The Nuclear Power Program of India

The installed electricity generation capacity (as of 31 March, 2017) in Megawatt (MW) through different sources in India is:

- Thermal Power plants (coal, diesel etc.) - 218,330 MW
- Nuclear Power plants – 6,780 MW
- Hydro Power plants – 44,478 MW
- Other renewable sources (wind, solar etc.) - 57,260 MW
- Total – 326,848 MW

According to the data released by worldbank.org, the average per capita electricity consumption in India in the year 2014 was 806 kilowatt-hour. Now considering a population of 1.32 billion and the present electricity consumption statistics, India would need at least 1,000,000 MW of power within the next few years. This calls for an additional installation of about 670,000 MW over the existing total of 326,848 MW.

India has a proven coal reserve of about 126 billion tons, 40 billion tons of which can be mined. At the present energy generation rate, India is already utilizing about 0.6 billion tons per year. For a total energy generation of about 1,000,000 MW, coal mining would have to be increased to 3.25 billion tons per year. At this rate, the available coal would be exhausted within the next 50 years.

The obvious question is then which source to utilize and no answer can be as fulfilling and appropriate as Nuclear. Burning 1 kg of uranium in a power plant can generate about 950 MW of power per day. Whereas, the amount of coal that would be needed to produce the same amount of power is 2,750 tons. India houses about 80,000 tons of Uranium and 390,000 tons of thorium that can be mined. Together these add to about 1,620 billion tons of coal equivalent. At the present consumption rate, this would be enough to serve the electricity needs of India for the next 500 years.

The three-stage program

India has forever been involved in a struggle when it comes to the availability of nuclear fuel. Since India is not an NPT (Nuclear Non-Proliferation Treaty) signed country, it has encountered a greater resistance while trying to import Uranium to be able to run its Nuclear Reactors even for peaceful power production purposes.

After the successful nuclear test of Pokhran in 1974, additional opposition was faced by India by the international community. While India has always maintained that it was a peaceful nuclear test with no intentions of militarizing her nuclear program, it was not received positively by most other countries. The plutonium used for the test was created in the CIRUS (Canadian-Indian Reactor Uranium System). CIRUS was a research reactor at the Bhabha Atomic Research Center (BARC) in Mumbai that was supplied by Canada and the heavy water used in that reactor was supplied by the US. The Pokhran test, therefore, especially received a backlash from these two countries.

During that period, US. and Canada contributed a major portion of the economic aid provided to India for her nuclear power programme. Post the Pokhran test, Canada concluded that it was a violation of an agreement between the two countries and revoked all nuclear energy assistance for two heavy water reactors that were then under construction. In light of all these controversies and increasing pressure on the Indian economy to meet the Uranium demands for its reactors, a paradigm shift was necessary that would make India self-sufficient in nuclear reactor technology and ease out the issues with the procurement of nuclear fuel.

The Indian Nuclear Power Program came into being in the 1950s. Dr. Homi J. Bhabha often credited as the Father of the Nuclear Power Program in India came up with the '*Three-stage program*'. The motivation behind this programme was to ensure that India can come up as an energy independent nation not having to rely on other countries for raw material in the form of uranium. Uranium ores in India are located in Singhbhum district of Jharkhand, Mahadek district of Meghalaya and Cuddapah district of Andhra Pradesh. Mining in Mahadek and Cuddapah is not done yet due to local opposition. The only uranium mill under operation at present is at Jaduguda with a capacity of 200 Tons/years. This limitation served to further strengthen the motivation behind the three-stage programme because even though India does not have a lot of uranium resources, it houses almost about 25% of the world thorium resources most of which are available in the thorium-rich monazite sands of Kerala beaches.

India	***963,000***
United States	***440,000***
Australia	***300,000***
Canada	***100,000***
South Africa	***35,000***
Brazil	***16,000***
Malaysia	***4,500***
Other countries	***90,000***
World total	***1,913,000***

Table1. United States Geological Survey (USGS) survey of thorium reserves in tons in the year 2011.

The Indian nuclear establishment has estimated that the country is capable of producing 500 GWe for at least four centuries using just the country's economically extractable thorium reserves. However, the problem with thorium is that it is not capable of sustaining a chain reaction as needed for the operation of commercial reactors.

Chain reaction, meaning, a reaction that has the ability of causing a subsequent reaction by itself. For eg, 235U is capable of undergoing a fission reaction and then using neutrons released from the previous reaction to sustain the next fission thereby causing a chain reaction. 235U is therefore called fissile (capable of fissioning). Thorium (232Th) is not fissile but a nuclear reaction allows us to convert 232Th to 233U. 233U is fissile and can be successfully employed to run a commercial nuclear power plant. This requires a reactor fueled by some other fissile material that provides a suitable environment for the conversion of 232Th to 233U and then extracting 233U to fuel a another reactor.

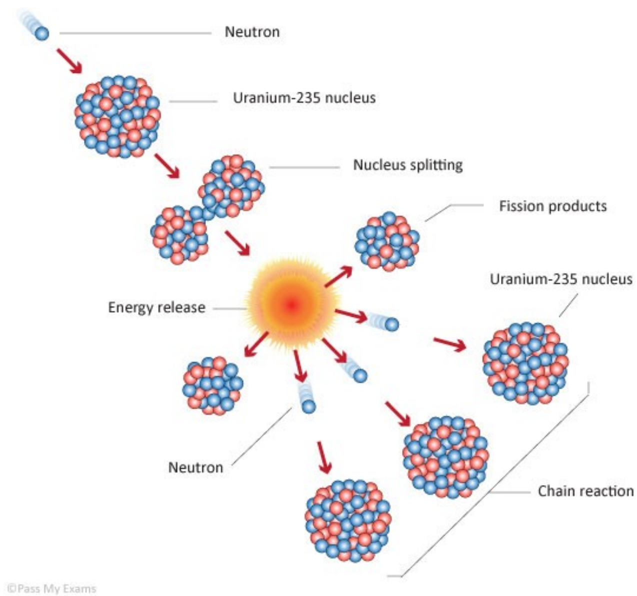

Fig.1 A simple demonstration of a nuclear chain reaction with 235U nucleus.

Utilizing this plan is a way to overcome the issues faced by India due to its limited uranium resources and create an independent workforce to empower the country's nuclear programme. The three-stage nuclear power programme in its simplified form can be described as follows:

Stage 1:

- Use natural uranium in Pressurized Heavy Water Reactors (PHWR) to produce electricity.
- Build a capacity of 10,000 Mwe.
- Extract the plutonium and the depleted uranium from the discharged fuel.

Stage 2:

- Construct Fast Breeder Reactors (FBR) with plutonium obtained from the 1st stage for the production of electricity.
- Breed plutonium in the depleted uranium of the fuel.
- Extract and recover plutonium, 233U, depleted uranium and thorium.
- Recycle plutonium, depleted uranium and thorium in the 2nd stage itself.

Stage 3:

- Construct FBRs with 233U obtained from the 2nd stage for production of electricity.
- Breed 233U from thorium and reprocess for 233U and thorium.
- Recycle 233U to multiply the number of FBRs.

Stage 2 involves the breeding of plutonium and 233U in the reactors. Breeding means providing an environment for the nuclear reaction to convert depleted uranium and thorium to plutonium and 233U respectively. These serve as the raw material for the 3rd stage of the programme. All these three stages combined together serve as a closed cycle that is efficient and can provide self-sustainability. Ability to produce more fuel (233U and plutonium) than that consumed in the 2nd stage actually puts nuclear power in the category of conventional renewable energy sources such as solar and wind.

The fissile materials of plutonium and 233U can be used in any of the stages described. India has already demonstrated her mastery in the first stage by successfully operating 22 nuclear reactors at eight sites. These collectively have an installed capacity of 6780 MW and producing a total of 35,000 GWh of electricity.

The second stage is already in progress. The Fast Breeder test reactor (FBTR) has been successfully operating at the Indira Gandhi Center for Atomic Research (IGCAR), Kalpakkam. FBTR first started operation in 1985, making India the seventh nation to have the technology to build and operate a breeder reactor after US, UK, France, Japan, Germany and Russia. Using the experience gained from the operation of the FBTR, a 500 MWe Prototype Fast Breeder Reactor (PFBR) is in construction at Kalpakkam. PFBR, when completed, will be the first commercially operating 2nd stage reactor in India.

As far as the 3rd stage is concerned, India is progressing on that too. The evidence comes in the form of KAMINI (Kalpakkam Mini reactor) which is a research reactor also stationed at IGCAR, Kalpakkam. It started operation on October 29, 1996 and produces about 30 kW of thermal power. Kamini uses light water as coolant and moderator and 233U as primary fuel. This 233U is provided by the thorium fuel cycle generated by the FBTR reactor. India is credited as the world's first country to have designed an experimental reactor especially based on the thorium-based nuclear fuel cycle.

At present, India imports thousands of tons of uranium from Russia, Kazakhstan, France, and Uzbekistan. However, the Indo-US Nuclear Deal and the Nuclear Suppliers Group (NSG) waiver has played an extraordinary role in ending the three decades old isolation by the international community of the Indian civil nuclear programme. This has definitely proved to be a boost towards the success of the three-stage nuclear power programme.

This programme as devised by Dr. Homi J. Bhabha has the potential to put India at the forefront of the world's nuclear community. The ever-increasing electricity demands that continue to plague all the developing countries must be put to an end and India, with her three-stage nuclear power programme is all set to tackle the problem head-on.

Plants under operation

Name of Plant	**Type of plant**	**No. of Units & Generating capacity (MWe)**
Tarapur Atomic Power Station	*BWR, PHWR*	*BWR: 2x160, PHWR: 2x540*
Rajasthan Atomic Power Station	*PHWR*	*1x100, 1x200, 4x220*
Madras Atomic Power Station	*PHWR*	*2x220*
Narora Atomic Power Station	*PHWR*	*2x220*
Kakrapar Atomic Power Station	*PHWR*	*2x220*
Kaiga Atomic Power Station	*PHWR*	*4x220*

Kudankulam Atomic Power Station	*PWR*	*2x1000*

Plants under construction

Name of Plant	**Type of plant**	**No. of Units & Generating capacity (MWe)**
Rajasthan Atomic Power Station	*PHWR*	*2x220*
Kakrapar Atomic Power Station	*PHWR*	*2x220*
Kalpakkam Atomic Power Station	*PFBR*	*1x500*