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Thorium Fuel: No Panacea for Nuclear Power

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Thorium "fuel" has been proposed as an alternative to uranium fuel in nuclear reactors. There are not "thorium reactors," but rather proposals to use thorium as a "fuel" in different types of reactors, including existing light-water reactors and various fast breeder reactor designs.

Thorium, which refers to thorium-232, is a radioactive metal that is about three times more abundant than uranium in the natural environment. Large known deposits are in Australia, India, and Norway. Some of the largest reserves are found in Idaho in the U.S. The primary U.S. company advocating for thorium fuel is Thorium Power (www.thoriumpower.com). Contrary to the claims made or implied by thorium proponents, however, thorium doesn't solve the proliferation, waste, safety, or cost problems of nuclear power, and it still faces major technical hurdles for commercialization.

Not a Proliferation Solution

Thorium is not actually a "fuel" because it is not fissile and therefore cannot be used to start or sustain a nuclear chain reaction. A fissile material, such as uranium-235 (U-235) or plutonium-239 (which is made in reactors from uranium-238), is required to kick-start the reaction. The enriched uranium fuel or plutonium fuel also maintains the chain reaction until enough of the thorium target material has been converted into fissile uranium-233 (U-233) to take over much or most of the job. An advantage of thorium is that it absorbs slow neutrons relatively efficiently (compared to uranium-238) to produce fissile uranium-233.

The use of enriched uranium or plutonium in thorium fuel has proliferation implications. Although U-235 is found in nature, it is only 0.7 percent of natural uranium, so the proportion of U-235 must be industrially increased to make "enriched uranium" for use in reactors. Highly enriched uranium and separated plutonium are nuclear weapons materials.

In addition, U-233 is as effective as plutonium-239 for making nuclear bombs. In most proposed thorium fuel cycles, reprocessing is required to separate out the U-233 for use in fresh fuel. This means that, like uranium fuel with reprocessing, bomb-making material is separated out, making it vulnerable to theft or diversion. Some proposed thorium fuel cycles even require 20% enriched uranium in order to get the chain reaction started in existing reactors using thorium fuel. It takes 90% enrichment to make weapons-usable uranium, but very little additional work is needed to move from 20% enrichment to 90% enrichment. Most of the separative work is needed to go from natural uranium, which has 0.7% uranium-235, to 20% U-235.

It has been claimed that thorium fuel cycles with reprocessing would be much less of a proliferation risk because the thorium can be mixed with uranium-238. In this case, fissile uranium-233 is also mixed with non-fissile uranium-238. The claim is that if the uranium-238 content is high enough, the mixture cannot be used to make bombs without a complex uranium enrichment plant. This is misleading. More uranium-238 does dilute the uranium-233, but it also results in the production of more plutonium-239 as the reactor operates. So the proliferation problem remains – either bomb-usable uranium-233 or bomb-useable plutonium is created and can be separated out by reprocessing.

Further, while an enrichment plant is needed to separate U-233 from U-238, it would take less separative work to do so than enriching natural uranium. This is because U-233 is five atomic weight units lighter than U-238, compared to only three for U-235. It is true that such enrichment would not be a straightforward matter because the U-233 is contaminated with U-232, which is highly radioactive and has very radioactive radionuclides in its decay chain. The radiation-dose-related problems associated with separating U-233 from U-238 and then handling the U-233 would be considerable and more complex than enriching natural uranium for the purpose of bomb making. But in principle, the separation can be done, especially if worker safety is not a primary concern; the resulting U-233 can be used to make bombs. There is just no way to avoid proliferation problems associated with thorium fuel cycles that involve reprocessing. Thorium fuel cycles without reprocessing would offer the same temptation to reprocess as today's once-through uranium fuel cycles.

Not a Waste Solution

Proponents claim that thorium fuel significantly reduces the volume, weight, and long-term radiotoxicity of spent fuel. Using thorium in a nuclear reactor creates radioactive waste that proponents claim would only have to be isolated from the environment for 500 years, as opposed to the irradiated uranium-only fuel that remains dangerous for hundreds of thousands of years. This claim is wrong. The fission of thorium creates long-lived fission products like technetium-99 (half-life over 200,000 years). While the mix of fission products is somewhat different than with uranium fuel, the same range of fission products is created. With or without reprocessing, these fission products have to be disposed of in a geologic repository.

If the spent fuel is not reprocessed, thorium-232 is very-long lived (half-life:14 billion years) and its decay products will build up over time in the spent fuel. This will make the spent fuel quite radiotoxic, in addition to all the fission products in it. It should also be noted that inhalation of a unit of radioactivity of thorium-232 or thorium-228 (which is also present as a decay product of thorium-232) produces a far higher dose, especially to certain organs, than the inhalation of uranium containing the same amount of radioactivity. For instance, the bone surface dose from breathing an amount (mass) of insoluble thorium is about 200 times that of breathing the same mass of uranium.

Finally, the use of thorium also creates waste at the front end of the fuel cycle. The radioactivity associated with these is expected to be considerably less than that associated with a comparable amount of uranium milling. However, mine wastes will pose long-term hazards, as in the case of uranium mining. There are also often hazardous non-radioactive metals in both thorium and uranium mill tailings.

Ongoing Technical Problems

Research and development of thorium fuel has been undertaken in Germany, India, Japan, Russia, the UK, and the U.S. for more than half a century. Besides remote fuel fabrication and issues at the front end of the fuel cycle, thorium-U-233 breeder reactors produce fuel ("breed") much more slowly than uranium-plutonium-239 breeders. This leads to technical complications. India is sometimes cited as the country that has successfully developed thorium fuel. In fact, India has been trying to develop a thorium breeder fuel cycle for decades but has not yet done so commercially.

One reason reprocessing thorium fuel cycles haven't been successful is that uranium-232 (U-232) is created along with uranium-233. U-232, which has a half-life of about 70 years, is extremely radioactive and is therefore very dangerous in small quantities: a single small particle in a lung would exceed legal radiation standards for the general public. U-232 also has highly radioactive decay products. Therefore, fabricating fuel with U-233 is very expensive and difficult.

Not an Economic Solution

Thorium may be abundant and possess certain technical advantages, but it does not mean that it is economical. Compared to uranium, the thorium fuel cycle is likely to be even more costly. In a once-through mode, it will need both uranium enrichment (or plutonium separation) and thorium target rod production. In a breeder configuration, it will need reprocessing, which is costly. In addition, as noted, inhalation of thorium-232 produces a higher dose than the same amount of uranium-238 (either by radioactivity or by weight). Reprocessed thorium creates even more risks due to the highly radioactive U-232 created in the reactor. This makes worker protection more difficult and expensive for a given level of annual dose.

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