Revamping India's Nuclear Energy Sector

This editorial is based on "Nuclear muddle" which was published in The Hindu on 07/05/2024. The article brings into picture the recent NPCIL RFP for Bharat Small Reactors, highlighting progress in nuclear technology but also the limitations on private sector involvement. It emphasizes the need for policy reforms, increased private participation, and clearer regulations to fully realize India's nuclear potential.

For Prelims: Bharat Small Reactors, India's nuclear sector, Atomic Energy Act, 1962, Atomic Energy Regulatory Board,Civil Liability for Nuclear Damage Act, 2010, Non-Proliferation Treaty, Kudankulam Nuclear Power Plant ,Solar and wind energy, Fukushima disaster, Radioactive waste disposal, Bhabha Atomic Research Centre, Right to Fair Compensation and Transparency in Land Acquisition Act, 2013.

For Mains: Current Regulatory Landscape of the Nuclear Energy Sector in India, Significance of Nuclear Energy for India, Key Issues Associated with India's Nuclear Sector.

India's Nuclear Power Corporation of India Ltd (NPCIL) recent Request for Proposal (RFP) for **Bharat Small Reactors (BSRs)** reflects a significant step towards **small modular reactors,** but the conditions imposed raise concerns **about private sector participation.** Despite significant strides in nuclear technology and strategic capabilities, **India's nuclear sector** continues to grapple with structural impediments. **Transformative policy reforms, enhanced private sector engagement, and more transparent regulatory frameworks** remain critical to realizing the full potential of India's nuclear infrastructure development.

What is the Current Regulatory Landscape of the Nuclear Energy Sector in India?

- **Centralized Control**: Governed by the **Atomic Energy Act, 1962**, the **central government has exclusive authority over nuclear energy.**
  - The **Atomic Energy Regulatory Board (AERB)** is responsible for overseeing safety standards and compliance within the nuclear industry in India
- **Civil Liability for Nuclear Damage Act, 2010**: This law caps operator liability at ₹1,500 crore, with a government backstop.
  - The **India Nuclear Insurance Pool (INIP)** provides insurance coverage for accidents.
- **International Compliance**: India adheres to IAEA safeguards under the **Indo-US Civil Nuclear Agreement** but is not a signatory to the **Non-Proliferation Treaty (NPT), maintaining strategic autonomy.**

What is the Significance of Nuclear Energy for India?

- **Diversification of Energy Mix:** Nuclear energy provides a **stable and reliable source of electricity,** reducing India's **over-dependence on coal**, which currently accounts for **55% of the country's energy needs.**
    - By diversifying energy sources, **nuclear power mitigates supply risks associated with volatile fossil fuel markets** and complements intermittent renewables like solar and wind.
    - As of May 2023**, nuclear energy contributed 1.6% of India's total energy generation,** with plans to increase nuclear capacity from 7.5 GW to 100 GW by 2047.
    - Furthermore, **nuclear power is envisioned to supply 25% of India's electricity by 2050,** crucial for ensuring energy independence.
- **Climate Change Mitigation and Decarbonization:** Nuclear energy, a low-carbon energy source, plays a **critical role in India's commitment to achieving net-zero emissions by 2070**.
    - With an **emissions intensity of near-zero CO2 per unit of electricity generated,** nuclear energy is vital to replacing coal and offsetting the intermittency of renewables.
    - India pledged at **COP26** to achieve **500 GW of non-fossil fuel energy by 2030,** and **nuclear energy is projected to help achieve this,** contributing **22.48 GW by 2031-32**.
        - The **"Synchronizing Energy Transitions Report 2024"** emphasized the necessity of nuclear energy for a clean energy future.
- **Reducing Import Dependence:** Nuclear energy reduces **India's reliance on imported fossil fuels, which constitute over 85% of crude oil** and **50% of natural gas needs.**
    - This reliance increases economic vulnerabilities to global price fluctuations and geopolitical tensions.
    - By 2024, India's progress with indigenous technologies, such as the **Fast Breeder Reactor at Kalpakkam,** reflects its capability to develop domestic nuclear solutions.
- **Economic Growth and Job Creation:** The nuclear energy sector stimulates economic growth through investments in infrastructure, manufacturing, and R&D.
    - Large-scale nuclear projects, such as the **Kudankulam Nuclear Power Plant expansion (adding 2,000 MW by 2026)**, provide employment opportunities and spur local economies.
    - India's nuclear energy capacity nearly doubled from **4,780 MW in 2014 to 8,180 MW in 2024**, generating jobs in construction, operation, and equipment manufacturing.
        - The **proposed Bharat Small Modular Reactors (BSMRs)** can further drive innovation and create employment in advanced technologies.
- **Base-Load Energy Support for Renewables:** Unlike **solar and wind energy,** which are **weather-dependent**, nuclear provides **consistent base-load electricity,** stabilizing the grid as renewable penetration increases.
    - India's energy demand is predicted to double to around 1200 Mtoe (Millions tonnes of oil equivalent) by 2070, **necessitating a robust grid supported by nuclear power**.
    - Current developments, such as the **addition of 10 reactors totaling 8,000 MW,** showcase nuclear's capacity to bridge supply gaps.
- **Geopolitical Leverage and Strategic Alliances:** Nuclear energy strengthens **India's position in global energy geopolitics** by fostering partnerships and enhancing its energy diplomacy.
    - India's indigenous advancements, such as the **Prototype Fast Breeder Reactor (Kalpakkam),** underscore its technological prowess, helping India counter strategic vulnerabilities and **negotiate better terms in global energy deals.**
- **Sustainable Urbanization and Industrialization: With India's urban population projected to grow to 600 million by 2031**, nuclear energy can meet the rising demand for clean and uninterrupted electricity in cities.
    - It supports **industrial growth,** particularly energy-intensive sectors like manufacturing and steel, which require a steady power supply.
    - Upcoming projects like the **Rajasthan Atomic Power Station Units 7 and 8 (1,400 MW)** aim to address such demands sustainably.
- **Disaster Resilience and Energy Reliability:** Nuclear energy ensures resilience in energy supply during natural disasters or geopolitical disruptions, unlike imported fossil fuels prone to supply

chain risks.
    - For example, the **Kakrapar Atomic Power Station in Gujarat** demonstrated reliable performance during recent grid disruptions.

What are the Key Issues Associated with India's Nuclear Sector?

- **Limited Share in Energy Mix:** Despite d**ecades of investment,** nuclear energy contributes only **1.6% to India's total energy generation,** far below its potential.
    - The reliance on coal and slow expansion of nuclear capacity indicate that the sector has not achieved scalability.
    - Current nuclear capacity is 7.5 GW, with a modest increase to **8.18 GW in 2024,** far from the ambitious goal of 22.48 GW by 2031-32.
    - The limited progress is concerning, **given India's target of 25% electricity from nuclear by 2050**.
- **Financial and Investment Challenges:** Nuclear energy projects require massive capital investments with long gestation periods, deterring private and foreign investment under current policies.
    - The **Atomic Energy Act, 1962, restricts private sector involvement** in reactor operations, while FDI is prohibited in the atomic sector.
    - **India aimed to attract $26 billion in private investment in nuclear energy,** but operational and regulatory bottlenecks remain.
    - Even with **100% FDI allowed in nuclear equipment manufacturing,** financial constraints delay projects like the **Rajasthan and Kakrapar reactor units.**
- **Dependence on Imported Nuclear Fuel:** India's nuclear sector faces significant challenges in securing a **stable supply of uranium**, as domestic reserves are limited and fuel imports are subject to geopolitical risks.
    - For instance, the sanctions following the **1998 nuclear tests** underscored India's vulnerability to disruptions.
    - As per the 2024 "**Energy Transition Report**," the government is exploring strategic nuclear fuel reserves, but current progress is insufficient.
- **Safety Concerns and Public Opposition:** Safety issues, real and perceived, have led to widespread public opposition to nuclear projects, delaying critical infrastructure.
    - Incidents like the **Fukushima disaster (2011) in Japan** and apprehensions around radioactive waste have fueled protests, as seen at **Kudankulam (Tamil Nadu).**
    - Despite advancements, India lacks a permanent radioactive waste disposal system.
    - The **Supreme Court's 2024 judgment** upholding the Atomic Energy Act further emphasized the necessity for stringent safeguards, **but public trust remains fragile.**
- **Technological Delays and Project Inefficiencies:** India's nuclear expansion is marred by d**elays in project execution** due to outdated technology, inefficiencies, and bureaucratic hurdles.
    - For instance, the **Prototype Fast Breeder Reactor (Kalpakkam) was expected to be operational by 2012** but has yet to achieve full functionality.
        - These delays hinder **India's target to triple its nuclear capacity by 2031-32**.
    - Acquiring land for nuclear projects has been a contentious issue, **often leading to delays and escalating costs.**
        - Protests over land acquisition have stalled projects like **Jaitapur Nuclear Power Plant in Maharashtra,** which has faced resistance for over a decade.
- **High Cost of Nuclear Energy:** Nuclear power has a high upfront capital cost compared to renewables, making it less attractive for domestic investment.
    - For instance, according to a 2017 report, the **construction of the fifth and sixth units at India's largest nuclear power plant in Tamil Nadu** is expected to cost around **Rs 50,000 crore**, with half of the funding provided by **Russia as a loan.**
    - Also, the **levelized cost of electricity (LCOE)** for nuclear power is higher than solar and wind, which benefit from declining technology costs.
- **Waste Management and Environmental Risks:** India has **not yet established a long-term solution for radioactive waste disposal**, raising environmental and safety concerns.
    - India produces about four tonnes of nuclear waste for every gigawatt (GW) of electricity generated each year.
    - This waste primarily consists of **spent nuclear fuel and radioactive materials that**

result from the operation of nuclear reactors.
    - The accumulation of such waste poses significant challenges for disposal and long-term storage.
- **Dependence on Foreign Technology:** India's nuclear program heavily relies on foreign technology for reactors and other critical infrastructure.
    - Collaborations with **Russia (Kudankulam) and France (Jaitapur)** demonstrate this dependency, which limits technological self-reliance.
    - This reliance hinders India's strategic goal of achieving full nuclear self-sufficiency.
- **Limited Skilled Workforce:** The nuclear sector requires a highly skilled workforce, but India faces a shortage of trained personnel for reactor operations and R&D.
    - Institutions like **BARC have limited intake capacity**, and expanding the workforce to meet upcoming projects remains challenging.
    - Without addressing this gap, India risks delays in project execution and safety compliance.

What Measures can India Adopt to Revamp its Nuclear Sector?

- **Enhancing Private Sector Participation:** India should amend the **Atomic Energy Act, 1962**, to allow private sector participation in reactor operations, ensuring stringent regulatory safeguards.
    - Private investment can accelerate technological innovation, reduce project delays, and unlock funding for large-scale projects.
    - A **hybrid development model,** combining government oversight with private expertise, would fast-track projects like **Bharat Small Modular Reactors (BSMR)**.
- **Expanding Indigenous Technology Development:** Collaborations between government agencies like **BARC (Bhabha Atomic Research Centre)** and private players should focus on indigenous technologies like **Fast Breeder Reactors** and **Small Modular Reactors (SMRs)**.
    - **Public-private partnerships can enable rapid R&D,** reduce dependence on foreign technology, and ensure faster scalability of reactors.
    - These partnerships can also integrate domestic MSMEs into the nuclear supply chain, as successfully demonstrated in the **Kalpakkam Fast Breeder Reactor** project.
- **Accelerating Land Acquisition and Rehabilitation Policies:** Streamlining land acquisition for nuclear projects requires integrating the **Right to Fair Compensation and Transparency in Land Acquisition Act, 2013**, with expedited project clearances under the **Ease of Doing Business (EoDB)** initiative.
    - The government should establish special land banks for nuclear projects, ensuring equitable compensation and sustainable rehabilitation for displaced communities.
- **Establishing Strategic Nuclear Fuel Reserves:** India must ensure a **strategic nuclear fuel reserve** to address risks of supply chain disruptions caused by geopolitical uncertainties.
    - Leveraging agreements with countries like Russia, Kazakhstan, and Canada under the **Civil Nuclear Cooperation Agreements** can secure long-term uranium supplies.
    - Alongside these, **India should invest in advanced fuel-cycle technologies,** including **thorium utilization**, aligning with its abundant domestic reserves and long-term sustainability goals.
- **Fast-Tracking Regulatory Approvals through Institutional Reforms:** India needs to reform the **Atomic Energy Regulatory Board (AERB)** to streamline the approval process for nuclear projects without compromising safety standards.
    - Establishing an **independent National Nuclear Energy Authority (NNEA)** with clear mandates for reactor approvals, safety monitoring, and collaboration with state governments would reduce bureaucratic delays.
    - This aligns with India's broader **regulatory ease reforms** under the **Gati Shakti National Master Plan** to boost infrastructure efficiency.
- **Boosting Financial Support through Sovereign Green Bonds:** To address the high capital costs of nuclear projects, India should allocate funds through **Sovereign Green Bonds** under its climate financing strategy.
    - Green bonds can attract international climate-focused investors, aligning nuclear projects with India's **Net Zero by 2070** goals.
    - Creating a **Nuclear Energy Development Fund** under green financing frameworks would help mitigate financial constraints and ensure timely project execution.
- **Fostering Skill Development in the Nuclear Sector:** Developing a skilled workforce for India's

nuclear sector requires integrating **Skill India Mission** with specialized training programs led by **BARC** and other institutions.
    - Programs focusing on advanced nuclear technologies, reactor operations, and waste management would address workforce shortages and enhance safety compliance.
    - Collaborations with international institutions under agreements like **IAEA (International Atomic Energy Agency)** partnerships could further bolster technical expertise.
- **Developing Long-Term Radioactive Waste Management Solutions:** India must establish a comprehensive **Radioactive Waste Management Framework**, focusing on permanent disposal facilities and advanced waste processing technologies.
    - Collaborating with countries that have operational waste management solutions, such as **Finland and Sweden,** could accelerate the adoption of best practices.
    - Linking this effort with India's **Circular Economy Framework** can enhance sustainability by focusing on safe reuse of byproducts, like in the thorium fuel cycle.
- **Incentivizing Local Manufacturing in Nuclear Supply Chains:** India should integrate the nuclear sector into the **Make in India** and **PLI (Production Linked Incentive)** schemes to boost domestic manufacturing of nuclear components.
    - Incentives for MSMEs and startups in nuclear equipment manufacturing could reduce costs and reliance on imports.
    - This model, similar to the **Belagavi Aerospace Cluster,** can expand India's industrial base while enhancing self-reliance in critical technologies.
- **Improving Public Awareness and Addressing Opposition:** The government should launch extensive public awareness campaigns about nuclear safety, benefits, and environmental sustainability.
    - Engaging local communities through consultations, **sharing safety records (e.g., Kudankulam's safety track record),** and providing benefits like free electricity or local development initiatives can reduce opposition.
    - Transparent communication and community partnerships are key to fostering trust and expediting project approvals.
- **Promoting Small Modular Reactors:** India should focus on developing **Small Modular Reactors (SMRs)** to meet the decentralized energy needs of remote and rural areas.
    - These reactors are cost-effective, safer, and easier to deploy compared to large reactors.
    - By integrating SMRs with the **Deendayal Upadhyaya Gram Jyoti Yojana (DUGJY)**, India can provide sustainable energy to underserved regions while reducing transmission losses.
- **Strengthening International Technology Transfer Agreements:** India should aggressively pursue technology transfer agreements with countries like the USA, Japan, and South Korea to gain access to cutting-edge reactor designs and fuel cycle technologies.
    - For example**, leveraging the 123 Agreement with the US** can boost light-water reactor capabilities.
    - Such collaborations can expedite the deployment of advanced reactors while aligning with **India's Vision 2047 energy roadmap.**
- **Leveraging AI and Digital Twins for Reactor Operations:** India can integrate **Artificial Intelligence (AI)** and **Digital Twin** technology to monitor and optimize reactor performance in real time.
    - AI can predic**t maintenance needs, detect anomalies,** and improve operational safety, reducing risks of human error.
      Digital Twins—virtual models of reactors—can simulate operations, allowing for predictive analysis and efficient training of operators.

Conclusion:

India's nuclear energy sector holds **immense potential to drive energy security, climate goals, and economic growth,** but structural and regulatory challenges persist. By amending outdated policies, fostering **private sector participation, enhancing indigenous capabilities, and streamlining regulatory frameworks**, the sector can be revitalized. Innovative approaches like small modular reactors, AI integration, and sustainable waste management are crucial to overcoming current bottlenecks.

Drishti Mains Question:

Evaluate the role of nuclear energy in India's energy security. How can Small Modular Reactors (SMRs) address the challenges related to the sector, and what policy reforms are needed?

UPSC Civil Services Examination, Previous Year Questions (PYQs)

Prelims

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 privately owned

Ans: (b)

Mains

Q. With growing energy needs should India keep on expanding its nuclear energy programme? Discuss the facts and fears associated with nuclear energy. (2018)