Facilitating Fission: How the NRC Can Improve the Licensing of Small Modular Reactors

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INTRODUCTION

In September 2020, the Nuclear Regulatory Commission (NRC), approved a standard design for a small modular reactor (SMR) designed by NuScale Power LLC (NuScale), the first SMR to receive standard design approval in the United States. [1] While the NuScale SMR is the first effort by the United States to promote an advanced reactor design, elsewhere in the world similarly advanced reactors are already being constructed and operated in places like Russia, China, and Argentina.[2] Of the approximately seventy advanced reactors currently being developed worldwide, only eighteen, or twenty-five percent, are being designed by parties in the United States.[3] If the United States, home of first self-sustaining nuclear reactor, does not take action to promote the development of advanced reactors, it risks falling behind the international community.[4] In order to maintain its dominance in the nuclear energy market, the NRC must update its regulations to accommodate the advanced reactor designs of the twenty-first century. This note discusses the regulations that should be revised by the NRC to facilitate SMR licensing

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[1] *See* Dave Levitan, *First U.S. Small Nuclear Reactor Design is Approved*, SCI. AM. (Sept. 9, 2020), https://www.scientificamerican.com/article/first-u-s-small-nuclear-reactor-design-is-approved/.

[2] *See* INT'L ATOMIC ENERGY AGENCY, ADVANCES IN SMALL MODULAR REACTOR TECHNOLOGY DEVELOPMENTS 1 (2020) [hereinafter ADVANCES] (reporting that a two-module SMR began commercial operation in Russia in May 2020 and two "SMRs are in advanced stages of construction" in Argentina and China with anticipatory operational dates between 2021 and 2023").

[3] *See id.*

[4] *See* June Sawyers, *The Day Fermi Ushered in the Atomic Age*, CHI. TRIB., Nov. 29, 1987, at C10 (describing the invention of the first self-sustaining nuclear reactor by Enrico Fermi at the University of Chicago).

and the advances in SMR technology that enable such changes to be made without compromising reactor safety.

"Small modular reactor" is the universal term used to describe advanced reactors that have individual operating capacities less than 300 MW_e and can be combined with other modules to increase the energy capacity of a single site.[5] There are a number of different categories of SMRs that use different materials as the moderator.[6] This note focuses on light water reactor (LWR) SMRs. A light water reactor (LWR) uses normal water, H_2O, to slow down neutrons. This is different from a heavy water reactor which uses deuterium oxide.[7]

It is beneficial for the United States to encourage the develop of SMRs for both commercial and environmental reasons. The Nuclear Energy Agency estimates that the worldwide demand for advanced reactors will be one hundred billion dollars by 2035.[8] Currently, nuclear power supplies eleven percent of the world's electricity from reactors located in thirty-two countries.[9] Worldwide energy consumption was 25.4 trillion kilowatt-hours in 2015 and is expected to increase to 34 trillion kilowatt-hours by 2040.[10] Energy consumption in the United States, alone, is expected to grow one percent per year.[11] During that same time period, total nuclear power plant capacity is expected to decline by six gigawatts.[12] Thus, while the demand for electricity is increasing, the supply from nuclear power plants is decreasing as countries fail to replace aging large LWRs.

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[5] MASS. INST. OF TECH., THE FUTURE OF NUCLEAR ENERGY IN A CARBON-CONSTRAINED WORLD 60 (2018) [hereinafter THE FUTURE].

[6] *See* ADVANCES, *supra* note 2, at 4; Definition of Moderator, U.S. NRC, https://www.nrc.gov/reading-rm/basic-ref/glossary/moderator.html (last visited Dec. 3, 2020) (defining "moderator" as "a material, such as ordinary water, heavy water, or graphite, that is used in a reactor to slow down high-velocity neutrons, thus increasing the likelihood of fission").

[7] *See* Heavy Water, ENCYCLOPEDIA BRITANNICA, https://www.britannica.com/science/heavy-water (last visited Dec. 3, 2020).

[8] Andrew Maykuth, *Going Small; Nuclear Power's Next Big Thing is Reducing the Size of its Reactors*, PHILA. INQUIRER, Mar. 17, 2019, at E1.

[9] THE FUTURE, *supra* note 5, at 3.

[10] *Id.* at 1.

[11] *Id.*

[12] *Id.* at 4.

In addition to widespread demand, SMRs offer a more cost-effective solution than the large LWRs of the twentieth century. Unlike the nuclear dinosaurs of the past which were constructed onsite, SMRs "can be mass-produced at existing U.S. manufacturing facilities."[13] Newport News Shipbuilding, the Virginia company that builds nuclear-powered submarines and aircraft carriers for the United States Navy, reported that a reactor construction task which normally requires eight man-hours to complete onsite is able to be performed in one man-hour at a modular fabrication shop.[14] It is estimated that such cost-saving realities of SMRs will be able to reduce the construction of nuclear power plants by approximately one thousand six hundred dollars per kilowatt, or roughly thirty percent.[15]

SMRs offer environmental advantages as well. In order to reach the climate benchmarks established by the Paris Agreement, the country will have to reduce the amount of carbon dioxide produced in electricity generation by 97 percent.[16] Nuclear power plants, with a carbon footprint that is equivalent to windmills and lower than solar power, provide the solution.[17] In fact, according to models prepared by the Massachusetts Institute of Technology, decarbonization goals *cannot be achieved* without relying upon nuclear power unless there are significant developments in renewable and battery storage capacities.[18]

While the success of SMRs relies, in part, on research and development, it also depends upon enabling regulations that are tailored to twenty-first century technologies. The Nuclear

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[13] *Id.* at xx ("Countries with high labor rates and low productivity have stronger incentives to use modular construction in factories and shipyard to reduce labor requirements").
[14] *See id.* at 45.
[15] *Id*. at 46.
[16] *See id.* at 3.
[17] Simon Evans, *Solar, Wind and Nuclear Have 'Amazingly Low' Carbon Footprints, Study Finds*, CARBON BRIEF, https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-footprints (last visited Dec. 3, 2020) (reporting the following lifetime carbon dioxide produced per kilowatt-hour: nuclear, 4 grams; wind, 4 grams; solar, 6 grams; hydro, 97 grams; natural gas, 78 grams; coal, 109 grams).
[18] *See* THE FUTURE, *supra* note 5, at 23.

Regulatory Commission is the agency tasked with regulating and licensing nuclear power plants.[19] During the licensing process for the NuScale SMR, the NRC acknowledged that some of its design criteria were inapplicable to the new reactor design, such criteria having been "developed based on the licensing of early commercial water-cooled reactor plant designs."[20]

This purpose of this note is to explain how and why the NRC can update its regulations to facilitate the develop of small modular reactors. Part I provides a background of the NRC to include a discussion of the legislation that both empowers it to regulate and demands that it promote technological advancement. Part II presents a technical comparison of large LWRs to SMRs. By comparing and contrasting the operating parameters and safety features, the note presents evidence for why more conservative regulations are no longer necessary. Part III then describes several regulations that inhibit the development of SMRs and how the NRC has considered updating its design requirements.

I. THE NUCLEAR REGULATORY COMMISSION

A. History of the Nuclear Regulatory Commission

Before the NRC was established by Congress, the Atomic Energy Commission (AEC) oversaw nuclear operations, both for military and civil purposes, in the United States.[21] As the development of nuclear reactors increased in the 1960s and 70s, the regulatory burdens on the AEC increased as well, and it became clear to Congress that nuclear responsibilities must be split between two organizations, one to perform research and development and the other to oversee licensing and regulation.[22] As a result, Congress passed the Energy Reorganization Act of 1974

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[19] *See* 42 U.S.C. § 5841(f) (2018).

[20] NUCLEAR REG. COMM'N, NUSCALE POWER EXEMPTION REQUEST FROM 10 CFR PART 50, APPENDIX A, GENERAL DESIGN CRITERION 27, "COMBINED REACTIVITY CONTROL SYSTEMS CAPABILITY" (2018).

[21] *See* ALICE BUCK, THE ATOMIC ENERGY COMMISSION 1–4 (1983).

[22] *See id.* at 16–18.

which split the AEC into two separate agencies by creating both the NRC and the Energy Research and Development Administration. [23] The latter was directed to oversee nuclear military and production activities, while the NRC received "all the licensing and regulatory functions of the Atomic Energy Commission."[24]

In passing the Energy Reorganization Act, Congress provided a legislative purpose for the two new agencies when it wrote,

> "Congress hereby declares that the general welfare and the common defense and security require effective action to develop and increase the efficiency and reliability of use of, all energy sources to meet the needs of present and future generations, to increase the productivity of the national economy and strengthen its position in regard to international trade, to make the Nation self-sufficient in energy, to advance the goals of restoring, protecting, and enhancing environmental quality, and to assure public health and safety."[25]

By enabling and supporting the development of SMRs, the NRC would be fulfilling the above legislative goals, written over thirty years ago. By approving cost-efficient electrical generation, the NRC is *increasing* "the productivity of the national economy."[26] By permitting the construction of modular reactors in factories, the NRC is opening the door for the United States to become exporters of nuclear reactors thus *strengthening* the country's "position in regard to international trade."[27] Finally, by promoting an industry with the lowest carbon footprint, the NRC is "enhancing environmental quality."[28]

B. Federal Legislation to Promote the Development of Advanced Reactors

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[23] *See id.* at 19.
[24] 42 U.S.C. § 5841 (f) (2018). *See* 42 U.S.C. § 5801 (b) (2018).
[25] 42 U.S.C. 5801 (a) (2018).
[26] *Id.*
[27] *Id.*
[28] *Id.*

Congress did not just leave it to a creative reading of the Energy Reorganization Act for the NRC to find a congressional directive to promote the development of advanced reactors. In 2018 and 2019, it passed a pair of laws specifically directed towards nuclear power plant innovation, the Nuclear Energy Innovation Capabilities Act (NEICA) and the Nuclear Energy Innovation and Modernization Act (NEIMA).[29]

The NEICA is directed predominantly towards the Department of Energy (DOE) and aims to create "partnerships between private sector innovators in nuclear energy with government researchers to create the next generation of clean, advanced nuclear power."[30] The NEICA impacts the NRC when it calls for coordination with the DOE to ensure that the NRC "has sufficient knowledge to support the evaluation of applications for licenses, permits, and design certifications . . . for advanced nuclear reactors" and mandates the creation of a cost-sharing program in which the DOE pays out "grants to applicants for the purpose of funding a portion of the [NRC] fees" for application review.[31]

While the NEICA emphasizes the actual innovation of advanced reactor technology, the NEIMA focuses on the development of the necessary regulatory and licensing process to encourage that innovation.[32] In NEIMA, Congress recognized that the NRC's regulatory framework was developed to address challenges presented by large LWRs "and may not be suitable for advanced technologies with unique characteristics that may warrant different safety

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[29] *See* Nuclear Energy Innovation Capabilities Act of 2017, Pub. L. No. 115-248, 132 Stat. 3154 (codified as amended in scattered sections of 42 U.S.C.); Nuclear Energy Innovation Modernization Act, Pub. L. No. 115-439, 132 Stat. 5565 (codified as amended in scattered sections of 42 U.S.C.).

[30] *Bipartisan Energy Innovation Bill Heads to President's Desk*, SENATE COMMITTEE ON ENERGY & NAT. RESOURCES (Sept. 13, 2018), https://www.energy.senate.gov/2018/9/bipartisan-nuclear-energy-innovation-bill-heads-to-president-s-desk.

[31] 42 U.S.C. § 16278 (2018); 42 U.S.C. § 16280 (2018).

[32] *See* Nuclear Energy Innovation Modernization Act, Pub. L. No. 115-439, 132 Stat. 5565 (codified as amended in scattered sections of 42 U.S.C.).

requirements."[33] The purpose of the act, therefore, is to establish "a program to develop the expertise and regulatory processes necessary to allow innovation and the commercialization of advanced nuclear reactors."[34]

The Senate Committee on Environment and Public Works (the Committee) wrote that the NRC's new regulatory processes must be "more holistic" and "technology-inclusive."[35] To become "more holistic," per the NEIMA, the NRC must implement "strategies for the increased use of risk-informed, performance-based licensing evaluation techniques . . . within the existing regulatory framework."[36] The Committee suggested that a "risk-informed, performance-based" approach to licensing will give the NRC the necessary flexibility to approve a diverse range of reactor designs to which the typical safety requirements for LWRs may not apply. To become "technology-inclusive," the NEIMA requires the NRC, by the end of 2027, "to complete a rulemaking to establish" a regulatory framework that accommodates advanced reactor designs.[37]

The NEIMA calls for the creation of a staged licensing process "for the purpose of predictable, efficient, and timely reviews" to facilitate fundraising efforts by the companies that design advanced reactors.[38] The Committee suggested that it is easier for "companies to seek investment as a design successfully completes each stage rather than attempting to raise $1 to $2 billion dollars at the start of the process without a predictable schedule."[39]

C. Implementation of Congressional Acts

The NRC has taken several actions to implement Congress' latest statutory requirements as reported by the agency in an update to Congress on its progress. The NRC has held

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[33] S. REP. NO. 115-86, at 5 (2017).
[34] 42 U.S.C. § 2215 (2018).
[35] 42 U.S.C. § 2133 (2018); S. REP. NO. 115-86.
[36] 42 U.S.C. § 2133 (2018).
[37] *Id.*
[38] *Id. See* S. REP. NO. 115-86.
[39] S. REP. NO. 115-86.

workshops with shareholders to develop guidance for both applicants and NRC staff members regarding the submission and review of advanced reactor license applications.[40] Additionally, they have partnered with the Licensing Modernization Project (LMP), "a team of advanced reactor technology and licensing" experts led by Southern Company, and the Nuclear Energy Institute (NEI) "to establish a technology-inclusive regulatory framework for advanced reactors."[41]

More recently, the NRC set a 2024 deadline for its staff to finalize a new section to govern licensing of advanced reactors under Title 10.[42] This is three years prior to the 2027 deadline set by Congress in the NEIMA.[43] As part of the rulemaking required for the development of 10 C.F.R. 53, as it would be labeled, the NRC announced in November 2020 that it would be periodically publishing proposed rules on the federal register for updating its regulations to be risk-informed, performance-based, and technology-inclusive.[44]

II. Comparison of SMR and Traditional LWR Reactor Technology

A. Casualty of Concern

To understand the importance of SMR's safety features, it is necessary to understand the casualty of concern that reactors are designed to avoid, the damage that can result, and the mechanisms by which the casualty comes about.

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[40] *See* NUCLEAR REGULATORY COMM'N, UPDATE ON THE NUCLEAR REGULATORY' COMMISSION'S (NRC) IMPLEMENTATION OF THE NUCLEAR ENERGY INNOVATION AND MODERNIZATION ACT (NEIMA) (2020).

[41] *Id;* WAYNE MOE, LICENSING MODERNIZATION PROJECT FOR ADVANCED REACTOR TECHNOLOGIES: FY 2018 PROJECT STATUS REPORT V (2018).

[42] *See* Alex Polonksy, Jane Accomando, Roland Backhaus, *NRC Commissioners Accelerate Schedule for New Part 53 for Advanced Reactors*, MORGAN LEWIS (Oct. 7, 2020) https://www.morganlewis.com/blogs/upandatom/2020/10/nrc-commissioners-accelerate-schedule-for-new-part-53-for-advanced-reactors.

[43] 42 U.S.C. § 2133 (2018).

[44] *See* Alex Polonsky, Jane Accomando, & Ariel Braunstein, *Action Required on NRC Rulemaking for Advanced Reactors*, MORGAN LEWIS (Nov. 16, 2020) https://www.morganlewis.com/blogs/upandatom/2020/11/action-required-on-nrc-rulemaking-for-advanced-reactors.

The casualty of concern is the release of radiation and radioactive materials to the environment. Congress calls this casualty an "extraordinary nuclear occurrence" and defines it as "any event causing a discharge or dispersal of source, special nuclear, or byproduct material from its intended place of confinement in amounts offsite, or causing radiation levels offsite."[45] Source material includes natural or depleted uranium or thorium.[46] Special nuclear material is defined as the enriched uranium or plutonium used in the fission process.[47] Byproduct material "includes any radioactive material (except enriched uranium or plutonium) produced by a nuclear reactor."[48] Extraordinary nuclear occurrences can result in a "nuclear incident" which is any occurrence within the United States that causes "bodily injury, sickness, disease, or death," or property damage, "resulting from the radioactive, toxic, explosive, or other hazardous properties of source, special nuclear, or byproduct material."[49]

Bodily injury occurs when a person is exposed to either gamma or alpha radiation resulting from radioactive decay of atoms. [50] Both of these types of radiation are stopped by the materials used to construct reactor containment boundaries.[51] Gamma radiation causes cell damage when it passes through the human body.[52] Alpha radiation is unable to penetrate human skin, but can be harmful if swallowed or inhaled.[53] Most radiation damage manifests through cancer years after exposure. However, radiation sickness, or Acute Radiation Syndrome, is a severe, but infrequent,

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[45] 42 U.S.C. § 2014 (j) (2018).

[46] *See Source Material*, U.S. NRC, https://www.nrc.gov/materials/srcmaterial.html (last visited Dec. 18, 2020).

[47] *See Special Nuclear Material*, U.S. NRC, https://www.nrc.gov/reading-rm/basic-ref/glossary/special-nuclear-material.html (last visited Dec. 18, 2020).

[48] *Byproduct Material*, U.S. NRC, https://www.nrc.gov/reading-rm/basic-ref/glossary/byproduct-material.html (last visited Dec. 18, 2020).

[49] 42 U.S.C. § 2014 (q) (2018).

[50] *Radiation in Everyday Life*, INT'L ATOMIC ENERGY AGENCY, https://www.iaea.org/Publications/Factsheets/English/radlife (last visited Dec. 18, 2020).

[51] *See id.*

[52] *See id.*

[53] *See id.*

occurrence in which exposure to a large amount of radiation in a short amount of time results in critical injury and death, examples of such exposure being the emergency responders at the Chernobyl explosion and victims of the atomic bombings in Hiroshima and Nagasaki.[54]

The reactor accidents at Fukushima and Three Mile Island are two well-known examples of extraordinary nuclear occurrences that demonstrate how such casualties occur and the importance of certain reactor safety features. In both situations, the reactors lost their ability to circulate water through the core where the fuel plates containing the radioactive elements and fission products were located. When this happened, the reactor temperature and pressure increased uncontrollably until the barrier separating the fuel from the coolant channels cracked and radioactive material, once contained within the fuel plate, was released into the environment.

At Fukushima, the accident began with an earthquake that caused three of the plants operating reactors to shut down automatically as designed.[55] The earthquake also damaged the power plant's connection to off-site AC power sources, which was necessary to power the decay heat removal system.[56] The emergency diesel generators started as a result and would have been sufficient to keep the reactor in a safe condition were it not for the subsequent tsunami that rendered the generators out of commission.[57] The power plant's electrical system switched to backup batteries which had enough stored energy to supply eight hours of DC power.[58] When the batteries died, the plant lost all means for removing decay heat from the reactor which continued to heat up, the water in the coolant channels flashed to steam, temperature and pressure increased until it exceeded the design pressure of the containment boundary, and radiation was discovered

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[54] *See Radiation Emergencies*, CTR. FOR DISEASE CONTROL AND PREVENTION, https://www.cdc.gov/nceh/radiation/emergencies/arsphysicianfactsheet.htm#:~:text=Acute%20Radiation%20Syndrome%20(ARS)%20(,usually%20a%20matter%20of%20minutes) (last visited Dec. 18, 2020).

[55] *See* DIRECTOR GEN., INT'L ATOMIC ENERGY AGENCY, THE FUKUSHIMA DAIICHI ACCIDENT 25 (2015).

[56] *See id.*

[57] *See id.* at 31.

[58] *See id.*

outside of the reactor compartment indicating that there was "some uncontrolled radioactive release from primary containment."[59]

The accident at Three Mile Island began when a feedwater pump malfunctioned resulting in a loss of feedwater to the steam generator.[60] Feedwater is converted into steam by heated reactor coolant water passing through tubes in the steam generator. The steam generator, therefore, acts as a heat sink in which heat created by the fission process is transferred from the hot coolant water to the feedwater to create steam and colder coolant water is returned to the reactor core. When the feedwater pump malfunctioned at Three Mile Island, the power plant lost the method by which it was removing decay heat from the shutdown reactor.[61] Reactor pressure and temperature increased until a pressure relief valve lifted prompting the watch team to take action to lower plant pressure.[62] Despite lowering plant pressure, the relief valve remained stuck open.[63] Operators failed to recognize the casualty due to an instrument failure, pressure continued to drop due to the open valve, and the reactor coolant pumps stopped due to a loss of net positive suction head.[64] Without operating reactor coolant pumps, the water stopped circulating through the reactor core and heat up to become steam.[65] Without water to remove heat from the fuel plates, the temperature increased until the fuel plates blistered and fractured, releasing fission products into the environment.[66]

Both the Fukushima and Three Mile Island accidents resulted from a loss of an ability to remove decay heat from a shutdown reactor. In Fukushima, the reactor lost decay heat removal

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[59] *Id.* at 35–36.

[60] *See Backgrounder on the Three Mile Island Accident*, U.S. NRC (June 21, 2018), https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html#impact.

[61] *See id.*

[62] *See id.*

[63] *See id.*

[64] *See id.*

[65] *See id.*

[66] *See id.*

capabilities when it lost electric power. In Three Mile Island, the reactor lost this capability when plant parameters dropped to a point where a pump could no longer operate. The problem, therefore, in both situations, was reliance upon an operating pump to remove heat from the reactor. Commercial LWRs in the United States do not operate much differently than the reactors at Three Mile Island and Fukushima as will be discussed in the following section.

B. Technical Specifications and Safety Features of Large Commercial LWRs

The last commercial LWR to be constructed in the United States was the Watts Bar Nuclear Plant, Unit Two, which obtained its operating license from the NRC in October 2015.[67] It is a Westinghouse four loop reactor with an operating capacity of 3,411 MW_{th} and electrical output of 1,160 MW_e.[68] The reactor is located on 1,770 acres in southeastern Tennessee.[69] Its operation is similar to that of the power plant at Three Mile Island and other LWRs in the United States. The water, or reactor coolant, is circulated by reactor coolant pumps through the reactor core where it absorbs the heat created by the nuclear fission process thus keeping the reactor at a safe temperature.[70] The hot reactor coolant is then pumped through the hot leg piping to the steam generators where it transfers heat to the colder feedwater in the steam generator converting it to the steam that drives the turbine generators to create electricity.[71] The, now cold, reactor coolant then travels back to the reactor core through the cold leg where the cycle begins again.[72] As a four

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[67] *See Watts Bar Nuclear Plant, Unit 2*, U.S. NRC, https://www.nrc.gov/info-finder/reactors/wb2.html (last visited Jan. 15, 2015).

[68] *See id*; TENNESSEE VALLEY AUTHORITY, WATT'S BAR NUCLEAR PLANT, UNIT 2 FINAL SAFETY ANALYSIS REPORT, AMENDMENT 103 1.1-1 (2011) https://www.nrc.gov/docs/ML1108/ML110840665.html [hereinafter FINAL SAFETY ANALYSIS REPORT].

[69] *See* FINAL SAFETY ANALYSIS REPORT, *supra* note 68, at 1.1-2.

[70] *See Pressurized Water Reactors*, U.S. NRC (Jan. 15, 2015), https://www.nrc.gov/reactors/pwrs.html.

[71] *See id.*

[72] *See id.*

loop reactor, the Watts Bar Nuclear Plant has four reactor coolant pumps, four steam generators, and four sets of hot and cold leg piping.[73]

The reactor coolant pumps used in LWRs are powered by offsite electricity.[74] Similar to those at Fukushima, upon a loss of electricity, onsite diesel generators turn on to supply power to pumps that ensure cooling water is circulated through the reactor.[75] To help mitigate the effect of a loss of pumping power the Watts Bar Nuclear Plant is designed to facilitate natural circulation of water through the core.[76] In the process of natural circulation, water is driven through the core by density differences between hot and cold water.[77] To enable natural circulation, the steam generator is installed at a higher position than the reactor core.[78] Hot water leaving the core is at a lower density and, therefore, rises towards the steam generator where heat is pulled from the system.[79] The colder water is at a higher density and then falls back to the reactor.[80] This process allows for some amount of core cooling in the event of a loss of pumping power.

The Watts Bar reactor contains an Emergency Core Cooling System (ECCS).[81] The ECCS is designed to shut down and cool the reactor in two specific casualties which could result in a reactor accident: loss of coolant through either broken primary piping or a stuck open relief valve (like at Three Mile Island), and an abnormal increase in reactor power resulting from either excessive steam demand caused by a break in steam piping or a lifting steam pressure relief valve or an ejection of control rods.[82] The ECCS is designed to keep the reactor core covered with water

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[73] *See Watts Bar Nuclear Plant Unit 2*, *supra* note 67.
[74] *See Pressurized Water Reactors*, *supra* note 70.
[75] *See id.*
[76] *See* FINAL SAFETY ANALYSIS REPORT, *supra* note 68 at 5.5-10.
[77] *See id.*
[78] *See id.*
[79] *See id.*
[80] *See id.*
[81] *See id.* at 6.3-1.
[82] *See id.*

and circulate water through the reactor following shutdown in order to remove decay heat.[83] Like Fukushima, the power plant accomplishes this objective by using a series of pumps designed to operate at different pressures that take suction from a variety of makeup water tanks and can be powered by both offsite electrical power and onsite diesel generators.[84] To facilitate rapid shutdown of the reactor, the ECCS also injects borated water into the primary system using pumps or pressurized accumulators.[85] Boron, a chemical poison, functions similar to the control rods in that it absorbs neutrons that would otherwise interact with the uranium fuel to cause nuclear fission.[86]

C. Technical Specifications and Safety Features of SMRs

Two SMRs in development in the United States are the NuScale reactor and Holtec International's SMR-160. As discussed previously, the NuScale reactor has obtained a standard design approval from the NRC. The SMR-160 has applied for pre-application review from the NRC.[87] These reactors utilize similar operating principles to account for the challenges faced by large LWRs building upon all that engineers have learned through decades of nuclear engineering.

The modular design means that each module is its own self-sustaining, independent unit with a single reactor, one steam generator, a pressurizer, and all the auxiliary and control equipment necessary to support reactor operation.[88] For the NuScale, twelve modules can be connected in series to increase the power output of the plant.[89] The modular design enables the power plant to

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[83] *See id.* at 6.3-2.
[84] *See id.* at 6.3-3–6.3-4.
[85] *See id.* at 6.3-2.
[86] *See Boron in Nuclear Energy*, 20 MULE TEAM BORAX, https://www.borax.com/applications/nuclear-energy (last visited Jan. 18, 2021).
[87] *See Pre-Application Review of the SMR-160 Design*, U.S. NRC (Nov. 25, 2020), https://www.nrc.gov/reactors/new-reactors/smr/holtec/review.html.
[88] *See* José N. Reyes, *NuScale Plant Safety in Response to Extreme Events*, 178 NUCLEAR TECH. 153, 153 (2012).
[89] *See id.*

continue operation even if one module is lost due to maintenance or a casualty.[90] This is different from the large LWRs, for which a similar scenario would require the entire reactor to be shut down resulting in the loss of thousands of megawatts of power from the electric grid.

Unlike the large LWRs, SMRs use minimal piping and do not require pumps to drive coolant flow, relying entirely upon natural circulation.[91] Without an extensive network of pipes, the reactors are less likely to experience a primary leak.[92] Without pumps, the reactors are not beholden to either onsite or offsite electrical power.[93] In the NuScale reactor, water heated by the reactor rises due to its low density through the hot leg riser around which the steam generator tubes are wrapped.[94] Heat is pulled from the coolant, and the water falls back down to the reactor through the downcomer region where it is again heated by the reactor.[95] This entire cycle happens within the reactor pressure vessel at the top of which are located the heaters and spray used to control plant pressure. [96] These two features are contained in a separate pressurizer bubble in large LWRs.[97] Each NuScale reactor compartment is immersed in a body of water that serves to both shield the environment from radiation and provide makeup water in the event of a leak.[98]

SMRs also rely upon basic thermodynamic principles to drive flow through the core following a casualty with their decay heat removal and emergency cooling systems.[99] As a result, unlike LWRs which rely on electrically driven pumps, SMRs will still be able to maintain the reactor in

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[90] *See id.*
[91] *See* Reyes, *supra*, at 88; *Safe and Secure*, HOLTEC INT'L, https://holtecinternational.com/products-and-services/smr/features/safe-and-secure/ (last visited Jan. 15, 2021).
[92] *See Safe and Secure*, *supra* note 91.
[93] *See* Reyes, *supra* note 88, at 155.
[94] *See NuScale: A Versatile and Economical Plant*, A SUPPLEMENT TO MECHANICAL ENGINEERING MAG., Jun. 2014, at 60-61.
[95] *See id.*
[96] *See* Reyes, *supra* note 88, at 155.
[97] *See id.*
[98] *See NuScale: A Versatile and Economical Plant*, *supra* note 94, at 60–61.
[99] *See id.* at 154–59; *New Products, Services & Contracts*, NUCLEAR PLANT J., July-Aug. 2014, at 16.

a stable, cooled condition without a connection any electrical power supplies. NuScale's decay heat removal system is capable of cooling the reactor for three days without any pumps or electrical power and its emergency cooling system is capable of operating for thirty days, after which any decay heat generation is low enough that it can sufficiently be offset by heat losses to the ambient environment surrounding the reactor.[100] Contrast that with the Fukushima reactor which only had sufficient battery power to operate its decay heat removal system for eight hours without an AC power supply.

The NuScale reactor's decay heat removal system functions by directing steam from the steam generator through piping located on the outside of the reactor compartment where it is condensed back into water by heat transfer to the common pool of water in which the reactor is immersed.[101] This condensed water than returns to the reactor vessel where it is heated again into steam.[102] The steam generation process, just as during normal operations, removes heat from the reactor coolant. When the emergency cooling system is in operation, steam is vented out of the top of the reactor vessel and then collects on the inner wall of the reactor containment, which is at a lower temperature due to the cool common pool that surrounds the reactor modules, where it is condensed into water.[103] As steam is vented and condensed, the level of water outside the reactor vessel rises and the level of coolant inside the reactor vessel lowers.[104] Recirculation valves open to allow the cool water to flow into the reactor vessel further cooling the reactor.[105] This cooled water is heated into steam by the reactor, and the cycle repeats.[106]

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[100] *See id.*

[101] *See Passive Systems*, NUSCALE, https://www.nuscalepower.com/benefits/safety-features/passive-systems (last visited Jan. 18, 2021).

[102] *See id.*

[103] *See id.*

[104] *See id.*

[105] *See id.*

[106] *See id, supra* note 101.

The Holtec NuScale reactors will be built underground in an aircraft-impact resistant building.[107] The purpose is to mitigate the severity of an earthquake like the one that damaged Fukushima.[108] During an earthquake, the underground buildings are "constrained and supported by the surrounding medium" and "less likely to experience vibration amplification."[109]

The small size of the NuScale reactor also enables engineers to build a more robust containment vessel that is able to withstand internal pressures up to 600 psia, meaning that the pressure within the containment must be greater than 600 psia for there to be any possibility of radioactive fission products escaping into the environment.[110] This value is ten times the pressure boundary of conventional containments.[111] Including the containment vessel, there are "seven barriers between the nuclear fuel and the local community and environment."[112] Current commercial LWRs in operation typically have only three.[113]

Ultimately, all of these safety features and operating characteristics should enable SMRs to be constructed on smaller plots of land among higher population densities. This would enable a reactor to power, for example, a domestic military base thus eliminating the military's reliance on the security of the local energy grid.[114] The Holtec SMR-160 is designed to fit on four and one half acres.[115] A full complement of twelve NuScale SMRs, providing approximately 720 MW_e is

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[107] *See NuScale: A Versatile and Economical Plant*, *supra* note 94; *Safe and Secure*, *supra* note 91.
[108] *See* Reyes, *supra* note 88, at 159.
[109] *Id.*
[110] *See id.* at 154. The containment vessel is the final shield between the environment and the reactor. It surrounds the reactor vessel and serves to contain fission products in the event of a reactor accident and to minimize radiation levels in the environment.
[111] *See id.* at 156.
[112] *See NuScale: A Versatile and Economical Plant*, *supra* note 94, at 60.
[113] *See id.*
[114] *See* Aaron Mehta, *Pentagon Awards Contracts to Design Mobile Nuclear Reactor*, DEFENSE NEWS (Mar. 9, 2020), https://www.defensenews.com/smr/nuclear-arsenal/2020/03/09/pentagon-to-award-mobile-nuclear-reactor-contracts-this-week/ (discussing the Defense Department's goal of having an NRC-licensed reactor to power a domestic military base by 2027).
[115] *See Economical and Efficient*, HOLTEC INT'L, https://holtecinternational.com/products-and-services/smr/features/economical-and-efficient/ (last visited Jan. 15, 2021).

designed to fit on thirty-five acres.[116] Recall that the Watts Bar power plant requires almost two thousand acres.[117]

III. Regulatory Revisions Required to Accommodate Small Modular Reactors

The NRC has published General Design Criteria as an appendix to 10 C.F.R. 50 that "establish minimum requirements for the principal design criteria for water-cooled nuclear power plants similar in design and location to plants for which construction permits have been issued by the commission."[118] Not only do the GDC apply to those reactors which emulate the LWRs previously approved by the NRC, but they are "also considered to be generally applicable to other types of nuclear power units and are intended to provide guidance in establishing the principle design criteria for such other units."[119] Separately, the NRC has explained that, although agency publications such as regulatory guides (RG) provide "acceptable methods for implementing the general criteria," companies "are free to select other methods to achieve the same goal."[120] Thus, while the NRC has reiterated the GDC are *minimum* requirements, the commission appears to be willing to grant some leeway in how they are implemented. Despite such flexibility, however, there are four categories of GDC that should be reevaluated by NRC personnel pertaining to SMRs. These are the criteria governing reactor control, electrical redundancy, the control room, and site selection. The approach applied by the NRC in reevaluating its site selection requirements provides a framework for the agency to follow in analyzing other guidelines.

A. Reactor Control

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[116] *See Cost-Competitive Energy*, NUSCALE, https://www.nuscalepower.com/newsletter/nucleus-spring-2019/cost-competitive-energy (last visited Jan. 19, 2021).
[117] FINAL SAFETY ANALYSIS REPORT, *supra* note 68, at 1.1-2.
[118] 10 C.F.R. § 50 app. A (2020).
[119] *Id.*
[120] Letter from Thomas Bergman, Vice President, Regulatory Affairs, NuScale Power, LLC, to U.S. Nuclear Regulatory Comm'n (Nov. 2, 2016), https://www.nrc.gov/docs/ML1630/ML16307A449.pdf.

The NRC's interpretation of its reactor control design criteria must be reevaluated in order to permit SMR innovation because its traditional understanding of the rules require the reactor to be shut down, and SMRs have demonstrated an adequate margin to a safety violation despite allowing for low returns to the power range.

The two design criteria that govern reactor control are GDC 26 and 27. GDC 26 deals with "reactivity control system redundancy and capability" and requires that there be two independent methods of controlling reactivity, one of which must be control rods, to ensure that "specified acceptable fuel design limits are not exceeded."[121] In other words, per GDC 26, a reactor must have two separate means for reducing reactor power by stopping the self-sustaining process of nuclear fission.

GDC 27 discusses "combined reactivity control systems" and requires that these systems "be designed to have a combined capability, in conjunction with poison addition by the emergency core cooling system, of reliably controlling reactivity changes to assure that under postulated accident conditions and with appropriate margin for stuck rods the capability to cool the core is maintained."[122] LWRs meet the requirements of GDC 27 with boron injection systems to chemically shutdown the reactor in the event that the insertion of control rods are unable to do so.[123]

These GDC, as traditionally interpreted and applied by the NRC, are excessively burdensome for SMRs by requiring them to include unnecessary redundancies for reactor shutdown. The NRC historically requires a reactor design to be able to demonstrate indefinite

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[121] 10 C.F.R. § 50 app. A (2020).
[122] *Id.*
[123] *See* discussion *supra* p. 14.

subcriticality in order to satisfy GDC 26 and 27.[124] LWRs are able to provide indefinite subcriticality both mechanically and chemically.[125] Control rods are designed such that even if one were to remain stuck in the fully withdrawn position, the remaining rods would sufficiently interrupt the fission process so as to shut down the reactor, and, as an emergency backup in a worst-case scenario, the ECCS is capable of flooding the reactor with boron.[126]

The NuScale SMR, on the other hand, is designed such that "a low-level return to power is predicted during the long term response" despite the insertion of control rods[127] However, it's passive cooling system is able to "maintain adequate core cooling to safely cool the core and prevent radiological release" despite the temporary return to power.[128] Therefore, while the NuScale SMR is unable to provide indefinite subcriticality, its reactor control system and passive cooling system combine to prevent a violation of fuel design limits.[129]

The NRC had previously adopted a conservative understanding of GDC 26 and 27. In a casualty, the reactor must be shutdown, by hook or by crook. GDC 26 and 27, however, do not require the reactor to be shutdown, as pointed out by NuScale. The criteria only require that "fuel design limits are not exceeded" and "the capability to cool the core is maintained." The engineers who designed the NuScale SMR have demonstrated that there are alternate, innovative methods for keeping the reactor safe besides just shutting down. The NRC should, likewise, update its interpretation to encourage such innovation.

B. Electrical Redundancy

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[124] *See* Letter from Frank Akstulewicz, Director, Division of New Reactor Licensing, Office of New Reactors, to Thomas Bergman, Vice President, Regulatory Affairs, NuScale Power, LLC (Sept. 8, 2016), https://www.nrc.gov/docs/ML1611/ML16116A083.pdf.

[125] *See id.*

[126] *See id.*

[127] Letter from Thomas Bergman, *supra* note 120.

[128] *Id.*

[129] *See id.*

The criterion requiring redundant electrical systems should be precluded from application to passively cooled SMRs because it requires them to incorporate unnecessary electrical backups. GDC 17 governs electrical power systems. It requires there to be "an onsite electrical power system and an offsite electric system." Each system must be designed that it is able

> "to provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents."[130]

Unfortunately, as demonstrated by the Fukushima reactor accident, the electrical system required by GDC 17 is insufficient to protect the reactor in all possible scenarios.

SMRs have solved the problem witnessed at Fukushima as discussed previously. By applying thermodynamic principles of natural circulation, convection, and conduction, they are able to ensure adequate core cooling without any pumps, thus freeing themselves from reliance upon electricity. The electrical redundancy required, therefore, by GDC 17 is unnecessary. SMRs have demonstrated an improved way to maintain reactor core cooling and GDC 17 would require companies to burden themselves with antiquated technology in order to satisfy outmoded requirements.

C. The Control Room

The NRC's should re-evaluate its criterion for a reactor control room because SMRs are designed to be "walk-away safe." GDC 19 governs reactor control room standards. It requires there to be a control room "from which actions can be taken to operate the nuclear power unit

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[130] 10 C.F.R. § 50 app. A (2020).

safely under normal conditions and to maintain it in a safe condition under accident conditions."[131] Radiation shielding for the control room must be such that a person inside will not receive greater than five rem of exposure during the course of the accident.[132]

SMRs are designed to protect themselves. They are designed such that, during a reactor accident, operators can take no action at all and the reactor will shut down into a safe condition and cool itself indefinitely. Additionally, as autonomous technology continues to improve, it is conceivable that what little operator action is required will soon be able to be performed by autonomous agents.[133] The day is coming when reactors will not require human operators at all, and, by having rigid control room requirements, the NRC may be imposing unnecessary construction costs and spatial constraints that could make it difficult for companies to lower the price of nuclear energy generation and install small reactors everywhere they are needed.

D. Site Selection

The versatility of SMRs can only be achieved if the reactors are permitted to be installed adjacent to the facility or community to which it is supplying power. It would be cost prohibitive for a company to purchase thousands of acres in a sparsely populated region only to be able to provide a military base, for example, that is many miles away with several hundred megawatts of power. In order to realize the full potential of SMRs, the NRC must provide a path for reactor construction on small lots in densely populated areas.

Current reactor siting is governed by Regulatory Guidance (RG) 4.7 which requires that the population density surrounding the site be less than five hundred people per square mile out to

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[131] *Id.*

[132] *See id.*

[133] *See* Jonghyun Kim et al., *Conceptual Design of Autonomous Emergency Operation System for Nuclear Power Plants and its Prototype*, 52 NUCLEAR ENGINEERING & TECH. 308 (2019) (presenting "a conceptual design for a plant-wide autonomous operation system that uses artificial intelligence techniques").

twenty miles.[134] Additionally, the total population must be less than 157,000 people within ten miles and less than 628,000 people within twenty miles.[135]

The NRC has recognized the incongruence between its siting requirements and the technological capabilities of SMRs, acknowledging, "compared to previous generations of reactor designs, advanced reactor designs are expected to have a reduced likelihood of accidents and result in a smaller and slower release of radioactive material in the unlikely event of an accident."[136] The NRC is exploring methods for updating its siting requirements to accommodate innovative reactor designs.[137] How the NRC is approaching siting requirements provides an example for how they might address updates related to reactor control, electrical redundancy, and the control room.

E. The Way Forward

In reviewing the siting requirements, NRC staff members proposed four ways in which they can be updated. These four proposals provide a possible framework by which other NRC design requirements, like those concerning reactor control, electrical redundancy, and a control room, can be updated to facilitate SMRs. The proposals include the following: grant individual exemptions from the current guidelines on a case-by-case basis; change the regulations exclusively for SMRs; create "technology-inclusive, risk-informed, and performance-based criteria" that reactor designs would have to satisfy; and, finally, the proposal endorsed by the Union of Concerned Scientists, create a cost-benefit system for analyzing plant safety driven by societal and environmental risks expressed in dollar values.[138]

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[134] *See* Memorandum from Margaret Doane, Exec. Dir. for Operations, Nuclear Regulatory Comm'n to the Comm'rs 2 (May 8, 2020).

[135] *See id.* at 3.

[136] *Id.* at 2.

[137] *See id.*

[138] *See id.* at 3–6.

Under the first proposal, the NRC would maintain the status quo, but permit individual exemptions from requirements upon a showing by the reactor's engineers that "the attributes of a particular advanced reactor design . . . could support a finding that the frequency of and consequences from accidents with radiological releases were both acceptably low."[139] To some extent, this appears to be the strategy adopted by the NRC during the licensing process of the NuScale SMR by waiving certain requirements which NuScale demonstrated to be inapplicable to their design.

The advantage of this methodology is that it would be easier and less expensive for the NRC.[140] The regulatory body would not have to expend resources analyzing and updating its guidance when it is uncertain how, exactly, innovative reactor designs will evolve in the coming years.[141] Otherwise, the NRC may find itself in an everlasting cycle of regulatory guidance updates to accommodate the latest and greatest reactor designs. The disadvantage of this option is that it does not provide reactor design companies with regulatory certainty.[142] Engineers would be working under an ambiguous regulatory cloud in which they could never be completely sure that their new innovations will gain NRC approval.

In the second proposal for updating regulatory guidelines, the NRC would change the regulations by adding specific provisions which would only apply to SMRs and other advanced designs.[143] Contrary to the first proposal, the advantage of the second option is that it would "promote regulatory stability, predictability, and clarity."[144] However, it would require the NRC to spend time and money creating the new guidelines. Proponents and opponents of nuclear power

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[139] *Id.* at 3.
[140] *See* Memorandum from Margaret Doane, *supra* note 134, at 3. ("The agency would not spend its resources on developing the related guidance documents within the current planning horizon").
[141] *See id.*
[142] *See id.*
[143] *See id.* at 3–4.
[144] *Id.* at 4.

both took issue with this proposal being too narrowly focused[145] To stakeholders in the nuclear power industry, the new regulations could fail to consider all possible attributes of advanced reactors that mitigate the impact of reactor accidents. To those focused upon the possible harm of nuclear energy, the new regulations may enable a reactor to acquire a license by satisfying simple tailor made guidelines rather than passing the scrutiny of a more holistic review.

The third proposal is the preferred method for the NRC and those in the nuclear power industry. Under this plan, the NRC would develop "technology-inclusive, risk-informed, and performance-based criteria" that reactor designs must satisfy.[146] This approach "is more comprehensive than Option 2 in that it considers the integrated safety performance of the entire reactor design."[147] Besides being the preferred option for NRC and nuclear power stakeholders, this plan satisfies the requirement in the NEIMA that the NRC pursue the use of risk-informed, performance-based, technology-inclusive licensing techniques.[148]

The advantage of the third proposal is that it would provide a more supportive and reliable regulatory path for SMRs while also being flexible enough to accommodate unforeseen reactor innovations because of the plan's "more design-specific assessment of risks."[149] The disadvantage, like that of the second option, is that it would require the expenditure of NRC resources to develop the new criteria.[150]

The fourth proposal considered by the NRC would involve the implementation of societal considerations beyond the regulations already required.[151] This method is less about facilitating the development of SMRs, and more about the imposition of additional requirements. This plan

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[145] *See id.*
[146] Memorandum from Margaret Doane, *supra* note 134, at 7.
[147] *Id.* at 4–5.
[148] *See* discussion, *supra* p. 7.
[149] Memorandum from Margaret Doane, *supra* note 134. at 5.
[150] *See id.*
[151] *See id.*

was the "stated preference of the [Union of Concerned Scientists] if the NRC were to pursue any option other than the status quo.[152] Instead of lifting a regulatory burden, it would require the NRC to consider the monetary impact of a reactor accident emanating from a particular reactor design at a specific location pertaining to the local economy, "land availability, population displacement, and decontamination costs."[153] This type of analysis "would require significant resources" and be difficult to conduct in a timely fashion.

CONCLUSION

The United States is at a crossroads. Do we want to include nuclear power in our national effort to lower carbon emissions? Or do we want to allow it to fade into American history and become a failed twentieth century experiment? Congress has strongly indicated through the NEIMA and the NEICA that we choose the former. Words, however, in an act of congress are just that, words. Those words will only acquire importance and meaning when they are put into action by the NRC and DOE. The NRC can begin by revising its regulatory guidelines and design criteria to facilitate the development of SMRs, the next step in nuclear reactor innovation.

SMRs are to large LWRs what the Tesla Model S is to the Ford Model T. SMRs incorporate innovative technology built upon nearly a century of research and experience operating nuclear reactors. The regulations put into place by the NRC to defend against another "Three Mile Island" are no longer relevant because SMRs are nothing like the reactor at Three Mile Island.

When the NRC licensed the NuScale SMR, it was only the beginning. By addressing outdated regulations like those governing reactor control, electrical redundancy, the control room, and site selection, the NRC can pave the path to licensing for other SMR designs. By adopting technology-inclusive, risk-informed, and performance-based regulation, the NRC can usher

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[152] *Id.* at 6.
[153] *Id.*

nuclear power plants into the twenty-first century and make the United States the global leader in nuclear energy once again.

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