AN OVERVIEW ABOUT 3- STAGE ENERGY NUCLEAR POWERPLANT

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ABSTRACT

India's three-stage nuclear power programme was formulated by Homi Bhabha in the 1950s to secure the country's long term energy independence, through the use of uranium and thorium reserves found in the monazite sands of coastal regions of South India. The ultimate focus of the programme is on enabling the thorium reserves of India to be utilised in meeting the country's energy requirements.[1][2] Thorium is particularly attractive for India, as it has only around 1–2% of the global uranium reserves, but one of the largest shares of global thorium reserves at about 25% of the world's known thorium reserves. However, thorium is not economically viable because global uranium prices are much lower. The country published about twice the number of papers on thorium as its nearest competitors, during each of the years from 2002 to 2006. The Indian nuclear establishment estimates that the country could produce 500 GWe for at least four centuries using just the country's economically extractable thorium reserves.

Keyword: - Coal, Hydrocarbons, Fast Breeder Reactor. Thorium Based Reactors

1. INTRODUCTION ABOUT 3- PHASE NUCLEAR POWERPLANT:-

Homi Bhabha conceived of the three-stage nuclear programme as a way to develop nuclear energy by working around India's limited uranium resources. Thorium itself is not a fissile material, and thus cannot undergo fission to produce energy.Instead, it must be transmuted to uranium-233 in a reactor fueled by other fissile materials.The first two stages, natural uranium-fueled heavy water reactors and plutonium-fueled fast breeder reactors, are intended to generate sufficient fissile material from India's limited uranium resources, so that all its vast thorium reserves can be fully utilised in the third stage of thermal breeder reactors.

Bhabha summarised the rationale for the three-stage approach as follows:

The total reserves of thorium in India amount to over 500,000 tons in the readily extractable form, while the known reserves of uranium are less than a tenth of this. The aim of long range atomic power programme in India must therefore be to base the nuclear power generation as soon as possible on thorium rather than uranium… The first generation of atomic power stations based on natural uranium can only be used to start off an atomic power programme… The plutonium produced by the first generation power stations can be used in a second generation of power stations designed to produce electric power and convert thorium into U-233, or depleted uranium into more plutonium with breeding gain… The second generation of power stations may be regarded as an intermediate step for the breeder power stations of the third generation all of which would produce more U-233 than they burn in the course of producing power.

In November 1954, Bhabha presented the three-stage plan for national development, at the conference on "Development of Atomic Energy for Peaceful Purposes" which was also attended by India's first Prime Minister

Jawaharlal Nehru. Four years later in 1958, the Indian government formally adopted the three-stage plan.[19] Indian energy resource base was estimated to be capable of yielding a total electric power output of the order shown in the table below. Indian government recognised that thorium was a source that could provide power to the Indian people for the long term.

Energy resource type	Amount (tonnes)	Power potential
Coal	54 billion	11
Hydrocarbons	12 billion	6
Uranium (in PHWR)	61,000	0.3–0.42
Uranium (in FBR)	61,000	16–54
Thorium	~300,000	155–168 or 35

Table No 1.0 :- Energy Distribution

2. Fuel reserves and research capability

According to a report issued by the IAEA, India has limited uranium reserves, consisting of approximately 54,636 tonnes of "reasonably assured resources", 25,245 tonnes of "estimated additional resources", 15,488 tonnes of "undiscovered conventional resources, and 17,000 tonnes of "speculative resources". According to NPCIL, these reserves are only sufficient to generate about 10 GWe for about 40 years.[26] In July 2011, it was reported that a four-year-long mining survey done at Tummalapalle mine in Kadapa district near Hyderabad had yielded confirmed reserve figure of 49,000 tonnes with a potential that it could rise to 150,000 tonnes. This was a rise from an earlier estimate of 15,000 tonnes for that area.

Although India has only around 1–2% of the global uranium reserves, thorium reserves are bigger; around 12–33% of global reserves, according to IAEA and US Geological Survey. Several in-depth independent studies put Indian thorium reserves at 30% of the total world thorium reserves Indian uranium production is constrained by government investment decisions rather than by any shortage of ore.

As per official estimates shared in the country's Parliament in August 2011, the country can obtain 846,477 tonnes of thorium from 963,000 tonnes of ThO_2, which in turn can be obtained from 10.7 million tonnes of monazite occurring in beaches and river sands in association with other heavy metals. Indian monazite contains about 9–10% ThO_2.] The 846,477 tonne figure compares with the earlier estimates for India, made by IAEA and US Geological Survey of 319,000 tonnes and 290,000 to 650,000 tonnes respectively. The 800,000 tonne figure is given by other sources as well.

It was further clarified in the country's parliament on 21 March 2012 that, "Out of nearly 100 deposits of the heavy minerals, at present only 17 deposits containing about 4 million tonnes of monazite have been identified as exploitable. Mine-able reserves are ~70% of identified exploitable resources. Therefore, about 225,000 tonnes of thorium metal is available for nuclear power program.

India is a leader of thorium based research.[36][13] It is also by far the most committed nation as far as the use of thorium fuel is concerned, and no other country has done as much neutron physics work on thorium.[The country published about twice the number of papers on thorium as its nearest competitors during each of the years from 2002 to 2006.Bhabha Atomic Research Centre (BARC) had the highest number of publications in the thorium area, across all research institutions in the world during the period 1982-2004. During this same period, India ranks an overall second behind the United States in the research output on Thorium. Analysis shows that majority of the authors involved in thorium research publications appear to be from India.[39] According to Siegfried Hecker, a former director (1986–1997) of the Los Alamos National Laboratory in the United States, "India has the most technically ambitious and innovative nuclear energy programme in the world. The extent and functionality of its nuclear experimental facilities are matched only by those in Russia and are far ahead of what is left in the US.

3. 3- STAGE OF NUCLEAR POWERPLANT:-

Stage I – Pressurized Heavy Water Reactor [PHWR]

- In the first stage of the programme, natural **uranium** fuelled pressurized heavy water reactors (PHWR) produce electricity while generating **plutonium-239 as by-product**.

[U-238 → Plutonium-239 + Heat]

[In PWHR, enrichment of Uranium to improve concentration of U-235 is not required. U-238 can be directly fed into the reactor core]

[Natural uranium contains only 0.7% of the fissile isotope uranium-235. Most of the remaining 99.3% is uranium-238 which is not fissile but can be converted in a reactor to the fissile isotope plutonium-239].

[Heavy water (deuterium oxide, D 2O) is used as moderator and coolant in PHWR].

- PHWRs was a natural choice for implementing the first stage because it had the most **efficient reactor design [uranium enrichment not required]** in terms of uranium utilization.
- India correctly calculated that it would be easier to create heavy water production facilities (required for PHWRs) than uranium enrichment facilities (required for LWRs).
- Almost the entire existing base of Indian nuclear power (4780 MW) is composed of first stage PHWRs, with the exception of the two Boiling Water Reactor (BWR) units.

In the first stage of the programme, natural uranium fuelled pressurised heavy water reactors (PHWR) produce electricity while generating plutonium-239 as by-product. PHWRs was a natural choice for implementing the first stage because it had the most efficient reactor design in terms of uranium utilisation, and the existing Indian infrastructure in the 1960s allowed for quick adoption of the PHWR technology.] India correctly calculated that it would be easier to create heavy water production facilities (required for PHWRs) than uranium enrichment facilities (required for LWRs).[41] Natural uranium contains only 0.7% of the fissile isotope uranium-235. Most of the remaining 99.3% is uranium-238 which is not fissile but can be converted in a reactor to the fissile isotope plutonium-239. Heavy water (deuterium oxide, D_2O) is used as moderator and coolant. Indian uranium reserves are capable of generating a total power capacity of 420 GWe-years, but the Indian government limited the number of PHWRs fueled exclusively by indigenous uranium reserves, in an attempt to ensure that existing plants get a lifetime supply of uranium. US analysts calculate this limit as being slightly over 13 GW in capacity.[43] Several other sources estimate that the known reserves of natural uranium in the country permit only about 10 GW of capacity to be built through indigenously fueled PHWRs.[44][45][46][47] The three-stage programme explicitly incorporates this limit as the upper cut off of the first stage, beyond which PHWRs are not planned to be built.

Almost the entire existing base of Indian nuclear power (4780 MW) is composed of first stage PHWRs, with the exception of the two Boiling Water Reactor (BWR) units at Tarapur.[49][50] The installed capacity of Kaiga station is now 880 MW, making it the third largest after Tarapur (1400 MW) and Rawatbhata (1180 MW).[The remaining three power stations at Kakrapar Kalpakkamand Narrow]Rall have 2 units of 220 MW, thus contributing 440 MW each to the grid. The 2 units of 700 MWe each (PHWRs) that are under construction at both Kakrapar and Rawatbhata, and the one planned for Banswara would also come under the first stage of the programme, totalling a further addition of 4200 MW. These additions will bring the total power capacity from the first stage PHWRs to near the total planned capacity of 10 GW called for by the three-stage power programme.

Capital costs of PHWRs is in the range of Rs. 6 to 7 crore ($1.2 to $1.4 million) per MW, coupled with a designed plant life of 40 years. Time required for construction has improved over time and is now at about 5 years. Tariffs of the operating plants are in the range of Rs. 1.75 to 2.80 per unit, depending on the life of the reactor. In the year 2007–08 the average tariff was Rs.2.28.

Stage II – Fast Breeder Reactor

- In the second stage, fast breeder reactors (FBRs)[**moderators not required**] would use plutonium-239, recovered by reprocessing spent fuel from the first stage, and natural uranium.
- In FBRs, plutonium-239 undergoes fission to produce energy, while the uranium-238 present in the fuel transmutes to additional plutonium-239.

Why should Uranium-238 be transmuted to Plutonium-239?

Uranium-235 and Plutonium-239 can sustain a chain reaction. But Uranium-238 cannot sustain a chain reaction. So it is transmuted to Plutonium-239.

But Why U-238 and not U-235?

Natural uranium contains only 0.7% of the fissile isotope uranium-235. Most of the remaining 99.3% is uranium-238.

- **Thus, the** Stage II FBRs are designed to “breed” more fuel than they consume**.**
- Once the inventory of plutonium-239 is built up thorium can be introduced as a blanket material in the reactor and transmuted to **uranium-233** for use in the third stage.
- The surplus plutonium bred in each fast reactor can be used to set up more such reactors, and might thus grow the Indian civil nuclear power capacity till the point where the third stage reactors using thorium as fuel can be brought drags on online
- As of August 2014, India’s first **Prototype Fast Breeder Reactor at Kalpakkam** had been delayed – with first criticality expected in 2015, 2016...and it.

In the second stage, fast breeder reactors (FBRs) would use a mixed oxide (MOX) fuel made from plutonium-239, recovered by reprocessing spent fuel from the first stage, and natural uranium. In FBRs, plutonium-239 undergoes fission to produce energy, while the uranium-238 present in the mixed oxide fuel transmutes to additional plutonium-239. Thus, the Stage II FBRs are designed to "breed" more fuel than they consume. Once the inventory of plutonium-239 is built up thorium can be introduced as a blanket material in the reactor and transmuted to uranium-233 for use in the third stage.The surplus plutonium bred in each fast reactor can be used to set up more such reactors, and might thus grow the Indian civil nuclear power capacity till the point where the third stage reactors using thorium as fuel can be brought online, which is forecasted as being possible once 50 GW of nuclear power capacity has been achieved.[59][60][61] The uranium in the first stage PHWRs that yield 29 EJ of energy in the once-through fuel cycle, can be made to yield between 65 and 128 times more energy through multiple cycles in fast breeder reactors.[62]The design of the country's first fast breeder, called Prototype Fast Breeder Reactor (PFBR), was done by Indira Gandhi Centre for Atomic Research (IGCAR). Bharatiya Nabhikiya Vidyut Nigam Ltd (Bhavini), a public sector company under the Department of Atomic Energy (DAE), has been given the responsibility to build the fast breeder reactors in India.The construction of this PFBR at Kalpakkam was due to be completed in 2012 It is not yet complete. A start date in 2015 has been suggested.addition, the country proposes to undertake the construction of four FBRs as part of the 12th Five Year Plan spanning 2012–17, thus targeting 2500 MW from the five reactors. One of these five reactors is planned to be operated with metallic fuel instead of oxide fuel, since the design will have the flexibility to accept metallic fuel, although the reference design is for oxide fuel. Indian government has already allotted Rs.250 crore for pre-project activities for two more 500 MW units, although the location is yet to be finalised.

Fig No 1 :- Monazite powder, a rare earth and thorium phosphate mineral, is the primary source of the world's thorium

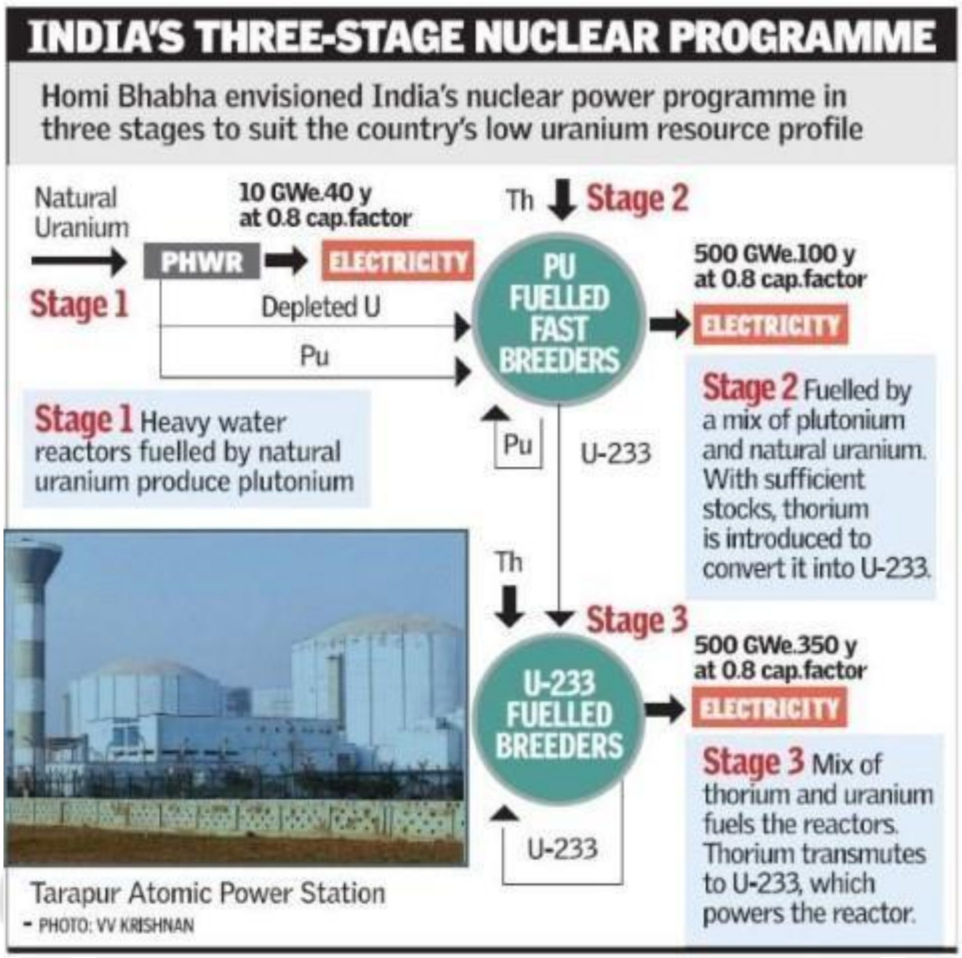

Fig No2:- 3 Stage Nuclear Programme

Stage III – Thorium Based Reactors

A Stage III reactor or an Advanced nuclear power system involves a self-sustaining series of **thorium-232-uranium-233** fuelled reactors. According to replies given in Q&A in the Indian Parliament on two separate occasions, 19 August 2010 and 21 March 2012, large scale thorium deployment is only to be expected 3 – 4 decades after the commercial operation of fast breeder reactors. [2040-2070] As there is a long delay before direct thorium utilisation in the three-stage programme, the count. Three options under consideration are the Accelerator Driven Systems (ADS), Advanced Heavy Water Reactor (AHWR) and Compact High Temperature Reactorry is now looking at reactor designs that allow more direct use of thorium in parallel with the sequential three-stage programme.

Present State of India's Three-Stage Nuclear Power Programme

- After decades of operating pressurized heavy-water reactors (PHWR), India is finally ready to start the second stage.
- A 500 MW Prototype Fast Breeder Reactor (PFBR) at Kalpakkam is set to achieve criticality any day now and four more fast breeder reactors have been sanctioned, two at the same site and two elsewhere.
- However, experts estimate that it would take India many more FBRs and at least another four decades before it has built up a sufficient fissile material inventory to launch the third stage.

What is a fissile material?

- A fissile material is one that can sustain a chain reaction upon bombardment by neutrons.
- Thorium is by itself **fertile**, meaning that it can transmute into a fissile radioisotope **[U-233]** but cannot itself keep a chain reaction going.
- In a thorium reactor, a fissile material like uranium or plutonium is blanketed by thorium.
- The fissile material, also called a driver in this case, drives the chain reaction to produce energy while simultaneously transmuting the fertile material into fissile material.
- India has very modest deposits of uranium and some of the world's largest sources of thorium. It was keeping this in mind that in 1954, Homi Bhabha envisioned India's nuclear power programme in three stages to suit the country's resource profile.

1. In the first stage, heavy water reactors fuelled by natural uranium would produce **plutonium [U-238** will be transmuted to Plutonium 239 in PHWR]
2. the second stage would initially be fuelled by a mix of the plutonium from the first stage and natural uranium. This uranium would transmute into more plutonium and once sufficient stocks have been built up, thorium would be introduced into the fuel cycle to convert it into **uranium 233** for the third stage [thorium will be transmuted to U-233 with the help plutonium 239**]**.
3. In the final stage, a **mix of thorium and uranium** fuels the reactors. The thorium transmutes to U-233 which powers the reactor. Fresh thorium can replace the depleted thorium [can be totally done away with uranium which is very scares in India] in the reactor core, making it essentially a thorium-fuelled reactor **[**thorium keeps transmuting into **U-233**. It is U-233 that generates the energy].

4. CONCLUSIONS

According to the Chairman of India's Atomic Energy Commission, Srikumar Banerjee, without the implementation of fast breeders[116] the presently available uranium reserves of 5.469 million tonnes can support 570 GWe till 2025. If the total identified and undiscovered uranium reserves of 16 million tonnes are brought online, the power availability can be extended till the end of the century. While calling for more research into thorium as an energy source and the country's indigenous three-stage programme, he said, "The world always felt there would be a miracle. Unfortunately, we have not seen any miracle for the last 40 years. Unless we wake up, humans won't be able to exist beyond this century.

BIOGRAPHIES

	Parikh Maulesh Hiteshbhai received his Diploma degree in Mechanical from Parul Institute Of Engineering And Technology in 2015, the B.E. Degree in optics from Parul Institute Of Engineering And Technology, Limda, Vadodara, and Gujarat, India.
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