Three Stages of the Indian Nuclear Power Program

Domestic reserves of uranium in India are limited, whilst those of thorium are quite large. In order to fully exploit these resources, India has adopted a three-stage nuclear power program, based on a closed fuel cycle, requiring reprocessing of spent fuel from every reactor so as to judiciously utilize the available fissile material for peaceful purposes. In the first stage of the indigenous program, natural uranium-fuelled pressurized heavy water reactors (PHWRs), which produce electricity efficiently, also generate plutonium to launch the second stage.

The second stage, based on fast breeder reactors (FBRs), initially using plutonium recovered from the spent fuel of the first stage reactors, multiplies the installed capacity several times by converting the fertile material (reprocessed uranium, and at a later stage thorium) to fissile material whilst producing electricity.[3] The third stage envisages utilization of thorium to provide a sustainable supply of energy to meet the country's needs. A multiplication of India's fissile inventory is also needed to establish a higher power base for using thorium in the third stage of the program.

Historical Growth and Current Status of Nuclear Power in India

Dr. Homi Jehangir Bhabha formulated the strategy for setting up a nuclear research program in India even before India had attained independence. He wanted India to be self-reliant in this newly emerging area. The Indian nuclear program began in 1945 with the establishment of the Tata Institute of Fundamental Research (TIFR).

Research and Development

Bhabha Atomic Research Centre

In 1957, research and development work specific to nuclear energy was shifted to the newly established Atomic Energy Establishment Trombay (AEET), renamed the Bhabha Atomic Research Centre (BARC) in 1967. Over the past several decades, a multidisciplinary infrastructure for conducting research and development in nuclear sciences and engineering has been set up at BARC. These include several research reactors, and a large number of laboratories and other research facilities dealing with basic as well as applied sciences and engineering development. Most of the other units of the Indian Department of Atomic Energy (DAE), dealing with various aspects of the nuclear power program, also had their origins in BARC.

Research Reactors

One of the earliest decisions Dr. Bhabha made was to build research reactors of different types to develop an intimate understanding of the complex issues involved in the control of the nuclear chain reaction. The design of reactors involves optimization of geometry, fuel design, safety, materials selection, irradiation behavior of fuel and structural materials. The first of these research reactors was a swimming pool-type reactor (see Figure 9.2), aptly christened "APSARA" – after the celestial water nymph – by the first Prime Minister of India, Pandit Jawaharlal Nehru.[4] With APSARA, India became the first Asian country outside the erstwhile Soviet Union to have designed and built its own nuclear reactor. It is useful to recall how close the date of criticality of APSARA (August 4, 1956) was to the first electricity-generating reactor, the AM-1, a 5 MW graphite-moderated and water-cooled reactor that began operation at Obninsk in Russia on June 27, 1954. The next crucial step materialized in 1960 with the building of CIRUS, a high power (40 MWth) research reactor. This reactor, then known as the Canada India Reactor and now as CIRUS, was built in collaboration with Canada. Experiments carried out with CIRUS and APSARA have provided the necessary confidence and expertise for the design and safe operation of many other nuclear power reactors in the country. In early 1961, a zero energy critical facility named ZERLINA (Zero Energy Reactor for Lattice Investigations and New Assemblies) was built to study various geometrical aspects (lattice parameters) of a reactor fuelled with natural uranium and moderated with heavy water. The next logical step was to build a critical facility, which used plutonium as fuel. Such a test reactor was built in 1972 and was named PURNIMA (Plutonium Reactor for Neutron Investigations in Multiplying Assemblies). This reactor was intended for studying the behavior of plutonium fuel in a pulsed fast reactor (which was contemplated as an experimental facility for neutron scattering experiments but ultimately was not taken up for construction). Following this, a critical facility called PURNIMA-2 was also designed, with a solution containing 400g of uranyl (based on U-233) nitrate serving as the fuel for this facility. It attained criticality in 1984. The need was then felt for a research reactor with even larger neutron flux and irradiation volumes than CIRUS, to meet the growing requirements for radioisotopes and research. This culminated in building of a totally indigenous 100 MW research reactor, boasting the highest flux in Asia at that time. It attained criticality in August 1985 and was named DHRUVA .

Indira Gandhi Center for Atomic Research

Initial R&D work on fast reactors, including on sodium technology, was started at BARC. The work on setting up a Reactor Research Centre at Kalpakkam was begun in 1971, essentially to pursue a program for developing fast breeder technology. RRC was renamed the Indira Gandhi Center for Atomic Research (IGCAR) in December 1985. This Center has modern facilities for developing and testing fast breeder reactor materials, components and systems including those required to work with high temperature sodium.

A fast breeder test reactor (FBTR) was commissioned in 1985, with indigenous plutonium–uranium mixed carbide fuel, providing valuable design and operational experience. Based on the successful operation of the FBTR, it was decided to embark on the commercial phase of the fast reactor program, in terms of a 500 MWe FBR at Kalpakkam, in 2003.

As part of the studies with U-233 fuel, a 30 kWt pool-type research reactor, KAMINI (Kalpakkam MINI), was designed and built (Figure 9.4).[6] Prior to this, a mock-up of the core of this reactor was built and became critical in April 1992. It was given the name PURNIMA-3. KAMINI was became operational in 1996. This reactor is being extensively used as a neutron source for research applications such as neutron radiography of irradiated nuclear fuel and pyro devices for the Indian space program.

Commercial Nuclear Power Plants

Nuclear Power Corporation of India Limited (NPCIL)

Initially, work on the PHWR program was conducted at BARC. In 1967, the Department of Atomic Energy constituted a Power Projects Engineering Division (PPED) with the responsibility for design, engineering, procurement, construction, commissioning, operation and maintenance of atomic power plants. With the proposed expansion of the nuclear power program, a Nuclear Power Board was constituted in 1984 to implement the program. The Nuclear Power Board was converted into a Corporation and the Nuclear Power Corporation of India (NPCIL) was registered as a Public Limited Company in 1987.

The setting up of PHWRs and associated fuel cycle facilities is already in the industrial domain. NPCIL is presently operating seventeen nuclear power units (including two BWRs) at six locations, is implementing the construction of six (including two PWRs and one FBR) on-going nuclear power projects, and is handling other related activities. The existing operating power stations are: Tarapur Atomic Power Station (TAPS) Units 1, 2, 3, and 4 in Maharashtra; Rajasthan Atomic Power Station (RAPS) Units 1, 2, 3, and 4 in Rajasthan; Madras Atomic Power Station (MAPS) Units 1 and 2 in Tamil Nadu; Narora Atomic Power Station (NAPS) Units 1 and 2 in Uttar Pradesh; Kakrapar Atomic Power Station (KAPS) Units 1 and 2 in Gujarat; and Kaiga Atomic Power Station Units (Kaiga) 1, 2, and 3 in Karnataka.

The Tarapur Atomic Power Station (TAPS)

The Tarapur Atomic Power Station (TAPS), based on a BWR, was an exception to the three-stage nuclear power program drawn up by the AEC. This deviation was also based on the fact that the power shortage in the western region could be most economically reduced by building a nuclear power plant. This station, built by the General Electric (GE) Company, USA on a turnkey basis, began commercial operation in 1969. The construction of TAPS was very useful in acquiring initial experience in the construction and operation of nuclear power plants.

Pressurized Heavy Water Reactors (PHWRs)

In parallel with the construction of TAPS-1 and -2, work started on a second nuclear power station near Kota, Rajasthan, as a joint Indo-Canadian venture. The first unit of this station began commercial operation in 1972. This was followed by the construction of one more reactor at Rajasthan and two more reactors at Kalpakkam. The emphasis at this stage was on increasing local participation in design, equipment manufacture and construction. A standardized Indian version was designed at this point, with several important improvements such as two fast-acting shutdown systems, high pressure as well as low pressure Emergency Core Cooling System (ECCS) injection, full double containment, new ball-filled end-shield design, etc. This design was used from Narora onwards. A chronological account of the construction of currently operating Indian nuclear power plants is available elsewhere.

Nuclear power in India has passed through various stages of development. TAPS-1 and -2, and RAPS-1 served to demonstrate the technology through international co-operation. Subsequent efforts led to the indigenization of the technology (RAPS-2, MAPS-1 and -2), followed by standardization and consolidation of the knowledge base (commissioning of NAPS-1 and -2, KAPS-1 and -2, RAPS-3 and -4). India has now successfully achieved commercialization of the PHWR technology and is engaged in the design and deployment of enhanced capability PHWRs.

On the route from the Rajasthan-1 to Kakrapar-2, the designs of the PHWRs were progressively upgraded to further improve their safety, economics and reliability. At present, three units of 220 MWe PHWRs are in an advanced stage of construction at Kaiga and Rajasthan. While TAPS-3 and -4 are 500 MWe PHWRs, a program of construction of additional PHWRs of 700 MWe capacity has been chalked out. In addition, two VVER type PWRs, each of 1,000 MWe capacity, being built with Russian collaboration, are in the advanced stages of construction in Kudankulam, Tamil Nadu.

Gestation Period and Construction

The construction period of Indian nuclear power plants is comparable with the best practices in other plants in the world (about five years). The completion cost of an indigenous Indian nuclear power plant (PHWR) is substantially lower than international costs.

Fast Reactor Program

Studies on the content of the FBR program, and type of test reactor to be built, were undertaken in the early 1960s. A collaboration agreement was signed in 1969 with France for technical know-how to build a test reactor in India similar to the French RAPSODIE reactor. In order to gain experience with the steam generators and power plants in the context of FBRs, it was decided to add these facilities to the FBTR.

The construction of the FBTR was completed in 1984. Critical components of the FBTR, such as the reactor vessel, rotating plugs, control-rod-drive mechanisms, sodium pumps, steam generators and component-handling machines were manufactured in India with know-how from France. Only 20 percent of the total cost of the reactor was in foreign exchange, paid mainly for know-how and raw materials. Sodium for the reactor was procured from local suppliers and purified in IGCAR. After commissioning of various systems in 1984–85, the FBTR was made critical in 1985. The reactor produced nuclear steam in January 1993 and reached a milestone when the power level was increased to 10.5 MWt in December 1993. The rolling of the turbine using nuclear steam was achieved in 1996 and the reactor was connected to the grid on July 11, 1997. A highlight of the operation of the FBTR is the excellent performance of the sodium pumps, intermediate heat exchangers and the steam generator.

After completing the design, associated R&D and the development of manufacturing technology for a 500 MWe prototype fast breeder reactor (PFBR), whose characteristics[10] are given in Table 9.2, the construction of the PFBR plant at Kalpakkam was started in 2003 and is now in an advanced stage. An independent corporation called BHAVINI has been set-up for this purpose. This new venture exemplifies the synergy between the research and development strengths of Indira Gandhi Centre for Atomic Research and the project planning and construction expertise of NPCIL.