Nuclear Power in India

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Preamble

This year, as we celebrate Azadi ka Amrit Mahotsav, the 75th anniversary of our independence, we feel proud to be recognized by the world as a nation with advanced nuclear technologies. Today, India has expertise in all aspects of nuclear power - siting, design, construction, operation and maintenance, ageing management, renovation and modernization to decommissioning. For a country that had a very small technological base at the time of Independence, to have achieved such a status in this frontier technology is a great achievement. It is time to reflect on the evolution of our nuclear power programme, the efforts put in and the visionaries who made it possible.

Today, as the world struggles to contain the impending catastrophic effects of climate change and nations plan their energy transition towards net zero goals, clean energy sources like nuclear power and renewables are becoming increasingly important. Nuclear power in India, apart from helping its energy transition to a net zero economy by 2070, has a vital role to play in ensuring the country's long term energy security.

Nuclear energy development in India

Unlike in the developed countries where energy of the atom was initially harnessed for destruction (the atomic bomb), in India, nuclear energy development began with the objectives of improving the quality of life of the people and self-reliance in meeting their energy needs.

Three-Stage Programme

In 1954, Dr. Bhabha presented the three-stage nuclear power programme for the country, which remains robust and relevant even today. The adoption of the unique sequential three-stage programme and associated technologies was also based on the key principle of self-reliance. It envisaged optimum utilization of the indigenous nuclear resource profile of modest Uranium and abundant Thorium resources. The sequential three-stage programme was based on a closed fuel cycle, where the spent fuel of one stage is reprocessed to produce fuel for the next stage. The closed fuel cycle thus multiplies manifold the energy potential of the fuel and greatly reduces the quantity of waste generated. It was thus an inherently sustainable solution.

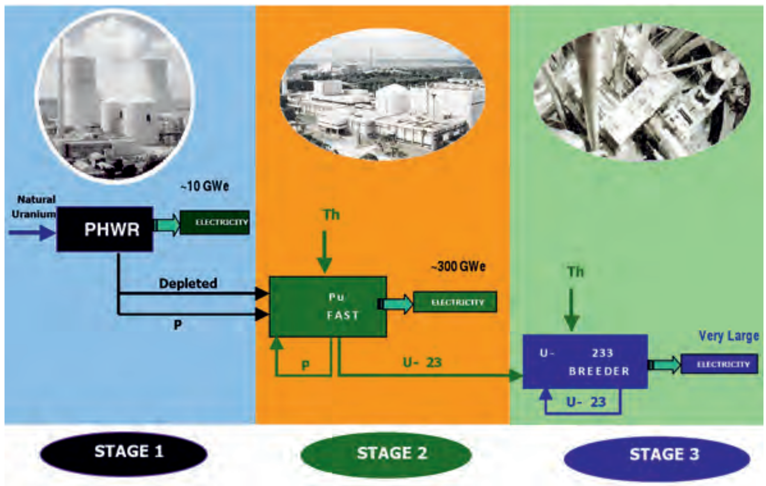

Fig. 1 :Three Stage programme

The three-stage programme comprises of Pressurised Heavy Water Reactors (PHWR) in the first stage, Fast Breeder Reactor in the second stage and thorium based systems in the third stage. The stages have important fuel cycle linkages.

The first stage comprises of Pressurised Heavy Water Reactors fuelled by natural uranium. Natural uranium contains only 0.7% of Uranium^{235}, which undergoes fission to give energy. The remaining 99.3% comprises Uranium^{238}, which is not fissile. In the fission process, among other fission products, a small quantity of Plutonium^{239} is formed by transmutation of Uranium^{238}, which again is fissile.

The spent fuel (spent of Uranium^{235}) is cooled for about five years to remove decay heat before reprocessing to recover Uranium^{238} and Plutonium^{239} and remove other fission products. The second stage, comprising of Fast Breeder Reactors (FBRs) are fuelled by mix of Uranium^{238} and Plutonium^{239} recovered by reprocessing of the first stage spent fuel. In FBRs, Plutonium^{239} undergoes fission producing energy, and at the same time, producing Plutonium^{239} by transmutation of Uranium^{238}. Thus, the FBRs produce energy and fuel, hence are termed Breeders. FBRs produce more fuel than they consume. Over a period of time, Plutonium inventory can be built by feeding Uranium^{238}.

Thorium^{232} is not fissile and has to be converted to Uranium^{233} by transmutation in a reactor for use as a fissile material. In the second stage, once sufficient inventory of Plutonium^{239} is built up, Thorium^{232} will be introduced as a blanket material to be converted to Uranium^{233}, which is fissile.

In the third stage, breeder reactors based on a Thorium^{232}-Uranium^{233} fuel cycle are planned to be deployed.

Building of Institutions

For going ahead with the nuclear power programme, the nation went about a process of building institutions to achieve self reliance.

Soon after independence, the Atomic Energy Commission (AEC), the apex policy making body was constituted for framing policies related to atomic energy in India. The Department of Atomic Energy was established in 1954 for implementing the national policies on atomic energy.

Institutions for Research & Development, exploration, mining and processing of minerals, production of heavy water, fuel fabrication, fuel and spent fuel management, nuclear instrumentation, etc. required for the nuclear power programme were established. Human Resource and training infrastructure was developed for the specialized skills needed for nuclear power.

In parallel, the Indian industry also evolved to manufacture components/ equipment required to the exacting standards of the nuclear industry with initial handholding and joint development.

The Atomic Energy Regulatory Board (AERB), a safety regulatory authority independent of the DAE was also established.

The nuclear power programme in the country went through distinct phases of Demonstration, Indigenisation, Standardisation, Consolidation, and Commercialisation thereafter.

Demonstration Phase:

India's first nuclear power plant – TAPS 1&2

To demonstrate the feasibility of introduction of nuclear power in the then existing electricity grids, after extensive studies, it was decided to set up two units of Boiling Water Reactors (BWR) to be supplied by GE, USA on a turnkey basis. The construction of these reactors commenced at Tarapur, Maharashtra in 1964. They began commercial operation in October 1969. At 210 MW each, they were then the largest size power plants in the country. They were the first nuclear power plants in Asia.

Fig. 2: Tarapur Atomic Power Station 1&2

India's first PHWRs – RAPS 1&2

Even as TAPS 1&2 were being constructed, India embarked on the construction of the first PHWR in collaboration with Atomic Energy of Canada Limited at Rawatbhata in Rajasthan. Canadians then had been building PHWRs in their country. This project was very important as it would be the harbinger of a series of PHWRs of 220 MW that were envisioned as the first stage of India's indigenous three-stage programme.

Fig. 3: Rajasthan Atomic Power Station 1&2

The Turning point

The first unit, RAPS-1 was completed in 1973. The second unit RAPS-2 was under construction, when in 1974 all assistance by Canada was withdrawn and an international technology denial and embargo regime commenced following the conduct of the first Peaceful Nuclear Experiment by India.

This challenge was overcome by Indian scientists and engineers who successfully completed and commissioned the unit in 1981, which continues to operate even today. This also set the ball rolling for full indigenization of the country's nuclear power programme.

Indigenisation:

Subsequently, MAPS units 1&2 (2X220 MW) at Kalpakkam, Tamilnadu were designed, constructed and commissioned with indigenous efforts. The setting up of MAPS involved challenges of evolving Indian designs, high precision manufacturing, challenges in construction and commissioning of units on the eastern sea coast and large scale construction planning. These units commenced commercial operation in 1984 and 1986, respectively.

Standardisation:

Following the successful operation of the first indigenous nuclear power plants at Madras, it was sought to standardize the 220 MW PHWR design for rapid expansion. In parallel, improvements in safety features were also made like introduction of secondary shutdown system, double containment, etc. The first standard Indian PHWR was set up at Narora,Uttar Pradesh (NAPS 1&2)

Consolidation:

The standard design of NAPS was further consolidated by setting up a 2X220 MW PHWR station at Kakrapar, Gujarat. While NAPS 1&2 commenced commercial operation in 1991 and 1992, respectively, KAPS 1&2 commenced commercial operation in 1993 and 1995, respectively.

Evolution of Organisations:

The design, construction and operation of nuclear power plants in the country was started as a departmental activity in the early sixties, by the Department of Atomic Energy (DAE), Government of India. In the year 1967, Power Projects Engineering Division (PPED), a division of the DAE, was formed and entrusted with this responsibility. PPED was converted to Nuclear Power Board (NPB) in the year 1984, with increased delegation of powers.

For the planned expansion of nuclear power programme, it was felt necessary to create a framework for faster decision-making and also to tap funds from capital market. Accordingly, NPB was converted into Nuclear Power Corporation of India Limited (NPCIL), a fully owned company of the Government of India, Department of Atomic Energy and registered on 3rd September 1987, under the Companies Act of 1956. The company started functioning from 17th September, 1987. The assets of the Nuclear Power Board excluding Unit-1 of Rajasthan Atomic Power Station (RAPS-1) were transferred to NPCIL on its formation.

NPCIL activities include all aspects of nuclear power reactors. These include Siting, Design, Construction, Commissioning, Operation & Maintenance, Renovation & Modernisation, Life Extension and Waste Management.

Similarly, another company, BHAVINI was incorporated to set up Fast Breeder Reactors of the second stage in the commercial domain in the year 2003.

Commercialisation & Expansion

The 220 MW PHWR design which evolved from RAPS 1&2 (AECL Canada) to MAPS 1&2 (first indigenous PHWR) prior to formation of NPCIL was indigenised, improved and standardised with NAPS-1&2 and KAPS-1&2. Eight more 220 MW reactors – Kaiga 1 to 4 and RAPS 3 to 6 of the design were set up by NPCIL.

The PHWR design was scaled up to 540 MW capacity and two such units (TAPS-3&4) were set up at Tarapur Maharashtra site. This design was further uprated to the state of the art 700 MW with advanced safety features; and the first 700 MW PHWR, KAPP-3 was synchronized to grid on 10th January 2021. Five more units of 700 MW PHWR are under construction and ten more have been accorded sanction, which are being set up in fleet mode. These are expected to be progressively completed by 2031.

Additionalities to the three-stage programme of India:

In parallel to the indigenous three-stage programme, additionalities based on imports have been introduced, essentially for faster nuclear power capacity addition in the near term, considering the lead times involved in the indigenous nuclear power programme.

International Cooperation in Nuclear Energy

Following the fruition of International cooperation in nuclear energy, international agreements for cooperation in nuclear energy were concluded to end the country's international isolation and access global markets for nuclear commerce. This opened up the possibility of import of fuel for use in reactors under IAEA safeguards and setting up nuclear power reactors based on technical cooperation with foreign countries.

NPCIL has also set up two 1000 MW Pressurized Water Reactors (PWR) in cooperation with Russian Federation at Kudankulam (KKNPP 1&2) and has gained valuable experience in construction and operation of these reactors. Four more 1000 MW PWRs (KKNPP- 3 to 6) are being set up at the same site in Tamilnadu.

Comprehensive capabilities

NPCIL has, over the years, developed comprehensive capability in the core nuclear technology. This encompasses design of Systems, Structures & Components, Safety analysis, Licensing, manufacture of nuclear equipment (with Indian industries), Construction and Operation of NPPs. In addition, NPCIL has developed technologies for life management and maintenance, in association with other units of DAE. Adopting these technologies, NPCIL has successfully carried out Enmasse Coolant Channel Replacement (EMCCR), Enmasse Feeder Replacement (EMFR), introduction of Spargers in MAPS-1&2, repair of Calandria Vault in KAPS-1, in situ repair of tri-junction joint in Kaiga-3 Endshield and Over Pressure Relief device in RAPS-1 etc.

Thus NPCIL has evolved today into an organisation with expertise in PHWRs of different sizes, BWRs, and large capacity PWRs.

Performance of Operating Plants:

a. Safety performance

Ever since its inception, Indian nuclear power plants have had an impeccable safety record. There has not been any accident or incident of release of radioactivity in the public domain beyond stipulated limits. Indian nuclear power reactors have registered over 570 reactor-years of safe operation (as of June 15, 2022).

Environmental Survey Laboratories (ESL) are established at each site before the start of reactor operation which collect site-specific baseline radiation data from natural sources like cosmic rays, rocks, soil etc. After the plant goes into operation, environmental matrices like air, water, soil, crops, fish, milk etc. are monitored for radioactivity in an area upto 30 km around the plant. The data collected over 50 years of operation in India has shown that the increase in radiation level around nuclear power plants has been negligible and within the variations in the natural background. The average natural background (dose for natural sources like radon in rocks, soil, cosmic rays etc.) dose is 2400 micro-Sievert per year.

The public dose at the site boundary of NPCIL sites vis-à-vis the AERB limit is shown below in Fig 4.:

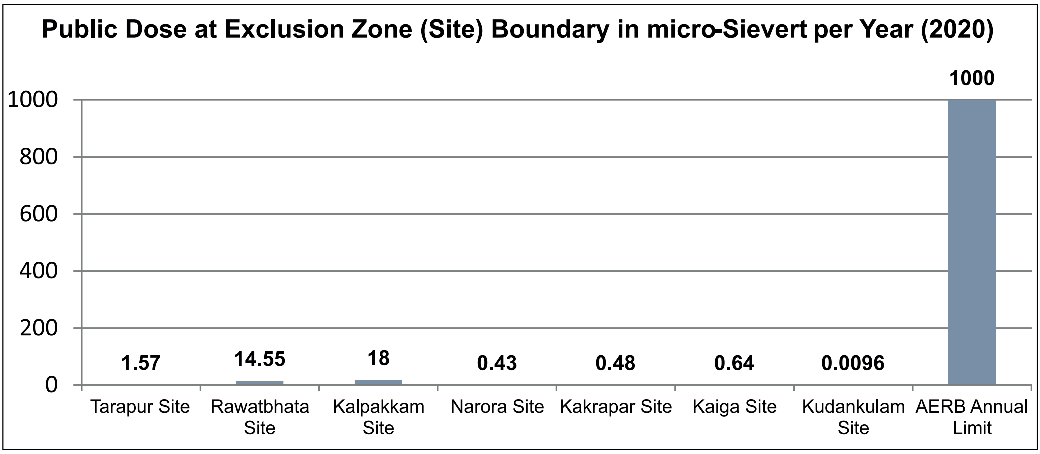

Fig. 4: Public Dose at NPP sites

Expert safety reviews, following the Fukushima incident in Japan, found that NPCIL reactors are safe against extreme natural events and have margins and features in design to withstand them. The recommendations made to take the safety to a higher level have also been backfitted in existing plants and incorporated in design of new projects.

b. Generation

Indian nuclear power plants have so far (upto March 2022) generated about 772721 Million Units of clean electricity, avoiding about 665 million tons of CO_2 emissions. Nuclear power presently contributes about 3.14% of the total electricity generation in the country.

Landmark Achievements

Completion of 52 Years of Safe operation of TAPS 1&2:

These reactors commenced operation in 1969 and were the first nuclear power reactors in India & Asia. They are presently the oldest reactors in operation in the world having completed 50 years of operation in October 2019. These were originally set up by IGE, USA on turnkey basis. Indigenous technological solutions were developed and implemented to ensure highest level of safety and efficient operation of the units (in an international technology denial and embargo regime prevalent from 1974 to 2008). The units underwent major upgradations in 2005 and 2016.

Continuous Operation - World Record of 962 Days by KGS-1

Kaiga Generating Station Unit-1 had set the world record by operating continuously for 962 days before being shutdown on 31st December 2018 for planned surveillance checks and mandatory tests (It now holds the record for the second longest continuous run among nuclear power reactors in world till date). Being a fully Indigenous PHWR fuelled by domestic fuel, this feat bears testimony to the maturity achieved by the country in all aspects of nuclear power technology.

In addition, NAPS-2 (852 days), RAPS-3 (777 days) and RAPS-5 (765 days) have operated continuously for more than two years. NPCIL reactors have operated for more than a year 39 times so far.

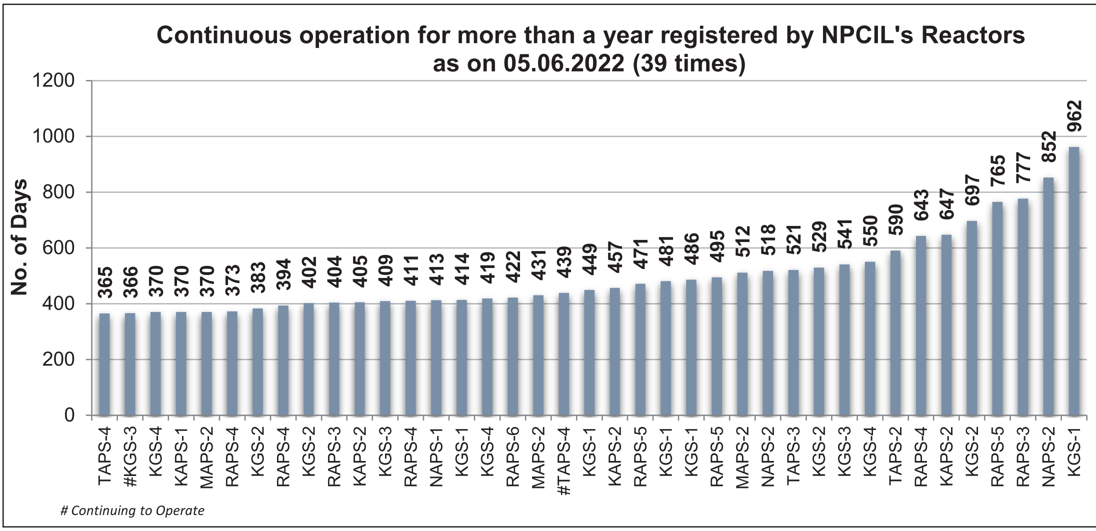

Fig 5. Continuous Operation of more than a year by NPCIL's reactors

Joint Ventures of NPCIL

NPCIL has entered into Joint Ventures (JV) with public sector energy majors for setting up future projects for meeting the equity requirements. Joint Venture companies between NPCIL and NTPC (Anushakti Vidhyut Nigam Limited), NPCIL and IOCL (NPCIL-Indian Oil Nuclear Energy Corporation Limited) have been incorporated. NPCIL is discussing with JV partners for identifying the projects to be taken up by the JV companies. The amendment in Atomic Energy Act-1962 has enabled participation of these Joint Venture companies in nuclear power generation in the country.NPCIL has also entered into a JV with M/s. L&T for manufacture of special steels and heavy forgings.

Present Status of Nuclear Power Programme

1. Reactors In Operation

There are presently 22 reactors with a capacity of 6780 MW, including RAPS-1 (100 MW), which is presently under long term shutdown. The details are:

Unit-Location	Reactor Type	Capacity (MW)	Commercial Operation
TAPS-1 Tarapur, Maharashtra	BWR	160	28 October 1969
TAPS-2 Tarapur, Maharashtra	BWR	160	28 October 1969
RAPS-1 Rawatbhata,* Rajasthan	PHWR	100	16 December 1973
RAPS-2 Rawatbhata, Rajasthan	PHWR	200	01 April 1981
MAPS-1 Kalpakkam, Tamilnadu	PHWR	220	27 January 1984
MAPS-2 Kalpakkam, Tamilnadu	PHWR	220	21 March 1986
NAPS-1 Narora, Uttar Pradesh	PHWR	220	01 January 1991
NAPS-2 Narora, Uttar Pradesh	PHWR	220	01 July 1992
KAPS-1 Kakrapar, Gujarat	PHWR	220	06 May 1993
KAPS-2 Kakrapar, Gujarat	PHWR	220	01 September 1995

KAIGA -2, Kaiga, Karnataka	PHWR	220	16 March 2000
RAPS -3 Rawatbhata, Rajasthan	PHWR	220	01 June 2000
KAIGA -1Kaiga, Karnataka	PHWR	220	16 November 2000
RAPS -4 Rawatbhata, Rajasthan	PHWR	220	23 December 2000
TAPS -4 Tarapur, Maharashtra	PHWR	540	12 September 2005
TAPS -3 Tarapur, Maharashtra	PHWR	540	18 August 2006
Kaiga -3 Kaiga, Karnataka	PHWR	220	06 May 2007
RAPS -5 Rawatbhata, Rajasthan	PHWR	220	04 February 2010
RAPS -6 Rawatbhata, Rajasthan	PHWR	220	31 March 2010
Kaiga -4 Kaiga, Karnataka	PHWR	220	20 January 2011
KKNPP -1, Kudankulam, Tamilnadu	LWR	1000	31 December 2014
KKNPP -2, Kudankulam, Tamilnadu	LWR	1000	31 March 2017

Note: '' Owned by DAE. Under extended shutdown from October 2004*

2. *Reactors Under Construction*

Of the reactors presently under construction, one reactor, KAPP-3 (700 MW) was connected to the grid on January 10, 2021. There are nine more reactors presently under construction by NPCIL. The details are:

Project	Location & State	Capacity (MW)
KAPP 3 *&4	Kakrapar, Gujarat	2 X 700
RAPP 7&8	Rawatbhata, Rajasthan	2 X 700
KKNPP 3&4	Kudankulam, Tamilnadu	2 X 1000
KKNPP – 5&6	Kudankulam, Tamil Nadu	2 X 1000
GHAVP 1&2	Gorakhpur, Haryana	2 X 700

**KAPS-3 was connected to the grid on January 10, 2021 and is generating infirm power*

In addition, the first commercial reactor of the second stage, a 500 MW Prototype Fast Breeder Reactor (PFBR) is at an advanced stage of construction.

3. *Reactors Accorded Administrative Approval & Financial Sanction*

The Government has also accorded administrative approval and financial sanction for the following ten (10) more reactors in fleet mode with a total capacity of 7000 MW, are scheduled to be completed progressively. The details are as follows:

Project	**Location & State**	**Capacity (MW)**
Kaiga -5&6	Kaiga, Karnataka	2 X 700
GHAVP – 3&4	Gorakhpur, Haryana	2 X 700
Chutka -1&2	Chutka, Madhya Pradesh	2 X 700
Mahi Banswara - 1 to 4	Mahi Banswara, Rajasthan	4 X 700

Pre-project activities are in progress at these sites. Land is available at Kudankulam, Kaiga, Gorakhpur and Chutka sites. Land acquisition proceedings are in progress at Mahi Banswara site. Process of obtaining various statutory clearances are in progress at various stages at the sites. Environmental clearance has been obtained for GHAVP, Chutka and Kaiga 5&6 projects. In respect of Mahi Banswara, public hearing has been held.

On progressive completion of the projects under construction and accorded sanction, the installed nuclear power capacity will increase to 22480 MW from 6780 MW at present

4. Future Sites

In addition to the projects under construction and new projects accorded sanction, the Government has accorded 'In-Principle' approval for the following sites for setting up nuclear power projects in future:

<table>
<tr><th>Location & State</th><th>Capacity (MW)</th><th>In Cooperation with</th></tr>
<tr><td>Bhimpur, Madhya Pradesh</td><td>4 X 700</td><td>Indigenous</td></tr>
<tr><td>Jaitapur, Maharashtra</td><td>6 x 1650</td><td>France</td></tr>
<tr><td>Kovvada, Andhra Pradesh</td><td>6 x 1208</td><td rowspan="2">USA</td></tr>
<tr><td>Chhaya Mithi Virdi, Gujarat</td><td>6 x 1000*</td></tr>
<tr><td>Haripur, West Bengal</td><td>6 x 1000*</td><td>Russian Federation</td></tr>
</table>

**Nominal Capacity*

Pre-project activities are initiated at these sites. At Jaitapur, land has been acquired and necessary statutory clearances from MoEF & CC have been obtained. The land acquisition and obtaining MoEF & CC clearance are in process at Kovvada.

Techno-commercial discussions to arrive at project proposals are in progress with M/s. EDF, France for Jaitapur project and with M/s Westinghouse, USA for Kovvada project.

Road Ahead

The national objective of becoming a net zero economy by 2070 involves a major energy transition from the predominantly fossil fuel based technologies to cleaner electricity generating technologies. Nuclear power in this context has a very important role. The present nuclear power capacity expansion is a step in this connection.

The sequential three-stage nuclear power programme envisioned by Dr. Homi Bhabha is robust and on course. Large capacity addition in the second and third stages is planned in future. The programme will be pursued along with LWRs as additionalities. Nuclear power, being a clean source of power has also an important role in production of clean Hydrogen, as the country makes strides towards a Hydrogen economy.

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