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Innovation in Nuclear Energy Technologies: Implications for US National Defense

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I. Introduction: Nuclear Energy and US National Defense

Technological change is revolutionizing the national security environment and the nature of warfare; in the United States, both the public and private sectors are collaborating to develop new technologies critical to national defense. Nuclear energy is one key area of innovation in which both the US Departments of Energy (DOE) and Defense (DOD) are working with industry to finance research, development, and demonstration on promising technologies. The next generation of civilian nuclear technologies—especially small modular reactors (SMRs) and micro nuclear reactors (MNRs)—can advance the US national security mission by providing reliable, resilient power of certain military installations; powering advanced weapons systems; reinvigorating the nuclear supply chain; and supporting US nonproliferation goals.

One of the biggest obstacles to developing the next generation of nuclear technologies is the significant financial investment required to bring new reactors to demonstration. Historically, DOD funding has often played a role in supporting the research and development of technologies that are—at least initially—too expensive to be financed by the private sector, but which often are ultimately deployed for civilian commercial use. The recent DOE report, *Restoring America's Competitive Nuclear Energy Advantage*, argues that, "The purchasing power of US departments and agencies, in particular the Department of Defense, is an important component for sustaining a baseline of US nuclear power generation, while strengthening the durability of many US critical national security facilities."[1] Additionally, US government support for advanced nuclear technologies will further US national security goals in a new era of great power politics by enhancing US warfighting capabilities. DOD procurement of SMRs and MNRs could help bring the new reactor types to demonstration and commercialization, which would bolster US efforts to compete against Russian and Chinese international civil nuclear exports.

The Global Energy Center promotes energy security by working alongside government, industry, civil society, and public stakeholders to devise pragmatic solutions to the geopolitical, sustainability, and economic challenges of the changing global energy landscape.

1 *Restoring America's Competitive Nuclear Energy Advantage: A Strategy to Assure US National Security*, US Department of Energy, April 23, 2020, https://www.energy.gov/sites/prod/files/2020/04/f74/Restoring%20America%27s%20Competitive%20Nuclear%20Advantage_1.pdf.

There are many US and international efforts under way to develop new, advanced nuclear energy reactors that can replace the current Generation III designs that are large, complex, and have safety systems that require active intervention in emergency scenarios. This development work can be grouped into four major types: advanced light-water reactors (LWRs), molten salt-fueled reactors, tristructural-isotropic (TRISO)-fueled reactors, and fast-neutron-spectrum reactors.[2] The new technologies allow for smaller reactors than current LWRs, which typically exceed 1,000 megawatts (MW), and the smaller reactors hold potential for new applications, both for the military and commercially. These smaller reactors are generally either SMRs of 10 MW to 300 MW, or MNRs ranging from 200 kilowatts (KW) to 10 MW. Both categories have different characteristics than the commercial reactors in operation today in terms of fuel, safety systems, modularity, factory manufacturing processes, site construction, installation times, cooling sources, refueling intervals, sizes of exclusion zones, transport requirements, upfront capital costs, ability to follow loads, and security provisions. Although small nuclear power systems are not new—and US Navy submarines and aircraft carriers are powered by specialized small reactors of less than 300 MW, using highly enriched uranium (HEU)—there are, as yet, no commercial, civilian demonstrations of these new advanced SMR and MNR systems in the United States.

Over the last several years, DOD has expressed interest in the military applications of SMRs. However, many early papers on the topic conflate "small" and "micro" nuclear reactors; for example, a National Defense University (NDU) study from 2009 described all "small, modular, and potentially transportable" reactors as "microreactors."[3] Conversely, more recent reporting has grouped both SMRs and MNRs as "small nuclear reactors."[4] Although the Army may remain interested in military applications for SMRs, its focus now—especially through its Project Pele initiative—is primarily centered on MNRs (with the "m" in this case standing for "micro," not "mobile").[5] Therefore, this paper also primarily focuses on DOD procurement of MNRs.

The DOD Strategic Capabilities Office (SCO) is evaluating the feasibility of mobile MNRs for support bases that depend on high-cost, vulnerable fossil fuel systems. As part of the Project Pele initiative, SCO has awarded contracts to three companies, Westinghouse, X-energy, and BWXT, which are targeting a potential demonstration by 2023–2024.[6] This issue brief addresses some of the reasoning behind DOD's interest in MNRs, and it also highlights some of the issues that DOD procurement of MNRs raises. These issues include the potential for MNRs to meet the unique energy demands of the US military, as well as the role that DOD is playing in procuring advanced nuclear technologies. This issue brief also explores how DOD can coordinate its efforts with Congress, DOE, and the US Department of State in order to support the development, demonstration, and deployment of nuclear energy systems for military use.

II. Potential US Military Applications for SMRs and MNRs

DOD is a large consumer of energy in its hundreds of installations and mobile units. DOD reported that in FY2018 it spent $3.4 billion on energy to power more than 585,000 facilities and 160,000 nontactical vehicles.[7] And of the more than $100 billion DOD spends on research, development, testing, and evaluation annually, an estimated $1.6 billion goes toward energy-related research, though limited resources have gone to

2 *Advancing Nuclear Innovation: Responding to Climate Change and Strengthening Global Security*, Global Nexus Initiative, June 3, 2019, http://globalnexusinitiative.org/results/reports/advancing-nuclear-innovation-responding-to-climate-change-and-strengthening-global-security/.

3 Richard B. Andres and Hanna L. Breetz, *Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications*, Institute for National Strategic Studies, February 2011, https://ndupress.ndu.edu/Portals/68/Documents/stratforum/SF-262.pdf.

4 Aaron Mehta, "Pentagon Awards Contracts to Design Mobile Nuclear Reactor," *Defense News*, March 9, 2020, https://www.defensenews.com/smr/nuclear-arsenal/2020/03/09/pentagon-to-award-mobile-nuclear-reactor-contracts-this-week/.

5 Ibid.

6 Ibid.

7 "Energy Action Month Puts Spotlight on DOD Efforts," US Department of Defense, October 1, 2019, https://www.defense.gov/Explore/News/Article/Article/1972916/energy-action-month-puts-spotlight-on-dod-efforts/.

support advanced nuclear energy systems.[8] Most funding for nuclear energy technology development has been included in the DOE budget, including for the joint Naval Nuclear Propulsion Program. Recently, DOE—with strong congressional support—has increased its programs with private industry to develop and demonstrate a new generation of smaller and safer reactors. The success of these development efforts will be critical to the goal of restoring US global nuclear energy leadership, as well as addressing the challenge of developing carbon-neutral economies and enhancing US national security.

This section considers three major potential military applications of new nuclear energy technologies: microreactors for installations, as well as for remote and strategic support bases, power systems for directed-energy weapons, and nuclear energy systems for spaceflight and off-world bases.

Reliable and secure power for US military bases and installations

The US Navy has also expressed interest in the next generation of nuclear reactors. Lucian Niemeyer, the acting assistant secretary of the Navy for energy, installations, and environment, spoke in 2018 before the House Committee on Armed Services about the Navy's need for "stationary micro-reactors to provide long-term energy resiliency to [the Navy's] US-based installations."[9] The use of advanced reactors to provide low-carbon, reliable fuel to Navy installations is not dissimilar from potential Army applications for advanced reactors; however, it is separate from the Navy's maintenance of its naval reactor fleet.

The Nuclear Energy Institute's (NEI) study on microreactors states that the average electricity load of US military bases is 40 MW or less.[10] This indicates that an SMR, or a set of MNRs, could likely provide more reliable and resilient power, even if at higher costs than the local grid. As a result, the Department of Defense has shown increasing interest over the last several years in the potential for MNR use at military installations to increase security and resilience, and reduce reliance on vulnerable grid electricity and backup diesel generators. DOD has also focused on mobile MNRs for remote or strategic support bases that are off grid or vulnerable to cut-offs of conventional petroleum fuel supplies. A Deloitte study found that "the number of convoys required to transport an ever increasing requirement for fossil fuels is itself a root cause of casualties, both wounded and killed in action" among US troops in Iraq and Afghanistan.[11] DOD's interest in nuclear energy primarily hinges on its desire to reduce resource requirements and casualties resulting from managing and protecting extended energy supply lines; enable endurance in critical mission settings; facilitate the use of electronic systems and advanced weapons; and support humanitarian and disaster relief efforts.

The Army Deputy Chief of Staff G-4's 2018 report on mobile nuclear power plants states, "Energy is a cross-cutting enabler of military power and nuclear fuel provides the densest form of energy able to generate the electrical power necessary at forward and remote locations without the need for continuous fuel resupply."[12] This 2018 report provides examples of locations that might be potential sites for deployment of 5-megawatt and 10-megawatt microreactors.[13] These twelve potential sites have a total electrical requirement of about 282 MW, and are currently supplied by diesel generators. Diesel delivery to many of these locations can be expensive and unreliable.

8 Dorothy Robyn and Jeffrey Marqusee, "The Clean Energy Dividend: Military Investment in Energy Technology and What It Means for Civilian Energy Innovation," Information Technology and Innovation Foundation, March 2019, http://www2.itif.org/2019-clean-energy-dividend.pdf?_ga=2.143290421.1853477210.1597516533-1044648996.1597516533.

9 Lucian Niemeyer, "Testimony before the Subcommittee on Intelligence and Emerging Threats and Capabilities and Subcommittee on Readiness of the House Committee on Armed Services," US House of Representatives, October 16, 2019, https://docs.house.gov/meetings/AS/AS26/20191016/110061/HHRG-116-AS26-Wstate-NiemeyerL-20191016.pdf.

10 *Roadmap for the Deployment of Micro-Reactors for US Department of Defense Domestic Installations*, Nuclear Energy Institute, October 4, 2018, https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/Road-map-micro-reactors-department-defense-201810.pdf.

11 *Energy Security: America's Best Defense*, Deloitte, May 2010, https://www.offiziere.ch/wp-content/uploads/us_ad_EnergySecurity052010.pdf.

12 Juan Vitali, et al., *Study on the Use of Mobile Nuclear Reactor Power Plants for Ground Operations*, United States Army, October 26, 2018, https://apps.dtic.mil/dtic/tr/fulltext/u2/1064604.pdf.

13 The mentioned sites include Thule, Greenland; Kwajalein Atoll in the Marshall Islands; Guantanamo Bay, Cuba; Diego Garcia; Navy and Air Force bases in Guam; Ascension Island in the South Atlantic; Fort Buchanan in Puerto Rico; Bagram Airfield in Afghanistan; Camp Buehring in Kuwait; Ft. Greely in Alaska; and Lajes Field in the Azores.

Of the twelve mentioned sites, Bagram has the largest requirement at 56 MW, but most are 10–35 MW. The report estimates a procurement requirement of 35 to 105 10-megawatt units and 61 to 108 5-megawatt units.

DOD is separately pursuing the potential for the use of MNRs at more than five hundred installations in the continental United States (CONUS). In this context, the issue of reliability of electrical supply from local grids, due to both cyber threats and severe climate events, is of increasing importance. DOD has been assessing the impact of climate change on installations for several years, and the January 2019 *Report on Effects of a Changing Climate to the Department of Defense* considers the vulnerability of seventy-nine mission-assurance priority installations to recurring "flooding, drought, desertification, wildfires and thawing permafrost."[14] The impact of such threats on the installations' energy and water supply infrastructure, and how to increase resilience, has been one of the important considerations. The development of microgrids providing both heat and power is occurring at many sites. A recent report indicates that the military has forty-four microgrids in operation and many more planned.[15] In considering the potential for MNR application at CONUS bases, an important issue of discussion has been how these systems should be managed, especially given the specialized technical expertise required. Contracting with private MNR system operators through long-term power purchase agreements is clearly one option, and the Senate recently passed the Nuclear Energy Leadership Act, which would extend the allowable length of government power procurement contracts from new nuclear plants beyond ten years.

Powering directed-energy weapons

One of DOD's priorities for new Navy ships, as well as stationary and tactical vehicle applications, is the development of directed-energy weapons, including free-electron lasers and high-powered microwave systems as well as rail guns. These systems require new and more powerful types of power sources and management. As one report about the Navy states: "Legacy power systems found on all existing ships do not possess the inherent electrical 'inertia' to withstand the ramp-up/down (on/off), or ripple (pulsation) effects of complex power profiles of these advanced mission systems. These effects include excessive generator heating (thermal stress) and negative torques (mechanical stress) applied to prime movers such as diesel and gas turbine engines. Countering these harmful effects requires mitigation such as advanced controls or energy storage."[16]

To address this problem, the Navy is working on the development of an electrical energy magazine unit that is a modular, scalable cabinet that manages and distributes the pulsed power needed for directed-energy weapons, as well as electronic-warfare and sensor systems in a way that protects the ship's main power and propulsion systems.[17] In early 2019, the Navy's Electric Boat Office (PMS 320) issued a request for information for an energy magazine and suggested that a full request for proposals might be issued for development and production between 2021 and 2023.[18]

The potential for nuclear-pumped lasers, in which ions from nuclear reactions can create the high-power densities necessary for a narrow collimated beam, has been considered for decades, including under the Strategic Defense Initiative (sometimes referred to, pejoratively, as "Star Wars").[19] In recent years, DOD has changed its directed-energy weapons' strategy to favor nearer-term applications and away from large "Star Wars" concepts. Research has been oriented toward chemical and increasingly electrical solid-state systems. DOD Undersecretary for Research and Development Mike Griffin has stressed the priority of moving from existing systems that range in the tens of kilowatts to systems that range in the hundreds of kilowatts, and eventually the

14 *Report on Effects of a Changing Climate to the Department of Defense*, US Department of Defense, January 2019, https://media.defense.gov/2019/Jan/29/2002084200/-1/-1/1/CLIMATE-CHANGE-REPORT-2019.PDF.

15 *2020 Sustainable Energy in America Factbook*, Business Council for Sustainable Energy, February 2020, https://www.bcse.org/wp-content/uploads/2020-Sustainable-Energy-in-America-Factbook-Executive-Summary.pdf.

16 *Naval Power and Energy Systems Technology Development Roadmap*, Naval Power and Energy Systems, 2019, https://news.usni.org/2019/06/26/u-s-naval-power-and-energy-systems-technology-development-roadmap.

17 "US Navy Seeks Energy Magazine for Directed Energy Weapons," *Naval Today*, January 9, 2019, https://www.navaltoday.com/2019/01/09/us-navy-seeks-energy-magazine-for-directed-energy-weapons/.

18 Ibid.

19 Claire Zau, "Nuclear Pumped Lasers and the Strategic Defense Initiative," Stanford University coursework, March 16, 2018, http://large.stanford.edu/courses/2017/ph241/zau2/.

US Air Force (USAF) aircraft sit on the snow-covered flight line of Eielson Air Force Base, Alaska, on Dec. 21, 2004. *USAF PHOTO by Senior Airman Joshua Strang*

megawatt size.[20] The development of high-powered microwave systems is also a focus as a means of countering attacks involving a swarm of drones.[21]

The various services are all engaged in promoting these new weapons, especially in light of the evolution of tactical warfare toward the use of drones and cruise missiles, as seen in the Iranian attacks on Saudi oil facilities in November 2019. The Navy has contracted with Lockheed Martin for the development of its 60–150 KW HELIOS laser system for deployment on the new Arleigh Burke destroyers.[22] DOD has a variety of plans under way for ship- and land-based lasers and microwaves that could have capacity as high as 1 MW.[23] One laser-weapon system that is mounted on an all-terrain vehicle (ATV) has reportedly been delivered.[24] As these systems scale up to higher power ratings, MNR applications should become increasingly attractive.

20 Sydney J. Freedberg Jr., "Lasers, Hypersonics, and AI: Mike Griffin's Killer Combo," *Breaking Defense*, March 20, 2019, https://breakingdefense.com/2019/03/lasers-hypersonics-ai-mike-griffins-killer-combo/; Aaron Mehta, "Bioengineering, Lasers and more Drones: Griffin Outlines Pentagon's Tech Wish List," *Defense News*, September 4, 2019, https://www.defensenews.com/smr/defense-news-conference/2019/09/04/bioengineering-lasers-and-more-drones-griffin-outlines-the-pentagons-tech-wishlist/.

21 Kyle Mizokami, "The U.S. Army Wants to Microwave Drones in Midair," *Popular Mechanics*, August 13, 2019, https://www.popularmechanics.com/military/research/a28678829/microwave-drones-midair/.

22 Sydney J. Freedberg Jr., "New Army Laser Could Kill Cruise Missiles," *Breaking Defense*, August 5, 2019, https://breakingdefense.com/2019/08/newest-army-laser-could-kill-cruise-missiles/.

23 Ibid.; "Team Dynetics Wins $130 Million 100kW-class High Energy Laser Contract for U.S. Army," *GlobeNewswire*, May 15, 2019, https://www.globenewswire.com/news-release/2019/05/15/1825439/0/en/Team-Dynetics-wins-130-million-100kW-class-high-energy-laser-contract-for-U-S-Army.html; Sydney J. Freedberg Jr., "EXCLUSIVE Killing Cruise Missiles: Pentagon to Test Rival Lasers," *Breaking Defense*, December 2, 2019, https://breakingdefense.com/2019/12/exclusive-three-ways-to-kill-cruise-missiles-pentagon-to-test-rival-lasers/; Kyle Mizokami, "The U.S. Army Plans to Field the Most Powerful Laser Weapon Yet," *Popular Mechanics*, August 7, 2019, https://www.popularmechanics.com/military/weapons/a28636854/powerful-laser-weapon/.

24 Shaun Waterman, "Directed Energy Weapons Move Closer to Prime Time," *Air Force Magazine*, October 29, 2019, https://www.airforcemag.com/directed-energy-weapons-move-closer-to-prime-time/.

Energy for spaceflight and off-world bases

A third major military application is in the space domain, which is increasingly viewed as a potential area of military competition and warfare. The essential role of satellite communications networks to military command-and-control systems, and the physical and cyber threats to these systems, has elevated this area in DOD policy and programs. And the fiscal year 2020 (FY20) Defense Authorization Act established an independent Space Force within the Department of the Air Force.[25]

Work is proceeding on both nuclear-powered rockets and reactors for installations on the Moon or Mars, in addition to radioisotope electric-propulsion (REP) systems and radioisotope thermal generators (RTG) that have been used for many years on National Aeronautics and Space Administration (NASA) exploratory missions to the outer planets. RTGs are very expensive, use plutonium-238 fuel, and do not have the power capacity for off-world bases where solar photovoltaic systems are not sufficient for long-distance space fight. Companies like Zeno Power Systems are investigating less expensive alternative isotopes such as Strontium 90 to power RTG systems that can provide up to 1 KW of power, as well as heat. These RTGs could be used for smaller-scale sensing and mobility platforms and with radioisotope heating units (RHUs) could keep rovers and critical infrastructure from freezing in extreme environments like the far side of the Moon.[26]

NASA has been working on MNR applications utilizing high-assay low-enriched uranium (HALEU) fuel for years under its KiloPower Project, which has focused on 1–10 KW modules. Now, with the new White House Space Policy and the NASA Artemis Project to pursue exploration on the Moon and a Mars mission, there is interest in new reactors for stations on the Moon and for powering long-distance space rockets, including reactors that would use HALEU fuels. The Nuclear Thermal Propulsion (NTP) project at NASA Marshall Space Flight Center is currently seeking to determine the viability and affordability of a HALEU-fueled NTP engine, and is studying the options for ground tests and an in-space demonstration of an NTP system. NTP rockets are expected to be able to cut space travel time in half compared to traditional chemical systems.[27]

The Donald Trump administration requested an increase to $25.2 billion in NASA's fiscal year 2021 (FY21 budget), which represents a 12 percent increase over the FY20 congressional appropriations.[28] Nuclear energy systems will be a focus under its proposed $430 million Lunar Surface Innovation Initiative. This work by NASA's Glenn Center in Cleveland, together with the Marshall Center and DOE's Los Alamos National Laboratory, will follow up on the successful 2018–2019 demonstration of a 1-10 KW system for Moon stations.[29] The budget request for DOD's Defense Advanced Research Projects Agency (DARPA) also included $21 million for the development of a HALEU nuclear rocket.[30] Space energy systems work will need to clarify the launch-approval process for nuclear systems (and the steps for commercial involvement) to allow time for manufacturers to incorporate regulatory standards into early-stage design. Additionally, there is a need for a dedicated mechanism, such as the DOE Gateway for Accelerated Innovation in Nuclear (GAIN) program, to access DOE facilities for qualification testing.

25 Vivienne Machi, "Happy Birthday, Space Force: Trump Signs FY '20 NDAA, Brings New Branch to Life," *Defense Daily*, December 20, 2019, https://www.defensedaily.com/happy-birthday-space-force-trump-signs-fy-20-ndaa-brings-new-branch-life/pentagon/.

26 Communication with Zeno Power Systems officers, in April, 2020

27 "Nuclear Thermal Propulsion: Game Changing Technology for Deep Space Exploration," NASA, last updated August 26, 2019, https://www.nasa.gov/directorates/spacetech/game_changing_development/Nuclear_Thermal_Propulsion_Deep_Space_Exploration.

28 Jeff Foust, "White House Requests Significant NASA Budget Increase to Fund Artemis Program," *SpaceNews*, February 10, 2020, https://spacenews.com/white-house-requests-significant-nasa-budget-increase-to-fund-artemis-program/.

29 "Demonstration Proves Nuclear Fission System Can Provide Space Exploration Power," NASA, last updated March 16, 2020, https://www.nasa.gov/press-release/demonstration-proves-nuclear-fission-system-can-provide-space-exploration-power; "FY 2020 Explore Budget Estimates," NASA, https://www.nasa.gov/sites/default/files/atoms/files/fy_2020_congressional_justification.pdf.

30 Theresa Hitchens, "DARPA Doubles Dough for Nuclear-Powered Cislunar Rocket," *Breaking Defense*, February 18, 2020, https://breakingdefense.com/2020/02/darpa-doubles-dough-for-nuclear-powered-cislunar-rocket/.

III. The Role of Congress and the Federal Government in Supporting Nuclear Energy Systems for the Military

DOD has a key role to play as a potential purchaser of MNRs, and as a catalyst for innovation and nuclear energy system development, e.g., powering directed-energy weapons. However, DOE remains the lead US government (USG) agency in supporting research and development on advanced nuclear energy technologies, and any movement forward on these issues would require coordination between Congress, several federal agencies, and the Nuclear Regulatory Commission (NRC). This section analyzes the current status of congressional funding for advanced reactor demonstrations, as well as congressional funding for deployment at DOD facilities; the involvement of the NRC in the DOD advanced reactor program; DOD's potential role in helping to fund advanced fuel fabrication; and safety and nonproliferation concerns inherent in deploying advanced reactors at military bases in foreign countries.

Congressional funding of DOE MNR demonstrations

With the budget pressures from the COVID-19 pandemic, how Congress addresses the nuclear energy needs of both DOE and DOD will be increasingly important. In the past, Congress has demonstrated strong support for the DOE's nuclear energy budget, increasing it to levels beyond those requested by the administration. Congress has placed a high priority on the demonstration of advanced nuclear energy technologies. Out of the FY20, $1.49 billion budget for DOE's Office of Nuclear Energy, Congress appropriated $230 million for a new advanced reactor demonstration program.[31] The emphasis on demonstrations is consistent with the US Nuclear Energy Leadership Act, S. 903, introduced by Senate Committee on Energy and Natural Resources Chairman Lisa Murkowski (R-AK) and Senator Cory Booker (D-NJ) and passed in July 2020 as an amendment to the NDAA for Fiscal Year 2021. The companion legislation in the House, H.R. 3306, is being led by Representatives Elaine Luria (D-VA) and Denver Riggleman (R-VA) and also maintains wide bipartisan support. After an initial request for information in February 2020, DOE formally released a $230 million funding opportunity announcement on May 14, 2020, which established three pathways for funding with private partners: Advanced Research Demonstration awards for two demonstrations within 5–7 years; Risk Reduction for Future Demonstrations awards for technologies with a ten-year horizon; and Advanced Reactor Concepts awards for even longer-term prospects of fifteen years or so.[32]

Congressional support for MNRs for DOD facilities

Congress has taken actions to encourage DOD to consider MNRs for its installations. This has taken two forms. First, the 2019 National Defense Authorization Act (NDAA) Section 327 directed the Secretary of Energy to produce "a report describing the requirements for, and components of, a pilot program to provide resilience for critical national security infrastructure at Department of Defense facilities with high energy intensity and currently expensive utility rates and Department of Energy facilities by contracting with a commercial entity to site, construct, and operate at least one licensed micro-reactor at a facility identified under the report by December 31, 2027."[33] DOD's Office of Acquisition and Sustainment is working with DOE on this effort, which will evaluate the deployment of MNRs at domestic military installations with high utility costs.[34] As of this writing, the report requested by Congress has still not been provided. Second, in an initiative separate from the 2019 NDAA, Congress—although not requested by the administration—added $70 million in the FY20 NDAA for SCO to undertake an MNR design-and-testing program focused on mobile reactors for forward operating bases. With this funding, SCO has started to implement Project Pele. SCO announced contract awards on March 9, 2020, totaling approximately $39.769 million to three companies—BWXT, Westinghouse, and X-energy—for a two-year design phase for mobile reactors in the

31 Jacqueline Toth, "NELA or Not, Congress Funds Reactor Demonstrations at DOE," *Morning Consult*, December 20, 2019, https://morningconsult.com/2019/12/20/nela-or-not-congress-funds-reactor-demonstrations-at-doe/.

32 "DOE Invites Feedback on Advanced Reactor Programme," *World Nuclear News*, February 7, 2020, https://world-nuclear-news.org/Articles/DOE-calls-for-feedback-on-advanced-reactor-program; "Advanced Reactor Demonstration Program," Office of Nuclear Energy, https://www.energy.gov/ne/nuclear-reactor-technologies/advanced-reactor-demonstration-program.

33 John S. McCain National Defense Authorization Act for Fiscal Year 2019, H.R. 5515, 115th Congress, 2nd Session, January 3, 2018, https://www.congress.gov/115/bills/hr5515/BILLS-115hr5515enr.pdf.

34 Mehta, "Pentagon Awards Contracts to Design Mobile Nuclear Reactor."

1–10 MW size.[35] Following the design phase, the project's plan is to build and test a prototype at the Idaho National Laboratory (INL) and then, by 2024, transport it by C-17 aircraft to a remote base, such as in Alaska, for operational testing and demonstrating its rapid mobility. In March 2020, SCO issued for public comment a "Notice of Intent to Conduct an Environmental Impact Assessment for Construction and Demonstration of Prototype Advanced Micronuclear Reactor."[36] This notice describes the proposed activity and DOD's intention to address a range of safety, nuclear waste management, and environmental issues in close coordination with DOE and NRC. DOD makes it clear in this notice that it will utilize DOE capacities and authorities, particularly at INL, for the "construction, and demonstration" of the prototype microreactor.

DOD's FY21 budget request of $106.6 billion for research, development, testing, and evaluation (RDTE) is the largest in DOD's history.[37] However, in its FY21 DOD budget request, the administration again did not request funds for Project Pele. The nuclear industry has advocated additional funding to carry out the full SCO testing-and-demonstration program. NEI estimates that $140 million is needed in FY21, and industry sources indicate that costs for the full testing-and-demonstration program could be around $500 million.[38]

Critical role of the US Nuclear Regulatory Commission (NRC)

The NRC plays a critical role in developing advanced reactors for both civilian and defense applications. The NRC is becoming involved in the DOD/SCO prototype microreactor project, and DOD expects that NRC will "provide SCO with accurate, current information on the NRC's regulations and licensing processes."[39] For the initial construction and testing of the prototype MNR at INL facilities, DOD can use DOE authorities under the Atomic Energy Act and will not be required to obtain an NRC license.[40] However, given DOE's interest in ultimately deploying microreactors in a variety of jurisdictions worldwide, there is a clear potential role for NRC to provide review, as well as coordination with foreign regulators.

The NRC has made changes in how it licenses advanced reactors, as opposed to its traditional licensing process for light-water reactors. The new regulatory guides are intended to take the variety of advanced reactor "coolants, fuel forms, and safety system designs" into account by creating a methodology for assessing safety and potential risk of advanced reactors, instead of the "prescriptive guidance" issued for light-water reactors.[41] NRC meetings with the three recipients of DOD contracts have begun within the framework of a memorandum of understanding between NRC, DOD, and DOE to address how the NRC will assist in peer reviews on the program, which is likely to be in a manner that is similar to how the NRC reviews the Navy's reactor designs (i.e., through support for project management and technical reviews).[42]

35 BWXT, Inc., Lynchburg, Virginia ($13.5 million); Westinghouse Government Services, Washington, D.C. (around $11.96 million); and X-energy, LLC, Rockville, Maryland ($14.309 million); Arun Mathew, "U.S. DOD Awards Contracts for Development of a Mobile Microreactor," *DefPost*, March 9, 2020, https://defpost.com/u-s-dod-awards-contracts-for-development-of-a-mobile-microreactor/.

36 "Notice of Intent to Prepare an Environmental Impact Statement for Construction and Demonstration of a Prototype Advanced Mobile Nuclear Microreactor," *Federal Register*, March 2, 2020, https://www.federalregister.gov/documents/2020/03/02/2020-03809/notice-of-intent-to-prepare-an-environmental-impact-statement-for-construction-and-demonstration-of.

37 Aaron Mehta, "Pentagon Budget Request Increases R&D Funding, Cuts Legacy Planes," *Defense News*, February 10, 2020, https://www.defensenews.com/smr/federal-budget/2020/02/10/pentagon-budget-request-increases-rd-funding-cuts-legacy-planes/.

38 Mehta, "Pentagon Awards Contracts to Design Mobile Nuclear Reactor."

39 "Notice of Intent to Prepare an Environmental Impact Statement for Construction and Demonstration of a Prototype Advanced Mobile Nuclear Microreactor," *Federal Register*, March 2, 2020, https://www.federalregister.gov/documents/2020/03/02/2020-03809/notice-of-intent-to-prepare-an-environmental-impact-statement-for-construction-and-demonstration-of.

40 Ibid.

41 "Guidance for a Technology-Inclusive, Risk-Informed, and Permance-Based Methodology to Inform Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors," US Nuclear Regulatory Commission, June 2020, https://www.nrc.gov/docs/ML2009/ML20091L698.pdf.

42 "Non-Power Facilities," US Nuclear Regulatory Commission, last updated April 23, 2020, https://www.nrc.gov/reactors/non-power.html.

As a growing number of companies enter the pre-licensing and license application stages with the NRC, the question of the capacity of NRC to manage these requests—as well as its other safety, waste, life extension, and decommissioning responsibilities—may become more urgent.[43] Out of the NRC's enacted budget in FY20 of $855.5 million, roughly half ($426.7 million) was for reactor safety for operating and advanced reactors. Appropriations for new and advanced reactors—including units 3 and 4 of Plant Vogtle, which will be the first new nuclear builds in the US in three decades—was $84.1 million and supported 332 full-time-equivalent staff. Despite the growing demands in this area, the administration's budget request in FY21 reduced both funding and staffing levels, to $80 million and 285 full-time-equivalent staff. In the past, Congress has provided higher appropriated levels than requested. Major proposed and anticipated activities in the FY21 request included about $35 million for advanced reactors, including for the NuScale/UAMPS applications; the pre-application reviews for the companies mentioned above; and research and other infrastructure development in line with projected new technologies and industry plans.[44] These appropriations are important because NRC only charges fees to advanced reactor developers that are undergoing formal licensing reviews, yet they are extensively involved with companies in pre-application reviews.

DOE support for HALEU fuels production

Many of the new advanced reactor designs for military and civilian application intend to use HALEU fuel that is enriched up to 19.9 percent and is, in some cases, fabricated into TRISO microspheres, which may be an extremely robust and stable type of nuclear fuel and could enable the next generation of nuclear reactors.[45] These fuels allow lighter reactors, offer longer intervals between refueling than with standard LWR fuel, and produce less waste due to higher burnup rates.[46] However, because advanced reactors have not yet been commercialized, there is little demand for the types of advanced fuel that they require. At the same time, without fuel fabrication, it is difficult to test the reactors. Government funding, especially from DOD, could end the stalemate between reactor and fuel development.

DOE is making HALEU fuels for early testing available, the European (UK, Dutch, German) enrichment company URENCO has indicated that it may add a HALEU production line to its New Mexico facility, and DOE is undertaking a three-year, $115 million program to demonstrate US-origin technology for HALEU production.[47] The April 2020 DOE report supports this effort and actions to permit quick licensing of the facilities after the demonstration is completed in 2022.[48] DOE in November

43 The NRC is gearing up for additional SMR and MNR reviews. NuScale submitted its first application to the NRC in 2017 and received NRC design certification approval in September 2020. With DOE funding support, NuScale is also working with the Utah Associated Municipal Power Systems (UAMPS) on a Combined Construction and Operating License application for its planned reference plant at the Idaho National Laboratory. As of February 25, 2020, the NRC indicated that the following seven companies have formally notified the NRC of their interest in engaging in regulatory interactions: General Atomics, Oklo, X-energy, Kairos Power, Terrestrial Energy, TerraPower, and Westinghouse. In addition, GE-Hitachi has submitted a "topical licensing report" to the NRC for its advanced BWRX-300 boiling water reactor. "NRC: Application Review Schedule for the NuScale Design," US Nuclear Regulatory Commission, August 7, 2020, https://www.nrc.gov/reactors/new-reactors/smr/nuscale/review-schedule.html; "NuScale Wins U.S. DOE Funding for its SMR Technology," NuScale Power, accessed August 14, 2020, https://www.nuscalepower.com/about-us/doe-partnership; "GE Hitachi Initiates US Licensing of BWRX-300," World Nuclear News, January 31, 2020, https://www.world-nuclear-news.org/Articles/GE-Hitachi-initiates-US-licensing-of-BWRX-300.

44 "Congressional Budget Justification: Fiscal Year 2021," US Nuclear Regulatory Commission, https://www.nrc.gov/docs/ML2002/ML20024D764.pdf.

45 TRISO fuels are "small, uniform microspheres of uranium oxycarbide coated with several layers of pyrocarbon and silicon carbide that are dispersed into (a) graphite pebbles (e.g. billiard-bass sized) or (b) prismatic, hexagonal graphite fuel blocks in which the TRISO fuel particles are dispensed into a graphite block matrix," as defined in *Advancing Nuclear Innovation: Responding to Climate Change and Strengthening Global Security*; Mihai Andrei, "Why TRISO Particles Could Open a New Age for Nuclear Power," *ZME Science*, June 4, 2020, https://www.zmescience.com/other/feature-post/triso-particles-nuclear-04062020/.

46 "High-Assay Low-Enriched Uranium: Developing a U.S. Fuel Source for Advanced Reactors," Centrus Energy Corp., accessed August 14, 2020, https://www.centrusenergy.com/what-we-do/nuclear-fuel/high-assay-low-enriched-uranium/.

47 Amy Roma and Sachin Desai, "Highlighting Recent Progress Towards HALEU Fuel Production," Hogan Lovells, March 4, 2019, https://www.hlnewnuclear.com/2019/03/highlighting-recent-progress-towards-haleu-fuel-production/; Sonal Patel, "Facing Urgency, DOE Moves to Demonstrate HALEU Fuel Production Capability for Advanced Nuclear Reactors," *Power Magazine*, January 10, 2019, https://www.powermag.com/facing-urgency-doe-moves-to-demonstrate-haleu-fuel-production-capability-for-advanced-nuclear-reactors/.

48 "Restoring America's Competitive Nuclear Energy Advantage: A Strategy to Assure US National Security," US Department of Energy, April 23, 2020, https://www.energy.gov/sites/prod/files/2020/04/f74/Restoring%20America%27s%20Competitive%20Nuclear%20Advantage_1.pdf.

2019 contracted under a cost-sharing arrangement with Centrus Energy for construction and operation of AC100M centrifuge machines at the American Centrifuge Plant in Piketon, Ohio, to produce a small amount of HALEU fuel.[49] Congress provided $40 million in FY20 for the program and directed DOE to convene an expert review group with industry to assess options for meeting future HALEU demand.

In December 2019, BWXT announced that it is restarting its TRISO fuel-production capability to meet expected requirements for DOD microreactors, space reactors, and civilian advanced reactors.[50] With its NRC Category 1 license for HEU supply to the Navy, BWXT claims it has the human resources capacity and infrastructure to do down-blending and Category 2 HALEU-fuel production, possibly at lower initial costs and with the required safety, security, and accountability standards. As mentioned above, BWXT is one of three companies awarded a mobile, microreactor design contract by DOD's SCO. In November 2019, a second SCO awardee, X-energy, which has been involved in a pilot TRISO fuel facility at DOE's Oak Ridge National Laboratory, announced a collaboration with Global Nuclear Fuel (GNF) to produce fuel for defense and space applications. In addition to these public-private efforts in HALEU-fuel production, DOE is also beginning at INL to evaluate the potential to use processed HALEU fuel, recovered from INL's decommissioned Experimental Breeder Reactor-II, in an MNR. MNR developer Oklo has received a site license from INR for the testing of its 1.5-MW Aurora microreactor, as well as an award from INL for providing spent fuel for use in the reactor.[51] The transport of HALEU fuel is also an important technical and safety issue.

Addressing international security and safeguards issues

The development of this new generation of reactors using nuclear fuels with a higher level of enrichment than for LWRs requires careful consideration of international security and safeguards issues. Although DOD is planning initial deployment of its mobile MNRs in strategic support areas—and not immediately in frontline locations—such deployment still raises several issues for DOD to address in the design and testing of the prototypes. In addition to the general concern about the safety of personnel operating these units, and the risks of exposure to radioactive releases in the case of accidents or during transport, the vulnerability of MNR systems to drone or missile attacks is a real consideration despite their passive safety, automatic shutdown features, and use of TRISO fuel pellets that can maintain their integrity even in very high temperatures.[52]

Although some systems might be buried for protection, this could reduce their mobility and create difficulties for rapid removal. Theft of these truck-sized reactors by hostile groups is another conceivable threat. This possibility raises concerns about release of radioactive material and use by terrorists to create public fear; protection of sensitive design information and use by foreign intelligence agencies; and removal and upgrading of the HALEU fuel to bomb-grade material by malign actors.[53] The consideration of the safeguard implications of the various types of SMRs is at an early stage, but it is an urgent priority. The July 2019 Global Nexus Initiative Report provides an initial assessment for three types of reactors—molten salt, TRISO fueled, and fast neutron spectrum—and how they are different from LWRs. Given that several of the SMR and MNR designs will use TRISO fuels, it will be especially important to access and assess information on fuels for specific reactor designs and the behavior and measurement of the fuels during fueling.[54] One positive feature of some of

49 "Centrus Signs HALEU Contract with Department of Energy," *World Nuclear News*, November 6, 2019, https://www.world-nuclear-news.org/Articles/Centrus-signs-HALEU-contract.

50 "TRISO Fuel," BWXT, Inc., accessed August 14, 2020, https://www.bwxt.com/what-we-do/strategic-nuclear-materials/triso-fuel.

51 "Oklo Wins Access to Used Fuel for Aurora SMR," *World Nuclear News*, February 20, 2020, https://world-nuclear-news.org/Articles/Oklo-wins-access-to-used-fuel-for-Aurora-small-rea.

52 Sydney J. Freedberg Jr., "New TRISO Nuclear Mini-Reactors Will Be Safe: Program Manager," *Breaking Defense*, April 8, 2020, https://breakingdefense.com/2020/04/new-triso-nuclear-mini-reactors-will-be-safe-program-manager/.

53 Communication from Ambassador Laura Holgate, in April, 2020.

54 "Advancing Nuclear Innovation: Responding to Climate Change and Strengthening Global Security."

Artist's rendering of Oklo's Aurora powerhouse. *Creative Commons/Gensler*

the MNRs under development is that they have sealed fuel modules that can operate for 5–10 years or more before removal or replacement to allow operation for up to sixty years. The proposed DOD Project Pele mobile systems generally assume no refueling in the field.

One remaining question about nuclear reactors on US military bases in foreign countries is whether the International Atomic Energy Agency (IAEA) or the host country might have oversight. While there is, as yet, no official policy on this issue, there are several precedents that can shed some light on how the IAEA or host countries might treat nuclear reactors on US military bases. First, there is a set of agreements between the US government and countries with US naval reactors in their harbors, so it is possible to imagine that the US government might sign similar agreements with host countries for reactors based on land. Secondly, there are a few examples of portable reactors that the United States has used on land in places like Greenland, Antarctica, and the Panama Canal. Looking again to the naval reactor program as precedent, the Non-Proliferation Treaty (NPT) allows countries to "block inspection of nuclear material designated for naval fuel."[55] Based on what many consider to be a loophole in the NPT, it is likely that the IAEA would not inspect nuclear reactors designated for non-explosive military use.

IV. Conclusion

The new generation of smaller nuclear energy technologies, under development by the US private sector in collaboration with DOE, has the potential to contribute significantly to the future US defense posture and the increasing electrification, decarbonization, resiliency, and digitalization of US military systems. Although many of the military applications for advanced nuclear reactors are unlikely to be deployed commercially, the primary DOD application of advanced nuclear technologies—i.e., providing reliable, low-carbon energy to smaller grids or more remote areas—is likely to become commercially available, and it could have a dramatic impact on global energy systems and on US nuclear exports. As the naval reactor program has shown, there is significant overlap between civilian and military supply chains,

55 Alan J. Kuperman, "The US Navy Should Start Weaning its Reactors off Bomb-Grade Uranium," *Defense One*, March 13, 2018, https://www.defenseone.com/ideas/2018/03/its-time-wean-us-navy-reactors-bomb-grade-uranium/146648/.

both for personnel (i.e., individuals who are trained to operate nuclear submarines have a skillset that is useful in working in the civilian nuclear energy sector) and material. This will presumably continue to be the case, even for individuals who work on military-only applications of advanced reactors, such as directed-energy weapons or spacecraft.

There has been notable progress in innovative reactor designs, led primarily by the private sector, over the last several years. However, in the United States, the private sector has looked to the US government for financial support. In order to leverage DOD procurement to enable commercialization of MNRs, the US Army should consider taking the following steps:

- Demonstrate the features that will enable the safe operation of new nuclear technologies in remote, or even dangerous, locations;
- Take steps—such as concluding agreements with host countries that are similar to those that the US Navy has with countries that provide harbor for its naval reactors—to address international safety and nuclear safeguards concerns;
- Through Congressional funding, DOD should continue to support Project Pele;
- Work effectively with the NRC through the regulatory process;
- Invest in the development of advanced fuels to power new nuclear reactors;
- Consider that the competition with Russia and China is not merely a race for nuclear energy capabilities, but rather a question of trade agreements with third-party countries, and advocate for the US government to value nuclear energy accordingly.

In the absence of state-owned nuclear enterprises, the US military has a critical role to play in speeding the commercialization of advanced nuclear reactors that have the potential to provide large quantities of low-carbon energy in the United States and internationally. If DOD can help bring first-of-a-kind advanced reactors to demonstration and commercialization, then private companies will be more able to afford making nth-of-a-kind reactors. A more robust nuclear energy sector will bolster the US civil nuclear export program, which is integral to US national security.

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