Roadmap for the Deployment of Micro-Reactors for U.S. Department of Defense Domestic Installations

Prepared by the Nuclear Energy Institute
October 4, 2018

Acknowledgements

This document was developed by the Nuclear Energy Institute, in collaboration with General Atomics, NuScale Power, Oklo, Southern Company, X-energy and Westinghouse Electric Corporation. This document was informed by discussions with the Department of Defense Office of Energy Installation and Environment, the Air Force Office of Energy Assurance, the Department of Energy Office of Nuclear Energy, and the Idaho National Laboratory. NEI acknowledges and appreciates the contributions of NEI members and other organizations in providing input, reviewing and commenting on the document.

NEI Project Lead: Marcus Nichol, Director New Reactor Deployment, mrn@nei.org

Executive Summary

Time and action are of the essence to deploy the first micro-reactor for a U.S. Department of Defense (DoD) domestic installation before the end of 2027. Micro-reactors are a source of resilient energy that can enable a wide range of DoD installations to enhance their range, endurance, agility and mission assurance. Micro-reactors are being designed with island-mode operations, black-start capabilities, an ability to protect against severe natural phenomena as well as man-made physical and cyber security threats, and to operate for several years without the need to shutdown for refueling.

This report identifies the timeline, major challenges and recommended actions to ensure successful deployment of the first micro-reactor at a DoD domestic installation. The deployment scenario modeled in this report is consistent with language in the 2019 National Defense Authorization Act. This includes the DoD contracting through a power purchase agreement with a commercial entity to site, construct and operate a micro-reactor located on DoD property that is licensed and regulated by the U.S. Nuclear Regulatory Commission (NRC). The roadmap is not based upon the deployment for forward operating bases. Deployment of the first micro-reactor is expected to take 7 years, but could take as few as 5 years or as many as 10 years, depending on the ability to address deployment challenges identified in the report, as well as the readiness of the technology, of which an assessment is outside the scope of this report.

> *"DoD installations rely almost entirely on the grid, which is highly vulnerable to prolonged outage from a variety of threats, placing critical missions at unacceptably high risk of extended disruption. Backup power is often based on diesel generator sets with limited on-site fuel storage, undersized for new Homeland defense missions, not prioritized to critical loads and inadequate in duration and reliability."* Defense Science Board Task Force

As with the deployment of any first-of-a-kind technology, the deployment of micro-reactors faces a number of challenges. This report recommends the following actions be taken in order to address these challenges and reduce the first deployment risks:

1. DoD should identify the host installation and site requirements, perform an assessment of the designs, and enter into a contract or agreement with a commercial entity by the end of 2019.

2. The Department of Energy (DOE) should provide High Assay Low Enriched Uranium (HALEU) for the commercial nuclear industry by the end of 2022, and begin supporting the design, qualification, licensing and fabrication of larger HALEU transportation packages by the end of 2019.

3. Developers should sustain the development of micro-reactor designs in a manner that enables critical deployment milestones to be achieved along the timeline outlined in this report, incorporates a design for manufacturability, constructability and operability approach that will minimize schedule risks for those activities, and which could include the option of entering into private-public partnerships with DOE.

4. DoD should immediately begin a sustained engagement with the industry and the NRC to identify and resolve unique regulatory issues associated with the deployment of micro-reactors for a DoD installation.

5. Industry should immediately begin working with the NRC to explore options for accelerating the review schedule for micro-reactors and expediting the process for training and licensing operators for micro-reactors.

Table of Contents

1 INTRODUCTION

This report outlines a roadmap for the deployment of the first micro-reactor for a U.S. Department of Defense (DoD) domestic installation. The roadmap is not based upon the deployment of a micro-reactor for Forward Operating Bases discussed in a Defense Science Board report.[1] Micro-reactors are very small nuclear reactors capable of operating independently from the electric grid to supply highly resilient power for critical loads, as well as primary power under normal and emergency conditions. Appendix A provides an overview of various micro-reactor technologies.

This report provides an industry perspective on the use of micro-reactors to meet DoD energy needs. Section 2 provides a description of the expected conditions for using a micro-reactor to power a DoD installation, and Appendices B and C provide an assessment of possible alternate conditions. The 2018 National Defense Authorization Act (NDAA) directed DoD to "ensure the readiness of the armed forces for their military missions by pursuing energy security and energy resilience." Energy security and resilience enhance the range, endurance, and agility of the DoD and are critical to mission assurance.[2] DoD is pursuing cost-effective measures to increase energy resilience in order to prepare for and recover from energy disruptions that impact mission assurance on military installations.[3]

The roadmap is intended to identify the timeline, major challenges, and recommended actions to ensure successful deployment of the first micro-reactor at a DoD domestic installation. It is not intended as an exhaustive legal or regulatory analysis of the subject – but rather as background information that highlights a variety of legal, licensing, regulatory, and business issues that should be considered in connection with this scenario. Sections 3, 4 and 5 present the details of the activities necessary to successfully deploy a micro-reactor. Section 6 discusses the timeline and recommends actions to overcome challenges to the deployment of the first micro-reactor for a DoD installation. Appendix D provides a graphical depiction of the timeline under the nominal and accelerated deployment scenarios.

This roadmap is also intended to inform the U.S. Department of Energy's (DOE's) development of a Federal Pilot Program study for micro-reactors. The 2019 NDAA Section 327 requires the Secretary of Energy to develop a report to describe the requirements for and components of a pilot program for micro-reactors. The pilot program would contract with a commercial entity to site, construct and operate micro-reactors of no greater than 50 MWe to provide resilience for national security infrastructure at DoD and DOE facilities by December 31, 2027.

The U.S. Congress and DoD have been interested in the use of small nuclear reactors for nearly a decade. The 2010 NDAA Section 2845 directed DoD to conduct a study to assess the feasibility of developing nuclear power plants on military installations. In response, the Center for Naval Analyses issued a 2011 report for DoD, which concluded that small modular reactors, defined as less than 300 MWe, offer the ability to contribute to DoD missions.[4] However, the study also concluded that the small modular reactors available at that time were much larger than the energy needs at domestic military installations. Since that time, micro-reactor designs have emerged that are 10 MWe or less and are more aligned with the energy demands at DoD installations.

---

[1] https://www.acq.osd.mil/dsb/reports/2010s/Energy_Systems_for_Forward_Remote_Operating_Bases.pdf
[2] DoD Quadrennial Defense Review 2014
[3] DoD Annual Energy Management and Resilience Report FY2016
[4] https://www.cna.org/CNA_files/PDF/D0023932.A5.pdf

2 MEETING DEFENSE INSTALLATION ENERGY NEEDS WITH MICRO-REACTORS

DoD manages over 500 fixed installations, which includes activities of the U.S. Air Force, Army, Navy, Marine Corps, and numerous Defense Agencies. DoD is the single largest energy consumer in the U.S., with installation energy accounting for 21% of the total Federal energy consumption. In FY2016, DoD installations used 201,410 billion British thermal units (Btu), costing approximately $3.7 billion. Overall energy demands at DoD installations were met by a mix of energy sources including electricity (53%), natural gas (32%) and other fuel sources such as fuel oil and coal (15%).[5]

The Department of Defense distinguishes installation energy from operational energy. This report focuses on installation energy, which includes energy needed to power fixed installations and enduring locations as well as non-tactical vehicles. In contrast, operational energy is the energy required for training, moving and sustaining military forces and weapons platforms for military operations and training – including energy used by tactical power systems and generators at non-enduring locations. Nuclear propulsion for naval vessels is handled separately from installation and operational energy.[6]

2.1 Location, Acquisition and Use

Micro-reactors are capable of supplying energy to a wide range of DoD installations, and are particularly well suited to power and heat remote domestic military bases that are a critical part of the national security infrastructure. Remote domestic military bases typically have significant energy needs and high electricity costs.

Eielson Air Force Base, located approximately 26 miles southeast of Fairbanks, Alaska, is used as a reference for the first deployment of a micro-reactor for a DoD installation. Eielson Air Force Base currently has a combined heat and power coal plant that began operation in the early 1950s. The coal plant can produce up to 25 MWe, although it typically produces much less than this. The winter sees the highest level of sustained power, about 13 to 15 MWe, using up to 800 tons of coal per day. The base maintains a 90 day supply of coal on site, and the plant has a thaw shed to de-freeze the coal prior to use. The Eielson Air Force Base is connected to the grid, primarily for voltage stability, and has the infrastructure needed to support black start and island mode capabilities if the grid is unavailable.[7]

For the purposes of this report, it is assumed that the DoD installation is located on U.S. territory and will purchase power from a micro-reactor. This is typically done through a utility sales contract pursuant to 10 USC 2922a. The micro-reactor is assumed to be located on DoD property, and is owned and operated by a commercial entity. This report does not address how the owner/operator will secure the rights (e.g., through a land lease agreement) to utilize the DoD property to site, construct, operate and decommission the micro-reactor.

Ninety percent of military installations have an average annual energy use that can be met by an installed capacity of nuclear power of 40 MWe or less.[8] It is anticipated that most DoD installations will seek one or more micro-reactors in the 2 MWe to 10 MWe range. It is assumed that DoD's use of the first micro-reactor will be to supplement the existing electricity generation, and will not initially be used to supply power to the grid or to provide heating requirements. However, the micro-reactor can be

5 DoD Annual Energy Management and Resilience Report FY2016
6 DoD 2016 Operational Energy Strategy
7 http://airman.dodlive.mil/2015/04/27/power-plant/
8 Feasibility of Nuclear Power on U.S. Military Installations, 2011

deployed with the capability to provide heat in addition to power. The capability to provide heating can also be added after the micro-reactor is deployed, although this may require a license amendment and some plant modifications.

Alternative scenarios, including deployment for forward operating bases, and considerations for scaling deployment beyond the first micro-reactor are discussed in Appendix B.

2.2 Regulatory Authority

The roadmap assumes that the NRC will license and regulate the construction, operation and decommissioning of micro-reactors for defense installations. An NRC-licensed commercial micro-reactor would also require NRC-licensed personnel to operate it. The NRC licensing process is mature, well understood and transparent, relative to the licensing of commercial nuclear reactors by another federal agency. However, it is one of the longest critical-path activities in the deployment timeline of micro-reactors. Alternative licensing authorities are discussed in Appendix C. This report does not address the need to engage other federal agencies for permits, such as the Department of Transportation for the transportation of micro-reactors to and from the site. An evaluation of the state and local laws that may be applicable to the deployment of a micro-reactor for a DoD installation are outside the scope of this report.

2.3 DoD Requirements

Resilience is a primary requirement for DoD. Resilience is defined in the 2018 NDAA as "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 task critical assets and other mission essential operations related to readiness, and to execute or rapidly reestablish mission essential requirements." The 2018 NDAA also defines energy security as "having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet mission essential requirements.'' Energy resilience must be achieved in a manner that does not negatively impact the mission. Generation sources that minimize usage of land, air and water resources, including site access for fuel receipt and storage, will enhance the installation's ability to focus on mission critical activities.

Currently, DoD installations rely almost entirely on the grid, which is highly vulnerable to prolonged outage from a variety of threats, placing critical missions at unacceptably high risk of extended disruption. Backup power is often based on diesel generator sets with limited on-site fuel storage, undersized for new Homeland defense missions, not prioritized to critical loads and inadequate in duration and reliability. This is according to a Defense Science Board Task Force on DoD Energy Strategy that also found "critical national security and Homeland defense missions are at an unacceptably high risk of extended outage from failure of the grid."[9]

DoD Instruction 4170.11, Installation Energy Management, provides policy direction to ensure energy resilience at military installations. Each military branch appears to address energy resilience differently, for example the Army contextualizes resilience in terms of energy security, while the Air Force contextualizes resilience in terms of energy assurance. Efforts to enhance resilience also appear to focus along the lines in which resilience has been contextualized.[10] While the detailed scenario and

[9] https://www.acq.osd.mil/dsb/reports/2000s/ADA477619.pdf
[10] DoD Annual Energy Management and Resilience Report FY2016

capability requirements necessary to provide resilience at DoD installations are not known and may be unique to each facility, there are a number of considerations that appear to be universally important. These include minimization of outages due to maintenance and failures, being robust against natural and man-made threats, the ability to quickly restore critical operations, and having secure access to the source, delivery and on-site storage of fuel. More detailed requirements for resilience for Air Force Installations are contained in a 2017 RAND report.[11]

Micro-reactors offer the ability to assure energy resilience at DoD installations. Micro-reactors can operate 24 hours a day, 7 days a week, 365 days a year, and are being designed to operate for several years without the need to shutdown for refueling. Micro-reactors are being designed to protect against severe natural phenomena as well as man-made physical and cyber security threats, and many are being designed with the ability to operate in island-mode and include black-start capabilities. Micro-reactors are also being designed to be able to adjust output to meet changes in demand.

Micro-reactors will be able to provide heat and other products, such as desalinated water and hydrogen that can meet the needs of DoD installations. Micro-reactors can also enhance DoD's use of new technologies, such as advanced computing, "big data" analytics, artificial intelligence, autonomy, robotics, directed energy, hypersonics, and biotechnology. The very technologies that ensure the U.S. will be able to fight and win the wars of the future.[12]

Other requirements such as cost, environmental impacts, power characteristics and site parameters, including land area, water sources, seismicity, precipitation, and wind speed, are not known and are likely to be site specific.

---

[11] https://www.rand.org/content/dam/rand/pubs/research_reports/RR2000/RR2066/RAND_RR2066.pdf
[12] DoD Summary of the National Defense Strategy of the United States of America

3 DEVELOPMENT AND LICENSING

Development and licensing activities for a micro-reactor include technology development, license application preparation, site characterization, and regulatory review and acceptance. Technology development for micro-reactors has been in progress for several years, and builds upon decades of research and development by DOE, the U.S. national laboratories, and industry. Some developers have begun pre-application interactions with the NRC, and development of license applications for commercial installations.

To minimize uncertainty in the roadmap, the timeline starts with the preparation of the license application for a micro-reactor at a specific DoD installation. This marks the point at which the technology is sufficiently developed that there is confidence the design can be licensed, constructed and operated. The start of the timeline is when DoD would enter into a contract or agreement with the owner/operator. It also marks the point at which the owner typically enters into contracts for pre-EPC (engineering, procurement and construction) activities. The pre-EPC contract typically covers license application preparation, site characterization, and the license review by the NRC.

3.1 Technology Development

Technology development activities include research and development of the underlying technologies, conceptual design, and preliminary testing and validation of design features. The scope and duration of technology development activities will depend on the maturity and complexity of the technology, and could take from a few to several years for a micro-reactor. DOE and DoD have their own sets of Technology Readiness Levels, which may differ from each other, that they use to assess technology maturity. However, the Technology Readiness Level does not predict how long it will take to complete the pre-licensing activities for a given technology. Appendix A provides brief descriptions of several micro-reactor technologies. Durations for developing micro-reactor designs to the point of preparing a license application are not included as the information is not publicly available.

Testing and validation of the technology will be required to support the licensing of a design. For the purposes of this paper, it is assumed that testing and validation of the design is performed through separate effects and integral testing, along with use of computer modeling and simulation programs. It is noted that the NRC does not require that a test, prototype or non-commercial demonstration reactor be constructed or operated in order to receive a license for the commercial reactor design. Although, having a test, prototype, non-commercial demonstration reactor, or commercial reactor licensed by the NRC could enable a shorter development and licensing schedule for a micro-reactor deployed at a DoD installation.

3.2 Licensing Application Preparation

It typically takes about 12 to 24 months to prepare and submit a license application, and it is expected that the first micro-reactor application can be developed in 18 months. The license application includes documentation of the safety basis of the design, and characterization of the site. The license application requires a sufficiently complete design to demonstrate that the reactor meets all of the applicable rules and regulations, including fuel qualification. The NRC has a voluntary pre-application interaction process that the owner/operator may utilize in order to improve the predictability of the NRC license review, and which may start during or before the preparation of a license application.

Development of the license application requires access to site information, and assurances that the DoD will allow the owner/operator to construct and operate a micro-reactor on the site. Therefore, DoD will need to enter into a contract or agreement with the owner/operator and/or developer in order to begin the preparation of a license application. Applicants will need to demonstrate that they there is reasonable assurance that they can obtain necessary funds and have the ability to conduct the activities of the license, and the NRC will need access to the site for inspections.[13] Site characterization requires accumulation of 24 months of meteorological data, as well as core borings to characterize the soil structure for structure supports and hydrology, and should be started before beginning the preparation of the license application. It is noted that some DoD installations may already be collecting meteorological data that can be used to meet the application content requirements, and which may reduce the lead-time for submitting a license application.

3.3 NRC Review

The NRC has two licensing pathways for power reactors described in 10 CFR Part 50 and 10 CFR Part 52. In the Part 50 licensing pathway, the NRC will initially approve a construction permit that only allows for construction of the nuclear power plant, and is later followed by NRC approval of an operating license. In the Part 52 licensing pathway, the NRC will approve a combined construction and operating license (COL). The COL may, but does not have to, reference a design certification, which allows for NRC pre-approval of the design of a nuclear power plant without a specific site, and/or an early site permit, which allows for NRC pre-approval of certain aspects of a site, including the environmental review. After construction is completed, the NRC must verify the completion of the Inspections, Tests, Analyses and Acceptance Criteria (ITAAC) before the reactor can begin operations. These licensing pathways are discussed in more detail in the NRC's FAQ about license applications for new reactors.[14]

For Part 50, the NRC recently issued a construction permit for the SHINE radioisotope production facility in 36 months, measured from application tender to a decision on the construction permit. The NRC's target review schedule for a Part 52 COL that references a certified design is 30 months from docketing to approval.[15] A Part 52 COL application does not need to reference a design certification, and can describe a design that has not previously been approved by the NRC. The NRC has not established a target review schedule for a COL that does not reference a certified design; however, under this scenario, the design review is likely to be the pacing NRC review activity. The NRC target schedule for a design certification review is 46 months. In addition to the licensing review schedule, the NRC also performs a review to determine if the application can be accepted, which typically takes 60 days.

The NRC review schedule for a COL or construction permit typically ranges between 30 months and 46 months, and it is expected that the first micro-reactor license could be reviewed and approved in 36 months, including the acceptance review. Micro-reactors are much smaller and simpler than a large light-water reactor (LWR), with small source terms and a small fraction of the power output. In fact, micro-reactors are more analogous to research reactors than larger utility scale nuclear power plants. Thus, the NRC should be able to review and approve the first micro-reactor design on the shorter side of their standard review schedules, even though new technologies sometimes take longer to review than designs based on technologies that have been previously approved. A key to improving the likelihood of a shorter NRC review schedule would be to proactively engage the NRC in pre-application meetings that

---

[13] 10 CFR 50.33
[14] https://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0468/index.html
[15] NRC's NRO-REG-100; https://www.nrc.gov/docs/ML1407/ML14078A152.pdf

highlight safety related design features and to ensure that a sufficiently complete design is provided in the license submittal.

The NRC is currently capable of reviewing an application for a micro-reactor, even though NRC requirements were developed decades ago based upon large LWR designs in operation today and micro-reactor designs differ significantly from the large LWRs. The 2018 NEI white paper *Ensuring the Future of U.S. Nuclear Energy: Creating a Streamlined and Predictable Licensing Pathway to Deployment*[16] outlines the benefits of near-term regulatory changes to make the NRC licensing more streamlined and efficient. Better alignment of the NRC regulatory framework with the inherent enhanced safety and simplified designs of micro-reactors is particularly important to make the licensing process more efficient. The NRC continues to make progress on enhancing its ability to efficiently review advanced reactor license applications.[17]

The NRC licensing of a micro-reactor for a defense installation introduces some unique considerations. NRC licenses for commercial reactors have typically been issued for plants to be located on private property and operated to generate electricity for sale to the grid. In contrast, this report examines the siting of micro-reactors on DoD property for the purposes of supplying power to DoD. Deployment of micro-reactors for DoD installations may involve novel issues. As an example, the NRC and DoD are likely to both require National Environmental Policy Act reviews. Micro-reactors sited on a defense installation will also need to address NRC dose regulations to military personnel that are considered part of the general public. Another example is that the DoD installation will have physical security and emergency response capabilities that are not available to owners/operators of reactors located on private property. These kinds of novel issues associated with licensing a micro-reactor on a defense installation will need to be identified and resolved early in the license application process.

[16] https://www.nrc.gov/docs/ML1803/ML18030A771.pdf
[17] https://www.nrc.gov/reactors/new-reactors/advanced.html#visStrat

4 ENGINEERING, PROCUREMENT AND CONSTRUCTION

Engineering, procurement and construction include certain predecessor activities, such as supply chain development and site preparation. These can begin during the license application preparation and proceed in parallel with licensing. It is a best practice to complete these activities prior to beginning the procurement, manufacturing and construction activities. The EPC contract between the owner/operator, constructor and developer is typically dependent on a certain level of design completion in order to provide confidence in the contract terms.

4.1 Final Design and Engineering

For the purposes of this report, the final design and engineering begins from the point of the design at the time the license application is submitted to the NRC and continues through completion of the design. For Part 52, the NRC requires an essentially complete design – finalized to the point that procurement specifications and construction drawings and installation specifications can be completed for significant portions of the plant – in order to approve a COL.[18] Since significant additional man-hours are necessary to develop ever greater detail of the design for specifications and drawings, an essentially complete design may only represent 40% to 50% of the total design and engineering man-hours. For a Part 50 construction permit, the NRC requires design information sufficient for a preliminary safety analysis report, which may only represent 20% or less of the total design and engineering man-hours.

The duration of the final design and engineering activity depends on many factors, the most important of which are the level of design completion when the license application is submitted, the total number of man-hours required and the rate of man-hours per month that are dedicated to the effort. Historically it has taken around 3 to 6 years to perform the final design and engineering, roughly the time it has taken for the NRC to review and approve the license. Micro-reactors are expected to require significantly fewer total man-hours to finalize the design and engineering due to the reduced size and increased simplicity of the design. Thus, it is assumed in this report that design finalization will take between 2.5 years and 4 years, with a nominal target of 3 years. The level of design completion has an impact on the start of manufacturing and construction. Best practices suggest the design should be as close to fully complete as possible before beginning construction in order to avoid schedule and cost overruns. However, 100% design completion is not feasible under many circumstances, and beginning construction with a design that is 60% to 80% complete is typically more achievable.

4.2 Manufacturing

Manufacturing is preceded by the selection of suppliers, and includes the activities to procure long lead materials, perform the factory fabrication, and source the components, materials and parts necessary to construct the plant. Supplier selection is expected to take 1 year to 2 years, with a nominal target of 1.5 years. Supplier selection should occur at least 1 to 2 years prior to ordering long lead materials.

Due to the smaller size of micro-reactors, a greater portion of the plant can be fabricated in the factory than what is typically done for larger nuclear plants. Greater use of factory fabrication offers the opportunity for better control over the quality, a reduction in the overall construction schedule, and reduced costs for subsequent units through an improved ability to incorporate lessons learned and the potential for mass production.

[18] https://www.nrc.gov/docs/ML0037/ML003707892.pdf

For larger nuclear plants, it typically takes 5 or 6 years from the order of long lead materials to the delivery of the largest component (e.g., reactor vessel) to the plant. Due to the reduced size and increased simplicity of micro-reactors, it is estimated that this procurement and manufacturing cycle can be reduced to between 3 and 5 years from the order of long lead materials to the delivery of the largest component, with a nominal target of 4 years. Most of the components will need to arrive on-site at least 6 months prior to startup in order to support the achievement of construction milestones.

For safety related components, manufacturers will be required to have the appropriate ASME certification. The nuclear industry has unique and strict quality requirements, and the manufacturing base that is qualified to manufacture nuclear grade quality (i.e., NRC's 10 CFR Part 50, Appendix B, and ASME NQA-1) components has been shrinking, especially for fabrication of large components. It should be noted that a facility that manufactures safety related components for the micro-reactor will undergo NRC audits and inspections and may have an onsite NRC inspector to review procedures for fabrication, observe craft work on the factory floor, audit documentation and ensure compliance with NRC requirements prior to offsite shipping.

Some micro-reactor designs may include unique components that have never been manufactured before. For these first-of-a-kind components, and other non-routine components, it is important that the suppliers be incorporated into the design efforts to ensure that the manufacturing is feasible and efficient. It is noted that, for Part 52 COL applications that do not reference an NRC certified design, some long-lead safety related components may need to begin fabrication at-risk before the NRC issues the micro-reactor license. Note that for a Part 50 construction permit, all fabrication, and even construction, activities proceed 'at-risk', as the NRC operating license is typically issued just before fuel loading.

4.3 Construction

On-site construction is preceded by site preparation activities. Site preparation includes excavation, grading, site mobilization, and non-safety related activities that can begin prior to the issuance of a license by the NRC; although some of these activities may require an NRC limited work authorization in order to begin prior to issuance of the license. Site preparation typically takes 2 years or longer for a large nuclear plant. In contrast, micro-reactors will utilize a much smaller site footprint, and it is expected that the site preparation for micro-reactors can be performed in 12 to 24 months, with a nominal target of 18 months.

The first placement of safety-related concrete is a significant milestone, and cannot be performed until the NRC issues a construction permit, for the Part 50 pathway, or a COL, for the Part 52 pathway. The first safety concrete milestone also marks the point at which construction activities quickly ramp up in intensity. It is important that the design completion and manufacturing activities are on-schedule to support timely construction.

Construction of a large nuclear reactor typically takes 6 to 8 years; however, these are mega-projects in comparison to micro-reactors that have power outputs that are a small fraction of large nuclear reactors. Micro-reactors utilize far fewer structures and components, and move more of the on-site construction activities into the factory. Thus, it is estimated that on-site construction for the first micro-reactor can be performed in 18 months to 36 months, with a nominal target of 24 months.

4.4 Startup

The reactor startup activities include pre-operational testing and initial on-site fuel loading. The construction organization typically turns over systems to the operations organizations as they are completed, rather than waiting for the entire plant to be constructed. This allows the operations organization to begin testing some systems earlier. The initial fuel loading is a significant milestone.

For a plant licensed under the Part 50 pathway, the NRC must approve an operating license before fuel can be loaded, which can be submitted before construction is completed.[19] Part 50 provides an opportunity for a public hearing before the Commission grants the operating license. The owner/operator will need to prepare an operating license application that describes the as-built plant and submit the application for the NRC's review and approval. It is expected that it would take the NRC between 30 months and 48 months to review and approve an operating license, with a nominal target of 36 months. It is noted that there is little recent experience with NRC issuance of a Part 50 operating license. The last NRC review of a Part 50 operating license, issued in 2015 for Watts Bar 2, lasted just over 6 years. However, this experience is not expected to be representative of the review time for a much smaller and simpler micro-reactor.

For a plant licensed under the Part 52 pathway, the NRC must verify that all ITAAC have been completed and issue a finding pursuant to 10 CFR Part 52.103(g). Part 52 also provides an opportunity for an adjudicatory proceeding (an "ITAAC hearing") before the NRC Atomic Safety and Licensing Board, at least 180 days before the scheduled fuel load date, on the question of whether the facility as constructed complies with the acceptance criteria in the COL.[20]

The plant startup encompasses the activities from fuel loading to providing 100% power to the grid, and includes the hot functional testing and power ascension testing. Startup typically takes 6 months from the time construction is completed. For a highly simplified micro-reactor, startup is expected to take between 2 and 6 months, with a nominal target of 3 months. Additional initial tests may be required by the NRC for the startup of the first-of-a-kind of a new design that could take an additional 3 months.

NRC-licensed operators are required to operate the plant. The NRC requires that these operators be licensed prior to fuel loading, and prior to either issuing the Part 50 operating license, or making the 10 CFR Part 52.103(g) finding. Operator training and licensing is a process that has historically taken several years, and in some cases is on the critical path for reactor startup, even for larger reactors that take longer to construct. Due to the simplicity of micro-reactor operations, it is expected that the operator training and licensing can be reduced to 18 to 36 months, with a nominal target of less than 24 months.

[19] 81 FR 28905
[20] 10 CFR 52.103

5 FUEL CYCLE

The NRC will regulate the fuel cycle for NRC licensed micro-reactors for defense installations, since the fuel cycle contains fissile and radioactive materials. Generally the nuclear fuel cycle is characterized as the 'front-end', which is the supply of new fuel, and the 'back-end' which is the storage, transportation and disposal of used fuel.

5.1 Fuel Supply

The supply of fuel for nuclear reactors includes the fuel design, fuel fabrication, and transportation. The existing commercial nuclear fuel industry is experienced in supplying uranium-dioxide fuel pellets enriched to less than 5% U-235 with a zirconium based cladding configured in a square array. Some micro-reactors may have fuel designs and materials that differ from the traditional LWR fuel. Most of these differences do not pose significant schedule or licensing risks, although some fuel designs and materials may require additional testing and validation.

New fuel design, testing and licensing typically takes between 3 years and 6 years, and is modeled with a target of 4 years for the first micro-reactor. However, the actual duration for new fuel development will be design specific. Efforts are underway to accelerate the pathway to NRC's approval of new fuel designs through increased use of modeling and simulation. In order to design the fuel, a substantial portion of the reactor design will need to be completed.

Fuel fabrication typically takes 9 months to 18 months, for the refueling core for a large reactor. Micro-reactors utilize substantially less fuel than a large reactor, reducing the time to fabricate fuel. However, the first micro-reactor is also likely to need new capabilities for fuel fabrication that have not reached the mass production efficiencies that are possible for large reactors today. Thus, the fabrication of the first micro-reactor is targeted to take 12 months. Depending on the fuel design, the fuel fabrication facility may need a license amendment. DOE also has capabilities and facilities that could be a resource for development, fabrication, and testing of fuel for the first micro-reactor.

New fuel designs are likely to require new or modified transportation packages to ship the fresh fuel to the micro-reactor site. It is expected that it will take between 3.5 years and 5 years, with a nominal target of 4 years, to furnish a new fresh fuel transportation package. This schedule is based upon allowing 2 years for the design and testing, 1 year for the licensing by NRC, and 1 year for the fabrication of the transportation package.

5.2 Uranium Supply

The supply of uranium includes the mining, milling, conversion and enrichment. The commercial nuclear fuel industry currently only produces fuel enriched up to 5% by weight of U-235. However, some micro-reactors will utilize fuel enriched up to 20% by weight of U-235, known as "high assay low enriched uranium" or "HALEU". A recent NEI paper outlines the challenges to supplying HALEU for commercial reactors.[21] Establishing a commercial supply of HALEU for micro-reactors would require a sufficient demand for the material and a minimum of 7 years to develop the fuel cycle infrastructure.

[21] https://www.nrc.gov/docs/ML1810/ML18103A250.pdf

DOE has access to high enriched uranium that can be down-blended to supply the HALEU needs for commercial micro-reactors and other advanced reactor and fuel technologies, until a commercial supply is available. It is estimated that it would take DOE 1.5 to 3 years to supply HALEU, with a nominal target of 2 years for the first micro-reactor deployment. The U.S. has been supplying HALEU fuel to replace high enriched fuel in U.S. and foreign research reactors.

HALEU will need to be transported for fabrication of the fuel. Unfortunately, there are no transportation packages currently licensed by the NRC to transport HALEU at commercial scale quantities. Although some existing and licensed cylinders could potentially be used, they may be uneconomical to use for commercial production of HALEU even if there were a sufficient inventory of these cylinders. While DOE and DoD have experience shipping high enriched uranium (HEU) above 20% U-235, these shipments have not been in the form of UF6, which is the typical form for commercial uses. The HEU packages also only allow a small fraction of material requiring a high volume of shipments for commercial uses of HALEU. Similar to fresh fuel transportation packages, it is expected that it will take between 3.5 years and 5 years, with a nominal target of 4 years, to furnish a new transportation package for HALEU.

5.3 Used Fuel Management

Used nuclear fuel is in a solid intact form that can be managed safely and securely.[22] On-site storage will be design specific, and most designs will incorporate life of plant storage on-site. For current light-water reactors, used fuel is stored in pools or dry casks, both of which have a long safety track record. There is also a long history of safe transportation of used nuclear fuel. For some micro-reactor designs, the used fuel may utilize different materials from those used by light-water reactors. While this may require additional testing and validation, use of alternative materials is not a significant risk to safety or regulatory approval. Used fuel storage and transportation casks are not required to be licensed before the plant begins operation, and will not be needed for years later. Thus, there is sufficient time to design, test and license new storage and transportation casks for used fuel before they are needed.

The plant owner will be required to sign a contract with DOE for final disposal of the used fuel, and the final disposal will be the responsibility of the Federal government. A disposal contract with DOE is needed in order to obtain a license by the NRC, and is expected to take between 1.5 years and 3 years to finalize, with a nominal target of 2 years.

[22] Molten salt reactors may have used fuel that is not in a solid form; however, no micro-reactors are currently being designed based on the use of molten salt fuel.

6 PATH FORWARD

Throughout this report, schedule durations and challenges for the deployment of the first micro-reactor for a DoD installation are identified. This section summarizes the timeline and identifies factors that can affect the deployment schedule. This section also provides recommendations to address critical challenges to a successful and timely deployment.

6.1 Timeline

The nominal schedule for the first micro-reactor deployment is 7 years from entering a contract or agreement with DoD (also when the pre-EPC contract is entered and the license application preparation begins) to commercial operation and generation of power for the DoD installation. It is important to note that deployment of a first-of-a-kind technology involves certain challenges and risks that can impact schedule durations. Many activities have a range of possible durations depending on numerous variables, therefore, it is feasible that the deployment of the first micro-reactor could be accomplished in as few as 5 years and in as many as 10 years. Table 1 consolidates the durations described within the report, and Table 2 consolidates the factors that can accelerate the deployment schedule. In order to meet the timelines described here, it is important that the project has sufficient access to the funds, resources and information needed to perform all of the activities.

Appendix D provides graphical depictions of the timeline for deployment of the first micro-reactor for a defense installation based upon the nominal and accelerated activity durations. These deployment timelines are based upon entering a contract with DoD in the third quarter of 2019.

Table 1. Activity Durations

Activity	Nominal	Accelerated	Maximum
Preparation of License Application (3.2)	1 ½ years	1 year	2 years
NRC Licensing (3.3)	3 years	2 ½ years	4 years
Final Design and Engineering (4.1)	3 years	2 ½ years	4 years
Supplier Selection (4.2)	1 ½ years	1 year	2 years
Manufacturing (4.2)	4 years	3 years	5 years
Site Preparation (4.3)	1 ½ years	1 year	2 years
Construction (4.3)	2 years	1 ½ years	3 years
Operator Training (4.4)	2 years	1 ½ years	3 years
Start-up (4.4)	½ years	¼ years	¾ years
Fuel Design and Testing (5.1)	4 years	3 years	6 years
Fuel Fabrication (5.1)	1 year	¾ years	1 ½ years
Fuel Transport Package (5.1)	4 years	3 ½ years	5 years
HALEU Supply (5.2)	2 years	1 ½ years	3 years
HALEU Transport Package (5.2)	4 years	3 ½ years	5 years
Used Fuel Disposal Contract (5.3)	2 years	1 ½ years	3 years
Total Critical Path Duration (License application, NRC licensing, construction and start-up)	**7 years**	**~5 years**	**~10 years**

Table 2. Factors that Can Reduce Activity Durations

Activity	Factors that Reduce Durations
License Application (3.2) and NRC Licensing (3.3)	• Technology is mature and design is substantially complete with significant amount of testing and validation completed before beginning the license application preparation • Meteorological data and site characterization are complete before beginning application preparation • DoD provides ready access to the physical site for site characterization activities (exploratory drilling, archeological surveys, etc.), site information for licensing activities, and to the NRC for inspection • DoD supports the license application preparation and responses to NRC requests for information • Policy issues and application specific issues are identified and resolved early in the application preparation process • Licensee has extensive pre-application interactions • Based upon previously approved or currently submitted design • NRC is familiar with the technology • NRC implementation of modernization and transformational change initiatives. • Government resources (e.g., funding, facilities, inter-governmental agency coordination) support the development of the technology and design (not necessary for all designs)
Final Design and Engineering (4.1)	• Design is at a very high level of completion at the time the license application is submitted • The design is simple and has a minimal number of structures, systems and components • The engineering and design organization is well staffed • Government resources (e.g., funding and facilities) support the design and engineering (not necessary for all designs)
Supplier Selection (4.2) and Manufacturing (4.2)	• Minimize use of safety-related components • Maximize use of suppliers experienced in the nuclear industry (for safety-related components) • Reliance on off-the shelf components (non-safety related) • Maximize use of materials and manufacturing processes common in the nuclear industry • Early identification and selection of suppliers for long-lead components • Early order of long lead materials and placement in factory queues
Site Preparation (4.3) and Construction (4.3)	• High degree of design completeness when construction begins • Minimize use of land area • Minimize the number and size of structures, systems and components • Maximize the amount of factory fabrication and minimize the amount of on-site construction

	• Experienced EPC consortium and construction management • Detailed construction planning prior to starting construction • There is a sufficient supply of qualified craft (e.g., rigging, electrical, piping)
Operator Training (4.4) and Start-up (4.4)	• Minimize operational complexity • Minimize number of systems and active components • Minimize number of controls and data for operators • Maximize automation
Fuel Design and Testing (5.1) and Fuel Fabrication (5.1)	• Maximize use of design tools that have been previously approved by the NRC • Maximize use of materials previously approved by the NRC for use in nuclear reactor fuel • Accelerate development of reactor design to allow an early start to the fuel design • Engage the fuel supplier early • Perform testing and validation early • Engage with NRC early on a defined fuel qualification program • Government resources for facilities and testing to qualify new fuel designs
HALEU Supply (5.2) and HALEU Transport Package (5.2)	• DOE accelerates production of HALEU for micro-reactors • Engage transport package designers and submit license applications early-on
Used Fuel Disposal Contract (5.3)	• Engage DOE early • Unique micro-reactors issues for the disposal contract are identified and resolved early-on

6.2 Recommended Actions

Deployment of micro-reactors faces a number of challenges, as would any first-of-a-kind technology. Sections 2, 3, 4 and 5 identified major challenges for deploying a micro-reactor for a DoD installation by December 31, 2027. The following recommended actions address these challenges and are essential to enabling a project to progress along the established timeline. Thus, an inability to adequately address these challenges in a timely manner, will delay the deployment timeline.

Recommended Action #1: DoD should identify the host installation for the deployment of a micro-reactor and enter into a contract or agreement for a micro-reactor before the end of 2019. The target deployment timeline shows a micro-reactor beginning commercial operations by the middle of 2027, based upon the DoD entering a contract/agreement with the owner/operator in the third quarter of 2019. DoD will need to identify the host installation, the site characteristics and other requirements necessary to enter into a contract/agreement for a micro-reactor. Identification of the installation and all relevant requirements is necessary in order to begin preparation of the license application and to inform the design of the micro-reactor. DoD should evaluate the designs, to the extent necessary, in order to assess the technology readiness and suitability. DoD should also evaluate the applicable state and local laws that would affect the procurement of a micro-reactor for the host installation. DoD may wish to consider the establishment of an interagency group that includes the NRC and DOE and engages with the commercial nuclear industry to inform DoD's activities.

Recommended Action #2: DOE should provide HALEU (e.g., UF6, UO2, metal) for the commercial nuclear industry to fabricate fresh fuel, and should support the design, license and fabrication of larger HALEU transportation packages. DOE supplied HALEU is needed for the initial deployment of micro-reactors and other advanced reactor and fuel technologies until there is enough demand to establish a commercial fuel supply. There is no domestic commercial supply of HALEU currently available, and a supply is not likely to materialize until there is sufficient market demand. HALEU is required for most of the micro-reactor designs, and DOE has access to high enriched uranium that can be down-blended to supply the commercial needs until a commercial supply becomes available. DOE would furnish HALEU no later than the end of 2022. There are also no transportation packages currently licensed to transport commercial scale quantities of HALEU. The design of a generic HALEU transportation package would need to begin before the end of 2019. Congress should direct, and DoD should request DOE to support these actions, as appropriate.

Recommended Action #3: Developers should sustain the development of their designs in a manner that enables critical deployment milestones to be achieved along the timeline outlined in this report. This could include the option of entering into private-public partnerships with DOE to help support the development and design work. The ability to meet timeline milestones for the license application preparation, NRC review, manufacturing, construction, and fuel supply activities depend on achieving each milestone's requisite level of detail in the design. Thus, the ability to develop the design to meet these milestones represents one of the largest risks to the deployment of a micro-reactor before the end of 2027. Developers should incorporate a design for manufacturability, constructability and operability approach that will minimize schedule risks for those activities. This approach would include engaging the EPC consortium, supply chain and operator early in the design process. Innovative designs that result in minimal operator actions, will also simplify training requirements to operate the reactor.

Recommended Action #4: DoD should immediately begin a sustained engagement with the industry and the NRC to identify and resolve unique regulatory issues associated with the deployment of micro-reactors for a DoD installation. The licensing issues unique to deployment of reactors for DoD installations are not known, and should be addressed before the submittal of license application. Resolution of new issues can take the NRC a few years or more, and thus the issues need to be identified relatively soon in order to assure sufficient time for their resolution in a manner that does not negatively impact the NRC review schedule.

Recommended Action #5: Industry should immediately begin working with the NRC to explore options for accelerating the review schedule for micro-reactors. The NRC review is the longest duration activity on the critical path for deployment, even though the estimated duration is on the shorter side of NRC's standard review schedule. It is expected that the NRC can perform a quicker review for micro-reactors because they are smaller and simpler than the traditional large LWRs. However, the NRC will likely need to make changes in its approach to reviewing micro-reactors in order to accomplish a shorter review schedule. This work should also include an expedited process for training and licensing operators for micro-reactors in a way that recognizes the simplicity of the design and operations. Work in this area should begin immediately, since it is likely to take time to identify and implement any opportunities to accelerate the NRC review schedule, and these changes will need to be implemented prior to submitting a license application, targeted for the first quarter of 2021 in the nominal deployment timeline.

APPENDIX A: MICRO-REACTOR TECHNOLOGIES

General Atomics, NuScale, Oklo, Westinghouse, and X-energy assisted in the development of this report, and each are developing micro-reactor designs. Included here is a high level summary of each of their designs to provide context for the roadmap. Other developers working on micro-reactor designs are also identified. Inclusion of these designs is for information only, and this report does not assess the maturity of these designs nor their ability to meet the milestone of submitting a license application outlined in the timelines in Appendix D.

A.1. General Atomics

General Atomics (GA) is developing a mobile nuclear power supply that fits within a standard CONEX container and is capable of autonomous generation of 4-10 MWe with a refueling period greater than 10 years. The compact power supply builds on GA's development of high temperature materials and fuels which enable high performance, a high degree of safety and protection against potential threats. It is also able to rapidly respond to large fluctuations in small military base loads. Its autonomous features derive from GA's integrated defense systems (e.g., unmanned aircraft interdiction and reconnaissance missions) and supply of military hardware for power production, communications and mission control. The design also builds on GA's experience in supplying dozens of research reactors under 10 MWt and GA's work on an advanced commercial reactor.

A.2. NuScale

NuScale is in the process of evaluating multiple micro-reactor concepts in the 1 MWe to 10 MWe reactor size range. Two of these concepts, the single-unit NuScale Power Module (NPM) and the reduced size NPM are light-water micro-reactors that will leverage the current NuScale design and licensing efforts (NRC Docket No. 52-048). Both concepts can serve as the basis for a diverse energy platform that can provide electricity, heat, desalination, and hydrogen production for DOD facilities, as well as towns and industry. These concepts utilize highly automated control rooms, and natural circulation for cooling. Both concepts can operate for 10 or more years without refueling, with the single-unit NPM using fuel enriched to less than 5.0% U-235, and the reduced size NPM using HALEU fuel.

A.3. Oklo

Oklo is developing a compact 2 MWe fast spectrum reactor. It is designed to serve remote, rural and native communities as well as industrial and military sites. The reactor operates purely on natural physical forces, with very few moving parts. The reactor is designed to operate for up to 20 years before refueling, and uses HALEU fuel.

A.4. Westinghouse

The Westinghouse eVinci micro-reactor is a semi-autonomous, transportable, and scalable energy generator ranging from 200 KWe to 15 MWe. The eVinci, which is an evolution of the Los Alamos National Lab's *Megapower* concept and advanced heat pipe technology, is designed to provide combined heat and power for military installations, remote communities and mining installations for high resiliency operation. The eVinci utilizes HALEU and has a solid state reactor with minimal moving parts and is being targeted to operate for at least 10 years without refueling, and maintenance .

A.5. X-energy

The X-energy X-battery is a road transportable high temperature, gas-cooled pebble bed reactor with a thermal rating of 10 MWt. It features HALEU graphite pebble fuel elements with UCO TRISO fuel particles. The reactor can be run autonomously, without any operators present on-site, or in first of a kind demonstration plants to require very few operators. The Xe-100 MICRO reactor is designed to be flexible in its application and can be configured to use a combination of power and heat, and to support the production of hydrogen. Various advanced fuel cycles have been tested in the past, such as the (Th,U)O2 can operate for around 10 years with a single core load.

A.6. Other Developers

In addition to the developers that contributed to this report, there are other companies that may also be developing micro-reactor designs. These include HolosGen, LeadCold Nuclear, NuGen, Starcore Nuclear, Urenco, and Ultra Safe Nuclear. It is noted that not all of these are U.S. companies, which could be a requirement for deployment at a DoD installation. Design details and development status are not included as there is limited public information available.

APPENDIX B: ALTERNATIVE SCENARIOS

The roadmap assumes that the micro-reactor is owned and operated by a commercial entity, that it will provide power to the DoD installation, but not initially be used to provide heating requirements or to provide power to the grid.   This section identifies advantages and challenges to alternative arrangements.

B.1. Department of Defense as Owner

General statutory authority exists for DoD to construct and operate a micro-reactor to provide electricity to critical military infrastructure.[23] DoD has experience operating nuclear reactors; however, this experience is decades old. The Army, Navy, and Air Force each separately operated fixed nuclear power plants from the 1950s through the 1970s. To our knowledge, there appears to be no existing program with the necessary capabilities to own, manage and construct such a project or to train and certify key personnel required to operate the micro-reactors for DoD installations. Although it is noted that the Army owns and is decommissioning nuclear reactors, and the Navy owns and operates reactors for use in some naval vessels. This could be remedied through expansion of these programs or creating a new program possibly through legislation or an Executive Order. It should be noted that the Navy designs, licenses and operates numerous nuclear propulsion-power reactors in its submarine and aircraft carrier fleet. However, these naval reactors are not designed for the same purpose as the micro-reactors in this paper.

An advantage to DoD ownership is the ability to better control the procurement, construction, and operation of the micro-reactor. This advantage would be further amplified if the micro-reactor is licensed by DoD or DOE. Another advantage would be the availability of an existing manufacturing infrastructure of suppliers that are used for the naval reactors program.

A disadvantage to DoD ownership is that operating a micro-reactor is not one of DoD's core missions. While DoD could contract for the operation, and still maintain ownership, this would arguably diminish the benefit of control. However, DoD would likely still retain the risk and liability for the micro-reactor, including the responsibility for decommissioning. Another disadvantage is that a micro-reactor owned by DoD may not be able to provide power to the grid. Although there is authority for DoD to provide power to the grid, this authority may be very narrow and only allowable under very specific conditions.[24]

B.2. Combined Heat and Power

Micro-reactors are being designed to produce combined heat and power, and may also be used for other energy products such as hydrogen. In developing the timeline for the first micro-reactor deployment, it was assumed that the micro-reactor would initially be used only for electricity production. This was assumed to minimize challenges to licensing the first micro-reactor, and recognizing that these capabilities can be incorporated at a later date through a license amendment and with potential plant modifications. While there may be regulatory policy issues to address, such as technical questions related to hybrid energy use (e.g., electricity and heat) and environmental review questions related to the purpose and need of the micro-reactor, it is expected that obtaining approval

[23] See 42 U.S.C. §2121(b)
[24] See 10 U.S.C. §2686

for combined heat and power would be relatively straight forward.[25] The Midland Nuclear Plant is the single identified historical precedent for a commercial power plant providing steam offsite to an industrial facility.[26] A construction permit was issued on Dec 15, 1972 and the operating license filed in 1977. Construction of the plant was halted and not completed as a nuclear power plant. Process steam to the industrial facility was to be supplied at various pressures and quantities. Approximately 75 percent of the steam heat energy was to generate electricity and the remaining 25% transported to the site boundary for process heat use

B.3. Sale of Power to the Grid

In considering the use of the first micro-reactor for a DoD installation, this report assumes that the micro-reactor would not be used to provide electricity to the grid. As noted above, sale to the grid may be limited if DoD is the owner. For a commercial entity, transmitting that energy in "interstate commerce" or selling it at wholesale in interstate commerce, is subject to the regulatory provisions of the Federal Power Act.[27] The Federal Energy Regulatory Commission, the host State, and, depending on the state, the Public Utility Commission or Regional Transmission Organization/Independent System Operator may also have jurisdiction over the sale of electricity.

Broadly speaking, the benefit of selling excess power to the grid would be to reduce the cost of power for the DoD installation. It can also enhance resilience through increased redundancy resulting from the deployment of more micro-reactors to meet a larger aggregated demand, and having the ability to redirect and dedicate that power to DoD for critical loads. It is important to note that it is not necessary for a micro-reactor to be located on the DoD installation in order to achieve energy resilience. One, or several micro-reactors can be located close to the DoD installation with a hardened transmission and distribution infrastructure that provides a similar resilience profile to a scenario where the generation source is located on the DoD installation. To ensure DoD benefits from the resilience provided by a micro-reactor that also provides power to the grid, DoD may need to reserve the right to decouple the micro-reactor from the grid and enter into island mode to provide power only to the DoD installation, for example during emergencies or to assure power for critical missions. In addition, any grid connection must be governed and controlled to avoid cyber security vulnerability.

B.4. Subsequent Deployments

The roadmap is established for the first micro-reactor for a defense installation, which necessarily will have more challenges and take longer than deployment of subsequent micro-reactors at defense installations. In terms of challenges, most will be addressed with the deployment of the first micro-reactor, namely those related to design finalization, licensing, the supply chain and the fuel supply. Schedules for deploying subsequent micro-reactors are expected to be shorter not only because the generic challenges will have been resolved, but also because of the incorporation of lessons learned, and also from the potential for establishing a manufacturing order book.

It is expected that over time, the deployment of a micro-reactor could be accomplished in roughly 3 years from the entering of a contract with DoD to the initial operations. This would be accomplished by shortening the timeframes as follows: license application preparation of 6 months, NRC license review of

---

[25] https://www.nrc.gov/docs/ML1410/ML14100A648.pdf

[26] NUREG-0793, "Safety Evaluation Report related to the operation of Midland Plant, Units 1 and 2," Docket Nos. 50-329 and 5—330, May 1982.

[27] See 42 U.S.C. §2019 and provisions of 12 U.S.C. Chapter 12 Subchapter II

18 months, manufacturing from the order of long lead materials to delivery on-site of 18 months, site preparation of 6 months, construction of 12 months, and startup of 3 months. It is recognized that achieving a 3 year micro-reactor deployment schedule will require addressing new challenges. For example, obtaining a license in less than 30 months will likely require significant changes to programmatic aspects of the NRC review, such as the 6 separate phases in the Part 52 pathway, and the environmental review. However, identifying and analyzing these challenges is beyond the scope of this report.

B.5. Forward Operating Base

The micro-reactors being developed for DoD domestic installations may also be suitable for forward operating bases, depending on the application requirements. A Defense Science Board task force concluded in a 2016 report that "energy usage on the battlefield is likely to increase significantly over the next few decades, therefore, making energy delivery and management a continuing challenge."[28] The task force also concluded that "The U.S. military could become the beneficiaries of reliable, abundant, and continuous energy through the deployment of nuclear energy power systems." The FY2017 NDAA encouraged DoD and DOE to collaborate on micro-reactors for forward operating bases and to implement the Defense Science Board's recommendations.

Nuclear energy already enhances the U.S. fighting power through powering some naval vessels. Micro-reactors offer the ability to further enhance the U.S. fighting power by producing an abundance of resilient energy in the form of electricity, heat, and hydrogen, as well as the ability to desalinate water and serve other needs at forward operating bases. Micro-reactors for forward operating bases will also enable greater use of energy-based weapons systems and the achievement of DoD goals to develop the technologies, such as directed energy weapons, that ensure the U.S. will be able to fight and win the wars of the future.[29]

Micro-reactors can operate for long periods of time without the need for an off-site resupply of fuel, and can significantly reduce the need to transport water and other supplies by producing them close to where they are needed. Transportation of fuel and water to forward operating bases is costly and results in the majority of the resupply casualties, which historically account for about 10-12% of total Army casualties.[30] The resupply of fuel also introduces vulnerabilities in the base's ability to perform mission critical activities.

The use of micro-reactors by DoD outside of U.S. territory and in theaters of war introduce new challenges to deployment, many of which are non-technical and include consideration of placing a nuclear reactor on foreign soil.[31] Limitations on using a Power Purchase Agreement with a commercial owner/operator, and licensing by the NRC would need to be assessed. Some unique technical challenges, such as transportability, qualification to battlefield conditions, and shielding, would also need to be assessed. Identification and analysis of the deployment timeline and challenges for micro-reactors at forward operating bases is beyond the scope of this report.

[28] https://www.acq.osd.mil/dsb/reports/2010s/Energy_Systems_for_Forward_Remote_Operating_Bases.pdf
[29] DoD Summary of the National Defense Strategy of the United States of America
[30] http://www.aepi.army.mil/docs/whatsnew/SMP_Casualty_Cost_Factors_Final1-09.pdf
[31] https://www.acq.osd.mil/dsb/reports/2010s/Energy_Systems_for_Forward_Remote_Operating_Bases.pdf

APPENDIX C: ALTERNATIVE REGULATORY AUTHORITIES

Consistent with the language in the 2019 NDAA, this roadmap assumes that the U.S. Nuclear Regulatory Commission will license the construction, operation and decommissioning of micro-reactors for a DoD installation, as well as the related fuel cycle. There are a number of advantages to this approach, including experience with a mature regulatory agency that is currently prepared to review micro-reactor applications. This also assures that designs utilized for DoD installations are the same as the designs being used for non-defense applications, such as remote villages.

However, DoD does not require an NRC license to own and operate a micro-reactor.[32] This appendix explores the advantages and disadvantages of using another federal agency as the regulatory authority.

C.1. Authorized Federal Agencies

The Atomic Energy Act of 1954, as amended, (AEA) allows the President of the United States to authorize the DoD to manufacture, produce or acquire any utilization facility for military purposes.[33] The AEA specifically does not require an NRC license for "the manufacture, production, or acquisition by the Department of Defense of any utilization facility… or for the use of such facility by the Department of Defense or a contractor thereof."[34]

Nuclear reactors for defense installations were licensed by military departments from 1954 to 1977.[35] The Army Reactor Office, which historically licensed and regulated Army reactors, is still operational.[36] Although, the Army Reactor Office has not licensed a new reactor since the 1970s, and today is mainly focused on the decommissioning of retired Army nuclear reactors. Therefore, the Army Reactor Office would need to acquire the capabilities and expertise to license the advanced micro-reactor technologies being developed.

DOE has a licensing authority, established in 2000[37], regarding Atomic Energy for Military Applications given to the National Nuclear Security Administration (NNSA). Part of the mission is to enhance national security through "the military application of nuclear energy," support U.S. "leadership in science and technology," and provide the Navy with "safe, military effective nuclear propulsion plants and to ensure the safe and reliable operation of those plants." Within the NNSA, the Office of Naval Reactors was established by Executive Order 12344 (42 U.S.C. 7158), "Naval Nuclear Propulsion Program." Naval Reactors oversees a nuclear-powered fleet of 82 warships, 6 shipyards, 4 training reactors with a throughput of 3,500 students/year, 2 dedicated labs (Bettis/Knolls), prime contractors and hundreds of suppliers, and a used fuel facility. The program covers the naval nuclear reactors from "cradle to grave," including personnel training and selection, reactor design, research, development, acquisition, specification, construction, inspection, installation, certification, testing overhaul, refueling, operating practices and procedures, maintenance, supply support, and ultimate disposition.

The Office of Naval Reactors authority is currently limited to naval nuclear propulsion and support applications. While the AEA appears to permit the DOE to license micro-reactors for DoD installations, it

32 This position is supported by an NRC letter to the Washington State Attorney General dated April 13, 2001
33 See 42 U.S.C. §2121(b)
34 See 42 U.S.C. §2140(b)
35 https://www.acq.osd.mil/dsb/reports/2010s/Energy_Systems_for_Forward_Remote_Operating_Bases.pdf
36 https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/r50-7_Web_FINAL.pdf
37 50 U.S.C. §2401

is likely that programmatic authority to license micro-reactors for defense installations would need to be established (e.g., by federal statue or through an Executive Order, similar to the one that established Naval Reactors). Once the requisite authority is established, DOE might opt to license micro-reactors for remote domestic bases through the Office of Naval Reactors. It should be noted that Naval Reactors licensing of micro-reactors would require changes to the license basis documents being used for naval nuclear propulsion because the design criteria are different for a stationary electric power and/or steam producing reactor. Alternatively, DOE could presumably establish a separate office on the basis that the missions of licensing naval reactors and micro-reactors are sufficiently different. Nonetheless, we understand that Naval Reactors has a deep institutional expertise and long operational excellence in licensing small reactors, from which the licensing of micro-reactors could benefit.

C.2. Advantages and Disadvantages

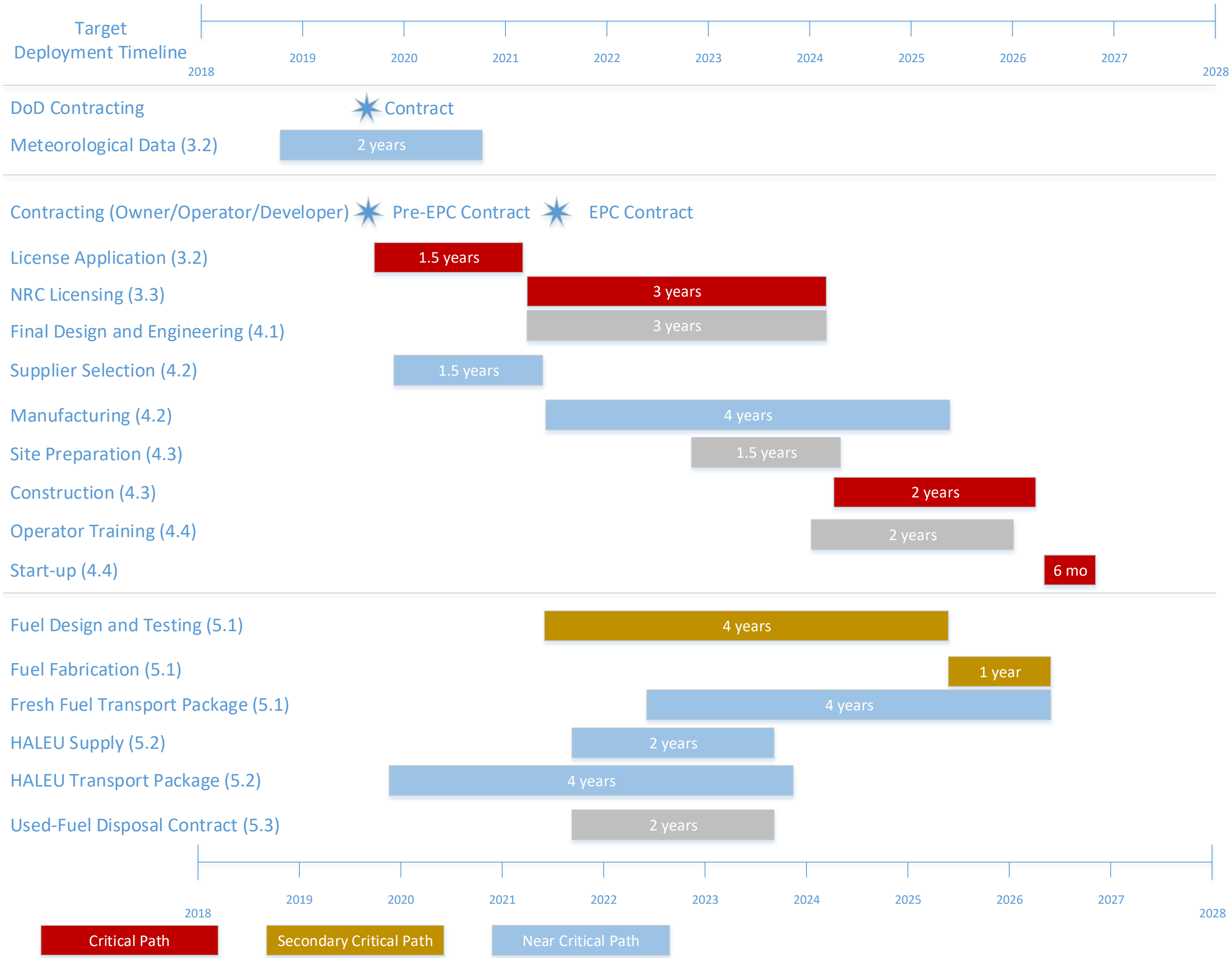
An advantage to having DOE or DoD license micro-reactors for defense installations is that the government could maintain greater control over the siting requirements and licensing schedule. However, it is unclear whether DOE or DoD could license micro-reactors in less time than it would take the NRC to do so. Furthermore, it would take a significant amount of time (likely years) and expense to establish a DOE or DoD program to perform the licensing. In contrast, the NRC has significant experience and expertise (including ongoing reactor licensing projects) in licensing nuclear facilities, and has already begun to implement changes that will make the licensing of micro-reactors more efficient. Thus, DOE or DoD would need to establish a regulatory framework before the end of 2020 (within roughly 2 years) in order to be prepared to receive a license application, and would also need to be able to review and approve a micro-reactor application in less than 3 years in order to have a schedule advantage over licensing by the NRC. Subsequent license reviews would need to be performed in less than 2.5 years, and possibly less than 1.5 years, in order to be faster than expected future reviews by the NRC.

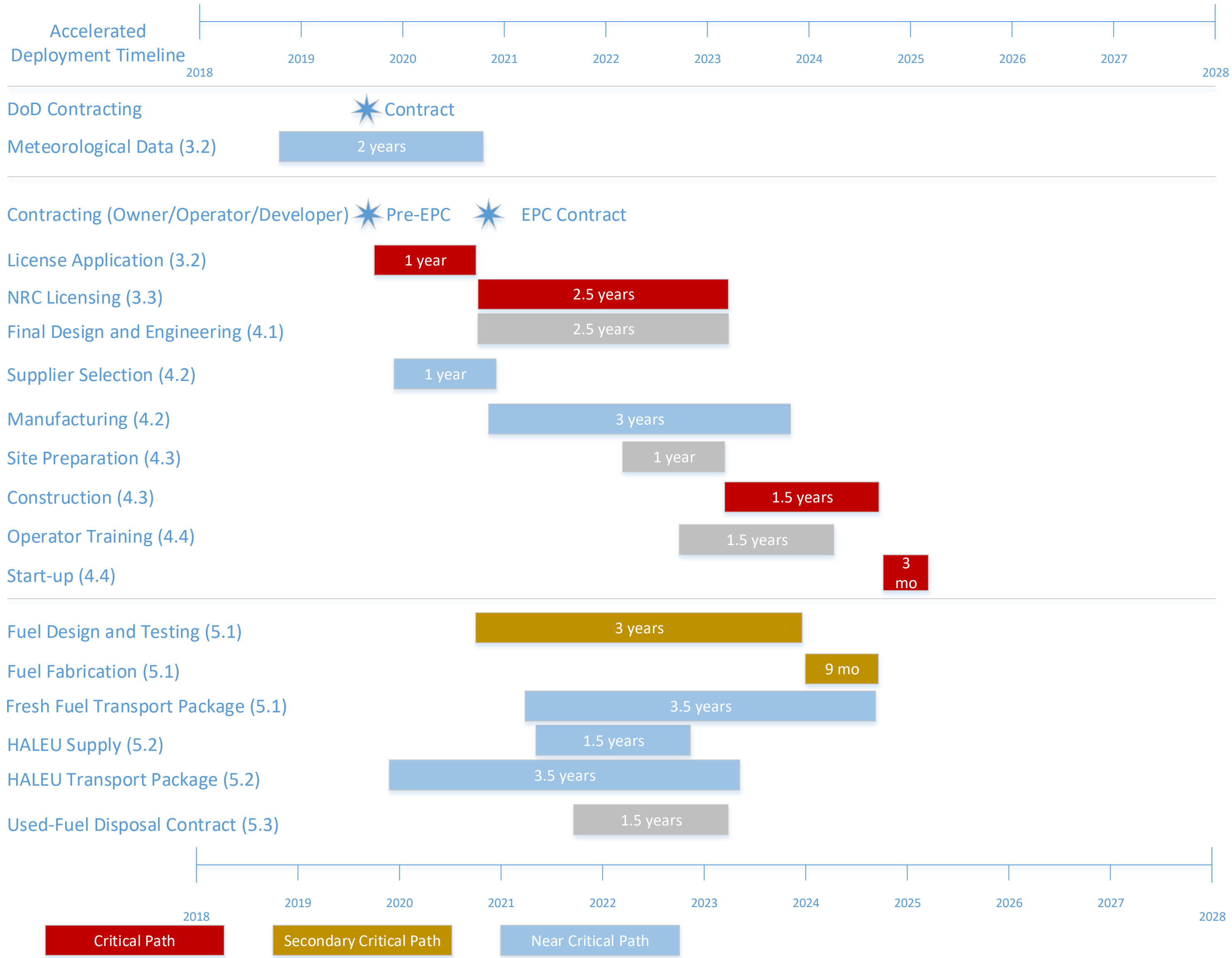
A possible disadvantage is that the legal authority that permits licensing by DOE or DoD may be limited to micro-reactors that are owned and operated by DoD. Non-DOD entities (or their Contractors) require an NRC license "to transfer or receive in interstate commerce, manufacture, produce, transfer, acquire, possess, use, import, or export… utilization or production facilities for industrial or commercial purposes"[38] Excepting DoD, it is unlawful for any person within the United States to transfer or receive in interstate commerce, manufacture, produce, transfer, acquire, possess, use, import, or export any utilization or production facility except under and in accordance with a license issued by the NRC.[39] Even a (non-DoD) government agency would require an NRC license for a utilization facility for the primary purpose of producing electric energy for disposition for ultimate public consumption.[40]

Another possible disadvantage is that licensing a micro-reactor by DOE or DoD for defense installations and by the NRC for commercial facilities could result in two variations of the design, due to differences in the requirements from two separate regulatory authorities. Having two versions of the same design makes it more difficult to learn lessons on the manufacturing and construction and to gain other economies of scale, likely resulting in higher costs of power to DoD.

[38] See 42 U.S.C. §2133(a)
[39] See 42 U.S.C. §2131
[40] See 42 U.S.C. §2020

APPENDIX D: DEPLOYMENT TIMELINES




Accelerated Deployment Timeline
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
DoD Contracting
Contract
Meteorological Data (3.2)
2 years
Contracting (Owner/Operator/Developer)
Pre-EPC
EPC Contract
License Application (3.2)
1 year
NRC Licensing (3.3)
2.5 years
Final Design and Engineering (4.1)
2.5 years
Supplier Selection (4.2)
1 year
Manufacturing (4.2)
3 years
Site Preparation (4.3)
1 year
Construction (4.3)
1.5 years
Operator Training (4.4)
1.5 years
Start-up (4.4)
3 mo
Fuel Design and Testing (5.1)
3 years
Fuel Fabrication (5.1)
9 mo
Fresh Fuel Transport Package (5.1)
3.5 years
HALEU Supply (5.2)
1.5 years
HALEU Transport Package (5.2)
3.5 years
Used-Fuel Disposal Contract (5.3)
1.5 years
Critical Path
Secondary Critical Path
Near Critical Path