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STEP CHANGE: IMPROVEMENTS TO U.S. NUCLEAR POWER REGULATION

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EXECUTIVE SUMMARY

Whether the United States retains and grows its domestic nuclear industry in the coming decades depends largely on whether the federal agencies most involved with nuclear power regulation enact real reform in the next several years.

The current regulatory regime at the Nuclear Regulatory Commission (NRC) involves an unbalanced amount of attention and resources toward the safety and upkeep of currently operating reactors at the expense of new generations of reactor technology. Additionally, export control rules regarding unclassified nuclear technology are so poorly administered by the Department of Energy (DOE) that, in recent years, they have undermined U.S. participation in the global marketplace.

Given how embedded nuclear power is within the international energy system, , the expansion of affordable, market-driven nuclear power would considerably improve prospects for achieving a low carbon future by mid-century. Policymakers should therefore focus on the mitigation of artificial costs created by regulatory processes, which cause delays that decrease the net present value of potential investments and unfairly shut out U.S. firms from international business consideration.

Specifically, Congress and the Trump administration should make the reduction of uncertainties and delays regarding nuclear energy a priority. Improvements in the way the NRC handles regulation of new technology (both reactors and accident-tolerant fuels) and the way DOE handles its unclassified export regulation and proceeds with its fast-test reactor construction could help the United States recover what is becoming more than a decade of lost ground in a very competitive international marketplace.

To this end, the following executive and legislative priorities for the Trump administration are suggested:

1. Because of material improvements in design and safety features, the NRC should make a clean break in regulatory guidance between current Generation II light-water reactor (LWR) oversight and Generation IV non-LWR advanced nuclear reactors. This would involve moving the Office for New Reactors out from under the current directorate and the creation of a directorate for new reactors. This change would help NRC staff move away from their LWR-centric review plans and toward more high-level guiding principles for future safety-focused reviews of new technology.
2. The Department of Energy should increase its funding for fast-test reactors and Congress should permit federal agencies to enter into purchase power agreements of up to 30 years for Small Modular Reactors (SMRs) or other approved technology.

3. Expedite the licensing and construction of testing infrastructure for advanced nuclear fuel concepts.

4. Lift the onerous export restriction related to Part 810 and create a standing inter-agency committee that would operate as a backstop to any bureaucratic bottlenecks that occur within the current Part 810 export controls.

INTRODUCTION

The nuclear power industry in the United States has reached an inflection point. Two decades of increasingly inflexible regulation of the nuclear industry by the U.S. Nuclear Regulatory Commission (NRC) and the Department of Energy (DOE) threaten to undermine the industry just as a safer generation of reactors is beginning to reach the marketplace.

Starting in the 2000s, the attempted "renaissance" of the nuclear industry failed to materialize with only one project, the Georgia-based Vogtle plant, which is still under construction. Since 2010, eight nuclear reactors in the United States have been scheduled for closure.[1] Meanwhile, countries across the globe are expanding their reactor fleets over the next three decades, especially in Asia.[2] Right now, about 50 plants are under construction and the world's nuclear electrical generating capacity may increase from 391 Gigawatts (GW) to 554 GW by 2030. High estimates suggest capacity may be 874 GW by 2050.[3] This represents a 42% increase over current levels by 2030 and a doubling of capacity by 2050.[4]

In the United States, reactor investment has been undermined by historically low natural gas prices, but a key social driver for global growth is expected to be bolstered by a desire to combat climate change through low-emission energy sources. Accordingly, the atrophying within the U.S. industry comes just at the time when many other nations are developing climate goals that specifically depend upon new nuclear technology.[5]

Irrespective of the direction U.S. climate change policy takes, many nations across the world have accepted the need to adapt to a carbon-constrained world and are attracted to nuclear power's future development.

In addition to undermining an important domestic industry, unchanged regulatory behavior will likely cause the transfer of nuclear technological leadership to nations such as China and Russia, two states that helped destabilize the current non-proliferation regime by supporting nuclear weapons development in Pakistan and North Korea. To cede the future of nuclear power to these nations, then, would place both countries as the chief influencers of the future of the Nuclear Non-Proliferation Pact (NPT), the half-century-old international agreement that has done more to constrain the spread of nuclear weapons than any other political agreement.

As is the case in many industries, the tyranny of the status quo and path dependent mindsets can determine whether the industry is adaptive enough to survive the periods of "creative destruction" that force businesses to invent new operating models and engineering processes. Nuclear power is no different than other industries in this way. The three most important and damaging nuclear energy accidents – Three Mile Island (1979), Chernobyl (1986) and Fukushima (2011) – all had major impacts on the NRC regulatory culture and decision-making, ultimately forcing millions of dollars each year in additional safety and security costs onto individual reactors.

Whether the United States can remain a nuclear energy power in the 21st Century depends upon whether the NRC and the DOE can enact new reforms to policies that will lower the artificial barriers to entry created by licensure uncertainty and delays that increase financing costs.

There are signs that the NRC is taking seriously the criticism that the existing regulatory regime constrains innovation. In January 2018, it approved NuScale Power's "Safety Classification of Passive Nuclear Power Plant Electrical System," which allowed its 50 MW reactor to operate without the need for safety-related backup electrical systems.[6] This approval makes the reactor's operation less expensive and increases the likelihood of its commercial deployment by the 2020s.

Starting in 2010, executives and engineers at Nuscale held over 250 meetings with the NRC before submitting its reactor application to the agency in March 2017.[7] While admirable in terms of due diligence, such extended engagement is not the best regulatory standard by which to justify oversight because of the burdens it places on private industry.

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1. Sonal Patel, "More Premature Nuclear Unit Retirements Loom," *Power Magazine*, Feb. 1, 2018. http://www.powermag.com/more-premature-nuclear-unit-retirements-loom.

2. "Plans For New Reactors Worldwide," World Nuclear Association, January 2018. http://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx#ECSArticleLink0.

3. "Electricity and Nuclear Power Estimates for the Period up to 2050," International Atomic Energy Agency, 2017, p. 18. http://www-pub.iaea.org/MTCD/Publications/PDF/17-28911_RDS-1%202017_web.pdf.

4. Ibid.

5. "Nuclear Energy to Provide 25% of UAE's Needs by 2021," *Gulf News*, Oct. 30, 2017. http://gulfnews.com/news/uae/society/nuclear-energy-to-provide-25-of-uae-s-needs-by-2021-1.2115750.

6. Dan Yurman, "NRC Says NuScale SMR Won't Need Backup Electrical Power," The Energy Collective, Jan. 15, 2018. https://www.theenergycollective.com/dan-yurman/2419557/nrc-says-nuscale-smr-wont-need-backup-electrical-power.

7. Ibid.

Accordingly, this paper aims to explore solutions that can both support the industry's extremely high safety standards as well as reduce the red tape and regulatory disincentives that currently surround nuclear power. Risk analysts consider nuclear energy a "fat-tail" domain in which major harm comes from a large, single event, rather than from the collective effect of many, small events.[8] This means there should be no expectation of similar regulatory treatment to other competing fuels that do not share the same type of risk.[9] The present study, therefore, focuses on the possibilities that major improvements in the speed and efficacy of nuclear regulation can be found. Indeed, if the proper changes in policy are made, the benefits of non-carbon electricity, decades-long guaranteed baseload power and decreasing safety risks of new technologies all point toward a new chapter in nuclear power.

REGULATORY ARCHITECTURE

It is rare for an industry as important as the U.S. nuclear power one to be so dependent on a federal regulatory body, but nuclear energy is not a typical industry. From the beginning of the atomic age, nuclear power has been intertwined with the U.S. military's massive build-out of nuclear weapons and the slow but steady accumulation of scientific knowledge regarding the health risks of nuclear radiation.

Over decades of nuclear power, scientific and engineering advances have allowed for the creation of a nomenclature of reactor designs first proposed by the DOE in 2000. This concept involves four "generations" of commercial reactors, with each generation representing major technical and safety advances from the previous design:

- Generation I reactors were developed in the 1950-1960s in the United States and United Kingdom. These were early research reactor prototypes developed as "proof-of-concept."[10] Most of these were shuttered in the 1970s and 80s and were replaced by Generation II reactors. The last Generation I reactor was shut down in 2012 in the United Kingdom.[11]

- Generation II reactors represent the bulk of the world's over 400 commercial reactors. Two designs predominate—the pressurized-water-reactor (PWR) and the boiling water reactor (BWR)—each of which uses water as a coolant and as a neutron moderator.

- Generation III reactors represent evolutionary improvements in fuel technology and safety systems—especially passive safety – that lowered the risks of a core meltdown and potentially lowered operating costs.

- Generation IV reactors represent a major breakthrough from past designs, with smaller, modular designs and passive safety systems that preclude the possibility of a core meltdown. This, in turn, dramatically lowers the risk profile of the technology. These designs have been slow in their development and will not be operational before the 2020s in the United States and Europe, although China may complete its first two Gen IV reactors in 2018.[12]

Now, late into the second decade of the 21st Century, we have a new generation of technology that cannot enter the marketplace due to an ineffective approval process and a lack of acceptance of risk-informed analysis of newer generation nuclear reactor design. However, a streamlined and predictable pathway to the deployment of new technology is in every stakeholder's interest.

Historical regulatory developments

In the wake of nuclear weapons use in Japan at the end of World War II, the U.S. Congress scrambled to create statutory authority over nuclear science. At the time, lawmakers did not contemplate the private, commercial application of atomic energy.[13] Instead, Congress passed the Atomic Energy Act of 1946 to keep the technology behind splitting the atom a military secret for as long as possible. But Soviet espionage and the successful testing of a nuclear bomb on the Kazakhstan steppe in 1949 put an end to any hope that the nuclear age would remain exclusively an American affair. By the early 1950s, both the Soviet Union and Great Britain had made strides toward developing the controlled nuclear reactions necessary to create the first nuclear power plants.[14]

In response to this "nuclear power race," Congress and the Eisenhower administration agreed to a civilian energy

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8. Nassim Nicholas Taleb et al., "The Precautionary Principle: (with Application to the Genetic Modification of Organisms)," *NYU School of Engineering Working Paper Series*, Oct. 17, 2014. https://arxiv.org/pdf/1410.5787.pdf.

9. There is no discussion within this paper of policy issues regarding the disposition of nuclear waste. In 2014, the NRC concluded that nuclear fuel can be safely stored on site in dry caste storage for between 60 to 100 years (or longer), which mitigates the immediate need for a long-term nuclear waste facility. See, e.g., Sonal Patel, "NRC Issues Final Rule to Replace Waste Confidence Decision, Ends Licensing Suspension," *Power Magazine*, Aug. 26, 2014. http://www.powermag.com/nrc-issues-final-rule-to-replace-waste-confidence-decision-ends-licensing-suspension.

10. Stephen M. Goldberg and Robert Rosner, "Nuclear Reactors: Generation to Generation," American Academy of Arts & Sciences, 2011, pp. 3-4. https://www.amacad.org/pdfs/nuclearReactors.pdf.

11. "World's Last Operating Magnox Reactor Closes," *World Nuclear News*, Jan. 4, 2016. http://www.world-nuclear-news.org/WR-Worlds-last-operating-Magnox-reactor-closes-31121501.html

12. "Safety of Nuclear Plant Reactors," World Nuclear Association, May 2016. http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors.aspx.

13. J. Samuel Walker and Thomas R. Wellock, "A Short History of Nuclear Regulation 1946-2009," September 2010, pp. 1-2. https://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0175.

14. Ibid., p. 2.

program through passage of the Atomic Energy Act of 1954.[15] The Act ended the U.S. government's monopoly on technical data and set up the U.S. Atomic Energy Commission (AEC) as the primary governmental agency in charge of nuclear weaponry and commercialization.

From the beginning, the AEC's competing responsibilities to promote nuclear technology through free-enterprise, boost its military uses and lower the safety risks of nuclear power proved challenging. Disagreements over radiation science, the durability of steel, and the complex interactions between water and metals within a reactor challenged scientific experts for years.[16] Meanwhile, industry was aggressively increasing the size and scale of power plants, which in turn, expanded the potential scale of damage in the event of a major accident.

During the period between 1965-1968, nuclear venders sold more than 70 nuclear plants to utilities across the country, overwhelming the AEC's licensing and inspection caseload at a time when reactors were becoming increasingly complex.[17]

In 1974, the AEC was split into two parts, the Nuclear Regulatory Commission and the Energy Research and Development Administration (ERDA), the latter of which took over AEC's energy research and development (R&D) program. In 1977, ERDA was rolled into the creation of the Energy Department itself.[18]

The NRC was in a better position to focus on risk and possible improvements to nuclear technology. Yet a spike in public fears over core meltdowns after Three Mile Island and an increased focus on non-proliferation shifted regulatory oversight away from technological innovation toward a more status quo approach—one that has remained largely the same for several decades.

Current Regulatory Challenges

The current regulatory environment can be described as risk-averse and backward-looking. This is because the impacts of both the 9/11 attacks and the Fukushima accident have been steep and should not be understated. The 2001 attacks led to increased security requirements at plants around the United States that cost the industry roughly $2 billion.[19] The Fukushima accident caused regulators in the United States to spend several years focusing on how to make the current generation of light-water reactors safer. While laudable, this took away significant resources from the design of future regulation for more advanced reactors that were much safer in their initial design than any improvements that could be made to Generation II technology.

One of the chief cost factors involving the current generation of reactors involves the inflexible rules regarding quality assurance (QA) that only apply to the nuclear industry. These nuclear quality assurance (NQA-1) standards created and maintained by the American Society of Mechanical Engineers (ASME)[20] mandate that an entirely separate industrial line of manufacture must be used only for nuclear plants—for everything from bolts and screws to air vents. Many analysts believe the special quality control rules do little in risk reduction but instead add enormously to cost—up to five times per item.[21] This specialized demand for essentially artisanal, small-batch parts limits the number of qualified suppliers, and this creates bottlenecks and shortages of available skilled labor at the few manufacturing facilities that make the specialized equipment. Such problems with QA/fabrication have also occurred at nuclear projects in Finland and France, as well as at the Vogtle site in Georgia, which suggests that the problem is industry-wide.[22]

Further, the over-broad application of NQA-1 standards also does not make the nuclear industry heathier going forward. Because of significant design improvements, several of the advanced nuclear reactors (ANRs) have shown very low probability of core damage or radiation release.[23] For example, NuScale's initial probabilistic risk assessment (PRA) showed its core damage frequency to be on the order of 10^{-7}, meaning less than 1 in 10,000,000 reactor years.[24] Currently operating PWRs have a core damage frequency of less than roughly 10^{-5}—100 times higher than NuScale's. While the current safety level of 1 in 1,000,000 is sufficient, there should be no undue burden on new technologies that bring enhanced safety to the current nuclear fleet.

The regulatory environment that has developed at the NRC has thwarted competition and built up barriers to entry by

15. Ibid., p. 3.

16. Ibid., p. 8.

17. Ibid., p. 27.

18. Richard Dickson, "Farewell ERDA, Hello Energy Department," U.S. Department of Energy, Oct. 2, 2012. https://energy.gov/articles/farewell-erda-hello-energy-department.

19. "Safety of Nuclear Plant Reactors." http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors.aspx.

20. "Quality Assurance Program Criteria," U.S. Nuclear Regulatory Commission, June 2010. https://www.nrc.gov/docs/ML1001/ML100160003.pdf.

21. Interview by author with Nuclear Energy Institute staff members John Butler and Michael Tschiltz, December 2017.

22. Jim Hopf, "How Can Nuclear Construction Costs Be Reduced?", American Nuclear Society, Jan.24, 2013. http://ansnuclearcafe.org/2013/01/24/how-can-nuclear-construction-costs-be-reduced/#sthash.AuO9IPJY.dpbs.

23. Jim Hopf, "Update and Perspective on Small Modular Reactor Development" American Nuclear Society, March 21, 2013. http://ansnuclearcafe.org/2013/03/21/update-and-perspective-on-smr-development/#sthash.dJZtlKQo.dpbs

24." Protection Against Extreme Events," NuScale Power, 2018. http://www.nuscale-power.com/smr-benefits/safe/extreme-event-protection small companies with potentially breakthrough nuclear technologies. Currently, dozens of companies and organizations are developing up to 60 designs in the United States and elsewhere that qualify as either an SMR or an ANR, both of which have lower risk profiles than the current Gen II operating fleet.

RECOMMENDED SOLUTIONS

Clearing away some of the most serious regulatory barriers now in place for the U.S. nuclear industry is a challenge, but a worthy one. Because many of the fixes necessitate changes in legislative language and the passage of that language through Congress, political capital must first be formed and then used. And since political polarization in the United States has increased in the past decade, strong arguments must be made to justify bipartisan action. This challenge can be overcome, but more work needs to be done to show the enormous value to the nation of improving its nuclear regulatory regime.

Luckily, many of the technical and engineering solutions to the current state of the nuclear power industry were initially developed and tested in decades past and are still available if market forces are allowed to function as Congress initially intended. Many of these technologies offered greater safety, but a combination of U.S. military decisions and the need to simplify the nuclear reactor fleet in the 1960s and 1970s caused light-water and boiling-water reactor technology to be disproportionally selected by the U.S. Navy and industry. In light of this, the U.S. nuclear fleet is in need of updating to bring it into the 21st century and to this end, the following sections outline the steps that should be taken to do so.

Develop and Fund Advanced Nuclear Reactor Technologies

Some reactor designs from the 1950s and 1960s, combined with substantial improvements in computer power and automation, can now be built at a much smaller size than current reactor technology and thus can also be built with less capital outlay. They can even be fabricated in a factory setting where tighter quality control assurances are available. Most of these qualify as Generation IV reactors with passive safety systems that dramatically lower or perhaps eliminate the possibility of a core meltdown. Some of these new technologies include:

Small Modular Reactor (SMR). Small Modular Reactors are small enough in design to be brought to building sites already fully constructed. They are, therefore, much cheaper to build. Their modular, standardized design can be used for areas of demand that do not justify a full-fledged 600-1000-Megawatt (MW) power plant.[25]

Molten Salt Reactor (MSR). A Molten Salt Reactor uses a molten salt mixture as both the fuel and the primary coolant for the reactor. It runs "passively safe," which means it can be shut down without an operator interaction and without the threat of core meltdown and does not need an expensive containment system. Disadvantages involve the risk of corrosion and the proliferation risk of creating weapons-grade nuclear material if used as a breeder reactor.[26]

Sodium Fast Reactor (SFR). The SFR's main advantage is that it can burn spent uranium and plutonium. It can also operate at lower pressurization because sodium has a much higher boiling point than water and also does not corrode steel reactor parts. Disadvantages include that liquid sodium burns when in contact with air and explodes when in contact with water.[27]

Lead Fast Reactor (LFR). An LFR operates in a similar manner to sodium-cooled fast reactors but uses lead instead of sodium. This type of reactor does not need refueling. Instead, the entire core can be replaced after 15-20 years of operation.[28] These reactors run "passively safe" because the liquid lead-bismuth alloy it uses cannot explode and, in the event of a leak, quickly solidifies, improving safety.

High Temperatures Gas Reactor (HTR). An HTR uses a graphite-moderated core and can use helium or other gases as the coolant. The reactor is "passively safe" because its design allows it to shut down without operator interaction and its fuel temperatures remain below design limits even when there is a loss of cooling.

Advances in this technology will need future investment by the DOE in test facilities, and funding should come through congressional appropriation. Given the public benefits of zero-carbon energy sources and the general belief that research and development spending is a proper role for government, funding support for new test reactors should be part of the federal government's continued cooperation with the industry.

25. "Small Reactor Designs," Nuclear Energy Institute, 2018. https://www.nei.org/Issues-Policy/New-Nuclear-Energy-Facilities/Small-Reactor-Designs.

26. Stephen Williams, "How Molten Salt Reactors Might Spell a Nuclear Energy Revolution," *ZME Science*, March 15, 2017. https://www.zmescience.com/ecology/what-is-molten-salt-reactor-424343.

27. Geert De Clercq, "Can Sodium Save Nuclear?", *Scientific American*, October 2014. https://www.scientificamerican.com/article/can-sodium-save-nuclear-power.

28. Idaho National Laboratory, "Lead-Cooled Fast Reactor (LFR) Fact Sheet," U.S. Dept. of Energy, 2018. http://www4vip.inl.gov/research/lead-cooled-fast-reactor.

Expand research and roll-out of Accident Tolerant Fuels

While there are facilities in the United States that are available to test Accident Tolerant Fuels (ATF), there is no fast-spectrum test reactor to test advanced fuels intended for non-light-water advanced reactors. For this reason, a related avenue integral to the success of expanding ANRs is more research and roll-out of ATF. These fuels offer enhanced safety, which makes nuclear power plants more efficient to operate and gives operators additional coping time to deal with unplanned events. The impetus for the industry's Research and Development program on ATF was, in part, created by the 2011 Fukushima accident, as Congress pushed the industry to find ways to increase reactor resiliency if "beyond design-basis events" occurred.[29]

Language in the 2012 Appropriations Bill directed the Department of Energy to spend resources "to give priority to developing enhanced fuels and cladding[30] for light water reactors" and urged that a "special technical emphasis and funding priority be given to activities aimed at the development and near-term qualification of meltdown-resistant, accident-tolerant nuclear fuels that would enhance the safety of present and future generations of Light Water Reactors."[31]

In December 2017, the NRC launched a draft proposal to regulate new accident-tolerant fuels after fuel vendors—largely in coordination with the DOE—began seeking approval for a number of new fuel designs. These include:

Chromium-coated claddings. Chromium is coated over the zirconium-based alloys used throughout light-water reactor nuclear systems to reduce hydrogen production, increase oxidation resistance, and improve wear resistance and mechanical behavior.

Chromia-doped Uranium. The introduction of chromium oxide into the uranium dioxide fuel reduces fission gas production, improves fission gas retention and provides enhanced pellet-cladding interaction resistance.

FeCrAl cladding. Iron-chromium-aluminum (FeCrAl) cladding reduces hydrogen production and corrosion while improving wear resistance and mechanical behavior.

SiC cladding. Silicon carbide (SiC), which is being pursued in both a fully-ceramic silicon carbide cladding and hybrid silicon carbide-metal cladding form, takes advantage of its high melting point and low oxidation rate.[32] The SiC cladding reduces hydrogen production and provides improved mechanical behavior at elevated temperatures compared to zirconium cladding.

U3Si2 pellets. Uranium silicide pellets have higher uranium density and thermal conductivity than the current UO2 pellets.

Metallic Uranium Alloy fuel. New metallic uranium alloy fuel in a helical-cruciform geometry[33] increases surface area for higher heat conductivity and lowers the temperature of the fuel.[34]

While the NRC's current preparation for ATF licensing is focused on LWR fuel for the existing Gen II fleet, there are some synergies between ATF fuel development and safety qualifications for some types of advanced reactor designs. This is because developing licensing mechanisms for new fuel and cladding concepts will benefit advanced reactor fuel technology, the designs of which differ from the current uranium oxide fuel assemblies common in Gen II plants. Many advanced reactor designs require higher enrichment and different fuel forms than those used by the current reactor fleet. These new technologies would ultimately fulfill the promises made in the 2012 Appropriations Bill to improve the safety of Gen II reactor fuels and would help rebuild a fuel cycle infrastructure to help deploy advanced reactors by the 2020s.

Create a new regulatory infrastructure for future reactors

Many in the nuclear industry are interested in leveraging the NRC's draft new nuclear fuel proposal into a larger framework that ends the unfortunate "chicken and egg" dynamic of the past decade. The industry claims it wants to build new prototype advanced reactors and test reactors through which to test new fuel regimes and technologies but feels stymied by the NRC's reluctance to promulgate new regulations. Meanwhile, the NRC argues that the agency is resource constrained and struggles to create standards in the absence of a "demand signal" from industry users, due in part to the requirement that 90% of the NRC's operating

29. Martin Ševeček et al., "Development of Chromium Cold-Spray Coated Fuel Cladding with Enhanced Accident Tolerance," *Nuclear Energy and Technology* 50:2 (March 2018), pp. 229-36. https://www.sciencedirect.com/science/article/pii/S1738573317307283.

30. Current fuel technology uses uranium dioxide pellets that are stacked and filled into sealed tubes that separate the reactor coolant from nuclear fuel pellets. These tubes are called "cladding" in nuclear parlance.

31. John Carmack, "Update on U.S. Accident Tolerant Fuel Program," *Nuclear Regulatory Commission Briefing*, Feb. 9, 2016. https://www.nrc.gov/reading-rm/doc-collections/commission/slides/2016/20160620/carmack-20160620.pdf.

32. Shannon Bragg-Sitton et al., "Studying silicon carbide for nuclear fuel cladding" Nuclear Engineering International, April 19, 2013. http://www.neimagazine.com/features/featurestudying-silicon-carbide-for-nuclear-fuel-cladding.

33. This resembles a ridged piece of licorice.

34. Richard Martin, "This New Fuel Could Make Nuclear Power Cheaper and Safer," *MIT Technology Review*, March 31, 2016. https://www.technologyreview.com/s/601121/this-new-fuel-could-make-nuclear-power-safer-and-cheaper.

funds are derived by current licensees and not from federal appropriations.[35]

This "Catch-22" could be solved if the NRC expands its recent embarkation of a new form of evaluation of non-LWR design applications. To this end, the agency's executive director for operations said in recent congressional testimony that the NRC was implementing a "small core team" review approach that would produce a more cost-effective evaluation of non-LWR designs.[36]

But the timeframe for the process is still too slow. Under the NRC's current schedule, the full-blown operation of a regulatory framework for the new, non-LWR designs necessary for the deployment of advanced nuclear reactors is not expected to occur until at least the late 2020s.

A way to combat this noncompetitive situation is to set up a separate regulatory process for non-LWR reactors by moving the Office of New Reactors out from under the current directorate for Reactor and Preparedness Program and creating a directorate for New Reactors.[37] The splitting off of advanced reactor licensing would allow a new deputy executive director to build up a separated staff and focus on furthering risk-informed regulatory processes.

An example of how a new, risk-informed licensing framework could work should take into account the factory-build nature of many of the proposed SMR nuclear steam supply (NSS) systems. The factory construction of an entire NSS system would allow construction processes to be much better controlled and able to use expert staff to make exact copies of reactors. In turn, this would likely result in increased quality and fewer cost overruns. It would also allow regulators to station staff within fabrication plants.

This segregation of the manufacturing of nuclear and non-nuclear components would make NQA-1 rules both less common and more relevant and would alleviate the high paperwork costs and difficulty in maintaining a certified workforce. The NRC already has the ability to allow a utility or designer to individually risk inform each component through the current Title 10 CFR 50.69 regulations, but this authority is currently used too narrowly.[38]

For on-site construction that involves non-nuclear supply materials, the industry could use the more typical set of industrial quality requirements (such as ISO-9000). Presumably, quality control for components used in bridges, skyscrapers, chemical plants and oil refineries are sufficient for parts of the plant that lay outside the quarantined NSSS.[39] Meeting "nuclear grade" fabrication requirements for non-nuclear components is one of the industry's most cited reasons for cost overruns at nuclear projects.[40]

By better focusing regulatory attention on the highest risk technologies, the NRC would be better able to budget resources and ease the burden on private industry by cutting the cost of procuring non-nuclear-related materials from a much larger marketplace of potential vendors.

Adjust Regulations for New Nuclear Fuels

Perhaps the most immediate need for action explained in this paper is to focus on the development of High Assay Low Enriched Uranium (HALEU), which is uranium fuel manufactured up to 20 percent enrichment. The current nuclear fuel cycle infrastructure for use in Generation II and III reactors uses low-enriched uranium with uranium-235 levels of less than 5 percent. The higher percentage enrichment allows for higher burn-up rates and better plant economics in Gen IV reactors and thus U.S. companies are now at a disadvantage against foreign competitors and in export markets if they cannot supply HALEU to future Gen IV reactors.[41]

Currently, the only U.S. source of uranium enrichment available is to down-blend government-owned, high-enriched uranium (HEU) in surplus weapons or reprocessed naval reactor fuel at government facilities in Idaho and Tennessee.[42] To establish a new HALEU fuel cycle in the immediate future, financial and technical support from the Department of Energy is necessary. Additional engineering and design changes need to take place at several U.S. nuclear fuel fabrication facilities, including security modifications, before

35. Tom Boyce, "NRC Strategy and Priorities," U.S. Nuclear Regulatory Commission, April 26, 2017. https://www.nrc.gov/public-involve/conference-symposia/adv-rx-non-lwr-ws/2017/boyce.pdf

36. Victor M. McCree, "Statement of Victor M. McCree Executive Director for Operations U.S. Nuclear Regulatory Commission before the House Committee on Energy and Commerce Subcommittee on Energy," Feb. 8, 2018. http://docs.house.gov/meetings/IF/IF03/20180206/106823/HHRG-115-IF03-Wstate-McCreeV-20180206.pdf.

37. "Organizational Chart," U.S. Nuclear Regulatory Commission, 2018. https://www.nrc.gov/about-nrc/organization/nrcorg.pdf.

38. "Risk-Informed Categorization and Treatment of Structures, Systems and Components for Nuclear Power Reactors," 10 CFR 50.69, *Regulatory Analysis*, November 2004. https://www.federalregister.gov/documents/2004/11/22/04-25665/risk-informed-categorization-and-treatment-of-structures-systems-and-components-for-nuclear-power.

39. See, e.g., Hopf. http://ansnuclearcafe.org/2013/01/24/how-can-nuclear-construction-costs-be-reduced/#sthash.AuO9lPJY.dpbs.

40. Ibid.

41. See, e.g., Michael Tschiltz et al., "Addressing the Challenges with Establishing the Infrastructure for the Front-End of the Fuel Cycle for Advanced Reactors," Nuclear Energy Institute, January 2018. https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/white-paper-advanced-fuel-cycle-infrastructure-201801.pdf.

42. Ibid. p. 3.

HALEU fuel can be introduced into these facilities. In January 2017, the Department of Energy began a procurement process to secure a new domestic uranium enrichment capability that would have HALEU for research reactors by 2030 and test reactors by roughly 2025, but the authorization of legislation and funding must first occur.[43]

According to the Nuclear Energy Institute, licensing a HALEU facility must occur simultaneously with other build-outs of new nuclear infrastructure,[44] which makes action during the current legislative cycle vital. If Congress and the administration do not move quickly to build up HALEU infrastructure and strategic stocks, U.S. operators will simply buy the enriched uranium from China and Russia. This will create a scenario where the domestic industry will be dependent on critical supplies from major geopolitical adversaries.

Utilize purchase power agreements

One of the most important missing elements for emergent nuclear technology companies is the ability to sign long-term purchase power agreements (PPA). By providing a contractual commitment to purchase power from a plant, business risk for the project is lowered, thus improving the financial profile of the project for private investors.[45]

The federal government has used PPAs in the past to encourage domestic deployment of clean energy technology. In 2015, the U.S. Navy announced a 25-year, 150 MW purchase of solar energy from a developer in Arizona for 14 naval installations in California.[46] But PPAs with federal agencies are more difficult to implement than they should be. For example, generally, federal agencies (such as the 17 National Laboratories) are limited by the General Services Administration (GSA) from entering into PPAs beyond ten years. However, this is not long enough to help with the high up-front development costs for SMRs.[47] Under certain circumstances, the Department of Defense can purchase power up to 30 years, and federal agencies within the Western Area Power Administration (WAPA) can sometimes purchase power for 40 years.

To expand the contracting options to other federal agencies in the rest of the country, legislation would need to be enacted to free agencies from current GSA rules. Given the hundreds of major Defense Department and other federal installations around the United States, it is possible that the combination of carbon-free baseload power, modularity, small land requirements and improved energy security could give federal users reasons other than cost to contract with SMRs.

Relax export control regulations

In the same way regulatory culture at the NRC has slowed the industry's ability to adapt to market conditions, the rules controlled by the DOE regarding the export of unclassified nuclear technology have undermined U.S. industry participation in the market.

The market for nuclear exports is large—as much as 200 gigawatts of new nuclear energy capacity—which creates major opportunities but also major concerns for the global nonproliferation regime.[48]

Since the 1990s, increased competition from nuclear industries in Russia, China, France and South Korea has changed the nature of the international market. However, the export license structure remains based on 1970s agency thinking of the United States as the sole provider of nuclear materials. A watershed moment that should have served as a sign of things to come, however, was the South Korean nuclear industry's win in 2009 of $20 billion to build a 1,400 Megawatt nuclear plant in the United Arab Emirates. This showed the strengths of Korean technology transfer and the options countries have when seeking to build up a nascent nuclear power industry.[49]

Meanwhile, U.S. industry has pointed out changes in the way the Department of Energy grants specific authorizations for nuclear exports that have undermined our own ability to compete. In the 1990s, special authorizations to share proprietary information on reactor designs took an average of 130 days from receipt of the application by the DOE to final approval by the Secretary of Energy.[50] Since 2005, a changed license processing structure has made the U.S. Energy Secretary sign off all elements of the application. This has led to a dramatic increase in the amount of time it takes to process

43. Ibid. p. 3.

44. Office of Nuclear Energy, "Purchasing Power Produced by Small Modular Reactors: Federal Agency Options," U.S. Dept. of Energy, January 2017, p. 7. https://www.energy.gov/ne/downloads/purchasing-power-produced-small-modular-reactors-federal-agency-options.

45. Ibid. p. 15.

46. Matt Bowen, "Enabling Nuclear Innovation Leading on SMRs," Nuclear Innovation Alliance, October 2017. https://www.nuclearinnovationalliance.org/leadingonsmrs.

47. "Purchasing Power Produced by Small Modular Reactors," p. 6. https://www.energy.gov/ne/downloads/purchasing-power-produced-small-modular-reactors-federal-agency-options.

48. See, e.g., "International Energy Outlook 2017," Report No. DOE-EIA-0484, U.S. Energy Information Administration, Sept. 14, 2017. https://www.eia.gov/outlooks/ieo/exec_summ.php.

49. "UAE Picks Korea as Nuclear Partner," *World Nuclear News*, Dec. 29, 2009. http://www.world-nuclear-news.org/NN_UAE_picks_Korea_as_nuclear_partner_2812091.html.

50. Matt Bowen, "Enabling Nuclear Innovation: Part 810 Reform," Nuclear Innovation Alliance, December 2017, p. 2. https://www.nuclearinnovationalliance.org/part810reform.

export control applications to an average of close to 400 days. In some cases, it can exceed 600.[51]

The length of time foreign competitors, such as the Republic of Korea, Russia and Japan, take to process export control applications is 15 days, 25-45 days and 90 days, respectively.[52] This application-processing gap between competing nuclear energy powers has become so large that it now presents a major disincentive to foreign countries and companies interested in building up a nuclear industry.

Interestingly, the NRC has a parallel regulatory process for the export of nuclear equipment that is more efficient and effective by taking a more risk-informed view and offering a general license for minor reactor components to countries "sharing U.S. nonproliferation goals."[53] Essentially all nations with the exception of China, India and Russia are considered authorized under Part 810. Using similar criteria to the NRC would allow the Energy Department to design a faster approval pathway for light-water reactor technology.[54]

Enact legislative reforms

There are currently four bipartisan measures that have begun to move through the legislative process. All four bills deal in some way with challenges related to the build-out of advanced nuclear reactors:

Nuclear Energy Innovation Capabilities Act of 2017 (H.R. 431). Sponsored by Congressman Randy Weber (R-Texas) with 17 co-sponsors, the bill would prioritize research and development that supports private sector investment in advanced nuclear technologies.[55] It would also allow private companies to partner with national labs and require the DOE to produce a ten-year plan for prioritizing nuclear R&D programs.

Nuclear Energy Innovation and Modernization Act (S. 512). The bill is sponsored by Senator John Barrasso (R-Wyo.) and has 17 bipartisan co-sponsors. It would reform the funding of industry fees used to operate the NRC. By the end of 2024, the bill also aims to push the NRC to develop a new technology-neutral regulatory framework that encourages the development of advanced nuclear reactors and caps the annual license fee on operating reactors to 2015 levels plus inflation.[56]

Advanced Nuclear Technology Development Act of 2017 (H.R. 590). Sponsored by Rep. Robert Latta (R-Ohio), H.R. 590 is similar to S. 512 in that it directs the NRC to develop a regulatory framework specifically for advanced nuclear reactors and to cap some license fees. It passed through the House in January 2017.

Nuclear Energy Innovation Capabilities Act (S. 97). Sponsored by Senator Mike Crapo (R-Idaho) as a sister bill to H.R. 431, the bill was unanimously approved by a voice vote on March 7, 2018. The legislation authorizes construction of a fast-neutron-source reactor that allows for advanced nuclear fuel testing and for the creation of a National Reactor Innovation Center. It also gives the private sector permission to build and operate reactor prototypes at DOE sites.[57]

CONCLUSION

Due to low long-term natural gas prices, flat electrical demand growth and public fears caused by the potential for Fukushima-type accidents, the development of a new generation of safer, less expensive nuclear reactors has been harder than anticipated. What was considered a possible "renaissance" for nuclear power became more of a "fin de siècle," as large cost overruns and corporate bankruptcies undermined the confidence of investors and customers alike.

As evidenced herein, lengthy and ambiguous permitting and regulating processes at the federal level have created artificial barriers to entry that have undermined capital investment in the nuclear space for more than a decade. However, these regulatory burdens can be lightened by a combination of executive branch and legislative action. In any event, it is imperative that the industry is allowed to move forward with the design, testing and commercialization of Generation IV reactors, the fundamental designs of which are safer than the 99 reactors in current operation at more than 60 sites around the United States.[58]

It is important to note that the nuclear proliferation aspects of nuclear power should never be dismissed and the challenge is directly linked to the wellbeing of the U.S. nuclear industry. Just as all attempts in fables fail to "put the genie back in the bottle," so too, will any effort to halt the spread of nuclear science and engineering. Now that we have unleashed it, it will be put to use by competing economies for various reasons regardless of U.S. participation in the global marketplace.

51. Ibid., pp. 2-3.

52. Ibid., p. 3.

53. Ibid., p. 4.

54. Ibid., p. 4.

55. "Committee introduces nuclear R & D bill," *Daily Energy Insider*, Jan. 16, 2017. https://dailyenergyinsider.com/news/2919-committee-introduces-nuclear-rd-bill.

56. S. 512 "Nuclear Energy Innovation and Modernization Act." https://www.congress.gov/bill/115th-congress/senate-bill/512.

57. Chris Charles, "Senate Bill Looks to Speed Advanced Reactors Market," Nuclear Energy Institute, March 7, 2018. https://www.nei.org/news/2018/senate-bill-speed-advanced-reactors-to-market.

58. "How many nuclear power plants are in the United States and where are they located?", Energy Information Administration, Aug. 15, 2017. https://www.eia.gov/tools/faqs/faq.php?id=207&t=3.

As noted, China and Russia have been the nuclear states most responsible for nuclear proliferation in the past four decades. These two nations were recently highlighted in the U.S. Defense Department's National Strategy Document as highly "revanchist" states and they will be the chief participants in a "great power competition" against the United States over the coming decades.[59]

To abandon the field of nuclear energy to both countries would likely undermine the incredible efforts and relative successes of U.S. non-proliferation policy since the 1950s and with intolerable consequences.

In the same way, any attempt at deep-carbonization of the global economy (e.g., an 80 percent cut in annual greenhouse gas emissions from 1990 levels by 2050) will likely fail without the major expansion of nuclear power.[60]

A robust, profitable U.S. nuclear energy industry could forestall both of these issues indefinitely. Further, any future success of U.S. nuclear exports to currently unmet markets would create a powerful link between those purchasing economies and the U.S. non-proliferation regime that would last decades or longer. The removal of regulatory barriers to new nuclear technology is thus paramount for both a vibrant export economy and a safer world. With a small push from legislation and a new spirit within the industry's most important regulatory bodies, a new day could dawn for the U.S. nuclear industry and the wider world.

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59. "Summary of the 2018 National Defense Strategy of the United States of America," U.S. Dept. of Defense, 2018. https://www.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

60. See, e.g., John Timmer, "What might have been: US introduces plan for 'deep decarbonization,'" *Ars Technica*, Nov. 17, 2016. https://arstechnica.com/science/2016/11/what-might-have-been-us-introduces-plan-for-deep-decarbonization.