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The Element of Economic and Energy Policy Failure: Thorium and the Divergence of National Interests

Author

James Kennedy is an internationally recognized expert, consultant, author, and policy adviser on rare earths and thorium energy.

Disclaimer: The subject matter of the article is author James Kennedy's view, not that of the ASQ Energy & Environmental Division.

Shortly after World War II, a number of Manhattan Project scientists were tasked with quickly developing civilian nuclear power. One of the mission goals was to distribute the ongoing cost of producing bomb-making materials across our secretive Manhattan Project campuses onto a 'civilian' nuclear energy program. That program eventually morphed into the Atomic Energy Commission and then to the Department of Energy.

From an accounting standpoint, the DOE's primary purpose is to divert the balance sheet cost of our nuclear weapons programs off the military's books. For its entire history, 70% or more of the Department of Energy's budget has been directed towards nuclear weapons development, maintenance, and research programs (and cleanup funding of legacy Manhattan Project sites).

Results came quickly. The first reactor designs, the ones still in use today, are essentially 'first concept reactors': something more than a Ford Model A, but possibly less than a Model T, as economies of standardization were never achieved.

Every Light Water Reactor (LWR), including Pressurized Water Reactors and Boiling Water Reactors, is uniquely engineered from the ground up—maximizing its cost.

The original designs, largely developed by Alvin Weinberg, boiled water under pressure to turn a shaft, similar to the turbines of a coal fired power plant.

Weinberg knew he could achieve a better design, but government and military support rushed in to prop up the development of the Light Water Reactor design. Admiral Hyman Rickover was the leading advocate, quickly developing the first nuclear-powered submarine. The U.S. Army also got in the game, developing a prototype mobile field reactor. The Air Force, feeling left out, looked to Alvin Weinberg to develop a nuclear-powered aircraft.

Weinberg famously stated "it wasn't that I had suddenly become converted to a belief in nuclear airplanes. It was rather that this was the only avenue open to ORNL for continuing in reactor development. That the purpose was unattainable, if not foolish, was not so important. A high-temperature reactor could be useful for other purposes even if it never propelled an airplane"

The Air Force Reactor project required that he develop something entirely new; keeping in mind that this reactor would operate inside an airplane with a crew and live ordinance.[1,2,3] These are truly remarkable constraints in terms of weight, size, safety, and power output.

The Air Force Reactor program was able to prove out all requirements of the program. Despite Weinberg's initial doubts, ORNL proved that it was possible to build a nuclear-powered bomber aircraft and keep the crew 'reasonably safe',[4] even if it was not entirely practical.

Today the human safety and practicality issues are no longer relevant if you apply the technology to mega-bomber drones.

The original Air Force Reactor Experiment evolved into the Molten Salt Reactor Experiment.[5,6] This moderated reactor operated for 19,000 hours over 5 years. The reactor was designed to run on a thorium-uranium mixed fuel.[7] Prior to termination of the project all operational, safety, material science, and corrosion issues were resolved.

More importantly, the Oak Ridge MSRE project proved that you could build a revolutionary nuclear reactor that eliminated all of the inherent safety concerns of the LWR while minimizing the spent fuel issue.

The new reactor, commonly known as a Molten Salt Reactor (MSR), used heated salt, with a fluid-to-boiling temperature range of 1000°C or more (a function of chemistry), to act both as coolant and fuel. The recirculation of the liquid fuel/coolant allowed for the full utilization (burn up) of the actinides and fission products.

Water's natural liquid range is 1 to 99°C. Water's natural boiling temperature does not generate sufficient pressure to economically operate traditional steam turbines so all LWR type reactors use high pressure to force water to remain liquid at higher temperatures. The need to contain coolant failures in such a high-pressure operating environment greatly effects the safety and cost of the entire system.

> *Utilizing molten salts as the coolant allowed for a significantly expanded range of operational temperatures at low pressure.*

Salt's natural liquid range, depending on chemistry, is in the 1000°C range (~600 to 1600°C). Consequently, MSR systems do not need to operate under pressure, significantly increasing the safety of the overall system while lowering risks and cost.

The other big advantage is that it allows for the utilization of high temperature Brayton turbines[8,9]—thus achieving much higher energy conversion efficiencies at much lower costs.

Another beneficial feature was the quantity and timeframe of storage requirements for spent fuel. By utilizing MSRs, less than 1% of the original fuel load ends up as spent fuel, and due to acceleration of decay under the recirculation of the fuel/coolant load the residual spent fuel decays to background in as little as 300 years.

LWRs utilize less than 5% of the available energy in solid fuels and the spent fuel does not decay to background levels for tens of thousands of years.

The most promising MSR design feature was found to be that fission criticality is self-regulating due to the reactor's geometry and self-purging features that dumped the fuel/coolant into holding tanks that terminated fission, based on geometry, if the reactor exceeded design operating temperatures.[10] These features made a reactor "meltdown" impossible.

Because the salt coolant allowed for high operating temperatures, enhanced operating pressure and complicated cooling systems were not necessary. This eliminated the possibility of explosive events that can occur with water cooled reactors.

LWR reactor explosions are due to disassociation of water into hydrogen and oxygen when exposed to Zirconium at high temperatures during coolant system failure. The zirconium fuel casings act as a catalyst, causing a massive rapid atmospheric expansion. This atmospheric expansion was the cause of the explosive event associated with the Fukushima disaster.

The elimination of a high-pressure hydrogen event eliminated the potential for widespread radiation release and thus, the need for a massive containment vessel.

Alvin Weinberg's reactor design also solved another challenge of that time. Prior to the mid-1970s the U.S. government believed that global uranium resources were very scarce. This new reactor, fueled with a small amount of fissile material and thorium, could breed new fuel.

In 1962 President Kennedy tasked Glenn Seaborg with devising a national plan for sustainable civilian nuclear power.[11] Evaluating the relative safety, efficiency, and economy of the MSR vs. the LWR, Seaborg submitted his report to President Kennedy, recommending that the U.S. phase out LWRs in favor of Alvin Weinberg's MSR thorium "breeder reactor".

The relative cost of a commercial scale MSR reactor would be a fraction of traditional LWR reactors. Standardized and built on an assembly line, much like a large aircraft, MSRs could bring installed cost per megawatt in line with coal fired power plants because the MSR can be air cooled, does not require a massive containment vessel, and could utilize Bryton-type turbines. Public energy costs below $.02/kw were achievable. Since MSRs run much hotter than LWRs, the greatest benefit would be the direct utilization of thermal energy for industrial heat processes. Possibilities seemed endless.

However, there was an unexpected conflict. Fueled with thorium, the MSR did not produce plutonium (fissile bomb making materials) or anything else that was practically usable for the production of nuclear weapons. The reactor was highly proliferation resistant—and who would not like that?

The Nixon Administration, for one. American politics in 1968 were largely influenced by the U.S.'s relative status in the nuclear weapons arms race with Russia. Nixon, a nuclear hawk, killed the MSR program and committed the country to the development of fast spectrum breeder reactors (the program was a total failure), circa 1972.

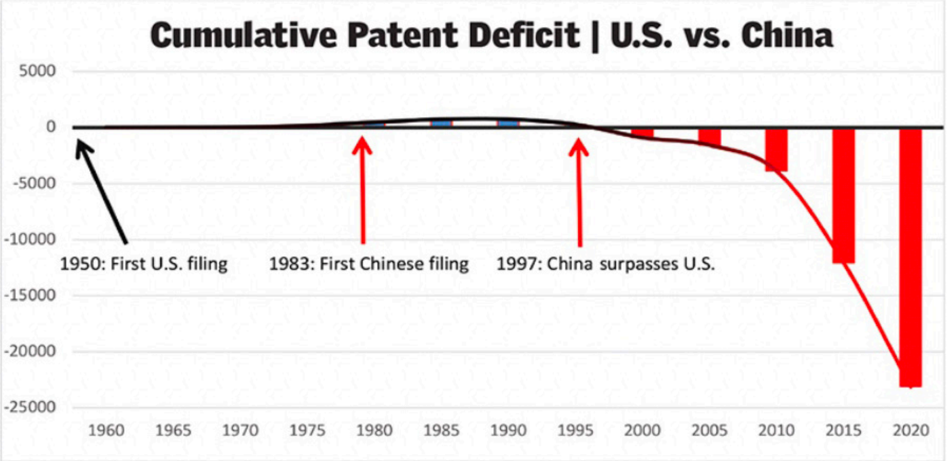
By 1970 a new, safe, clean, cost-efficient, and self-generating energy economy was technically possible but was sacrificed to the objectives of the cold war and preservation of the existing LWR fleet.

A decade later the production and proliferation of nuclear weapons material became an international matter of concern. In 1980 the U.S. Nuclear Regulatory Committee (NRC) and International Atomic Energy Committee (IAEA) collaborated on regulations to ratchet down on the production and transportation of uranium. The regulatory mechanism (10 CFR 40, 75)[12] applied rules and definitions specific to the uranium mining industry to all mining activity, using the 1954 Atomic Energy Agency terminology of "source material" to define the materials to be controlled.

> *The regulatory term "source material" is the classification of all known nuclear fuels (uranium, plutonium, and thorium) for the production of energy, not weapons. There is no proliferation risk associated with thorium. It is not fissile and cannot be used to produce a nuclear weapon.*

This caused a new and unintended problem. At the time, nearly 100 percent of the world's heavy rare earths contained thorium in their mineralization and were the byproduct of some other mined commodity. Consequently, when these commodity producers extracted their target ores (titanium, zirconium, iron, phosphates, etc.) they triggered the regulatory definition of 'processed or refined ore' for these historical rare earth byproducts, causing the thorium-bearing rare earth mineralization to be classified as "source material".

In order to avoid the onerous costs, regulations, and liabilities associated with being a source material producer these



As of August 2018 China has accumulated 23,000 more rare earth patent filings than the U.S.

SOURCE: THREE CONSULTING

commodity producers disposed of these thorium-bearing resources along with their other mining waste and continue to do so today.

Currently, in the U.S. alone, the annual quantity of rare earths disposed of to avoid the NRC source material regulations mentioned above exceeds the non-Chinese world's demand by a factor of two or more. The amount of thorium disposed of with these rare earths could power the entire western hemisphere if utilized in MSRs.

The scale of this potential energy waste dwarfs the efforts of every environmentalist's collective efforts and sacrifices on a global basis.

As a result, all downstream rare earth value chain companies in the U.S. and IAEA compliant countries lost access to reliable supplies for these rare earth resources.

Capitalizing on these regulatory changes, China quickly became the world's RE producer.

During the 1980s, China increased its leverage by initiating tax incentives and creating economically favorable manufacturing zones for companies that moved rare earth technology inside China. These strategies allowed China to quickly acquire a foothold in metallurgical and magnet capabilities.

For example, China signed rare earth supply contracts with Japan that required Japan to transfer rare earth machinery and process technology to mainland China while establishing state-sponsored acquisition strategies for targeted U.S. metallurgical and magnetic manufacturing technologies.

In just two decades China moved from a low value resource producer to having monopoly control over global production and access to rare earth technology metals.

By 2002 the U.S. became 100% dependent on China for all post-oxide rare earth materials. From this point on China was able to force rare earth technology companies to move manufacturing, and thus IP, to China for access to these materials.

One example is Apple. Because the iPhone is highly rare earth dependent, Apple was forced to manufacture it in China. In January 2007 Apple introduced its revolutionary iPhone. By August of the same year high quality Chinese knockoffs were being produced by a largely unknown company named Huawei. By 2017 Huawei was outselling Apple on a worldwide basis.

This story is not uncommon. It is the typical story of what happens to Western companies who move their manufacturing inside China. Apple knew this but had no choice: developing a domestic rare earth value chain was impossible for any single company, industry, or even country by this point in the game.

In 2019, Japan, the only country that continued to produce rare earth metals outside of China, informed the U.S. government that they no longer make new rare earth metals.[13]

Today China's monopoly power, at all levels of the rare earth resource and post-oxide value chain, continues to allow them to force technology companies to locate manufacturing, and more importantly the relative IP, inside China. China controls the supply chain of the U.S. military and NATO defense contractors for all post-oxide rare earth materials.

The Pentagon, somehow unable to understand or unwilling to acknowledge that China's monopoly is a National Program of Industrial and Defense Policy, is betting U.S. national security on a collection of junior mining ventures and the twice-bankrupt Mountain Pass Mine, located in California.

It's not the first time the Pentagon made this bet. The Pentagon bet our national security on the company, Molycorp, who controlled the Mountain Pass mine back in 2010.

The Pentagon was forewarned that Molycorp's deposit was incompatible with U.S. technology and defense needs, due to its lack of heavy rare earths, and its business plan was 'unworkable'.[14]

The company was bankrupt in just 5 years.

Today Molycorp is resurrected as MP Minerals and effectively operates under Chinese control (China holds its equity, debt, and is its only customer). Despite this fact, the Pentagon has once again bet all of our nation's national security chips on this two-time loser—somehow expecting a different outcome.

Breaking China's monopoly is not easy because China can bankrupt any emerging competitor through manipulating commodity costs, at any time and at any level of the value chain.

That hasn't prevented governments from trying. Japan and the EU have committed significant financial and governmental resources to overcome this threat, with little to show for it. The U.S., late to the game, has spent less than one-tenth of what Japan has spent. The results are proportionally dismal. Collectively, U.S., Canadian, European, Australian, and South African capital market funded projects, added to all direct investment by the Japanese, EU, Russia, Korean, and U.S. government, amounts to a price tag of around $15 billion.

The measurable results of those investments are reflected in over 400 bankruptcies. Only two of these ventures actually went into production. One of them, Molycorp, filed for bankruptcy in less than 5 years. The other, Lynas, is less than a year away from losing its Malaysian operating permit and has accumulated hundreds of millions of dollars in losses. The only reason Lynas has not filed for bankruptcy yet is that it has ongoing price support from its customers.

What is the common thread? The rare earth regulatory issues outlined above and our nation's failure to develop MSR share a common thread: thorium.[15]

> *America's failure to pursue a safer and more sustainable energy future was largely because thorium-fueled MRSs challenged the LWR/solid fuel paradigm and did not conform to the political goals of the cold war.*

Today, China is leading the world in the development of thorium MSRs.[16,17,18] Their first two-megawatt prototype reactors will be operating by the first half of 2020,[19] outpacing the rest of the world by a decade or more. China's MSR program was contingent upon the direct transfer of U.S. technology by the Department of Energy beginning in 2010.[20]

The U.S. has no real program to speak of. The only operating salt loop (a non-nuclear flow simulator) in the U.S. was partially funded by the Chinese in exchange for U.S. national lab and university support that included the transfer of all material science, chemistry, mechanical, operational, and application data associated with MSRs developed by Oak Ridge and our other National Laboratories.

China provided about $3 million in funding for the completion of a salt loop at Oak Ridge. The value of the technology transfer may prove to be worth trillions of dollars. In retrospect, that Oak Ridge salt loop may turn out to be the most expensive salt loop ever built.

China's first to market strategy, combined with their tendency to vertically and horizontally monopolize industries, like rare earths, suggest that they will control the global roll out of this technology—displacing the U.S. as the global energy hegemon.

Thorium was also the leading culprit in America's failure to lead the world in the evolution of the rare earth value chain and our inability to retain control over all rare earth dependent technologies and IP. As a result, all future U.S. breakthroughs in material science or commercial application of new rare earth dependent IP will be commercially developed in China.

Because the U.S. failed to take on the rational utilization, management, and control of thorium, it has lost control of its destiny in both rare earths and the future of safe, clean, affordable, and sustainable energy.

The rare earth issue has never been a resource issue but rather a regulatory issue. The U.S. continues to mine enough rare earths, as the byproduct of some other commodity, to meet the entire non-Chinese world demand. These resources would quickly become available if the U.S. rationalized its thorium policy.

Today the obstacle to achieving safe, clean, affordable and sustainable energy is directly linked to the financial and political intersection of legacy and renewable energy producers, their sophisticated PR campaigns to the public, and their cash contributions to members of Congress that translate into manufactured support, regulatory obstacles, and government mandates (about ethanol, renewables, etc).

Regulations are more about protecting legacy interests than public safety. In nuclear regulation it is all about protecting the legacy fleet from new entrants.

For example, the company Nuscale spent over $600 million to certify a new nuclear reactor design. This expense was not to build a reactor. It is only the regulatory cost of permitting a new reactor design that highly conforms to existing designs.

What may not be obvious is that the real cost and risk in new reactor design is a function of time and money as it relates to investor expectations.

In the case of Nuscale, the regulatory and construction cost of a new reactor would far exceed $1 billion, with over a decade of investor money tied up in the highly speculative investment: speculative in regulatory outcomes and orders against existing technology and potential competitors—making this the highest risk money imaginable.

Accounting for the size and scope of these risks, return requirements for investors can move beyond the outer bounds of what is achievable in the abscense of a monopoly. That is why the public investment was always necessary in the development of this industry—and still is.

There are solutions. To learn more about advancing U.S. interests in the development of MSRs and ending China's rare earth monopoly please visit the Thorium Energy Alliance.

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