The Hype About Thorium Reactors

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www.ccnr.org/thorium_hype_2021.pdf

There has recently been an upsurge of uninformed promotion of thorium as a nuclear fuel as if it were a brand new discovery with astounding potential. Some describe it as a nearly miraculous and hitherto overlooked material that can provide unlimited amounts of problem-free energy. Such hype is grossly exaggerated.

While there are some interesting advantages to thorium if one is a nuclear enthusiast, there is no excuse for making over-the-top claims that fly in the face of the historical record and basic scientific facts.

Thorium and nuclear weapons

One of the most irresponsible statements is that thorium has no connection with nuclear weapons. On the contrary, the initial motivation for using thorium in nuclear reactors was precisely for the purposes of nuclear weaponry.

It was known from the earliest days of nuclear fission that naturally-occurring thorium can be converted into a powerful nuclear explosive – not found in nature – called uranium-233, in much the same way that naturally-occurring uranium can be converted into plutonium.

Working at a secret laboratory in Montreal during World War II, nuclear scientists from France and Britain collaborated with Canadians and others to study the best way to obtain human-made nuclear explosives for bombs. That objective can be met by converting natural uranium into human-made plutonium-239, or by converting natural thorium into human-made uranium-233. These conversions can only be made inside a nuclear reactor.

The Montreal team designed the famous and very powerful NRX research reactor for that military purpose as well as other non-military objectives. The war-time decision to allow the building of the NRX reactor was made in Washington DC by a six-person committee (3 American, 2 Brits and 1 Canadian) in the spring of 1944.

The NRX reactor began operation in 1947 at Chalk River, Ontario, on the Ottawa River, 200 kilometres northwest of the nation's capital. The American military insisted that thorium rods as well as uranium rods be inserted into the reactor core. Two chemical "reprocessing" plants were built and operated at Chalk River, one to extract plutonium-239 from irradiated uranium rods, and a second to extract uranium-233 from irradiated thorium rods. This dangerous operation required dissolving intensely radioactive rods in boiling nitric acid and chemically separating out the small quantity of nuclear explosive material contained in those rods. Both plants were shut down in the 1950s after three men were killed in an explosion.

The USA detonated a nuclear weapon made from a mix of uranium-233 and plutonium-239 in 1955. In that same year the Soviet Union detonated its first H-bomb (a thermonuclear weapon, using nuclear fusion as well as nuclear fission) with a fissile core of natural uranium-235 and human-made uranium-233.

In 1998, India tested a nuclear weapon using uranium-233 as part of its series of nuclear test explosions in that year. A few years earlier, in 1994, the US government declassified a 1966 memo that states that uranium-233 has been demonstrated to be highly satisfactory as a weapons material.

Uranium reactors are really U-235 reactors

Uranium is the only naturally-occurring material that can be used to make an atomic bomb or to fuel a nuclear reactor. In either case, the energy release is due to the fissioning of uranium-235 atoms in a self-sustaining “chain reaction”. But uranium-235 is rather scarce. When uranium is found in nature, usually as a metallic ore in a rocky formation, it is about 99.3 percent uranium-238 and only 0.7 percent uranium-235. That's just seven atoms out of a thousand!

Uranium-238, the heavier and more abundant isotope of uranium, cannot be used to make an A-Bomb or to fuel a reactor. It is only the lighter isotope, uranium-235, that can sustain a nuclear chain reaction. If the chain reaction is uncontrolled, you have a nuclear explosion; if it is controlled, as it is in a nuclear reactor, you have a steady supply of energy.

But you cannot make a nuclear explosion with uranium unless the concentration of uranium-238 is greatly reduced and the concentration of uranium-235 is drastically increased. This procedure is called "uranium enrichment", and the enrichment must be to a high degree – preferably more than 90 percent U-235, or at the very least 20 percent U-235 – to get a nuclear explosion. For this reason, the ordinary uranium fuel used in commercial power reactors is not weapons-usable; the concentration of U-235 is typically less than five percent.

However, as these uranium-235 atoms are split inside a nuclear reactor, the broken fragments form new smaller atoms called “fission products”. There are hundreds of varieties of fission products, and they are collectively millions of times more radioactive than the uranium fuel itself. They are the main constituents of “high-level radioactive waste” (or “irradiated nuclear fuel”) that must be kept out of the environment of living things for millions of years.

In addition, stray neutrons from the fissioning U-235 atoms convert many of the uranium-238 atoms into atoms if plutonium-239. Reactor-produced plutonium is always weapons-usable, regardless of the mixture of different isotopes; no enrichment is needed! But that plutonium can only be extracted from the used nuclear fuel by "reprocessing" the used fuel. That requires separating the plutonium from the fiercely radioactive fission products that will otherwise give a lethal dose of radiation to workers in a short time.

Thorium reactors are really U-233 reactors

Unlike uranium, thorium cannot sustain a nuclear chain reaction under any circumstances. Thorium can therefore not be used to make an atomic bomb or to fuel a nuclear reactor. However, if thorium is inserted into an operating nuclear reactor (fuelled by uranium or plutonium), some of the thorium atoms are converted to uranium-233 atoms by absorbing stray neutrons. That newly created material, uranium-233, is even better than uranium-235 at sustaining a chain reaction. That's why uranium-233 can be used as a powerful nuclear explosive or as an exemplary reactor fuel.

But thorium cannot be used directly as a nuclear fuel. It has to be converted into uranium-233 and then the human-made isotope uranium-233 becomes the reactor fuel. And to perform that conversion, some other nuclear fuel must be used – either enriched uranium or plutonium

Of course, when uranium-233 atoms are split, hundreds of fission products are created from the broken fragments, and they are collectively far more radioactive than the uranium-233 itself – or the thorium from which it was created. So once again, we see that high-level radioactive waste is being produced even in a thorium reactor (as in a normal present-day uranium reactor).

In summary, a so-called "thorium reactor" is in reality a uranium-233 reactor. Some other nuclear fuel (enriched uranium-235 or plutonium) must be used to convert thorium atoms into uranium-233 atoms. Some form of reprocessing must then be used to extract uranium-233 from the irradiated thorium. The fissioning of uranium-233, like the fissioning of uranium-235 or plutonium, creates hundreds of new fission products that make up the bulk of the high-level radioactive waste from any nuclear reactor. And, as previously remarked, uranium-233 is also a powerful nuclear explosive, posing serious weapons proliferation risks. Moreover, uranium-233 – unlike the uranium fuel that is currently used in commercial power reactors around the world – is immediately usable as a nuclear explosive. The moment uranium-233 is created it is very close to 100 percent enriched – perfect for use in any nuclear weapon of suitable design.

Uranium-232 — a fly in the ointment

There is a complication that arises in the form of another human-made uranium isotope, uranium-232. In a thorium reactor, the uranium-233 that is created is accompanied by a very small quantity of uranium-232. As it happens, U-232 (along with its decay products) gives off very powerful gamma radiation that makes it difficult to fabricate an atomic bomb, given the danger to the workers and the heat generated by the intense radioactivity of U-232 and its decay products. But these difficulties can be overcome, or even avoided altogether, by making suitable adjustments to the reactor operation.

Without going into too much detail, when a thorium-232 atom absorbs a neutron, it is transformed into an atom of protactinium-233, which in turn is spontaneously transformed into an atom of uranium-233. But if either of those two non-thorium atoms absorbs an additional neutron, before the conversion is complete, atoms of uranium-232 can be created – which act as unwanted pollutants. However, if the protactinium atoms are removed from the reactor core, additional neutron collisions are avoided and an uncontaminated supply of almost 100 percent pure uranium 233 can be obtained by just waiting for the spontaneous conversion to be completed.

Is the thorium-fueled "Molten Salt" reactor a proven technology?

The first thorium-fueled molten salt reactor ever built was intended to power an aircraft engine in a long-range strategic bomber armed with nuclear weapons. Despite massive expenditures, the project proved unviable as well as prohibitively costly and was ultimately cancelled by President Kennedy. However, the Oak Ridge team responsible for the aircraft engine reactor project, under the direction of Alvin Weinberg, was allowed to conduct a further thorium-fuelled molten salt reactor experiment for a period of four years, from 1965 to 1969. At the beginning, only U-235 was used; soon afterwards, a smaller amount of U-233 was used.

During its four years of operation under experimental conditions, the Oak Ridge molten salt reactor experienced over 250 shutdowns, most of them completely unplanned. The molten-salt thorium fuelled experience of 52 years ago at Oak Ridge – the only such experience available to date – consumed about one quarter of the total budget of the entire Oak Ridge nuclear complex. It is difficult to understand how anyone could construe this experiment as demonstrating that such a technology would be viable in a commercial environment.

There are, at the present time, no thorium reactors operating anywhere in the world.

Summary – thorium reactors

Thorium reactors pose the same safety problems, qualitatively speaking, that afflict existing nuclear reactors. Requirements for the management of nuclear waste and the potential for proliferating nuclear weapons are fundamentally the same – even though the details are by no means identical. Since a nuclear reactor accident has off-site consequences only due to the unintended release of high-level nuclear waste materials from the reactor fuel into the environment, there is no qualitative difference there either.

There are some major disadvantage of thorium reactors that are not shared by existing power reactors. Initially, thorium may require the use of plutonium to achieve a self-sustaining chain reaction, as thorium is not a fissile material and cannot sustain a chain reaction by itself. From a non-proliferation point of view, however, assigning any commercial value to plutonium is ill-advised, since civilian traffic in plutonium will increase the risk of it being eventually diverted by criminals, terrorists or militaristic regimes for use as a nuclear explosive.

Moreover, once the thorium has become irradiated, some form of reprocessing will be needed to separate the fissile uranium-233 from the irradiated thorium and from the intensely radioactive fission products. No reprocessing is necessary for existing power plants. Reprocessing is an inherently dirty and dangerous operation that releases and mobilizes – in liquid or gaseous form – many radioactive poisons contained in irradiated nuclear fuel. As a result, sites chosen for reprocessing, such as Hanford (Washington), Sellafield (England), La Hague (France) and Mayak (Russia), are among the most radioactively contaminated places on Earth.

The "front end" of the nuclear fuel chain

So much for the "back end" of the fuel chain, but what about the "front end"? What about the dangers and environmental consequences associated with mining a radioactive ore body to obtain the uranium or thorium needed to sustain a uranium-based or thorium-based reactor system?

Thorium versus Uranium

Uranium and thorium are naturally occurring heavy metals, both discovered a couple of centuries ago. Uranium was identified in 1789. It was named after the planet Uranus, that was discovered just 8 years earlier. Thorium was identified in 1828. It was named after Thor, the Norse god of thunder.

In 1896, Henri Becquerel accidentally discovered radioactivity. He found that rocks containing either uranium or thorium give off a kind of invisible penetrating light (gamma radiation) that can expose photographic plates even if they are wrapped in thick black paper.

In 1898, Marie Curie discovered that when uranium ore is crushed and the uranium itself is extracted, it is indeed found to be a radioactive substance, but the crushed rock contains much more radioactivity (5 to 7 times more) than the uranium itself. She identified two new elements in the crushed rock, radium and polonium – both radioactive and highly dangerous – and won two Nobel Prizes, one in Physics and one in Chemistry.

The radioactive properties of both radium and thorium were used in medical treatments prior to the discovery of fission in 1939. Because of the extraordinary damage done to living tissues by atomic radiation (a fact that was observed before the advent of the twentieth century) these radioactive materials derived from natural sources were used to shrink cancerous tumours and to destroy ringworm infections in the scalps of young children. It was later observed that while acute doses of atomic radiation can indeed kill malignant as well as benign growths, atomic radiation can also cause latent cancers that will not appear until decades later, even at chronic low dose radiation levels that cause no immediately perceptible biological damage.

Uranium Mining and Mill Tailings

It turns out that 85 percent of the radioactivity in uranium ore is found in the pulverized residues after uranium is extracted, as a result of many natural radioactive byproducts of uranium called "decay products" or "progeny" that are left behind. They include radioactive isotopes of lead, bismuth, polonium, radium, radon gas, and others. Uranium mining is dangerous mainly because of the harmful effects of these radioactive byproducts, which are invariably discarded in the voluminous sand-like tailings left over from milling the ore. All of these radioactive decay products are much more radioactive and much more biologically damaging than uranium itself. See www.ccnr.org/U-238_decay_chain.png .

Thorium Mining and Mill Tailings

Thorium is estimated to be about three to four times more plentiful than uranium. Like uranium, it also produces radioactive "decay products" or "progeny" – including additional radioactive isotopes of lead, bismuth, polonium, radium, radon gas, thallium, and others. These radioactive byproducts are discarded in the mill tailings when thorium ore is milled. See www.ccnr.org/Th-232_decay_chain.png .

Most of the naturally-occurring radioactivity found in the soil and rocks of planet Earth are due to the two primordial radioactive elements, uranium and thorium, and their many decay products. There is one additional primordial radioactive element, potassium-40, but it has no radioactive decay products and so contributes much less to the natural radioactive inventory.

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P.S. I have written about thorium as a nuclear fuel several times before, beginning in 1978. See www.ccnr.org/AECL_plute.html ; www.ccnr.org/aecl_plute_seminar.html ; www.ccnr.org/think_about_thorium.pdf ; and www.ccnr.org/Thorium_Reactors.html

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