

INDIA'S THORIUM MISSION: “THREE STAGE NUCLEAR POWER PLANT”

KEY NOTE SPEAKER

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NPCIL

It's a public sector undertaking (PSU) under the Govt. of India , Department of Atomic Energy headquartered in Mumbai, Maharashtra.

Core Responsibilities:-

1) Electricity Generation

Design, Construction, Commissioning and operation of Nuclear Power reactors across India.

2) National Grid Support:-

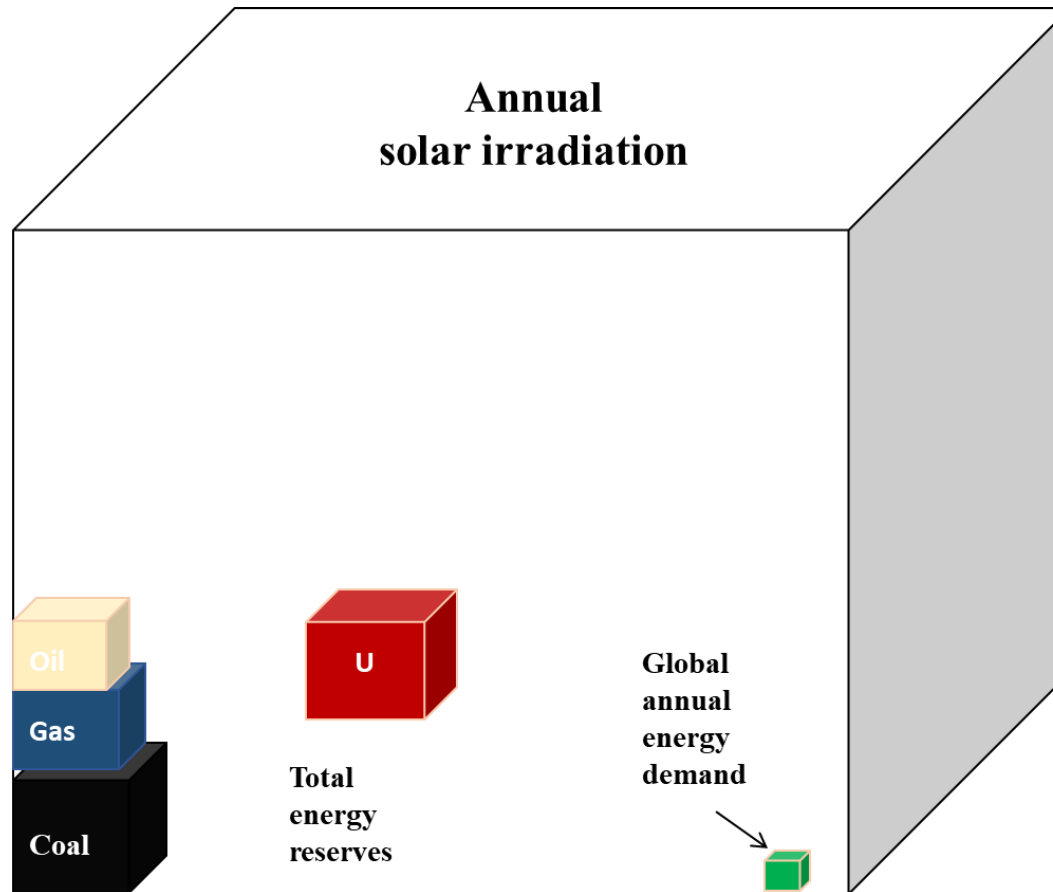
Operates multiple power atomic stations (**Kudankulam & Tarapur**) to supply clean non-carbon emitting electricity to the national grid.

- The sustainable harnessing and advancement of Nuclear energy for transforming India is **SHANTI ACT 2025** passed in December 2025.
- Overhauls India's nuclear governance by replacing the 1962 and 2010 Acts allowing upto **49% Foreign Direct Investment (FDI)** and private sector participation in building and operating nuclear power plant, while the state retains control over strategic areas like fuel and waste management.
- The act aims to modernize the sector & accelerate the country's clean energy transition towards a target of **100 GW** of nuclear capacity by **2047**.

Year 2047 to be embarked as Energy Security Year

Under Viksit Bharat 2047

***Energy Cubes: The Annual Solar Irradiation Exceeds
Several Times of the Total Global Energy Demand
and All Fossil Energy Reserves***



Need to Move Towards Nuclear Energy

- **Threat for Climate Change:** Causing Seasonal Disturbances.
- **Pollution with the use of coal:** Increased Carbon Content.
- **Global Warming:** Increased per degree rise in temperature.
- **Management of Nuclear Waste:** Control nuclear byproducts.

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India' Three stage nuclear program was conceived by Dr. Homi Jehangir Bhabha to systematically move from Uranium to Thorium.

India's nuclear thorium program is a unique, long- term vision to achieve energy independence by utilizing the country's vast coastal thorium reserves. The multi-generational strategy uses a closed fuel cycle and is implemented in three distinct technological stages.

a. Stage 1 (Pressurised heavy Water Reactors):

Natural uranium is used to generate power while producing plutonium as a byproduct

b. Stage 2 (Fast Breeder Reactors):

The plutonium from stage 1 is utilized to convert depleted uranium into more fissile material, breeding Uranium-233. A key milestone was achieved with the 500 Mwe **Prototype Fast Breeder Reactor (PFBR)** at Kalpakkam, Tamil Nadu, which achieved its first **Criticality (Safety issues)**.

c. Stage 3 (Thorium Reactors):

Fissile Uranium-233 produced in the second stage is combined with thorium to generate clean nuclear energy.

In all these stages what we are doing?

We are using nuclear waste as fuel for the other stage

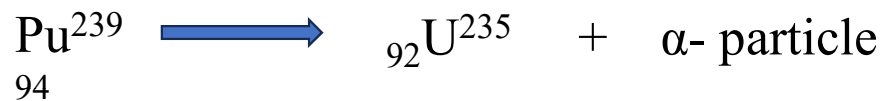
Stage 1: Pressurised Heavy Water Reactors (PHWR)

- It uses natural uranium.
- It contains **0.71% Uranium-235**.
- It contains **99.28% Uranium-238**.
- Traces of **Uranium-234 (0.006% by weight)**.
- Heavy water is used as moderator (medium that reduces the speed of fast neutrons) and coolant to generate electricity and produce **Plutonium-239**.

PLUTONIUM

Pu-239

- Plutonium is naturally radioactive and decays by emitting an α - particle
- Half life  Approx. 24100 years



- Pu-239 is a synthetic element not found in nature. It is artificially created inside nuclear reactor through irradiation of U-238 which is the most common isotope of Uranium.
- Plutonium-238 is a vital power source for deep space mission.

Stage 2: Fast Breeder Reactors

- Use Plutonium from PHWR to breed more fissile material

Fissile material is a substance that can sustain a nuclear fission chain reaction. They are used as fuel in nuclear reactors to generate electricity. They can maintain a self-sustaining nuclear chain reaction and they are suitable for Nuclear Reactors Eg. U^{235} , Pu^{239}

U^{235} : **Only 0.7% of natural uranium is U^{235} (Isotope).**

Pu^{239} : It is artificially produced fissile material created from the fertile material U^{238}

U^{233} : Another artificially produced fissile material made from Thorium 232 (Th^{232}).

- The prototype Fast Breeder Reactor (500 Mwe) is central to this stage.
- Thorium Blanket in FBR enable the breeding of Uranium-233, bridging the transition to thorium-based system.
- India holds an estimated 846.5 thousand tonnes of thorium representing One Third of global reserves which is found in the monazite sands along coastal regions, with **Kerala** being the largest producer.

- The spent fuel from thermal reactors contains **Pu239**, which is most efficiently burnt in a fast reactor.
- Thorium-bearing monazite too, is a fertile material that has to be converted to fissile material **U233**.
- India has adopted a “closed fuel cycle” approach, which involves the reprocessing of spent fuel to separate the useful **Pu239** and **U233** isotopes from **U238** and **Th232**.

Stage III- Thorium Based Reactors

- Focusses on reactors operating primarily on the thorium **U- 233** fuel cycle (manufactured isotope and is a key fissile isotope in the thorium fuel cycle).
- The advanced Heavy Water Reactor (**AHWR- 300 MWe**) is designed with passive safety and high thorium utilization.
- Large Reserves: India has limited domestic uranium but one of the world's largest thorium reserves, mainly in monazite sands (**((Ce,La,Nd,Th)PO** (the most common member)) of **Kerala, Tamil Nadu** and **Odisha**.
- This program envisages a pathway to utilizing India's abundant thorium reserves- found in coastal and inland placer sands on the beaches of **Kerala, Tamil Nadu, Odisha, Andhra Pradesh, Maharashtra and Gujrat**, and in the inland riverine sands of Jharkhand and West Bengal- to generate electricity.

Energy & Environmental Benefits

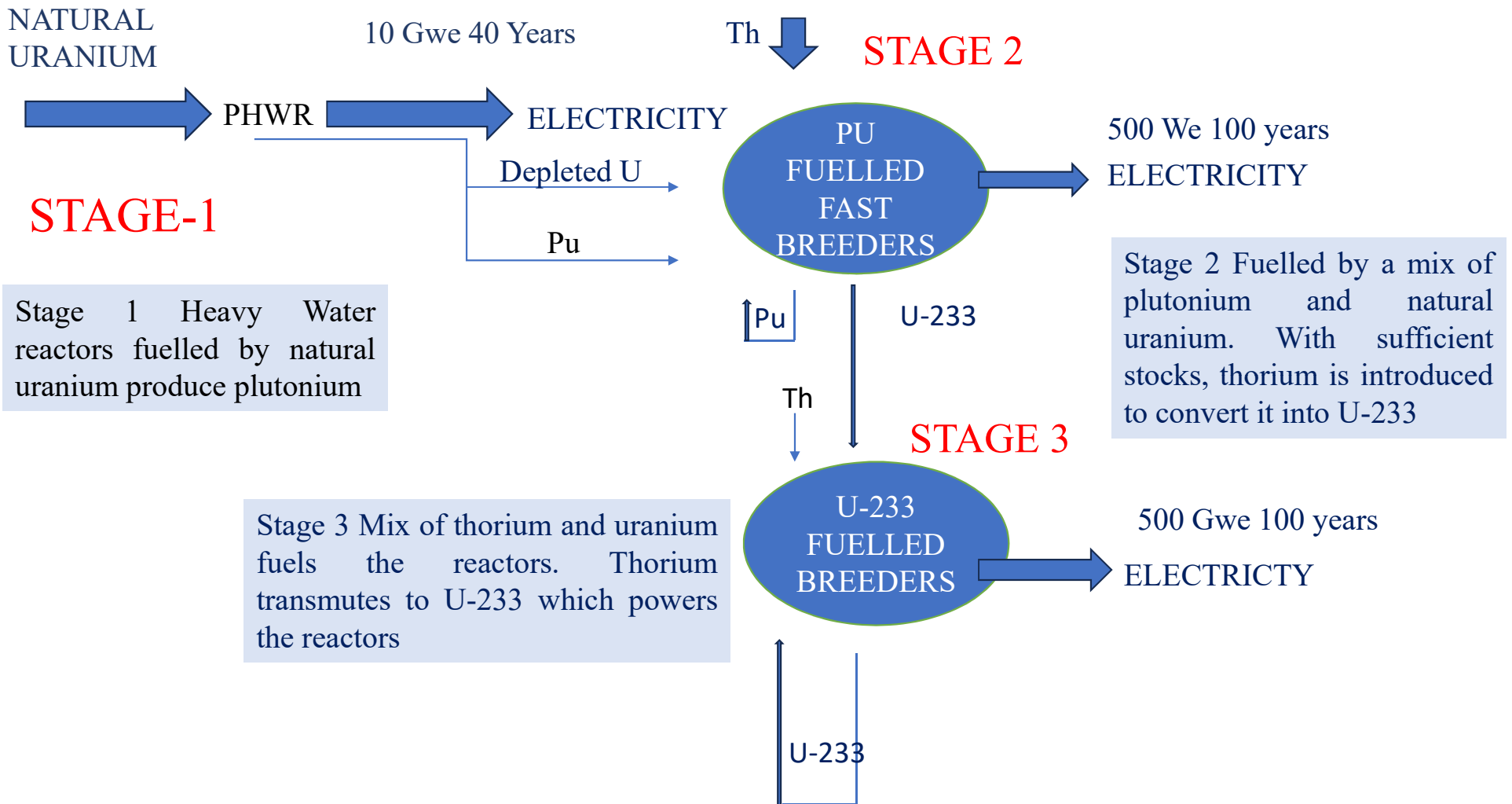
- **Energy Security:**

Thorium offers long-term energy security by enabling a largely indigenous nuclear fuel cycle, reducing dependence on imported Uranium.

- **Environmental Benefits:**

Nuclear power is low-carbon and reliable, supporting India's net-zero target (2070) and rising baseload demand.

The Three Stage Roadmap



FBR Project Program

- The project was expected to be completed by **September 2010**, but was delayed due to technological issues.
- The last set of approvals had revised the completion target to October 2022.
- Once commissioned, India will be the second country after **Russia** to have a commercial FBR.
- **China** has a small programme on fast breeders; programmes in countries such as Japan, France, and the United States were shut down and safety concerns.

HALEU- High Assay Low-Enriched Uranium

- Conventional commercial nuclear reactors currently run on **Low Enriched Uranium (LEU)** which contains 3% to 5 % of U-235.
- **HALEU** contains 5% to 20 % Uranium used in advanced reactors
- **HEU (Highly Enriched Uranium)** contains above 60% Uranium.
- **HALEU** bridges the gap between **LEU** and **HEU**. It has higher concentration of fissile material. It is an advanced nuclear fuel.
- It is the essential fuel required to power most of the next generation **Small Modular Reactors (SMR)** and advanced nuclear systems (Micro Reactors)
- Micro Nuclear Reactors produce **20MW** electrical power.
- These reactors are movable.
- Small Modular Reactors produce **20MW -300MW** power and units can be added.

Benefits of HALEU

- **Higher Energy Density:**

HALEU allows reactor cores to be much smaller while producing more power per unit volume

- **Longer Core Life:**

It enables reactor to operate for years without refueling

- **Reduced Waste:**

It produces significantly less radioactive waste per unit of energy generated and helps maximize fuel utilisation.

CLADDING

- In nuclear reactor cladding is the outer metal jacket surrounding fuel pellets. It acts as a primary safety barrier, preventing radioactive fission products from leaking into the coolant and shielding the fuel from corrosion.
- Traps radioactive gases and fission products inside the fuel rod
- Efficiently transfers the intense heat generated by nuclear fission to the coolant.
- Holds fuel pellets in a precise geometry to maintain controlled nuclear reactivity.
- Cladding materials must not readily absorb neutrons, which would hinder the nuclear chain reaction.
- High thermal conductivity to allow heat to pass through quickly to prevent overheating's.
- Must structurally support the fuel column without deforming.

Critical Mass and Criticality

- **Criticality** is a nuclear term that refers to the balance of neutrons in the system.
- **“Subcritical”** refers to a system where the loss rate of neutrons is greater than the production rate of neutrons and therefore the neutron population decreases as time goes on.
- **“Supercritical”** refers to a system where the production rate of neutrons is greater than the loss rate of neutrons and therefore the neutron population increases.
- Attaining criticality is a key milestone before full power generation indicating that the reactor core is functioning as designed and that each fission event in the core now releases a sufficient number of neutrons to sustain an ongoing series of reactions.
- It is a balance between **“Subcritical”** and **“Supercritical”** situations.

ACHIEVEMENTS

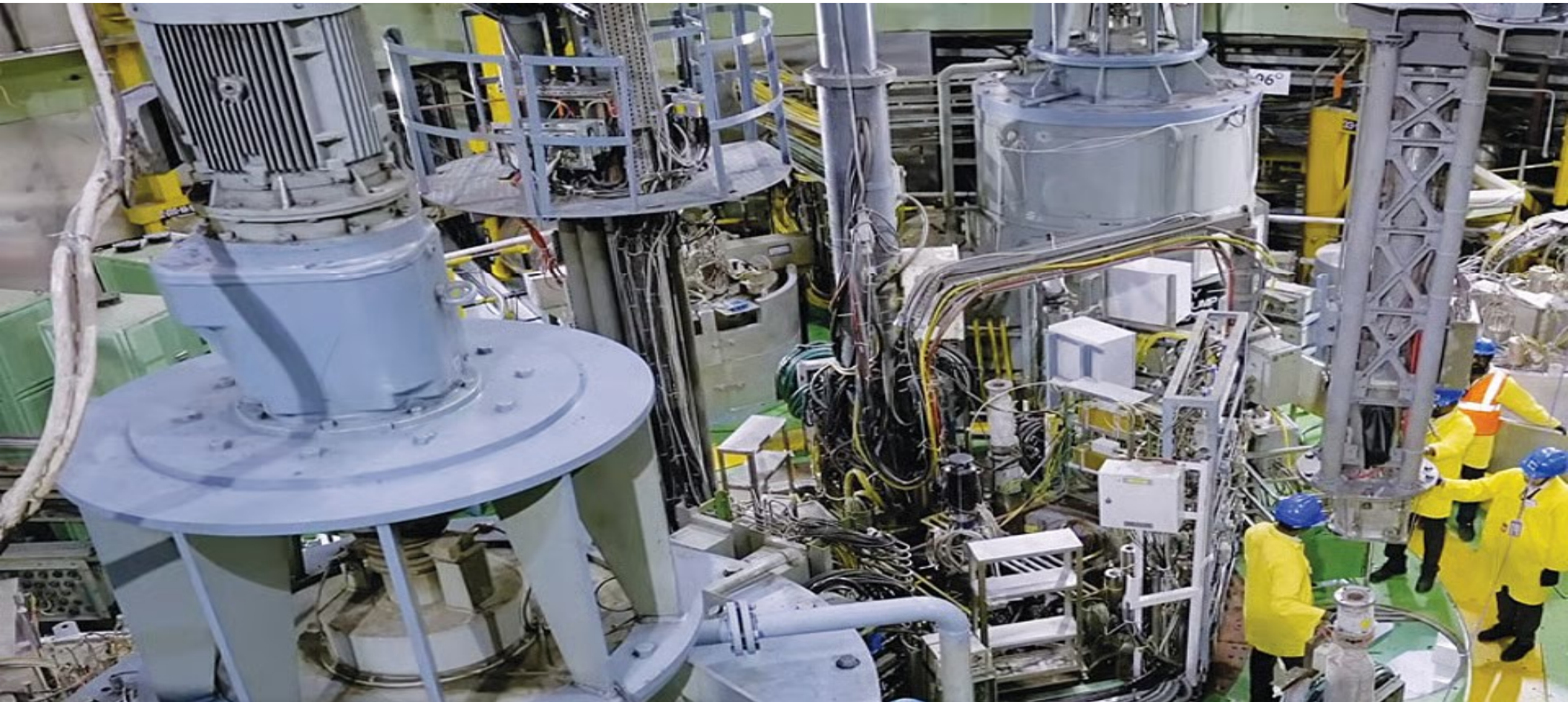
- **Long-term Power Potential:** Capability to generate electricity for centuries using domestic resources.
- **Economic Gains:** Reduced uranium imports and development of indigenous nuclear technologies.
- **Strategic Autonomy:** High proliferation resistance due to U-232 contamination.
- **Climate Resilience:** Clean baseload power complementing renewables.

- India is one of the few countries in the world with a long experience of developing nuclear technologies, including the generation of nuclear power.
- This includes a mastery over the pressurized heavy water reactor (PHWR) technology, or reactors that use natural uranium as fuel and heavy water (deuterium oxide) as coolant and moderator.
- These reactors now comprise the bulk of India's installed atomic power capacity of 8,180 Mwe (megawatt electric), alongside some imported light water reactors (LWR) units.

Initiatives to be taken

- **Thorium** is not directly fissile: requiring initial fissile material (enriched uranium).
- **Handling issues:** Due to high gamma radiation from U 232.
- **High Capital costs:** Long Gestation period, and need for skilled manpower.
- Requirement of Greater Private Sector Participation: and Sustained R&D environment.
- Ongoing projects including the Advanced Heavy Water Reactor (AHWR) and Molten Salt Breeder Reactor (MSBR), will help perfect the handling and reprocessing of thorium-based fuels for full scale commercial thorium powered reactor.

The 500 MW prototype fast breeder reactor at Kalpakkam, Tamil Nadu



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