Thorium – Fuelling a Sustainable Future for Nuclear Power

a report by
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History and Origins

Thorium, which is located in the actinide series of the periodic table, having the chemical symbol Th, was discovered by the Swedish chemist Jöns Jakob Berzelius in 1828, who named the element in honour of Thor, the Norse god of thunder. The actinide series, which is named after actinium, the first element in the series, encompasses 15 elements, having the atomic numbers of 89 through to 103, of which thorium is number 90. Of the 15 elements in the actinide family only thorium and uranium occur in considerable quantity in the earth's crust.

Uranium, which has the atomic number of 92 and which was discovered 39 years before thorium by the German chemist Martin Heinrich Klaproth in 1789, has been the accepted fuel of choice for nuclear power since Enrico Fermi invented the first nuclear chain reaction, Chicago Pile Number One, in America in 1942. After the end of World War II, nuclear research turned to producing electricity, which resulted in Experimental Breeder Reactor I being constructed in Idaho in 1951. With nuclear research focusing primarily on generating power from uranium, there was little interest at that time in the potential of thorium as a fuel for nuclear reactors.

The Benefits that Thorium Offers

Today, however, there is a growing consensus that thorium represents a crucial part the future of civil nuclear power generation, for several key reasons. The first and most advocated reason for using thorium in the nuclear fuel cycle is the non-proliferation benefits that it offers. All uranium-fuelled reactors produce a certain quantity of plutonium, but when the fertile thorium is the dominant fuel and is bombarded with neutrons it decays to become uranium-233, no utilisable plutonium is bred and, furthermore, there is very low and significantly less radio\toxicity from spent thorium fuel than that of spent uranium-235, uranium-238 and plutonium-239, the only isotopes currently used as nuclear fuel for reactors. Spent uranium-235 has a half-life of around 700 million years, spent uranium-238 has a half-life of 4.5 billion years, while the spent uranium-233, from the thorium fuel cycle has a half-life of 160,000 years and would remain radioactive for 500 years. It is also possible for the spent fuel to be reprocessed so that the thorium and fissile uranium can be recycled.

A further benefit from uranium-233 is its higher neutron yield per neutron absorbed, thus providing for a greater fuel efficiency than uranium-235, uranium-238 and plutonium-239.

As an element, thorium is understood to be at least three times as abundant in the earth's surface as that of uranium. All mined thorium can be used in a reactor, compared with 0.7% of natural uranium. This means that up to 40 times the amount of energy per unit mass could be available from thorium. In comparison to coal, the energy contained in one kilogram of thorium is equivalent to 4,000 tons of coal. In summation, thorium has the potential to provide the world's energy requirements for several thousand years, with minimal radioactive waste that is unsuitable for producing weapons grade material.

Geology

To date, exploration for thorium has been minimal, largely due to there being no major demand for the element. The average concentration of thorium in the earth's crust is 10 parts per million, with the element typically being located in concentration with uranium and other rare earth elements. The largest reserves of thorium are found in monazite, a phosphate that is rich in rare earth elements, especially thorium, lanthanum and cerium. The most substantial reserves of thorium are located in Australia, India, Brazil, Turkey and Norway, with total known world reasonably assured reserves of 2.23 million tonnes. The world's total reserve of monazite is estimated to be in the region of 12 million tonnes, of which eight million tonnes is found in the beach sands of India, in particular in the states of Kerala, Tamil Nadu, Andhra Pradesh and Orissa.

India – Leading the Advancement of Thorium Nuclear Technology

The rapid economic growth of India has resulted in its consumption of electricity doubling over the past decade, leaving the country with a supply deficit. Nuclear power generation has, to date, only been able to supply 3% of India's demand, largely due to the country having minimal uranium reserves, estimated at 78,000 tonnes, with production coming from the Jaduguda, Narwapahar, Bhatin, and Turamdih mines, controlled and operated by the Uranium Corporation of India. India's thorium reserves, meanwhile, have been estimated at 360,000 tonnes, a figure which will increase substantially as further exploration confirms new reserves. As a result of its need to harness nuclear energy as a primary source of electricity, India has been developing nuclear technology centered on the thorium fuel cycle.

At the Indira Gandhi Centre for Atomic Research in Kalpakkam, South-East India, the world's first thorium-fuelled reactor, Kamini, achieved criticality in October 1996. Kamini, which was constructed jointly between the Indira Gandhi Centre and the Bhabha Atomic Research Centre of Trombay, is a 30kWth experimental reactor that is powered by uranium-233.

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Moving forward with its 'three-staged' nuclear power programme, in 2003 work commenced on a 500MWe fast breeder reactor at Kalpakkam, which will have a blanket of thorium and uranium to breed uranium-233 and which is anticipated to be in operation by 2010. It is understood that the Bhabha Atomic Research Centre is to commence construction of a 300MWe advanced heavy water reactor in 2007, which will be the next demonstration reactor for generating energy from thorium. The long-term plan for India is to generate its energy from an advanced heavy-water reactor that utilises the country's vast thorium reserves. India's expertise in developing nuclear technology to harness energy from thorium is likely to see its technology rolled out internationally, and the country is already promoting the benefits of the thorium fuel-cycle and its non-proliferation benefits.

Thorium Power – Developing a Novel Thorium Nuclear Fuel

The public-listed American company Thorium Power Inc. is developing a patented new thorium fuel, initially targeted for use in Russia's seven Voda-Vodyanoi Energetichesky Reaktors (VVERs) (Russian: pressurised water reactor)-1000 reactors in order to eliminate weapons-grade plutonium, of which Russia is home to around 140 metric tons. The fuel design ensures that the used fuel is proliferation resistant, ensuring that no plutonium in the used fuel is suitable for weapons purposes. The technology is being developed in the Kurchatov Institute, Moscow, with funding from the US government and in-kind contributions from the Russian government. The key criterion for the technology's development is:

- full compatibility with existing VVER-1000 reactors;
- full utilisation of existing nuclear fuel fabrication infrastructure in Russia;
- minimising the hazards associated with handling plutonium in a fuel cycle;
- minimising costs associated with the plutonium disposition program in Russia;
- minimising production of reactor-grade plutonium in spent fuel;
- accelerating the rate of plutonium disposition in VVER-1000 reactors; and
- providing enhanced proliferation resistance so that no weapons-suitable plutonium could be extracted from spent fuel.

The technology is in the form of a seed and blanket fuel assembly design, whereby the outer layer of the technology is composed of 228 blanket rods, which are fueled with a combination of thorium oxide (ThO_2) and uranium oxide (UO_2). The uranium is 20% enriched in uranium-235. The inner layer of the technology is the seed fuel rods, which consists of 108 star-shaped twisted rods per assembly, which has plutonium-zirconium metal as the driver fuel. The seed assembly is a self-contained structure which is inserted into the centre region of the blanket assembly. Subsequently, the blanket captures neutrons from the ThO_2-UO_2 seed fuel, which breeds and burns uranium-233. The blanket assembly of the Thorium Power technology has the same outer design as that of a regular VVER-1000 fuel assembly.

Thorium Power's fuel design has been endorsed by nuclear technology specialists Westinghouse, which believes that the technology has good prospects for success. Westinghouse also believes the thorium fuel design to be superior to mixed oxide fuel (MOX), which is an alternative means of burning weapons-grade plutonium to produce electricity. It is understood that the thorium fuel assembly can eradicate plutonium three times faster and at up to 50% of the cost of MOX. Furthermore, MOX has yet to be tested in Russian reactors, meaning that potential commercialisation is at least a decade away. It is Thorium Power's stated intention to move the fuel from testing in a research reactor to commercial reactors.

Thorium is certainly an important strategic answer to long-term, safe and sustainable nuclear power.

Emerging Promise for Thorium Reactors in Poland and Norway

Whilst the principle countries driving the research behind thorium-fuelled reactors are India, America and Russia, there has been a growing interest in recent months from Norway and Poland. One of the most vocal supporters promoting the argument for using thorium in Norway is Professor Egil Lillestøl of the Institute of Physics and Technology at the University of Bergen. Norway has an estimated 180,000 tons of thorium – the world's fourth largest reserves – and Lillestøl is advocating investment in building a prototype accelerator driven reactor based on thorium. Recently, there have been an increasing number of people in the media and in government who have taken note of Lillestøl's proposals, but no indications have been given as to the future of thorium-fuelled reactors in Norway.

Poland, meanwhile, has been investigating options for power generation, which has included the possibility for using thorium, potentially through a venture with Thorium Power. The American Company has been in discussions with senior Polish government officials, where it has discussed how cutting edge nuclear technologies can address Poland's energy requirements.

The Future for Thorium

As of now, the two principle drivers of thorium-fuelled technology are India, through the development of its advanced heavy water reactor, and Thorium Power, through the development and ensuing commercialisation of its thorium seed and blanket fuel technology. Both India and Thorium Power Inc. are advocating the benefits of the thorium fuel cycle and there are reputable individuals backing the technology, including the former UK Conservative Party leader, Michael Howard, and Ambassador Thomas Graham, a renowned expert in nuclear non-proliferation. India has been intent on utilising its thorium reserves for a number of years and will push ahead with the development of the technology to produce energy from thorium. However, Thorium Power has much work to do before its technology is adopted in a Russian VVER-1000 reactor, or other designs. It is too early to foresee the extent of the role that thorium will play in the civil nuclear power generation industry, but with the support for, and understanding of, the thorium fuel cycle increasing, along with the tightening uranium supply market and accompanied price rise, there is a strong likelihood that we will see the first commercial thorium-fuelled reactors being constructed within the next decade. Thorium is certainly an important strategic answer to long-term, safe and sustainable nuclear power. ■

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