Thorium’s Long-Term Potential in Nuclear Energy: New IAEA Analysis

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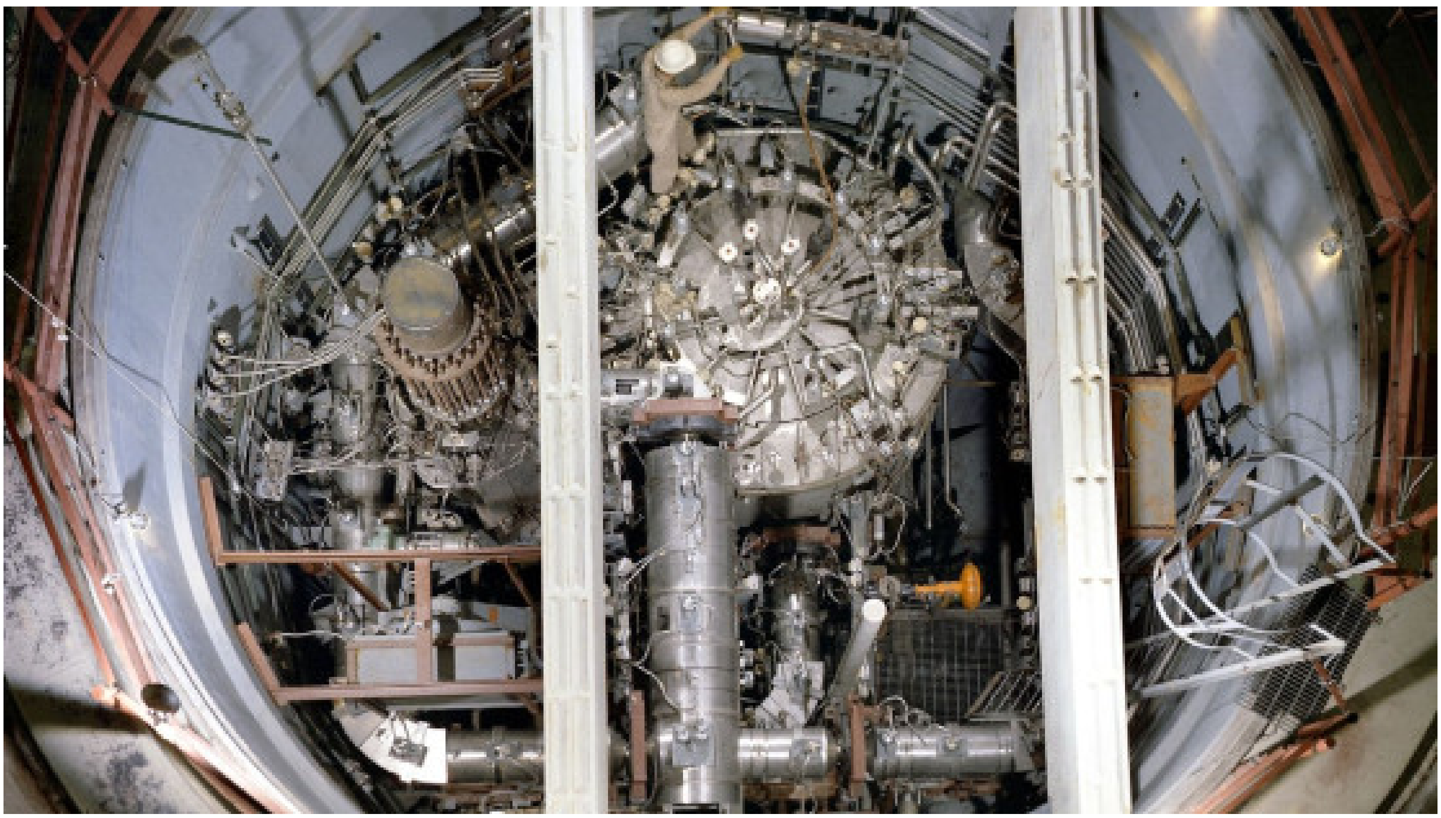

(https://www.iaea.org/sites/default/files/styles/original_image_size/public/thoriumstoryusreactorexperiment.jpg?itok=JNA6YXsT)

Early experimental thorium-based nuclear reactor at Oak Ridge National Laboratory, USA, 1960s (Photo: Oak Ridge National Laboratory/US DOE)

In August 2021, China announced the completion of its first experimental thorium-based nuclear reactor (https://www.france24.com/en/asia-pacific/20210912-why-china-is-developing-a-game-changing-thorium-fuelled-nuclear-reactor). Built in the middle of the Gobi Desert in the country’s north, the reactor over the next few years will undergo testing. If the experiment proves successful, Beijing plans to construct another reactor potentially capable of generating electricity for more than 100 000 homes (https://www.nature.com/articles/d41586-021-02459-w).

China is not alone in its intentions to reap thorium's unique properties. In the past, India, Japan, the United Kingdom, the United States of America and other countries have demonstrated enthusiasm for research into the possible application of thorium in nuclear power. The appeal of this metal is its potential to be a more abundant and efficient substitute for uranium, the dominant nuclear fuel.

However, using thorium for energy production is not without challenges, and these are discussed in a new IAEA publication Near-Term and Promising Long-Term Options for the Deployment of Thorium-Based Nuclear Energy (/publications/15215/near-term-and-promising-long-term-options-for-the-deployment-of-thorium-based-nuclear-energy). Comprehensively summarising the results of a four-year IAEA coordinated research project focused on the possibilities of developing thorium-based nuclear energy, the report examines the benefits and the challenges of using thorium as a fuel and analyses its application in different types of reactors — from the most commonly deployed water-cooled reactors (/topics/water-cooled-reactors#:~:text=Light%20water%20reactors%20(LWRs)%20are,directly%20in%20the%20steam%20turbine.) to molten-salt reactors (/topics/molten-salt-reactors).

“Many countries consider thorium as both a viable and very attractive option for generating power and meeting their growing energy needs,” said Kailash Agarwal, a Nuclear Fuel Cycle Facilities Specialist at the IAEA and one of the authors of the report. “Our research project helped share valuable knowledge and experience among national laboratories and research institutions in the use of thorium, culminating in this publication.”

Thorium is a silvery, slightly radioactive metal commonly found in igneous rocks and heavy mineral sands. It was named after Thor, the god of thunder in Norse mythology. It is three to four times more abundant (/publications/13550/world-thorium-occurrences-deposits-and-resources) in nature than uranium but historically has found little use in industry or power generation. This is partly because thorium in itself is not a nuclear fuel, but it can be used to create one. Thorium-232, the only naturally occurring isotope of thorium, is a fissionable material but not a fissile one, meaning that it needs high-energy neutrons to undergo fission — the splitting of atomic nuclei which releases energy that is used for electricity generation. However, when irradiated, thorium-232 undergoes a series of nuclear reactions, eventually forming uranium-233, a fissile material that can be burned up as fuel in nuclear reactors.

What can thorium offer?

Thorium boasts several advantages over the conventional nuclear fuel, uranium-235. Thorium can generate more fissile material (uranium-233) than it consumes while fuelling a water-cooled (/topics/water-cooled-reactors#:~:text=Light%20water%20reactors%20(LWRs)%20are,directly%20in%20the%20steam%20turbine.) or molten-salt reactor (/topics/molten-salt-reactors). According to estimates, the Earth's upper crust contains an average of 10.5 parts per million (ppm) of thorium (https://www-pub.iaea.org/MTCD/Publications/PDF/TE-1877web.pdf), compared with about 3 ppm of uranium.

“Because of its abundance and its fissile material breeding capability, thorium could potentially offer a long-term solution to humanity’s energy needs,” Agarwal said.

Another advantage is that thorium-fuelled reactors could be much more environmentally friendly than their uranium counterparts. In addition to the fact that these reactors — and nuclear power in general — do not emit greenhouse gases in operation, they also produce less long-lived nuclear waste than present-day uranium-fuelled reactors.

Not without challenges

However, there are several economic and technical obstacles making the deployment of thorium challenging. Despite its abundance, the metal is currently expensive to extract.

“The mineral monazite, which is a major source of rare earth elements, is also a primary source of thorium,” said Mark Mihalasky, a Uranium Resources Specialist at the IAEA. “Without the current demand for rare earth elements, monazite would not be mined for its thorium content alone. Thorium is a by-product, and extraction of thorium requires methods that are costlier than for uranium. So, as it stands, the amount of thorium that can be pulled out of the ground in a cost-effective manner is not as great as for uranium. This, however, could change if there was a higher demand for thorium and its application in nuclear power.”

Equally expensive are research, development and testing of thorium-powered nuclear installations due to a lack of significant experience with thorium and uranium's historical pre-eminence in nuclear power. “Another hurdle for thorium is that it can be difficult to handle,” said Anzhelika Khaperskaia, Technical Lead on Fuel Engineering and Fuel Cycle Facilities at the IAEA. Being a fertile and not fissile material, it needs a driver, such as uranium or plutonium, to trigger and maintain a chain reaction.

“To meet growing energy demand and achieve global climate objectives, the world is looking for alternative sustainable and reliable energy technologies. Thorium may become one of those,” concluded Clément Hill, Section Head at the IAEA. “We will continue our research to deliver credible and science-based results for those interested in working with thorium.”

Related resources

- Near Term and Promising Long Term Options for the Deployment of Thorium Based Nuclear Energy (https://www.iaea.org/publications/15215/near-term-and-promising-long-term-options-for-the-deployment-of-thorium-based-nuclear-energy)
- Energy (https://www.iaea.org/topics/energy)
- Nuclear fuel cycle (https://www.iaea.org/topics/nuclear-fuel-cycle)
- Role of Thorium to Supplement Fuel Cycles of Future Nuclear Energy Systems (https://www.iaea.org/publications/8703/role-of-thorium-to-supplement-fuel-cycles-of-future-nuclear-energy-systems)
- Thorium Fuel Cycle - Potential Benefits and Challenges (https://www.iaea.org/publications/7192/thorium-fuel-cycle-potential-benefits-and-challenges)

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