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PFBR Kalpakkam Achieves First Criticality — India Enters Stage 2 of Nuclear Programme

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PFBR Kalpakkam Achieves First Criticality — India Enters Stage 2 of Nuclear Programme

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WHY IN NEWS

India’s **Prototype Fast Breeder Reactor (PFBR)** at **Kalpakkam, Tamil Nadu** achieved **first criticality** in early April 2026 — a landmark moment that takes India into the **second stage of its three-stage nuclear power programme**, originally envisaged by **Dr. Homi Bhabha** in the 1950s. India becomes only the **second country after Russia** to operate a commercial-scale fast breeder reactor.

WHAT IS THE PFBR?

PARAMETER	DETAILS
Full name	Prototype Fast Breeder Reactor
Capacity	500 MWe (Megawatts electric)
Reactor type	Sodium-cooled, pool-type fast breeder reactor
Fuel	Mixed Oxide (MOX) — Uranium-238 + Plutonium-239
Coolant	Liquid sodium
Builder	BHAVINI (Bharatiya Nabhikiya Vidyut Nigam Limited)
Location	Kalpakkam, Tamil Nadu
Commissioning approved	2003; construction began 2004

Key Features

- **Pool-type design:** Reactor core, primary coolant pumps, and intermediate heat exchangers all immersed in a single pool of liquid sodium — provides passive safety
- **Negative void coefficient:** If sodium boils away, reactor power decreases (a critical safety feature)
- **Indigenous design:** 70%+ of components manufactured in India — a major Aatmanirbhar Bharat achievement

WHAT DOES “CRITICALITY” MEAN?

In nuclear physics, **criticality** is the state where a nuclear chain reaction becomes **self-sustaining** — each nuclear fission event produces enough neutrons to trigger one more fission, on average. It is the moment a reactor “goes live” and begins generating heat through controlled fission.



STAGE	DESCRIPTION
First criticality	The reactor achieves a self-sustaining chain reaction at low power for the first time — a major milestone
Power ascension	Gradually increase power output, testing safety systems
Commercial operation	Reactor connects to grid and generates power at full capacity

PFBR has now achieved **first criticality**; the next steps are power ascension and grid connection.

INDIA'S THREE-STAGE NUCLEAR PROGRAMME

Designed by **Dr. Homi Bhabha** in the 1950s, India's nuclear programme is structured around its **abundant thorium reserves** but limited uranium reserves.

STAGE	REACTOR TYPE	FUEL	OUTPUT	STATUS
Stage 1	Pressurised Heavy Water Reactors (PHWRs)	Natural uranium	Electricity + plutonium-239	Operational (~24 reactors, 8,180 MW)
Stage 2	Fast Breeder Reactors (FBRs)	Plutonium + uranium-238 (MOX)	Electricity + more plutonium + U-233 from thorium	PFBR critical April 2026 ✓
Stage 3	Thorium-based reactors (AHWR, MSR)	U-233 from thorium-232	Electricity from India's vast thorium reserves	Future (2030s-40s)

Why Three Stages?

India has only **~1-2% of global uranium reserves** but **~25-30% of global thorium reserves**. The three-stage programme is designed to **convert thorium** (which cannot directly fuel reactors) into fissile **U-233** through neutron capture in fast breeder reactors. Stage 2 is the **bridge** between Stage 1 (uranium) and Stage 3 (thorium).



WHAT IS A FAST BREEDER REACTOR?

A **Fast Breeder Reactor (FBR)** is a special type of nuclear reactor that **produces more fissile material than it consumes** — hence “breeder.” It does this by:

- ❶ Using **fast neutrons** (uncooled by moderators like water/graphite)
- ❷ Surrounding the reactor core with a “**blanket**” of fertile material (uranium-238 or thorium-232)
- ❸ The fast neutrons convert $U-238 \rightarrow \text{Plutonium-239}$ (or $Th-232 \rightarrow U-233$) — both fissile

Net result: The reactor produces more fissile material than it started with, multiplying nuclear fuel reserves.

WHY SODIUM COOLANT?

Conventional reactors use water as coolant, but water slows down neutrons (acting as a moderator). FBRs need **fast neutrons**, so they use:

- **Liquid sodium** — does not moderate neutrons; excellent heat transfer
- High boiling point ($\sim 880^\circ\text{C}$) — operates at atmospheric pressure
- Drawback: reacts violently with water and air \rightarrow requires elaborate safety systems

GLOBAL FAST BREEDER REACTORS

COUNTRY	REACTOR	STATUS
Russia	BN-600 (Beloyarsk)	Operational since 1980
Russia	BN-800 (Beloyarsk)	Operational since 2016
India	PFBR (Kalpakkam)	Critical April 2026
China	CFR-600	Under construction
France	Superphénix (decommissioned)	Operated 1985-1997
Japan	Monju (decommissioned)	Closed 2016

India is now in an **exclusive club of FBR operators**.



STRATEGIC SIGNIFICANCE

Energy Security

Once Stage 3 is operational (2030s+), India's vast thorium reserves can power the country for **centuries** without uranium imports. This is a fundamental energy independence play.

Climate Change

Nuclear is **carbon-free**. India's commitment to net-zero by 2070 requires massive low-carbon generation — the SHANTI Act (2025) enables private sector entry into nuclear, and PFBR is critical to scaling up.

Aatmanirbhar Bharat

PFBR is **70%+ indigenous** — its successful operation validates decades of investment in domestic nuclear technology by **BARC, IGCAR (Indira Gandhi Centre for Atomic Research), and BHAVINI**.

UPSC RELEVANCE

GS Paper 3 — Science & Technology, Energy

- Three-stage nuclear programme: stages, rationale, status
- Fast Breeder Reactors: principle, advantages, safety
- India's nuclear ecosystem: BARC, IGCAR, BHAVINI, DAE
- Thorium and India's energy security
- SHANTI Act and private sector entry into civil nuclear

Prelims Fast Facts:

- PFBR location: **Kalpakkam, Tamil Nadu**
- PFBR capacity: **500 MWe**
- Fuel: **MOX (Uranium-238 + Plutonium-239)**
- Coolant: **liquid sodium**
- Builder: **BHAVINI**
- Programme designer: **Dr. Homi Bhabha (1950s)**
- Stage 1: **PHWRs (uranium)**; Stage 2: **FBRs (MOX)**; Stage 3: **Thorium reactors**
- India's installed nuclear capacity: **8,180 MW** (target: 100 GW by 2047)



FACTS CORNER

- **BHAVINI (Bharatiya Nabhikiya Vidyut Nigam Limited)** was incorporated in **2003** specifically to build and operate PFBR — it is the only Indian company dedicated to fast reactor technology.
- The **PFBR project** has faced delays — originally targeted for 2010 commissioning, the project encountered technical challenges with sodium handling, MOX fuel fabrication, and component manufacturing.
- **India's thorium reserves** are estimated at **~12 lakh tonnes** — about 25-30% of global reserves. Found mainly in monazite sands of Kerala, Tamil Nadu, and Odisha beaches.
- The **Indira Gandhi Centre for Atomic Research (IGCAR)** in Kalpakkam is India's premier R&D institute for fast reactor technology — it operated the **Fast Breeder Test Reactor (FBTR)** since 1985, which provided the technological foundation for PFBR.
- **India's civil nuclear cooperation** with countries (US, France, Russia) is enabled by the 2008 NSG waiver — but India's three-stage programme is largely indigenous, since fast reactors and thorium technology are not part of standard international nuclear commerce.
- The **SHANTI Act, 2025** (Strategic and Hybrid Atomic Nuclear Technology Initiative) opens civil nuclear projects to private participation up to 49% equity — a **paradigm shift** from state monopoly that should accelerate India's nuclear capacity expansion.

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