An Issue of National Security: Aiding the Chinese in the Development of Molten Salt Reactors

Jon Paul Morrow M.Econ, B.S. PoliSci.
Nuclear Policy/Economic Consultant for the eGeneration Foundation

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Premise

If China were to commercialize and weaponize Liquid Core Molten Salt Nuclear Reactor Technology before the United States does, as it has every intention of doing, the cost of energy used in Chinese manufacturing will be half the cost of the same amount of energy available to manufacturers of the same goods in the United States.

- In the battle of economies, China will win; the United States will lose.
- In the "battle" of nuclear deterrence, China will win; the United States will lose.
- In the competition for weapons development, China will win; the United States will lose.
- In a regional naval war in the western Pacific, the South China Sea and the East China Sea, odds are that the United States would be driven from the field.

Summary

Among the fears of the American public is the re-ignition of hostile relations in a Cold War style engagement with a super-power. Ameliorating such a potential conflict from ever occurring is the tremendous might of the American military. America's military superiority serves as a formidable deterrent to attack. But America's military superiority is at grave risk of vanishing due to a disruptive technology now in development by a likely adversary.

The Chinese government is racing to develop a game changing (disruptive) advanced nuclear technology that will give China a tremendous advantage in manufacturing energy intensive products through lower energy costs. If successfully commercialized, it is very doubtful that America could successfully compete with China in steel, alloy, and aluminum production, strategically important industries for the military, national security, and to America's economy. Successful development of this technology by the Chinese is both an immediate economic and military national security concern for the United States.

In 2015 the Ohio General Assembly passed, by an overwhelming bipartisan vote (House 97-1, Senate 32-1), House Concurrent Resolution 9 (HCR 9), a resolution

> "To establish a sustainable energy-abundance plan for Ohio to meet future Ohio energy needs with affordable, abundant, and environmentally friendly energy.

HCR 9 states that the State of Ohio shall encourage the research and development of liquid-core- molten-salt-reactors and small-modular-reactors technologies as a long-term solution to Ohio's energy needs; and shall advocate that the Congress of the United States mandate, and provide an adequate budget for, the Department of Energy and the Nuclear Regulatory Commission to establish rules for manufacturing, siting, and licensing of small modular reactors and liquid core molten salt reactors to be built and operated in the United States by private industry for the production of energy and medical isotopes.

Dr. Beth-Anne Schuelke-Leech in 2015 was an Assistant Professor at the John Glenn School of Public Affairs at the Ohio State University. She was a professional engineer with an MBA and a Ph.D. In her testimony in support of HCR 9 before the Ohio House Public Utilities Committee, Dr. Schuelke-Leech made these sobering points regarding Thorium-fueled Molten Salt Reactors and the U.S. competition with China:

- For our future energy sustainability and security, and for our economic competitiveness, it is crucial that we allow innovation in the nuclear industry.

- Alternative reactor designs and different fuels, such as Thorium, have the potential to make nuclear power safer and more economical.

- Currently the United States is making little public investment in these alternative designs, and regulatory uncertainty and constraints make investments by the private sector unattractive.

- The government of China is making significant investments in a nuclear power future. They are innovating and experimenting. They see nuclear power as a component of their energy future.

- China has a stated purpose of becoming a global exporter of nuclear technologies.

- China is investing billions of dollars into the development of their nuclear industry, including aggressively designing and building new reactors, with 17 currently constructed, 30 under construction, and another 45-50 proposed and under review.

- According to the World Nuclear Association, the China is expected to surpass the United States in installed generating capacity by 2030.

- China has committed hundreds of millions of dollars to develop new reactors, including $350 million to a molten salt reactor and $476 million to a high-temperature-gas-cooled reactor.

- The Chinese Molten Salt Reactor project is led by Jiang Mianheng, son of Jiang Zemin, former President of the People's Republic of China and Secretary General of the Communist Party, which indicates significant political commitment to this project.

- China's success in developing a viable alternative reactor and commercializing it at an economically competitive price (or even potentially at a significantly lower than current competitive price as they did in the solar industry) will be a disruptive technological innovation in the nuclear industry. China will become technology leaders and global suppliers of a reactor that the rest of the world has little practical knowledge of or experience with.

- China will come to dominate the global supply of nuclear energy technologies. The Chinese are particularly adept at standardizing a design and then being able to undercut competitors on the cost. They are cost innovators, often being willing to lose money in the short-term in order to build market dominance.

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[1] The Oakridge National Laboratory did operate a small research Molten Salt Reactor briefly in the 1960s. However, the reactor was never commercialized. Weinberg, Alvin (1994), *The First Nuclear Era: The Life and Times of a Technological Fixer*, New York, NY: The American Institute of Physics.

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[1] http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/

[2] ibid

[3] http://www.wired.com/wiredscience/2011/02/china-thorium-power/ and http://www.the-weinberg-foundation.org/page/9/?archive=1

[4]
http://www.world-nuclear-news.org/enf-chinese_htgr_fuel_plant_under_construction-2103134.html and http://www.china.org.cn/business/2013-01/06/content_27606925.htm

Very recently, (December 6, 2017) [1]the South China Morning Post announced that China would be spending $3.3 billion U.S. dollars in research and development to utilize this new nuclear technology for Chinese warships and nuclear powered flying drones. The dark irony of this announcement is that the nuclear technology China seeks to weaponize was developed in America during the 1950's, 1960's, and 1970's, and then abandoned. It was abandoned largely for political, not technical reasons.

Federal agencies, American companies, and America's state universities are actively aiding China in the development of this disruptive energy source. They began doing so starting under the Obama administration in 2011. Agencies within the federal government were putting globalist interests above American interests.

The advanced nuclear energy source in question is smaller, lighter, safer, more powerful, and has the potential to be much more cost efficient than America's best naval reactors, and commercial light water reactors, natural gas, coal, wind, solar, and geothermal technologies.

The advanced nuclear technology is MSR (Molten Salt Reactor) technology, which is a United States Department of Energy-recognized Generation IV nuclear technology [2]. An [3]FHR (Fluoride salt cooled High-temperature Reactor) is commonly associated with the MSR because they share some of the same technologies, and an FHR reactor is commonly perceived as a technological stepping stone to a MSR reactor.

China and U.S. work Together on Clean Energy

With China having the largest fossil fuel CO2 emissions and the United States being higher in per capita emissions, both countries have a strong mutual interest in appealing to the environmentalist movement to at least appear to be stabilizing climate change and reducing air pollution.

[1] http://www.scmp.com/news/china/society/article/2122977/china-hopes-cold-war-nuclear-energy-tech-will-power-warships
[2] https://en.wikipedia.org/wiki/Generation_IV_reactor
[3] https://www.ornl.gov/msr

The USDOE's (United States Department of Energy's) Office of International Affairs leads a strong partnership with China on clean energy cooperation. The two governments cooperate on a number of joint clean energy initiatives, including the [4] U.S.-China Clean Energy Research Center (CERC) and the Energy Efficiency Action Plan (EEAP). The USDOE focuses on using the strong, broad U.S.-China bilateral collaboration on clean energy to lead the way for collaboration on new nuclear technologies. This collaboration is premised upon driving down the cost of clean energy technologies, and deploying those technologies at scale. DOE works with China to utilize clean energy technology to help promote growth, security and prosperity.

The United States and China view the safe and secure development of nuclear power as a key solution to the development of a low-carbon energy source to reduce emissions from the global power sector.

This collaboration, developed by the last administration, guarantees that the American public will be the loser, and China will be the winner. The reality is that there is no competitive path towards new nuclear commercialization and licensing within the United States. This necessarily means that any joint development efforts on new reactor technology with other nations will directly benefit other nations and not the United States.

Why on earth is America helping China develop a technology that would compromise our own economic and national security?

A large part of the answer is that America's LWR (Light Water Reactor) industry is the guiding force behind all of America's nuclear decisions. Its lobbyists, industry experts, military, and even regulatory agencies are so focused upon maintaining and refining current, 65 year old LWR technology, that the resulting culture makes the development and commercialization of new nuclear technologies an impossibility. If America is to be a winner, and not a loser, this must quickly change.

Frameworks and National Security

The United States and China have numerous frameworks under which they cooperate on the development of nuclear energy.

[4] http://www.us-china-cerc.org/

The Office of Nuclear Energy Policy and Cooperation (INEPC) works with international partners on civil nuclear cooperation, ranging from advanced fuel cycle countries such as France, Russia and Japan, to those nations considering the development of nuclear energy for the first time. There are several categories of activity for our civil nuclear cooperation: bilateral technical collaboration arrangements, including technical action plans or MOUs, the International Nuclear Energy Research Initiative (INERI), and the International Cooperation (INC) framework.

The most disconcerting frameworks, however, are CRADA's (Cooperative Research and Development Agreements), for which there seems to be inadequate guidance, reporting, and oversight by the United States.

CRADAs were created to provide a mechanism for federal agencies to join more readily with their colleagues from industry and academia in the pursuit of common research goals to benefit Americans. The purpose of a CRADA is to make government facilities, intellectual property, and expertise available for collaborative interactions to further the development of scientific and technological knowledge into useful, marketable products. In the case of MSR/FHR technology being developed in cooperation with China, not only is it questionable as to whether America could benefit in any capacity relative to China, given the institutional angst towards nuclear energy by Congress and federal agencies, but it is overtly apparent that China is positioning itself to take full advantage of the commercialization of this technology.

Title 15 U.S.C. 3710 gives federal agencies and laboratories the authority to enter into CRADAs to foster collaborative relationships with industry, academia, local and state governments, and with other federal agencies to attain technology research goals and benefits with little to no [5]oversight. Section [6]3710 does not specifically mention foreign governmental entities. Clearly the intent of Congress with CRADA legislation was to reduce the barriers to research and development within the United States to benefit the citizens of the United States, not necessarily to benefit another country.

In the case of MSR research and development with China, clearly China stands to gain much more economically and militarily relative to the United States.

Not all research and development with foreign governmental entities is necessarily bad. Joint research and development between countries can, in many cases, benefit all countries involved. For example: joint wind and solar development between China and

[5] https://energy.gov/sites/prod/files/igprod/documents/IG-0826.pdf
[6] https://www.law.cornell.edu/uscode/text/15/3710a

the United States has a greater potential to be equally exploited by both countries because they both provide markets conducive to wind and solar.

The United States market, however, is risk averse towards new nuclear technology, and as a result America has only ever commercialized one type of nuclear technology, LWR technology. Due to several external causes, there is little will from the free market in the U.S. to commercialize new nuclear technology within this country: overly risk averse regulators that make commercial licensing cost prohibitive; a presently-large supply of cheap natural gas; inordinately large subsidies and mandates by government for wind and solar energy, making nuclear energy artificially uncompetitive, and a prohibitively litigious atmosphere for nuclear site selection and construction. As a result, many American companies looking to pursue MSR/FHR development will likely find a much cheaper and easier path to commercial licensing and a profit in China.

Are CRADAs with Foreign Governmental Entities Legal?

[7]Yes, such CRADAs are within the law. Legal professionals, using their expertise in legal drafting, have indeed found a way to rationalize permitting bureaucrats to make agreements with foreign governmental entities, without regard or concern that such CRADA agreements may disproportionately benefit foreign nations and potentially compromise our national security.

Often bureaucrats are political appointees who may not have America's best interests at heart or may be politically naive about national security concerns. Allowing bureaucrats self-oversight over the sharing and collaboration of new nuclear technologies is very dangerous and must be eliminated.

Many in the [8]academic community can rationalize the commercialization of a game changing nuclear technology by China because they either perceive climate change as an impending threat to the globe or see the benefits of this technology to aid in lifting much of the world out of poverty. With this global savior mindset, enriching and empowering a communist nation with such a technology might seem acceptable to the most naive amongst us.

[7] http://globals.federallabs.org/pdf/2010/CRADAs_Charles.pdf
[8] https://www.wired.com/2016/10/molten-salt-reactors-soon-help-power-earth-one-day-mars/

China hopes cold war nuclear energy tech will power warships, drones

Beijing pumping billions into the development of 'molten salt' reactors, amid revived interest among nations in the potentially safer and more powerful technology

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Would academia or bureaucrats' minds be changed if the technology developed in the name of humanity caused war and escalated deaths rather than prevented deaths? [9] Probably not, and in any case, such a change in attitude would come much too late.

In fact, we see our first report from a credible news source of the potential weaponization of molten salt reactors, and it is not in the United States. It is for this reason that the decision to share nuclear technology with a foreign nation should be a political decision made by those elected by the people, fully vetted against national security concerns, and not a decision left to bureaucrats.

International cooperation for the research and development of new nuclear technologies does not belong under a CRADA. Such an agreement belongs under a Congressionally

[9] http://www.scmp.com/news/china/society/article/2122977/china-hopes-cold-war-nuclear-energy-tech-will-power-warships

approved, State Department negotiated agreement, that has been properly vetted for national security concerns, and has proper oversight.

The Failure of Globalism

Most Americans are at least somewhat familiar with President John F. Kennedy's policy of MAD (Mutually Assured Destruction). The strategy of MAD was fully declared in the early 1960s, primarily by Kennedy's Secretary of Defense Robert McNamara. In McNamara's formulation there was the very real danger that a nation with nuclear weapons could attempt to eliminate another nation's retaliatory forces with a surprise, devastating first strike, and thereby"win" a nuclear war relatively unharmed. True second-strike capability could be achieved only when a nation had a guaranteed ability to fully retaliate after a first-strike attack.

America's MAD doctrine (retaliatory strike capability) was kept in place until President George H.W. Bush opted instead to transition to a policy of Globalism to keep America safe. The theory was that if all nations became economically interdependent, they would not engage in war, because doing so would negatively impact their economies. A military strike against a country meant either devastating the aggressor nation's economy -or- another country's economy that would in turn place sanctions on the aggressor country for perpetrating such an attack.

All U.S. Presidents since H.W. Bush, including Bill Clinton, George W. Bush, and Barack Obama, have pushed a greater globalist agenda based on trade. Greater globalism in theory should have spread prosperity and reduced America's military costs, but the opposite has happened. The more America and other countries have become dependent upon other countries for oil, the more the oil bearing countries gouged the American people by manipulating the supply of oil, and thereby manipulating the price of oil to enrich the coffers of some of the most dangerous regimes on the face of the planet. America's dependence on foreign oil has resulted in financing unspeakable acts of evil and helped to further embroil the United States in Middle Eastern wars and military action.

Gaining independence from an addiction brings with it a multitude benefits. With the oil industry's revolutionary new hydraulic fracturing technology, America has almost eliminated its addiction to Middle Eastern oil. The benefit is a lower price for oil, more domestic employment, and less of a need to involve America in Middle Eastern affairs.

MSRs (Molten Salt Reactors) are to the nuclear industry what hydraulic fracturing technology is to the oil industry; a game changing technology. Unlike the oil industry though, due to the current regulatory climate U.S. bureaucrats and politicians are unable to comprehend how our energy grid works, and a nuclear industry that is unwilling to risk innovation in the United States. MSRs will most likely be commercialized in China and benefit Chinese citizens - even though MSRs are an American technology, invented and tested here.

This should be no surprise to American globalists, as much of America's dependence on foreign nations is derived through self-imposed regulatory burdens. In the case of regulatory burdens in the nuclear industry, America is poised to become dependent upon the rest of the world for any new forms of nuclear energy.

Any dependency brings with it negative consequences. In the case of America's dependence on foreign countries to commercialize and license new nuclear technologies, the negative consequence is, among other bad outcomes, ceding much of America's military deterrence. America's homeland will be much more vulnerable to attacks.

Railguns: Eliminating America's Deterrence

Instead of gunpowder, railguns use electromagnetic energy to propel a projectile, with a potential for far greater speed and range—the equivalent of a cannon with missile effects. Essentially, a railgun is an electromagnetic-powered cannon that fires hypersonic shells by applying parallel magnetic fields (or "rails") on the shells.

There are two major problems holding back the deployment of the railgun. [10]The first is meeting the weapon's massive electric power requirements at sea. The second is demonstrating that it will be 'better' than existing weapons. Due to a MSR's small size and tremendous energy output, the MSR has the potential to satisfy the railgun's energy requirements on a wide array of naval ships. If other much smaller technical hurdles with the railgun can be overcome guaranteeing the railgun as a reliable weapons platform, the technology has the potential to revolutionize warfare and eliminate the threat of nuclear tipped ballistic missiles.

[10] http://nationalinterest.org/blog/the-buzz/us-navys-railgun-dream-could-be-denied-by-two-big-problems-17301?page=show

Most experts believe based upon testing, that a railgun will have a range between 100 and 220 miles. This opens up the possibility for a developed rapid fire railgun to shoot down ballistic missiles upon launch or upon descent after reaching their apogee ([11]1,200 miles in space). Railgun technology, if massively deployed, has the very real possibility of rendering nuclear tipped ballistic missiles vulnerable and, if developed by an enemy, of making America's nuclear deterrence obsolete.

An offensive weaponized space platform armed with railguns has the potential to strike anywhere in the world with more accuracy and, for operations other than "city-busting," more lethality than nuclear tipped ballistic missiles. It will do this without the worry of fallout and long lasting radiation hazards. Notably, the [12]MSR is a prime candidate to power space based applications due to its inherent stability, its high power to weight ratio, and its inherent ability to function without water.

The Chinese have been actively engaged in developing electromagnetic launch capabilities for their aircraft carriers. [13]Most recently, the Chinese have made a breakthrough that will allow them the ability to launch jets electromagnetically without the need of a nuclear powered reactor; an ability that even America does not possess. This breakthrough should be disconcerting to American military threat analysts, as such a technological breakthrough should be expected to be applied to the [14]Chinese development of railguns. Even more worrisome to American military threat analysts should be the simultaneous development path of MSRs and railguns.

America currently has only one ship that is practically capable of firing currently conceived railguns; the [15]Zumwalt class destroyer. While the Zumwalt has the power to fire multiple projectiles from a railgun, because it is powered by natural gas and not nuclear power it cannot do so for an extended period of time without needing to be refueled. Nuclear fuel is a million times more energy dense than natural gas and would therefore vastly outperform a natural gas power source.

The Zumwalt class destroyer has its [16]detractors, owing to the many technologies on the ship that are not considered mature enough for combat operations. Two of the three planned Zumwalt class destroyers have been built. [17]One is in operation, the [18]second is

[11] https://en.wikipedia.org/wiki/Ballistic_missile
[12] https://www.lpi.usra.edu/meetings/nets2012/pdf/3070.pdf
[13] https://www.defensenews.com/naval/2017/11/09/tech-breakthrough-chinas-next-carrier-could-feature-electromagnetic-launch-system/
[14] https://www.popsci.com/china-electromagnetic-railgun-catapults
[15] https://www.youtube.com/watch?v=QTXG-cP8QvY
[16] http://www.nationalreview.com/article/443165/zumwalt-class-navys-stealth-destroyer-program-failure
[17] http://usszumwalt.org/commissioning-2016/
[18] https://thediplomat.com/2017/12/2nd-zumwalt-class-guided-missile-destroyer-begins-sea-trials/

undergoing sea trials, and the third is under construction. The decision to power the Zumwalt class destroyer with what environmentalist termed a green energy power source is an "achilles heel" for any warship that purports to be a platform for high-energy weapons.

If that's the case, how will the Navy use the Zumwalt? Eric Wertheim, author and editor of the U.S. Naval Institute's Guide to Combat Fleets of the World, noted that "with only three ships, the class of destroyers could become something of a [very expensive] technology demonstration project."

The Economics of Producing Energy Affects National Security

Cheap energy powers the wheels both of commerce and of warfare. The production of many military assets is a function of energy intensive manufacturing, and the affordability of energy can ultimately determine battlefield decisions. The ability to produce steel, specialty alloys, and aluminum affordably, relative to the global market, is a vital national security concern. Tanks, aircraft, ships, submarines, and ordinance are all assets that are the result of energy intensive manufacturing.

As American environmentalists have been successful in lobbying for and imposing green regulations on power plants and on America's energy intensive manufacturing processes, America's ability to produce steel, specialty alloys, and aluminum affordably has been compromised. Green regulations that directly affect America's energy intensive manufacturing processes have raised costs to the point that many energy intensive manufacturers are seeking tariffs on foreign goods that will allow them to at least compete domestically against foreign companies which are not burdened with similar green regulations.

Few would debate that China already has a significant manufacturing advantage over the United States in energy intensive manufacturing. Chinese companies and Chinese energy producers do not have to contend with as many environmental laws and safety regulations as American companies do, and because of China's large population (supply of labor), labor costs are very low.[19]China's energy costs are thus already very low compared to the rest of the world.

[19] https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries/

But what would the result to the world's economy be if China were able to cut its already low cost of energy in half for its energy intensive manufacturers? Many economists believe that such a price disruption would affect global markets and would unduly benefit China and harm the economic capacity of the rest of the world.

[20]Very conservative estimates place Molten Salt Reactors as having the potential to produce electricity at a cost of less than $.02 cents per kilowatt/hour. Many experts believe that sub 1 cent per kilowatt/hour electrical generation is possible, but refrain from making such claims because they sound too good to be true. To put this into perspective:

- The real cost of electricity generated by our present U.S. LWR nuclear power plants is estimated to be between 6.7 cents per kilowatt hour (kwh) and 8 cents/kwh, depending on how high-level nuclear waste is expensed.
- Electricity from plants burning pulverized coal generally costs 4.2 cents/kwh to 6.5 cents/kwh to produce, depending upon emission controls in place.
- Electric power from natural gas costs 2.7 cents/kwh to 4.1 cents/kwh, though there is a general consensus that natural gas prices that would produce electricity at less than 3.5 cents/kwh is unsustainable.
- Power from a Molten Salt Reactor would cost, by comparison, an estimated 1.4 cents/kwh to 2 cents/kwh.

It is generally accepted that [21]20% of the cost of producing steel is the cost of energy. It is also generally accepted that [22]33% of the cost of producing aluminum is the cost of energy.

The average cost of industrial electricity for midwestern companies is about [23]6.97 cents per kilowatt hour (*note that there is a tremendous cost to distribute electricity and maintain the electrical grid). Molten Salt Reactors (MSRs) can be made very small and produce electricity as cheaply as a much larger traditional power plants; steel and aluminum manufacturers could elect to enter into a purchase agreement and produce electricity on site and thereby bypass the large distribution costs of electricity. A small

[20] http://www.ncpa.org/pub/ib149
[21] https://www.steel.org/~/media/Files/AISI/Public%20Policy/Testimony/2010/test_enr_caucusoncoal052510.pdf
[22] https://agmetalminer.com/2015/11/24/power-costs-the-production-primary-aluminum/
[23] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a

modular onsite MSR is conservatively expected to produce electricity at 3 cents per kilowatt hour, and that would equate to a 57% savings in energy costs for companies opting for small onsite modular MSRs. One hundred dollars of steel would be reduced to $88.60 (11.4% savings) and one hundred dollars of aluminum would cost $81.19 (18.8% savings). If such savings were applied to Chinese steel and aluminum manufacturers, it is very doubtful that American manufacturers would be able to compete in global markets, or even in domestic markets without tariff protections.

Policy Recommendations

It is very likely that if America ended its cooperation with China on the Molten Salt Reactor (MSR) project that China would still be able to develop and license this technology for civilian use. So the question becomes "How can Americans benefit from the development of this technology?" This, in turn, begs the question of "What led to America ceding its preeminence in nuclear technology in the first place?" As in most matters of policy, we need to know how we got here before we can understand fully our present situation and begin to create policy to better our position.

History - The [24]Omnibus Reconciliation Act of 1990 created the United States Nuclear Regulatory Commission (USNRC); by law, a cost recovery agency of the federal government. The passage of this act has had profound negative consequences for the U.S. nuclear industry.

Most of the rest of the world's nuclear regulatory programs are first funded by their respective governments. Then the costs to develop regulations are recovered either through licensing fees or a tax on energy generation.

In contrast, in America the individual first mover within the nuclear industry bears all the cost of licensing without gaining any exclusivity of such a license. As a result there are very few companies willing to risk plowing a path for their competition by absorbing the cost to develop licensing with the USNRC. The cost to license a new type nuclear reactor is exorbitant. In many cases it is estimated that the licensing of a new nuclear design will cost in excess of $1 billion. In some cases the licensing can exceed the actual construction costs of the reactor.

[24] https://www.nrc.gov/about-nrc/regulatory/licensing/general-fee-questions.pdf

Worse yet, a company has no guarantee of a license until a vast majority of the money is spent, so at the last minute the USNRC can determine that the applicant will not receive a license.

Experts estimate that Covidien (once a part of Mallinckrodt Pharmaceuticals) and Babcock and Wilcox spent in excess of $800 million to try to license their Medical Isotope Production System (MIPS) aqueous homogeneous reactor (shares some technology characteristics with the Molten Salt Reactor). After three years, there seemed to be no end in sight to the time and money needed to finish the licensing process, and in 2012 both Covidien and Mallinckrodt abandoned their quest to license the reactor that would supply America with badly needed medical isotopes.

Additionally, from an outsider's perspective, the USNRC seems to be very averse to building small experimental test reactors for study, instead opting for copious amounts of computer modeling that may or may not reflect the realities of the physical world. It can be argued that due to the policy of not actually building experimental test reactors until they can be completely understood virtually has led to such a slow pace and enormous cost in the development of new type nuclear reactors that anything other than a refinement of the current light water reactor designs has become a near impossibility.

In fact, one could argue, nuclear research and development was much more robust before computer modeling, and most of America's knowledge pertaining to nuclear technology was gained very quickly through physical, rather than virtual, experimentation.

Physical experimentation with very small experimental reactors is very important, not only to a better understanding of tapping the power of the atom, but also in rapidly developing nuclear technologies.

Additionally, there are many nuclear technologies, including Molten Salt Reactor technology, that can consume America's high-level nuclear waste. When [25]America's nuclear waste management fund was established (1982) many of the technologies we now know can consume nuclear waste were classified as top secret, and kept from the public.

In 1996, under the Clinton administration, U.S. Secretary of Energy Hazel O'Leary [26] declassified millions of Department of Energy documents that led to the release of many of America's previous experiments with different types of nuclear reactors, including those that had the potential to consume nuclear waste.

[25] https://en.wikipedia.org/wiki/Nuclear_Waste_Policy_Act
[26] https://en.wikipedia.org/wiki/Hazel_R._O%27Leary

There are many polls and studies that show that the public will accept nuclear technology when is educated about walk-away safe, proliferation resistant, new nuclear technologies that can eliminate over 90% of America's nuclear waste and produce clean carbon free electricity. This is especially true when this new technology is compared to sequestering nuclear waste for 300,000 years in a Yucca Mountain repository at an expense of $110 billion. Over 70% of the public chooses consuming nuclear waste rather than sequestering nuclear waste.

With over [27]$45 billion sitting in the Nuclear Waste Management Fund, and an estimated cost of $5 billion to commercialize and license nuclear waste consuming MSRs and another $25 billion for a nuclear waste processing center, it is very doubtful that the commercialization of this reactor would ever use any taxpayer dollars or pose any budgetary concerns. The results of commercialization have great potential greatly to improve the American economy and environment and would allow America to address any national security concerns from a position of strength.

Currently, the federal government directs almost all federal research in nuclear technologies, creating a monopoly that is subject to the whims of differing presidential administrations. There is not enough competition to break with group think and provide any type of financial continuity within the nuclear industry. Nuclear energy research and development was taken away from independent state development by the Atomic Energy Act of 1946, but the intention was not to keep states from developing new nuclear technology. In many places within the 1946 legislation it is stated that as a state's expertise in nuclear technologies comes to fruition that Congress should revisit legislation granting states more independence to develop its own new nuclear technologies.

Policy recommendations

1. Congress should consider directing the USNRC to promulgate a process that will allow states independently to develop and license small experimental research reactors within their respective states, outside of the auspices of the USNRC, when proper safety precautions are provided for, e.g., *containment and security*. This will spur competition to lower the cost of research and development of new nuclear technologies and bring more technologies to market more quickly. This type of an agreement with a state is no different than agreements that the U.S.

[27] https://energy.gov/sites/prod/files/2016/12/f34/OAI-FS-17-04.pdf (page 18)

Department of Energy has with a multitude of foreign nations jointly to develop new nuclear technologies.

2. Congress should make funds available from the Nuclear Waste Management fund to states and other agencies that partner with private industry to produce small experimental reactors that can economically consume nuclear waste. With a successful technology demonstrated, Congress should use funds to finance a pilot plant that can be used to develop licensing. Upon successful demonstration of a pilot plant and the development of licensing regulations Congress should utilize nuclear waste management funds to create a facility to process nuclear waste so it can be accepted by new waste consuming reactors. Congress should then reinstitute the waste management fee imposed on reactors that produce nuclear waste and use this fund to pursue research and development, and licensing efforts, to refine technologies that consume or eliminate the creation of nuclear waste.
3. Congress should review and specify how Cooperative Research and Development Agreements (CRADAs) are utilized by federal agencies.

Appendix

- https://www.engr.wisc.edu/uw-madison-forefront-innovation-nuclear-energy/
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