These measures ensure the protection of the reheater shells under various operating conditions.

2.3.5 BARRING GEAR

This system is positioned between the LP turbine and generator and is operated by a motor. It incorporated a gear system that enables engagement and disengagement with the turbine shaft during initial startup and run-down. Its purpose is to rotate the turbine shaft at a speed of 34 rpm, disengaging when the turbine shaft exceeds 34 rpm during startup. This mechanism is essential to prevent the turbine shaft from experiencing hogging and sagging. The motor continues to run after disengagement until it reaches 100 rpm, at which point it stops automatically. In the event of a turbine drip, The motor will start at 100 rpm.

During the shutdown of the machine, the barring gear plays a crucial role in maintaining and preventing direct contact between the bottoms of the journal bearing. This preventive measure eliminates any potential damage to the bearing.

2.3.6 GOVERNING SYSTEM

The governor comprises rotating assemblies that include two flyweights mounted on a pilot. Each weight has a right-angled extension that connects to a control yoke piece. The yoke piece is linked to the pilot valve plunger, and any change in the turbine's rotation causes the flyweights to swing. This movement of the flyweights adjusts the position of the yoke, resulting in variations in the seal oil pressure.

There are two types of governing systems available:

(1)Throttle governor

(2)Electronic governor

The governing system performs the following functions:

(1) It facilitates the startup of the turbine, bringing it up to the rated speed.

(2) It maintains a constant speed when the turbine is operating without any load.

(3) When the turbine is connected to the grid, it is capable of tracking the reactor powerand adjusting accordingly.

(4) It serves as a safety mechanism to trip or protect the turbine in the event of abnormal conditions

2.4 GENERATOR

Power is generated at 16.5 KV by Turbo Generator each rated for 237.7 MW (264 KV, 0.9 lag pf). The rating of the generator is based on the standard BHEL machine available in the country. The generator stator is water-cooled. The rotor and stator core are hydrogen cooled. The generator's reactive power capabilities are as follows:

Maximum line charging - 74 MVAR

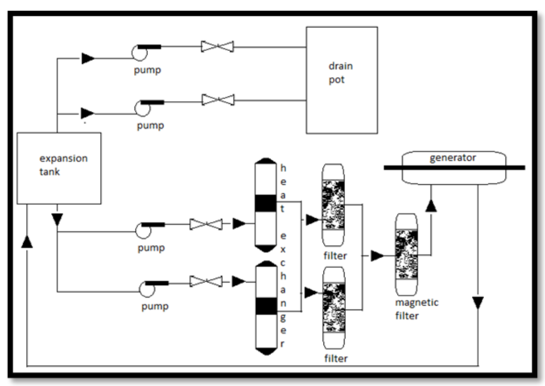
Maximum inductive power - 203 MVAR

2.4.1 STATIC EXCITATION UNIT

The static excitation system regulates the voltage at the terminals of the generator, thereby controlling the flow of reactive power in parallel operation. It achieves this by directly adjusting the excitation current, ensuring that the generator field is adequately supplied under different load conditions. The system consists of a thyristor converter, a power pack automatic voltage regulator, a field breaker, and field flashing equipment.

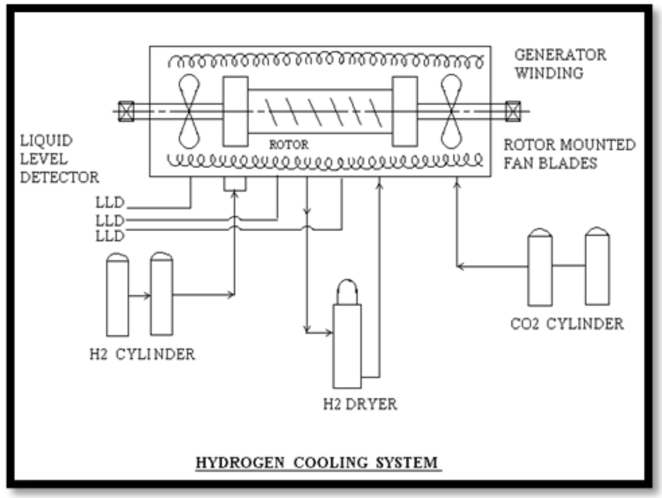
2.4.2 STATOR WATER COOLING SYSTEM

This system is used to cool down the stator winding. A lot of heat is produced due to relative motion between the stator and rotor due to rapid magnetization and demagnetization. The system consists of Stator Water Pump (2), Stator Water HX(2), Mechanical Filter(2) Magnetic Filter: (1), Expansion Tank(1), Vacuum Pump(2), Stator Water IX(1).



2.1.1.HYDROGEN COOLING SYSTEM

The hydrogen gas filled in the casing cools the rotor or the core of the generator. Due to rotation at high speeds, a large amount of heat is produced despite the lubrication. Hence a hydrogen cooling system is used to cool the core where maximum magnetic flux is produced. The system consists of hydrogen cylinders, hydrogen driers, and CO_2 cylinders.



2.5 COMPRESSORS

At KAPS, a total of six compressors are utilized, with three of them allocated for Unit-1 and the remaining three for Unit-2. Within each unit, one compressor operates with a Class-IV power supply, while the other two compressors are equipped with Class-III power supplies. This categorization of compressors into class 4 and class 3 power supplies is done to ensure safety. In the event of a power failure in the Class-IV supply, the compressors are designed to continue functioning by drawing power from the Class-III power supply. This arrangement allows for uninterrupted operation and maintains the reliability of the compressors.

In this compressor design, each row consists of two crankpins positioned 180 degrees apart. This arrangement ensures balance as the two pistons within each row move in opposite directions. By doing so, the primary and secondary forces generated by the pistons cancel each other out, effectively eliminating any vibrations that could impact the compressor’s base. To provide optimal guidance for the crossheads, the compressor incorporates crosshead guides with low friction, ensuring smooth movement and operation. The air compressors are complete with suction filters, inter and after coolers, drive motorswith belt drive and belt guard, and all instrumentation.

Application of the compressed air:

(1) Instrument air: Used for tasks related to instrumentation and control, such as operating pneumatic valves, measuring various parameters, and transmitting signals.
(2) Mask air: It is utilized for breathing and providing air to protective clothing in the reactor building, ensuring the safety and well-being of personnel.
(3) Service air: It serves multiple purposes including operating pneumatic tools, facilitating cleaning and drying operations, operating dampers, and transferring resins within the deuteration system.

2.6 **CHILLERS**

In KAPS, the chillers operate based on the Refrigeration Cycle, incorporating superheat and subcool systems. The centrifugal single-stage compressor draws in the gaseous refrigerant R-134a (Tetra Fluoro Ethane) from the evaporator. The centrifugal chiller consists of a hermetic motor that is coupled to the compressor, meaning both the compressor and motor are enclosed within the same casing. A lubrication oil system is in place to provide lubrication and cooling forthe motor.

The compressor compresses the refrigerant and pushes it into the condenser through a Vapour Inlet Valve (VIV), which controls the flow of vapor into the condenser. In the condenser, the refrigerant is condensed by the cold water from the Non-Active Low Pressure (NALP) pump. The condenser is designed as a shell and tube type, with the refrigerant flowing in the shell side and the cold water flowing through the tubes. The cold water cools the refrigerant, which then becomes heated and is directed to the NDCT (natural draught cooling tower) for further cooling. The cold water enters the environment of the evaporator, the refrigerant evaporates, absorbing heat from the water and producing chilled water, which is supplied to various parts of the plant. The cold water enters the evaporator at approximately 35°C and exits at around 6°C.

condenser at approximately 30°C and exits at around 38°C. The liquid refrigerant is then guided to the evaporator through an Expansion Valve, driven by the pressure generated by the compressor. The Expansion Valve regulates the flow of liquid refrigerant into the evaporator, maintaining a constant enthalpy. Similar to the condenser, the evaporator is designed as a shell and tube type, with the refrigerant flowing in the shell side and the cold water flowing through the tubes. In the low-pressure The operation of the chillers is controlled by a Program Logic Control (PLC). The refrigerant undergoes the refrigeration cycle continuously, providing a steady supply of chilled water at a temperature of 6°C. The chillers require a class IV power supply to operate, but they lack a class III supply. Therefore, they function as long as there is a class IV supply. However, they do have a class II power supply and can provide chilled water to limited loads in the event of a class IV power failure.

The chilled water system serves various loads, including heavy water vapor recovery, heavy water upgrading plant, air conditioning and process cooling for the reactor building, air conditioning and cooling for the service building, air conditioning and cooling for the turbine building, and air conditioning and cooling for the administrative building and canteen.

The main components of the chillers are the centrifugal compressor and motor, condenser, evaporator, lubrication oil supply unit, and MicroTech control panels.

2.7 FEED WATER SYSTEM

Feed water is the water supplied to the steam generators to be converted into steam through the heat generated by burning fuel. In the case of KAPS, heat is generated in the calandria through the nuclear fission of Natural Uranium, and it is transported to the steam generators by the primary heat transport.

The feed water system includes the Deaerator, Main Boiler Feed Pumps(3x50%), Auxiliary Boiler Feed Pumps (2x2.5%), HP drain cooler, LP heaters 1, 2, and 3, HP heaters 5 and 6, the boiler feed control station and the interconnecting piping and valves from the deaerator to the BFP the from BFP to the steam generators. This system ensures the supply of water from the deaerator storage tank to the steam generators under all operating conditions.

Under normal operating conditions, the feed water flow to the steam generators at maximum continuous rating (MCR) is 1254.9 T/hr. To prevent the possibility of high PHT pressure, which may lead to an unnecessary reactor trip, three 50% capacity boiler feed pumps are used, each with a rated capacity of 630 T/hr. This setup allows for one running pump to trip and the standby pump to come online automatically without causing a reactor trip.

Auxiliary boiler feed pumps (ABFP) with a capacity of 36T/hr are also employed with 100% redundancy. They ensure the normal cooldown of the PHT system after a reactor trip, even when the steam generators have low levels or maintain the reactor in a hot shutdown condition by providing sufficient inventory in the steam generators at their lowest level.

Considering the shut-off head of the BFP, the feed water system downstream of the BFPs is designed to withstand a pressure of 70 kg/cm^2 and a temperature of 171°C.

2.8 CONDENSATE SYSTEM

Feed water is converted into steam by passing through Steam generators. This steam then flows through HP and LP turbines before entering the condenser. The cooling water in the main condenser condenses the steam from the LP cylinder, forming condensate. The condensate is pumped by the condensate extraction pump through various components, including inter, condenser, gland steam condenser, LP drain cooler, and LP feed heaters 1, 2, & 3. The main condensate system utilizes two 100% capacity MCEPs, capable of delivering 1100 T/Hr with a head of 125 MWC, to transport condensate from the hot well to the deaerator. The condensate system includes main extraction pumps, air ejector condenser, gland steam condenser, LP drain cooler, and low-pressure feed heaters 1, 2, & 3. The cooling water in the main condenser condenses the exhaust steam from the LP cylinder. The extraction pumps transport the condensate to the deaerator through inter, after condenser, gland steam condenser, LP drain cooler, and LP feed heaters 1, 2 & 3. This system ensures a continuous supply of condensate from the condenser hot well to the deaerator. The auxiliary condensate system maintains a flow of 32 T/Hr to the deaerator for operational requirements. The condensate recirculation control valve ensures the minimum flow through the extraction pump.

2.8.1 CONDENSER

The condenser is a surface type with a 2-pass arrangement and four tube nests within a single shell. It is inclined by ½ degree towards the outer water boxes for self-draining during the shutdown. The condenser has a hot well with a storage capacity of 50 tons and includes makeup water and condensate outlets. Makeup water, heated by exhaust steam, maintains low oxygen content in the condensate. Four steam dumping devices reduce pressure and desuperheat steam before entering the condenser. The condenser is designed for Out-of-Box-Event (OBE) conditions and features protective coatings for corrosion prevention.

Using condensate as the feed for the boiler offers cost savings in power generation. The temperature of condensate is consistently higher than water from an external source, resulting in reduced heat input required by the boiler for steam generation. Furthermore, increasing the vacuum in the condenser enhances plant efficiency by increasing the enthalpy drop. Lowering the backpressure of the prime mover contributes to a significant increase in useful enthalpy drop. Additionally, using condensate helps prevent salt deposition in the boiler, which can decrease boiler efficiency. Overall, incorporating a condenser in a steam power plant improves thermal efficiency and reduces the overall cost of power generation.

2.8.2 AIR EJECTOR CONDENSER

Steam air ejectors with inter and after condensers are employed to eliminate air from the main condenser. This ensures that the condenser maintains a negative pressure, allowing steam to exhaust at a negative pressure, which is directly beneficial to the water discharge. Both service air ejectors share a common inter and after the condenser. The condensate, resulting from the steam used for air removal in the inter condenser's shell side, is connected to the outlet of the low-pressure flash tank through a 4-meter loop seal. During startup, a significant amount of air removal is necessary, which is accomplished by the startup air ejector. During normal operation, a small continuous air removal is required to counteract any air leakage, which is carried out by the air ejector.

2.8.3 GLAND STEAM CONDENSER

The prevention of steam leakage at the shaft of the steam turbine is achieved through the use of a component known as the gland-sealing system. The gland steam condenser, positioned horizontally, is located in the main condensate circuit near the air ejector. The condensate from the air ejector condenser passes through the gland steam condenser, where it absorbs the heat from the steam drawn from the turbine gland seals. Two vapor extractors (fans) are installed in the gland steam condenser to extract the steam and air mixture that leaks through the turbine shaft, thereby maintaining a negative pressure in the steam space of the gland steam condenser. As the steam comes into contact with the tubes, it condenses, while the air and non-condensable gases are expelled into the atmosphere by the fans. The condensate side of the gland steam condenser can be isolated using manual isolating and bypass valves. In normal operation, both the manual isolating valve and the bypass valve are partially open, with the bypass valve being open 50%. The gland steam condensate drain is connected to the area drain or main condenser through a U-loop, equipped with two isolating valves.

2.8.4 **LP DRAIN COOLER**

This heat exchanger is a shell and tube type situated at an elevation of 95m. It utilizes the main condensate cooling water. The main condensate flows through the tubes, while the drain from the L.P. heaters flows through the shell side, transferring heat to the main condensate before beingdischarged Into the condenser hot well.

2.8.5 LP HEATER1 :

This heater is a plain condensing type without a drain cooling section for steam. It is situated at an elevation of 100m in the turbine building. Steam enters the heater through two connections located in the middle of the shell. To protect the tubes from direct impingement of steam, impingement baffles are installed in the path of the incoming steam. The heater features a nest of U-shaped tubes made of stainless steel. The ends of the tube bundles are expanded into a steel tube plate, which is welded to the water box. The shell has connections for steam inlet, vent, and drain. By using manual isolating and bypass valves, L.P heater 1 and L.P drain cooler can be isolated from the condensate side. The drain from L.P 2 undergoes flashing in the condensing zone of LPH 1. After condensation, the saturated drains are extracted and directed to LPDC for further heat recovery.

2.8.6 LP HEATER 2 & 3:

LP heaters 2 and 3, mounted horizontally, are designed as condensing and integral drain cooling types. The main condensate follows a four-pass flow pattern through the tubes of this heater. It starts at the main condensate inlet, passing through the drain cooling section and circulating the outer tubes returning through the center tubes to reach the feed water outlet.

Steam is introduced into the heaters at the entrance of the shell and guided across the tubes using a series of baffles, creating a convoluted path. An impingement baffle is strategically placed near the steam inlet for the same purpose. The steam that condenses on the tubes flows down to the bottom of the drain cooling section and is carried over through cutouts in the baffles.

Each heater contains a nest of U-shaped tubes made of stainless steel. The tube ends are expanded into steel plates to which the water box is welded. The tube nest is enclosed within a fabricated steel shell, which incorporates connections for the steam inlet, drain, vent, and steam standpipe to facilitate level indicators. The drain from heater 3 is sprayed into heater 2 using a dispenser, and the drain from heater 2 is sprayed onto heater 1.

After passing through LP heater 3, the condensate is heated up to a temperature of 133°C. It is then supplied to the deaerator, which is a component of the feed water system. Thus, both the feed water system and the condensate system handle the same fluid as a working medium but in different phases.

2.8.7 CONDENSATE EXTRACTION PUMPS

The condensate system is equipped with two 100% capacity condensate extraction pumps (CEPs) and two 2.5% auxiliary condensate extraction pumps. Their purpose is to transfer the condensate from the hot well to the deaerator. During regular operation, one of the 100% CEPs is active while the other remains on standby.

The auxiliary condensate system is designed to ensure a continuous flow of condensate to the deaerator in the event of a power failure of Class-IV, which is crucial for maintaining feed to the steam generator and removing decay heat during reactor shutdown. The auxiliary CEPs are normally set to AUTO mode and will automatically start when both 100% pumps experience a trip or malfunction.

2.8.8 COOLING TOWERS

Steam after expansion in Low Pressure (L.P.) The turbine is led to a condenser where the steam is condensed by the condenser cooling water flowing through the tubes and steam condensate is led to condenser hot wells. The condensate is pumped to the cooling towers.

(1) Natural Draft Cooling Tower (NDCT): The condensate water in the secondary cycle is sprayed in the cooling tower and from the bottom of the cooling tower cold air comes and absorbs the heat and discharges from the top of the cooling tower due to pressure difference.

(2) Induced Draft Cooling Tower (IDCT): Here the cooling water in the primary cycle is cooled down by the axial fans placed at the top of the cooling tower and creating low pressure which would reject the heat to the atmosphere

2.9 WASTE MANAGEMENT SYSTEM

Nuclear Power Station operations result in the production of liquid, gaseous, and solid waste. The generation of these waste materials is carefully monitored, and they are discharged following regulated treatment procedures. Consent has been obtained from the Gujarat Pollution Control Board to ensure that the discharge of treated gaseous and liquid effluents complies with the specified limits set by the Atomic Energy Regulatory Board (AERB).

(1) Gaseous discharge:

The gaseous effluents are passed through banks of pre-filters and highly efficient particulate absorbing filters (HEPA) to ensure no radioactive gaseous effluents are discharged into the atmosphere. The 100m high stack facility is designed to ensure adequate dispersion and delay of noble gases before they reach the ground level.

(2) Liquid Effluents:

Taking into consideration the presence of 310 cubic feet per second of water for dilution at the blowdown location, the concentration of radionuclides at the discharge points is maintained at a level lower than 10-8 microcuries per milliliter of the diluted solution. This extremely minimal discharge aligns with the guidelines set by the International Commission for Radiation Protection (ICRP).

(3) Solid Waste:

The solid waste produced during operations is categorized and undergoes various processes as outlined below:

(i) Incineration is employed for low-level combustible waste.

(ii) Bailing is utilized to reduce the volume of waste.

(iii) Disposal and storage take place in the RCC vault.

(iv) High-level radioactive water is stored in high-integrity tile holes within a landrepository (burial ground) located within the station's boundaries.

KAPS does not generate any chemical pollution, thermal pollutants, dust, or noise pollution. The nuclear power station is free from any negative physical, biological, chemical, and environmental impacts. Concerns such as acid rain and the greenhouseeffect are completely absent in the operation of nuclear power plants.

2.9.1 SURVEILLANCE

The Environmental Survey Laboratory (ESL) regularly monitors and compiles data regarding the impact on food, vegetables, meat, fish, crops, and air. The responsibility of the laboratory includes establishing allowable release limits to air and water from the plant and establishing procedures for emergency action and monitoring of radiation levels in the environment during the operational phase.

Chapter 3: Summary and Conclusion

In conclusion, my internship at the Kakrapar Nuclear Power Plant has been incredibly beneficial and illuminating. I gained a thorough knowledge of the many systems used in nuclear power generation during my time there. Working with industry professionals gave me the chance to observe the complex procedures and strict safety precautions put in place to maintain the integrity of the plant. I had the honor of witnessing the plant's constant dedication to safety, which included both worker safety and environmental protection. The greatest safety standards were always maintained by strict adherence to rules and constant observation.

This internship improved my technical abilities while also fostering a deep respect for nuclear energy as a trustworthy and long-term source of power in me. Its importance in the energy sector has been highlighted by seeing personally how nuclear energy helps to meet global demands while reducing environmental damage.