ANNEXURE - 1

LECTURE-1

The legislative framework for nuclear energy in India

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Three important terms

- In nuclear parlance, we use three terms: safeguards, security and safety.
- Safeguards refer to nuclear material accounting.
- Security refers to the physical protection of nuclear material and facilities.
- Nuclear safety refers to achieving proper operating conditions, preventing accidents and mitigating their consequences to protect workers, the public and the environment from undue radiation risk.
- The safety and physical security of nuclear facilities and material are important.
- Issues influencing the increased exploitation of nuclear power are safeguards and export controls. Both are linked to NPT. (However, they predate NPT)

The complexity of the nuclear regime

- The global nuclear regime is complex, comprising international treaties, UN resolutions, guidelines of the International Atomic Energy Agency, standards of the International Commission on Radiation Protection, and informal understandings.
- India is engaged in harnessing nuclear science and technology for the welfare of the nation, and while doing so, has honoured its legal obligations and informal understandings.
- Also, India has demonstrated a commitment to safety following a science-based approach to regulation. This must continue when India expands the role of nuclear power.
- The regime's influence on nuclear power arises because of the intertwining of the nuclear fuel cycle for generating electricity and nuclear weapon technologies. This influences the growth of nuclear power.

Non-Power Applications

- Non-power applications of nuclear science and technology are important, but the regime does not influence their use. Applications are in the areas of health care (diagnosis, therapy, and sterilisation), industry (scanning, gauging, cross-linking within polymer molecules, etc.), agriculture (mutation of seeds, fertiliser uptake studies, food preservation, etc.) and research. You can see the Annual Report of AERB to see the latest numbers.

The evolution of the nuclear regime: early developments

- Trinity tests on 16 July 1945; Use of weapons on 6 and 9 August 1945 in Japan.
- Acheson-Lilienthal report, 1946

"The development of atomic energy for peaceful purposes and the development of atomic energy for bombs are in much of their course interchangeable and interdependent."

"A system of inspection superimposed on an otherwise uncontrolled exploitation of atomic energy by national governments will not be adequate safeguard."

- The UN Charter does not mention nuclear weapons, as it was concluded about three weeks before the Trinity test.
- **Atoms for Peace**: speech to UNGA by US President Eisenhower – 1953 – proposed an IAEA. It combined sharing with surveillance. The "Atoms for Peace" evolved into "**Control over the atom even when used for peace**".
- The Eighteen-Nation Committee on Disarmament (ENCD) was sponsored by the United Nations in 1961. ENCD negotiated NPT. By 1964, there were five nuclear powers in the world.
- **The treaty on the non-proliferation of nuclear weapons** was drafted and opened for signature on 1 July 1968. It entered into force on 5 March 1970. It was extended indefinitely on 11 May 1995.
- These dates are important. India enacted the Atomic Energy Act in 1962.

Nuclear regime that resulted from the treaty

- Five states recognized as Nuclear Weapon States. For this Treaty, an NWS is one which has manufactured and exploded a nuclear weapon or other nuclear explosive device before 1 January 1967.
- Nuclear programmes of NNWS only under safeguards by IAEA. Safeguards obligations are met by signing comprehensive safeguards agreements.
- Facility-specific safeguards agreements for countries that are not a Party to NPT. Safeguards agreements are intended to prevent the diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices.
- The Zangger Committee was set up in 1971 to implement export controls. Zangger's understandings establish lists of material and equipment and three conditions for the supply: a non-explosive-use assurance, an IAEA safeguards requirement, and a re-transfer provision that requires the receiving State to apply the same conditions when re-exporting these items.
- The Nuclear Suppliers Group was set up in 1975; it adopted guidelines for international trade in nuclear technology. It was inactive during the period 1975 – 1992. It established a framework for dual-use items in 1992. NSG guidelines require the application of full-scope safeguards as a condition for nuclear supplies. It thus goes beyond NPT.

Problems with the treaty

- Absence of an explicit prohibition on deploying nuclear weapons in territories of third states, sharing of nuclear forces, and providing guarantees to allies.
- Lack of provisions to curb vertical proliferation, both qualitative and quantitative, by NWS.
- NWS didn’t agree to give a strong commitment to disarmament in response to the renunciation of nuclear weapons by NNWS.
- 1995 Review and Extension Conference extended NPT indefinitely. Over the years, NPT has been supplemented by strengthened safeguards by IAEA, guidelines of the Nuclear Suppliers Group, and national export control legislation, but there has been no progress toward disarmament.

India and the NPT

- India was a member of the Eighteen Nation Committee on Disarmament and took active part in drafting the treaty.
- China detonated first nuclear weapons on October 16, 1964 at the Lop Nur test site. It was a uranium-235 implosion fission device made from weapons-grade uranium (U-235) enriched in a gaseous diffusion plant in Lanzhou. The bomb had a yield of 22 kilotons.
- India looked for security guarantees and they were not forthcoming. Therefore, India decided not to sign the NPT. Calls on India to join NPT are being made even now. (Jayita Sarkar, Ploughshares and Swords, Cornell University Press, 2022)
- Atal Bihari Vajpayee in Lok Sabha on 27 May 1998, “India is now a nuclear weapon state. This is a reality that cannot be denied. It is not a conferment that we seek; nor is it a status for others to grant. It is an endowment to the nation by our scientists and engineers.”
- In response to a question from Fareed Zakaria on GPS show on 29 November 2009, Manmohan Singh stated that India was prepared to join NPT as a sixth NWS.

Evolution of the nuclear regime

- The Treaty on the Non-Proliferation of Nuclear Weapons (NPT), entered into force in 1970, eight years after the Atomic Energy Act of 1962; The Comprehensive Nuclear Test-Ban Treaty (CTBT) was negotiated and signed, but has not entered into force. It can be considered dead; The Fissile Material Cut-off Treaty (FMCT) is a proposed international agreement designed to ban the future production of highly enriched uranium and plutonium, the key components for nuclear weapons.
- No progress toward disarmament. No (qualitative and quantitative) checks on vertical proliferation. However, instruments that are restrictive for Non-Nuclear-Weapon States (NNWS) are thriving.
- Nuclear Suppliers Group. Export controls: reporting obligations for governments.
- Safeguards (Comprehensive, facility-specific), Strengthened safeguards (Additional Protocol).
  - Safeguards and export controls are linked to NPT. (However, they predate NPT).
- Guidelines of the International Atomic Energy Agency, standards of the International Commission on Radiation Protection.
- Nuclear Security Summit process. Strengthened security regime. Convention on the Physical Protection of Nuclear Materials and its 2005 amendment.

Where do we stand today?

- India conducted nuclear tests in 1998.
- An intense diplomatic activity followed to ensure a growing acceptance of India as a responsible nuclear power. These efforts led to NSG revising its guidelines in 2008 to facilitate international civil nuclear trade with India.
- This was a reversal of its 1995 decision and resulted in the restoration of facility-specific safeguards.
- This removed a major constraint for the expansion of the nuclear power programme. In parallel, NPCIL has developed the 700 MW PHWR. Its supply chain is in India.
- Having overcome the uranium availability constraint and met the challenge of developing indigenous technology, India is ready for an ambitious nuclear power programme.

Implications of safety, security and safeguards

- There is no issue with the implementation of provisions related to safety and security. With the implementation of safety measures, plant safety and plant capacity factors have improved.
- Security is a necessity due to the prevailing geopolitical scenario.
- Compliance with safeguards provisions is burdensome.
- Why safeguards? One needs to recall the fundamentals of physics: the fission reaction and the concept of a critical mass.
  - By appropriate engineering, only about 5 kilograms of nearly pure or weapon-grade plutonium-239 or about 15 kilograms of uranium-235 is needed to achieve critical mass.

A summary of major international commitments – 1

- Safeguards
  - Agreement between the Government of India and the International Atomic Energy Agency for the Application of Safeguards to Civilian Nuclear Facilities. INFCIRC/754, 29 May 2009.
  - Protocol Additional to the Agreement Between the Government of India and the International Atomic Energy Agency for the Application of Safeguards to Civilian Facilities, INFCIRC/754/Add.6, 1 August 2014.
  - INFCIRC/754/Add.12, 13 January 2023. List of facilities.
- Security
  - Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Rev. 5), 2011.
  - Convention on Physical Protection of Nuclear Material and its 2005 amendment
- Safety
  - Convention on Nuclear Safety and there are several documents and guides by IAEA.

A summary of major international commitments – 2

- Civil Liability for Nuclear Damage
  - Convention on Supplementary Compensation
- Statement by EAM on Civil Nuclear Initiative (05 September 2008)
  - “We have in place an effective and comprehensive system of national export controls, which has been constantly updated to meet the highest international standards. This is manifested in the enactment of the Weapons of Mass Destruction and their Delivery Systems Act in 2005. India has taken the necessary steps to secure nuclear materials and technology through comprehensive export control legislation and through **harmonization** and **committing to adhere** to Missile Technology Control Regime and Nuclear Suppliers Group guidelines.”
  - “India will not be the source of proliferation of sensitive technologies, including enrichment and reprocessing transfers.”

A summary of major international commitments – 3

- Export Controls
  - On 8 Sept 2008, FS wrote to DG, IAEA, enclosing various documents related to India's export controls.
  - On 9 May 2016, PMI, Vienna, wrote to DG, IAEA, enclosing an updated version of documents related to export controls, and Acts related to Atomic Energy, WMD, etc. This communication also says, "India would like to convey its decision to continue to act in accordance with the NSG Guidelines …."
  - As per the NSG website, the date of adherence to NSG guidelines by India is 9 May 2016, the date when PMI, Vienna, wrote to DG, IAEA.
  - Accordingly, India has been periodically updating its export controls to ensure that they are harmonious with NSG Guidelines.

Any person engaged in atomic energy must take cognisance of safety, security, safeguards, export controls, civil liability for nuclear damage, etc. All this is built into the SHANTI Act. The Act has placeholders to provide details in Rules, Regulations and Notifications.

The legislative framework transparently informs newcomers about their duties and liabilities.

A Message to Newcomers

"For a successful technology, **reality must take precedence over public relations**, for nature cannot be fooled." Richard Feynman.

- Nuclear technology is unforgiving and needs **long-term commitment**. There is no place for indulging in **regulatory tricks**.
- For example, no one can fudge the half-life of a radioisotope, or circumvent the fact that prompt neutrons are emitted within about 10^{-14} seconds.

The nuclear power programme in India has matured, underpinned by its strengths in nuclear science and technology, industrial prowess, and responsible conduct of atomic affairs, including export controls, safeguards, safety, and security. All newcomers must adhere to responsible conduct.

The Message: The nuclear industry can thrive only if we imagine, conceive and pursue it as a well-regulated engineering endeavour.

The SHANTI Act

Salient features of the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India Act, 2025

The long title: An Act to provide for the promotion and development of nuclear energy and ionizing radiation for nuclear power generation, application in healthcare, food, water, agriculture, industry, research, environment, innovation in nuclear science and technology, for the welfare of the people of India, and for robust regulatory framework for its safe and secure utilisation and for matters connected therewith or incidental thereto.

The Act has a long preamble that,

- informs about the responsible pursuit of nuclear energy by India with an excellent record in nuclear safety and radiation safety;
- describes nuclear energy as clean and abundant;
- reiterates ongoing pursuit of a closed fuel cycle to enable sustainability of nuclear fuel resources;
- underlines India’s commitment to enhance the share of nuclear energy in the energy mix;
- highlights applications of nuclear science and technology in energy, healthcare, food, water, agriculture, research, etc.
- notes the desirability to harness the potential of nuclear energy through active involvement of both private and public sectors.

The private sector participation

- Both public and private sectors to own and operate nuclear power plants under a license by DAE, and safety authorisation by the Board.
- The source material and the fissile material remain under the surveillance and control of the Central Government and prescribed safeguards.
- Spent fuel to be delivered to the Central Government.
- Heavy water used in a nuclear facility is to remain under the supervision of the Central Government.
- It permits research, development and innovation by the private sector.
- Reprocessing and heavy water production to remain under the Central Government. Enrichment up to a certain threshold may be allowed, but only after a notification has been issued.
- It allows private sector participation, but maintains strategic control over sensitive technologies in line with the responsible path India has followed in nuclear affairs.

Licensing framework to be prescribed

- Section 7 (1): …the Central Government may grant a licence in such manner and subject to such terms and conditions as may be prescribed, including compliance with the financial, technical, management and other organisational capabilities covering the aspects of design, construction, commissioning, operation, maintenance, life management, decommissioning, quality assurance, radioactive waste management, liability, security, as it may deem necessary, for the entire life time of the facility or mine.
- This calls for developing a licensing procedure. That is work in progress.

Guardrails have been built in

- Section 7(4)…no licence may be granted to—

  (a) any company, if the Central Government knows or has reason to believe that it is owned, controlled or dominated by entities who are inimical to defence and national security, or health and safety of the public;

  (b) any person in India, if in the opinion of the Central Government, the issuance of a licence to such person would be inimical to defence and national security, or health and safety of the public.

- Section 8 provides for suspension or cancellation, etc. of a license or safety authorisation.
- Private companies incorporated outside India are not permitted to operate nuclear facilities (Section 2(9) of the Act defines "company" by reference to Section 2(20) of the Companies Act, 2013, and expressly excludes companies incorporated outside India.)

Duties and liabilities have been specified in Section 10

- Every person who has been granted a licence or safety authorisation under this Act, shall
  - comply with the terms and conditions of the licence and safety authorisation and the rules, regulations, orders and regulatory documents issued under this Act in respect of safety, security and safeguards, quality assurance and control, radioactive waste management, decommissioning of the facilities, and maintaining design support throughout the lifetime of the facility or mine;
  - maintain sufficient financial security in the prescribed form for waste management, decommissioning, settlement of claims caused by radiation, etc.

Overall, the Act ensures that the prime responsibility for safety, security, and safeguards lies with the licensee or the employer of the facility, etc.

General powers and functions of the Central Government

- Framing of the national nuclear energy policy consistent with the National Electricity Policy.
- Framing of national policy for **safety, security and safeguards**.
- Framing the national policy for management of spent fuel and radioactive waste.
- Framing policies for quality assurance and quality control of facilities.
- Establishing Directorates, Wings and Divisions under it as necessary (for providing services related to environmental surveillance, personnel monitoring, dosimetry and other matters related to radiological protection, etc.).
- Coordinating and supporting Government agencies to ensure nuclear and radiological emergency preparedness and response.

Safety Regulation

- The Act established the regulator, 'AERB', under section 17.
- Powers and functions of AERB are defined in section 24.
- AERB empowered for entry and inspection (Section 28), conduct of investigation (Section 29), etc.
- It provides for a separate regulation for the strategic sector (Section 25).
- It established an Atomic Energy Redressal Advisory Council (Section 47).
- The Appellate Tribunal (APTEL) for Electricity established under section 110 of the Electricity Act, 2003, has been designated as the Appellate Tribunal under the Act (Section 49).
- Beyond APTEL, an aggrieved person can go to the Supreme Court (Section 52).
- This results in a four-tier adjudication architecture.

The CLND Act has been merged into it

- The basic principles of liability remain the same as earlier. Basic principles: Liability is strict, based on the principle of no-fault, channelled only to the operator, liability is limited in amount and time during which claims have to be filed, the regulatory body is to notify an incident (parameters for such announcement have already been notified), and a single court of jurisdiction. (Chapter 3). Specifies liability amounts in the second schedule.
- Right of recourse is left to the operator and supplier to negotiate (Section 16). This can be based on specific technology under negotiation.
- Provides for a review of liability amount having regard to deployment of nuclear installations with advanced technology, enhanced safety features and other relevant criteria. Section 83 (1) (b).
- Section 14 of the Act places the liability beyond the Second Schedule on the Union Government, thereby limiting the scope of exposure for operators, but not the compensation to be paid to victims. Sub-section (2) of section 14 provides for establishing a Nuclear Liability Fund. While developing Rules, one can elaborate about the use of the Fund. That can include contributions to CSC when an accident takes place elsewhere.

Limits of Liability of the Operators for Different Categories of Nuclear Installations

Sl. No.	Categories of nuclear installation	Limit of operator’s liability (INR) in crore
1.	Reactors having thermal power above 3600 MW	3000
2.	Reactors having thermal power above 1500 MW and up to 3600 MW	1500
3.	Reactors having thermal power above 750 MW and up to 1500 MW	750
4.	Reactors having thermal power above 150 MW and up to 750 MW	300
5.	Reactors having thermal power up to 150 MW, fuel cycle facilities other than spent fuel reprocessing plants and transportation of nuclear materials.	100

Supplementary information

- Fuel ownership: See Section 3.(4)(a).
- High-energy radiation generating equipment: Section 4(2)
- Tariff: See section 37(1)
- Licensing terms and conditions: See Section 7 (1).
- Provisions to deny a license: See Section 7 (4).
- Provisions to cancel a license: Section 8.
- Government may establish directorates, wings and divisions as necessary to carry out various functions. Section 32.
- Section 42 deals with the Occupational Safety, Health and Working Conditions Code, 2020.

Summary

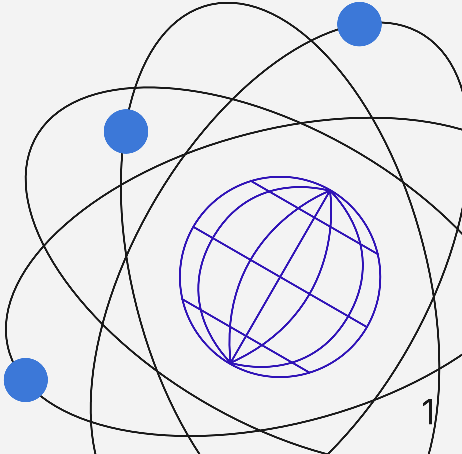
- Single law: The Act consolidates regulation, enforcement, civil liability, and dispute resolution within a single statute. It transparently informs licensees about duties and liabilities.
- It separates permission to establish a facility from authorisation to operate it safely, requiring both a license and safety authorisation.
- Clear licensing regime and a statutory regulator. A four-tier adjudication architecture.
- Central control on core functions as they involve sensitive technologies.
- The Act embeds safety oversight across the entire lifecycle of nuclear facilities.

Thank you

LECTURE -2

Indian Nuclear Power Programme: Journey so far (1944-2026)

-Mukesh Singhal, Ex-CMD(i/c), NPCIL



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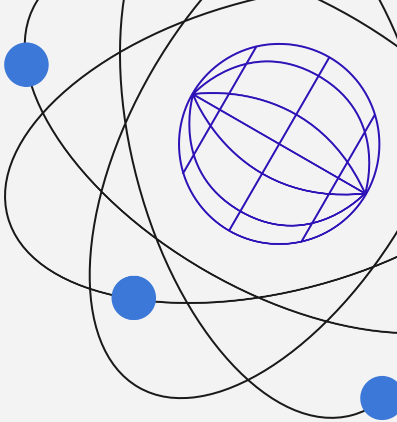


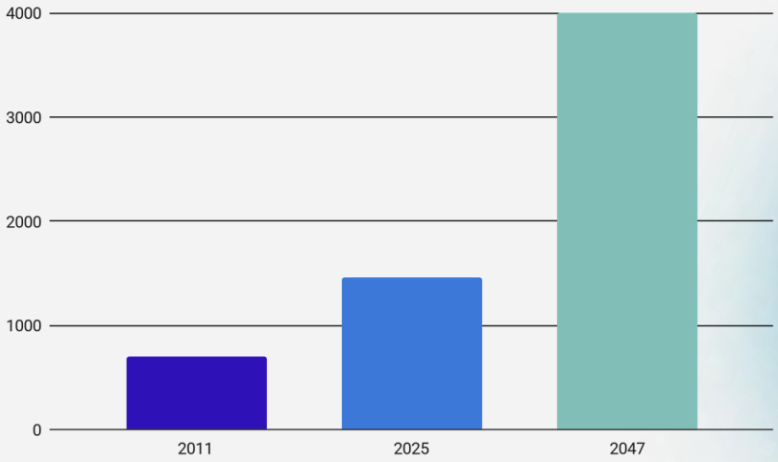
1

Importance of Nuclear energy in India

India needs ~3x energy by 2047 to become a developed country

- India being the most populous country of about 1.46 billion population, with GDP growth rate 6-8% needs large electricity expansion plan
- Correlation exist between Human Development Index (HDI) and per capita energy consumption

Per Capita Electricity Consumption across years (kWh per year)



Nuclear energy is the green energy of choice

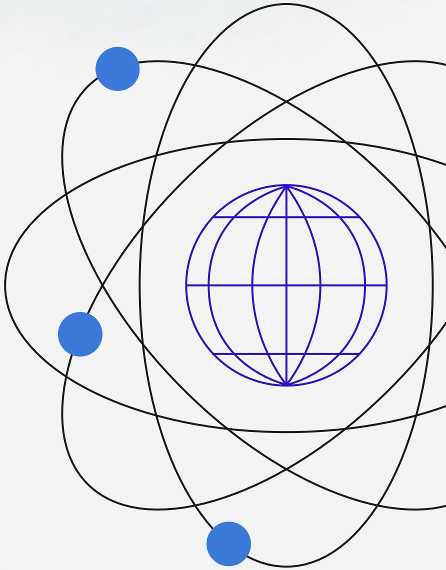
- To meet energy demand, all resources need to be explored to their full capacity
- Climate change arising out of greenhouse gases is among the most important challenge facing the world today
- India is committed to have net zero target by 2070; under this the first target is to have 100 GWe Nuclear Power by 20247
- Life cycle emissions (from mining of ore to waste disposal) of nuclear power are very low: 2.5-5.7 gCeq/kWh vs 206- 357 gCeq/kWh for coal and 106-188 gCeq/kWh for gas technologies
- Baseline CO2 emissions in India from the predominant technology, coal, are ~ 1kg/kWh
- Thus, every unit of nuclear power generated saves ~1 kg of CO2 emissions
- Nuclear Power is benign and life cycle GHG emission of nuclear power is comparable to Solar and wind

2

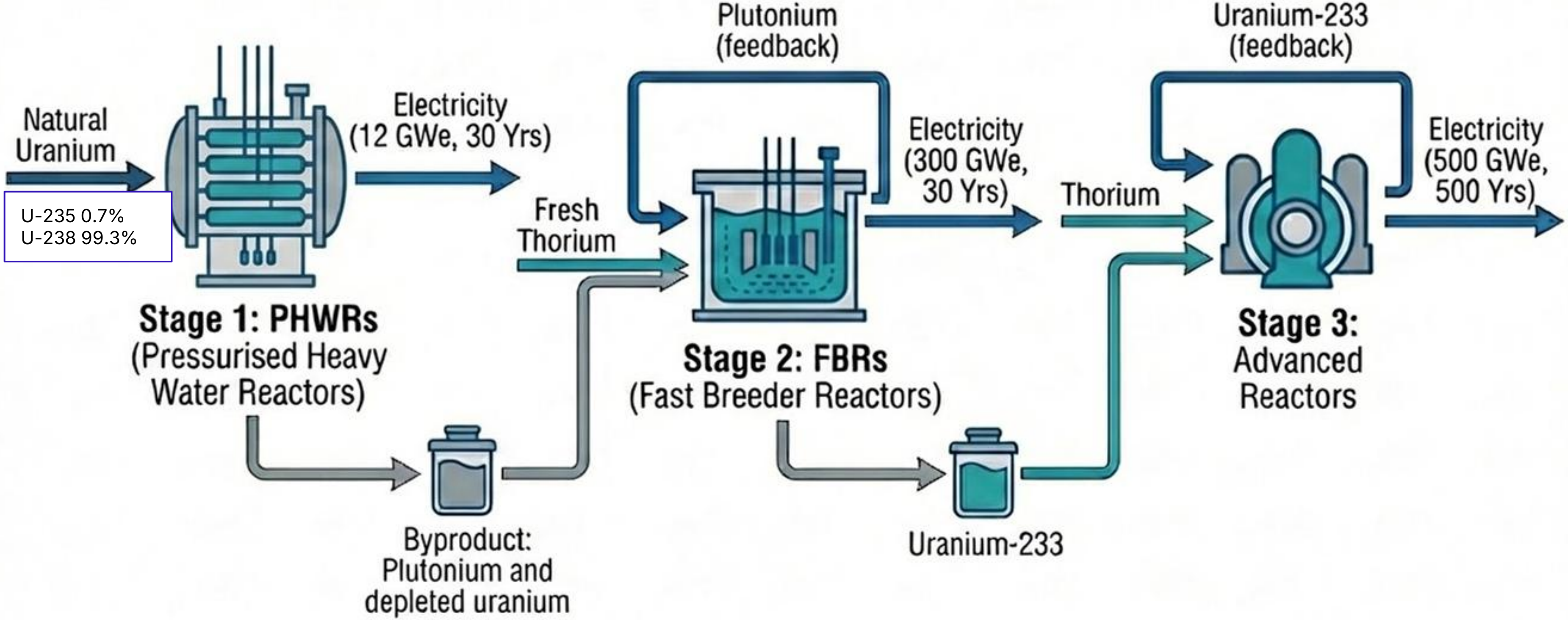
Guiding principle of Indian Nuclear programme

In 1944, Dr H J. Bhabha, the father of Indian Nuclear programme, addressed a letter to Sir Dorabji Tata Trust, outlining the urgent need to initiate nuclear research in India to keep abreast with international developments

Subsequently, in 1948, Atomic Energy Commision was constituted and exploration of availability of raw material resources was one of the key tasks



With limited Uranium but vast Thorium, Dr. Bhabha conceived a three-stage Indian Nuclear programme



In 1954, DAE was established for required infrastructure for Nuclear Programme: various plants and institutions

3

Evolution of Nuclear Power Plants

Stage 1 reactors: Across operation; construction and pre-project phases

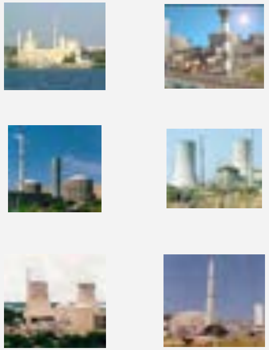
Operational NPPs
8800MWe

BWR
2

PHWR
21

VVER
2

220 MWe	540 MWe	700 MWe
RAPS-1&2	TAPS-3&4	KAPP-3&4
MAPS-1&2		RAPP-7
NAPS-1&2		
KAPS-1&2		
RAPS-3&4		
RAPS-5&6		
KGS-1&2		
KGS-3&4		



Construction NPPs
6100MWe

VVER
4

PHWR
3

700 MWe
RAPP-8
GHVAP-1&2

Pre project NPPs
7000MWe

PHWR
10

700 MWe
Kaiga 5&6 Mahibanswara 1-4 Others 4

Fleet mode 2 also approved

1

BWR: India's 1st Nuclear power reactor, world's oldest optg reactor; soul of Indo-US nuclear deal

- First nuclear power project was commenced at Tarapur, Maharashtra (TAPS-1 & 2) in 1964 and the reactor type chosen was Boiling Water Reactor (BWR)
- India figured on the nuclear map of the world in 1969, when these BWRs, TAPS-1 and TAPS-2, were commissioned at Tarapur Atomic Power station (TAPS)
- TAPS-1&2 were turnkey projects from General Electric (GE), USA, which were to be handed over on completion to DAE for operation and maintenance
- The main objectives of setting up these units were to
  - prove techno economic viability of nuclear power
  - obtain experience in operation and maintenance of nuclear power plants and
  - demonstrate technical viability of operating nuclear stations in Indian regional grid
- All the components of the power plant and nuclear fuel were imported and the role of Indian industries was limited to construction, erection and service contracts
- Health assessment carried out with advanced technique; plant life extended with suitably replacing the components including recirculation pipes/ upgrading and enhancing safety systems
- Generated 100 billion units of clean energy.
- **Cheapest power in India at < INR 2/unit**

PHWR: Main Stage 1 reactor; in-house R&D expertise; world's longest 962 days optg record until 2020 (I/III)

- As a part of main thrust of developing PHWR designs, Rajasthan Atomic Power Station (RAPS) consisting of two units, RAPS-1 and RAPS-2, was taken up as a joint Indo-Canadian venture in 1960s, at Rawatbhata, Rajasthan
- Canada furnished nuclear designs and supplied all the main equipment for the first unit
- India retained responsibility for construction, installation and commissioning activities.
- For the second unit (RAPS-2), manufacture of components was taken up in India and the import content was reduced considerably.
- Canada withdrew support for the plant in 1974 due to the Pokhran tests
- Indian engineers carried out remainder of the design, construction and commissioning work of the RAPS second unit
- Madras Atomic Power Station (MAPS) consisting of two units, MAPS-1 and MAPS-2, at Kalpakkam, Tamilnadu, India had started carrying out all facets of the work on its own
- Notable number of design changes were incorporated at MAPS; improved reactor designs were developed to keep abreast with evolutionary changes worldwide

PHWR: Main Stage 1 reactor; in-house R&D expertise; world's longest 962 days optg record until 2020 (II/III)

- To establish PHWRs at various sites in different electricity regions of the country, it was also necessary to evolve designs that met site specific environmental and seismic criteria
- For simultaneous construction, it became necessary to evolve a standardized design
- Improvements were incorporated to enhance reliability of operation and productivity, reduce costs and attain better capacity factors
- The first two units of PHWR using indigenously developed standardized 220 MWe plant design were set up at the Narora Atomic Power Station (NAPS)
- Three more twin units with capacity of 2 x 220 MWe each, were built and commissioned at Kakrapar, Kaiga and Rawatbhata using indigenous technology
- Subsequently, two more twin units with similar capacity were built
- Successful commissioning and subsequent operation of these stations clearly demonstrated India's mastery in the technology involved and commercial capability
- This also established nuclear power as a safe, environmentally benign and economically viable source of power that offers energy security for the country

PHWR: Main Stage 1 reactor; in-house R&D expertise; world's longest 962 days optg record until 2020 (III/III)

- To realize economy of scale, design for 540 MWe PHWR was developed and construction of two such units was taken up at Tarapur
- Construction of these units in a record time in line with international benchmark and later smooth commissioning and successful operation confirms maturity achieved in design, development and construction and commissioning of nuclear power plants
- In order to further optimize the cost of electricity production by exploiting economy of scale, NPCIL has modified the 540 MWe PHWR design to that of 700 MWe capacity
- Three units of this design are being operated at present at Kakrapar and Rawatbhata. Fourth unit is in advance stage of commissioning at Rawatbhatta
- Two units are being set up at Gorakhpur, Haryana site
- Futurer, PHWR programme: 10 Reactors in fleet mode (Kaiga 5&6, Mahibanswara, Gorkharpur, Chhutka) will essentially use this design
- 10 more units on existing sites in fleet mode are being lined up

2

PHWR: Upgradation and renovation is key to extending the life of NPPs

- Aging Management programme is in place involving inspection and planned replacement
- Cost of renovation vs cost of shutdown- important changes done together
- Enmass Coolant Channel Replacement with better material in short planned period
- Feeder thinning Observed first, in Canadian Reactors in 1995
- Appropriate measures taken in upgradation, renovation and modernisation
- Besides routine maintenance special repair/ maintenance was taken up in mission mode
  - Repair of RAPS-1 End-shield
  - Introduction of Spargers in MAPS-1&2
  - Repair in Kaiga-3 End-shield

3

VVER (LWR): Rapid expansion of nuclear energy within Stage 1 programme

- To accelerate growth of nuclear power capacity using uranium based thermal reactors, 2 X 1000 MWe VVER reactors are commissioned and operated at Kudankulam with the cooperation of the Russian Federation
- 4 X 1000 MWe VVER reactors of similar design are being installed at Kudankulam
- Similarly, it is planned to install large size Light Water Reactors (LWRs) through international cooperation
- These plants are an additionality to the indigenous PHWR programme of first stage
- Discussion and negotiations are being held with EDF, France for six units of 1600 MWe at Ratnagiri site, Maharashtra
- Discussion and negotiations are being held with westinghouse, USA for six unit at Kovada site, Andhra Pradesh

Stage 2 reactors: Fast Breeder Reactor Programme in its initial phase

- For initiating second stage programme, plutonium reprocessing facility was inaugurated at BARC in 1965
- Critical facility/ Research reactor utilising Plutonium fuel was developed as ZERLINA/ ZERLINA-2 in 1972
- To gain first hand experience in Fast Reactor Technology, Fast Breeder Test Reactor (FBTR) was constructed and commissioned at Kalpakkam in 1985 utilising indigenous Plutonium Uranium mixed carbide fuel
- This provided valuable design and operational experience besides high burnup fuel, demonstrating the breeding capability.
- Prototype Fast Breeder Reactor (PFBR) was initiated in 2004 at Kalpakkam and is in advance stage of commissiong
- This stage will have its importance till all depleted Uranium gets converted into plutonium

Stage 3 reactors: Full fledged utilisation of Thorium in its R&D phase

- As a part of studies with 233U fuel, a 30 kW pool type research reactor, KAMINI (Kalpakkam MINI), was designed and built
- Prior to this, a mock up of the core of this reactor, was built and made critical in April 1992. It was given the name PURNIMA-3
- KAMINI was made operational in 1996. This reactor is being extensively used as a neutron source for research applications such as neutron radiography of irradiated nuclear fuel
- Full fledged stage 3 will take control after depletion of Uranium/Plutonium in stage-2

4

Evolution of Nuclear safety

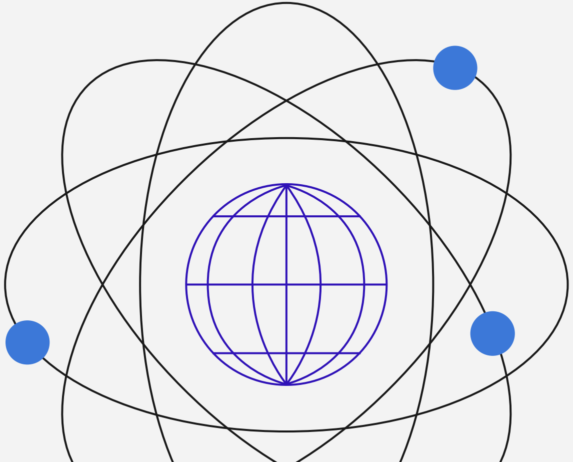
Fundamental safety objective: Protect people & environment of harmful effect of ionizing radiation

This fundamental safety objective has to be achieved without unduly limiting

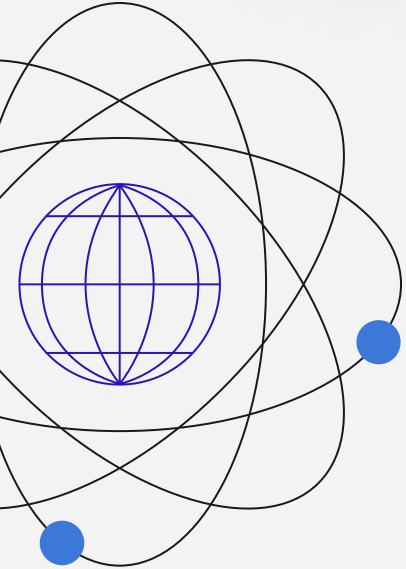
- the operation of facilities or
- the conduct of activities that give rise to radiation risks

To achieve fundamental safety objective in all stages of Nuclear facilities, 10 safety principles have been formulated

The genesis of Nuclear Reactor safety in NPP is that **fuel should be cooled at all given times and the radioactive fission products and minor actinides are confined** within the plant



10 Safety Principles



1. Responsibility for safety
2. Role of government
3. Leadership and management for safety
4. Justification of facilities and activities
5. Optimization of protection
6. Limitation of risks to individuals
7. Protection of present and future generations
8. Prevention of accidents – with provisions of Defence-in-Depth
9. Emergency preparedness and response
10. Protective actions to reduce existing or unregulated radiation risks

Defense in depth: Reduces the probability of an accident equivalent to a star falling on earth

Levels	Objective	Essential means
Level-1	• Prevention of abnormal operation and failures	• Conservative design and high quality in construction and operation
Level-2	• Control of abnormal operation and detection of failures	• Control, limiting and protection systems and other surveillance features
Level-3	• Control of accidents within design basis	• Engineered safety features and accident procedures
Level-4	• Control of severe plant conditions, including prevention of accident progression and mitigation of the consequence of severe accidents	• Complementary measures and accident management
Level-5	• Mitigation of radiological consequences of significant releases of radioactive materials	• Off Site emergency response

TMI

Chernobyl

Fukushima

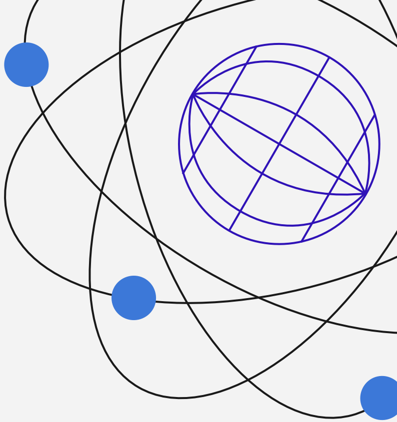
Evolution with experience from Fukushima

- Lesson learnt from Fukushima accident and outcome of safety reviews post Fukushima utilized for safety enhancement of Indian NPPs
- Safety review post Fukushima focused on
    - Unavailability of designed power supplies and
    - Unavailability of designed water sources
    - Extreme external events and margin assessment
- Safety enhancements were identified for implementation in phases and completed

Safety is ensured at multiple levels, all independent

- Deterministic and probabilistic safety assessments
- Multi Layer Safety review: SORC, Corporate Review, WANO review, IAEA Review
- Independent multi-tier safety reviews & the detailed process of authorizations for new plants and periodic safety reviews of operating units by Atomic Energy Regulatory Board (AERB) add value and maintain vigil on all aspects of safety
- Safety encompasses all the stages of the nuclear power plant execution from siting, design, construction, testing, commissioning and operation to eventual decommissioning
- Very important for all layers to be independent because nuclear accidents are not merely an accident they can be a disaster
- The releases to the environment have been a small fraction of the limit prescribed by the Atomic Energy Regulatory Board (AERB)
- PHWR are the safest wrt to severe accidents

5 Importance of R&D in Nuclear energy



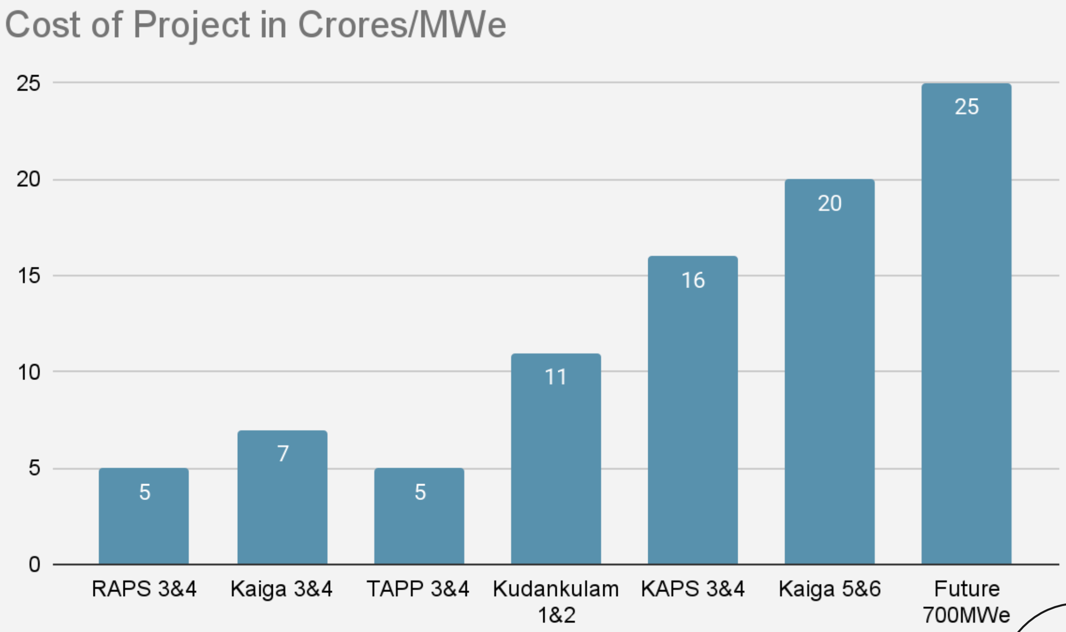
Evolution of R&D: India has acquired expertise in the entire range of nuclear fuel cycle activities

- Various units of DAE have a strong R&D base; in-fact due to technology denial regime over a period of time, it has become much stronger
- R&D activities pertain to wide range of material testing, conceptual design, pilot studies, design verification, validation data generation, system performance and various first of a kind activities
- International collaboration through various agencies, where ever possible is extended, namely, IAEA, WANO, COG, ITER, OECD-NEA
- Capability in all aspects of R&D and safety design, reactor physics design and engineering design was demonstrated in the country
- Strong R&D base is one of the important assets in the nuclear field
    - Any abnormal event happened during the plant life is examined in detail and reasons are well understood before implementing corrective measures.
    - This is one of the major strength leading to sustain long operation and scaling up of the PHWRs capacity
    - Which brought the indigenous nuclear power programme to maturity

6 Tariff and project cost across reactors

Tariff and project cost across reactors

Power Station	Tariff (P/kWh)
Tarapur Unit-1,2	192
Madras Unit-1&2	261
Rajasthan Unit-2,3,4	334
Narora Unit-1&2	299
Rajasthan Unit-5,6	392
Tarapur Unit-3,4	290
Kaiga Unit 1 to 4	348
Kudankulam 1&2	412
KAPP 3&4	450
Average Tariff for year 2023-24	383
RAPS 7	525



Capital Costs: Breakdown by activity for PWR

Design, architecture, engineering and licensing	5%
Project engineering, procurement and construction management	7%
Construction and installation works:	
○ Nuclear island	28%
○ Conventional island	15%
○ Balance of plant	18%
Site development and civil works	20%
Transportation	2%
Commissioning and first fuel loading	5%
Total	100%

Source WNA

Capital Costs: Breakdown by labour, goods, and materials for PWR

- Equipment
  - Nuclear steam supply system 12%
  - Electrical and generating equipment 12%
  - Mechanical equipment 16%
  - Instrumentation and control system (including software) 8%
- Construction materials 12%
- Labour onsite 25%
- Project management services 10%
- Other services 2%
- First fuel load 3%
- Total 100%

Source WNA

Summary | Key achievements

Taps-1&2, being the oldest station in the world, are operating satisfactorily with renovation and modernisation meeting safety standards and producing cheapest electricity in the country

Performance of Indian nuclear power reactors in terms of safety has been excellent, with over 600 reactor years of safe, accident free operation

Each experience, national and international is reviewed and safety provisions revisited and improved upon, if required

Attained one time longest operating reactor (PHWR) world record.

Continuous long operation giving rise to large capacity and availability factor

Very low level of releases to the environment

Proven PHWR design is ready and industry can come forward and implement them to reduce India's carbon footprint

Thank You

LECTURE - 3

NUCLEAR REACTOR TECHNOLOGY

RELENTLESS COMMITMENT TO QUALITY, RELIABILITY AND SAFETY

Sameer Hajela

Executive Director (Reactor Safety & Analysis)

Nuclear Power Corporation of India Limited

Indian Nuclear Society, Theme Meeting, February 18-19, 2026, Vashi, Navi Mumbai

NUCLEAR REACTOR TECHNOLOGY

RELENTLESS COMMITMENT TO QUALITY, RELIABILITY AND SAFETY

COVERAGE

What is not covered

Nuclear power generation, nuclear fuel, reactor types, present capacity and targets ....

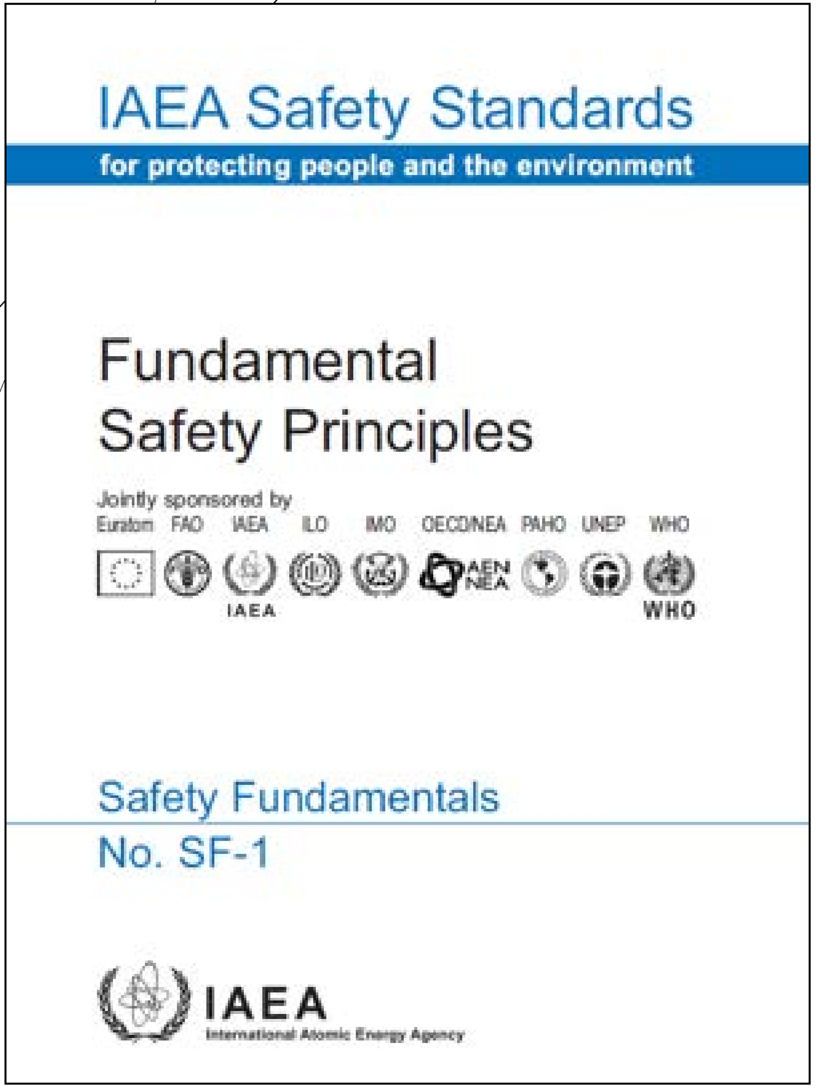
Instead, this presentation covers

Safety, Safety principles and practices, Safety assessment – Nuclear Power Plants

SAFETY

The state of being safe; not being dangerous or in danger

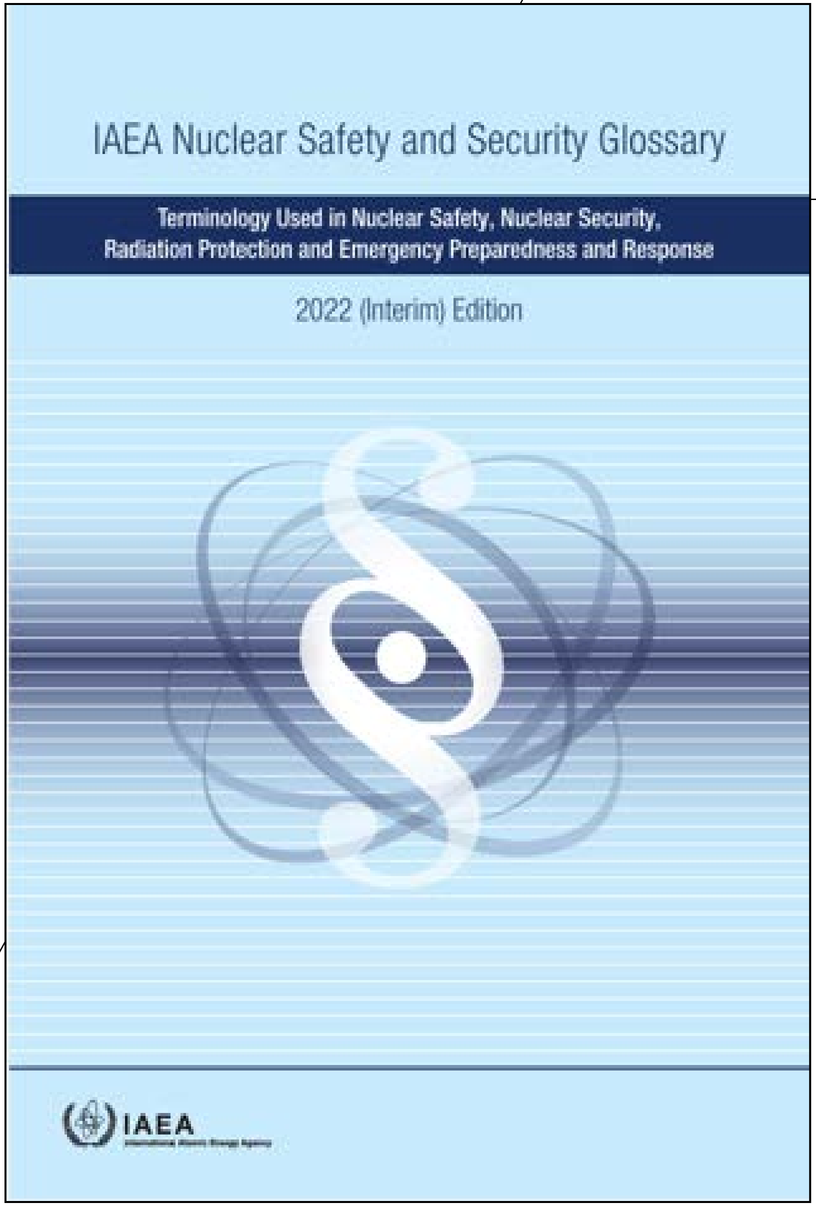
SAFETY OBJECTIVE



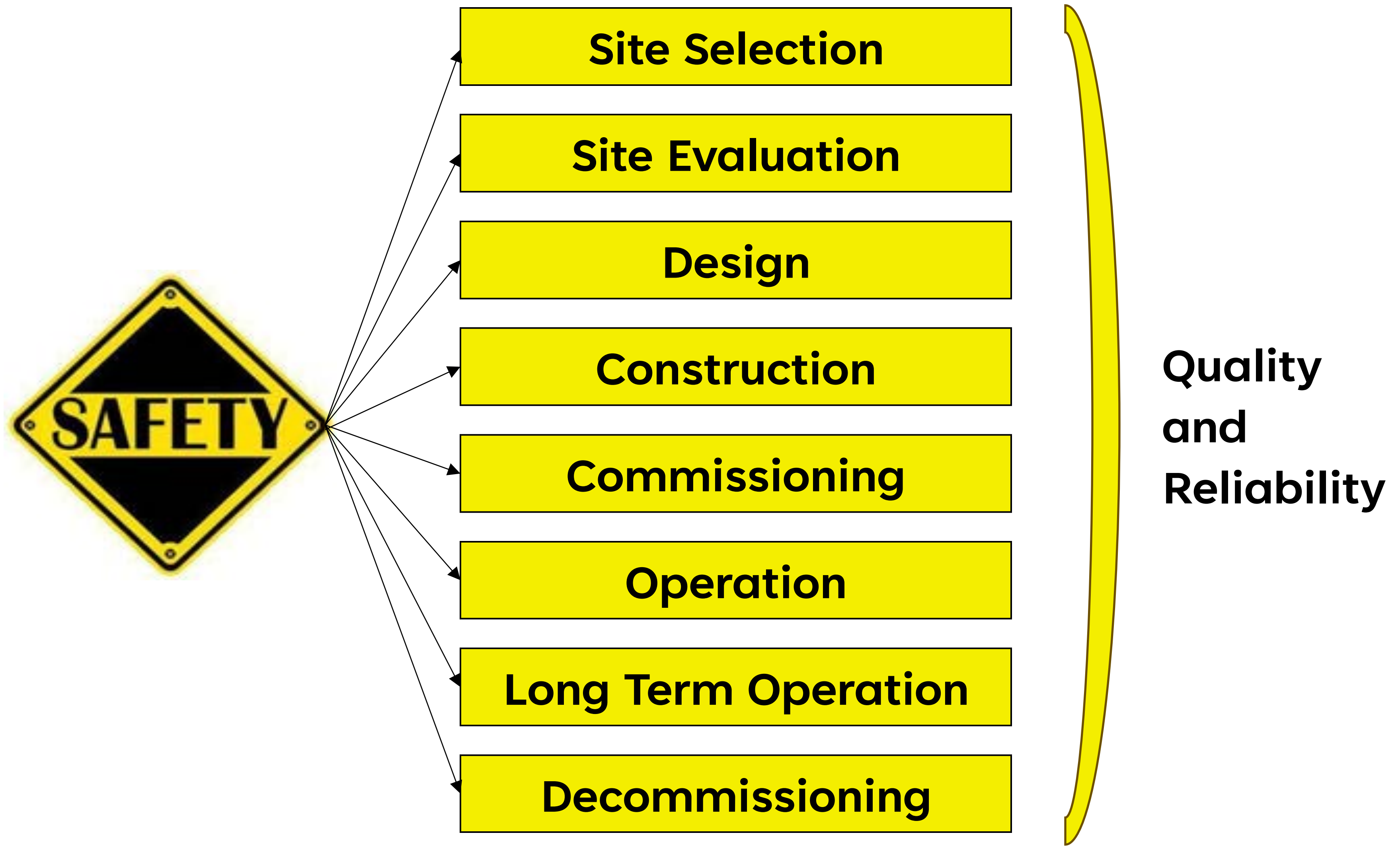
The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation

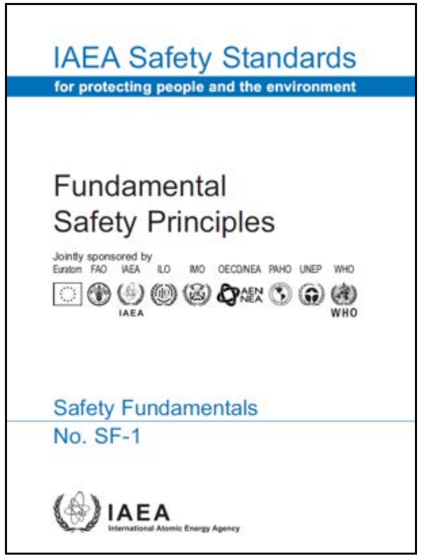
NUCLEAR SAFETY

The achievement of proper operating conditions, prevention of accidents and mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation risks



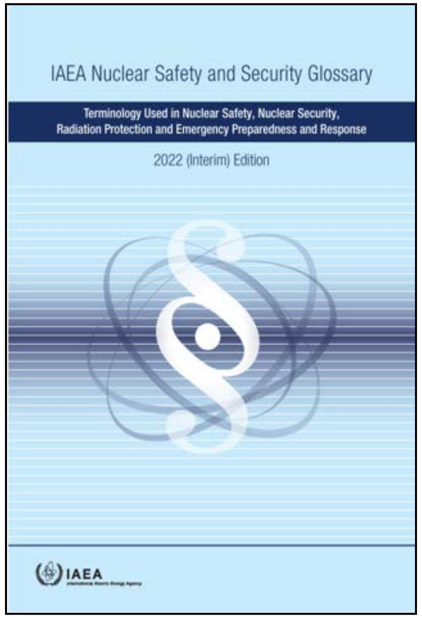
SAFETY IN ALL PHASES





Safety Objective

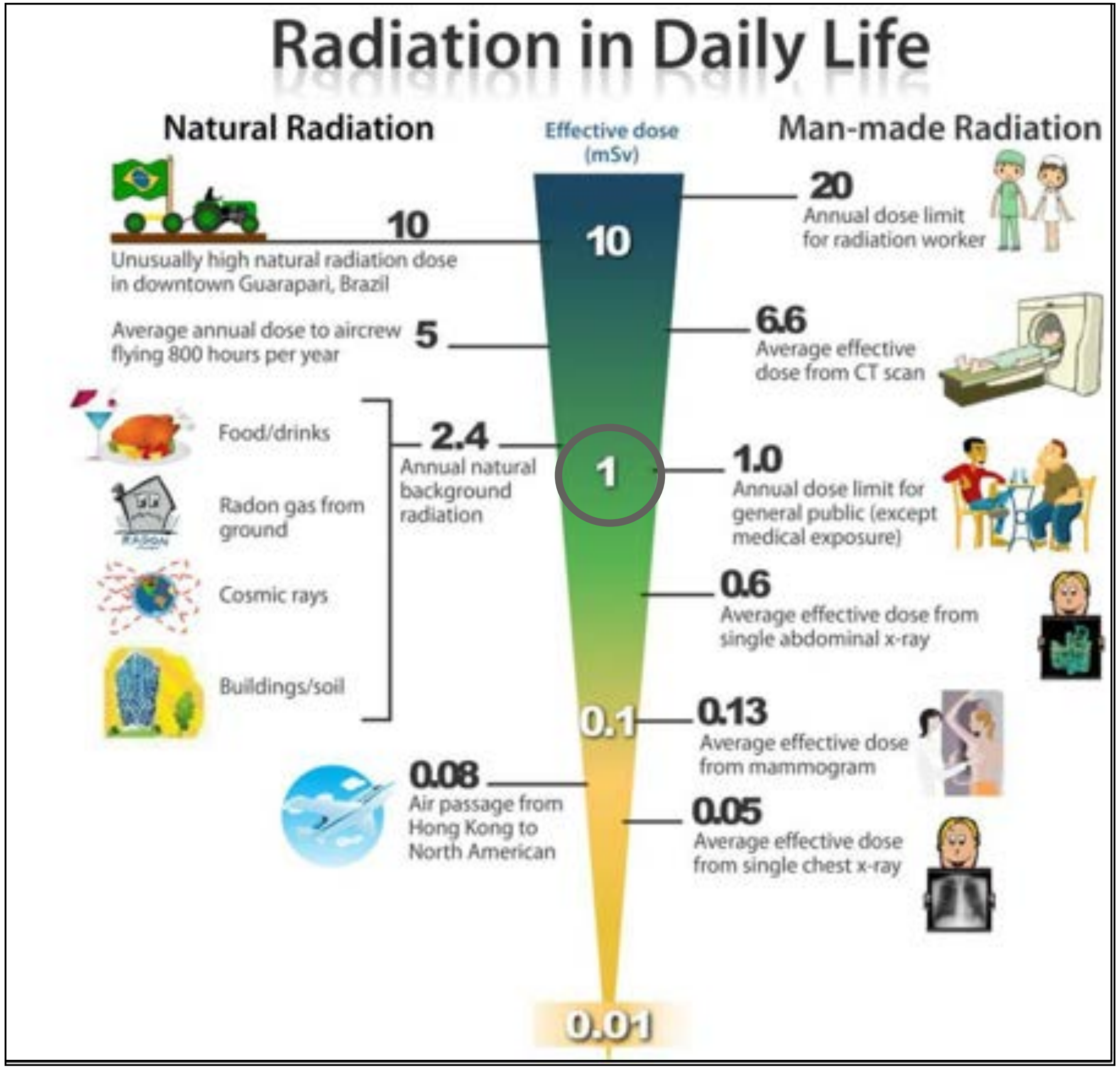
The fundamental safety objective is to protect people and the environment from <u>harmful effects of ionizing radiation</u>



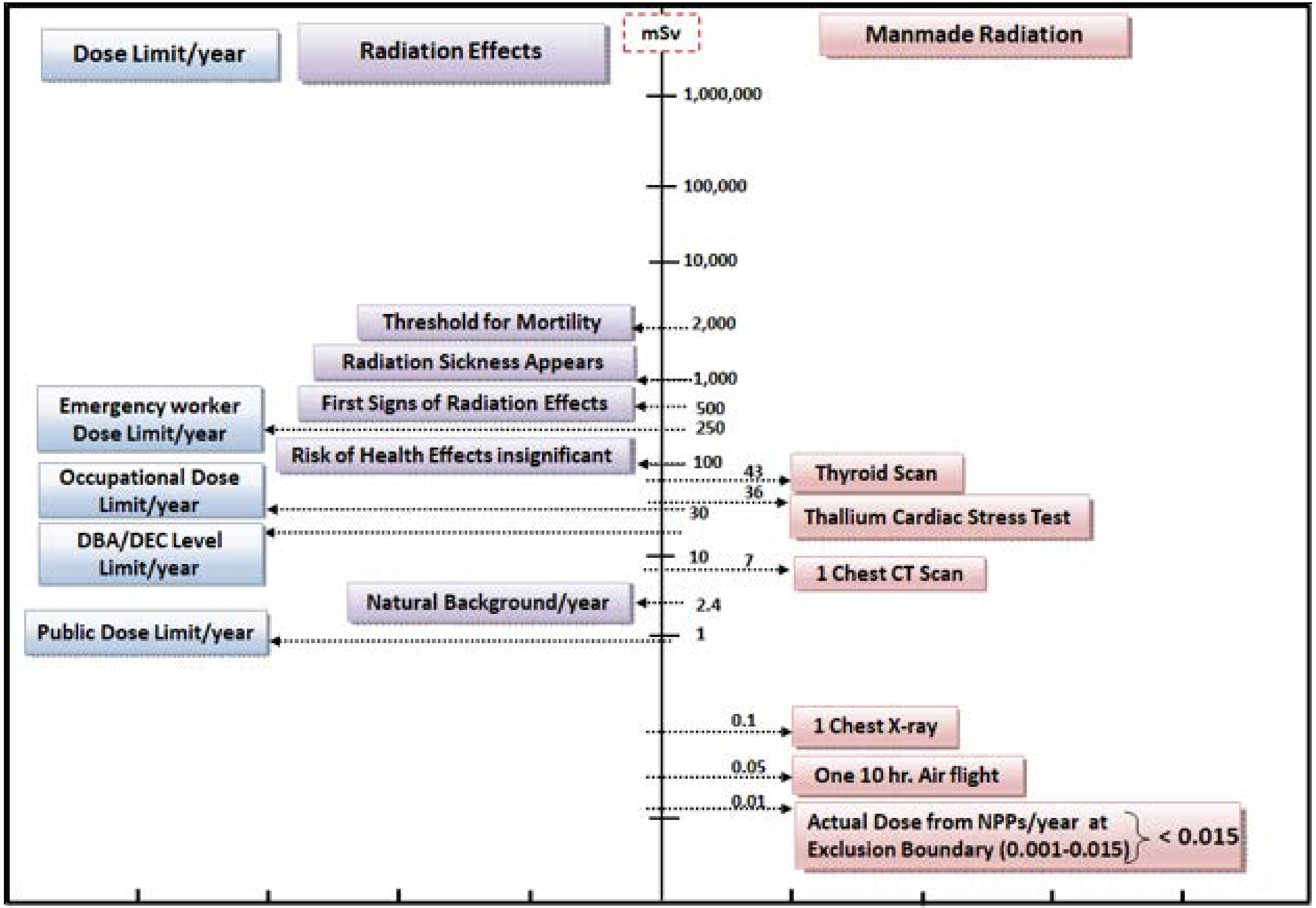
Nuclear Safety

The achievement of proper operating conditions, prevention of accidents and mitigation of accident consequences, resulting in protection of workers, the public and the environment from <u>undue radiation risks</u>

UNDERSTANDING RADIATION RISK IN ORDER TO …



UNDERSTANDING RADIATION RISK IN ORDER TO …



TARGET IS TO BE WITHIN …

- Site Selection
- Site Evaluation
- Design
- Construction
- Commissioning
- Operation
- Long Term Operation
- Decommissioning

1 mSV in normal operation

20 mSV in accident conditions

DISSECTING DEFINITION OF NUCLEAR SAFETY

1

Careful site selection and evaluation, conservative design, meticulous construction, proper commissioning, operation within OLCs

2

Control of operational events ensuring no damage to fuel and coming back to normal operation, plant procedures

The achievement of proper operating conditions, prevention of accidents and mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation risks.

3,4

Control of events through safety systems and safety features, emergency operating procedures, accident management measures

5

Radiological consequences assessment, Emergency preparedness and response

PUTTING 1,2,3,4,5 IN PERSPECTIVE OF DEFENCE IN DEPTH

Hierarchical deployment of different <u>**independent level** of equipment and procedures</u> to maintain effectiveness of <u>**physical barriers**</u> placed between radioactive materi worker, public environment during operation and pot accident condition.

Level 1 — Preventi normal operation and failures

Level 2 — l operation and detection of failures

of accidents within the design basis

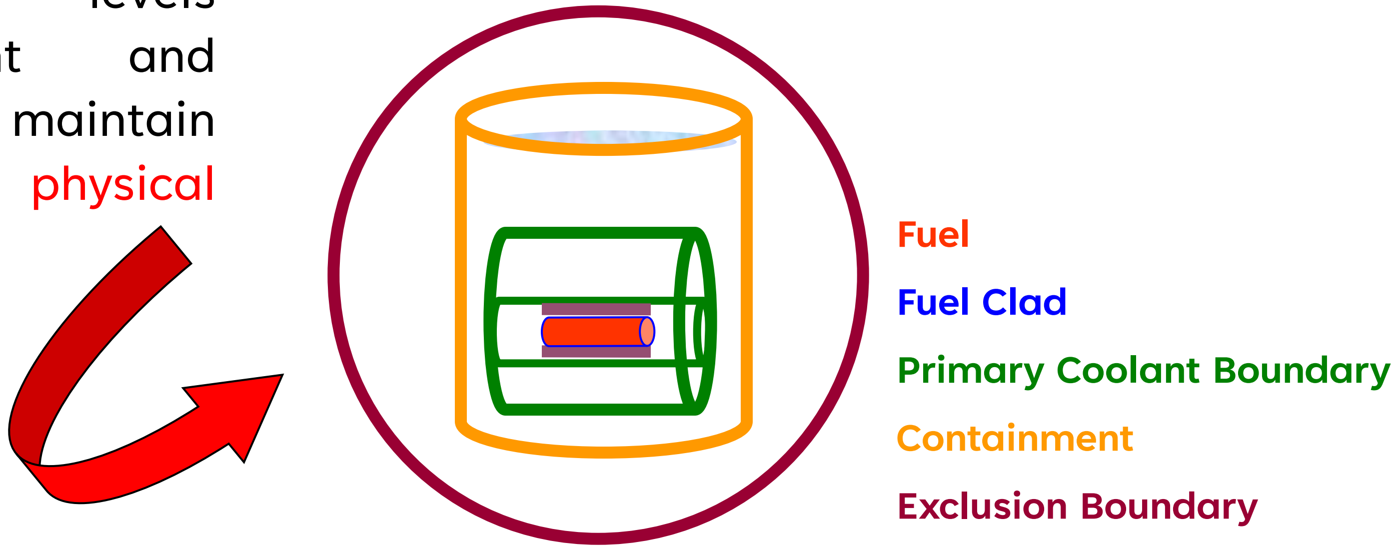
Accident Management including confinement protection

Level 5 — Mitigation of Radiological Consequences of significant releases of radioactive materials

BARRIERS TO RADIOACTIVITY RELEASE

Defence in Depth (DID)

Hierarchical deployment of different levels and equipment and procedures to maintain effectiveness of physical barriers

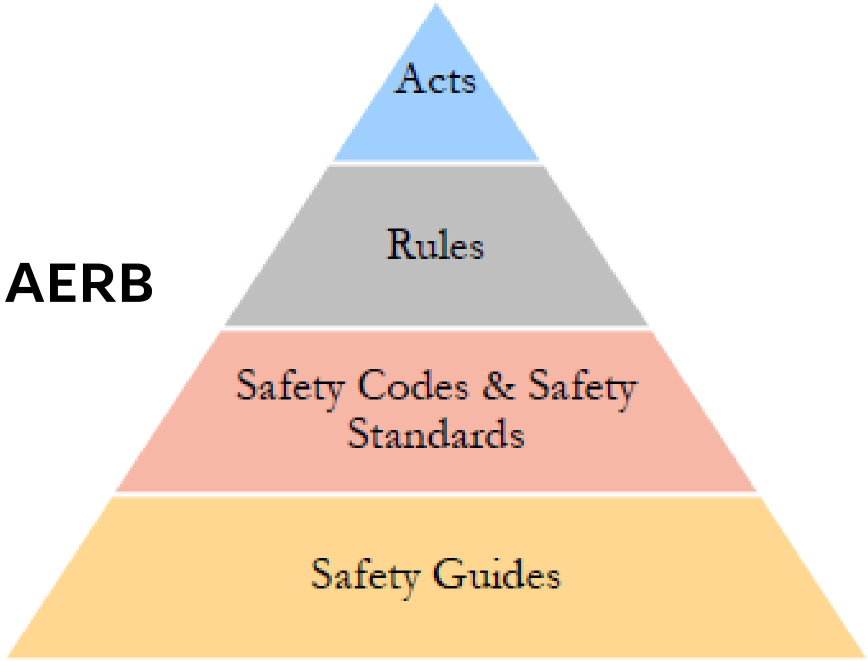


Level	1	2	3	4		5
				4A	4B	
Domain	Accident Prevention		Accident Mitigation			Managing release of radioactivity
Plant State	Normal Operation	Anticipated Operational Occurrences	Design Basis Accidents	Design Extension Cond		Practically Eliminated Conditions
				Without Core da	ith Core Damage/Melt	
Design	Plant Design Envelope					Beyond Plant Design Envelope
Fundamental Safety Functions	✓ Reactivity Control ✓ Fuel Cooling (Core and Spent fuel) ✓ Confinement of radioactivity					NA
Objective	Prevention of deviation from normal operation	Control of Off-normal conditions	Control with mits	Management to avoid severe damage to core	Ensuring confinement of radioactivity	Mitigation of radiological consequences
State of Barriers	Fuel Sheath	Fuel Sheath	uel Sheath	Fuel Sheath	Fuel Sheath	NA
	Fuel	Fu	Fuel	Fuel	Fuel	
	Coolant Boundary	Co ary	Coolant Boundary	Coolant Boundary	Coolant Boundary	
	Containment	ontainment	Containment	Containment	Containment	
Systems	Process	Process and Control systems	Safety systems and ESFs	Additional Safety Features	Complementary Safety Features	Off-site Protective Actions
Plant Control	R	MCR	MCR, SCR	MCR, SCR	OESC	Off-site Emergency Control Centre
Procedures	Technical Spes, Normal Operating Procedures	Alarm Response Procedures	Emergency Operating Procedures	Accident Management Guidelines		Off- site Emergency Preparedness Plan
			Plant/Site /Offsite Emergency Preparedness Plans			
Preparedness	Class room training/Plant Simulators			Class room training, drills		Table top exercises, drills

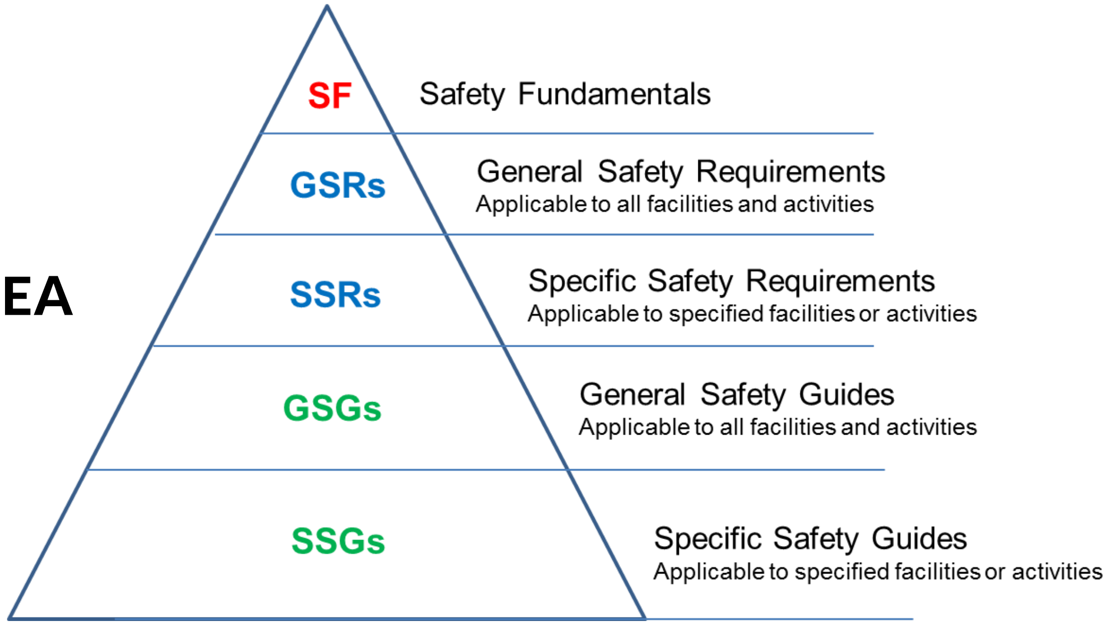
Design, Quality, Reliability, Operation, Safety

REGULATORY DOCUMENTS

AERB



IAEA



SITE EVALUATION (AFTER SITE SELECTION)

3

- Impact of natural and human-induced external events on the facility
- Radiological impact of facility on public and environment
- Feasibility of effective implementation of emergency management plans in the public domain

- Quality and reliability of site investigations and assessments, and various engineering activities

4

- Exclusion Zone
- Natural Growth Zone
- Emergency Planning Zone
- Radiological Surveillance Zone

SITE EVALUATION

Impact of Site characteristics on NPP

3

External Natural Phenomena

- Seismic (S1,S2)
- Wind
- Flood
  - Inland (Rains, Flood, Dam break ...)
  - Coastal (Cyclone, Tsunami)

  } Dry Site
- Loss of UHS
- ...

Human induced External Events

- Aircraft Crash (accidental / malevolent)
- External Fire
- Explosions/ Toxic gas release
- Oil slicks
- Blasting operation

Change of Hazard with time

- Climate change
- Other changes

SITE EVALUATION

Consideration for exceedance of Design Basis

Beyond design basis or extreme external events

Photo from Google Images

SITE EVALUATION

Rejection Criteria and Screening Distance Value

S. No.	Characteristics	Screening Distance Value
1.	Distance from airports including military airfields	16 km
2.	Distance from military installations storing ammunitions etc.	16 km
3.	Distance from industrial facilities involving storage/handling of chemicals, explosives, etc.	16 km
4.	Distance from places of architectural/historical monuments, pilgrimage and tourists interest that could attract large floating population	5 km

SITE EVALUATION

Rejection Criteria and Rejection Potential

Rejection Criteria

- Site in seismic zone V (IS 1893 – 2016)
- Existence of active fault within 5 km of proposed site
- Active /capable fault can cause potential surface faulting affecting safety

Rejection, if suitable engineering solutions are not feasible

- Slope instability
- Surface collapse, subsidence or uplift
- Soil liquefaction
- Sand dunes
- Volcanism
- Shoreline erosion
- Water availability for long term heat removal
- Unacceptable human induced events

SITE EVALUATION

Impact of NPP on Public and Environment

- Radiological dose assessment using site specific data
- Population distribution
- Land and water use
- Ambient radioactivity

DESIGN

- Maintaining design integrity for the lifetime (Responsible organization and Design Authority)
- Management system for plant design
- Independent Verification of design
- Proven design practices and requirements for FOAK systems/features
- Safety classification and seismic categorization
- Redundancy and Diversity
- Fail safe
- Testability
- Reliability of items important to safety
- Avoidance of common cause failure
- Independence of safety systems
- Equipment Qualification
- Human Factors consideration

CONSTRUCTION, COMMISSIONING AND OPERATION

- Approved Procedures and Practices
- Quality Assurance Plans
- Documentation
- Collection of Baseline Data
- Pre-Commissioning Checks
- System Integrated Tests

- Technical Specifications For Operation
- Surveillance and Testing
- Qualified Manpower
- In-service Inspection
- Procedures for all practices and events handling

PERIODIC SAFETY REVIEW

A. Safety factors relating to the plant

1) Plant Design
2) Actual Condition of SSCs
3) Equipment Qualification
4) Ageing Management

B. Safety factors relating to safety analysis

5) Deterministic Safety Analysis
6) Probabilistic Safety Assessment
7) Hazard Analysis

C. Safety factors relating to performance and feedback of experience

8) Safety Performance
9) Use of Experience from other NPPs and Research Findings

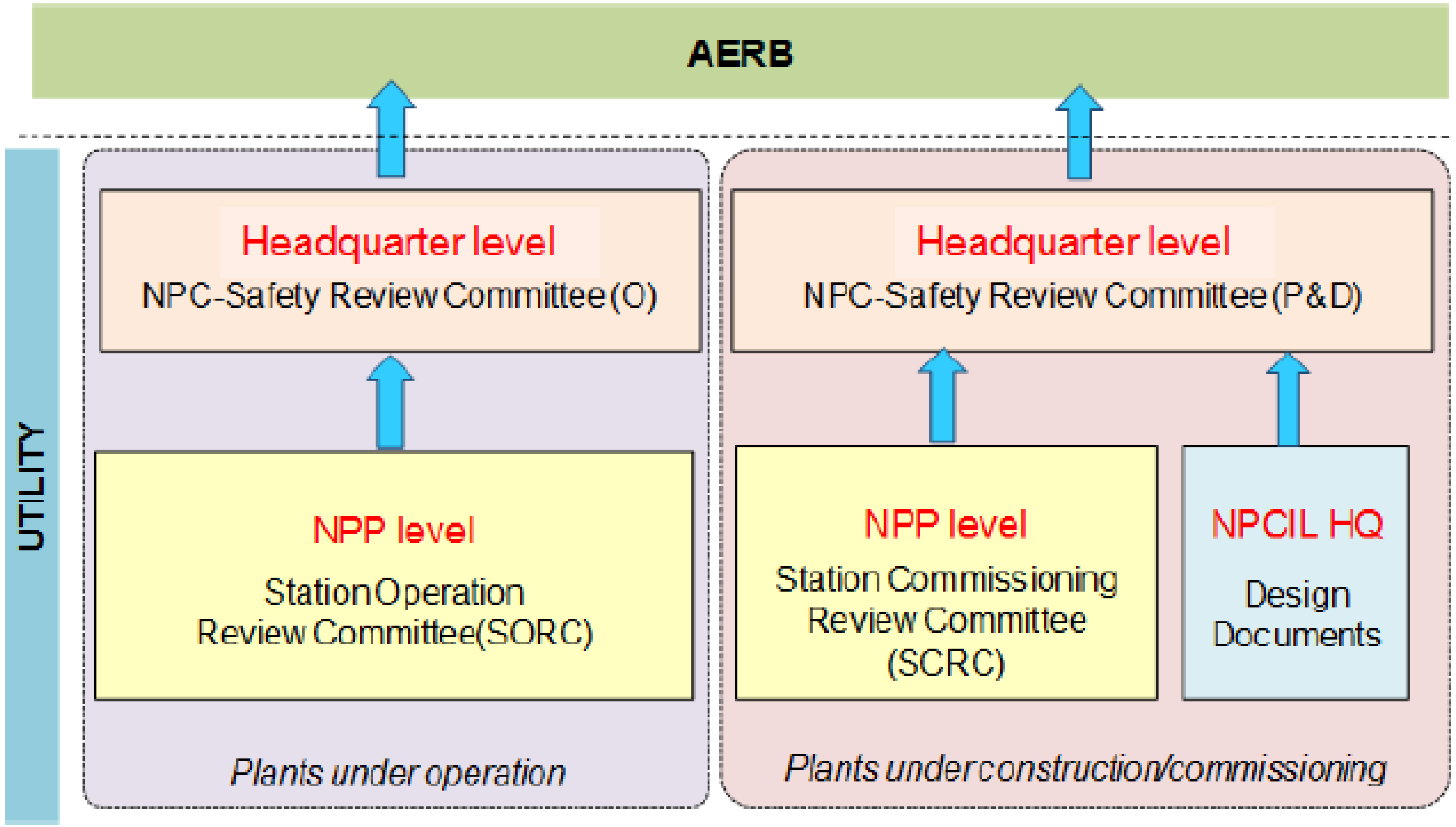
D. Safety factors relating to management

10) Leadership and Management for Safety
11) Procedures
12) Human Factors
13) Emergency Planning

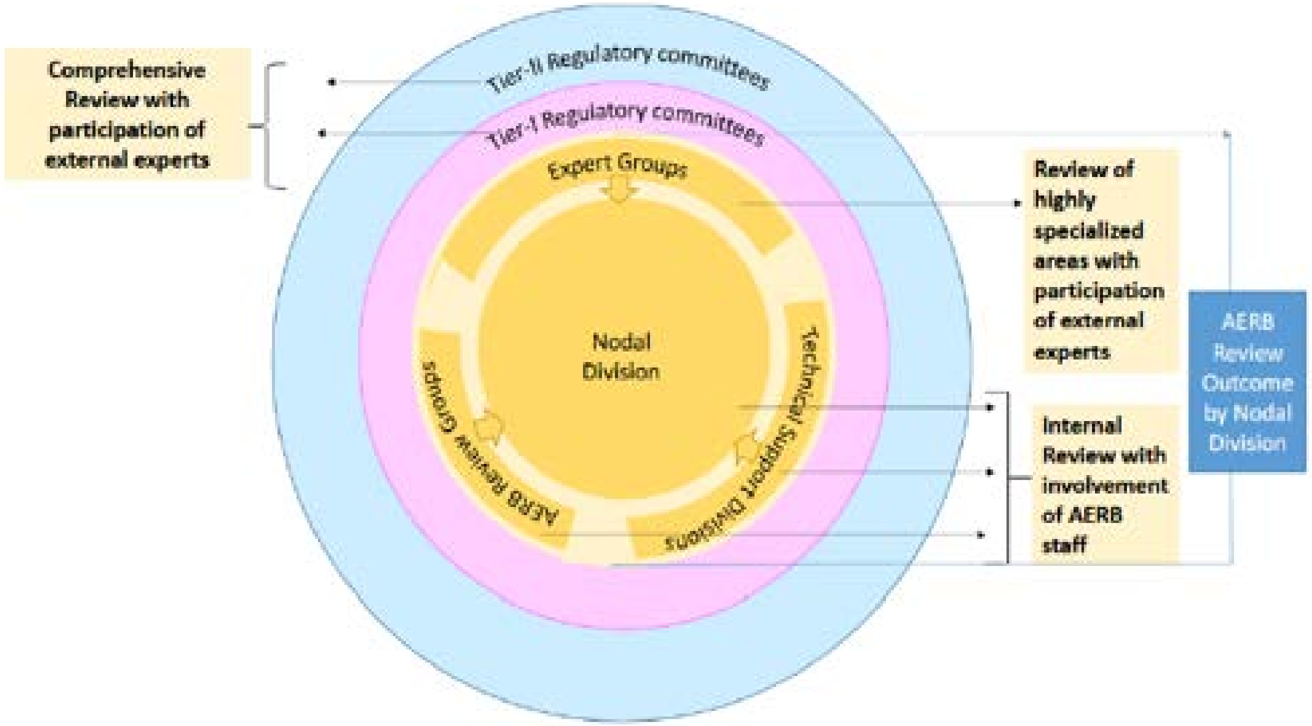
E. Safety factors relating to the environment

14) Radiological Impact on Environment

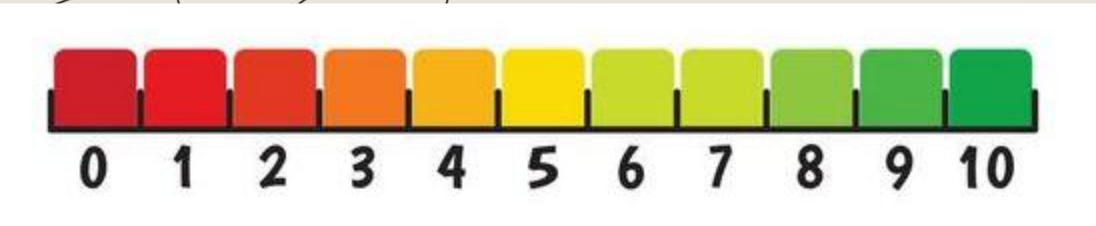
MULTI TIER REVIEW



MULTI TIER REVIEW



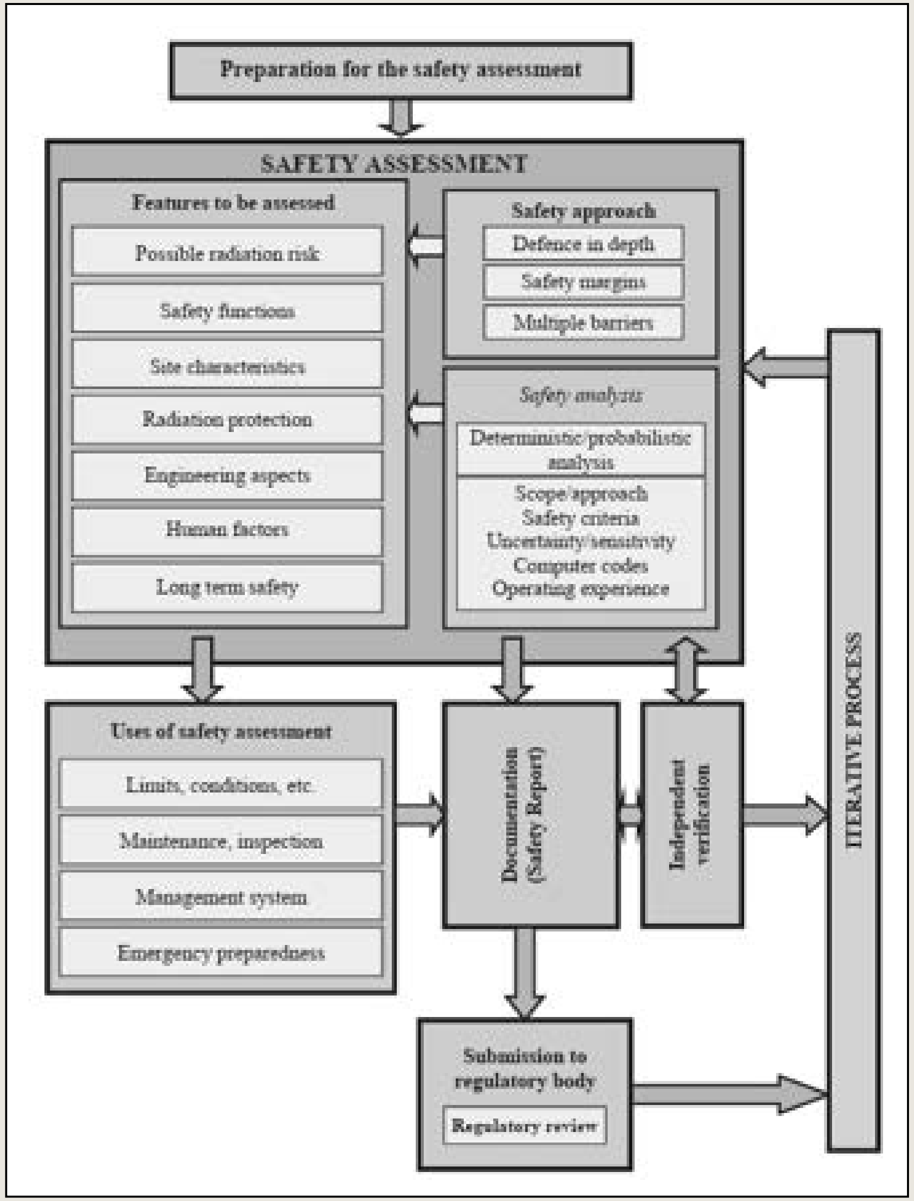
DESIGN / SAFETY QUANTIFICATION …?



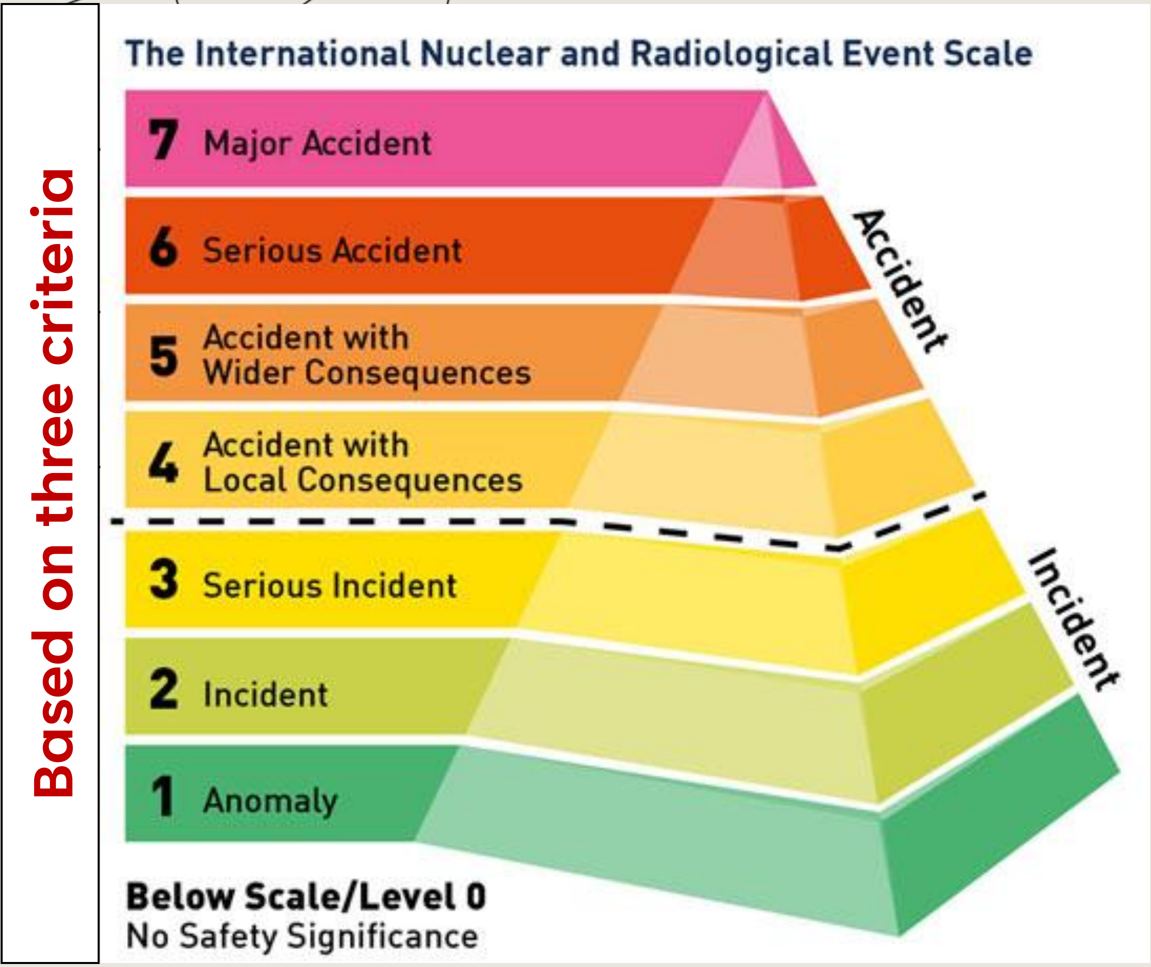
Safety Assessment

- Initial Licensing

- Periodic Reviews
- Special Reviews



SAFETY RECORD



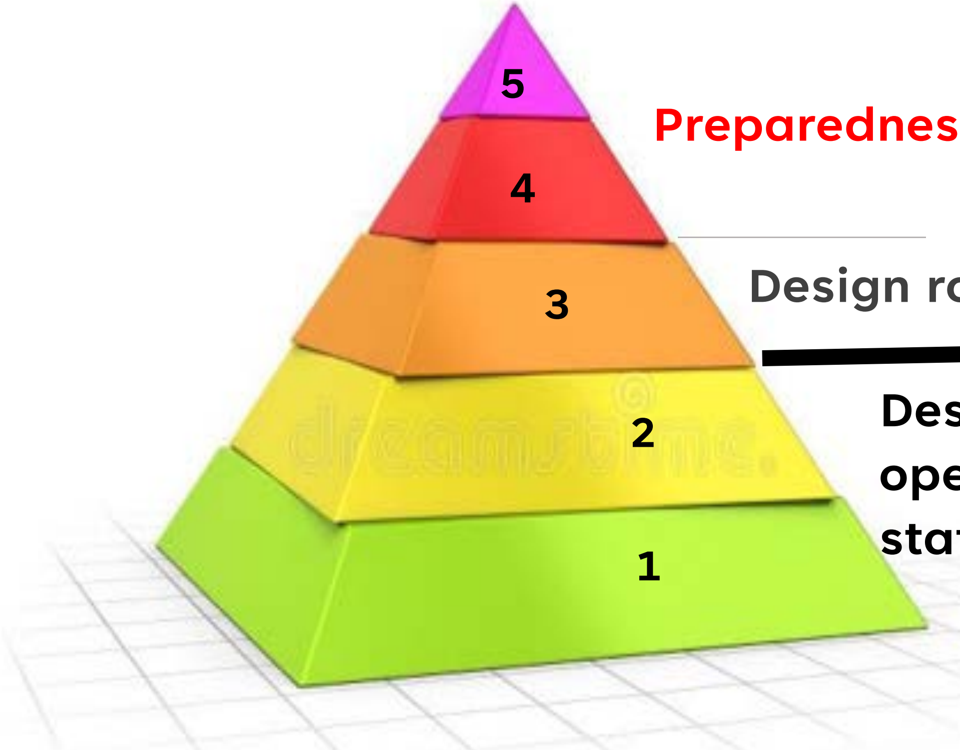
In India, cumulative experience of 650 years of operation …..

- Most of the events at level-0/ level-1
- For all operating NPPs, in past four years …

Year	INES-0	INES-1
2020	29	3
2021	31	0
2022	25	2
2023	19	1

SAFETY IS …DRAWING A LINE, AND ENSURING THAT …

≅ ***Prevention should be the aim of safety***



Preparedness – training and drills, applicable procedures

Design robustness, training, emergency operating procedures

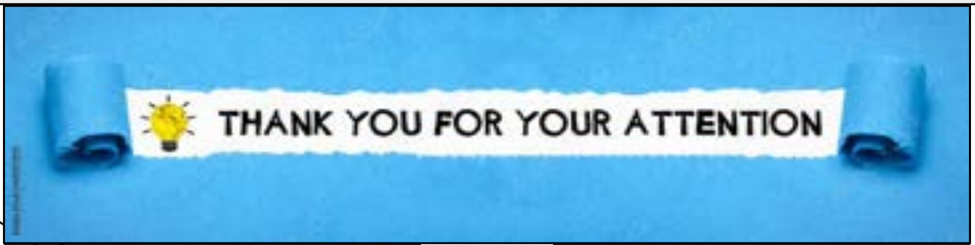
Design robustness, training, surveillance and testing, operating and maintenance procedures, adherence to station technical specifications

NUCLEAR REACTOR TECHNOLOGY

RELENTLESS COMMITMENT TO QUALITY, RELIABILITY AND SAFETY

NUCLEAR REACTOR TECHNOLOGY

RELENTLESS COMMITMENT TO QUALITY, RELIABILITY AND SAFETY



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LECTURE - 4

Operational Priorities and Challenges in Operating a Nuclear Power Plant

By Shri S.M.Mulkalwar

Outstanding Scientist

Ex Site Director, Tarapur Maharashtra Site, NPCIL

Email smulkal@yahoo.com Mob 9423533448

Objective

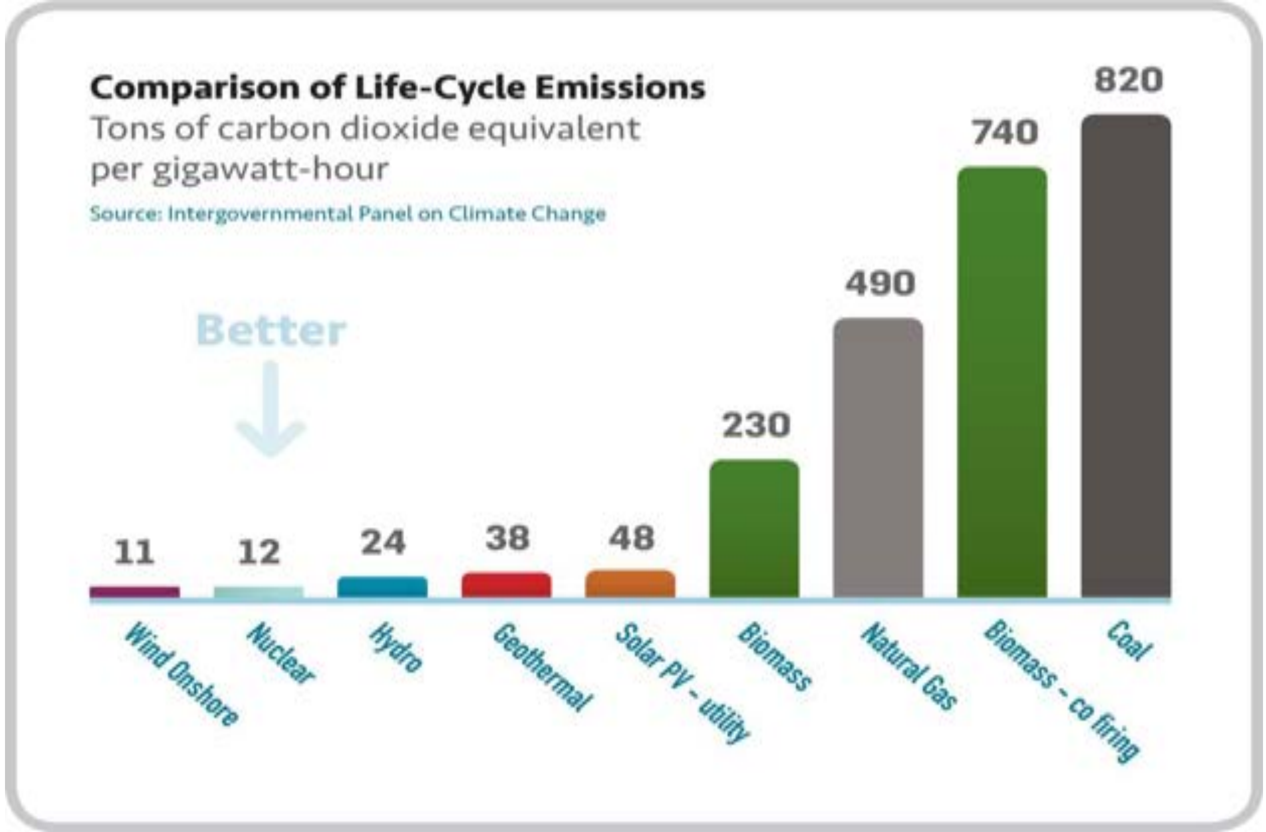
1. Introduction to Nuclear Power
2. Operational priorities
3. Reactor Reliability & Performance
4. Regulator Compliance
5. Radiation Protection
6. Nuclear Security and cyber security
7. Nuclear Waste & Fuel Management
8. Operational Challenges
9. Solutions & Future Outlook

Nuclear Power

- Nuclear power is proven, 24X7 source of clean, reliable, sustainable and cost effective electricity. Provides reliable base-load power

- Nuclear power plants do not emit green house gases or other harmful pollutants, thus helps in fighting global warming.

- Merits of nuclear power makes it, an inevitable option for addressing our nation's long term energy needs in a sustainable manner.
- Complex systems.Requiring strict operational control.
- Safety and reliability are top priorities



Nuclear Power Scenario

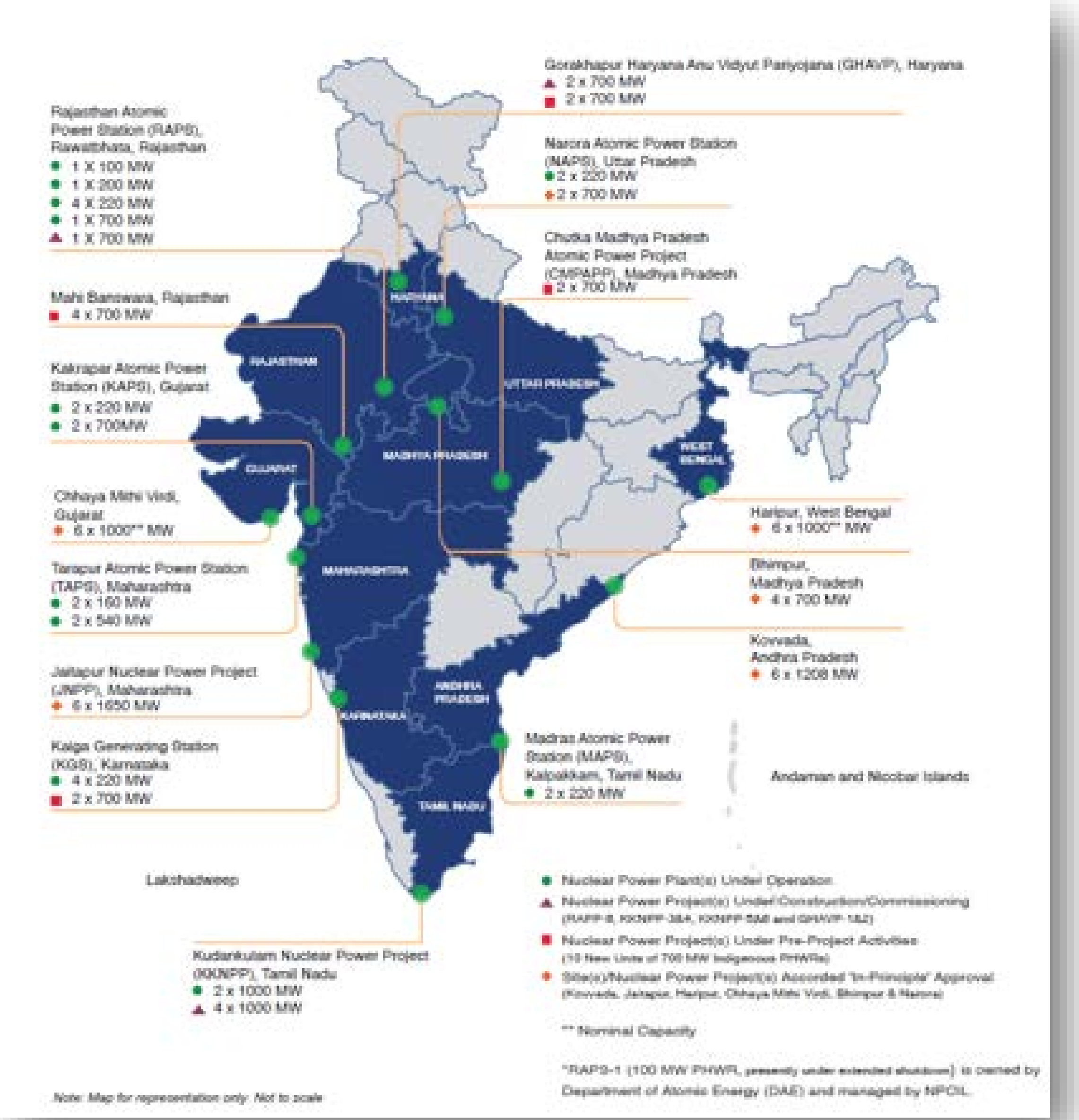
- Worldwide 440 reactors are in operation and producing 3,90,000 MWe and it is 10% of the worlds total electricity production.
- USA is having 93 reactors and producing 95,00 MWe of nuclear power, France is having 56 reactors, China is having 55 operating reactors.
- INDIA is having 24 operating reactors and is producing 8780 Mwe, only 1.9% of the total electricity production. Our country would like to increase nuclear power share to 10%. Target for year 2030 is kept at 21,000 MWe.
- In order to reduce Green House effect worldwide, India has committed to reduce emission levels 45% below 2005 levels by 2030.

About NPCIL

- Formed on September, 1987 as a PSE of DAE, fully owned by the Government of India
- Expertise in multiple reactor technologies - PHWR, BWR & PWR
- Assets of Rs. 1,91,607 crore, Net worth of Rs. 65,475 crore.
- Large expansion plans based on indigenous PHWRs and LWRs with foreign cooperation

PHWR: Pressurised Heavy Water Reactor
BWR: Boiling Water Reactor.
PWR: Pressurised Water Reactor

NPCIL's Presence



- **Reactors in Operation**
  - 24 Reactors (8780 MW)
  - [excluding RAPS-1 (100 MW)]
- **Reactors under Construction**
  - 7 Reactors (6100 MW)
- **Reactors at Pre-Project Activities**
  - 10 Reactors (7000 MW)

On progressive completion of these projects, nuclear power capacity in the country will reach 22,380 MW by the year 2031-32

Nuclear Energy Mission – Roadmap for 100 GW by 2047

NPCIL	
Present Capacity	8780 MW
Capacity under implementation	13,100 MW
Planned Future Capacity Additions	
• 2nd Fleet of PHWRs at existing and in-principle approved sites (10x700 MW)).	7000 MW
• LWRs at Jaitapur (6x1730 MW) & Kovvada (6x1208 MW)	17,628 MW
• *3rd Fleet of PHWRs (10x700 MW) at New Sites*	*7000* MW
BHAVINI PFBR (500) + FBR-1&2 (500) at Kalpakkam + Additional FBRs at new sites	3800 to 7400 MW
Others : NTPC, PSUs, Private Parties	
Multiple Technologies – 700 MW PHWRs, LWRs, BSRs of 220 in Captive mode, BSMRs 200 MWe, BSMRs 300 MWe, SMRs 55 MWe, IPWRs-1000 MWe etc. at various sites	39,000 to 42,000 MW (approximately)
Total cumulative capacity	> 100,000 MW

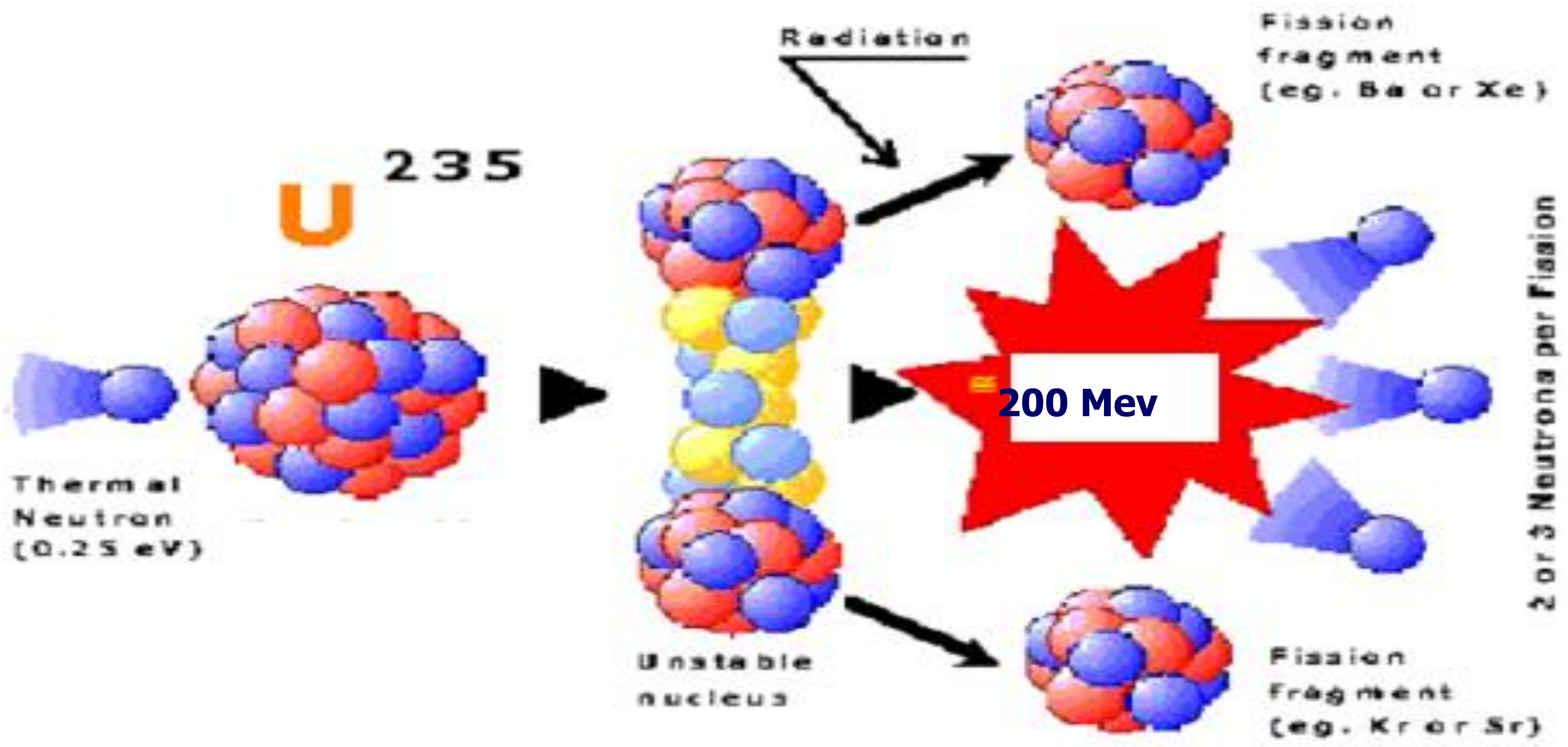
NPCIL plans to contribute half of the capacity of 100 GW by 2047

Nuclear Reactor

- A Nuclear Reactor is a source of heat, which is produced by self-sustained and controlled chain reaction within the reactor core.

- The natural uranium is used as a fuel in Pressured Heavy Water Reactors (PHWRs) and Enriched uranium is used in Boiling Water Reactors(BWRs) and Pressurized Water Reactors(PWRs) .

- The essential components of a Thermal Reactor are Reactor Vessel, Fuel, Moderator, Coolant, Control Rods, Neutron monitors etc.



Fission of Uranium 235

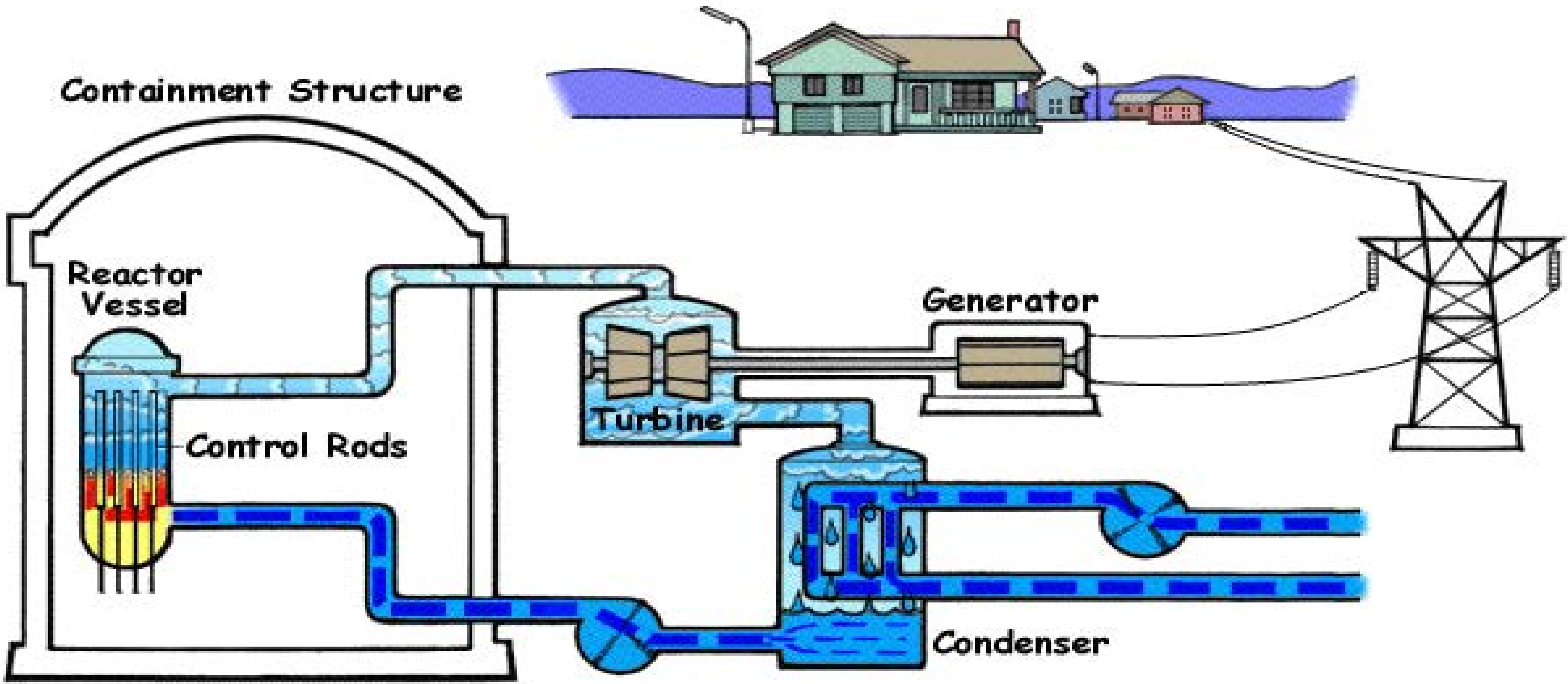
How a Nuclear Reactor Works

- When slow neutron strikes the atom of U-235, fission (splitting) takes place by breaking it up into two or more fragments. During this process enormous heat energy is generated along with production of two to three fast moving neutrons.

- These fast moving neutrons are slowed down by the moderator (heavy water in PHWRs & Light water in BWRs/PWRs). The slow or thermal neutrons are again used for sustaining the fission chain reaction.

- The heat produced in the reactor is used to generate light water steam at high pressure, that drives the turbo-generator to produce electrical energy.

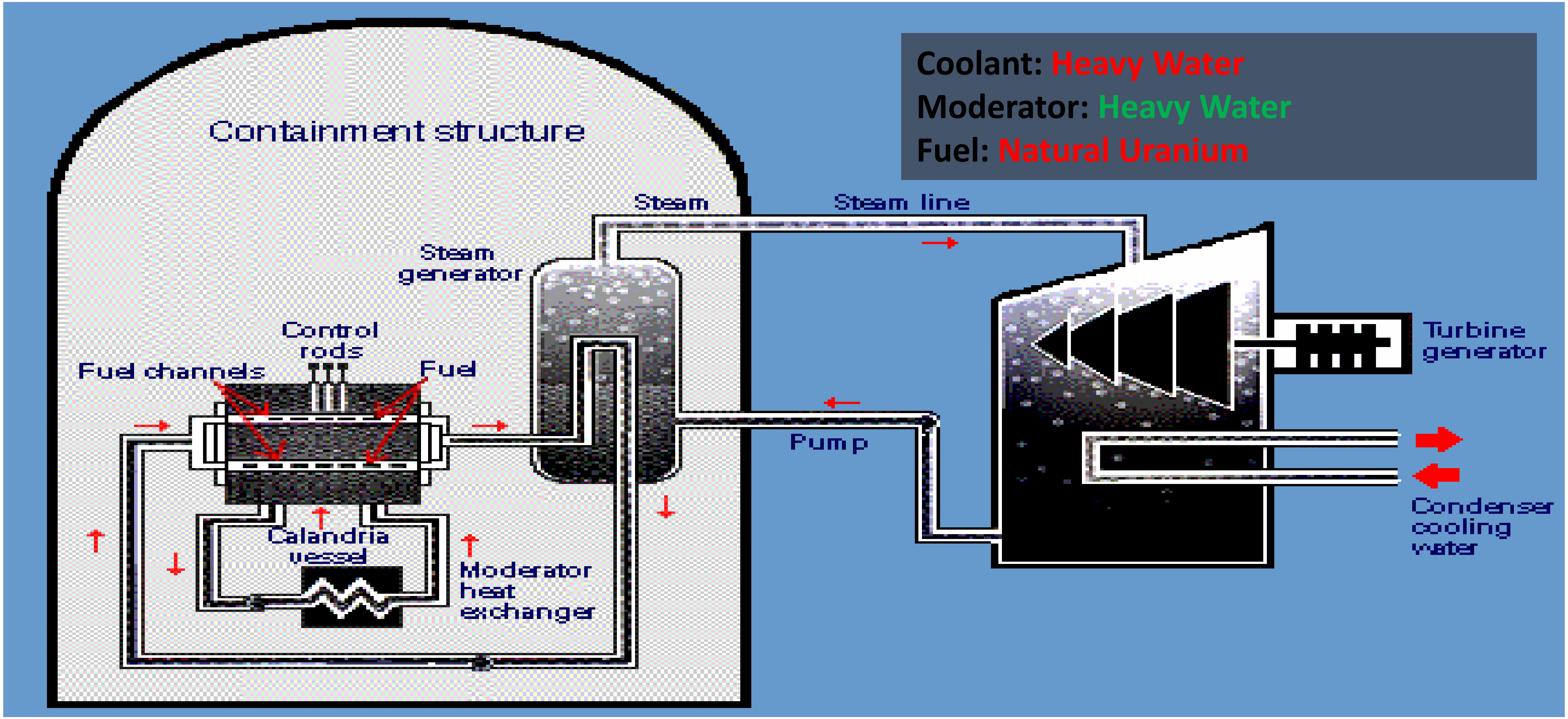
BWR



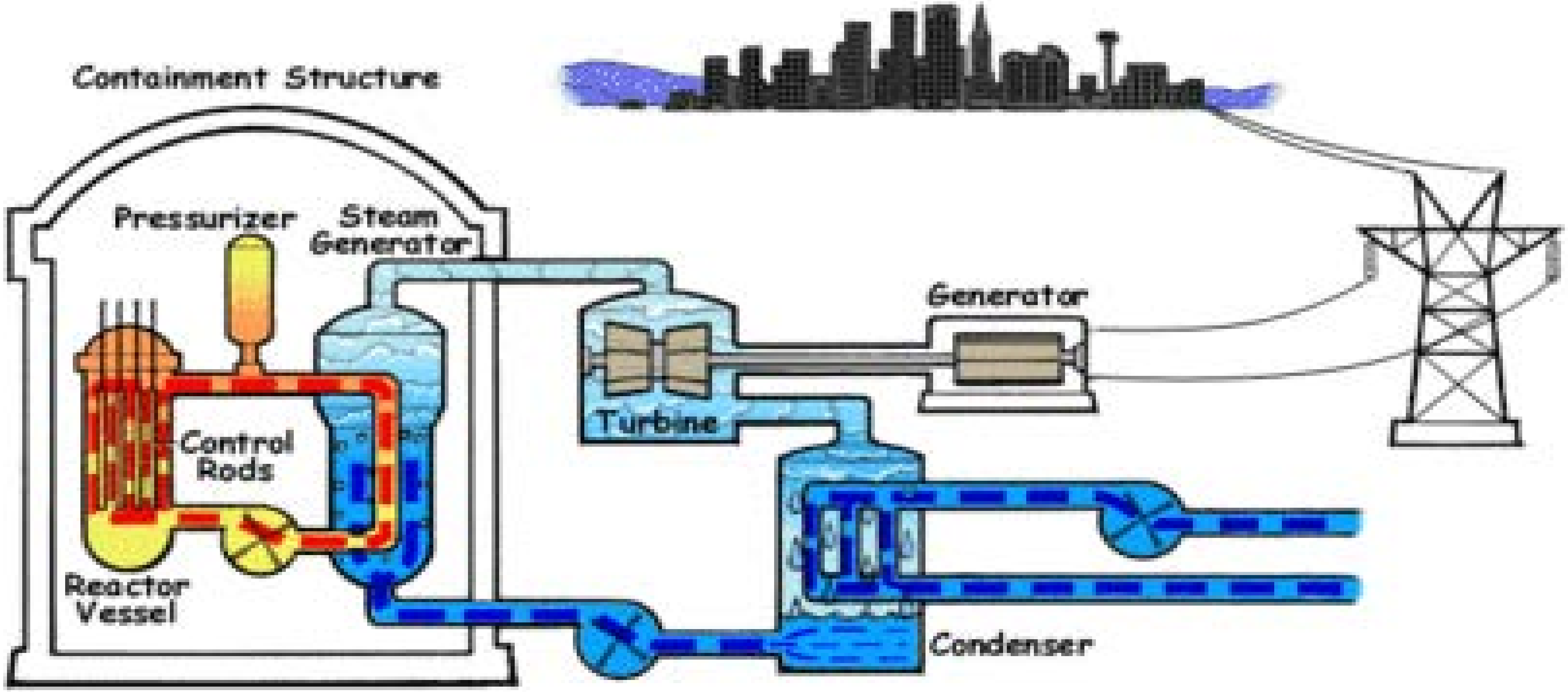
Containment Structure
Reactor Vessel
Control Rods
Turbine
Generator
Condenser

Pressurized Heavy Water Reactor

Coolant: Heavy Water
Moderator: Heavy Water
Fuel: Natural Uranium



PWR



Containment Structure
Pressurizer
Steam Generator
Control Rods
Reactor Vessel
Turbine
Generator
Condenser

Good Reactor Features

- **HWR**
  - Natural uranium
  - Simple fuel assembly
  - Good uranium usage
  - On-power fuelling
  - Good neutron dynamic behaviour
  - Automatic plant operation
  - In accidents, fuel is always below melting temperature
- **PWR**
  - Simple fuelling
  - High fuel burnup
  - Simple primary heat transport system
  - Small number of water systems
  - Large in-service reactor population

Slide 8

Bad Reactor Features

- **HWR**
  - Heavy water is expensive
  - Tritium must be controlled
  - Complicated piping
  - Two coolant systems
  - Positive coolant void reactivity
- **PWR**
  - Fuel is expensive
  - Big excess reactivity
  - Big pressure vessel
  - Big power coefficient
  - Fast operator action is needed on shutdown
  - Short neutron life
  - Fuel melting in accidents

Heat transport system

- The PHWR and PWR are both a pressurized water reactor. It uses a closed primary circulation loop to transport heat to the steam generators. In a second closed loop which includes the turbine, light water steam acts as the working fluid. The primary loop is (almost) completely full of liquid heavy water in PHWR and light water in PWR. Pressure control is maintained in both of these systems by a steam space in a pressurizer connected to the circuits power
- In BWR light water directly boils in the reactor and same is transported to Turbine

DIFFFERENCE 1

	PHWR	BWR	PWR
Reactor type	Horizontal, Heavy water coolant and moderator	Vertical. Light water coolant and moderator	Vertical. Light water coolant and moderator
Fuel	Natural uranium oxide	Uranium oxide 2.1 % Enriched	Uranium oxide 3.8 % Enriched
Power	220 MWe / 540 MWe / 700 MWe	210 MWe but as SG not in service (due to tube leak) rerated to 160 Mwe	1000 MWe
Efficiency of thermal cyl	28 %	30%	33 %
Void Coefficient	PHT :- Positive Moderator:- Negetive	Negative (Coolant lost leads to loss in moderation)	Negative (Coolant lost leads to loss in moderation)

DIFFFERENCE 2

	PHWR	BWR	PWR
Steam Generator	Vertical	Reactor itself. Secondary SG not in use	Horizontal
Coolant channels	306 No. in 220 MWe 392 No. in 540 MWe & 700 MWe	285 Fuel assembly enclosed in Fuel channel	No channels.
Containment	Double containment) V1 and V2 area separated depending on enthalpy Gets communicated through suppression pool	Single containment + Pi system for spray. .	Double containment with SS liner + containment spray + hydrogen suppression(re combiners)
Spent Fuel Pool	Outside Containment	In Secondary Containment	In Primary Containment

DIFFFERENCE 3

	PHWR	BWR	PWR
Steam Generator	Vertical	Reactor itself. Secondary SG not in use	Horizontal
Shut Down System	By rods and injection of poison	By Control Rods	Adding Boric acid by normal operating system in Coolant and By Control Rods -Passive addition of Boric Acid by safety system -- Active addition of Boric Acid by safety system

DIFFFERENCE 4

	PHWR	BWR	PWR
Safety system	No train concept. Equipment redundancy De nergized to actuate Crash cool down + fire water injection	No train concept. Equipment redundancy De energized to actuate	Four independent train concepts. Energized to actuate SG ECD
ECCS	High pressure passive Low pressure passive Low pressure active		High pressure injection –active and passive Low pressure active and passive

Refuelling

	PHWR	BWR	PWR
Performed	ONLINE	OFF LINE Batch (1/3 rd Core)	OFF LINE Batch (1/3 rd Core)
Operating Cycle	Approx 900 Days possible.	547 Days (18 months).	300 Days Being reviewed to increase it to 18 month cycle (including RSD) after 5 cycles by employing new fuel design.
Capacity factor	High	Better then KKNPP	low
Replacement of on power failed fuel	Possible	Not possible	Not possible
Fuel utilization	Better		
Discharge burn up MWD/T	7000	21000	43000

Refuelling

	PHWR	BWR	PWR
Excess Reactivity	Very less	High	High
Poison out time (Xe)	24-36 hours	Infinite	Infinite
Pressure boundary manipulated	yes	No	No
Fuel handling systems	complicated and need regular maintenance	Simple but require skilled manpower as done manually	Automated
On line Leaky fuel detection	Possible	No Only Gross	No Zone can be identified
offline	NA	By analyzing water sample	Bt analyzing gas

Operational Priorities

DESIGN & OPERATION CONSIDERATIONS

- Plants are designed to withstand all Natural disasters Earthquake, Tsunami, Windstorm, Cyclone, Floods, Lightening and Thunderstorms etc.

- Plants are Designed ,Constructed and Operated based on the CODES and STANDARDS OF ATOMIC ENERGY REGULATORY BOARD. Main aim of the AERB is to regulate the use of atomic energy for peaceful purposes while taking complete care of employees and general public residing in the vicinity of plants.

- Plants are Operated by highly qualified Engineers ,Supervisors and Technicians. Standard Operating Procedures are used for all the activities.

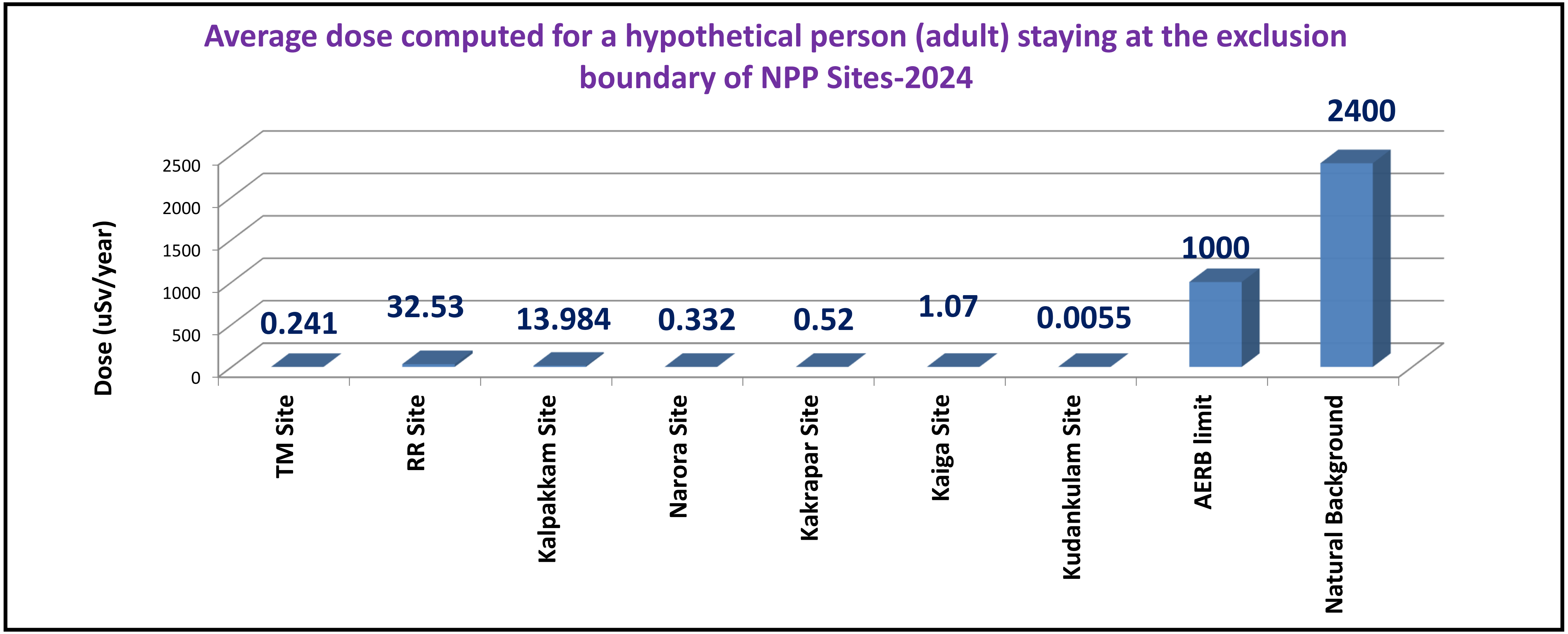
Safety in Indian NPPs

Accords utmost importance to Nuclear, Radiological, Industrial, Fire and Environmental safety overriding the demands of production. Protection of workers, public, and environment is highest priority.

- ✓ Redundancy & Diversity for fail Safe Operation.
- ✓ Independent, Diverse Shut Down Systems.
- ✓ Emergency Core Cooling.
- ✓ Double containment.
- ✓ Seismically qualified buildings and structures.
- ✓ Multi-tier Safety Reviews.
- ✓ Robust Regulatory Mechanism.
- ✓ Continuous safety training & drills

Impeccable Safety Record

- No incident of release of radioactivity beyond stipulated limits in public domain in over 55 years (~643 reactor-years) of operation.
- Public dose insignificant fraction of AERB limit & Natural Background.

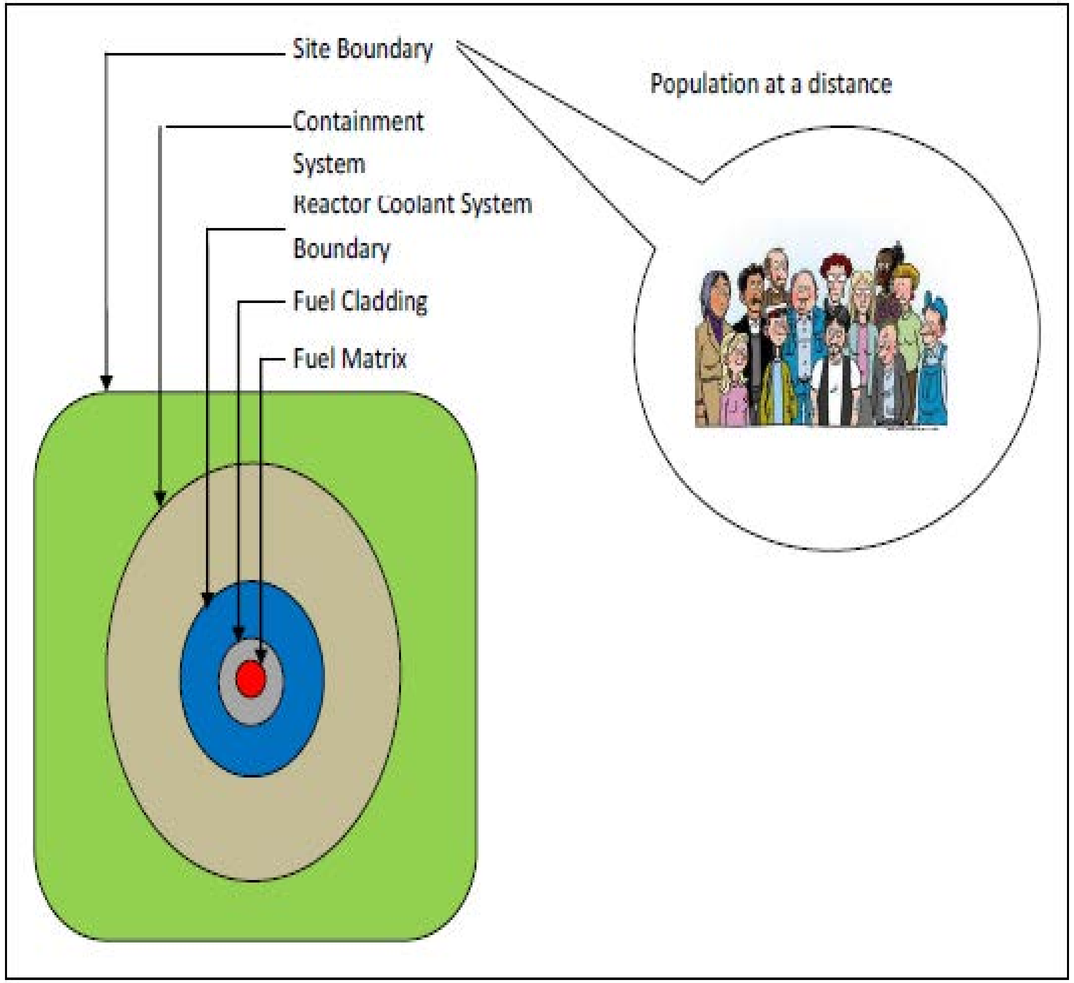


Safety Barriers

Series of barriers are available which would in principle never be jeopardized. These barriers provide for the confinement of radioactive material.

These barriers are :

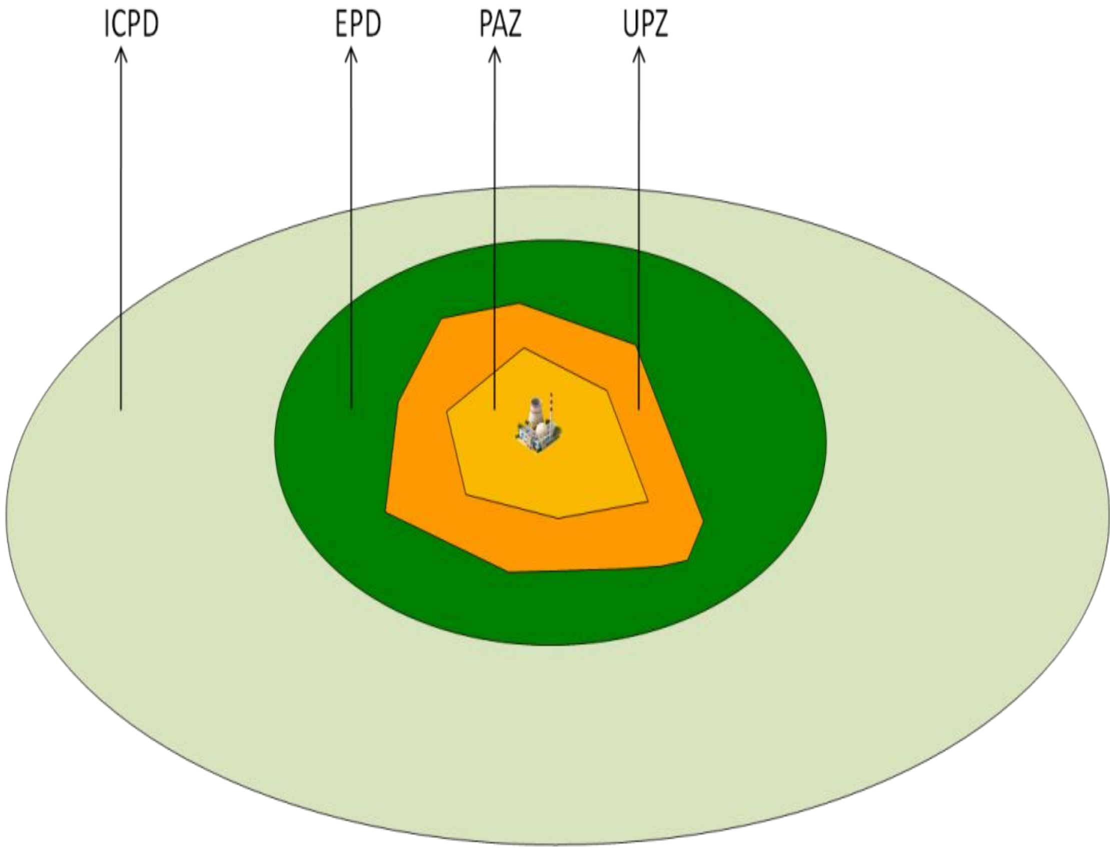
- **First** barrier: The fuel matrix
- **Second** barrier: Fuel cladding
- **Third** barrier: Primary heat transport system.
- **Fourth** barrier: Primary containment
- **Fifth** barrier: Secondary containment
- **Sixth** barrier: Exclusion zone



Emergency Planning Zones

Off-site emergency zones / distances around the nuclear power plant are identified in the preparedness stage to ensure the effectively implementation of optimum protective actions in case of emergency situations that may arise.

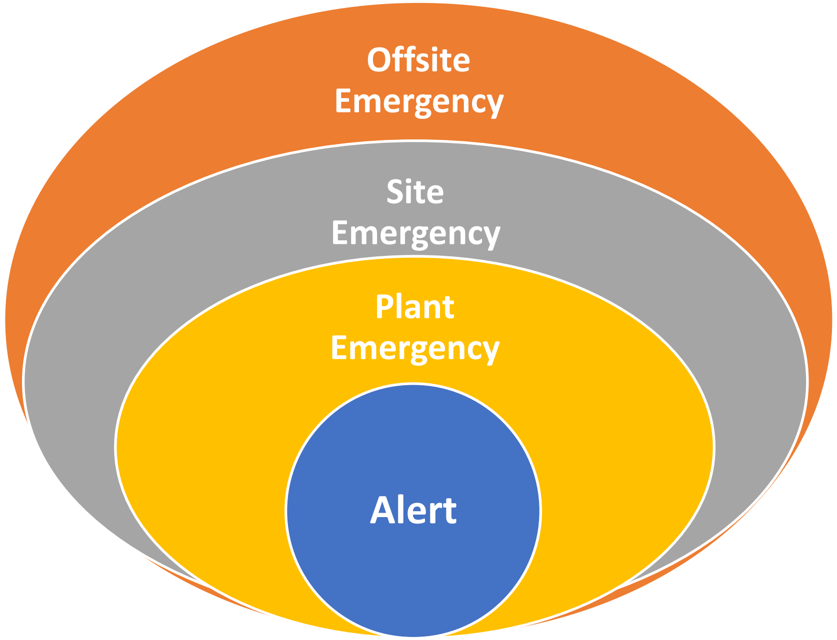
- **Precautionary action zone (PAZ)** **-2.8 km**
- **Urgent Protective action planning zone (UPZ)** **-18 km**
- **Extended Planning Distance (EPD)**
- **Ingestion and Commodities Planning Distance (ICPD).**



Emergency Classification

The emergency classifications, in ascending order of severity are as follows:

- Emergency Alert
- Plant Emergency
- Site Emergency
- Off-site Emergency



The emergency class is identified by Plant specific Initiating Conditions and Emergency Action Levels established

Protective Actions required during an Off-Site Emergency

Early Phase
Control of Access
Sheltering
Iodine Thyroid Blocking
Food restriction and Control (open food, water and milk)
Evacuation

Intermediate Phase
Temporary Relocation
Decontamination
Long term food restriction

Accident Analysis of TAPS 1&2 and TAPS 3&4

Core damage Frequency due to full power internal events

TAPS-1&2:- 3.2E-06 /Rx/Yr

TAPS-3&4 :-6.5E-07 /Rx/Yr

- Even after Core damage, Radioactivity will be contained within Containment with adequate provisions.

- For worst case accident scenario, Reactor Containment reaches design pressure at **38 hours** for TAPS-3&4 and **60 hours** for TAPS-1&2.

- Activity may releases into the Environment only in case of Containment Functional Failure or during CFVS operation.

There is sufficient time available for implementing the required protective actions in the public domain.

Reactor Reliability & Performance of NPPs

Performance indicators have been adopted to provide a quantitative indication of plant performance in the areas of nuclear plant safety and reliability, plant efficiency, and personnel safety .They are compared with world medians .

- ✓ Unit capability factor
- ✓ UNPLANNED CAPABILITY LOSS FACTOR (UCLF)
- ✓ FORCED LOSS RATE (FLR)
- ✓ GRID-RELATED LOSS FACTOR (GRLF)
- ✓ UNPLANNED AUTOMATIC SCRAMS PER 7000 HOURS CRITICAL (UA7)
- ✓ UNPLANNED SCRAMS PER 7000 HOURS CRITICAL (US7)
- ✓ SAFETY SYSTEM PERFORMANCE (SSPI)

Reactor Reliability & Performance NPPs

- ✓ FUEL RELIABILITY (FRI)
- ✓ CHEMISTRY PERFORMANCE (CPI)
- ✓ COLLECTIVE RADIATION EXPOSURE (CRE)
- ✓ INDUSTRIAL SAFETY ACCIDENT RATE (ISA)
- ✓ CONTRACTOR INDUSTRIAL SAFETY ACCIDENT RATE (CISA)

In most of the cases we are comparable or better than world median. fuel failure, chemistry performance, scrams are some areas which have to be improved

Maintain stable reactor operation , Avoid unplanned shutdowns (scrams),Optimize fuel usages, Scheduled refueling outages, Carry out Predictive & preventive maintenance.

Regulatory Compliance

- ✓ Strict national & international regulations
- ✓ Regular inspections & audits
- ✓ Compliance with IAEA standards
- ✓ Benchmarking though WANO
- ✓ Documentation and operational transparency

Regulatory Compliance

Every NPP has its own Technical specification and station policies which are approved by regulators – To guide for plant operation

.

- ✓ SAFETY LIMITS (SL) : Safety limits are limits on process variables within which the operation of the NPP has been shown to be safe. Safety limits are based on the best conservative design estimates.

- ✓ LIMITING SAFETY SYSTEM SETTINGS (LSSS) : LSSS are the instrument set points for actuation of appropriate automatic protective devices, which are intended to initiate action to prevent a safety limit being exceeded and to cope with anticipated operational occurrences.

- ✓ LIMITING CONDITIONS FOR OPERATION (LCO) : LCO are established to provide acceptable margins between the normal operating parameters and the established LSSS.

- ✓ RADIOLOGICAL SAFETY :

- ✓ SURVEILLANCE REQUIREMENTS

Radiation Protection

The primary aim of radiation protection is to provide an appropriate standard of protection for man without unduly limiting the beneficial practices giving rise to radiation exposure

- ✓ It is developed based on

  Radiation Protection Rule-2004 (Under Atomic Energy Act-1962)

  AERB codes, Guides and manual

- ✓ Justification of practices (Net positive benefit)

- ✓ Optimization of protection (ALARA)

- ✓ Dose limits to individuals

Radiation Protection-contd

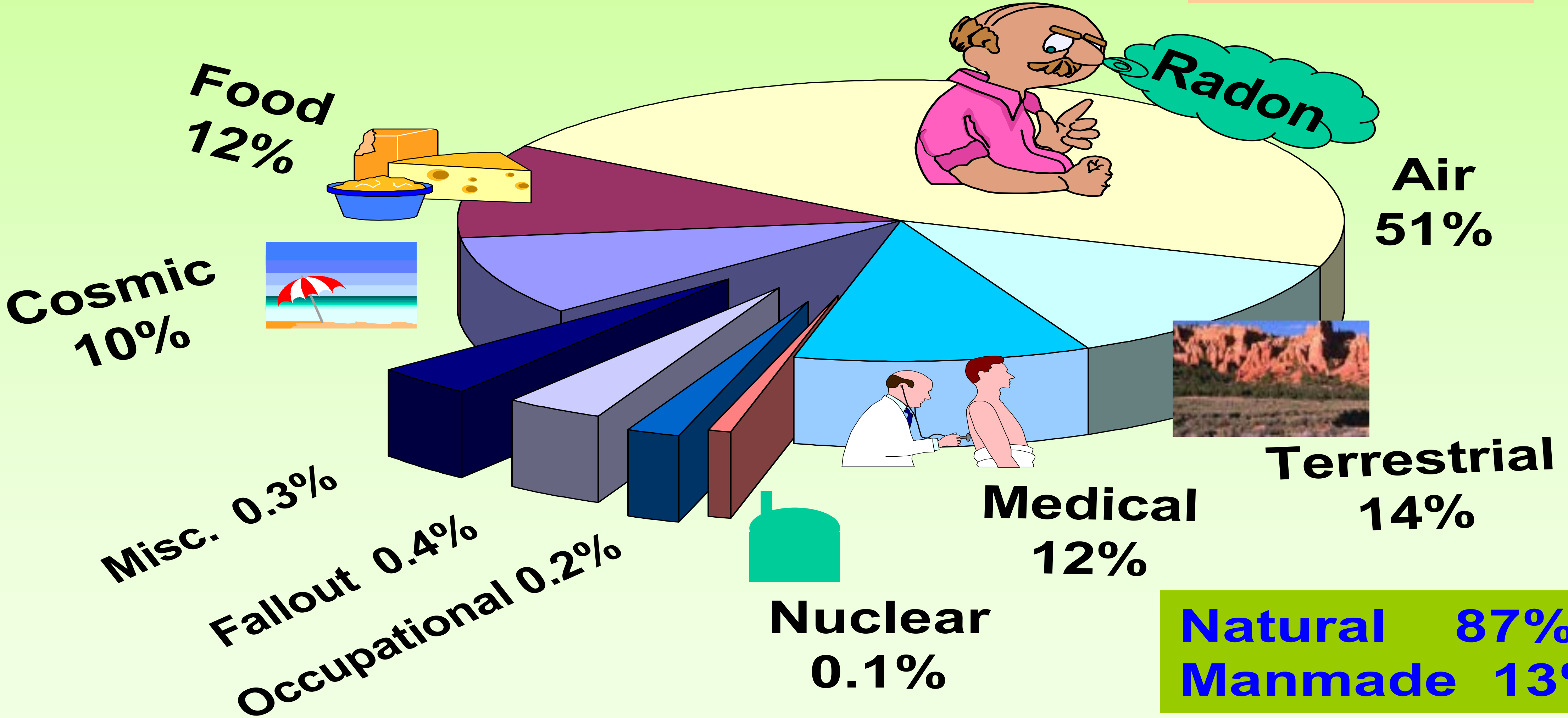
Effective implementation of radiation protection program shall be ensured by:

- Work Place monitoring (Radiation, contamination monitoring)
- Personnel monitoring (Dose, Contamination) (External and internal)
- Process monitoring (Through installed monitors and sampling & analysis)
- Effluent monitoring (Through installed monitors and sampling & analysis)
- Environmental Monitoring (Through installed monitors and sampling & analysis)
- Shielding and access control

GENERAL

Radiation Exposure to Public

2.5 mSv/y

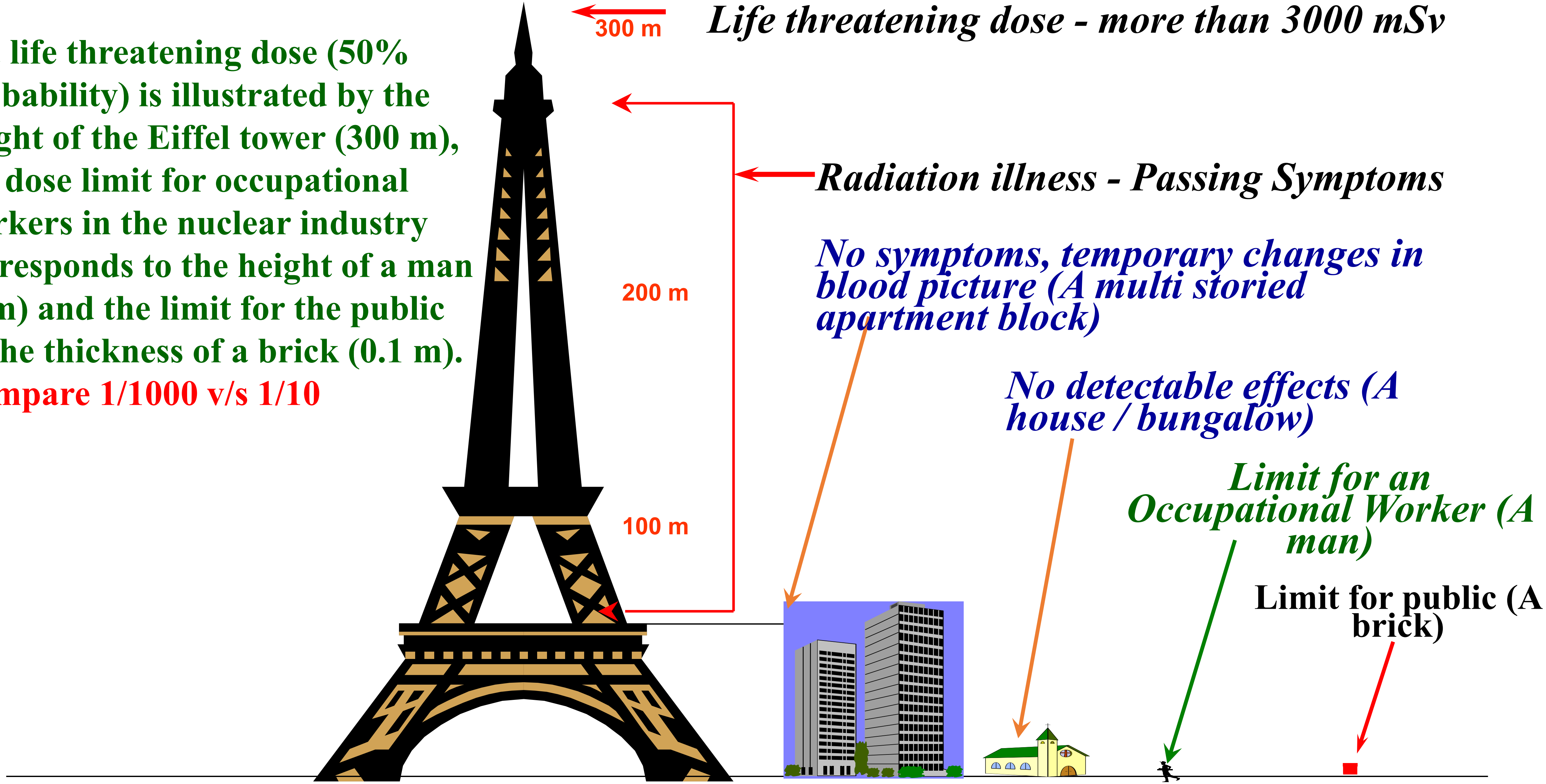


Natural 87%
Manmade 13%

A Perspective on radiation doses – in comparison to other industries, the limits are fixed at extremely low levels

If a life threatening dose (50% probability) is illustrated by the height of the Eiffel tower (300 m), the dose limit for occupational workers in the nuclear industry corresponds to the height of a man (2 m) and the limit for the public to the thickness of a brick (0.1 m).

Compare 1/1000 v/s 1/10



(*Source: IAEA (1997) Publication on Radiation, Health and Society - 97-05055 IAEA/PI/A56E*)

DIFFFERENCE Radiation

	PHWR	BWR	PWR
Liquid effluent treatment	Evaporator used in Kakrapara 3&4 onward		Evaporator
Solid waste	Bailing, cementation. incineration	Polymerisation	Bailing, cementation. incineration
Zoning	On contamination level	On contamination level	On Radiation field >2mr/hr unattended area
Neutron Dose	Less Streaming,	Nil	On line Boron sensor Uses Neutron source

DIFFFERENCE Radiation

	PHWR	BWR	PWR
Internal exposure	30 % dose consumption due to Internal exposure (Tritium)	Nil	Nil
Turbine Bldg contamination	Nil	20% of the dose consumed	Nil
Annual Collective Dose –Typical (Per Sv)	2	4.7	0.47 (0.2)
Stack release	Tritium, Ar -41		
Activity in primary system	Tritium,		K42, Na24


Gun Monitor


GM Survey
Meter


Neutron Badge
BARC


GM Survey
Meter


Polymaster


TLD


Target Identifier


Teletector


Personnel
Monitoring
Devices







MSA
AUER
N

Respirators

Types of Protective Clothing

Types of Protective Clothing

CONTAMINATION MONITORS

Contamination Control

Nuclear Security & Cyber security

- Physical security systems
- Armed security forces
- Protection against sabotage
- Cybersecurity for digital control systems

Nuclear Waste & Fuel Management

- Spent fuel pool storage
- Dry cask storage
- Long-term disposal challenges
- Safe transport of nuclear materials

Operational Challenges

Challenges

NPP are having Redundancy & Diversity for fail Safe Operation.

Independent, Diverse Shut Down Systems

- For maintaining them in poised state, on line checks/functional tests need to be carried out periodically. While carrying out such tests, probability of human errors increases. This can be overcome by excellent procedures, good training, peer review checks, pre job briefing.
- There are Limiting condition for operation. Equipments under maintenance/repair/preventive maintenance have to brought back in fixed time frame.
- Decontamination of equipments prior to work
- Few Equipments cannot be brought to workshops due to contamination. These have to be repaired in the field i.e Turbine

Radiation issues

- ✓ Few of the plant areas are in accessible during plant operation due to radiation/air born activity. Any degradation, causes Unit outages.
- ✓ There are radiation dose limits on individual as well as collective dose. So many experts are required.
- ✓ Limits on contractor doses during outages.
- ✓ Maintaining controlled area
- ✓ High cost of life extension
- ✓ Disposal of radioactive waste

In service Inspection

Extensive time and technology are required for ensuring the healthiness of RPV, its support system , containment structure. Detailed manuals and documents are in place for compliance which is approved by Regulator

- ✓ Ageing Infrastructure :

  Many plants >30–40 years old

- ✓ Component degradation (corrosion, fatigue)
- ✓ High cost of life extension
- ✓ Need for modernization

Workforce & Skill Retention

- ✓ Highly specialized workforce required
- ✓ Aging nuclear workforce
- ✓ Training, retraining & certification programs
- ✓ Knowledge transfer challenges
- ✓ Site locations are remote
- ✓ Simulators, extra crews

High Capital & Operating Costs

- ✓ High construction cost
- ✓ Long project timelines
- ✓ Maintenance & safety upgrades
- ✓ Competition from renewable energy
- ✓ Security threat and measures

Public Perception & Social Acceptance

- ✓ Impact of Chernobyl & Fukushima
- ✓ Fear of radiation
- ✓ Political and environmental opposition
- ✓ Need for transparency & public trust

Emergency Preparedness

- ✓ Natural disasters (earthquakes, floods)
- ✓ Human error risks
- ✓ Severe accident management
- ✓ Emergency response planning

Fuel Supply & Geopolitical Issues

- ✓ Uranium supply chain dependency
- ✓ Fuel enrichment requirements
- ✓ International political factors
- ✓ Long-term fuel security planning

Solutions & Future Outlook

Technological Advancements

- ✓ Small Modular Reactors (SMRs)
- ✓ Generation IV reactors
- ✓ Passive safety systems
- ✓ Digital monitoring & AI-based diagnostics

Strengthening Safety Culture

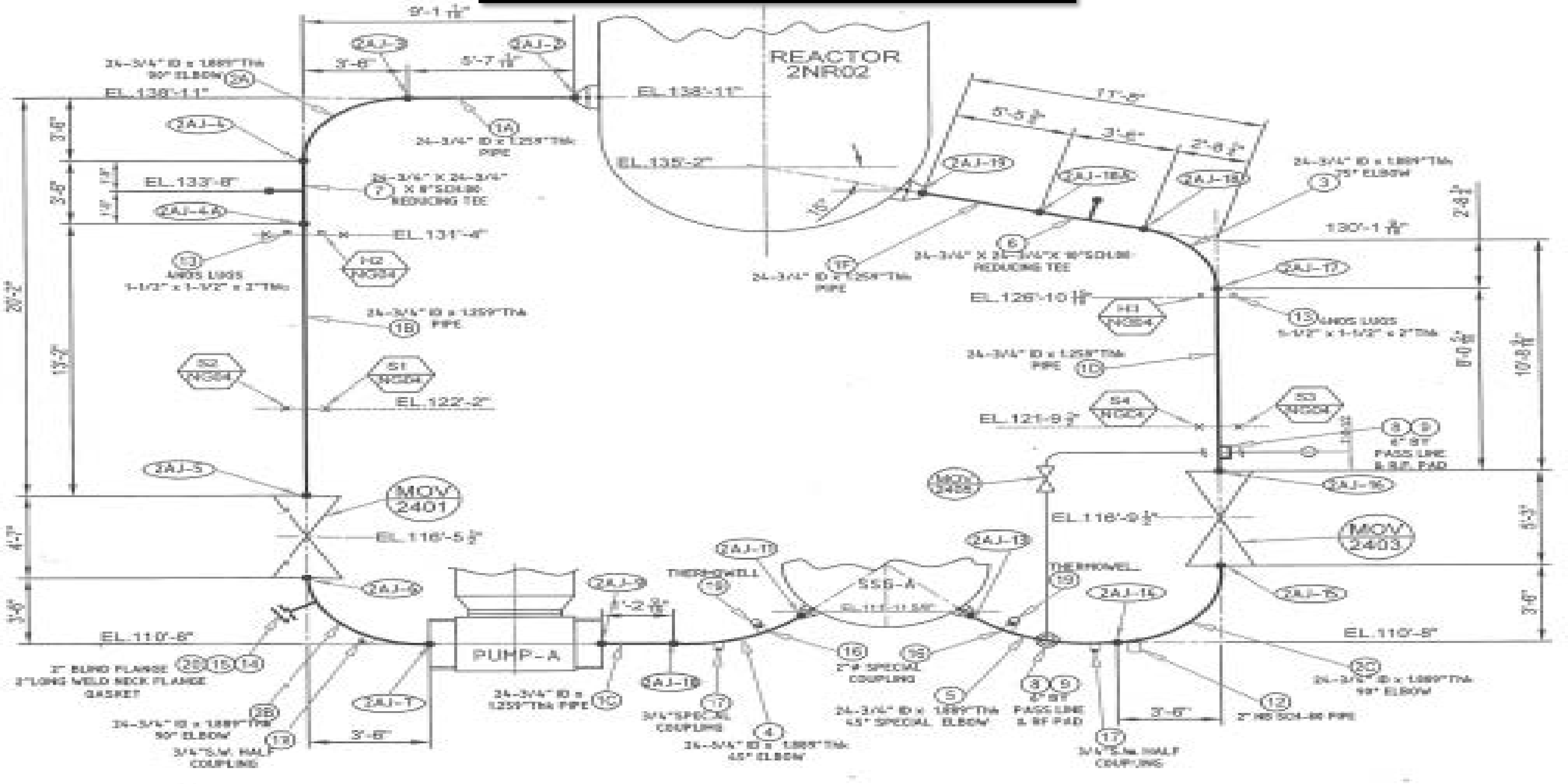
- ✓ Continuous operator training
- ✓ Learning from past accidents
- ✓ International cooperation
- ✓ Operational experience sharing

CONCLUSION

- Safety is the top operational priority
- Nuclear plants face technical, economic, and social challenges
- Strong regulation + innovation = sustainable future
- Nuclear power remains key for low-carbon energy

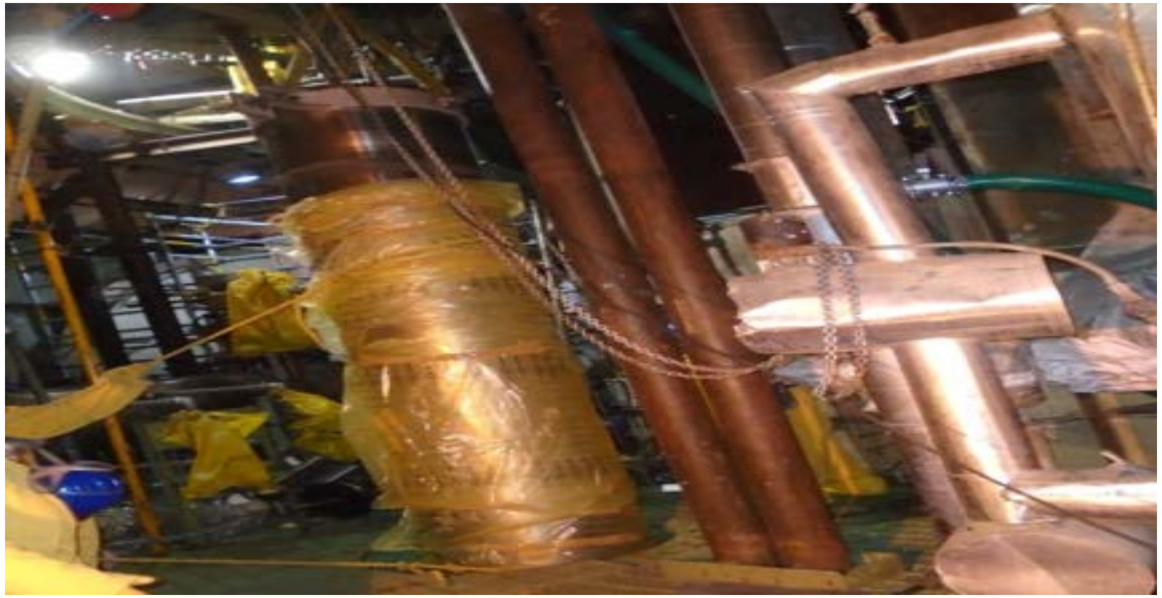

Thank You...

UNIT#2 Rx. RECIRC. PIPING LOOP-A AS BUILT DRAWING



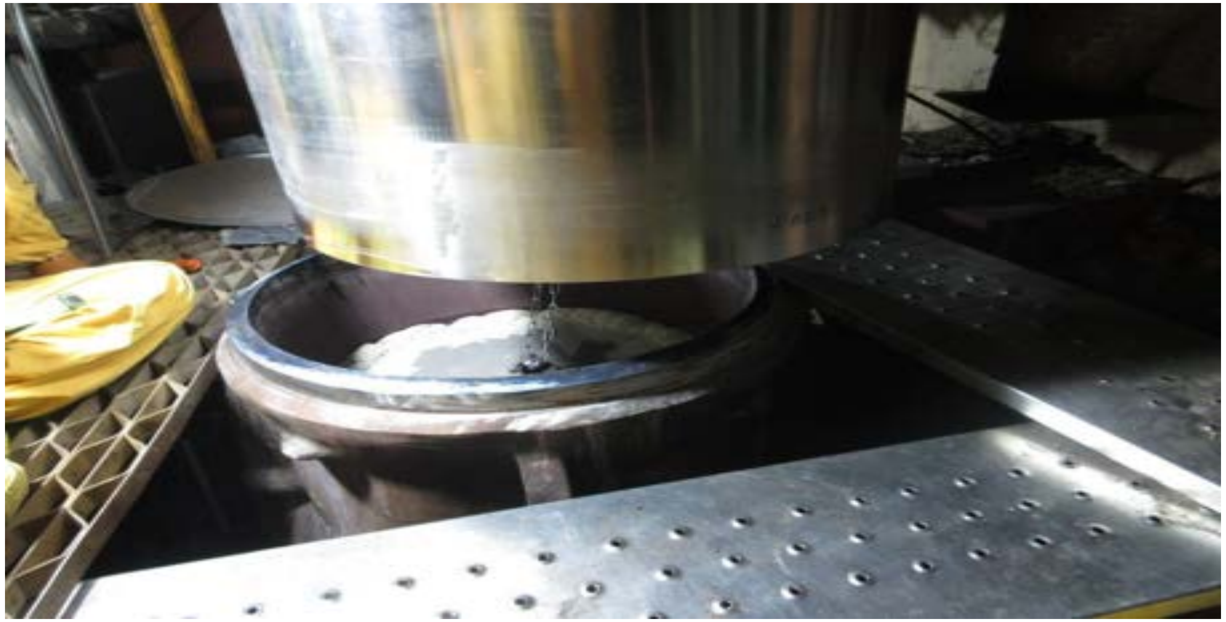
Shifting & Material handling activities

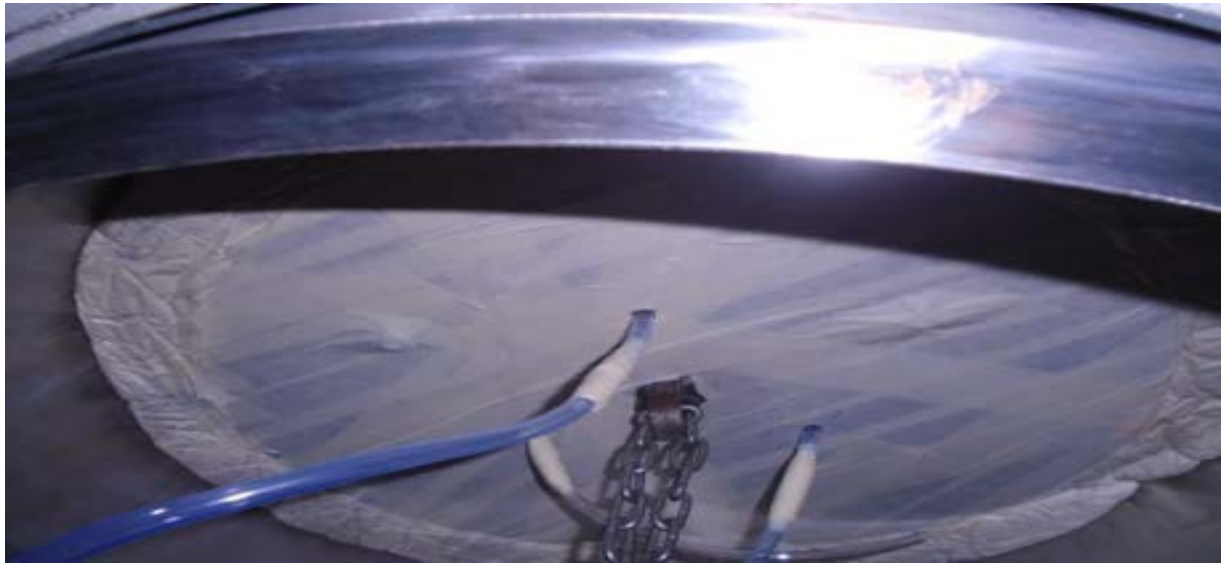
Shifting & Material handling activities



Shifting & Material handling activities

Purge Dam Installation/Removal activities





Fit-up work during piping and motor installation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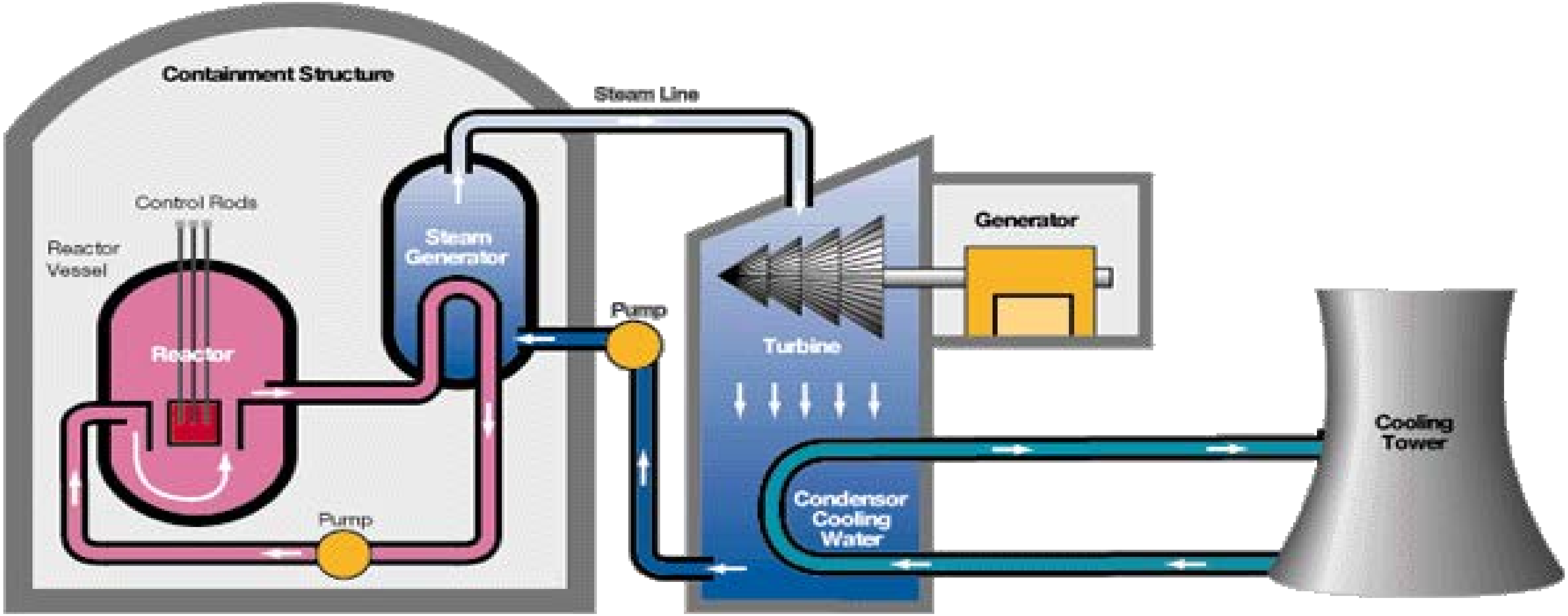
Permanent Hanger Support

Fixtures & support used during piping installation

PWR


Containment Structure
Steam Line
Control Rods
Reactor Vessel
Steam Generator
Reactor
Pump
Pump
Generator
Turbine
Cooling Tower
Condensor Cooling Water

Nuclear Plants Operating in India

Presently, NPCIL operates 24 reactors (as on September 2025) with an installed capacity of 8780 MW

State	Location	Units	Capacity(MW)	Rector Type
Maharashtra	Tarapur	TAPS-1&2	2 x 160	BWR(LWR)
		TAPS-3&4	2 x 540	PHWR
Rajasthan	Rawatbhata	RAPS-2	1x 200	PHWR
		RAPS-3&4	2x 220	PHWR
		RAPS-5&6	2x 220	PHWR
		RAPS-7	1x 700	PHWR
Tamil Nadu	Kalpakkam	MAPS-1&2	2x 220	PHWR
	Kudankulam	KKNPP-1&2	2x 1000	PWR(LWR)
Uttar Pradesh	Narora	NAPS-1&2	2x 220	PHWR
Gujarat	Kakrapar	KAPS-1&2	2x 220	PHWR
		KAPS-3&4	2x 700	PHWR
Karnataka	Kaiga	KGS-1&2	2x 220	PHWR
		KGS-3&4	2x 220	PHWR
Grand Total			**8780**	

Nuclear Plants under Construction in India

State	Location	Project	Capacity(MW)	Rector Type
Rajasthan	Rawatbhata	RAPS-8	1x 700	PHWR
Tamil Nadu	Kudankulam	KKNPP-3&4	2x 1000	PWR(LWR)
		KKNPP-5&6	2x 1000	PWR(LWR)
Haryana	Gorakhpur	GHAVP-1&2	2x 700	PHWR
Grand Total			**6100**	

Nuclear Power Projects (Under pre-project activities)

State	Location	Project	Capacity(MW)	Rector Type
Karnataka	Kaiga	Kaiga-5&6	2x 700	PHWR
Rajasthan	Mahi Banswara	MBRAPP-1&2	2x 700	PHWR
		MBRAPP-3&4	2x 700	PHWR
Haryana	Gorakhpur	GHAVP-3&4	2x 700	PHWR
Madhya Pradesh	Chutka	CMAPP-1&2	2x 700	PHWR
Grand Total			**7000**	

TARAPUR MAHARASHTRA SITE

Nuclear facilities in Operation at Tarapur Maharashtra Site

Generating Stations

TAPS-1&2 (2 BWR Units of 160 MWe) – First criticality **31.10.1968**

TAPS-3&4 (2 PHWR Units of 540 MWe) – First criticality **06.03.2005**

BARC

PREFRE - Power Reactor Fuel Reprocessing Plant

WIP - Waste Immobilization Plant

TRAP - Tarapur Radwaste Augmentation Plant

SSSF - Solid Storage Surveillance Facility

AFFF - Advanced Fuel Fabrication Facility

Emergency Communication

- On declaration of a Plant / Site emergency, communication is given to District Collector (Responsible Officer), AERB, CMG-DAE, CMD-NPCIL & other identified officials.

- CMG-DAE further notifies the Emergency situation to MHA Control Room and NDMA Control room.

- Multiple modes of communication are available at NPCIL sites for communication of the emergency conditions:

  - **Dedicated Hot Line to District Emergency Operation Center.**
  - **Landlines / Mobiles / e-mail / Fax.**
  - **Satellite phones.**

Off-Site Emergency Handling

- On declaration of an Off-Site Emergency, handling emergency situation in public domain becomes the responsibility of the District Disaster Management Committee (DDMC).

- DDMC is headed by the Divisional Commissioner /District Magistrate / Collector of the District (Responsible Officer) and having officials of the district organization as the members (*Superintendent of Police, District Agricultural Officer, District Medical officer, District Animal Husbandry officer, District Disaster Management Officer, etc*).

Role of District Administration during an Off-Site Emergency

- The District Administration will implement the Protective Actions in the affected sector and villages in the public domain.

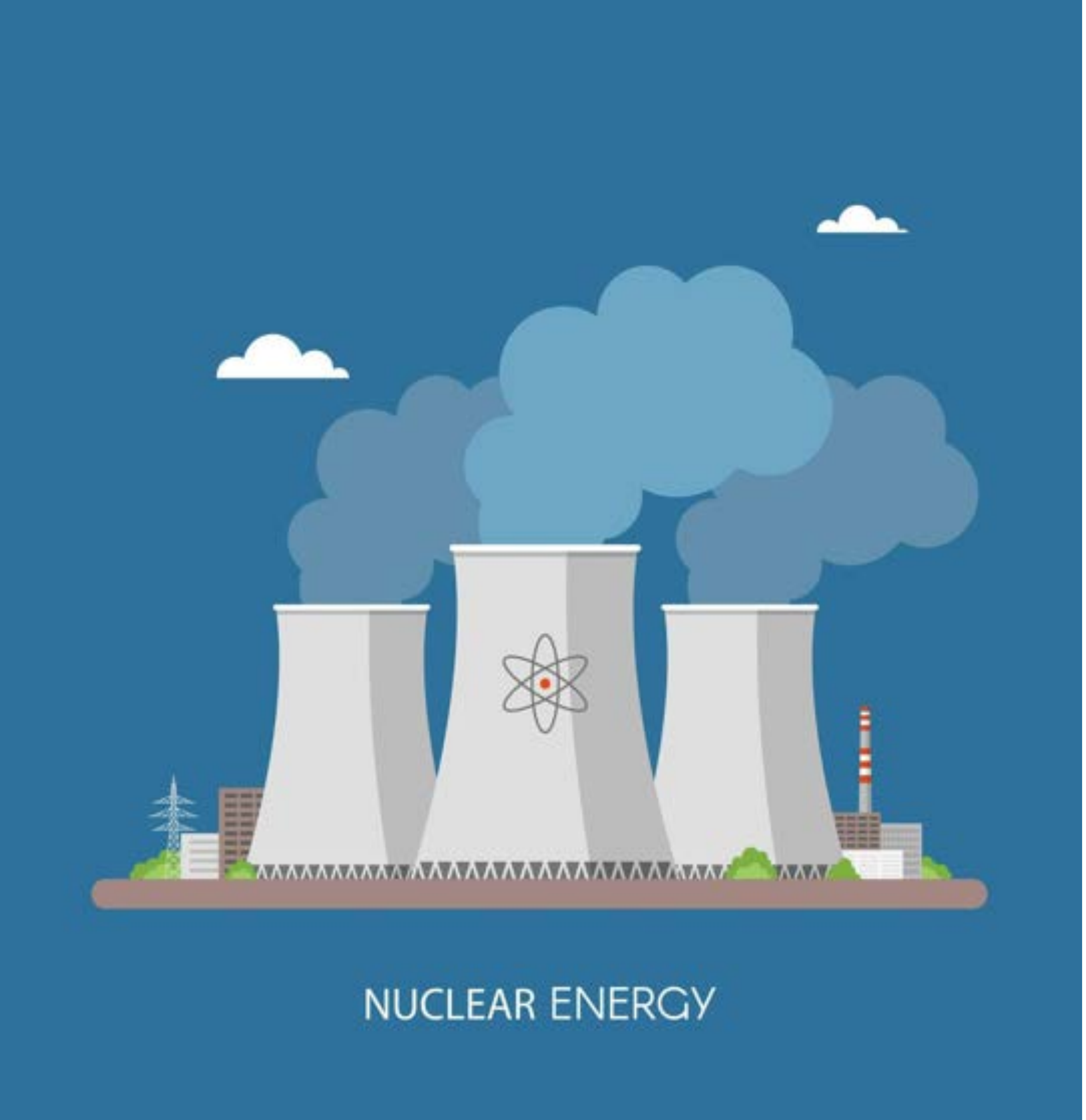
- The protective actions and the time within which the protective actions are to be implemented in the affected villages will be communicated to the Responsible Officer by the Site Emergency Director (SED) and the Radiation Emergency Response Director (RERD) based on the plant and meteorological conditions using Decision Support System (DSS) and field measurements.

- Based on the Protective Action Recommendation (PAR) communicated, the Responsible Officer will implement the suggested Protective Actions in the affected villages.

LECTURE - 5

Overview of NPP Project Management

Mr. Ranjay Sharan
Former Director (Projects), NPCIL



1. Introduction
2. Practices
3. Bottlenecks
4. Strategies

INTRODUCTION

Evolution of Project Management

Introduction to NPP Project Management:

- Key elements –
  - **Site related**
  - **Organization & people**
  - **Package formulation**
  - **Contract Management**
  - **Change Management**
  - **Industries**
  - **Timeline**
  - **Optimization of cost & tariff**

PROJECT MANAGEMENT & INTERNATIONAL NEGOTIATION

NEGOTIATION

INTEREST (POLITICAL/ STRATEGIC/ COMMERCIAL)


INDIVIDUALISM
USA
EU
GULF
INDIA
CHINA
JAPAN
GEOGRAPHICAL DISTANCE

PREVAILING PRACTICES

Prevailing PM Practices

Modularization
- Mechanical activates like Dome and Ring Liner

Mega pours
- Executing big pours for Major Structures

Fragmented packages
- 20 major construction packages in KAPP 3&4 / RAPP 7&8

Project Planning & Monitoring
- Manual & PM tool for KAPP 3&4 / RAPP 7&8

- 600000 M3 OF CONCRETING
- 150000 TONNE REINFORCEMENT
- 6000 TONNE HEAVY STRUCTURAL STEEL

- 250 KM PIPING
- 160 KM TUBING
- 3000 KM CABLING
- 1 MILLION WIRE TERM.

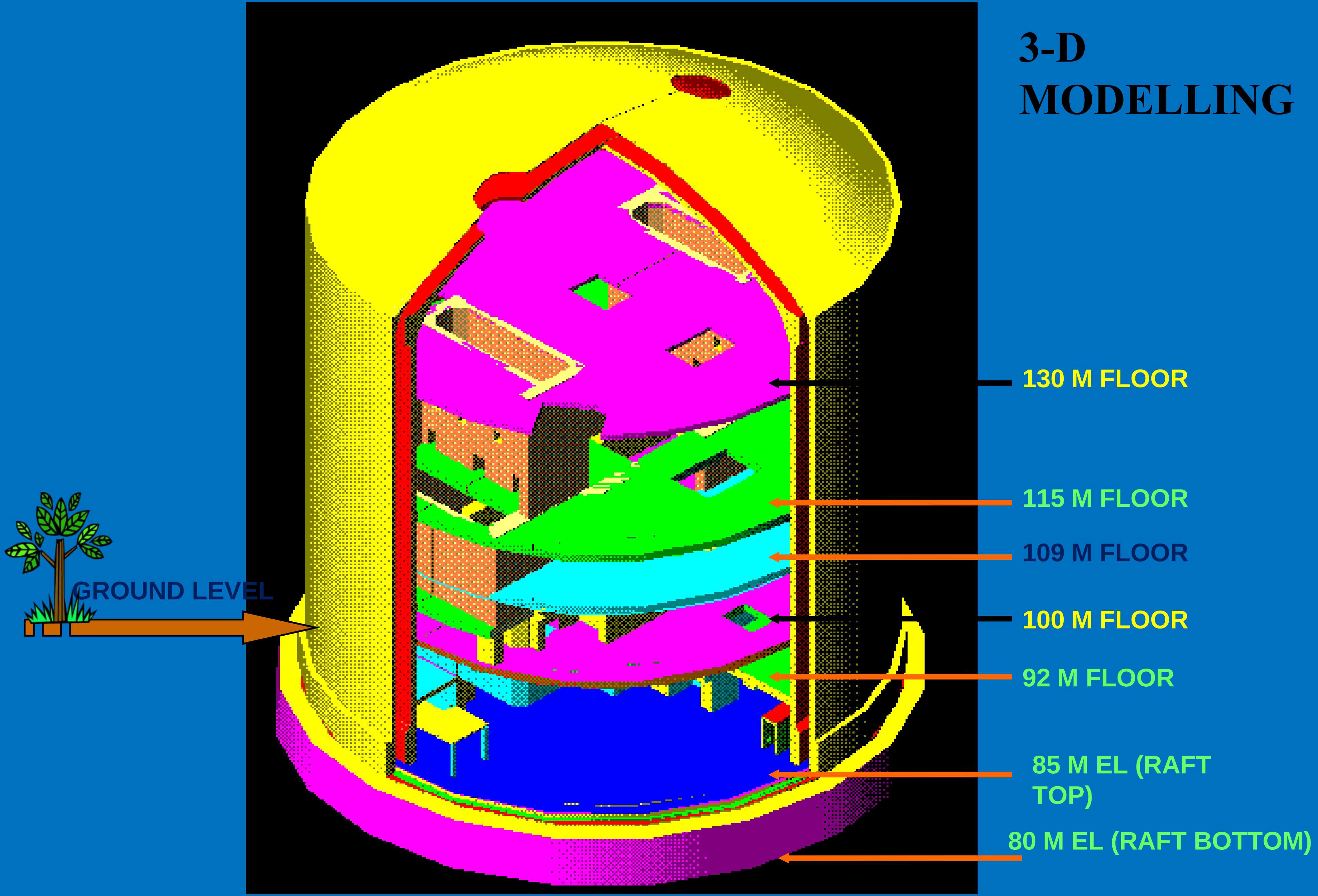
TAPP-3&4

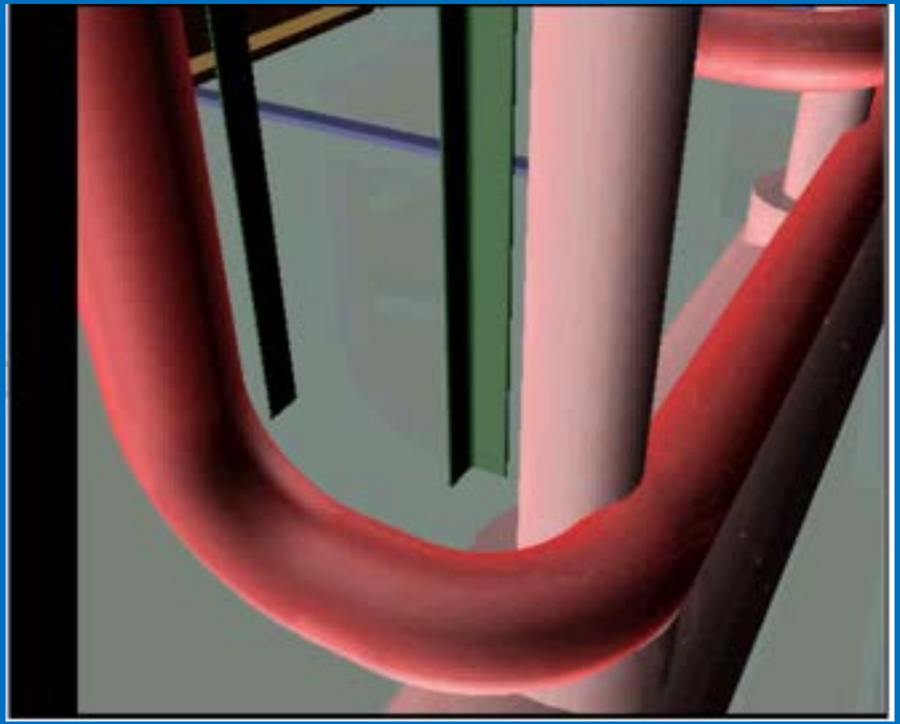
Quantities at KAPP-3&4

Concreting: 14 Lakh Cu.M.
Steel: 2 Lakh Te
Piping: 350 Km
Piping welding: 12 Lakh ID
Piping Erection: 16 Lakh IM

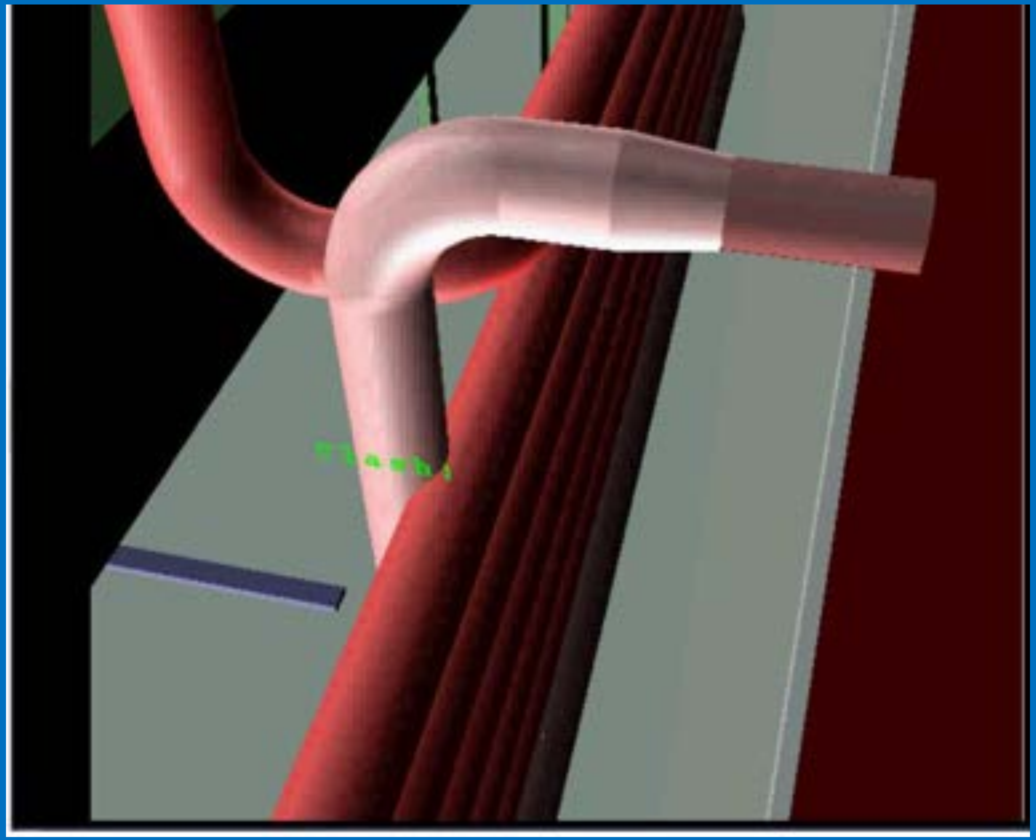
Cabling: 5200 Km
SS Tubing: 160 Km
Cu Tubing:80 Km
Eqpt. Tonnage: 13500 Te
Large Valves: 4100 Nos
Small Valves: 20000 Nos
GSS ducting: 60000 Sq. M
CS ducting: 6000 M

3-D MODELLING





INTERFERENCE CHECKING
BY 3-D MODELLING



ADVANCED CIVIL TECHNOLOGY: SELF CLIMBING SHUTTER

HORIZONTAL & VERTICAL CONSTRUCTION

PUMP CONCRETING AT HEIGHT

PARALLEL CONSTRUCTION

2001

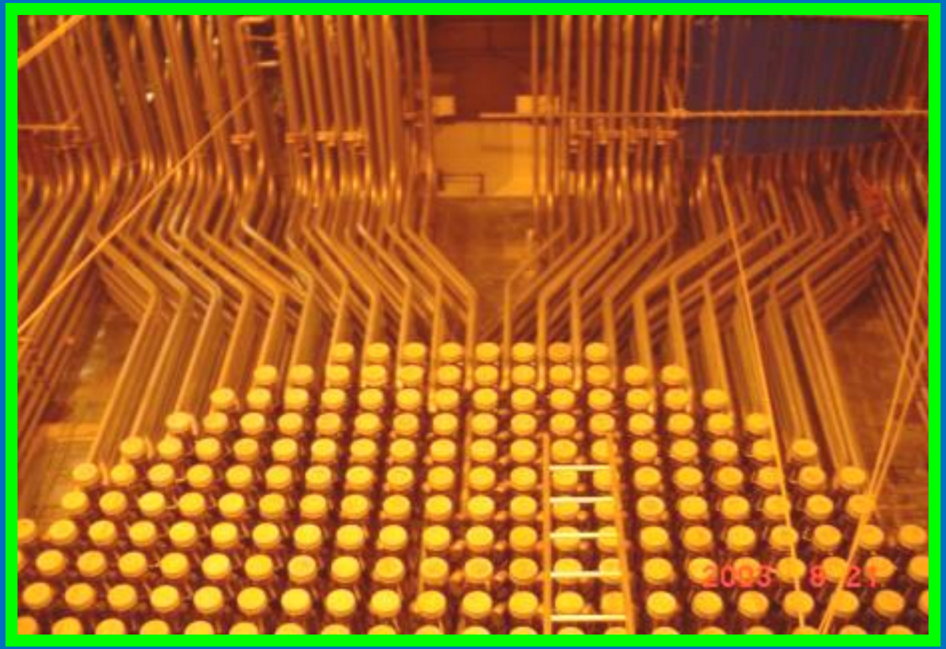
2002

2003

OPEN TOP CONSTRUCTION

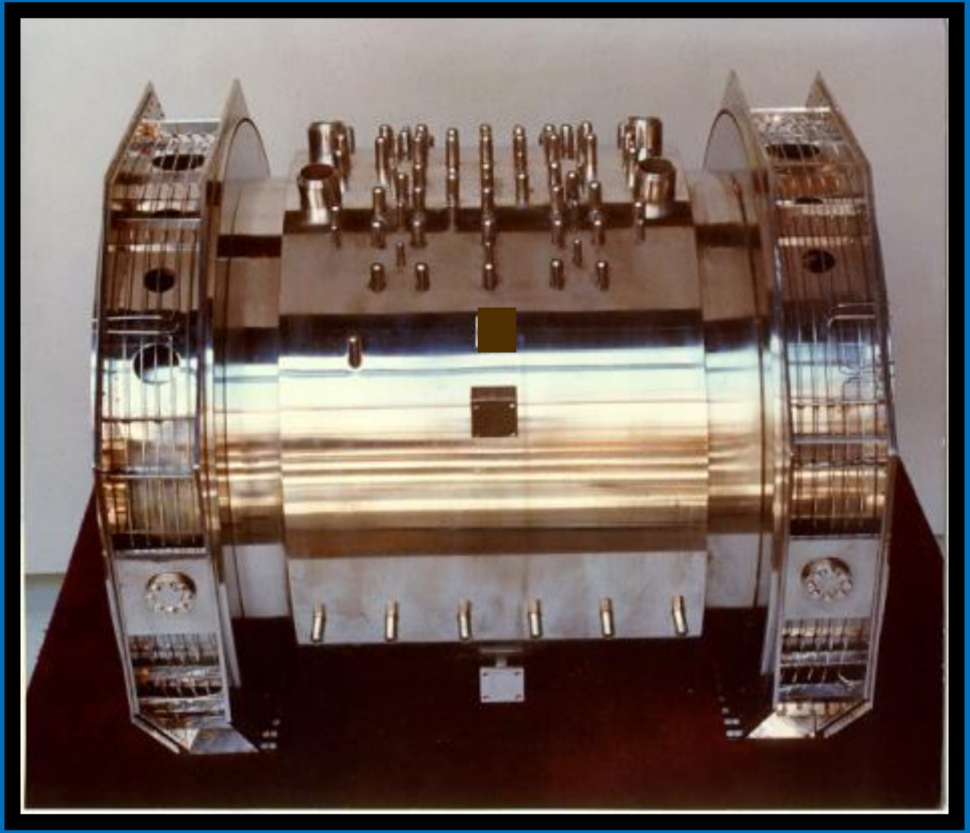
OPEN TOP CONSTRUCTION

PRECISE SHOP FABRICATION



MODULAR CONSTRUCTION

MOCK-UP FOR COMPLEX & CRITICAL JOBS

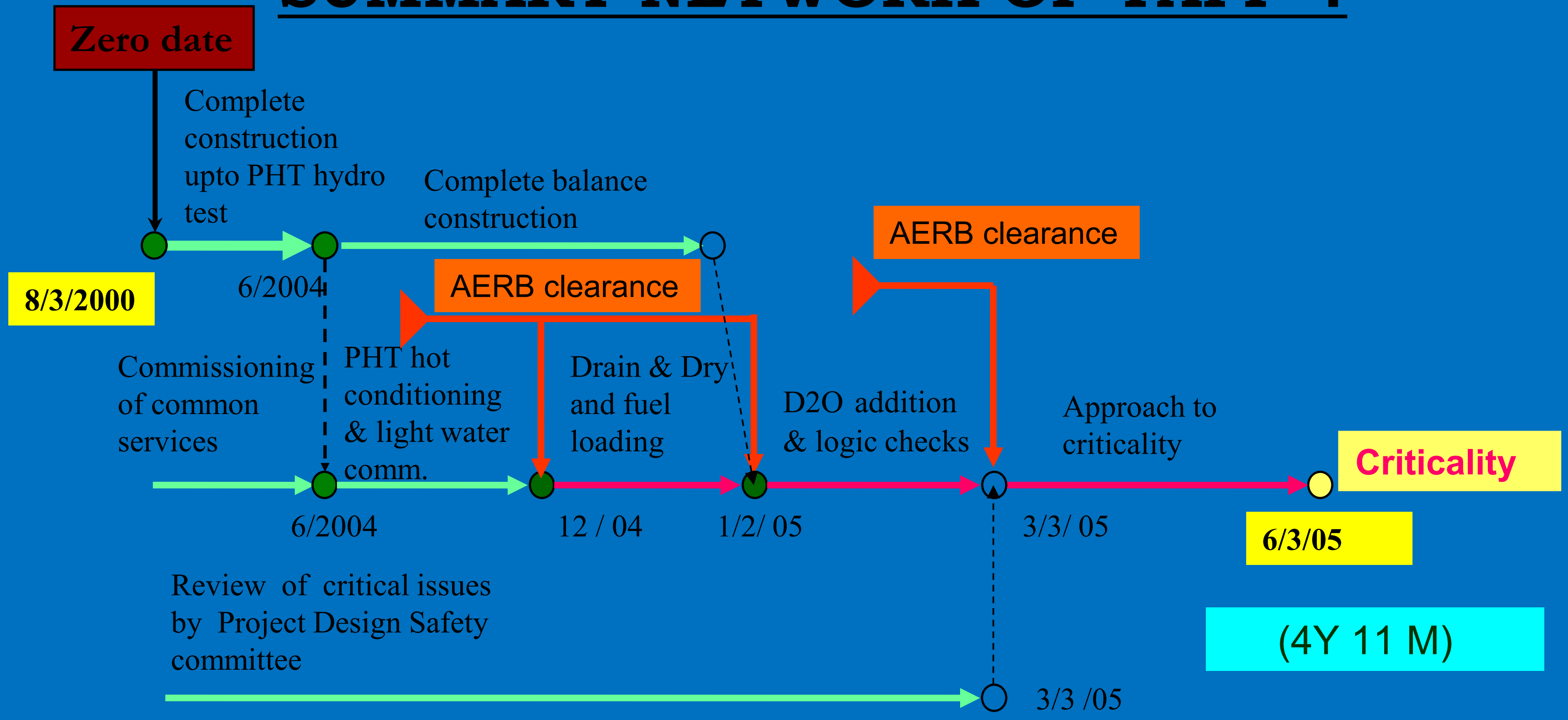



PARALLEL
WORKING WITH
COMMISSIONING
TEAM

PARALLEL COMMISSIONING

CONTINGENCY PLAN

SUMMARY NETWORK OF TAPP-4



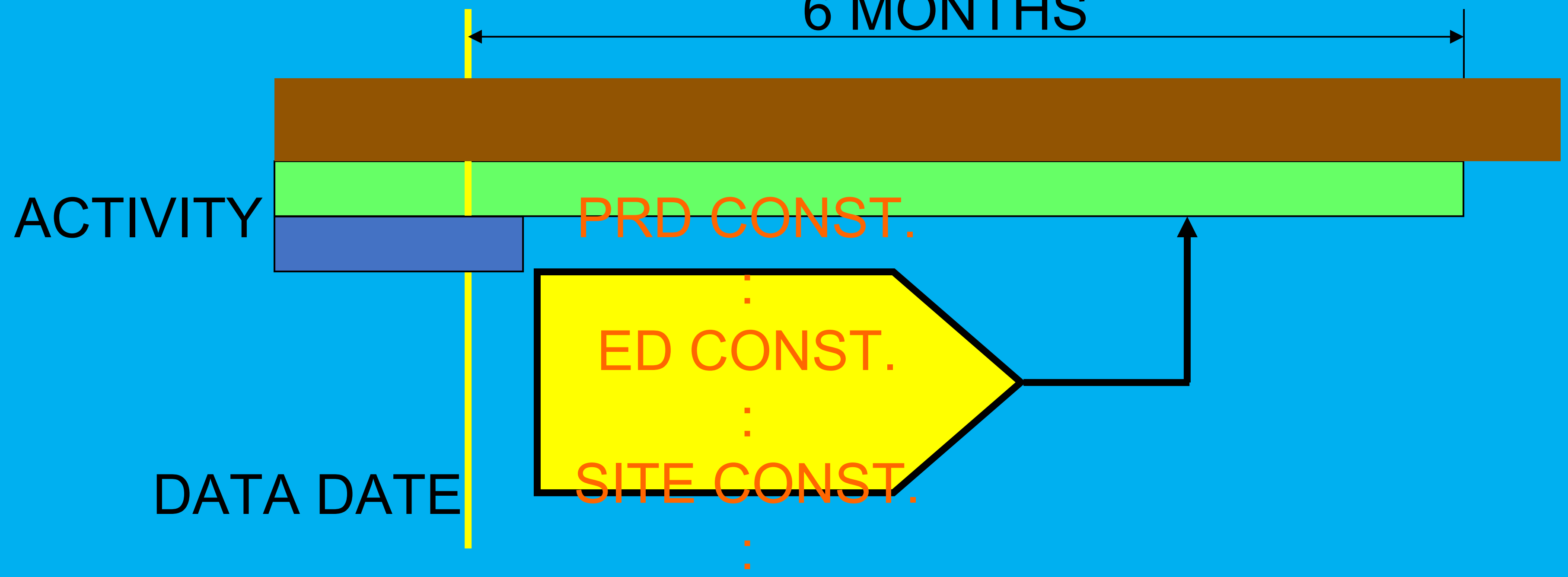
Overriding Priority:

- Nuclear codes
- Industrial safety
- Radiation safety

3-Tier approach for Regulatory clearance:

- Review by PDSC
- Review by ACPSR
- Final clearance by AERB

SIX MONTHLY PLAN



1. 24x7 work-schedule followed.
2. All project work were broken down in 30,000 activities for close monitoring.
3. Special lay-out using project planner software was developed for six monthly plan for timely monitoring of constraints & the same was launched on NPCIL intra-net.
4. Progress monitoring was done on daily basis using Local Area Network.

CIVIL PACKAGE

(TARGET DATE OF COMMERCIAL OPERATION FOR TAPP-3 : JULY 2006)

AGENCY : M/s. L & T

Package II

Wo No.	COST OF PACKAGE IN CRORES.
0094 DT: 24/5/99	351.25 Cr.
Exptd. Compln. Cost with Esc.	451.88 Cr.

SCHEDULE OF COMPLETION :

AS PER TENDER		EXPECTED
TAPP # 4	3.02.03	30.12.03*
TAPP # 3	3.08.03Oct-04	30.05.04**

CUMULATIVE EXPENDITURE TILL DATE :	451.88 Cr.
Physical Progress for both Units.	100% Completed

* Contract is completed & final extension upto 31.05.04 is approved.

Package III

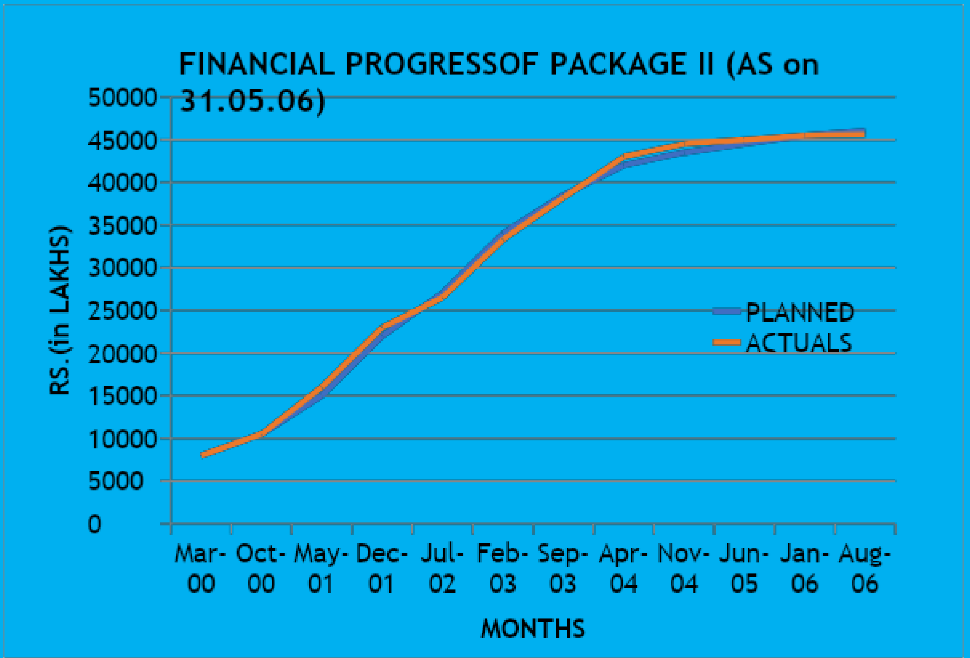
Wo. No	COST OF PACKAGE IN CRORES.
99	142.09 Cr.
Exptd. Compln. Cost with Esc.	189.898 Cr.

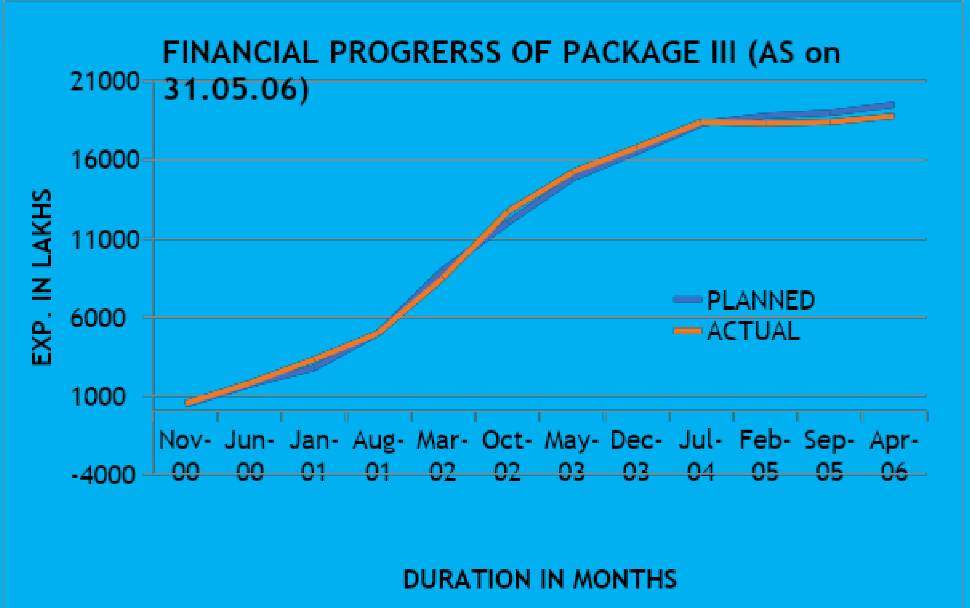
SCHEDULE OF COMPLETION :

AS PER TENDER		EXPECTED
TAPP # 4	31.12.02	30.11.03*
TAPP # 3	03.06.03	31.05.04**

** Work completed & extension approved upto 31st May 04

Cumulative Exp. Till date	18988.63 Lakhs
Physical progress for both units.	100% Completed





PRIMARY PIPING PACKAGE
(TARGET DATE OF COMMERCIAL OPERATION FOR TAPP-3 : JULY 2006)
AGENCY : M/s. L & T.

	PO NO.	COST OF PACKAGE IN CRORES.
SUPPLY	6200	211.42Cr.
ERECTION & COMMG.	6201	55.5Cr.

SCHEDULE OF COMPLETION :

AS PER TENDER		EXPECTED
TAPP # 4	14.09.04	31.03.05*
TAPP # 3	14.03.05	30-06-06**

*Completed.
**Contract being extended.

Cum. Expenditure till date:	4962.89 LAKH

Major Activities completed during this month:

Unit-3

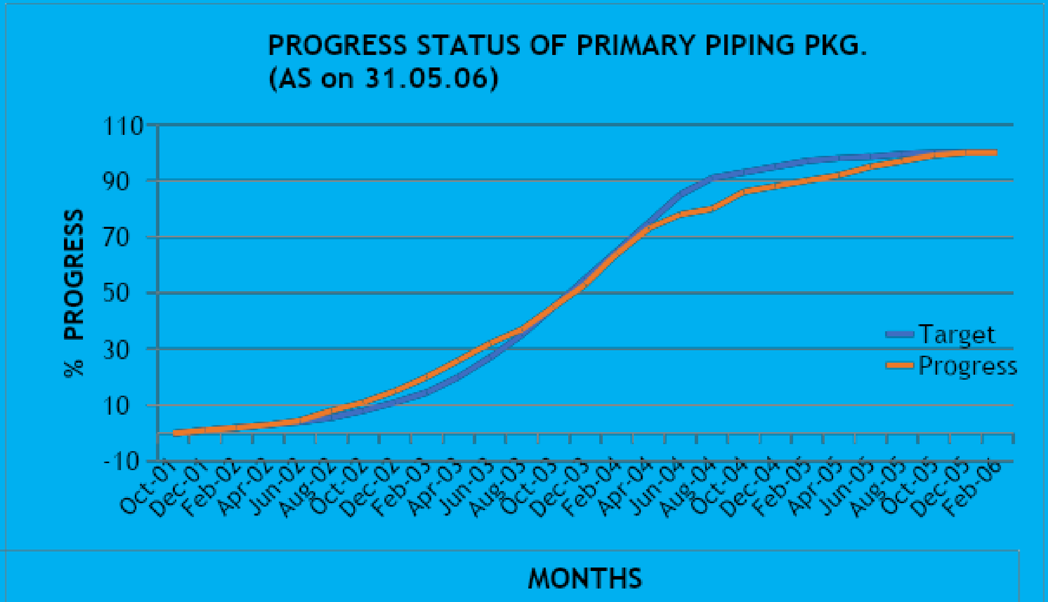
1	Material Accounting & submission of Final bill in progress

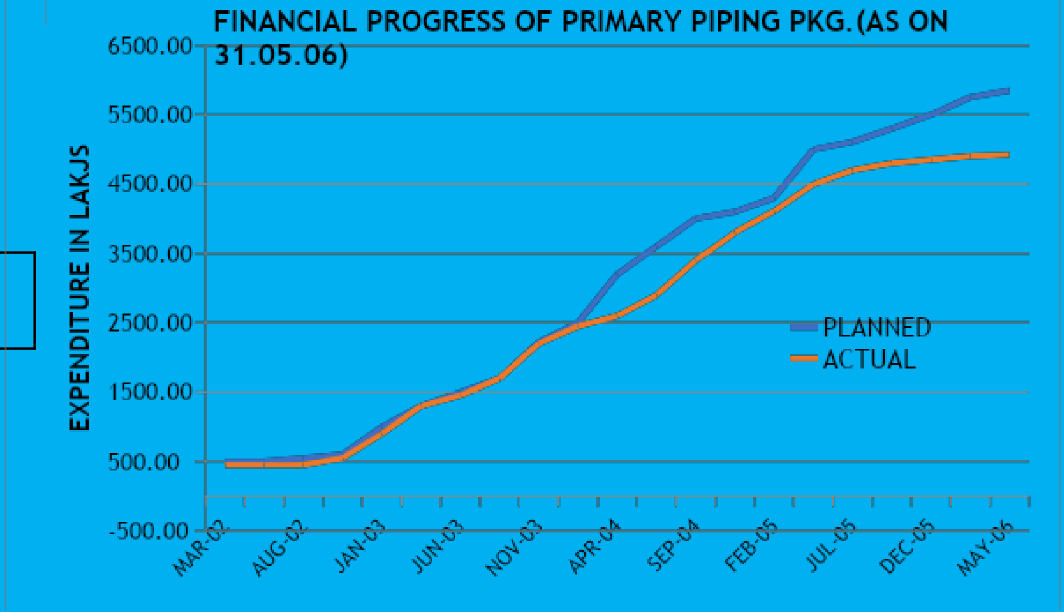
Plan for Next month:
Unit -3

1	Material Accounting & clearance of Final bill.

Constraints

NIL

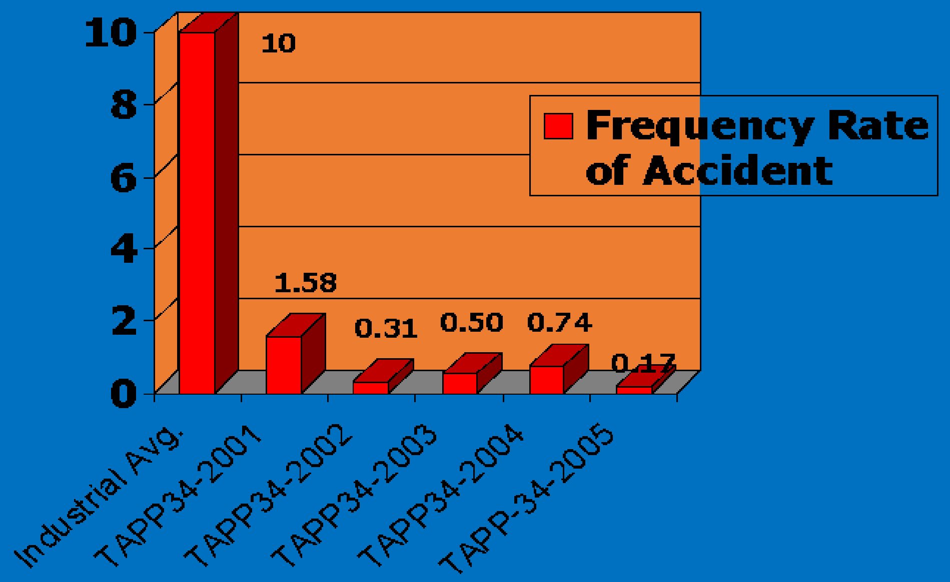




Industrial & Fire Safety

145 MILLION MAN HOURS

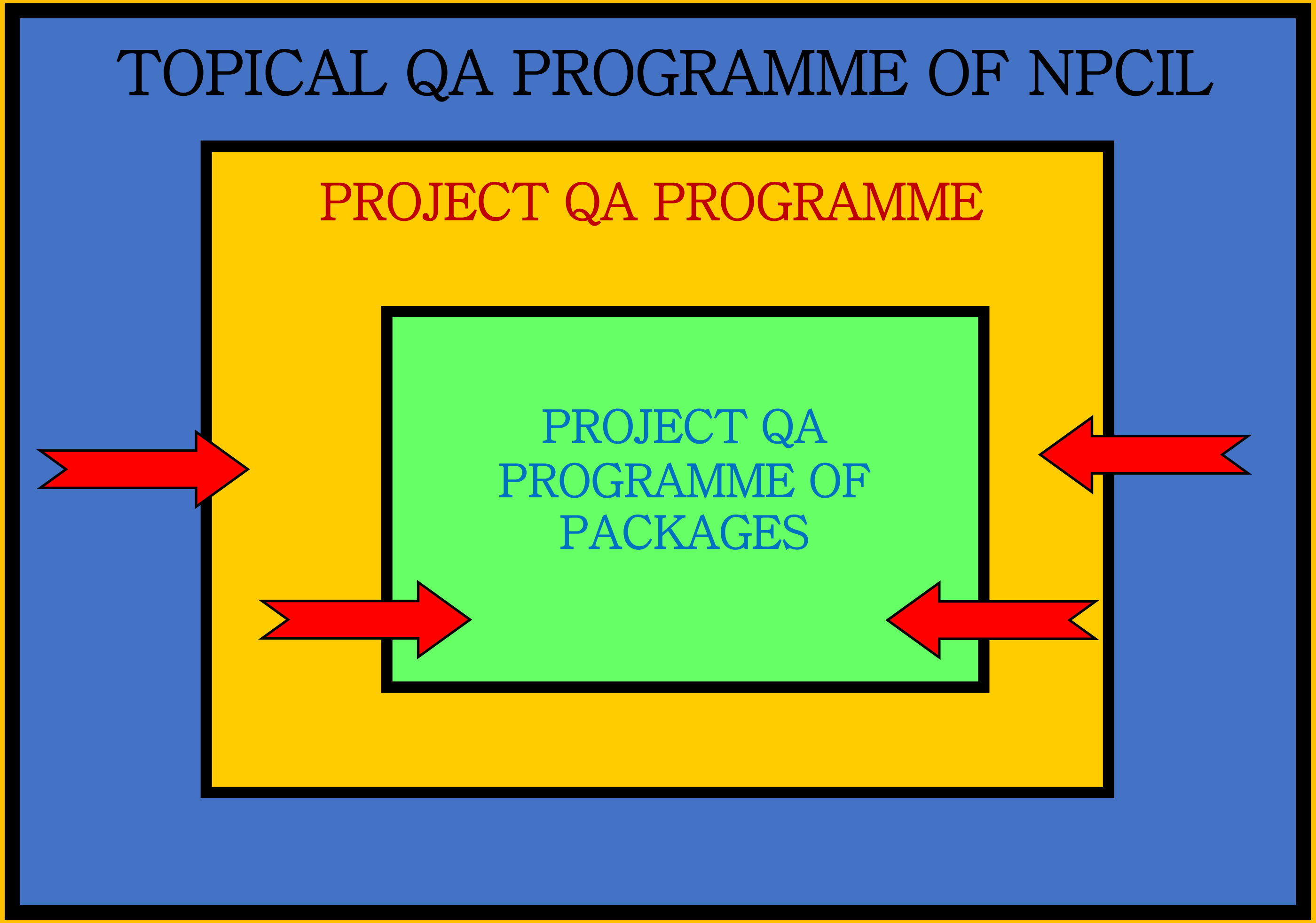
INDUSTRIAL SAFETY



(REPORTABLE INJURIES PER MILLION MAN HOUR)

QUALITY ASSURANCE PROGRAMME

- 3 TIER APPROACH



Modularization

Erection of Pre-Fabricated Ring Liner: KAPP 3&4

No. of Ring Liners	8 Nos
Weight of Each Ring Liner	75 MT
Diameter of the Liner	49.5 m
Height of the liner	5 m

Modularization

No. of Domes	2 Nos
Weight of Each Dome	355 MT
Diameter of Each Dome	47 m
Height of the Dome	8.25 m

KAPP#4 IC dome Liner erection

Modularization

No. of Domes	1 Nos
Weight of Each Dome	305 MT
Diameter of Each Dome	42.5 m
Height of the Dome	16.4 m

Modularization

No. of cage	9 Nos
Weight of Each Cage	14 to 18.5 MT
Dimensions of Each Cage	13.7 X 4.4 X 2.6 m (Max.)

No. of Segments	12 Nos
Weight of Each Segment	35 MT
Height of Each Segment	1.8 m
Length of Each Segment	12 m

Mega Pours

KAPP 3&4

- RB-3 Raft : 5100 Cum
- RB-4 Raft : 5100 Cum
- CB Raft : 5500 Cum
- IC wall : 350 Cum

KKNPP 3&4

- TB-4 Raft : 6000 Cum
- RB-3 +5.4m Slab : 3500 Cum
- RB-4 +5.4m Slab : 3500 Cum
- IC wall : 900 Cum

KKNPP 5&6

- RB-5 Raft: 6100 Cum
- RB-6 Raft: 6100 Cum
- TB-6 Raft: 11050 Cum

Mega pours are currently executed in Raft and Containment structure.

Mega Pours

TB-6 Raft KKNPP-5&6: Single Big Pour

Concrete Quantity	**11,050 Cum**
Reinforcement Quantity	**1500 MT**
Embedded Parts	**922 Nos**
Depth of Raft	**1.5 m**

Fragmented packages

Major Construction packages of KAPP 3&4 – 20 Nos	
Main Plant civil Works	Balance of Turbine
Natural Draught Cooling Towers	Plant Water Package
Induced Draught Cooling Towers	HVAC
Common Service Piping	Primary Piping
Switch yard	Turbine
Field Instrumentation	DG Package
End Shield	GT Package
Steam Generator	Electrical System
Electric Bay Building	Control Center
WMP & D20 Upgradation	SUT & UT

Supply Contracts – XX Nos

EPC packages – XX Nos

Site Packages – XX Nos

FHS items – XX Nos

BOTTLENECK ISSUES

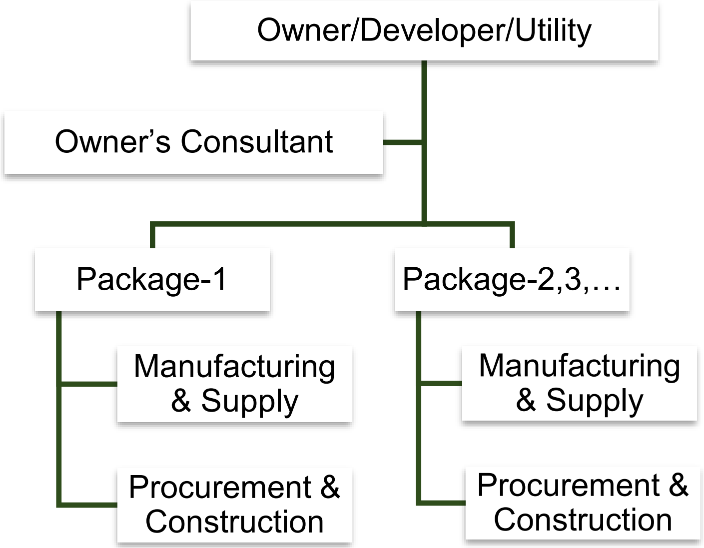
Bottleneck Issues:

- Pre-project activities
- Interface Management
- Limited suppliers & Contractors
- Vendor development for Continued Supplies
- Industry preparedness to handle mega projects
- Long lead items

STRATEGIES

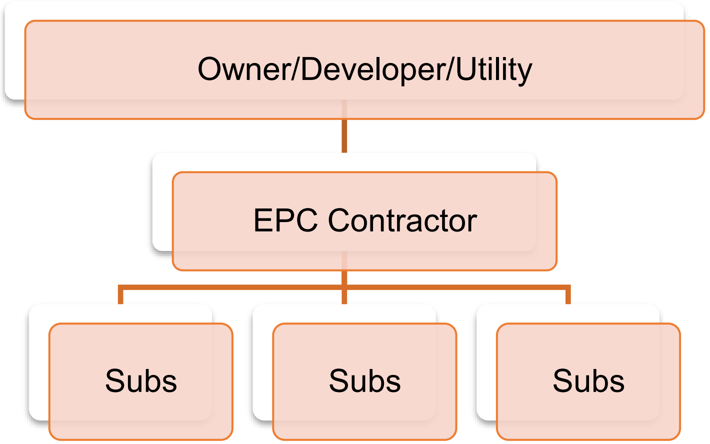
NPP Business Model – Existing & Emerging- Large NPP

Multi-Contract	20+ Packages
	Ex. KAPP - 3&4

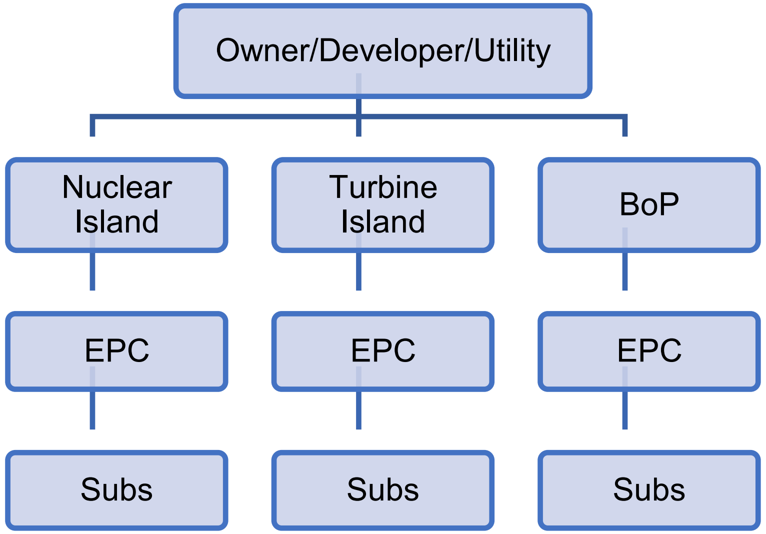


Existing

Mega Project-1	7+ Major Packages
	Near Future Indian PHWRS



Mega Project-2	2+ Major Packages
	Future Projects in fleet mode

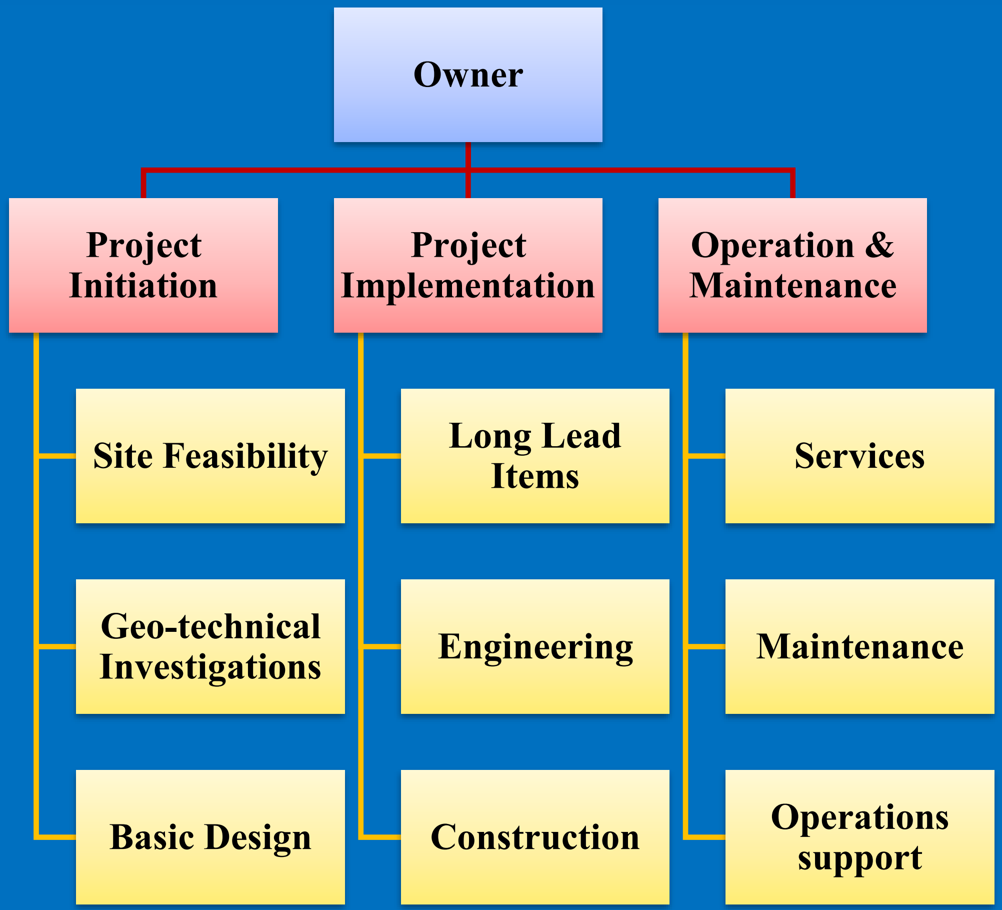


Future Nuclear projects will be of Mega Projects type like in other infrastructure business

2

Project Contract Model

Adopting Integrative approach for similar nature of jobs for better project delivery and success



- ✓ Migration from Least Cost Selection to Quality Cost Based Selection
- ✓ Thrust on Technical and Quality parameters of the stakeholders
- ✓ Timely decisions lead to timely actions that lead to moving project progress forward
- ✓ Digitization (3 D Model, PM tool, PLM/ERP etc)

GREEN BELT

WELFARE ACTIVITIES IN NEARBY AREA

THANK YOU

LECTURE - 6

Nuclear Fuel Cycle

Theme meeting on the National Mission of 100 GWe Nuclear Energy by 2047

Indian Nuclear Society

19th Feb., 2026

S A Bhardwaj
sabhardwaj@gmail.com

Nuclear Fuel available in nature

Uranium

U

U^{235} 0.7%

~~U^{238} 99.3%~~ ← Not a fuel

Thorium

~~Th 232~~ ← Not a fuel

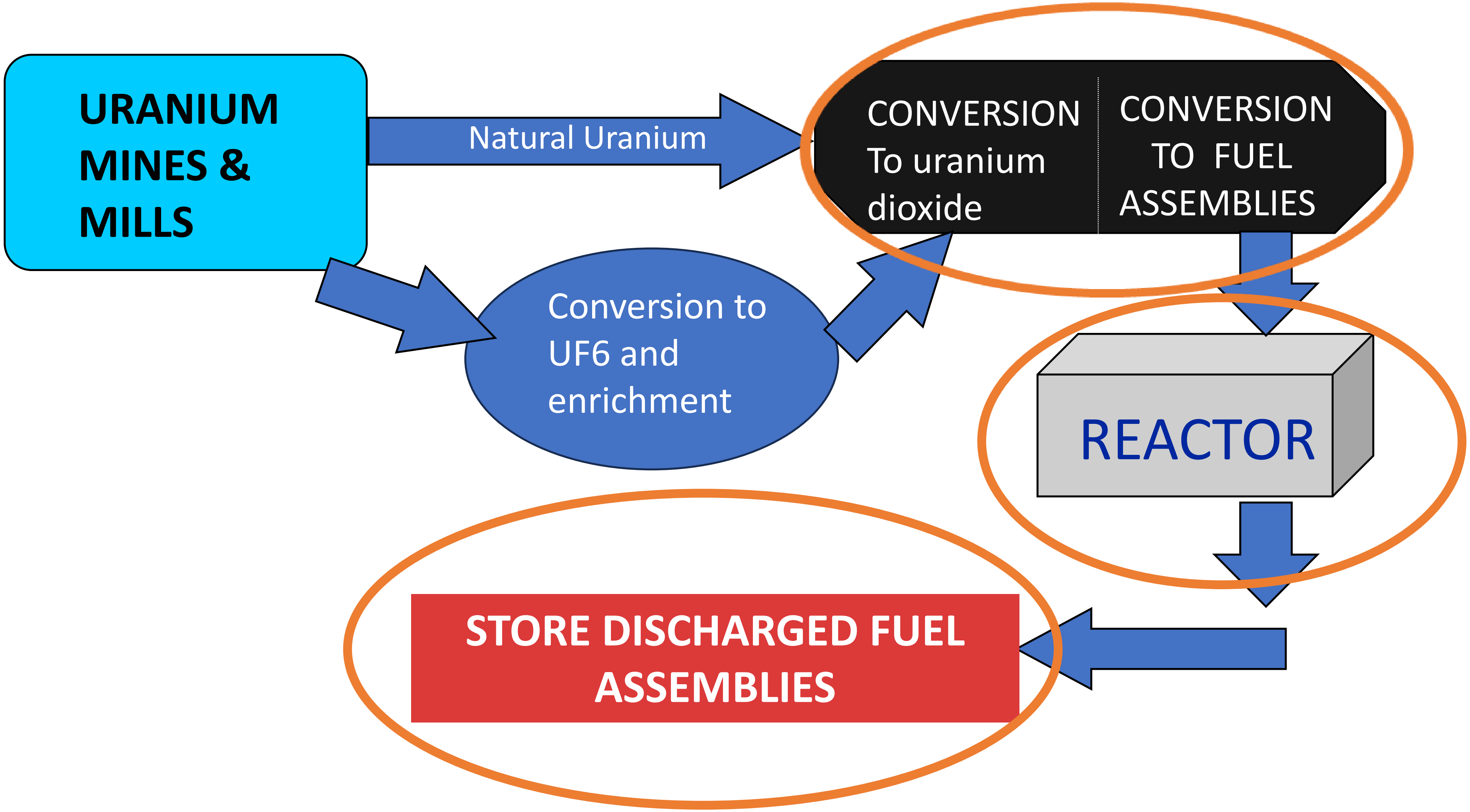
But

- Uranium 235, the small fraction of natural uranium, while it produces a large amount of energy, can simultaneously convert a small fraction of uranium 238, invariably present along with uranium 235, into a man-made nuclear fuel PLUTONIUM.
- Similarly, Thorium can be supported by uranium or plutonium to produce artificial fuel Uranium 233.

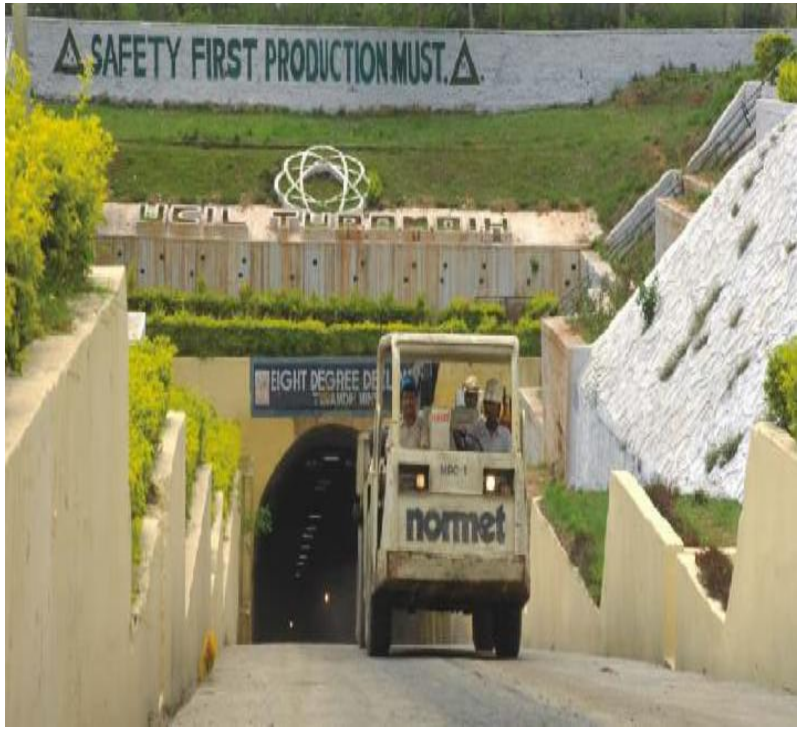
FUEL IN PRESENT COMMERCIAL NUCLEAR POWER PLANTS

REACTOR TYPE	FUEL
Pressurized heavy water reactor (PHWR)	Natural Uranium
Pressurized water reactor (PWR)	Enriched Uranium
Boiling water reactor (BWR)	Enriched Uranium

THE NUCLEAR FUEL CYCLE

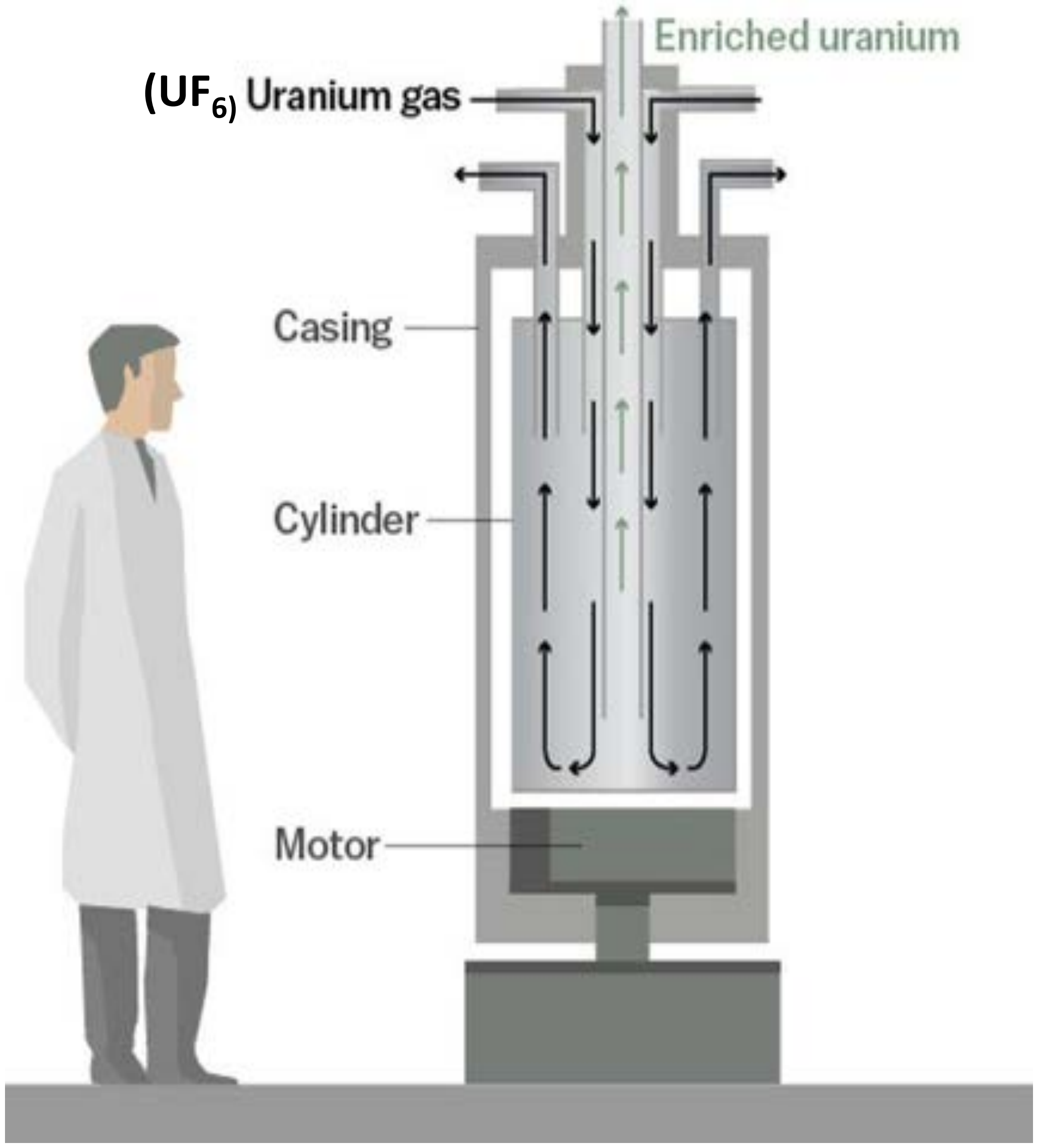


Uranium Mining & Milling



Yellow Cake

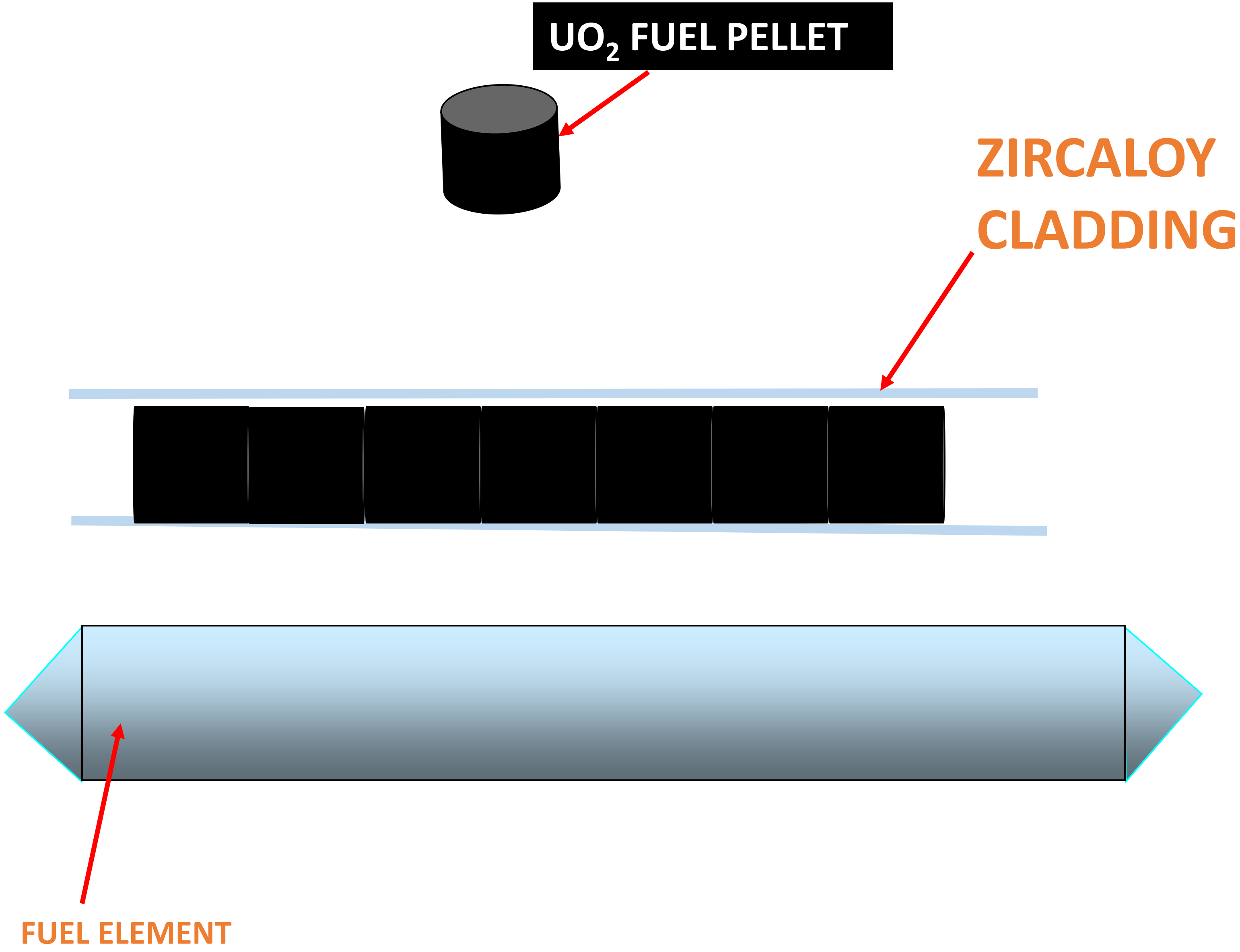
Uranium Enrichment by centrifuges



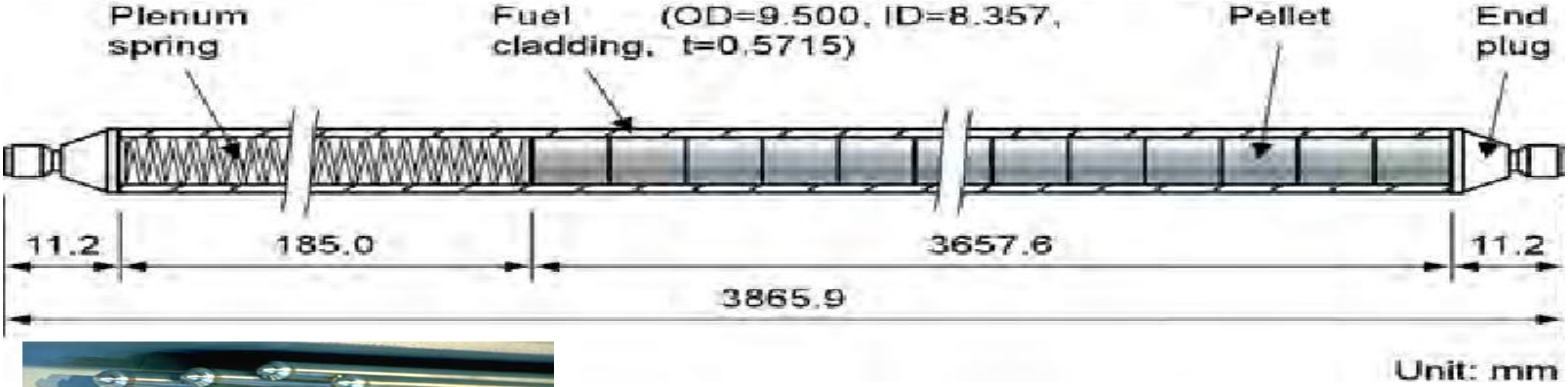
FUEL ASSEMBLY

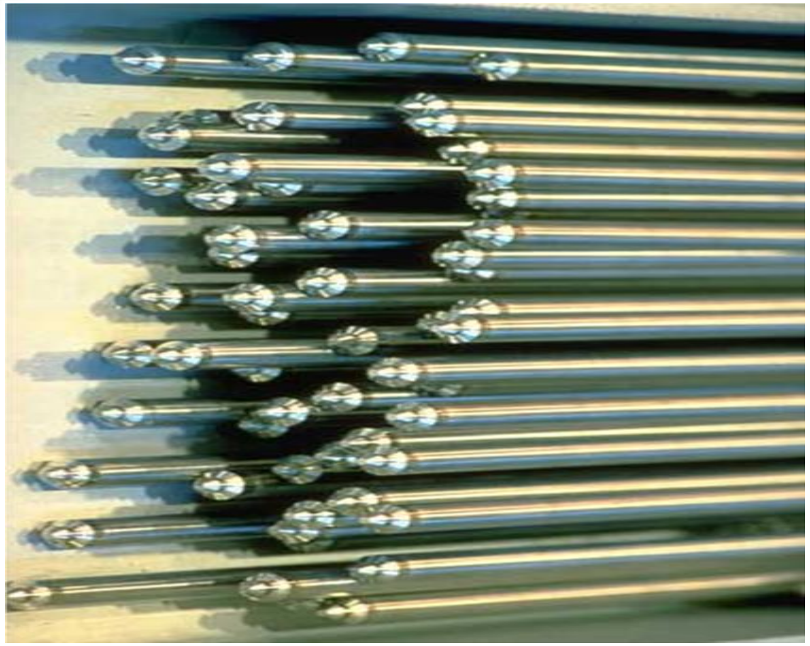
UO$_2$ Powder and Sintered UO$_2$ pellets

Typical Fuel Rod or Fuel Element

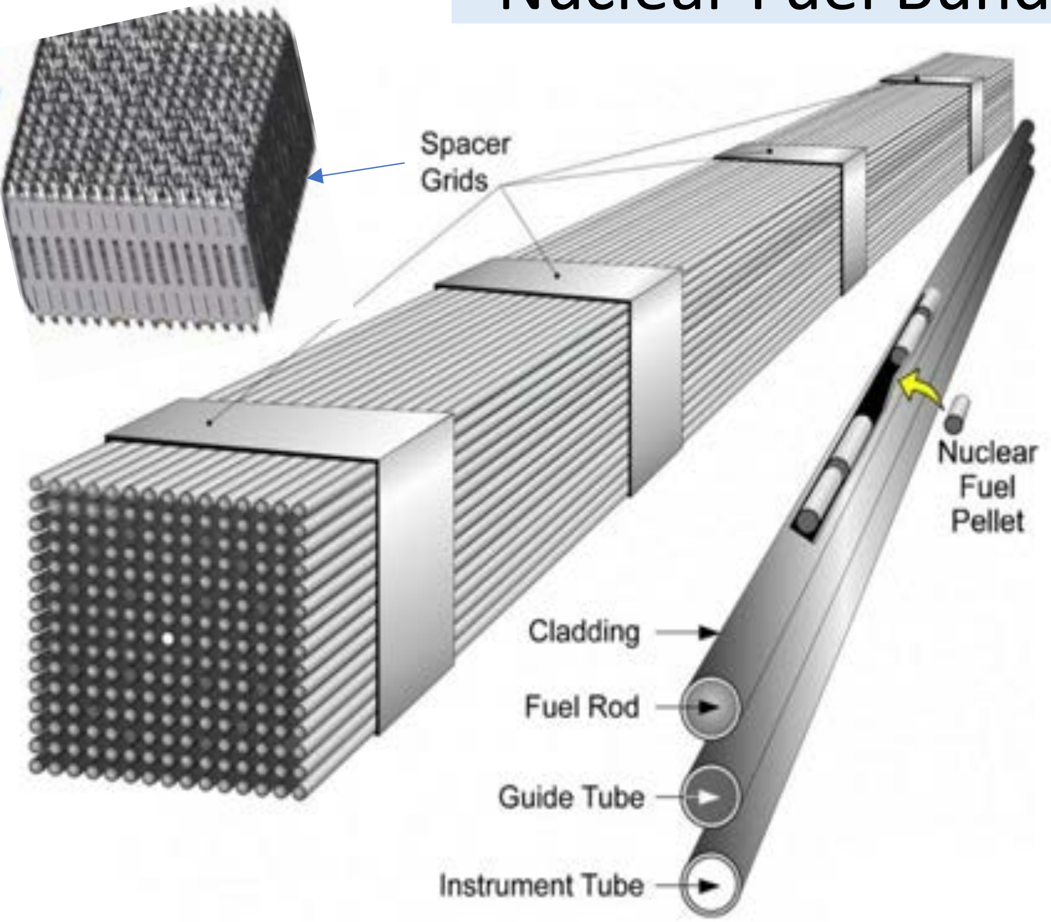


Typical PWR Fuel Rod

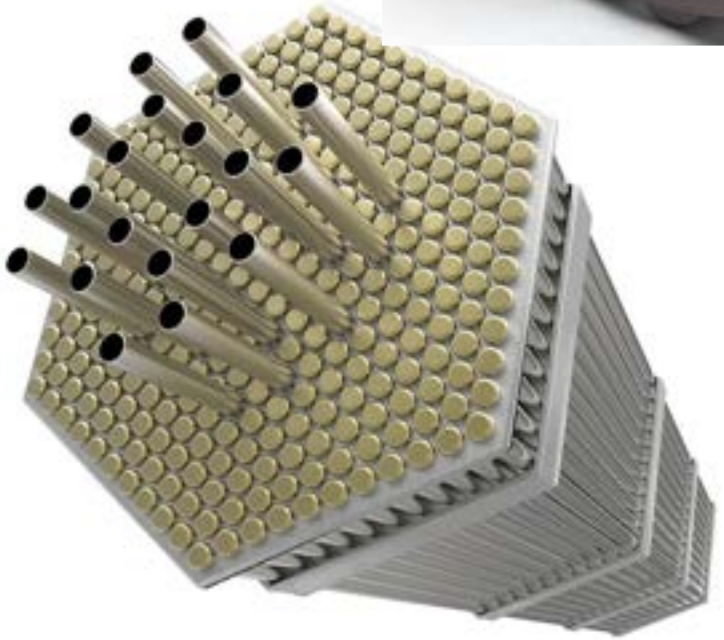




Nuclear Fuel Bundles

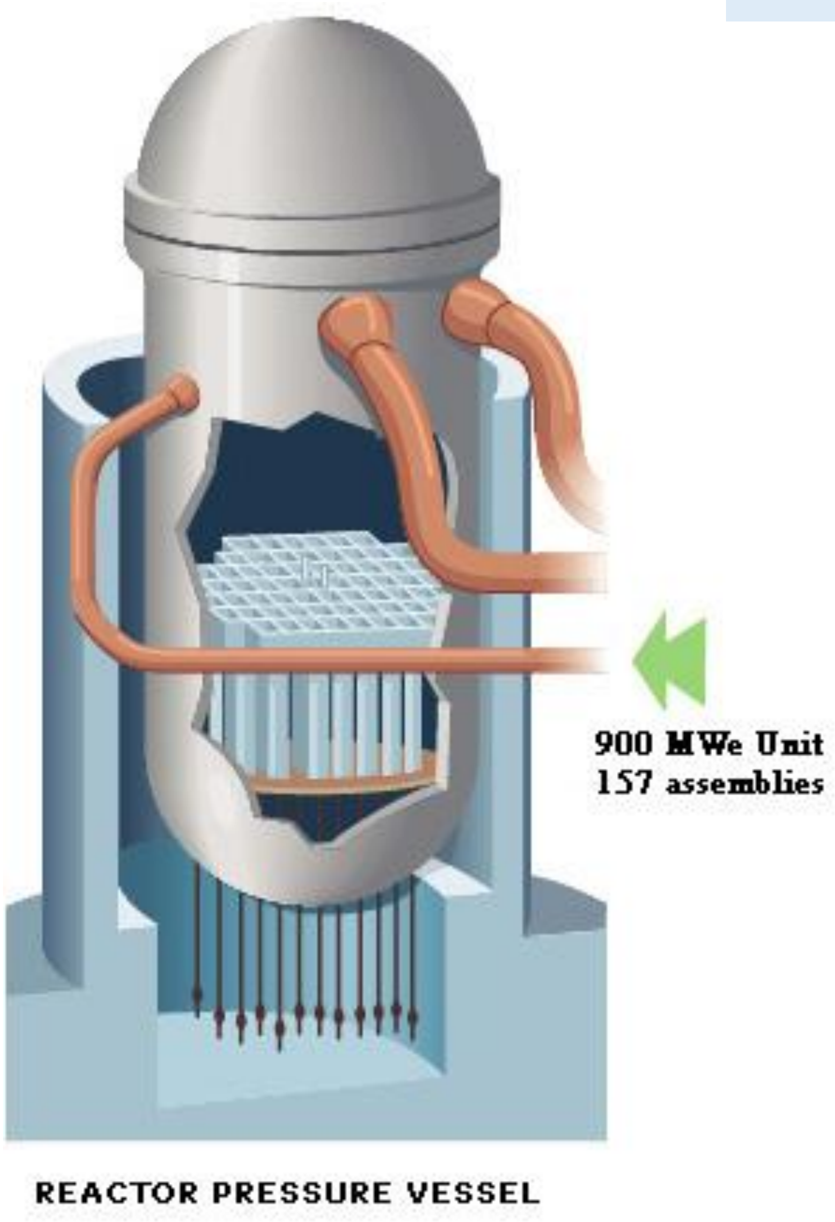


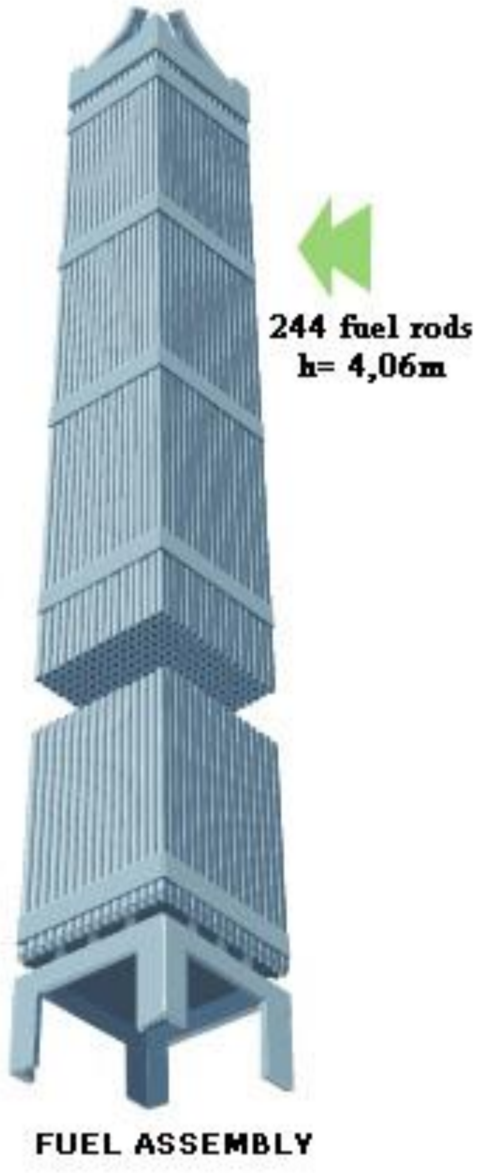
PHWR Fuel Bundle



PWR Fuel Assemblies

PWR Fuel Assembly

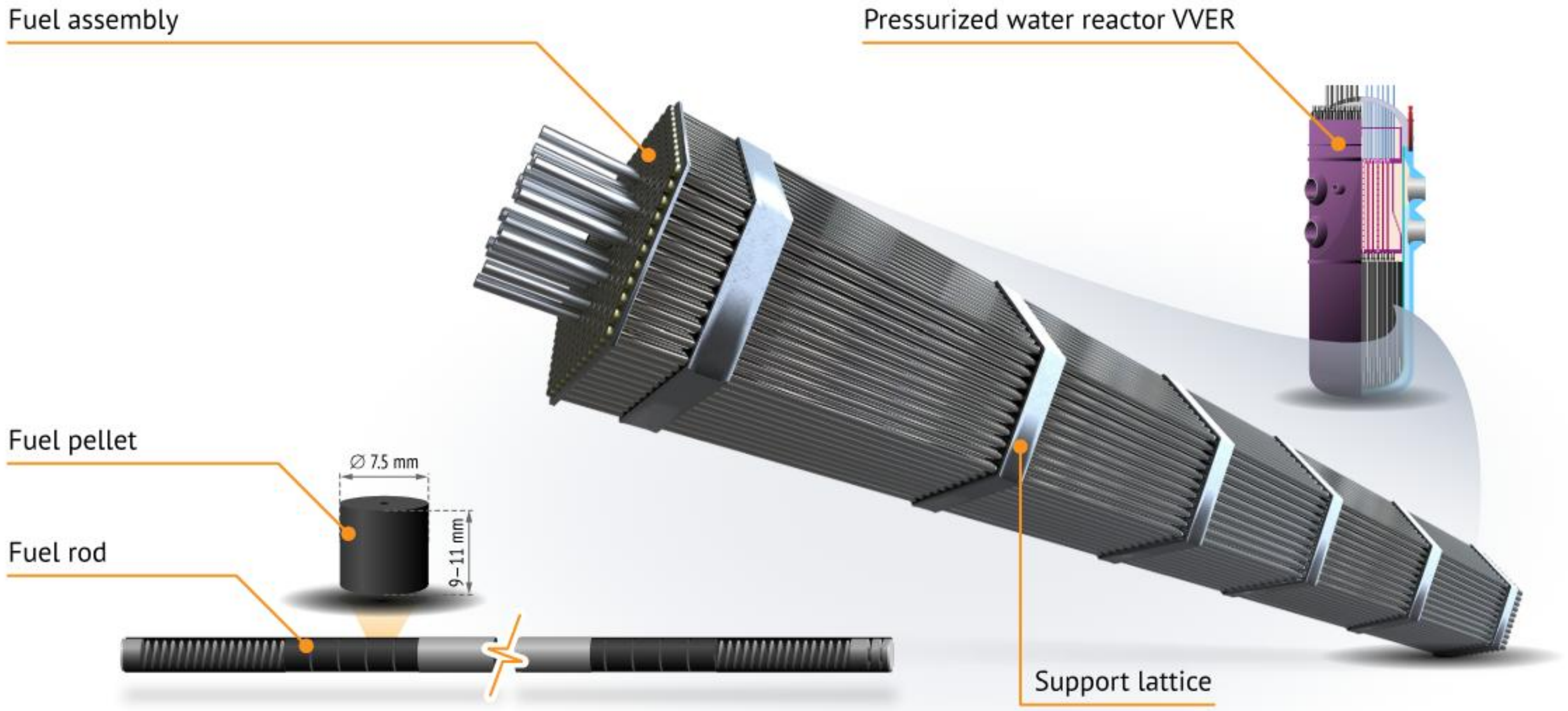




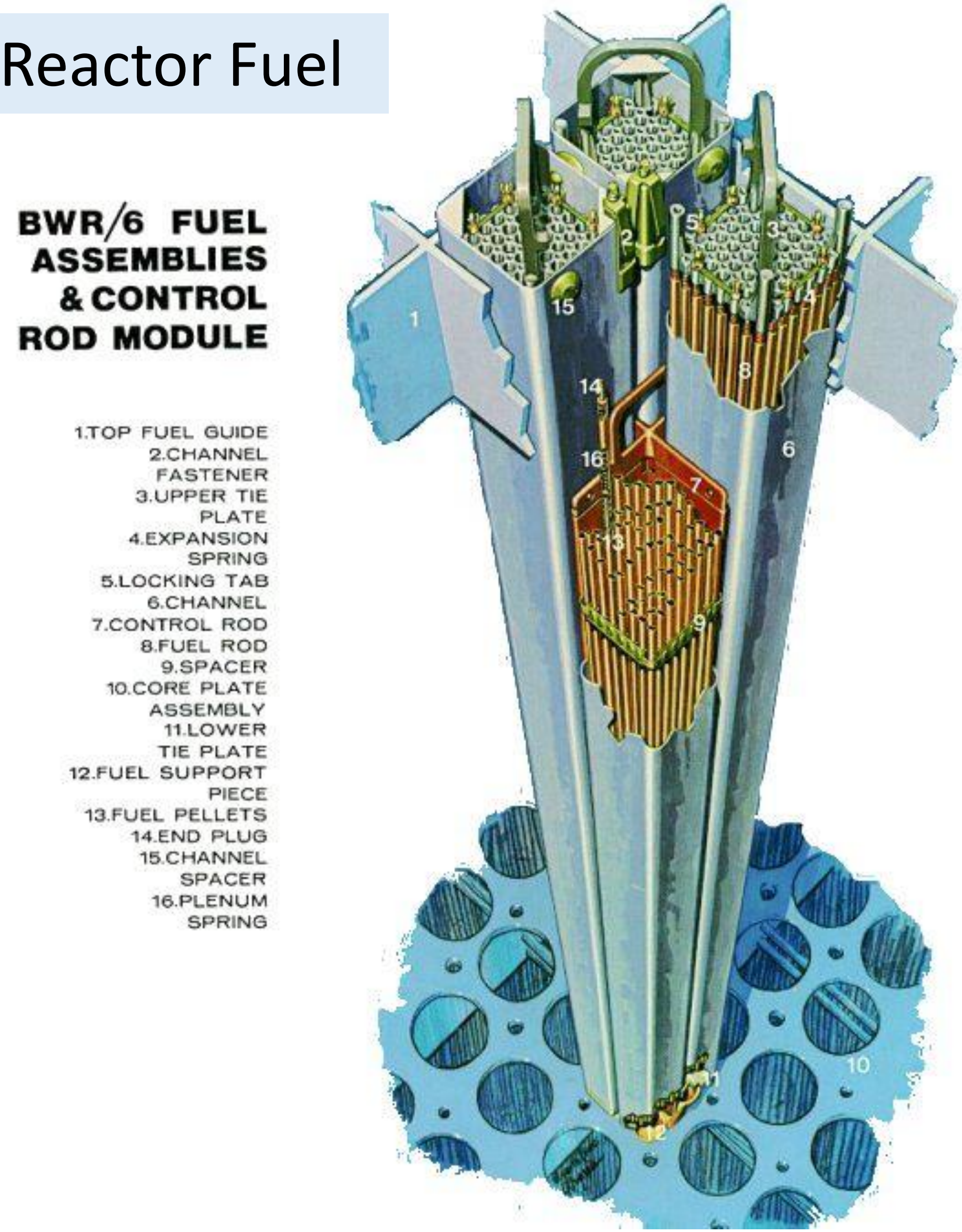
PWR fuel assembly is about 4 metres high, 20 cm square across and weighs about 500Kg.

The assembly has vacant rod positions for the vertical insertion of a control rod. (Not every assembly requires control rods.) Some locations are also used for a neutron source rod, specific instrumentation, etc.

VVER (Russian PWR) Fuel



Boiling Water Reactor Fuel



PHWR Fuel Bundles

19 Elements PHWR Fuel Assemblies

37 Elements PHWR Fuel Assemblies

Use in Reactor
And
Storage of Spent Fuel after Use

Nuclear Fuel available in nature

Uranium

U

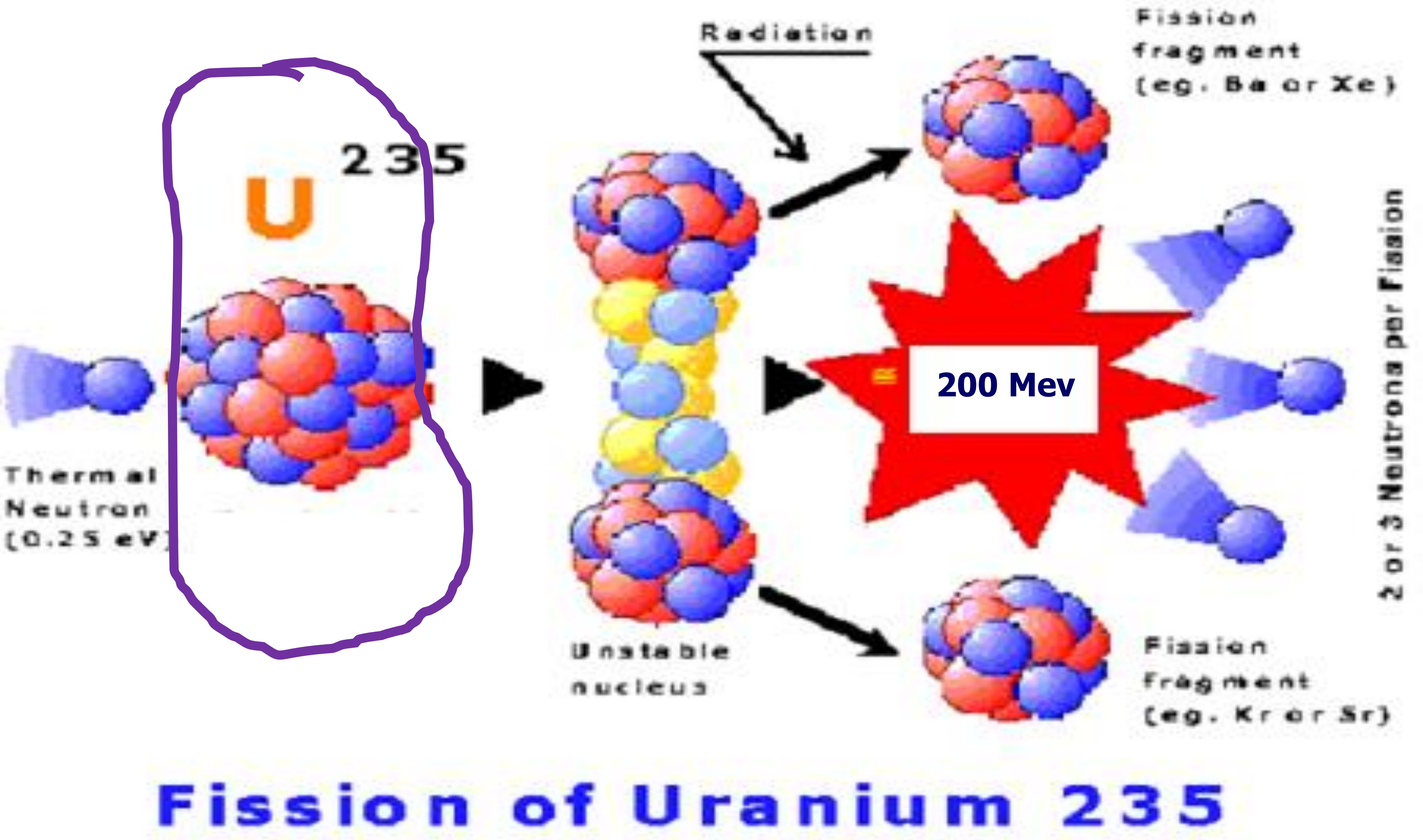
U^{235} 0.7%

~~U^{238} 99.3%~~ ← Not a fuel

But

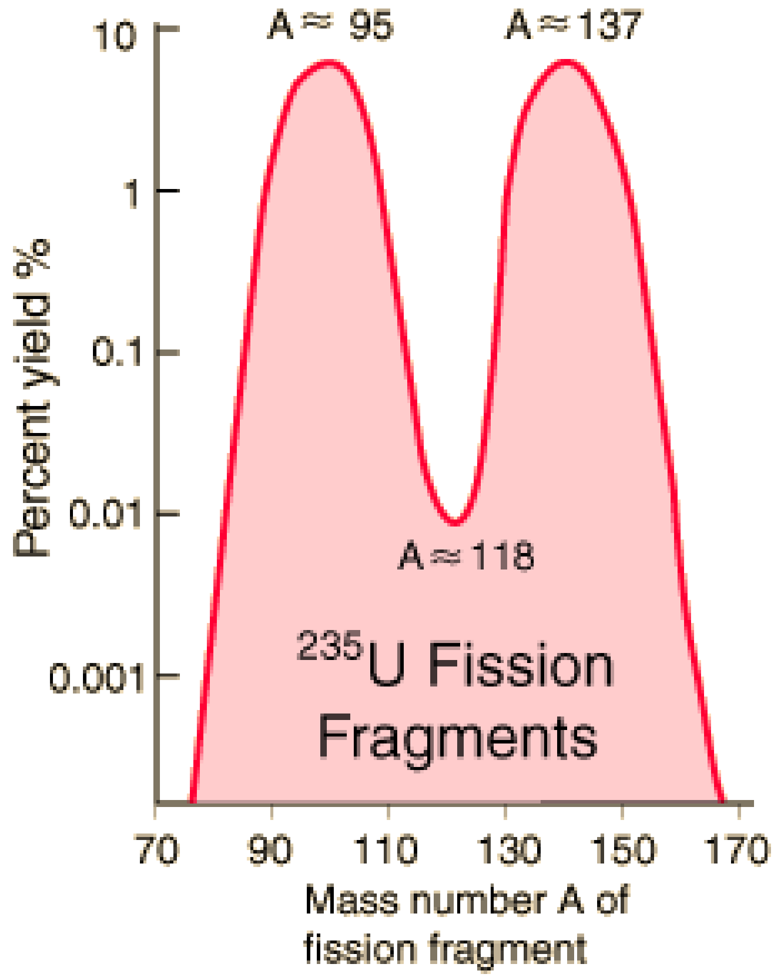
- Uranium 235, the small fraction of natural uranium while it produces large amount of energy can simultaneously convert a small fraction of uranium 238, invariably present along with uranium 235, into a man made nuclear fuel PLUTONIUM.

Nuclear fission typically produces (i) **two major, lighter atomic nuclei** called fission fragments/products, along with approximately (ii)200 MeV of energy
(iii) 2–3 free neutrons,

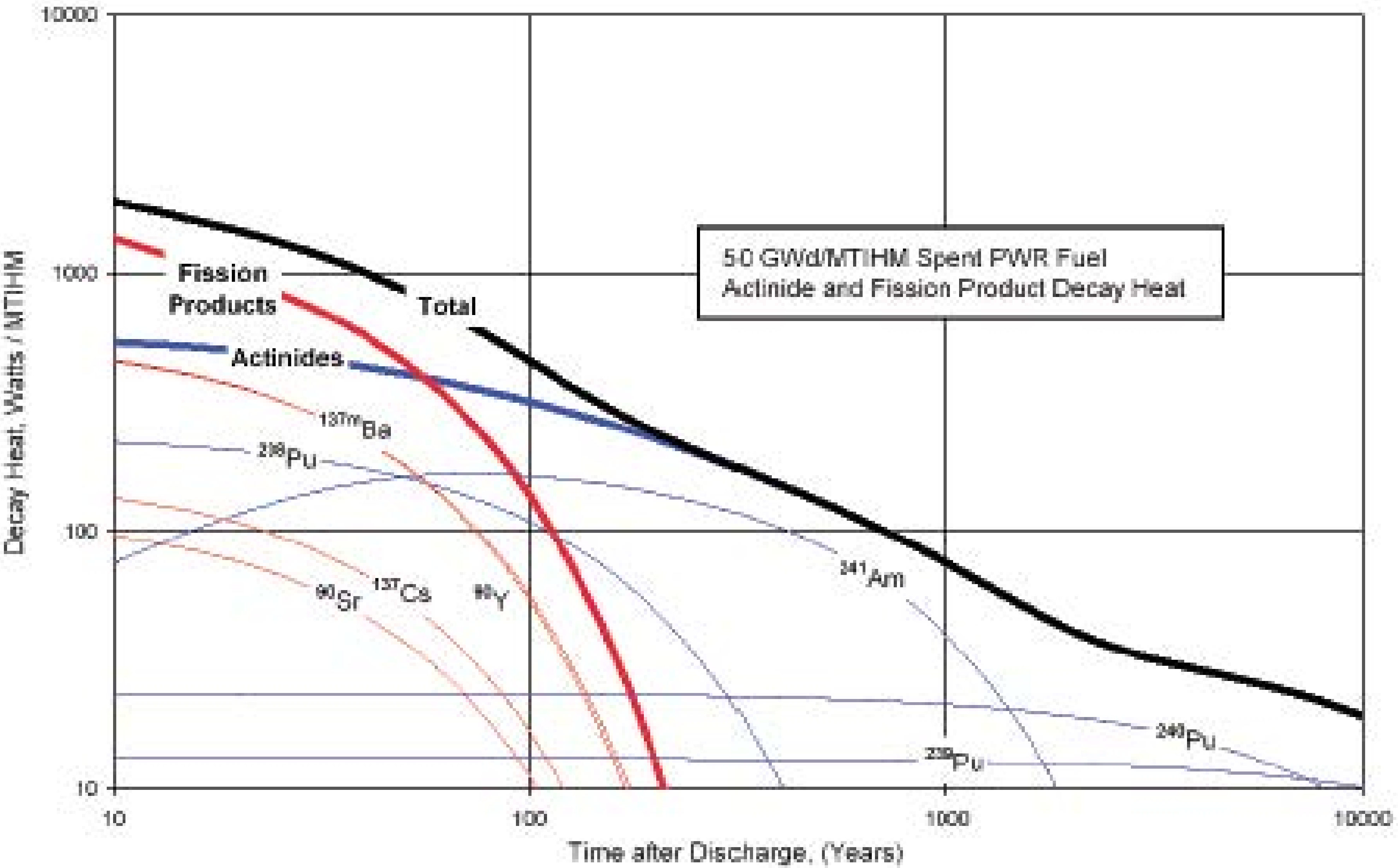


Fission products

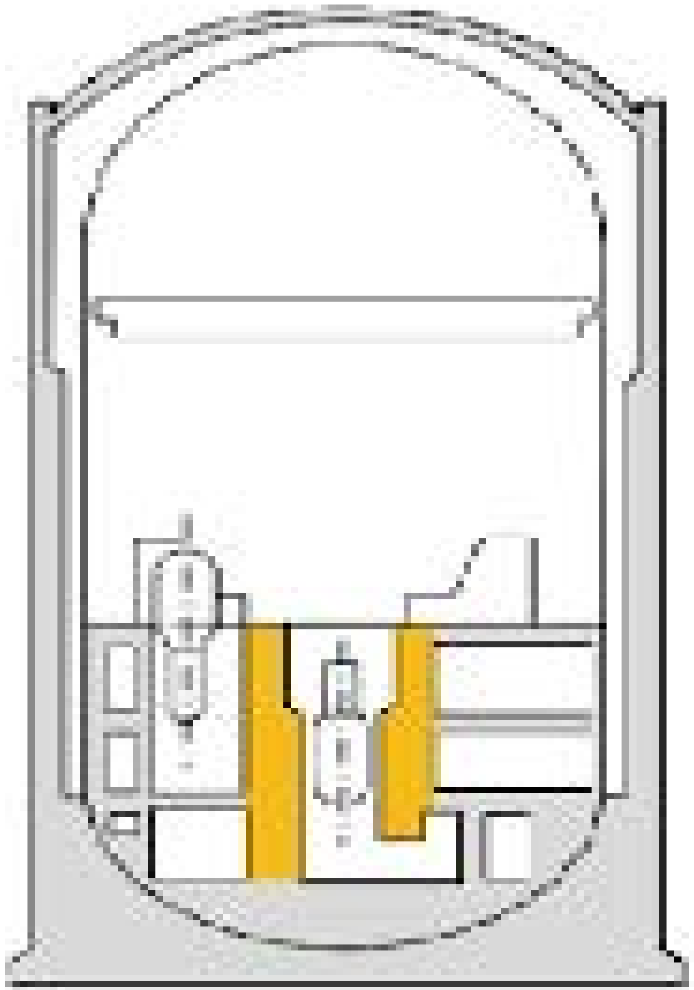
- Over 200 different radioactive nuclides can be generated in total across many reactions. Each fission event splits one heavy nucleus into two primary radioactive fragments. The primary fragments decay further into other daughter radioactive products and so on till the product is stable.

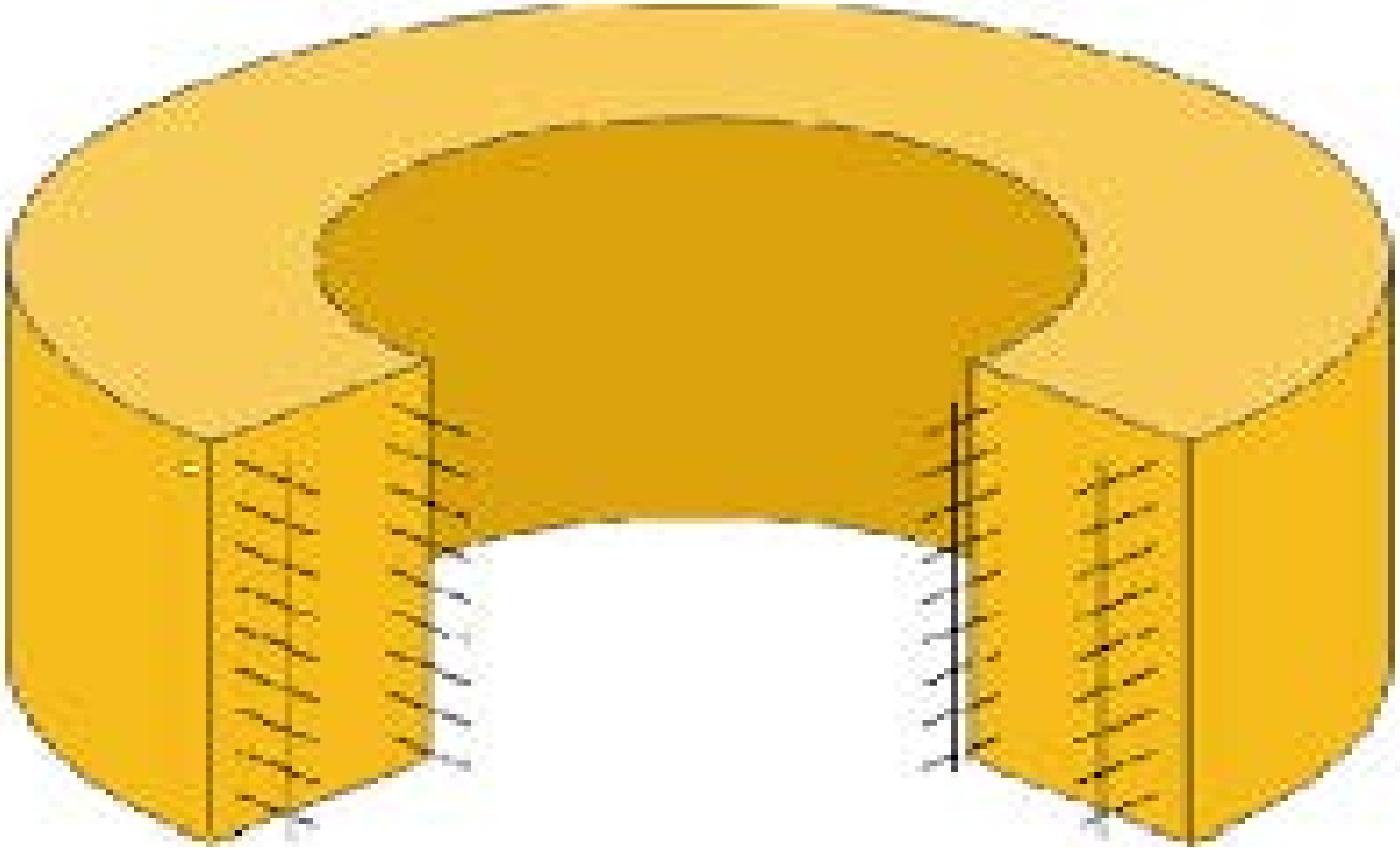


Radioactive and hot for ....years

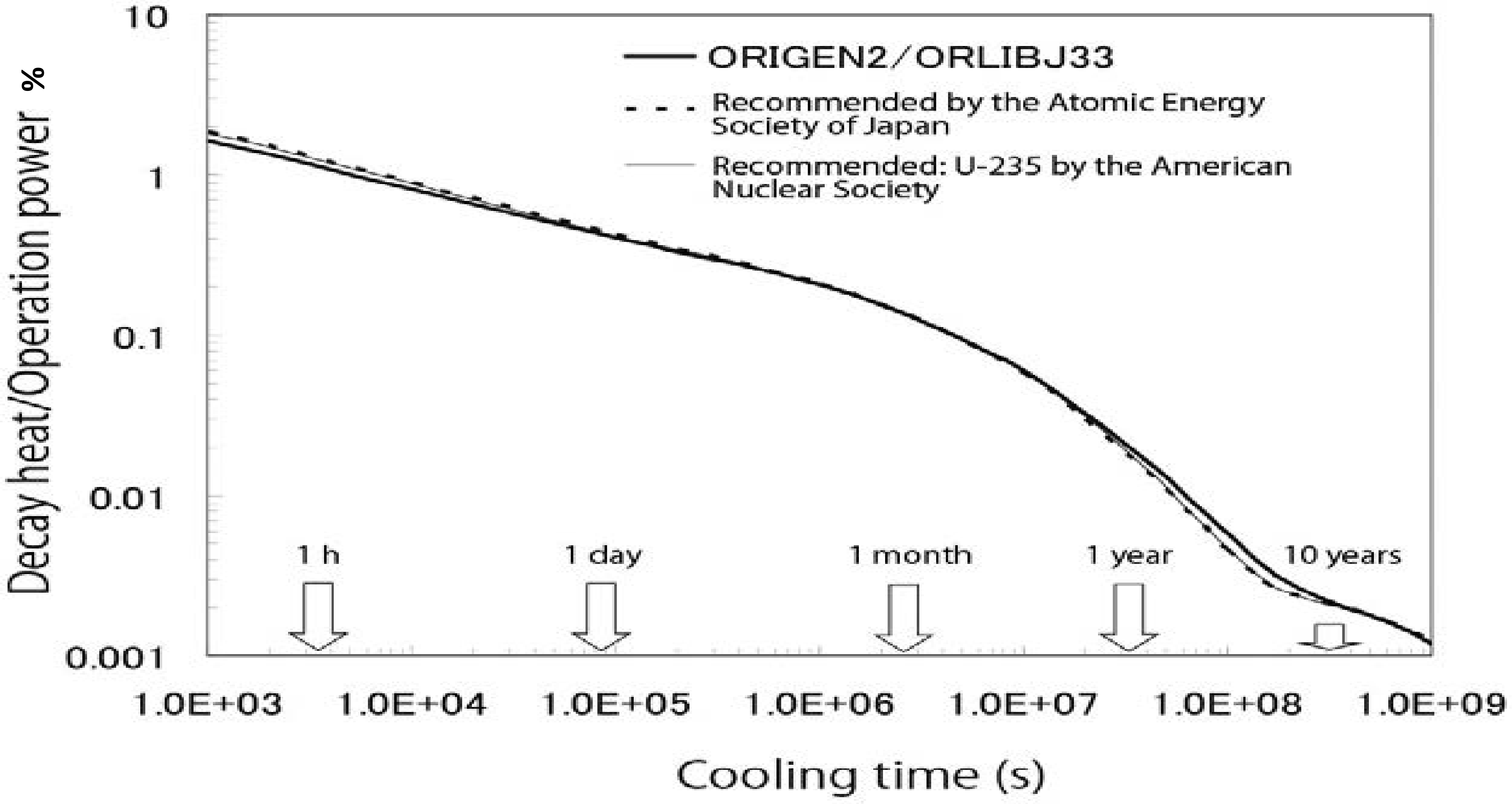


Fuel is always to be shielded during and after use





Decay Heat From Discharged Fuel



Most Important Aspect for Safety In NPP

- Heat produced should be equal to heat removed

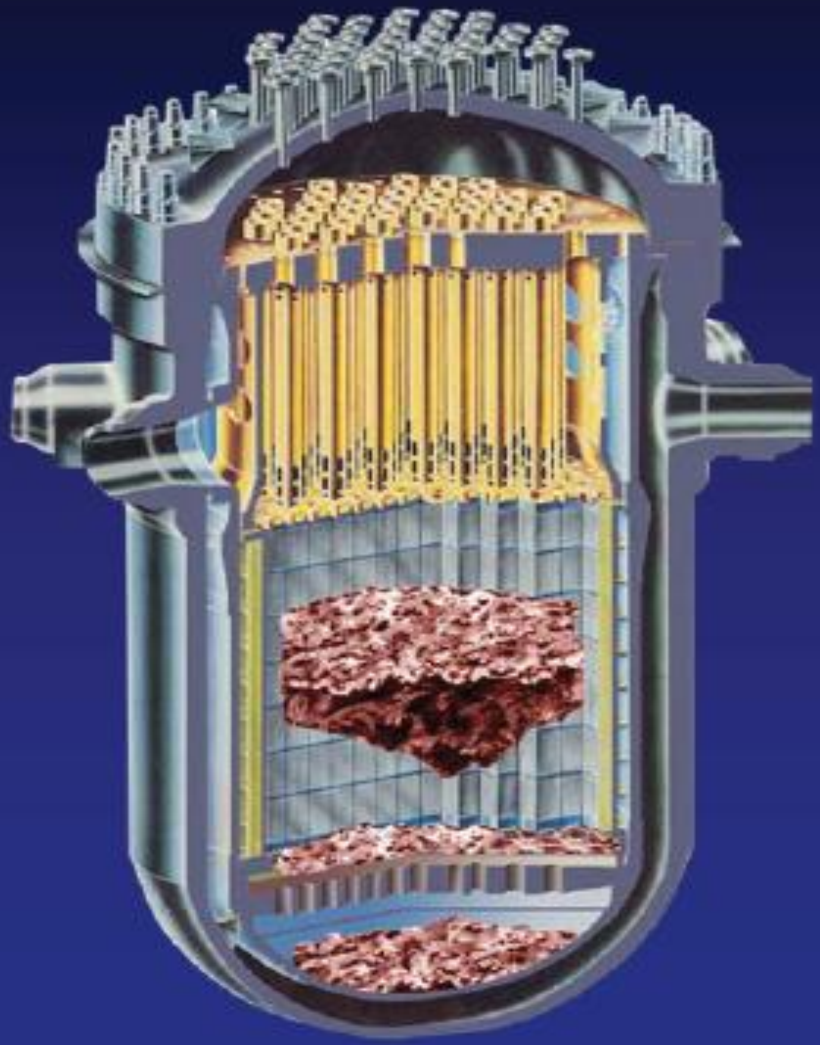
at all times

Including even when the plant is not operating

Once put into operation, the FUEL is always HOT and needs COOLING almost forever, at a decreasing rate.

What might happen if not able to cool?

TMI-Final Core Situation



Some important Fission Products

ISOTOPE	HALF LIFE
I-131	8.01 d
I-132	2.23 hr
I-133	20.8 hr
I-134	52.5 min
I-135	6.57 hr
Cs-134	2.07 y
Cs-137	30.14 y
Kr-85	10.7 y
Kr-87	1.27 hr
Kr-88	2.83 hr
Xe-133	5.24 d
Xe-135	9.1 hr
Xe-138	14.17 min

Hydrogen Formation

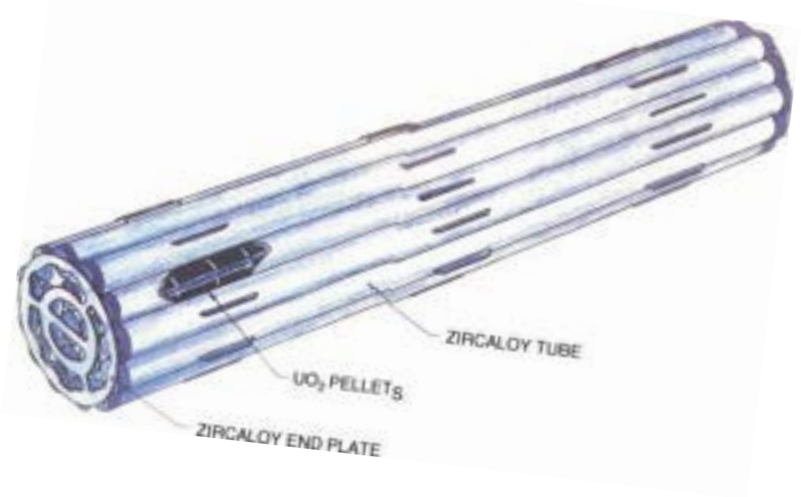
- The corrosion reaction on zircaloy, a metal used to cover fuel, becomes excessive at high temperatures.
- Therefore, when fuel overheats, because of a lack of cooling, any interaction with water or its vapour provides oxygen for the corrosion reaction, and hydrogen is left free at a fast rate. The reaction is exothermic, which adds heat.

FUEL BURNUP

Nuclear fuel burnup is the measure of energy extracted from nuclear fuel, defined as the total fission energy released per unit mass of initial fuel (typically gigawatt-days per metric ton of heavy metal, GWd/MTU or MWd/kgU).

It represents the cumulative fission energy produced relative to the mass of fuel, rather than just the percentage of fuel consumed.

Equivalent Coal



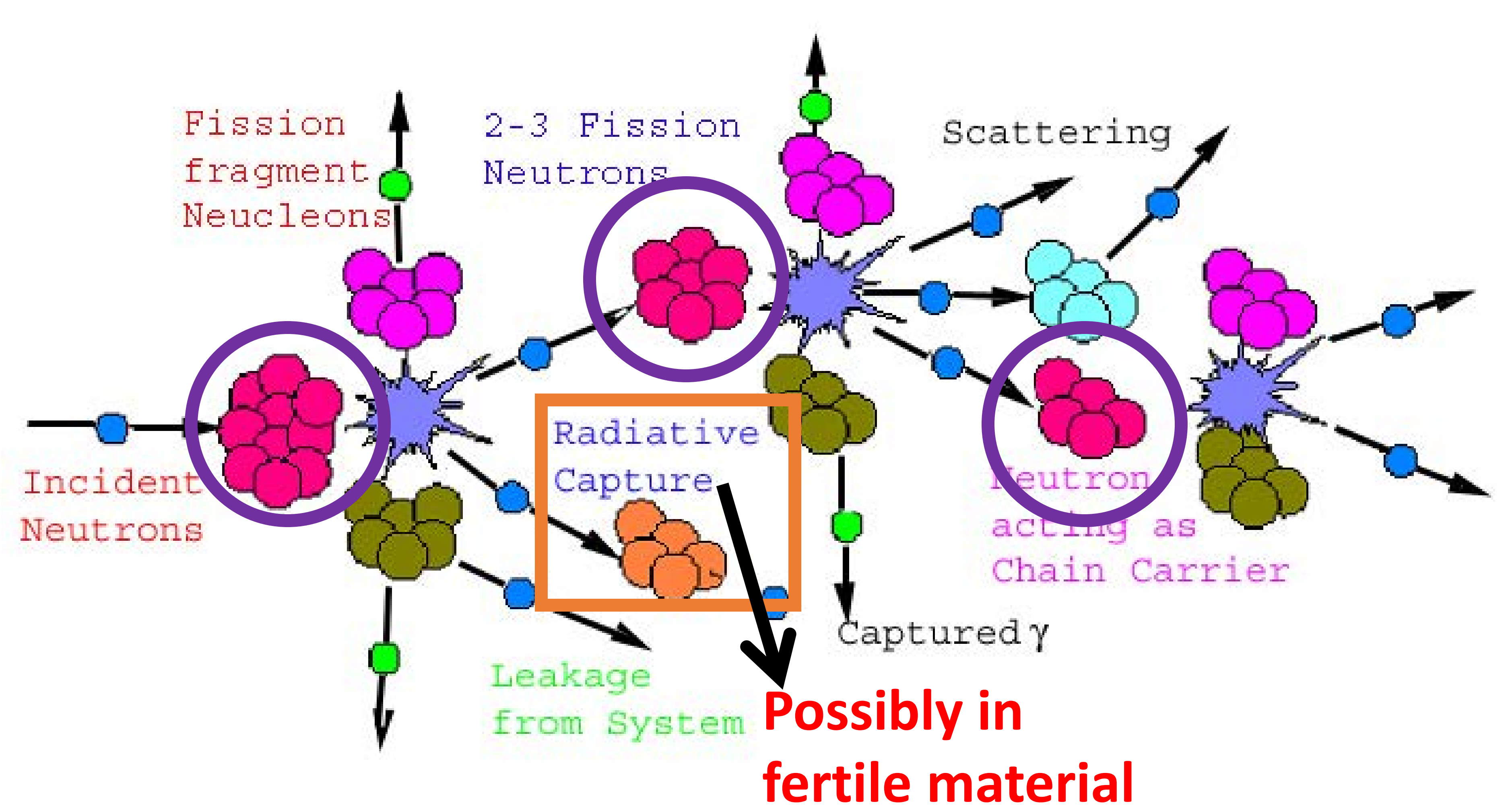
- FUEL BURNUP achievable from Natural uranium in PHWRs is around 7 GWd/ton of uranium.

- Uranium in one 19-element fuel bundle used in a PHWR 220 MWe unit is 13.4 Kg

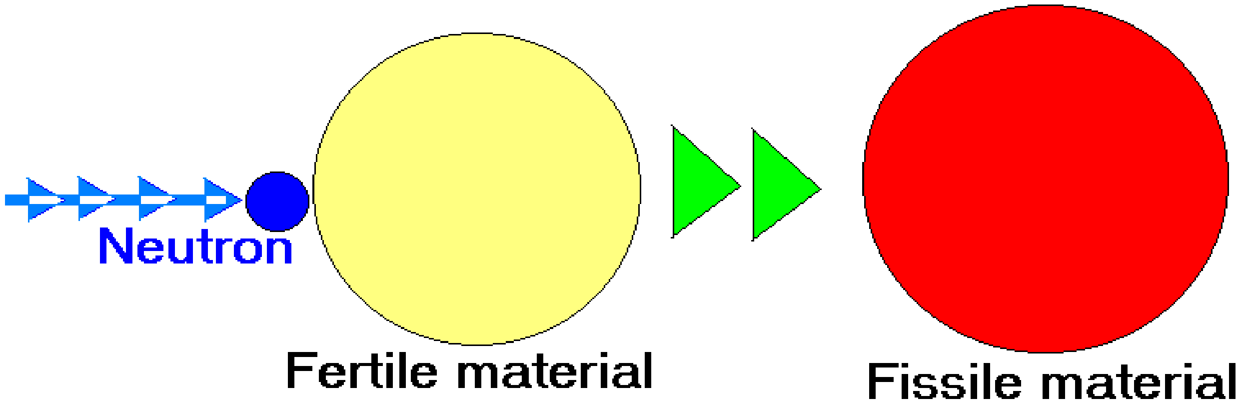
- On average, a 19–element natural uranium fuel bundle in a PHWR yields energy equivalent to about 270 tons of good-quality coal. (1 GWd of energy is equivalent to 86400 Mega Joules of energy. Good quality coal gives 30 MJ/Kg of energy)

- On average, 8 bundles are discharged from a 220 MWe PHWR. Thus, equivalent to 2160 Tons of coal, and saves the environment from about 4000 Tons of CO2 per day.

FISSION CHAIN REACTION



WHAT IS FERTILE MATERIAL



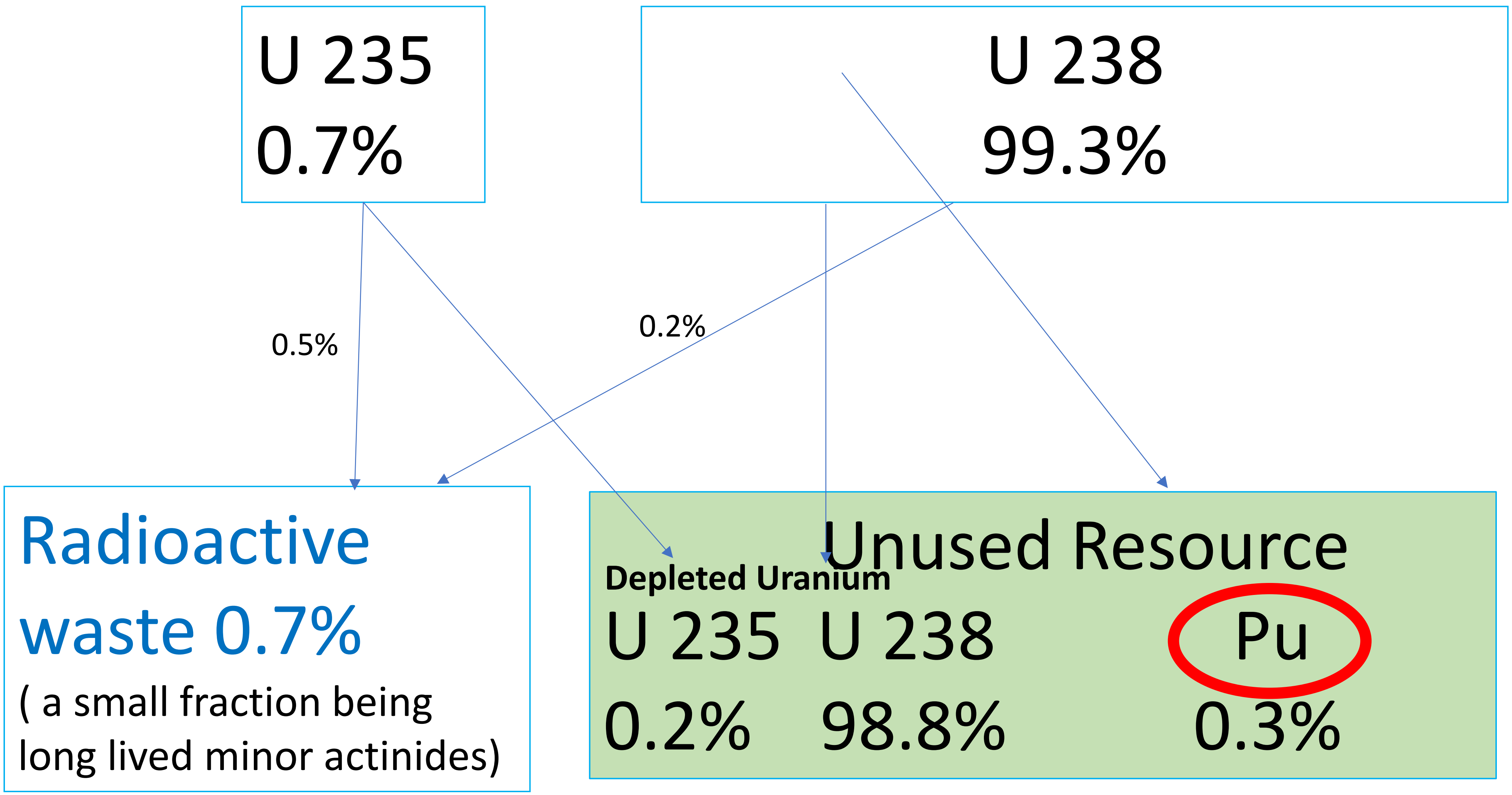
Fertile U-238 + Neutron ⟶ Pu-239 Fissile

Since fuel contains both, fissile and fertile materials, additional fissile material is invariably produced in a reactor along with power generation.

Uranium 235 in Nuclear Reactor

- Produces
  - Power
  - as well as converts Fertile materials to Fuel, therefore, more reactors- more power follow without additional mining

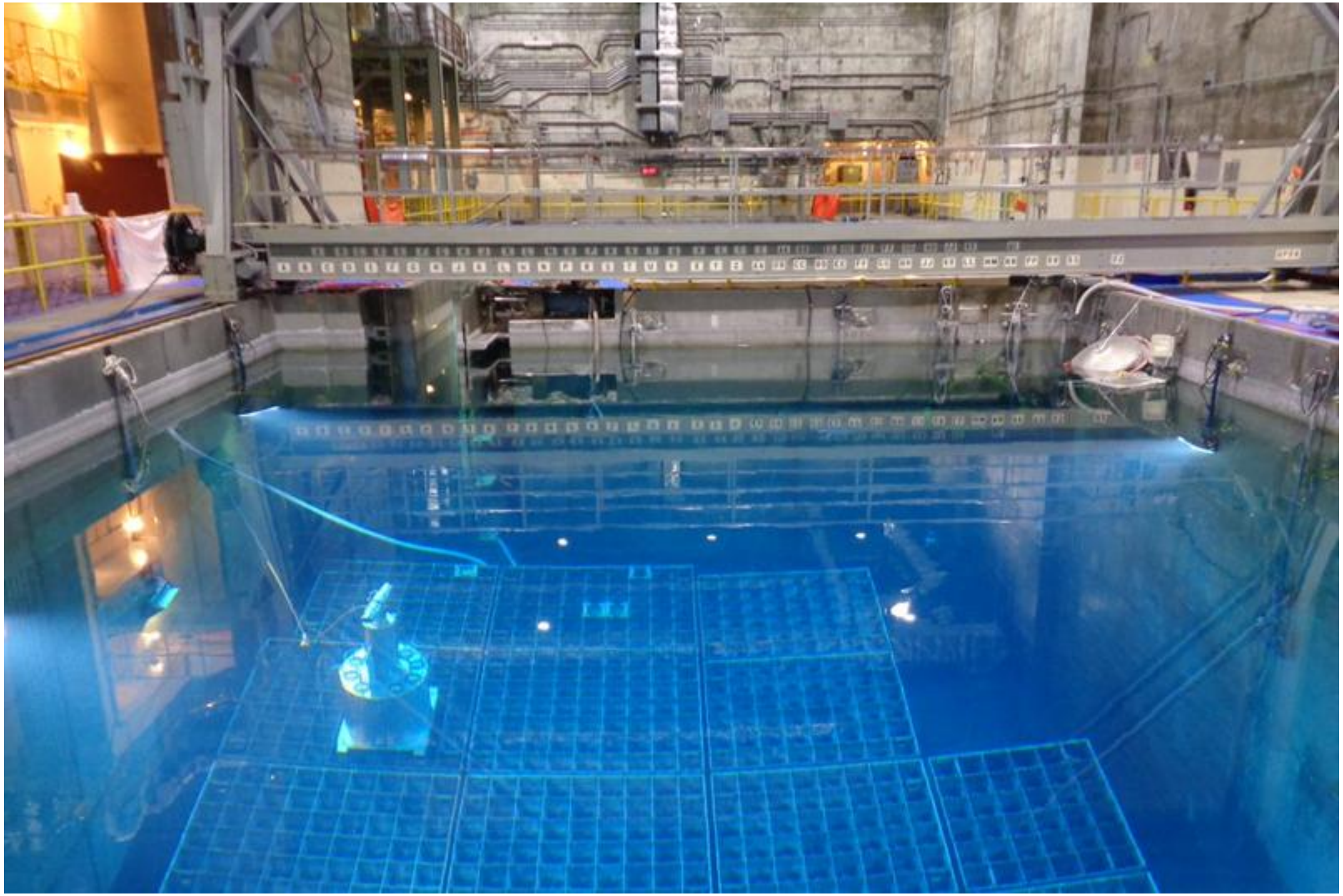
Left Overs in Discharged Fuel from PHWRs



Safeguards

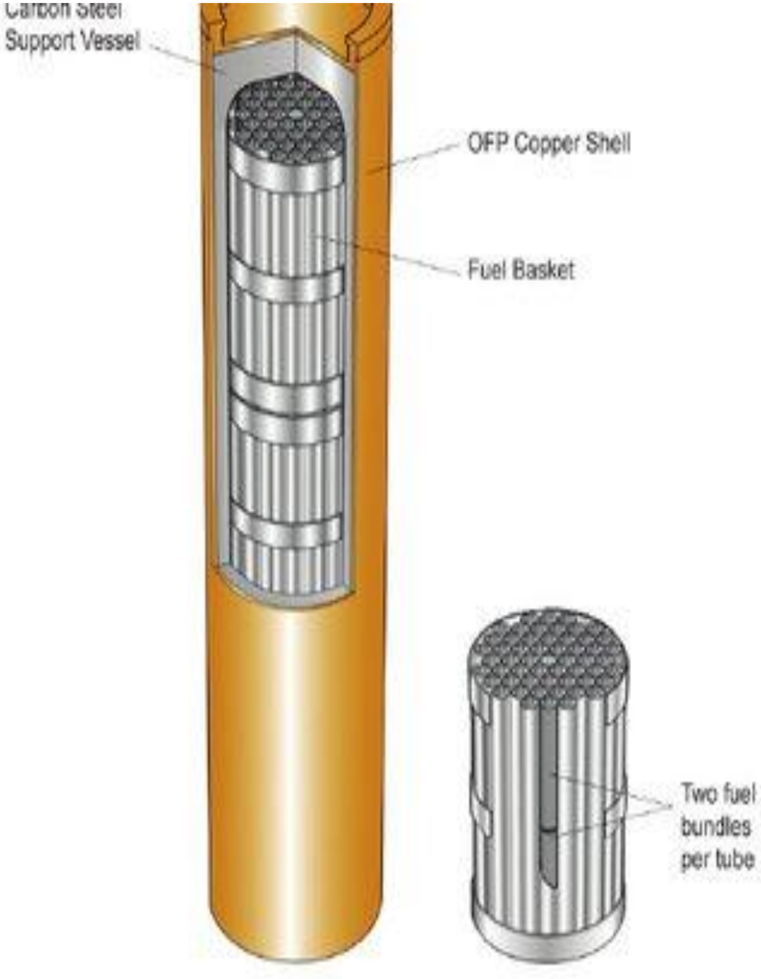
- The objective of IAEA Safeguards is to deter the spread of nuclear weapons by the early detection of the misuse of nuclear material or technology.
- This provides credible assurances that States are honouring their legal obligations that nuclear material is being used only for peaceful purposes.
- Safeguards are a set of technical measures applied by the IAEA on nuclear material and activities, through which the International Atomic Energy Agency (IAEA) independently verifies that nuclear facilities are not misused and nuclear material is not diverted from peaceful uses.

Spent Fuel Storage Bay



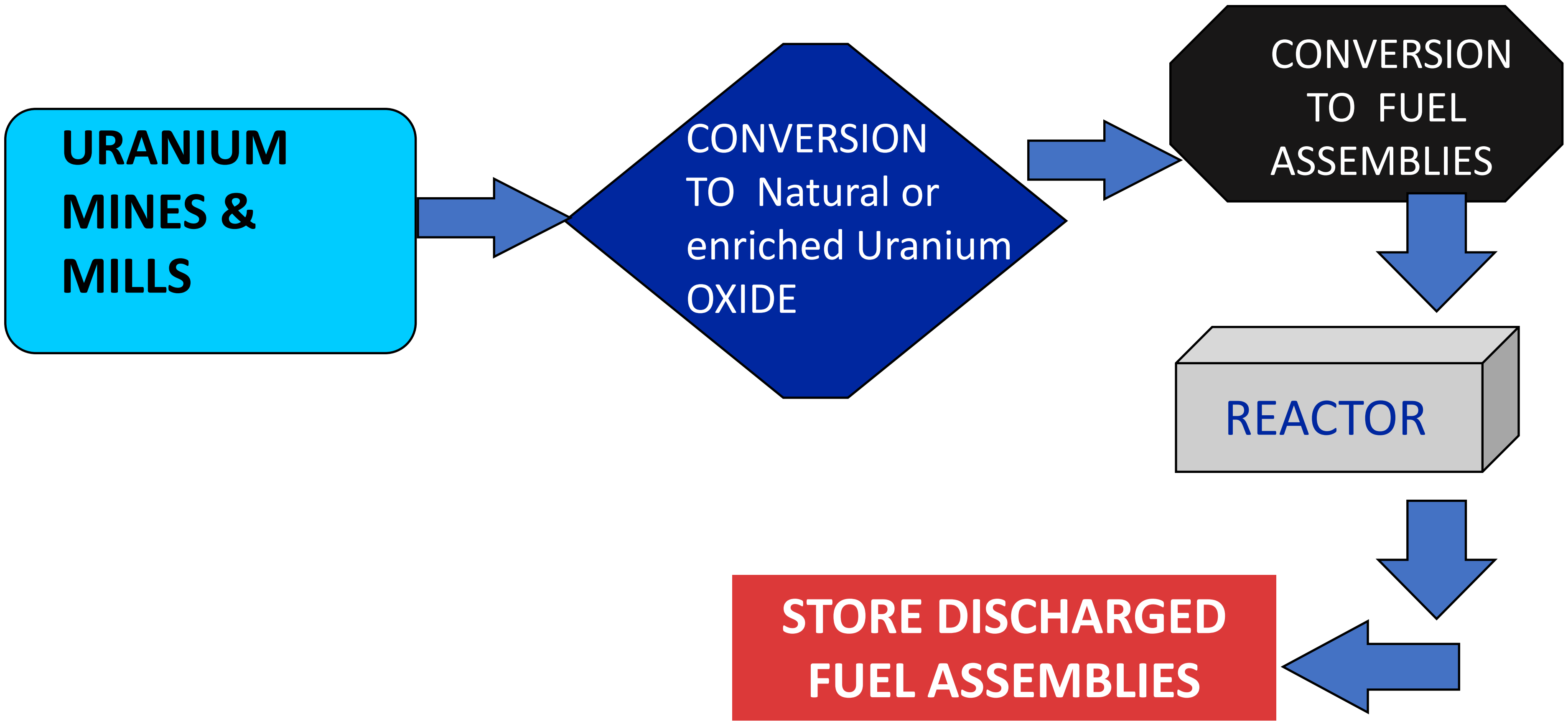
Dry Casks- Temporary Storage of Discharged Fuel at Nuclear Power Stations

(Permanent)Deep Geological Storage Facilities



After storage of spent fuel

THE NUCLEAR FUEL OPEN CYCLE



Fuel Before and After Use

Fresh Fuel

- Present 400 GW capacity around the world requires 67000 tons of uranium per year.
- Fissile (fuel) uranium 235 component in this is about 470 tons only.

Discharged Fuel After Use has

- Radioactive waste after use- about 440 tons (a small fraction of this is very long lived).
- 300 to 400 tons of fissile plutonium and balance (mostly uranium 238) remain unutilised.

Reprocessing

Reprocessing of discharged fuel can be *chemically* separates out:

- Radioactive waste
- Plutonium
- Large amount of Unused(depleted) uranium

By REPROCESSING, all the above can be separated and

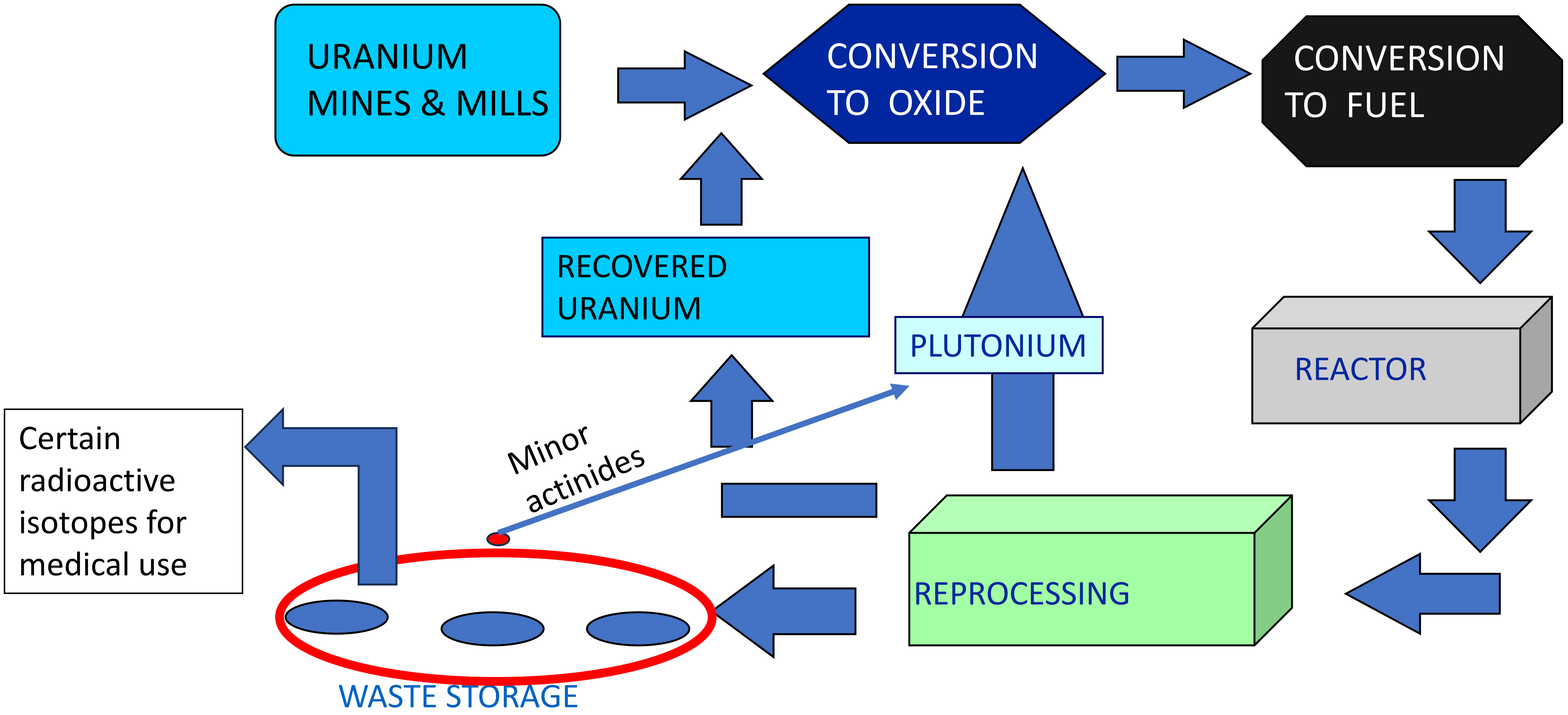
Unused U & Pu-239 can be further used in Fast Breeder Reactors.
(Very few countries reprocess discharged commercial reactor fuel.)

Reprocessing in India

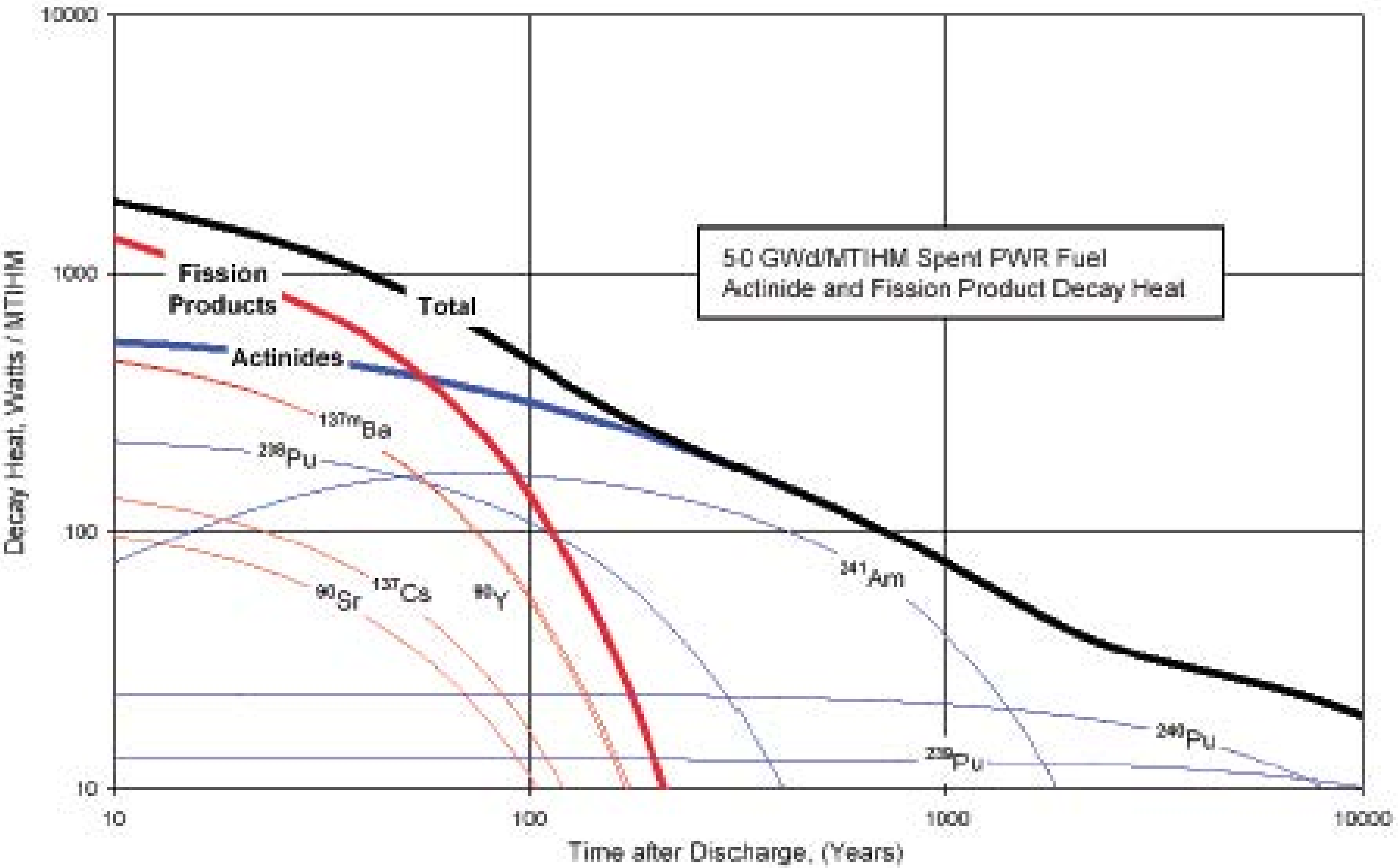
INDIA began reprocessing of spent fuel in the year 1964.
Making available Plutonium and depleted uranium fuel materials for the next generation ADVANCED reactors.

- Recovery of valuable radionuclides from radioactive waste for medical use like ^{137}Cesium, ^{90}Stronium, ^{106}Ruthenium.
- *Technologies for novel extractants and partitioning processes to separate out long lived wastes have been developed.*
- The vitrification for Waste Immobilisation regularly performed.

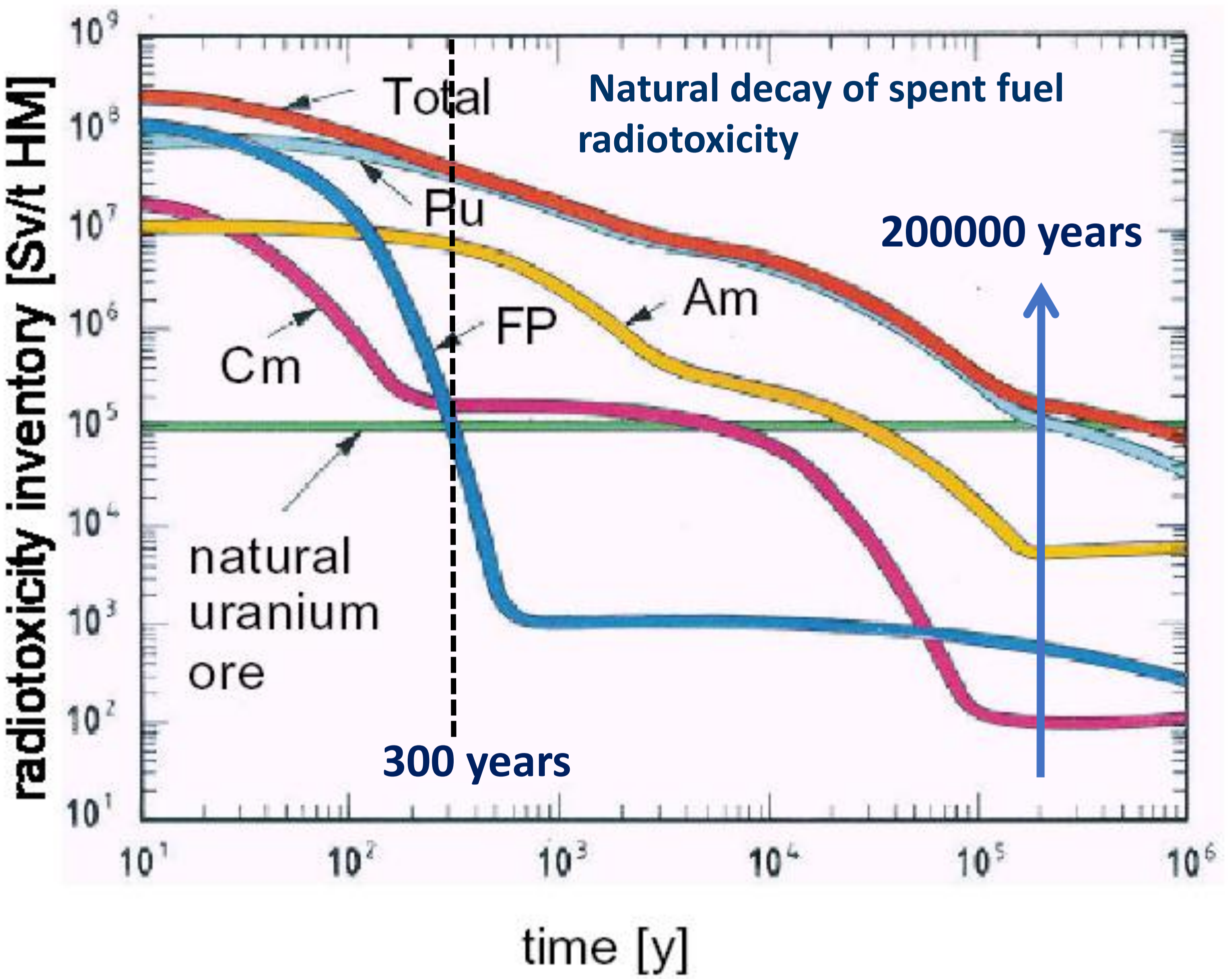
THE NUCLEAR CLOSED FUEL CYCLE



Radioactive and hot for ………..years



Adopting closed fuel cycle reduces nuclear waste burden



Radio-toxicity of spent fuel is dominated by :

FPs for first 100 years.

subsequently, Pu (>90%)

After Pu removal

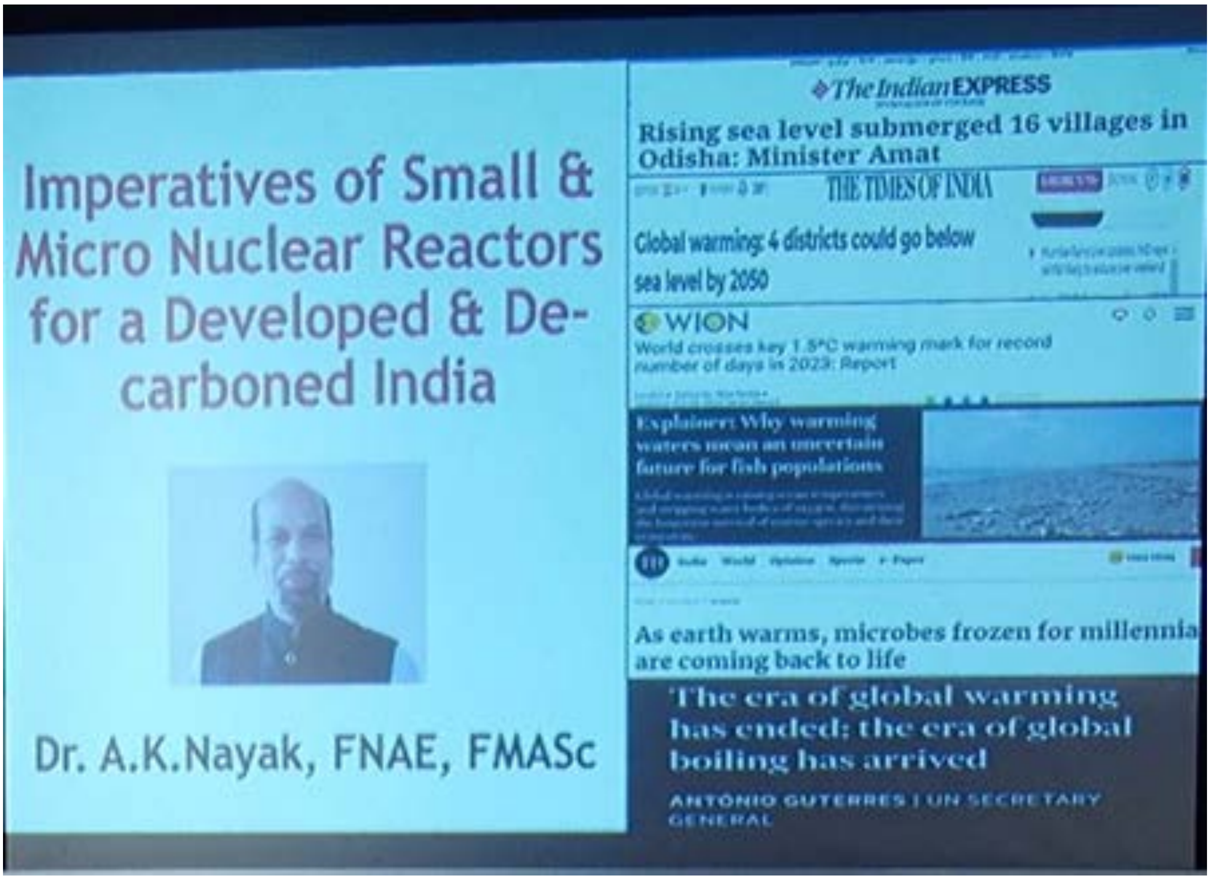
Minor Actinides specially Am (~ 9%**)**

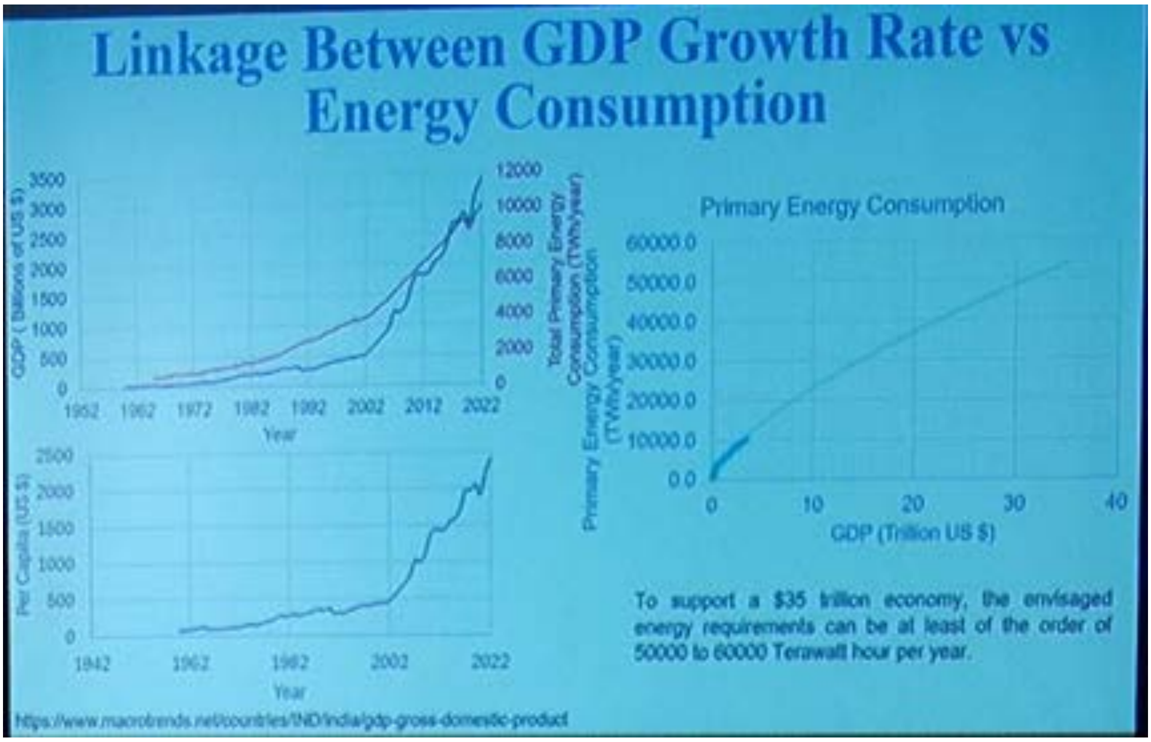
With early introduction of fast reactors using (U+Pu+Am) based fuel, long term raditoxicity of nuclear waste will be reduced.

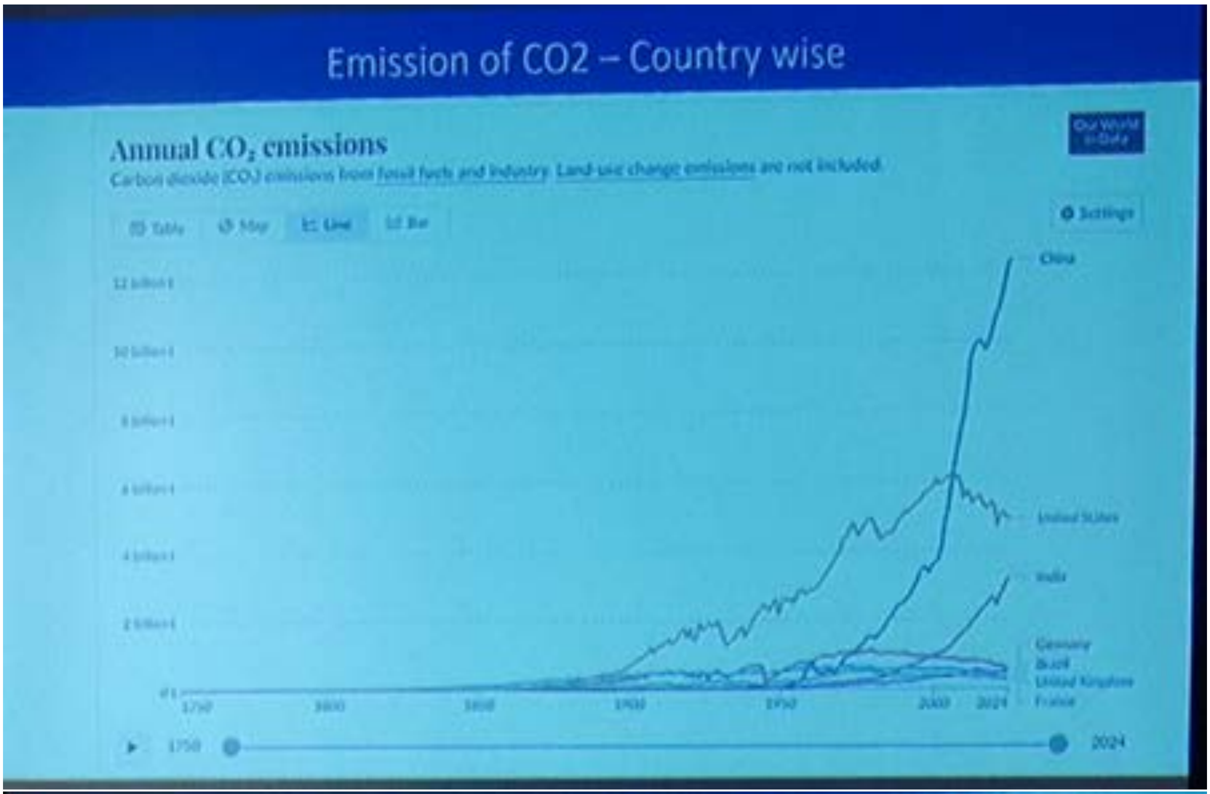
Closing the fuel cycle is necessary for sustaining nuclear power.

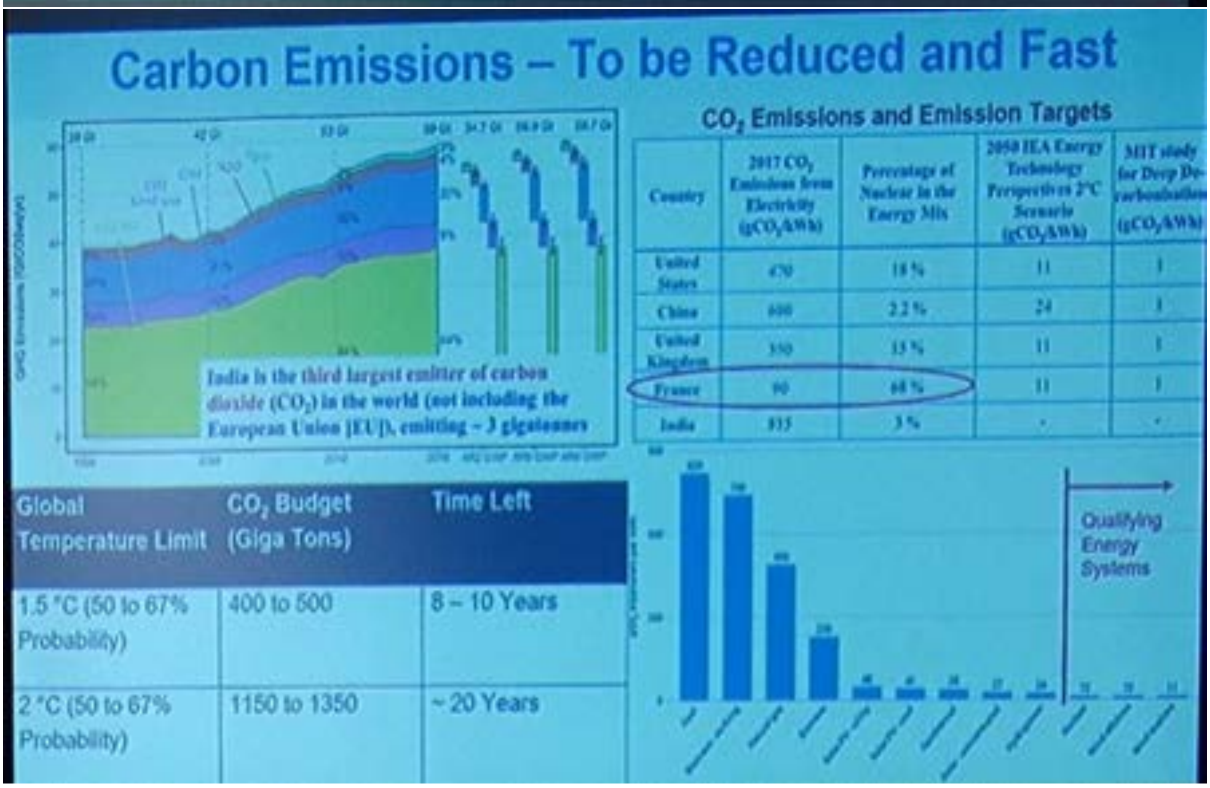
Thank you for your kind attention

Your questions?


Imperatives of Small & Micro Nuclear Reactors for a Developed & De-carboned India
Dr. A.K.Nayak, FNAE, FMASc
The Indian EXPRESS
Rising sea level submerged 16 villages in Odisha: Minister Amat
THE TIMES OF INDIA
Global warming: 4 districts could go below sea level by 2050
WION
World crosses key 1.5°C warming mark for record number of days in 2023: Report
Explainer: Why warming waters mean an uncertain future for fish populations
As earth warms, microbes frozen for millennia are coming back to life
The era of global warming has ended; the era of global boiling has arrived
ANTÓNIO GUTERRES | UN SECRETARY GENERAL


Linkage Between GDP Growth Rate vs Energy Consumption
GDP (Billions of US $)
Total Primary Energy Consumption (TWh/year)
Year
Per Capita (US $)
Year
Primary Energy Consumption
Primary Energy Consumption (TWh/year)
GDP (Trillion US $)
To support a $35 trillion economy, the envisaged energy requirements can be at least of the order of 50000 to 60000 Terawatt hour per year.
https://www.macrotrends.net/countries/IND/india/gdp-gross-domestic-product


Emission of CO2 – Country wise
Annual CO2 emissions
Carbon dioxide (CO2) emissions from fossil fuels and industry. Land-use change emissions are not included.
China
United States
India
Germany
Brazil
United Kingdom
France
1750
2024


Carbon Emissions – To be Reduced and Fast
India is the third largest emitter of carbon dioxide (CO2) in the world (not including the European Union [EU]), emitting ~ 3 gigatonnes
CO2 Emissions and Emission Targets
Country
2017 CO2 Emissions from Electricity (gCO2/kWh)
Percentage of Nuclear in the Energy Mix
2050 IEA Energy Technology Perspectives 2°C Scenario (gCO2/kWh)
MIT study for Deep De-carbonisation (gCO2/kWh)
United States
China
United Kingdom
France
India
Global Temperature Limit
CO2 Budget (Giga Tons)
Time Left
1.5 °C (50 to 67% Probability)
400 to 500
8 – 10 Years
2 °C (50 to 67% Probability)
1150 to 1350
~ 20 Years
Qualifying Energy Systems

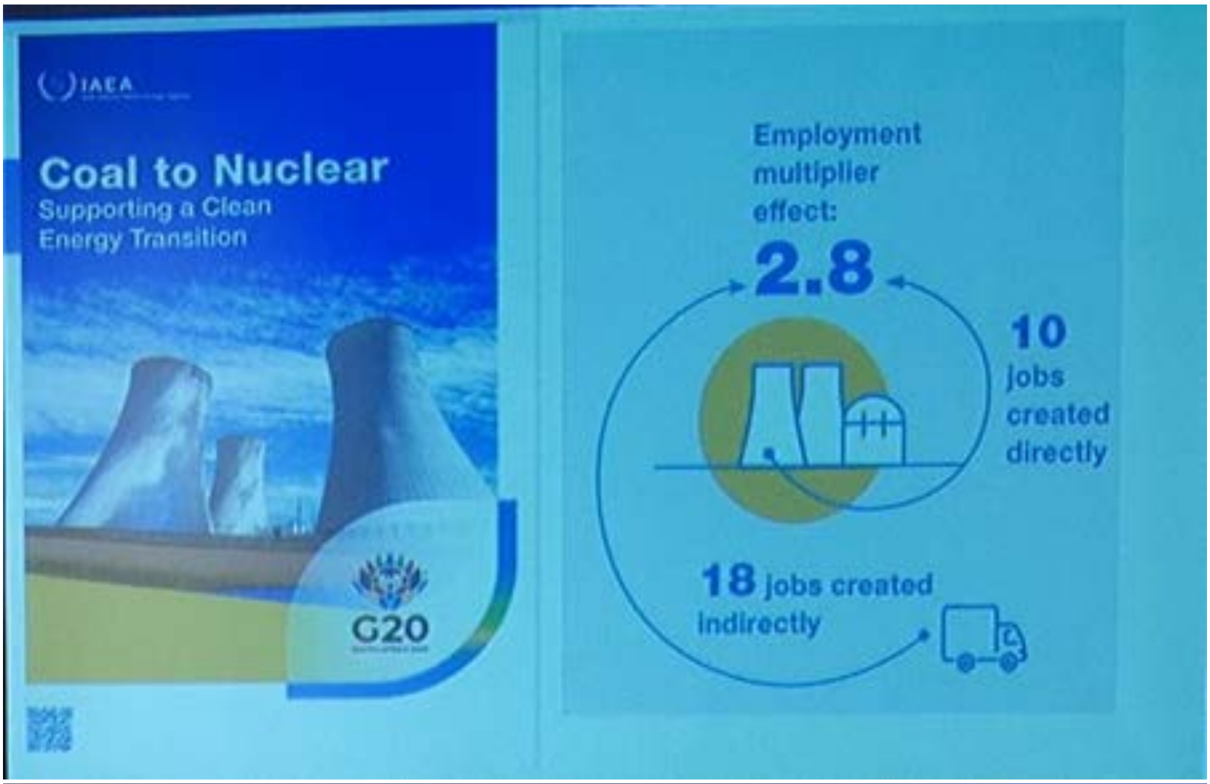
Can a Developed India get Decarboned by Renewables Alone?

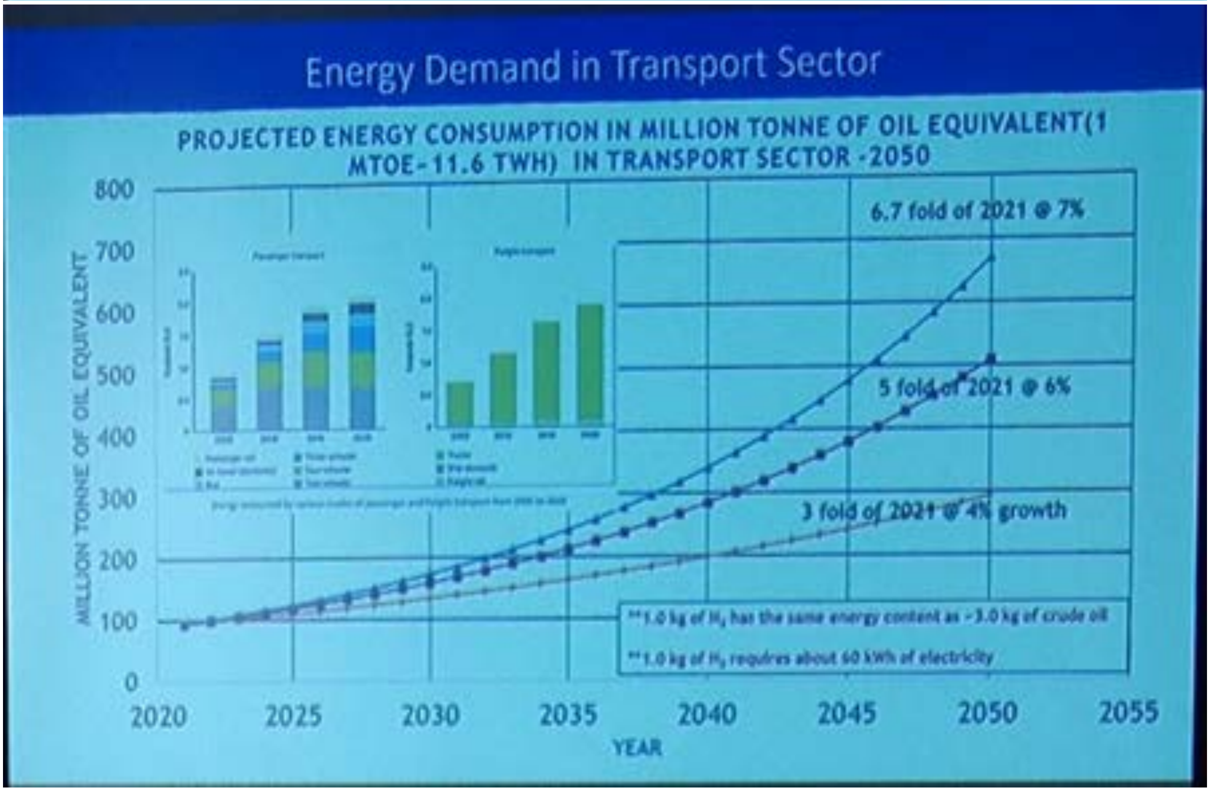
What is the maximum potential off renewables in India?

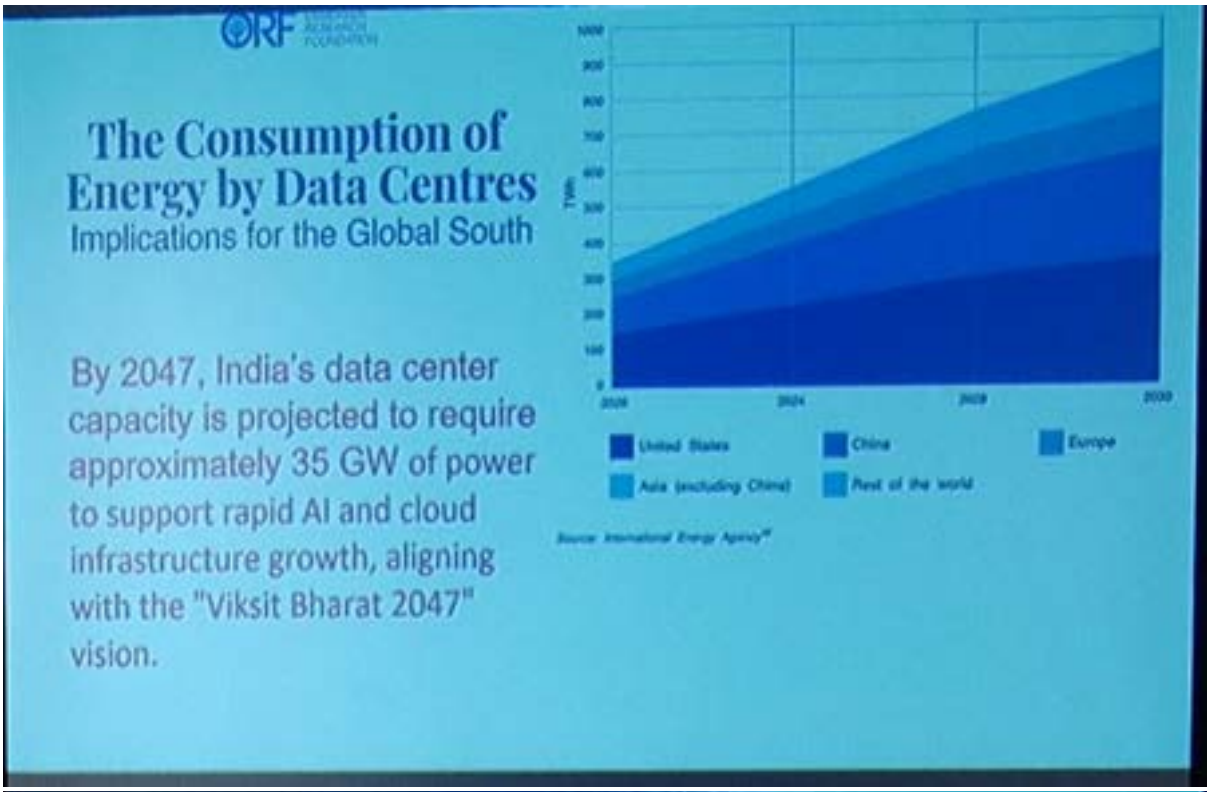
Renewable source	Prerequisite	Total generation TWh/annum
Solar	Utilization of 10% of barren and uncultivated land in India (30000 Sq km). (Sukhatme et al). Storage technology available, smart grids in place.	2000-3000
	MNRE - solar potential of the country is around ~ 1640 TWh/annum assuming 3% of the waste land (~ 3% of 500000 Sq km = 15000 Sq km) area to be covered by Solar PV modules.	
	NITI Aayog - potential to be around 2040 TWh/annum with storage technology available and smart grids in place.	
Wind	100 meter mast height, smart grids and storage in place (MNRE)	978
Hydro	All the 150 GWe potential utilized with 60 % PLF (CEA)	788
Bio	All the potential utilized (MNRE)	60
	Total	3826 - 4826

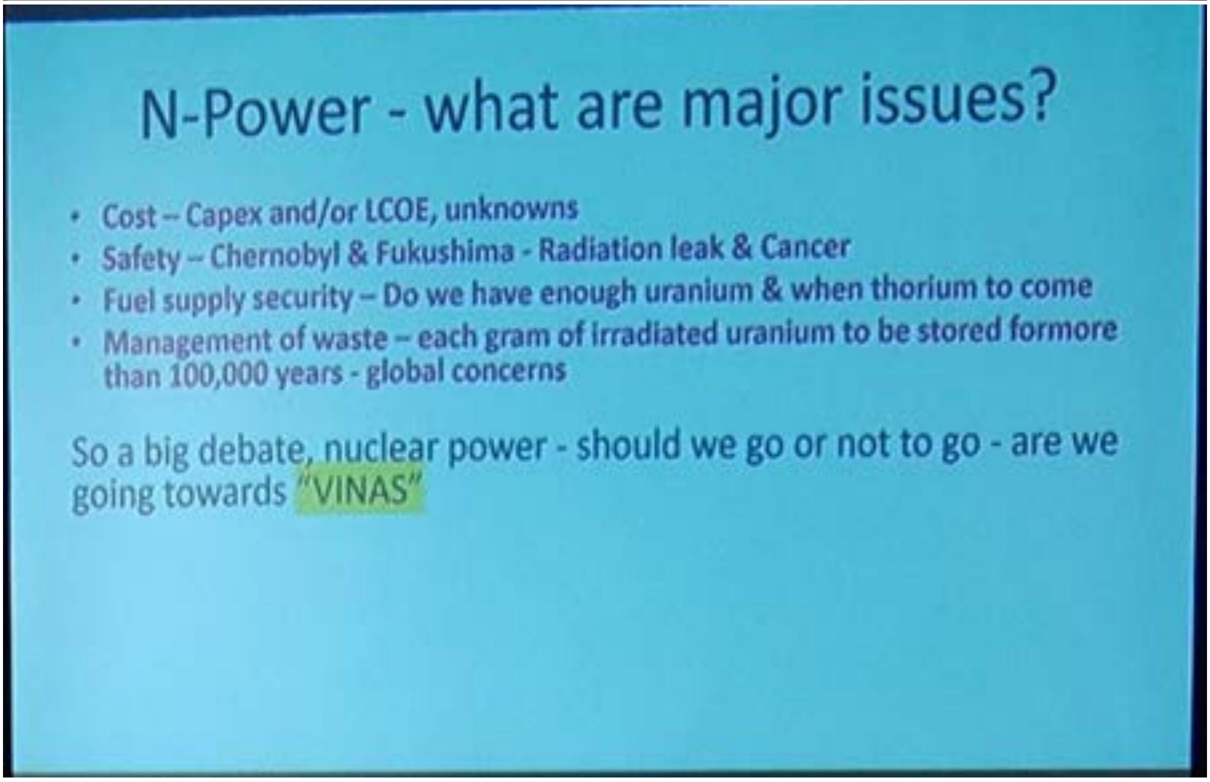
How Much N-Power India would Require?

1. The total potential for India from renewables is hardly close to 4000 Terawatt hour per year, which is just 40 % of India's today's total energy consumption.
2. Assuming the developments in the energy efficiency, smart grids and excellent storage systems in place, the capacity may rise to a maximum of ~8000 Terawatt hour per year.
3. Even for today's total energy De-carbon requirement; the Balance from Clean Energy will be ~ 2000 Terawatt hour per year.
4. And for India's further development to reach a $35 trillion economy by 2047, the balance from clean energy requirement will be of the order of several thousand Terawatt hour per year (more than 2500 GWe) apart from utilisation of full potential of renewables.


IAEA
Coal to Nuclear
Supporting a Clean Energy Transition
G20
Employment multiplier effect:
2.8
10 jobs created directly
18 jobs created indirectly


Energy Demand in Transport Sector
PROJECTED ENERGY CONSUMPTION IN MILLION TONNE OF OIL EQUIVALENT(1 MTOE-11.6 TWH) IN TRANSPORT SECTOR -2050
MILLION TONNE OF OIL EQUIVALENT
YEAR
800
700
600
500
400
300
200
100
0
2020
2025
2030
2035
2040
2045
2050
2055
6.7 fold of 2021 @ 7%
5 fold of 2021 @ 6%
3 fold of 2021 @ 4% growth
**1.0 kg of H2 has the same energy content as ~3.0 kg of crude oil
**1.0 kg of H2 requires about 60 kWh of electricity

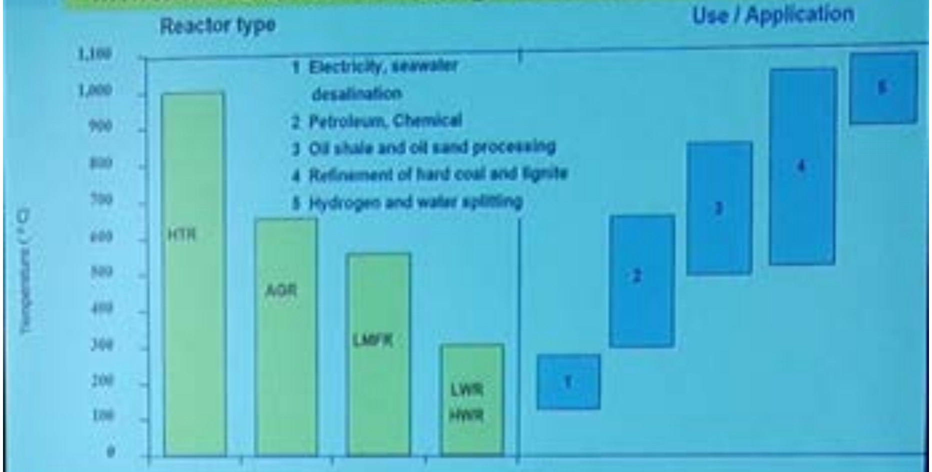

ORF
The Consumption of Energy by Data Centres
Implications for the Global South
By 2047, India's data center capacity is projected to require approximately 35 GW of power to support rapid AI and cloud infrastructure growth, aligning with the "Viksit Bharat 2047" vision.
United States
China
Europe
Asia (excluding China)
Rest of the world
Source: International Energy Agency

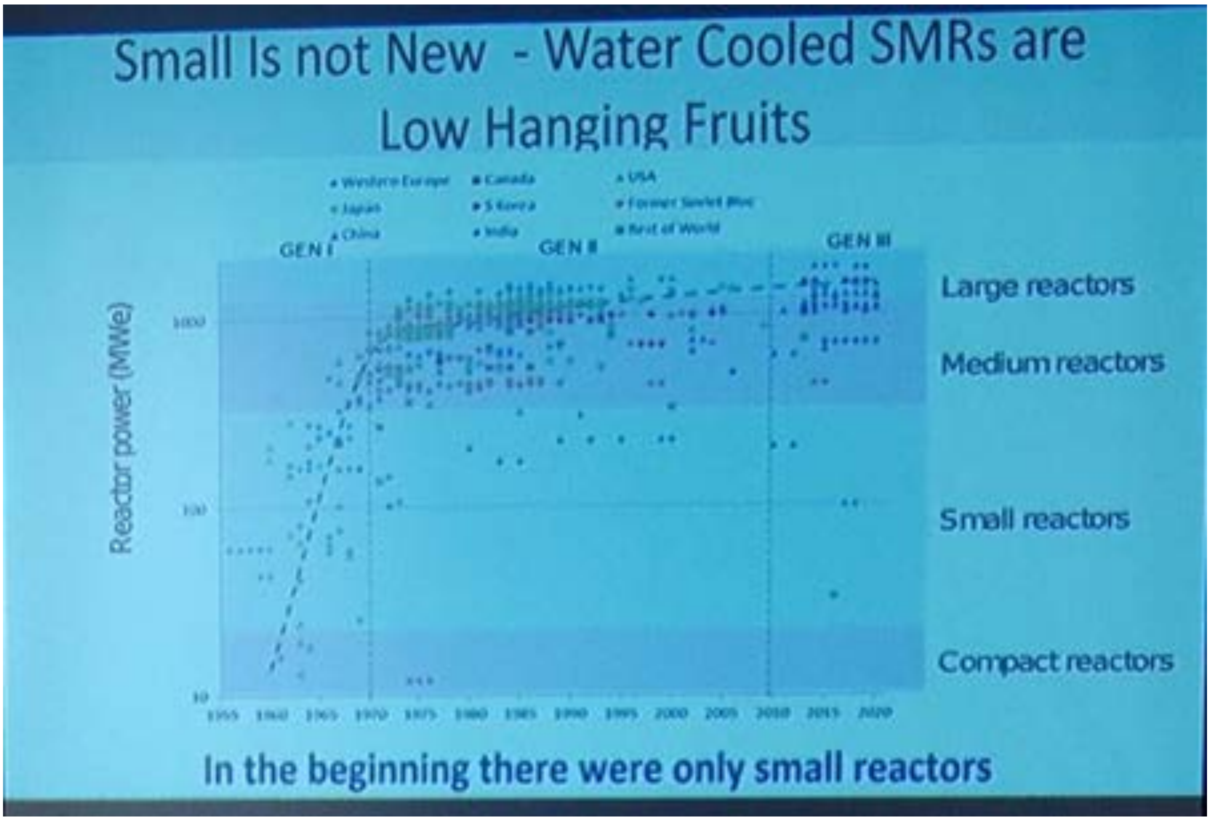

N-Power - what are major issues?
• Cost – Capex and/or LCOE, unknowns
• Safety – Chernobyl & Fukushima - Radiation leak & Cancer
• Fuel supply security – Do we have enough uranium & when thorium to come
• Management of waste – each gram of irradiated uranium to be stored formore than 100,000 years - global concerns
So a big debate, nuclear power - should we go or not to go - are we going towards "VINAS"

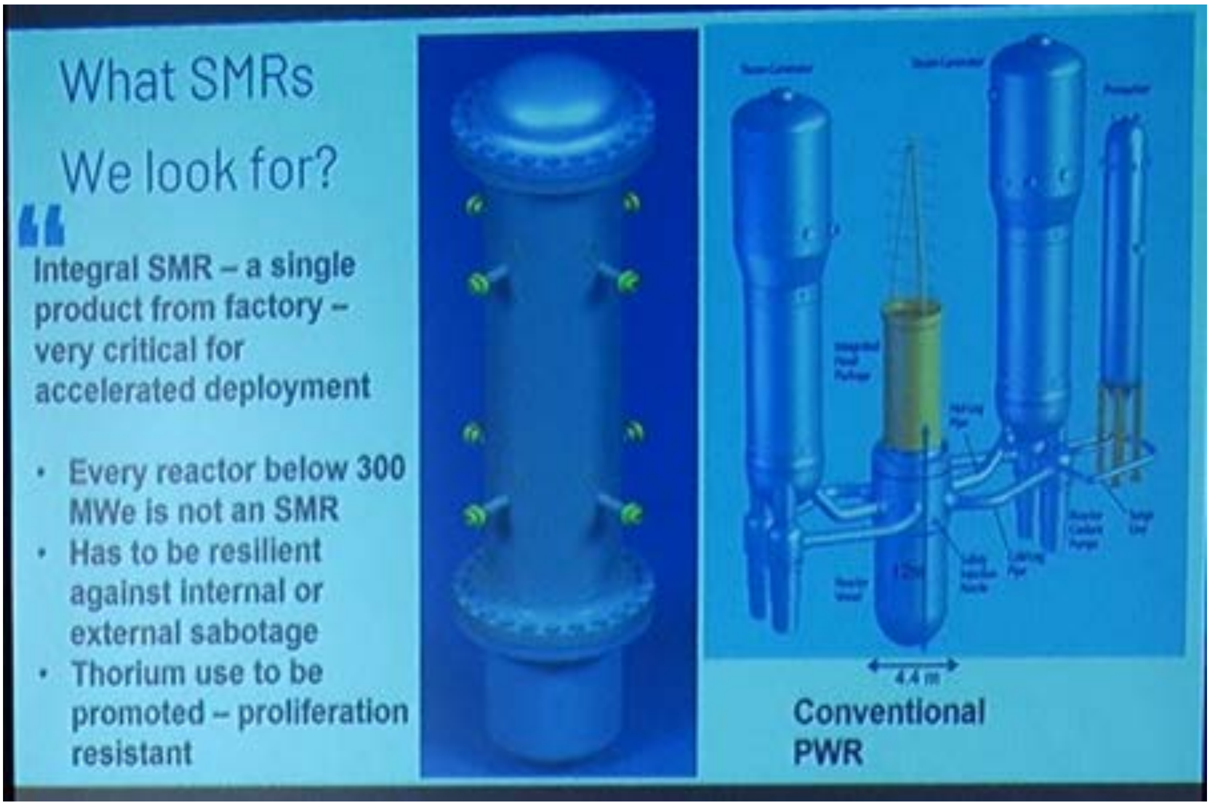
Lets us discover - Limitations of current commercially large nuclear reactors

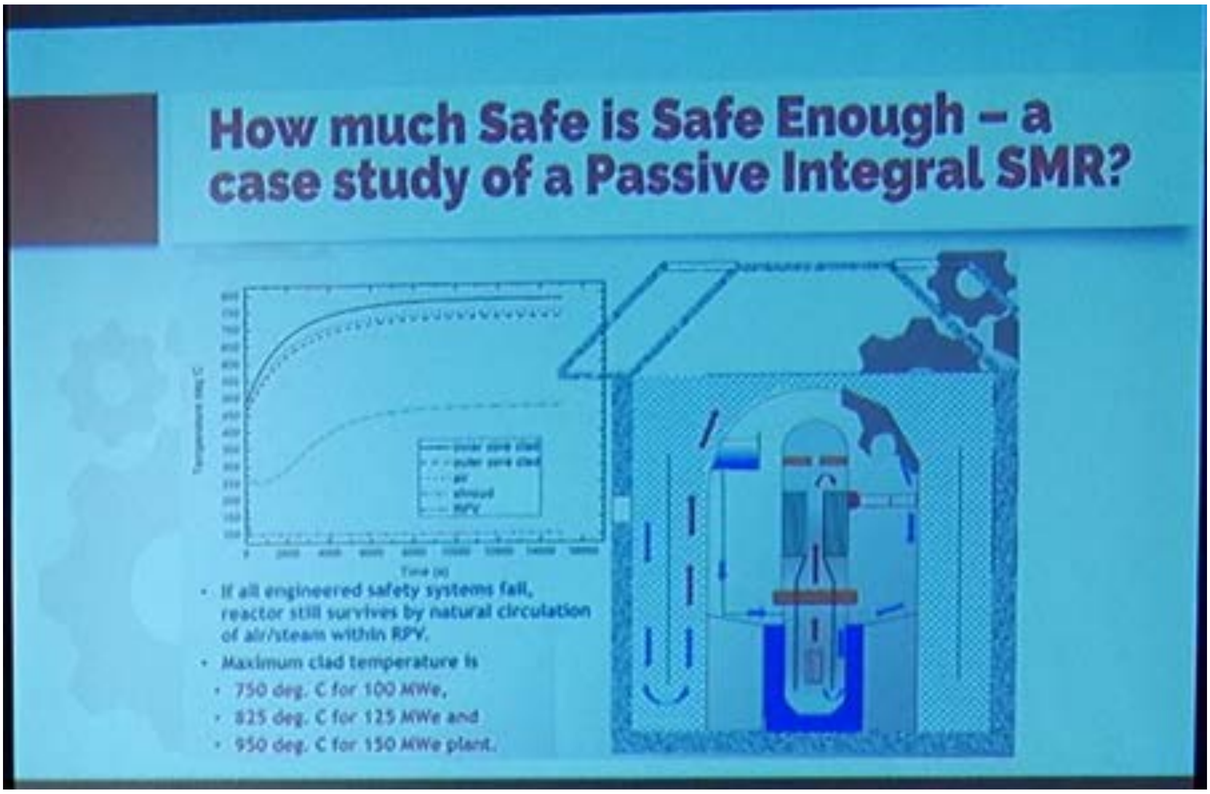
- **Acquiring several sites in India – qualifying seismic conditions - no seismic fault for 5 km radius – where to get???**
  - large population density of India
  - Requirement of ExZ (1 km rad), EPZ (16 km rad) to meet dose criteria of large plants
  - Coastal sites – availability is poor
  - Interior India – water availability, seismic zone qualification, seismic faults
- **Large project cost and construction delays**
  - Large investment because of large size of plants
  - Significant onsite work and civil construction delays
  - Non modularity in design, issues in delay in construction
  - High IDC (30 to 40%)
- **Safety issues of current reactors**
  - very low probable core melt accident may occur – Gen III plus designs have core catchers, hydrogen mitigation devices, containment venting – additional cost and safety issues remain – these reactors cannot satisfy no emergency planning in the public domain

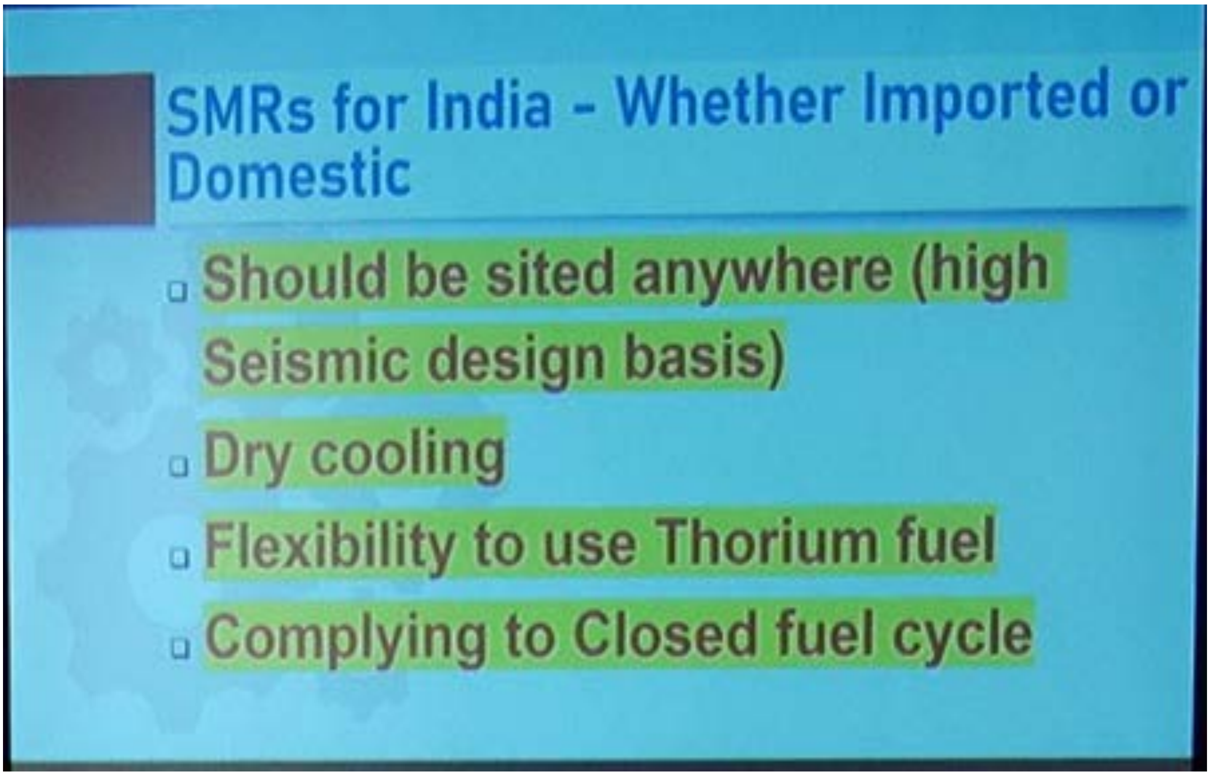
Nuclear power: More than just electricity generation – – limitations of current large conventional reactors




Small Is not New - Water Cooled SMRs are Low Hanging Fruits
Western Europe
Japan
China
Canada
S Korea
India
USA
Former Soviet Bloc
Rest of World
GEN I
GEN II
GEN III
Reactor power (MWe)
1000
100
10
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Large reactors
Medium reactors
Small reactors
Compact reactors
In the beginning there were only small reactors


What SMRs We look for?
Integral SMR – a single product from factory – very critical for accelerated deployment
• Every reactor below 300 MWe is not an SMR
• Has to be resilient against internal or external sabotage
• Thorium use to be promoted – proliferation resistant
4.4 m
Conventional PWR


How much Safe is Safe Enough – a case study of a Passive Integral SMR?
If all engineered safety systems fail, reactor still survives by natural circulation of air/steam within RPV.
Maximum clad temperature is
750 deg. C for 100 MWe,
825 deg. C for 125 MWe and
950 deg. C for 150 MWe plant.


SMRs for India - Whether Imported or Domestic
Should be sited anywhere (high Seismic design basis)
Dry cooling
Flexibility to use Thorium fuel
Complying to Closed fuel cycle

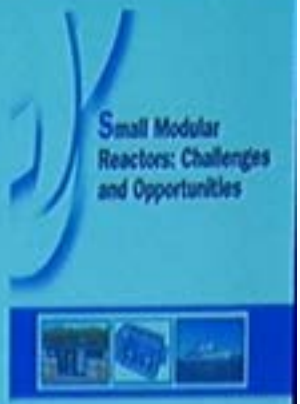
SMRs third party liability – May be excluded

5.2. Nuclear third party liability and SMRs

The international conventions governing nuclear third party liability are:

- the Paris Convention on Third Party Liability in the Field of Nuclear Energy ("Paris Convention" or PC),[11] which will soon be amended by a 2004 Protocol yet to enter into force ("Revised Paris Convention" or RPC);[12]
- the Vienna Convention on Civil Liability for Nuclear Damage ("Vienna Convention" or VC);[13]
- the Vienna Convention as amended by the 1997 Protocol ("Revised Vienna Convention" or RVC);[14]
- the Convention on Supplementary Compensation for Nuclear Damage (CSC).[15]

SMRs are included in the definition of "nuclear installation" provided in the conventions, which covers "reactors other than those comprised in any means of transport".[16] Having regard to the nature of the nuclear installation involved and to the likely consequences of a nuclear incident originating therefrom, the conventions (except for the Vienna Convention) allow countries to establish a lower amount of liability for that installation, provided that in no event shall any amount so established be less than the amounts provided in the conventions for low-risk installations.[17] The aim of this option is to avoid burdening the nuclear operators concerned with unjustified insurance or financial security costs.[18] Therefore, SMRs may be considered as low-risk installations if the installation states' applicable convention(s) and national laws allow for such a case.



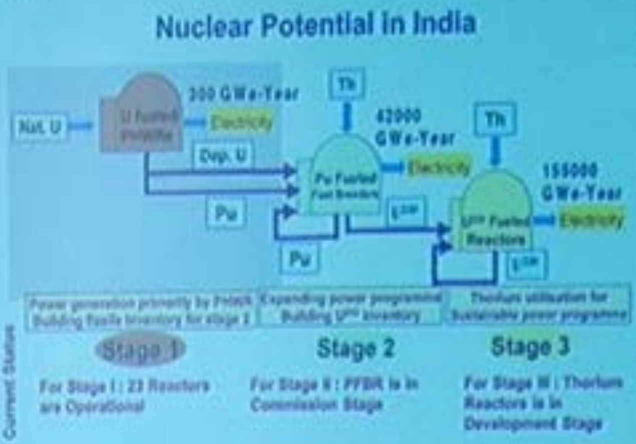
OECD NEA

Potential of Micro Modular Reactors for Hydrogen Production and Rapid Deployment in NE Region, Data Centres, Maritime industries, Isolated regions, Malls, Hospitals, Airports, etc. for Uninterrupted Power Supply

- Power less than 20 MWe
- Drive Cargo Ships - Several thousands
- Data Centres - Compact Uninterrupted Power Supply
- Small Captive Power Plants require clean/ green energy for production of Hydrogen/ localized electricity supplu
- High temperature MMRs- ideal for Hydrogen production - for Transport and Industry energy consumption:
  - Typically, per MWe, around 480 kg of hydrogen can be generated per day using standard low temperature electrolysis. If high temperature steam electrolysis is used, 630 kg of hydrogen can be generated per day per MWe by dedicated SMRs/Micro Reactors.

Nuclear Potential in India through Domestic Fuel Reserves

Fuel



- The first stage targets to generate close to 10 GW electricity through NU.
- The second stage envisages generating close to 42000 GWe-years (~4,00,000 TWh) through Pu FBR.
- The final stage is the development of advanced nuclear power reactors targeting energy production of 155000 GWe-years (~14,00,000 TWh) through thorium fuel.
- If we consider the need for 100 years, the second and third stage combined can provide nearly 18000 TWh/year.
- Further can be enhanced through imported fuel.

Accelerating Thorium Deployment

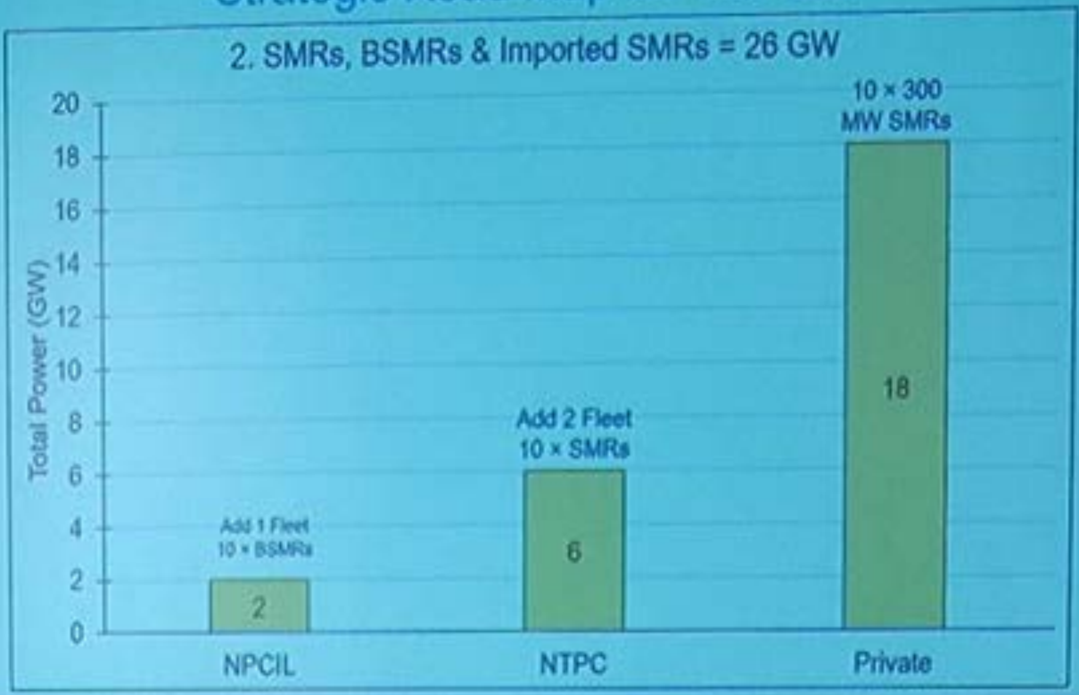
- PHWRs (BSR & 700 MWe) – ANEEL fuel
- AHWRs (LEU-Th) (has potential to be converted to SMR)
- ADS

Establish the thorium front end & back end – job by DAE institutions

Deploy Advanced SMRs/MMRs using thorium in different platforms :

- MSBRs
- GCRs
- Other technologies (Hybrid)

Strategic Road Map for 100 GW



Task Ahead (1) - Technologies & Vendors Establishment

Task Ahead (2) - Fuel Supply

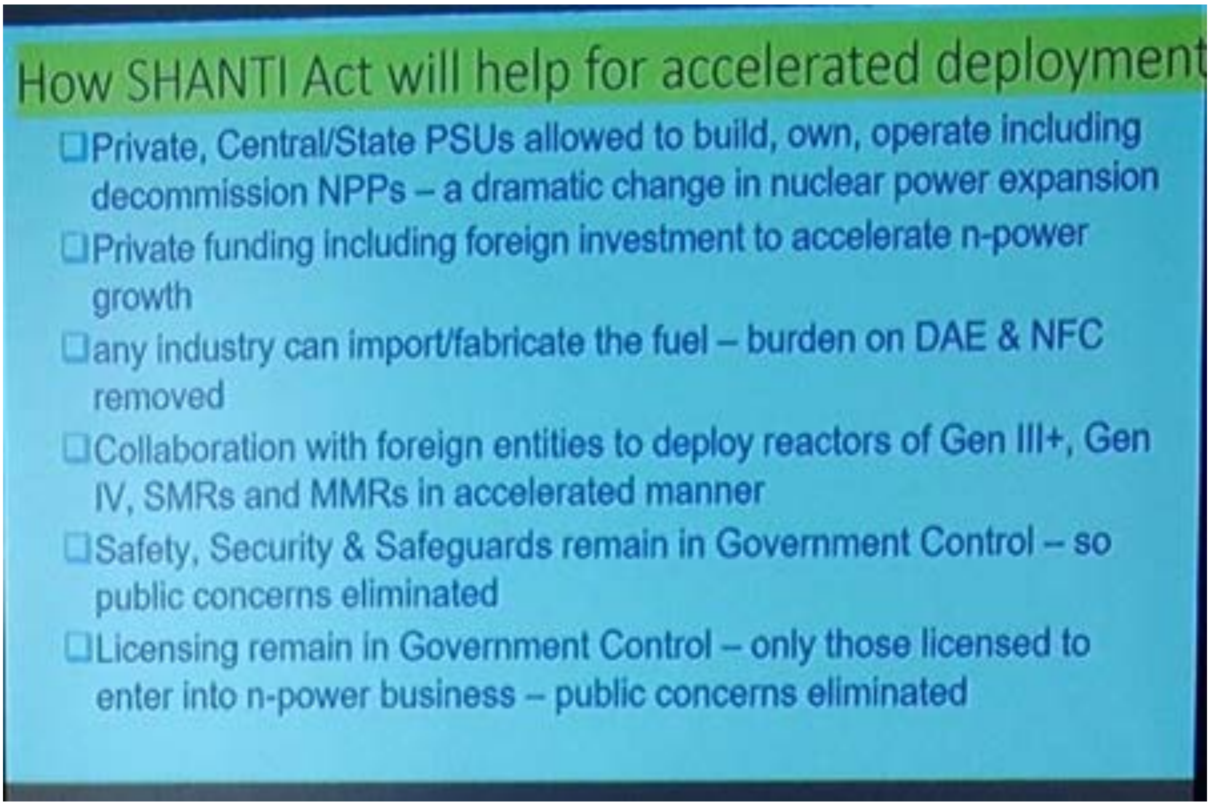
Task Ahead (3) – Establishment of fuel fabrication facilities

Task Ahead (4) - Supply Chain Development

Task Ahead (5) - Financing

Task Ahead (6)- Licensing aspects

Task Ahead (7) - Human Resources Development & Capacity Building


How SHANTI Act will help for accelerated deployment
Private, Central/State PSUs allowed to build, own, operate including decommission NPPs – a dramatic change in nuclear power expansion
Private funding including foreign investment to accelerate n-power growth
any industry can import/fabricate the fuel – burden on DAE & NFC removed
Collaboration with foreign entities to deploy reactors of Gen III+, Gen IV, SMRs and MMRs in accelerated manner
Safety, Security & Safeguards remain in Government Control – so public concerns eliminated
Licensing remain in Government Control – only those licensed to enter into n-power business – public concerns eliminated

LECTURE - 8

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Nuclear Energy Mission – 100GW by 2047

Nuclear Power Expansion and Role of PSUs and Private Industries

R. Raghavan, Vice President

Head – Power & Nuclear Business

TOPICS COVERED

TATA

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01 TCE Overview

Tata Consulting Engineers

TATA

63+ YEARS
of Technical Excellence

$35+ BN WORTH PROJECTS
under management

12,000+ PROJECTS
Delivered Globally

9500+ ENGINEERS
across all domains

33,000+ MLD WATER & WASTEWATER
treatment done

15+ MN HOURS
3D engineering across businesses

250+ GW POWER PLANTS
engineered globally

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02 TCE's Power Business & Nuclear Portfolio

Power Business Unit – Areas of Operation

"Engineers to the Nation", with 250 GW+ of Power generation Globally

6 Decades of Value-added Engineering Services across Project and Asset Life Cycle Management

- **Nuclear:** PHWR, FBR – **10+ GW**
- **Green Power:** Hydro & PSP (**50+GW**), Solar (**40+GW**), Wind (**10+GW**), Biomass, WtE
- **Thermal:** Coal, Gas, Captive & Cogen – **200+ GW**
- **T&D:** Transmission Lines, Substation (AIS/GIS), Distribution and System Studies – **12000+ c.kms and 250+ substations**
- **Emerging Areas:** Digital, AI, Green Hydrogen, Nuclear Fusion, SMR, Energy Storage

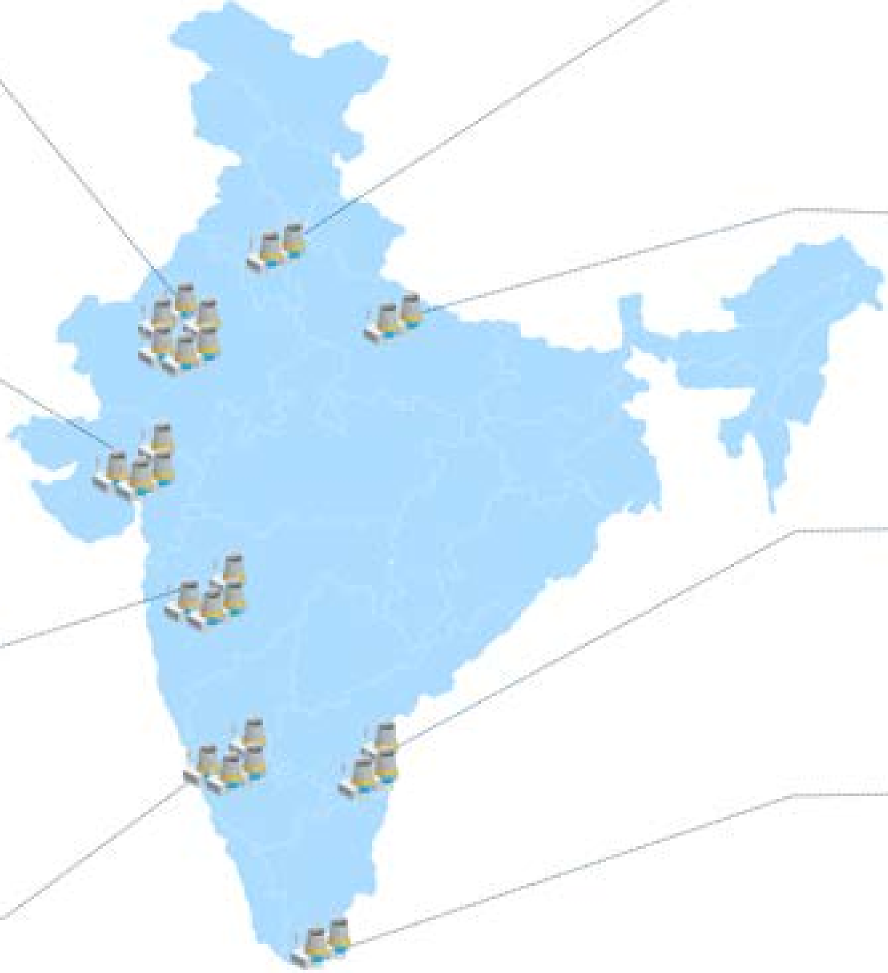
TCE's association in Indian Nuclear Programme

Rajasthan Atomic Power Station
- Unit 1, PHWR CANDU 100 MWe (1972)
- Unit 2, PHWR CANDU 200 MWe (1980)
- Unit 5, PHWR IPHWR 220 MWe (2009)
- Unit 6, PHWR IPHWR 220 MWe (2010)
- Unit 7, PHWR IPHWR 700 MWe (2025)
- Unit 8, PHWR IPHWR 700 MWe (ongoing)

Kakrapar Atomic Power Station
- Unit 1, PHWR IPHWR 220 MWe (1992)
- Unit 2, PHWR IPHWR 220 MWe (1995)
- Unit 3, PHWR IPHWR 700 MWe (2021)
- Unit 4, PHWR IPHWR 700 MWe (2024)

Tarapur Atomic Power Station
- Unit 1, BWR 160 MWe (1969)
- Unit 2, BWR 160 MWe (1969)
- Unit 3, PHWR IPHWR 540 MWe (2006)
- Unit 4, PHWR IPHWR 540 MWe (2005)

Kaiga Atomic Power Station
- Unit 3, PHWR IPHWR 220 MWe (2007)
- Unit 4, PHWR IPHWR 220 MWe (2011)
- Unit 5, PHWR IPHWR 700 MWe (ongoing)
- Unit 6, PHWR IPHWR 700 MWe (ongoing)



Gorakhpur Nuclear Power Plant
- Unit 1, PHWR IPHWR 700 MWe (ongoing)
- Unit 2, PHWR IPHWR 700 MWe (ongoing)

Narora Atomic Power Station
- Unit 1, PHWR IPHWR 220 MWe (1989)
- Unit 2, PHWR IPHWR 220 MWe (1992)

Madras Atomic Power Station
- Unit 1, PHWR IPHWR 220 MWe (1983)
- Unit 2, PHWR IPHWR 220 MWe (1985)
- Unit 3, FBR PFBR 500 MWe (ongoing)

Kudankulam Atomic Power Station
- Unit 1, PWR VVER 1000 MWe (2013)
- Unit 2, PWR VVER 1000 MWe (2016)

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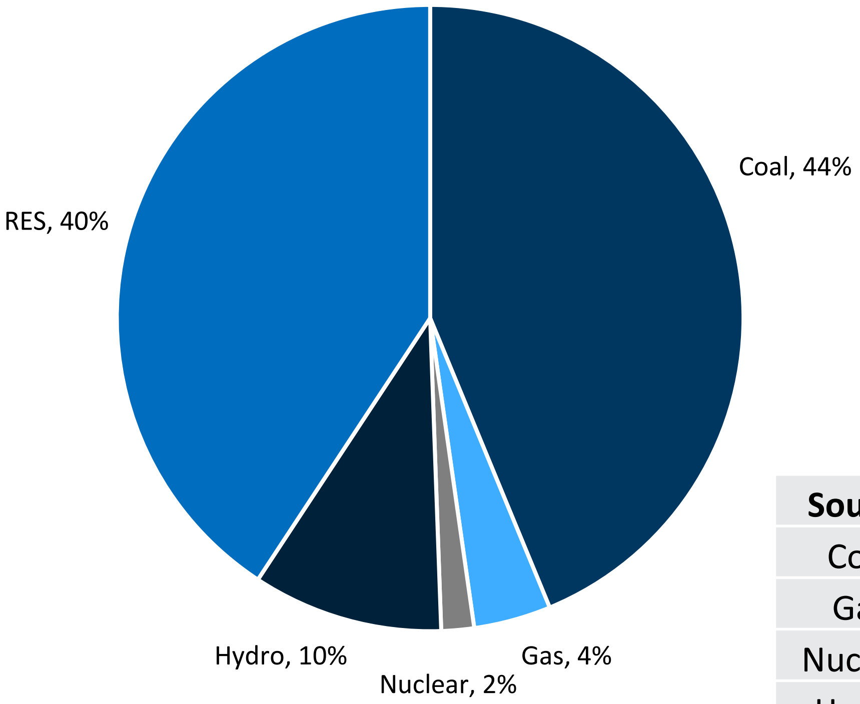
03 Power Sector Scenarios in India

Current Power Generation Mix in India

Installed Capacity as of Jan' 2026

Total Installed Capacity: 520,511 MW

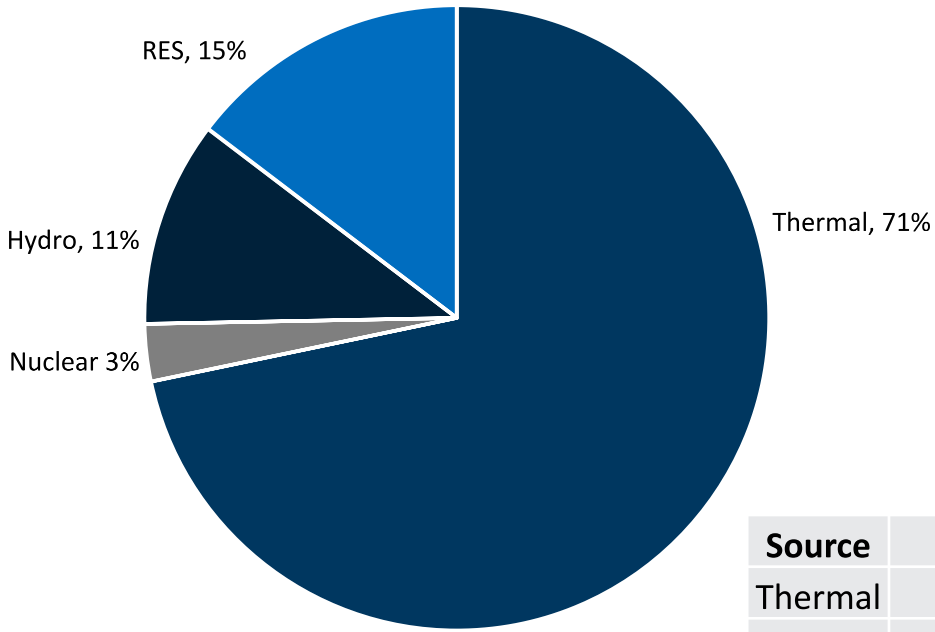


Source	MW
Coal	227,830
Gas	20,711
Nuclear	8,780
Hydro	51,164
RES	212,024
Total	520,511

Source - CEA

Electricity Generation, Billion Units (Apr'25-Dec'25)

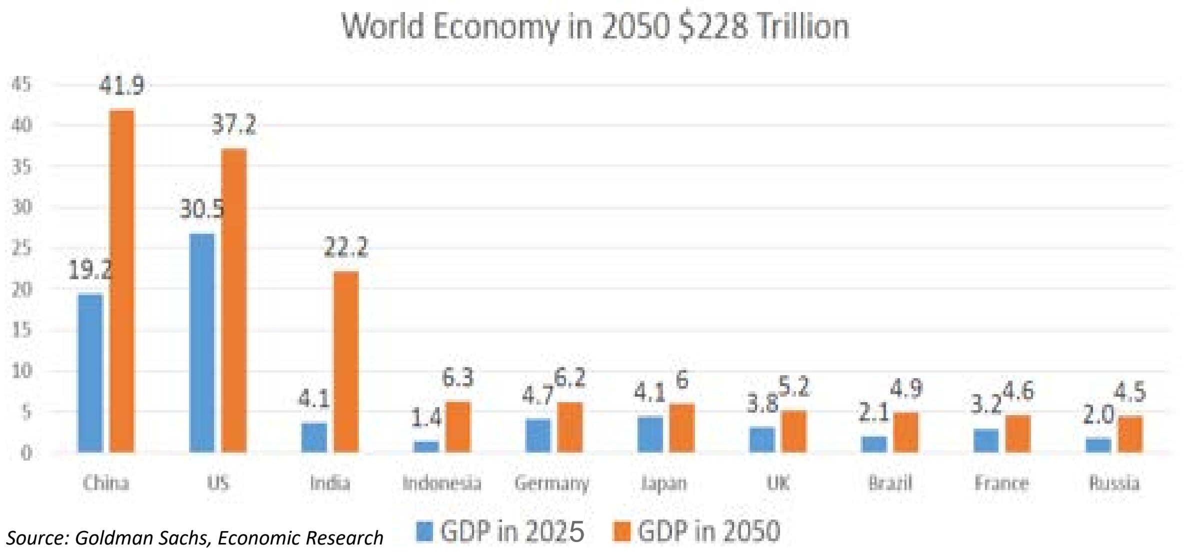
Electricity Generation,FY26, Up to DEC 25: 1320.20 BU



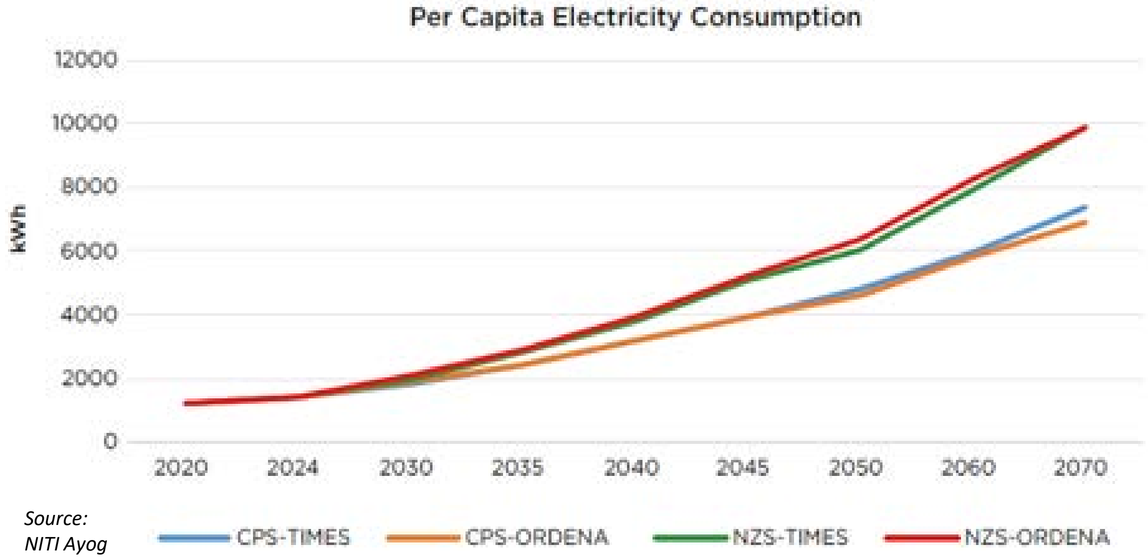
Source	BU
Thermal	947
Nuclear	39.10
Hydro	140.50
RES	193.60
Total	1320.20

Source - CEA

India's Growth Forecast

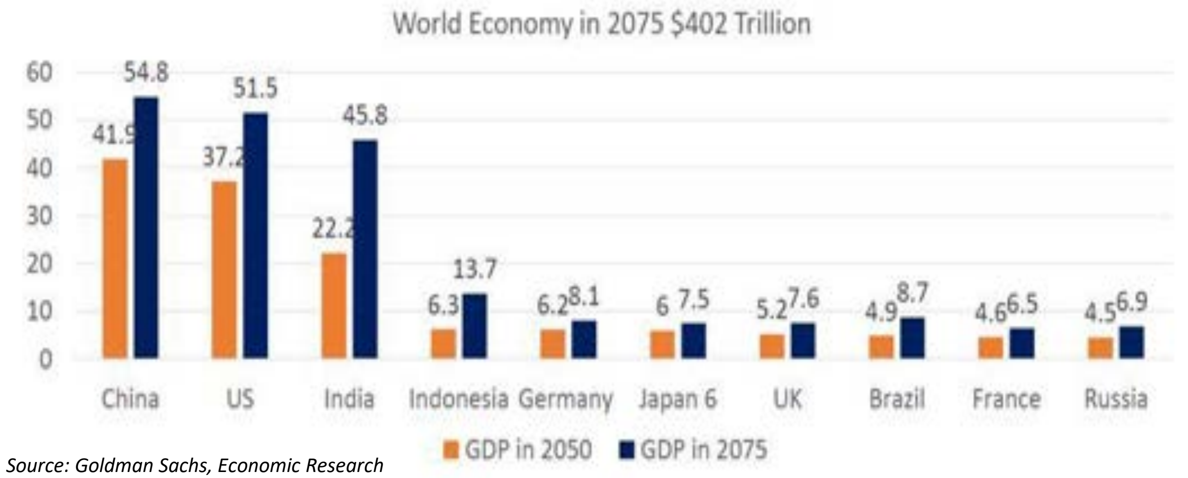


Source: Goldman Sachs, Economic Research



Source: NITI Ayog

*- India Aspires to become US$30 Trillion by 2047



Source: Goldman Sachs, Economic Research

1. India's current HDI value 0.685, aiming to reach between 0.8-0.9
2. Per capita electricity consumption is set to reach 6,400 kWh by 2050 and 10,000 kWh by under Net Zero Scenario.
3. **CO_2 emission expected to be ~0.3 $kgCO_2/kWh$ by 2050 & ~0.07 $kgCO_2/kWh$ (CPS) & 0.00 $kgCO_2/kWh$ (NZS) by 2070**

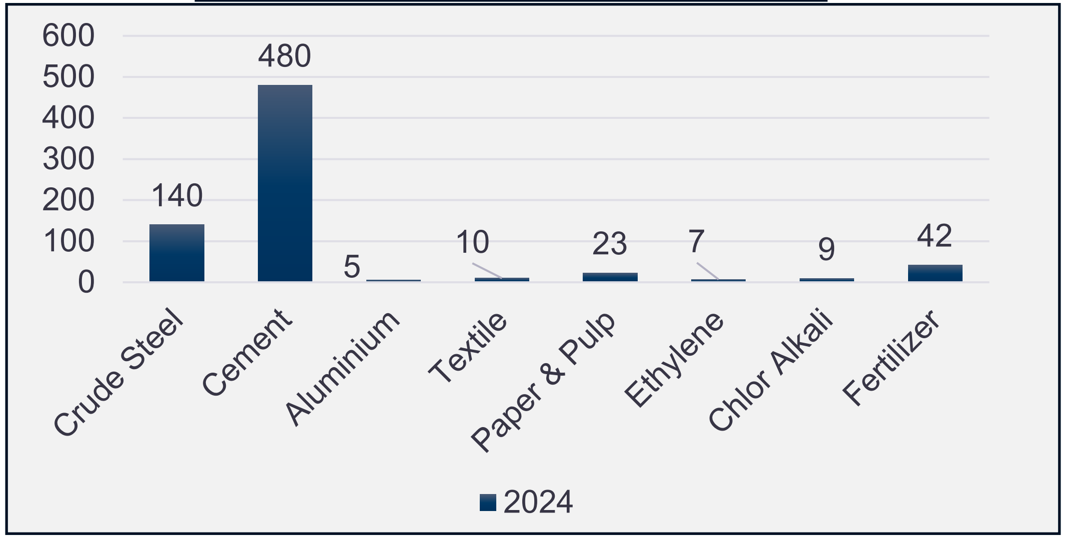
Simulation Models:

TIMES - The Integrated MARKAL-EFOM System

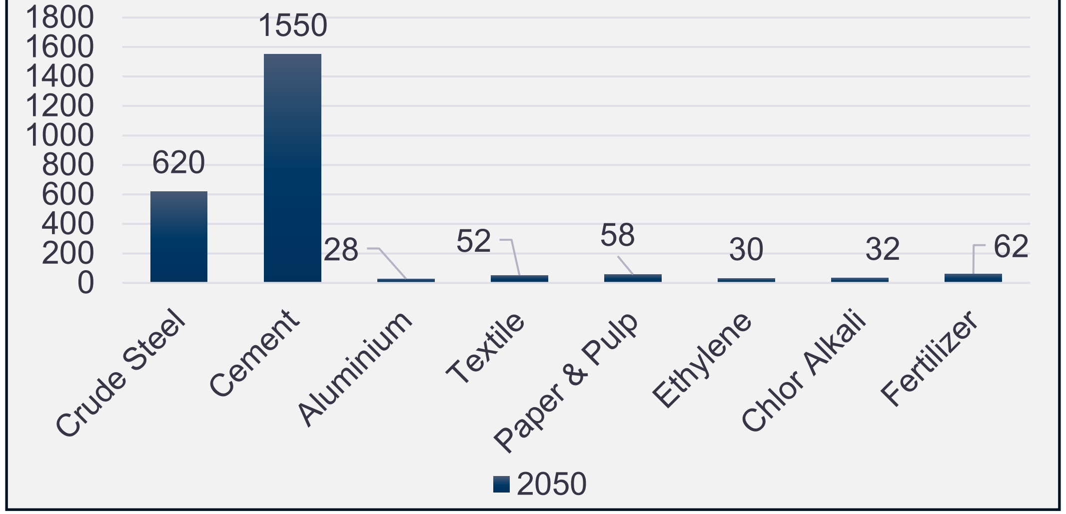
ORDENA - ORigin-DEstiNAtion Data Exploration

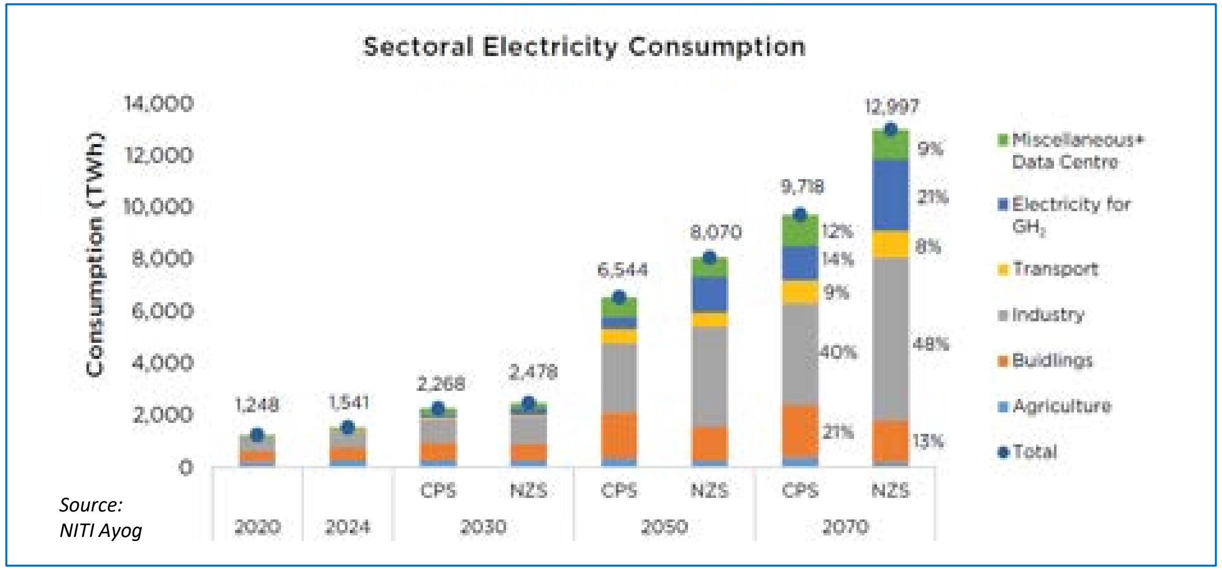
India's Industrial Production & Electricity Consumption forecast

Annual Production 2024 (in MT)



Annual Production 2050 (in MT)



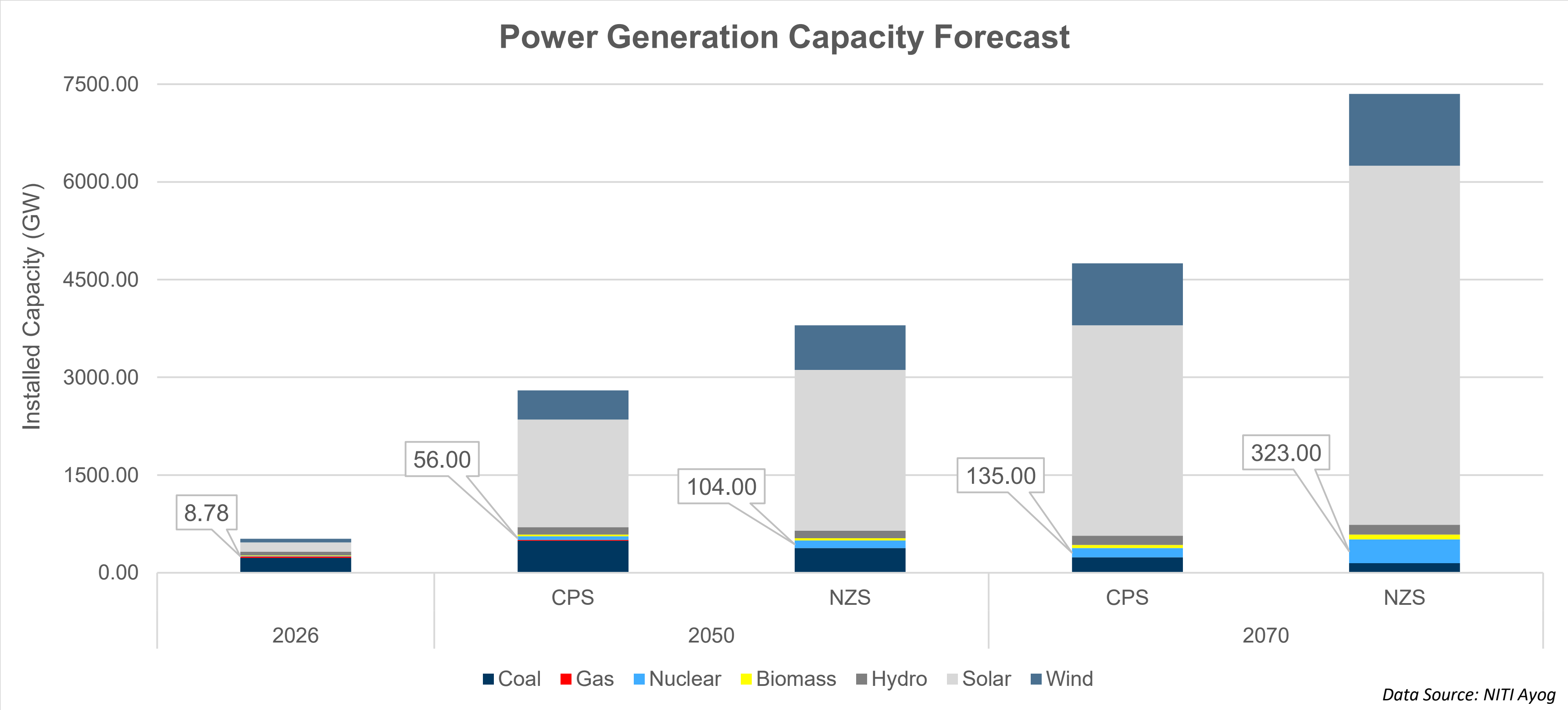


Electricity consumption to reach 8070 TWh by 2050 with a CAGR of 6.6% under Net Zero Scenario.

Industrial sector shall play a major role in electricity consumption reaching 6270 TWh in 2070 under NZ scenario.

Other major consumption sectors: Commercial Buildings (1627 TWh), Data Center (700TWh), GH2 production (2770 TWh), Transportation (870 TWh)

Generation Capacity Addition Programme



CPS: Current Policy Scenario
NZS: Net Zero Scenario

Current Policy scenario

- Total installed capacity set to rise from ~500 GW in 2024-25 to **4,650-4,750 GW** (~9 times) in CPS by 2070.
- Total nuclear capacity projected to reach around **~135 GW by 2070.**
- Cumulative investment requirements reach approximately **USD 250 Billion (USD 5.5 Billion/year)** in Current Policy Scenario.

Net Zero Scenario

- Total installed capacity set to rise from ~500 GW in 2024-25 to **6,800 - 7,350 GW** (~14 times) in Net Zero Scenario (NZS) by 2070.
- The Net Zero Scenario reflects the achievement of India's nuclear mission target of **100 GW by 2047** and total nuclear capacity projected to reach around **323 GW by 2070.**
- Cumulative investment requirements reach approximately **USD 600 Billion (USD 13.5 Billion/year).**

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04 Nuclear Energy Essentials & Current Landscape

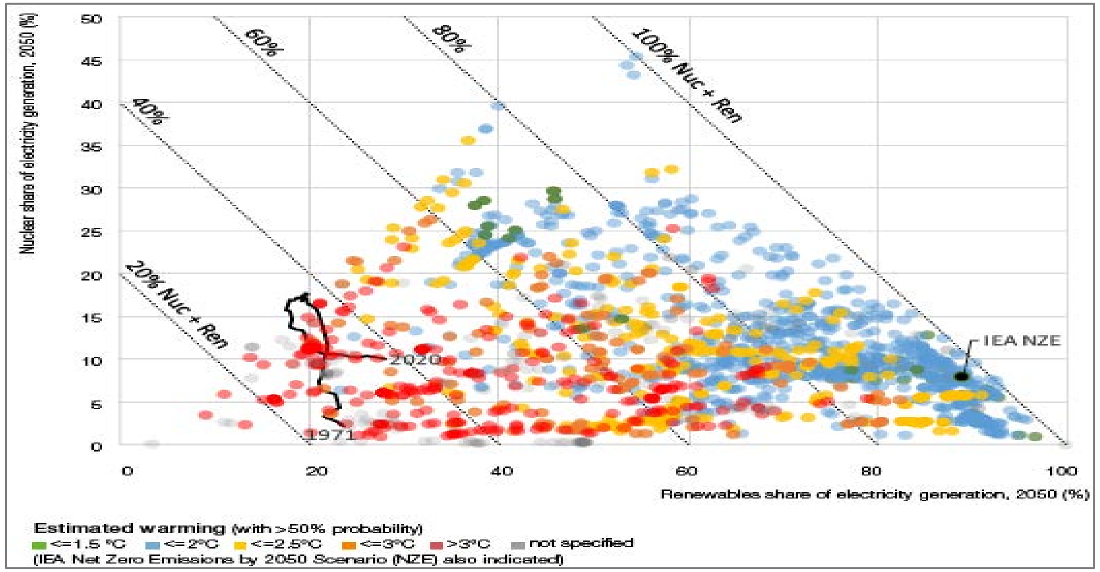
Nuclear Option – Key Imperatives

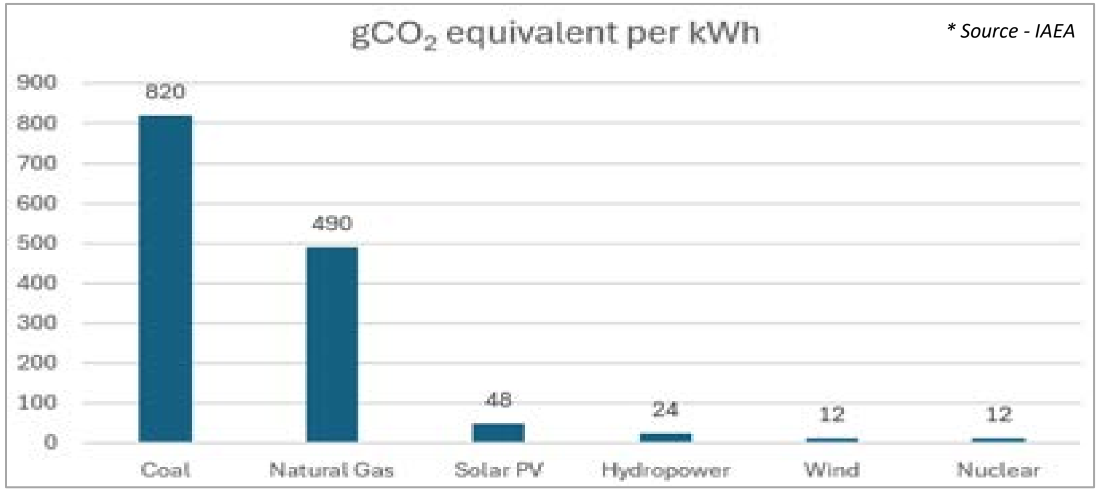
KEY DRIVERS

- Increasing Demand of Clean energy in Global Market
- Global Competitiveness & Carbon Tax
- Lowest Carbon Footprint
- Lower Operating Cost
- Baseload Power Source Reliability and Security
- Scarcity in Fossil Fuel Domestic Supply

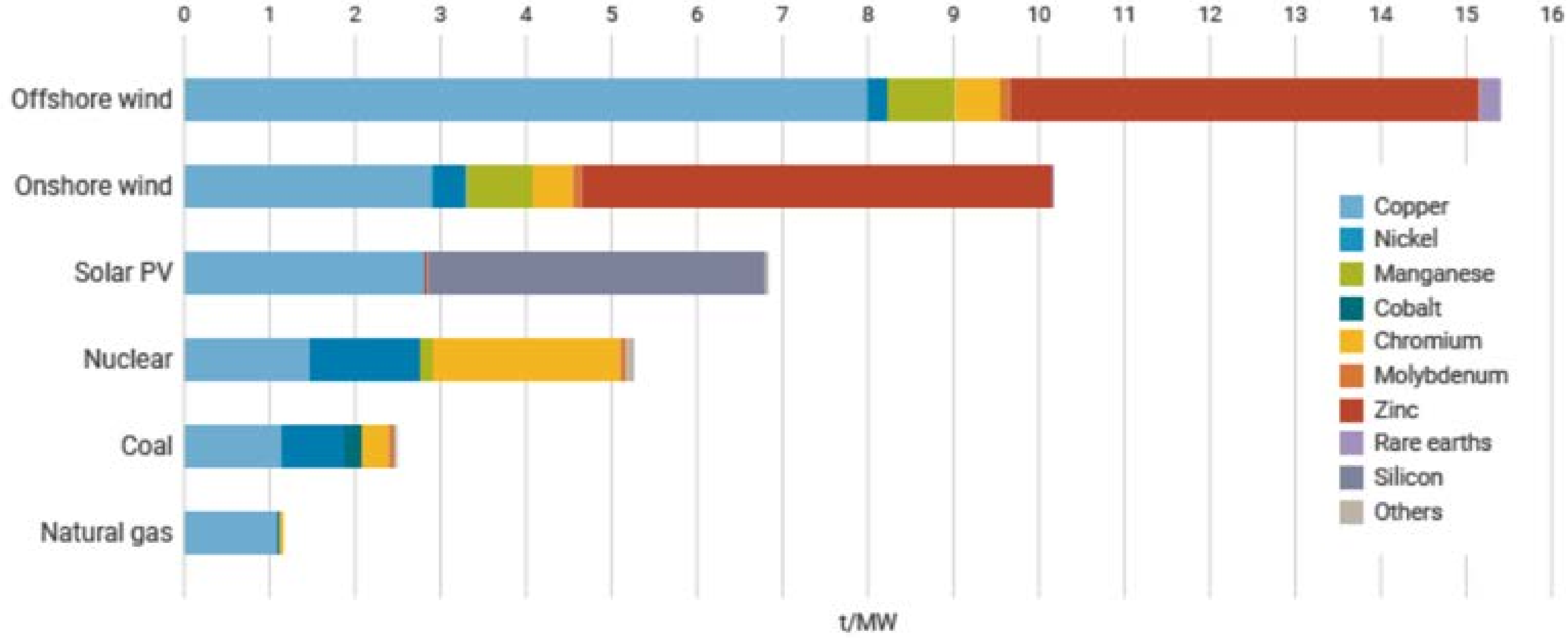
Clean Energy Policy Enablers

- Global industry policy is increasingly shaped by carbon pricing, higher import duties
- Carbon Border Adjustment Mechanism (CBAM) imposes tariff on imported high emission products
- GHG emission intensity target rules imposed by MoP under carbon trading scheme
- Nuclear Power provides 24*7 clean power support to variable RE power, higher plant life





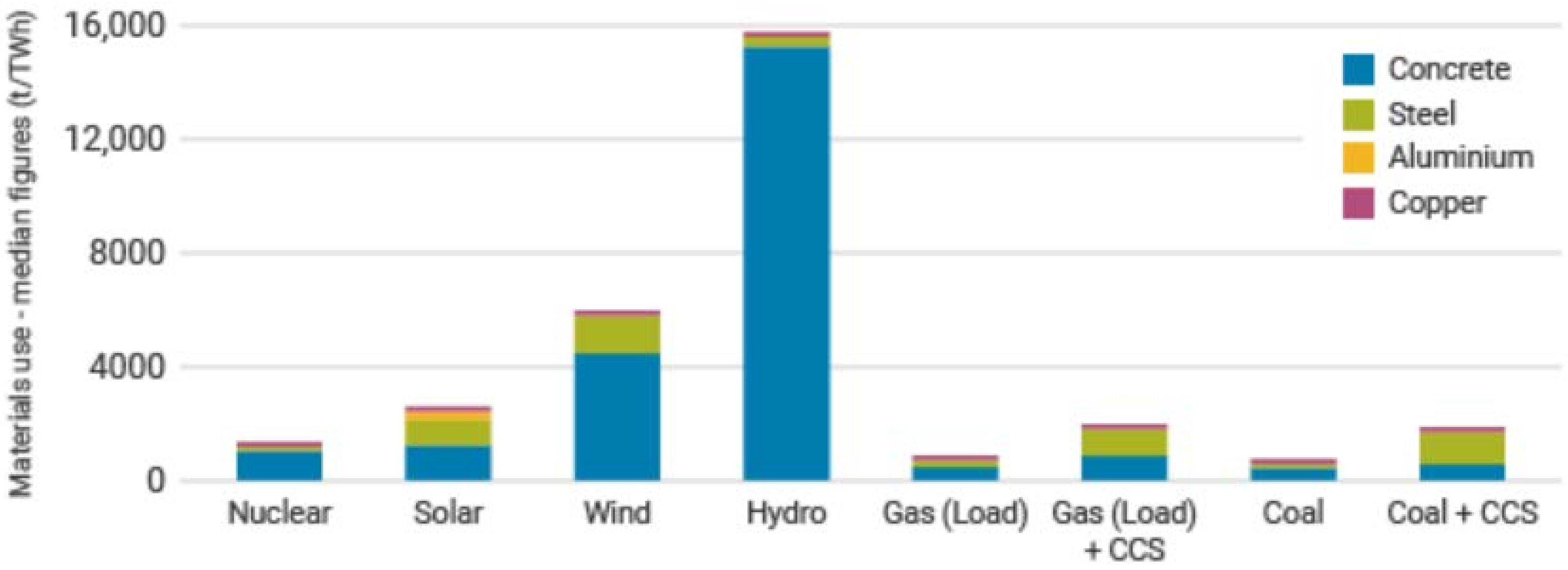
Critical Minerals Requirement



Critical minerals required for different generating technologies (source: IEA)

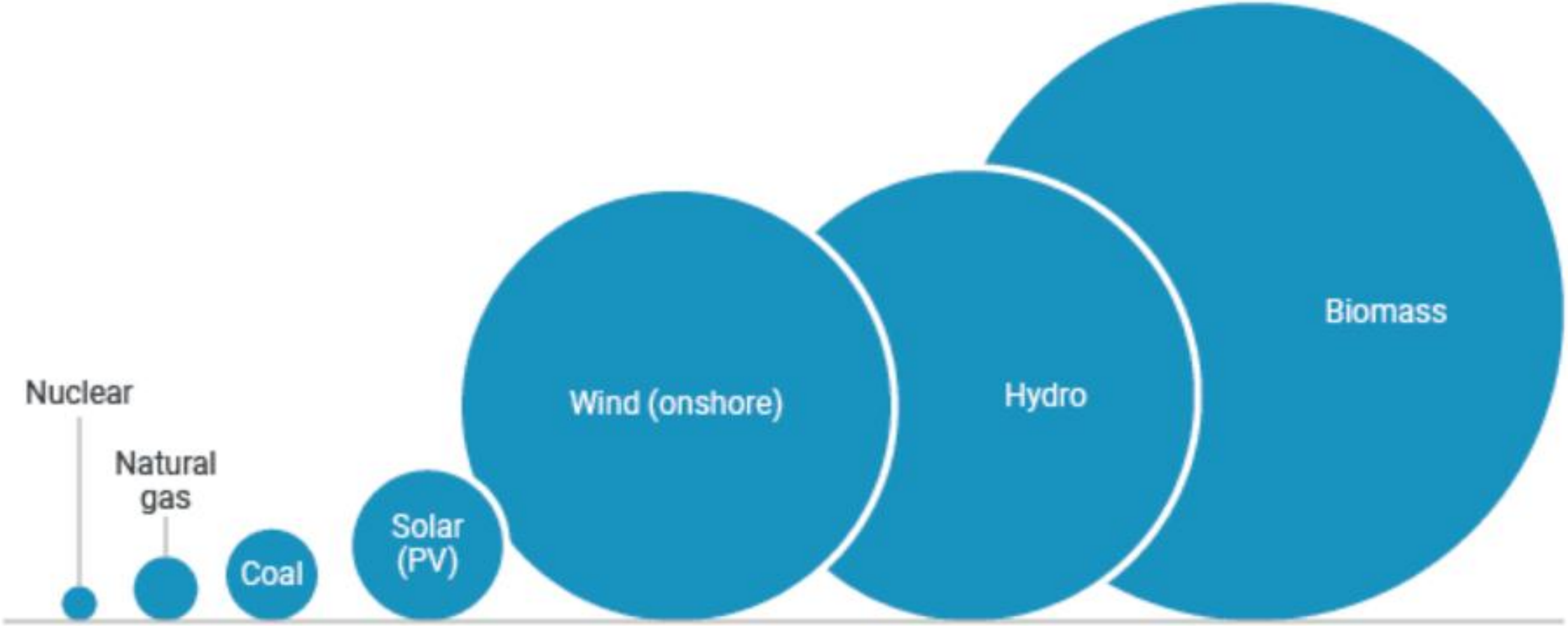
Nuclear has lesser critical mineral requirements (t/MW installed capacity) than renewables

Material Requirement



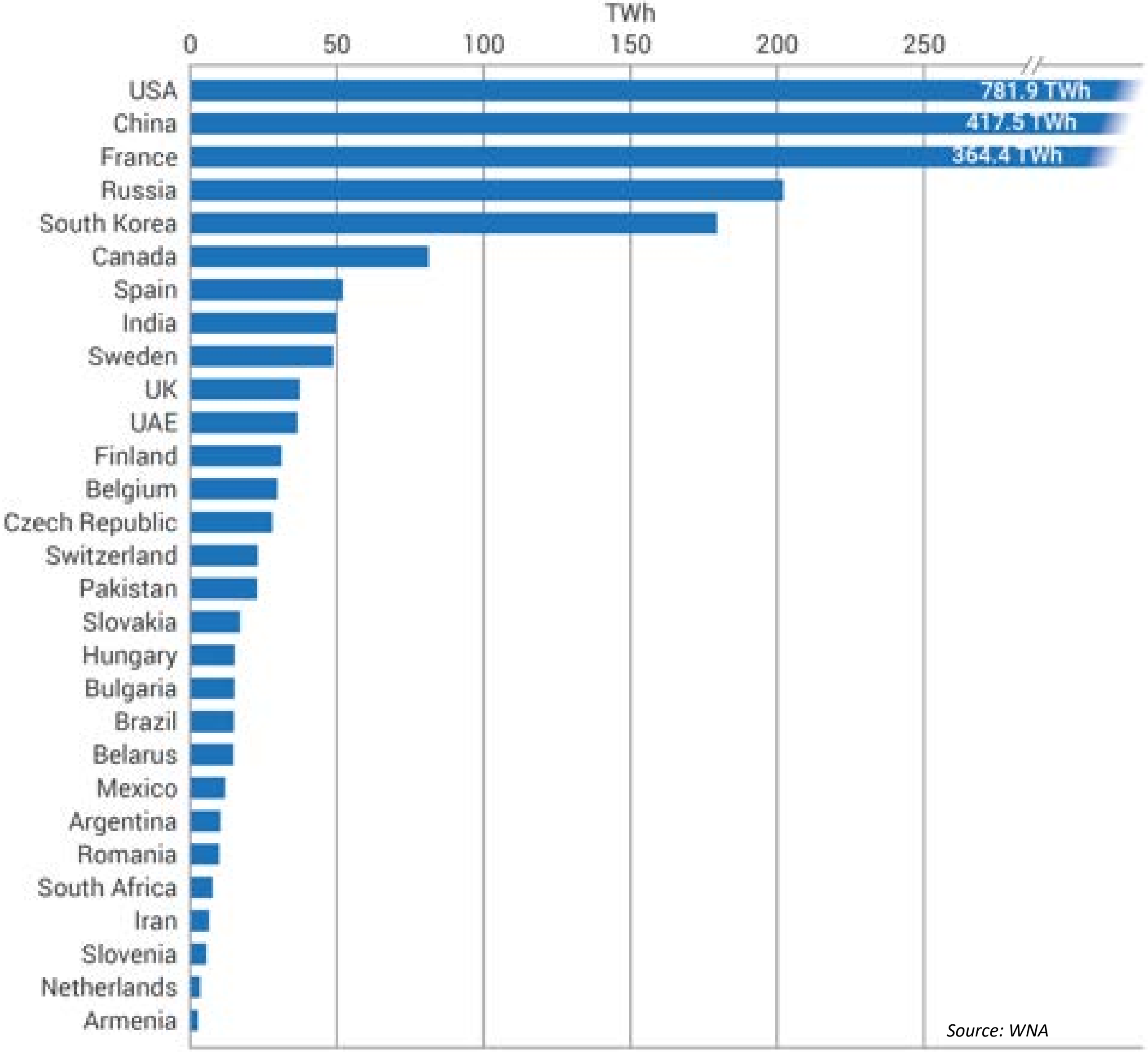
Nuclear has lesser material requirements than renewables
(t/TWh electricity generated)

Relative Land Use



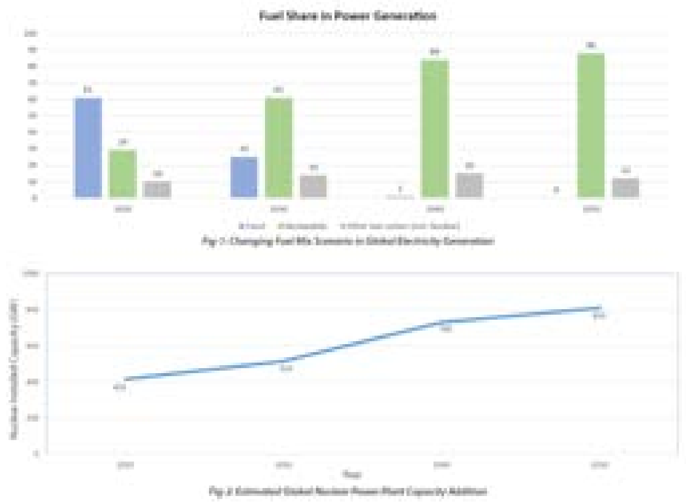
Nuclear has the lowest relative land use considering fuel mining and generating footprint

Share of Nuclear Power in total electricity generation

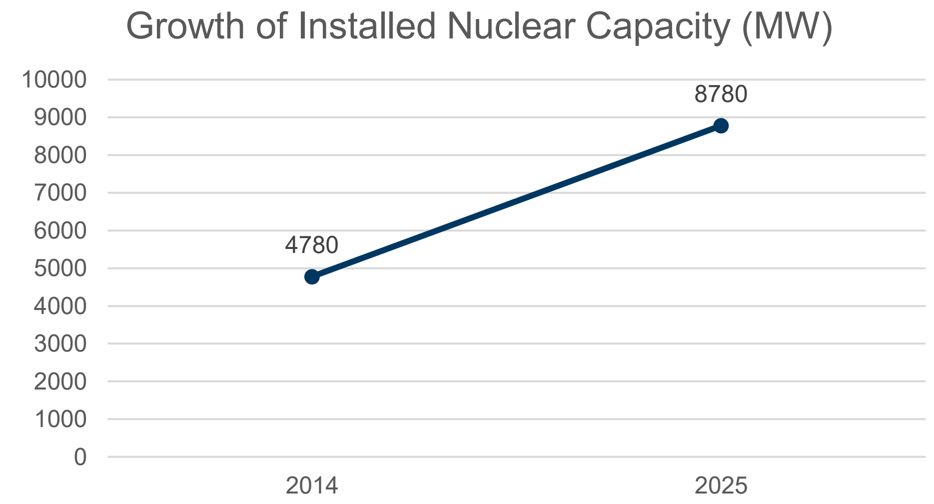


Source: WNA

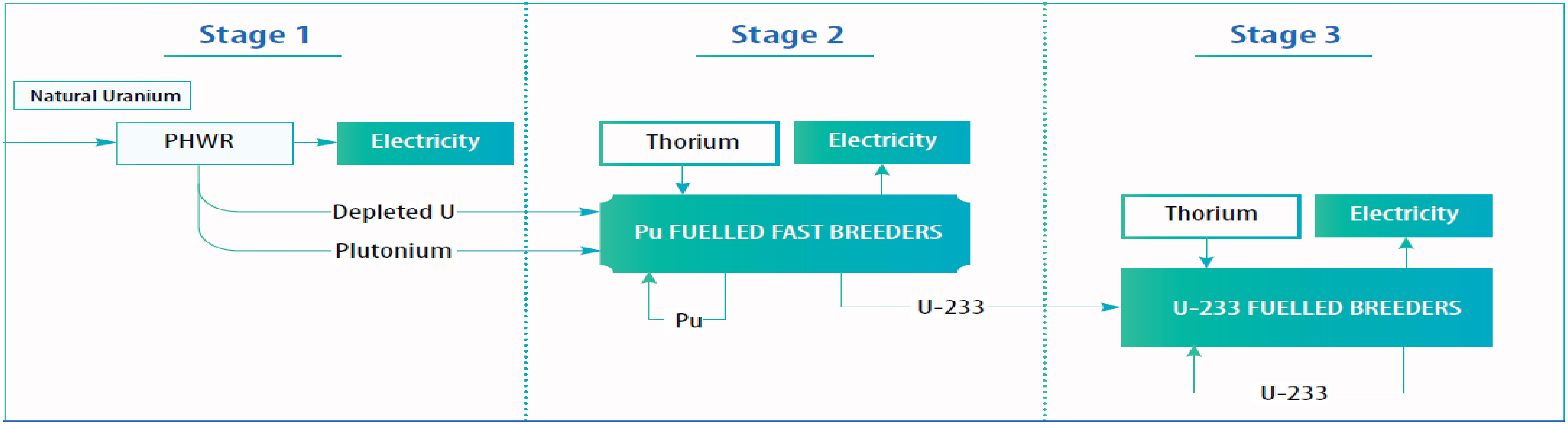
Global fuel mix scenario and Nuclear power capacity addition



Nuclear Installed capacity in India in last 10 years



India's Three Stage Nuclear Programme



Pressurized Heavy Water Reactor PHWR)	Fast Breeder Reactor (FBR)	Advanced Heavy Water Reactor (AHWR)
▪ Fueled by Natural Uranium: U-238 consisting of 0.7% U235 – fissile material which undergoes fission. ▪ Remaining U-238 is converted into Pu-239.	▪ Fuel: Mixed oxide of Pu-239 & U-238 – Pu-239 undergoes fission ▪ U-238 breeds more Pu-239. ▪ Th-232 is introduced to produce U-233	▪ Fuel: U-233 ▪ Th-232 breeds more U-233. ▪ Th-232 is introduced to produce U233

Current Status of Indian 3-stage

20 PHWR units are in operational	40 MWth FBTR operating at kalapakkam for over 25 years	U-233 fuelled 30 KWth KAMINI reactor is in operational
2 BWR & 2 PWR units are in operational	500 MWe PFBR is under commissioning and expected to achieve criticality by March 2026.	300 MWe AHWR is under development stage
3 PHWR + 4 LWR are under construction	Once commissioned, the PFBR will be only the second reactor of its kind in the world	Potential for Thorium usage on large scale

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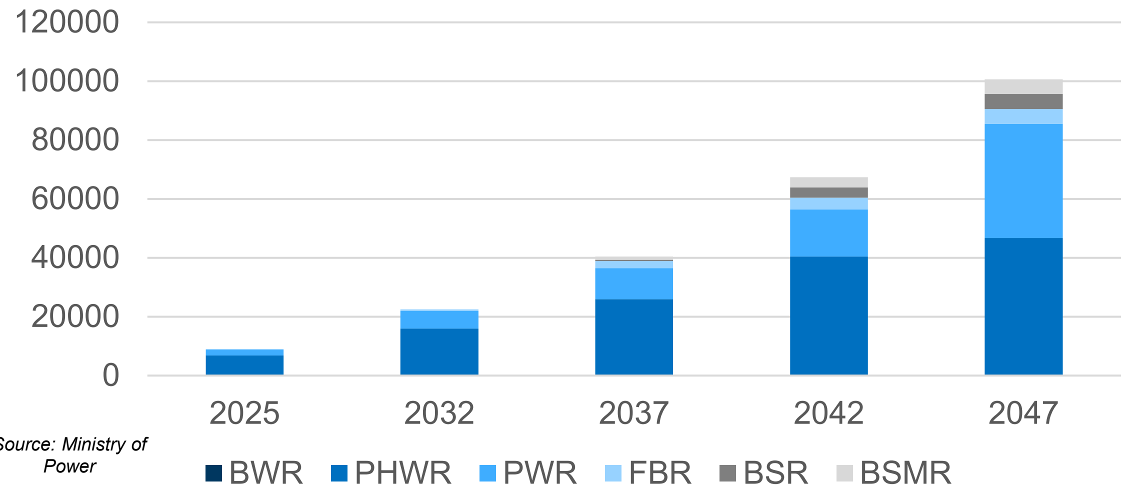
05 Nuclear Energy Expansion Roadmap and Role of Public & Private Sectors

100 GW Nuclear Power by 2047 – Broad Road Map

Nuclear Energy Mission for Viksit Bharat has set an ambitious goal to reach 100GW of Nuclear Power Generation by 2047 from its existing portfolio of 8.78 GW translating to an average capacity addition of ~ 4.14 GW per year pan India.

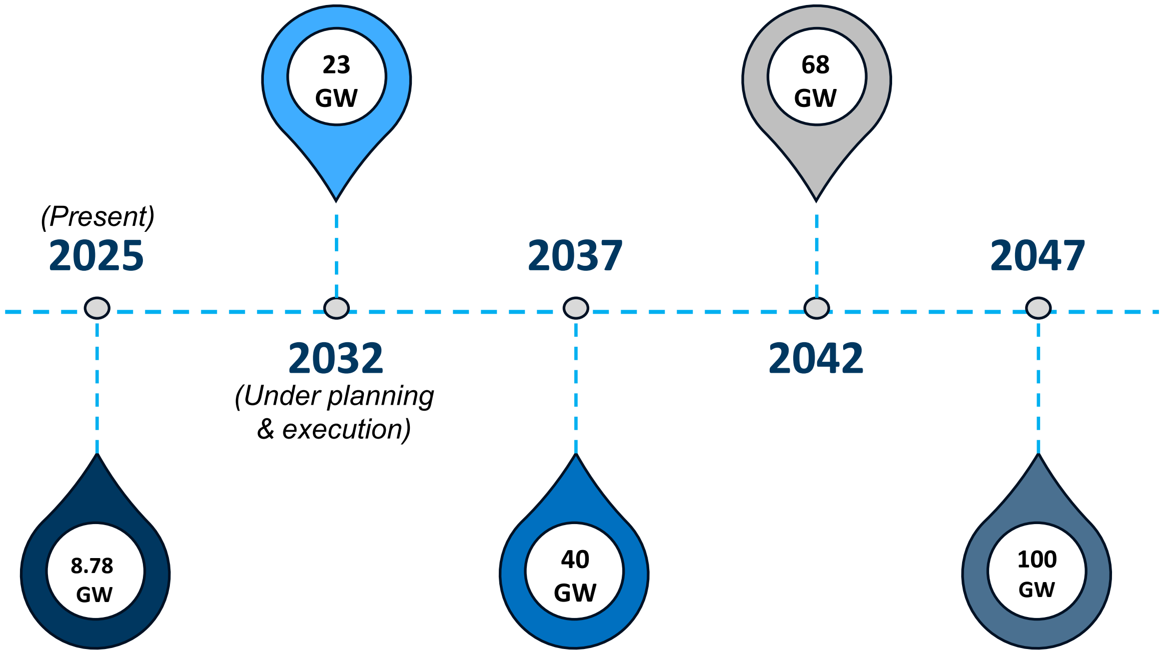
Technology-wise Capacity Addition Projection (in MW)



Source: Ministry of Power

GoI has already initiated steps to increase the current Nuclear capacity to 22.48 GW by 2032

Nuclear Energy Road Map till 2047



Possible options for achieving additional 75 GW capacity

1 3rd PHWR fleet of **10x700 MW**	4 2nd fleet of PHWR **(2x700 MW)** at existing sites of Kakrapar, Rajasthan, Narora	7 **4 PHWR (4x700 MW)** at Bhimpur, Madhya Pradesh
2 PWRs at Kovvada , Andhra Pradesh **(6x1208 MW)** & Jaitapur, Mahararashtra (**6x1730 MW)**	5 Small Modular Reactors **(SMR-55)** & **High Temperature Gas Cooled Reactor (5 MWth)** at off grid locations	8 **2x 500 MWe at FBRs** at Kalpakkam
3 Fast breeder reactors **(~ 3 GW)**	6 Foreign **LWR based power plants** (~ 17 GW)	9 **Private sector participation** for BSR, BSMR, PHWR, foreign LWR/SMR based projects (~ 40 GW)

SHANTI Bill – Key Highlights

Private Sector Participation | Tiered Licensing Model | Foreign Partnerships | Regulatory Enhancements | Governance Framework | Liability Reforms

Benefit Areas	Opportunities Unleashed	Relevance for Mission 100 GW
Private Sector Participation in New Builds	▪ Licenses can be granted to Indian private firms and JVs with govt. entities to build, own, operate & decommissioning nuclear plants.	▪ Would accelerate project development & capacity addition speed, scaling to 100 GW with higher capital access.
Foreign Partnerships (upto 49% FDI)	▪ Enables foreign companies to participate through joint ventures. ▪ Technology collaboration becomes easier with foreign entities.	▪ Access to advanced reactor designs (viz. PWR, SMRs), reduces technology gap. ▪ Boosts supply chain & investment towards manufacturing hubs.
Unified Legal Framework	▪ Consolidates regulation, licensing, safety and liability rules into one comprehensive law, reducing administrative friction.	▪ Would accelerate consenting & permitting process to faster deployment of new reactors.
Nuclear Liability Regime (Tiered Structure)	▪ Introduces graded operator liability ranging from ₹100 Cr. to ₹3,000 Cr. as per reactor capacity; central government covers excess liability. ▪ Eliminates supplier right-of-recourse liability, except in specific cases.	▪ Reduces financial risk for investors & suppliers, unlocking large-scale private and foreign capital needed for 100 GW expansion.
Statutory Status & Stronger Safety Oversight	▪ Grants legal backing to the Regulatory Board, mandating safety authorizations for radiation-related activities.	▪ Builds investor & public confidence, ensuring large-scale nuclear growth without compromising safety.
Policy Provision to boost Supply Chain	▪ Opening the sector to domestic private firms and foreign JVs expands manufacturing of components, reactor modules, fuel cycle facilities. ▪ Supplier liability relaxation improves vendor participation and policy also encourage modular manufacturing ecosystems.	▪ Strengthens domestic and global supply chains to support rapid, large-scale reactor construction. ▪ Would ensure availability of critical components, fuels, and technology to achieving the 100 GW nuclear mission.
Nuclear Governance Framework	▪ Establishes Atomic Energy Redressal Advisory Council to bring higher clarity in Govt. systems.	▪ Transparent regulatory environment improves investor confidence and reduces project risks & delays; key for mega-capacity targets.

Nuclear Value Chain – PSUs, Private Sector Engagement Opportunities

Role of Govt. PSUs

Pre-Project Activities
- Lead candidate site selection process
- Community engagement & land acquisition
- Water allocation & grid integration planning

Financing & Capital Investment
- Equity funding in public sector projects
- Viability gap support
- Nuclear investment fund, green financing

Plant Design & Engineering
- Technology ownership for indigenous reactors
- Engg. oversight for foreign technologies

R&D Activities
- Lead nuclear R&D programs
- Development & prototyping of BSMR technology.
- Foundation for three stage deployment

Supply Chain & Manufacturing
- Qualification & regulation of nuclear vendors.
- Expanding vendor ecosystem with investment in component manufacturing hub

Construction & Commissioning Activities
- Lead construction activities for PSU projects.
- Supervision, nuclear safety & quality compliance checks for all new builds

Role of Private Sector

Pre-Project Activities
- Participate in PFS & FS along with PSUs.
- Support in site characteristics, environmental & radio-active assessment
- Power demand assurance via PPAs

Financing & Capital Investment
- Co-investment in SPVs,
- Foreign investment under regulatory provisions
- Raising capital via green bonds,

Plant Design & Engineering
- Detailed engineering & balance-of-plant design,
- 3D/4D engineering with design modularization
- Plant design optimization & automation

R&D Activities
- Support in SMR modularization,
- Partnership in developing plant design for new technology options

Supply Chain & Manufacturing
- Expansion of nuclear-qualified private manufacturing firms,
- Support in building indigenous manufacturing facility
- Facilitating foreign technology through global supply chain

Construction & Commissioning Activities
- Lead construction activities for private sector projects under supervision of regulators & SMEs
- EPC execution, schedule optimization, cost control, project management systems

Nuclear Value Chain – PSUs, Private Sector Engagement Opportunities (Contd..)

Role of Govt. PSUs

Plant O&M and Decommissioning
- Lead O&M activities
- Control radioactive surveillance program & regulatory interface
- Developing roadmap for decommissioning activities

Fuel Cycle, HW, Waste Management
- Expansion of mineral mining & fuel fabrication/ enrichment facilities
- Development of alternate Th-based fuel cycle
- Lead in radioactive waste management

Human Resource Development
- Development of national nuclear training institutes
- Skill development & Regulatory certification programs

Risk & Liability Management
- Covering excess liability in addition to operators' liability
- Strengthening nuclear insurance pools

AI & Digital System Integration
- Mandating cyber-security standards
- Implementing digital & smart systems in nuclear fleets/ installations

Regulatory & Licensing Aspects
- Simplifying consenting & approval processes for large-scale expansion.
- Interfacing with regulators during deployment and plant operations

Role of Private Sector

Plant O&M and Decommissioning
- O&M services support, (near term) and O&M handover (long term).
- Developing optimal plant maintenance & asset management strategies.

Fuel Cycle, HW, Waste Management
- Partnership in fuel fabrication, fuel innovation and HW production
- Support in logistics
- Import from overseas countries

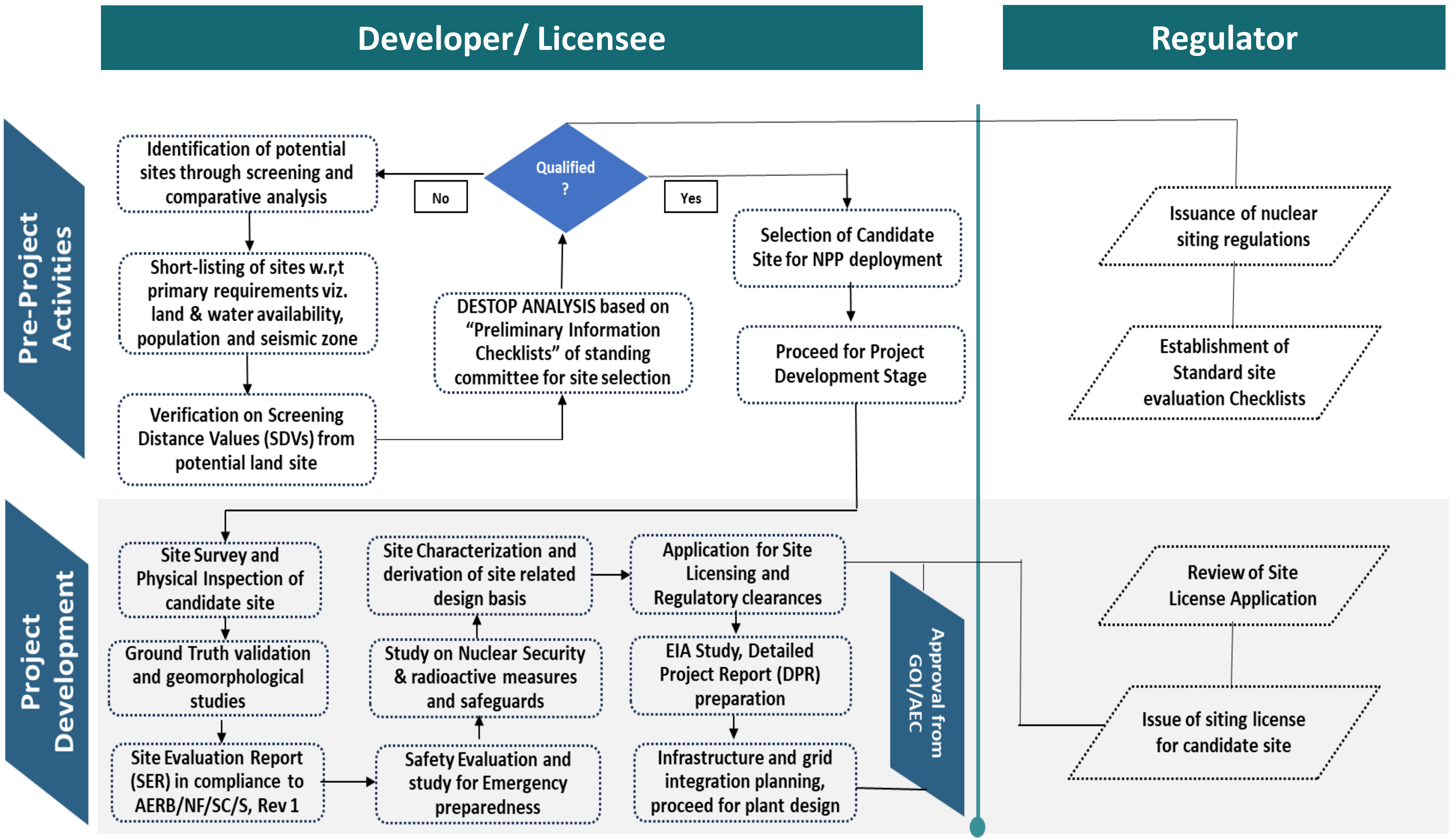
Human Resource Development
- Facilitating industry-academia collaboration to develop nuclear skilled workforce
- Partnership in certified training programs

Risk & Liability Management
- Limited liability exposure at par with global practice
- Risk sharing during project development & execution
- Managing insurance pool

AI & Digital System Integration
- Developing mechanism for AI/ML-based predictive maintenance, digital twins, advanced control systems and cyber-security solutions

Regulatory & Licensing Aspects
- Compliance with nuclear safety and regulatory standards.
- Structured interface through licensed operators
- Obtaining licenses for build, own & operate

Project Development Stage Collaboration



Strategic Steps

i. Developing core team for potential candidate site identification across country

ii. Empowering more private firms for pre-project studies and survey works

iii. Community engagement by central/ state govt. for facilitating land acquisition

iv Accelerating siting consent & licensing process

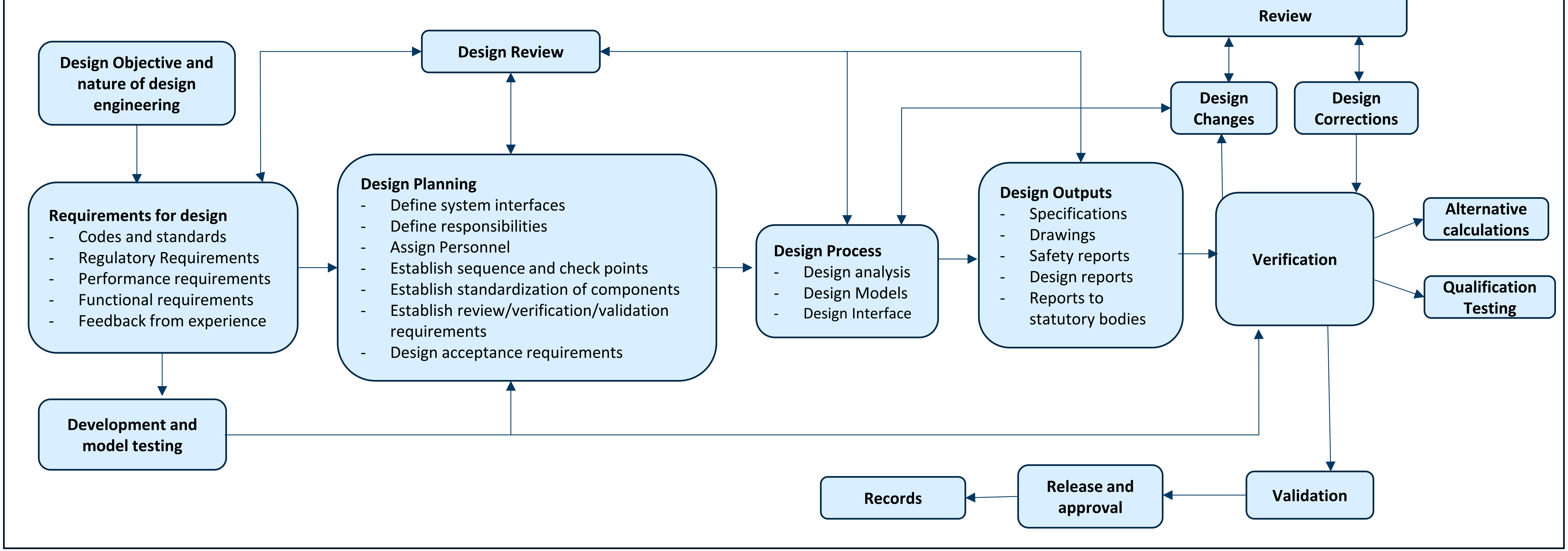
v Classify nuclear plants under "Green category" of CPCB

Strategies for Nuclear Plant Design

Strategies

- Indigenous reactor design (PHWR, BSR, BSMR) to be shared by BARC/ NPCIL
- Engagement of private firms for BSMR development and R&D activities
- Continue investment in India's Stage-3 Programme (Thorium)
- Delegation of TG & BoP island design to private developers

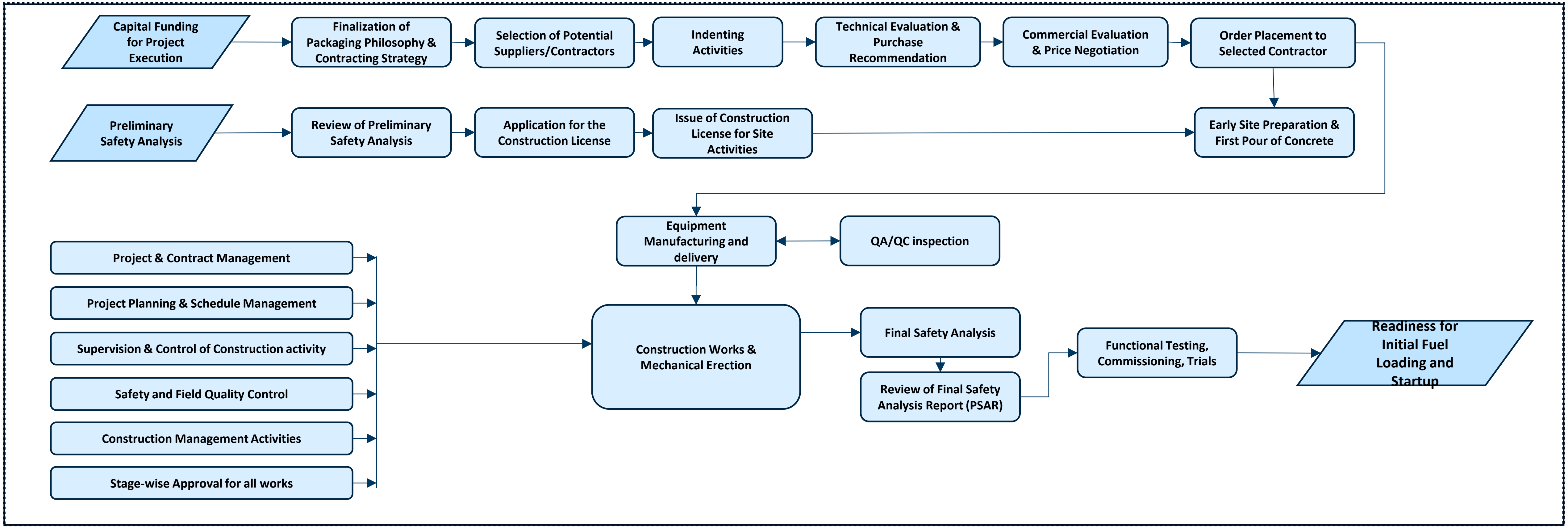
Design Stage



Strategic Approach for Contracting & Construction Phase

Strategies

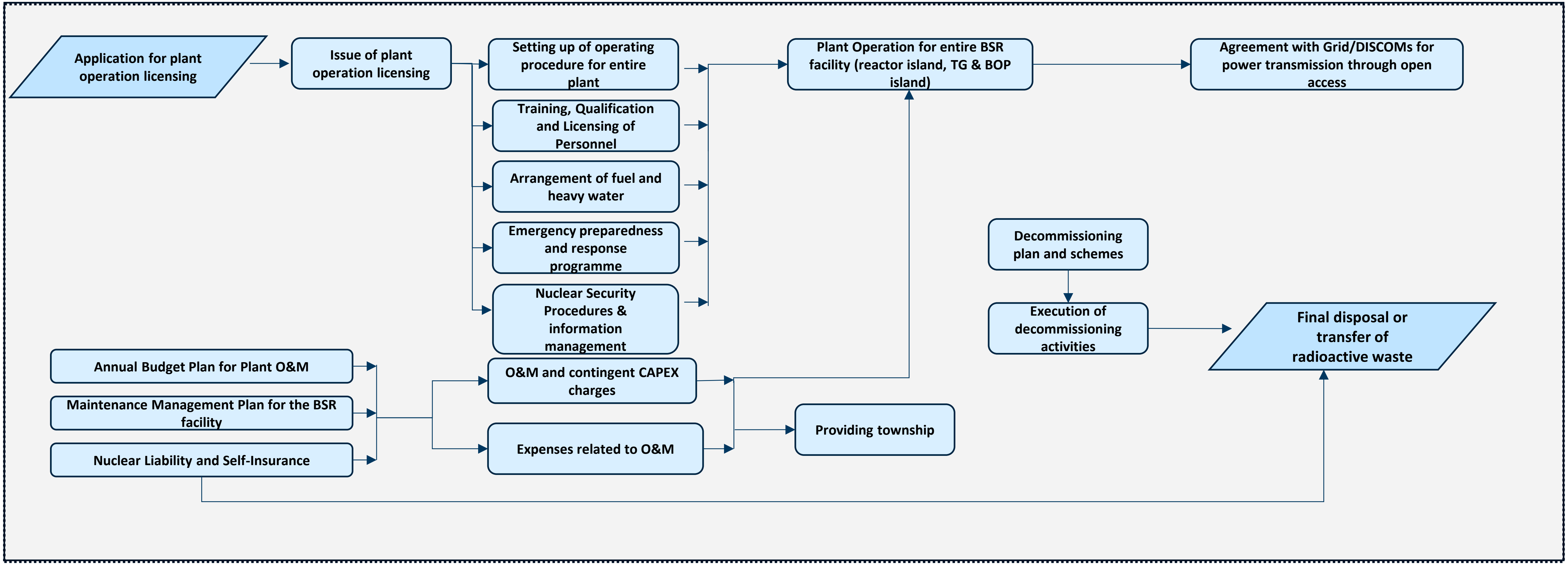
- Expanding domestic supply chain and manufacturing eco-system with necessary govt. support to both public/ private suppliers
- Developing indigenous manufacturing & delivery programs for large scale deployment of new reactor technologies
- Fleet mode implementation of nuclear plants and long-term order visibility for suppliers
- Enabling Foreign Direct Investment (FDI) in manufacturing and construction activities



Strategic Approach for Operation & Maintenance Phase

Strategies

- Establish a Clear Spent Fuel & Waste Management Framework
- Enhance Vendor Ecosystem & O&M Supply Chain
- Strengthen Human Resources, Training & Licensing
- Developing AI/ML based maintenance & asset management strategies.
- Create a Robust National Decommissioning Policy + Corpus Fund
- Ensure Fuel Security including exploration of alternative Th fuel cycle



Financing Strategy for Nuclear Power Expansion

Cost Reduction Measures

- Timely Project Completion
- GST Reduction/ Duty Exemption
- Enhance PLF to minimum 85%
- Fleet Mode Procurement
- Competitive Bidding Mechanism

Securing Affordable Financing

- Soft Loans & Clean Energy Fund
- Credit Enhancement & Overseas Bonds
- Long-term Loans (30 years)
- Allowing 49% FDI in Nuclear Sector
- Inclusion in Climate Finance Taxonomy

Non-Fossil Consumption Obligation

Long-term PPA & Green Financing

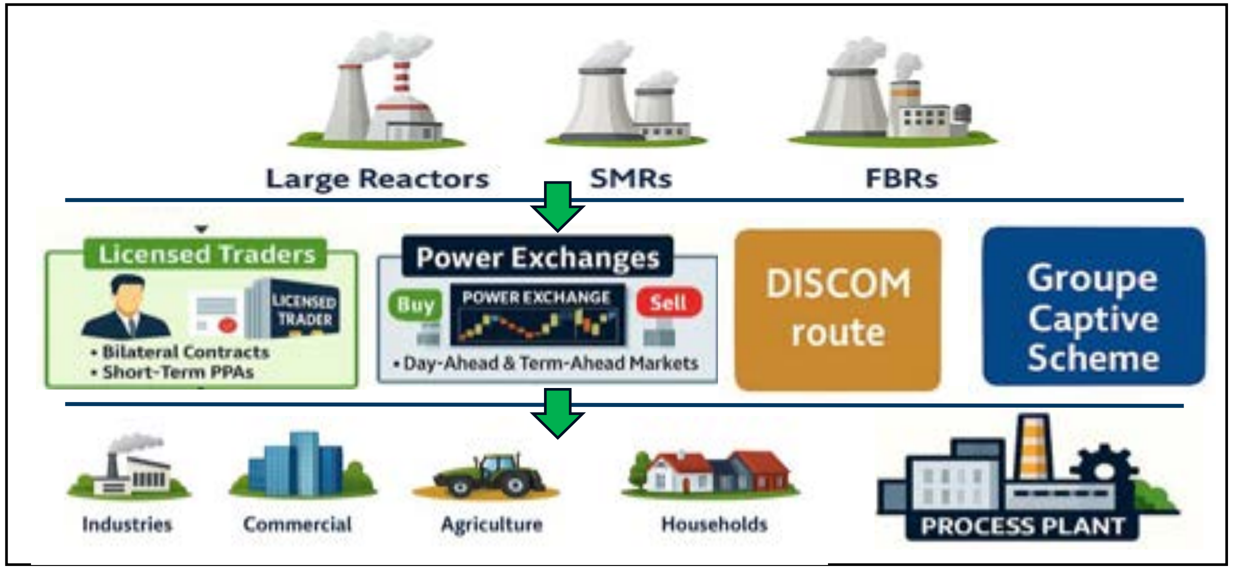
Nuclear Power – Consumer Aspects

Possible Power Purchase Mechanisms for Consumers

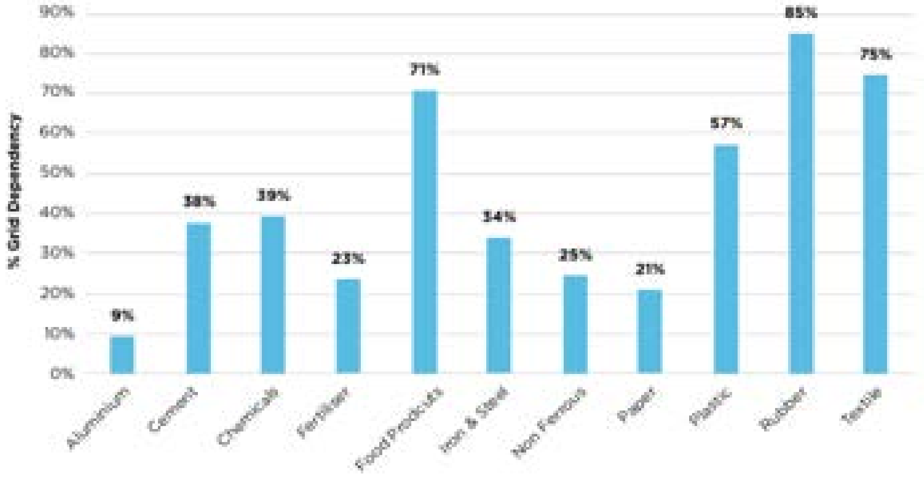
- Open Access Long Term & Medium-Term **Bilateral Agreements**
- **Group Captive Scheme** with framework under **PPP model**
- Short-Term Power Exchange route through **DAM, TAM, RTM**
- Nuclear Power purchase through **DISCOM route**
- Power purchase from GoI Licensed **Electricity Traders**
- Using **BOO, BOOT models** with the involvement of Domestic private power generation companies

Benefits

- **Reliable & Firm Power with/without dependency on Grid**
- **Relief from carbon penalties (CBAM, Carbon Tax)**
- **Replacement of coal-based captive with BSRs or SMRs**
- **Meeting ESG targets, Clean Energy obligation**



Key Sectors:
Cement, Steel, Aluminum, Fertilizers, Food products, Chemicals



% Grid Dependency for Captive Power requirement

Strategic Partnership for AI & Digital Solutions

- Understanding of client's operation KPIs
- Data collection from DCS database (physical sensors)

- Filter validated data (anomalies to be cleaned)
- Data Pre-processing

- Developing mathematic model based on technical know-how
- Algorithm based on validated data

- Implementation of the algorithm in the tool based on the practical use cases
- Pilot Deployment

- Evaluation of the preliminary outcome of the model
- Optimization of the model w.r.t result

- Fine tune the tool & re-training of the model with new learnings
- Final Deployment

Project Case Study

Key Issue: A TPP faced heat rate degradation – TCE & Technology Provider collaborated to address this issue

TCE's Role: TCE leverages its thermal plant expertise to tune base control, deploy digital APC systems for optimization

Technology Provider's Role: Smart Platform aggregates real-time data, KPIs and analytics to APC, enabling alerts and benchmarks for optimized control.

Collaborative Outcome: Lower auxiliary power consumption, improved heat rate across all load ranges (including 25% MCR), and stable, efficient operation during solar integration.

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06 Concluding Remarks

Concluding Remarks..

Project infrastructure enabler	Spearheading by PSUs in community engagement, land acquisition, water allocation, liasioning with state govt. to amend their land sub-lease policy. PSU to lead in candidate site selection, Private firms to support in feasibility assessment
Accelerated licensing processes	Accelerated regulatory clearances and safety approval process at each stage for siting, construction, operation to avoid cost & time overrun and build investor confidence. PSU to lead in regulatory interface; Private firms to obtain BOO license under new policy framework
Capital Sourcing Strategy	Sourcing options for funding (government grant, private sector, Foreign Direct Investment, bilateral funding, etc.) to be ascertained for nuclear energy sector. Equity funding by PSUs, co-investment from Private & foreign sectors.
Effective tariff mechanism	GoI/Regulatory commission to develop effective tariff mechanism with must-run status for nuclear plants, flexibility for selling surplus power, concession in interest rates & taxes, exemptions in open access charges, additional surcharges, allowing ISTS waiver, carbon credits etc.
Indigenization of the manufacturing ecosystem	1. Focus needs to be given to development of indigenous and large-scale manufacturing ecosystem and supply chain for nuclear reactor. 2. Committed focus on indigenous R&D for development of reactors suitable for Thorium – both large scale reactor and SMR. Govt bodies to lead nuclear R&D programs; Private to support in Advance technology modularization
Fuel Security and Scalability	Augmentation of heavy water & fuel processing facilities to assure fuel security and commitment on fuel price and heavy water charges. PSUs to lead the mining expansion, fuel fabrication/enrichment & development of alternate/new fuel options; Private sector to support logistics, innovation & studies for new options
Resource development	PSUs to develop National level nuclear training & skill development programs; Private sector to support industry-academia collaboration and large-scale pool of skilled resources

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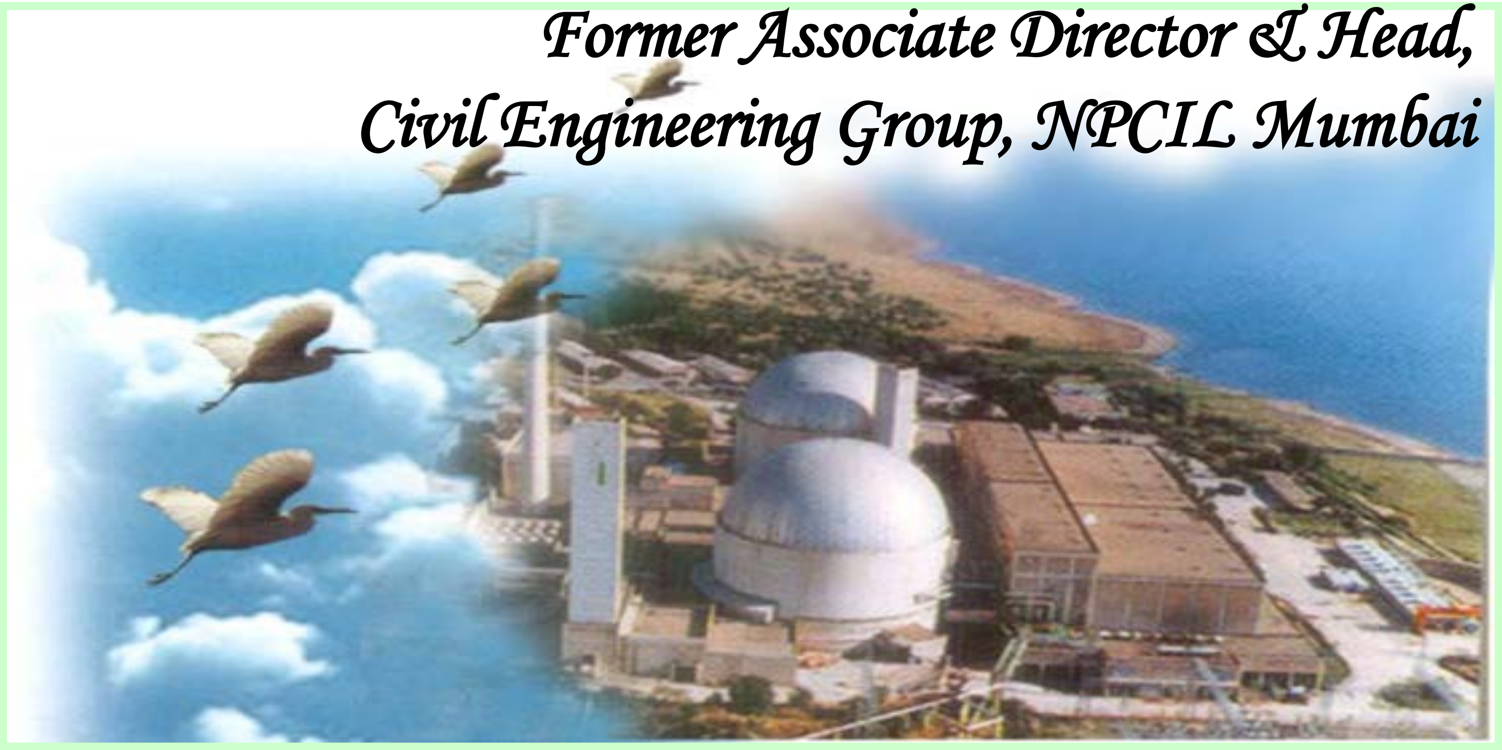
THANK YOU

LECTURE - 9 Type tex

SITING OF NUCLEAR POWER PLANT FACILITIES

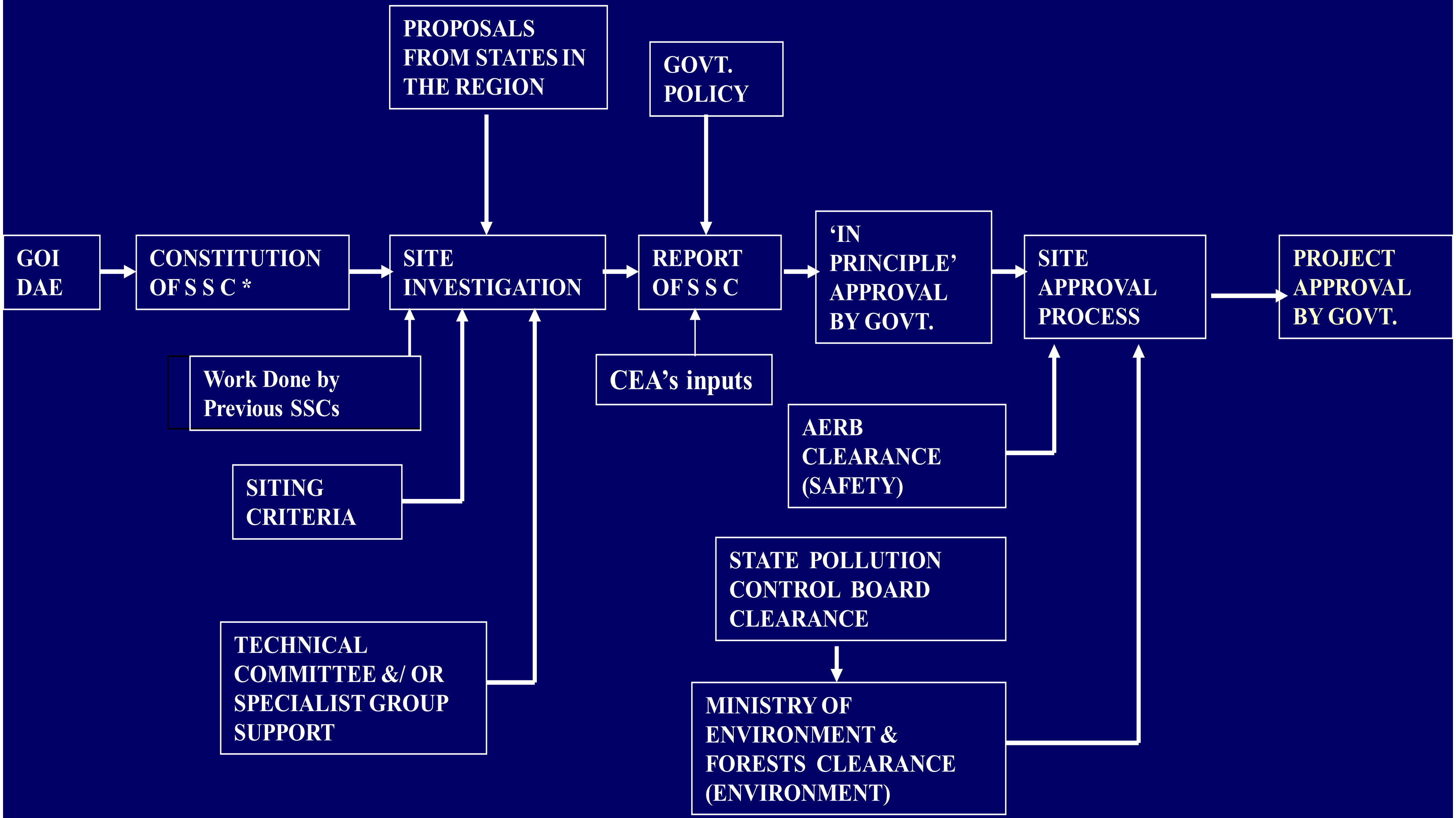
Arvind Shrivastava
Outstanding Scientist
Former Associate Director & Head,
Civil Engineering Group, NPCIL Mumbai



Stages of Site selection

- **Stage-1 – Site Selection (Identification)**
- **Stage-2 – Site Survey and Site Evaluation**

Site selection and approval of NPP Facilities



* S S C – SITE SELECTION COMMITTEEE

Site Selection Stage

- The Guidelines to be followed for empaneling a site have been defined in enclosed tables based on the following code & Guides.

AERB SAFETY CODE NO. AERB/NF/SC/S
SITE EVALUATION OF NUCLEAR FACILITIES

AERB SAFETY GUIDE NO. AERB/SG/S1 to S11

List of AERB safety guides related to siting of NPPs Safety Series

1. **AERB/SG/S-1** Atmospheric Dispersion and Modelling
2. **AERB/SG/S-2** Hydrological Dispersion of Radioactive Materials in Relation to Nuclear Power Plant Siting
3. **AERB/SG/S-3** Extreme Values of Meteorological Parameters
4. **AERB/SG/S-4** Hydrogeological Aspects of Siting of Nuclear Power Plants
5. **AERB/SG/S-5** Models for Radioactive Dose Computation Methodologies from Radioactivity Concentrations in Environment
6. **AERB/SG/S-6A** Design Basis Floods for Nuclear Power Plants on Inland Sites
7. **AERB/SG/S-6B** Design Basis Floods for Nuclear Power Plants at Coastal Sites
8. **AERB/SG/S-7** Man-Induced Events and Establishment of Design Basis Events (Draft)
9. **AERB/SG/S-8** Influence of Site Parameters on Emergency Preparedness
10. **AERB/SG/S-9** Population Distribution and its Analysis in Relation to Siting of Nuclear Power Plants
11. **AERB/SG/S-10** Quality Assurance in Siting
12. **AERB/SG/S-11** Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites

Brief outlines of screening criteria are summarized below:

SR.NO.	CRITERIA	ESSENTIAL REQUIREMENTS	DESIRABLE REQUIREMENTS	REMARKS
1	Seismicity	Site falling in seismic zones II to IV (IS 1893)		
2	Distance from capable fault	more than 5 km		
3	Distance from small air field	more than 5 km		
4	Distance from major air field	more than 8 km		
5	Distance from military air field	more than 15 km		

SR.NO.	CRITERIA	ESSENTIAL REQUIREMENTS	DESIRABLE REQUIREMENTS	REMARK
6	Distance from facilities storing involving handling inflammable, toxic corrosive or explosive material and mining activities from site		More than 5 kms	
7	Distance from military installations storing ammuniations, etc.	more than 10 km		

SR.NO.	CRITERIA	ESSENTIAL REQUIREMENTS	DESIRABLE REQUIREMENTS	REMARK
8	Grade level above astronomical tide level	4 m	6.5 m	
9	Population Density		Less than 2/3 of state average	
10	Population within 5 km radius		Less than 20, 000	
11	Population centre > 10,000		more than 10 km	
12	Population centre > 1,00,000		more than 30 km	

SR.NO.	CRITERIA	ESSENTIAL REQUIREMENTS	DESIRABLE REQUIREMENTS	REMARK
13	Places of Architectural/Historical monuments & tourist centres	more than 5 km		
14	Flooding of site	Site Grade Level to be at least equal to Safe Grade Elevation		Safe grade elevation to be evaluated for flooding due to combination of highest high tide plus storm surge / Tsunami which ever is more plus wave run up.

SR.NO.	CRITERIA	ESSENTIAL REQUIREMENTS	DESIRABLE REQUIREMENTS	REMARK
15	Fresh Water requirement			The quantity that can be spared from existing sources may be indicated
	Construction stage	100 cu.m per hour		
	(Coastal) Operation Stage (4X1000 MWe) Plant Township Total	15000 cu.m per day 1000 cu.m per day 16000 cu.m per day		
	(Inland) Operation Stage with NDCTs(2x1000 MWe)	24000 cum per hour		

SR.NO.	CRITERIA	ESSENTIAL REQUIREMENTS	DESIRABLE REQUIREMENTS	REMARK
16	Sea Water for cooling per 1000 Mwe unit	3,00,000 cu.m per hour		
17	Power requirement i) construction power ii) Start up power		Min 10 MVA Min 80 MVA from two independent sources.	
18	Land Requirement i) Plant site ii) Township		About 1000 Ha for 6 units, 840 Ha for 4 units About 300 Ha	

SR.NO.	CRITERIA	ESSENTIAL REQUIREMENTS	DESIRABLE REQUIREMENTS	REMARK
19	Power Evacuation			Feasibility for smooth power evacuation of about 6000 MWe.
20	Over Dimensional Consignment (ODC) movement		Wide road and nearby Port facilities	

* Capable fault is one which has significant potential for relative displacement at or near the ground surface.

Note :
These are only brief initial screening criteria. Acceptability of a site will be based on detailed evaluation.

➢ *What is Site?*

For nuclear power plants, the ‘site’ is defined as an area surrounding the plant, defined by a boundary and under effective control of the plant management.

➢ *What is Siting?*

Siting is the process of selecting a suitable site for a facility, including appropriate assessment and derivation of the related design bases.

Siting process involves two basic stages – site survey and site evaluation.

➢ *Site Survey*

Activities during site survey stage are

- Identification of prospective locations
- Collection of information/data related to factors affecting site selection
- Conducting preliminary investigations.

➢ *Site Evaluation*

Site evaluation involves

- ❖ Demonstration of acceptability of the site on the basis of established criteria for selection of NPP sites.
- ❖ Derivation of site related design basis.

Site evaluation is continued till the end of operating life of the plant to ensure safety against hazards associated with events of origin external to the plant operation, called external events.

This is important due to changing perception of the hazard from external events as well as changing natural and/or human made environment in the site region over a period of time.

➢ *Various Stages During the Lifetime of Nuclear Facility*

- Siting
- Design and construction
- Commissioning
- Operation
- Decommissioning

Objectives of Site Selection

➢ *Objectives in Siting NPP*

The main objective in siting nuclear power plants from the point of view of nuclear safety is

"to be able to construct and operate nuclear power plants safely and to provide protection of the public against radiological impact"

The basic criteria for selection of a site for the location of a nuclear power plant is to ensure that the site-plant interaction will not introduce any radiological risk or others of an unacceptable magnitude.

➢ *Objectives in Siting NPP*

This is achieved by ensuring:

- ❖ The radiological risk to the nuclear power plant due to external events should not exceed the range of radiological risk associated with accidents of internal origin.
- ❖ The possible radiological impact of a nuclear power plant on the environment should be acceptably low for normal operation and accident conditions and within the stipulated criteria for radio-logical safety.

Safety Aspects and Factors Governing Site Selection

➢ *Safety During Site Selection of NPP*

Safety of the plant personnel, public and the environment from radiological hazard is one of the most important considerations for siting of nuclear power plants

Like any other facilities, nuclear power plants are designed to withstand the forces due to hazards from external events caused by natural phenomena like earthquake, wind etc.

The magnitude of such force in case of NPP is derived based on a more stringent criteria compared to other conventional facilities and is termed as design basis.

➢ *Aspects Governing Site Selection*

In evaluating the suitability of a site for locating a nuclear power plant, the following major aspects are considered:

- Effect of external events (natural and man-induced) on the plant.
- Effect of plant on environment and population.
- Implementation of emergency procedures particularly protective counter-measures in the public domain.
- Effect of other facilities on site

➢ *Factors Affecting Site Selection of NPP*

Important factors affecting selection of site for major industrial installations, including nuclear power plants (NPPs) are

- Infrastructure
- Economics
- Sociological aspects
- General safety in terms of its impact on the public and environment, technical feasibility
- Engineerability.

Criteria for Site Selection of Nuclear Power Plant

➢ *Criteria for NPP Siting*

- ❖Site Specific Criteria
- ❖General Design Criteria
- ❖Design Basis for External Natural Events
- ❖Design Basis for External Man-Induced Events
- ❖Radiological Impact on the Environment
- ❖Population Considerations and Emergency Measures

➢ *Site Specific Criteria*

- ❖ Site Specific Criteria that may affect the safety of NPP are investigated and assessed
- ❖ Frequency and severity of external events and phenomenon, natural and man-made are examined
- ❖ Events having a very low probability of occurrence are not required to be considered.
- ❖ A probability value of 10^{-7} per year is considered low for this purpose

Site Specific Criteria (Contd..)

- Proposed sites for nuclear power plants are examined with respect to the frequency and the severity of external events and phenomena, natural and man-induced that could affect the safety of the plant
- The design basis external events are determined for the combination of the proposed site and nuclear power plant.
- All those events, with which significant radiological risk may be associated, are selected for consideration and their design bases determined.

➢ *General Design Criteria*

- ❖For external events the design basis parameters should be such as to ensure that SSCs important to safety will maintain their integrity and will not suffer loss of function during or after the design basis event

- ❖If, after thorough evaluation, no engineering solution can be found to provide adequate protection against design basis external events, the site shall be deemed unsuitable for the location of the NPP of the type and size proposed.

General Design Criteria (Contd..)

- For each proposed site the potential radiological impact on people in the region during operational states and accident conditions shall be assessed.

- In assessing the suitability of the site, consideration shall be given to safety aspects of storage and transportation of new and spent fuel and radioactive wastes. Possible radiological consequences in the event of locating a reprocessing plant for the spent fuel with associated waste treatment facility should also be considered

➢ *General Design Criteria (Contd..)*

❖ A site is re-evaluated in the following cases:

✓ If the total nuclear power is increased to a value greater than what was previously specified.

✓ If there are any expansion activities around the site in the future that may have a radiological impact on the site.

❖ Suitability for implementing emergency measures effectively in case of an accident are determined

➢ *Design bases for External Natural Events*

- ❖Natural phenomena are identified and are classified as per their importance.
- ❖Historical records of the occurrences and severity of the important natural phenomena are collected for the region. The data are carefully analyzed for reliability, accuracy and completeness
- ❖If data for a particular type of natural phenomenon are incomplete for a particular region, then data from other regions which are sufficiently similar to the region of interest may be used in the formulation of the design basis event.

➢ *Design Basis for External Man-Induced Events*

- ❖ Proposed sites is adequately investigated with respect to all the design basis man-induced events that could affect the plant safety.
- ❖ The site is examined for facilities and human activities that may affect the safety of the NPP.
- ❖ Information concerning the frequency and severity of those important man-induced events are collected and analyzed for reliability, accuracy and completeness.
- ❖ For most of the criteria, **Screening Distance Values (SDVs)** considering both probability of occurrence of the concerned event and the impact on plant safety are evaluated.

➢ *Radiological Impact on the Environment*

- Impact on the environment arising out of the operation of the NPP should be as low as reasonably achievable (ALARA) for normal operation and postulated accident conditions
- The direct and indirect pathways by which radioactive materials released from the nuclear power plant could reach and affect people, shall be identified for use in the estimation of the radiological impact.

Population Considerations and Emergency Measures

- Radiological impact on the critical group as well as to the public as a whole due to the operation of nuclear power plant are considered and evaluated.
- Effective implementation of emergency measures in case of an accident
- Population characteristics and its distribution in the region studies
- Data on permanent residents, transient and seasonal population, present and future uses of land and water resources, cattle and livestock, agricultural produce, fish catches on annual basis collected

Effect of Site Characteristics on NPP

➢ *Site Characteristics: Natural*

- ❖Seismological and Geological Considerations
- ❖Geotechnical: Soil Liquefaction
- ❖Slope Instability
- ❖Site Surface Collapse, Subsidence or Uplift
- ❖Hydrological-Flooding at site: Internal and External Origin
- ❖Extreme Meteorological Events: Wind, Shoreline erosion

➢ *Site Characteristics: Man-made*

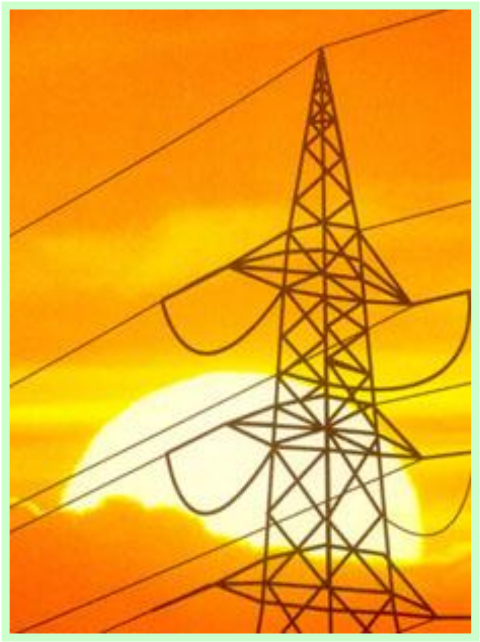
- Aircraft crash
- Chemical explosions and Toxin Gas Releases
- Oil Slick
- Blasting Operation
- Mining, Drilling and Water Extraction
- Extreme Meteorological Events: Wind, Shoreline erosion

Other Characteristics

- Regional Energy Sources and Demand
- Power Evacuation and its stability
- Manpower, material, Roads and railways
- Transportation for ODC
- Foundation Considerations
- Thermal and Chemical Pollution
- Extreme Meteorological Events: Wind, Shoreline erosion

➢ *Other Characteristics*

- ❖ Land Availability
- ❖ Water Availability
- ❖ Construction power

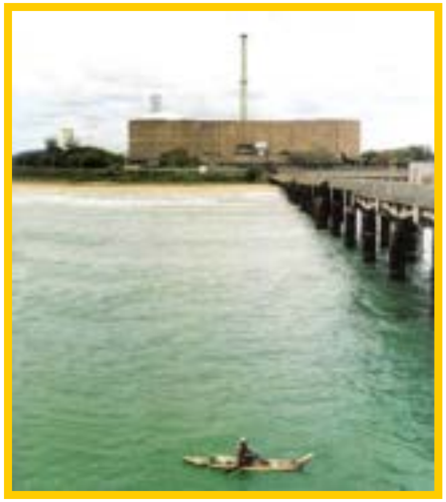


Effect of NPP on Site

➢ *Site Characteristics: Natural*

- ❖ Dispersion through air
- ❖ Dispersion through surface water
- ❖ Dispersion through sub-surface water
- ❖ Population Distribution
- ❖ Land and Water use
- ❖ Considerations for Emergency Planning

Desirable Characteristics for Locating NPP



Criteria for NPP Siting

- Rejection Criteria

  -Engineering measures not possible for site qualification

- Mandatory Criteria

  -Engineering measures possible for site qualification

- Desirable Criteria

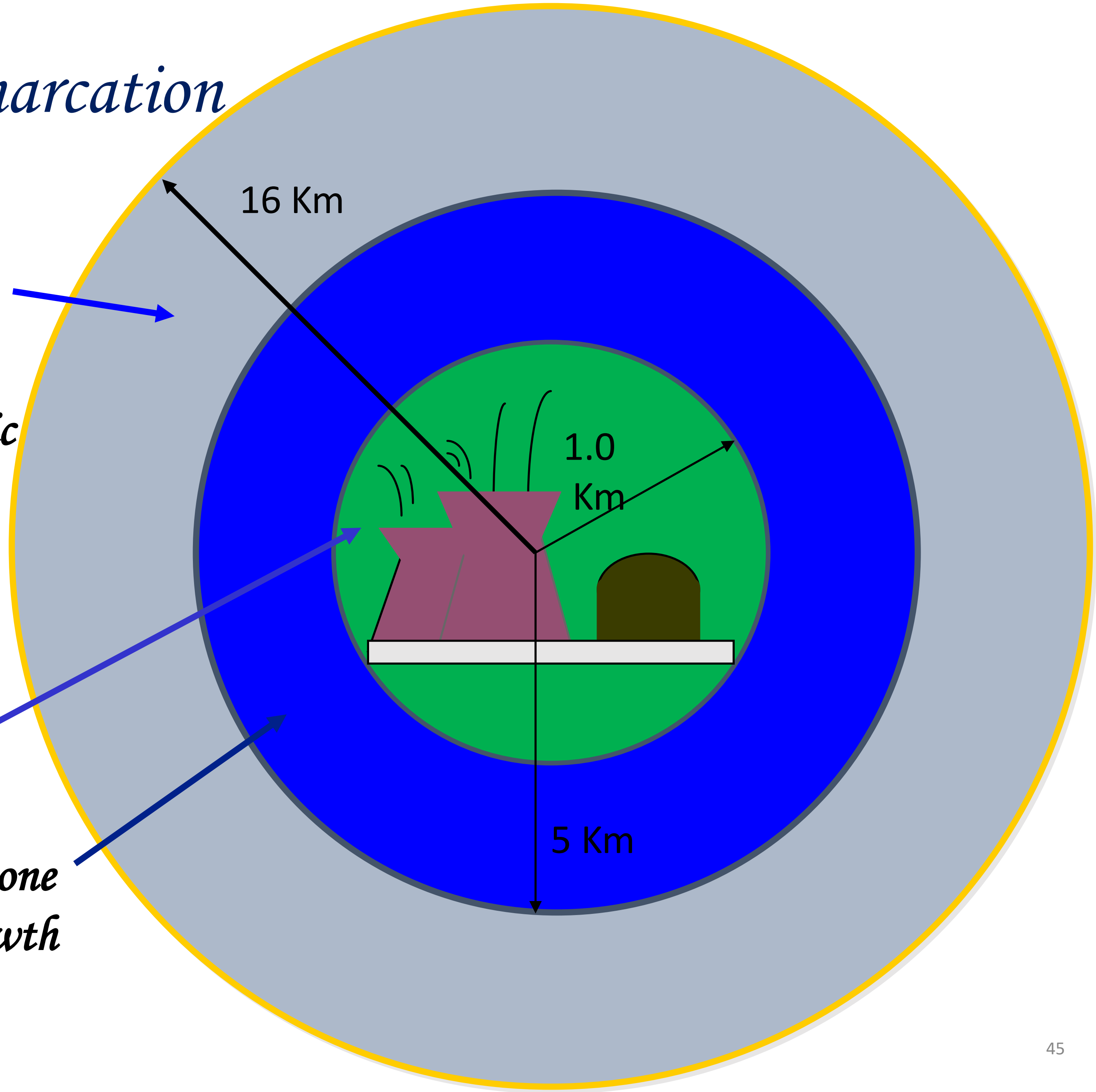
  -Economy. Site selection may or may not depend upon it

➢ *Desirable Characteristics*

Sr. No.	Characteristics	Desirability
1	Land Area	• Exclusion zone (1.6 Km R) & Sterilized zone(5 Km R) • Land availability for 2000 MWe potential - 200 Ha for locating plant structures - Total 650 to 1050 Ha depending on site features (Including Exclusion zone & plant area) • Barren land without much cultivation • No forest land • Grade level above design flood level • At least five kilometer away from storing inflammables, toxic, corrosive or explosive material • Away from international borders • Availability of more than two evacuation routes • In sterilized zone natural growth of population is permitted and is under administrative control

➢ *Site Demarcation*

Emergency Planning Zone (EPZ)
Action Plans drawn for Public



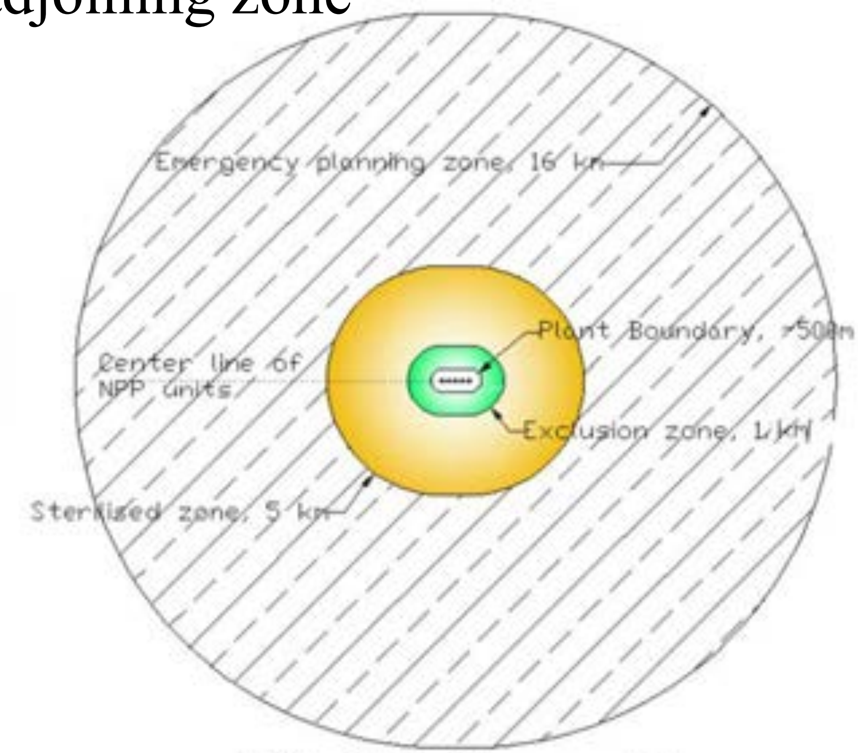
Exclusion zone (1.0 Km radius
No habitation

Sterilization zone
Regulated growth

Indian Practice of NPPs Siting

General Criteria for Site Evaluation of Nuclear Facilities: Site and adjoining zone

Different zones for NPP



Radiological Surveillance zone = 30 Km

➢ *Desirable Characteristics*

Sr. No.	Characteristics	Desirability
2	Water for Condenser cooling and other use	• Cooling water (2000 MWe potential) - **Inland sites(fresh water)** i) Once through : 400,000 m^3/ hr or ii) Cooling Towers : 24,000 m^3/hr (Make-up) Consumptive : 12,000 m^3/hr - **Coastal sites (Sea water)** i) Once through : 400,000 m^3/hr • Should not have much of turbidity and carbonates • Fresh Water for Plant : 1000 m^3/hr • Fresh Water for Township: 500 m^3/hr

➢ *Desirable Characteristics*

Sr. No.	Characteristics	Desirability
3	Environmental	• Avoid Forest land, sanctuaries •Water pollution as per guidelines of Pollution Control Board •Thermal pollution as per mandatory guidelines of Ministry • Radioactive effluent discharge within ICRP limits
4	Electrical System	• Nearby availability of start-up power • Proximity of load centers for economics of power transmission •Appropriate power demand for life of the plant
5	Meteorology	•Atmospheric dispersion should be good •Atmospheric inversion should not be there •Avoid areas prone to cyclones, hurricanes •Preferable to have not much variation in temperature •Preferable to have as less population and population centers in predominant wind direction

➢ *Desirable Characteristics*

Sr. No.	Characteristics	Desirability
6	Population	• The population of the district shall be 2/3rd of State Average Population •As little as possible population in the exclusion zone •No population centers with population > 10,000 in 5 Km radius •No population centers with population > 1,00,000 in 30 Km radius •Total population in the sterilized zone < 20,000
7	Land Use	•Not much cultivation in the land within 10 Km •No reserved forest
8	Water use	•Avoid areas with large fishing activity •Avoid areas with ground water substantially •Avoid areas having shallow water table

➢ *Desirable Characteristics*

Sr. No.	Characteristics	Desirability
9	Subsoil Condition	• Preferable to have rock foundation •Avoid areas prone to liquefaction, surface collapse, subsidence or uplift
10	Seismic	•Site should be in Zone-IV or below •Detailed seismotectonic and seismological studies in 300 Km radius area •Detailed study to determine the values of OBE and SSE
11	Flood Analysis	•For coastal site, astronomical high tide level, wave surge-up, wave run-up and tsunami considered •For inland site, maximum water level due to precipitation and Dam Break considered •Provisions to avoid flooding at site. Site Safe Grade Level Based on the flood analysis

➢ *Desirable Characteristics*

Sr. No.	Characteristics	Desirability
12	Solid Waste Management	•Areas preferred with rocky strata •Deep ground Water Table •Minimum irrigation around site
13	Radiological Burden	•Radiological burden on the atmosphere due to all associated facilities to be within ICRP limits
14	Access	•Site to be accessible by roads and railways •Transportation by ODC •Two independent emergency evacuation routes

Acceptance/Rejection Criteria During Preliminary Site Investigation Stage

Siting Requirements

Sr. No.	Criteria	Rejection Standard	Desirable Parameters	Remarks
1	Seismicity	Sites falling beyond zone IV according to IS Classification (IS-1893: 1984)		Sites falling in Zones I to IV to be evaluated in detail.
2.	Distance from capable fault	Less than 5 km.		Detailed evaluation should be carried out for identifying the fault.
3	Distance from small airfields	Less than 5 km.		
4	Distance from major airports	Less than 8 km.		
5	Distance from military airfields	Less than 15 km.		

➢ *Siting Requirements*

Sr. No.	Criteria	Rejection Standard	Desirable Parameters	Remarks
6	Distance from facilities involving storing handling inflammable, toxic, corrosive or explosive material and any mining activities.		More than 5 km.	Detailed analysis shall be carried out regarding the impact of toxic and hazardous gas released under all postulated conditions. Site shall be deemed as rejected if safety is not established after such analysis.
7	Distance from military installations storing ammunitions	Less than 10 km.		

➢ *Siting Requirements*

Sr. No.	Criteria	Rejection Standard	Desirable Parameters	Remarks
8	Ground water depth			Perferable to have max. water depth more than 2m. from grade level.
9	Grade elevation above Astronomical Tide level.	Less than 4.0 m (eastern coast) Less than 3.0 m (western coast)		A detailed evaluation at design stage shall be carried out to arrive at the still water level.
10	Terrian		Reasonably flat upto 20km.	Valleys with hills on either side at distances 20 times the ridge height are accept-able. Bowl like structures need analysis at design stage on a case by case basis.

➢ *Siting Requirements*

Sr. No.	Criteria	Rejection Standard	Desirable Parameters	Remarks
11	Population density within 10 km radius		Less than two-third of state average	These are desirable for plain terrain
12	Population within sterilized zone (5Km radius)		Less than 20000	These are desirable for plain terrain.

In complex terrain expert judgment shall be made based on topography and meteorology. Site shall be considered as acceptable if implementation of emergency measures under accident conditions can be ensured for the entire population. Offsite emergency response plan prepared by the Applicant should demonstrate adequate capability to handle such situations.

➢ *Siting Requirements*

Sr. No.	Criteria	Rejection Standard	Desirable Parameters	Remarks
13	Distance of population centers (> 1000 person)		More than 10 km	
14	Distance of large population centers (>1,00,000 person)		More than 30 km.	
15	Distance of places of architectural/ historical monu- ents, piligrimage, tourists interest			Preferably more than 20 km.

Rejection Criteria

➢ *Rejection Criteria*

- Site in Zone V & VI
- Site having liquefaction potential
- Fault (Active and Capable) < 5Km
- Site prone to ground movement, subsidence, slope instability
- Formation of sand dunes

➢ *Rejection Criteria*

- ❖Small Airport (f<20,000/year) < 5Km
- ❖Major Airport (f>20,000/year) <8 Km
- ❖Military Airfield <10 Km
- ❖Military Ammunition Depot < 10 Km
- ❖Mining and Blasting Activities < 5 Km
- ❖Grade Elevation above Astronomical Tide Level <4m (Eastern Coast) and <3m (Western Coast)

Challenges & way forward

- Land acquisition, Rehabilitation and Resettlement
- Physical accessibility to new sites for conducting site specific investigations.
- Collection of adequate relevant meteorological data at new sites for carrying out Extreme Value Analysis.
- Limited number of expert agencies available for conducting specialised investigations for multiple sites in a short span of time

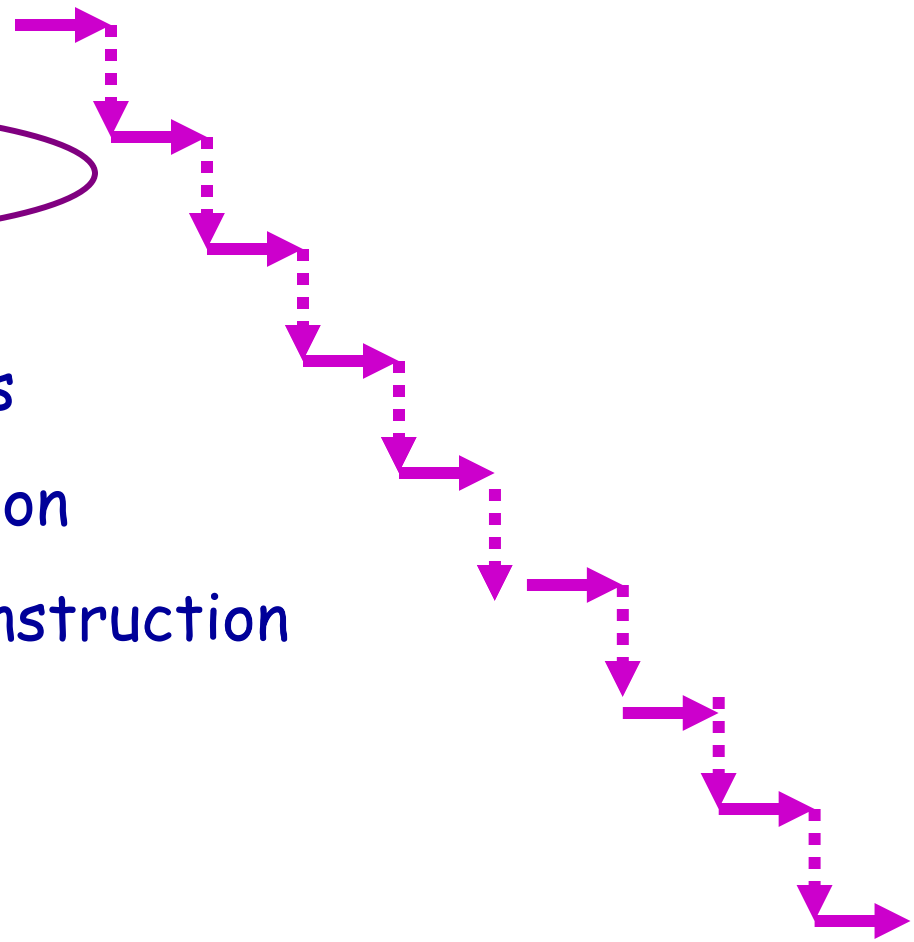
➢ *Siting: Acts and Agencies*

- Atomic Energy Act 1962(AE Act)-For Handling Radioactive Material
- Central Electricity Authority (CEA)
- Water Act 1962-For use of water
- Explosive Act-For excavation of site & use of oil etc.
- Fisheries & Agriculture Department-Discharge into river etc.
- Pollution Control Board-for sewage from plant & colony
- Air Act 1981- Ministry of Environment & Forest
- Wild Life Protection Act- Ministry of Environment & Forest
- Forest Conservation Act 1986- Ministry of Environment & Forest

Thank You for Your Attention

➢ *Different Phases of Nuclear Power Plant*

1. Site Survey
2. Site Selection
3. Siting consent
4. Cost estimates
5. Project Sanction
6. Design and Construction
7. Commissioning
8. Operation
9. Decommissioning



Small Modular Reactors (SMR)

- SMRs are defined as small nuclear reactors with a maximum output of 300 Megawatt electric (MWe) and can produce 7.2 million kWh per day.
- They are factory-assembled, compact, and designed for scalability, allowing multiple modules to be linked.
- SMRs offer lower initial capital investment, faster deployment, and enhanced safety, making them ideal for replacing old coal plants

Topic Given: Regulatory Framework and Safety of NPPs

My presentation order: Safety and Regulatory Framework of NPPs

Dinesh Kumar Shukla

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OUTLINE

- Indian Nuclear programme
  - Vision and arrangement for Human Resource Development
  - Vision of Nuclear Safety Regulation
- Safety Outlook of NPPs: Typicality
- Understanding of Regulation: Control+ Safety Regulation
  - Existing Legal Framework for Regulation (Control and Safety)
- SHANTI Act-2025 in context of this presentation
- Knowledge to Rule: Cycle and Balance : Approach to Safety Regulation
- Regulatory Framework (Safety) and its Implementation
- To Sum Up…

INDIAN NUCLEAR PROGRAMME – LARGELY HOME-GROWN

Technology deployment and capacity expansion - strong backing of long term R&D Programme

National Strength
Self Reliance

Department of Atomic Energy

R&D Centres & Aided Institutions

- Thermal Reactor Technology
- Fast Reactor Technology
- Advanced Technologies
- Atomic Minerals

PSUs

- NPCIL
- BHAVINI
- UCIL
- ECIL
- IREL (India) Ltd.

Industrial Org

- Fuel production
- D_2O production
- Fuel Reprocessing
- Isotope production

Service Organizations

Human resource development & knowledge management

Other Industrial Infrastructure support

Industries in Public and Private sector

Vision and arrangement for HUMAN RESOURCE DEVELOPMENT

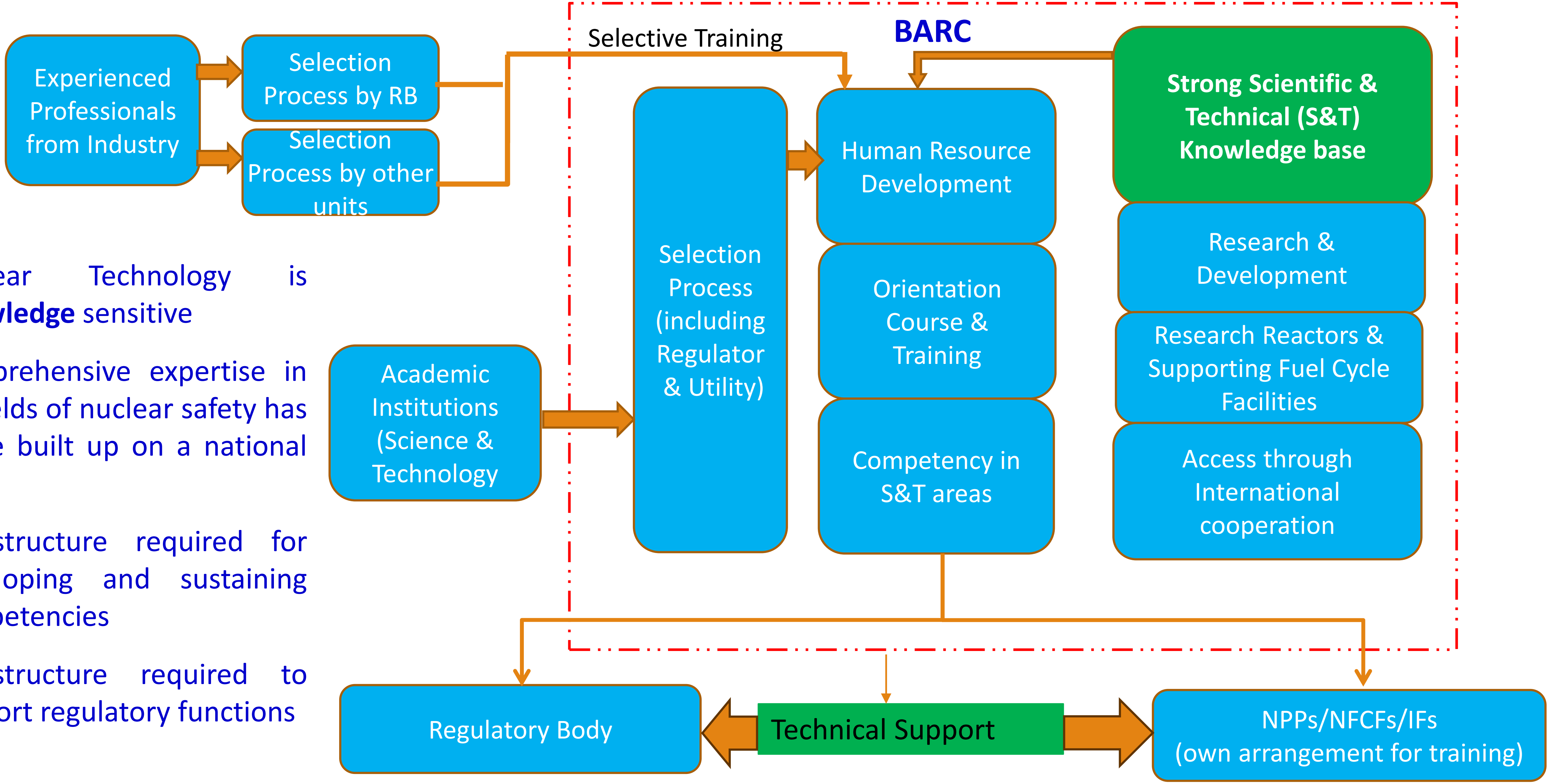
"When Nuclear Energy has been successfully applied for power production in, say a couple of decades from now, India will not have to look abroad for its experts but will find them ready at hand" - Homi J. Bhabha, 1944

Actions:

- **Training Centres** – First Training School in 1957, expanded later progressively (IGCAR, NFC; RRCAT)
- **Nuclear Training Centres at NPCIL sites:** Rawatbhata, Kaiga, Tarapur, Kudankulam , Kalpakkam, Kakrapar, Narora
- **Year 2005-Homi Bhabha National Institute (HBNI)** - To
  - nurture in-depth capabilities in nuclear science and engineering
  - conduct Master's and Ph.D. degrees programmes in Engineering & Science:
  - be a catalyst to accelerate the pace of basic research and facilitate its translation into technology development and applications

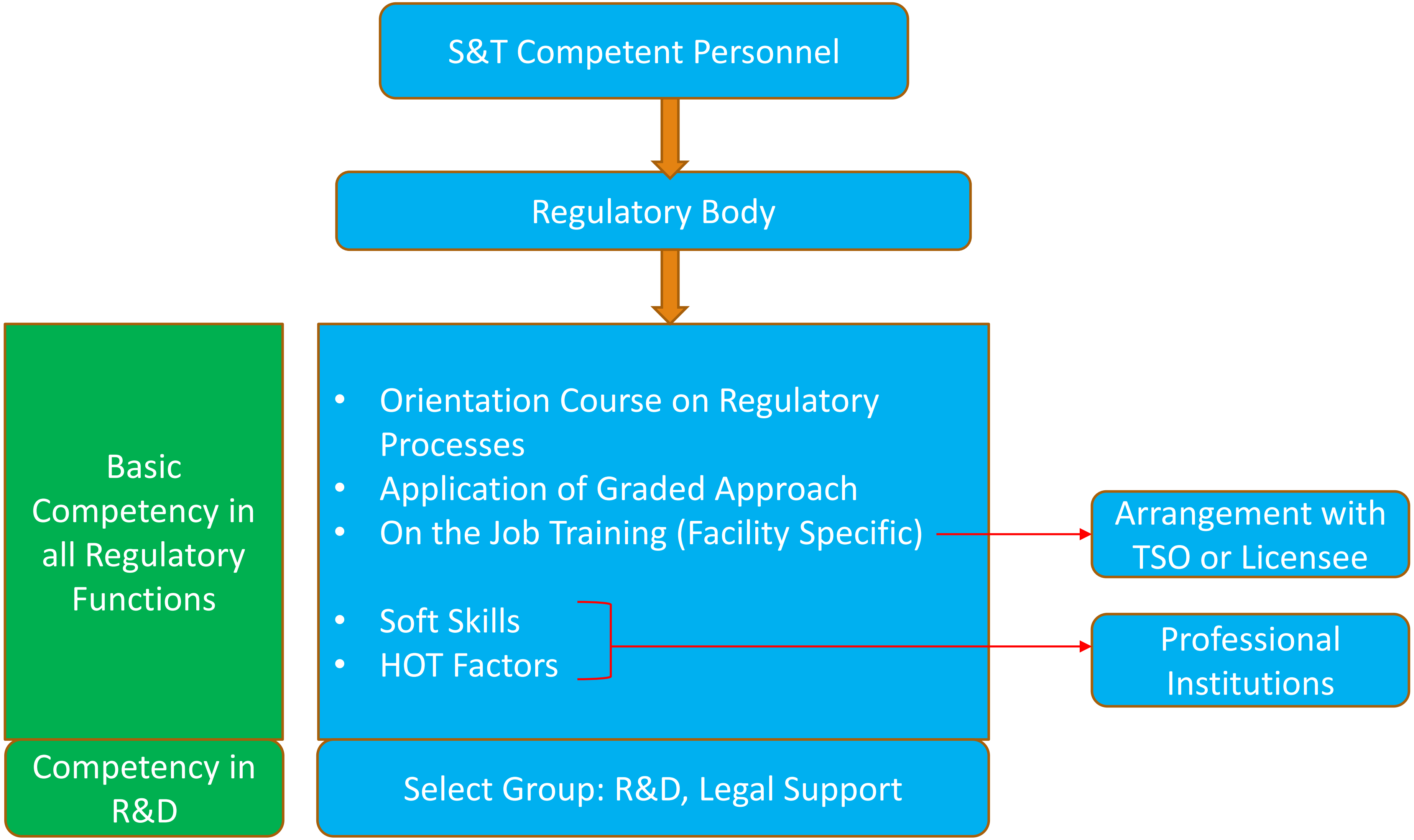
With opening of Nuclear sector : This is the most important aspect
-special focus on health physics experts

National Nuclear Knowledge Management (1/2)



- Nuclear Technology is **knowledge** sensitive
- Comprehensive expertise in all fields of nuclear safety has to be built up on a national level
- Infrastructure required for developing and sustaining competencies
- Infrastructure required to support regulatory functions

National Nuclear Knowledge Management: To AERB (2/2)



VISION OF NUCLEAR SAFETY REGULATION

"Radioactive material and sources of radiation should be handled in Atomic Energy Establishment, in a manner, which not only ensures that no harm can come to workers in the Establishment or anyone else, but also in an exemplary manner so as to set a standard which other organization in the country may be asked to emulate".

- H.J. Bhabha; Directive issued 27 Feb, 1960

Initial Phase: RRs, TAPS 1-2, RAPS-1/2, MAPS 1-2: Emphasis on Self Regulation

Expanding Phase: Functional Separation: 1983: Atomic Energy Regulatory Board established as National Nuclear Safety Regulator

-Concurrent development of regulation with technology : Practical

-Influence of Technology (PHWR) and the regulated single Entity (NPCIL)

SAFETY OUTLOOK OF NPPS: TYPICALITY

- Nuclear Industry ; Event somewhere, Impact everywhere
- Production and safety performance: Key to public confidence

Therefore, cautious approach in realizing quality in all phases of NPPs: Stringent regulatory requirements and oversight

Siting

Design-Manufacturing

Construction

Commissioning

Operation

Decommissioning

STRONG DESIGN & MANUFACTURING / CONSTRUCTION SAFETY

How Different are Nuclear Grade Components?

- **Design** as per Highest Standards;
- High level **Manufacturing / Construction** Control;

- Principle of **Defense in Depth**
- Good Design Consideration
  - Single Failure – **Redundancy**
  - Common Cause Failure – **Diversity**
  - **Fail Safe** – Assured safety even in failed state

- Fundamental safety functions
  - Control of reactivity;
  - Removal of heat;
  - Confinement of radioactive materials;

Stringent Quality Assurance in Design, Manufacturing / Construction is essential for Safety Assurance;

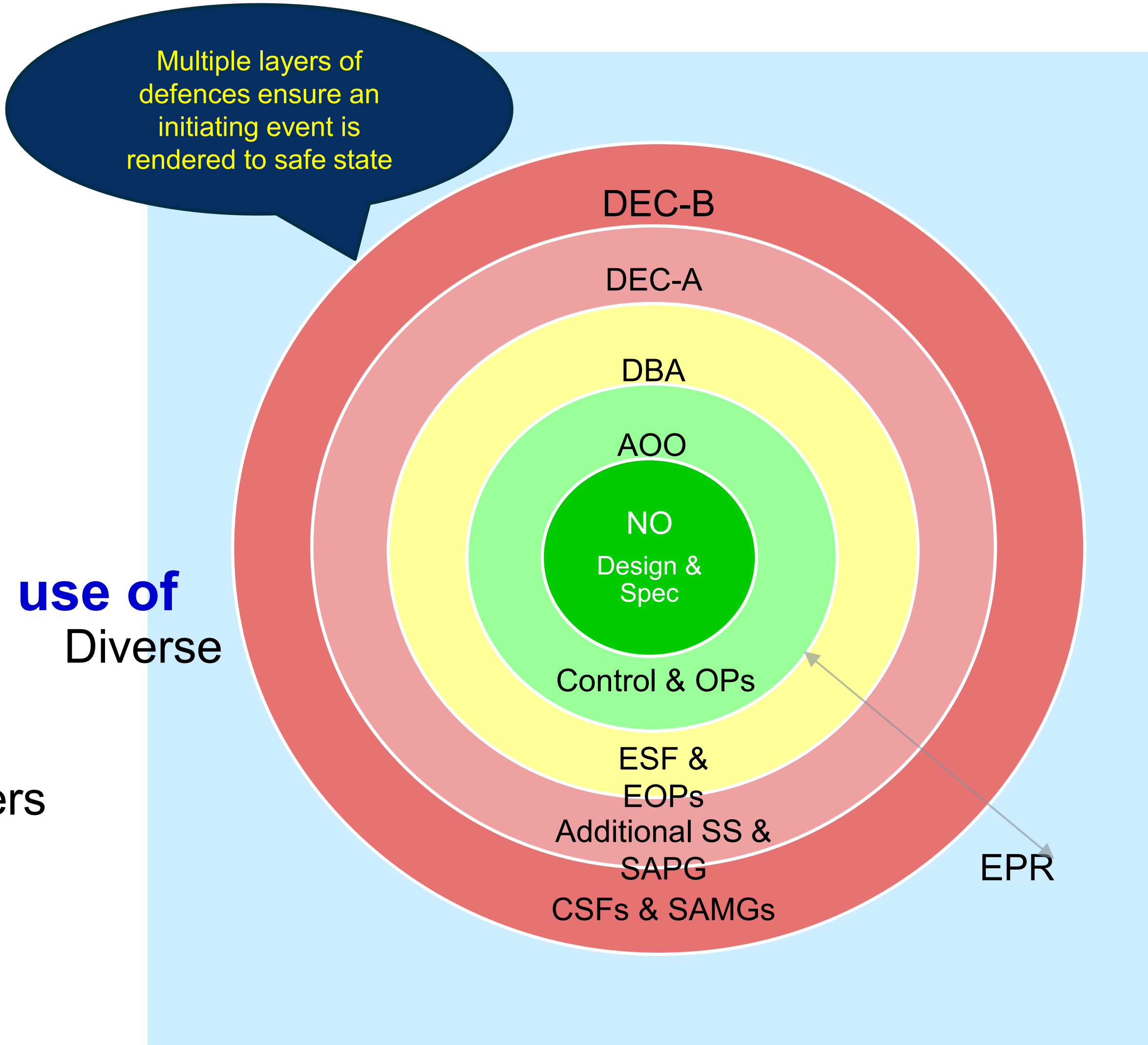
No Undue Risk from ionizing radiation

- Non-replaceable & non-accessible for repair, Etc
- Dimensional tolerances
- Grain size and orientation
- Material Properties

- Avoid leakages
- Radiation effect on property
  - End of life characteristics
- Inspectability
- Etc

DESIGN: DEFENSE IN DEPTH (DID)

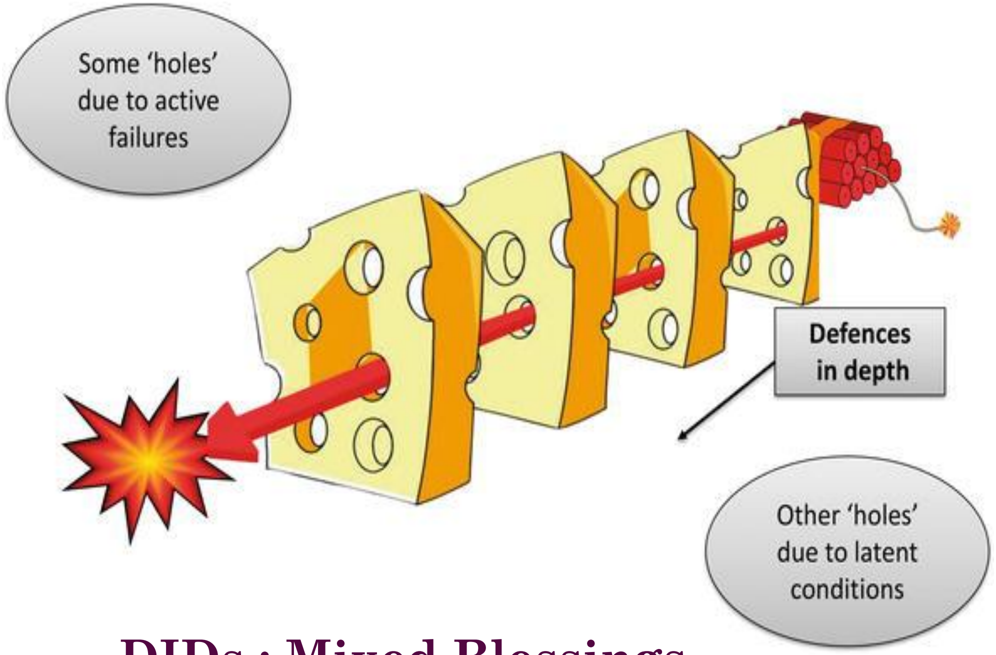
- The principle of 'Defence in Depth' underlies the safety technology of nuclear power.
- Key is creating multiple independent layers of defense to compensate for potential failures so that no single layer, no matter how robust, is exclusively relied upon.



DiD includes the use of

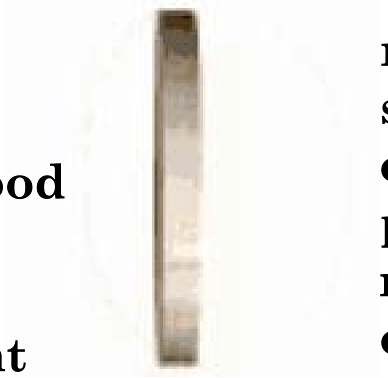
- ✓ Redundant & Diverse layers
- ✓ Physical barriers,
- ✓ Procedural Barriers

Importance of Safety Culture for NPPs



DIDs : Mixed Blessings

greatly reduce likelihood of an severe accident



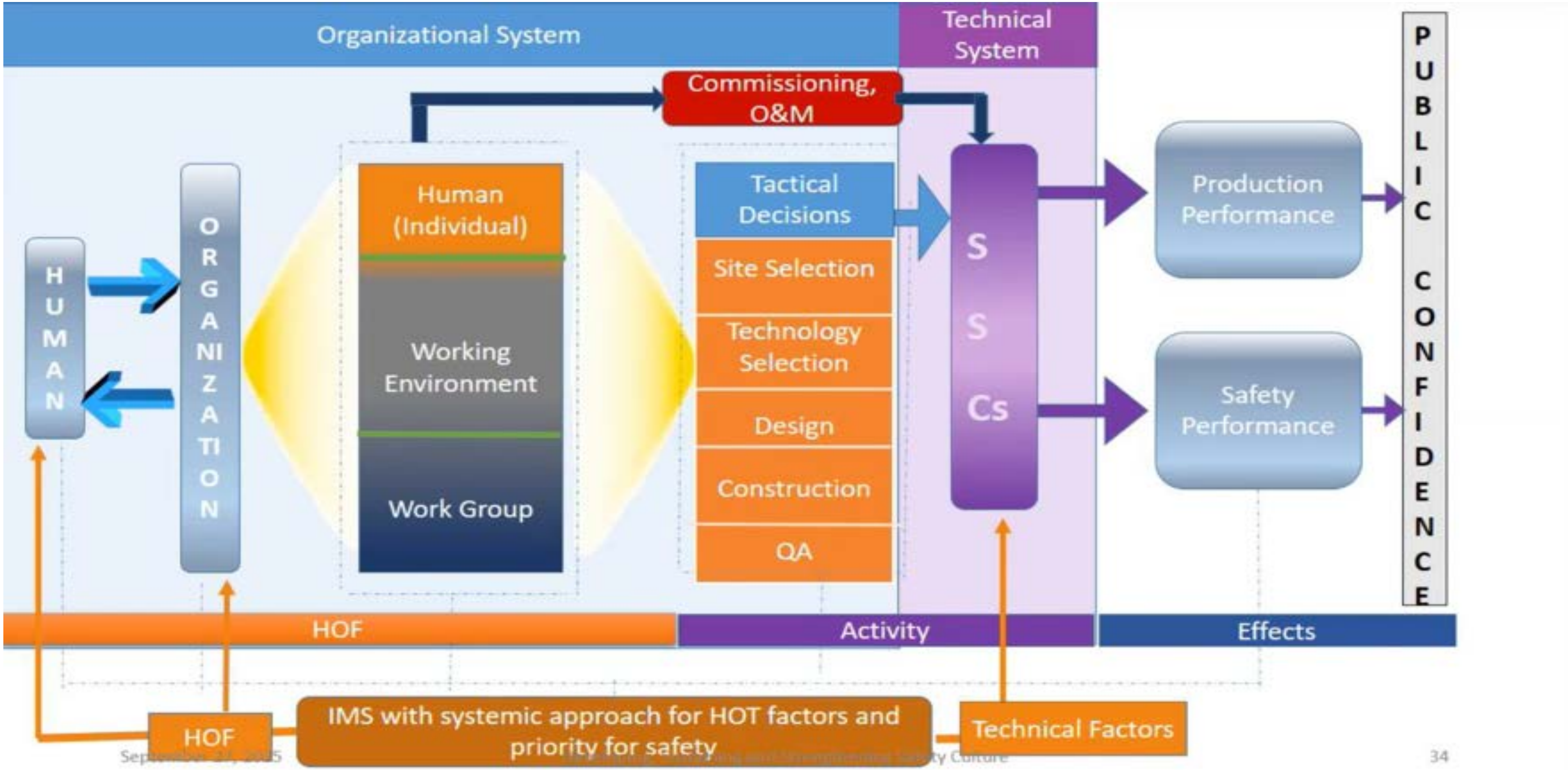
render system more opaque to people who manage and operate them

In a well defended system, such as NPP, only safety cultural influences are sufficiently widespread to increase substantially the probability of lining up a penetrable series of defensive weaknesses.

Because of this, modern, high tech, well defended technologies – such as NPPs, chemical process plants and commercial aviation – are more vulnerable to the effects of a poor safety culture/poor management of HOFs than traditional industries

Both, distancing effect and rarity of reportable events – Overconfidence.

NPP- SAFETY : INTEGRATED DEPICTION



Understanding of Regulation: Control+ Safety Regulation

Atomic Energy Act, 1962

An Act to provide for the development, control and use of atomic energy for the welfare of the people of India and for other peaceful purposes and for matters connected therewith.

CONTROL REGULATION	SAFETY REGULATION
What activities to be permitted: National Policies (Safety, Waste Management and others as applicable) including strategic requirements, International considerations including treaties, conventions, safeguards, diplomatic terms with other countries wrt trade & Commerce- defence etc . (input from safety regulator, as required) **Who should be permitted:** Capability-Organizational + Financial + safety of workers+ security of source, etc (input from safety regulator, as required) **Where to be permitted? Site**	**Safety in permitted activities:** – selected site fulfills the safety requirements – permitted activity is carried out in a safe manner throughout the facility's lifetime

Inter-ministry coordination for:

- Approving justification of new application/practices
- for clear understanding of control function and coordination for seamless regulatory interface

Existing Legal Framework for Regulation (Control and Safety)

Control of Nuclear Facilities and material

Department of Atomic Energy

**Sec.14 of AE Act (who (org. capabilities), what (technology), where (siting) security & safeguards*

Control of Radiation applications

Department of Atomic Energy

Sec.16 of AE Act (Ex-import of radioactive substance)

Other Line Ministries under relevant laws (*Ex- radiation generating equipment)*

Safety of nuclear and radiation facilities and activities

Atomic Energy Regulatory Board

***Certain** Regulatory and Safety functions under section 16,17 and 23 of The Atomic Energy Act, 1962*

Administration of industrial safety under Factories Act-1948 (units of DAE)

Regulation of nuclear security having bearing on safety within Main Plant Boundary of NPPs/security of radioactive sources (Additional mandate by AEC)

*Notification of Nuclear Incident-CLND Act 2010**

[RPR 2004-License –section 14- Competent Authority-Chairman, AERB]*

Environmental Protection

(EPA, 1986)

MoEF & CC-

-Includes consideration of RIA as per AERB requirements

- Public Hearing

Disaster Management

National Disaster Management Authority

(DM Act, 2005)

Interface with DAE/AERB

LEGAL & REGULATORY FRAMEWORK

- **Atomic Energy Act, 1962 – also providing administration of Factories Act in factories of DAE**
- **Rules under Atomic Energy Act (Concerning NPPs)**
  - Atomic Energy (Radiation Protection) Rules, 2004
  - Atomic Energy (Safe Disposal of Radioactive Wastes) Rules, 1987
  - Atomic Energy (Working of Mines, Minerals and Handling of Prescribed Substance) Rules, 1984
  - Atomic Energy (Factories) Rules, 1996
- **Civil Liability for Nuclear Damage Act & Rules**
- **Associated Acts:** Environment (Protection) Act, 1986,, Disaster Management Act, 2005, Indian Electricity Act,2003, Air & Water Acts, The Explosives Act, 1884; The Indian Boilers Act, 1923; etc

SHANTI Act-2025 in context of this presentation 1/2

To provide for promotion and development of nuclear energy and ionizing radiation with **robust regulatory framework** for safe and secure utilization

- Four-Tier adjudication architecture
- Validity of license/ safety authorization: as specified
- Explicit Clarity w.r.t. implicit understanding of "Control" and " Safety Regulation"
- Control- License for Control-DAE-Prescribed by rules
  - Promotion and providing services related to radiological protection
  - Policies for QA& QC –including manufacture and construction
  - Coordination and support to other agencies for EPR
  - Notifying nuclear incident

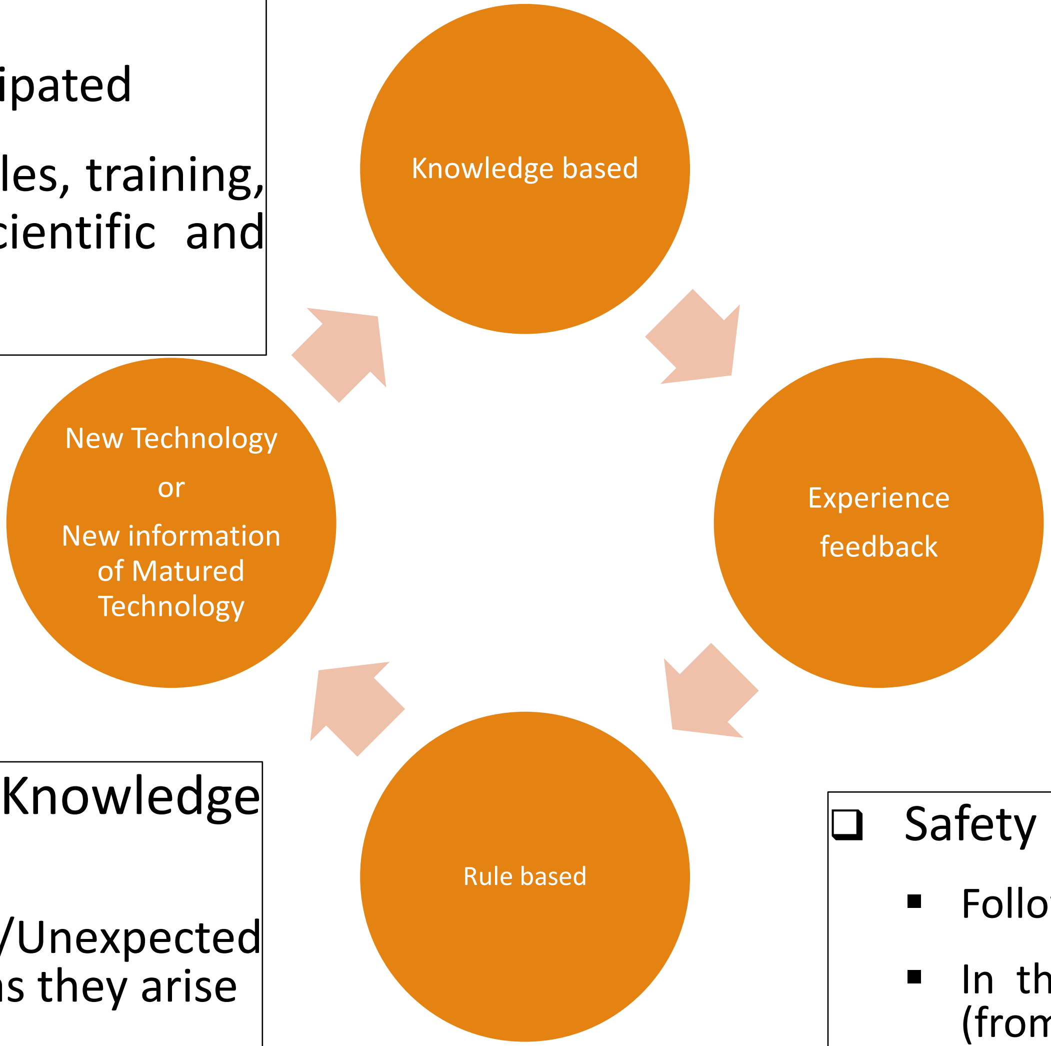
SHANTI Act-2025 in context of this presentation 2/2

- Safety Regulator and Safety Regulatory Framework- Statutory Status
  - Safety Authorisation- AERB- Specified by Regulations
  - Evolved Regulatory practices get legal basis
    - Frame safety codes and such other regulatory documents- important addition-management system, qualification, training and recognition of qualified or certified personnel
    - Frame regulations and establish implementation mechanism for the recognition and certification of persons for performing the tasks or carrying out the functions entrusted to them
    - Recognise agencies, institutes, and testing and calibration laboratories
    - Specify criteria for nuclear incident, provide recommendation to central Government
  - Duties of licensed or authorized *person :* Explicitly mentioned: Shall
    - Have the primary responsibility for the safety, security and safeguards
    - Comply with applicable regulatory documents (safety codes, safety standards, safety guides, safety manuals and such other documents issued by AERB)
    - Maintain design support throughout the lifetime of the facility
    - Provide access and necessary infrastructure : site officers
    - Maintain sufficient financial security

Knowledge to Rule : Cycle and Balance

❑ Rule based Safety

- All situations are anticipated
- Formal procedures, rules, training, implementation of scientific and technical knowledge.



❑ *Managed Safety*- Knowledge based safety

- Rules not available/Unexpected situations are handled as they arise
- Human expertise, quality of initiatives, management

❑ Safety Regulation

- Follows the evolution of the technology.
- In the beginning: knowledge based regulation (from scientific principles and R&D inputs)
- Knowledge + experience →Rules

APPROACH TO SAFETY REGULATION

- Holistic Approach to Regulation*
  - Knowledge cum Rule based: Wisdom to choose/combine
  - Following Graded approach- commensurate with radiation risk
    : Responsive Regulation
  - Emphasis on Influencing over Enforcement
  - Inclusive, Participative, Non-Intrusive and Independent
  - Close monitoring of HOFs to detect early signs of decline in safety culture

"Accountability- oriented, enabling regulations" as per OECD-NEA

Encompasses elements of various regulatory approaches in varying degree and extent, depending on the specific issue :
Prescriptive, outcome based, risk-informed and hazard informed, process based, self assessment based, education/influence based

REGULATORY FRAMEWORK (SAFETY)

AERB has issued

~ 165 REGDOCs

From Cradle to Grave Consenting Stages

Act
Rules

Directives/Orders/
Gazzette Notifications

*Safety Codes /
Safety Standards

Safety Guides

Safety Manuals

Legal
(Control & Safety)l

Regulatory Framework
(Safety)

Siting
Diverse NPPs: PHWR, LWR, FBR
NPP – Design
NPP – Operation
NPP – Quality Assurance

Fuel Cycle Facilities

Radiation Facilities

FUNCTIONS OF REGULATORY BODY

Core Regulatory Functions

- Development & Revision of Regulations and Guidance (Regulatory Framework)
- Licensing
- Regulatory Oversight

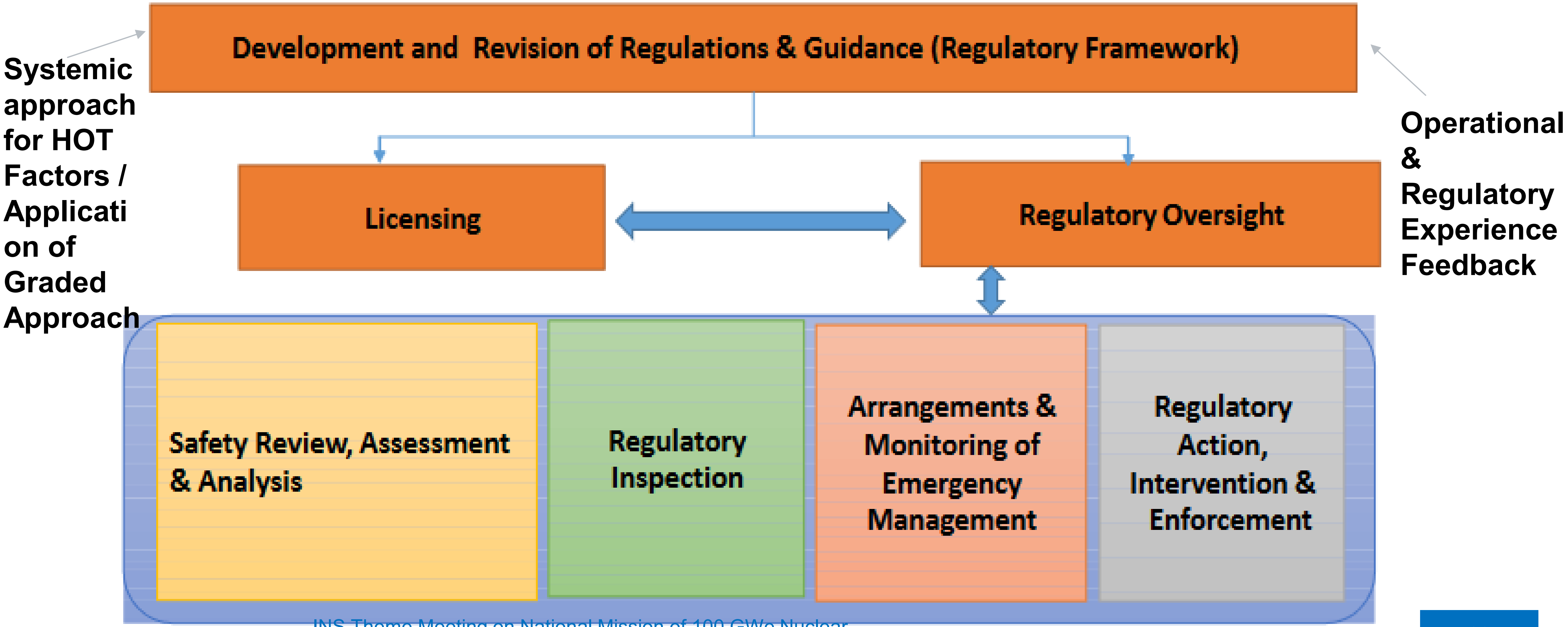
Functions to Support Core Regulatory Functions

- Conduct of Safety Research
- Legal Support
- Interested Parties (including Stakeholders) Engagement
- External Relations (includes technical and other support)
- Resource Management
- Document, Record & Information Management

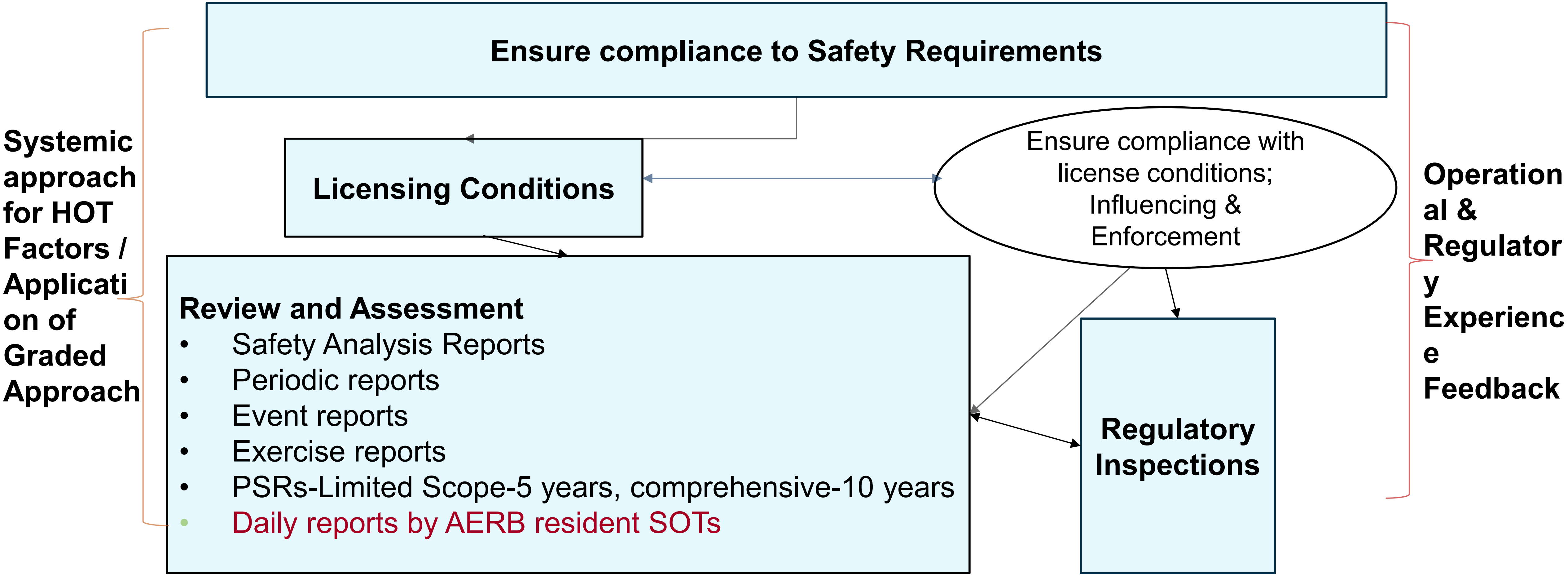
Administration Functions to Support Organisation

- Office Management
- Establishment matters
- Personnel matters
- General administration matters (Purchase, contracts, office infrastructure)
- Finance & Accounts matters

CORE REGULATORY FUNCTIONS : INTERACTIONS



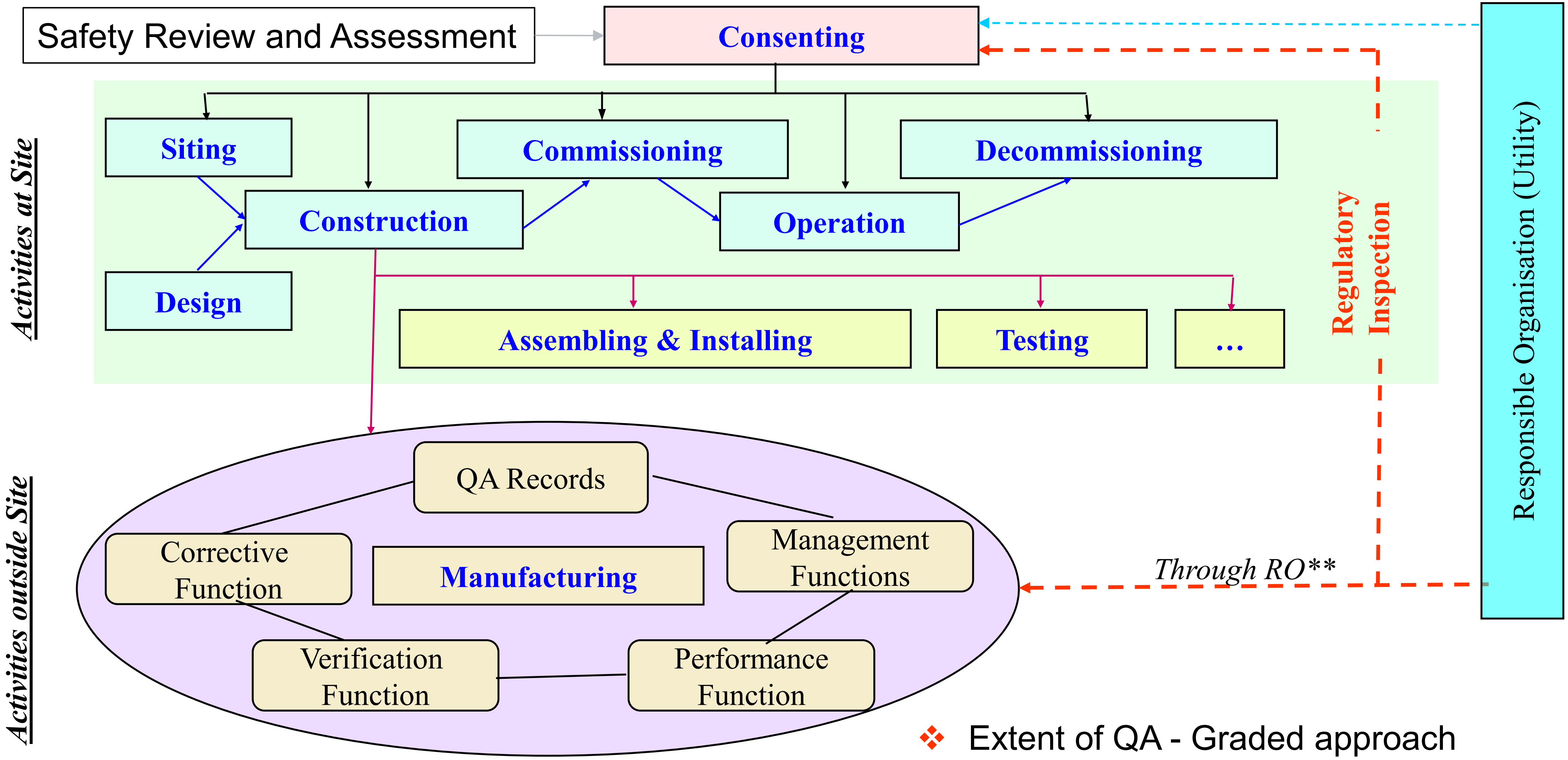
REGULATORY OVERSIGHT



LTO: PSR for whole period + other applicable conditions for renewal of license

HOT- Factors-Human, Organizational and Technical Factors, SOT-Site Observers Team

REGULATORY OVERSIGHT



- Extent of QA - Graded approach

CONSENTING PROCESS FOR NUCLEAR POWER PROJECTS

- **AERB Safety Code "Regulation of Nuclear and Radiation Facilities" (AERB-SC-G)- Under Revision as SC-SR**
- **Major Stages of Consent**
  - Siting
  - Construction
  - Commissioning
  - Operation
  - Decommissioning
- **Construction Clearance - Single stage or 3 sub-stages**
  - Excavation
  - First Pour of Concrete
  - Erection of Major Equipment

Safety Guide AERB-SG-G1

REGULATORY OVERSIGHT: FROM CRADLE TO GRAVE

Siting: Evaluating Site suitability, impact of plant on site and site on plant, defining design bases.
Site characteristics, Evaluation and Design basis generation, SSE, OBE etc, Radiological Impact Assessment (RIA)

Construction: Detailed design, manufacturing, erection, testing and assembling components of a NF.
Design & Manufacturing control as per Nuclear grade standard, Plant Layout

Commissioning: Making constructed SSCs of NF functional & verify performance as per design.
test procedure, result assessment to meet design intent

Operation: Operational limits & Conditions (Tecnical Specification) are consistent with regulatory requirements, Adequate level of safety is maintained during operation

Decommissioning: NF is finally taken out of operation in a safe manner.
process control for safe decommissioning
waste management and organisational commitments meet regulatory requirements

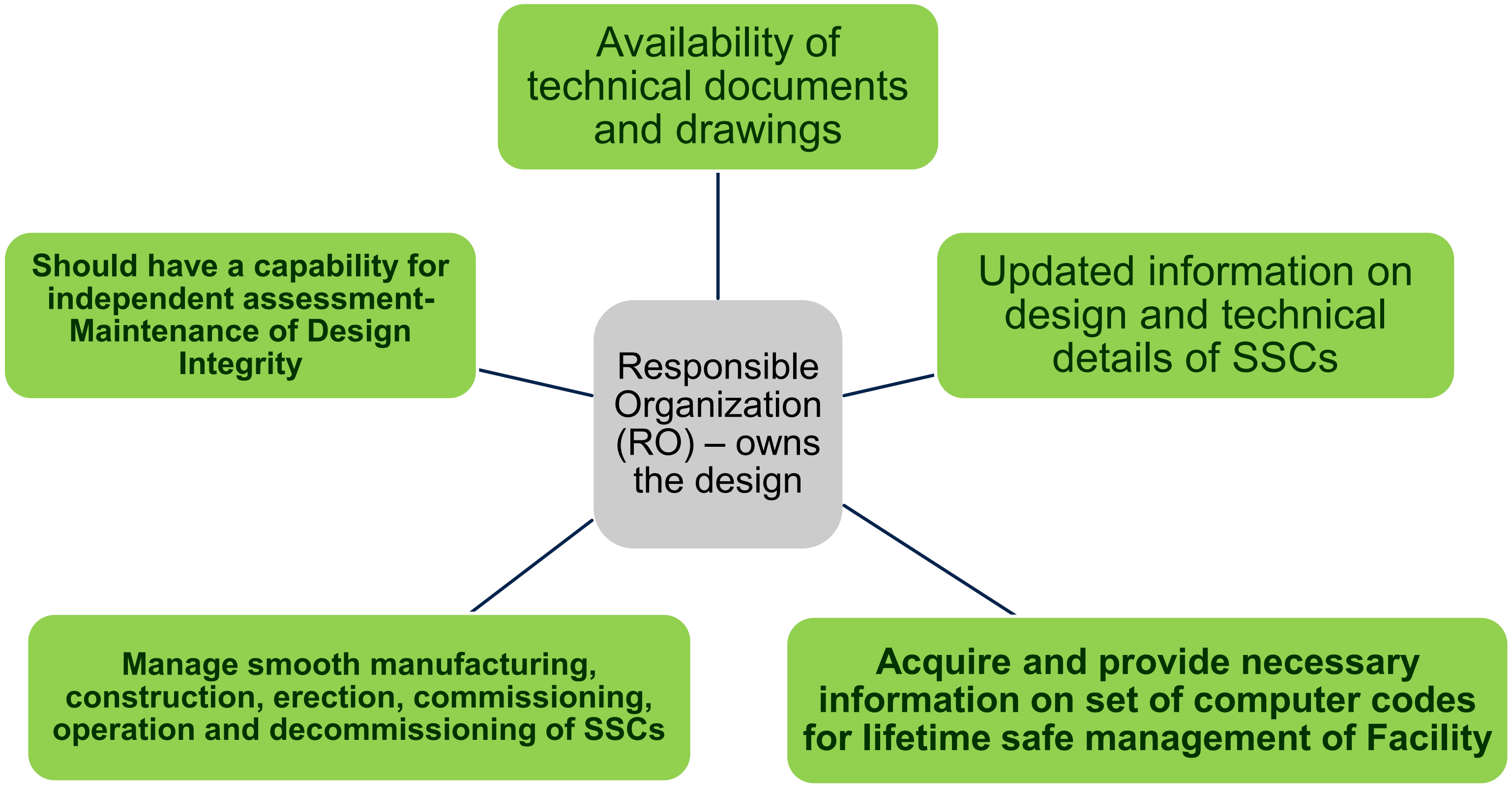
Application of graded approach for regulation

Multi-tier review mechanism

APPLICANT – RESPONSIBLE ORGANISATION

Applicant to submit Application +

- Identified Submissions
- Supporting Documents
- Additional Information during course of review



Regulation of Digital I&C

- Demonstration of quality & reliability of digital I&C
  - ✓Present approach is rigorous but qualitative for demonstrating Reliability & Integrity of Digital I&C.
- Smart devices & COTS Systems
  - ✓ Limitations on sharing proprietary info.
  - ✓ Producing a safety case poses challenge during licensing. Compensatory evidences needed
- Common Cause Failure (CCF) due to Software
  - ✓ Plant design to account for CCF to preserve layers of DID
  - ✓ Incorporate & demonstrate adequate diversity
- Use of field programmable devices
  - ✓ Demonstration of quality of 'field programming' & V&V, especially w.r.t. to tool qualification, Use of life cycle approach
- Cyber Security aspects
  - ✓challenge to address security concerns
- Updating the regulations to keep pace is a challenge (D-25 amended)
  - ✓ AERB is following up international approaches & trying to assess reliability of digital I&C during V&V process based state of the art.

LICENSING BASIS

▶ Generic Requirement

- That define building safe and reliable facility
  - DiD Approach
  - SFC & Fail-Safe features
  - Redundancy and Diversity
  - Safety Classification
- Quality Assurance
- Radiation Protection
- Emergency Preparedness
- Waste management
- Site Evaluation
- Training and licensing of operating staff

▶ Technology Specific Requirement

- Technological details adopted in the facility
  - Specific system requirement
  - Technology specific hazards

SAFETY REVIEW & LICENSING: NEW BUILD

- Applicable AERB Safety Requirements
- Applicable IAEA and International Requirements

First of its kind systems

- Complete spectrum of safety functional demonstration by technical inputs and R&D experiments – Basis of Acceptance
- Extensive commissioning tests and additional surveillance to the extent practicable
- Experience feedback from similar design
- In-house checks and analysis

Imported NPPs

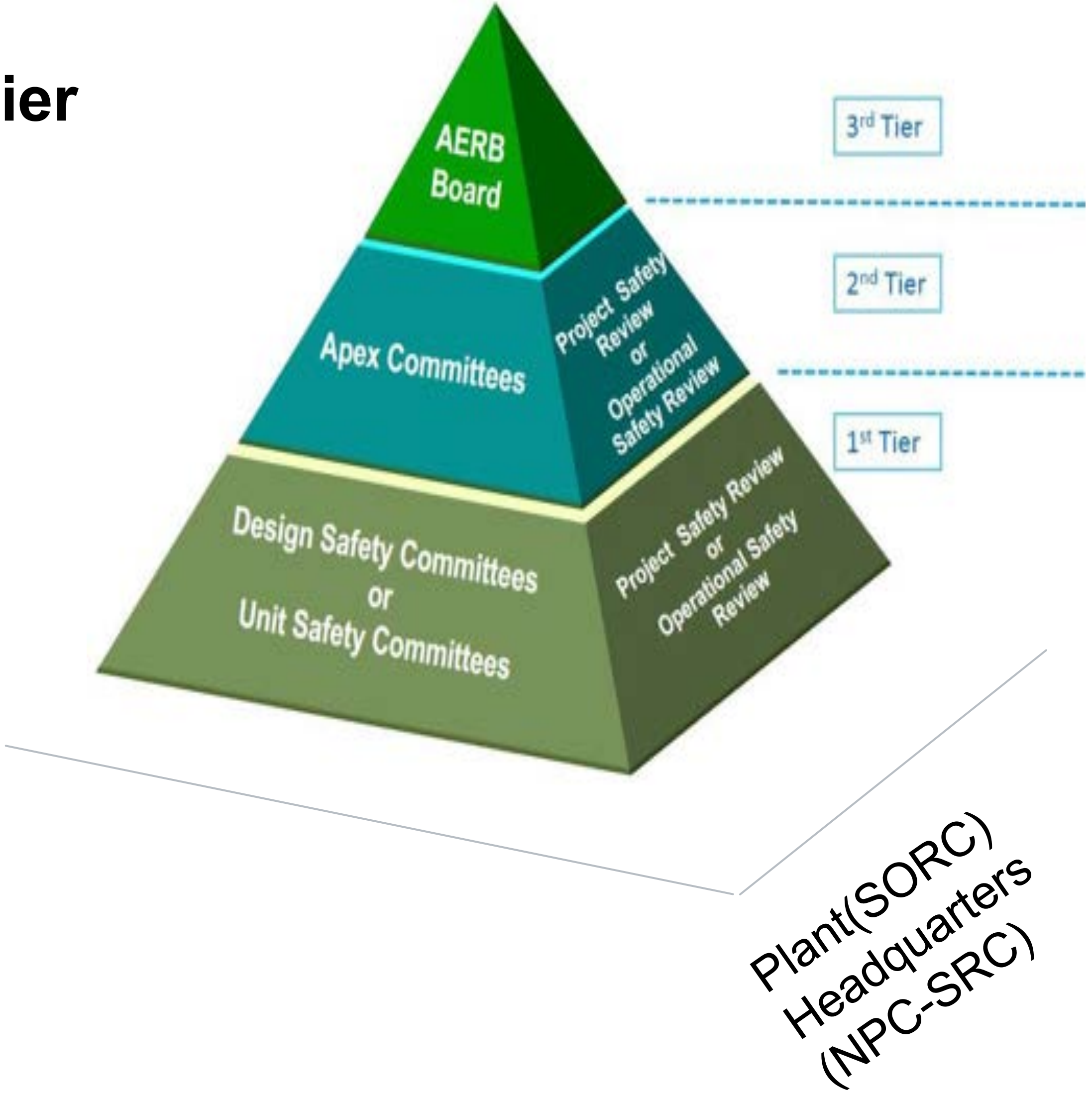
- Plant to be Licensable in Exporting Country
- Operating Experience Feedback (Reference Plant)
- Design Authority and Plant Life Management

MULTI-TIER SAFETY REVIEW MECHANISM-SAFEGUARD AGAINST DECISION MAKING TRAPS/BIASES

Safety Reviews carried out at multi-tier levels: (Graded Approach-IMS)

- AERB staff, Review Groups, TFs & EGs
- Safety Committees
- Advisory Committees
- AERB Board

- Technical Support (R&D institutes, Academic institutions and Retired Experts)



ROLE OF A REGULATOR

- Reduce Risk to Stakeholder – Public

- While making Risk 'Acceptable' to stakeholder, it is done with 'Ease of Meeting Regulatory Requirements' by Applicant/Licensees

EFFECTIVE MANAGEMENT OF RESOURCES

- Regulatory Safety Codes, Safety Guides and Safety Standards
  - Holistic revisit and revision for clarity & simplicity, consistency and harmony among them as well as with legal provisions and current international standards : Refer recently issued codes: AERB/NPP-SFR/SC/D, AERB/NPP-SFR/SC/D: Foreword, Objective, and Scope

In case of any experience of event in NPP, Regulatory requirements may Change (Recent Ex.-Post Fukushima):Careful Consideration for Graded implementation of compliance to changed requirements.

EFFECTIVE MANAGEMENT OF RESOURCES: NEW INITIATIVES

- Revision of Consenting Process of NPPs : Simplification (Pre-Project consultation, synchronization/Integration of licenses, long term license for design life…): to be aligned with SHANTI Act.

- Repeat Designs – NPP designs reviewed earlier by AERB (Attention to changes from earlier approved designs) :In Practice: **Standardization key to avail this.**

- Application of Graded Approach- Optimization of Review Levels-Implementation of Integrated Management System: IMS implemented, Guidance for Application of Graded Approach

- Competency Development for New technologies-
  - Participation in National/International Forums/Peer Reviews

MANAGEMENT OF CONCERNS: NEW AND INNOVATIVE DESIGNS

Concerns

Basic Concepts

Design Standards used by vendors

Materials used in Design

Research and Experimental studies

Clear Roadmap for demonstrating Safety

- Established regulatory framework evolved over time applicable for new build
- Experience of concurrent development of technology and safety regulation: strength to regulate new and emerging technologies
  - ‘Safety goals’ remain same
  - Technology specific requirements covered for PHWRs,WCRs & SFRs
  - Technology specific aspects may need to be evolved during concurrent review process

- Intrusive Review Required (as explained under FOK systems)
- Delinked ‘Site’ and ‘Design’ Reviews – Additional Options to existing consenting process-(Under consideration)
- To reduce ‘Regulatory Oversight time’ – Regulator may accept these details (even partly) for review ‘well in advance’ of actual launch of NPP Project as part of “Pre-Project consultation practice”

TO SUM UP…1/2

- Necessary infrastructure and regulatory processes for effective implementation of legislative provisions to ensure safety of nuclear and radiation facilities are well established.
- Regulation of emerging technologies: Framework provides flexibility:
  - Experience of concurrent development of regulation with the technology (LWR, SFR)
  - Experience of regulating wide ranging technologies (already regulating-PHWR,BWR,PWR,SFR)
- The regulatory approach followed is inclusive, participative, flexible, facility specific and balances well rule based safety and knowledge based safety to regulate any kind of technology without compromising on safety
- The accident free safety performance of nuclear facilities in the country over the years and the acknowledgment of IRRS-IAEA peer review are testimony to the effectiveness of Indian safety regulation and commitment for ensuring high level of safety in nuclear facilities and activities

TO SUM UP…2/2

- Besides regularizing the evolved regulatory practices, SHANTI Act 2025 provides for promotion and development of nuclear energy and ionizing radiation with robust regulatory framework for safe and secure utilization
- Event somewhere, Impact everywhere: Unlike other industry, nuclear industry demands defense in depth with independent or common cause failure causing no impact, compliance to highest design standards, best quality compliance and continuous monitoring and oversight.
  - Safety is prime responsibility of the Licensee : Self Regulation and strong Safety Culture, arrangement for maintenance of design integrity throughout the NPP life cycle - Key to fulfill this responsibility
  - Areas need priority attention: Human resource and nuclear knowledge management

    : Public Outreach-Public Confidence

REFERENCES

1. The book is available on AERB's website @
https://www.aerb.gov.in/images/PDF/Ruby_Jubilee_Book_FINAL_HD.pdf
Chapter 4 : Winds of Change
Epilogue: Manthan

Four Decades of Safety Regulations
Celebrating Past and Ready for Future

2. Latest IMS document is available at AERB's website @

https://www.aerb.gov.in/storage/uploads/News/news9bbEV.pdf

3. Indian Nuclear Society's Annual Conference INSAC-2024 Regulatory Framework for Nuclear Renaissance November 19-21, 2024; Recording of presentations available
4. INS Newsletter July - December 2024 Special Issue on regulatory activities of AERB - 3 &4 Vol. 25
5.D.K.Shukla: Enhancing Nuclear Safety and Security Through Technical and Scientific Support Organizations (TSOs):
Challenges and Opportunities in a Rapidly Changing World: Indian Perspective and Experience-IAEA conference-Dec 2024
6. D.K. Shukla: Developing, Sustaining and Strengthening Safety Culture; Special Colloquium -AERB, INS, IEF Sept 2025
7. D. K. Shukla: IEF webinar-Nov 2023: Safety and Regulatory Aspects of Nuclear Power Plants

THANK YOU