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Thorium Based Indian Nuclear Program

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ABSTRACT

India has the largest thorium reserves in the world. Normally, it is deposited in the rocks and can be extracted through specific processing, however, in India, it is available in pure and refined form. India has included utilization of Thorium as a major goal in its nuclear energy program because it has the large amount of thorium as compared to meager uranium reserves. Indian ambitious three stage nuclear program is aimed to fulfill its objective to achieve energy security whereas nearly 300 million of the population in India is estimated to be out of the national electricity grid. India is expanding its nuclear energy production to achieve the target of 63 GW into the total power share by 2032 and plans to further increase this share to 25% by 2050. However, the technology to use thorium as a fuel is quite complicated and no country has yet achieved this capability owing to the involvement of reprocessed nuclear fuel, which is quite hard to handle. While India is struggling to achieve a breakthrough in the development of technology to use thorium as blanket fuel for use in advanced reactor. The overall implications of such developments would result in the exponential increase in Indian fissile materials consequently jeopardizing the deterrence stability in South Asia. Once India is able to tap the weapon grade U-233 from thorium, then its fissile material stocks would increase exponentially resulting in exacerbating the Pakistani security dilemma vis-à-vis India.

Keywords: *Thorium, Indian Thorium Potential, Indian Three Stage Nuclear Program*

1. Introduction

In 1828, Jons Jacob Berzelius, a Swedish scientist, discovered Thorium [1]. It is naturally occurring element 3-4 times abundant than Uranium. It was named after “Thor”. According to Norse (Scandinavian) mythology, ‘Thor’ was the god of war who is widely known as hammer-wielding god protecting the mankind. According to this mythology, Thorium is also attributed as “Asgard’s Fire”, Asgard being a small planetary body which is home of their gods [2].

Thorium is a radioactive material which occurs in nature; however, it cannot be readily used as a fuel. So to call it as “Thorium Fuel” is wrong because it is fertile material rather than a fissile material which itself cannot be used as a fuel but it can be de-generated or irradiated through certain process to convert it into uranium-233 which is fissile material and can be used as a powerful fuel. Due to its high radiation properties, Uranium-233 can be used in nuclear weapons. Although Thorium is found three times more as compared to uranium, yet it has never been used into reactors because it does not have the ability to start fission reaction. This aspect is associated with the proliferation-resistant trait of thorium as nuclear fuel.

The earliest reactor using thorium was introduced in United States in 1962[3]. However, the pace was slow because the focus was on Uranium based fuel and it was present in abundance in developed states. In 1996, International Atomic Energy Agency (IAEA) started a study to determine potential use of thorium as nuclear fuel. This was followed by USA’s Shippingport Atomic Power Station project which was the first of a kind to breed thorium [4]. Currently, Norway is in test phase of two types of Thorium fuels since 2013 and is hoping to market it as soon as the regulatory formalities are met [5].

The top five countries with the most thorium reserves and the overall world reserves are shown in the table [Ref. 5]:

Table 1: Data showing top 5 countries with most thorium reserves and total reserves in the world

Country	Reserves in Kilo Tones
India	846
Brazil	632
Australia	595
USA	595
Egypt	380
World total	6,355

India has the largest known thorium reserves. It had envisioned its Thorium potential very early and had the three-stage program that would use thorium as fuel in the advanced reactors. India is pursuing its ambitious program but there are challenges of technological barriers and economic constraints. It is significant for India because it does not have large reserves of Uranium whereas it has huge Thorium reserves. India has been conducting research on utilizing Thorium for producing energy. For that purpose, it has developed a “Fast Breeder Test Reactor (FBTR)” and operating it for 27 years now for experimentation. However, still it is estimated that it would start production in 20 to 30 years from now [6].

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It is hard to ascertain the financial benefits right now but if the technology matures, then it would be vital for ever growing energy requirements of India.

In order to dig into the issue, it is important to have an understanding of; (i) how thorium is used as a fuel, (ii) Indian thorium reserves and potential, (iii) Indian three stage nuclear ambitions, (iv) thorium and issues of non-proliferation and (v) possible implication for Pakistan.

2. Thorium as Fuel

Thorium does not undergo fission automatically; therefore, it cannot be used directly in a reactor as a fuel. It is a fertile material which can absorb a neutron to make uranium-233 which is radioactive and produces fission. So, when we talk about Thorium as a fuel, it requires a certain fissile material that can be used as a 'driver' so that a chain reaction can start. There are two options for "fissile driver"; (i) to use Uranium-233 or Uranium-235 as drivers, or (iii) to use Plutonium-239 mix-oxide fuel [8]. However, all of these drivers cannot be readily supplied in a reactor because they are highly radioactive in this form and are very difficult to handle.

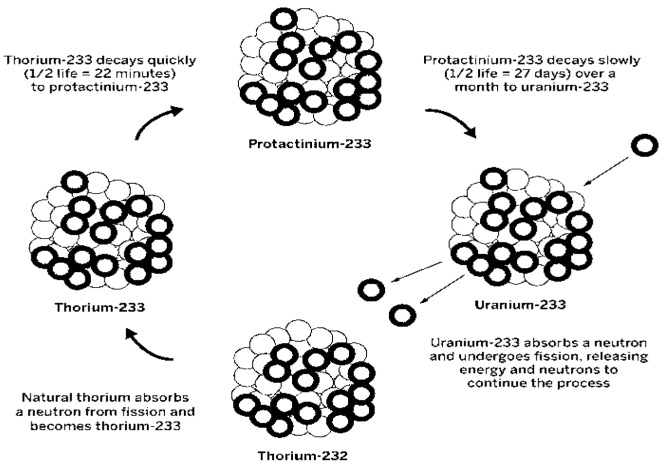

Fig. 1: Thorium energy cycle.

For the first option of using Thorium as fuel is through use of breeder reactor which can produce more U-233 than it consumes. Resultantly, this U-233 produced can be used as driver. But the breeder reactor requires good "neutron economy" i.e. the neutron loss during the reaction should be minimum possible to zero and all the neutrons are consumed. This can only be achieved in a slow neutron environment. With Uranium fuels having high speed neutrons, it becomes impossible to achieve slow neutron system which is ideal for thorium. The second option for the use of Thorium is to use it as "fertile matrix" in the form of "Mixed Thorium Plutonium Oxide (Th-Pu Mox)" wherein Plutonium serves as a "fissile driver".

The technology to use Thorium as a fuel is sophisticated but once developed; it is highly efficient as compared to the conventional reactors using Uranium as fuel. There are two types of fuel cycle of Thorium [7]:

2.1 Open Fuel Cycle

In this process Th-232 is irradiated by carrying out in-situ fission of U-233. During this process, U-233 is not separated from the product through chemical processing and the cycle remains open.

2.2 Closed Fuel Cycle

In this type of fuel cycle, U-233 is separated by chemically reprocessing Thorium. The resultant product U-233 is re-fabricated for further use as fuel in the reactor.

There are certain types of nuclear reactors in which Thorium can be used. According to World Nuclear Association (WNA), following reactors can utilize Thorium as fuel: "(i) The Pressurized Heavy Water Reactor (PHWRs), (ii) High Temperature Gas Cooled Reactors (HTRs), (iii) Pressurized Light Water Reactors (PWRs), (iv) Boiling Light Water Reactors (BWRs) and (v) Fast Neutron Reactors (FNRs)". In addition to that, there are further two types of reactors but they are still in conceptual phase. These include: "Molten Salt Reactors (MSRs)" and "Accelerator Driven Subcritical Reactors (ADSR)" [10].

3. Indian Thorium Reserves/Potential

The world's largest reserves of Thorium are found in India [8]. Coastal areas of Orissa sand complex, sands of Tamil Nadu (Manavalakkuricci), Kerala (Aluva and Chavara) are rich with monazite, ilmenite and garnet which are the sources of thorium. These reserves constitute 32 % of the world resources [9]. The following table shows the estimated thorium reserves in India according to "Atomic Minerals Directorate for Exploration and Research, India" [Ref.9]:

Table 2: Estimated Monazite reserves in India

State	Monazite (Kilo Tons)
Odhisa	2410
Andhra Pradesh	3720
Tamil Nadu	2460
Kerala	1900
West Bengal	1220
Jharkhand	220
Total	11930

According to Indian sources, these reserves are 11.94 million tones. These reserves can contribute to 360,000 tons of Thorium [10]. According to conservative calculations, 400,000 MW of electricity can be generated through these reserves in a year for about next 4 centuries.

4. Indian Three Stage Nuclear Program

Indian nuclear policy rests on the vision of Jawaharlal Nehru, the first Prime Minister of India, who laid the foundations of atomic research in India along with Dr. Homi Bhabha. The three stage program was proposed by Bhabha in November 1954. This proposal was well received by Nehru who supported it for the formal adoption by the government in 1958 [11].

The three stages include three steps for nuclear development.

First stage includes; installation and operation of "Pressurized Heavy Water Reactors (PHWRs) and light water reactors" to produce electricity as well as to produce plutonium from reprocessing of spent fuel.

In the second stage, India will develop Fast Breeder Reactors (FBRs) in which plutonium would be used to produce more and more U-233 from Thorium. In this process, a blanket of uranium and Thorium is used in the core to produce more uranium and plutonium than it was fed in the system.

At the final stage, Advanced Heavy Water reactors will be developed to use thorium plutonium fuel in order to produce U-233 which in turn is used as fuel for reactors. During the process of thorium fission, about 66% power is produced [12].

In all of these stages, used fuel needs to be reprocessed to recover fissile materials for recycling.

5. Thorium Based Program

India has become the first country to experiment utilization of Thorium in the breeder reactor [13]. For the last 27 years, India is working on operationalizing fast reactors of 500 MWe using Sodium as coolant. This type of fast reactors would produce the required amount of plutonium and uranium which will be used by the third stage advanced reactors. However, experts say that it would take India another 20 to 30 years for maturation of technology let alone its operationalization and benefitting from it [14].

6. Prototype Fast Breeder Reactor (PFBR) and KAMINI

India is still working on development of its first Prototype Fast Breeder Reactor (PFBR). The objective of fast reactor is to generate fissile material for utilizing Thorium. This is done by using fertile material like U-238 or Th-232 and bombarding them with neutrons. The sodium cooled PFBR does not use thorium; rather it uses U-238. There are several technological challenges attached to fast reactors. These challenges include: (i) the problem of corrosion of pipes and steel vessels, (ii) production of high amount of radiation and (iii) the fuel cycle is costlier because of involvement of automated cycles like re-fabrication, reprocessing and chemical separation of used fuel. These challenges have been a major hurdle in any breakthrough in the FBR technology.

The "**KAMINI** (Kalpakkam Mini reactor)" is located in Kalpakam at Indira Gandhi Center for Atomic Research. It is a research reactor that became critical in 1996 and has the capacity to produce 30 KW of energy. It was one of a kind reactor particularly contrived to use Thorium as fuel. It is the only reactor in the world to have Thorium-plutonium blanket [15]. It is not only a fast breeder reactor but the output of plutonium breed has dual use: (1), for use in the next reactor; and (2), for use on a nuclear-tipped inter-continental missile.

Conditioned to materialization, the concept of using thorium as a fuel is wrought with complications. Theoretical explanation of thorium as nuclear fuel suggests that there are two complications in using thorium in a FBR [16]; (i) it requires a huge amount of plutonium to initiate the FBR containing thorium blanket. India does not have the indigenous uranium which can be reprocessed to get the plutonium. However, the Indo-US nuclear deal allows India to get uranium from other countries [17]; and (ii) to avoid creation of U-232 which is a highly radiotoxic material.

Under the process, the concept of fertile to fissile conversion of Thorium is used to get the U-233 which is capable of fission in nuclear reactor. Thorium-232 is natural raw material which is used to create uranium-233 which is done by bombarding it with neutrons. This can be done by putting thorium inside the reactor in the form of blanket over the plutonium fuel.

Thorium-232 transmutes into protactinium-233 upon absorption of neutron. Spontaneously, protactinium transmutes into uranium-233 which is highly radioactive and can be readily used in a nuclear weapon. The explosive power of uranium-233 is more as compared to uranium-235 so there is no need to enrich it and it is quite different from plutonium because it can be simply employed in a gun-type bomb like the one dropped on Hiroshima and does not require implosion like that of a plutonium based nuclear weapon.

Along with Uranium-233, there is also uranium-232 isotopes are produced which are highly undesirable because it produces burst of gamma radiations that damages the electronic equipment [18]. Alternatively, to avoid this problem, protactinium can be removed chemically from the reactor and wait until it is converted into uranium 233. This is a recipe for making any type of nuclear weapon. Development of such a capability would result in multiplying the Indian capability to produce U-233 which equivalent to HEU.

7. Thorium and issues of non-proliferation

While one narrative goes on that, Thorium, also called the "other" nuclear fuel, is considered to bring revolution in the nuclear industry which would have the traits of being environment friendly, economical and nuclear proliferation resistant. However, the counter narrative also exists that nothing related to nuclear can be risk free.

It is claimed that Thorium is the most suitable fuel for future nuclear reactors. But in an article of the journal, *Nature* of Dec 2012, the scholars are of the view that it is not as advantageous as being portrayed. The researchers consisting of Dr Stephen F. Ashley and Dr. Geoffrey T. Parks from the University of Cambridge; Professor William J. Nuttall from The Open University; Professor Colin Boxall from Lancaster University; Professor Robin W. Grimes from Imperial College London have highlighted that Thorium decays in four stages: to start with, thorium-232 breaks into thorium-233 which is unstable and converts into protactinium within 22 minutes. Then after 27 days it decays into uranium-233 which has the capability to undergo fission reaction.

There is a chance of proliferation during the chemical separation of protactinium-233 which is then transmuted into uranium-233 [19]. These chemical processes are not much complicated and it can be done by using chemical lab equipment with complete secrecy.

Importantly, the authors have pointed out that from total of 1.6 tons of Thorium, nearly 8kg uranium-233 can be separated which is enough for one nuclear weapon. More strikingly, it can be done "in less than a year [Ref.19]." Considering that, one can imagine the potential of India in terms of fissile material stocks using Thorium.

Furthermore, the smuggling and illegal mining of thorium has been reported in India. Several news reports have highlighted a major scam of 2.1 million ton of Monazite that has been disappearing from Indian shores. This amount is equal to 19.5 kilo tons of thorium [20]. Furthermore, it was allowed by the Indian Government.

8. Implications for Pakistan

For Pakistan it can cause two kinds of implications: one, the FBR is out of safeguards and India can divert excessive plutonium to its nuclear program at will; and second, if thorium fuel cycle gets operationalized, then it would provide India with abundant stock of U-233. These implications will further reinforce the fissile material quandary of Pakistan [21].

In this scenario, policy options for Pakistan in terms of matching the fissile material stocks become increasingly limited owing to its limited uranium reserves. However, Pakistan should continue to bring innovations in its arsenal and steadily increase its fissile material stockpiles in order to maintain the full spectrum deterrence. In addition to that Pakistan should continue to voice its principled stance regarding FMCT and condemn the discrimination at all levels.

9. Conclusion

India has embarked on a journey to exploit its thorium reserves for energy generation using a modern, indigenous designed and locally produced fast breeder reactors for more than 20 years. However, this Indian dream is decades away from becoming true as according to R. Rajaraman, Professor of Theoretical Physics, Jawaharlal University, Delhi, it would take 20 to 30 years for the Thorium based nuclear reactors to be functional.

Considering the huge Thorium reserves Indian dream of Thorium energy is practically possible. It would not only cater for the energy needs of India but it would also enable it to be less dependent on other countries for the uranium based nuclear fuel as it does not have sufficient indigenous reserves of Uranium.

Strategically, if India is able to mature its technology for utilizing Thorium, it would bring anxiety for Pakistan because it would give two pronged advantage to India in terms of increasing its nuclear stockpile. One that it would enable India to reserve its indigenous Uranium for military purposes; and second that with further technological innovation, India may be able to chemically extract U-233 from the reactor process. However, this is highly difficult and involves sophisticated technology.

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