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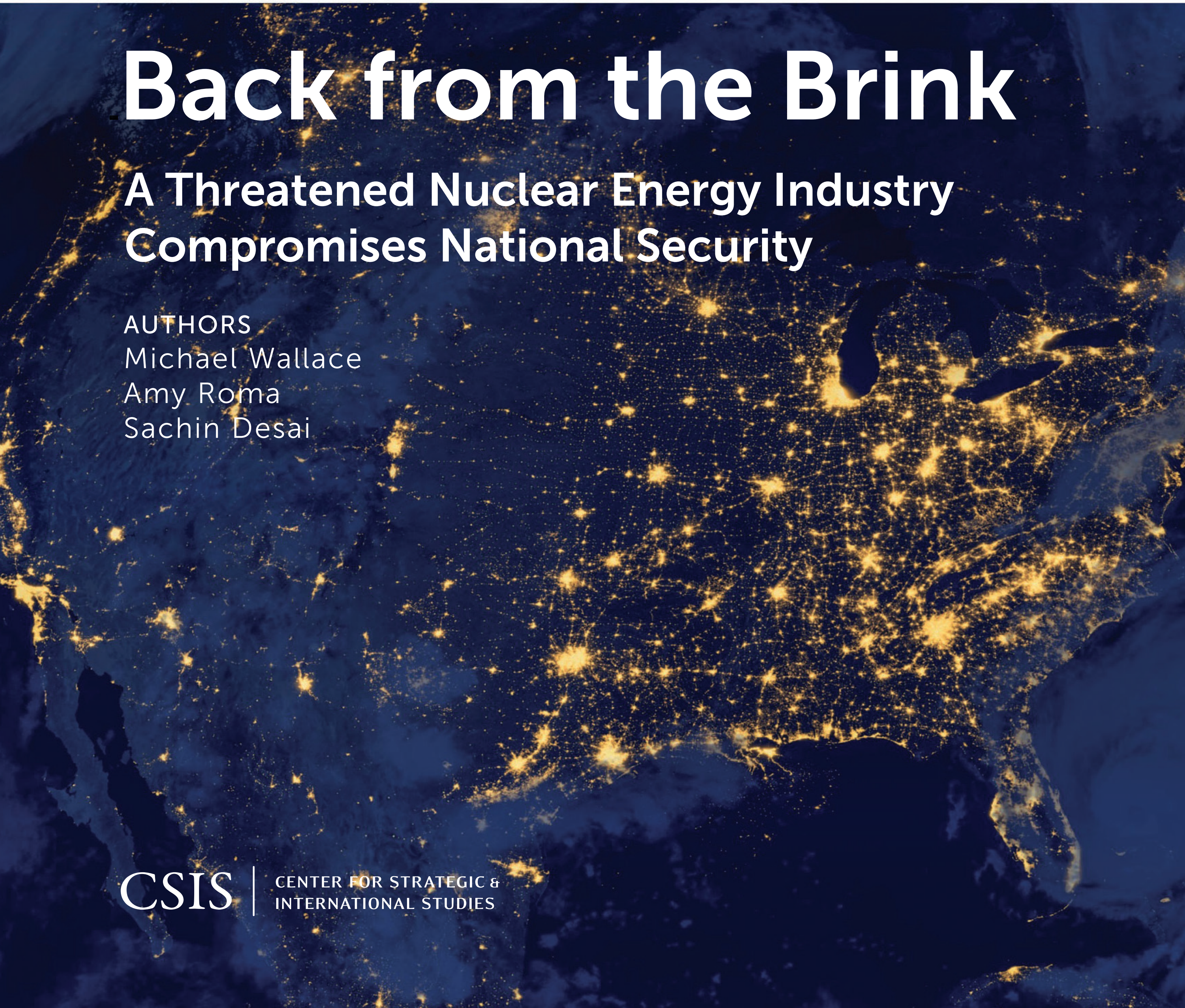

Back from the Brink

A Threatened Nuclear Energy Industry Compromises National Security

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Amy Roma
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Executive Summary: Critical Takeaways and Path Forward

The U.S. commercial nuclear energy industry helps the U.S. government meet several key national security objectives. But the industry is struggling to survive. We are not the first to say this and we will not be the last.

We are also not the first to call for U.S. government support for this struggling industry—but this call to action is different. We are urging U.S. government action—not with the focus of protecting the commercial sector, but with a focus to protect *U.S. government interests* impacted by the decline in the commercial nuclear energy sector. This is a key distinction and warrants attention at the highest level of government. This paper is not intended for those in the nuclear energy industry. They know the issues. It is intended for the U.S. government and the U.S. public—to explain the reasons *why* U.S. government action is critical at this moment, and to explain *how* we can move forward in a manner that best protects our country's national security.

But what are these national security objectives and how are U.S. government and national security interests undermined by a decline in the commercial nuclear energy sector? In this paper we explain the critical importance of the U.S. commercial nuclear energy industry in support of U.S. defense, research, economics, geopolitics, and international nonproliferation. We walk through how the U.S. commercial nuclear energy industry arose out of and with the support of the U.S. government—and how President Eisenhower's reasons for bringing nuclear energy to the world in the 1950s are the very same reasons that the United States needs to continue to do so today. We unravel the web of interconnections between the commercial nuclear energy industry and achieving U.S. government and national security goals. And we explain the impact that a declining commercial nuclear energy sector has on achieving those crucial goals.

Moreover, we set forth a recommended *path forward* to come "back from the brink" and preserve critical commercial nuclear energy sector assets—including technology, knowhow, people, and influence—before they are lost forever, and U.S. national security is damaged as a result.

This industry must survive—and it can—if the U.S. government and private industry work together, recognizing the government and civilian *integrated nuclear infrastructure* moving forward. Notably, the response must be *U.S. government led* to take the approach that is *best for the country*, rather than any particular company or technology. We recommend *five core U.S.-government-led actions* to move forward that focus.

The critical takeaways from this paper and our recommended path forward are summarized below.

United States' Investment in Nuclear Energy:

- Today's commercial nuclear energy industry was born out of a public-private partnership, and it has made tremendous progress when the government and private sector have worked together. U.S. nuclear reactor designs—built by U.S. contractors—are the foundation of safe and secure nuclear energy plants built around the world.

- The United States' technological dominance in nuclear energy has been the foundation of the international nonproliferation regime that has been so successful over the past 60 years.

- And, for as many reactors as there are on land, there are just as many in our submarines and aircraft carriers, enabling us to project power far from our shores. This capability is tied to the fate of the commercial nuclear sector—its nuclear fuel cycle, vendor base, and engineering talent.

Where the Nuclear Industry Is Now:

- Despite its many contributions to our industrial base, technology, and defense prowess, and worldwide proliferation success, the commercial nuclear energy industry in the United States is dying.

- Roughly half of the 99 U.S. nuclear power plants are facing economic stresses, and potential premature shutdown, due to current energy market structures. The rest of the U.S. fleet is not fairing much better as they near the end of their operating lives.

- Around the world, the U.S. view is also bleak. The vast majority of nuclear power plants now under construction—approximately 70 percent—are of Russian or Chinese origin. And with these foreign designs comes foreign influence and a "100 year" relationship (for the operating life of the facility) with the host country.

Why Is This and Why Does It Matter?

- Critical benefits of U.S. nuclear power plants and the U.S. industry currently go largely uncompensated and unrecognized, and the U.S. nuclear export control regime is dated and restrictive.

- The benefits of commercial nuclear power reach beyond the huge amounts of carbon-free baseload power these plants generate: United States' dominance in nuclear energy has allowed the U.S government to set best practices for nuclear nonproliferation around the globe, exert geopolitical influence, and support our naval propulsion program and nuclear weapons program. The important dividends nuclear power provides to the global safety and security is threatened when the industry is threatened.

- For now, fortunately, the United States leads in the next generation of advanced reactor designs, which tend to be smaller, scalable, safer, and more secure than their large-scale cousins. These designs include nuclear fission and fusion, and present huge potential, such as the capability to generate power for 20 years without refueling, provide off-grid power for remote communities and military installations, use nuclear waste as fuel, power space vehicles and stations, and propel a faster fleet of ships using more powerful weapons—including nuclear submarines and aircraft carriers—across the world's oceans.

- There are about 75 domestic ventures in these next-generation nuclear technologies, and that number keeps growing. The United States is currently well positioned to deliver on this new technology but without strong government support for this nascent industry, it is likely to yield leadership to China and Russia.

Where the Nuclear Industry Is Headed—a 2050 Outlook:

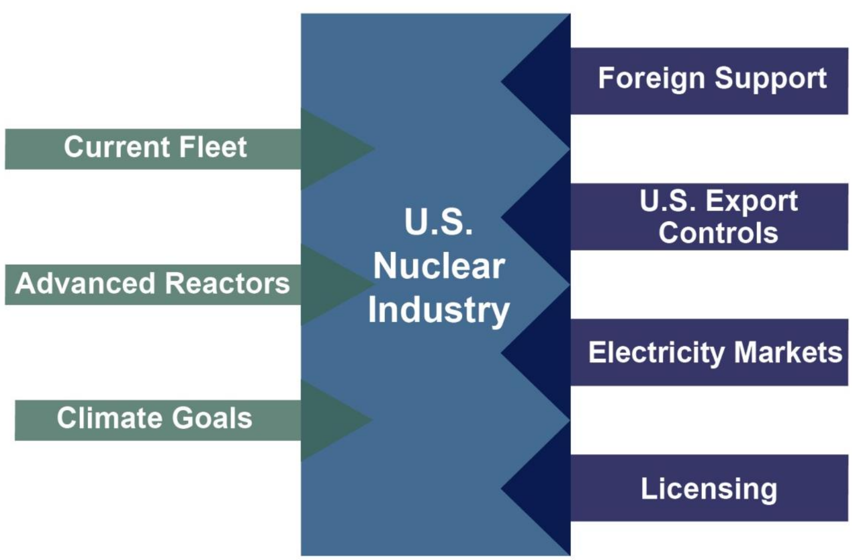
- Under current conditions, the entire U.S. merchant fleet could be out of operation within the next 20 years or so.

- Even if some plants can renew their licenses and remain in operation past 2050, the loss of the other plants would make it harder for suppliers to stay in the nuclear business. The loss of key suppliers would make it harder for the current aging fleet to stay operating. A vicious cycle of shutdowns, followed by suppliers exiting the business, presents a real threat that *all currently operating nuclear plants* in the United States will be shut down by 2050.

- Abroad, the International Energy Agency expects that the world's nuclear capacity could *double* by 2050, and it is growing in some particularly strategic locations: Asia, the Middle East, and North Africa. Yet, under current trends, the vast majority of these plants constructed will be Russian or Chinese. The United States will not only lose out on the economic benefits of these projects, but its safety and security standards will not be implemented, and its nonproliferation voice and geopolitical influence will be weakened as a result of its global absence.

- By 2050, the United States will also lose our leadership in the next wave of nuclear technologies. With a diminishing commercial nuclear power sector, and without strong government support for the nascent advanced reactor industry, ventures will languish or move overseas for further development.

Figure 1: U.S. Nuclear Industry – Long-Term Pressures



- The headwinds facing the industry are immense, and they are largely government-centered. Left alone, and unable to compete for new projects abroad—where nuclear growth is active—against government-backed Russian and Chinese competitors, we will lose the mantle of nuclear leadership.

Recommendations:

(1) Form a Nuclear Leadership Program as a central government resource to kick-start a new public-private partnership to grow the U.S. nuclear power industry. This new U.S. body should centralize the multitude of U.S. agencies that work with the nuclear industry. While working with private-sector support, the program should be U.S. government led.

(2) Form a Nuclear Energy Advisory Council, generally composed of current and former business and engineering executives, and U.S. government leaders, to advise the president and National Security Council on the commercial nuclear industry, mirrored after the National Infrastructure Advisory Council (NIAC).

(3) Use the Nuclear Leadership Program and the Nuclear Energy Advisory Council to Drive Forward Critical *Domestic* Nuclear Energy Industry Policy Changes: These include (i) supporting the completion of our present nuclear projects under construction, (ii) readying the next wave of U.S.-origin advanced reactors, and (iii) developing a "ready reserve" option for some U.S. stressed nuclear plants.

(4) Use the Nuclear Leadership Program and the Nuclear Energy Advisory Council to Drive Forward Important *International* Nuclear Energy Industry Policy Changes: These include (i) creating a framework for a joint "USA, Inc." public-private partnership for international new-build nuclear projects, and (ii) marketing the benefits of the U.S. regulatory framework and nonproliferation regime abroad.

(5) Look at the Saudi Nuclear New-Build RFP as a Potential Turnaround Opportunity and Test Case. The U.S. industry has an opportunity to regain some of its lost ground with one of the biggest potential nuclear new-build opportunities in the world—a 16-reactor project currently contemplated in Saudi Arabia. The U.S. government will need to work together and with industry to succeed here if the project moves forward. The United States also needs to align to resolve the underlying policy issues associated with the project. This cooperation between government and industry—to operate as "USA, Inc."—can serve as a model and test case for future bids around the world.

The U.S. commercial industry is a national resource facing a national crisis. The time is right to engage in a new public-private partnership to rebuild the nuclear energy promise made to the U.S. public and to the world at the advent of nuclear power, and make the United States safer and stronger in the process.

01 United States' Investment in Nuclear Power Has Made the World Safer

The commercial nuclear power industry and U.S. government share a long history, and one that is intertwined with the global struggle for peace and democracy. Remarkably, the same arguments used to support the U.S. government's decision to bring nuclear power to the world in the 1950s are still just as relevant today—for the United States to bring power to the world. And if we do not, another country will, undermining U.S. influence, safety, and nonproliferation.

The United States' civilian nuclear sector got its start from the U.S. government. Our first civilian nuclear power project to supply electricity to the grid, the Shippingport Atomic Power Station, was a public-private partnership, based on a military reactor design coming from the U.S. national laboratories.[1] And, that civilian power project was quick to return national security benefits.

Early on, the U.S. government understood that its monopoly on nuclear weapons and nuclear technology was short lived. Four years after the United States used nuclear technology to end the Second World War, the Soviet Union conducted its first nuclear test explosion (1949), followed by the United Kingdom (1952), France (1960), and China (1964).[2] In particular, the Soviet Union was catching up with the United States, and could share the information with other countries, *to benefit its own geopolitical aims*.[3] A theme we see repeating itself today.

Along with its military uses, the U.S. government in the 1950s saw the value that peaceful use of nuclear power could bring to the world, and also the threats that would confront and arise from such peaceful use if the United States did not take the lead role in this exchange.[4] In response, in his December 1953 Atoms for Peace speech, President Dwight D. Eisenhower presented a bold nuclear initiative to the United Nations: *The U.S. would share its nuclear energy technology with other nations if the receiving nation committed to not use the technology to develop nuclear weapons*.[5]

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[1] Including the Bettis Atomic Power Laboratory, Oak Ridge National Laboratory, Argonne National Laboratory, and what is now the Idaho National Laboratory. *See* C. Clayton, "The Shippingport Pressurized Water Reactor and Light Water Breeder Reactor," Westinghouse Report WAPD-T-3007, 1993, http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/25/025/25025940.pdf; Argonne National Laboratory webpage, "Reactors designed by Argonne National Laboratory," https://www.ne.anl.gov/About/reactors/lwr3.shtml; Argonne National Laboratory News Release, January 21 1996, https://www.ne.anl.gov/About/hn/news960121.shtml.

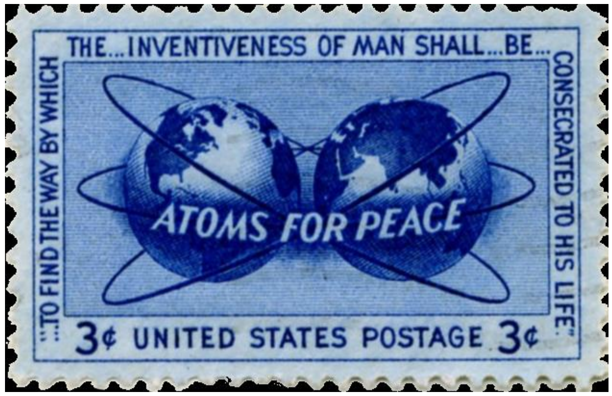
[2] Arms Control Association, "Factsheet on Nuclear Weapons: Who Has What," last updated March 2018, https://www.armscontrol.org/factsheets/Nuclearweaponswhohaswhat.

[3] Peter Lavoy, "Arms Control Today, The Enduring Effects of Atoms for Peace," Arms Control Association, December 1, 2003, https://www.armscontrol.org/act/2003_12/Lavoy. "U.S. officials feared that the Kremlin would score a huge propaganda victory, especially in the developing world, if the United States did not alter its own nuclear export policy."

[4] Ibid.

[5] Address by Mr. Dwight D. Eisenhower, President of the United States of America, to the 470th Plenary Meeting of the United Nations General Assembly, December 8, 1953, https://www.iaea.org/about/history/atoms-for-peace-speech.

Atoms for Peace U.S. postage stamp (1955)



President Eisenhower's historic move has paid dividends for decades. With the United States at the forefront, the Atoms for Peace policy gave rise to many of the most important elements of today's nuclear world.

The direct and indirect benefits to national security from the domestic nuclear energy industry are (at least) six-fold: (a) the global adoption of U.S. reactor designs that are safety-focused; (b) a global nuclear power community focused on safety and security; (c) the world's most powerful navy; (d) keeping the U.S. at the cutting edge of nuclear innovation; (e) an effective nuclear deterrence that is an ultimate guarantor of U.S. safety; and (f) a domestic high-technology industry supporting U.S. jobs, influence abroad, and other endeavors.

We walk through each of these benefits in turn below.

The Global Adoption of U.S. Reactor Designs That Are Safety-Focused

Today, there are some 440 operating nuclear power reactors. The International Energy Agency (IEA) expects that the world's nuclear capacity could *double* by 2050, as developing economies face growing energy demand and more nations turn toward low-carbon energy sources to meet emissions goals and combat climate change.[6] And the demand is growing in particularly strategic locations, including Asia, the Middle East, and North Africa.

When the U.S. made the decision to share its nuclear power technology following President Eisenhower's Atoms for Peace speech more than 60 years ago, it was able to promote reactor designs and standards that favored nuclear safety and security, which has made nuclear power the safest of all energy sources around the world.[7] *And, fortunately, because of the historical*

[6] International Energy Agency, "World Energy Outlook 2017, Tracking Progress: Nuclear Power," May 2017, https://www.iea.org/etp/tracking2017/nuclearpower/; World Nuclear Association, "IEA: Nuclear generation to double to meet sustainable development goals," November 2017, http://www.world-nuclear.org/press/press-statements/iea-nuclear-generation-to-double-to-meet-sustainab.aspx.

[7] There has never been a major accident at a U.S. nuclear power plant that resulted in a significant release of radiation to the environment. The number of U.S. deaths from direct nuclear power production can be argued to be zero. Few or no other form of power generation can claim that mantle. Scott Montgomery and Thomas Graham, Jr., *Seeing the Light: The Case for Nuclear Power in the 21st Century* (Cambridge University Press, September 2017), 9.

U.S. dominance in the world nuclear industry, these are the same designs and standards that most owners and operators of nuclear power plants in the world follow today.

The first civilian nuclear power project to supply electricity to the grid was the Shippingport reactor, in Shippingport, Pennsylvania. Construction of the Shippingport facility began in early 1954, soon after President Eisenhower's Atoms for Peace speech, and the reactor started to produce power for the grid in 1957. Just a few years before, in 1951, Congress authorized construction of the world's first nuclear-powered submarine, USS *Nautilus*, which was launched in early 1954. Both the Shippingport reactor design and the *Nautilus* reactor design came out of the U.S. national laboratories, both were constructed by Westinghouse, and both were developed under the leadership of Capt. Hyman Rickover, the father of the then-emerging U.S. nuclear Navy.

USS Nautilus during her initial sea trials, January 1955

Source: U.S. Navy

The light water reactor design that originated in the United States with the Shippingport project and *Nautilus* is now the design used in 80 percent of the 440 commercial nuclear reactors operating in more than 30 countries around the world.[8] Because the United States has led in

[8] Ibid., 95.

reactor design, many of these reactors are also directly based on U.S.-developed designs, or have key design features based on U.S. input. For example, China is building four of Westinghouse's AP1000 reactors, and it has a number of plants planned using the CAP1000 and CAP1400 designs, Chinese versions of Westinghouse's AP1000. South Korea also has constructed a number of Westinghouse-based plants, and its design, the APR-1400, draws on the Combustion Engineering/Westinghouse System 80+ design.[9] And Japan's new ABWR design was co-created by General Electric and Toshiba.

The seed of the U.S. safety-focused design foundation continues to spread, as South Korea has exported the APR-1400 to the United Arab Emirates, which is constructing four of these reactors, and China relentlessly continues to push its plans to export the Hualong One and CAP1400 reactors around the world. U.S. influence is aided by the fact that the U.S. domestic nuclear regulator, the U.S. Nuclear Regulatory Commission (NRC), has licensed and overseen over 130 commercial nuclear reactors, and nearly 50 research and test reactors. As the NRC has more collective experience than any other nuclear regulatory agency in the world,[10] other countries look to it when setting nuclear safety and security standards, whether using U.S. designs or developing their own, based on U.S. precedent. *To date, the United States has set the standards for "safety focused" design, construction, operations, and regulation around the world.*

A Global Nuclear Power Community Focused on Safety and Security

The United States has frequently used its technological dominance in nuclear energy to promote nonproliferation objectives worldwide. This started with the Non-Proliferation Treaty (NPT) in 1968. The NPT was a compromise agreement—countries gave up their ability to make nuclear weapons, because they sought access to nuclear expertise for peaceful uses of nuclear energy. Indeed, this compromise was at the foundation of the NPT. The NPT allowed the United States to take the lead in sharing its nuclear technology with the world—on the United States' terms. *And, in the years since the NPT's enactment—because the United States had the technological edge—the United States has been able to ask each country with whom it has worked to sign and enforce strict commitments on the sharing of nuclear technology (i.e., U.S. 123 Agreements);[11] adopt U.S. operational safety standards (e.g., those promulgated by the U.S. Institute of Nuclear Power Operations); and set forth a global fuel supply framework that reduces risk of proliferation (e.g., 2007 U.S. Assured Fuel Supply Program).[12]*

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[9] World Nuclear Association, "Nuclear Power in Korea" last updated December 2017, http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx.

[10] *See* Center for Strategic and International Studies report, *Ensuring Leadership in Nuclear Energy: A National Security Imperative*, June 2013, 25, https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/130614_RestoringUSLeadershipNuclearEnergy_WEB.pdf.

[11] National Nuclear Security Administration (NNSA), 123 Agreements, https://www.energy.gov/nnsa/missions/nonproliferation; *see, for example,* Text of U.S.-UAE 123 Agreement, 2009, http://www.nti.org/media/pdfs/StateandUAEPeacefulNucJan2009.pdf?_=1316627912.

[12] U.S. Department of Energy Press Release, "NNSA Announce Availability of Reserve Stockpile of Nuclear Power Reactor Fuel Material from Down-blending of Surplus Weapons-Usable Uranium," August 18, 2011; World Nuclear Association, "U.S. Nuclear Fuel Cycle," last updated June 2018, http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-fuel-cycle.aspx.

The success of the NPT and its affiliated agreements cannot be overstated. Despite certain failures, since the NPT has been signed there remain only a handful of countries that have developed nuclear weapons outside of the global nonproliferation framework, despite decades of globalization and the fact that the first nuclear weapon was developed about 75 years ago, around the same time as the first jet engine.

In short, the NPT has kept the world a safer place,[13] *but the NPT's success has relied on U.S. technological dominance.*

This following statement from the Center for Strategic and International Studies 2013 report, *Ensuring Leadership in Nuclear Energy: A National Security Imperative*, sums it up well:

> The desire to learn from U.S. regulatory and operational experiences is one of the factors that caused nations in the past to want to enter into agreements for nuclear cooperation with the United States, and it has given Washington an important edge in negotiating such agreements.
>
> Cooperating with other countries on issues of nuclear safety, in turn, gives the United States an opportunity to shape behaviors in other areas, particularly with respect to plant security, materials safeguards, emergency response, and nonproliferation. Other leading supplier nations don't always adhere to the same strict controls the United States has adopted in these areas.[14]

The World's Most Powerful Navy

The U.S. Navy has approximately 100 nuclear reactors in its submarines and surface ships—there are about just as many Navy reactors as there are commercial power reactors. A nuclear-powered submarine can stay under water as long as there are sufficient supplies for the people on aboard. And nuclear reactors are the only power source capable of propelling U.S. aircraft carriers across the oceans at high speeds over long distances. Newer reactors can go for an astounding *50 years* (for aircraft carriers) and *30–40 years* (for submarines) between refueling.[15]

Notably, since the launch of *Nautilus* in 1954, the U.S. Navy has accumulated over 6,200 reactor-years of accident-free experience, involving 526 nuclear reactor cores, going a distance over 150 million miles, without a single radiological incident.[16] As of 2017, the U.S. Navy operated some 81 nuclear-powered ships—11 aircraft carriers, 70 submarines—with 92 reactors.[17]

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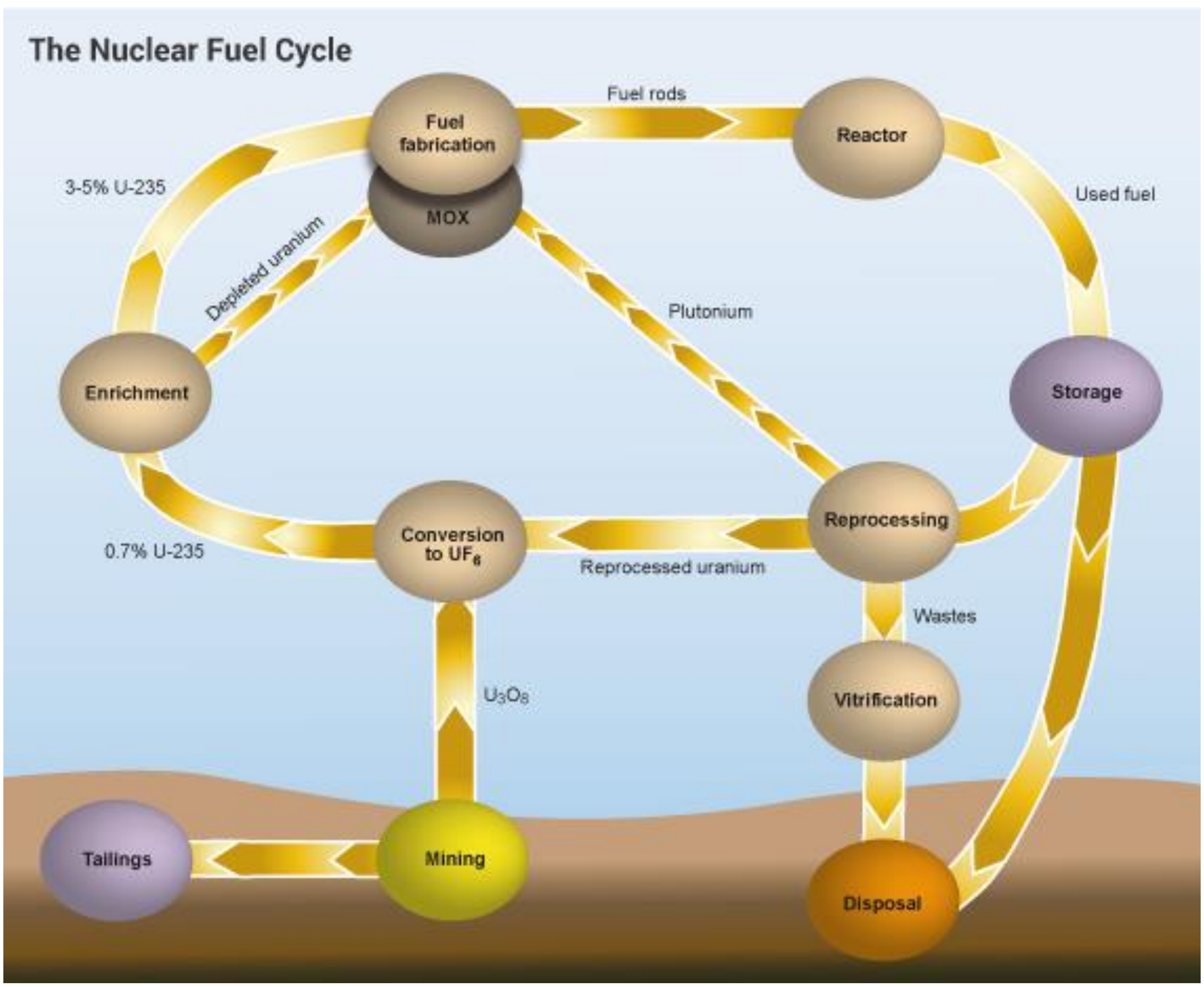
[13] United Nations Office of Disarmament Affairs, "Treaty on the Non-Proliferation of Nuclear Weapons (NPT)," https://www.un.org/disarmament/wmd/nuclear/npt/.
[14] *See* Center for Strategic and International Studies report, *Ensuring Leadership in Nuclear Energy: A National Security Imperative*, 25.
[15] World Nuclear Association, "Nuclear Powered Ships," last updated December 2017, http://www.world-nuclear.org/information-library/non-power-nuclear-applications/transport/nuclear-powered-ships.aspx.
[16] Ibid.
[17] Ibid.

But our nuclear Navy depends heavily on the health of the broader U.S. nuclear energy industry, for fuel, technical support, and knowhow. Unfortunately, that health is not good.

Among other things, U.S. naval reactors rely on a U.S. nuclear fuel cycle, a healthy U.S. nuclear support community, and staying at the cutting edge of nuclear innovation. Each one of these elements face significant challenges.

U.S. Naval Reactors Rely on the U.S. Nuclear Fuel Cycle—Which Is Not Complete.

Nuclear fuel production includes steps that take place at different facilities: mining, milling, converting and enriching the uranium, and then fabricating the fuel itself from the enriched uranium. To achieve its astounding feats, the U.S. Navy uses reactors powered by highly enriched uranium. Under current law, in order to enrich uranium for defense uses, the entire nuclear fuel supply chain must be of U.S. origin. That means that not only the uranium needs to be U.S. origin, but each facility the uranium goes to along the way until it is finally ready to go into a naval vessel's reactor must use U.S.-origin technology.



Source: World Nuclear Association

The U.S.-origin requirement is a real problem when almost all of our uranium comes from *abroad*—roughly 90 percent.[18] The only U.S. enrichment facility is limited to enriching fuel for nonmilitary use; and the United States' sole conversion facility recently shut down.[19]

As a result, the U.S. Navy currently uses surplus highly enriched uranium stockpiles to supply fuel for the naval reactor program. The U.S. Department of Energy's National Nuclear Security Administration (NNSA), which maintains the government's enriched uranium supply, needs both a reliable supply of U.S.-origin low-enriched uranium (enriched up to 19.75 percent) for research reactors and high-enriched uranium (enriched at 20 percent or above) for naval reactors. As of August 2015, NNSA reported that it had enough enriched uranium to use for research reactors and the nuclear Navy to get to 2038—*just 20 years* from now.[20] Afterward, the future is unclear.

U.S. Naval Reactors Rely on a Healthy U.S. Nuclear Vendor Support Community—Which Is on the Decline.

The successful construction and maintenance of nuclear reactors requires a robust supply chain capable of meeting the stringent safety requirements of the NRC for commercial reactors, and the U.S. nuclear Navy for naval reactors.[21] Forty-four states have companies participating in the nuclear supply chain, providing nuclear equipment, components, and services. Some of these vendors serve both civilian and military reactors. For example, Bechtel Corporation, a major nuclear constructor, serves the civilian nuclear industry, develops advanced naval nuclear propulsion technology, and provides technical support for aircraft carriers.[22] A shutdown of a nuclear supplier—or a shutdown of one of their large customers at a commercial power plant—undermines the strength of this supply chain.

We must stem the downward spiral in U.S. nuclear vendor viability, now, in order to provide innovation, equipment, maintenance, and fuel for our submarines and aircraft carriers and maintain the deterrence and credible threat provided by our nuclear weapons stockpile.[23] As stated previously, a healthy commercial nuclear power industry supports and maintains U.S. technological dominance and thus nonproliferation. We must stay relevant in the nonproliferation discussion by leading in research, development, and production. And the only

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[18] U.S. Energy Information Administration, "Nuclear Explained—Where Our Uranium Comes From," July 6, 2017, https://www.eia.gov/energyexplained/index.php?page=nuclear_where.
[19] "Honeywell to Idle Metropolis Plant, Cut 170 Jobs," *West Kentucky Star*, November 21, 2017, http://www.westkentuckystar.com/News/Local-Regional/Southern-Illinois/Honeywell-to-Idle-Metropolis-Plant-Cut-170-Jobs.aspx.
[20] World Nuclear Association, "U.S. Nuclear Fuel Cycle," Updated June 2018, http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-fuel-cycle.aspx.
[21] Nuclear Energy Institute, "Supply Chain Map: Nuclear Reactor Components."
[22] Andrew Wheeler, "Engineering Destruction: The Terrifying and Awesome Power of the U.S.S. Gerald R. Ford," *Engineering.com*, August 7, 2017, https://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/15330/Engineering-Destruction-The-Terrifying-and-Awesome-Power-of-The-USS-Gerald-R-Ford.aspx.
[23] To make clear, our domestic production shortfall is not a resource problem—the United States has sufficient domestic uranium resources to support U.S. government (and commercial) needs. The United States ranks ninth in the world for known uranium resources, with about 4 percent of the world total. At peak production, around 1980, there were over 250 uranium mines in operation, but there has been a steady decline in production since that time. At this point, a handful of operating uranium mines produce a small fraction of the uranium consumed by U.S. nuclear plants. World Nuclear Association, "U.S. Nuclear Fuel Cycle."

way that the United States will be able to promote best practices for nonproliferation in the digital age is if it leads the way in nuclear technology advancements and commercial operating best practices.

When nuclear work is idled, the knowledge and skillset necessary to construct, maintain, and operate a nuclear plant quickly vanishes not only within the vendor and operator companies, but within the nuclear workforce population generally. The nuclear brain drain has already proved devastating for the two current nuclear new-build projects at the Vogtle and Summer nuclear power plants. It is well recognized within the nuclear industry that "[t]he issues during construction of Summer and Vogtle that led to them being far over budget and behind schedule are closely tied to trying to do something again after having not done it for 30 years. They were basically first-of-a-kind builds."[24] Make no mistake: the experience with these plants was the canary in the coal mine, and we need to heed its clear warning.

While the U.S. Navy is careful to develop a supply chain generally capable of weathering commercial fluctuations, a continuing downward spiral and disappearance of the commercial nuclear supply chain cannot be weathered. As commercial reactors continue to disappear, the economic case for nuclear vendors and reactor suppliers to continue to operate weakens, and domestic suppliers will continue to disappear. The heart of the nuclear supply chain is skilled talent, and nuclear skilled craft and technicians take time to develop, educate, and train. With the decline in companies that hire nuclear workers comes a decline in attractive nuclear industry opportunities, destroying incentives for people to enter into the nuclear field. This, in turn, drives U.S. universities to discontinue offering or building their nuclear engineering programs, and U.S. naval personnel to pursue other career paths that offer post-service livelihoods. The U.S. government needs skilled nuclear engineers for its naval reactors program, nuclear weapons program, and the national laboratories, among other places. The nuclear engineers needed to support these positions need to be U.S. citizens. We simply cannot wait to pay attention to this issue, or it could take decades after the need arises to turn back the tide. At that point, the damage will have been done.

Staying at the Cutting Edge of Nuclear Innovation

Maintaining U.S. Naval propulsion leadership relies on the United States maintaining leadership in nuclear innovation—which is currently strong but faces challenges in the United States that slow or stop developments, or cause projects to move overseas.

New nuclear reactors will be needed as U.S. naval power-projection needs grow. The United States risks falling a step change behind other countries in the ability to dominate the sea if it is not the first to the scene with new reactor designs—which are likely to move the ship faster and more efficiently. For example, China is building a molten salt reactor (a new type of advanced nuclear reactor) for potential application on aircraft carriers and flying drones. Because molten salt reactors can be much smaller and safer than conventional pressurized light water reactors,

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[24] Aspen Institute Roundtable on the "Future of Nuclear Energy, Crisis and Opportunity: The Future of Nuclear Energy," November 2017, https://assets.aspeninstitute.org/content/uploads/2017/11/2017NuclearEnergy.pdf.

and require less maintenance,[25] the United States risks Chinese naval warships and offensive/defensive air systems quickly outpacing those of the United States[26]

For now, the U.S. leads in advanced reactor design. There are about 75 domestic ventures in next-generation nuclear technologies[27]—a number that keeps growing—and many have moved from the whiteboard to the machine shop. Some want to use liquid metal coolants, some want to use gaseous helium, and some want to greatly improve current light water reactor designs. Some want to have liquid uranium (or thorium) fuel, and some want to use nuclear waste as fuel. Some propose to cut out fission altogether and move straight to nuclear fusion. Nearly all of them offer modular designs that can start small and scale with customer needs. TerraPower, a company founded and chaired by Bill Gates, is a molten salt reactor design that proposes to use spent nuclear fuel as feedstock . It has garnered multiple rounds of financing and is moving toward development of a demonstration plant. NuScale, which promotes a factory-built-and-shipped small modular reactor design, has submitted a design certification application to the NRC.[28] Lightbridge, which is debuting a completely new type of metallic clad uranium fuel rod, is publicly listed and has just entered into a joint venture with French nuclear fuel giant, Framatome.[29] *Continued development of all of the foregoing technologies likely will provide further opportunities for new naval and air nuclear powered propulsion systems, and we must do all that we can to ensure such continued development.*

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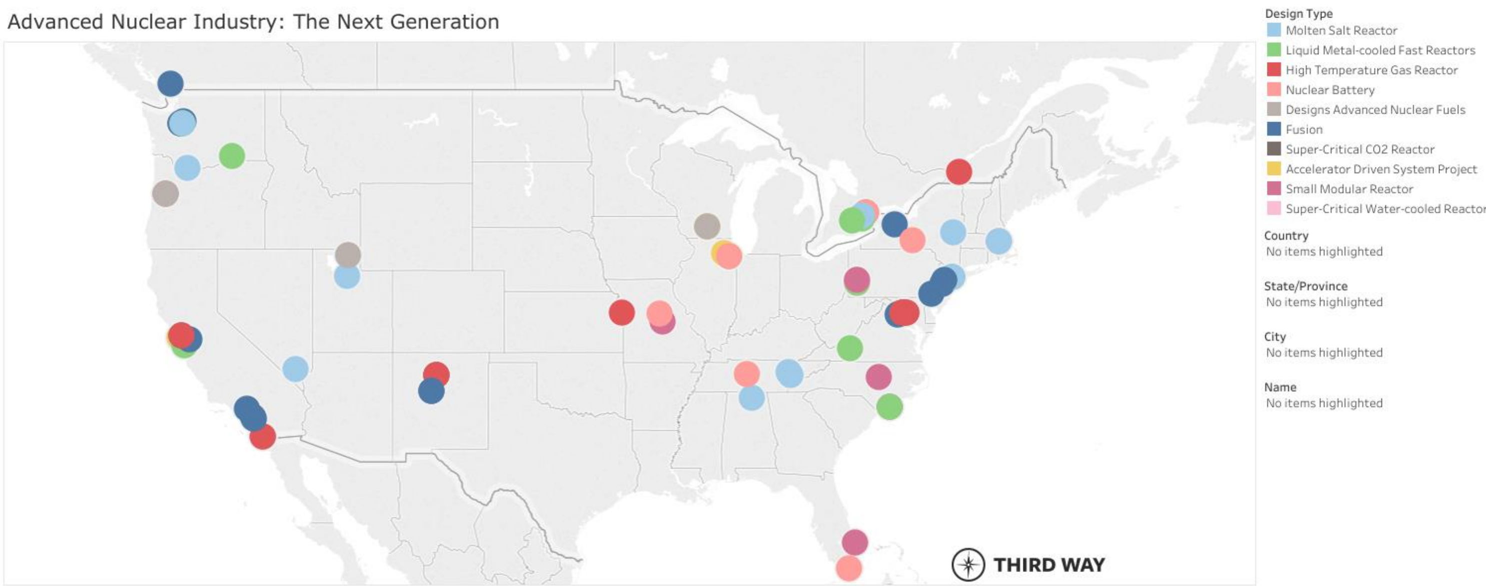
[25] Next Big Future, "China Spending US$3.3 billion on Molten Salt Nuclear Reactors for Faster Aircraft Carriers and in Flying Drones," December 6, 2017, https://www.nextbigfuture.com/2017/12/china-spending-us3-3-billion-on-molten-salt-nuclear-reactors-for-faster-aircraft-carriers-and-in-flying-drones.html.
[26] This pattern also follows a potential downswing in U.S. space dominance. NASA has decided to re-explore the use of nuclear fission rockets for Mars exploration—seemingly in reaction to Russia planning to test a nuclear rocket in 2018, as part of a plan to potentially beat the United States to land a person on Mars. BWXT, "BWXT Awarded $18.8 Million Nuclear Thermal Propulsion Reactor Design Contract by NASA" August 2, 2017, https://www.bwxt.com/news/2017/08/02/BWXT-Awarded-188-Million-Nuclear-Thermal-Propulsion-Reactor-Design-Contract-by-NASA; "NASA Wants to Use Nuclear Rockets to Get to Mars," *Daily Mail UK*, March 18, 2016, http://www.dailymail.co.uk/sciencetech/article-3499441/Nasa-wants-use-nuclear-rockets-Mars-Space-agency-claims-technique-effective-way-reaching-red-planet.html.
[27] Third Way, "Keeping Up with the Advanced Nuclear Industry," January 2018, https://www.thirdway.org/graphic/keeping-up-with-the-advanced-nuclear-industry. This number shows a marked increase from the previous year, so the advanced reactor field is currently growing. *See* Third Way, "The Advanced Nuclear Industry: 2016 Update," December 12, 2016, https://www.thirdway.org/infographic/the-advanced-nuclear-industry-2016-update..
[28] U.S. Nuclear Regulatory Commission, Design Certification Application – NuScale, https://www.nrc.gov/reactors/new-reactors/design-cert/nuscale.html.
[29] Framatome, "Lightbridge and Areva NP [now Framatome] Sign Binding Agreement for U.S. Joint Venture for Advanced Nuclear Fuel," September 6, 2017, http://ir.ltbridge.com/news-releases/news-release-details/lightbridge-and-areva-np-sign-binding-agreement-us-joint-venture.

Figure 2: Advanced Reactor Projects under Development around the United States as of February 2018



Source: Third Way

To that end, the U.S. Department of Energy has provided considerable first-round funding in support of initial research and development of advanced reactors.[30] Yet, after initial research is done domestically, oppressive and archaic regulatory regimes and financial challenges drive nuclear ventures to look abroad as they move to the test and demonstration stage. Among these is TerraPower, which has moved much of its activities to China to develop its future reactor.[31] TerraPower's president said that "China is where the demand exists and where *willing partners exist* for this kind of plant" [emphasis added].[32] Thus, more—much more—needs to be done to maintain the momentum of this public-private partnership and to ensure these new U.S.-based innovative technologies do not die on the vine—or move overseas.

An Effective Nuclear Deterrence That Is an Ultimate Guarantor of U.S. Safety

All nuclear weapons in the United States are required to be maintained by skilled nuclear-trained engineers and scientists who are U.S. citizens.[33] According to the September 2017 New

[30] *See, for example,* X-energy, "X-energy Wins Department of Energy Development Grant," January 15, 2016, https://www.prnewswire.com/news-releases/x-energy-wins-department-of-energy-development-grant-300205086.html.
[31] TerraPower, "TerraPower Establishes Joint Venture with CNNC [China National Nuclear Corporation] for TWR Co-Development," October 2, 2017, http://terrapower.com/updates/terrapower-establishes-joint-venture-with-cnnc-for-twr-co-development/.
[32] Stephen Stapczynski, "Nuclear Exports Head to China to Test Experimental Reactors," Bloomberg, September 22, 2017, https://www.bloomberg.com/news/articles/2017-09-21/nuclear-scientists-head-to-china-to-test-experimental-reactors.
[33] Mark Thompson, "U.S. Faces Challenges Maintaining Aging Nuclear Arsenal," *Time*, April. 1, 2014, http://time.com/44648/u-s-faces-challenges-maintaining-aging-nuclear-arsenal/; DOE/IG-0902, U.S. Department of Energy Office of Inspector General Office of Audits and Inspections, "Audit Report: National Nuclear Security Administration Nuclear Weapons Systems Configuration Management," DOE/IG-0902, March. 2014, http://time.com/44648/u-s-faces-challenges-maintaining-aging-nuclear-arsenal/. "Finding that NNSA had not

Strategic Arms Reduction Treaty (New START) declaration, the United States has 1,393 nuclear warheads deployed on 660 intercontinental ballistic missiles (ICBMs), submarine-launched ballistic missiles (SLBMs), and heavy bombers.[34] This force balances Russia's roughly equivalent arsenal.[35] Much of what has been discussed above about the nuclear Navy applies here as well.

A concrete example of how the military relies on a commercial nuclear power plant concerns tritium. Most of our nuclear warheads need tritium to boost the efficiency of the bomb's fission trigger.Without the use of tritium, nuclear warheads would be too heavy for current nuclear weapon delivery systems. Due to its relatively short half-life (12 years), tritium needs to be replenished in nuclear weapons every few years. That is problematic, as the United States has a very limited ability to produce tritium in quantities sufficient to maintain its nuclear weapons. The United States currently produces tritium by irradiating special rods in a single reactor run by the Tennessee Valley Authority (TVA). As is the case when producing fuel for the U.S. Navy's reactors, the TVA reactor needs to operate on U.S.-origin uranium when the reactor is used to produce tritium. Existing U.S. supply of "unobligated"—that is, not restricted to commercial use—low-enriched uranium is expected to *run out in just over a decade*, after which point, these TVA reactors will need to use downblended highly enriched uranium that is now set aside for other defense purposes—*this would likely shorten the current U.S. government supply of enriched uranium supply to even less than its current projected 20-year supply.*[36]

A Domestic Source of High Technologies That Supports U.S. Jobs, Influence Abroad, and Other Endeavors

The world's fleet of nuclear power plants traditionally has been supported in the United States by multiple reactor designers, services and maintenance professionals, fuel cycle facilities (i.e., uranium mining, milling, conversion, enrichment, fuel fabrication vendors), and a vast network of other suppliers (such as cask, equipment and components, and technical service providers). Tens of thousands of U.S. engineering, science, technology, math, and other professionals and highly trained/skilled craft workers have worked in various technical fields in nuclear power plants and supporting industries. Many of these individuals come from the nuclear Navy—choosing to be a "Navy nuke" precisely because of these future opportunities— and nearly all of the professional engineers and scientists have earned their degrees from well-respected U.S. research universities with robust science, technology, engineering, and math programs.[37] The

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maintained accurate and complete configuration management information for its nuclear weapons and components needed to maintain the weapon throughout its life cycle, not ensuring that unauthorized design changes were not made to weapons drawings, and not ensured NNSA that the process being used for acceptance of nonconforming parts in nuclear weapons was effective, and that these issues could "could negatively impact the reliability and safety of U.S. nuclear weapons." Ibid., 4–5.

[34] U.S. Department of State, "New START Treaty Aggregate Numbers of Strategic Offensive Arms," October 2017, http://time.com/44648/u-s-faces-challenges-maintaining-aging-nuclear-arsenal/.

[35] Ibid.

[36] "Commentary: The Looming Crisis for U.S. Tritium Production," *Defense News*, March 6, 2017, https://www.defensenews.com/opinion/commentary/2017/03/06/commentary-the-looming-crisis-for-us-tritium-production/.

[37] *See, for example,* Department of Energy, "Nuclear Energy University Program," https://www.energy.gov/ne/nuclear-reactor-technologies/nuclear-energy-university-program. Since 2009, the Nuclear Energy University Program has awarded "approximately $290 million to 89 colleges and universities in 35 states and the District of Columbia to train the next generation of nuclear engineers and scientists in the United States and continue U.S. leadership in clean energy innovation."

U.S. Department of Commerce estimates that the international market for nuclear equipment and services will be about *$740 billion over the next 10 years, and that every $1 billion of such exports by U.S. companies supports 5,000 to 10,000 domestic jobs.*[38]

In addition to jobs, nuclear power plant export collaborations create strong geopolitical ties between the selling and recipient countries that last as long as the life of the project—which can be *nearly 100 years*. Civilian nuclear power deals create long-term partnerships and greater chances for international cooperation. It is no surprise that our core strategic allies—Japan and the United Kingdom—are also our core strategic nuclear generation partners. Our younger alliances with countries such as the United Arab Emirates are solidified through equally strong nuclear cooperation agreements and activities.

Apart from nuclear power, nuclear technology adds value to the U.S. research mission. There are 31 nuclear "research reactors" in the United States that use neutron emissions to study a variety of activities.[39] These reactors perform neutron scattering analyses that help in the design of "superconductors, polymers, metals, and proteins"; they also perform neutron radiography, which is "used to determine structural integrity and provide quality control for aerospace, automotive and medical components."[40] Most research reactors are located at universities, where they often function as a centerpiece of that university's research program. Facing rising costs and limited national support, many of these reactors have shut down over the past decades, further eroding our science, technology, engineering and math edge over other countries.

Finally, in our most "far-reaching" nuclear export category, any significant extra-orbital space research relies on nuclear power. The Voyager spacecraft, which are the farthest man-made objects, still work 40 years after launching, using their Radioisotope Thermoelectric Generators (RTGs).[41] The Mars rover, Curiosity, has functioned for five years on Mars using its RTG, and keeps on going.[42] And, yet, at this critical juncture in the modern space race, NASA is just a few years away from potentially having to cut back on deep-space explorations for a lack of plutonium fuel for its space probes and scientific missions.[43]

[38] Nuclear Energy Institute, "Nuclear Exports & Trade Overview," https://www.nei.org/advocacy/compete-globally.
[39] U.S. Nuclear Regulatory Commission, "Backgrounder on Research and Test Reactors," last updated August 5, 2015, https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/research-reactors-bg.html.
[40] Ibid.
[41] NASA, "Voyager Spacecraft," https://voyager.jpl.nasa.gov/mission/spacecraft/.
[42] NASA, "Radioisotope Power Systems," https://rps.nasa.gov/.
[43] Dave Mosher, "NASA's Plutonium Problem Could End Deep Space Exploration," *Wired*, September 19, 2013, https://www.wired.com/2013/09/plutonium-238-problem/.

02 A Look to 2050 and the Consequences of Yielding Leadership

In June 2013, the Center for Strategic and International Studies (CSIS) convened a special task force explaining the intrinsic link between the U.S. commercial nuclear power program and U.S. national security interests. The resulting report, *Ensuring Leadership in Nuclear Energy: A National Security Imperative*,[44] noted that the United States' nuclear energy industry is on the decline and that the decline could happen much faster than policymakers and stakeholders anticipate. The report suggested that such a decline would have significant impact beyond the nuclear power sector:

> [a]ffecting university physics and engineering programs, materials, science laboratories, manufacturing, labor programs for training nuclear welders, and much more. It would undoubtedly affect the defense establishment and our Navy's capabilities, as well as the United States' ability to shape global standards for safety, security, operations, emergency response and nonproliferation.

Five years after the CSIS report, the U.S. nuclear industry continues to decline and is declining much more quickly than anticipated.

Currently, the United States cannot fabricate nuclear fuel for its civilian nuclear reactor fleet without help from abroad. And, given the difficult economics and rampant cost overruns experienced recently in constructing first-of-a-kind new nuclear power plants in over 30 years,[45] U.S. utilities likely will not be able to build any new nuclear reactors. This reality, combined with the fact that well over 10,000 MW of existing baseload nuclear generation is planning to shut down permanently in the near term, will undoubtedly strain power grid stability and security.

Westinghouse, one of the U.S. pioneers of nuclear power, is currently in bankruptcy with its future uncertain. The only new nuclear power plants under construction in the United States may never be completed, and indeed one of the two projects has already been terminated. The only uranium conversion facility in the United States—a critical part of the fuel cycle supply chain—just shut down its facility. The only domestic uranium-enrichment facility relies on foreign technology, and cannot be used to produce fuel for the nuclear Navy.

The U.S. position abroad is no better, with the vast majority of new plants under construction or planned around the world being offered as turnkey cradle-to-grave projects clearly subsidized, financed, built, fueled, managed, and therefore controlled by the governments of Russia and China. This undermines not only safety and nonproliferation, but also nullifies U.S. nuclear influence, particularly in developing economies such as those growing in Asia, the Middle East,

[44] CSIS report, *Ensuring Leadership in Nuclear Energy: A National Security Imperative*, 2013, https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/130614_RestoringUSLeadershipNuclearEnergy_WEB.pdf.

[45] *See, for example,* Tom Hals and Jessica DiNapoli, "Power plant owners limit Toshiba's Westinghouse liabilities: sources," *Reuters,* May 14, 2017, https://www.reuters.com/article/us-toshiba-accounting-southern-co/power-plant-owners-limit-toshibas-westinghouse-liabilities-sources-idUSKCN18A120.

and Africa. If current trends continue, U.S. influence will be nil, and our views in the nuclear discussion will become irrelevant. This would be an unacceptable outcome.

A Long-Term Force Field Analysis of the U.S. Nuclear Industry

We performed a Force Field analysis to examine where the commercial nuclear energy industry will be in 2050. A Force Field analysis allows decisionmakers to analyze the forces acting in favor and against a particular situation, to help evaluate how it will evolve over time. Given the myriad external pressures facing the U.S. commercial nuclear power industry, a Force Field analysis is a particularly apt means to examine how it will be shaped over time.

Looking over the long term is important because faults brewing now may take a long time to become visible. By the time they are obvious, it will be too late, and the industry will be in a non-recoverable catastrophic downward spiral. As the "cures" to avoiding this fate will take just as long to implement, to stop disaster in 2050, we must take action immediately.

The following Force Field framework seeks to capture the forces acting on the industry over the *long term*, not just 5 or 10 years out, but until 2050. In the worst case, by 2030, a large number of nuclear plants will probably remain operational, due to their comparatively low operating costs and long-term operating licenses (most currently operating nuclear plants are licensed to operate for another 10–20 or so years). Further, our nuclear Navy likely will have fuel until 2030, just from current reserves, and we will probably still have a military technical edge. However, by 2050, we could be facing a situation where *no nuclear plants are operating in the United States*, and there is no U.S. nuclear energy industry. We could be looking at a reality where there is no fuel for the nuclear Navy, and competing nations are fielding nuclear-powered ships, aircraft, and spacecraft powered by a whole new generation of reactors, and as a result are deploying energy-intensive weaponry (e.g., electromagnetic rail guns and lasers)[46] that our fleet is unable to match. Nearly all of the new nuclear plants built around the world—which the International Energy Agency expects to double the current capacity—would be supplied by Russia or China.

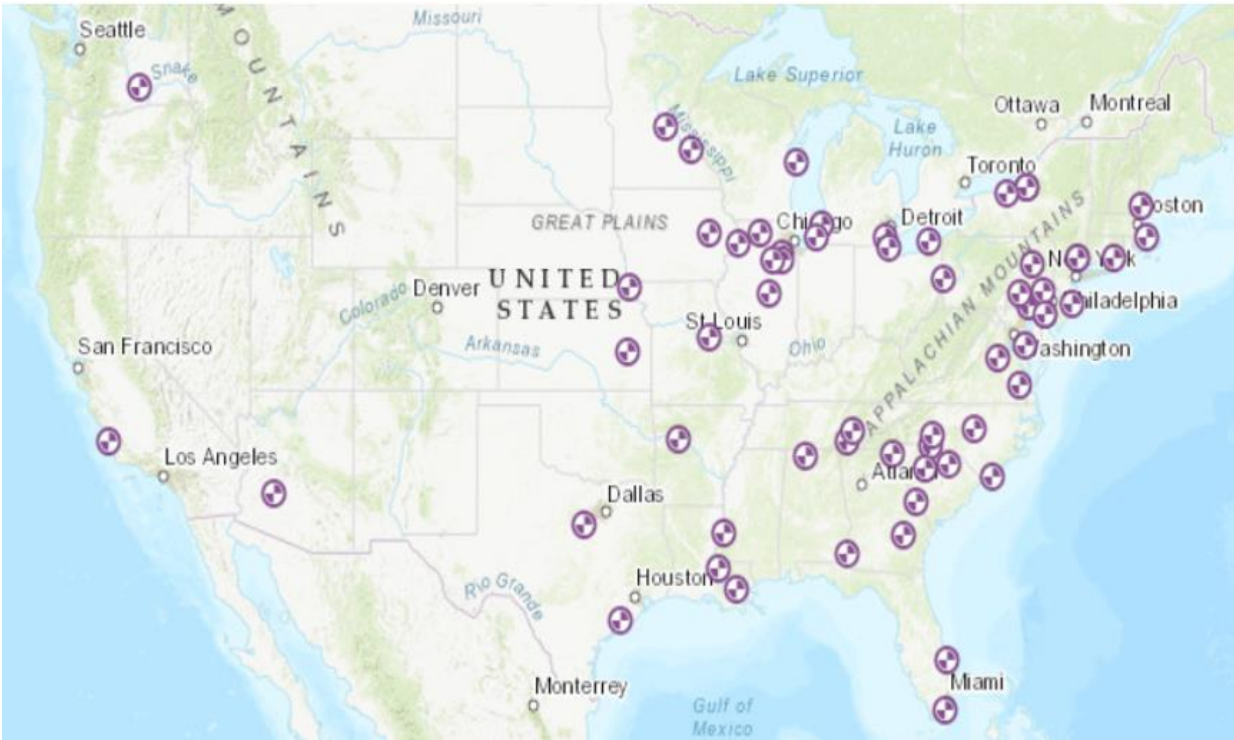
The Forces in Favor of a Strong U.S. Nuclear Industry

We start by acknowledging those forces currently supporting the industry.

- Current Commercial Nuclear Fleet: The current nuclear fleet of 99 nuclear reactors is likely to remain the most significant source of work and investment going forward. These reactors generate electricity at relatively low long-term operational costs, and generate thousands of high-paying jobs. They are designed and able to operate up to 60 and 80 years and—if they are permitted to do so—maintenance, refueling, and upgrades will keep nuclear experts employed and nuclear suppliers with contracts.

[46] U.S. Naval Institute News, "In Pursuit of the U.S. Navy's Next Surface Combatant," January 14, 2014, https://news.usni.org/2014/01/14/pursuit-u-s-navys-next-surface-combatant.

Figure 3: Locations of U.S. Nuclear Power Plants



Source: U.S. Energy Information Administration, U.S. Energy Mapping System, April 17, 2018

However, this is a *weak* force in favor of the industry, because it is unclear if nuclear plants will be able to operate as long as they technically are capable. As discussed elsewhere, an increasingly large percent of the current fleet is at risk of shutting down (or has already planned to shut down). With roughly half of the nuclear fleet operating in "merchant" markets priced for the short term, the low price of natural gas is making nuclear plants temporarily uncompetitive. At the same time, however, certain critical benefits of nuclear power plants (e.g., reliability, grid stability) go largely uncompensated. Unfortunately, while a natural gas plant can, for all intents and purposes, temporarily shut down in bad times, baseload nuclear plants cannot. And, when they do shut down, regulatory requirements essentially mean that the shutdown will be permanent.[47] If current market and economic trends continue, the entire merchant fleet could be out of operation within the next 20 years or so.[48] Indeed, the current U.S. power market structure serves as a larger, more powerful, negative pressure facing the nuclear industry.

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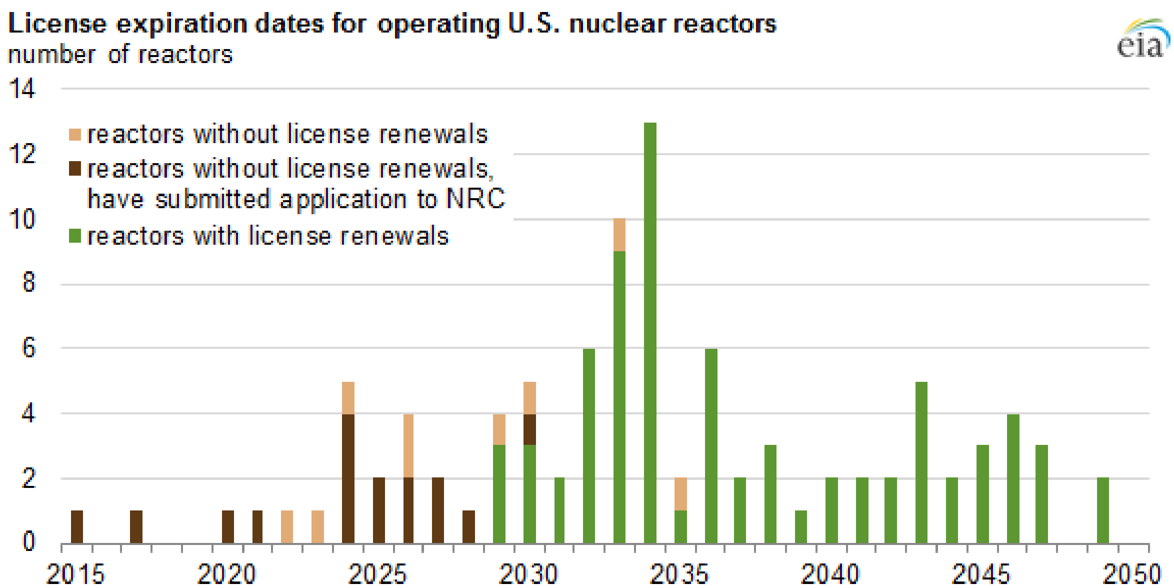
[47] The NRC does not begin to grant relief from its strict regulatory requirements, including plant staffing and the NRC's high annual fee, until the plant licensee has gone through a number of regulatory steps. Once the decision is made to permanently cease operations, the licensee must notify the NRC in writing within 30 days. The notification must contain the date when the power generation operations stopped or will stop. The licensee then must remove the fuel from the reactor and submit a written certification to the NRC confirming its action. Once this certification has been submitted, the licensee is no longer permitted to operate the reactor or to put fuel into the reactor vessel. At this point, the licensee can seek to relax some of its regulatory burdens, but the plant cannot be restarted. *See* 10 C.F.R. 50.82.

[48] Jim Polson, "More Than Half of America's Nuclear Reactors Are Losing Money," Bloomberg, June 15, 2017, https://www.bloomberg.com/news/articles/2017-06-14/half-of-america-s-nuclear-power-plants-seen-as-money-losers.

Moreover, if no new nuclear plants come online, then within 20–30 years it is possible, if not probable, that the *entire* nuclear fleet will have shut down, as their licenses to operate will have expired. Currently, most plants face operational license limits by 2050, and even if a few plants decide to seek further extension of their operating licenses, by 2050, nearly the entire nuclear fleet will be facing imminent shutdown. Further, if the momentum in the direction of shuttering nuclear plants increases, it is quite possible that, with lack of infrastructure and forecasted improvement, more plants will shutdown prematurely (before the end of their licensed life), which will be further exacerbated by the reduction of a nuclear workforce pipeline due to the unavailability of future viable nuclear industry job opportunities.

Figure 4: Nuclear Operating License Expirations (U.S. Nuclear Regulatory Commission)[49]



Source: U.S. Energy Information Administration

Indeed, even if some plants can renew their licenses and remain in operation past 2050, the loss of the other plants will make it harder for suppliers to stay in the nuclear business. The loss of key suppliers will make it harder for the current fleet to stay operating. A vicious cycle of shutdowns, followed by suppliers exiting the business, and the complete cessation of a nuclear talent pipeline *present a real threat that could virtually guarantee that all currently operating nuclear plants will be shut down by 2050.*

[49] U.S. Energy Information Administration, "Nuclear Regulatory Commission Resumes License Renewals for Nuclear Power Plants," October 29, 2014, https://www.eia.gov/todayinenergy/detail.php?id=18591.

Table 1: Recent and Announced Retirements of U.S. Nuclear Reactors[50]

Reactor	Size (MW)	Region	State	Owner	Retirement Date
Crystal River 3	860	Southeast	FL	Duke Energy	Feb. 2013
Kewaunee	556	MISO	WI	Dominion	May 2013
San Onofre 2	1,070	California	CA	SCE and SDG&E	Jun. 2013
San Onofre 3	1,080	California	CA	SCE and SDG&E	Jun. 2013
Vermont Yankee	620	New England	VT	Entergy	Dec. 2014
Fort Calhoun	479	SPP	NE	Omaha PDD	Oct. 2016
Fitzpatrick	847	New York	NY	Exelon	*
Ginna	582	New York	NY	Exelon	*
Nine Mile Point 1	637	New York	NY	Exelon	*
Clinton	1,065	MISO	IL	Exelon	*
Quad Cities 1	934	PJM	IL	Exelon	*
Quad Cities 2	937	PJM	IL	Exelon	*
Oyster Creek	608	PJM	NJ	Exelon	*
Pilgrim	677	New England	MA	Entergy	2019 (p)
Diablo Canyon 1	1,118	California	CA	PG&E	2024 (p)
Diablo Canyon 2	1,122	California	CA	PG&E	2023 (p)
Beaver Valley 1	921	PJM	PA	FirstEnergy Solutions	2021 (p)
Beaver Valley 2	905	PJM	PA	FirstEnergy Solutions	2021 (p)
Davis-Besse	908	PJM	OH	FirstEnergy Solutions	2020 (p)
Perry	1,268	PJM	OH	FirstEnergy Solutions	2021
Summary:	4,665 MW closed	12,529 MW planned		17,194 MW total	

(p) planned retirement date

** New York, Illinois, and New Jersey all passed legislation that will provide zero emissions credits to these facilities. If the standard survives legal challenges, these plants will continue operation. If not, then they will likely be shutdown.*

[50] The authors updated a 2016 Third Way chart depicting similar information, available at https://www.thirdway.org/report/preserving-americas-clean-energy-foundation.

- **Advanced Reactor Innovation:** A new generation of entrepreneurs is currently helping to bring forward new advanced reactor designs that promise to be cheaper and even safer than current reactors. If these reactors can get off the ground, the United States could be looking at a true nuclear renaissance. There is a great deal of interest on university campuses, among startup ventures, and also by venture capital and other funding sources to make this happen.

  Nonetheless, for now, this is only a *weak* force in favor of the current nuclear industry. There currently is no nuclear demonstrated regulatory framework in place for the licensing of advanced reactors. And, while the NRC has publicly recognized the need for streamlining the regulatory review process for advanced SMRs, it has only really nibbled around the edge of meaningful reform.[51] NuScale, a small modular light water reactor developer, is proposing a novel SMR design, but one that still relies on well-proven and demonstrated light water technology principles that date back to Shippingport, and relies on the existing fuel cycle. Nonetheless, it look *16 years* from the time that the concept was first invented for the company to be able to *submit* a design certification to the NRC, and the NRC's total design certification application technical review will not be complete until *late-2020*, with the final rule for the design likely being issued about a year later in 2021.[52] Next-generation reactors that use different coolants (other than water), or need novel fuel designs, are going to face significantly harder regulatory paths forward.

- **Climate Change Push:** Nuclear power generates approximately 60 percent of the nation's zero-carbon emissions electricity, making it by far the largest source of zero-emissions energy in the country.[53] The use of nuclear energy in 2016 prevented the emission of 553 million metric tons of carbon, which equals the amount released in a year by 117 million passenger cars.[54] That is over *double* the amount of zero-carbon electricity produced by solar, wind, biomass, and geothermal power sources *combined*.[55]

  Moreover, nuclear power is the *only* source of zero-emissions baseload generation.[56] In 2016, while nuclear power plants operated with a capacity factor of 92.2 percent (i.e., those that were online produced 92.2 percent of their potential maximum power over the year), solar plants operated with capacity factors around 27 percent, and wind

[51] *See* U.S. Nuclear Regulatory Commission, "Advanced Reactors (non-LWR designs)," last updated April 25, 2018, https://www.nrc.gov/reactors/new-reactors/advanced.html. The source discusses various NRC actions to prepare for advanced reactor applications, which primarily entail preparing guidance and framework documents on how to use the NRC's *existing framework for large LWRs for very different advanced reactor designs*.
[52] *See* U.S. Nuclear Regulatory Commission, "Application Review Schedule for the NuScale Design," last updated April 13, 2018, https://www.nrc.gov/reactors/new-reactors/design-cert/nuscale/review-schedule.html.
[53] Nuclear Energy Institute, "Nuclear Plants: Protecting Air, Water, Soil, and Wildlife," July 2015, https://www.nei.org/resources/fact-sheets/nuclear-protects-air-water-soil-wildlife.
[54] Nuclear Energy Institute, "Fact Sheet, New York and Nuclear Energy," https://www.nei.org/CorporateSite/media/filefolder/resources/fact-sheets/state-fact-sheets/New-York-State-Fact-Sheet.pdf.
[55] U.S. Energy Information Administration, "Frequently Asked Questions: What Is U.S. Electricity Generation by Energy Source?," last updated April 18, 2017, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.
[56] According to the U.S. Department of Energy, baseload generation sources consist of "coal, nuclear, and natural gas combined-cycle plants." *See* U.S. Department of Energy, "Transforming the Nation's Electricity System: The Second Installment of the Quadrennial Energy Review," 2017, 1–21, https://www.energy.gov/policy/initiatives/quadrennial-energy-review-qer/quadrennial-energy-review-second-installment.

power plants at around 37 percent.[57] This means that, on average, 3 to 4 megawatts' worth of wind and solar capacity has to be constructed to generate the same amount of net electricity as 1 megawatt of nuclear power capacity. And, in periods of low solar and wind potential, carbon-emitting generation sources such as those fueled by coal or natural gas have to operate to make up the difference.

This is a *medium* force in favor of the industry. Unlike the other forces noted above, this force has the potential to grow in strength over the long term. While the federal government is not acting on climate change issues, it is an important issue to a number of states and abroad. While some states, such as New York and Illinois, have taken significant action to provide economic incentives to keep nuclear plants operating due to their climate benefits, those actions are being challenged in court, and it is unclear if other states will do the same. As a result, there is a large risk that by the time there's significant action on climate change, it will already be too late to have an impact on the nuclear industry.

The Forces against a Strong U.S. Nuclear Industry

Lined up against these encouraging forces is an array of headwinds. Some of these are global, and some of these are domestic. But, all of them are likely to grow in the long term unless we act.

- Foreign Government-Supported Competition: Chinese and Russian state-owned enterprises are investing billions of dollars into new reactor designs, including non-light water reactor designs, in order to leapfrog ahead of U.S. competitors. Moreover, when it comes to global competition for new plants, both countries field "turnkey" packages, which include construction, operation, financing, and fuel management. U.S. commercial vendors cannot match these proposals on their own. Compared to the United States' complex export control and regulatory regimes, which act as a barrier to global commerce, their governments actively support global proposals for new nuclear power projects. To be clear, the vast majority of nuclear power plants planned around the world are Russian, with China coming in second. When U.S. plants are not built, in most cases a Russian[58] or Chinese plant will be. And these plants are not built to the same exacting safety and security standards that a U.S. plant is built.

  This is a *strong* force against the domestic U.S. nuclear industry. Further, as the Russian and Chinese nuclear industries continue to grow through sustained success at home and abroad, their advantages moving them ahead of U.S. vendors will only increase. And, as discussed above, because operating a nuclear plant is a long-term endeavor, U.S.

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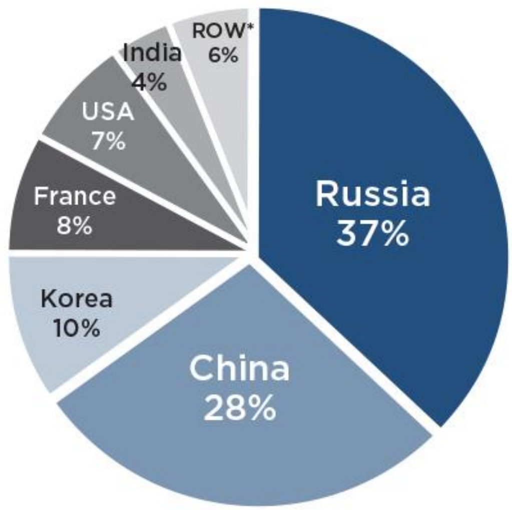
[57] U.S. Energy Information Administration, "Electric Power Monthly, with Data for February 2018," Table 6.7.B, April 2018, https://www.energy.gov/policy/initiatives/quadrennial-energy-review-qer/quadrennial-energy-review-second-installment. Nuclear power plants also operated at a much higher capacity factor than even coal and natural gas combined-cycle plants, which in 2017 operated with capacity factors just above 50 percent. Ibid., Table 6.7.A.

[58] S&P Global, Platts, "Russian Looks to Boost Nuclear Generation" Nucleonics Week (Vol. 59, No.28), July 12, 2018 (Russian officials have explained that Rosatom intends to set a record for nuclear power generation in Russia and expand its currently $133 billion international order book with new contracts).

vendors are likely to be further disadvantaged as potential customers watch the decline in U.S. nuclear energy infrastructure.

Figure 5: Reactors Planned and Under Construction



Source: World Nuclear Association
*As of 2016; ROW=Rest of World

- U.S. Nuclear Export Control Regime: The U.S. statutory framework around exports of nuclear technology and equipment is designed to significantly restrict, rather than encourage, global nuclear commerce. That strategy may have made sense in 1960, at the height of the Cold War. In today's global economy, however, it is a hindrance to U.S. nuclear global competitiveness. As growth in nuclear power is primarily occurring outside of the United States, U.S. vendors must continue to be competitive in order to survive. Already, our vendors do not have the benefit of government assistance like that of their foreign competitors. However, the U.S. export control regime takes things a step further.

  In particular, for U.S. companies to be considered for participation in foreign reactor projects, the U.S. government must put in place a "123 Agreement" to permit "nuclear cooperation," and it will only do so if the other country agrees to a litany of restrictive commitments. Many of these requirements only have a tangential tie to nonproliferation, but they are requested because other nations agreed to them in the past, when there were only a few nuclear vendor nations able from which to choose. But, these requirements do not make sense now, and simply serve to eliminate U.S. companies from participating in the global nuclear marketplace, which, ironically, only serves to weaken the nonproliferation goals for which the commitments were designed.

  This is a *strong* force against the U.S. nuclear industry. Ironically, as these export regimes leave U.S. vendors out of the running for many competitions, other countries are turning to countries such as Russia and China for nuclear reactors, which bring with them increased safety and proliferation risks.

- U.S. Short-Term Electricity Market Structure: While a complex issue, the short-term "day-ahead" and "hour-ahead" merchant electricity markets developed since the 1990s generally focus on immediate and near-term power generation needs; however, the short-term marketplace and its pricing does not generally take into account long-term baseload power planning for the U.S. electric grid.[59] Currently, low natural gas prices push down the short-term market price for power, and threaten the economic viability of nearly half of the current domestic nuclear fleet, which are operating at or near a loss. This current electric market structure favors those generators that have low operational and fuel costs and can ramp production up and down quickly; it does not value other attributes of power generation—such as the baseload and carbon-free benefits that nuclear generation provides. So, under the current market structure, and the abundant supply of natural gas, these downward price and market forces will likely continue to dominate and devastate the viability of reliable baseload nuclear generators.

  This is a *strong* force against the nuclear industry. Moreover, as more merchant nuclear plants shut down due to economic headwinds, a weakening nuclear supply chain means the remaining plants risk becoming less competitive, increasing their economic distress. While some states have taken action to value those attributes of nuclear generation currently ignored by U.S. regional electricity markets (such as carbon and grid stability benefits), as noted above, the impact of those programs is currently limited to a select few states, and faces legal challenges.

- U.S. Nuclear Licensing Regime: The current U.S. nuclear regulatory regime is geared toward the current light water reactor fleet, because that is what it has worked with for the past four decades. As a result, rather than maintaining a flexible licensing regime to accommodate new plant designs, the NRC has codified by rule a number of requirements that only make sense for large light water reactors. Although the NRC states that it is ready to review and license an advanced reactor design today, the reality is that it will cost millions to bring the NRC up to speed with any non-light water reactor technology. While Congress should fund the NRC to do just that, instead, it will be up to the applicant, as the NRC charges hundreds of dollars per hour for its time spent certifying or licensing a new reactor design. That is why the licensing costs for a new reactor design can reach *half a billion dollars or more*, and that's before the start of any true construction. Under these facts, the business case for a new nuclear technology developer becomes very challenging if left only to the private-sector commercial market.

  This is a *medium* force facing the industry. The NRC is working to reform its regulatory regime and adopt more flexible licensing approaches. While more can be done, it is possible that the NRC regulatory framework could improve over time. Congressional action to help fund the NRC's transformation and reform the licensing process would

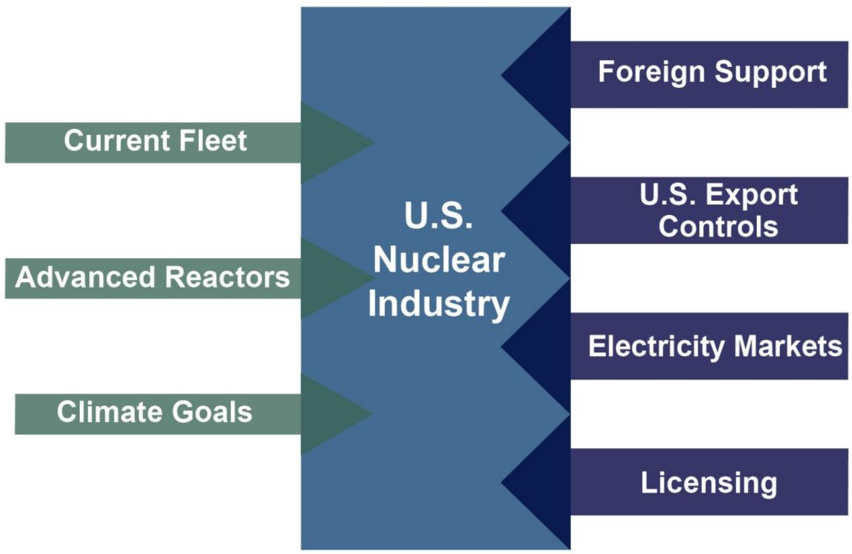
[59] It is recognized that there are sophisticated power needs and grid stability analyses, along with robust bilateral power contracting, conducted in many markets; however, the downward force of natural gas-affected short-term prices on the economic viability of these massive and reliable baseload plants is very real.

greatly help. The concern is that, by the time the NRC is able to meaningfully reform its regulatory licensing processes, the advanced reactor community will have taken its technology abroad (like TerraPower), and the U.S. nuclear industry will have lost its best chance for a resurgence.

Force Field Analysis

Comparing the positive and negative forces facing the current nuclear industry, it is clear that something must be done now to prevent an increasing degradation of this national resource.

Figure 6: Force Field Analysis through 2050



If the strength of each force were given a value (e.g., weak as 1, medium as 2, and strong as 3), then the result would be that the strength of the forces currently in *favor* of the nuclear industry total 4, while the forces aligned *against* the industry total 11. While this exercise is only representative, it highlights that—unless action is taken now—the forces arrayed against the nuclear industry in the long term will prove *overwhelming*. And as those forces increase in strength while the supportive forces weaken, this will only accelerate the decline of the U.S. nuclear industry.

National Security Implications from the Force Field Analysis

To accept the above, and do nothing now to address these forces against the nuclear industry, would be giving up on more than just commercial nuclear power. We would be giving up on the benefits and national security enhancements that the nuclear energy industry has brought to the United States and the world—from the strength and ability to project that strength of our Navy and nuclear deterrence, to our ability to lead the nonproliferation discussion. To summarize and highlight just a few of the key challenges the United States will face in a post-nuclear leadership world:

- **Our military weakens.** The lack of a nuclear fuel supply chain threatens the Navy's operational capacity after the mid 2030s, while our adversaries deftly adapt, strive to overtake our technology lead, and continue to grow in strength. The lack of a healthy vendor community supported by a growing nuclear industry and trained nuclear workforce means that the next generation of nuclear technologies, such as smaller reactor designs, will not make it from U.S. suppliers to our ships to support growing power requirements. We will be shedding nuclear expertise while other countries bolster theirs, further threatening the United States' current military dominance.

  Our nuclear deterrent, the cornerstone of U.S. security in an increasingly dangerous world, will fall increasingly behind its counterparts in modernization without a strong, educated nuclear talent pool to staff our nuclear needs. Moreover, basic elements of the nuclear arsenal, tritium in particular, risk running low and further straining the reliability of our military's deterrence capabilities.

- **Our voice on safety and nonproliferation disappears.** The NPT was premised on an exchange. The world will only adhere to U.S. demands for reactor safety and safeguards if we have something valuable, and not available "less expensively" and more easily elsewhere, to offer in return. Already, we have yielded leadership with the next generation of light-water reactors. Of light-water reactors planned or under construction in 2015, 37 percent were Russian and 28 percent were Chinese, while only a handful were U.S. or of U.S. origin. Since then, our competitors' lead has only grown.[60] Their reactors likely do not meet U.S. standards, but with no competing U.S. offer, these technologies will become the new mainstream.

  The advent of advanced reactors will set the stage for a major battle for global nuclear technological dominance. If the United States leads in implementing this new technology wave, safety will improve and proliferation will drop. If others lead, these benefits will fall to the wayside in an environment of low costs and false promises. We currently are well-positioned to deliver this new technology but are increasingly yielding the mantle of nuclear technology leadership to China and Russia. TerraPower has moved its U.S.-origin reactor design to China. We have to make sure that the reasons for TerraPower leaving are addressed—and that others do not follow suit.

- **Our global influence wanes.** Russian and Chinese governments recognize the geopolitical and economic benefits to building new nuclear projects abroad. The Russian energy policy, in particular, expressly recognizes the export of energy technologies as a geostrategic tool.[61] Lower-cost "turnkey" projects offered by the Russians and Chinese—which include state-supported financing packages—are leaving the United States without a seat at the table. As China and Russia succeed in the deployment of their nuclear energy technologies in emerging economies, they immediately gain a broad geopolitical foothold in these countries by effectively being able to control needed

[60] Third Way, "Getting Back in the Game: A Strategy to Boost American Nuclear Exports," January 2017, 4, https://www.thirdway.org/report/getting-back-in-the-game-a-strategy-to-boost-american-nuclear-exports.
[61] Ibid.; Ministry of Energy for the Russian Federation, "Energy Strategy of Russia for the Period up to 2030," 2010, http://www.energystrategy.ru/projects/docs/ES-2030_(Eng).pdf.

baseload power and the fuel cycle (and spent fuel byproducts) to run these nuclear units. This most certainly will bring longer-term implications for the geopolitical balance of power and economic influence, as well as new threats to U.S. peace and security.

As our global market share in nuclear power dwindles, so too does our ability to influence agreements that affect national and international security. As a result, the U.S. is facing long-term damage to its geostrategic influence, and Russia is taking its place. Recently, Egypt and Russia finalized a $21 billion contract for the Russians to supply four reactors in Egypt.[62] A few months later, Egypt and Russia announced a preliminary agreement to allow Russian military jets to use its airspace and bases. If finalized, the agreement will give Russia its deepest presence in Egypt since 1973.[63]

With Saudi Arabia and Jordan both currently moving forward with nuclear power programs, the United States is again competing against the Russians and the Chinese. Yet, at this point, we do not have the necessary foundational agreement—the 123 Agreement, a legal prerequisite to supplying a reactor and nuclear fuel—in place to even engage in meaningful nuclear trade discussions with either country. This puts us in, at best, a reactive position, which means we will—if we are fortunate enough to even secure a seat at the nuclear table—be left ironing out complicated policy and commercial issues *after* an opportunity arrives, not before. This scrambling threatens our seat at the bargaining table: not only in the Middle East, but eventually in other emerging nuclear power markets in Asia and Africa.

- **The country's (and the world's) energy and climate security is undermined.** Nuclear power's reliability and capacity, along with its carbon-free emissions and safe operation, disappear over the next decade as plants retire and the supply chain and workforce evaporate. Over 100,000 jobs will be lost or put at risk, with cascading impacts on local communities and universities.[64] The U.S. talent pool and research community suffers, and we take second place—or perhaps become irrelevant—in the space race. Carbon emissions skyrocket, eliminating any reasonable chance of meeting important climate goals.

  The lack of U.S. leadership fundamentally impacts global nuclear security as well. A nuclear marketplace lacking the U.S. focus on safety, reliability, and security immensely increases the risk for catastrophic failure. Another Chernobyl or Fukushima not only will harm countless lives, but risks putting an end to nuclear power around the world, and all

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[62] *See* Al-Masry Al-Youm, "Construction of First Nuclear Reactor at Dabaa Station to Start after Christmas Holidays," *Egypt Independent*, December 13, 2017, http://www.egyptindependent.com/construction-first-nuclear-reactor-dabaa-station-start-christmas-holidays/. The article notes that of the $21 billion price tag for the four new reactors, Russia will fund 85 percent of the plant through a loan, and the rest will be financed by Egypt. The deal was finalized in September 2017.

[63] *See* David D. Kirkpatrick, "In Snub to U.S., Russia and Egypt Move toward Deal on Air Bases," *New York Times*, November 30, 2017, https://www.nytimes.com/2017/11/30/world/middleeast/russia-egypt-air-bases.html. "The United States has provided Egypt more than $70 billion in aid in the four decades since, at a rate of more than $1.3 billion a year in recent years. The cost is often justified in part by the argument that it secures the use of Egypt's airspace and bases for the U.S. military."

[64] *See* Nuclear Energy Institute, "Economic Growth & Job Creation," https://www.nei.org/advantages/jobs.

the immeasurable benefits it brings. We are quickly ceding our safety-focused nuclear leadership to world players with far less regard for safety.

- We give up our technological leadership, and accompanying economic benefits. Companies such as TerraPower will continue to take their new nuclear designs abroad for testing, licensing, and eventual commercialization. In doing so, they will provide their IP to foreign powers that are willing to invest and move forward these innovative technologies.

  In such a world, not only will we lose these cutting edge designs, but, more importantly, we will lose the talent behind them, and all the underlying benefits that come with an ecosystem of nuclear innovation. A nuclear brain drain is well acknowledged as experts retire and new talent looks elsewhere. *This affects both the commercial nuclear energy industry and military nuclear industry.*[65] The loss of high-technology talent to China or other less friendly destinations will harm the United States for decades to come. Imagine what the world would have looked like if Silicon Valley was located in Moscow instead of California? This could happen for nuclear power and its related industries and future innovators.

[65] Russell Ray, "Who Will Replace Nuclear Power's Aging Work Force?," *Power Engineering*, February 5, 2015, https://www.power-eng.com/articles/npi/print/volume-8/issue-1/nucleus/who-will-replace-nuclear-power-s-aging-work-force.html.

03 How Can We Come Back from the Brink?

All is not lost—yet. But we *are at* the defining moment in time that will determine important aspects of our country's future. If that future is to be bright, we must move quickly in a different direction. The current industry is hurting, but is not yet out of commission. Our nuclear Navy is looking at problems down the road, but still remains the world's dominant military force. And, as noted above, there are currently about 75 new U.S. ventures developing next-generation nuclear power reactors, covering a variety of designs.[66] Advanced reactors promise to reenergize the nuclear dream for the next generation of scientists and engineers. The current secretary of energy has laid forth a proposal to "make nuclear energy cool again,"[67] and bring top talent back into the field.[68] The chance is there for a true nuclear Renaissance, if we act to put the pieces in place now.

An Integrated Civilian-Government Approach

Given all of the benefits the commercial nuclear power industry provides, it seems hard to imagine that it is at risk of extinction in the United States. But it is. And the reason for it is simple—arguably, all of the benefits of nuclear power described above, currently go uncompensated. The nonproliferation benefits, geopolitical advantage, and infrastructural support to the Navy are all simply ancillary benefits of an industry otherwise forced to compete in a brutal energy marketplace focused on what is essentially a single metric—the hourly cost of electricity. But the solution is not necessarily to change the market. While that may help, something as foundational to national security as the nuclear industry simply cannot be left to the vagaries of the competitive commercial market.

Rather, the U.S. needs to take a different approach, and think of hybrid civilian and government nuclear infrastructures together as one *integrated nuclear infrastructure*. An integrated nuclear energy infrastructure is a fundamental strategic national asset for any major nation—and the United States is no exception. Like the interstate highway system, nuclear energy provides broad-based benefits to the entire United States, from domestic energy security to geopolitical influence, and is thus a non-market asset. It is a public good that needs public support.

An *integrated nuclear infrastructure* approach seeks to buttress the infrastructure necessary to support (1) the peaceful uses of nuclear technology, and (2) U.S. defense needs, and to maintain those elements of the civilian nuclear industry that provide a national security benefit and are at risk of disappearing. This would essentially mandate support of the following:

- *The infrastructure necessary to support advanced reactor development and nuclear medicine* (including domestic research reactors, medical isotope reactors, a domestic

[66] Third Way, "The Advanced Nuclear Industry: 2016 Update," December 12, 2016, https://www.thirdway.org/infographic/the-advanced-nuclear-industry-2016-update.
[67] Rick Perry, "Make nuclear energy cool again," Reuters, June 27, 2017, https://www.reuters.com/video/2017/06/27/make-nuclear-energy-cool-again-rick-perr?videoId=371976394.
[68] Nuclear Energy Institute, "Millennial Leaders Offer Nuclear Industry a Bright Future," October 26, 2017, https://www.nei.org/news.

fuel cycle capable of supporting next-generation reactors, and safe high-level waste storage and spent fuel reprocessing technology as needed).

- *A healthy pool of nuclear expertise needed to fuel innovation in nuclear technology* (found in the civilian reactor and vendor communities, along with the national laboratories and the nuclear naval complex).

- *The civilian infrastructure necessary to support the defense complex* (including modern commercial reactors, and a fully domestic fuel cycle).

Strong U.S. leadership in peaceful uses of nuclear power also enables the United States to continue to set the standards for safety and security globally, and exert greater leverage over other countries that may seek to use nuclear power programs as an avenue for weapons development and deployment. Returning U.S. dominance in this field enables us to become more competitive against other nations that seek to deploy cheap but lower-standard nuclear energy facilities across the world with their "build, own, fuel, and operate" approach. We need to create the ability and incentives for other nations to enter into a strategic alliance with, and indeed, reliance on, the U.S., with its high safety and security standards, so that we—rather than the Russians, Chinese, and potentially others—have a positive strategic influence on the host country's energy infrastructure, and on the host country overall.

Recommendations

Developing an *integrated nuclear infrastructure* approach will require a change in mindset as to how we view the commercial nuclear power industry. The following are five concrete actions that we can take as a country to kick things off:

(1) Form a U.S. Government/National Security Council-Driven Nuclear Leadership Program to Oversee this Initiative.

A new U.S. body should be established that centralizes the multitude of U.S. agencies that work with the nuclear industry. This body should include private-sector support, but with U.S. government leadership, to take the approach that is *best for the country*—rather than any particular company or technology. The program would be National Security Council directed and driven. While the private sector would be engaged, the National Security Council would ultimately be responsible for choosing the path to pursue.

The Nuclear Leadership Program would be responsible for developing a compelling initiative for ensuring:

- U.S. Leadership in nuclear energy for energy production;
- U.S. Leadership in nuclear technology for naval and weapons readiness; and
- U.S. Leadership in nonproliferation restraint of rogue regimes in weapons development.

The Nuclear Leadership Program would provide both financial and nonfinancial assistance, with an emphasis on coordination, streamlining the bureaucracy, and technology assistance. It would focus on helping to revitalize our industry base domestically, and facilitate (as other countries do) our ability to compete globally.

(2) Form a Nuclear Energy Advisory Council as a Federal Advisory Committee Act (FACA) Body to Advise the President and National Security Council on the Domestic and International Approaches for Nuclear Energy.

The Nuclear Energy Advisory Council could be mirrored after the National Infrastructure Advisory Council (NIAC), which addresses homeland security matters, and is generally composed of former business and engineering executives, as well as U.S. government leaders. This council would be able to serve as a platform to bring ideas together, and present a clear, unified vision to the president and National Security Council. Its scope would likewise focus on what to do to help revitalize the commercial nuclear power industry domestically as well as globally.

(3) Use the Nuclear Leadership Program and the Nuclear Energy Advisory Council to Drive Forward Critical *Domestic* Nuclear Industry Policy Changes:

i. Support the completion of our present nuclear projects under construction.

Westinghouse's AP-1000 is the only entirely U.S.-origin nuclear reactor design under construction in the United States, and this "first of a kind" technology needs to be proven—and the U.S. ability to build the plant, not only to the U.S. but the world—through the completion of the new nuclear power plants under construction in the Southeastern U.S. at Southern Company's Vogtle 3&4 project.

Once these plants are operating, the U.S. government should continue to provide support for the first five to seven years of operation, in order to address first-of-a-kind issues that are likely to be encountered. This type of support is not unprecedented. And in fact, the United States has done this for many first-of-a-kind designs over the past decades, including our first nuclear plant at Shippingport. This support could take the form of support for completion of construction and operations.

ii. Ready the next wave of U.S.-origin advanced reactors and fuel.

Advanced reactors, including small and modular reactors, are likely the next wave of nuclear power plants deployed in the United States and around the world. Despite their potential, advanced reactors are primarily in the R&D phase, and only one—NuScale—has submitted an application for approval of its reactor design to the NRC. There is a desperate lack of test reactors for new nuclear fuels, and there is no fuel cycle in place that can currently supply the unique types of liquid and other fuel designs, even for testing purposes, much less for power generation. A private company, acting alone, has a very challenging time building the business case for success when it needs to address *all* development costs, over a period of more than a decade, and do so without an "order book" for cost recovery. This challenge is made nearly insurmountable when there is no regulatory framework in place to help bring legal certainty to the fuel supplier or its end user (the reactor vendor).

The United States has an incredible opportunity to do what it does best—foster innovation through providing a common infrastructure, such as a suite of test reactors across its national labs. These test reactors would then be able to be used by the nuclear Navy to test smaller reactor designs for the next generation of warships.

The United States should consider becoming the first customer for advanced reactors, using a Shippingport model, to help the industry deal with the first-of-a-kind challenges that will exist when prototypes are built. Prototypes can be deployed at energy-intensive national laboratories or military installations, among a host of other places. At least three U.S. government sites should be chosen to support three different advanced reactor technologies (e.g., high-temperature gas-cooled reactors, molten salt reactors, and lead-cooled reactors).

The United States should pair this with an increase in government funding to support the development of these new designs, including through nonfinancial assistance. Universities and a vibrant "secondary" economy of suppliers and talent should be fostered to participate in these programs. These participants will help form the future of a new/revitalized vendor base for advanced reactors.

The United States should explore ways to accelerate the development of advanced fuel designs, including accident-tolerant fuel for existing and future nuclear power plants in the United States and abroad. Russia has recently announced that it intends to introduce accident tolerant fuel to market in early 2020, which is intended for use in western nuclear reactors (including U.S. reactors).[69] In the U.S., a number of advanced and accident-tolerant fuels are also under development, but they often struggle to find a research reactor capable of testing these fuels before insertion in a commercial power reactor. The United States should explore ways to expedite the development of these fuels and bring them to market, including by potentially using existing U.S. commercial plants in the United States for research purposes.

The NRC must also return to its roots as a regulator that is open to all technology options, and revamp its regulatory framework geared toward light-water reactors. Some work has been done on this front, but it has been largely nibbling around the edge of the problem. The NRC needs to step away from a license-by-guidance model that has proven disastrous for advanced reactor projects, and instead, the agency should move toward a more flexible method of regulation, in which applicants can make their safety case all at once to the agency, instead of piecemeal. The NRC staff should also weigh in on the design along the way, instead of maintaining its rigid pre-application and application process where the NRC staff provides little input. More than token funding is required by Congress to enable the agency to take this leap. Moreover, the NRC cannot

[69] S&P Global, Platts, "Rosatom to offer accident tolerant fuel to customers by early 2020s: TVEL," *Nucleonics Week* (Vol. 59, No. 21), May 24, 2018.

be required to charge applicants for its own time to be brought up to speed in analyzing first-of-a-kind issues, at a cost of hundreds of millions of dollars to reactor license applicants. An educated regulator is a public good and should be paid for by the public. The Nuclear Leadership Program is well aligned to both push for reforms and assist the NRC in implementing and funding them.

The overriding goal of these programs should be to give advanced reactors a path to commercialization within the United States before they go somewhere else. This path to commercialization should take into account the broad geopolitical, economic, and military benefits of keeping this technology at home.

iii. Develop a "ready reserve" option for some U.S.-stressed nuclear plants.

Unlike other power generation sources, nuclear power plants cannot be mothballed once they shut down, because the NRC essentially requires a plant to be fully staffed even in a nonoperational state. A commercial entity cannot sustain such costs without an operating plant producing electricity and revenue, and must instead move toward decommissioning. Once decommissioning starts, the operator essentially reaches a point of no return, after which restart is economically or physically not possible.

When economic stress otherwise drives a nuclear power plant to entertain premature shutdown and decommissioning, a utility could instead apply for "ready reserve" status, and the U.S. government could exercise an option to procure the plant, if warranted by national security or grid reliability considerations. Under this scenario, the U.S. government, working with the NRC, could keep a plant in "safe shutdown" mode with the limited staffing (O&M, surveillance, inspections, maintenance) necessary to maintain the plant for future restart. The fact that the plant is under government control can help reduce certain regulatory requirements. The utility would retain decommissioning liability and title to spent fuel. The plant may also be able to be used to support R&D for advanced reactors and advanced fuel, as appropriate, such as for irradiation testing to support new fuel designs for advanced reactors.

The utility could retain an option to reacquire the plant and return it to future operation if economics turn favorable. The U.S. government could return the plant to the utility for operations if needed, or for decommissioning at any time if the U.S. government deems the option for operation not viable. The jurisdictional issues and NRC oversight framework would need to be detailed further, but with congressional support a solution could be quickly reached.

(4) Use the Nuclear Leadership Program and the Nuclear Energy Advisory Council to Drive Forward the Important *International* Nuclear Energy Industry Policy Changes:

i. Create a framework for a joint "USA, Inc." public-private partnership for nuclear new-build projects to enable the United States to compete abroad.

Working with the Nuclear Leadership Program and the Nuclear Energy Advisory Council, the Executive Branch needs to create a framework in which all key participants in a nuclear new build project—the reactor vendor, suppliers, EPC contractors, fuel fabricators, etc.—can put forward a single, joint proposal backed by U.S. government support, including through loan guarantees and relevant insurance. This framework can offer something as close as possible to the cradle-to-grave approach utilized by Russia and China. This framework would maximize use of a U.S. supply chain, but may include foreign partners with expertise in areas where the U.S. does not currently excel. An experienced U.S. operator would also be part of the "USA, Inc." consortium, to provide key operating expertise—expertise often lacking from the low-cost proposal put forth by our geopolitical competitors.

First trial runs of this approach could be executed in countries with strong U.S. ties, such as in the United Arab Emirates, which wants to entertain an expansion to its current reactor project. The United Arab Emirates already works with the U.S. nuclear community on a number of facets of its current program and has a bilateral agreement for nuclear cooperation—a 123 Agreement—in place with the United States. But, with nuclear expanding around the world, opportunities should present themselves to perfect this model. Saudi Arabia and Jordon are currently moving forward with programs, and countries in Southeast Asia and Africa are expected to follow. In fact, the USA, Inc. consortium should be prepared to bid on any new venture that are seen as advancing U.S. interests—especially in areas of the world where the U.S. government wants and needs to maintain influence, such as the Middle East and emerging countries of Africa.

The USA, Inc. consortium could be led initially by traditional light water reactor teams. This would include U.S.-sourced engineering, as well as equipment and technology. But USA, Inc. could be expanded to include small modular reactors and advanced reactors as they come into their own—such as NuScale. These companies should be able to work with the Nuclear Leadership Program to develop their own USA, Inc. consortia to market their technologies around the world. Indeed, a small modular reactor/advanced reactor may be better suited for a number of countries around the world because of its intended flexibility, lower capital costs, and inherent safety features—such as underground construction. But jumpstarting new designs like these will require major engagement and support by the U.S. government.

ii. *Market the benefits of the U.S. regulatory and oversight framework and nonproliferation regime abroad.*

The best way for the United States to regain its voice in the nonproliferation arena is to have a robust nuclear technology "carrot." At the same time, countries looking to build a nuclear reactor that choose China and Russia as vendors also need to understand the risks they are taking by adopting a design or operations regime that has not been validated to meet the superior standards of the NRC and the Institute of Nuclear Power Operations. It is important that the United States, through the Nuclear Leadership Program, and with the voice of the U.S. government, communicate globally the value and importance of high nuclear safety standards, and the logic and experience of why everyone benefits when all plants around the world are built with safety, security, and nonproliferation as core goals.

The U.S. nuclear operations record supports that position. In fact, the United States led the now globally recognized concept of nuclear safety culture—that is, "the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment"[70]—and the United States is critical to establishing the highest standards of nuclear safety and security abroad. The widely successful U.S. model of nuclear safety culture requires that *anyone* within an organization be free to raise a safety issue to anyone else—a supervisor, a manager, executives, the board of directors, even directly to the regulator. For any other type of business this concept may seem foreign—to have a low-level employee directly engage with the highest echelons of an organization or even to circumvent that structure and go directly to a regulator.

In the U.S. nuclear industry, these concepts are ingrained. But, for other countries, whose corporate and societal cultures may be very different from our own, "safety culture" concepts may be difficult to instill, to the detriment of nuclear safety. The best way to overcome these difficulties, however, is to embed them into the entire nuclear corporate and regulatory culture. The more that the United States stays involved globally in supporting nuclear owners, nuclear operators, and new nuclear projects, the more likely it will be that a country with a new nuclear program will be able to understand these principles, how they are instilled in practice, and—just as importantly—what practices can undermine them.

(5) Look at the Saudi Nuclear New Build RFP as a Potential Turnaround Opportunity and Test Case.

Saudi Arabia has recently announced that it is interested in building a large number of new nuclear reactors from foreign vendors—potentially up to 16.[71] If it moves forward as planned, this project could represent one of the largest nuclear new-build opportunities in the world. Many factors line up in our favor to support this project, including generally favorable relations with the government, and an understanding that U.S. nuclear reactor designs promise long-term safety and security benefits unmatched by other potential respondents. In particular, a U.S. partnership with a Korean nuclear reactor vendor, which has been successfully previewed in the United Arab Emirates, could provide a compelling counteroffer to Russian or Chinese proposals.

However, this Saudi nuclear new-build opportunity also represents a challenge for the U.S. government, as it will likely have to rethink its approach to nuclear cooperation in order to enable U.S. participation in the competitive process—which is currently underway. The United States will need to move fast to iron out key policy considerations, support the U.S. vendor community, and seek to harmonize regulatory and financial incentives into a single, clear, marketable package. The Nuclear Leadership Program and the Nuclear Energy Advisory Council may not be established in time to support this

[70] U.S. Nuclear Regulatory Commission, "Safety Culture Policy Statement," June 14, 2011, https://www.nrc.gov/about-nrc/safety-culture/sc-policy-statement.html.
[71] "Saudi Arabia aims to prequalify firms by April or May for first nuclear plant," Reuters, January 15, 2018, https://www.reuters.com/article/us-saudi-nuclear/saudi-arabia-aims-to-prequalify-firms-by-april-or-may-for-first-nuclear-plant-idUSKBN1F4187.

effort, but the concepts can be set in motion through the executive branch, as U.S. leadership in the evolving Saudi nuclear initiative is critical. The competitive process is already favoring foreign bids. So, the United States would need to bring a number of policy and commercial issues "in line" in order for U.S. companies to be competitive in this bid.

As a bigger picture, cooperation between U.S. government and U.S. industry—where collectively they operate as "USA, Inc."—can serve as a model and test case for future bids around the world.

04 Conclusion

We do recognize that there are critical areas to be further evaluated, and critical questions to be asked and answered. There is an incompleteness of solutions to the situation today, and, therefore, the critical need for leadership engagement from within the U.S. government—including the National Security Council, the Department of Defense, the Department of Energy—that also includes private-sector participation, as well as congressional engagement. But this further evaluation can be part of a broader conversation and determination of specific actions that would be the work of the Nuclear Leadership Program and Nuclear Energy Advisory Council.

The United States is at a pivotal moment. The time to act is now.

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COVER PHOTO THE USS JOHN WARNER (SSN-785), CONDUCTING SEA TRIALS IN THE ATLANTIC OCEAN ON JUNE 9, 2015. US NAVY PHOTO

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