New Chapter in India's Nuclear Journey

Mains: *GS - III – Science & Technology*

Why in News?

India has marked a major milestone in its nuclear energy programme marking the initiation of a sustained nuclear chain reaction with its Prototype Fast Breeder Reactor (PFBR) at Kalpakkam in Tamil Nadu.

What about the Prototype Fast Breeder Reactor (PFBR)?

- **Fast Breeder Reactor (FBR)** – It is a nuclear reactor that *generates more fissile material (fuel) than it consumes* by using fast neutrons to convert non-fissile materials like Uranium-238 into Plutonium-239.
- These reactors are designed for high fuel efficiency, enabling the utilization of *over 60 times more energy from natural uranium*, and are critical for India's 3-stage nuclear program.
- **PFBR** – It represents decades of *indigenous research, design, and engineering*.
- **Technology development** – Indira Gandhi Centre for Atomic Research (IGCAR), an R&D centre under the Department of Atomic Energy.
- **Fuel & Design** – Unlike conventional thermal reactors, the PFBR uses *Uranium-Plutonium Mixed Oxide (MOX) fuel*.
- The fissile material used is recovered from the reprocessing of spent fuel from Pressurised Heavy Water Reactors, closing the loop on Stage 1.
- **Breeds More Than It Burns** – The core of the PFBR is surrounded by a blanket of Uranium-238.
- Fast neutrons convert this fertile material into fissile Plutonium-239, enabling the reactor to produce more fuel than it consumes.
- **Bridge to Stage 3** – The reactor is designed to eventually use Thorium-232 in the blanket.
- Through transmutation, Thorium-232 will be converted into Uranium-233, the fuel that will power India's third stage of nuclear energy based on thorium.
- **Closed Fuel Cycle** – The spent fuel generated by the PFBR will be reprocessed and recycled back into the reactor.
- This closes the second-stage fuel cycle and paves the way for large-scale use of India's abundant thorium reserves in Stage 3.
- **Recent Achievement**
- **Attained Criticality** – The indigenously designed & built Prototype Fast Breeder Reactor (PFBR) at Kalpakkam in Tamil Nadu successfully attained its first criticality.
- **PFBR at Kalpakkam** – It is a 500 MWe (MegaWatt electrical) reactor built by

Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI) at the Kalpakkam Nuclear Complex.

- **Significance** – With this achievement, India has *officially entered the second stage of its three-stage nuclear power programme*, a vision first conceived by Dr. Homi Jehangir Bhabha, the architect of India's nuclear programme.
- Once fully operational, India will become ***only the second country*** in the world **after Russia** to operate a commercial fast breeder reactor.

What is Criticality?

- **Criticality** – It is the point at which a *sustained and controlled nuclear fission chain reaction begins*.
- At this stage, neutrons produced by fission equal those lost through absorption and leakage, resulting in a stable power output.
- It marks the *transition* from the construction phase to the operational phase and is the essential first step towards generating heat and, ultimately, electricity.

What about India's Three-Stage Nuclear Power Programme?

- **Goal** – To progressively multiply domestic fissile resources and secure long-term energy independence.
- **Reserve status** – India holds limited uranium reserves but one of the largest thorium reserves in the world.
- **3 stage Nuclear Programme**
- **Stage 1: Pressurised Heavy Water Reactors (PHWRs)**
  - Natural uranium is used as fuel in PHWRs to generate power.
  - The spent fuel from these reactors produces plutonium, which becomes the primary input for the next stage.
- **Stage 2: Fast Breeder Reactors (FBRs)**
  - The plutonium obtained from Stage 1 is used as fuel in Fast Breeder Reactors, which generate more fuel than they consume.
  - The PFBR at Kalpakkam marks India's entry into this stage.
  - These reactors will be used to breed Uranium-233 from thorium, laying the groundwork for Stage 3.
- **Stage 3: Thorium-Based Reactors**
  - This stage will harness India's vast thorium reserves at scale, using the Uranium-233 bred in Stage 2 as fuel.
  - Thorium is considered a practically vast energy source and this stage holds the key to India's long-term energy security.
- Each stage feeds into the next, making India's nuclear programme one of the most forward-looking energy strategies in the world.

What about India’s Current Nuclear Power Landscape?

- **Electricity mix** – India's nuclear energy programme has maintained a *steady presence* in the country's electricity mix, now stands at a pivotal moment, with significant expansion planned over the coming years.
- **Installed Capacity** – India's current nuclear capacity is 8.78 Gigawatt (GW).

- In 2024–25, nuclear power plants generated 56,681 Million Units of electricity across the country.
- **Stable Contribution** – Nuclear power has *consistently accounted for around 3%* of India's total electricity generation, in 2024–25, its share stood at 3.1%.
- **Planned Expansion** – India's nuclear capacity is set to grow nearly 3x in the coming years.
- With indigenous 700-Megawatt (MW) reactors and 1,000 MW reactors being developed through international cooperation, the installed capacity is projected to reach 22.38 GW by 2031–32.
- **International Cooperation** – India has signed *Inter-Governmental Agreements (IGAs) on Civil Nuclear Cooperation* for peaceful purposes with 18 countries, reflecting the growing global confidence in India's nuclear programme.
- Taken together, Nuclear energy is no longer just a supplementary source of power in India, it is fast becoming a cornerstone of the country's clean energy future.

What is India's Long-Term Mission?

- **Nuclear Energy Mission** – Announced in the Union Budget 2025–26, with the aim of *achieving 100 GW* of nuclear power generation capacity *by 2047*.
- It also supports India's broader goal of achieving net zero carbon emissions by 2070.
- **India's need for Nuclear Power**
  - **Demand** – India's energy demands are growing rapidly and its clean energy commitments are firm.
  - **Base-load reliability** – Nuclear power is a base load source of electricity available round the clock, with lifecycle emissions comparable to renewables such as hydro and wind.
  - **Industrial backbone** – It is uniquely placed to meet the always-on power needs of data centres, advanced industries, and emerging technologies.
  - **Energy security** – Scaling nuclear capacity is therefore not just a strategic choice but a practical necessity for India's long-term energy security and clean power transition.

What are the measures taken by the government to drive India's nuclear vision forward?

- **Financial Commitment** – The Nuclear Energy Mission allocates Rs.20,000 crore towards the design, development, and deployment of Small Modular Reactors (SMRs), signaling a serious long-term investment in indigenous nuclear technology.
- **SMR Target** – At least five indigenously designed SMRs are to be operational by 2033, strengthening India's clean and reliable energy roadmap.
- **BARC Initiatives** – The Bhabha Atomic Research Centre (BARC) is leading the development of next-generation reactor designs, including
  - The 200 mwe Bharat Small Modular Reactor (BSMR-200),
  - The 55 mwe SMR-55, and
  - A High-Temperature Gas-Cooled Reactor of up to 5 mwth (Megawatt thermal) designed for hydrogen generation.
- **SHANTI Act, 2025** – The Government has enacted the 'The Sustainable Harnessing

and Advancement of Nuclear Energy for Transforming India (SHANTI) Act, 2025, which consolidates and modernises India's nuclear legal framework.
- It enables *limited private participation* in the nuclear sector under regulatory oversight, opening new avenues for collaboration and investment.
- **India's nuclear future** – India's long-term nuclear vision is ambitious by design.
- With policy backing, dedicated funding, and indigenous research at its core, the country is building a nuclear future that is both self-reliant and globally significant.

What lies ahead?

- The attainment of criticality at the Prototype Fast Breeder Reactor marks more than a technological milestone.
- It reflects the maturity of India's long standing nuclear vision and the strength of its indigenous capabilities.
- From limited uranium resources to a future powered by thorium, India's three stage programme is now moving steadily from design to delivery.
- This moment therefore stands as both an achievement and a turning point, strengthening the country's pathway towards energy security, technological self-reliance, and its net zero commitment for 2070.

Reference

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