Michael S. (Mickey) Fulp
M.Sc., C.P.G.

MercenaryGeologist.com
contact@mercenarygeologist.com

The Future of Thorium as Nuclear Fuel

A Monday Morning Musing from Mickey the Mercenary Geologist

Contact@MercenaryGeologist.com

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Thorium is one of the five abundant, long-lived, naturally-occurring radioactive elements in the Earth's crust. The others are potassium, radon, radium, and uranium. There are several other naturally-occurring radioactive elements but they are rare and/or have short half-lifes.

Potassium, thorium, and uranium are the important internal fuels that cause the Earth's interior to be hot, magmas and volcanoes to exist, the crust to float on the mantle, tectonic plates to move, the outer iron core to be liquid, and the inner iron core to be solid. Radioactive decay of these elements into radionuclides allows the Earth to be a dynamic planet. There are about 340 naturally occurring radionuclides, more than 60 are radioactive, and as they decay, energy is released that fuels the Earth.

Without radioactivity, our world would be dead as the moon, a barren rock with no ocean or atmosphere.

Radioactivity also fuels modern society. Approximately 14% of the world's electricity is generated by radioactive fuel. This fuel is mostly low-enriched uranium ($U^{235)}$.

Therefore, I must conclude that radioactivity is a very good thing.

Back to the subject at hand: I recently spoke at the Cambridge House World Resource Investment Conference and on Mercenary Musings Radio about thorium and its prospects for future use in nuclear power plants. Since then I've had several subscribers request that I put my thoughts on the subject to paper.

Thorium is a silvery-white metal that was discovered in 1828 in the mineral monazite, a rare earth-thorium phosphate. It is one of the heaviest elements at number 90 on the periodic table, two spots below uranium. Thorium is a relatively common element at 15 ppm in the Earth's crust, which is three times the abundance of uranium. It consists almost entirely of one isotope, Th^{232}, with an extremely long half-life of 14 billion years, about the age of the universe.

In 1898 Madam Curie discovered thorium is radioactive and emits alpha particles, the least penetrative decay product. If you remember high school chemistry, alpha particles are relatively benign and can be stopped by a single sheet of paper.

Thorium was first used in mantles for gas lighting because it is refractory and creates a bright white light. Today's uses also include magnesium-thorium alloy, tungsten-thorium arc welding, carbon arc lamps and spotlights, heat resistant ceramics, and petroleum catalysts. However, the amounts that are used are miniscule, largely because of modern-day concerns about low-level radioactivity and waste disposal. The total value of thorium used in the United States in 2009 was only about $150,000.

Simply put: There is no supply because there is no demand. Because there is no demand, there is no exploration, development, or mining of thorium.

Thorium occurs mainly in the mineral monazite, a relatively common rock-forming mineral in alkalic igneous rocks. It also occurs with uranium in a silicate mineral called thorite.

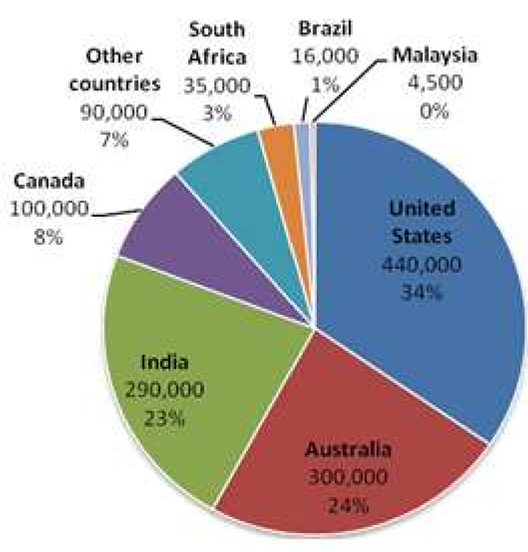
Monazite was first mined for its rare earth content in the early 1900s. It is resistant to weathering and is a common constituent of heavy mineral sands. Heavy mineral sands are placer deposits formed in beach environments where mineral grains are concentrated because of their high density. They are strip-mined thru out the world and are especially important as sources of titanium, zirconium, tin, niobium, tantalum, and garnet.

Many heavy minerals sands contain significant monazite. After the valuable minerals are recovered, waste products, called "tails", with concentrated monazite are left behind.

Monazite usually contains between 60 to 65% rare earth elements and 6-12% thorium. Monazite-rich sands were the world's main source of REEs from 1900 until 1954 when the Mountain Pass mine came into production and historically have produced all of the world's thorium.

There are abundant and readily available supplies of monazite-rich tails in many countries of the world. But currently monazite is nothing more than waste material.

According to the USGS, world resources of thorium are as follows:



World Resources of Thorium (t)

Thorium has long been known as a potential source of nuclear fuel to produce electricity. The United States government first built an electricity-only nuclear reactor in Shippingport, Pennsylvania in 1957 as part of President Eisenhower's "Atoms for Peace" initiative. This relatively small reactor ran on thorium from 1977 until decommissioned in 1982.

However, thorium is much different than uranium when used as a nuclear fuel. It is not fissile; meaning it cannot go "critical" and generate a nuclear chain reaction. It must undergo neutron bombardment to produce a radionuclide that can sustain a nuclear reaction. A thorium-fueled reactor must be jump-started with a fissile isotope such as uranium (U^{235}) and/or plutonium (Pu^{239}; Pu^{241}). Neutron bombardment of thorium results in this reaction: Th^{232} + Neutron = U^{233}.

Uranium^{233} is a man-made fissile isotope with a half-life of 160,000 years, and is well-suited for use in nuclear reactors. After Th^{232} is converted, U^{233} can be unloaded and then fed to the core of another reactor to be used as fuel in a closed cycle.

Alternatively, U^{233} can be bred from thorium in an outer blanket surrounding a plutonium and/or uranium core, the U^{233} separated, and then fed back into the core. These are called "breeder reactors" because thorium is the fertile fuel that breeds a fissile radionuclide. Radioactive materials are recycled so there is little waste left behind.

There are other significant advantages to the use of thorium in nuclear reactors. The raw material, thorium, is much more abundant than uranium and emits only low-level alpha particles. It has one isotope and therefore, does not require an enrichment cycle to be used as fuel. It is many times more energy efficient than uranium.

A thorium reactor produces no plutonium that can be made into atomic weapons and less longer-lived radionuclides than a uranium-based reactor. Because there is no chain reaction, there is no chance of a meltdown. Nuclear waste from past operations that contain fissile uranium and plutonium can be used as start-up fuel.

There are only a couple of disadvantages: Fuel fabrication is more difficult than in a uranium reactor and the U^{233} fuel that is bred can be used to make atomic weapons, albeit with difficulty.

With the obvious advantages thorium presents over uranium as nuclear fuel, the question becomes why doesn't the United States or the world have a thorium-based nuclear power industry? There are two major reasons:

- In the early days of the atomic age in the late 1940s to early 1950s, thorium, being much more abundant than uranium, was envisioned as nuclear fuel to take the place of uranium when limited sources of that metal were depleted. However, prospectors and geologists armed with Geiger counters soon discovered many new, rich uranium deposits in the Western United States. By the mid-1950s, this incentive to develop thorium-fueled reactors disappeared.

- Uranium-fueled nuclear reactors produce plutonium that can be used to make atomic bombs. During the Cold War of the mid-1950s, the United States military wanted a steady source of plutonium for its burgeoning nuclear weapons program and thorium reactors do not produce plutonium as a by-product.

There are several types of thorium reactors and they share these common characteristics compared to conventional uranium reactors: They can operate at relatively low temperatures, the infrastructure footprint can be small, and they are very power dense making them amenable to size scaling. Types currently being researched include: Liquid-Fluoride; Light Water and Heavy Water; Pebble Bed; and Sodium Fast Reactors.

Countries that have experimented with thorium-fueled reactors in the past include the United States, China, Canada, France, Germany, Great Britain, Japan, Russia, Norway, and Sweden. Those with current research, demonstration, or development plans for nuclear power plants include Brazil, Canada, China, France, India, Russia, and the United States. These are not new technologies but refinement of previous efforts.

Besides the Shippingport, Pennsylvania plant, an experimental molten salt reactor at Oak Ridge National Laboratory successfully ran from 1964 until 1969 when Congress cut funding. In what has been called a political move, the US Atomic Energy Commission shut down all research on liquid-fluoride reactors in the mid-1970s. The commercial-scale Fort St. Vrain reactor ran on thorium and high-enriched uranium fuel from 1976-1989.

Current domestic thorium-based reactor research is being carried out by US-based Lightbridge Corporation, formerly Thorium Power. Lightbridge is collaborating with French and Russian private and government interests to develop commercial thorium-fueled reactors.

Canada has signed agreements with three Chinese entities to demonstrate and develop the use of thorium fuel in their CANDU reactors. Thorium can be used in most advanced nuclear fuel cycle systems including the newest Generation IV reactors.

Because of its abundant resources of thorium and domestic lack of uranium, India has been the only country with a sustained effort to use thorium in large scale nuclear power generation. Its 20 year goal is to generate 75% of nuclear power from thorium. Used fuel will be reprocessed to recover fissile material for recycling.

The World Nuclear Association states that development of thorium-based nuclear reactors on a commercial scale is held back by high fuel fabrication costs, problems in recycling thorium and reprocessing solid fuels, and because U^{233} can be made into weapons.

However, in my opinion the main reason comes down to basic economics. The world’s entire nuclear fleet is founded on uranium-fueled reactors. Previous and current investments in time, people, and money to produce cheap electricity from nuclear power are astronomical.

Therefore, even though there are significant safety and environmental advantages, most governments and corporate entities are reluctant to commit the enormous time, human resources, and capital required to develop alternative thorium fueling methods.

Thorium as nuclear fuel is clean and safe and offers significant advantages over uranium. The technology for several types of thorium reactors is proven but still must be developed on a commercial scale. I opine that the world is at least a decade away from any major commercialization of thorium nuclear reactors and that it is likely to happen in India and China.

I also think there could be a near-term synergy between a rare earth element producer that processes monazite for its REE content and consigns the thorium to a government or private entity seeking a source of thorium for nuclear fuel.

Perhaps the most promising niche for thorium-fueled electrical power is in small modular reactors designed for remote locations.

In my opinion, thorium will supplement base load electrical generation within the next decade or so but it will not replace uranium-fueled nuclear power in our lifetimes.

Like it or not, folks, burning uranium to make the light switch work is not going away anytime soon. With that in mind, I suggest you pick your speculations carefully.

Ciao for now,

Mickey Fulp
Mercenary Geologist

Acknowledgement: Jeff Stuart provided a much-needed editing of this musing.

The **Mercenary Geologist Michael S. "Mickey" Fulp** is a Certified Professional Geologist with a B.Sc. Earth Sciences with honor from the University of Tulsa, and M.Sc. Geology from the University of New Mexico. Mickey has over 30 years experience as an exploration geologist searching for economic deposits of base and precious metals, industrial minerals, uranium, coal, oil and gas, and water in North and South America, Europe, and Asia.

Mickey has worked for junior explorers, major mining companies, private companies, and investors as a consulting economic geologist for the past 24 years, specializing in geological mapping, property evaluation, and business development. In addition to Mickey's professional credentials and experience, he is high-altitude proficient, and is bilingual in English and Spanish. From 2003 to 2006, he made four outcrop ore discoveries in Peru, Nevada, Chile, and British Columbia.

Mickey is well-known and highly respected throughout the mining and exploration community due to his ongoing work as an analyst, writer, and speaker.

Contact: **Contact@MercenaryGeologist.com**