Jamison Reifsteck and Even Lydon

Sustainable and Renewable Energy

Dr. Beck

03-25-2017

Thorium

Recently, Thorium has reemerged as a powerful potential energy source. Thorium has a lot of the benefits of nuclear energy without the disadvantages of the typical Uranium or Plutonium reactors. A few of the benefits that Thorium has over Uranium or Plutonium is reduced waste and limited potential for nuclear weapon proliferation, smaller required facility size, and a safer design.

Background:

Thorium became important for nuclear energy in 1945 when Glenn Seaborg and his team discovered that Thorium could absorb a neutron and become U-233 and then fission (1). In a thorium reactor, thorium is bombarded with neutrons from a neutron source such as Pu or U, then decays to U232 which further absorbs a neutron to form fissile U233. Thorium 232 has a half-life of 14 billion years (3) while Uranium 232 has a half-life of 74 years(4), making Th232 a more advantageous route to U233 than U232. The decay chain is shown below in **Figure 1**. The decay of U 232 is significantly faster than the half-life of U 235 or 238 which are 700 million years and 5 billion years respectively. So the waste production will not only be smaller in quantity, but will be around for far less time. When U-233 fissions it releases 2-3 neutrons, which can be used to breed more U233 from Th232 (1). The cycle of this reaction is Thorium absorbs a neutron and becomes Th-233 which has a half-life of 22.3 minutes, which decays quickly to protactinium 233 by beta decay. Protactiniun-233 decays again by beta decay to U-233, the half-life for protactinium-233 is 27 days. Uranium-233 is then struck by a neutron and fissions which releases 2-3 neutrons. Thorium has a greater neutron capture cross section than U238, making it a more a more efficient source of fissile material.

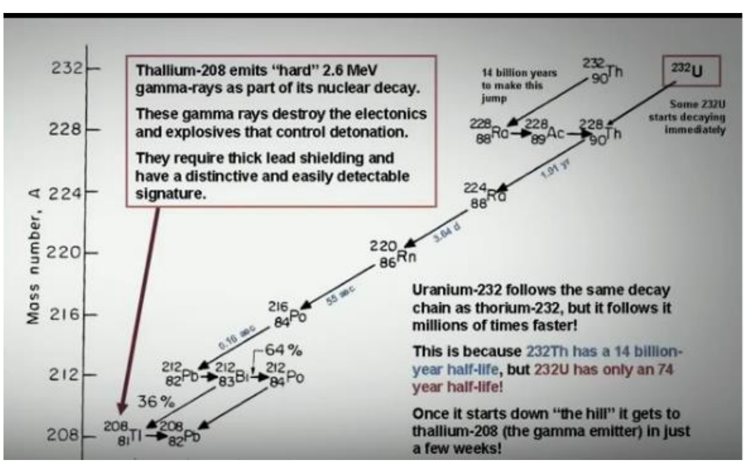

Figure 1: Decay chain of Thorium 232 and Uranium 232.

After WWII, nuclear power was being sought as a source of energy rather than as a bomb. Eugene Wigner was the major advocate for Thorium. However, he was largely unsuccessful. Part of the reason he was unsuccessful was that Uranium and Plutonium were thoroughly understood and the infrastructure was already there. Thorium was almost unexplored in comparison. Wigner did manage to convince Alvin Weinberg about the importance of Thorium and its potential. Alvin Weinberg got a job leading Oakridge national labs. He was not allowed to work on nuclear reactors, due to the fact that the Atomic Energy Commission gave all reactor research to other national labs, like Argonne National Laboratory. However, he was able to eventually work on a Thorium reactor. The air force was looking into building a nuclear powered bomber. Water cooled reactors would not be possible on a plane and a Thorium reactor was a much more feasible idea. Weinberg built a proof of concept reactor called the "Aircraft Reactor Experiment" (1). It tested the idea of liquid Fluoride reactor concept and it was functioning for 11 days. Later he conducted the "Molten Salt Reactor Experiment" which ran from 1965-1969 (1). Both of these reactors proved that Thorium could be used in a nuclear reactor.

There are different types of reactors that use Thorium as a fuel source. There is the Indian Three Stage Reactor **Figure 2**, the Accelerator-Driven System (ADS) (5), and Liquid Fluoride Thorium Reactors.

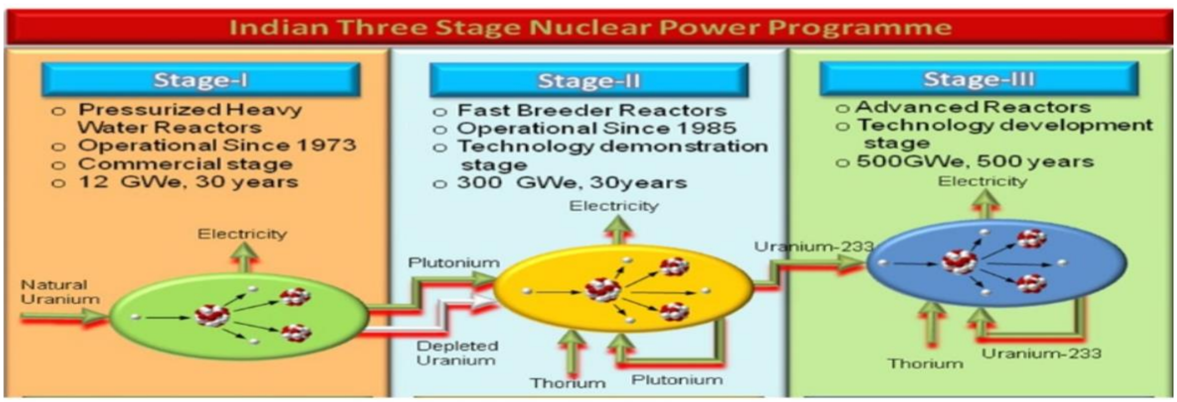

Figure 2.

Liquid Fluoride Thorium Reactors or LFTRs are a part of Molten Salt Reactors. The LFTR principal is shown in **Figure 3**.

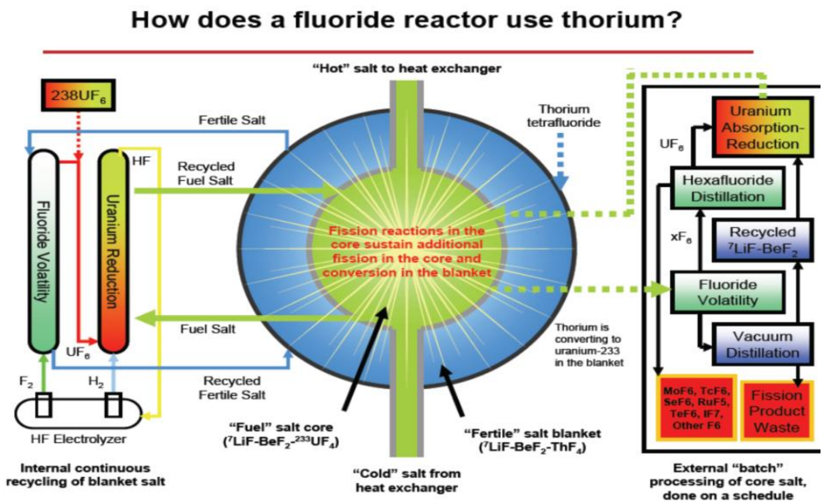

Figure 3.

Molten salt reactors (MSRs) are a type of reactor in which the fuels are dissolved into a molten salt mixture. MSRs can potentially be employed for any fission cycle, however, the most interesting application is in liquid fluoride thorium reactor (LFTR). In LFTRs, thorium and uranium are mixed together to form a breeder type reactor. The uranium initiates the fission process by converting thorium to U233 which fissions releasing heat and more neutrons to continue breeding Th232 into U233. LFTR have the advantage of being easily processed to remove protactinium and actinide waste from the reactor to prevent parasitic neutron loss. LFTRs can also be run continuously, with no need to shut down the reactor to add more fuel. The extremely high temperature of MSRs allow for much greater heat efficiency when transferring the heat to generators. The major issue with LFTRs seems to be the stew of chemical elements present in the reactor leading to complex issues with degradation and maintenance. Another downside to MSRs is that they are slightly more vulnerable to proliferation than solid state reactors because the fuel exists as an easily extractable liquid and it is difficult to keep track of the exact composition of the reactor mixture because of the complex mixture of radio active components, so if some fuel was removed, it would not be immediately evident.

There are reactors that try to reduce the size of the blankets, called blanket fragmentation (6). The blanket is fragmented into smaller elements while maintaining the same neutronic parameters, such as the moderator-fuel volume ratio, and the same amount of materials inside of the reactor (6).

There are quite a few advantages that Thorium has over Uranium. LFTR reaction run close to 1 atm vs water cooled reactors which run at/over 70 atm. The number one concern people have about water cooled reactors is a loss of pressure in the reactor and the water flashes to steam which expands 1000 fold. This is why water cooled reactors need such big containment buildings and multiple ways to get water to the reactor to keep it cool no matter what happens. All of this is unnecessary with LFTRs. There is nothing in the reactors that will have a significant change in volume, which makes the buildings housing the reactors much more compact (1). The reactor materials are already liquids and there is a piece of frozen salt that is kept solid by a fan blowing over the pipe. If the reactor loses power, the fan stops blowing, and that frozen salt melts allowing the fuel to flow into a drainage container, stopping the reactor. This is an inherently safe and passive nuclear safety system (5).

Thorium also has the advantage of being more abundant than Uranium. Thorium is around 8.1ppm (3) in the crust, while U-235 is around 0.018ppm (4), making Thorium almost three orders of magnitude more abundant. The world has an estimated 1.4 million tonnes and of that the US has the majority of any country with an estimated 440 thousand tonnes, Australia has the next most with 410 thousand tonnes (3).

One of the decay products, Thallium-208, emits hard gamma radiation which is easy to detect, which is a deterrent against proliferation. Furthermore, LFTRs do not form the same hazardous waste such as transuranics like Plutonium and Curium (1). They can actually use up some of that waste generated from water cooled reactors for fuel. Out of 1000kg of U-233 most of which will fission, 15 kg wont fission and that is Plutonium-238 which is useless for bombs which require Pu-239, but is very valuable to NASA since they use it in their deep space probes' batteries (1). Thorium also has an energy density of 79,420,000 MJ/kg (3), Uranium does have a higher energy density at 80,620,000 MJ/kg (4), however these are far more efficient than fossil fuels which only have an energy density of 46 MJ/kg. Thorium has fewer issues with waste than both Uranium and fossil fuels. The efficiency of Thorium can be seen below if Figure 4.

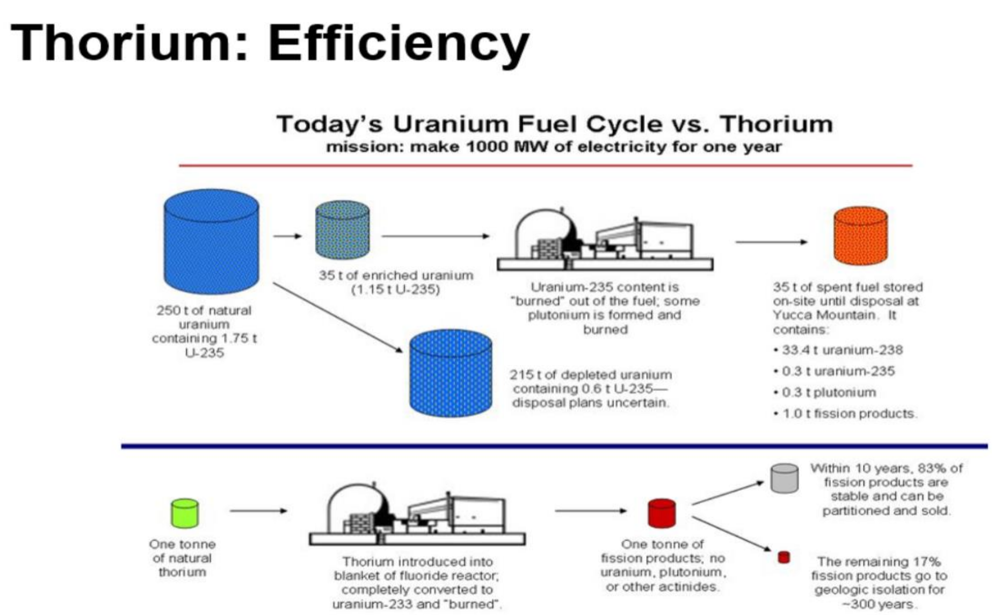

Figure 4.

The major prohibitive factor that seems to be impeding Thorium's emergence as a fuel source is that it requires Uranium to continue reacting, so unlike traditional reactors which are self-sustaining, Thorium reactors would require continuous addition of more Uranium. This being said, Thorium is a promising energy source and India and China are both in the process of building Thorium reactors and Europe and the US are investigating pilot scale test facilities.

In our current era, no country is more heavily invested in thorium than India and as such they represent a good case study of large scale Thorium power generation. While truly sustainable power sources such as solar and wind are being implemented, high concentrated, reliable power output is important to insure the stability of India's power supply. Because the region is abundant in Thorium but lacks in Uranium, and coal's future is questionable, thorium power was a viable option. India is employing an Advanced Heavy Water Reactor (AHWR) which uses solid state mixed oxide fuels. This type of reactor will use Th-U and Th-Pu fuel cycles to breed fissile material. (2)

Resources:

(1)https://www.youtube.com/watch?v=49WV3DH_tHs

(2)P.K. Vijayan′, V. Shivakumar, S. Basu, R.K. Sinha; Role of thorium in the Indian nuclear power programme. Progress in Nuc. Energy. 2017

(3)https://en.wikipedia.org/wiki/Thorium

(4)https://en.wikipedia.org/wiki/Uranium

(5) M. Schaffer; Abundant thorium as an alternative nuclear fuel Important waste disposal and wepon proliferation advantages. Energy Policy. 2013

(6)F.J. Arias; Minimization of U-232 content in advanced high-conversion multirecycling thorium reactors by blanket fragmentation. Progress in Nuclear Energy. 2013