India’s Nuclear Expansion Raises Long-Term Challenges of Radioactive Waste Management, Financing and Institutional Responsibility

Published On: 29-09-2026

Recent Developments:

- India’s **Nuclear Energy Mission** aims to raise nuclear power capacity to **100 GW by 2047**, increasing the role of nuclear energy as a reliable, low-carbon baseload source while supporting the Net Zero target for 2070. The expansion also envisages wider participation of the private sector.
- The **SHANTI Act, 2025** has enabled wider public and private participation in the nuclear power sector while modernising the legal framework for nuclear energy, safety and liability. Sensitive nuclear fuel-cycle activities continue to remain under sovereign control.
- As of 2026, India’s installed nuclear power capacity was **8.78 GW**, with the government roadmap targeting about **22 GW by 2031–32** and 100 GW by 2047. The roadmap envisages contributions from NPCIL, other public-sector entities, private companies and joint ventures.
- The expansion of nuclear capacity increases the importance of **spent-fuel management, radioactive-waste conditioning, interim storage, decommissioning and eventual geological disposal** over much longer time horizons than the operating life of individual reactors.

Radioactive Waste Management: Concept and India’s Approach:

Closed Fuel Cycle:

- In a conventional **once-through fuel cycle**, nuclear fuel is used in a reactor and the discharged spent fuel is ultimately treated as waste requiring long-term disposal.
- India follows a **closed nuclear fuel cycle**, under which spent fuel is reprocessed to recover uranium and plutonium for further utilisation. The approach is intended to maximise energy extraction from limited uranium resources and support the long-term transition towards thorium utilisation.
- Spent fuel is therefore not treated entirely as waste in the Indian system because it contains **potentially reusable nuclear material**.
- Reprocessing can substantially reduce the volume of high-level waste requiring geological disposal, but it **does not eliminate radioactivity or the need for long-term isolation**. According to the Atomic Energy Regulatory Board, only around 2–3% of reprocessed spent fuel ultimately becomes waste, while the remaining material can be recycled.

Nuclear Fuel and Radioactive-Waste Management Chain:

Cooling and Interim Storage:

- Freshly discharged fuel remains **highly radioactive and thermally hot**, requiring initial cooling in spent-fuel pools followed by appropriate interim storage arrangements.
- Interim storage provides time for radioactive decay, heat reduction and subsequent treatment before final disposal.

Reprocessing:

- Spent fuel can undergo chemical reprocessing to recover **uranium and plutonium**, which can subsequently support further fuel fabrication and the closed fuel cycle.
- Reprocessing also separates high-level radioactive residues from materials that can potentially be reused.

Waste Conditioning:

- Radioactive residues that cannot be reused are converted into **stable and immobilised forms** suitable for storage and disposal.
- High-level liquid radioactive waste can be immobilised through **vitrification**, in which radioactive material is incorporated into a stable glass matrix.
- India has continued to develop high-level waste-management technologies, including an advanced vitrification facility at Tarapur.

Final Disposal:

- **Deep geological disposal** is intended for long-lived high-level radioactive waste that requires isolation from the biosphere over very long periods.
- India's regulatory framework recognises geological disposal as the eventual pathway for high-level waste, while the country continues to undertake technological and geological studies for such facilities.

Geological Repository: Long-Term Solution:

What is a Deep Geological Repository?

- A **deep geological repository** is an engineered facility designed to isolate long-lived radioactive waste deep underground within stable geological formations.
- Safety depends on a **multi-barrier system**, combining the waste form, engineered containers, surrounding materials and geological formations to prevent radionuclide migration.
- A geological repository differs from an interim storage facility because its primary purpose is **long-term isolation rather than temporary holding**.
- India has considered geological disposal for high-level waste, with repository planning linked to the volume, characteristics and long-term management strategy for radioactive waste.

Why Long-Term Radioactive-Waste Management Matters:

Intergenerational Responsibility:

- Radioactive waste can remain hazardous for **very long periods**, making its management fundamentally different from conventional industrial waste.
- Present-day nuclear expansion therefore creates responsibilities that may extend across several generations.

Financial Responsibility:

- Waste treatment, long-term storage, reactor decommissioning and geological disposal can generate significant costs **decades after a nuclear plant begins operation**.
- If adequate financial provisions are not created during the operating period, future governments and taxpayers may ultimately bear a disproportionate share of these costs.

Institutional Continuity:

- Nuclear reactors may operate for several decades, whereas radioactive-waste management and monitoring can continue for much longer.

- Responsibility must therefore remain clearly defined even if an operator **changes ownership, exits the sector, becomes financially inactive or shuts down a reactor**.

Emerging Concerns with Private Participation:

Defining Responsibility Across the Fuel Cycle:

- The expansion of private participation makes it necessary to clearly distinguish the responsibilities of **private operators, public-sector entities, regulators and the government** for spent fuel, radioactive waste, decommissioning and long-term disposal.
- The SHANTI Act enables wider participation while retaining sovereign control over sensitive areas of the nuclear fuel cycle.

Public Acceptance and Environmental Justice:

- Communities may oppose radioactive-waste facilities because of concerns regarding **radiation exposure, environmental safety, land use, property values and long-term ecological risks**.
- Transparent risk communication, independent monitoring and meaningful public consultation are therefore important for social acceptance.

Regulatory Continuity:

- The **Atomic Energy Regulatory Board (AERB)** regulates radioactive-waste management associated with nuclear and radiation facilities and reviews waste management across the lifecycle of nuclear power plants, from siting and construction to operation and decommissioning.
- Radioactive-waste disposal is governed by the **Atomic Energy (Safe Disposal of Radioactive Wastes) Rules, 1987**, under which authorisation is required for disposal.

India's Three-Stage Nuclear Power Programme:

Stage I: Pressurised Heavy Water Reactors:

- India's three-stage nuclear programme was conceptualised under **Dr Homi Jehangir Bhabha** to maximise energy extraction from limited uranium resources and progressively utilise India's large thorium resources.
- The first stage is based primarily on **Pressurised Heavy Water Reactors (PHWRs)** using natural uranium as fuel and heavy water as moderator and coolant.
- Natural uranium contains predominantly **Uranium-238 (U-238)** with a small fraction of fissile **Uranium-235 (U-235)**.
- A major objective of Stage I is to generate **Plutonium-239 (Pu-239)** from U-238 during reactor operation. Pu-239 subsequently serves as an important fuel for the second stage.
- India's indigenous PHWR programme has become a major component of the current nuclear expansion strategy, including the deployment of **700 MWe PHWRs**.

Stage II: Fast Breeder Reactors:

- The second stage is based on **Fast Breeder Reactors (FBRs)**, which use fast neutrons and are designed to produce more fissile material than they consume.
- The **Prototype Fast Breeder Reactor (PFBR)** at Kalpakkam uses uranium-plutonium mixed-oxide fuel and a U-238 blanket.
- Fast neutrons convert U-238 into **Pu-239**, thereby increasing the availability of fissile material.
- The reactor design can also use **Th-232 in the blanket**, which can be converted through nuclear transmutation into **U-233**, providing the bridge towards the third stage.

- The government has approved pre-project activities for **2 × 500 MW Fast Breeder Reactors** at Kalpakkam based on the PFBR design.

Stage III: Thorium-Based Reactors:

- The third stage seeks to utilise India's substantial **thorium resources** for large-scale nuclear energy generation.
- **Thorium-232 (Th-232)** is fertile rather than fissile; it is converted into fissile **Uranium-233 (U-233)** through neutron irradiation.
- U-233 can subsequently serve as nuclear fuel, creating a thorium-based fuel cycle.
- The **Advanced Heavy Water Reactor (AHWR)** has been developed as an important technology demonstration for this stage, combining thorium-based fuel with advanced safety features.
- The three-stage programme therefore creates a strategic sequence: **natural uranium and PHWRs ? plutonium and fast breeders ? thorium and U-233**.

Way Forward:

Create Dedicated Financial Provisions:

- A dedicated **nuclear-waste management fund** can be considered, with contributions linked to electricity generation and accumulated throughout the operating life of nuclear facilities.
- Such provisions can support future **spent-fuel management, transportation, decommissioning, long-term storage and geological disposal** rather than shifting the entire burden to future taxpayers.

Define Private-Sector Obligations:

- Nuclear regulations should clearly specify the **financial, operational and liability responsibilities** of private operators for spent fuel and radioactive waste.
- Contracts and licences should ensure that waste-management obligations remain enforceable even after ownership changes or plant closure.

Begin Early Repository Planning:

- India does not necessarily need immediate large-scale construction of a geological repository, but it should undertake **systematic site identification, geological characterisation, safety assessment, technology development and public consultation** well before disposal becomes necessary.
- Long-term planning is particularly important because geological repositories require extensive scientific assessment and societal consensus.

Apply the Polluter-Pays Principle:

- The costs associated with radioactive waste should be **internalised into the economics of nuclear electricity** rather than being transferred entirely to future generations.
- Financial mechanisms should reflect the full lifecycle cost of nuclear power, including waste management and decommissioning.

Conclusion:

India's nuclear expansion is increasingly linked to **energy security, decarbonisation and long-term technological self-reliance**, but a larger nuclear fleet also creates obligations extending far beyond reactor operation. India's closed fuel cycle reduces the volume of high-level waste and enables recovery of uranium and plutonium, while vitrification and engineered storage provide intermediate management pathways. However, long-lived high-level waste ultimately requires durable isolation. The combination of **private-sector participation, the 100 GW nuclear**

target, the three-stage nuclear programme and emerging fast-breeder capacity therefore makes financial provisioning, regulatory continuity, institutional accountability and geological-disposal planning central to India’s nuclear policy.

Value Addition for UPSC:

- **GS-I:** Scientific developments, nuclear technology and India’s technological evolution.
- **GS-III:** Nuclear energy, energy security, radioactive-waste management, environmental protection and low-carbon development.
- **GS-II:** Regulatory institutions, public accountability, private-sector participation and intergenerational governance.
- **Prelims Facts: Atomic Energy Commission — 1948; Apsara — 1956; Tarapur Atomic Power Station — 1969; Nuclear Energy Mission — 100 GW by 2047; SHANTI Act — 2025; PFBR — 500 MW; India’s nuclear programme — three stages.**
- **Conceptual Chain: PHWR ? Pu-239 ? FBR ? U-233 ? Thorium-based third stage.**
- **Core UPSC Insight:** *India’s nuclear-energy transition is not complete when electricity is generated; responsible nuclear governance extends across the entire fuel cycle, including spent fuel, radioactive waste, decommissioning, financing and final disposal.*

Kamaraj IAS Academy
Plot A P.127, AF block, 6 th street, 11th Main Rd, Shanthi Colony, Anna Nagar, Chennai, Tamil Nadu 600040
Phone: **044 4353 9988 / 98403 94477** / Whatsapp : **09710729833**