Micro Nuclear Reactors

Prospects for Deploying Land-Based Nuclear Energy for the US Military

ASP

American Security Project

Perspective

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Andrew Holland

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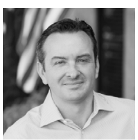

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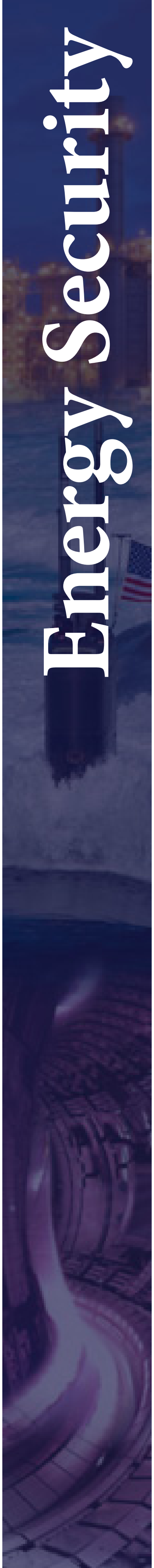

In this Report:

Energy is a critical, if often overlooked, part of the military's mission. The U.S. military is considering investments into micro nuclear power plants to enhance energy security and energy resilience. While the Navy has a long history with nuclear power, these new reactors would deploy in support of Army and Air Force missions.

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IN BRIEF

- Energy innovation is a "force multiplier" as the military embarks on a concerted effort to upgrade its technology as a part of "Great Power Competition" with countries like China and Russia.
- Energy security and energy resilience are growing areas of interest for the U.S. military. Long and vulnerable fuel supply lines have shown how adversaries target weakest areas. Meanwhile, increasing threats from cyber attacks pose threats to the energy supply of bases in the continental United States.
- New technologies and new designs of nuclear power plants enable smaller size and smaller capacity, enable micro nuclear reactors to be more mobile and less vulnerable.
- The Navy has a long history of safe operation of nuclear reactors. As the Departments of the Army and Air Force develop plans to utilize nuclear power, they should seek best practices from the Navy.

About the Author

Andrew Holland is the American Security Project's Chief Operating Officer. For more than 15 years, he has worked at the center of debates about how to achieve sustainable energy security and how to effectively address climate change. He has written widely about energy security, environmental threats, and policy options to address them.

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Introduction – Energy Innovation as a "Force Multiplier"

In 2014, the Department of Defense embarked on a major strategic initiative to ensure that the US military remains ahead of its near-peer adversaries over the coming decades. Then called the "Third Offset Strategy," the military was seeking technology to cost-effectively counter potential adversaries' challenges to U.S. national interests. The military would utilize emerging technologies, coupled with a shift in strategic posture, to ensure that American forces retain an asymmetric advantage over potential adversaries. Earlier "offsets" had paired the 1950s American advantages in nuclear weapons development with a strategic choice to counter Soviet conventional superiority with nuclear deterrence; the 1970s advances in microchips and computing power helped develop precision munitions and stealth aircraft. Then-Secretary of Defense Chuck Hagel explained these in September 2014:

> "The critical innovation was to apply and combine these new systems and technologies with new strategic operational concepts, in ways that enable the American military to avoid matching an adversary 'tank-for-tank or soldier-for-soldier.'"[1]

Today, the military is making a conscious effort to take advantage of developments around Silicon Valley. The Department's Defense Innovation Unit Experimental (DIUX) was located at Moffet Field in the South Bay, next to a facility owned by Google. They planned to utilize advances in Artificial Intelligence, machine learning, and more to develop new capabilities to ensure American superiority against its adversaries.

With the change of Administration, the leadership of the Department of Defense no longer talks much about an "Offset Strategy," but the National Defense Strategy, published in 2018, carries forward the themes developed there. It writes that the security environment is also affected by "rapid technological advancements and the changing character of war." Specific technologies identified as key to winning the wars of the future include: advanced computing, data analytics, artificial intelligence, autonomy, robotics, directed energy, hypersonics, and biotechnology.[2]

Notably absent from that list is energy, a stunning oversight. Energy is integral to how the U.S. has fought and won wars in the past. And because so many of the advanced technologies listed as critical to future warfare are extremely energy-intensive, the wars of the future will require even more energy than today's force.

The U.S. military has used "energy dominance" as its preferred way of war since the Civil War, when the North's dominance in coal and steel enabled the military machine that would strangle the South. At the beginning of World War Two, the United States produced 60% of world oil supplies, allowing American oil to power the Allies' war machine that would topple fascism in Europe and Japan.[3]

In recent wars, though, the American dependence on liquid fossil fuels was turned into a vulnerability. At the height of the fighting in Iraq and Afghanistan, the single largest cause of death was on convoys carrying fuel and water.[4] In later testimony to Congress, General James Mattis, who had led the 1st Marine Division in the march to Baghdad would say that the military must be "unleashed from the tether of fuel."[5] At the urging of Congress and successive presidents, the Department of Defense undertook a radical effort to both reduce these logistical supply lines by increasing efficiency and relying on alternative energy sources.[6] This program was successful in changing how the military procures energy for the force, and significantly changed thinking about energy vulnerability.

However, without new strategic forethought, energy vulnerability for the force will only grow as its energy footprint grows. New weapons platforms like electromagnetic railguns, directed energy weapons, drones, and networked warfighters will enhance the military's ability to protect the force and take the fight to the enemy. New threats, like cyber warfare, allow enemies to deny networked power at mission-critical times. That means the military needs innovation in energy.

Nuclear Power is the Next Step in Energy Innovation

While weapons systems and information technology are revolutionizing the battlefield, today's military still relies largely on the same petroleum-based liquid fuel system – delivered by pipelines, trucks, and ships – that the Allied Expeditionary Force relied on in 1944's invasion of Europe. Although there are now more solar power arrays at front-line bases, more efficient micro-grids allowing generators to run at higher capacities, and a culture change against wasting energy, the fact remains that the military requires ever-growing amounts of petroleum-based liquid fuels.

The military is faced with a strategic choice about how to power the force. The growth of energy demand from new systems will be mostly electrical, so dependence upon liquid fuels is not necessary. Electricity can be generated by an internal combustion engine – today's diesel generators – or it can come from advanced energy sources.

For the last decade, warfighters have recharged batteries with solar power, and advances in battery technology allow for lighter, more resilient energy storage. To meet the higher energy needs of the next generation of weapons systems, the military will need something with higher energy density. Only nuclear power can meet the demand for a small footprint with no logistical tail.

In addition to addressing logistical challenges at temporary sites, micro nuclear reactors can provide energy resilience for certain mission-critical permanent bases. The electrical grid is not reliable enough to ensure national security. Outside the U.S., cyber-attacks against the electrical grid have demonstrated the ability of hostile foreign powers to turn off electricity at will.[7] It is now clear that any kinetic attack by a hostile adversary would be preceded by a cyber-attack upon defensive installations. Bases that provide situational awareness, like radar stations, and those that provide always-on defense services, like missile defense, should have energy resilience. Similarly, extreme weather or other climate-related events also threaten the viability of power to perform national security operations.

New innovations in nuclear power mean that no one is prescribing that the military simply adapts the light-water reactor design used by submarines and commercial power plants for use. Next-generation micro nuclear reactor designs are meant to be inherently safe, utilizing passive design features to ensure security. There are at least 14 different designs for micro reactors, each with its own characteristics.[8] This report will detail some of the characteristics that will be needed in different military situations.

As American warfighters move towards a future that is increasingly powered by electricity, advanced nuclear power can provide the centralized, resilient, always available source of power that can quickly be deployed.

Global Competition in Micro Reactors for Remote Operations

The U.S. military is not the only global power to foresee a national security need for mobile nuclear power plants. Reports indicate that China could build as many as 20 floating nuclear stations to power the bases its created in the South China Sea.[9]

In May 2019, Russia's Rosatom launched the Akademik Lomonosov, a floating nuclear power plant capable of producing 70 megawatts of electrical power. It deployed across Russia's Northern Sea Route to the far-eastern Arctic in support of resource extraction operations.[10] Russia has plans to build several more. Although it is not currently supporting military operations, Russia has heavily invested in new military bases across their Arctic coastline.

As the United States military plans for an age of "Great Power Competition" it should ensure that it leads in energy, just as it leads in other areas.

The U.S. Navy's Unmatched History With Nuclear Power

The Navy has utilized nuclear power on its ships since the first nuclear-powered operation of the *USS Nautilus* in 1955. The fleet has never had a nuclear accident, an unmatched safety record. Today, there are more nuclear reactors aboard the submarines and aircraft carriers of the Navy than are operating in the entire U.S. commercial reactor industry.[11]

The Navy's history of building a nuclear fleet shows the value of nuclear power. Strategically, nuclear power allows submarines to make long patrols, hidden underwater, as a part of the nation's strategic nuclear deterrent. Only the unique capabilities of nuclear power allow for this advantage. Similarly, nuclear power aboard aircraft carriers, applied since the *USS Enterprise* in 1962, mean that the ships are able to operate without refueling for 20 years. For the Navy, nuclear power provides operational effectiveness. Naval reactors provided a strategic and tactical advantage (an "offset") in the early years of the Cold War contest with the Soviet Union.

The Navy has often pioneered new fuel sources because there's more than just cost to account for. When new fuel sources can provide operational advantages over an adversary, it can be decisive in battle. Like the transition from sail to steam or coal to oil, the transition to nuclear energy for the Navy provided advantages to the fleet measured in more than just dollars.

About Micro Nuclear Reactors

Most currently-operating commercial nuclear power plants provide in the range of 1,000 megawatts (MW) of electrical power when operational. In the near future, Small Modular Reactors (SMRs), providing 50- 300 MWs of electrical power will receive licenses and enter into commercial operation. Micro nuclear reactors, however, are intended for different markets. There are various designs from several companies with many different capabilities, so attempts to generalize may miss certain differences. Their capacity, ranging from less than 1 MW up to around 20 MWs, is intended to be matched by their small physical size.

Most micro reactors as designed would be fueled with a type of nuclear fuel enriched to higher enrichment levels than the Low Enriched Uranium used in commercial power plants. The so-called high-assay low-enriched uranium (HALEU) fuel would be enriched to between 5% and 20% of U-235.[12] This is still below the level of enrichment for nuclear weapons, but it does require specialized handling.

As Deputy Secretary of Energy Dan Brouillette said about HALEU fuel:[13]

> "...it provides more power per volume than conventional reactors. Its efficiency allows for smaller plant sizes, it allows for longer core life, and it allows for a higher burn up rate of nuclear waste."

Defining Energy Resilience and Energy Security

Congress has defined both energy security and energy resilience in law, requiring the Secretary of Defense to report on them, and prioritize them for military installations.[16]

Energy security: having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet mission essential requirements.[17]

Energy resilience: the ability to avoid, prepare for, minimize, adapt to, and recover from anticipated and unanticipated energy disruptions in order to ensure energy availability and reliability sufficient to provide for mission assurance and readiness, including mission essential operations related to readiness, and to execute or rapidly reestablish mission essential requirements.[18]

Under those definitions, energy security is about assured access to the supplies needed to meet the mission, while energy resilience is about the ability to avoid or bounce back from disruptions to energy security. Though not legally designated as such, "energy security" is more often used about access to energy during operations, while "energy resilience" is about ensuring mission-readiness at installations.

The Department of Defense anticipates that its Micro Reactors would be fueled by Tri-structural Isotropic particle (TRISO) fuel. In this fuel design, the HALEU fissile uranium is fabricated inside small kernels encapsulated with carbon and ceramics.[14] Testing indicates that TRISO fueled reactors would be resistant to melt-downs, with their ability to withstand extreme temperatures far higher than current nuclear fuels. This allows for inherent safety inside the reactor core. It also would minimize threats from attack, as each kernel minimizes the release of fissile or irradiated material from battle damage or enemy attack.

A further feature of micro reactors (as outlined in a 2019 Request for Solutions from Office of the Secretary of Defense Strategic Capabilities Office), is that the reactor would be designed with passive cooling upon loss of power.[15] That means it would not require backup diesel generators that failed so spectacularly during the Fukushima Daiichi accident in 2011. Nor would it require access to a water source.

Once the fuel within the reactor reaches the end of its lifetime, the spent nuclear fuel would be transferred to interim storage sites operated by the Department of Energy. Spent nuclear fuel from naval reactors has been transferred to Idaho National Lab, where it is stored. Similar arrangements for spent fuel storage would have to be undertaken for spent fuel from micro reactors.

While micro nuclear plants built for the military would not be designed for commercial use – these capabilities would also have clear commercial applications in off-grid locations. They are not designed to be cost-competitive with utility-scale power, but they could provide clear applications in specialty situations.

Applications for Stationary Micro Nuclear Power

Critical Air Force missions are no longer limited to supporting and deploying aircraft in war zones. Increasingly, Air Force missions include protection of the United States homeland, remote control of unmanned aircraft, and domain awareness of threats. As the military invests further into advanced technologies, and the nature of global warfare continues to change, these missions will only grow. Missions like missile defense, remote drone operations, and domain awareness in space rely on Air Force personnel and resources located largely in continental United States (CONUS) installations. These operations are supported by a global network of largely remote domain-awareness installations, particularly radar stations.

CONUS bases largely rely on the local electricity grid for power, with backup provided locally by diesel generators. Increasingly, those energy resources are supplemented by renewable power located on base. While these resources are enough for normal operations, a recent RAND report indicated concern that multi-level crises could lead to long-term outages because of failures to prioritize energy resilience.[19]

While radar stations or other remote facilities may not feature the concentration of command and control personnel and equipment, their operation is critical to meeting mission assurance. Additionally, they often require significant amounts of electrical power to operate. Micro-reactors of various sizes can provide the energy resilience necessary for both remote bases like radar stations and CONUS support bases.

Air Force operations provide key strategic national security resources. America's strategic opponents will directly target those resources in a crisis. Unlike a simple power outage, in an international crisis, these installations would be targeted by multi-level attacks. Micro reactors would add an additional layer of protection to ensure that these critical national security installations are protected.

Example: Homeland Defense Radar – Hawaii

Currently undergoing siting review, the U.S. Missile Defense Agency is planning to build a new radar station on the island of Oahu to detect ballistic missiles from Asia. This radar station, authorized in 2017 by Congress, will become a key part of U.S. ballistic missile defenses, defending both the Hawaiian Islands and the Continental United States from attacks by North Korea or other hostile actors in Asia.[20]

A $585 million contract for the HDR-H has been awarded to Lockheed Martin, which is exploring several sites in Hawaii for environmental and operational feasibility.[21] Currently, the plan is to connect the radar station to Hawaii's electrical grid at a purpose-built electrical substation and building diesel-powered generators as backup. This would require an upgrade of commercial power lines as well as on-site storage of up to 150,000 gallons of fuel.[22]

We know that commercial power grids are susceptible to cyber attack. Additionally, large power lines or large storage tanks are vulnerable to sabotage or attack. To be operationally effective, this radar station must have assured access to power. A loss of power would "blind" the missile defense system at a critical point, reducing its effectiveness. A micro nuclear reactor that is "islanded" from the Hawaiian electric grid would provide a more secure, resilient resource. Additionally, these reactors would operate without being connected to global communications networks, an important asset when cyber-attacks are a clear threat. There are similar facilities serving missile defense and space operations around the world which would likewise benefit from the resilience that nuclear power can provide.

Applications for Mobile Micro Nuclear Power

The Army's energy priorities focus on energy security – the ability to bring soldiers and equipment to the battlefield. The current energy system creates a long logistical "tail" that American adversaries are able to exploit. Insurgents in Iraq perfected the art of the Improvised Explosive Device (IED) attack against American and allied convoys. Future adversaries will certainly also concentrate their attacks on fuel supplies, as they know that our military needs energy to fight effectively.

From 2001 until 2010, more than half of the American casualties in Iraq and Afghanistan, over 18,000 men and women, were from convoy operations – missions focused on bringing fuel and water to sustain the force in the battlefield.[23]

As the Army of the future transitions from petroleum-based fuels to electrical power, it will require far more power than today's army. Directed energy weapons, electromagnetic railguns, electric vehicles, drones, and soldiers connected into a secure communications network will all require electric power. The Army is testing ideas for an "all electric brigade" and the next-generation of combat vehicles, to replace M1 Abrams tanks and M2 Bradley fighting vehicles could feature electric drives. These weapons platforms promise an enhanced ability to protect the force and take the fight to the enemy, even as they require more power.

However, if that electrical power is provided simply by generators fueled by diesel, it will be an opportunity missed. The Army envisions micro nuclear power plants for their use to be mobile, about the size of a shipping container, capable of being fit on a truck or a cargo plane. These reactors would be capable of providing power on demand in short order. Beyond the battlefield, a more immediate mission than combat operations would be disaster response. As the U.S. military is increasingly called upon to provide Humanitarian Assistance and Disaster Response in the wake of growing global vulnerability to extreme weather, mobile micro nuclear power plants can provide immediate power supplies.

A Brief History of the Army's Nuclear Fleet

The Army's nuclear power program began in 1954, after the demonstrations of initial success in the Navy's reactor program. Based at Fort Belvoir, Virginia in the Washington suburbs, the program designed and built seven small nuclear reactors, three of which were deployed to bases outside the Continental United States.[24]

The longest-serving Army nuclear reactor was deployed to supply two megawatts of electrical power in the Panama Canal Zone (then considered an unincorporated territory of the United States) from 1968 until 1975. Other power plants were deployed to support remote, off-grid locations in Greenland and Antarctica. The program was closed in 1977 due to the expense of operating these power plants.

Initially, the Army does not envision placing nuclear power plants in combat zones. Instead, they would power logistics bases near combat. Nuclear power would help to "unleash us from the tether of fuel" as General Mattis said.

Conclusion: Optimism about Micro Nuclear Reactors is Warranted, but More Work Remains

While the micro nuclear reactors provide important tactical and strategic advantages, the drawbacks of nuclear power are also well-known. It is important that any nuclear reactor program ensures America's long-term national security. That means the policy of the Department of Defense must maximize the benefits of nuclear power while striving to mitigate its limits. The Navy provides an object lesson of how to do this. For nearly 65 years, the Navy has safely and effectively operated mobile compact nuclear power plants in extreme conditions around the world. The important lesson is that harnessing nuclear power is not simply a technical issue – it must also be a part of a dedicated culture. The Navy has built a safety culture by making the sailors working within the nuclear Navy an elite part of the force. As the Air Force and Army move forward with their plans to utilize nuclear power, they should draw direct lessons from the Navy.

Micro nuclear reactors could provide significant operational advantages on the battlefield and at mission-critical installations around the world. There are still important questions that need to be answered about their survivability in active combat zones. Until such questions are answered, these reactors are likely to become more appropriate for "near combat" areas, or in remote locations where fuel shipments are difficult and vulnerable.

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The American Security Project (ASP) is a nonpartisan organization created to educate the American public and the world about the changing nature of national security in the 21st Century.

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We believe that America must lead in the pursuit of our common goals and shared security. We must confront international challenges with our partners and with all the tools at our disposal and address emerging problems before they become security crises. And to do this we must forge a bipartisan consensus here at home.

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