PROTOTYPE FAST BREEDER REACTOR – SCIENCE & TECHNOLOGY

NEWS: India's **first prototype fast-breeder reactor (BHAVINI's 500 MW PFBR)** is in the **advanced stage of integrated commissioning,** with expected **first criticality by 2025-26.**

WHAT'S IN THE NEWS?

About the Prototype Fast Breeder Reactor (PFBR)

1. **Location and Capacity**
    - The **Prototype Fast Breeder Reactor (PFBR)** is designed to generate **500 megawatts of electrical power (MWe)**.
    - It is situated in **Kokkilamedu**, near **Kalpakkam**, in the **state of Tamil Nadu**, India.
2. **Reactor Type**
    - The PFBR is a **sodium-cooled fast breeder reactor**.
    - **Fast breeder reactors (FBRs)** do not use moderators to slow down neutrons, enabling them to convert more fertile material into fissile fuel than they consume.
    - **Sodium**, a liquid metal, is used as the coolant instead of water due to its superior heat transfer properties and its ability to remain liquid at high temperatures without requiring high pressure.
3. **Strategic Significance**
    - The PFBR is a **key component of the second stage** of **India's three-stage nuclear power programme**.
    - This project aims to **improve India's energy security** by utilizing domestic resources and minimizing the need for **imported uranium**, which is scarce and geopolitically sensitive.
4. **Fuel Type**
    - The reactor will use **Uranium-Plutonium Mixed Oxide (MOX)** fuel, which combines plutonium extracted from spent fuel with natural or depleted uranium.

- This form of fuel is efficient and helps **recycle plutonium** generated from the first stage of nuclear reactors.

5. **Coolant Choice**

    - **Liquid sodium** is employed as the coolant because it allows for **efficient heat removal** and maintains the fast neutron spectrum needed for breeding reactions.

    - Sodium's non-moderating nature helps sustain a fast neutron environment suitable for converting fertile material (like U-238) into fissile material (like Pu-239).

6. **Use of Spent Fuel**

    - The PFBR will also **reprocess and utilize the spent fuel** from **Stage 1 Pressurised Heavy Water Reactors (PHWRs)**.

    - This process ensures **better fuel efficiency and sustainability** by closing the nuclear fuel cycle.

7. **Implementing Agency**

    - The project is being implemented by **Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI)**, a public sector undertaking under the **Department of Atomic Energy (DAE)**, Government of India.

    - BHAVINI was specially established to build and operate fast breeder reactors in India.

About India's 3-Stage Nuclear Programme

1. **Stage 1: Pressurised Heavy Water Reactors (PHWRs)**

    - In this stage, **natural uranium** is used as fuel.

    - **Heavy water (D_2O)** acts as both a moderator and coolant in PHWRs.

    - During reactor operation, uranium-238 is partially converted to **plutonium-239**, a fissile material, as a byproduct.

    - PHWRs form the **foundation of India's current nuclear power generation capacity**.

2. **Stage 2: Fast Breeder Reactors (FBRs)**

- This stage uses the **plutonium obtained from Stage 1** as a key fuel component.
- The reactor uses a combination of **plutonium and natural uranium**, where plutonium provides energy and uranium-238 acts as a fertile material to breed more plutonium.
- **Breeder reactors** are capable of producing more fissile material than they consume, hence enhancing fuel sustainability.
- The PFBR is a **prototype to demonstrate and commercialize this second stage**.

3. **Stage 3: Thorium-Based Reactors**
    - This future stage is designed to utilize **India's vast thorium reserves**, which are more abundant than uranium in the country.
    - **Thorium-232** is a fertile material that can be converted into **uranium-233**, a fissile material, inside the reactor.
    - This stage envisions the development of **Advanced Heavy Water Reactors (AHWRs)** or **Molten Salt Breeder Reactors (MSBRs)** to efficiently harness thorium.
    - It aims to ensure **long-term energy independence** for India by transitioning to **thorium-based fuel cycles**.

Background of India's Nuclear Energy Programme

- **Atomic Energy Commission:** The Atomic Energy Commission (AEC), set up in 1948 under the leadership of Homi J. Bhabha, marked the beginning of India's nuclear program.
- **Atomic Energy Establishment:** In 1954, the Atomic Energy Establishment, Trombay (AEET), was founded, which later became the Bhabha Atomic Research Centre (BARC).
- **Nuclear Power:** India's first nuclear power plant was commissioned in 1969 at Tarapur, Maharashtra, which marked a **significant step in the country's nuclear power generation.**
- **Pokhran Tests: I**ndia demonstrated its nuclear capabilities to the world with the peaceful nuclear explosion at Pokhran in 1974, and later in 1998.

- **Indigenous Development:** Post the Pokhran tests, India faced international embargos which led to the development of indigenous technology for both power generation and strategic purposes.

What is India's 3 Stage Nuclear Program:

- The goal of the three-stage nuclear programme is to use India's enormou**s uranium deposits, which make up around 25% of the global total.**
    - **In addition, India only possesses 2% of the world's uranium deposits, making them scarce.**
- **Stage I: Pressurized Heavy Water Reactors (PHWRs):**
    - Pressurized heavy water reactors (PHWRs) are used in the first phase of India's three-stage nuclear power development.
    - These reactors create **plutonium-239** as a byproduct in addition to power.
    - PHWRs were selected for the first phase because of their effective reactor design, which maximizes the use of uranium.
    - **Utilization and Operation of Uranium:**
        - **Use of Natural Uranium:** PHWRs burn natural uranium, which is primarily composed of uranium-238.
        - **Production of Plutonium:** In a reactor, uranium-238 can be transformed into plutonium-239.
        - **Heavy Water Usage:** In PHWRs, heavy water, or deuterium oxide, or D2O, is used as a coolant and moderator.
    - **PHWR Series:** Based on the original Canadian CANDU reactors, India has built a series of PHWRs known as the IPHWR series.
        - Reactor designs with capacities of 220 MWe, 540 MWe, and 700 MWe are part of the IPHWR series.
    - **Installed Capacity:** First-stage PHWRs from the IPHWR series make up the majority of India's current nuclear power capacity.
    - **Upcoming Developments:** In order to augment PHWRs, India is developing reactors based on Pressurised Water Reactor technology, such as the **IPWR-900 reactor platform.**
- **Stage II: Fast Breeder Reactor (FBR):**

- Fast breeder reactors (FBRs) are used in the second phase of India's three-stage nuclear power development.
- **Composition and Type of Fuel:**
    - **Type of Fuel:** FBRs use a **mixed oxide (MOX) fuel** composed of plutonium-239 recovered from spent fuel from the first stage and natural uranium.
    - **Fission Process:** In order to produce energy in FBRs, plutonium-239 undergoes fission.
    - **Breeding Fuel:** FBRs are able to "breed" more fuel than they consume because uranium-238 in the mixed oxide fuel transmutes to more plutonium-239.
- **Change to Thorium:**
    - When there is enough plutonium-239 in stock, thorium can be added to the reactor as a blanket material.

- **Stage III: Thorium-Based Reactors:**
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    - In the third stage of India's three-phase nuclear power programme, self-sustaining reactors powered by **uranium-233 and thorium-232 will be deployed.**
    - **Features of Reactors:**
        - **Refueling:** Reactors classified as thermal breeder reactors are able to be refuelled with naturally occurring thorium following the initial fuel charge.
        - **Fuel Composition:** The main fuel used in the reactor is thorium-232, which is converted to uranium-233 to provide energy.
    - **Implementation Plan:**
        - **Capacity Growth:** By using PHWRs and FBRs, the third stage is expected to help India's nuclear energy sector grow beyond 10 GW.
        - **Timeline:** It is anticipated that full thorium reserve exploitation in India **would take place three to four decades after fast breeder reactors begin commercial operations.**

- **Other Methods:**
    - **Indian Accelerator Driven Systems (IADS):** To exploit thorium, innovative accelerator-driven systems are being developed in partnership with Fermilab, a US laboratory.
    - **Advanced Heavy Water Reactor (AHWR):** The Advanced Heavy Water Reactor (AHWR) is a reactor design that is ready for deployment and runs on fuel composed of uranium-thorium MOX and plutonium-thorium MOX. It can use thorium to produce a sizable amount of its electricity.
    - **Molten Salt Reactor:** An experiment to determine whether molten salt technology can be used to produce thorium is being conducted with the Indian Molten Salt Breeder Reactor (IMSBR).

Prototype Fast Breeder Reactor

- **Beginning of Stage II:** The country's three-stage nuclear power programme begins with PFBR, the second stage, where the **spent fuel from the first stage will be "reprocessed and used as fuel."**
- **Feature:** This sodium-cooled PFBR's ability to create more fuel than it consumes makes it special **and contributes to future fast reactors' ability to become self-sufficient in their fuel supply.**
- **Design and Construction: T**he nation's first fast breeder reactor, the PFBR **was created by the Indira Gandhi Centre for Atomic Research (IGCAR).**
- **Responsibility:** The Department of Atomic Energy's (DAE) public sector enterprise Bharatiya Nabhikiya Vidyut Nigam Ltd (Bhavini) is in charge of constructing fast breeder reactors in India.

Advantages of Fast Breeder Reactors

- **Efficient Utilization of Resources:** FBRs can utilize uranium more efficiently by converting non-fissile uranium (U-238) into fissile plutonium (Pu-239). An example of this is the Prototype Fast Breeder Reactor (PFBR) at Kalpakkam.
- **Reducing Nuclear Waste:** FBRs can help in reducing the amount of nuclear waste due to their ability to **burn actinides, which are major contributors to long-term radiotoxicity of nuclear waste.**
- **Energy Security:** FBRs are vital for long-term energy security in India, which has limited reserves of uranium but abundant reserves of thorium. **This thorium can be converted into fissile uranium-233 in FBRs.**

Status of Nuclear Power in India

- **Fifth Largest source:** After gas, coal, hydroelectricity, and wind power, nuclear power is the fifth-largest source of electricity in India.
- **Capacity:** With a total installed capacity of 7,380 MW, India operates 22 nuclear reactors spread over 8 nuclear power stations as of November 2020.
    - 3.11% of India's total power generation in the fiscal year **2020–21 came from nuclear power, which produced 43 TWh out of 1,382 TWh.**

Source: https://www.thehindu.com/news/national/indias-first-prototype-fast-breeder-reactor-to-be-commissioned-by-september-2026/article69467909.ece