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)?

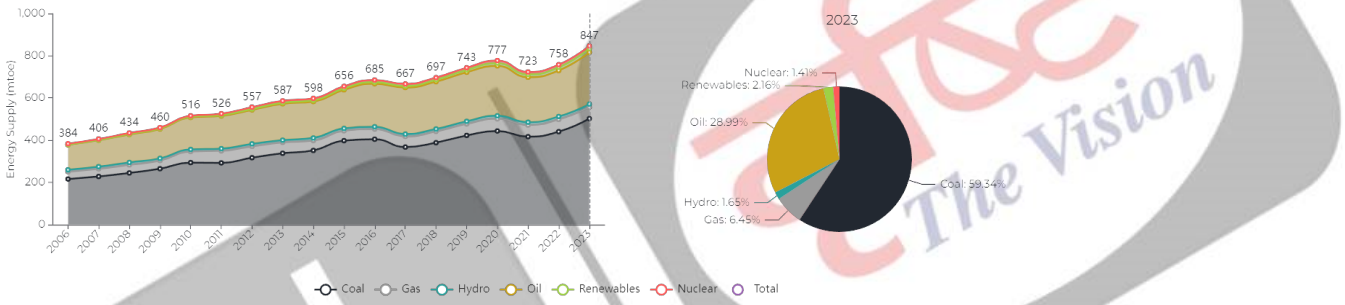
- **About:** ANEEL is a patented **nuclear fuel** that is a blend of **Thorium** and **High Assay Low Enriched Uranium (HALEU)**.
  - The fuel is named to honor **Dr. Anil Kakodkar**, one of India's foremost nuclear scientists.
  - HALEU is **uranium enriched between 5% and 20%**, required for many advanced 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 CCTE 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.

//



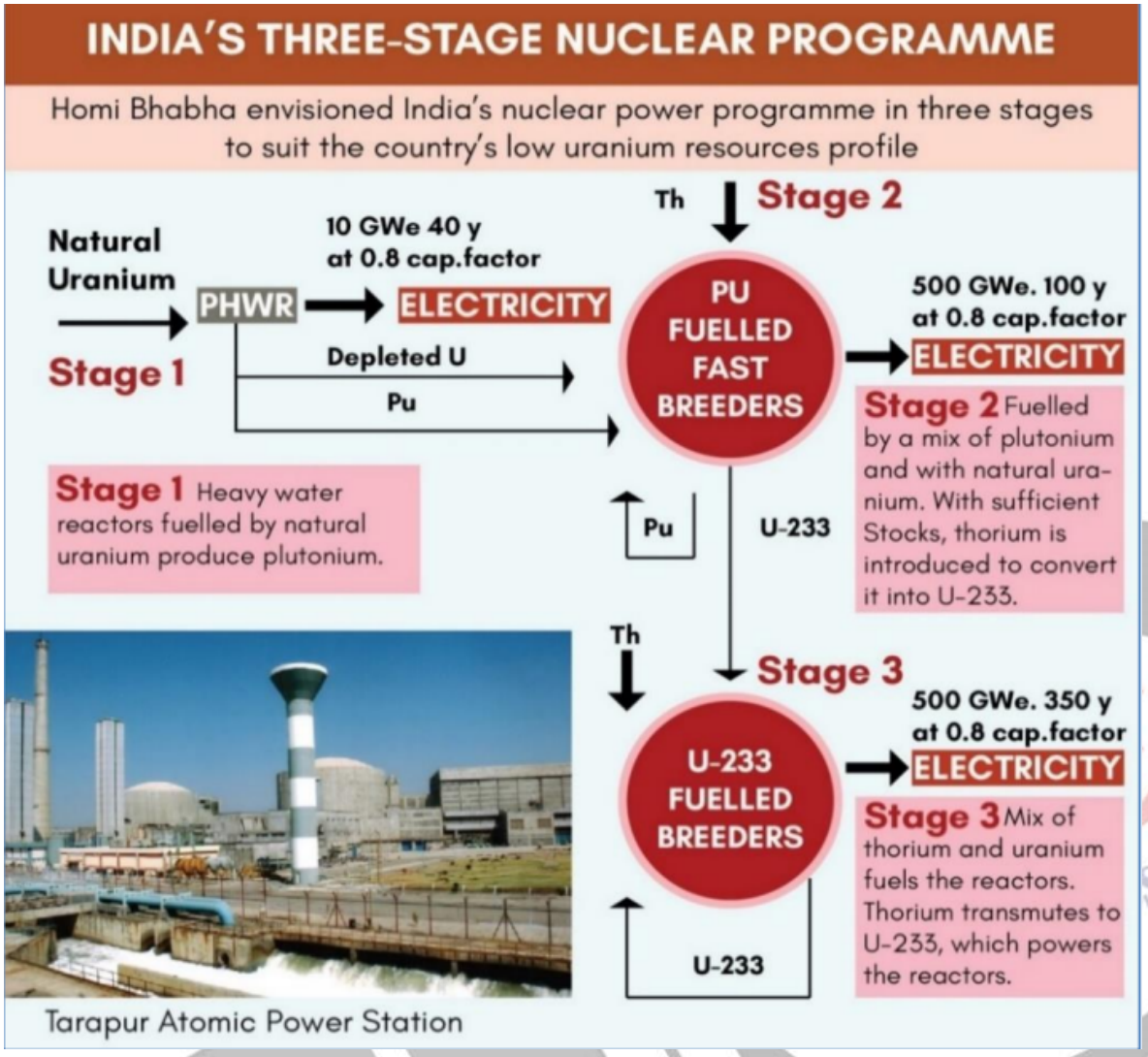
What is a Thorium-based Nuclear Reactor?

- **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.**



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 CCTE 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)

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)**