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Role of thorium in the Indian nuclear power programme

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ABSTRACT

In the context of Indian nuclear power programme, thorium has always had a prominent place due to its unique resource position with large thorium deposits and limited uranium reserves. A three-stage programme has been devised to efficiently utilise the available resources in a sustainable manner. Work on thorium fuel cycle has therefore been carried out right from the inception of Indian nuclear power programme. Engineering scale studies have been carried out on all aspects of the thorium fuel cycle - mining and extraction, fuel fabrication, utilisation in different reactor systems, evaluation of its various properties and irradiation behaviour, reprocessing and recycling. To provide impetus to these studies and to embark on a large-scale programme, the thorium fuel cycle based Advanced Heavy Water Reactor (AHWR) is being developed. The large-scale deployment of thorium based reactors will also require several additional features such as economic competitiveness, practically no impact on public domain, and enhanced safety which has several technological challenges to be overcome. The paper brings out the design aspects of the AHWR besides the ongoing work on other thorium based reactors such as the High Temperature Reactor (HTR) and the Molten Salt Reactor (MSR).

1. Introduction

For a large country like India, the long-term strategy for energy supply has to be based on indigenous resources and calls for deployment of an optimum mix of different energy sources. Apart from environmental issues associated with large-scale use of coal, it should be noted that the reserves of coal are also limited. Solar and other non-conventional renewable sources have an important role and need to be deployed to the fullest extent possible. However, several high power base load power stations are required for maintaining power grid stability and to meet the needs of industries and urban centres. Nuclear energy therefore has an important role to play as a sustainable option. In the context of Indian Nuclear Power Programme, (INPP) thorium has a prominent place due to its unique resource position of having large thorium deposits, but limited uranium reserves. This not only provides a greater incentive for large-scale use of thorium, but also calls for deployment of thorium based systems much earlier than that contemplated by other countries. In addition, thorium offers a number of attractive features:

- It has higher melting point, better thermal conductivity and a better capability of retention of fission gases. These provide higher safety margins during operation in reactor systems.
- The good dimensional stability against radiation and better fuel performance characteristics in terms of fuel temperatures and fission gas release offers potential for higher fuel burnups and longer reactor operating cycles.
- Thorium matrix is chemically inert, and stable. Also it is an excellent host for fissile materials. It has lower deterioration in the event of a fuel failure during operation in reactor (Sah et al., 2008) and provides improved waste form characteristics.
- The lower production of long lived minor actinides in thorium leads to reduction in the radioactivity levels in the waste generated from thorium (Lung, 1997).
- The conversion of fertile to fissile species is governed by the capture cross section which is 2.47 times that of ^{238}U and hence thorium offers greater competition to parasitic absorption in structural materials (Umasankari and Krishnani, 2013).
- ^{233}U has the required physics characteristics for use in a sustainable mode in Th-^{233}U based reactor systems. It has the highest η (eta) value covering a wide range of neutron energy in the thermal and epithermal spectrum resulting in high conversion ratio with thorium fuel (Umasankari and Krishnani, 2013).

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- ^{232}U is invariably present along with ^{233}U. The daughter products of ^{232}U (^{212}Bi and ^{208}Tl) are hard gamma emitters and it therefore provides resistance to the proliferation of the fissile ^{233}U.

It should, however, be noted that thorium despite its greater abundance in nature and a number of superior characteristics as described above lags behind uranium in use, as it does not have a fissile component. Thorium has to be first converted to uranium-233 in a nuclear reactor for its use. With this in view, a three-stage nuclear power programme has been chalked out in India with an intention to use thorium as the main stay of its long-term nuclear power programme. Fig. 1 shows a schematic of the Three Stage INPP.

The key elements in this programme are adoption of closed nuclear fuel cycle, use of breeder systems and a self sustainable thorium fuel cycle. It aims to multiply the domestically available fissile resource through the use of natural uranium in Pressurised Heavy Water Reactors (PHWRs), followed by the use of plutonium and depleted uranium obtained from the spent fuel of PHWRs in Fast Breeder Reactors (FBRs). After initially operating the FBRs with MOX fuel, it is planned to switch to metallic fuel which enhances the breeding ratio and substantially reduces the doubling time, thereby accelerating the growth of fissile inventory. Large scale use of thorium will subsequently follow in self sustainable reactors making use of Uranium-233 that will be bred in FBRs. This is expected when adequate nuclear installed capacity in the country has been built. The third stage, therefore, will optimally be after the plutonium-based FBRs have enabled accelerated growth in the nuclear generation capacity. After attaining the required level of installed capacity in the third stage, it would be possible to maintain this level of nuclear power capacity primarily with thorium practically without any fissile resources. The first stage has reached a state of commercial maturity, with 18 PHWRs in operation and many under construction and planning stages. The second stage is well underway with a Fast Breeder Test Reactor (FBTR) operational since 1985 and a 500 MWe Prototype Fast Breeder Reactor (PFBR) in final stages of construction. A Fast Reactor Fuel Cycle Facility (FRFCF) is also under construction at Kalpakkam. Work on Commercial Fast Breeder Reactors (CFBRs) and use of metallic fuels to achieve shorter doubling periods are in an advanced stage. In preparation for the third stage, development of technologies for thorium utilisation has been a part of ongoing activities in Department of Atomic Energy (DAE). With sustained efforts over the years, India has engineering scale experience over the entire thorium fuel cycle (Anantharaman et al., 2008). Efforts are currently underway to utilise this experience for industrial scale thorium utilisation. All efforts towards technology development and demonstration are being made now, so that, a mature technology is available in time. An Advanced Heavy Water Reactor (AHWR) based on thorium fuel is being developed to provide impetus for development of thorium based technologies for the 3rd stage and to demonstrate industrial-scale use of thorium. This experience will essentially pave the way forward for development of various advanced reactors using thorium with uranium-233 on a large scale. The utilisation of thorium in High Temperature Reactors (HTR) and Molten Salt Breeder Reactor (MSBR) is being studied. In addition, development of Accelerator Driven Subcritical (ADS) Systems is also being pursued. Various technologies associated with these systems in the area of material science and fuels are also being developed.

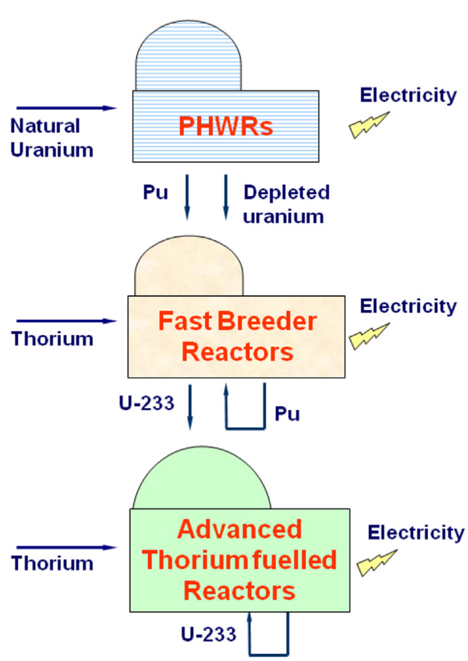

Fig. 1. Schematic of the three stage indian nuclear power programme.

This paper brings out an overview of thorium utilisation programme including Indian and international experience, the advanced reactor designs being pursued and the challenges associated with thorium utilisation.

2. Indian experience with thorium utilisation

In India, work on thorium fuel has been carried out right from the inception of its nuclear programme. Studies have been carried out on all aspects of thorium fuel cycle - mining and extraction, fuel fabrication, utilisation in different reactor systems, evaluation of its various properties and irradiation behaviour, reprocessing and recycling.

Monazite is the most important thorium bearing mineral in the country. It is one of the heavy minerals found along with others like ilmenite, sillimanite, garnet, rutile, zircon, etc. in the beach and inland placer deposits of the country. The Atomic Minerals Directorate for exploration and research (AMD), a constituent unit of Department of Atomic Energy (DAE), has so far established 11.93 million tons of monazite (thorium bearing mineral) in the country. Typical Indian monazites contains about 8–10% ThO_2 along with rare earths like lanthanum, cerium, praseodymium, neodymium, etc.

The present production of thorium is almost entirely as a by—-product of rare earth extraction from monazite sand (Patra, 2014). The mining and extraction of thorium is relatively easy. Wet mining operation involving the use of Dredger and Wet Concentrator (DWC) is carried out to exploit the inland deposits away from the beaches. The mineral free sand coming out of the concentrator is simultaneously pumped back and the heavy mineral rich sand obtained is subjected to further concentration to enrich it to have 97–98% heavy minerals. The beach sand minerals are then separated from each other to their mineralogically purer forms by taking advantage of their differences in size, density, electrical and magnetic properties. The overburden during mining is much smaller than in the case of uranium and the total radioactive waste production in mining operation is about two orders of magnitude lower than that of uranium. The so—called radon (Rn^{220}) impact is also much smaller than in the uranium case due to the short lifetime of thoron as compared to that of radon, and needs therefore, much simpler tailings management than in the case of uranium, to prevent long term public doses. As far as occupational doses are

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