POWER PLANT ENGINEERING

DIPLOMA WALLAH

MECHANICAL

Jharkhand University Of Technology (JUT)

Unit - IV Nuclear Power Plant

Introduction, Site Selection Criteria, Nuclear Fuel, and Layout of a Nuclear Power Plant (NPP)

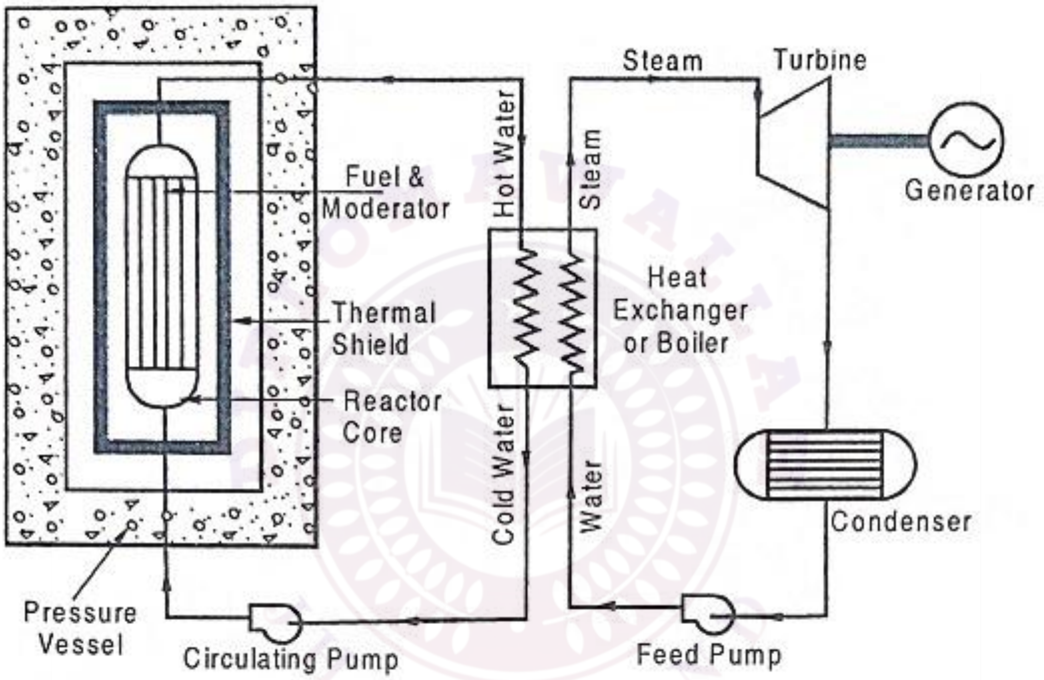

Fig:3.4 Layout of Nuclear Power Plant

SITE SELECTION CRITERIA FOR NUCLEAR POWER PLANTS AND EVALUATION OF SITE SPECIFIC DESIGN BASIS EARTHQUAKE PARAMETERS

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1. INTRODUCTION

The fundamental objective of any nuclear power plant operator is to protect people and the environment from the harmful effects of ionizing radiation due to any unforeseen incidents or accidents, leading to radiological consequences. The prevention of any such accident and release of radiation could be prevented by defence in depth in the design stage itself. Hence, adequate care is to be taken for site selection, good design and engineering safety features, which may in-turn provide safety margins, diversity and redundancy. Thus, site selection, characterisation and evaluation form an important part of establishing a Nuclear Power Programme and can be significantly effected by cost and public acceptance. The role of geologists, geo-technologists is significant in this regard. Viewing these aspects, the present practices being followed for site selection and evaluation of design basis earthquake parameters for NPPs are discussed further.

2. SITE SELECTION AND CHARACTERIZATION

The purpose of characterisation of any particular area during the site selection stage is to determine the suitability of particular site for setting up a Nuclear Power Project (NPP). In this stage, geological, geo-morphological and geo-technical aspects are considered and regions or areas are usually identified that are excluded from further consideration. Subsurface information for this stage is usually obtained from current and historical documents, field reconnaissance, including geological surveys. In the recent past, remote sensing played great role in obtaining detailed and accurate information with minimum effort within least possible time frame.

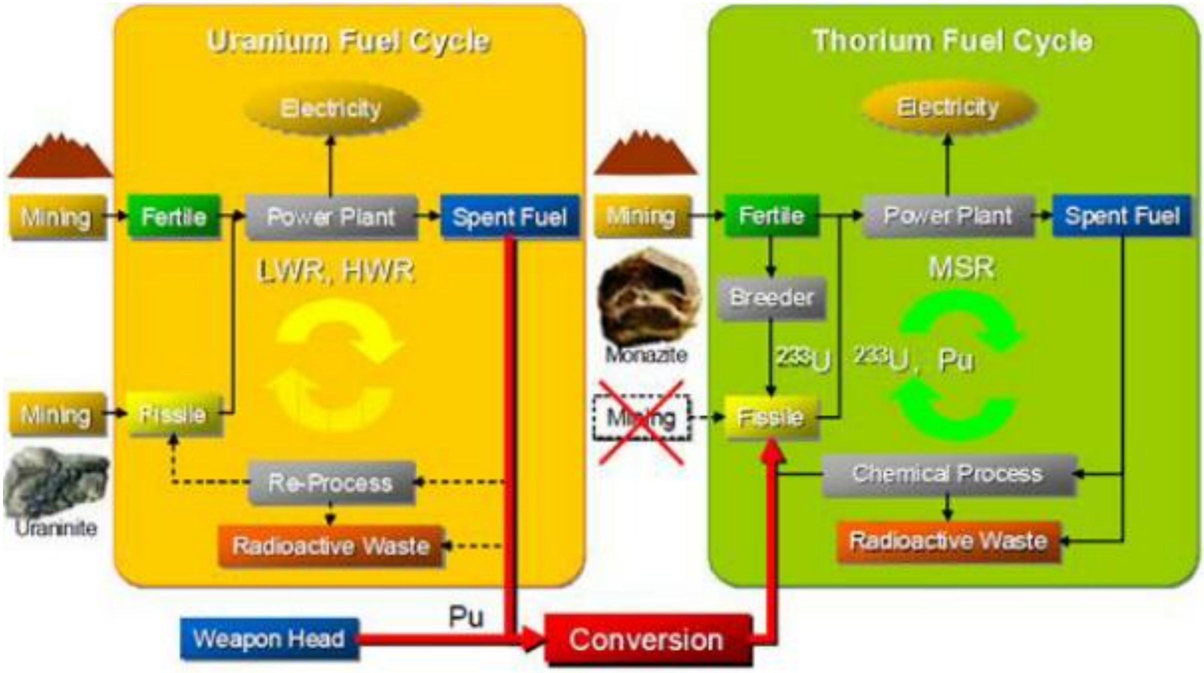
For a nuclear power plant, site evaluation typically involves the following stages,

a. Selection stage: One or more preferred candidate sites are selected after investigation of a large region, rejection of unsuitable sites, and screening and comparison of the remaining sites.

b. Characterization stage: This stage is further subdivided into:
   - Verification, in which the suitability of the site to host a nuclear power plant is verified mainly according to predefined site exclusion criteria;
   - Confirmation, in which the characteristics of the site necessary for the purposes of analysis and detailed design are determined.

c. Pre-operational stage: Studies and investigations from the previous stages are continued to refine the assessment of site characteristics. Data obtained from site allow a final assessment of simulation models used in the ultimate design of foundation and superstructure as well.

d. Operational stage: Selected investigations are pursued over the lifetime of the plant, to ensure that the variation of engineering properties are not varying significantly during the operating life of the plant.



Below are **detailed student-notes** for Section 4.1, structured for deep understanding and exam readiness. You may use these for your website, study notes, or revision.

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1. Introduction to Nuclear Power Plants (NPPs)

- A **Nuclear Power Plant (NPP)** is a power-generation facility in which nuclear fission (or in advanced designs, nuclear fusion) is used as the heat source instead of burning fossil fuels. This heat is transferred to a working fluid (usually water) which produces steam that drives a turbine connected to a generator to produce electricity. (Testbook)
- Key differences compared to conventional thermal power plants:
  - The fuel has extremely high energy density (a small mass of nuclear fuel can produce a very large amount of heat).
  - Unlike coal or oil, there is no large stack of combustion gases (though there are steam, coolant and waste systems).
  - Safety, radiation protection, shielding, containment structures and long-term waste management become major engineering concerns.
- From a mechanical/plant-engineering perspective you will focus on: reactor vessel, coolant systems, steam generation systems,

turbine-generator interfaces, auxiliary equipment, cooling systems, containment and structural aspects.

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2. Site Selection Criteria for Nuclear Power Plants

Selecting a site for an NPP is far more stringent than for many other power plants, due to the need for safety (both operational and postulated accident scenarios), environmental protection, cooling water sourcing, seismic and external hazard resilience, and public acceptance. Below are major criteria with explanation:

Criterion	Importance & Explanation	Key considerations
Availability of Water / Heat-Sink	NPPs typically require **large quantities** of cooling water (for condensers, reactor coolant cooling, steam cycle cooling). Without an adequate heat-sink (river, lake, sea or cooling towers) the plant cannot reliably operate. (Rama University)	Proximity to a river/sea; seasonal variation of water; water quality; environmental impact of discharge (thermal pollution)
Distance from Load Centre / Grid Connectivity	To reduce transmission losses and cost, siting relatively near major load centres is beneficial — while still satisfying safety and other constraints. (eeeguide.com)	Existing grid infrastructure, transmission line routing, future load growth
Distance from Populated Areas and Exclusion Zones	In the event of any radiological release (however unlikely), adequate buffer distance improves safety margin and public confidence. (aerb.gov.in)	Population distribution, future urban growth, evacuation planning
Geological / Seismic Hazard	The site must withstand natural hazards	Geological history, fault lines, seismic

/ External Events	(earthquakes, floods, tsunamis, high winds, volcanic activity). Design basis for these hazards must be supported by site investigation. (ResearchGate)	zoning, flood risk (inland/coastal)
Land Area, Terrain & Geotechnical Conditions	Stable soil, good bearing capacity, no large subsidence risk; terrain should allow construction, heavy equipment transport, future expansion. (eeeguide.com)	Soil tests, floodplain data, ground water uplift, bearing capacity
Waste Disposal and Environmental Impact	The site must have capacity for handling radioactive wastes (solid, liquid, gaseous), along with environmental monitoring and long-term management. (Rama University)	Waste storage location, isolation from public, long-term control infrastructure
Transport & Infrastructure Access	Heavy plant equipment, fuel delivery (uranium, heavy water, reactor components), workforce access all require good transport (road/rail/sea) and supporting infrastructure. (eeeguide.com)	Road/rail links, ports (if needed), construction logistics, workforce housing
Social, Economic & Regulatory Acceptability	Local acceptance, land acquisition, compensation, minimal disruption to local economy/environment, regulatory clearances. (Taylor & Francis Online)	Public hearings, environmental impact assessment (EIA), regulatory body requirements
Future Expansion &	As nuclear plants often have long life spans, the site should allow for future units	Master site plan, zoning controls,

Land Use Planning	or auxiliary facilities, buffer zones, and long-term decommissioning planning. (eeeguide.com)	surplus land availability

Summary of process:

- **Screening stage**: Large region screened for broad suitability (water, population, geology).
- **Candidate site stage**: Several sites undergo detailed investigation (geology, hydrology, hazard analysis).
- **Site evaluation stage**: One final site is selected and fully characterised (soil, seismic, external events, population, evacuation). (aerb.gov.in)
- **Operational/monitoring stage**: Even after commissioning, site parameters are monitored over plant life (soil changes, hydrology, seismic events).

For your exam: you should list **at least 6–8 criteria** and give a sentence of explanation for each.

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3. Nuclear Fuel Used in Nuclear Power Plants

- Types of nuclear fuel commonly used:
  1. **Natural Uranium** (mostly U-238 with ~0.7% U-235) — used in certain heavy-water reactors (like the Indian PHWRs).
  2. **Enriched Uranium** — U-235 concentration increased (for light-water reactors e.g., PWR, BWR).
  3. **Mixed Oxide (MOX) Fuel** — a mixture of plutonium and uranium oxides, used in some advanced designs.
  4. **Thorium-Based Fuel** — (Th-232 → U-233) India's long-term strategy emphasises thorium because India has large thorium reserves. (World Nuclear Association)
- Key characteristics from an engineering viewpoint:
  - Extremely high energy density: small mass of nuclear fuel produces very large amounts of heat compared to coal/oil.

   - Fuel handling complexity: fabricating fuel rods, handling radiation, burn-up management, and procurement of enriched material or fabrication of MOX.
   - Fuel cycle aspects: mining → fuel fabrication → reactor use → spent fuel → reprocessing or disposal.
   - Reactor type dependency: The choice of reactor (e.g., PHWR, PWR, BWR) depends on fuel type and coolant/moderator selection.
- For a student: be able to identify fuel types, why thorium is significant in India, and how fuel type influences reactor design and operation.

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4. Layout of a Nuclear Power Plant

Understanding the layout is important for maintenance, safety, mechanical systems design, and process flow.

Major functional blocks & flow:

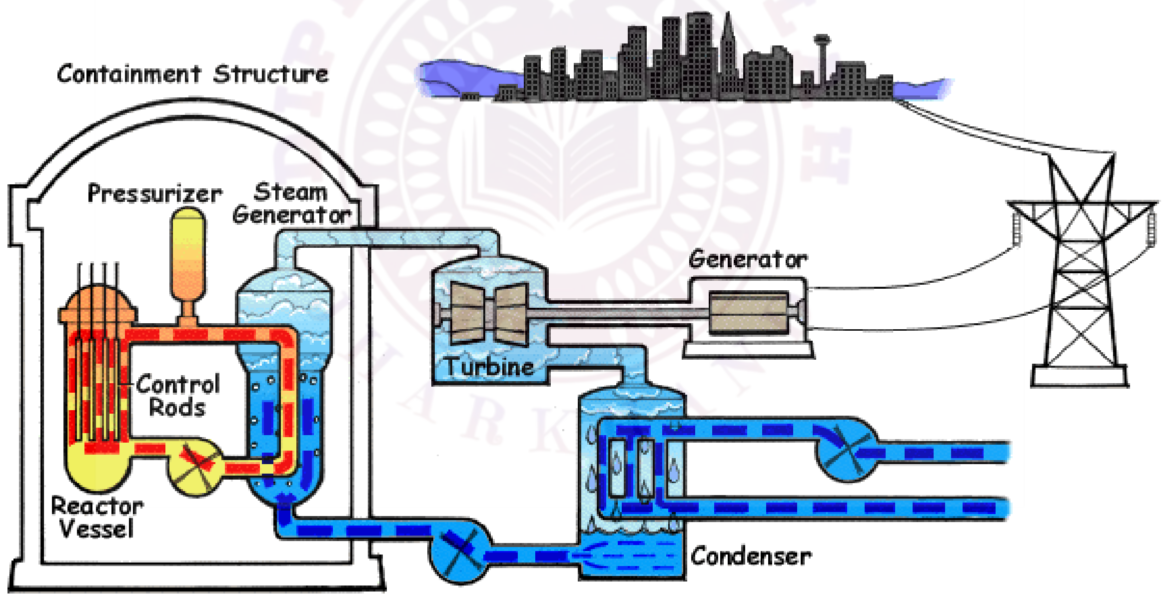
1. **Reactor Building / Reactor Vessel** – contains the reactor core (fuel, moderator, control rods). High containment, shielding materials.
2. **Primary/Secondary Circuits (depending on reactor type)** – coolant takes heat from reactor core → heat exchanger/steam generator → steam.
3. **Steam Turbine / Generator** – steam drives turbine; turbine drives generator to produce electricity.
4. **Condenser / Cooling System** – steam exhaust from turbine is condensed; heat is rejected via cooling water (sea, river, or cooling towers).
5. **Auxiliary Buildings** – fuel handling, control rooms, emergency systems, pumps, etc.
6. **Switchyard / Grid Connection** – delivers generated power to the grid.
7. **Waste Management & Spent Fuel Storage** – includes spent fuel pools, dry cask storage, radioactive waste buildings.

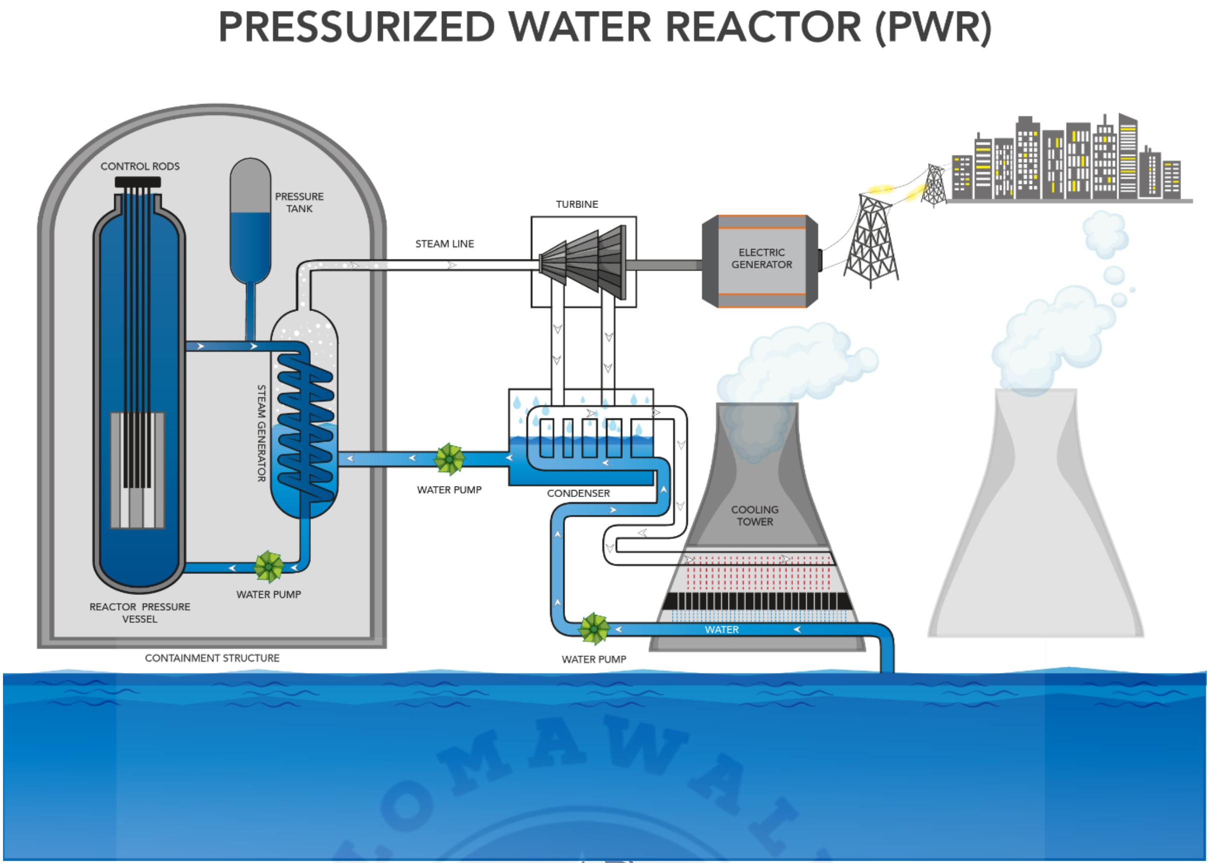
8. **Support & Safety Systems** – containment structures, radiation shielding, emergency cooling, backup power, monitoring.

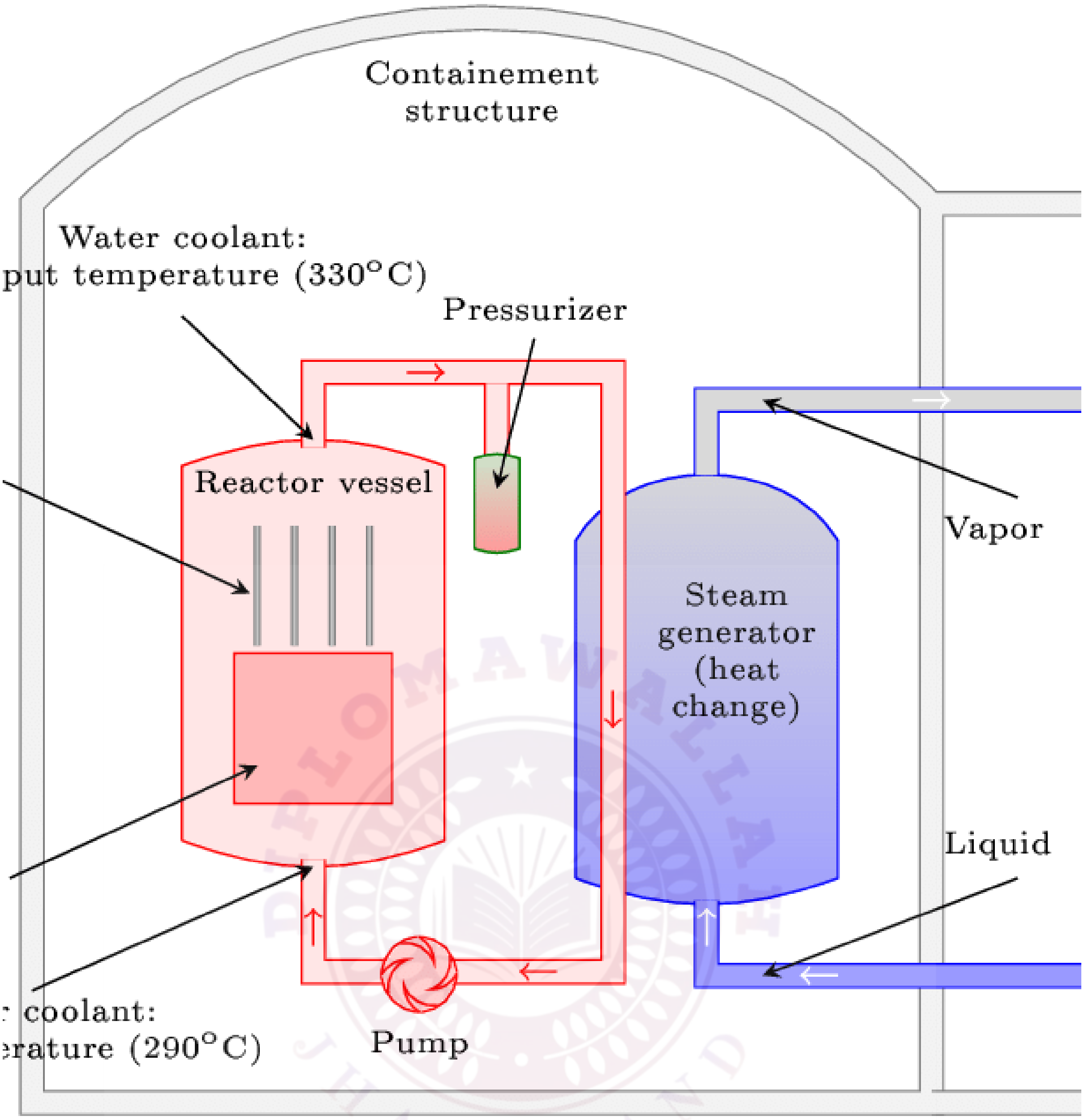
Important layout features for plant engineering:

- Clear segregation of radioactive systems (reactor coolant) and non-radioactive (steam turbine) as far as possible for maintenance.
- Backup and redundant systems for cooling, emergency power, safety injection.
- Cooling water system location must consider seasonal variation, environmental discharge, intake location.
- Accessibility for maintenance: turbine hall, reactor maintenance area, fuel handling, waste storage.
- Buffer zones and access control for safety and security.

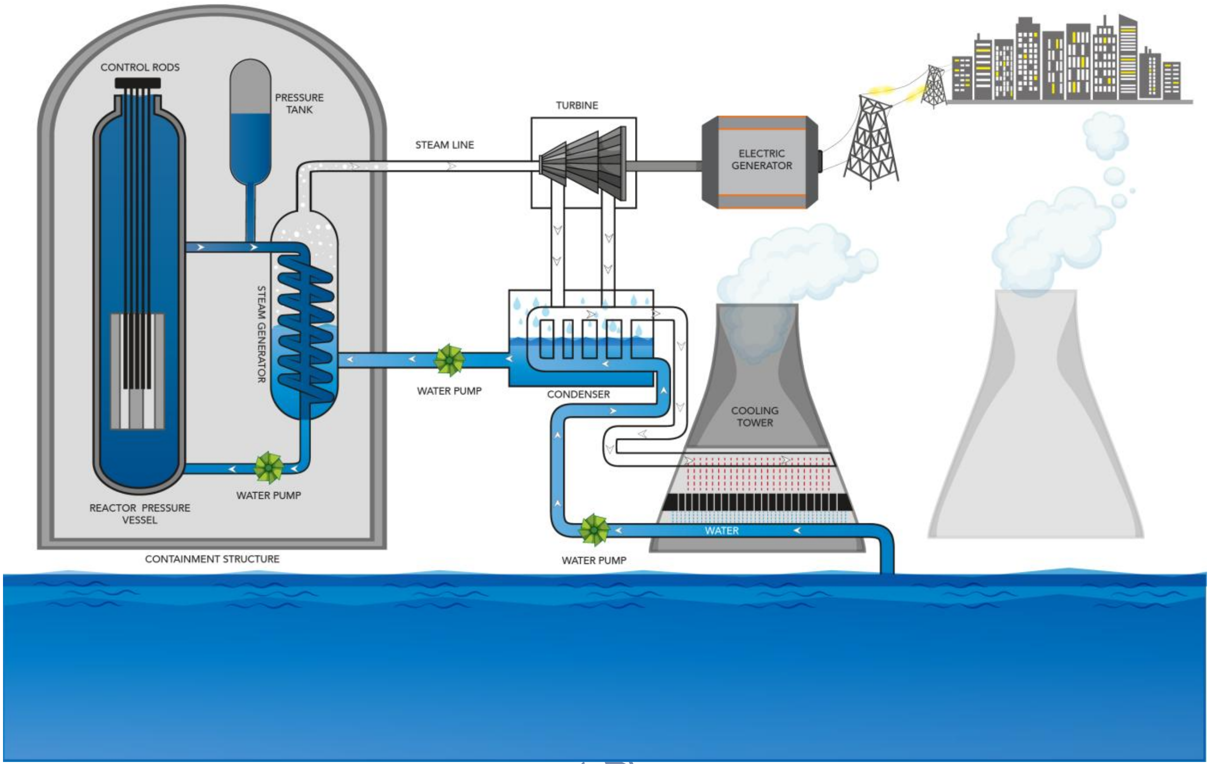
Pressurized Water Reactor (PWR)




PRESSURIZED WATER REACTOR (PWR)
CONTROL RODS
PRESSURE TANK
STEAM GENERATOR
REACTOR PRESSURE VESSEL
WATER PUMP
CONTAINMENT STRUCTURE
STEAM LINE
TURBINE
ELECTRIC GENERATOR
WATER PUMP
CONDENSER
COOLING TOWER
WATER
WATER PUMP


Containement
structure
Water coolant:
put temperature (330°C)
Pressurizer
Reactor vessel
Vapor
Steam
generator
(heat
change)
Liquid
: coolant:
erature (290°C)
Pump

PRESSURIZED WATER REACTOR (PWR)



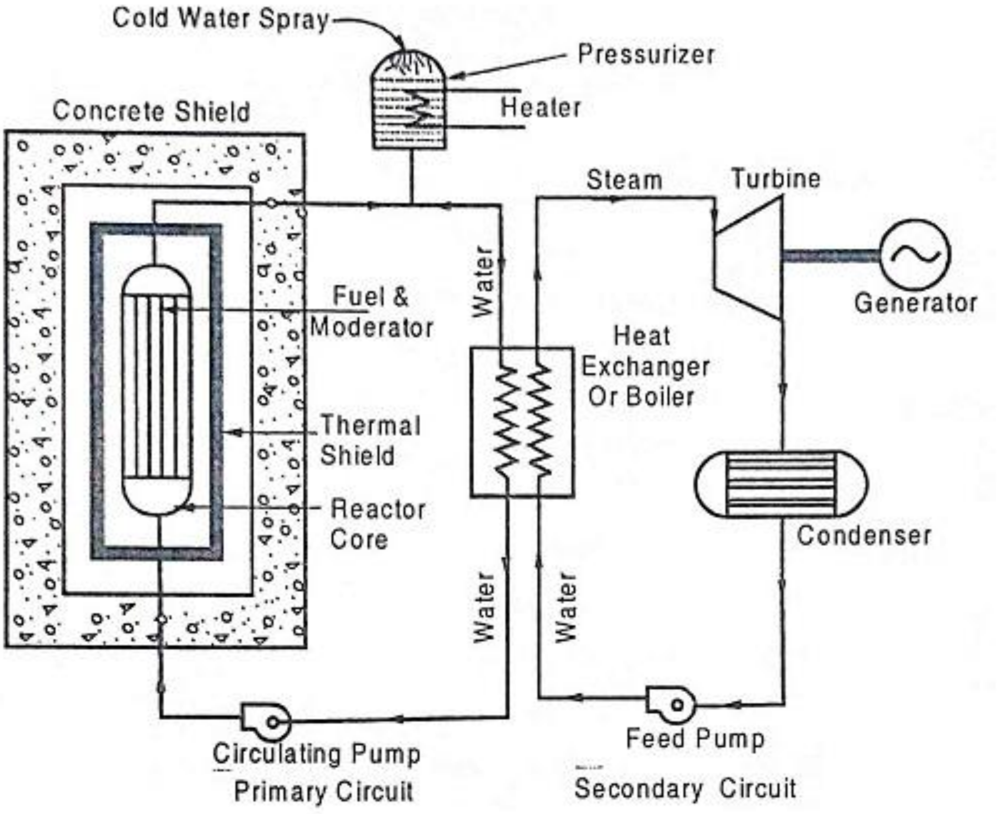


Fig:3.7 Pressurized Water Reactor Nuclear Power Plant

Construction & Working

- In a PWR, the reactor core is filled with water under **very high pressure**, typically around ~150 – 160 bar (≈15–16 MPa), which prevents the water from boiling despite high temperatures. (Wikipedia)
- The high-pressure (primary) coolant flows through the reactor core, absorbing heat generated by nuclear fission of fuel rods (uranium or MOX).
- This hot primary coolant then passes through a **steam generator** (a heat exchanger), where it transfers heat to a separate water circuit (secondary loop) thus generating steam that drives the turbine/generator. (Duke Energy | Nuclear Information Center)
- The primary and secondary loops are **separate**, so the water/steam driving the turbine is non-radioactive, while the primary loop remains contained and under high pressure. This gives a safety & maintenance advantage. (Wikipedia)
- After the steam turbine, steam is condensed and returned to the steam generator feed pumps; the condensation and cooling part forms the tertiary loop (cooling water).
- Key components: reactor pressure vessel, pressuriser (to control primary loop pressure), steam generator(s), primary and secondary pumps, turbine/generator, condenser, cooling system. (Duke Energy | Nuclear Information Center)

Advantages & Disadvantages

Advantages:

- Isolation of radioactive primary loop makes turbine side simpler and safer (non-radioactive steam).
- PWR is the most widely used reactor type worldwide (so mature technology, good support). (Wikipedia)
- Control of core temperature and pressure is robust; the design is well proven.

Disadvantages:

- Complexity of dual-loop system increases component count (steam generators, pumps) and may reduce thermodynamic efficiency due to extra heat-exchange losses. (difference.minaprem.com)
- High pressure means thicker / more robust vessel & piping, increased cost and maintenance challenges (material stress, corrosion).
- The primary coolant remains radioactive; though turbine system is separate, primary loop maintenance is more safety-critical.

Key Points for Exams

- Definition: PWR uses water under high pressure so that it remains liquid while absorbing heat; steam is produced in a separate secondary loop.
- Working principle:
  1. Reactor core heats up high-pressure water (primary loop)
  2. Primary loop transfers heat via steam generator to a secondary loop → steam → turbine → generator
  3. Condenser & cooling system handle steam exhaust
- Major components: reactor vessel, pressuriser, steam generator, primary/secondary pumps, turbine/generator, cooling system.
- Important parameters: primary pressure ~15–16 MPa, coolant temperature ~300–330 °C.
- Safety/maintenance aspects: separation of loops; high pressure; proven technology.

Boiling Water Reactor (BWR)

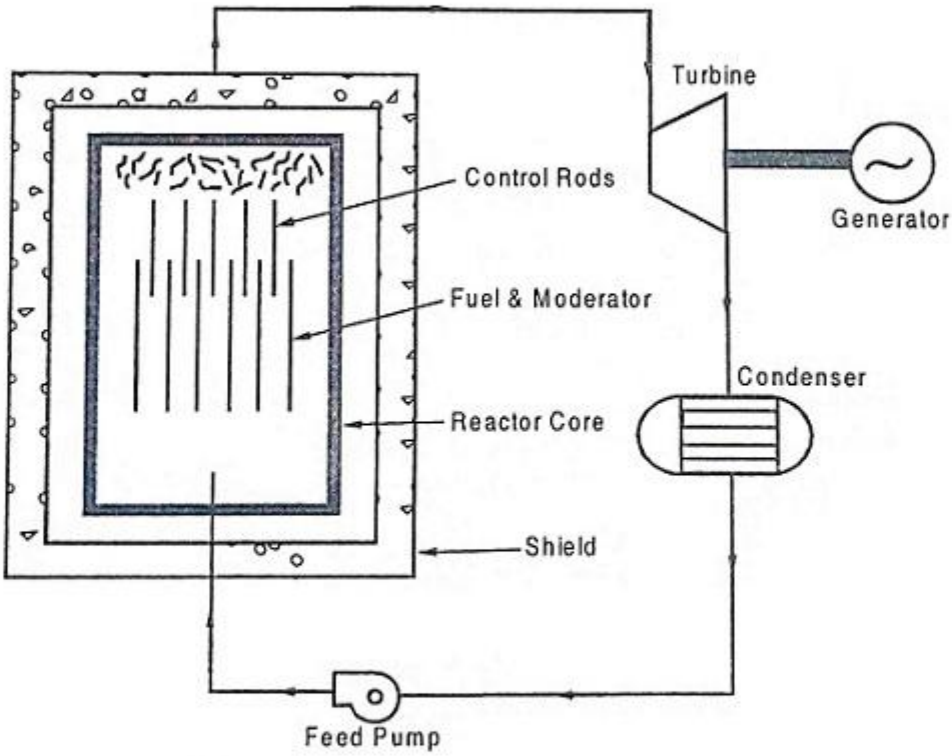
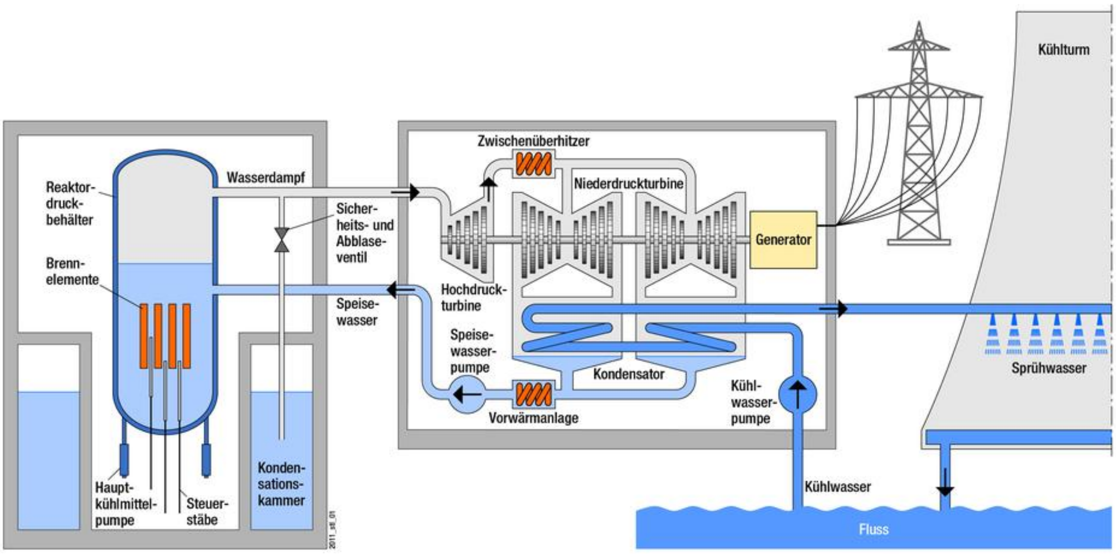
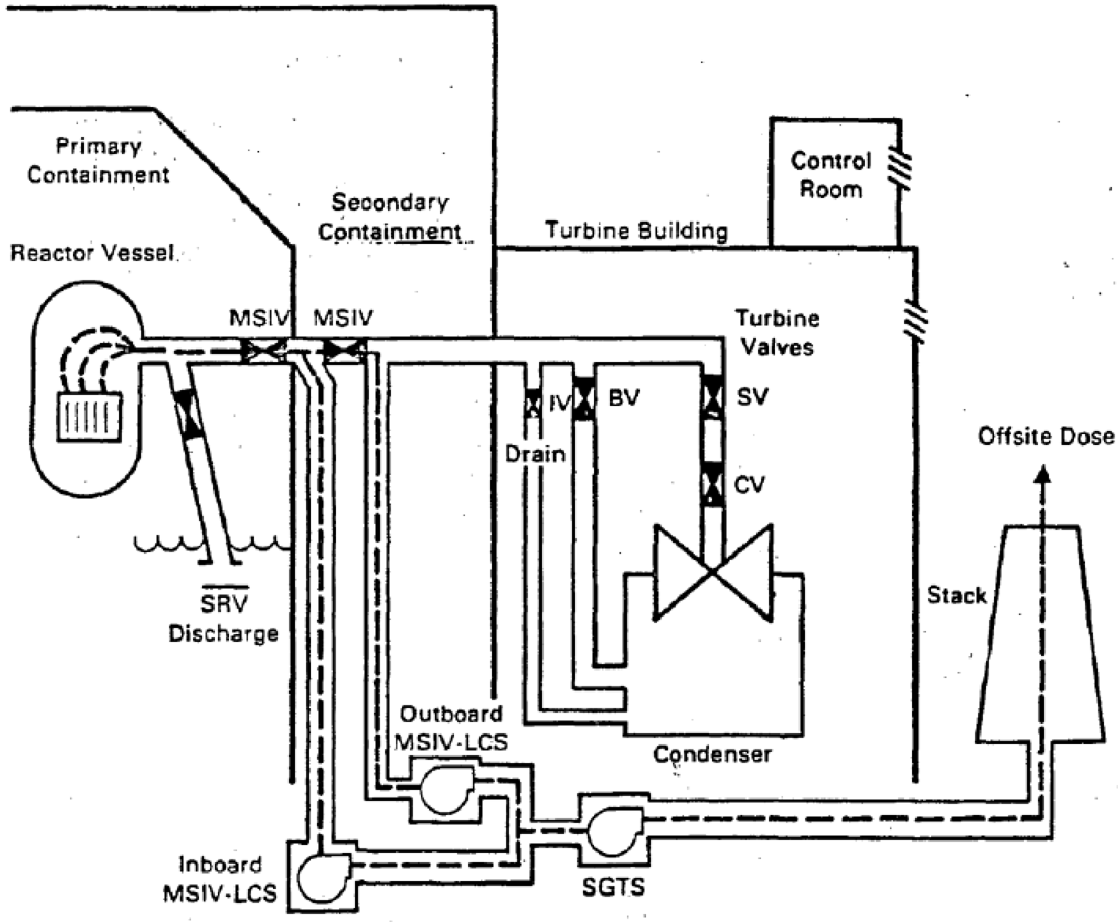
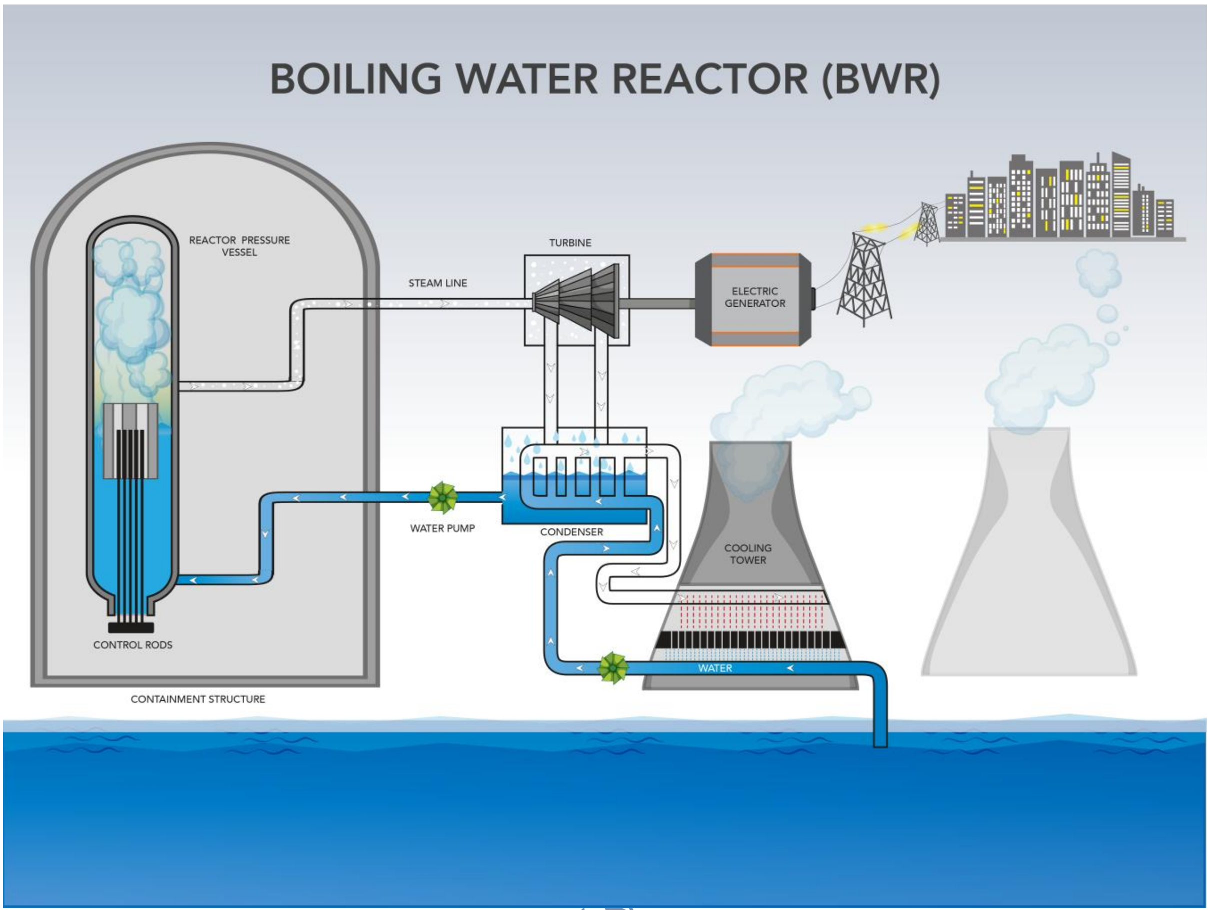
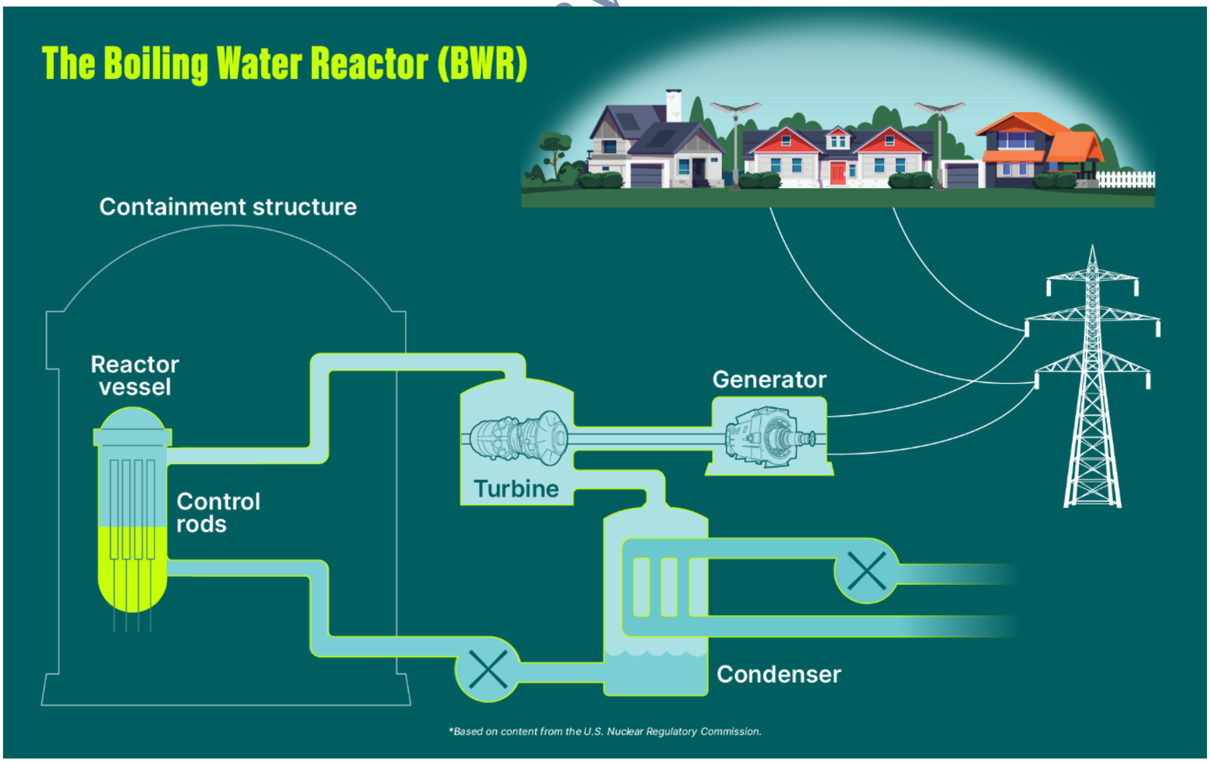


Fig:3.6 Boiling Water Reactor




Primary Containment
Secondary Containment
Turbine Building
Control Room
Reactor Vessel
MSIV
MSIV
Turbine Valves
IV
BV
SV
Drain
CV
Offsite Dose
SRV Discharge
Stack
Outboard MSIV-LCS
Condenser
Inboard MSIV-LCS
SGTS





Construction & Working

- In a BWR, water is used as both coolant and moderator, and **boils directly in the reactor core** at moderate pressure (typically ~70

– 75 bar) to form steam. That steam goes directly to the turbine. (Wikipedia)

- The layout has fewer loops: the reactor coolant becomes the turbine steam (i.e., one loop), and then after turbine the steam is condensed in the condenser and returned as feedwater. (Duke Energy | Nuclear Information Center)
- Key components: reactor pressure vessel with core, steam separators/dryers inside the vessel, turbine/generator directly connected, condenser & feedwater pumps, cooling system.
- Since steam from the core goes directly to the turbine, the steam and turbine-side equipment are exposed to radiation (though designed for it).

Advantages & Disadvantages

Advantages:

- Simplified system (fewer loops) reduces some heat-exchange losses and may lead to higher thermal efficiency in certain designs. (difference.minaprem.com)
- Lower pressure in the reactor vessel compared to PWR; mechanical design can be somewhat simpler in that regard.

Disadvantages:

- Because the steam/gas that drives the turbine has come directly from the reactor core, turbine side components must be designed to handle radioactivity (maintenance harder, more shielding). (Wikipedia)
- The reactor vessel and core conditions require careful management of boiling, two-phase flow, and associated thermo-hydraulic challenges.

Key Points for Exams

- Definition: BWR uses light water as coolant/moderator; the water boils inside the reactor core to produce steam that directly drives the turbine.
- Working principle:
    1. Reactor core heats water → boiling and steam generation in vessel

2. Steam separated and dried inside vessel → goes to turbine → generator
3. Steam exhaust condensed → feedwater pumped back.

- Major components: reactor vessel with steam separator/dryer, turbine/generator, condenser, feedwater system, cooling system.
- Important parameters: operating pressure ~70 bar; steam dryness & separation important.
- Safety/maintenance aspects: direct connection to turbine, radioactivity in turbine loop, more challenges in turbine maintenance.

Comparison: PWR vs BWR

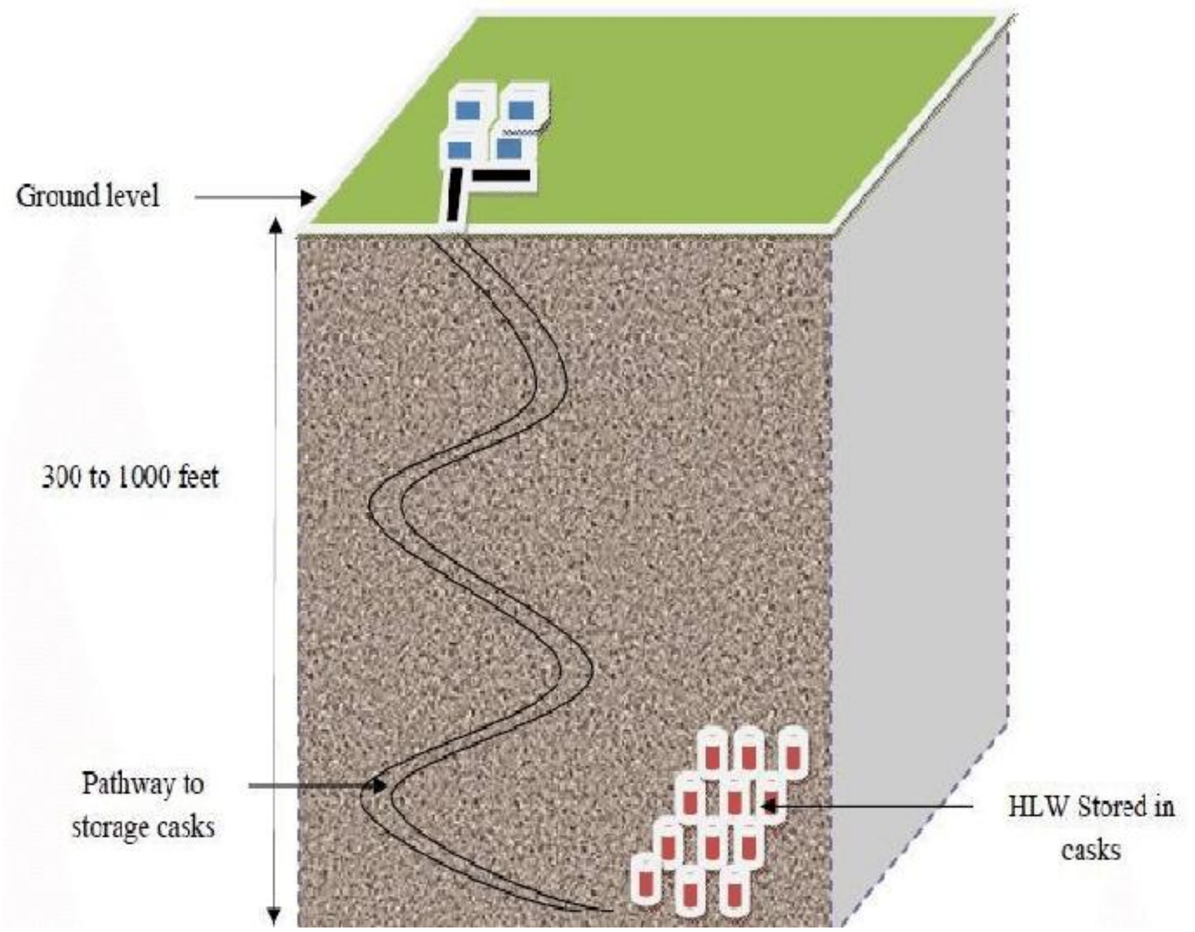
Summary Table

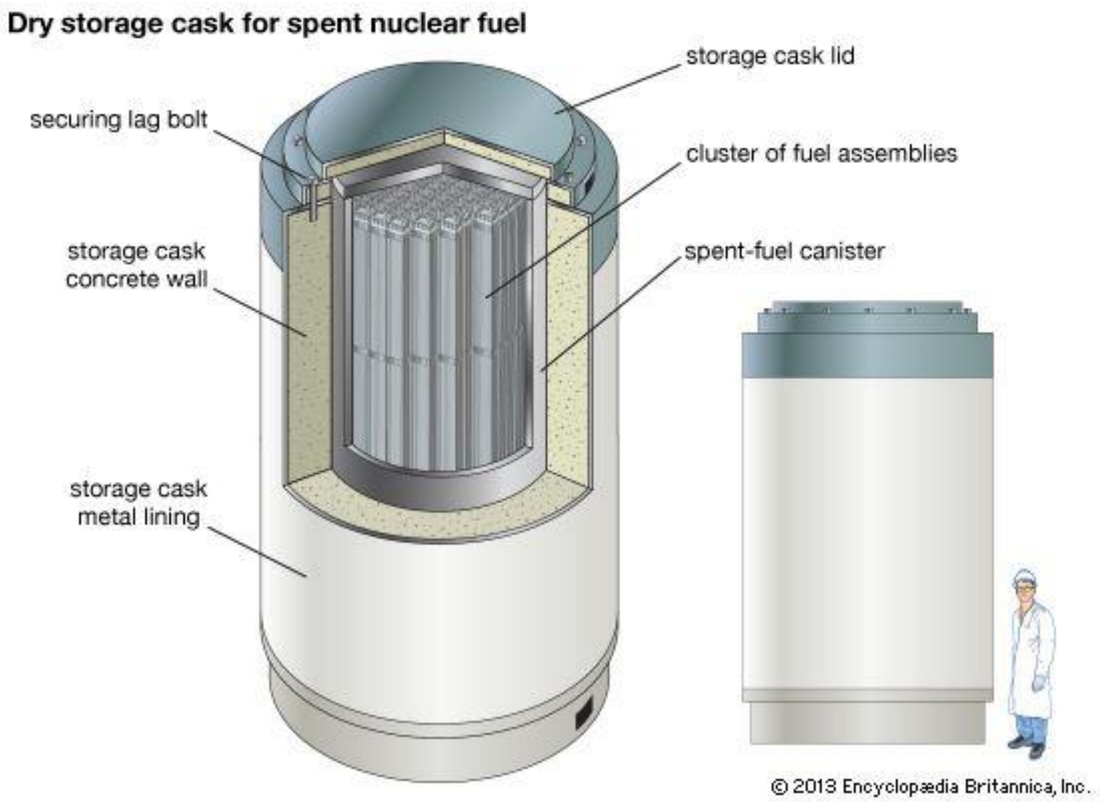
Feature	PWR	BWR
Steam generation location	Secondary loop via steam generator (primary stays liquid)	Inside reactor vessel directly
Number of loops	Two main loops (primary + secondary)	One loop (reactor coolant = turbine steam)
Pressure & boiling in core	High pressure (~150 bar), no boiling in core	Lower pressure (~70 bar), boiling in core
Radiation exposure on turbine side	Turbine side non-radioactive (secondary loop)	Turbine side sees radioactive steam
Complexity of system	More components (steam generator, pressuriser)	Simpler loop, fewer components
Maintenance & safety trade-offs	Easier turbine side maintenance; higher cost and complexity	Simpler design; turbine side radiation, maintenance more challenging

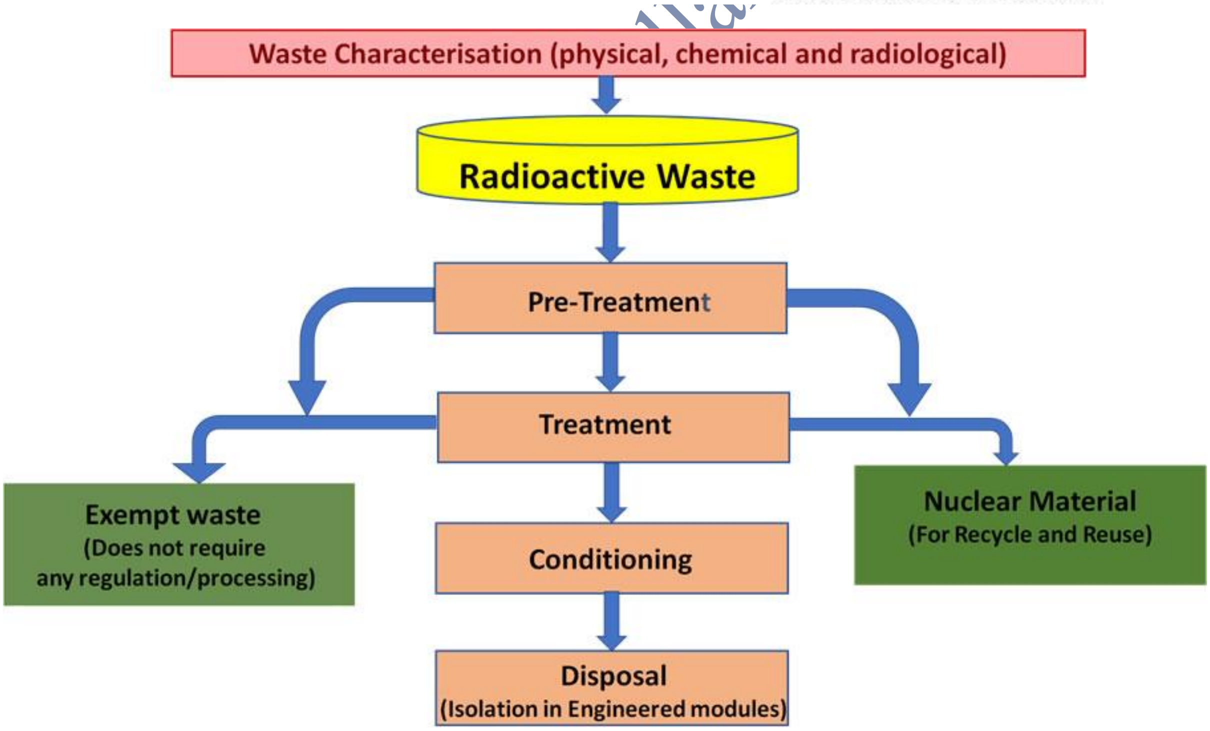
Important differences to mention in exams

- In PWR the fluid that goes to turbine is **not** the reactor coolant, hence turbine-loop is non-radioactive; in BWR the steam that goes to turbine is from reactor core, hence turbine side is radioactive. (difference.minaprem.com)
- The method of steam generation: PWR uses heat exchanger (indirect), BWR uses direct boiling in core.
- Pressure levels: PWR higher; BWR lower but many two-phase flow challenges.
- In India context, though PHWRs (pressurized heavy water reactors) are common, understanding PWR/BWR is essential for global context and for designing nuclear-plant mechanical systems.

4.3 Nuclear Waste and Disposal







A. Definition & Why It's Important

- Nuclear waste refers to materials generated during the nuclear fuel cycle (mining, fuel fabrication, reactor operation, reprocessing, decommissioning) that contain radioactive nuclides and hence require management so as not to pose undue risk to people or the environment. (Bhabha Atomic Research Centre)

- It is important because unlike many industrial wastes, radioactive wastes may remain hazardous for **very long periods** (decades, centuries or millennia) and must be isolated, contained or neutralised. (PMF IAS)
- Proper disposal and storage of nuclear waste is essential for safe operation of nuclear power plants, public acceptance of nuclear energy, environmental protection, and meeting regulatory/legal obligations.

B. Classification of Nuclear Waste

Nuclear waste is classified by **radioactivity level**, **physical state**, and **origin**. Key categories:

1. **By radioactivity / hazard level**
   - Low-Level Waste (LLW): items with low radioactivity (gloves, filters, paper, clothing) – mostly associated with routine operations. (Bhabha Atomic Research Centre)
   - Intermediate-Level Waste (ILW): higher radioactivity, may include reactor components, resins, sludge. Requires shielding and more containment. (TÜV SÜD)
   - High-Level Waste (HLW): spent fuel or waste from reprocessing, very high heat and radioactivity, needs extensive shielding and isolation. (World Nuclear Association)
2. **By physical state**
   - Solid waste: structural components, contaminated tools, waste sludges solidified.
   - Liquid waste: aqueous solutions with radionuclides, coolant water, process effluents.
   - Gaseous waste: radioactive gases released from reactors or processing systems. (aerb.gov.in)
3. **By origin**

- Operational waste: from nuclear power plant operation (fuel assemblies removed, filters, coolant sludge).
- Decommissioning waste: from dismantling or retiring nuclear facilities (reactor vessel, contaminated structures).
- Fuel cycle waste: from mining, fuel fabrication, reprocessing.

C. Treatment, Storage, and Disposal Methods

1. Storage (Interim)

- **Spent fuel pools**: After removal from the reactor, spent fuel assemblies remain in deep water pools for cooling (decay of heat & radioactivity) for several years. (PMF IAS)
- **Dry cask storage**: After sufficient cooling, spent fuel can be transferred to sealed casks (steel/concrete) stored above ground or near-surface. These provide shielding and isolation while awaiting final disposal. (Wikipedia)
- Rationale: Storage gives time for decay of short-lived radionuclides and reduces thermal load for the next phase.

2. Treatment & Conditioning

- Liquid wastes may be evaporated, chemically treated (precipitation, ion-exchange), filtered, solidified (cementation, vitrification) to reduce volume and fix radionuclides in stable matrices. (PMF IAS)
- Solid wastes can be compacted, incinerated (for low level organic wastes), encapsulated in concrete, glass, ceramics. Engineered packaging is important for isolation. (www.slideshare.net)

3. Final Disposal

- **Near-surface disposal**: Often for LLW/ILW with relatively short half-lives; disposed in ground trenches or engineered vaults near surface. (aerb.gov.in)
- **Deep geological disposal**: For HLW/spent fuel long-term isolation (hundreds to thousands of years), commonly in stable rock formations hundreds of metres underground (granite, clay, salt). Multibarrier systems (engineered + geological) are used. (World Nuclear Association)

- **Reprocessing & recycle**: Some national programmes (including India) reprocess spent fuel to recover uranium/plutonium, reducing volume of high-level waste. (aerb.gov.in)

D. Challenges in Nuclear Waste Management

- Long timescales: HLW remains hazardous for thousands of years; ensuring containment and monitoring over such periods is a major challenge. (Drishti IAS)
- Public acceptance & site selection: Finding and licensing geological disposal sites often faces regulatory, social and political hurdles. For example, long-term risk perceptions, community consent. (World Nuclear Association)
- Technological reliability: Packaging, materials (corrosion resistance), barrier behaviour over decades/centuries, radiation effects on materials.
- Cost & infrastructure: Waste treatment, packaging, monitoring, transportation require large investments and operational infrastructures.
- Interim storage growth: Many countries accumulate large inventories of spent fuel awaiting final disposal solutions.
- Environmental & safety compliance: Ensuring no undue release of radionuclides, protection of environment, compliance with regulatory dose limits to public. (aerb.gov.in)

E. Indian Context

- In India, the Bhabha Atomic Research Centre (BARC) states that safe management of radioactive waste has been a priority and follows international guidelines. (Bhabha Atomic Research Centre)
- The Atomic Energy Regulatory Board (AERB) regulates waste management: rules for disposal, near-surface disposal facilities, storage, transport, monitoring. (aerb.gov.in)
- India adopts a **closed fuel-cycle approach**, where spent fuel is reprocessed and recycled; only a small fraction becomes final waste. (aerb.gov.in)

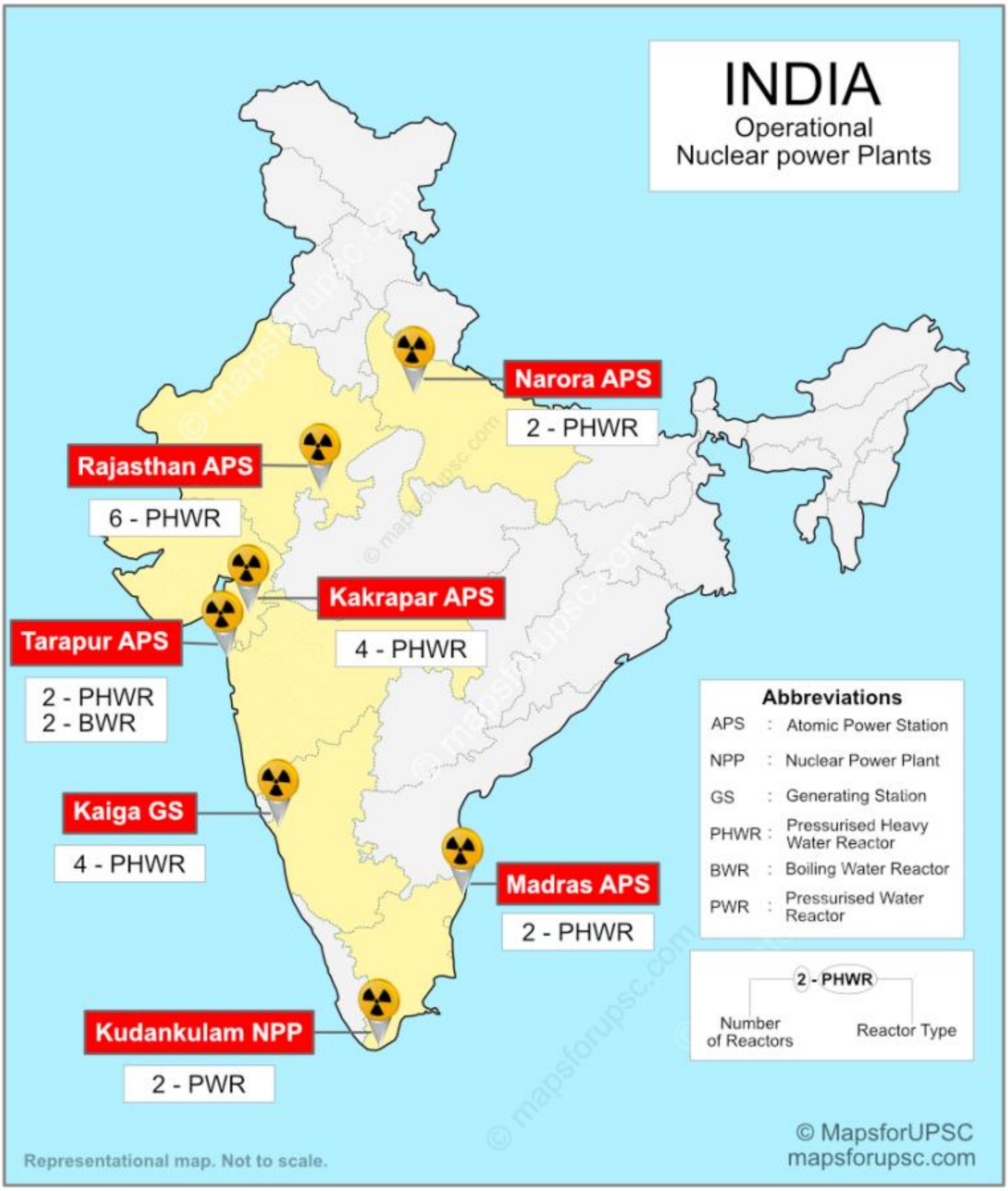
- Example practice: Low & Intermediate Level wastes managed at plant sites by concentration, immobilisation in cement/concrete and disposed in trenches, tile holes; continuously monitored via bore-wells for groundwater, soil. (Press Information Bureau)

F. Key Exam-Point Summary

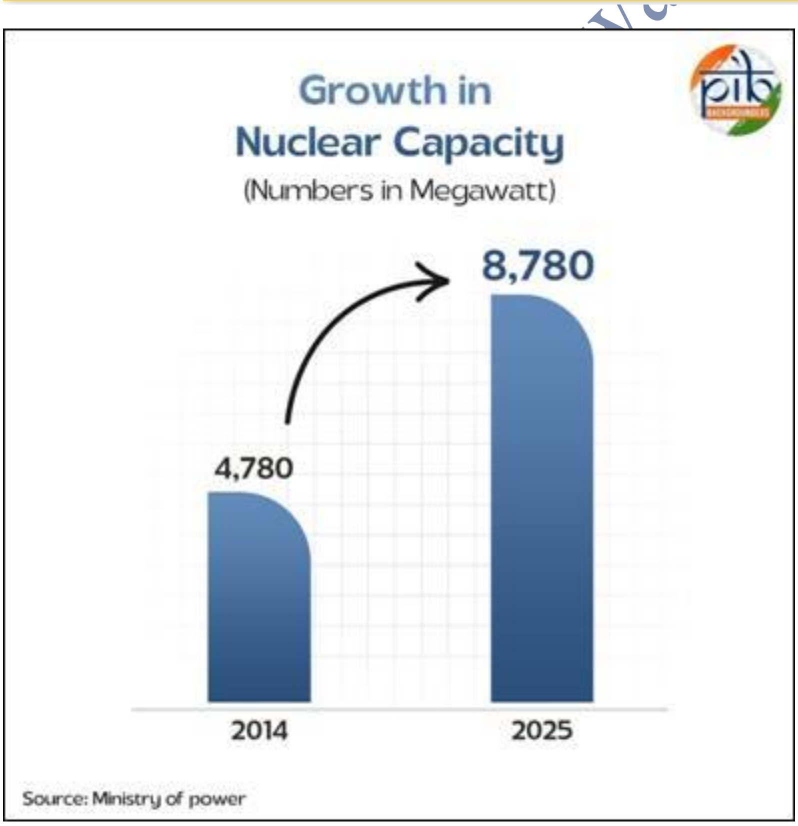
- Define nuclear waste and its significance.
- List classification (LLW, ILW, HLW) + physical state categories (solid, liquid, gas).
- Explain the three main stages of management: storage → treatment/conditioning → disposal.
- Describe methods: spent fuel pools, dry casks, vitrification, near-surface disposal, deep geological disposal.
- Mention major challenges (long timescales, public acceptance, material technology, cost).
- Provide Indian context: regulatory bodies (AERB), practices (closed fuel cycle, on-site disposal, monitoring).
- Emphasise importance for safe and sustainable nuclear power plant operation.

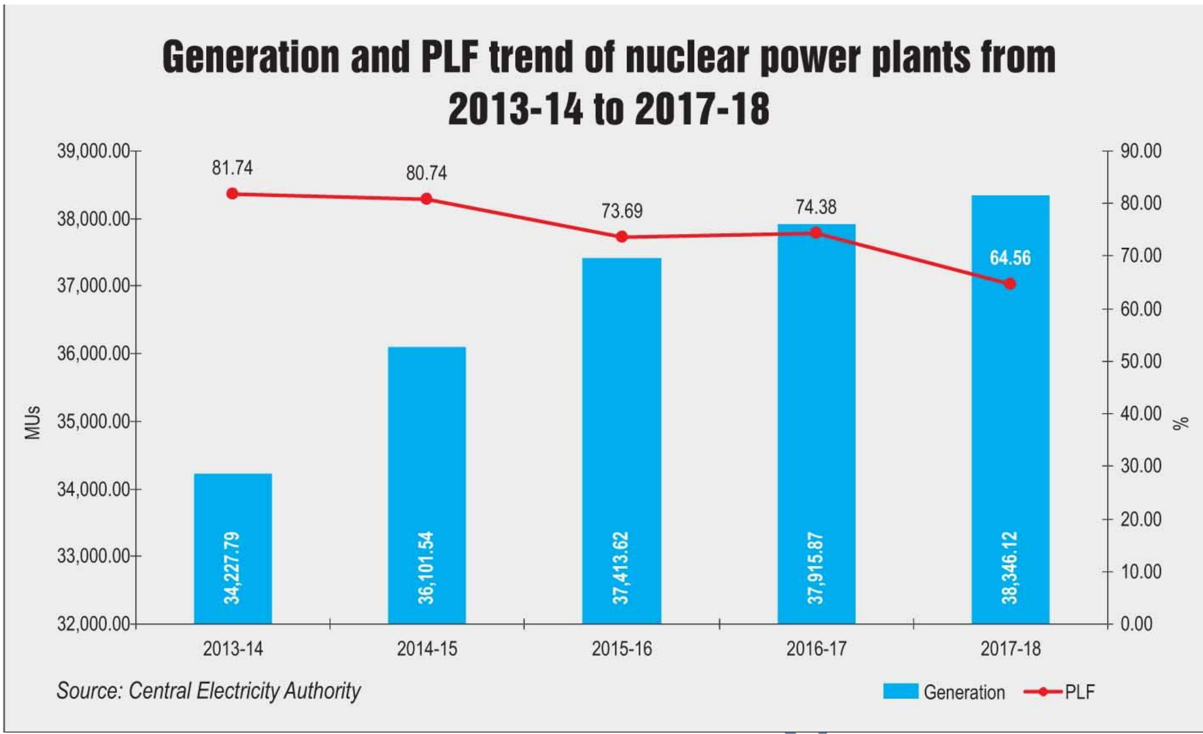
4.4 Present Nuclear Power Scenario in India

INDIA
Nuclear Power plant
N
TAJIKISTAN
AFGHANISTAN
PAKISTAN
CHINA (TIBET)
NEPAL
BHUTAN
BANGLADESH
MYANMAR (BURMA)
Pokharan (Test Site)
Rajasthan Atomic Power Plant
Narora Atomic Power Station
Kakrapar Atomic Power Plant
Tarapur Nuclear Reactor
Kaiga Atomic Power Plant
Kalpakkam Nuclear Reactor
ARABIAN SEA
BAY OF BENGAL
SRI LANKA
INDIAN OCEAN
LEGEND
Nuclear Power Plant
Map not to Scale
Copyright © 2022 www.mapsofindia.com

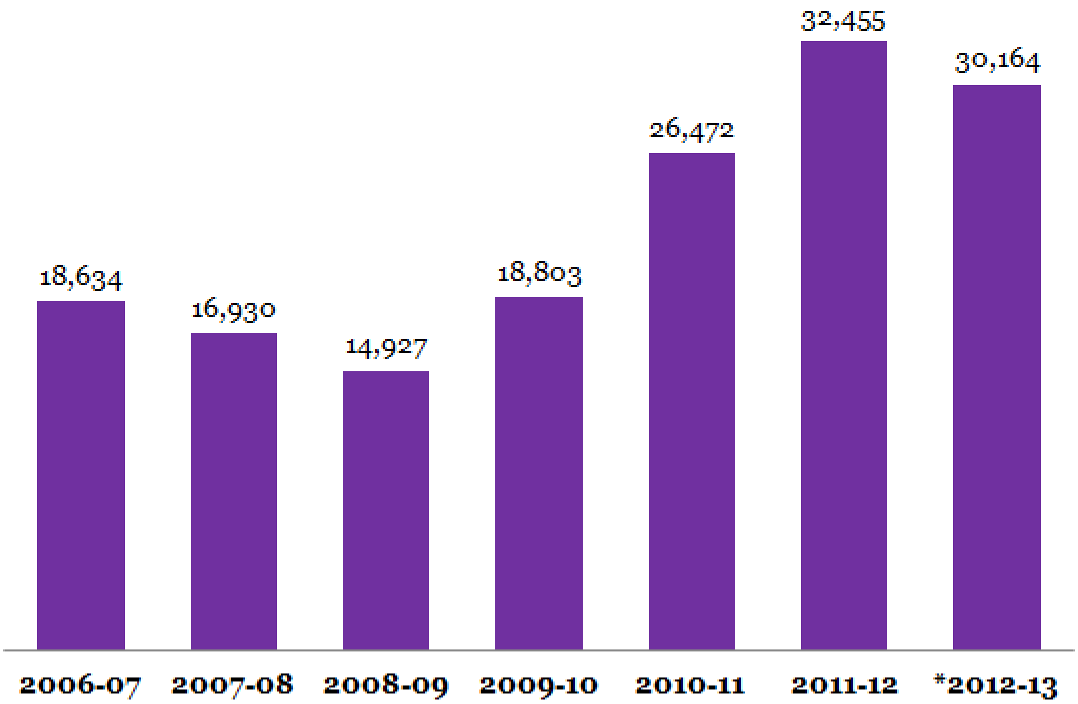

INDIA
Operational
Nuclear power Plants
Narora APS
2 - PHWR
Rajasthan APS
6 - PHWR
Kakrapar APS
4 - PHWR
Tarapur APS
2 - PHWR
2 - BWR
Kaiga GS
4 - PHWR
Madras APS
2 - PHWR
Kudankulam NPP
2 - PWR
Abbreviations
APS : Atomic Power Station
NPP : Nuclear Power Plant
GS : Generating Station
PHWR : Pressurised Heavy Water Reactor
BWR : Boiling Water Reactor
PWR : Pressurised Water Reactor
2 - PHWR
Number of Reactors
Reactor Type
© MapsforUPSC
mapsforupsc.com
Representational map. Not to scale.

Energy Source	As on 31 Dec 2024	As on 31 Mar 2025	Change (MW)	% of New Capacity Added*
Wind Power	48,163	50,038	1,875	13.9
Solar Power*	97,865	105,646	7,782	57.7
Small Hydro	5,101	5,101	-	0.0
Biomass	10,728	10,743	15	0.1
Waste to Energy*	620	840	220	1.6
Large Hydro	46,968	47,728	760	5.6
Nuclear	8,180	8,180	0	0.0
Coal (+ Lignite)	218,970	221,813	2,843	21.1
Gas	24,818	24,533	-285	-2.1
Diesel	589	589	0	0.0
Total	462,002	475,212	13,210 (Net capacity added)	-





Nuclear Power Generation: 2006-07 To 2012-13



*Figures In Million Units, *2012-13: Till February*
Source: Nuclear Power Corporation

A. Current Status & Installed Capacity

- As of January 30, 2025, India's nuclear installed capacity is reported as **8,180 MW (≈8.18 GW)**. (Press Information Bureau)
- Another source states that India has **25 operational nuclear reactors** in seven power plants with a combined installed capacity of **8,880 MW (~8.88 GW)**. (Wikipedia)
- The nuclear share in electricity generation is about **3%** of India's total electricity production. (Wikipedia)
- Growth trajectory: from ~4,780 MW around 2014 to ~8,780 MW in 2025. (Press Information Bureau)

B. Growth Targets & Future Plans

- For the medium term, India aims to reach about **22,480 MW (~22.48 GW)** of nuclear capacity by around 2031-32. (Drishti IAS)
- In the long term, the government has set an ambitious goal of **100 GW (100,000 MW)** of nuclear capacity by the year **2047** (India's centenary of independence). (World Nuclear Association)
- To support this, the "Nuclear Energy Mission" under Budget 2025 allocated significant resources (e.g., INR 20,000 crore) for research, development and deployment including Small Modular Reactors (SMRs). (Sustainable Futures Collaborative)

C. Significance & Role in India's Energy Mix

- India, as one of the world's fastest-growing energy markets, needs large supplies of **reliable baseload electricity**. Nuclear power provides such non-intermittent generation, unlike many renewables.
- With over 70% of India's current electricity still produced from fossil fuels (coal, oil, gas), scaling up nuclear helps reduce carbon-emissions intensity and enhance energy security. (AP News)
- The planned expansion also ties into India's broader target of non-fossil energy capacity and decarbonisation—for example its NetZero 2070 commitment.

D. Technology & Projects

- India's nuclear fleet largely consists of indigenous Pressurised Heavy Water Reactors (PHWRs) that use natural uranium fuel and heavy water moderator.
- Newer projects and future units are expected to include advanced reactor types including imported designs and SMRs. A 2025 report notes India is seeking private and foreign participation for ~15 GW of new reactor capacity. (Reuters)
- Repurposing old thermal-plant sites for nuclear capacity is also under consideration to expedite capacity addition. (The Economic Times)

E. Challenges & Constraints

- **High upfront capital cost & long construction time**: Nuclear projects take many years (often a decade or more) from approval to commercial operation, which lags behind faster ramp-up renewable options.
- **Fuel cycle and supply chain issues**: Uranium mining, enrichment, fuel fabrication, heavy-water production, waste management gear – all require sustained investment and domestic capability.
- **Regulatory and public acceptance hurdles**: Site selection, land acquisition, environmental clearances, local activism (especially near coastal or ecologically sensitive zones) cause delays.
- **Scale-up intensity**: Moving from ~8-10 GW to ~100 GW by 2047 demands vast investment, streamlined approvals, manufacturing, skilled workforce, and logistics.
- **Competitiveness**: Compared to renewables (solar & wind) which have seen dramatic cost declines, nuclear power must demonstrate cost-effectiveness and reliability benefits to secure market share. (AP News)

F. Key Figures & Facts for Exam

- ~8–9 GW nuclear capacity currently (2025) in India.
- Target ~22.4 GW by ~2031-32; long-term target ~100 GW by 2047.
- ~25 reactors in operation across ~7 sites.

- Nuclear share about 3% of electricity generation.
- Budget 2025: Major push for SMRs, private participation, domestic manufacturing.
- Challenges: lead time, cost, fuel cycle, approvals, local acceptance.

G. Implications for Mechanical/Power Plant Engineering Students

- **Design & maintenance**: As nuclear capacity expands, you will encounter more mechanical systems (reactor coolant loops, steam turbines, containment systems) requiring advanced engineering, maintenance and safety protocols.
- **Project management**: Understanding long timeframes, regulatory interfaces, integrated systems manufacturing becomes essential.
- **Fuel & technology transition**: Be aware of changing technology (e.g., moving to SMRs or breeder reactors) and how mechanical systems evolve (cooling, materials, modular design).
- **Safety & environment**: With nuclear, mechanical maintenance doesn't just mean operational uptime—it also means radiation safety, shielding, regulatory compliance, waste management, stringent quality control.

💡 Summary

India's nuclear power scenario is at a pivotal point. While the current capacity (≈8–9 GW) is modest, the planned expansion (to ~22 GW by early 2030s and ~100 GW by 2047) reflects a strategic intention to scale nuclear as a cornerstone of clean, reliable baseload power. For students studying power plant engineering, this means nuclear systems will increasingly become part of the mainstream power-plant engineering curriculum—not just in layout and fuel but in equipment design, regulation, lifecycle maintenance, and integration with other technologies.

Section 4.5 – Regulating Agencies & Regulations for Nuclear Power Plants

A. Key Agencies – Roles & Responsibilities

Atomic Energy Regulatory Board (AERB) – India

- AERB was established under the Atomic Energy Act, 1962 and is India's national regulatory body for nuclear and radiation safety. (aerb.gov.in)
- Its mission: "to ensure the use of ionising radiation and nuclear energy in India does not cause undue risk to the health of people and the environment." (aerb.gov.in)
- Scope of AERB's regulation: nuclear power plants, nuclear fuel cycle facilities, radiation applications (medical, industrial), waste management, decommissioning etc. (aerb.gov.in)
- Regulatory process: AERB follows consent/licensing/inspection at various phases – siting, construction, commissioning, operation, decommissioning. For example: licensing of nuclear facilities includes safety review of site, design, construction. (aerb.gov.in)
- They issue safety codes, standards and guides. For instance: "Regulation of Nuclear & Radiation Facilities" is a safety code developed by AERB. (aerb.gov.in)

International Atomic Energy Agency (IAEA)

- The IAEA is an international organisation under the United Nations system that develops and promotes international safety standards for nuclear installations, radiation protection, transport of radioactive material, waste management etc. (IAEA)
- It publishes the "Safety Standards Series" which includes:
  - *Safety Fundamentals*: high-level objectives and principles. (IAEA Publications)
  - *Safety Requirements*: what must be met to ensure safety. (IAEA Publications)
  - *Safety Guides*: how to implement the requirements. (IAEA)
- The IAEA also supports regulatory review services (e.g., IRRS – Integrated Regulatory Review Service) to evaluate national regulatory frameworks against their standards. (IAEA)

B. Regulation Methods & Mechanisms

- **Licensing / Consent Regime**: Before proceeding with major phases of a nuclear facility (e.g., siting, construction, operation, decommissioning), the regulator must grant consent/licence. AERB employs this approach. (aerb.gov.in)
- **Codes & Standards Development**: Regulators lay down standards/codes for design, construction, operation etc. AERB's "Safety Code No. AERB/SC/G – Regulation of Nuclear & Radiation Facilities" is an example. (aerb.gov.in)
- **Safety Reviews & Inspections**: Regular inspections, monitoring compliance, review of operational performance and design safety. AERB uses a "graded approach" (i.e., more severe regulation depending on hazard). (aerb.gov.in)
- **Legal & Regulatory Framework**: The national regulator works under legislation (Atomic Energy Act etc) and issues regulations/rules. IAEA emphasises countries must have effective independent regulatory bodies. (Office for Nuclear Regulation)
- **International cooperation & peer review**: Through IAEA frameworks (safety standards, conventions) nations align their regulatory regime to global best practice. (IAEA)

C. Why It's Important for Power Plant Engineering Students

- Engineers must design, operate, maintain nuclear power plants *within* strict regulatory frameworks. Understanding regulation is essential for ensuring safety, compliance, reliability.
- Mechanical/plant engineering decisions (choice of materials, component design, layout, systems integration, backup systems) must satisfy regulatory codes and safety standards.
- Regulatory requirements affect cost, project timeline, maintenance regimes, life-extension, decommissioning — so they tie in with economics (CO5) as well as safety (CO4).
- The evolving regulatory context (new technologies like SMRs) means engineers must stay updated on codes, licensing, oversight.

Unit IV – Final Summary (Hinglish)

Nuclear Power Plant (Unit IV) ka ek summary aapke liye Hinglish mein:

4.1 Introduction, Site-Selection, Fuel & Layout

Nuclear power plant wo facility hai jahan fossil fuel nahi, balki **nuclear fission** ke through heat generate hoti hai, jo steam bana ke turbine chalaati hai. Site select karna bahut important hai: water supply honi chahiye, seismic hazard low hona chahiye, population se safe distance ho, infrastructure acchi ho. Fuel types: natural/enriched uranium, MOX, aur India ke liye important hai thorium fuel strategy. Layout mein reactor building, steam generation, turbine-generator, cooling system, waste storage sab included hote hain.

4.2 Nuclear Reactor Types: PWR & BWR

- **PWR (Pressurized Water Reactor)**: Core mein water bahut high pressure mein hota hai (boil nahi hota) aur heat steam generator ke through secondary loop mein transfer hoti hai, phir turbine chalti hai.
- **BWR (Boiling Water Reactor)**: Core mein water directly boil hota hai, steam directly turbine ko feed hoti hai.
  Dono ka working principle similar hai (fission → heat → steam → turbine → electricity) lekin loops, pressure levels, maintenance aspects alag hain.

4.3 Nuclear Waste & Disposal

Nuclear fuel use ke baad waste banta hai: low-level, intermediate-level, high-level wastes. Inka treatment hona chahiye: spent fuel pools, dry cask storage, vitrification, geological disposal. Long term safety, environmental protection aur public health ke liye waste disposal policies essential hain.

4.4 Present Nuclear Power Scenario in India

India ke paas abhi approx ~8-9 GW ki nuclear capacity hai (jo electricity generation ka ~3% hai). Lekin target bahut bada hai: 2031-32 tak ~22 GW aur 2047 tak ~100 GW nuclear capacity achieve karne ka plan hai. Nuclear power India ke energy mix mein low-carbon baseload generation provide karta hai, lekin challenges bhi hain jaise capital cost, fuel cycle, approvals, public acceptance.

4.5 Regulating Agencies & Regulations

India mein regulatory body hai AERB, jo nuclear/radiation facilities ko regulate karti hai jisse safety, environment aur public health safe rahe. International level par International Atomic Energy Agency (IAEA) hai, jinhone globally safety standards banaye hain. Licensing, codes & standards, inspections, peer reviews in sab methods se plants safe operate hoti hain.

Diploma Wallah

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