Challenges of Handling Nuclear Waste

For Prelims: Prototype fast breeder reactor (PFBR), Uranium and plutonium, Nuclear waste, Spent fuel, Liquid waste treatment facilities, International Panel on Fissile Materials (IPFM).

For Mains: Developments Related to Nuclear Energy, Ways to Enhance Nuclear Power Capacity, Issues related to Nuclear Waste

Source: TH

Why in News?

Recently, India loaded the core of its long-delayed prototype fast breeder reactor (PFBR) vessel, bringing it to the cusp of stage II — powered by **uranium and plutonium** — of its three-stage nuclear programme.

- By **stage III**, India hopes to be able to **use its vast reserves of thorium** to produce nuclear power.
- Managing nuclear waste poses a significant challenge due to the widespread use of nuclear power.

Prototype Fast Breeder Reactor (PFBR):

- A breeder reactor is a nuclear reactor that **generates more fissile material than it consumes** by irradiation of fertile material, such as Uranium-238 or Thorium-232 that is loaded into the reactor along with fissile fuel.
- These are designed to extend the nuclear fuel supply for electric power generation.
- PFBR is a 500-megawatt electric (MWe) fast-breeder nuclear reactor presently being constructed at the Madras Atomic Power Station in Kalpakkam (Tamil Nadu).
    - It is fuelled by Mixed Oxide (MOX) Fuel.

What is Nuclear Waste?

- In a **fission reactor, neutrons bombard the nuclei of atoms of certain elements**. When one such nucleus absorbs a neutron, it destabilises and breaks up, yielding some energy and the nuclei of different elements.
    - **For example**, when the **uranium-235 (U-235)** nucleus absorbs a neutron, it can fission to **barium-144, krypton-89, and three neutrons.** If the '**debris' (barium-144 and krypton-89)** constitute elements that can't undergo fission, they become nuclear waste.
    - Fuel loaded into a nuclear reactor becomes irradiated and must eventually be removed, at which point it is known as **spent fuel.**
- Nuclear waste is **highly radioactive** and needs to be **stored in facilities reinforced to prevent leakage** into and/or contamination of the local environment.

Note

- Fission is a process in which the nucleus of an **atom splits into two or more smaller nuclei** and some byproducts.
    - When the **nucleus splits, the kinetic energy** of the fission fragments (primary nuclei) is transferred to other atoms **in the fuel as heat energy**, which is eventually used to produce steam to drive the turbines.
- Fusion is defined as the **combining of several small nuclei into one large nucleus** with the subsequent release of huge amounts of energy.
    - Harnessing fusion, **the process that powers the Sun** could provide a limitless, clean energy source.
        - In the sun, the extreme pressure produced by its immense gravity creates the conditions for fusion to happen.

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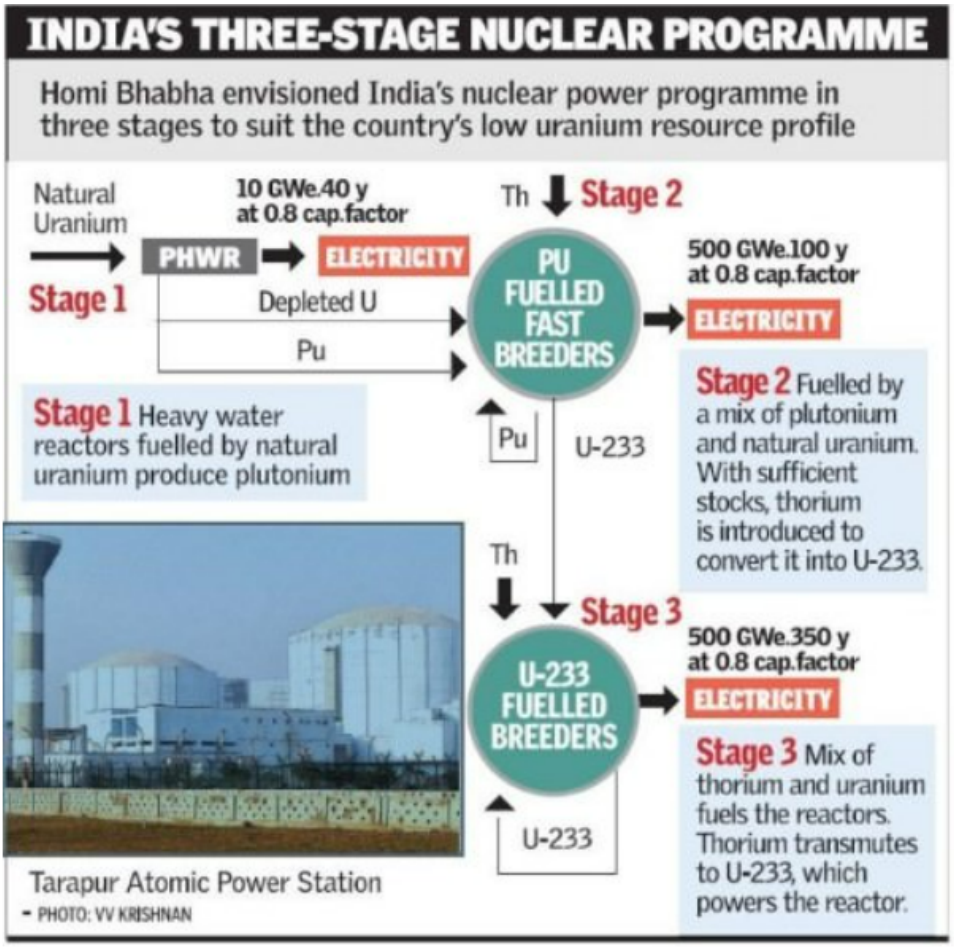


How can Nuclear Waste be Managed Safely and Effectively?

- The primary challenge is managing **spent fuel**, which is hot and radioactive. It must be **submerged in water for several decades before it can be transferred to dry casks** for long-term storage once it has cooled.
    - All countries with longstanding nuclear power programmes have accumulated a considerable inventory of spent fuel.
    - For example, the **US had 69,682 tonnes (tn), Canada 54,000 tn**, and **Russia 21,362 tn.**
- Depending on radioactivity levels, **the storage period can run up to a few millennia (1000 years)**, as they have to be isolated from human contact for periods of time that are longer than

anatomically modern **Homo sapiens** have been around on the planet.
    - Nuclear power plants also have **liquid waste treatment facilities.**
        - Japan is currently discharging, after treatment, such water from the Fukushima nuclear power plant into the Pacific Ocean.
    - Other such waste, depending on their hazard, can be evaporated or "chemically precipitated" which means the sludgy substance can be managed by either being soaked up by solid materials or burned.
    - **Liquid high-level waste** contains "almost all of the fission products produced in the fuel". It is **vitrified to form a storable glass.**
- Some experts advocate for **geological disposal, where the waste is sealed in special containers and buried underground in granite or clay.**
- Another way to deal with the **spent fuel is Reprocessing** — which separates fissile from non-fissile material in spent fuel.
    - The material is chemically treated to separate fissile material left behind from the non-fissile material.
    - Because spent fuel is so hazardous, reprocessing facilities need specialised protections and personnel of their own.
    - Such facilities present the **advantage of higher fuel efficiency** but are also expensive.
    - Reprocessing also yields weapons-usable (different from weapons-grade) plutonium.
        - **Weapons-grade plutonium is highly pure**, ideal for efficient and compact nuclear weapons.
        - Weapons-usable plutonium, including **reactor-grade or from dismantled weapons**, may require more material or special designs, impacting efficiency and design options.

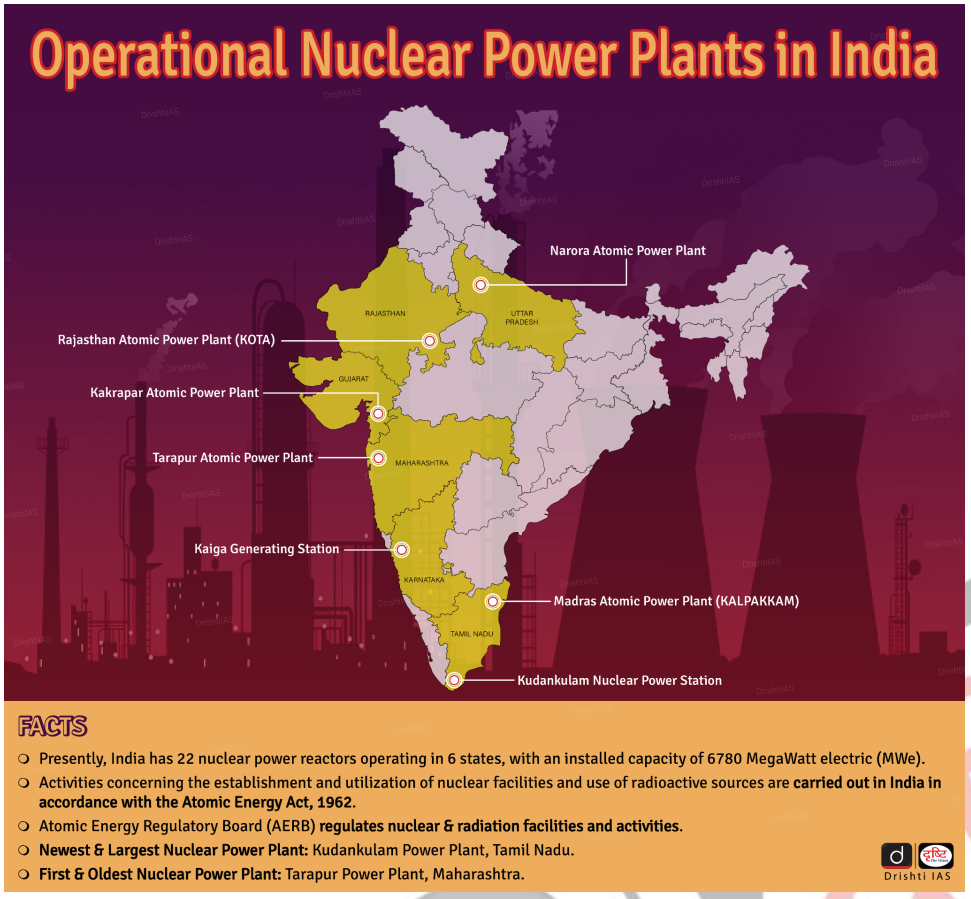
What are the Challenges in Managing Nuclear Waste?

- **Geological Disposal Leakage**: The **geological disposal of nuclear waste poses the risk of radioactive material** being exposed to humans in the event that containers are disturbed, for instance, **through nearby excavation activities.**
    - **Example:** Waste Isolation Pilot Plant, US, has a licence to store waste for a few millennia. In 2014, an **accident at the site released small quantities of radioactive materials into the environment**, revealing serious failures in its maintenance.
- **Exclusion of Private Sector**: Private sector involvement often drives innovation through competition and market incentives. **Without private sector participation,** there may be **less incentive to develop new technologies and processes** for more efficient and effective nuclear waste treatment.
- **Unutilized Fund**: The US's **Nuclear Waste Policy Act of 1982** mandated that a portion of electricity generated from nuclear power be allocated to a '**Nuclear Waste Fund,**' which would finance a geological disposal facility.
    - Despite amassing a corpus of USD 40 billion as of July 2018, **the fund has faced criticism for remaining unutilized for its intended purpose.**
- **Lack of International Cooperation**: Stakeholders often lack cooperation, hindering effective management of nuclear waste. As nuclear waste is a global issue, international collaboration is essential to share knowledge, develop best practices, and ensure responsible management across all countries utilizing nuclear energy.

How does India handle nuclear waste?

- According to a 2015 report from the **International Panel on Fissile Materials (IPFM),** India has reprocessing plants in **Trombay, Tarapur, and Kalpakkam.**
    - The **Trombay facility** reprocesses 50 tonnes of heavy metal per year (tHM/y) as spent fuel from two research reactors **to produce plutonium for stage II reactors as well as nuclear weapons.**
    - Of the **two in Tarapur,** one used to reprocess 100 tHM/y of fuel from some **pressurised heavy water reactors (stage I)** and the other, commissioned in 2011, has a capacity of 100 tHM/y.
    - The third facility in **Kalpakkam processes 100 tHM/y.**
- The report also suggested the **Tarapur and Kalpakkam facilities** operate with a combined

average capacity factor of around 15%.



Way Forward

- **Reprocessing**: It involves **separating usable materials from spent nuclear fuel.** Reprocessing allows for the recycling of valuable elements like plutonium and uranium, reducing the volume of high-level waste that requires long-term storage.
- **Vitrification:** The process involves **encasing radioactive waste in glass,** which immobilises the hazardous components and **prevents leaching into the environment.**
    - It is used for high-level radioactive waste and helps ensure long-term stability.
- **Research and Development**: Need to invest in research to **explore alternative disposal methods and innovative technologies** for nuclear waste management.
    - This includes investigating advanced materials for containment, exploring geological disposal options, and developing more efficient waste treatment processes.
- **Regulatory Oversight:** Strict regulatory frameworks are essential **to ensure the safe handling, transportation, and storage of nuclear waste**. India's regulatory agencies monitor compliance with safety standards and enforce regulations to mitigate environmental and health risks associated with nuclear waste.
- **International Cooperation**: Nuclear waste is a global issue. International collaboration is necessary to **share knowledge, develop best practices, and ensure responsible management across all countries** utilizing nuclear energy.

UPSC Civil Services Examination, Previous Year Question (PYQ)

Prelims

Q. India is an important member of the 'International Thermonuclear Experimental Reactor'. If

this experiment succeeds, what is the immediate advantage for India? (2016)

(a) It can use thorium in place of uranium for power generation

(b) It can attain a global role in satellite navigation

(c) It can drastically improve the efficiency of its fission reactors in power generation

(d) It can build fusion reactors for power generation

Ans: (d)

Q. The function of heavy water in a nuclear reactor is to (2011)

(a) Slow down the speed of neutrons

(b) Increase the speed of neutrons

(c) Cool down the reactor

(d) Stop the nuclear reaction

Ans: (a)

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 privatelyowned

Ans: (b)

Mains:

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