



## Thorium-based Nuclear Energy Production

**For Prelims:** [Thorium](#), [Pressurised Heavy Water Reactors \(PHWRs\)](#), [Three-Stage Nuclear Power Program](#), [India's Clean Energy Goals](#), [Igneous Rocks](#), [Heavy Mineral Sands](#), [Plutonium](#), [Gamma Radiation](#), [Monazite](#), [Heavy Water](#), [Fast Breeder Reactors \(FBRs\)](#), [Thorium-Based Reactors](#).

**For Mains:** Need Thorium in India's nuclear energy production.

**Source:** [BS](#)

### Why in News?

India's largest power generator, **National Thermal Power Corporation (NTPC) Limited** has signed a **strategic pact** with US-based **Clean Core Thorium Energy (CCTE)** to explore development and deployment of **advanced nuclear energy for enriched life (ANEEL)**, thorium-based fuel.

- Developed by CCTE, Aneel is a [thorium-based fuel](#) for [pressurised heavy water reactors \(PHWRs\)](#).
- The Department of Atomic Energy (DAE) plans to utilize India's abundant **thorium** reserves in its [three-stage nuclear power program](#) as a long-term strategy.

### What is Advanced Nuclear Energy for Enriched Life (ANEEL)?

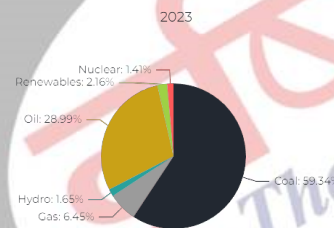
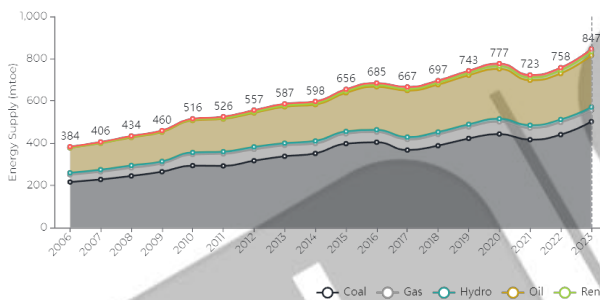
- **About:** ANEEL is a patented **nuclear fuel** that is a blend of **Thorium** and **High Assay Low Enriched Uranium (HALEU)**.
  - The fuel is named to honor **Dr. Anil Kakodkar**, one of India's foremost nuclear scientists.
  - HALEU is **uranium enriched between 5% and 20%**, required for many advanced nuclear reactor designs.
    - It is currently produced at scale only in **Russia and China**, with limited production in the US.
- **Compatibility with PHWRs:** ANEEL fuel can be used in **existing PHWRs**, which are the backbone of India's nuclear power fleet.
  - Presently, India has **22 operating reactors**, with an installed capacity of **6780 MWe**. Among these **18 reactors** are PHWRs and **4** are **Light Water Reactors (LWRs)**.
  - India is **building 10 more PHWRs**, each with a capacity of **700 MW**.
- **Ease of Thorium Deployment:** ANEEL provides an **easier and quicker alternative** for the deployment of thorium leveraging imported HALEU.
  - India's traditional approach involves creating **thorium blankets around uranium or plutonium reactors** to generate **uranium-233**, which is time-intensive.
- **Benefits:**
  - **Efficiency:** ANEEL fuel has a burn-up efficiency of **60,000 MW-days per tonne**, compared to **7,000 MW-days per tonne** for conventional natural uranium.
    - In a typical **220 MW PHWR**, the use of ANEEL fuel reduces the lifetime bundle requirement **from 1,75,000 to 22,000**, cutting waste volume and operational costs significantly.

- **Non-Proliferation:** Thorium and spent ANEEL fuel is **non-weaponizable**, easing proliferation concerns for foreign uranium suppliers and reactor operators.
- **Economic and Environmental Impact:** ANEEL fuel **reduces operating costs** for reactors due to its higher efficiency and longer-lasting fuel bundles.
  - It aligns with [India's clean energy goals](#) and the global commitment to **tripling nuclear capacity**, as highlighted during **COP28, Dubai, UAE**.
- **Global Collaboration:** The HALEU-thorium blend in ANEEL has gained **global attention** as **Canadian Nuclear Laboratories** signed an MoU with CTE to advance ANEEL fuel research and licensing.

## Thorium

- **About:** Thorium is a **silvery, slightly radioactive metal**. It is commonly found in [igneous rocks](#) and [heavy mineral sands](#).
- **Abundance:** Thorium is **three times more abundant** in the Earth's crust than uranium, with an average concentration of **10.5 parts per million (ppm)** of thorium, compared with about **3 ppm of uranium**.
- **Fissionable but Not Fissile:** The only naturally occurring isotope of [thorium](#) is thorium-232, which is **fissionable (can undergo fission) but not fissile (cannot sustain a chain reaction without external neutrons)**.
  - Thorium-232 requires **high-energy neutrons** to undergo fission.

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## What is a Thorium-based Nuclear Reactor?

- **About:** Thorium-based Nuclear Reactor uses **thorium-232 as a primary fuel** instead of uranium-235 or plutonium-239.
  - Thorium is **not a fissile material but a fertile material**, meaning it requires **pairing with Uranium-235 or Plutonium-239** to be used as nuclear fuel.
  - To **initiate and sustain** the nuclear reaction, thorium must be used along with a fissile material such as **233U, 235U or 239Pu**.
- **Fuel Cycle Strategies:**
  - **Thorium with Low Enriched Uranium (LEU):** LEU has a **235U enrichment of 19.75%** and is mixed with thorium to form **Thorium-LEU Mixed Oxide (MOX) fuel**.
  - **Thorium with Plutonium (Pu):** This configuration uses [plutonium](#) as an external fissile feed.
- **Advantages:**
  - **Reduced Nuclear Waste:** Thorium-based reactors produce significantly **fewer long-lived minor actinides** (ionizing radiation emitting elements) compared to uranium-plutonium fuel cycles.
  - **Safety:** The presence of 232U in spent fuel introduces **hard gamma radiation**, deterring weaponization.
  - **Recycling Potential:** Lower non-fissile absorption in 233U facilitates multiple recycling cycles, improving fuel efficiency.

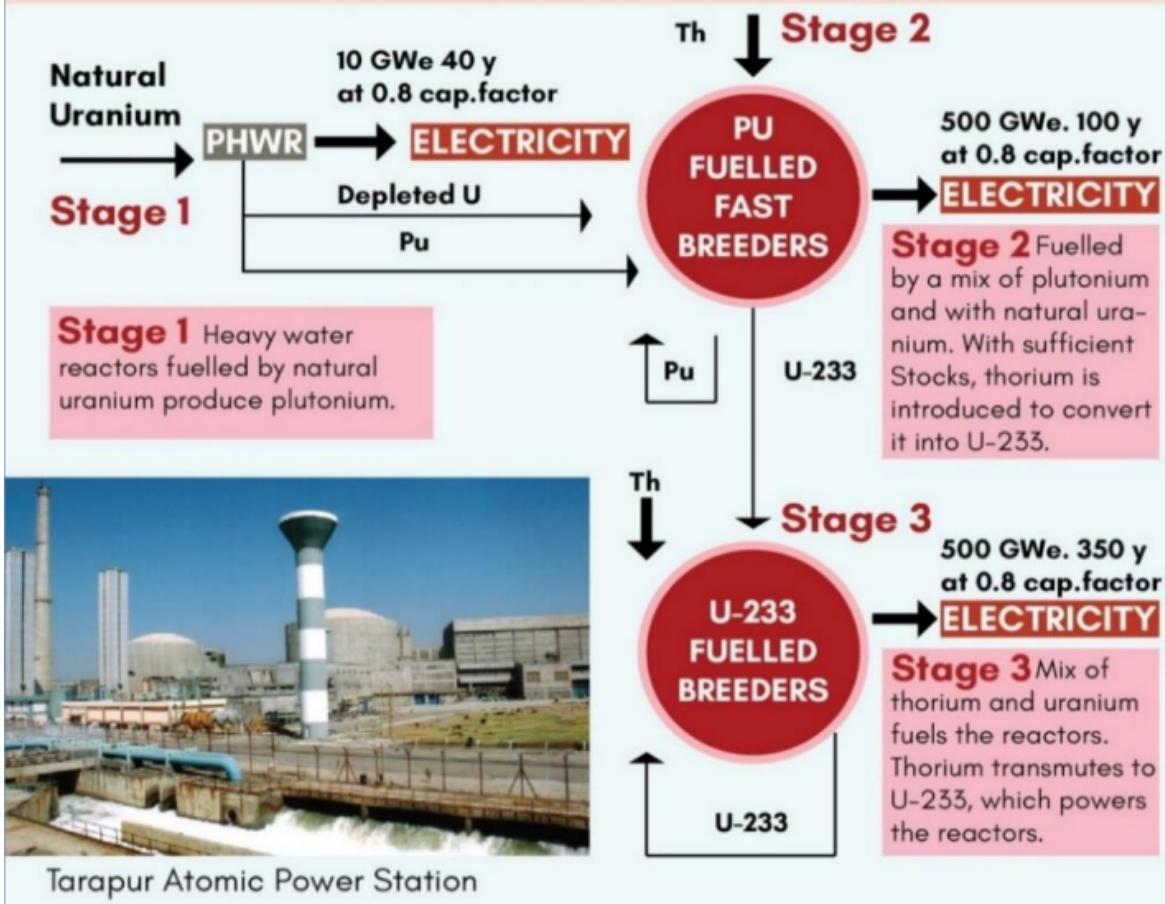
- **Enhanced Fuel Utilization:** Thorium can generate **more fissile uranium-233** than it consumes in water-cooled or molten-salt reactors, ensuring efficient fuel use.
- **Challenges:**
  - **Extraction Costs:** Thorium extraction is **costly**, as it is a **by-product of monazite mining** driven by rare earth demand, making dedicated mining uneconomical.
  - **Dependence on Fissile Drivers:** Thorium is a **fertile mineral**. It requires an **external fissile material** like **uranium-235 or plutonium-239** to initiate and sustain a chain reaction.
  - **Limited Experience:** Most nuclear power systems are **historically optimized for uranium**, leading to limited research, development, and operational experience with thorium.

## What is India's 3-Stage Nuclear Power Program?

- **About:** It is a strategy to develop nuclear energy that focuses on the **judicious utilization of limited uranium resources** and the **vast thorium reserves** available in the country.
  - It was formulated by **Dr. Homi Bhabha** to address India's long-term energy needs and ensure self-reliance.
- **3-Stages:** The 3-stage strategy integrates different types of reactors to gradually transition to thorium-based power generation.
  - **Stage I:** It includes the setting up of **PHWRs** and uses natural uranium (U-238) as fuel and **heavy water (deuterium oxide)** as coolant and moderator.
    - The spent fuel from these reactors is **reprocessed to obtain Plutonium**.
  - **Stage II:** It envisages use of **Fast Breeder Reactors (FBRs)** fuelled by **plutonium** produced in Stage I reactors.
    - In addition to using plutonium, **FBRs breed uranium-233 (U-233)** from thorium.
  - **Stage III:** It envisages use of **Thorium-Based Reactors** using **uranium-233 (U-233) and thorium as fuel**.
    - Stage III aims to use U-233, bred from **thorium, as India's primary nuclear fuel**.

# INDIA'S THREE-STAGE NUCLEAR PROGRAMME

Homi Bhabha envisioned India's nuclear power programme in three stages to suit the country's low uranium resources profile



**Note:** The operationalisation of the **prototype fast breeder reactor (PFBR)** will mark the start of **stage II** of India's three-stage nuclear power programme.

- The PFBR is a machine that **produces more nuclear fuel than it consumes**.
- Operationalisation of an **indigenous PFBR** has been initiated at the **Madras Atomic Power Station in Kalpakkam, Tamil Nadu**.

## Conclusion

India's nuclear strategy, based on its **3-stage program**, focuses on harnessing **abundant thorium reserves** for sustainable energy. Collaboration with CTE for advanced thorium fuel (ANEEL) highlights a **promising future for efficient, low-waste nuclear power**. Despite challenges, thorium's potential in **addressing India's energy needs is significant**.

### Drishti Mains Question:

Discuss the significance of thorium-based nuclear reactors in India's energy strategy. How does the 3-stage nuclear power programme align with this objective?

## UPSC Civil Services Examination, Previous Year Questions (PYQs)

### Prelims

**Q. In India, why are some nuclear reactors kept under “IAEA safeguards” while others are not? (2020)**

- (a) Some use uranium and others use thorium
- (b) Some use imported uranium and others use domestic supplies
- (c) Some are operated by foreign enterprises and others are operated by domestic enterprises
- (d) Some are State-owned and others are privately owned

**Ans: (b)**

**Q. In the Indian context, what is the implication of ratifying the ‘Additional Protocol’ with the ‘International Atomic Energy Agency (IAEA)’?(2018)**

- (a) The civilian nuclear reactors come under IAEA safeguards.
- (b) The military nuclear installations come under the inspection of IAEA.
- (c) The country will have the privilege to buy uranium from the Nuclear Suppliers Group (NSG).
- (d) The country automatically becomes a member of the NSG.

**Ans: (a)**

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### Mains

**Q. With growing energy needs should India keep on expanding its nuclear energy programme? Discuss the facts and fears associated with nuclear energy. (2018)**

**Q. Give an account of the growth and development of nuclear science and technology in India. What is the advantage of the fast breeder reactor programme in India? (2017)**