

# Nuclear Power in India

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**Preamble:** Nuclear power has come a long way in India since its inception in the early days after independence. For a country that had a very small technological base at the time of independence, being recognized by the world as a nation with advanced nuclear technologies with expertise in all aspects of nuclear power - siting, design, construction, operation and maintenance, ageing management, renovation and modernization to decommissioning is a great achievement.

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 vital. 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.

India is a country of young aspirational people that aspires to be a developed country (Vikasit Bharat) by 2047, the hundredth year of independence. It has an ambitious vision of reaching a nuclear installed capacity of 100 GW by then by deploying a host of technologies.

This paper reflects on the saga of nuclear power development in the country and its vision ahead.

### 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.

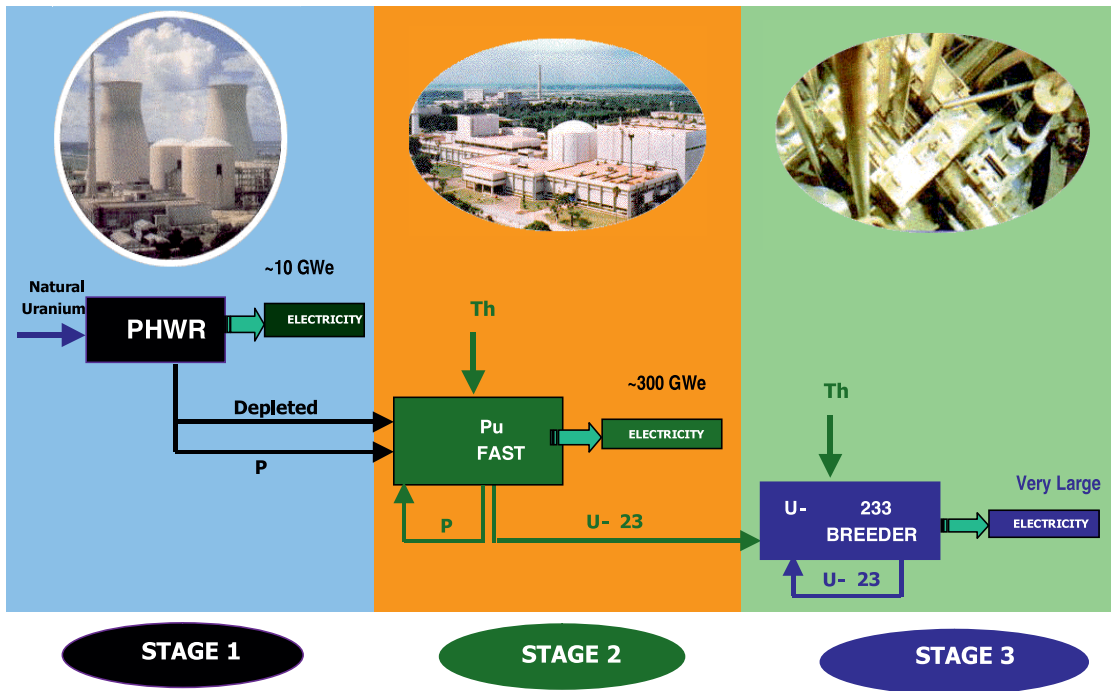


Fig 1. Three Stage programme

The three-stage programme comprises of Pressurised Heavy Water Reactors (PHWR) in the first stage, Fast Breeder Reactors (FBRs) 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  $U^{235}$ , which undergoes fission to give energy. The remaining 99.3% comprises  $U^{238}$ , which is not fissile. In the fission process, among other in addition to fission products, a small quantity of  $Pu^{239}$  is formed by transmutation of  $U^{238}$ , which again is fissile.

The spent fuel (spent w.r.t  $U^{235}$ ) is cooled for about five years to remove decay heat before reprocessing to recover  $U^{238}$  and  $Pu^{239}$  and remove other fission products. The second stage, comprises of FBRs, which are fuelled by mixed oxide of uranium and plutonium recovered by reprocessing of the first stage spent fuel. In FBRs,  $Pu^{239}$  undergoes fission producing energy, and at the same time, producing  $Pu^{239}$  by transmutation of  $U^{238}$ . Thus the FBRs produce energy and fuel, hence they are termed Breeders. FBRs produce more fuel than they consume. Over a period of time, plutonium inventory can be built by feeding  $U^{238}$ .

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

In the third stage, breeder reactors based on a  $Th^{232} - U^{233}$  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 in 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 has been 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 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***

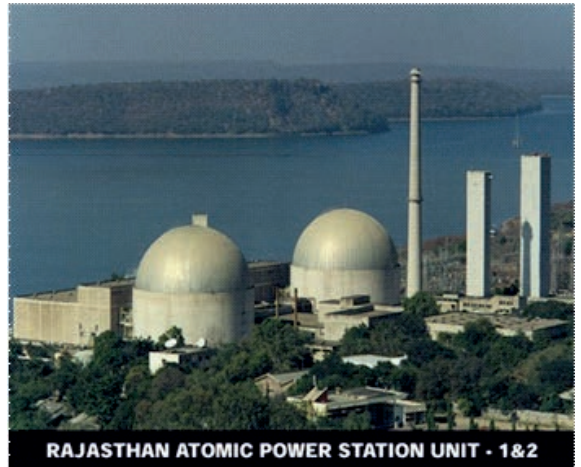
To demonstrate the feasibility of introduction of nuclear power in the then existing electricity grids, after extensive studies, it was decided to set up two units of Boiling Water Reactors (BWR) to be supplied by GE, USA on a turnkey basis. The construction of these reactors commenced at Tarapur, Maharashtra 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



**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, Tamil Nadu were designed, constructed and commissioned with indigenous efforts. The setting up of MAPS involved which challenges of evolving Indian designs, high precision manufacturing, challenges in construction and commissioning of units on the eastern sea coast and such 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.

Thereafter, eight more 220 MW PHWRs Kaiga 1 to 4 and RAPS 3 to 6 were set up. In line with the growing capacity of the electricity grid the PHWR unit sizes were increased to 540 MW and further to 700 MW two units each of which are presently in operation.

**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 updated to the state of the art 700 MW with advanced safety features; and the first twin unit 700 MW PHWRs, KAPP-3&4 commenced commercial operation in 2023-24. Four more units of 700 MW PHWR are under construction, of which one has already achieved criticality. Ten more have been accorded sanction in fleet mode and are under pre-project activities. These reactors are expected to be progressively completed by 2031-32.

## **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 under construction 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.

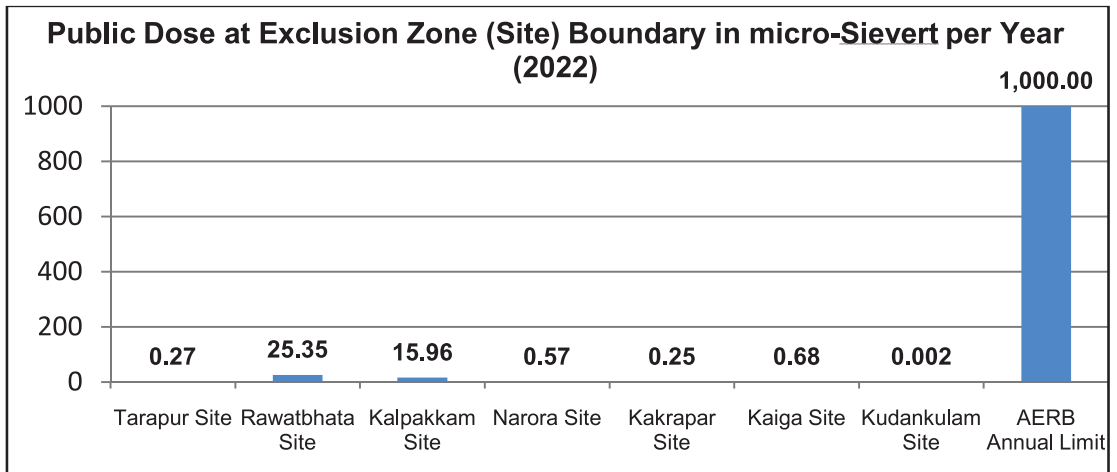
## Performance Of Operating Plants:

### 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 630 reactor-years of safe operation (as of January 2025).

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:



**Fig4. 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 back fitted in existing plants and incorporated in design of new projects.

### b. Generation

Indian nuclear power plants have so far (upto December 2024) generated about 910 Billion Units of clean electricity, avoiding about 782 million tons of CO<sub>2</sub> emissions. Nuclear power presently contributes about 3% of the total electricity generation in the country.

## Landmark Achievements

### Completion Of 50 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 continuously for more than a year 50 times so far.

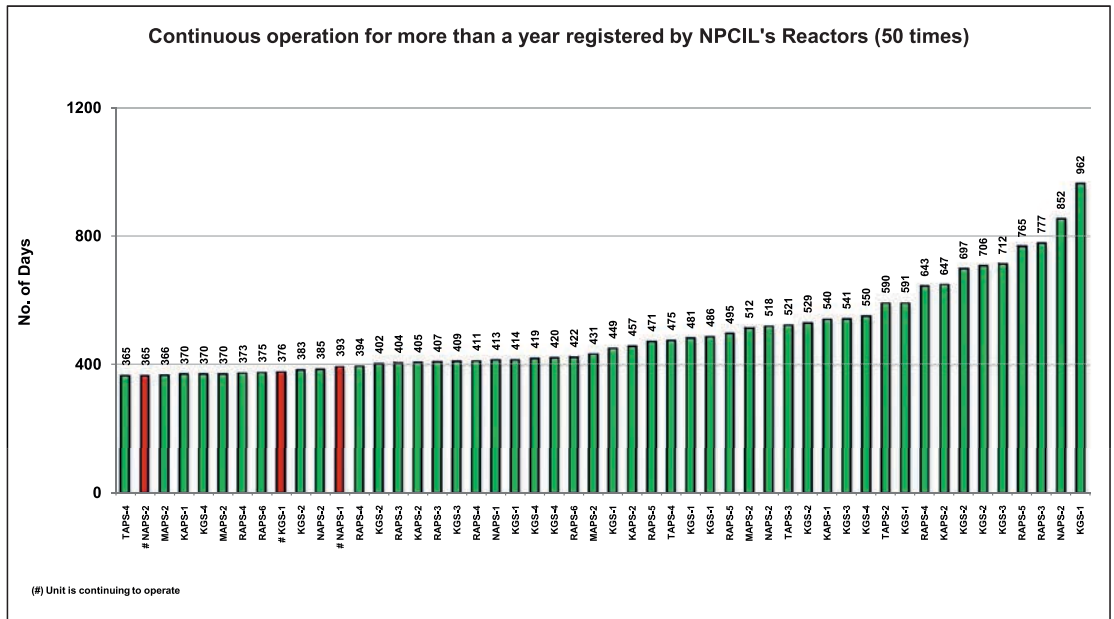


Fig 5. Continuous Operation of more than a year by NPCIL's reactors

## 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 (AnushaktiVidhyut Nigam Limited -ASHVINI), NPCIL and IOCL (NPCIL-Indian Oil Nuclear Energy Corporation Limited) have been incorporated. The amendment in Atomic Energy Act-1962 has enabled participation of these Joint Venture companies in nuclear power generation in the country. The Government in September 2024 accorded approval to ASHVINI to take up nuclear power generation and associated activities in accordance with the Atomic Energy Act, 1962.

## Present Status of Nuclear Power Programme

### 1. Reactors In Operation

There are presently 24 reactors with a capacity of 8180 MW, including RAPS-1 (100 MW), which is presently under long term shutdown. The details are:

Unit-Location	Reactor Type	Capacity	Commercial
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-5Rawatbhata, Rajasthan	PHWR	220	04 February 2010
RAPS-6Rawatbhata, Rajasthan	PHWR	220	31 March 2010
Kaiga-4Kaiga, Karnataka	PHWR	220	20 January 2011
KKNPP-1, Kudankulam,	LWR	1000	31 December 2014
KKNPP-2, Kudankulam,	LWR	1000	31 March 2017
KAPS-3,Kakrapar, Gujarat	PHWR	700	30 June 2023
KAPS-4,Kakrapar, Gujarat	PHWR	700	31 March 2024

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

## 2. Reactors Under Construction

There are nine reactors presently under construction by NPCIL. The details are:

Project	Location & State	Capacity (MW)
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

*\*RAPS-7 achieved first criticality on September 19, 2024*

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 with a total capacity of 7000 MW, which are scheduled to be completed progressively. The details are as follows:

Project	Location & State	Capacity
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. Environmental clearance has been obtained for GHAVP, Chutka and Kaiga 5&6 projects. In respect of Mahi Banswara, it is in progress.

The Government has allotted the Mahi Banswara project to ASHVINI, the JV of NPCIL and NTPC Ltd.

On progressive completion of the projects under construction and accorded sanction, the installed nuclear power capacity will increase to 22480 MW from 8180 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:

Location & State	Capacity	In Cooperation with
Bhimpur, Madhya Pradesh	4 X 700	Indigenous
Jaitapur, Maharashtra	6 x 1650	France
Kovvada, Andhra Pradesh	6 x 1208	USA
Chhaya Mithi Viridi, Gujarat	6 x 1000*	
Haripur, West Bengal	6 x 1000*	Russian Federation

*\*Nominal Capacity*

Pre-project activities are initiated at these sites. Land has been acquired in Jaitapur & Kovvada sites.

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**

India aspires to be a developed nation – Vikasit Bharat by 2047 the 100<sup>th</sup> year of independence, which involves a multifold increase in electricity generation. Together with the national objective of becoming a net zero economy by 2070 involves an energy transition from the predominantly fossil fuel based technologies to cleaner electricity generating technologies. Nuclear power in this context has a very important role.

Considering these objectives, the Government of India has announced an ambitious Nuclear Energy Mission of reaching a nuclear power capacity of 100 GW by 2047. This is planned to be accomplished by a mix of reactor technologies – PHWR, LWR, FBRs, SMRs and other emerging reactors & advanced systems.

One of the major contributions in this mission is expected to be from Small Modular Reactors. An ambitious target of operationalization of 5 indigenous SMRs by 2033 also has been set by the Government. The Government proposes to facilitate this capacity addition by roping in the private sector.

While many SMR designs are still under development, the standard 220 MW Pressurised Heavy Water Reactors (PHWR), though not exactly modular, that has an impeccable safety & performance record was found to be an ideal immediate solution for the addressing the de-carbonisation needs of major steel and metal industries. The upgraded 220 MW PHWR, termed as Bharat Small Reactor (BSR) has been designed and Request for Proposals (RFP) for BSRs to be set up with private capital in line in approved business model have been published by NPCIL.

While the sequential three-stage programme envisioned by Dr. Homi Bhabha remains at the core of India's nuclear power programme to utilize India's vast thorium reserves in the long term, multiple reactor technologies are being considered to reach the envisioned capacity of 100 GW by 2047 to enable the clean energy transition. 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.