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Assessment of Small Modular Reactor Suitability for Use On or Near Air Force Space Command Installations

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ABSTRACT

This is the final report of the Small Modular Reactor (SMR) Suitability study by Sandia National Laboratories and the Scitor Team (Scitor Corporation and Landrey & Company). SMRs are being considered by the U.S. government as a clean energy option that can meet the economic, environmental and energy security goals of the country. This report was sponsored by the US Department of Energy (DOE) under the SMR Licensing Technical Support program, of which one of the goals is to advance the commercial viability of domestic SMR designs. The study reflects the intent of the memorandum of understanding between the DOE and the Department of Defense (DoD) to enhance national energy security and demonstrate leadership in transitioning the United States (US) to a low carbon economy. This report assesses the suitability of using US-developed light water SMR technology to provide energy for Schriever Air Force Base, CO and Clear Air Force Station, AK, and for broader SMR applications to meet DoD and Federal energy needs. This report also outlines deployment scenarios to optimize the use of an SMR's capacity to meet aggregated DoD and Federal energy needs within selected regions of the US. Finally, the report includes recommendations for follow-on actions by DoD and DOE to further the development of US SMR technology and effectively address viable solutions for national energy security and clean energy goals.

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NOMENCLATURE

Acronym	Definition
ACC	Air Combat Command
AETC	Air Education and Training Command
AF	Air Force
AFB	Air Force Base
AFI	Air Force Instruction
AFPD	Air Force Policy Directive
AFRC	Air Force Reserve Command
AFS	Air Force Station
AFSPC	Air Force Space Command
AFY	Acre Feet Per Year
AK	Alaska
ANG	Air National Guard
ARC-V	Air Reserve Component Force Protection Volunteer Program
AZ	Arizona
BTU	British Thermal Unit
BWXT	BWX Technologies, Incorporated
CA	California
CES&S	Center for Energy, Security and Society
CO	Colorado
CO_2	Carbon Dioxide
COL	Construction and Operating License
CFR	Code of Federal Regulation
CHPP	Combined Heat and Power Plant
CPP	Clean Power Plan
CSU	Colorado Springs Utilities
DAF	Department of the Air Force
DCA	Design Certification Application
DHS	Department of Homeland Security
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DOE	Department of Energy
DOJ	Department of Justice
EE15	Energy and Environment Survey 2015
EIRP	Electric Integrated Resource Plan
EMP	Electromagnetic Pulse
EO	Executive Order
EPA	Environmental Protection Agency
EUL	Enhanced Use Lease

FEMP	Federal Emergency Management Plan
FL	Florida
FOAK	First of a Kind
FY	Fiscal Year
G&T	Generation and Transmission
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GPD	Gallons Per Day
GPM	Gallons Per Minute
GSA	General Services Administration
GVEA	Golden Valley Electric Association
HAF	Headquarters, Air Force
HAZMAT	Hazardous Materials
HQ	Headquarters
HQ AFSPC	Headquarters, Air Force Space Command
IOU	Investor-Owned Utility
ISFSI	Interim Spent Fuel Storage Installation
KWH	Kilowatt Hour
INL	Idaho National Laboratory
ITC	Investment Tax Credit
LCOE	Levelized (or Lifecycle) Cost of Energy
LOS	Line of Sight
LRDR	Long Range Discrimination Radar
MBTU	Million British Thermal Units
MDA	Missile Defense Agency
MED	Multi-Effect Distillation
MOU	Memorandum of Understanding
MVEA	Mountain View Electric Association
MWe	Megawatt Electric
MWh	Megawatt Hours
MWt	Megawatt Thermal
NASA	National Aeronautics and Space Administration
NSSS	Nuclear Steam Supply System
NORAD	North American Air Defense Command
NORTHCOM	United States Northern Command
NPM	NuScale Power Module
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
OR-SAGE	Oak Ridge Siting Analysis for Power Generation Expansion
PMA	Power Marketing Agency
PPA	Power Purchase Agreement
PTC	Production Tax Credit

PV	Photovoltaic
PWR	Pressurized Water Reactor
RA	Restricted Area
RFP	Request for Proposal
SAF	Secretary of the Air Force Staff
sCO_2	Supercritical Carbon Dioxide
SECDEF	Secretary of Defense
SME	Subject Matter Expert
SMR	Small Modular Reactor
SNL	Sandia National Laboratories
SSEC	Site Selection and Evaluation Criteria
SSPARS	Solid-State Phased Array Radar System
SW	Space Wing
SWS	Space Warning Squadron
TPD	Tons Per Day
TVA	Tennessee Valley Authority
UAMPS	Utah Associated Municipal Power Systems
UPS	Uninterruptible Power Supply
U.S.	United States
USAF	United States Air Force
USC	United States Code
USD(AT&L)	Undersecretary of Defense for Acquisition, Technology and Logistics
UT	Utah
VA	Department of Veterans Affairs
WACC	Weighted Average Cost of Capital
WAPA	Western Area Power Administration

EXECUTIVE SUMMARY

Deploying small modular reactors (SMR) to serve Department of Defense (DoD) facilities has been the subject of significant discussion and study during the past decade. The deployment is viewed as a potential strategy to enhance energy reliability at military installations, and achieve clean energy goals, while also accelerating commercialization of United States (U.S.) SMR technology. The Small Modular Reactor Licensing Technical Support Program of the Department of Energy (DOE) Office of Nuclear Energy funded this study to further evaluate this strategy. This study took an in-depth look at the considerations and requirements relevant to deploying SMRs to serve DoD installations. It focused on the suitability of the light water SMR designs currently under development in the US, as one or more of the designs are likely to be commercially available within the next 10 years. The leadership of Air Force Space Command (AFSPC) expressed interest in the concept in 2013, and cooperated in the study by providing subject matter experts and allowing access to two of its installations for case studies. The study Team (Sandia National Laboratories [SNL], Scitor Corporation, and Landrey & Company) established specific criteria to evaluate the suitability of AFSPC's 12 installations in the continental U.S. using the Oak Ridge Siting Analysis for power Generation Expansion (OR-SAGE) model developed by Oak Ridge National Laboratory (ORNL). Based on the ORNL results and additional analysis, the Team built case studies using Schriever Air Force Base (AFB) in Colorado, and Clear Air Force Station (AFS) in Alaska. The study finds that the near term SMRs are a suitable source of clean, secure energy for DoD installations, with some important considerations to address the lack of sufficient water on Schriever AFB and the seismic activity in the vicinity of Clear AFS. Further, it identifies pathways the U.S. government can take to facilitate the deployment of SMRs to serve DoD installations. The Team emphasized that the study's focus is on the *feasibility* of SMR deployment--no deployment decision would be a direct result of this effort. Additionally, none of the study's content is classified or for official use only.

The study focused on SMRs that will use light water reactor technology similar to what already is in use in the commercial U.S. fleet that supplies almost 20% of the nation's electricity. Currently, there are four light water SMR technologies under development in the U.S. The developers include the mPower division of Babcock & Wilcox, Holtec International, NuScale Power, and Westinghouse. The individual reactor designs range in size from 50 MWe to 225 MWe, but the power plants designed to house the reactors have different configurations. Holtec and Westinghouse are designing plants with individual reactors of 160 MWe and 225 MWe, respectively. mPower plans a plant with two, 180 MWe units for a total of 360 MWe. A NuScale power plant is scalable with up to twelve, 50 MWe reactors, with a net output of 570 MWe. The process to bring a design to the commercial market is lengthy and expensive. Industry estimates place the cost at about $1 billion for design, testing, U.S. Nuclear Regulatory Commission review, and First of a Kind engineering. All four companies predict they could have the first plant using their technologies in commercial operation in the 2023-2025 timeframe.

Economics

Numerous studies by government agencies, academia, trade associations, and technology developers have examined the economics of electric energy from SMRs. With an overnight capital cost of about $5,000 per kilowatt of net capacity, the figure frequently used by the SMR developers, most studies put the levelized cost of energy (LCOE) in the range of $0.075/kilowatt hour (kwh) for a publicly-owned utility to $0.10/kwh for an investor-owned utility, without incentives. In addition to the capital cost, the principal factors affecting LCOE are the ownership structure and the availability of incentives. Municipal and cooperatively-owned utilities have the ability to fund projects with low-cost, tax-exempt debt and do not pay income taxes. They also have access to Federal loan guarantees. The municipal and cooperative generation and transmission organizations that are participating in the Vogtle 3 & 4 projects, for example, are utilizing Federal loan guarantees to lower their cost of capital. Besides loan guarantees, the incentives available to the investor-owned utilities participating nuclear projects now under construction in the U.S. have access to a production tax credit of $0.018 /kwh and risk insurance. Those incentives were included in the Energy Policy Act of 2005 and required start of construction by the end of 2014. As a result, they have essentially expired, and are not available to the owners of new SMRs.

In contrast to nuclear, other clean energy sources such as solar and wind have had access to extensive incentive programs at the Federal and state level. Investor-owned developers of solar projects, for example, have had access to a production tax credit of $0.023/kwh, or an investment tax credit of 30% of project cost that is convertible to a cash grant at the time the project goes into operation. An analysis by NuScale Power found; however, that even if an SMR has access to the more generous incentives available to solar, the cost of power from an investor-owned SMR remains slightly higher than one with municipal or cooperative ownership.

Another factor affecting the cost of capital, and the LCOE, is the duration of power purchase agreements (PPA) between the owner of the SMR and the Federal purchaser of its power. Investors in both the debt and equity used to finance power projects perceive that the longer the duration the less the risk--with a longer PPA, investors are willing to ask for a lower return on investment. DoD currently can sign PPAs of up to 30 years. DOE and other Federal agencies; however, are limited to 10 years.

A concern expressed by one utility that serves several DoD installations is that the Office of Management and Budget (OMB) might require that a PPA with an SMR be “scored” in its first year. Scoring would mean that the full cost of the power purchases over the 10 to 30 year life of the agreement would need to be budgeted as if paid in total in the first year, with the funds appropriated by Congress. If put into place, this practice would be a significant impediment to the development of SMRs and other clean energy sources for the purpose of serving DoD or other Federal facilities.

Federal Mandates

Two important policy and regulatory documents were issued during the study period. All Federal agencies, including the DoD, have mandates to procure a significant percentage of their energy from renewable and alternative clean sources of power, and to reduce their energy consumption. The most recent mandate was set by President Obama in Executive Order (EO) 13693, *Planning for Federal Sustainability in the Next Decade*, issued in March 2015. The EO requires all Federal agencies to receive 25% of their electric and thermal energy from renewable and clean, alternative sources by 2025. Importantly, for the first time at the Federal or state level, the EO designates SMRs as a suitable "alternative" source of power for achieving these goals. In addition to the goals in the President's EO, in 2012 DoD established an ambitious goal to have each Service procure 1 GWe of electricity from renewable sources by 2020. It is not yet clear whether DoD will follow the President's lead and expand the definition of acceptable resources to include SMRs.

Also, in 2015 the Environmental Protection Agency (EPA) issued its Clean Power Plan (CPP), which sets state-by-state targets for reducing carbon emissions. The CPP seeks to achieve dramatic reductions in the emissions of CO_2 from power plants, and is expected to result in the closure of a significant number of coal-fired power plants in the contiguous 48 states. (EPA has not set emission targets for Alaska, Hawaii, and Guam due to the unique nature of the energy landscape in those locations). The CPP identifies new nuclear power plants as a potential clean energy resource to replace CO_2-emitting power plants. The CPP could increase interest in nuclear power, which already provides nearly 60% of the carbon-free electricity produced in the U.S.

Currently, nuclear power plants in the U.S. are required to store used nuclear fuel on site until the Federal government completes a permanent disposal facility. The light water SMRs are being designed to temporarily hold used fuel in a spent fuel pool for no less than five years after it is removed from the reactor. After five years, the used fuel can be moved to a dry cask storage system and stored on site at an Interim Spent Fuel Storage Installation. The interim storage of used fuel on land leased from a DoD installation for an SMR would require an agreement between the Secretaries of Defense and Energy. AFSPC personnel; however, questioned whether interim storage of used fuel would raise concerns among staff on site, or the residents of on-site housing.

DoD Policies

The U.S. government has written policies that inhibit DoD's ability to use SMRs to provide its installations with energy. The DoD has stated clearly that it will not own or operate SMRs, or other generating resources, except in unique situations. In fact, at installations such as Clear AFS, DoD is transitioning from producing its own energy to purchasing commercial power off the grid. This policy prohibits DoD from supporting the capital cost of an SMR developed to provide it with clean, reliable power. Federal policy also prohibits DoD from purchasing power for more than the current and forecasted market rate. Solar and wind project developers have been able to keep the price of power at or below market as a result of their access to financial incentives. Unfortunately, there is no mechanism that allows DoD to place a value on the “always-on” availability of SMR power, the improved reliability from synergies between the SMR and the installation, or the ability of the SMR to meet the installation’s EO goals for clean energy.

AFSPC/DoD Desired Capabilities for SMRs

The DoD, and AFSPC, have major priorities that drive energy requirements. Key among these are mission assurance, energy security, safety, security, reduced energy costs, and attainment of clean energy and greenhouse gas goals. DoD’s desired capabilities for an SMR could include a black start capability, island mode operations, smartgrid compatibility, non-electric applications, independence from the commercial grid, integration with renewable energy resources, mobility, forward-deployed site operations, and offsite storage and disposition of spent fuel.

Reliability

For most DoD installations, an uninterrupted supply of energy is critical for sustaining their missions. For example, AFSPC’s reliability requirements range from 99.9% to 99.999%. When commercial power does go out, mission critical functions immediately switch to uninterruptable power supplies (UPS), then transition to backup generators, mostly powered by diesel. Interestingly, many of the installations essentially act as their own microgrids. Schriever AFB has a single connection to its utility provider but isolates itself if there is a problem with the grid, relying on a backup plant with seven diesel generators. Clear AFS has been entirely self-sufficient with electric and thermal energy produced at an on-site, coal-fired, combined heat and power plant. In 2015, Clear AFS transitioned to receive electric service from its local cooperative utility and uses diesel-fired boilers on site to produce thermal energy. With outside temperatures falling to -40 F in the winter, thermal energy is critically important at Clear AFS. During extreme cold, personnel must evacuate the installation’s Composite Area (administration, services, housing) if thermal energy is lost for more than four hours. If thermal energy is lost, the damage to facilities is estimated at more than $200 million.

In addition to “three to five 9’s” in reliability, a DoD installation would benefit if the SMR is designed to operate in “island mode” to provide power to an installation’s microgrid and a larger microgrid encompassing the surrounding community. In the event of an SMR station blackout, an installation’s backup generators and UPS could help to support black start capabilities for the nuclear power plant. Where thermal energy is critical, an SMR can supply it at little incremental cost. Importantly, an SMR could use its residual heat after a shutdown to supply thermal energy to the installation for an extended period.

SMR Deployment Scenarios

The Team evaluated three deployment scenarios for an SMR:

- Conventional deployment at a suitable site with a connection to the grid serving the installation.
- Deployment immediately adjacent to, but not on the installation.
- Deployment on the installation.

Not surprisingly, the Team found that the greatest opportunity to achieve mutual benefit is if the SMR is sited on the installation. If not on site, the closer the better. On Schriever AFB, an SMR might be sited so that its security fence abutted the security fence for the installation's secure restricted area. This proximity would decrease response times between the operations in an emergency, and facilitate the sharing of electric and thermal energy. At the same time, an SMR must be sited so that it does not interfere with a DoD installation's operations. For AFSPC, these include line of sight requirements for radar operations and avoiding frequency interference.

Potential Synergies

DoD installations vary in size from a few hundred personnel to thousands and tens of thousands. Clear AFS, for example, has about 350 personnel on site daily, while Schriever AFB exceeds 7,500. Some installations are in remote locations while others are close to established communities. Schriever AFB is located in a sparsely populated area on the plains 16 miles east of Colorado Springs, but the city has grown up around nearby Peterson AFB and Fort Carson. Clear AFS is in a remote location about 75 road miles southwest of Fairbanks, AK. In contrast, Fort Wainwright, an Army post with approximately 7,000 personnel, is adjacent to the city of Fairbanks.

The installations provide on-site personnel with a number of services. Schriever AFB has a recreation center, a child care center, dining facilities, and a medical clinic. It also has 242 single and multi-family homes on site for assigned Air Force personnel. With the exception of child care, Clear AFS provides similar services, although to a lesser degree due its smaller size, and it has dormitories and apartments rather than houses. The installations also have capabilities that could offer synergies to the operation of an SMR including physical security, fire protection, emergency preparedness and response, and hazardous materials response.

The Team identified DoD mechanisms for an SMR operator to contract for the use of DoD services, including physical security. The DoD installations' existing services are sized to meet their current needs, so meeting the needs of an SMR would require additional personnel, equipment and facilities. By combining their needs, however, the DoD installation and the SMR could achieve economies of scale, lowering the costs for both and improving the overall level and quality of services.

Fully Utilizing Energy from an SMR

The energy requirements for DoD installations vary widely. More than 90% need less than 40 MWe, and more than half need less than 10 MWe. Schriever AFB requires about 10.7 MWe, while Clear AFS will require about 28 MWe after a mission expansion later in this decade. As exemplified by Schriever and Clear, the output of the individual reactors for the four SMR technologies exceeds the requirements of most DoD installations. In addition, the electrical output of the power plants, as currently designed, exceed the requirements of all individual DoD installations. There are several possible approaches that can allow DoD the opportunity to gain the benefits of clean energy from an SMR.

- Aggregation of Demand. The requirements of multiple DoD installations can be aggregated under a PPA or other contractual mechanisms to more fully utilize the output of an SMR nuclear power plant. The General Services Administration (GSA), for example, can establish “Area-Wide Contracts” with a utility that encompass all DoD customers within the utility’s service territory. Another option is for a Federal Power Marketing Agency (PMA), such as the Western Area Power Administration (WAPA) to contract for power for multiple DoD and Federal installations.
- Non-Electric Applications. Not all of the energy from an SMR needs to be used to produce electricity. Thermal energy can be used to provide heating to the DoD installation and the surrounding community. The thermal energy also can be used to support a process such as Fischer-Tropsch to convert coal into transportation fuels for DoD.
- Commercial Sales. Energy not used by DoD and other Federal customers can be sold into the grid to supply the commercial market.

Benefits to DoD of Non-Electric Applications

Energy produced by an SMR has the potential to provide the DoD and the surrounding communities with more than electricity. The Idaho National Laboratory (INL), other research institutions, and SMR technology developers have identified a number of possibilities. The studies note that the smaller output, and ability to install multiple reactors modules on site or within a facility, allows flexibility in the use of a reactor’s energy output and offers the potential for enhanced reliability. A portion of the thermal energy from a single reactor can be used to support a non-electric application, or a reactor can be dedicated entirely to that application. These applications include district heating; desalination; and the production of liquid fuels, hydrogen, and oxygen.

<u>District Heating.</u> Thermal energy from nuclear power plants already is used for district heating in eight countries in Europe and Russia. The study learned that a continuous supply of thermal energy is of critical importance to sustaining the missions at the DoD installations in Alaska, which can experience sustained outside temperatures as low as -40 F. Steam produced by an SMR could provide heat for a DoD installation and the community. Research by the INL indicates that thermal energy from an SMR can be transported a distance of as much as 60 miles for district heating purposes.

<u>Desalinated Water.</u> Nuclear power plants already support desalination in 15 locations. India, Kazakhstan, and Japan all have used nuclear power plants to support desalination efforts. Of the three processes in use today, the two distillation processes (Multi-stage Flash and Multi-Effect Distillation [MED]) require a thermal energy source as well as electricity. One 160 MWt source dedicated to MED can produce 88,000 cubic meters per day of clean water.

<u>Liquid Fuels.</u> The Fischer-Tropsch process for converting coal into liquid fuels has been in use for decades. The LWR SMRs under development in the U.S. produce super-heated steam at a temperature range of 300^{o}C to 320^{o}C. This is sufficient to support a High Temperature Fischer Tropsch process to convert coal to liquid fuels for transportation purposes. A study by INL estimates that feedstock of 12,000 tons per day (tpd) of coal, plus 290 million standard cubic feet

(mscf) of natural gas, can be turned into 58,000 barrels per day of gasoline and 9,000 barrels per day of Liquefied Petroleum Gas (LPG). Transportation fuels are one of DoD's largest expenses. The ability to use clean energy from an SMR to produce both electricity and transportation fuels offers tremendous value to DoD.

Hydrogen and Oxygen. The U.S. currently uses more than 12 million tons of hydrogen each year for fertilizer production, refining, and the food industry, according to an analysis by INL and NuScale. Using the emerging technology of High Temperature Steam Electrolysis, a single 160 MWt NuScale module could produce 2,900 lb/hr of hydrogen and 23,000 lb/hr of oxygen, according to the research. A production plant with six NuScale modules would produce hydrogen sufficient to supply a commercial ammonia plant producing 1,150 tpd, or a petroleum refinery of 40,000 to 50,000 barrels per day.

Public Perception

During the study period, the Center for Energy, Security, and Society, a joint research center of the University of Oklahoma and SNL, conducted its fifteenth annual Energy and Environment Survey (EE15). The survey was fielded in June 2015, and was implemented using a web-based questionnaire. It was completed by 2,021 respondents from the contiguous 48 states. SMRs are relatively new and the American public's perceptions about and support for SMRs have not previously been systematically studied. EE15 included questions designed to better understand how members of the U.S. public think about the risks and benefits associated with SMRs. Based on a preliminary review of the results, the responses indicate that SMRs are seen as safer and more desirable than conventional large light water reactors at either existing or new sites. The greatest public support was for the use of SMRs at military bases. Of the respondents, 81% said they believe SMRs are as safe as or safer than conventional nuclear reactors. In addition, 47% of the respondents said they support the construction and use of SMRs to generate electricity in the U.S. with 22% opposed and 32% neither favored nor opposed. On a scale of one to seven--with four denoting neutrality and a value less than four denoting an unfavorable view, and a value greater than four denoting a favorable view--the mean response for construction of nuclear reactors at new locations was 3.64 and at existing locations 3.91. The mean for SMR construction was 4.37, and SMR construction on military bases was 4.51.

Deployment Strategies

Based on the information gained during the study, the Team developed five potential scenarios to deploy SMRs to serve DoD installations. The Team believes all of the strategies are commercially-viable, and fit within the bounds of current DoD and Federal policies and commercial arrangements. The strategies below were developed for discussion purposes and are not specific recommendations. Each scenario requires additional analysis. In addition, if DoD and DOE decided to jointly pursue SMR deployment, they can draw on the elements of several scenarios to establish a comprehensive approach to project development.

Scenario 1 – Siting an SMR on Schriever AFB, CO, to Serve Regional DoD/Federal Facilities

In the first scenario, an SMR is sited on Schriever AFB in Colorado, with the intent of serving Schriever and other DoD and Federal facilities in the region. Land for the SMR is acquired through a 50 year Enhanced Use Lease (EUL) and Schriever is compensated for the land through a commensurate reduction in the price it pays for power. The SMR is owned by multiple public and investor-owned utilities. The GSA establishes Area-Wide Contracts with the utility-owners that facilitate PPAs with their DoD and other Federal customers. Each utility's ownership share is equal to the Federal load it will serve under the PPAs, unless the utility desires a larger ownership share to provide power to its non-Federal customers. To lower the LCOE of power, DOE provides loan guarantees to lower the cost of capital for the SMR. The SMR is operated under contract by an experienced nuclear operating utility, which may or may not be an owner of the project. In this scenario, the SMR is sited on, or immediately adjacent to, operations at Schriever in order to optimize the potential for synergies. The SMR operator and the host DoD installation achieve synergies through a services agreement included in the EUL, or as part of a separate services contract.

Scenario 2 – Siting an SMR on Clear AFS to Serve Regional DoD Facilities and Utility Load in Alaska

In the second scenario, the SMR is sited at Clear AFS, about 75 miles southwest of Fairbanks, AK. The land is acquired through an EUL or direct lease and the installation is compensated through a reduction in its cost of power. In this scenario, the SMR is owned by the local electric cooperative, Golden Valley Electric Association (GVEA). As a publicly owned utility, GVEA has access to tax-exempt debt and does not pay income taxes, which significantly lowers the LCOE of power. GVEA establishes PPAs for SMR power with the other DoD installations in its service territory--Fort Wainwright, Fort Greely, and Eielson AFB. Current retail electric rates for GVEA customers range from $0.13 kwh to $0.19 kwh, significantly higher than the projected LCOE of power from an SMR. Rates for the other utilities in the Alaska Railbelt (Fairbanks-Anchorage) are similar. To allow access to the lower cost power to a larger customer base, all Alaska Railbelt utilities have an opportunity to take ownership shares in the SMR and establish PPAs with their DoD customers. While the SMR is owned by GVEA, it is built and operated by an experienced nuclear utility.

Scenario 2b – SMR is Sited on a DoD Installation Near Fairbanks, AK

In a derivative scenario, the SMR is sited on Fort Wainwright or Eielson AFB, which are closer to Fairbanks than Clear AFS. In addition to lower cost electricity, the SMR provides thermal energy for district heating to the host installation, customers in Fairbanks, and other DoD installations in proximity to its location.

A variation to this approach could consider SMR deployment on off-shore, isolated DoD installations in a U.S. Territory such as Anderson AFB, Guam, or isolated DoD installations in non-U.S. territories such as Thule Air Base, Greenland.

Scenario 3 – Aggregation of DoD Demand Through a Federal Power Marketing Agency

To further facilitate the aggregation of Federal power requirements, in this scenario the SMR is sited on Schriever AFB, or another DoD installation within the territory served by the WAPA. This scenario also can be extended to other regions of the country that have Federal PMAs and large clusters of DoD and Federal installations, e.g., New Mexico: White Sands Missile Range, Kirtland AFB, SNL, Los Alamos National Laboratory, Waste Isolation Power Plant, Holloman AFB, and Cannon AFB. The SMR is owned by a generation and transmission cooperative with a broad base of publicly-owned utility members. As an alternative, DOE owns the SMR. The owner establishes a long-term PPA for power from the SMR with WAPA. WAPA establishes long-term PPAs with its current DoD and other Federal customers in the eight states that it serves. The land lease and operating structures are similar to Scenario 2a.

Scenario 4 – Aggregation of DoD and Federal Demand Through the Tennessee Valley Authority

The Tennessee Valley Authority (TVA) is a stand-alone Federal agency reporting to the President. It has seven operating nuclear power plants, provides power to 155 local power distributors that serve some nine million retail customers in seven states, and directly serves several DoD and DOE facilities in four states. TVA currently intends to file a generic Early Site Permit (ESP) in 2016 as a first step in potentially siting an SMR using one of the four technologies at the Clinch River site in east Tennessee. In this scenario, the ESP provides the starting point for siting an SMR at Clinch River. TVA would build, own, and operate the SMR, and finance it using its access to low-cost debt. It would establish specific PPAs with its DoD and DOE direct-served customers that allow them to take credit for the clean power. The Clinch River site is in proximity to the ORNL, which houses a number of operations that are critical to national security and defense. TVA could enhance energy security for ORNL by establishing a microgrid between the SMR and ORNL's operations.

Scenario 5 – Multiple Applications of SMR Energy

Beyond electricity and heat, the energy produced by an SMR can support other applications to help DoD meet its energy requirements. An SMR sited at a DoD installation in a coal producing region, or in proximity to one, can provide the electricity and steam to support a Fischer-Tropsch process to convert coal into transportation fuels. Similarly, electricity and thermal energy from the SMR can support any of the desalination processes to produce clean water for the DoD installation and nearby communities. Further, the SMR can be used to support the production of commodities such as hydrogen, oxygen and fertilizers with market values to offset the cost of energy production.

Recommendations

Based on the information and insights gained during the study, the Team has a number of recommendations that can directly affect the ability of DoD to access the benefits of SMR technology while accelerating the commercialization of the technology in the U.S..

1. As a starting point, DoD can remove uncertainties by clarifying policies regarding the duration of PPAs and the interim storage of used nuclear fuel on DoD installations. Congressional action would be required in some cases. At the same time, DOE can take the lead in ensuring that policies related to energy purchases are aligned and consistent across the Federal government. Again, longer duration PPAs are viewed by investors as being more favorable. This lowers the cost of capital and, ultimately, the price of energy.
2. DOE should conduct an analysis of EO 13693 and the CPP to identify and quantify the potential role of SMRs in meeting the goals these mandates establish. As a second step, DOE should establish a strategy for the use of SMRs to assist both Federal agencies and the states in achieving their EO and CPP goals.
3. DOE can accelerate the commercialization of U.S. SMR technology by providing Federal funding for licensing, First of a Kind design and engineering, and the capital costs of the initial projects. Validating SMR technology is of strategic importance to the U.S., domestically and internationally. Establishing an industry that supports the deployment of SMRs here and abroad will have long-term economic, environmental, and socio-political benefits to the U.S..
4. DOE and DoD should take the next step and, as a test case, establish the framework for deploying an SMR to serve a DoD installation. This would include evaluating potential locations using siting criteria and previously identified Federal clusters (e.g., in Colorado and New Mexico) as well as high cost markets (e.g., Alaska, Hawaii, Guam) and taking the first steps toward Nuclear Regulatory Commission licensing and a services agreement and land lease.
5. DOE should implement a deliberate, integrated communications plan focused on key stakeholders, to foster understanding and obtain feedback, advocacy, and support for a decision on the use of SMRs to provide energy to DoD installations. Additionally, DOE and DoD should convene a forum that includes representatives from key Federal departments and agencies, and other principal stakeholders, to determine how SMRs can best be used to meet Federal/DoD energy needs. The deployment scenarios outlined in this study could facilitate this discussion. Results of the forum would form the basis for a leadership decision on an SMR deployment test case and viable funding mechanisms.
6. When evaluating the potential deployment of SMRs at DoD installations, DoD and DOE should look for applications for SMR energy to provide value beyond electricity. The use of energy from an SMR for district heating, desalination, the conversion of coal to liquids such as transportation fuels, and production of hydrogen and oxygen all offer potential value to DoD.

In summary, there are no insurmountable impediments and substantial benefits from an initiative by DoD, DOE, and the Federal government to pursue the deployment of an SMR on or adjacent to a DoD installation. Electric energy from the SMR can be used at multiple DoD installations and other Federal facilities to achieve their mandates for clean energy. Energy from the SMR also can be used for non-electric applications such as the production of transportation fuels and desalination that have value to DoD and to the community.

1.0 INTRODUCTION

1.1. Background. This is the final report of the Small Modular Reactor (SMR) Suitability study by Sandia National Laboratories (SNL) and the Scitor Team (Scitor Corporation and Landrey & Company). This effort is based on the recognition that nuclear power is a key segment of the technologies that could help the United States (U.S.) achieve energy security and clean energy objectives. The continuing concern over military installations' dependence on the "fragile and vulnerable" commercial grid and the potential for adverse mission impact due to extended outages underscores the need for alternate means of achieving energy security [1]. Nuclear energy has a vital role in the President's strategy for a sustainable, clean energy future. Nuclear energy has provided nearly 20% of US electrical generation over the past two decades and currently produces nearly 60% of America's carbon-free electricity. Nuclear power is a promising option for low-carbon baseload power. The continued development of new and advanced nuclear technologies is an important component of U.S. clean energy strategy. Investing in the safe and secure development of nuclear power also helps advance other vital policy objectives such as enhancing nuclear nonproliferation efforts, nuclear safety and security, and energy security [2]. With these and related facts as a baseline, this study assesses the suitability of placing SMRs at Air Force Space Command (AFSPC) and other Department of Defense (DoD) installations for energy security and the attainment of clean energy goals.

1.2. Study Objectives. The Small Modular Reactor Licensing Technical Support Program of the Department of Energy (DOE) Office of Nuclear Energy funded this study. The primary focus is to assess the potential for SMR technologies to provide secure, carbon-free energy for DoD installations, and to accelerate commercialization of U.S. SMR technology to meet national energy needs. This study reflects the intent of the memorandum of understanding (MOU) between the DOE and the DoD to enhance national energy security and demonstrate leadership in transitioning the U.S. to a low carbon economy. The MOU declares DoD's intent to partner with other agencies to speed development of energy technology innovation and use military installations as possible test beds to demonstrate and create markets for these innovations. Most significantly for this study, the MOU endorses collaboration between DoD and DOE in evaluating energy technology solutions that include SMRs [3]. This study's objectives are to:

- Facilitate AFSPC and DoD understanding of the benefits of SMRs
- Identify DoD requirements for SMRs located on or near installations.
- Identify potential partnerships with utilities/operators for notional SMR deployments.
- Identify government actions to facilitate SMR deployment for DoD energy security.
- Inform discussion of broader market potential among other critical Federal installations.

1.3. Major Activities. While previous studies have explored SMR feasibility for multiple DoD installations, this SMR Suitability study is focused specifically on AFSPC installations due to their facility-centric space missions, relatively high energy densities, high system reliability requirements, and diverse geographic locations. AFSPC involvement in the study began in April 2013 when General William Shelton, the AFSPC Commander at the time, committed to partnering with SNL to share information and support the development of technical solutions to meet AFSPC facility power and energy security requirements. This report consolidates the results of the two major phases of the study--research and site visits--which were summarized in two interim reports. The research phase focused on the selection of two AFSPC installations for in-depth use case studies, based on criteria developed through research of existing guidance and studies, requests for information, discussion with subject matter experts (SME), siting analysis, mission prioritization, and unit operating characteristics. The site visit phase consisted of a detailed assessment of SMR suitability for on-site deployment at Schriever Air Force Base (AFB), CO, and Clear Air Force Station (AFS), AK, the AFSPC installations selected during the research phase. Three deployment scenarios are considered: siting an SMR *on* an AFSPC installation, *near* an installation, or *as part of the local commercial grid*. Throughout their activities, Team members emphasized that the study's focus is on the *feasibility* of SMR deployment—no deployment decision would be a direct result of this effort. Additionally, none of the study's content is classified or for official use only.

1.3.1. Research phase activities (March-June 2015):

- Review policies, guidance, and regulations--including DoD and Nuclear Regulatory Commission (NRC)--to identify potential impediments and preliminary solutions for SMR deployment
- Review studies and reports to gain insights from previous assessments of SMR capabilities, financial considerations, and applicability to DoD
- Interact with DoD and AFSPC stakeholders for their inputs on mission priorities, operating characteristics, and lessons learned, as well as energy requirements, goals, management, and processes to assess SMR integration into a DoD setting
- Interact with SMR vendors for their inputs on the current state of SMR technology and timelines associated with deployment of their capabilities
- Interact with nuclear operating utilities for their inputs into the feasibility of using SMRs to serve Federal facilities
- Develop criteria to identify two installations for further study, based on AFSPC-related factors, specific siting requirements (seismology, hydrology, etc.), and unique use case considerations (location, size, and installation characteristics)

1.3.2. Site visit phase activities (July-October 2015):

- Interaction with Schriever AFB and Clear AFS SMEs to obtain first-hand information on SMR siting, possible site locations, potential installation-SMR operator synergies, and perceived impediments
- Interaction with the utility companies local to Schriever AFB and Clear AFS to gain their perspectives
- Research on Federal, DoD, AF, state, regional, and local policies and guidelines unique to Schriever AFB and Clear AFS, as well as associated studies and reports
- Expanded interaction with DoD, AF, and AFSPC stakeholders for their inputs
- Development of DoD SMR deployment strategies
- Solicitation of SMR vendor inputs on suitability of their technology to Schriever AFB and Clear AFS
- Review of additional considerations that emerged as a result of study activities (e.g., dry heat rejection, Brayton cycle)
- High-level assessment of public perceptions on the use of nuclear power
- Develop an approach to communicating SMR benefits to stakeholders

1.4. This Final report assimilates the results of the two study phases and incorporates additional research to provide a detailed assessment of the feasibility of using SMRs for energy security and clean energy for the two AFSPC installations, and broader DoD applications. It provides recommendations to facilitate an approach for workable solutions for SMR deployments by DoD and DOE.

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2.0 SMR OVERVIEW

2.1. SMR Characteristics and Benefits

2.1.1. Characteristics. SMRs are nuclear power plants that are smaller in size ($\leq$300 MWe) than the current generation of baseload nuclear plants, which are on average $\geq$1,000 MWe. SMR's have smaller, compact designs and the major components are factory-fabricated and can be transported by truck, barge, or rail [4]. The US SMR designs that are the focus of this study use established light-water reactor technology and are projected to be deployable by 2025.

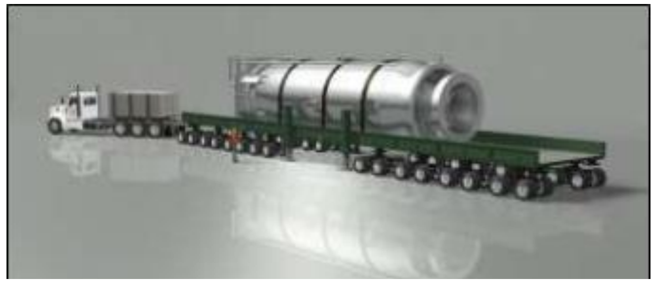

Figure 1. Prototype SMR Reactor in Transport

2.1.2. Benefits. SMRs are expected to offer several benefits [4].

- *Factory manufacturing.* Major SMR components can be factory-built and shipped to the deployment site, decreasing on-site preparation and construction times. SMRs provide simplicity of design, enhanced safety features, the economics and quality of factory production, and more flexibility (financing, siting, sizing, and end-use applications).
- *Lower capital investment.* SMRs can reduce a nuclear plant owner's total capital investment due to the smaller size and output of the power plant..
- *Siting flexibility.* SMRs can provide power for smaller electrical markets, isolated areas, smaller grids, sites with limited water and acreage, or unique industrial applications. As an energy source that does not emit greenhouse gases (GHG), SMRs can complement existing power plants.
- *Gain efficiency.* SMRs can be combined with other energy sources, including renewables and fossil, to produce higher efficiencies and multiple energy end-products while increasing grid stability and security. SMRs can provide electricity generation or thermal applications.
- *Safety.* Light water SMR designs incorporate passive safety features that utilize gravity-driven or natural convection systems for backup cooling in unusual circumstances. Light water SMRs would have a much lower level of decay heat than large plants and require less cooling after reactor shutdown [5].

2.1.3. DoD Applications. Based on the characteristics and benefits cited above, SMRs can help DoD and the U.S. energy environment in several significant areas.

- An SMR's smaller output makes it a better match for DoD installation requirements than large light water reactors.
- An SMR's baseload operation can enhance reliability, especially compared to solar or wind, which operate intermittently.
- SMRs provide carbon-free energy, which can help DoD achieve Executive Order (EO) and Clean Power Plan (CPP) targets

- Siting SMRs on or adjacent to DoD installations offers a range of potential synergies, with the largest potential for synergies for an SMR sited on the installation.
- DoD’s deployment of SMRs can accelerate commercialization of U.S. SMR technology.

2.2. Current US SMR Technologies

2.2.1. U.S. vendors. There are four U.S. light water SMR vendors with technologies capable of deployment by 2025. The *NuScale Power* design is based on a 50 MWe module with a scalable plant consisting of one to 12 modules totaling 570 MWe gross output. NuScale is in the pre-application phase prior to submitting a design certification application (DCA) to the NRC and anticipates DCA submission in December 2016, with a combined construction and operating license (COL) application in 2017 [6]. *Holtec International* is teamed with the US subsidiary of Mitsubishi Electric Corporation in development and licensing of its 160 MWe SMR [7]. Holtec is currently preparing safety analysis reports as part of the licensing approach defined in 10 CFR Part 50 [8]. *Generation mPower LLC,* formed between affiliates of BWX Technologies, Incorporated (BWXT) and Bechtel Power Corporation, planned development of a 180 MWe mPower SMR [9]. Generation mPower has recently restructured and is evaluating its options and monitoring market development [10]. The *Westinghouse* SMR is a $\geq$225 MWe integral pressurized water reactor. Westinghouse has completed conceptual and preliminary design and is assessing appropriate partners for an Engineering, Procurement, and Construction contract [11].

2.2.2. Features of US SMR Technologies. Each of the four SMR vendors provided information about its technology’s requirements and performance capabilities (Table 1). To meet the mission critical needs of an AFSPC installation following an abnormal event such as an earthquake or electrical grid failure, the SMR might need to achieve a black start, operate in “island” mode, and generate electricity at less than full power. (Electrical islands are created when parts of an interconnected power grid become separated from the main grid. This typically occurs during grid failures when portions of the area served are able to isolate themselves from the main grid and provide loads with sufficient power from generation within the area, the “island.” Islands can be created intentionally by establishing electrical boundaries using relays and controls to isolate loads) [1]. Each of the SMR respondents stated that its design is capable of achieving black start, provided there is a source of on-site, backup power to run certain components. The respondents also stated the nuclear power plants can operate in island mode. Both black start and island mode; however, might require license exemptions from NRC regulations, or other approvals from the NRC. The NRC, for example, currently requires that nuclear power plants have two sources of off-site AC power. With their smaller scale and use of passive safety systems, the SMRs might receive exemptions from this and other requirements. While not cost-effective, each vendor stated its SMR could operate at low power levels, some as low as 5 MWe, using steam bypass directly to the condenser. In addition, the site layout for three of the four designs includes an Independent Spent Fuel Storage Installation (ISFSI) to hold spent fuel for the life of the plant. None of the technologies are designed for protection against electromagnetic pulse (EMP), although companies believe it is feasible. One respondent noted that, for it to be of value, EMP protection would need to extend to the plant’s switchyard and the electrical grid and distribution system serving the DoD installation [6, 8, 11, and 12].

Table 1. SMR Technology Comparison

SMR Characteristic	BWXT mPower	Holtec SMR-160	NuScale NPM	Westinghouse
MWe / Nuclear Steam Supply System (NSSS)	180 MWe nominal	160 MWe	50 MWe (gross)	≥ 225 MWe
MWt / NSSS	530 MWt	525 MWt	160 MWt	800 MWt
Units per site	2 reactors per power plant	1 - 2	1 - 12	1
Total Output	360 MWe nominal	160-320 MWe	570 MWe (net)	≥ 225 MWe
Site Size	<40 acres	5 -7.5 acres	40 acres	15 acres
Coping time	> 7 days passive cooling with emergency core cooling system and passive containment cooling	Unlimited	Indefinite	≥ 7 days
Overnight Cost per kw	*Proprietary*	$4,062	$5,078	*Proprietary*
Overnight Cost per Net Primary Production	*Proprietary*	$650 million	$2.894 billion	*Proprietary*
Lifecycle Cost of Energy (LCOE)	*Proprietary*	$81.50/MWh	$78 - $96/MWh	*Proprietary*
Projected Capacity Factor	95%	95%	95%	95%
Cooling Options	Water cooling. Air cooling option	Wet or dry	Wet or dry	Wet or dry
Gallons per day (gpd) consumption for conventional cooling(e.g., mechanical draft)	10.37 million (two reactors)	4.5 million	13.1 million	7.5 million
Design Life	60 years	60 years	60 years	60 years
Refueling Interval	4 years	24 months	24 months	24 months
Refueling Outage Duration per Reactor	< 30 days	12 days	10 days	17 days
Spent Fuel Pool storage / cores / years	10 cores/20 years	3 full cores plus one full offload	≥ 10 years	14 years
On site ISFSI in plans	Yes	Yes	Yes	No

2.2.3. Highlights from SMR Vendors. Key points from the inputs provided by the four SMR vendors are provided below. The scope varies since this information is based on the vendors' responses to the Team's requests for information.

BWXT Generation mPower

- ISFSI space can be within or outside the main plant protected area. Flexibility necessary and costs somewhat unknown due to changing ISFSI regulations.
- Spent Fuel Pool design uses un-poisoned low density storage racks. Use of high density racks would increase capacity.
- Progress toward DCA includes four years of interaction with the NRC and 30 information and report submittals. NRC has established a Design Specific Review Standard.

- BWXT could submit a DCA in 2017 to support a mid-2020s commercial operation.
- Black start requires additional equipment to supply energy to start the plant and is not currently part of the DCA configuration.
- Overnight capital cost and LCOE comparable to a large reactor.
- Plant designed to meet Electric Power Research Institute Utility Requirements Document minimum of 20%, or 36 MWe.
- SMR designed to withstand a loss of all off-site power by transitioning to island mode with 100% steam turbine bypass. Once in island mode, mPower can operate indefinitely to support house loads and mission critical needs up to 100% stated output power.

Holtec International

- Holtec can submit a Construction Permit Preliminary Safety Analysis Report in 2017, start construction in 2020, with commercial operation in 2024.
- The Holtec SMR can load follow between 60% and 100% power (~95MWe-160 MWe). It can operate at less than 60% power using steam dump directly to the condenser.
- Holtec's SMR-160 can operate indefinitely off the grid at reduced power.

- "Operational performance of the turbine island for low power demands (5-25 MWe) is feasible."
- If black start is needed, "With non-safety related diesel power used to energize one startup pump, the reactor coolant system can be brought to natural circulation, control rods pulled, and the plant brought back to full operation."
- "SMR-160 is substantially smaller than existing nuclear plants, both in physical size and source term. The smaller source term and limited leakage paths translate into a credible case for reducing emergency planning zones, simplifying emergency planning measures and providing improved protection of public health and safety."
- The site layout includes the Holtec International Storage Module Underground Maximum Security System (an ISFSI), which would accommodate all spent fuel for the life of the plant.
- The first ISFSI utilization takes place eight years after the first outage.
- The ISFSI is designed to accommodate all spent fuel for the life of the plant.

NuScale Power

- Each module is rated at 50 MWe, gross. A plant with 12 modules requires 30 MWe for station load.
- "Each NuScale Power Module (NPM) has 100% steam bypass capability and can be configured to continue operation when the area AC grid is unavailable. This allows … for a black startup…."
- NuScale reactors are refueled sequentially with only one reactor out of service for refueling at a time.
- The Utah Associated Municipal Power Systems (UAMPS) has announced that it will submit a COL application to the NRC in 2017.
- The target commercial operation for the UAMPS Carbon Free Power Project is 2024.

- NuScale projects a security force of 70 personnel and sees savings if that number can be reduced by siting an SMR on a DoD installation.
- Fluor Corporation, which owns NuScale, conducted a detailed, bottoms-up cost estimate in 2015. It projects an overnight capital cost of $5,078 per kilowatt of capacity in 2014 dollars.
- Owner's costs are estimated at an additional $300 million.
- LCOE for the first plant is estimated at $78/MWh ($0.078/kwh) if the plant is owned by a municipal utility. LCOE is estimated at $96/MWh for an investor-owned utility.
- Minimum output per NSSS is 5 MWe.
- The system has a 40% per hour ramp rate and 20% step change.
- The plant can operate in island mode.
- If only one reactor and turbine generator is in operation, house loads require 60-70% of its output leaving 15-20 MWe.
- The ISFSI has capacity for all spent fuel produced during the 60 year design life of a 12-module plant.
- NuScale's timeline serves as a representative breakout of required actions (Appendix A)

Westinghouse

- Estimates one year to prepare DCA, 39 months for review, 36 months to construct the First of a Kind (FOAK) plant, 18 months for the Nth of a Kind plants.
- Daily load follow can be performed from 100% to 20% power at a rate of 5% change per minute; in continuous load follow, the plant can perform load changes of ±10% power at a rate of 2% per minute.
- The system is able to island and operate at a self-sustaining power level with zero output to the grid for more than 72 hours.
- The system is able to operate at power outputs between 0 and 100% power.
- A black start requires ~ 20 MWe of power for 10-15 hours.
- The site layout does not include an ISFSI.

2.2.4. Impediments to SMR Commercialization. Development of new nuclear power plants in the U.S. is challenged by two principal impediments: high capital cost compared to alternatives such as natural gas, and licensing uncertainty. Measured in dollars per kilowatt of generating capacity, the overnight capital cost of a new nuclear power plant is four to five times that of a new power plant that operates on natural gas. By choosing natural gas over nuclear, a utility has far less up-front money at risk for a shorter period of time. And although the price of natural gas can vary significantly, the cost of fuel is an operating expense that is passed along to customers, insulating the owner from much of the risk of fuel price volatility. Nuclear power from the existing fleet and new plants is currently one of the few options available if the US is to meet its goals for clean energy. The existing nuclear fleet provides nearly 60% of the carbon-free energy produced in the US, but the fleet is aging and without additional license extensions all plants will retire before 2050. Although a highly efficient combined cycle gas-fired plant emits less than half the carbon of a coal-fired plant, its emissions still have an adverse impact on attaining clean energy goals. For example, if a natural gas plant produces as much electricity as a 1,000 MWe nuclear plant operating at a 90% capacity factor, the gas plant will emit about 2.5 million tonnes of carbon in a year [13].

2.3. LCOE Considerations

2.3.1. SMR Levelized Cost of Energy Studies. Numerous models and studies have forecast the LCOE from the light water SMRs currently under development in the U.S. These include studies by the University of Chicago, the Center for Strategic and International Studies, the Energy Information Agency, the National Energy Technology Laboratory, utility Integrated Resource Plans, and the SMR technology vendors. The models project an LCOE that ranges from $0.07/kwh to $0.12/kwh.

2.3.2. DoD Position. As the result of Federal regulations, the DoD has consistently taken a position that the cost of the renewable and clean energy it purchases cannot exceed the current and projected future cost of energy [14, 15]. This policy might make it difficult to use an SMR to provide power to DoD installations in the contiguous 48 states. Most DoD installations pay less for power than the projected LCOE of power from an SMR. Schriever AFB, for example, currently pays Mountain View Electric Association (MVEA) a retail rate of $0.077/kwh. Further, that power is melded with low cost Federal power marketed by the Western Area Power Administration (WAPA), lowering the average cost of power to Schriever [16]. Schriever's power costs are less than the projected cost of power from an SMR sited on the installation. The situation is dramatically different in locations, like Alaska, that have to rely on an external supply of diesel fuel to produce electricity. Clear AFS will pay a commercial rate of $0.13/kwh after its connection to GVEA at the end of 2015. GVEA's residential customers pay about $0.19/kwh [17].

2.3.3. Key LCOE Factors. There are a number of key factors that affect the projected LCOE from an SMR. A change in one or more of these factors can dramatically affect the projected cost of energy. Lowering the LCOE of SMR power would broaden the accessible market of DoD installations. For example:

2.3.3.1. Reducing overnight capital cost. Nuclear power plants have high up-front capital cost and are referred to as "capital intensive." Of the SMR vendors, the most thorough cost estimate to date was completed by NuScale Power in 2015. To develop the estimate, Fluor Corporation, NuScale's engineering, procurement and construction partner, and major investor, invested 10,000 man-hours and secured price quotes on 14,000 line items. The estimate forecast an overnight capital cost of $5,078 per kilowatt of net capacity for a 570,000 kilowatt NuScale project, resulting in a total overnight capital cost of $2.9 billion. According to the company's modeling, the LCOE for power from a NuScale SMR owned by cooperative or municipal utility would be $0.078/kwh. The LCOE for a NuScale SMR owned by an investor-owned utility is $0.096kwh [6]. Additional considerations:

- Although electric and thermal energy from an SMR is categorized in EO 13693 as "alternative" energy that can be used to meet the order's targets, SMRs do not receive the incentives available to wind, solar, and other sources of clean energy. The most generous incentive for solar energy is an investment tax credit (ITC) of 30% that can be converted to a cash grant at the time of commercial operation [18]. As a result, converting the ITC to a grant essentially reduces the eligible portion of the capital cost of the plant by 30%. Cooperative and municipal utilities are non-taxable entities and are therefore unable to take advantage of tax credits. If the same ITC/cash grant incentive is made available to a NuScale SMR owned by an Investor-Owned Utility (IOU), the overnight capital cost of the plant is reduced and the LCOE drops to about $0.083/kwh.

- The FOAK cost to bring the first SMR to market, exclusive of capital cost, currently is estimated at about $1 billion. This includes licensing, testing, detailed design and engineering, and attorneys' fees [19]. DOE currently is supporting the efforts of NuScale Power and some utilities by sharing up to 50% of the costs associated with the NRC licensing process, including applications for Design Certification, Early Site Permit, and COL. Through DOE, the Federal government has also shared the capital cost for FOAK clean energy projects, including clean coal projects, to help ensure commercialization. Offsetting FOAK costs through a cost sharing program could be instrumental in commercializing U.S. SMR technology. According to an estimate by NuScale, a program that provided 50% matching funds for the capital cost of the first power plant would reduce the LCOE of power from a plant owned by a municipal or cooperative utility to about $0.06 per kwh, and for an IOU to about $0.068 per kwh.

2.3.3.2. Lowering the Cost of Capital. The *cost of interest on debt* borrowed and the *return on equity* to shareholders who help fund construction of a capital intensive project like an SMR also are major factors in LCOE. Further, debt historically carries a lower interest rate than equity so the ratio of debt to equity in the overall financing of the power plant directly affects the weighted average cost of capital (WACC) for the project. A higher percentage ratio of equity increases the project's overall cost of capital. Cooperative and municipal utilities are owned, respectively, by their customers or a local government and do not have shareholders. Many are able to finance 100% of the capital cost of a power project by issuing debt. As a result, the cost of capital for a cooperative or municipal utility is significantly less than for an IOU. All factors being equal, the LCOE for an SMR with an overnight capital cost of $5,000 per kilowatt will be approximately $0.078/kwh for a cooperative or municipal utility compared with $0.096/kwh for an IOU. In addition, the interest payments that investors receive on debt issued by cooperative and municipal utilities are exempt from income taxes. Investors, therefore, require a lower interest rate on cooperative and municipal debt. This further lowers the cost of capital by an average of 1% to 1.5% [20]. *Loan guarantees* from the Federal government are another mechanism for lowering the cost of capital on a new nuclear plant. Under the Energy Policy Act of 2005, DOE received authorization to issue up to $18 billion in loan guarantees for new nuclear projects. The owners of Vogtle Units 3 & 4 include investor-owned, cooperative and municipal utilities. Together the three organizations-- Southern Company, the Municipal Electric Authority of Georgia, and Oglethorpe Power Corporation--will receive $8.3 billion in loan guarantees to support the two units currently under construction. Southern Company alone estimates the loan guarantees it received have present value to its customers of $225 to $250 million. Loan guarantees are estimated to reduce the interest rate on debt by an average of 0.5% [20].

2.3.3.4. Lowering the Cost of Power. Production tax credits (PTCs) were made available for a number of clean energy sources under various pieces of Federal legislation passed in the last decade. PTCs provide a credit on income taxes for kilowatt hours produced over a given period. Because PTCs only apply to income taxes, they are of no value to cooperative and municipal utilities. They are of value; however, to IOUs. The Energy Policy Act of 2005 offered a PTC of $0.018/kwh for a period of eight years for the first 6,000 MWe of new nuclear power in the US, provided they meet certain milestones. Southern Company will receive approximately $875 million in PTCs for its share of Vogtle 3 & 4 during the first eight years of operation of the two units.

2.3.3.5. Financial Tools. ITCs with cash grants, loan guarantees, PTCs, exemptions from income taxes at the Federal or State level are all financial tools that can lower the LCOE for DoD installations and other customers and help accelerate the deployment of SMRs.

2.3.4. LCOE Comparisons. NuScale Power analyzed a range of LCOE variables including ownership type, capital structure and the effect of incentives. Key points are summarized below.

- LCOE ranges from $78/MWh for a cooperative utility to $96/MWh for an IOU
- A cooperative utility can finance with low-cost, tax-exempt debt
- A cooperative utility does not pay income taxes (IOU average tax rate = 39%)
- Loan guarantees lower costs for a cooperative utility or an IOU by ~ $3/MWh
- A production tax credit ($18/MWh) would lower the LCOE for an IOU by about $8 MWh, while an investment tax credit (solar = 30%) would lower the cost for an IOU by ~ $14/MWh
- The most significant reduction comes from 50-50 cost sharing of initial capital cost, which lowers LCOE for cooperative and municipally owned utilities to $60/MWh and to $68/MWh for IOUs

2.4. Associated Technologies

This section briefly discusses some related technologies that could affect SMR deployment.

2.4.1. Dry Heat Rejection. Nuclear reactors, and most other forms of electricity production, require large amounts of water to reject waste heat. A general estimate is 20 million gpd for a 1000 MWe light water reactor. SMRs require less per reactor, but may require slightly more water per unit of electricity produced due to their lower thermal efficiency. The demand for water is expected to rise over the coming decades, thus heightening the need to address any current water shortages. The Team discovered that, of the two sites selected for in-depth review during this study, Schriever AFB does not have the requisite water supply for an SMR. If predictions for increased water demand in the future are correct, it will be necessary to find means of rejecting waste heat that are more water efficient than current technologies.

2.4.1.1 Reduced water usage. Dry heat rejection technologies offer a means of reducing the amount of water required to cool a power plant. However, there are penalties associated with the use of dry cooling techniques. The most obvious of these penalties is a decrease in the thermal efficiency of the power generation cycle. The lowest possible rejection temperature for a dry cooling system is the dry bulb temperature, which is the actual temperature of the air. Wet cooling systems, on the other hand, can cool down to the wet bulb temperature, which is the temperature a parcel of air would have if it were cooled to saturation by the evaporation of water into the air. At 100% relative humidity, wet bulb and dry bulb temperatures are identical. This higher limit on the heat rejection temperature decreases the thermal efficiency of the plant. A second limiting factor is the cold-side heat transfer coefficient. Most information on this subject is given in terms of the overall heat transfer coefficient; steam-to-water coefficients can be 25-35 times greater than steam-to-air coefficients [21].

2.4.1.2. Impacts. The lower efficiency caused by dry heat rejection results in less power production and a decrease in revenue. There also are other costs associated with dry heat rejection. Recirculated cooling systems require more power than once-through cooling systems. This is a parasitic load on the power generating station. There are also additional maintenance costs related to the additional equipment that must be maintained. Dry heat rejection systems also require large areas for installation of the systems due to the low heat transfer coefficients. This drives up the capital cost [22].

2.4.1.3. Dry Heat Rejection Summary. Dry heat rejection systems exist that would allow SMRs to be built and operated in arid regions. There is efficiency and cost penalties, however, that are associated with the use of dry cooling systems. Research is ongoing into alternate water efficient systems that would mitigate the cost of water cooling, but these systems are not yet available.

2.4.2. Supercritical Carbon Dioxide Brayton Cycle. The SMRs considered in this study have all been designed with the intent of using a traditional steam Rankine power conversion cycle. These cycles operate with about 34% thermal efficiency in most large nuclear power plants. However, it is expected that this efficiency will drop to about 30% for SMRs. All the SMRs considered for this study are pressurized water reactors (PWRs). This is significant because, unlike boiling water reactors, the reactor coolant in PWRs is not the same fluid that is used in the power conversion cycle. Thus, the power conversion cycle (i.e., the steam Rankine cycle) could potentially be replaced with a supercritical carbon dioxide (sCO_2) Brayton cycle. There are multiple realizations of the sCO_2; one example is shown in Figure 2. The efficiency of this cycle is 50%.

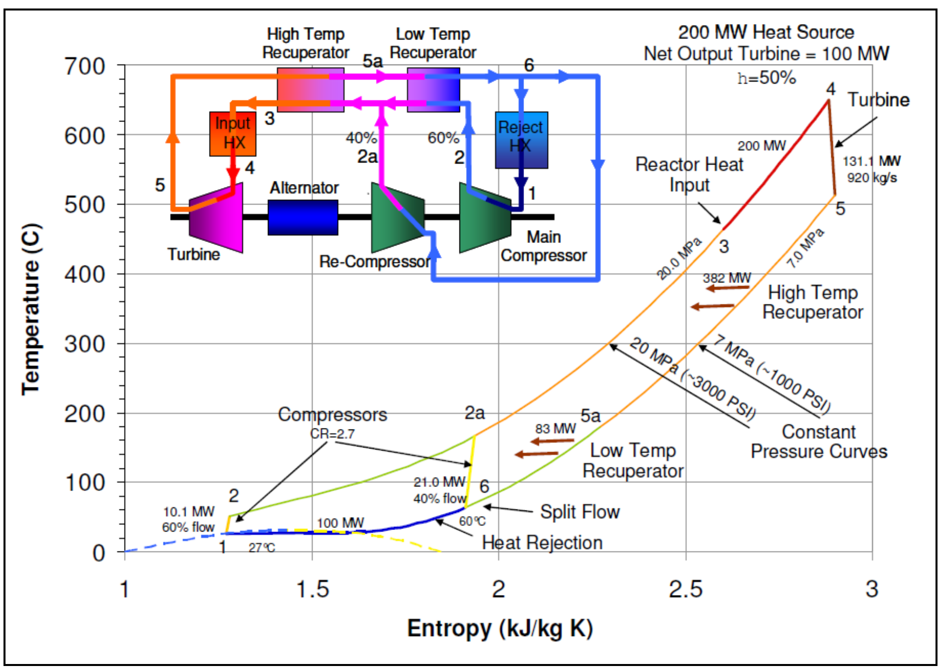

Figure 2. Diagram of SNL's sCO2 Split Flow Recompression Brayton Cycle [23]

2.4.2.1. Benefits. A Brayton cycle would offer multiple benefits over a traditional steam cycle. First, if it is assumed that water would be used as the ultimate heat sink, then the thermal efficiency of the Brayton power conversion system would allow the plant to produce approximately 50% more energy with the same reactor, as compared to a steam cycle. Second, if sufficient water is not available for cooling, the Brayton cycle would be much more efficient than a steam cycle at transferring heat from the power conversion working fluid to the air. This is due to the fact that Brayton cycles do not reject heat at a constant temperature, thereby allowing a heat rejection system to be engineered for a much higher rise in air temperature and allowing a smaller flow of air than allowed in a steam cycle. This concept is shown in Figure 3.

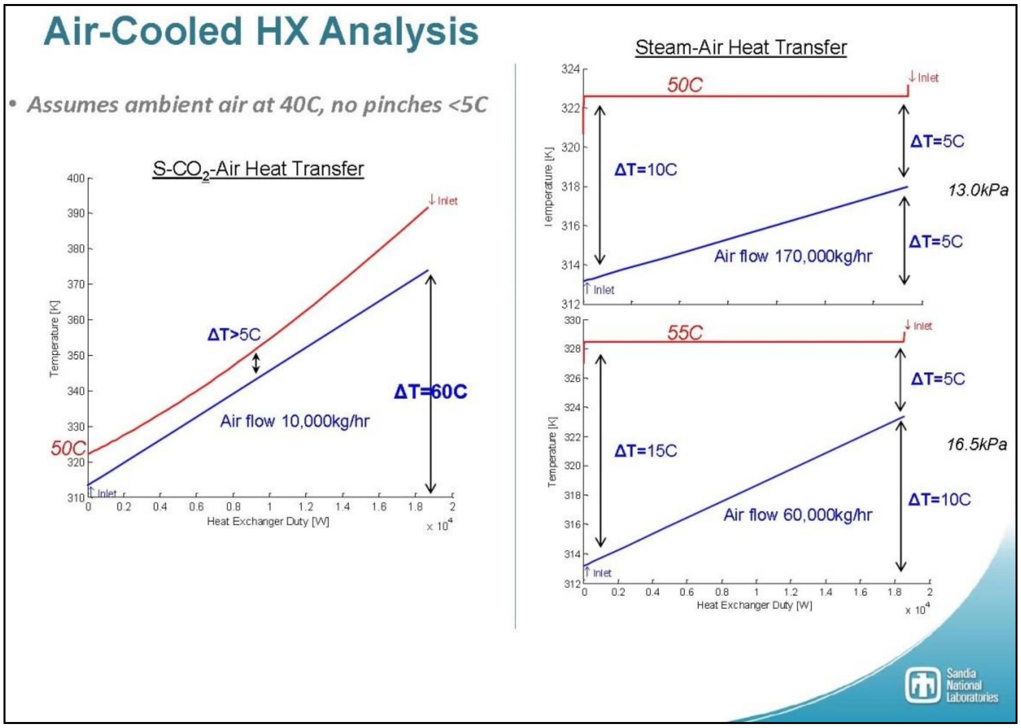

Figure 3. Comparison of sCO_2 Brayton Cycle Effectiveness vs. Steam Cycle [24]

A third benefit of Brayton cycles is the projected capital cost as it relates to steam cycle capital cost. Although Brayton cycles are highly efficient, the size of the components (e.g., turbine, alternator, compressor system) is on the order of 1% of the size of steam cycle components. The cost of large mechanical systems usually scales (not linearly, but increasingly) with the amount of material needed to produce them. Thus, it is expected that Brayton cycle capital costs will be on the order of 10% of conventional steam cycle capital costs. Although research is ongoing, successful operational tests have been performed and Brayton cycles are expected to be ready for commercialization by 2020.

2.4.2.2 Brayton cycle summary. Brayton cycles offer the opportunity for lower cost installation, higher efficiency, and better dry heat rejection capabilities. Although sCO_2 Brayton cycles are not currently ready for commercialization, it is expected that they will be ready by 2020, which will be in time for use by current SMR technologies.

3.0 THE DOD ENERGY LANDSCAPE

3.1. Background

3.1.1 DoD Energy Policy. DoD's policy is to enhance military capability, improve energy security, and mitigate costs in its use and management of energy. This includes the efforts below.

- Improve the energy performance of weapons systems, installations, and military forces.
- Diversify and expand energy supplies and sources, including renewable energy sources and alternative fuels.
- Include energy analyses in requirements; acquisition; and planning, programming, budgeting, and execution processes.
- Assess and manage energy-related risks to operations, training, and testing.
- Develop and acquire technologies that meet DoD energy needs and manage risks; use appropriate resources and energy expertise in other governmental organizations and the private sector.
- Educate and train personnel in valuing energy as a mission essential resource [25].

3.1.2. DoD Energy Demand. The DoD is a logical starting place for efforts to enhance Federal government energy programs. The DoD is the single largest energy consuming entity in the US; its operational and facility energy represent approximately 80% of total Federal energy consumption [26]. The DoD distinguishes facility energy from operational energy. *Facility energy* powers fixed installations, including energy from the electric grid and on-site energy sources [25]. *Operational energy* is required for training, moving, and sustaining forces and weapons for military operations, including energy used by tactical power systems and generators at contingency locations) [27]. A breakout of DoD's facility energy consumption by military service is provided in Figure 4. Figure 5 shows the top 10 facility energy consumers in the Federal Government for FY 2014. In 2014, the DoD spent $4.2 billion on facility energy, which included $4.0 billion to power, heat, and cool buildings; facility energy was 23% of the DoD's total energy *expenditures.* Additionally, DoD consumed 214,164 billion British thermal units (BTU) of facility energy--30% of the Department's total energy *consumption.* Nevertheless, DoD fell short of its FY 2014

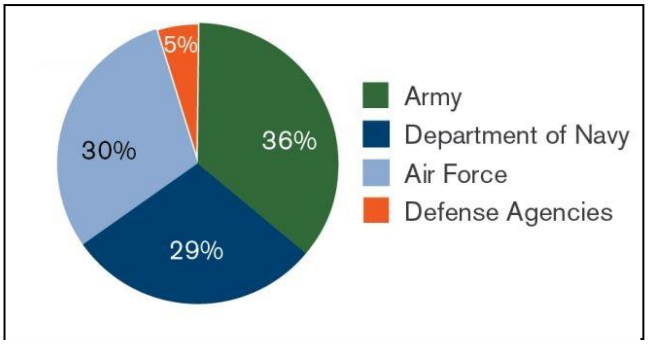

Figure 4. DoD FY 2014 Facility Energy Consumption [26]

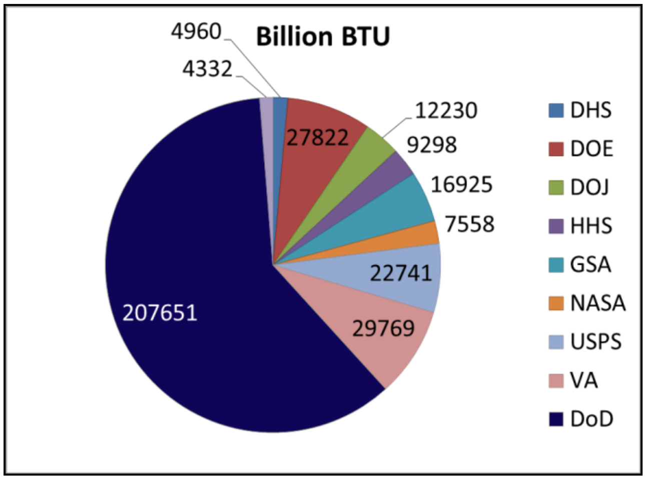

Figure 5. Top 10 FY 2014 Federal Energy Consumers [28]

goals for energy intensity reduction and renewable energy [26]. The energy requirements for individual DoD installations vary widely. More than 90% need less than 40 MWe, and more than half need less than 10 MWe [29].

3.1.3. Air Force Energy Demand. Energy is becoming a larger share of the AF budget, going from 3% of the total budget in 2003 to over 8% in 2011. The AF relies heavily upon electricity, obtained mainly from the commercial electric grid and generated by public utility companies, to support its installations,. Although generation is from variety of sources, the increasing age of the grid and its potential vulnerability to natural disasters and attacks can affect installation-based AF missions, perhaps most significantly the cyberspace and space missions. The AF acknowledges its energy security efforts must be integrated within DoD and with local, regional, state, federal, and international partners. The AF seeks to decrease reliance on the grid by diversifying generation and distribution options, with an emphasis on domestic supplies where appropriate. The AF is focused on developing on-site sources of renewable energy to provide consistent energy pricing and attain the environmental benefits by avoiding GHG emissions [30].

3.1.4. AFSPC Energy Demand. The overwhelming share of energy use for space domain operations is in terrestrial facilities and systems, since the space community relies heavily on ground based facilities to complete its mission. These facilities are in turn highly reliant on various data processing and computing technologies. Terrestrial facilities accounted for 97.2% of the energy consumed by AFSPC in 2010 [31]. In 2013, AFSPC ranked fifth among 13 AF major commands and agencies in facility energy usage (4,937,381 MBTU), consuming 7.8% of the AF facility energy total and 8.4% of the total cost. Air Force Materiel Command, with a large number of depots, laboratories, and test facilities, was the largest user with 15,192,383 MBTU, 24% of the usage, and was second to Pacific Air Forces (22%) with 17.5% of the cost [32]. Current AFSPC electric and heat demand data are provided in Table 2.

Table 2. AFSPC Installation Energy Requirements (FY 2014)

Installation	Electric					Heat (MBTU)			
	Base Average Demand (MWe)	Annual Use (MWh)	Annual Cost (in $1,000)	Peak Demand (MWe)	Highest Peak Month	Annual	Annual Cost (in $1,000)	Max	Month occur-red
Buckley AFB, CO	16.28373	142646	$9,157	5.58	July	129729	$1,028	23036	Dec
Cape Canaveral AFS, FL	16.69509	146249	$9,301	21.74	Apr	51449	$433	4635	Oct
Cape Cod AFS, MA	1.27989	11212	$653	1.52	July	10737	$282	2094	Feb
Cavalier AFS, ND	5.76610	50511	$2,429	7.00	Feb	56545	$793	5723	May
Cheyenne MT AFS, CO	2.70000	26369	$1,423	3.20	July	2162	$30	352	Dec
Clear AFS, AK CALCULATED (loads/costs)	4.50685	39480	$4,343	5.89	Mar	206916	$4,476	76386	Mar
Los Angeles AFB, CA	2.63550	23087	$2,893	4.56	Sep	28145	$207	3526	Dec

Installation	Electric					Heat (MBTU)			
	Base Average Demand (MWe)	Annual Use (MWh)	Annual Cost (in $1,000)	Peak Demand (MWe)	Highest Peak Month	Annual	Annual Cost (in $1,000)	Max	Month occur-red
New Boston AFS, NH	0.57534	5040	$516	0.70	Feb	12953	$327	1916	Feb
Patrick AFB, FL	10.42021	91281	$5,673	17.21	May	39181	$334	4855	Jan
Peterson AFB, CO	10.29276	90165	$5,084	15.99	July	192578	$1,367	30879	Dec
Schriever AFB, CO	9.20464	80633	$5,874	10.70	Oct	155595	$836	19651	Dec
Vandenberg AFB, CA	18.72146	164000	$17,035	25.46	May	280623	$2,391	35804	Nov

3.1.5. Mission-Critical Utility Reliability Requirements. Reliability of electrical power for AFSPC mission critical operations is of paramount importance. The Team researched applicable guidance on reliability requirements for AFSPC power systems and discussed the process with the HQ AFSPC energy reliability SME. This section summarizes the potential impact of SMR electrical and/or thermal energy on the reliability of mission critical utilities.

3.1.5.1. Findings. On select AFSPC facilities, commercial power and backup generator power are run through an Uninterruptible Power Supply (UPS). In most cases, diesel generators provide the backup power. Almost all mission critical functions (functions which, when compromised, would degrade the system's effectiveness in achieving its designed mission [33]) have backup power and, in most cases, the remainder of the installation relies solely on commercial power. AFSPC's ability to meet annual utility availability requirements is based solely on the backup power configuration. There are basically three configurations (see Table 3); each configuration is assumed to provide a given power availability when used in conjunction with a commercial utility power supply. When an availability number (such as 99.999%) is stated, this number generally refers to one of these configurations as opposed to a calculated prediction of availability. The on-site storage tank for backup generators is sized to hold enough fuel for 72 hours of operation [34]. Availability of a 7-day fuel capacity is required from either on-site storage or from a confirmed delivery source [35].

Table 3. Backup Power Configurations

Backup Configuration	Assumed Availability Provided
Minimum mission-required backup generators, single UPS	0.999
Minimum mission-required backup generators with parallel-redundant UPS	0.9999
Minimum mission-required backup generators with two sets of parallel-redundant with a hot-tie UPS	0.99999

3.1.5.2. Conclusion. Use of SMRs for power generation to an AFSPC installation should not change the methodology to determine if the site meets AFSPC availability requirements.

3.2. Guidelines and Studies

3.2.1. Guidelines--Potential Considerations/Impediments. Multiple existing guidelines would influence a decision to site an SMR on a DoD/AFSPC installation.

- 10 United States Code (USC) Section (§) 2692 prohibits storage, treatment, or disposal of any toxic or hazardous material that is not owned by DoD on DoD installations, except for temporary storage of nuclear materials in accordance with an agreement with the Secretary of Energy [36].
- Air Force Instruction (AFI) 32-9003 reinforces the DoD policy prohibiting storage or disposal of non-DoD-owned hazardous or toxic materials on AF real property. The Deputy Assistant Secretary of Defense (Environment) may grant exceptions [37].
- 10 USC § 2916 states that the applicable Service secretary will set the price and receive the proceeds for sale of energy from alternate energy or cogeneration facilities which are under the secretary's jurisdiction (or produced on land which is under that jurisdiction) [38].
- 40 USC § 591, states that DoD may not purchase electricity in a manner inconsistent with state law governing the provision of electric utility service [39].
- Department of Defense Instruction (DoDI) 4170.11 states that utilities privatization is the preferred method for modernizing and recapitalizing DoD utility systems. In most cases, larger scale, off-grid electrical generation systems should be non-DoD owned and operated. Off-grid generation systems owned and operated by the DoD components may make sense for mission criticality and remote sites when it is life cycle cost effective [40].
- EO 13693 sets electric and thermal energy targets, directing Federal agencies to obtain not less than 25% of their total facility energy from clean energy sources by 2025. The renewable electric target and clean energy target are fixed at 30% of electric energy and 25% of total energy, respectively. The role of SMRs, categorized in this EO as alternative energy sources, has yet to be clarified [41]. A 2012 DoD goal calls for each Service to procure 1 GWe of electricity from renewable sources by 2020 [42]. It is not yet clear whether DoD will follow the President's lead and expand the definition of acceptable resources to include SMRs.
- The Environmental Protection Agency's (EPA) CPP rules are designed to cut carbon emissions 32% from 2005 levels by 2030. Each state has its own target for existing power plants, based on that state's generation mix and electricity consumption (emission goals for Alaska, Hawaii, Guam, and Puerto Rico are pending). Under this rule, the five nuclear reactors under construction in Georgia, South Carolina, and Tennessee as well as any new units or upgrades can count toward compliance [43].
- The DoD has a policy, based on 10 USC § 2911 & § 2410q, that it will not purchase power for more than the current and forecasted market rate [44, 15].
- AFI 32-1061 provides six options, in preferred order of preference, for determining best value in acquiring new electric service for an installation. Preference goes to supplier transmission voltage, a supplier-owned substation, and a supplier/privately-owned distribution system. A government-owned plant option ranks sixth [45].
- Undersecretary of Defense for Acquisition, Technology and Logistics, USD (AT&L), policy states an Enhanced Use Lease (EUL) used for renewable energy projects must

include payment (in cash or in-kind) by the lessee in an amount not less than the fair market value of the leasehold [46] (See paragraph 3.3).

- Several documents overlap or are inconsistent in their guidance for the duration of utility service contracts, as itemized below. The variations in contract terms are open to interpretation requiring legal review.
  - 10 USC § 2688: contracts for utility services will not exceed 10 years, unless the Sectary of Defense (SECDEF) determines a contract for a longer term will be cost effective (not to exceed 50 years). It appears that EUL guidance is derived from this section since the maximum term is 50 years [47].
  - 10 USC § 2410q: contracts will not exceed 10 years for purchase from a renewable source, but SECDEF must determine if the contract is cost effective and would not be economical without a contract greater than five years [15].
  - 10 USC § 2922a: after SECDEF approval, the department secretary may enter into contracts for up to 30 years for the provision and operation of energy production facilities on real property under the secretary's jurisdiction or on private property and the purchase of energy produced from such facilities [48].
  - 10 USC § 2809: contracts cannot exceed 32 years, excluding the construction period [49].
  - *DoD Strategic Sustainability Performance Plan, FY2012:* Under a 20-year power purchase agreement (PPA), a financier purchased the solar system that a private solar company will design, build, operate and maintain. The role of the installation is to provide the land for the project and purchase electricity from it, at a rate that is locked in for 20 years below the current retail utility rate [42].
  - AFI 32-1061: General Services Administration (GSA) Area-Wide Contracts are between the government and a utility service supplier for a period not to exceed 10 years [45].

3.2.2. Studies on DoD use of SMRs. Several studies address the applicability of SMRs as a source of energy for DoD. The DoD focus is due largely to Congressional interest highlighted in the 2010 National Defense Authorization Act, in which Congress directed the DoD to assess the feasibility of nuclear power plants on DoD installations. In general, the studies emphasize the need for the DoD to pursue cost-savings in energy consumption and to decrease dependence on the commercial grid. This is especially important given the ever-constrained DoD fiscal environment and significant share of the DoD budget dedicated to energy. EOs and associated DoD goals for clean energy requirements have further influenced initiatives to seek more mission and cost effective sources for energy to support military operations, although much of the current emphasis is on renewable energy. The studies consistently cite the benefits of SMR technology in general and the applicability of those benefits to a military setting (see paragraph 2.1). Key points from selected studies are listed below.

3.2.2.1. Defense Science Board (2008) [1]:

- DoD missions are at an unacceptably high risk of extended outage from failure of the grid and other critical national infrastructure. DoD installations rely almost entirely on the national power grid.
- Backup power at installations is based on diesel generator sets with limited on-site fuel storage and not prioritized to critical tasks. As the reliability of the national grid has declined, the adequacy of backup power has become an issue.

3.2.2.2. Center for Naval Analyses (2011) [29]

- Nuclear power is a viable option if its cost is the same as alternative power sources, while reducing GHG emissions and contributing to electric energy assurance. If DoD places a value on energy assurance and reducing GHG emissions, nuclear could be viable even if the cost of power is higher than power from alternative sources.
- SMR-generated electricity on DoD installations would contribute to energy assurance for critical facilities
- If the DoD must independently fund FOAK costs, SMRs are not economically feasible for the DoD

3.2.2.3 United States Air Force Scientific Advisory Board (2009) [50]

- DoD should consider partnerships within DoD, with DOE/other government agencies, industry, and investors
- The most significant near-term energy technology is the use of nuclear energy to serve DoD installations
- Nuclear energy readily complements renewable energy sources and is the only major low-carbon option available
- The AF should identify bases that would derive the greatest benefit from nuclear power implementation, perform technical evaluations of nuclear power systems currently in development, and engage industry, other federal agencies, and the other services toward a concept demonstration.

3.2.2.4. National Defense University (2011) [51]

- If it chooses to be a "first mover" in the market, DoD has the opportunity to ensure SMRs meet its specific operational needs and requirements
- DoD should consider providing a "pilot installation" for SMR technology
- Potential SMR disadvantages: loss in economies of scale, financial uncertainty, regulatory timelines and costs, siting challenges, potential public resistance, and waste disposal

3.2.2.5. Air Force Chief Scientist (2012) **[**31**]**

- The AF should initiate the investment in revolutionary energy sources which will change the baseline equipment used today at radar and other terrestrial sites. The space systems portfolio can be used as a starting point for laying in the necessary research lines, and should consider piloting small modular nuclear systems as recommended by the AF Scientific Advisory Board.
- Efforts to reduce space operating systems energy costs should focus on ground facilities and systems—ranges, control stations, and data processing facilities. This would enhance resiliency, sustainability, and affordability.

3.2.2.6. Oak Ridge National Laboratory (ORNL) (2013)**:** SMR siting on DoD installations provides opportunities for beneficial synergies: DoD installations support high technology and national security missions, the staffs are considered capable and familiar with high technology activities similar to nuclear power plant operations, and they possess the necessary security capabilities [52].

3.3. Acquiring Use of DoD Land for Energy Production

Its guidelines on land use directly impact DoD's approach to energy purchases. Currently, these guidelines focus extensively on renewable energy sources.

3.3.1. Outgrants. An outgrant is a written, legal document that authorizes the right to use real property managed by DoD and establishes the timeframe, consideration, conditions and restrictions of its use [53,54].

3.3.2. Leases are a form of outgrants issued when the proposed use is compatible with multiple use, mission needs, and environmental criteria. The DoD leases the property to a lessee in exchange for cash/in-kind consideration that is at least equal to the property's fair market value. There are two primary types of leases that could facilitate an SMR deployment: a Direct Land Lease and an EUL. These leases are limited to five years, unless a longer period, not to exceed 50 years, is approved by the service secretary. [53,55]

3.3.2.1. Direct Land Leases are fairly simple transactions dealing directly with the use of the property for a period of time and a set cash/in-kind consideration. Direct leases do not normally address support services (i.e., support synergies) required by the lessee; these would have to be covered by a separate direct contract with the installation.

3.3.2.2. An Enhanced Use Lease is also a lease but EULs can address support services in a support agreement included in the lease. EULs may also be extended beyond the 50 year limit and can be renewed prior to the 50 year termination to cover the life span of a specific technology. EULs are either full and open competition (generally internal to the AF) or an unsolicited EUL proposal (generally non-governmental) [56]. Since it is unlikely that an installation would develop a competitive EUL for an SMR if the SMR power generation capability exceeds the installation's requirements (as is currently the case), an unsolicited EUL is the most logical approach. EULs have been used for renewable energy projects (e.g., the Luke AFB, AZ 10 MWe solar development EUL with Arizona Public Service). The Team identified several EUL lessons learned during the research study phase [57]. Selected examples are provided here.

- In-kind considerations vary widely. While cash is always beneficial, it may not be the best incentive for granting an EUL.
- The National Environmental Policy Act process will always be a major factor. This should be one of the earliest considerations and needs to have strong emphasis throughout the process.
- Review state and local laws impacting economic development, taxes, etc.
- Never assume. Unforeseen factors could unnecessarily delay projects--for example, undocumented archeological or hazardous material issues.
- Be innovative. Seek flexibility in financing and alternative approaches that will cut costs and save time.

3.3.3. Purchase of Energy from Property Lessees. To assist in meeting its energy goals, DoD uses both appropriated funds and third party (non-governmental) financing to fund energy projects on installations (renewable and non-renewable). Table 4 illustrates the authorities used for third party financing for energy projects. 10 USC § 2410(q) is limited to renewable energy sources [15].

Table 4. Funding Mechanisms

Funding Mechanism	Authority	Definition
Utility Service Contracts	10 USC § 2922(a)	A contract enabling the DoD to enter into agreements for the provision and operation of energy production facilities and the purchase of energy from such facilities.
Power Purchase Agreement	10 U.S.C. § 2410q	An agreement enabling the DoD to enter into a contract for the purchase of electricity from sources of renewable energy.
Outgrants	10 U.S.C. § 2667	An outgrant for the production of energy allows an installation to lease land to a lessee in return for cash or in-kind contributions. For renewable energy projects that use the authority found under 10 U.S.C. § 2667, DoD requires that the Military Department demonstrate more than a mere passive activity. For production or procurement of facility energy to qualify as being consistent with the DoD energy performance goals and master plan (and consequently qualify for an energy certification), DoD must do one of the following: • Consumption by the DoD Component of some or all of the facility energy from the project; • Structure the project to provide energy security for the installation by, e.g., retaining the right to divert to the installation the energy produced by the project in times of emergency; • Reinvest in renewable facility energy or program conservation measures of a minimum of 50 percent of the proceeds (including both in-kind and cash) from any lease.

4.0 THE DOD AND SMRS

4.1. Why Air Force Space Command?

AFSPC involvement in the SMR study is based on the initiative of General William Shelton, the former AFSPC Commander. In 2013, General Shelton offered the services of command personnel to assist SNL by providing key information and supporting development of technical solutions to meet AFSPC facility power and energy security requirements [58]. AFSPC's unique space missions, critical reliability requirements, and global locations made the command a logical choice to participate in this study.

4.1.1. AFSPC Characteristics. As illustrated in Figure 6 and in Table 5, AFSPC-owned installations are dispersed throughout the US and have a broad range of characteristics and missions [59]. Although AFSPC is also responsible for the AF cyberspace mission, the installations considered in this study are primarily focused on the space domain, since the cyberspace units are generally located on installations owned by other AF Major Commands. The Team used the definition of "United States" provided in EO 13693, "…the fifty States, the District of Columbia, the Commonwealth of Puerto Rico, Guam, American Samoa, the United States Virgin Islands, and the Northern Mariana Islands, and associated territorial waters and airspace" [41]. Given this definition, Thule Air Base, Greenland was not included among the installations in the assessment, although its energy requirements and characteristics may warrant future study.

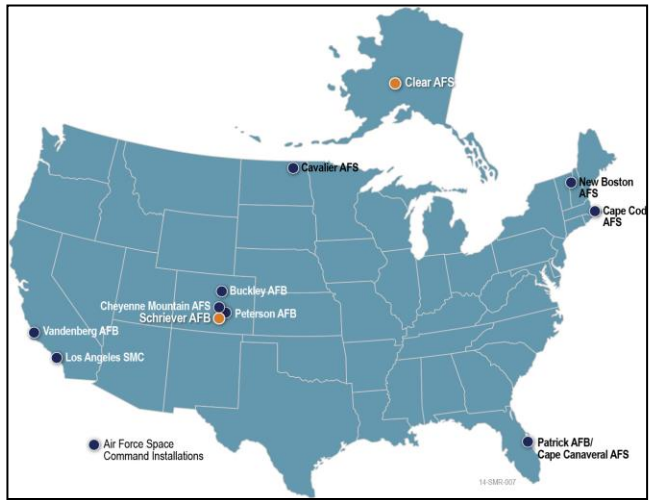

Figure 6. AFSPC Installations

Table 5. Overview of AFSPC Installations

Installation, Unit	Mission(s), *Major Tenants*	Operating Characteristics	Energy Supplier
Buckley AFB, CO 460th Space Wing (SW)	<u>Missile Warning/Space Surveillance, Intelligence</u> *Aerospace Data Facility-Colorado* *Navy Operational Support Center* *Colorado ANG* *Army Aviation Support Facility* *Air Reserve Personnel Center*	- 11,006' runway - Multiple radomes (line of sight requirement) - F-16, helicopter operations - Urban setting, immediately east of Denver, CO	Public Service of Colorado
Los Angeles AFB, CA	<u>Space systems acquisition</u> Space and Missile Systems Center	- No runway - Urban setting: Los Angeles, CA	Southern California Edison
Patrick AFB, Cape Canaveral AFS, FL 45 SW (considered as	<u>Space launch operations</u> *NASA operations* *Naval Ordinance Test Unit* *Commercial space activities*	- PAFB: 3993' runway - CCAFS: 10,000' runway - NASA, AFSPC, and commercial space launch	Florida Power and Light

Installation, Unit	Mission(s), *Major Tenants*	Operating Characteristics	Energy Supplier
separate installations)		operations	
Peterson AFB, CO 21 SW	Missile Warning/Space Surveillance *302 Air Wing (AFRC)* *HQ AFSPC* *NORAD/NORTHCOM* *Army Space and Missile Defense Command*	- Co-located with Colorado Springs Municipal Airport - 13,501' , 11022' , 8270' runways - C-130 operations	Colorado Springs Utilities
Schriever AFB, CO 50 SW	Satellite Operations *57 Adversary Tactics Group (ACC)* *310 SW (AFRC)* *Missile Defense Agency (MDA)*	- No runway - Multiple radomes (line of sight requirement)	Mountain View Electric Association
Vandenberg AFB, CA 30 SW	Space launch operations *Joint Space Operations Center* *HQ Fourteenth Air Force* *381 Training Group (AETC)* *576 Flight Test Squadron (ACC)*	- 8,500' runway - NASA and AFSPC launches - Emerging commercial launch operations	Pacific Gas & Electric
Cape Cod AFS, MA 21 SW	Missile warning	- No runway - Radars	Cape Light and N-Star
Cavalier AFS, ND 21 SW	Missile warning/space surveillance	- No runway - Phased array radar	Minkota
Cheyenne Mountain AFS, CO 21 SW	Integrated Tactical Warning and Attack Assessment operations	- No runway - Majority is within Cheyenne Mountain	Colorado Springs Utilities
Clear AFS, AK 21 SW	Missile warning *Missile Defense Agency*	- No runway	Golden Valley Electric Association (2015)
New Boston AFS, NH 50 SW	Satellite command and control	- No runway	Public Service of New Hampshire
ACC: Air Combat Command AETC: Air Education and Training Command AFRC: Air Force Reserve Command ANG: Air National Guard		NASA: National Aeronautics and Space Administration NORAD/NORTHCOM: North American Aerospace Defense Command/US Northern Command	

4.1.2. AFSPC Energy Priorities. As is the case throughout the DoD, AFSPC faces distinct and often conflicting challenges in the energy arena. The major priorities impacting AFSPC energy requirements are outlined below (not in priority order).

- *Mission assurance* is a process to protect or ensure the continued function and resilience of capabilities and assets--including personnel, equipment, facilities, networks, information and information systems, infrastructure, and supply chains--critical to the performance of DoD missions in any operating environment or condition [60].
- *Energy security* can be defined as having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet operational needs. Energy is critical to the AF's national defense mission and is a central element of strategic policies and plans [61].

- *Safety* programs preserve resources to maximize combat capability by eliminating mishaps through proactive hazard identification and risk management [62].
- *Security* involves measures taken by a military unit or installation to protect against all acts which may impair its effectiveness. It is the result of establishment and maintenance of protective measures that ensure a state of inviolability from hostile acts or influences [60].
- *Reduced energy costs*. As the DoD's largest energy consumer, the AF has established specific goals to decrease energy costs and reduce energy demand. Several goals apply to SMRs: explore methods of funding for energy initiatives, review energy economic and cost models, explore best practices for energy purchases, engage the Office of the Secretary of Defense to influence DoD financial regulations pertaining to energy as laws and policies change, and gain Congressional support for energy legislative initiatives/proposals with financial impact [63].
- *Clean energy and GHG goals*. DoD goals are impacted by guidance from EOs; updates in response to EO 13693 are pending. Examples of goals from the 2012 *DoD* S*trategic Sustainability Performance Plan*: [42]
    - By FY 2020, produce or procure energy from renewable sources in an amount that represents at least 20% of the electricity consumed by facilities
    - GHG emissions from Scope 1 and 2 sources reduced 34% by FY 2020, relative to FY 2008 (scope 1: GHG emissions from agency-owned or controlled sources, Scope 2: GHG resulting from electricity, heat, or steam purchased by an agency [41])
    - Greenhouse Gas Emissions from Scope 3 sources reduced 13.5% by FY 2020, relative to FY 2008 (Scope 3: GHG from sources not owned/controlled by an agency but related to agency activities [41])
- Desired energy capabilities for AFSPC (and DoD) could include a black start capability, island mode operations, smartgrid compatibility, non-electric applications, independence from the commercial grid, integration with renewable energy sources, mobility, forward-deployed site operations, and offsite storage and disposition of spent fuel.

4.2. Use Case Installation Selection Criteria

4.2.1. Approach. The Team used an iterative process to develop criteria to review AFSPC's 12 installations and identify two installations for in-depth use case assessments. This process included information from previous studies, stakeholder/SME inputs/discussions, and findings from the siting evaluation analysis of the installations. The results of this process evolved into the three categories of criteria below.

4.2.2. AFSPC-related criteria. These general criteria relate to military installations, their missions, and operating characteristics and are not unique to AFSPC.

- Mission priority. These priorities were based on the "Prioritized Space Superiority Activities" document signed by General John Hyten, the current AFSPC commander. This list includes the 14 mission areas performed by AFSPC space units, listed in priority order (see Appendix B).

- Potential for installation-SMR support synergies available on the installation through the host unit. Examples of support synergies could include physical security, fire protection, integrated defense, safety, hazardous material (HAZMAT) management, emergency management, and environmental monitoring/compliance.
- Installation operations. The Team identified additional aspects of DoD/AFSPC operations (e.g., military aircraft operations, missile/rocket launch activities, unexploded ordinance), to be considered when evaluating the suitability of the installation for SMR deployment.

4.2.3. Siting criteria. Working with the ORNL, the Team established values specific to the site selection evaluation criteria (SSEC) used in the Oak Ridge Siting Analysis for power Generation Expansion (OR-SAGE) model (see Appendix C). OR-SAGE uses NRC standards to develop criteria for screening reactor sites. It employs Geographic Information Systems (GIS) data sources to identify candidate areas through development of exclusionary, avoidance, and suitability criteria. The SSEC results tend to recommend *against* sites, that is, they identify challenges to using the site for SMR deployment. The OR-SAGE results provided valuable insights into AFSPC installations with challenges to successful SMR deployment and led to the elimination of several installations. Initially, OR-SAGE data were not available for Clear AFS, so the Team used the SSECs and GIS data available on the internet to evaluate Clear AFS. With funding from DOE, ORNL was able to provide OR-SAGE data for Alaska (and Clear AFS) during the second phase of the study.

4.2.4. Use Case Considerations. The final category of criteria deals with specific use case considerations that further characterize the nature of potential installations to refine the selection process. These considerations include installation location, size, and scope of capabilities.

4.2.5. Installations Selected. The initial list of 12 AFSPC installations was reduced to six through application of OR-SAGE SSECs and related information. Use of the AFSPC-related criteria shortened the list to four installations, rank-ordered by mission priority: Schriever AFB, Buckley AFB, Clear AFS, and New Boston AFS. Refinement of this list of four installations based on use case considerations resulted in identification of Schriever AFB and Clear AFS as the best candidates for the second phase of the study, which included site visits and first-hand interaction with installation SMEs.

4.3. Observations from Site Visits

4.3.1. Purpose. Once the use case installations were selected, the Team's effort centered on the feasibility of an SMR deployment on or adjacent to Schriever AFB, CO and Clear AFS, AK. The Team completed site visits to each location, interacted with installation personnel, researched site-specific data and guidance, interviewed representatives of the utilities serving the installations, refined economic considerations, and reviewed several additional factors with potential impact on SMR deployment. The site visits facilitated feasibility assessments of SMR deployment on actual AFSPC installations.

4.3.2. Schriever AFB is located on the Colorado prairie 16 miles east of Colorado Springs, CO. The Team conducted the Schriever AFB site visit from 21 to 23 July 2015. The 50 SW, Schriever's host unit, is responsible for the operation and support of 175 DoD satellites and installation support to 16 major tenant units with an overall workforce of more than 7,500 personnel. The wing operates satellite operation centers at Schriever and remote tracking stations and other command and control facilities around the world. The 50 SW has three functional groups (Operations Group, Network Operations Group, and Mission Support Group), each with two or more squadrons (e.g., Space Operations Squadron, Civil Engineer Squadron, Security Forces Squadron). Schriever AFB is considered a full scale Air Force Base with support capabilities sufficient to meet the majority of its mission needs. A distinguishing feature of Schriever AFB is its 640 acre, high security, restricted area (RA) within the 3,840 acre site. The RA houses key facilities and equipment associated with the operations and support of mission systems [64].

4.3.2.1. Energy Requirements and Systems. Schriever's peak electrical demand (Oct 2014) was 10.7 MWe and its peak thermal demand (Dec 2014) was 5.09 MWt. The installation's FY14 electric consumption was 80,633 MWh at a cost of just under $5.9 million. Thermal consumption in FY14 was 107,393 MBTU (or 31,474 MWh) at a cost of $577,000. If Schriever loses commercial power, the installation has backup capability to produce a monthly output of electric power at 17.55 MWe maximum/11.5 MWe sustained, as well as 9,000 MMBTU thermal. Backup power is provided by seven diesel generators (three 2.65 MWe, three 2.3 MWe, and one 2.7 MWe) with a seven day supply of fuel. All critical mission systems also have an uninterruptable power supply (UPS) [64].

4.3.2.2. Synergies. As noted above, Schriever AFB has support capabilities sufficient to meet most of its needs--fire protection, integrated defense, safety, existing studies and data, training, utilities, and Morale, Welfare and Recreation. Schriever also has limited capability in emergency management, environmental monitoring/compliance, and medical support. These limited services are augmented through support from the 21 SW at Peterson AFB and commercial contracts. None of these services would completely meet the needs of an SMR sited on the installation but they could be used to augment/supplement SMR requirements through agreements between the SMR and the installation. Specific synergistic benefits are expanded below.

- **Physical security.** Integration of SMR security with Schriever AFB security procedures could be achieved due to the similarity of requirements. The 50th Security Forces Squadron is authorized to have 177 active duty personnel and 24 Department of the AF (DAF) civilian policemen [64]. An SMR would require an estimated security force of 70 personnel. The security requirements for Schriever and the RA in particular are similar to NRC requirements for a nuclear reactor, currently defined in NUREG 0800 [65]. Other considerations:
  - Increased security capabilities required by the addition of an SMR could be addressed through three courses of action: 1) integrating the installation and the SMR security forces under the supervision of the AF Defense Force Commander, 2) maintaining separate installation and SMR security forces, but integrate training, and 3) maintaining entirely separate security forces, with a cooperative agreement for mutual support during abnormal events. Sitting an SMR immediately adjacent to the RA might provide opportunities to simplify and enhance shared services, e.g., the response time for security, fire and medical [66].

- Schriever AFB's use of DAF civilian policemen offers a potential synergy for establishing the SMR security force. The potential exists for an SMR owner/operator to fund DAF police positions at an AF installation to provide security for an on-site SMR plant, perhaps at a lower cost than a privately-owned security firm. This offers the advantages of integrated training for installation and SMR security forces, the potential for centralized control of the security forces under the Defense Force Commander, and fully coordinated responses to any security event [64].
- Another potential source of security force augmentation for the SMR is the Air Reserve Component force protection volunteer program (ARC-V), most likely during the SMR construction period. ARC-V is intended to be a short term supplement for active duty AF security force requirements. Under ARC-V, volunteers from the AF Reserve or ANG are selected for tours of varying length at active duty AF installations to supplement existing security capabilities [67]. Funding from the SMR owner/operator is the most realistic approach for use of ARC-V resources to support SMR construction.

- **Emergency services.** The size of the Schriever AFB *fire station* is based on the requirements of the original installation. There have been significant increases in AFSPC missions and the addition of tenant unit facilities and a base housing area, driving the need for a larger fire station. However, military construction funds will not be available for 6-10 years. Construction of a new fire station and funding for additional firefighters by an SMR owner/operator could alleviate this shortfall while providing the needed fire support for the SMR facility. *Emergency management* capabilities (protecting the installation against, and responding to threats, hazards and incidents) are limited at Schriever; it receives additional support from Peterson AFB in Colorado Springs. An SMR operator would also require significant capabilities in this area. SMR emergency services could augment existing infrastructure and personnel, since both the SMR and the installation would be impacted by events requiring emergency responses. An integrated response would optimize resource utilization.
- **Siting Data.** Existing data (hydrology, seismology, aquifer, and environmental impact) from the recent facility construction/upgrades could help facilitate SMR licensing
- **Training.** Combined but separately funded training for support functions (e.g., fire, emergency response) should meet Schriever and NRC requirements--with potential savings for each. The fire station has an on-site live fire training facility that could facilitate the mutual support relationship.
- **Morale, Welfare and Recreation.** Some base capabilities (service station, shoppette, MDA cafeteria, child care, gymnasium) could be available to SMR personnel on an appropriate cost share basis.
- **Medical.** Schriever AFB has a small medical clinic, manned by personnel from the 21 SW at Peterson AFB. Schriever contracts for ambulance and emergency medical technician support through a private Colorado Springs company. Support from the clinic for the SMR operator may be possible through an agreement or contract with the 21 SW. The ambulance contract could be similarly adjusted.
- **Environmental monitoring** (meteorology, protected species, wetlands, etc.)
  - Schriever AFB could provide limited non-nuclear compliance support.

- Schriever AFB has limited Bio-environmental engineering support and is augmented by Peterson AFB personnel. Support from Peterson AFB might be possible through a separate agreement or contract.
- Environmental data collected by Schriever AFB (e.g., prevailing winds, flood plains, protected species) could help facilitate SMR licensing.

- **Utilities.** An SMR could be linked to existing Schriever AFB capabilities:
  - A sewer line runs under the installation.
  - Water for uses other than power generation is available (see paragraph 2.2.3.5).
  - Communications lines and associated capabilities are available.

4.3.2.3. SMR Siting. The Team observed the following factors that could influence a decision to site an SMR on Schriever AFB:

- **Energy Requirements.** The current Schriever AFB 10.7 MWe and 19, 651 MBTU requirements can be met by any of the light water SMR designs currently under development in the US. In fact, all four SMRs would produce significantly more power (electric and thermal) than Schriever AFB needs, necessitating either aggregation of regional energy requirements or a combination of aggregation and a tie-in to the commercial market.
- **Mission operations considerations.** Schriever AFB has no runway or flight or missile operations. However, Schriever uses large antennas for communications with satellites in space. These antennas must have a clear "view" or line of sight (LOS) to the satellites, therefore, tall facilities must be sited to preserve this LOS. The maximum height of projected SMR facilities ranges from 89 to 118 feet, so LOS is a key siting consideration. In addition, frequency spectrum must be considered. AFSPC communications systems may be impacted by external emanations on or near the frequencies they use.
- **OR-SAGE analysis.** Water availability was the only potential siting issue identified (see Appendices C and D) [68]. OR-SAGE data show sufficient water available within 15 miles of Schriever AFB with a stream flow rate of 65,000 gallons per minute (gpm). However, the Schriever Civil Engineering staff clarified that the only consistently available water on the installation is from wells. Schriever receives its water from the Cherokee Metropolitan District, which has 10,850 acre-feet per year (AFY) available and commitments of 5,097 AFY, leaving a surplus of 5,753 AFY (approximately 5.1M gallons per day, 3,500 gpm). This flow rate is not sufficient to support the use of conventional cooling such as mechanical draft cooling towers [69].
- **Base Siting considerations.** Schriever AFB has ample land available to site an SMR (50 acres or greater). The Team toured the installation with the Schriever Civil Engineering staff and identified four sites suitable for an SMR (see Figure 7). These potential sites are not the result of a detailed siting analysis, but are a feasibility assessment made by installation SMEs, in conjunction with the Team members. The selection process ensured that all the possible sites avoided SMR LOS interference with the space systems antennas. Schriever's 242-unit base housing area, with an estimated 500 residents, is less than five miles from all potential SMR site locations. Evacuation routes for housing residents would need to be addressed in an SMR's emergency response planning. Siting an SMR in the southeast corner of the installation (see Figure 7, Site D) might provide the best option from the perspective of the base housing residents, but would lessen some of the potential synergies between the SMR and the installation.

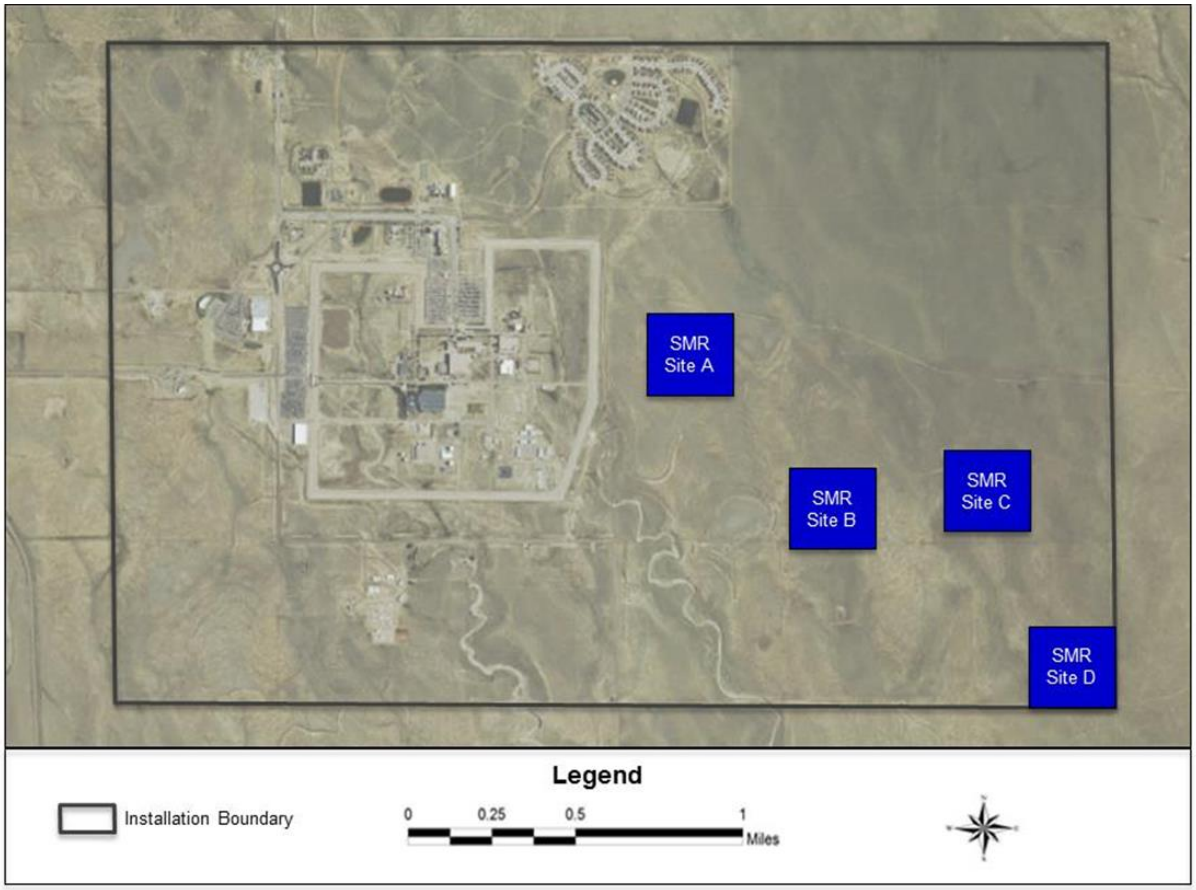

Figure 7. Potential SMR Sites on Schriever AFB

- **Emergency operations.** An SMR plant and the installation could have a unique cooperative relationship in emergencies following an abnormal event such as an earthquake or failure of the electrical grid.
  - Providing the SMR with access to power from Schriever's backup diesel generators would further increase redundancy for the nuclear power plant. Also, it is possible that backup power systems at an SMR could provide additional energy surety for Schriever AFB.
  - Each of the SMRs reviewed in this study is capable of achieving black start, provided there is a source of on-site, backup power to run certain components. Each SMR can also operate in island mode. Operating in island mode and achieving black start would return the installation to commercial power rapidly. Plans and procedures to utilize either black start or island mode would require approval from the NRC.
- **Protected species.** The Burrowing Owl nests on Schriever AFB and is on the Colorado State Threatened Species list. The Colorado Division of Wildlife guidelines recommend a "no human encroachment" buffer zone of 150 feet from the nesting sites from March 15 through October 31. This would be a factor for SMR plant siting and construction [70].

4.3.3. Clear AFS is located 56 miles southwest of Fairbanks, AK. The installation is accessed from the George Parks Highway, a major north-south corridor which also links Anchorage and Fairbanks. The Team conducted the site visit 10-11 August 2015. Missile warning, Clear's primary mission, is accomplished by its operations crews using the Solid-State Phased Array

Radar System (SSPARS). Clear's role is to detect and track intercontinental and sea-launched ballistic missile threats, and to perform space surveillance and satellite tracking. In addition to SSPARS, the MDA plans to install the Long Range Discrimination Radar (LRDR) system at Clear beginning in 2016, with LRDR becoming operational in 2020. The LRDR system will quintuple Clear's power requirements. Clear AFS does not have a wing structure like Schriever AFB, instead, the 13th Space Warning Squadron (SWS) is the host unit. Clear's mission is accomplished by the combination of 13 SWS personnel and Alaska Air National Guard (ANG) personnel from the 213 SWS. Clear has approximately 340 personnel on site daily. The 13 SWS members are AF active duty, normally assigned to Clear for a one year tour, whereas the 213 SWS personnel, DoD civilians, and contractor personnel are Alaska residents. As an Air Force Station with a squadron host unit, Clear is not self-sufficient in all support areas and relies on support from other installations--primarily Eielson AFB, near Fairbanks, AK and Peterson AFB, CO (location of the 21 SW--parent unit of the 13 SWS). A distinguishing feature of Clear AFS is the 11 story, dual-faced SSPARS facility within an approximately five acre RA on the 11,438 acre installation [66].

4.3.3.1. Energy Requirements and Systems. Until the end of 2015, Clear received its electric power and thermal energy from an on-site coal-fired combined heat and power plant (CHPP). Coal was delivered by rail car from a coal mine about 40 miles south of the installation. The CHPP went off line in December 2015 when Clear switched to commercial power provided by the Golden Valley Electric Association, Inc. (GVEA). Current retail electric rates for GVEA customers range from $0.13 kwh to $0.19 kwh [17]. The CHPP was abandoned in place. Clear's peak electrical demand (Mar 2014) was 5.89 MWe and its peak thermal demand (Mar 2014) was 30.09 MWt. The installation's FY14 electric consumption was 39,480 MWh at a cost of $4.3 million. Thermal consumption in FY14 was 206,916 MBTU (or 60,641 MWh) at a cost of $4.5 million. After the transition to commercial power from GVEA, in the event of a power failure, SSPARS has UPS and three 3.3 MWe diesel generators and the Composite Area (non-mission facilities) has one 1.25 MWe diesel generator. With the closure of the CHPP, its waste heat will no longer be available so three 13.3 MBTU boilers were added to heat the Composite Area. SSPARS has electric heat when needed [66].

4.3.3.2. Synergies. As noted above, Clear AFS is not self-sufficient in many support areas. It has utilities, fire protection training, and integrated defense capabilities sufficient to meet most of its needs, but only limited capability in emergency management, environmental monitoring and compliance, safety, Morale, Welfare and Recreation, and medical support. None of these services would completely meet the needs of an SMR sited on the installation but they could be used to augment/supplement SMR requirements through agreements between the SMR and the installation. Specific synergistic benefits are expanded below:

- **Physical security.** Integration of SMR security with the existing security function at Clear AFS could be achieved due to the similarity of Clear AFS and SMR security requirements. The Security Forces Flight is made up of 60 personnel from the Alaska ANG; an SMR facility would require a security force of approximately 70 personnel. Clear AFS security requirements, and the RA in particular, are similar to NRC requirements for a nuclear reactor and will increase with the addition of LRDR. This includes remote sensors, patrols, and response procedures; NRC requirements are similar. The installation does not have a security service road and perimeter fence. Currently, there are no significant structures or community population in proximity to the Clear AFS perimeter. The increase in security capabilities for the addition of an SMR facility could be addressed via courses of action similar to those for Schriever AFB (see paragraph 4.3.2.2.). As with Schriever AFB, the final organization would need to be developed through coordination between the installation and SMR owner/operator leadership.

- **Emergency services.** The size of the Clear AFS *fire station* is based on the requirements of the current installation. While the addition of the LRDR mission may increase the Clear AFS fire response capabilities, the addition of an SMR would still require additional capability. Adding to the existing fire station and funding for additional firefighters by an SMR owner/operator would provide the needed fire support for the SMR facility and enhance the current Clear AFS capability. *Emergency management* capabilities are extremely limited at Clear and it receives additional support from Eielson AFB (175 road miles away). As in the case of Schriever AFB, an SMR operator would have to bring significant capabilities to the installation. It is logical that those capabilities would augment existing infrastructure and personnel as both the SMR and the installation would be impacted by events requiring emergency responses. An integrated response would optimize resource utilization.
- **Siting Data.** Existing comprehensive studies from the recent upgrade to the Early Warning Radar and associated SSPARS facilities and design and engineering for LRDR could help facilitate SMR licensing by providing valuable data otherwise not readily available. These include a 141-page Site-Specific Seismic Hazard Assessment, a 48-page Aquifer Evaluation Report, an Army Corps of Engineers Wetlands Delineation, and a 104-page environmental assessment that addresses air, biological, water, and cultural resources; geology and soils; hazardous materials; and safety and occupational health. An LRDR siting study is underway.
- **Training.** Combined training for support functions (e.g., fire, emergency response) needed by both Clear AFS and the SMR operator, with separate funding, should meet Clear and NRC requirements with potential savings for each.
- **Morale, Welfare and Recreation.** Limited base capabilities (shoppette, outdoor recreation) could be available to SMR personnel on appropriate cost share basis.
- **Medical.** Clear AFS has a contracted ambulance on site. The contract could be expanded to include SMR personnel. Serious medical emergencies use helicopter airlift support from Fairbanks.
- **Environmental monitoring** (meteorology, protected species, wetlands, etc.). Clear AFS has limited, contracted environmental support on site. The contract could be expanded to cover specific SMR needs. Environmental data collected by Clear and MDA for the LRDR siting decision could help facilitate SMR licensing
- **Utilities.** An SMR plant could be linked to existing Clear AFS capabilities for administration facilities.
  - Potable water
  - Sewer
  - Communications

4.3.3.3. SMR Siting. The Team observed the following factors that could influence a decision to site an SMR on Clear AFS:

- **Electric Energy Requirements.** The Clear AFS electric energy requirement (currently 5.89 MWe, and approximately 28 MWe with the addition of LRDR) could be met by any of the light water SMRs currently under consideration. As with Schriever AFB, all four SMR designs would produce significantly more power (electric and thermal) than Clear AFS needs, even with the additional LRDR power requirement. This would necessitate either aggregation of regional energy requirements (see paragraph 4.4.) or a combination of aggregation and a tie-in to the commercial grid.
- **Clear AFS Thermal Requirement.** Steam heat for the installation was provided by the CHPP. With transition to the grid, Clear will use three 13.3 MBTU boilers for steam heat, supplied by a newly-constructed heat plant, which requires 8,000 gallons of fuel per week. During the winter months Clear experiences sustained -40ºF temperatures. If steam heat is lost to the Composite Area when the temperature is -40ºF or lower, it must be evacuated within four hours and an estimated $200 million in damage to the infrastructure may occur.
- **Clear AFS mission operations considerations.** The SSPARS and LRDR missions use large phased array antennas to identify and track missiles in flight; therefore, LOS is a key consideration due to the maximum height of projected SMR facilities. As with Schriever AFB, frequency spectrum is also a factor--power generation equipment (e.g., turbine power generators) must not interfere with communications frequencies.
- **Reliability.** Although the CHPP had been highly reliable, inefficiencies and required upgrades, as well as DoD guidance that off-grid generation systems should be non-DoD owned or operated [38], led to an AFSPC decision to close the CHPP and connect Clear to the commercial grid. Power is provided by GVEA through a single 138kv line and represents a single point of failure. While GVEA reliability is reported as 98%, 13 SWS personnel noted that Fort Greely (which uses GVEA commercial power) experienced 36 outages in the past year; six were unscheduled. GVEA has limited transmission capability and its infrastructure in the Clear AFS area is aging. Maintaining transmission system reliability is a challenge in the rugged environment and extremely cold winters in Alaska. Additionally, the transportation of diesel fuel for backup generators is vulnerable to disruptions caused by weather conditions and seismic activity. Locating an SMR on the installation would dramatically increase the reliability of its energy supply.
- **OR-SAGE analyses.** The ORNL recently added GIS data for Alaska to its OR-SAGE database. This allowed ORNL to review Clear AFS for potential siting using SMR-specific site evaluation criteria (see Appendices C and E). In the assessment, ORNL identified four potential full siting issues in the SSECs: *protected land, proximity to hazardous facilities, proximity to fault line, and peak ground acceleration*. The Team confirmed that the *protected land* issue related to Federal Reserve land or land formerly identified as protected, as well as a public school at one time located on the land. Since AF acquired this land in 1958 and the Team's site visit confirmed the school no longer exists, *protected land* is no longer an issue. The *hazardous facilities* issue relates to a small commercial airport approximately 2.5 miles east of Clear AFS. However, ORNL observed that the runway parallels the Clear site and would likely not pose a risk to an

SMR site. The remaining issues are ground acceleration values greater than 0.5 g and proximity to identified fault lines [71]. The seismic and fault issues would need to be addressed in the design and construction phases if an SMR were to be sited at Clear AFS.

- **Cooling Water.** Although the Nenana and Tenana Rivers are near Clear AFS, these rivers are not considered dependable cooling water sources due to seasonal flow rates and a high concentration of silt. Water is abundant in the local aquifer at a depth of 60 to 80 feet. The CHPP currently releases warm water into a 16,200,000 gallon cooling pond and lower temperature water into Lake Sansing (6,000,000 gallons, on the installation). The soil in the lake is hard-packed gravel, which allows replenishment of the aquifer.
- **Base Siting Considerations.** With 11,000+ acres, Clear AFS has ample land available to site an SMR. The Team toured the installation with the 13 SWS Maintenance Officer and identified one area as a possible SMR site (see Figure 8). This potential site is not the result of a detailed siting analysis, but is a feasibility assessment made by installation SMEs, in conjunction with the Team members. The selection process ensured that the possible site avoided SMR LOS interference with the SSPARS and LRDR missions.

Figure 8. Potential SMR Site on Clear AFS

- **Impact of Clear AFS Isolation.** Clear is located at 64º N latitude; therefore, sunlight is only available from 11AM until 2PM during December. All construction work must move indoors by the end of October due to snowstorms and severe cold. Due to the isolated nature of the area, talent retention for an SMR labor force could also be a major factor. According to the US Department of Labor, Bureau of Labor Statistics, [72] most labor costs are somewhat higher in Alaska while construction labor costs are significantly higher (see Table 6).

Table 6. Comparison of Colorado and Alaska Labor Rates

Construction Labor Comparison			Professional Labor Comparison		
	Mean Hourly wage			Mean Annual Wage	
Profession	CO	Fairbanks, AK	Profession	CO	Fairbanks, AK
Carpenter	$20.42	$30.10	Civil Engineer	$85,490.00	$107,600.00
Construction Laborer	$15.33	$21.95	Electrical Engineer	$97,340.00	$111,540.00
Electrician	$23.19	$35.20	Environmental Engineer	$86,620.00	$103,060.00
Painter	$16.58	$28.02	Power Plant Operator	$69,130.00	$63,550.00
Plumber	$22.71	$33.06	Industrial Production Mgr.	$107,490.00	$112,580.00
Sheet Metal Worker	$20.64	$28.76			
Construction Inspector	$30.78	$37.01			

- **Emergency operations.** As with Schriever AFB, an SMR plant and Clear AFS would have a unique cooperative relationship in emergencies following an abnormal event such as an earthquake or failure of the electrical grid.
  - Providing the SMR with access to power from the Clear backup diesel generators would further increase redundancy for the nuclear power plant
  - The installation's emergency power capabilities might also provide additional energy surety for an SMR. Also, it is possible that backup power systems at an SMR could provide additional energy surety for Clear.
  - An SMR operating in island mode and achieving black start would return the installation to commercial power rapidly.

4.3.4. Suitability of Use Case Installations. While both Schriever AFB and Clear AFS are excellent candidate SMR deployment sites, each has a major site selection challenge. Neither shortfall is insurmountable, but both would drive additional cost and design factors.

4.3.4.1. Schriever AFB Challenge. Schriever lacks adequate water supplies for conventional cooling, which would require some form of dry heat rejection, decreasing the plant's efficiency and increasing the cost per kilowatt hour of power (see paragraph 2.4.1).

4.3.4.2. Clear AFS Challenge. Clear is located in an area with significant seismic activity, which would necessitate additional design and construction considerations, increasing the associated time and the cost/kwh of power. In addition, Clear's relative remoteness could make it difficult to attract the talent to build and operate an SMR. Further, the lack of daylight and extreme cold in the winter months would adversely affect the cost to construct an SMR.

4.3.4.3. Potential benefits of SMR siting on Schriever AFB and Clear AFS:

- Synergies cited in paragraphs 4.3.2.2. and 4.3.3.2.
- Clean, secure power, allowing the installations to meet EO goals

- Power reliability
  - An SMR might require a second transmission line, eliminating the current single point of failure (unless this requirement is waived by NRC) [73]
  - Rapid return to primary power due to SMR black start capability
  - Additional backup generation for mission systems
- Thermal energy for heating and cooling--a critical need at Clear during the winter and also important for Schriever in the summer. Even when shut down and not producing electricity, an SMR will produce residual or decay heat that can continue to supply an installation's thermal energy requirements.
- SMR thermal energy for district heating, benefiting DoD installations and the surrounding communities, as occurs in eight European countries. Studies have been conducted into transporting thermal energy as far as 50 miles [74].
- More robust emergency response (security, fire, medical, HAZMAT)
- Additional environmental monitoring
- Schriever's proximity to Colorado Springs and Denver would facilitate the ability to attract the talent to build and operate an SMR.
- For Clear, the lessons learned/follow-on to LRDR construction and deployment activities could inform similar SMR activities. LRDR construction, projected to begin in 2016, will involve additional security, expanded transportation, and major changes in infrastructure to support a man-camp for a 350-person construction workforce.

4.3.4.4. Potential Benefits to the surrounding areas. Although only 16 miles from Colorado Springs (population 439,886), Schriever AFB is relatively isolated on the plains east of the city. Clear AFS is isolated within central Alaska's boreal forest, approximately 56 miles southwest of Fairbanks. There are several potential benefits to the surrounding communities from SMR siting:

- Property or "in-lieu-of" taxes on the $1 billion-$2.5 billion SMR plant capital project
- Housing growth resulting from the plant construction phase and addition of the SMR workforce
- New roads, expanded infrastructure
- Enhanced retail and other services (for Schriever, the majority of services are in the proximity of Peterson AFB, 22 road miles away; for Clear, Fairbanks is 77 road miles away)
- Increased local school funding. The rural Ellicott, CO school district supports families in Schriever AFB base housing. The Denali Borough School District has a K-12 school in Anderson, the closest community to Clear AFS.

4.3.4.5. SMR Siting Adjacent to Schriever AFB and Clear AFS. In general, siting an SMR adjacent to either of the installations could result in most of the benefits to the surrounding areas itemized in paragraph 4.3.4.4 for on-site SMR basing. Off-site basing; however, would alter some of the anticipated benefits.

- **Energy security**. In the event of failure, the priority of energy service provided to a DoD installation would have to be negotiated in advance with the SMR and local utilities, diminishing the availability of secure energy offered by an on-site power plant.
- **Potential synergies** may not be available or available only through specific agreements or added cost. For example:
  - Physical security and emergency services would require special consideration since DoD organizations cannot provide these capabilities without mutual aid agreements with local fire and law enforcement agencies, and the use of military personnel for law enforcement functions is restricted by law [75,76].
  - Morale, Welfare, and Recreation facilities and services would not be available to SMR employees since they would not have access to DoD installations without specific permission, and only for a limited time.
  - Medical clinic support would not be available to off-site, non-DoD personnel. Ambulance service, already provided to the installations through commercial contracts, would likely require a separate contract for SMR support.
  - If available on the installation, environmental monitoring support would require a separate support agreement.
  - Utilities, water, and communications capabilities would be the responsibility of the SMR owner/operator.

4.3.5. Utilities. During the site visits the Team held discussions with the utility providers for the two installations and other key utility providers in the area. Their characteristics, capabilities, future plans, and interest in SMRs are itemized below.

4.3.5.1. Mountain View Electric Association, Incorporated (MVEA). Schriever AFB purchases its electric power from MVEA, a rural electric cooperative which transmits power generated or purchased by Tri-State Generation & Transmission, Incorporated (Tri-State). About 86.5% of Schriever's power is generated by Tri-State. Schriever also receives an allocation of hydropower from the WAPA, which meets the other 13.5% of the installation's needs. MVEA's supply to Schriever experiences approximately two failures per year [64]. MVEA is in the fifth year of a multi-decade "all requirements contract" with Tri-State which requires it to purchase all power from Tri-State. Since MVEA does not own generation facilities but only the substations and distribution and transmission lines to its customers, it has little direct interest in an SMR [77].

4.3.5.2. Tri-State delivers both the WAPA allocation and supplementary power via its 115-kV transmission line to the MVEA point of delivery, the installation-owned substation at Schriever AFB [78]. The 115kv line to the Schriever substation is the installation's only connection to the grid and represents a single point of failure [64]. In 2014 Tri-State produced 12.4 million MWh. Tri-State's resource plan indicates it has little need for additional generating capacity within the next 10 years. Although, as a non-profit cooperative, Tri-State is not able to use many of the incentives provided for wind and solar, it does purchase renewables under long term PPAs. Tri-State has participated on the advisory boards of two of the SMR technology vendors and is interested in nuclear power and SMRs. Tri-State's primary consideration is the cost of power it provides to its members, and could be interested in purchasing power from an SMR if the price is competitive with other sources of power [78].

4.3.5.3. Colorado Springs Utilities (CSU) does not provide power to Schriever AFB, but it is the largest power provider in the vicinity of the base (1091 MWe generating capacity and 2011 peak load of 878 MWe) [79]. Therefore, CSU is a key stakeholder in energy decisions affecting the area. CSU is a municipally-owned utility, governed by a utilities board which is comprised of the members of Colorado Springs City Council. CSU's primary energy source is coal, but its portfolio also includes natural gas, purchases from WAPA, and small amounts of wind and solar energy. CSU currently is evaluating an Electric Integrated Resource Plan (EIRP) to determine the city's strategy to meet future power demands. SMRs were reviewed for the EIRP but were not considered cost-competitive with other sources of power at this time [80]. The Colorado Springs utilities board recently voted to close the city's primary coal-fired power plant by 2035, with a transition to natural gas as the primary replacement; details are evolving [81].

4.3.5.4 Golden Valley Electric Association, Incorporated, an electric cooperative based in Fairbanks, AK, began providing power to Clear AFS in 2015 via its 138-kV transmission line to their point of delivery. GVEA has seven generating facilities (a mix of oil, coal, wind and hydroelectric) with generating capacity of approximately 300 MWe. GVEA's 2014 peak load was 201.6 MWe; the system peak load of 223 MWe was set in December 2007. GVEA connects to utilities in the Anchorage and south central Alaska areas through the Alaska Intertie, which allows sharing of resources north and south and improves reliability. Adding the generating capacity of an SMR at Clear AFS would likely lead to the need for additional transmission capacity north and south. [82].

4.3.5.5. Utilities' SMR perspective. The resource plans of Tri-State, CSU, and GVEA do not currently include SMRs as an option. Each indicated interest in the possible purchase of power from an SMR, depending on price. Tri-State and CSU currently have adequate capacity and will not need additional generation capability for 10 to 15 years; GVEA does not forecast the need for additional capacity until 2040. As a distribution-only company, MVEA is not directly involved in energy resource planning and development [77, 78, and 80]. Other considerations:

- GVEA noted that any plant producing more than 100 MWe would be difficult to integrate into the system in Alaska. Alaska currently is not included in the CPP emission standards (along with Hawaii, Guam, and Puerto Rico) [43].
- CSU anticipates modest near term load growth (approximately 1%). Its investment policy requires 50% repayment of capital costs within four years, which deters investment in a capital-intensive technology [80].
- Tri-State noted the need for "policy certainty" regarding emissions and other issues before making decisions on the selection of energy technologies [83].
- A concern expressed by one utility that serves several DoD installations is that the Office of Management and Budget (OMB) might require that a PPA with an SMR be "scored" in its first year. Scoring would mean that the full cost of the power purchases over the 10 to 30 year life of the agreement would need to be budgeted as if paid in total in the first year, with the funds appropriated by Congress. If put into place, this practice would be a significant impediment to the development of SMRs and other clean energy sources for the purpose of serving DoD or other Federal facilities.

4.4. Aggregation of Demand

4.4.1. DoD Installation Energy Requirements. The US light water SMRs under development range in output from 50 MWe to 225 MWe. At 50 MWe, even the smallest SMR produces more energy than most DoD installations require. And, the power plant design for the 50 MWe SMR anticipates a scalable approach that houses up to 12 reactor modules producing a net total of 570 MWe. In its 2011 study, *Small Modular Reactors—Key to Future Nuclear Power Generation in the U.S.*, the University of Chicago Energy Policy Institute at Chicago observed that the size of SMRs may limit the number of federal facilities that could take advantage of an SMR's unique characteristics unless aggregation of several federal facilities' demand is considered [5], or energy from an SMR is also used for non-electric applications. DoDI 4170.11 encourages regional aggregation for *renewable* energy purchases to leverage DoD buying power and savings through economies of scale [40]. This approach could be broadened to include alternative sources of energy as well, including SMRs. Other studies also highlighted the need for additional users in addition to the DoD, given the output of current SMR technologies [29, 84]. This fact was underscored by several SMEs during the site visits and through the Team's review of energy requirements of selected additional DoD facilities. An approach that aggregates demand could involve supplying several of the DoD's military installations or a combination of military and other Federal facilities. For example, utilization of an SMR's capacity could be optimized if its customer base were expanded to include DoD, DOE, and other Federal facilities in the same region. This approach is illustrated in Section 5 using Schriever AFB and Clear AFS as examples, as well as additional possibilities for aggregated demand.

4.4.2. Funding for Aggregated Requirements. Taking advantage of SMR technology will require a mechanism to aggregate the needs of multiple DoD installations in a given region. The Federal government has contracting mechanisms that can achieve this aggregation.

4.4.2.1. GSA/FEMP Contracting. One potential mechanism is to have the GSA take the lead in establishing PPAs between the Federal customers and the SMR's owners. According to the GSA website, it can provide:

- Area wide contracts for the procurement of utilities and for the acquisition of value-added services such as utility financing of energy conservation projects
- Aggregate purchasing of natural gas and electricity in deregulated markets
- Energy usage and analysis data
- Advocacy in the public policy arena to include renewable power sources as part of the US energy portfolio
- Program advocacy on a national level with the OMB, Congress, and other Federal agencies.

The GSA Area Wide Contracts are an important potential contracting mechanism because they allow GSA to establish a single contract with a utility for all Federal facilities served by that utility. In another example of aggregation, under the Federal Energy Management Program (FEMP), the GSA issued a Request for Proposal (RFP) in June 2015 for the Capital Solar Challenge to provide as much as 3 MWe of solar energy to 18 Federal buildings in the Washington, DC area [85].

4.4.2.2. Energy Savings Performance Contract. Although focused on energy efficiency, the Coast Guard established an Energy Savings Performance Contract covering 12 sites in Florida. The contract eliminated the burden of establishing multiple stand-alone agreements. The Coast Guard found that a single contract helped accomplish the work sooner and more efficiently. It has implemented similar multi-site agreements in New York and Puerto Rico [86].

4.4.2.3. Multiple Award Task Order Contracts. In August 2012, the Army Corps of Engineers issued an RFP for up to $7 billion in Renewable and Alternative Energy Power Production for DoD Installations. The $7 billion is to be expended on PPAs of up to 30 years. It divided the energy resources into four categories--geothermal, solar, wind, and biomass. For solar, it subsequently used Multiple Award Task Order Contracts to "procure reliable, locally generated, renewable and alternative energy" from 22 companies [87].

4.4.2.4. Federal Power Marketing Agency Contracting. Another option is to have one of the Federal Power Marketing Agencies (PMA) contract for power from the SMR, then act as the distributor of that power to its Federal customers. There are four PMAs: Bonneville Power Administration in Portland, OR; Southeastern Power Administration in Elberton, GA; Southwestern Power Administration in Tulsa, OK; and Western Area Power Administration in Lakewood, CO. WAPA, for example, provides power to Schriever AFB and most of the DoD installations in Colorado, including Cheyenne Mountain Air Station, Fort Carson, Peterson AFB, and the US Air Force Academy. WAPA also provides power to: [88]

Beale AFB, CA	Hill AFB, UT	Naval Air Station Lemoore, CA
Cannon AFB, NM	Holloman AFB, NM	Nellis AFB, NV
Edwards AFB, CA	Kirtland AFB, NM	Tooele Army Depot, UT
FE Warren AFB, WY	March AFB, CA	Travis AFB, CA
Ellsworth AFB, SD	Marine Corps Air Station AZ	Yuma Proving Grounds, AZ

Locating an SMR on an installation such as Schriever AFB, and aggregating the requirements of many of the other local or regional DoD bases through a PPA with WAPA could fully utilize the output of the SMR. Further, it would ensure the DoD installations meet, and even exceed, the goals for clean energy in EO 13693.

4.5. DoD Benefits from Non-Electric SMR Applications

4.5.1. Additional SMR capabilities. Energy produced by an SMR has the potential to provide the DoD installations and the surrounding communities with more than electricity. Studies by Idaho National Laboratory (INL) and other research institutions, and SMR technology developers, have identified a number of possibilities. The studies note that the smaller output, and ability to install multiple reactors modules on site or within a facility, allows flexibility in how the energy output from a reactor is used, along with the potential for enhanced reliability. A portion of the thermal energy from a single reactor can be used to support a non-electric application, or a reactor can be dedicated entirely to that application. Major applications are outlined in the following paragraphs.

4.5.2. District Heating. Thermal energy from nuclear power plants is already used for district heating in eight European nations, and in Russia. The Team learned that a continuous supply of thermal energy is of critical importance to sustaining the missions at the DoD installations in

Alaska, which can experience outside temperatures as low as -40 F. Steam produced by an SMR could provide heat for a DoD installation, and the community. Research by INL indicates that thermal energy from an SMR can be transported a distance of as much as 60 miles for district heating purposes [74].

4.5.3. Desalinated Water. Nuclear power plants already support desalination in 15 locations. India, Kazakhstan, and Japan all have used nuclear power plants to support desalination efforts. Of the three processes in use today, the two distillation processes (Multi-stage Flash and Multi-Effect Distillation [MED]) require a thermal energy source as well as electricity. One 160 MWt SMR dedicated to MED can produce 88,000 cubic meters per day of clean water [89].

4.5.4. Liquid Fuels. The Fischer-Tropsch process for converting coal into liquid fuels has been in use for decades. The light water SMRs under development in the U.S. produce super-heated steam at a temperature range of 300 degrees C to 320 degrees C. This is sufficient to support a High Temperature Fischer Tropsch process to convert coal to liquid fuels for transportation purposes. A study by INL estimates that feedstock of 12,000 tons per day (tpd) of coal, plus 290 million standard cubic feet of natural gas, can be turned into 58,000 barrels per day of gasoline and 9,000 barrels per day of Liquefied Petroleum Gas [90]. Transportation fuels are one of DoD's largest energy expenses. The ability to use clean energy from an SMR to produce both electricity and transportation fuels offers tremendous value to DoD.

4.5.5. Hydrogen and Oxygen. The U.S. currently uses more than 12 million tons of hydrogen each year for fertilizer production, refining, and the food industry, according to an analysis by INL and NuScale [91]. Using the emerging technology of High Temperature Steam Electrolysis, a single 160 MWt NuScale module could produce 2,900 lb/hr of hydrogen and 23,000 lb/hr of oxygen, according to the research. A production plant with six NuScale modules would produce hydrogen sufficient to supply a commercial ammonia plant producing 1,150 tpd, or a petroleum refinery of 40,000 to 50,000 barrels per day.

4.6. Public Perception of Nuclear Energy

4.6.1. Site Visit Observations. During the site visits, the Team conducted an informal assessment of the historical acceptance of nuclear power by the use case installations' local populace. The Team gleaned inputs from installation points of contact and the local utilities, and by reviewing documents available through the internet and local media. Individual and documentary inputs relating to SMR siting generally focus on economics (e.g., costs for SMR licensing, infrastructure) and potential impacts of SMR operations (water limitations, used nuclear fuel management) rather than specific concerns over SMR nuclear technology. From an AFSPC context, Team members observed that the units' focus on mission accomplishment, the technical foundation of AFSPC operations, and support for leadership decisions that are based on mission execution and sound logic, suggest a favorable setting for the introduction of nuclear power for energy security [64, 66].

4.6.2. University of Oklahoma/SNL Survey. The Center for Energy, Security and Society (CES&S), a joint research center of the University of Oklahoma and Sandia, has fielded an annual *Energy and Environment Survey* since 2006 to measure Americans' views on various aspects of nuclear energy. The survey series has focused on a range of nuclear energy issues over time, but more recently the surveys were designed to facilitate understanding of public beliefs and perceptions on issues that include new or increased nuclear power generation. The 2015 iteration of the survey (EE15) was implemented using a web-based questionnaire. It was completed by 2021 respondents from the contiguous 48 states (32 respondents from Colorado) using an Internet sample that matches the characteristics of the adult US population, as estimated in the US Census [92].

4.6.3. Commercial SMRs are relatively new and the American public's perceptions about and support for SMRs have not been systematically studied. In EE15, the CES&S conducted a national study that included questions designed to better understand how members of the US public think about the risks and benefits associated with SMRs. The approach used in the study was to: 1) familiarize a national sample of survey respondents with the concept of SMRs, 2) provide them the necessary background knowledge (in the form of arguments made by both proponents and opponents) that would allow them to assess the costs and benefits of this new nuclear energy technology, and then 3) evaluate respondents' opinions about the safety of SMRs and evaluate their relative utility as compared to traditional nuclear power plants. The results from this study will provide a necessary baseline for the level of public support for SMRs and the perceived risks and benefits associated with these small reactors. The CES&S study was fielded in June 2015 and the analysis of its results is ongoing. Based on a preliminary review of the results, the responses indicate that SMRs are seen as safer and more desirable than are traditional nuclear reactors, either at existing or new sites. The greatest public support was for the use of SMRs at military bases. For example:

- 81% of the respondents believe SMRs are as safe or safer than traditional nuclear reactors
- 47% of the respondents supported the construction and use of SMRs to generate electricity in the US (22% opposed and 32% neither in favor nor opposed)
- On a scale of one to seven--with four denoting neutrality (neither in favor nor opposed), a value less than four denoting an unfavorable view, and value greater than four denoting a favorable view--the mean response for construction of nuclear reactors at new locations was 3.64, and 3.91 at existing locations. The mean for SMR construction was 4.37, and for SMR construction on military bases the mean response was 4.51
- 17% of the respondents were strongly opposed to construction of nuclear reactors at new locations; 5% were strongly opposed to construction of SMRs on military installations

5.0 DOD DEPLOYMENT STRATEGIES

Based on the information gained during the study, the Team developed several hypothetical strategies and scenarios as potential approaches to the deployment of an SMR deployment on a DoD installation. The scenarios described below are for discussion purposes and are not specific recommendations.

5.1. Key Considerations and Their Implications

- Under DoD policy, the cost of the power it purchases under a PPA must be equal to or less than the price of power purchased on the market. A change in Federal policy would be required to allow the Government to purchase power at above market rates. The value of clean power from an SMR needs to be quantified in order for the OMB to determine that the benefit exceeds the cost and agree with these types of policy changes.
- The LCOE from an SMR is lowest when it is owned by a publicly-owned utility because the utility is exempt from Federal and state taxes, and is able to finance the project with low-cost, tax-exempt debt. In the contiguous 48 states, it is unlikely that the LCOE of power from an SMR can compete with the price of power from other resources, such as natural gas, unless the SMR is owned by a public utility or a Federal agency.
- The LCOE of power from an SMR in Alaska would be about one-half the current cost of power in the state. The same is true on Hawaii and on Guam. Those markets also have large DoD operations.
- The duration of a PPA and whom it is with is important to the owner of an SMR and its creditors. The longer the duration--for example, 30 years as allowed by DoD policy--the better. PPAs with DOE and other Federal entities; however, are limited to 10 years. PPAs with Federal entities are seen as being backed by the full faith and credit of the Government, and are viewed favorably by investors.
- Thermal energy also is important for DoD installations. In locations such as Alaska it is critical to their survival. An SMR can provide thermal energy at little incremental cost, both during normal operations and through the use of its residual heat when shut down.
- The ability to divert power or process heat from an SMR to a desalination facility may be important to island locales such as Hawaii or Guam.
- The capacity of near-term, light water SMRs is greater than the needs of any single DoD installation. The energy needs of multiple installations must be aggregated if an SMR is deployed specifically to serve DoD installations.
- The Federal government has mechanisms to aggregate the needs of multiple Federal facilities. These include the use of Area Wide Contracts arranged with utilities by the GSA, and bulk purchases of power by the Federal PMAs.
- The configuration of the electrical distribution system, backup generation and UPS on some DoD installations essentially creates its own microgrid. Deploying an SMR on a DoD installation can further strengthen the microgrid, and offers the opportunity to extend it to the neighboring community.

- Potential synergies between an SMR and a DoD installation range from physical security to shared services to enhanced energy reliability. Deploying an SMR on a DoD installation would also provide economic benefits to the local community.
- The potential for synergies between an SMR operator and a DoD installation is greatest when the SMR is sited on the installation. The potential for synergies decreases when the SMR is not on the installation, even if it is immediately adjacent to the installation's operations.

5.2. Scenario 1: SMR Sited on Schriever AFB to Serve Regional DoD/Federal Facilities

5.2.1. Schriever-based Aggregation. Schriever's current energy requirements are 10.7 MWe and 19,651 MBTU thermal--well below an SMR's capability. Aggregation of the energy requirements for Schriever and other DoD/Federal facilities in the region would capitalize on an SMR's full capacity. The aggregated requirements for the Colorado Springs area DoD installations (see Table 7 and Figure 9) are approximately 83 MWe. To be economical, this would require either a revised SMR design (e.g., a two module NuScale plant at a higher cost per kwh) or a tie-in to the commercial grid. Adding Buckley AFB, 63 miles north in the Denver area, would increase the aggregated power requirement to 101 MWe [93, 94, and 95]. Inclusion of other DoD facilities in the area significantly increases the energy requirement and helps close the gap for the full capacity of current SMR technologies. In all likelihood there would still be a need for a tie-in to the commercial market.

Table 7. DoD Installations near Schriever AFB

Installation	Location	MWe	Acres
Schriever AFB	16 miles E of Colorado Springs	11	3,840
Peterson AFB	Colorado Springs	16	1,392
USAF Academy	Colorado Springs	16	18,000
Cheyenne Mtn AFS	Colorado Springs	3	587
Fort Carson	Colorado Springs Range: Pinon Canyon	37	137,000 Range: 236,000
Buckley AFB	63 miles N of Colorado Springs	18	3,897
	Total	101	400,716

Figure 9. DoD Installations in Colorado

5.2.2. Key elements of this approach:

- SMR is sited on Schriever AFB.
- Land is acquired through a 50 year EUL or Direct Land Lease.
- Schriever is compensated for the value of the land through a reduction in its cost of power.
- SMR is owned by multiple public and investor-owned

utilities.

- GSA establishes Area-Wide Contracts with the utility owners that facilitate PPAs with their DoD and other Federal customers.
- Each utility's ownership share is equal to the Federal load they will serve under the PPAs, unless the utility desires a larger ownership share to provide power to its non-Federal customers.
- DOE provides loan guarantees to lower the cost of capital for the SMR.
- The SMR is operated under contract by an experienced nuclear operating utility, which may or may not be an owner of the project.
- The SMR operator and the host DoD installation achieve synergies through a Services Agreement included in the EUL, or as part of separate contract.
- The SMR uses dry heat rejection technology for cooling to address the limited availability of water at Schriever AFB.

5.2.3. ORNL Studies. In a 2014 study, ORNL used OR-SAGE to analyze federal "energy clusters" in three regions of the US for placement of SMRs to achieve clean energy goals. The criteria used were based on previously developed screening criteria rather than the SSECs used for the SMR Suitability study, which included SMR-specific refinements for the emergency planning zone, stream flow, and ground acceleration. ORNL defined "Federal agencies" as military and other agencies (Homeland Security, DOE, Federal Bureau of Investigation, Social Security Administration, etc.) with missions of critical national importance. In its assessment of the Denver-Colorado Springs cluster, ORNL included OR-SAGE data on Fort Carson as well as three regional power plants and concluded the aggregated demand was in excess of 230 MWe. This study supplements a 2013 ORNL study which also focused on Fort Carson as part of a review of candidate DoD and DOE installations for SMR deployment. The data from both of these studies could be used to inform the demand aggregation scenario outlined here [52, 96].

5.3. Scenario 2: SMR Sited on Clear AFS to Serve Regional DoD Facilities and Utility Load in Alaska

5.3.1. Clear-based Aggregation. The addition of LRDR to Clear AFS will increase the electrical demand to 28 MWe and 76,386 MBTU thermal--again, less than an SMR's projected output. The DoD installations in the Fairbanks, AK area (Clear AFS, Eielson AFB, Fort Wainwright, and Fort Greely) have a total requirement of approximately 72 MWe (see Table 8 and Figure 10) [82, 97, 98, 99]. Fort Wainwright and Eielson AFB have their own coal-fired CHPPs which meet all power and heat needs of those installations. Fort Greely has a kerosene-based jet fuel-fired CHPP. Fort Greely's CHPP boilers provide daily heat to the installation and the generators are backups to GVEA commercial power [97]. As with Schriever AFB, inclusion of other DoD facilities in the area significantly increases the energy requirement, helping to close the gap for the capacity of current SMR technologies. In all likelihood there would still be a need for a tie-in to the commercial market.

Table 8. DoD Installations near Clear AFS

Installation	Location	MWe	Acres
Clear AFS	77 miles SW of Fairbanks	28*	11,438
Fort Greely	80 miles SE of Fairbanks	7	7,200
Eielson AFB	20 miles SE of Fairbanks	19	63,195
Fort Wainwright	Fairbanks	20	1 million+
Total		72	1,081,833+
* Includes future estimated load of 22MWe for LRDR			

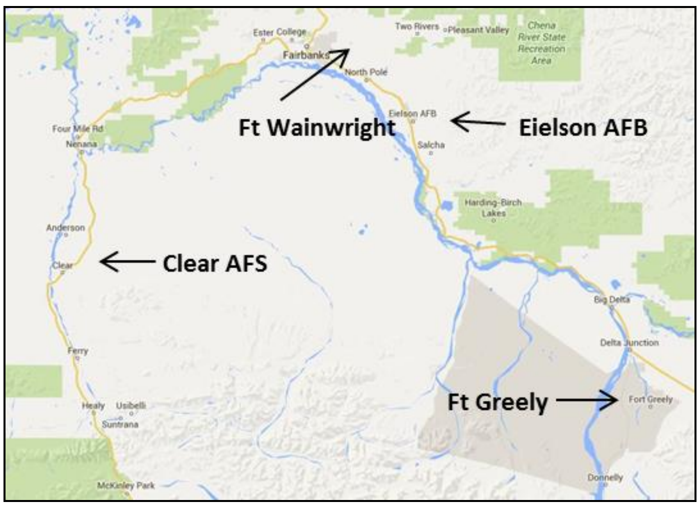

Figure 10. DoD Installations in the Fairbanks area

5.3.2. Key elements of this approach:

- SMR is sited on Clear AFS.
- Land is acquired through 50 year an EUL or Direct Land Lease.
- Clear AFS is compensated for land through a reduction in its cost of power.
- SMR is owned by GVEA, an electric cooperative.
- Other Alaska Railbelt utilities have the opportunity to purchase ownership shares in the SMR in order to lower costs for their customers.
- GVEA establishes PPAs with the DoD installations in its service territory.
- Other Alaska Railbelt utilities that take ownership shares in the SMR establish PPAs with their DoD customers.
- DOE provides loan guarantees to lower the cost of capital for the SMR.
- SMR is operated under contract by an experienced nuclear operating utility.
- The SMR operator and the host DoD installation achieve synergies through a Services Agreement included in the EUL or as part of separate contract.

5.4. Scenario 2b: SMR Sited on a DoD Installation Near Fairbanks, AK

5.4.1. Key elements of this approach:

- SMR is sited on Fort Wainwright or Eielson AFB, which are closer to Fairbanks than Clear AFS
- SMR provides thermal energy to the host installation, customers in Fairbanks, and other DoD installations in proximity to its location
- Structure similar to Clear AFS scenario

5.4.2. University of Alaska study. In a 2011 study, the University of Alaska Fairbanks partnered with the University of Alaska Anchorage to explore the viability of SMRs in meeting Alaska's energy needs in the near to intermediate future. The study noted the challenge associated with supplying isolated Alaskan communities with reliable, affordable energy, especially since 48% of the existing generating infrastructure would reach the end of its design life within 15 years. The study noted the possibility of using SMRs to provide electric and thermal energy for rural communities, the Alaska Railbelt, and other potential applications which could include military bases, remote mining operations, and other industrial users. Of interest for Scenario 2b is the study's discussion on the use of an SMR to meet aggregated energy demands, e.g., a Fairbanks-Eielson AFB approach to supply district heating to Eielson and power to the Fairbanks market, with a potential SMR deployment at Eielson AFB [100].

5.4.3. Off-shore installations. A variation to this approach could consider the deployment of an SMR on off-shore, isolated DoD installations in a US Territory such as Anderson AFB, Guam, or isolated DoD installations in non-US territories such as Thule Air Base, Greenland.

5.5. Scenario 3: Aggregation of DoD Demand Through a Federal Power Marketing Agency

Key elements of this approach:

- SMR is sited on Schriever AFB, or another DoD installation within the territory served by WAPA
- Land is acquired through a 50 year EUL or Direct Land Lease
- DoD installation is compensated for land through a reduction in its cost of power
- SMR is owned by a publicly-owned utility or the Federal government, e.g., Tri-State Generation & Transmission, or DOE
- Owner establishes a long-term PPA with WAPA
- WAPA establishes long-term PPAs with its current DoD customers, or melds the power from the SMR into the power it receives from other generating projects (see para 4.4.2.4.)
- DOE provides loan guarantees to lower the cost of capital for the SMR
- SMR is operated under contract by an experienced nuclear operating utility
- This scenario could apply to other regions with Federal PMAs and large clusters of DoD and Federal installations, such as New Mexico with White Sands Missile Range, Kirtland AFB, SNL, Los Alamos National Laboratory, Waste Isolation Power Plant, Holloman AFB, and Cannon AFB.

5.6. Scenario 4: Aggregation of DoD and Federal Demand Through the Tennessee Valley Authority (TVA)

5.6.1. The TVA is a stand-alone Federal agency reporting to the President. It has seven operating nuclear power plants, provides power to 155 local power companies that serve some nine million retail customers in seven states, and directly serves several DoD and DOE facilities in four states. TVA currently intends to file a generic Early Site Permit (ESP) in 2016 as a first step in potentially siting an SMR using one of the four technologies at the Clinch River site in east Tennessee. In this scenario, the ESP provides the starting point for siting an SMR at Clinch River. TVA would build, own, and operate the SMR, and finance it using its access to low-cost debt. It would establish specific PPAs with its DoD and DOE direct-served customers that allow them to take credit for the clean power. The Clinch River site is in proximity to the ORNL, which houses a number of operations that are critical to national security and defense. TVA could enhance energy security for ORNL by establishing a secure microgrid between the SMR and ORNL's operations.

5.6.2. Key elements of this approach:

- SMR is sited at the Clinch River site in Tennessee using the planned Early Site Permit as a first step
- TVA builds, owns, and operates the SMR
- TVA finances the project using its access to low-cost debt
- TVA establishes PPAs with its DoD and DOE direct-served customers (Table 9)

Table 9. TVA Direct-Served Federal Customers

DOE Facilities
USEC, Incorporated/Centrus Corporation
Oak Ridge National Laboratory
DoD Installations
Columbus AFB, MS
Fort Campbell, KY
Navy Support Activity, Mid-South, TN
Arnold AFB, TN
Redstone Arsenal, Huntsville, AL (includes multiple Army commands, MDA, NASA Marshall Space Flight Center)

5.6.2. The 2014 ORNL study highlights the East Tennessee/ORNL area as one of the top Federal energy clusters, with an energy demand of 234.3 MWe.

5.7. Scenario 5: Multiple Applications of SMR Energy

Beyond electricity and heat, the energy produced by an SMR can support other applications to help DoD meet its energy requirements, and to generate revenue. An SMR sited at a DoD installation in a coal producing region, or in proximity to one, can provide the electricity and steam to support a Fischer-Tropsch process to convert coal into transportation fuels. Similarly, electricity and thermal energy from the SMR can support any of the desalination processes to produce clean water for the DoD installation and nearby communities. Further, the SMR can be used to support the production of commodities such as hydrogen, oxygen and fertilizers with market values to offset the cost of energy production.

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6.0 RECOMMENDATIONS

6.1. Essential activities.

Several factors have set the stage for DoD and DOE to pursue the deployment of SMRs to provide DoD and other Federal agencies with clean, secure energy. A collaboration between the two agencies that accelerates the commercialization of SMRs in the U.S. not only will help the nation achieve its goals for carbon-free energy production, it will provide the U.S. with a technology offering that is of global strategic importance. Among the factors that have set the stage for a collaborative effort: the MOU between DOE and DoD provides a framework for cooperation to enhance national energy security; Congress previously called on the DoD to assess the viability of nuclear power plants as a secure, clean energy source; numerous studies highlighted the potential of SMRs to help DoD meet its energy needs; the 2013 Climate Action Plan seeks to "move our economy toward American-made clean energy sources", Executive Order 13693 and the Clean Power Plan both present an opportunity for SMRs to play a major role in providing carbon-free energy, and public perception appears receptive to siting SMRs on DoD installations. The following recommendations outline actions that DoD and DOE can pursue to support and accelerate the introduction of SMRs into the US energy landscape.

6.2. Clarify and align policies and guidance across Federal agencies

Policies and guidelines relating to the use of clean energy resources are not consistent or aligned within and across Federal agencies. As the largest Federal user of energy in all forms, DoD is affected by Federal policies and guidelines more than any other agency. In some cases these policies and guidelines limit DoD's latitude in seeking innovative approaches to meeting its energy needs through the use of new technologies, such as SMRs. DOE can take the lead to ensure that policies are consistent across the Federal government. Further, it can help to ensure that policies and guidelines are structured to facilitate the use of SMRs and other clean energy technologies. Active DoD advocacy and involvement in supporting DOE will increase the likelihood of success.

6.2.1. DoD policies. DoD can remove uncertainties by clarifying its policies regarding the duration of PPAs and the interim storage of used nuclear fuel. Although DoD has the ability to establish PPAs of up to 30 years, it is unclear whether it is able to consistently execute agreements of this duration. DoD directives should be updated to address SMR-related actions.

6.2.2. Federal energy contracting. DOE can take the lead in ensuring that policies related to energy purchases are aligned and consistent across all Federal agencies. DOE, for example, currently is limited to PPAs of no more than 10 years. Longer term PPAs are viewed by investors as having less risk and facilitate lower cost financing for power projects.

6.2.3. Value SMR clean energy and energy reliability. The clean energy and enhanced reliability that an SMR offers DoD installations have value. DOE and DoD should take steps to quantify that value and include that value in the price of energy from SMRs.

6.2.4. Provide support to state-level initiatives regarding SMRs. DOE can provide technical expertise, and perhaps financial assistance, to states that are evaluating the potential of SMRs to meet the energy needs of their citizens. DOE has tools (e.g., OR-SAGE) and SMEs to help states navigate the complexities of commercial nuclear power projects.

6.3. Enable the SMR's Role in the U.S. Energy Future

6.3.1. EO 13693 and the CPP. The issuances of EO 13693 and the CPP in 2015 open the door for nuclear power and SMRs to make a major contribution to the nation's ability to pursue carbon-free energy resources. DOE should clearly define and quantify the role SMRs can play as an "alternative energy" resource available to DoD and Federal agencies to meet the goals established in the EO. As the states develop their plans to comply with the CPP, DOE can articulate the potential for the use of SMRs and provide guidance on their deployment. Further, DOE can help to ensure that energy from SMRs receives the same treatment for Clean Energy Credits as other carbon-free energy resources.

6.3.1. SMR deployment strategy. DOE can establish a formal strategy for the use of SMRs to assist both Federal agencies and the states in achieving their EO and CPP goals.

6.3.2. Extend incentives to level the playing field. DOE should **e**ncourage Congress to offer the same incentives to new nuclear plants, including SMRs, which are currently available to renewable energy resources. These incentives include production and income tax credits, loan guarantees, accelerated depreciation and the ability to use and sell Renewable (or Clean) Energy Credits.

6.3.3. DoD energy planning. Each of the DoD services develops and periodically updates an energy resource plan, and DoD produces an annual energy management plan. DOE can support DoD in the analysis of SMRs and their inclusion in DoD energy planning.

6.4. Accelerate SMR Licensing and Commercialization

DOE should continue and expand its current efforts to support the licensing and commercialization of U.S. SMR technologies. These efforts can include:

- Receiving budget authority to extend cost-sharing to FOAK costs, including detailed design and engineering, ESP and COL applications, for the first SMRs.
- Continue to support analysis and research to facilitate NRC consideration of regulatory treatments for SMRs that reflect their unique characteristics and benefits. The current effort to address regulations and guidance for emergency preparedness for SMRs is an example.
- Consider expanding the SMR program to include DOE cost-sharing of the capital costs to construct the first SMRs. The first iteration of any new technology, whether a submarine or an SMR, comes with a premium that is later offset as experience is gained and the technology moves from FOAK to Nth of a kind. DOE cost sharing of the capital cost for the first projects can offset the FOAK premium.
- Task Federal PMAs to investigate using PPAs with SMRs to aggregate the demand of DoD and other Federal installations.
- Monitor and affect policies that might impede the use of nuclear and other clean energy resources, such as potential OMB scoring of PPAs.

- Continue to support advanced reactor development which may provide increased flexibility in meeting DoD's desired energy capabilities (e.g., less MWe output). The associated timeframe is beyond the scope of this study (~2030).

6.5. Delve deeper into SMR siting and licensing in support of DoD installations

In the near term, DoD and DOE should initiate a cooperative effort to determine the way ahead for SMRs in the DoD energy portfolio.

6.5.1. Test case. As a test case, DOE can establish a framework for deploying an SMR to serve a DoD installation. This would include evaluating potential locations using OR-SAGE criteria, and previously identified Federal clusters (e.g., in Colorado and New Mexico), as well as high cost markets (e.g., Alaska, Hawaii, Guam). This framework should consider installation missions and operating characteristics, SMR technology maturity, capabilities of the local utilities, and impact on installation and local communities. Development of a DoD test case would be consistent with the recommendations in several SMR studies.

6.5.2. Preliminary development of formal licensing applications and DoD agreements. By supporting steps to prepare an application to the NRC (ESP or COL), as well as PPAs, land lease and services agreements with DoD, DOE can help identify potential issues and resolve them. These documents can later serve as templates or the "reference" documents for full-scale licensing with the NRC and formal agreements with DoD. At various points, this process needs to involve DoD, DOE, the SMR vendors, potential owners and operators, and engineering, procurement, construction contractors.

6.6. Engage and Inform Stakeholders.

Proactive engagement and communication are essential to ensuring that the principal stakeholders understand SMR characteristics and capabilities and to gain the stakeholders' support. A deliberate, integrated approach by DOE to communicate with key stakeholders can foster understanding and obtain buy-in, feedback, advocacy, and ultimately, support for a decision on the use of SMRs to provide energy to DoD installations. The findings and recommendations from the SMR Suitability study can help enable this effort.

6.6.1. DoD Stakeholders. The SMR Suitability study includes information and insights from AFSPC personnel and SMEs throughout the AF. Formal communication of the study's findings with HQ AF, DoD, or the other Services, however, still is needed. Key DoD organizations with direct impact on energy decisions should be involved to identify their issues and priorities, and provide their feedback. Examples include the Undersecretary of Defense for Acquisition, Technology and Logistics; the Undersecretary of Defense for Installations and Environment; and the Service equivalents.

6.6.2. Federal Stakeholders. Several Federal entities significantly impact energy policy decisions. Congress has considerable interest in energy issues; therefore, contact with key congressional committees would be invaluable. In addition, contact with the U.S. Congressional staffs of selected states (e.g., Colorado and Alaska) would provide valuable inputs. The White

House Office of Science and Technology Policy, the Defense Science Board, the NRC, and the OMB would also provide meaningful insights.

6.6.3. Nuclear Community Stakeholders. Numerous organizations play major roles in influencing energy policy and are invaluable to the progress of national energy initiatives. For example, the Nuclear Energy Institute, the Nuclear Infrastructure Council, and the Center for Strategic and International Studies, as well as select utilities and academia can contribute significantly to the discussion on SMR deployment.

6.6.4. DOE-DoD Forum. In the near term, DoD and DOE should convene a forum to determine the way ahead for SMRs as part of the DoD energy portfolio. The forum should include representatives from key Federal departments and agencies (e.g., PMAs, TVA), the military services, SMR vendors, utilities, and select state agencies to determine if SMRs are a viable option for the DoD's energy needs. The scenarios outlined in this study can facilitate this discussion. Results of the forum would form the basis for a leadership decision on an SMR deployment test case, the associated timeline, and viable funding mechanisms. An implementation decision could be assigned to a dedicated task force under a lead command in one of the military services. Progress of this initiative would be tracked by a senior-level executive committee, similar to the body called for in the DOE-DoD MOU.

6.7. Explore Broader SMR Applications

6.7.1. Non-electric applications. The viability and feasibility of using thermal and electric energy from an SMR to support non-electric applications needs further evaluation. This includes technology readiness, an assessment of commercial risk, and quantification of the value of the non-electric application and its effect on project economics.

6.7.2. Opportunities. In addition to district heating, the use of SMR energy for desalination, liquid fuel conversion, and production of hydrogen and oxygen can greatly benefit DoD installations and their surrounding communities.

7.0 CONCLUSION

7.1. Summary.

The SMR Suitability study identified a number of benefits that DoD can receive from the use of SMR technologies to serve its installations. It also identified some challenges, although none are insurmountable. Importantly, it also found that some of the long-discussed potential synergies between DoD installation capabilities and SMR operating requirements are achievable.

7.1.1. Benefits. Based on the case studies of Schriever AFB and Clear AFS, the use of SMR technology can provide DoD installations with a number of benefits:

- Clean, carbon-free power to meet national goals and DoD specific goals
- A highly reliable supply of power, especially when the SMR is designed with the capability to produce less than its full capacity in certain situations, as well as the ability to operate in island mode and to achieve black start
- In high cost markets, such as Alaska, a long term power supply at a price that is substantially less than current electric rates
- Thermal energy for installation operations at little to no incremental cost
- Reduction or elimination of vulnerabilities including single point of failure and energy supply line disruption
- Economic and quality of life benefits to the surrounding communities and for the DoD personnel who live there

7.1.2. Challenges. Achieving these benefits comes with a set of challenges. Each has a solution.

- The output of the current light water SMR designs exceeds the needs of almost all individual DoD installations.
- Current Federal energy policy encourages the use of SMRs to meet clean energy goals but does not provide SMRs with the same incentives that are available to other sources of clean energy.
- SMRs face FOAK costs that adversely affect their levelized cost of energy.

7.1.3. Synergies. The study also identified significant potential synergies that are achievable if there is close cooperation and careful planning between the host DoD installation and the SMR owner/operator.

- Physical security: DAF personnel may be contracted to provide physical security to an SMR. Even if security is separated, DAF and SMR security personnel can strengthen each other’s capabilities through integrated training and threat response.
- Emergency preparedness and response: By combining capabilities, a DoD installation and an SMR will have greater ability to plan for and respond to emergencies.
- Backup power supply: DoD installations and SMRs both install and maintain backup power supplies. It’s conceivable that each could support the other to further strengthen reliability.
- Data availability to support SMR licensing: Schriever AFB and Clear AFS both have environmental data that could be used to support the licensing of an SMR.

MDA is compiling extensive geo-technical data for the design and construction of the LRDR at Clear AFS, which would further facilitate SMR design and licensing. Similar opportunities likely exist at other DoD installations.

- Shared facilities: From warehousing to training, a DoD installation and an SMR can share facilities to make better use of infrastructure and lower costs. For example, Clear AFS will build a man-camp capable of housing 300 workers to support the construction of the LRDR, which will be operational in 2020. This facility could subsequently be used to support the construction of an SMR.
- Training: A DoD and an SMR could integrate aspects of their non-operational training.
- Services: From child care to gymnasiums to medical clinics, a DoD installation and an SMR could integrate the provision of services to the benefit of all personnel.

7.2. Potential Solutions.

The challenges identified during the study have one or more potential solutions, applicable specifically to the use case installations, but with the potential for broader DoD applications.

7.2.1. Aggregation of the energy requirements of multiple DoD installations can ensure the output of an SMR is fully utilized. This aggregation can extend to other DoD and Federal installations. The Federal government has contracting mechanisms that can facilitate aggregation. Selection of an appropriate region would require careful study. Military service policies, funding, contracts, PPAs, EULs, and support agreements would require detailed orchestration to ensure the needs of each participant are satisfied.

7.2.2. Incentives. Alignment and consistency among the incentives for renewable and clean energy resources can further the cost competitiveness of energy from an SMR.

7.2.3. Loan guarantees. The use of lower cost financing through loan guarantees or public financing also can lower the cost of power.

7.2.4. Cost sharing of the FOAK costs can lower the capital costs of the first SMRs and advance the commercialization of SMR technologies.

7.3. The Way Ahead.

The SMR Suitability study identifies and addresses many of the uncertainties about the feasibility and merits of using SMRs to serve DoD installations. DOE and DoD can further ensure the success of US SMR technologies by delving deeper into the siting and licensing of SMRs through test cases at one or more DoD installations. Financial support for the first SMRs deployed at DoD installations, and the establishment of mutually- beneficial commercial agreements can further support this effort.

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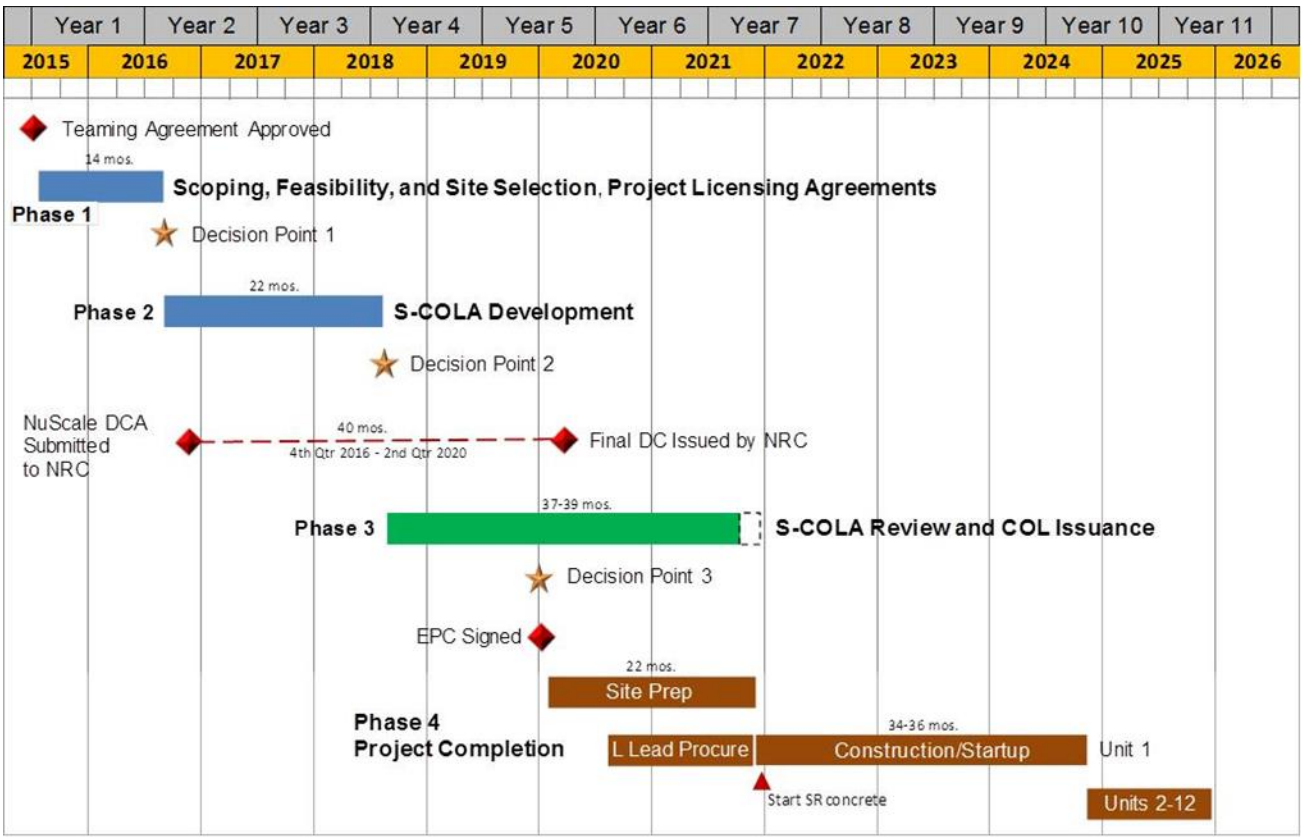
APPENDIX A: REPRESENTATIVE SMR DEPLOYMENT TIMELINE

Source: NuScale Power response to the SMR Technology Vendors Questionnaire, May 20, 2015



APPENDIX B: PRIORITIZED SPACE MISSIONS

Prioritized Space Superiority Activities (U)

1. Nuclear Survivable Communications
2. Launch Detection / Missile Warning
3. Position, Navigation and Timing (PNT)
4. Space Situational Awareness & Battlespace Awareness
5. Assured Space Access / Spacelift
6. Space Command and Control
7. Defensive Space Control
8. Satellite Operations
9. Protected, Tactical Communications
10. Offensive Space Control
11. Unprotected Communications
12. Space to Surface ISR
13. Terrestrial Environmental Monitoring
14. Nuclear Detonation Detection

APPENDIX C: SMR-SPECIFIC SITE EVALUATION CRITERIA

The Team worked with ORNL to establish values specific to the Site Selection Evaluation Criteria (SSEC) used in the OR-SAGE model.

- Power plant site ≥ 50 acres
- Population density < 500 people within 2 miles of site boundary (per DOE: 2 mile limit, based on projected SMR characteristics)
- Wetlands and open water are excluded
- Protected lands (e.g., national parks, historic areas, wildlife refuges) are excluded
- Land with moderate or high landslide hazard susceptibility is avoided
- Land within a 100 year floodplain is excluded
- Land with a slope > 18% (~10°) is avoided
- Land areas > 15 miles from sufficient cooling water makeup sources are excluded:
    - Upper threshold – stream flow of at least 84,000 GPM, makeup water of at least 8,400 GPM (12M GPD) based on a 600 MWe modular NuScale installation
    - Lower threshold – stream flow of at least 20,000 GPM, makeup water of at least 2,000 GPM (2.9M GPD) based on a 160 MWe modular Holtec 160 installation
    - An additional 64,000 GPM threshold for stream flow was included based on an assumption of lower water requirements for SMRs
- Land too close to fault lines is avoided (length of the fault line determines standoff distance)
- Land in proximity to hazardous facilities (within 5 miles of commercial airports and 1 mile of oil refineries) is avoided
- Land with safe-shutdown earthquake peak ground acceleration (2% chance in a 50 year return period) greater than 0.5 g is excluded. (included range from 0.25g to 0.5g, based on projected SMR characteristics)

APPENDIX D: SCHRIEVER AFB OR-SAGE RESULTS

Screening Criteria Summary Bar

(Colored Boxes indicate Screening Results)

No Siting Issue	Partial Siting Issue	Full Siting Issue

Inside Base	Pop Density	Wetlands	Protected Lands	Landslide	100-yr Flood-plain	Slope	Hazardous Facilities	Fault Lines

Inside Base	Streamflow (84K GPM)	Streamflow (20K GPM)	SSE (0.5g)	SSE (0.25g)	Ocean Cooling

Screening Criteria Table

Criteria	Value
Population Density within 2 miles	> 500 (people/square mile)
Wetlands and Open water are excluded	—
Protected lands are excluded	—
Land with moderate/high landslide hazard susceptibility are excluded	—
Land that lies within a 100-year floodplain is excluded	—
Slope	> 18% (~ 10^0)
Land located in proximity to hazardous facilities (Airport - 10mi; Oil Refineries - 1mi)	—
Land too close to identified fault lines is avoided	—
Streamflow within 15 miles	≥ 84,000 gpm (and ≥ 20,000 gpm)
Safe-shutdown earthquake peak ground acceleration	≥ 0.5g (and ≥ 0.25g)
Ocean Cooling within 20 miles	—

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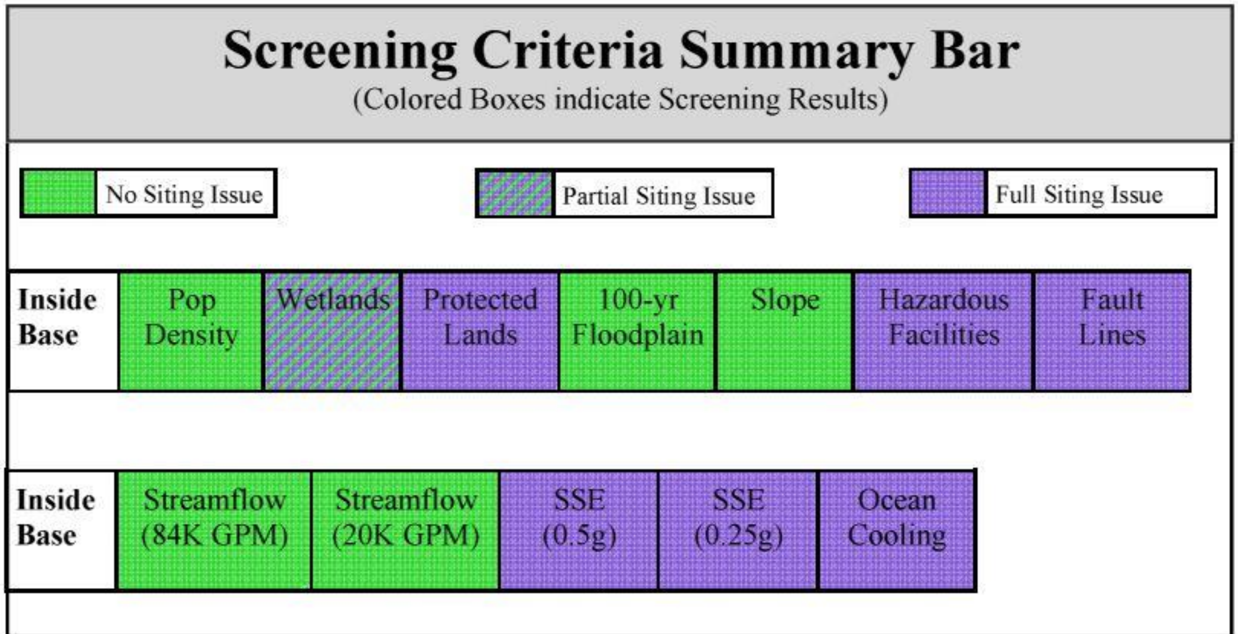
APPENDIX E: CLEAR AFS OR-SAGE RESULTS



Screening Criteria Table

Criteria	Value
Population Density within 2 miles	> 500 (people/square mile)
Wetlands and Open water are excluded	—
Protected lands are excluded	—
Land with moderate/high landslide hazard susceptibility are excluded	—
Land that lies within a 100-year floodplain is excluded	—
Slope	> 18% (~ 10^0)
Land located in proximity to hazardous facilities (Airport - 10mi; Oil Refineries - 1mi)	—
Land too close to identified fault lines is avoided	—
Streamflow within 15 miles	≥ 84,000 gpm (and ≥ 20,000 gpm)
Safe-shutdown earthquake peak ground acceleration	≥ 0.5g (and ≥ 0.25g)
Ocean Cooling within 20 miles	—

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