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Thorium reactors

Asgard's fire

Thorium, an element named after the Norse god of thunder, may soon contribute to the world's electricity supply

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WELL begun; half done. That proverb—or, rather, its obverse—encapsulates the problems which have dogged civil nuclear power since its inception. Atomic energy is seen by many, and with reason, as the misbegotten stepchild of the world's atom-bomb programmes: ill begun and badly done. But a clean slate is a wonderful thing. And that might soon be provided by two of the world's rising industrial powers, India and China, whose demand for energy is leading them to look at the idea of building reactors that run on thorium.

Existing reactors use uranium or plutonium—the stuff of bombs. Uranium reactors need the same fuel-enrichment technology that bomb-makers employ, and can thus give cover for clandestine weapons programmes. Plutonium is made from unenriched uranium in reactors whose purpose can easily be switched to bomb-making. Thorium, though, is hard to turn into a bomb; not impossible, but sufficiently uninviting a prospect that America axed thorium research in the 1970s. It is also three or four times as abundant as uranium. In a world where nuclear energy was a primary goal of research, rather than a military spin-off, it would certainly look worthy of investigation. And it is, indeed, being investigated.

India has abundant thorium reserves, and the country's nuclear-power programme, which is intended, eventually, to supply a quarter of the country's electricity (up from 3% at the moment), plans to use these for fuel. This will take time. The Indira Gandhi Centre for Atomic Research already runs a small research reactor in Kalpakkam, Tamil Nadu, and the Bhabha Atomic Research Centre in Mumbai plans to follow this up with a thorium-powered heavy-water reactor that will, it hopes, be ready early next decade.

China's thorium programme looks bigger. The Chinese Academy of Sciences claims the country now has "the world's largest national effort on thorium", employing a team of 430 scientists and engineers, a number planned to rise to 750 by 2015. This team, moreover, is headed by Jiang Mianheng, an engineering graduate of Drexel University in the United States who is the son of China's former leader, Jiang Zemin (himself an engineer). Some may question whether Mr Jiang got his job strictly on merit. His appointment, though, does suggest the project has political clout. The team plan to fire up a prototype thorium reactor in 2015. Like India's, this will use solid fuel. But by 2017 the Shanghai Institute of Applied Physics expects to have one that uses a trickier but better fuel, molten thorium fluoride.

Thorium itself is not fissile. If bombarded by neutrons, though, it turns into an isotope of uranium, ^{233}U, which is. Thorium can thus be burned in a conventional reactor along with enriched uranium or plutonium to provide the necessary neutrons. But a better way is to turn the element into its fluoride, mix that with fluorides of beryllium and lithium to bring its melting-point down from 1,110ºC to a more tractable 360ºC, and melt the mixture. The resulting liquid can be pumped into a specially designed reactor core, where fission raises its temperature to 700ºC or so. It then moves on to a heat exchanger, to transfer its newly acquired heat to a gas (usually carbon dioxide or helium) which is employed to drive turbines that generate electricity. That done, the now-cooled fluoride mixture returns to the core to be recharged with heat.

This is roughly how America's experimental thorium reactor, at Oak Ridge National Laboratory, worked in the 1960s. Its modern incarnation is known as an LFTR (liquid-fluoride thorium reactor).

The benefits of fluoridation

One of the cleverest things about LFTRs is that they work at atmospheric pressure. This changes the economics of nuclear power. In a light-water reactor, the type most commonly deployed at the moment, the cooling water is under extremely high pressure. As a consequence, light-water reactors need to be sheathed in steel pressure vessels and housed in fortress-like containment buildings in case their cooling systems fail and radioactive steam is released. An LFTR needs none of these.

Thorium is also easier to prepare than its rivals. Only 0.7% of natural uranium is the fissionable isotope ^{235}U. The rest is ^{238}U, which is heavier because it has three more neutrons, and does not undergo fission because of the stability these neutrons bring. This is why uranium has to be enriched by the complicated process of centrifugation. Plutonium is made by bombarding ^{238}U with neutrons in a manner similar to the conversion of thorium into ^{233}U. In its case, however, this requires a separate reactor from the one the plutonium is eventually burned in. By contrast thorium, once extracted from its ore, is reactor-ready.

It does, it is true, need a seed of uranium or plutonium to provide neutrons to start the ball rolling. Once enough of it has been converted into ^{233}U, though, the process becomes self-sustaining, with neutrons from the fission of ^{233}U transmuting sufficient thorium to replace the ^{233}U as it is consumed. The seed material then becomes superfluous and can, because the fuel is liquid, be flushed out of the reactor along with the fission products generated when ^{233}U atoms split up. Similarly, more thorium fluoride can be bled in as needed. The consequence is that thorium reactors can run non-stop for years, unlike light-water reactors. These have to be shut down every 18 months to replace batches of fuel rods.

Bombs away?

Thorium has other advantages, too. Even the waste products of LFTRs are less hazardous than those of a light-water reactor. There is less than a hundredth of the quantity and its radioactivity falls to safe levels within centuries, instead of the tens of millennia for light-water waste.

Paradoxically, though, given thorium's history, it is the difficulty of weaponising thorium which many see (as it were) as its killer app in civil power stations. One or two ^{233}U bombs were tested in the Nevada desert during the 1950s and, perhaps ominously, another was detonated by India in the late 1990s. But if the American experience is anything to go by, such bombs are temperamental and susceptible to premature detonation because the intense gamma radiation ^{233}U produces fries the triggering circuitry and makes handling the weapons hazardous. The American effort was abandoned after the Nevada tests.

The gamma-ray problem is created by a quirk of the process that turns thorium into ^{233}U. A small amount takes a different path and ends up as radioactive thallium—which is very radioactive indeed. Its gamma rays are so powerful that they can penetrate concrete a metre thick. Extracting, smelting and machining material containing even trace amounts of it is beyond the scope of all but a handful of national weapons laboratories. Rogue nations interested in an atom bomb are thus likely to leave thorium reactors well alone when there is so much poorly policed plutonium scattered around the world. So a technology abandoned because it could not be turned into weapons may now, in part for that very reason, be about to resurface.

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