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A Nuclear Solution for the Energy Security Vulnerabilities of the Department of Defense: Using a Small Modular Reactor to Power Military Installations

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To the Graduate Council:

I am submitting herewith a thesis written by Margaret Alva Kurtts entitled "A Nuclear Solution for the Energy Security Vulnerabilities of the Department of Defense: Using a Small Modular Reactor to Power Military Installations." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

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A Nuclear Solution for the Energy Security Vulnerabilities of the Department of Defense: Using a Small Modular Reactor to Power Military Installations

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Abstract

Due to its reliance on the civil electrical grid, the Department of Defense has significant energy security vulnerabilities. DoD does not have energy production capabilities within its organization necessary to sustain the operations of a military installation. Its current installation energy strategy is a combination of energy reduction measures and renewable production efforts. Therefore, increased threats from cyber attacks combined with an aging electrical infrastructure threaten DoD's energy supply to its installations. The electrical grid provides aggressors an opportune target for weakening military response capabilities in the event of a natural or man-made disaster. While DoD is successfully using energy more efficiently, it is failing produce power on the scale needed to secure its energy future.

This paper examines the Department of Defense energy security strategy and identifies a sustainable solution using nuclear power. The increased interest in Small Modular Reactor (SMR) Technology presents the Department of Defense with a power solution that is adaptable to military installation use. This paper examines potential SMRs for commercialization and use on a military installation. It identifies what reactor characteristics are important to the Department of Defense and selects an SMR design to fit DoD's energy needs. The paper then presents an implementation strategy taking into consideration the unique aspects of siting a small nuclear power facility on a military base. It presents financing options for the facility as well as addressing staffing and management considerations.

Small modular nuclear reactor technology is ideally suited to fill the supply voids in DoD's energy security portfolio. Through the adoption of reactor technology, DoD not only secures its ability to respond to man-made and natural threats, but it also secures the future of the American people it protects.

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Chapter 1: Introduction

Over the last decade, the threats to national security underwent a dramatic transformation. In addition to threats from direct aggressors such as those faced at Pearl Harbor or during the Cuban Missile Crisis, security professionals now face threats from a less overt enemy. A complicated network of loosely aligned, ideologically motivated activists, defines the threat environment today. At times these individuals act solely in support of their cause. In other situations, ideologues are used as weapons in a larger, state supported form of 21st century Cold War. While the threat of conventional terrorist attacks, such as the events of 9/11 or the Boston Marathon Bombing (2013), are still real and present, a more insidious and pervasive threat targets the national infrastructure. A new and dangerous weapon in the world of national security is the threat from cyber attacks.

In the 2010 Quadrennial Defense Review, Secretary of Defense Robert Gates described structuring the United States Military in order to be prepared to respond to the complicated security environment of the 21st century.

"We must prepare for a broad range of security challenges on the horizon-ranging from the military modernization programs of other countries to the non-state groups developing more cunning and destructive means to attack the United States and our allies and partners."[1]

State and non-state actors realize that Americans enjoy a sense of security stemming from its physical isolation. America has clearly defined boarders and shares ideological ties with its neighbors to the North and South. Oceans separate Americans from the upheaval felt in volatile nations of Southeast Asia and the constant geopolitical uncertainty in Western Europe. The American sense of security is misplaced. The world is truly interconnected. Oceans or fences no longer deter the threats to America. Terrorist groups travel easily across boarders or make attacks from remote locations with a computer and an Internet connection. Terrorists now target America by attacking its infrastructure networks. These attacks can be physical but more often are cyber based. Automation pervades society. The daily lives of Americans revolve around the use of technology for

even the most basic transactions. At the individual level, actions such as buying fuel for a car, picking up milk at the store or paying a mortgage payment are all done via digital transaction. On a community level, daily operations are equally automated. Communities use automation to dispatch emergency services, warn residents of threatening weather conditions and maintain a constant electrical supply. The increased automation in society promotes a feeling of security that stems from an expectation of quick and immediate reaction to problems of all kinds. However, Americans were stunned in 2013, when thousands fell victim to a cyber attack on the retail chain Target that resulted in loss of personal banking information. The size and scope of the attack were shocking, in part because Americans relied on a misplaced sense of security.

As Secretary Gates noted, the Department of Defense is fully aware of the changing nature of the threat to national security. In an effort to combat this threat, DoD is moving aggressively to protect itself from cyber attacks. In 2010, DoD established US Cyber Command (USCYBERCOM) to specifically combat these threats. DoD utilizes extensive security protocols for communication and information transfer. It maintains and operates over 15,000 different computer networks across 4,000 military installations worldwide. Daily, DoD personnel use over seven million computers and telecommunications tools.[1]

Yet at home, DoD still relies entirely on the civilian power grid to provide sustaining electricity to its computer networks. Despite having an extensive network security system, any operation can be brought to complete stop by simple removing its power source. Without electrical power movement orders, resupply requests and battlefield tracking all stop. The civilian power grid provides aggressors a way to directly influence the response capability of the US Military without directly attacking it.

DoD defines threats to its energy supply as threats to its energy security. Over the last decade, DoD has tied energy security and climate change together. It sought solutions through a reduction and optimization of energy use. It sought energy independence using renewable energy projects. Each year, the Department of Defense directs billions of

dollars toward increasing its energy efficiency in order to establish a more robust energy security posture.

The purpose of this paper is to propose a new approach to installation energy security using a nuclear small modular reactor (SMR) solution. This paper first examines the current DoD energy security strategy with a focus on installation energy security. It analyzes the combination of reduction initiatives and renewable production measures to determine if DoD is successfully securing its installation energy needs. The paper reveals a significant gap between the reduced energy demanded by DoD and the power that is supplied by its renewable energy projects. To fill the energy demand gap, the paper proposes the use of a small modular nuclear reactor. After a brief overview of SMR technology, the paper compares four proposed SMR designs and evaluates them for use on a military installation based on reactor characteristics. It then proposes an implementation strategy detailing how to most effectively utilize SMR technology to meet the energy demands of a military installation. The implementation strategy includes detailed siting considerations based impact to mission performance. A staffing solution is proposed that combines internal military nuclear specialists with external reactor operators. Finally, a technology readiness assessment is used to identify the steps still required to implement a nuclear reactor energy security solution.

Chapter 2: The Department of Defense Energy Demand

The mission of the Department of Defense is "to provide the military forces needed to deter war and to protect the security of our country."[2] The structure required to support the mission is enormous. DoD employs over 2.1 million military and civilian personnel who operate from several hundred thousand buildings located at one of over 5000 different locations. The total geographic footprint of DoD is over 30 million acres of land.[2] As such, DoD has at its command human and physical resources that rival all private sector organizations. DoD is one of the largest departments of the United States government. Furthermore, the US spends more than any other nation-state on defense, committing 4.4% of its annual GDP on DoD.[3]

In order to meets its mission, DoD works to efficiently allocate and properly locate of its resources to facilitate swift and effective responses to threats to national security. Doing so requires incredible amounts of energy. In 2012, DOD spent a total of $20B on energy. DoD used the energy purchased for a wide range of applications from fueling vehicles to powering installations. The majority of use was for powering tactical equipment in the form of operational energy. Of the total energy consumed, 26% went toward use within buildings or installation power.[4]

Installation energy is the power needed to maintain the base infrastructure. Installation energy is primarily sourced from local commercial power distributors who sell to the DoD facility like any other customer. Operational energy is used to project forces forward on the battlefield. Operational energy comes in many forms. Petroleum is the largest form of operational energy used in DoD. DoD uses petroleum fuels to fly aircraft, power boats, drive vehicles and run generators. Other sources of operational energy include the nuclear power used on naval vessels and battery power for individual soldier equipment.

Operational Energy

DoD is heavily dependent on petroleum as its main fuel source for operations. In 2011, DoD used 116.8 million barrels of fuel (mbbls) at a cost of $17.2B. In FY 13 DoD

budged $16.3B (104 mbbls) for fuel purchases.[5] DoD has long recognized over-reliance on petroleum-based fuel products is a significant threat to operational force projection. DoD is actively seeking alternative fuel sources. In FY13, DoD allocated $1.6B for operational energy initiatives, including research and development into alternative fuel sources for both Naval and Air Force equipment. The Navy is exploring options to replace diesel with biodiesel in its petroleum-powered vessels. The US Air Force is looking for alternative fuels for jets and cargo aircraft. In the FY13 Operational Energy Budget Certification Report, Sharon Burke, the assistant Secretary of Defense for Operational Energy Plans and Programs, expressed significant concerns for all departments of the military and their lack of "systems and tools required to incorporate energy security considerations in to their requirements and acquisition processes" All three major components lacked the ability to forecast into their acquisition programs the requirements needed to meet energy security needs. [6]

Installation Energy

DoD installation energy demand in FY2012 was 215 trillion BTU, which represents about 1% of the total US commercial sector energy consumption.[4] Unlike the operational energy needs, installation energy is used across the DoD vast physical footprint with the mission of sustaining, training, and equipping service members in preparation for their various military missions. DOD utilizes its installations in a variety of ways.

- Training: One of the single most important functions of military installations is to provide service members a place to conduct training on their specific set of skills. Given that military service members use a skill set that is unique to their organizations, the Department of Defense must have specialized locations to conduct training. For example, large plots of secluded land are required to conduct training on weapons systems larger than small arms. These types of systems include explosives, missiles, radar systems and many other large-scale weapons. DOD establishes a geographic footprint that allows its employees to train on the use of these weapons while keeping the civilian population safe from their effects.

- Operations: The operational infrastructure of DoD is vast. Traditional operational units such as Army brigades or Air Force Squadrons require a footprint from which to plan their training, manage their people and prepare for deployed operations. Command and control centers exist throughout the military providing continuous oversight of and communications capabilities for forces deployed and abroad. The command and control infrastructure of DoD requires continuous power supplies and communications channels to monitor operations worldwide and to be prepared to respond to national security threats.

- Sustaining: There are two major components to sustaining DoD forces; Equipment Sustainment and Manpower Sustainment

    - Equipment sustainment. This includes scheduled services and maintenance as well as unscheduled repairs. The specialized equipment within DoD requires specialized facilities to conduct maintenance on equipment. The spectrum of equipment in need of maintenance is broad ranging from a *Nimitz* class aircraft carrier to an F18 fighter to an M4 Carbine rifle. All of these items require continuous support and maintenance to stay operational and DoD must have the infrastructure network to support that maintenance.

    - Manpower Sustainment. Sustaining the employees of DoD includes a variety of infrastructure demands. Many service members and their families live on military installations. Housing for these individuals includes single-family homes, duplexes and barracks for single soldiers. In addition, the military has temporary housing for service members conducting training away from their home installations. To support the military manpower, there are extensive health and dental facilities as well as educational resources for employees and their families.

- Projection: DoD meets national security threats outside the contiguous United States by projecting forces onto the battlefield. It does this primarily through sea and air projection as a first step and then land projection. Moving forces from stateside operations via land or air requires projection platforms be situated and postured for movement. Infrastructure that supports these types of movements is naval stations and air bases. These facilities are geographic cache of logistical supplies needed to move operational units forward from the United States to face threats in other places.

In 2012, DoD spent $3.8B on electrical power, heat and cooling for facilities. DoD consumed 215,100 BBtu (billion British thermal units) of energy requiring approximately 7 GW of power production.[1] The largest consumer of facility energy within DoD is the Army, which accounts for 37% of the total facility energy consumed.[4]

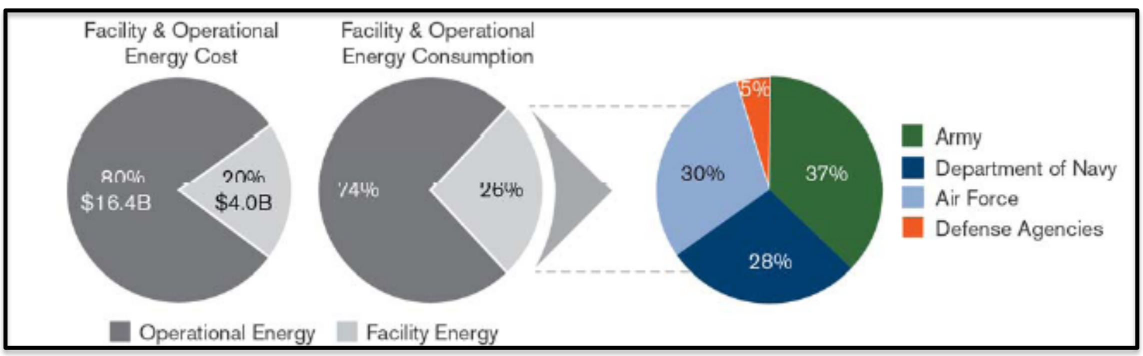

Figure 1: DoD Facility Energy Consumption and Cost[4]

[1]The energy to power conversion rate is based on a 24-hour day, 365-day year and a production capacity of 90%. The conversion rate is consistent throughout the entirety of the analysis in this document.

80% of the facility energy consumed by DoD goes toward natural gas and electricity. This is primarily used for power, climate control and water heating.

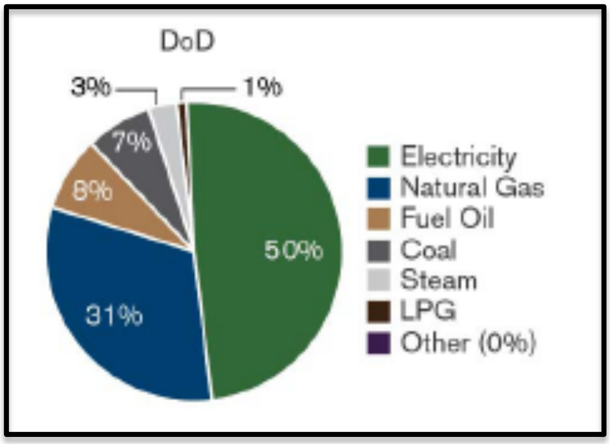

Figure 2: DoD Facility Energy Consumption by Type[4]

When looking across the spectrum of DoD fixed installations, there is a wide range in the amount of energy demanded. The demand is primarily influenced by the size of each installation, the environmental conditions surrounding the installation, its departmental mission and the square footage of buildings requiring energy. Thus DoD categorizes its energy usage using energy intensity. Energy intensity is measured in billion British thermal units per gross square foot of facility space (BBtu/Gsf). In an effort to identify the most energy consuming facilities, DoD began an aggressive campaign in FY2010 to monitor and track energy consumption at the installation level rather than as an aggregate whole. By measuring energy consumption at the installation level, DoD gained a more specific understanding of its energy uses and needs. For example, a small Naval Air Station in the Florida Keys will have a different energy consumption profile than a garrison army base in Fort Wainwright, Alaska. A large Air Force basic training facility in Texas will consume energy differently than Twenty Nine Palms, a remote weapons testing facility in the California desert. This data allowed planners to develop targeted energy reduction plans for each facility based on consumption, number of facilities, mission and the environment.[7]

Chapter 3: Department of Defense Energy Strategy

"Sustainability is not an individual Departmental program; rather it is an organizing paradigm that applies to all DoD mission and program areas"[8]

The Department of Defense outlines its strategic goals as an organization in the Quadrennial Defense Review Report. The latest report was published in February 2010 (QDR 10). In that report, DoD specifically addresses energy security as *"having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet operational needs."* [1] Further, DoD links, climate change and energy security. It devotes considerable effort to increasing its energy security by reducing its environmental impact. Infrastructure (installation) and operational energy efficiency programs are foremost in DoD's energy security strategies including alternative fuel sources, less pollutant fuel sources and the identification of new fuel-free technology. Domestically, DoD is looking to balance energy usage and production through reduction efforts as well as production initiatives. These efforts must be conducted without sacrificing the mission capabilities of an installation. [1]

Energy Security Defined

Energy security for the Department of Defense means always having an available supply of energy to conduct operations. Without power to conduct operations, the Department of Defense assets are useless. Energy is needed to maneuver, command and communicate and is essential to every element of every military operation. The energy itself is derived from many sources such as petroleum to power vehicles, aircraft and generators. It can also come from local commercial providers in the form of grid electricity and natural gas.

One of the largest threats to energy security for DoD is its dependence on fossil fuels, particularly in operations. In the missions in Afghanistan and Iraq, for example, fuel convoys were essential to support operations and fuel trucks were literally everywhere. Attacks on these convoys caused significant delays and disruptions of the operational fighting capabilities of forces on the ground. [8] In addition, simply acquiring and moving the petroleum to the necessary general location is often challenging as worldwide petroleum distribution networks are at increased risk for attack. Shipping lanes

transporting bulk oil to refineries face disruptions at choke points such as Strait of Hormuz and Straits of Malacca. Pirates, regional political instability and military actions all threaten shipments of petroleum worldwide. Such instability can lead to drastic price fluctuations in the cost of oil. To counter instability in the petroleum market, DoD has chosen to acquire and store vast amounts of petroleum reserves.[8]

Energy vulnerabilities also exist within the U.S. Most electrical power and natural gas for fixed installations in the U.S. is sourced from local commercial suppliers. As Dr. Dorothy Robyn, Deputy Under Secretary of Defense for Installations and Environment acknowledges:

> *"Facilities energy is critical to mission assurance. Our fixed installations support combat operations more directly than ever before, and the serve as staging platforms for humanitarian and homeland defense missions. These installations are largely dependent on commercial power grid that is vulnerable to disruption due to aging infrastructure, weather-related events and a potential kinetic or cyber attack."[8]*

Military installations at home provide not just housing for service members and storage for equipment. They provide key strategic staging locations for military force projection operations in the form of railheads and runways. Installations are an essential network of communications, command and control centers providing real time monitoring of defense operations worldwide. Installations are staging locations for disaster relief efforts following local natural disasters such as Hurricane Sandy and Hurricane Katrina. Yet these facilities are all vulnerable because they depend almost entirely on external sources of energy. In the event of a natural disaster or even just a simple outage, military installations must wait, like any other customer, for the utility to restore power. Some critical systems have backup generators that provide short-term power in these situations. These generators are limited in number and cannot be expected to run for extended operations.

It is important to note that physical threats to the electrical grid impact not only DoD installations but the general public as well. For example, an April 2013, an attack on a California power transmission substation highlighted the vulnerabilities of America's

power gird. During the 19-minute attack, assailants fired bullets into transformers that supplied power into Silicon Valley. The electric company was able to reroute power to prevent a blackout however the repairs to the substation took 27 days. Even more alarming was the relative ease with which the attackers executed the assault. The weapons used were not sophisticated. They faced no resistance or security at the substation. The assistants were able to methodically execute their attack exactly as planned with no interference from either the power company or local police agency. Across America, the electrical grid is no different from this California transmission station. Should America's enemies seek to cripple the military infrastructure, the power network used to sustain an installation is an excellent domestic terrorism target. [9]

Additionally, there are ever increasing concerns about the potential for a cyber attack on our nations electrical grid. A recent article by Dan Weissman of NPR describes an electrical grid security exercise conducted by North American Electric Reliability Corporation (NERC) called Grid Ex 2013 that took place in November of 2013. More than 2000 utilities workers, regulators and law enforcement officials participated in the exercise. While the results of this exercise have not yet been published, it is important to note that American utility companies are taking the treat of cyber security and kinetic attacks to the grid very seriously. Exercises such as this help to bring to light the true nature of our society in the event of a prolonged power outage.[10] In the event of a cyber or kinetic attack on the nations electrical grid, the military would be called upon to exercise its homeland defense mission and act as a staging location for relief and repair efforts. Unfortunately, due to its own dependence on commercial power, it is likely that military forces will be just as helpless as the average citizen in such a crisis.

Operational Energy Strategy

The three key operational energy goals of DoD were outlined in the May 2011 Operational Energy Strategy. [11]

1. More Fight, Less Fuel: Reduce the demand for energy in military operations

2. More options, less risk: Expand and secure the supply of energy to military operations.
3. More capability, less cost: Build energy security into the future force.

The total budget for operational energy from FY13-17 included $9.0B for operational energy programs outside the purchase of bulk fuel. Of the $9.0B, 92% of the budget is directed toward research, development, testing and procurement in support of energy initiatives. 90% of the energy initiatives are specifically focused on demand reduction solutions. This results in $8.1B between FY2013 to 2017 being used to find technology to help reduce demand.[6]

However, $8.1B represents a fraction of the money projected to be spent on bulk fuel purchases. Using the fuel purchase projections from FY2013 OE Budget Cert Report and accounting for an estimated reduction in use of 5%, the total number of barrels of fuel purchased between FY13-FY17 will be 384.8 mbbls at a cost of $56.7B ($3.51 a gallon).[2] DoD acknowledges the enormity of the energy resources:

> *"Our [energy] posture is imposing costs at all levels, strategic, operational, tactical and financial."* *S. Burke, the Assistant Secretary of Defense for Operational Energy Plans and Programs [8]*

The force projection capabilities of the US Military rely almost entirely on the use petroleum based fuel products. A significant technological shift is required to find alternative fuel sources for equipment such as helicopter's, aircraft and tanks which rely heavy on combustion of petroleum fuel for power. In the 1950s, the Navy made a technological leap forward in reducing fuel costs by switching to a nuclear powered vessel. Possible alternatives being explored are hydrogen-powered vehicles and battery-powered vehicles. The Department must be careful when looking at alternatives that it does not sacrifice its force projection capabilities in the name of energy efficiency. Petroleum is a reliable, portable and powerful source of fuel. Yet it is also limiting in that it is expended quickly and requires an extensive supply chain. However, until technology

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[2] 5% was chosen for a percentage reduction based on a projection report from the FY12 Operational Energy Annual Report. This report predicted a reduction of 5% from year FY13-14. I applied this reduction annually. The projection is purely an approximation. Factors such as the price of oil, the nature of military conflicts abroad and actually effectiveness of demand reduction initiatives will all impact usage.

evolves to replace petroleum, the Department of Defense looks to simply build efficiencies into the current combustion technologies. While this efficiency will reduce the amount of operational energy used, there will not be significant reductions unless the base use of combustion power is changed.

Installation Energy Strategy

In an effort to reduce its vulnerability to energy supply disruptions, DoD is focusing on reducing its energy consumption through conservation and improved efficiency. More than $1.1B has been budgeted for energy conservation improvements to buildings. Upgrades to facilities include measures such as replacing windows, updating HVAC systems and improving lighting.

Additionally, DoD is looking at ways to produce its own energy on-site. On-site energy production is a key element in reducing the energy security vulnerabilities within DoD in the event of a commercial grid collapse or outage. Recognizing that energy independence is critical to ensure operational security, DoD is analyzing the feasibilities of various renewable energy sources coupled with the use of "micro-grid technology" to control and store on-site energy.[8]

Energy Laws and Regulations

The Energy Policy Act of 2005 sets goals for annual energy consumption guidelines, which increase the usage of renewable energy sources for all federal facilities and agencies. Table 1 shows the required amount of energy consumed by federal agencies to come from renewable sources.

Table 1: Energy Policy Act of 2005 Renewable Energy Goals

Year	Percent Consumption from Renewables
FY07-09	3%
FY10-12	5%

Additionally, the Energy Independence and Security act of 2007 (EISA 2007) and Executive Order 13423 (Strengthening Federal Environmental, Energy and Transportation Management) combine to set further goals for federal agency consumption resulting in a 30% decrease by 2015 and an increase in renewable energy source consumption of 7.5% by FY2013. The regulations outline practices to enhance energy conservation and require the complete metering of all federal facilities for natural gas and electricity by given target years. Further, all new buildings must be constructed in accordance with energy efficient standards and equipment purchased for federal buildings to be energy efficient. Finally, by 2025, Federal regulations (10 U.S.C§2911e) requires 25% procurement of energy from renewable sources.[7]

Chapter 4: Energy Security Programs

Net Zero: Background

DoD is not conducting its research and implementing its energy programs in isolation. As early as 2006, the National Renewable Energy Laboratory (NREL), working with the Department of Energy, began using the term Net Zero to describe buildings and building construction that met certain characteristics related to cost effective, reduced energy use (NZEB). [12] According to the NREL, 40% of the primary energy used in the United States goes to commercial and residential buildings. 70% of the electricity used goes to these buildings. Due to increasing technological demands, the demand for electricity is only expected to rise in the future years. Figure 3 shows NREL's estimate for the project grown in building energy consumption by sector.

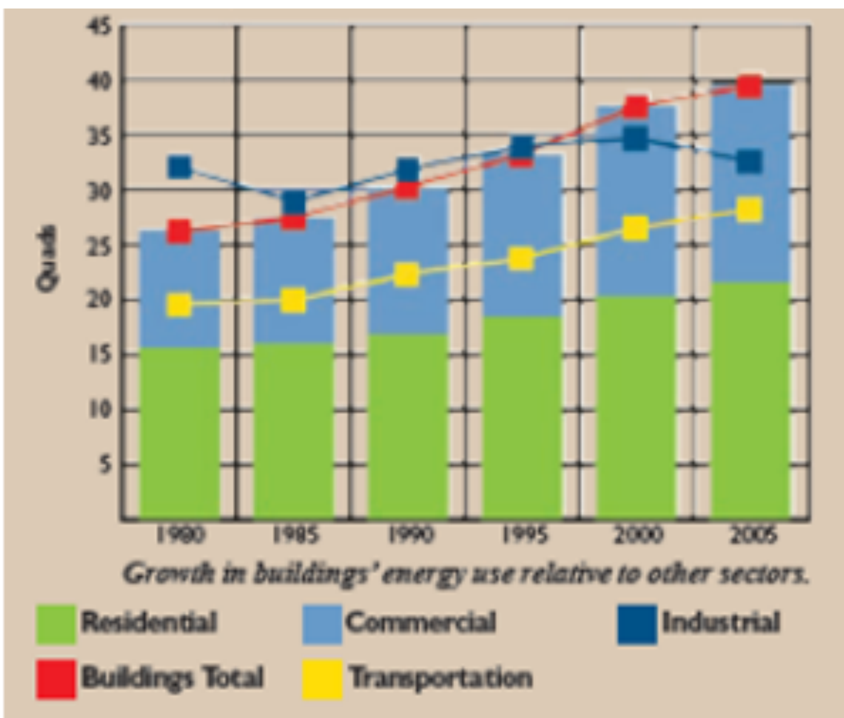

Figure 3: Projected Growth in building energy use relative to other sector[12]

Nested under the concept of reducing the negative impact of energy production, the NREL sought to find ways to reduce building energy consumption by promoting NZEBs. NZEBs are buildings that significantly reduce their energy consumption needs through technologically efficient upgrades, behavior modification and the use of renewable

energy. Significant effort went into actually defining and categorizing the energy use of a building as well as working to reduce consumption through efficiencies. To reach Net Zero, companies are encouraged to first focus on demand reduction because this is most cost effective. Only once demand has been appreciably reduced does the company began pursuing renewable energy supply options. [12]

NREL's study, *Lessons learned from Case Studies of Six High-Performance buildings,* discussed the efforts to take six commercial buildings and make them NZEB. [13] The results were mixed. The study demonstrated that while technology can reduce energy costs, achieving Net Zero is very difficult. All six buildings used more energy than anticipated and produced less than anticipated. Failure to reduce energy usage was attributed to a number of factors including an overly optimistic projection about the ability to modify energy usage behavior of individuals. Additionally, some concepts such as day lighting failed to provide adequate lighting causing an increase beyond prediction of electrical lighting. Energy usage from plug loading was higher than forecast. There was also failure on the supply side of the model. Photovoltaic (PV) energy production was less than models forecast. Overall the study learned that there is no single solution to making a building reach Net Zero energy balance and it takes a whole building approach to solve the problem. [13]

The Army Net Zero Program

Since DoD is the largest energy consumer in the US government, [14] it and DoE began a joint initiative in 2008 to study the energy use of the military and identify methods for reducing demand and increasing use of renewable energy. The NREL conducted the study and used Marine Corps Air Station Miramar as its prototype installation. Based on that study, the NREL issued *Net Zero Energy Military Installations: A Guide to Assessment and Planning* as a guide for the implementation of an energy conservation strategy for a military installation.

A key factor to strategy development is recognizing some of the unique constraints of a military installation. A primary consideration is project and mission compatibility. Under no circumstances can an energy reduction project hinder the accomplishment of a

military mission. Thus special understanding of military operations is necessary in order to find the right solution for each installation. For example, at an installation with high levels of fixed or rotary wing aircraft traffic, one would not want to provide additional energy via wind turbine power as these devices present obstacles to air movement. The impact on the security of the installation is another key factor. Ideally the power generation source would be located on the installation premises. This increases installation security as the logistics support for the power facility is contained within the parameters of the installation. An off-site power source forces the installation to be dependent on either a commercial electrical grid or constant supply lines such as fuel tankers. Installation environment will also play a role site selection and strategy. Military installations exist in a wide variety of climates so there is no single solution for all installations. Additional considerations include economic factors such as life cycle costs, storage costs and technology maturity. [14]

In 2011 the Army initiated its Net Zero Pilot program on 17 installations. Under this program, selected installations were provided assistance in achieving Net Zero in energy, water, waste or a combination of the three. In this paper, the focus will be on the Net Zero Energy programs rather than waste or water program. Figure 4 shows the locations of these installations and their Net Zero program

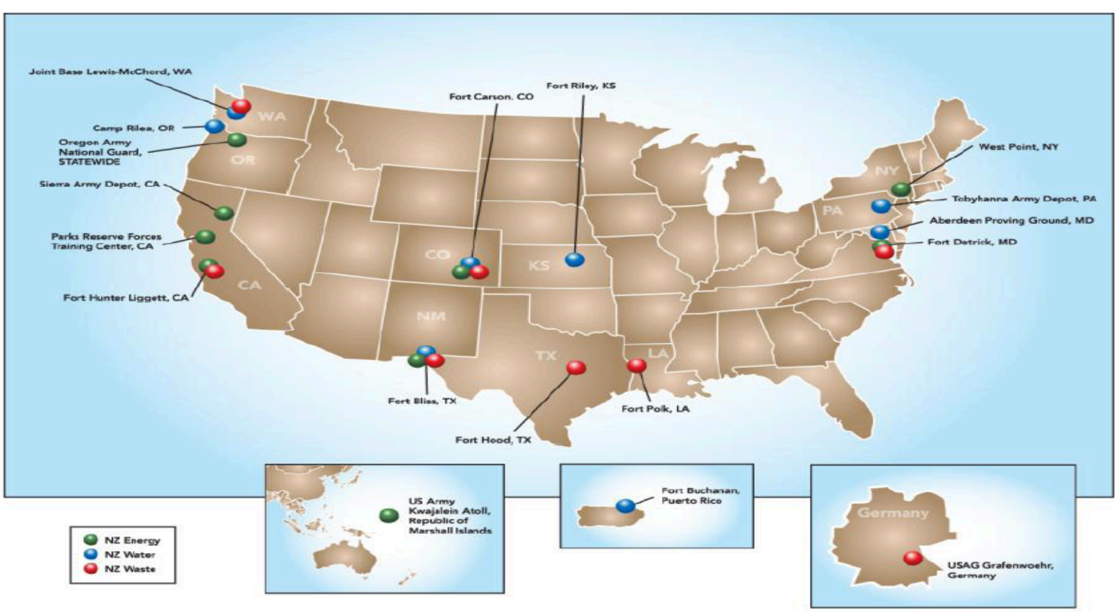

Figure 4: Army Net Zero Pilot Installations[15]

The Army Net Zero Energy goal is for an installation to produce as much energy as it uses. Within its pilot installations, the Army has made considerable effort to reduce energy demand. NREL theorizes that the most economic way to reach Net Zero energy is to reduce energy demand. Behavior modification accomplishes demand reduction without the need of capital expenditures and the use of energy efficient technology. [14] NREL calls upon installation leaders to find *"opportunities for procedural, behavioral, process and operational energy saving actions (relying) on engaging the attention and creativity of personnel."* [14]

Figure 5: Net Zero Energy Hierarchy

The Army has taken this suggestion as its first and primary step to reaching a Net Zero energy security solution. Figure 5 illustrates the Net Zero Hierarchy. [14] The Energy Engineering Analysis Program conducted energy surveys of the pilot installations to determine baseline energy needs and identify inefficiencies in energy usage. [14]

Energy surveys led to the development of the Army Meter Data Management System, which monitors installation energy usage at the individual building level and helps installation, appointed energy managers find solutions to energy waste at their location. The Army also built a robust staff of energy managers who monitor energy usage at each installation and provide reporting through the Army Energy and Water Reporting System. New buildings are required to following construction guidance with the aims of making them as energy efficient as possible. An award and recognition system was developed to recognize installation leaders who were innovators in energy reduction. These are all examples of procedural and policy measures aimed at simply reducing consumption. [16]

Additional energy reduction measures under Net Zero include building modernization projects. Improvements to HVAC systems, lighting systems, use of LED lights and improved control systems all helped reduce energy waste on military installations. Bases use thermal imaging technology to develop a building thermal envelope and find where buildings lack insulation. Energy managers improve control systems to allow for a more efficient use of building systems such as precooling buildings, automating lighting operations and optimizing the use of fans and blowers. [15] Many of these projects are paid for with all up front capital cost deferred from the military using unique financing options. One finance option is a utility energy service contracts (UESC) where a utility pays for the upfront capital costs of the project and is then repaid by the energy savings generated by the improvements. Energy saving performance contracts (EPSC) are arrangements between the Army and an energy service company where the company analyzes, develops, funds and manages energy savings projects and is repaid by the energy saved. [15]

The Army is aggressively pursuing a number of micro power renewable energy projects on its pilot installations. Most projects are solar photovoltaic projects producing between anywhere between 0.10 to 10 MW of energy. Most projects are small in scale and used to power outdoor lighting or heat water. Some projects use installation waste to produce energy to augment the base. The most successful installation is Fort Carson, which gets 3.5% of its total energy from renewable sources. [15]

Department of the Navy: Large Scale Renewable Projects

The Navy's renewable energy program results in the production of 20% of the Navy's electricity being produced from renewable sources, the majority from two large-scale projects: a 270 MW geothermal station at China Lake, CA and the Norfolk Naval Shipyard solid waste project in Portsmouth VA.

Figure 6: Geothermal Plant at China Lake, CA[4]

The China Lake Project produces 77% of the Navy's total renewable energy and the NNSY solid waste plant produces 20%. At both facilities, the electricity produced is sold to the local utility and not used by the installation. Because it is not consumed by the installation, it is not counted toward the EPA 2005 act goal of consuming 7% of all electricity from renewable sources by 2013. [7]

Chapter 5: Energy Security Program Analysis

In addition to analyzing energy security in terms of reducing greenhouse gases and conservation, an assessment of security of supply and reliability of supply of energy is also necessary. To achieve energy security, DoD key infrastructure must have a constant supply of energy regardless of the source or the situational environment. This section provides an analysis of energy source and reliability of energy source in order to frame the effectiveness of DoD's various energy programs in terms of energy security.

1. Will DoD meet its regulatory and legal energy efficiency requirements?
2. How effective are the energy reduction measures at optimizing the energy need by DoD to operate?
3. How effective are the renewable energy measures at producing a reliable source of power that meets the operational needs of an installation?

1. Will DoD meet its regulatory and legal energy security requirements?

DoD established a timeline to meet its legally mandated energy security targets. This is the most basic metric of program evaluation in that it is a known and established metric for DoD to meet. Table 2 illustrates DoD's internal analysis on its progress towards meeting its energy security goals. [4]

Table 2: FY 2012 Progress Report

Goals and Objective	Metric	DoD FY12 Performance	Target	Evaluation
Reduction in Facility energy intensity (EISA 2007)	BTU/gross square foot	-17.7%	-21.0%	**Fail**
Increase Renewable Energy Consumption (EPA 2005)	Renewable energy consumption as a percentage of total facility energy consumed	4.0%	5%	**Fail**
Increase Renewable Production (US Reg)	Renewable Energy produced and procured as a percentage of total facility energy consumed	9.6%	25% by 2025	**Failed to meet target**

Table 2 illustrates the DoD is not on track to meet any of its energy security goals. It is not in compliance with US law and regulation. The most significant failure is its goal to increase renewable energy production to 25% by 2025. Currently DoD is well below its target metric to be on track to meet that goal. Without a significant change in its renewable energy production category it will not meet the goal.

2. How effective are the energy reduction measures at optimizing the energy need by DoD to operate?

There are two variables in evaluating this metric; optimal energy consumption and cost of optimization. The first is the effectiveness of the energy reduction measures to reach optimal consumption levels. In order to achieve energy security, DoD needs to be using its energy in the most efficient ways. Figure 7 shows that 91% of DoD's energy project appropriations are aimed at reducing energy use.

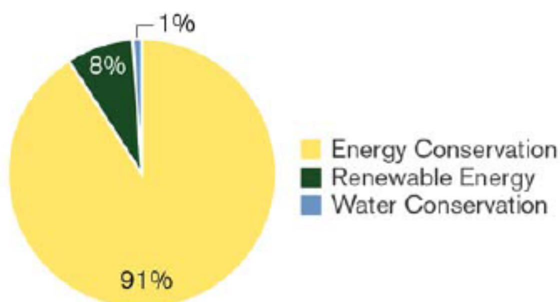

Figure 7: FY12 Energy Project Appropriations[4]

Internal analysis from the Department shows that it does not forecast meeting this requirement. DoD argues a more realistic goal would have allowed for smaller target percentages earlier on in the program to allow for time for funding, design and implementation of energy efficiency projects. It expects to meet the 30% goal by 2020 instead of 2015.[8]

Figure 8 shows DoD's progress in reducing its energy intensity footprint in order to meet the goals outlined in EISA 2007. Currently DoD must reduce energy intensity at a rate of 3% per year in order to meet the goal 30% reduction by 2015.

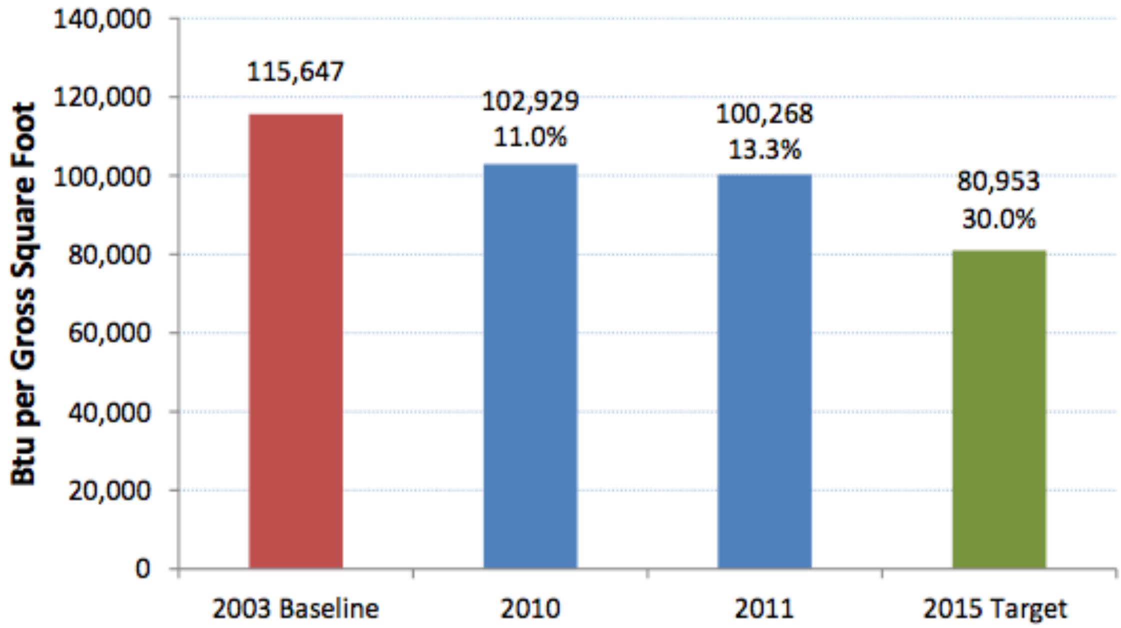

Figure 8 Progress Toward Facility Energy Intensity Reduction Goals[8]

While the Department has failed to meet the targeted reduction goals necessary to meet its targeted 30% reduction goal, it has been successful in reducing its installation energy use. It has instituted a robust system of procedural and technical tools to monitor consumption. EISA 2007 mandates a 30% reduction. This level of consumption might not be the optimal level of consumption for an origination as large and diverse as the Department of Defense. It has a unique mission and utilizes one of kind equipment in its day-to-day operations. It operates in a wide variety of physical environments. Understanding its constraints and having accurate systems to measure consumption will allow DoD to establish its own estimate for optimal consumption levels. Further analysis is needed to determine the optimal level of energy consumption for DoD that may differ from the mandated 30% reduction. Despite not meeting its goals, the Department has been effective at curbing energy use.

The second measure of the energy reduction programs is cost versus return on optimization. However, this measure is difficult to quantify. By using an energy performance savings contracts (EPSC) or utility energy service contracts (UESC) much of the up front cost is assumed by a contractor or utility. EPSC and UESC pass the cost of the project to the contractor or utility that is then repaid by the energy savings produced. DoD's costs relating to these projects are deferred yet they are very real. While DoD has little to no upfront expense, it also does not recognize any gain until the contractor or utility has recouped its costs. An installation experiencing a demand reduction will pay a reduced power bill. The difference however, between the reduced bill and the old bill, is paid to the contractor. Thus, DoD does not actually recognize any savings until the contract is completely recouped, which could be years or even decades later. During that time, many systems will require routine repair and upgrades; those costs are passed on to DoD, but again, any benefits are not recognized until much later.

In order to accurately analyze the cost effectiveness of energy reduction measures, all it is useful to assume to be incurred by DoD regardless if they are a direct procurement or on a delayed UESC/EPSC payment plan. Figure 9 illustrates the annual expense of energy efficiency investments (direct, EPSC, UESC) verse the annual energy savings from the projects FY2007 through FY2011.[3] Energy savings estimates came from either actual savings, in BBtu, or those projected by the contract if actual savings was not reported. Using the average cost for a BTU of energy during the specified fiscal year was to calculate the total savings from the energy efficiency projects.

Figure 9 contrasts the expense with the anticipated annual return from the projects. Expenses include the amount of money either directly appropriated or awarded through UESC and EPSC during each fiscal year to energy reduction measures. Returns are based on the anticipated savings (in Bbtu) estimated by the contractor.[4] Assuming that the savings realized from the project meet the anticipated goals, Figure 9 illustrates how long it will take each year's group of projects to pay for themselves. Amortization of the

[3] The data for figures 9 and 10 are from the Annual Energy Management Reports FY2007 to FY2011.
[4] Conversion of returns from Bbtu to dollars was done using DoD's average price per Btu for the given fiscal year.

project cannot be done without knowing their expected life cycle. Thus, returns on a project in the form of reduced energy cost will only be recognized once it has paid its capital costs.

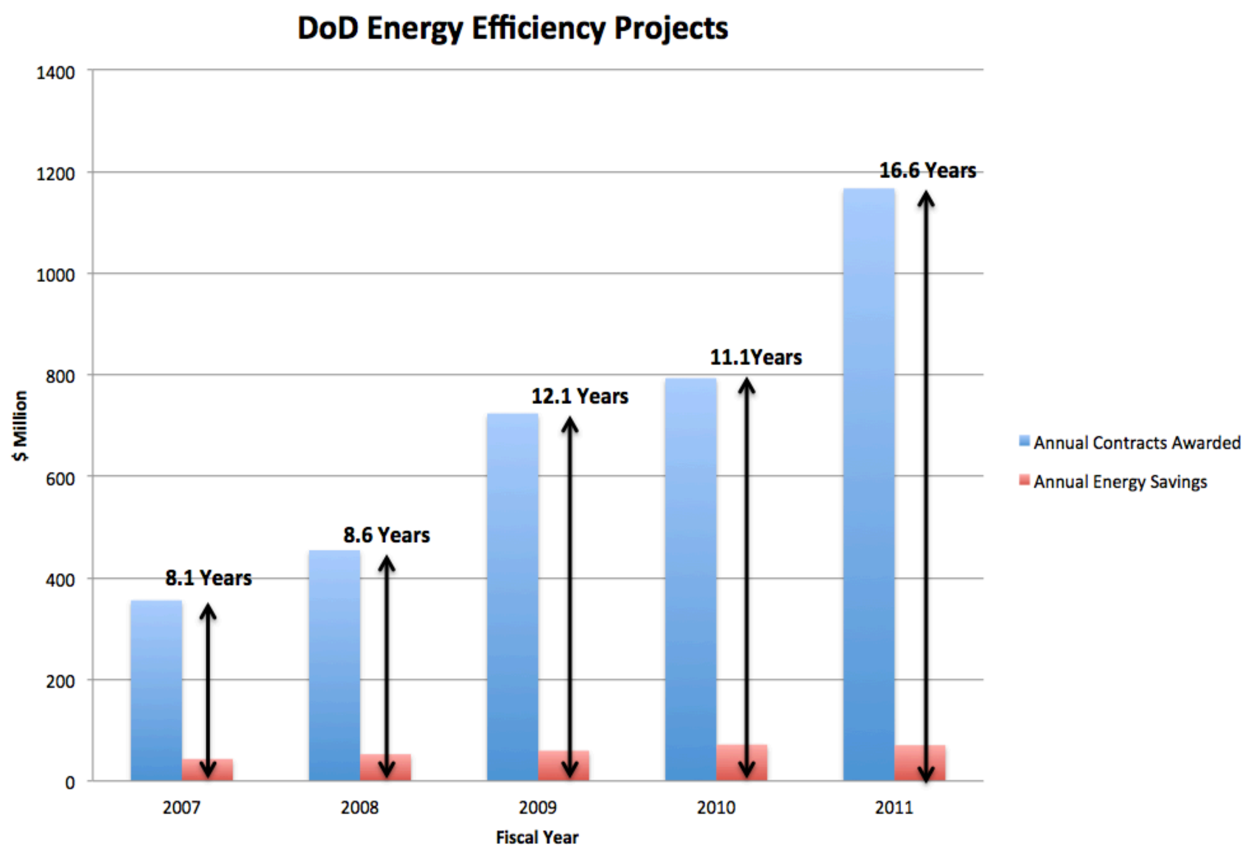

Figure 9: DoD Energy Efficiency Projects

Figure 10 looks only at energy efficiency projects started in FY2007 to FY2011. It contrasts the debt DoD assumes against the projects with the anticipated returns. It assume energy savings returns consistent with the estimate provided by the contractor, Figure 10 approximates that projects started between FY2007 and FY2011 will have fully repaid their capital cost by FY2021. This simple analysis does not include additional costs incurred for maintenance and repair of the newly installed systems. It also does not include the impact on both cost and returns of projects that could be started after FY2011. It does not include changes in return based on drastic changes in the price of energy.

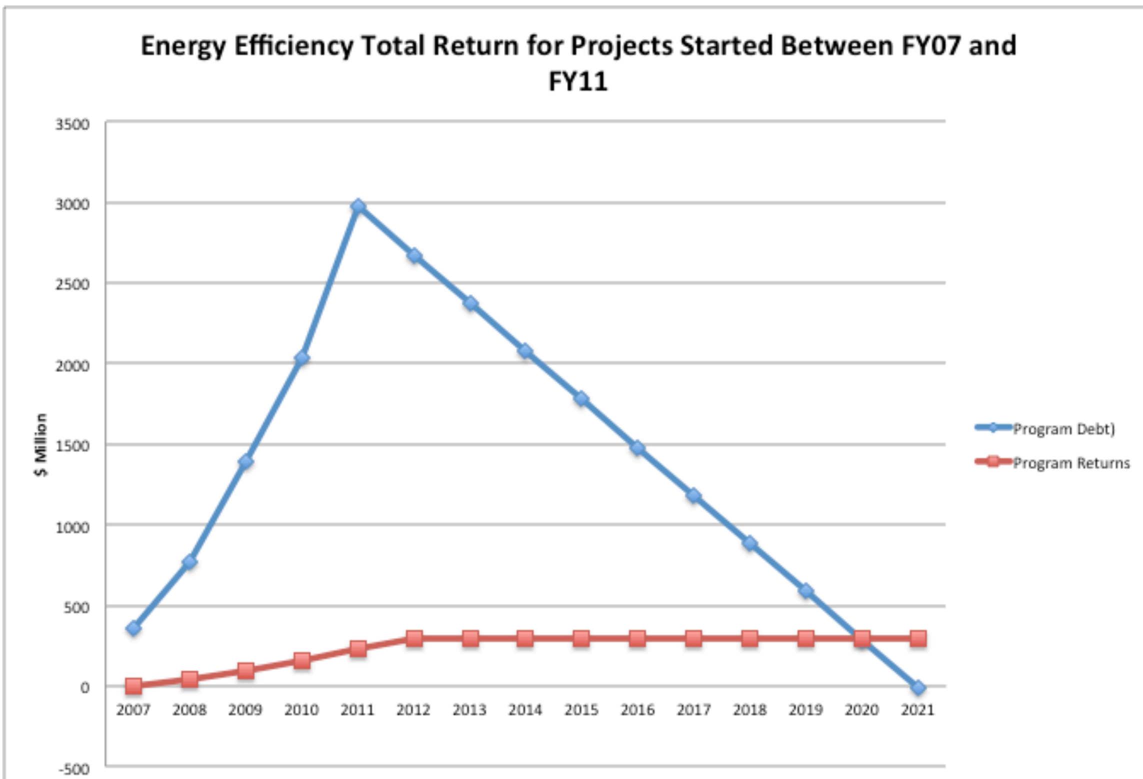

Figure 10: Optimal Repayment Schedule For Efficiency Projects

Figure 10 shows the large upfront costs of programs and the lengthy "payback" or "benefit" period. The benefit period is the number of years required for a project to "pay for itself" and DoD to recoup the upfront investment. Recoupment timelines are based on the extremely generous assumption that efficiency projects will return savings as intended. As the NREL studies noted, however, many efficiency procedures do not result the predicted levels of reduction. Individual behavior is extremely hard to modify. Energy

audits of buildings might not accurately capture building energy usage or as building purposes change, energy usage will change. Additionally, deviations in standard weather patterns and changes to the price of commercial energy will affect returns on the investments. Finally, expenditures for maintenance and repair of new technologies are not captured in the initial cost estimates. Therefore, one might conclude that Figure 10 represents an optimally or "best case" recoupment schedule.

3. How effective are the renewable energy measures at producing a reliable source of power that meets the operational needs of an installation?

Understanding the value of DoD's renewable energy measures requires an understanding of the distribution of DoD's renewable energy sources and the metrics being used to measure success. According to regulations, DoD will be required to produce 25% of its energy from renewable sources by 2025. At the present time, however, the energy produced from DoD's two largest renewable energy projects (China Lake Thermal Plant and Norfolk Naval Shipyard Waste Facility) is not yet directly used by DoD but is instead sold to local utilities. As a result, DoD is self-generating only a very small portion of its own energy. As illustrated in Table 3, many of the renewable energy projects produce small amounts of power. The first half of the table shows the total number of renewable energy projects in DoD as well as the total number producing less than 100 BBtu/year (4 MW). The second half of the table shows how much energy these projects produce in terms of percentage of DoD consumption.[5]

Table 3: DoD Energy Production as a Percentage of Consumption

Fiscal Year	2011	2012
Number of Renewable Energy Projects	476	679
Small Production Projects (<100 Bbtu/yr)	461	454
Energy Produced as a Percentage of DoD Total Annual Energy Consumption		
China Lake/Norfolk	2.53%	2.61%
All other Projects	0.96%	1.37%
Total	3.49%	3.99%

[5] The energy to power conversion rate is based on a 24-hour day, 365-day year and a production capacity of 90%.

As Table 3 further illustrates, the vast majority of DoD renewable energy projects are small and produce less than 100 Bbtu annually. Of the 454 small projects (producing less than 100 BBtu/year) in 2012, 91.9% produce less than 5 BBtu/year (0.19 MW). Most provide power to very small, ancillary pieces of equipment and thus do little, if anything to improve energy security. Major communication nodes, intelligence hubs, troop staging locations and operational installations still draw almost all of their power from conventional sources. Renewable sources are used sparsely to power a few outdoor lights or perhaps heat a single building.

Table 4 is a list of major installations and an analysis of their energy demands from FY 2012. The chart illustrates that most key operational installations could be fully powered by a facility the size of the China Lake thermal plant, which produced over 3600 Bbtu of energy in FY 2012. Conversely, if one uses the power from all 454 small energy projects in DoD (each producing less than 100 Bbtu/yr), the total energy produced in one year would be 1147 Bbtu. The combined output of all the small energy projects fail to meet the energy demands of most DoD installations.

Table 4: Installation Energy Demand Analysis

Installation, Location	FY12 Energy Consumption (Bbtu)	Primary Energy Source Viability		Emergency Energy Viability (25%)	
		China Lake (3671 Bbtu)	454 Small Projects (1147 Bbtu)	Emergency Energy (Bbtu)	Energy Source < 100 Bbtu
Fort Bragg, NC	3491	Y	N	873	N
Fort Campbell, KY	1578	Y	N	395	N
Ft Wainwright	3006	Y	N	752	N
Pearl Harbor, HI	846	Y	Y	212	N
Naval Station Norfolk	2032	Y	N	508	N
Florida Keys Air Station	199	Y	Y	50	Y
Twenty Nine Palms, CA	871	Y	Y	218	N
Lackland AFB, TX	1994	Y	N	499	N
Peterson AFB, CO	2188	Y	N	547	N
NSA, Various Locations	3042	Y	N	761	N

If DoD is to achieve energy security, it must produce energy on a scale that is usable. In an energy security crisis such as a grid collapse, a natural disaster or a cyber attack, DoD would depend on self-generated power. In the event of a crisis, DoD installations could

limit what facilities receive power and which do not. Table 4 shows the installation requirements for an emergency energy level set at 25% of normal demand. Assuming an emergency energy level of 25% consumption, military installations will need a reliable power source greater than 100 Bbtu/year. Most of DoD's renewable energy projects produce less than 100 BBtu per year and 91% of these projects actually produce less than 5 Bbtu in a year. The current size and scale of DoD's renewable energy project fails to provide an installation energy security in emergency situations.

Energy Security: A Problem Unchanged

DoD will continue it efforts to reduce energy consumption and find optimal consumption levels.. The focus of these efforts is continued improvements to existing buildings and building energy efficiency into new buildings. As the Defense Department restructures its force, however, consumption needs will change. A periodic assessment of power demands and reevaluation of the 30% target goal will better aid in finding the optimal energy demand level for the department.

However, reduction in energy usage alone will not provide protection against energy attacks. To be secure and remain mission capable in a time of threat to national security, the Department of Defense must have an independent, reliable source of power. In FY2012, DoD conducted an analysis of utility outages across its installations and found 87 outages that each lasted longer than 8 hours. Figure 11 shows a breakdown of these outages and their financial impact. The largest contributor to significant loss of power to an installation is acts of nature. [4]

Figure 11: FY2012 Utility Outages Lasting Longer Than 8 Hours[4]

Figure 11 focuses on outages lasting longer than eight hours. However, eight hours, in a time of crisis, is an eternity. For example, the time from when United Airlines Flight 175 crashed into the south tower of the World Trade Center to the time the building collapsed was fifty-six minutes. Thirty minutes later the north tower collapsed.[21] During that time, every person in America and many millions across the world watch their televisions anxiously. New York's first responders moved immediately, many to their own peril, to respond to the incident. Imagine if the response had been delayed 8 hours.

Figure 12 illustrates DoD's use of renewable energy as a percentage of total electrical energy consumption.

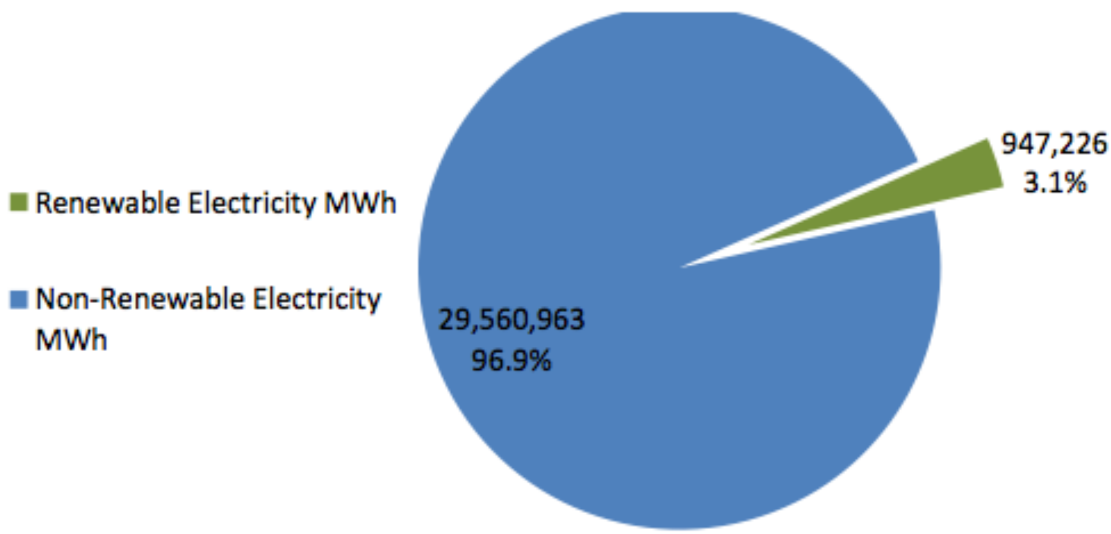

Figure 12: Use of Renewable Energy as a Percentage of Electricity Use[8]

Not only is the overall percentage of renewable energy sourcing small, the majority of all renewable energy is produced at only two locations. Further, 61% of its renewable energy projects for FY2012 produced less than 5 BBtu/yr (0.19 MW). Given that the average residential house in the United States has an annual energy rate of 0.0013 MW, a single 5 BBtu/yr project can power about 143 homes.[22] Clearly, such projects are ineffective in improving energy security. Nonetheless, DoD continues to invest in micro-energy projects, allocating just under $80 million in FY2012 for this type of renewable energy project. The myriad of micro-energy projects not only failed to increase energy

production to target levels, but also failed to advance any real energy security improvements.[4]

Despite these failures in renewable energy procurement, DoD decided to embark on an ambitious plan to meet its goals. DoD is actively exploring ways to develop renewable energy on its installations instead of purchasing renewable energy credits. Each department of the military (Air Force, Navy, Army) has set a goal of developing 1 GW of power from renewable energy by 2025. DoD plans to couple its goal of 3 GW of renewable power with efficient distribution using micro grid technology. Micro grid technology allows an installation to not only generate its own power, but also control the distribution and storage of that power. DoD estimates that such a system would allow a military installation to achieve independence from conventional power resources and reduce energy vulnerabilities.[4]
Yet improvements in grid control will do little good if the power supply is neither constant nor sufficient. Achieving 3 GW of self-produced power is an unrealistic goal given the current energy production model. Unless the Department of Defense considers alterative sources of energy for on-site production, it will never achieve 3 GW of self-produced power. It will also never truly be postured to meet the basic mission requirements needed to support the people of the United States in the event of a state side national crisis.

Chapter 6: Finding a Solution to Energy Independence

The Sustainable Definition of Renewable Energy

"The Department's vision of sustainability is to maintain the ability to operate into the future without decline-either in the mission or in the natural and man-made systems that support it." (DOD SSS FY12)

The Department's definition of sustainability has two parts; (1) protecting its ability to operate and (2) protecting natural and man-made support systems. The World Commission on Environment and Development describes sustainability as "*meeting the needs of the present without compromising the ability of the future generations to meet their own needs."* Hidden within this generalized definition of sustainable exist many interconnect factors.[23] The first part of a sustainable energy solution for DoD is to meet its energy needs. While DoD's current initiatives protect future generations they fail to allow the organization to function in the future. Failing to produce even 7% of its own power leaves DoD vulnerable to natural disasters, terrorist attacks and cyber threats. Increased energy production is vital to achieving energy security and to DoD developing a sustainability strategy that is both effective and lasting.

DoD's recently added goal to produce 3 GW of is own power by 2025 is ambitious, given its current levels of self-generation. By comparison, Georgia Power announced in February of 2013 that it would be shutting down 15 coal and oil fired units by April 2015. These facilities had a combined production capability of 2.016 GW.[24] That is an average production loss of 134 MW per plant. Only DoD's China Lake facility rivals the production levels of conventional plants. DoD's current production ratio per renewable energy project, excluding China Lake and NNS Norfolk, is 0.21 MW per project. When only looking at small projects (less than 100 Bbtu/year produced), the ratio is even lower at .09 MW per project. Using the more generous ratio, DoD would need 14286 projects to produce 3 GW of power. The Department of Defense must close the gap between its current renewable energy production and its energy demands in order to be sustainable.

In order to accomplish this, a reexamination of the definition of renewable technology is needed.[6]

DoD Redefining Renewable Technology To Meet Its Needs

Under its current energy strategy DoD attempts to provide sustainability using renewable energy technology.

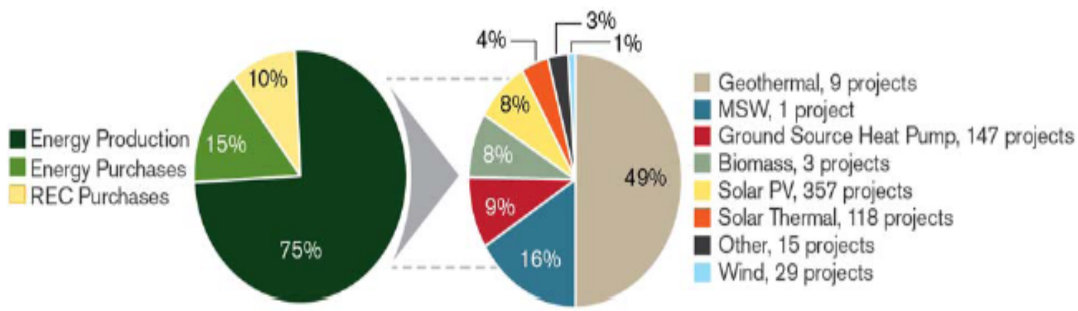

Figure 13: DoD Renewable Energy Projects by Type[4]

Figure 13 shows a breakdown of the renewable energy sources used by the Department of Defense in FY 2012 for its energy security projects. EPA 2005 defines renewable technologies as "electric energy generated from solar, wind, biomass, landfill gas, ocean (including tidal, wave, current and thermal), geothermal, municipal solid waste or new hydroelectric generation capacity achieved from increased efficiency or additions of new capacity for an existing hydroelectric project" (EPA2005) The EPA 2005 definition is in regards to how the federal government defines power consumed that is creditably toward EPA 2005 goals. A broader definition of renewable energy comes from the Department of Energy (DoE). DoE defines renewable energy, as

"Energy derived from resources that are regenerative or for all practical purposes can not be depleted." [25]

The DoE definition focuses on the sustainability aspects of renewable technology while the EPA2005 definition simply defines types of production. The EPA2005 definition is not intended to promote innovative and new technological developments. Instead it is

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[6] The energy to power conversion rate is based on a 24-hour day, 365-day year and a production capacity of 90%.

simply to be used for the purposes of the act, as a guide for how organizations receive renewable energy credit under the law. EPA2005 was never intended to promote energy security on a large scale. The intent of EPA 2005 was simple to promote conservation, reduce green house gas emissions and increase the use of currently recognized renewable energy platforms.

To be a sustainable organization, DoD much approach energy production with a much larger technological aperture of than limiting guidelines of EPA 2005. It must look to the root definition of renewable and apply it to technology promote its energy needs. DoD needs a source of power that is robust in energy output in order to sustain the small-scale cities, which are its installations. EPA2005 technologies do not produce power on the scale necessary to power a military installation. DoD needs a power source that operates in a variety of climates providing a consistent source of power year round. EPA 2005 technologies work in a spattering of climates with mixed rates of production dictated by seasonal conditions. DoD needs a technology that once in place, has a proven record of lasting for long durations providing consistent power with little overhaul or replacement of major components. EPA 2005 technologies are delicate and have not been shown to provide long lasting, consistent power outputs. Finally, DoD needs a power source that can operate in conjunction with the mission requirements of its installations without hindering operations. The use of EPA 2005 technologies will require a selective approach to technology implementation due to potential drastic impacts on mission performance. Thus, to truly meet its energy needs, the Department of Defense needs to re-evaluate its choice of renewable production technologies and find a source of long lasting, consistent, mission compatible power. To meet the spirit of EPA 2005, this power source must be renewable and reduce the production of green house gases.

Renewable and Sustainable: Nuclear Power

As the Cold War intensified in the later half of the twentieth century, the Navy sought a new source of power. The Navy needed a fuel for its submarine fleet so the vessels could travel long distances without the need for extensive supply chains. In the 1950s, Admiral H. V. Rickover of the US Navy pioneered an incredible new idea by applying atomic

technology to the propulsion of vessels. Working closely with partners in DoE, the Navy launched its first nuclear powered submarine, the *USS Nautilus*, in September of 1954. Nuclear power submariners could now stay submerged for extended periods and were limited only by life support restrictions of the crew. By 1961, the Navy had its first nuclear powered aircraft carrier, the *USS Enterprise*. [26] Through the unique utilization of atomic technology, Admiral Rickover drastically altered the energy vulnerability of the Navy.

Figure 14: Ohio Class Submarine *USS West Virginia* [27]

Nuclear technology gave the Navy a significant operational advantage by allowing it to conduct submerged, strategic operations for extended periods. Nuclear power allowed the Navy to remove these vessels from extensive, costly supply lines of coal and diesel fuel. Resupply lines were vulnerable to attack from enemy vessels and required their own sustainment systems. The shift to nuclear power was one of the most significant technological revolutions in marine operations.

Just as in the Cold War period, the DoD of today is once again looking to technological solutions for its energy security and consumption challenges. Unfortunately, current renewable initiatives to produce power have been ineffective at achieving real energy independence. The outputs from solar arrays, wind turbines and most geothermal projects have so far failed to meet the energy needs of a military installation. This paper suggests

that the DoD, following the lessons learned from its past, should once again look to nuclear energy as a sustainable solution to its power needs. Nuclear energy is reliable, powerful, and consistent. Nuclear energy, while only producing 20% of the electricity in the United States, is operated as the base load power producer. Nuclear power plants run continuously at maximum production capacity and only shutdown periodically for refuel operations. They emit no greenhouse gasses. Reactor fuel can be mined as an ore, salvaged from demilitarized nuclear weapons or harvested from used reactor fuel.

While the United States does not conduct nuclear fuel recycling in commercial facilities, many other countries recycle their nuclear waste. The US energy industry has not found it economical to recycle its fuel. The "once through" fuel cycle used by commercial operators in the United States leaves significant amounts of fissile material within the fuel. Spent LWR fuel contains much of the U^{238} isotopes as originally in the fuel as well as about 33% of the U^{235} isotopes. There are also recoverable plutonium isotopes.[28] There are concerns about the proliferation of reprocessed material for improper uses, which has led to a US political policy that opposes reprocessing efforts.

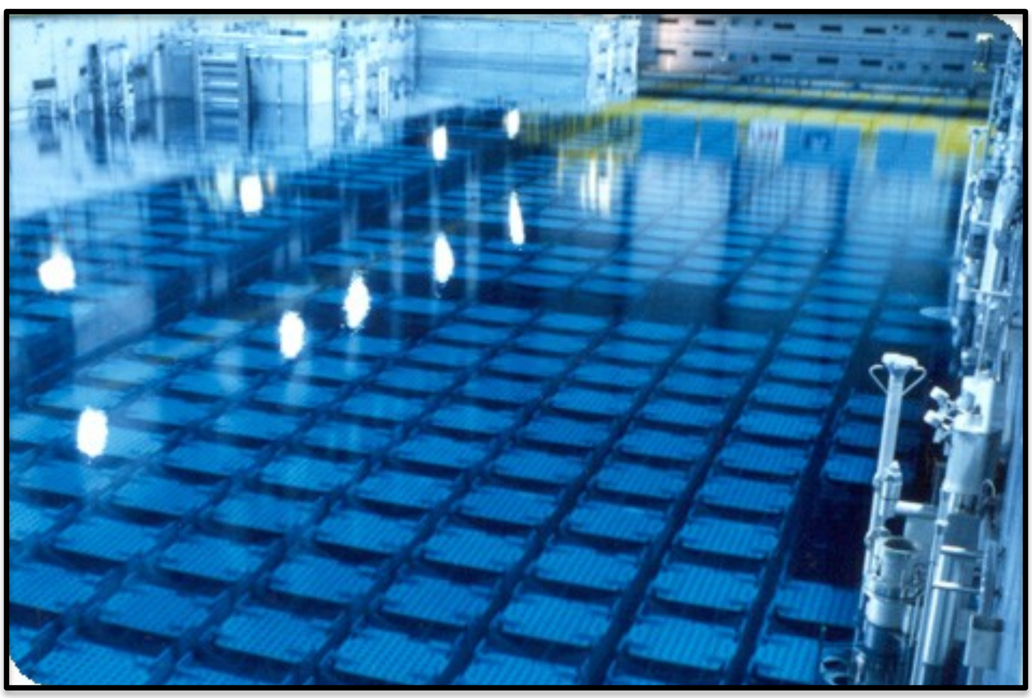

Figure 15: AREVA La Hague Reprocessing Facility in France[29]

The reprocessing of spent nuclear fuel isolates the useable isotopes from the waste materials in the fuel. The reprocessing of spent nuclear fuel reduces the amount of nuclear waste produced by one third. [23] The current amount of commercially generated spent nuclear fuel is about 65,000 metric tons. This approximately spans one football field at a depth of 20 feet. [30] Viewing this as a potential resource pool, one could utilize the spent nuclear fuel again with reprocessing and reduce the amount of waste to the size of an NHL hockey rink at a depth of 67 feet. Spent fuel reprocessing reduces not only the physical amount of nuclear waste but also significantly reduces the amount of isotopes with long radioactive half-lives While the commercial nuclear industry in the United States has not embraced reprocessing, the Defense Department does have experience reprocessing nuclear materials for commercial use.

The technology exists to recycle the fuel for repeated uses. Nuclear energy offers DoD a sustainable energy source that will allow installations to operate without decline in mission capabilities caused by lack of power. Additionally, nuclear energy has minimal impact on the environment. It emits no toxic greenhouse gases like coal or gas fired facilities. Nuclear energy has a proven history of long-term reliability in both commercial and defense operations.

Learning from the Past: The Army Nuclear Power Program

The idea of using a nuclear reactor to provide base power and heating is not a new idea. In the 1950s, the Army conducted a feasibly study with researchers at ORNL and determined that a nuclear reactor could be used to provide power and heating to remote installations. In a joint project conducted with the US Army Corps of Engineers and the AEC, a pressurized LWR was constructed and operated at Ft. Belvoir VA for 16 years. Over the next decade, seven reactors were built and operated. They provided heat and power to remote locations such as outposts in Greenland and Antarctica as well as to rural locations in the continental United States. The program even created a portable nuclear station on a floating barge platform that eventually was used to augment power in the Panama Canal Zone. A detailed history of the Army Nuclear Power program is found in Appendix A.

The Army Nuclear Power Program came to a close in the last 1960s and early 1970s. During that time, the Defense Department was shifting resources to support a war in Vietnam. The Army Nuclear Power Program was an expensive program because it developed 7 reactors that were all essentially prototype designs. There was extensive cost in the research and design of each facility as they served unique purposes. Additionally, the commercial price of electricity was very cheap compared to price to produce power. Despite the closure of the program, the Army had incredible success with its some of its prototype reactors. 50 years after the end of the Army Nuclear Power Program, military installations find themselves dependent on civilian provided power. At the time of the Army Nuclear Power Program, Americans felt safely insulated on their continent from the threats of a foreign enemy. Proxy wars were fought in places like Vietnam and Afghanistan rather than on our streets. Today, the world is interconnected through trade, information and the Internet. It is a truly global environment and geographical separations have little impact on a determined enemy.

Figure 16: Smog Surrounding 2008 Olympic Facilities in China[31]

Additionally, at the time of the Army Nuclear Power Program, little concern was given to the harmful effects of burning fossil fuels. There was more concern with acquiring enough coal or gas resources to fire a plant than what harmful by-products came from the facility. Today, the effects of fossil fuel burning are well known. Pollutants released

from the burring of fossil fuels are linked to increase rates of respiratory diseases such as lung cancer. Figure 16 illustrates the dire pollution problem in China showing an image of the 2008 Olympic facilities in China.[31] Production facilities utilizing the burning of coal or natural gas are under increased scrutiny by the American government and a concerned public.

The increasing threat to our commercial power supplies combined with the desire to produce clean energy make the Army Nuclear Power Program a file in military history which should be reexamined for potential application.

Chapter 7: Small Modular Reactor: A New Era With an Advanced Solution

Small modular reactors (SMRs) provide a flexible solution to power generation, to meet the diverse and growing demand for clean energy. "Small" is a relative term, and the IAEA defines SMRs as "small and medium reactors." Power outputs for small reactors are less than 300 MWe while medium reactors produce less than 700 MWe.[32] The American Nuclear Society (ANS) defines Small Modular Reactors (SMRs) in its position statement #25, published in June 2011, as reactors producing less than 300 MWe.[33] The US Department of Energy shares the same position as ANS by defining SMRs as

"nuclear power plants that [are] smaller in size (300 MWe or less) than current generation base load plants (1000 MWe or higher)"[34]

Hence, the wide variation in production levels (ranging from a few MWe to almost 300 MWe) allows for competitive market placement of the reactors to meet the needs of a specific community. Smaller production outputs allow for flexibility when siting and commercializing SMRs. SMRs offer solutions to communities that exist in remote locations. Such locations often have long supply lines for energy sources like heating oil and are often located at the end of power transmission lines. The long supply lines increase energy cost to remote locations and also make them prone to outages. Additionally, remote communities or developing countries might not have the electrical grid capacity capable of supporting a large power generation station. However, the smaller grids would be capable of integrating a smaller electrical production facility into their network.[35] The size and scalability of SMRs also makes them a viable replacement for fossil fuel facilities as utility companies look to replace aging, high polluting plants with cleaner technology that still meets needed output demands.

In addition to a more adaptable supply of electricity, the reactor facilities are modular. The primary components of the facility are constructed in a factory, separate from the power generation site and are then transported by highway or rail to power generation site and installed. Though small and modular, new generation SMR designs incorporate enhanced passive safety features as well as improved control technology. Due to the

plant's small size and modular construction concept, SMRs should be more economical to produce, install and operate than the conventional base load nuclear power stations.

Alternative and cogeneration uses for SMR facilities are presently under study. For example, district heating, desalination, hydrogen production and chemical production could all be powered using nuclear thermal energy. A cogeneration SMR could bring not only provide a remote, arid community stable electoral power, but it could also serve as a heat source for desalination processes needed to supply fresh water. The size, scalability and flexibility of SMRs make them an attractive, high potential product for the nuclear industry.

SMR reactor technology is further broken into three distinct types of reactors: light water; high temperature gas; and liquid metal and liquid salt cooled.

Light Water Reactors

SMRs utilizing Light Water Reactor (LWR) technology most closely mirror the current commercial reactor designs. Most SMR LWRs use pressurized water reactor technology (PWR). PWRs use pressurized water as a cooling and heat transfer mechanism. They produce steam that is then used in the production of electricity. Operating within the thermal neutron energy spectrum, LWR designs typically use low enriched uranium for fuel (less than 5% U235) formed in the shape of fuel pin assembly and moderated with water. Fuel rods are grouped into bundles and arranged for optimal power density and fuel burn-up.

The current regulatory structure is designed around the licensing of light water reactor facilities. LWR technology has well defined mechanical, material and structural standards for operating temperatures and pressures. Valve and pump technology is well developed as well as advanced neutron modeling techniques. While there are some questions about differences when licensing a SMR LWR verses a large commercial facility, it is thought that a SMR LWR will be the easiest reactor design to license under the current regulatory structure due to design stimulatory. Most questions involving the licensing of SMRs

involve changes in scale due to the size of the reactor. Other questions revolve around the licensing of individual modules verses an entire facility. Today's licensees must submit licenses for each reactor built. SMR developers hope to avoid licensing costs by licensing multiple modules with one license. Figure 17 shows a conceptual design for a NuScale SMR LWR module.

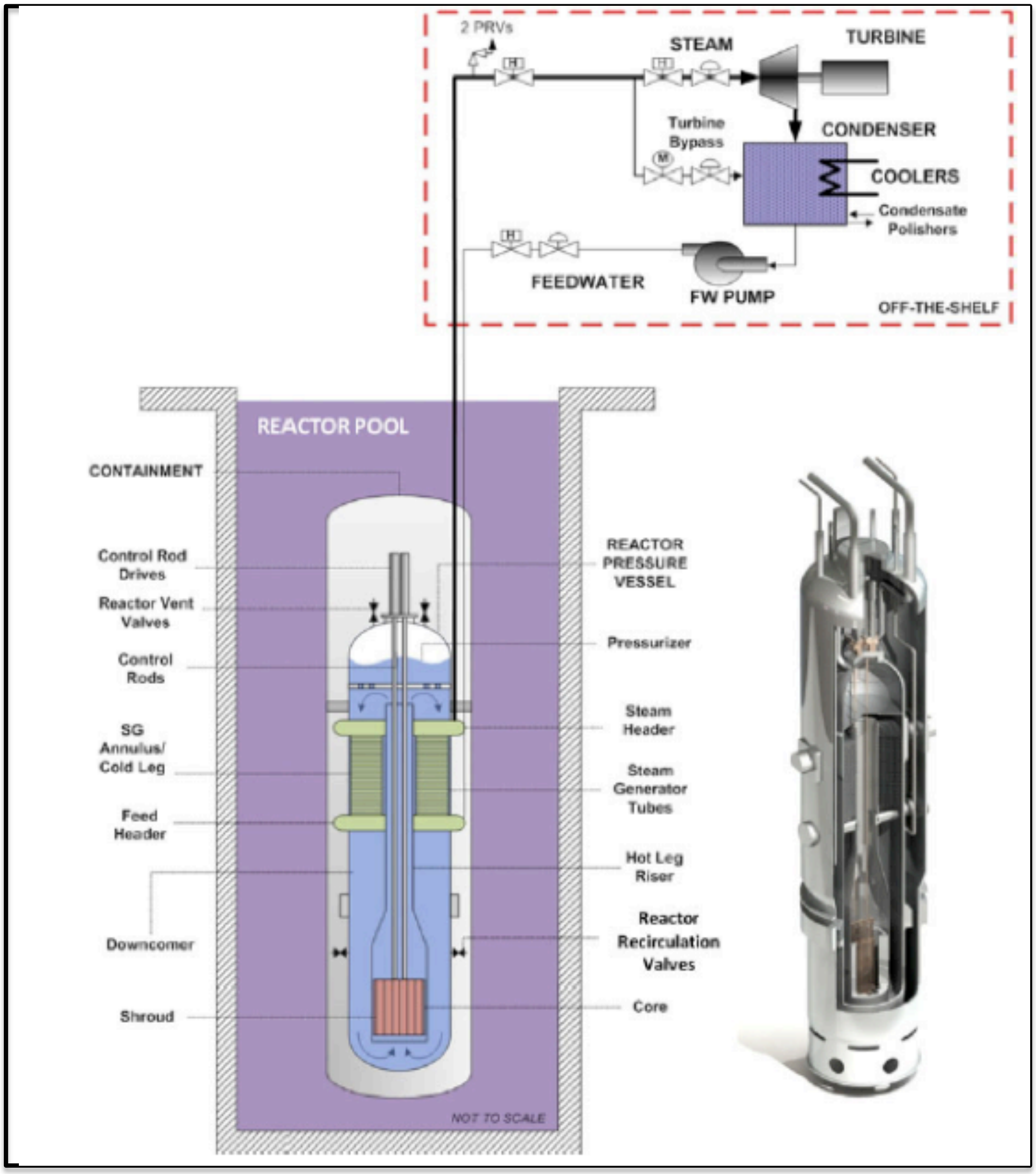

Figure 17: NuScale SMR LWR Concept[36]

High Temperature Gas Reactors

High temperature gas reactors (HTGR) are attractive for use in process heat applications due to their ability to produce a high temperature output. High output temperatures are extremely important in the production of hydrogen as well as some chemicals. The production of hydrogen on an industrial scale could be beneficial as an alternative to fossil fuels when powering vehicles. The United States has successfully operated HTGRs in previous years and international organization have also expressed interested in gas-cooled reactor technology. The current regulatory framework in the United States does not support the licensing of gas-cooled reactors. Small HTGRs not only will be subject to the same regulatory challenges associated with LWR SMRs related to their size and implementation but they will also face licensing challenges based on the advanced nature of their design. Despite the licensing challenges, they offer great flexibility for a customer in that they are ideal for cogeneration facilities.

Liquid Metal and Liquid Salt Cooled Reactors

Liquid metal cooled reactors utilize liquid metals such as sodium or lead as their primary coolants. Liquid salt reactors use fluoride and chloride salts (also called molten salts) and are also being examined as alternative coolants to water. Sodium, lead and molten salt cooled reactors have successfully been built and operated previously in the United States as well as aboard. These reactors have some unique safety features by virtue of using a liquid metal or salt for cooling rather than water or a gas. They operate at low pressures and have negative temperature void coefficients. Some molten salt designs dissolve fuel into the liquid coolant rather than being forming it into a solid. Liquid fuel designs have some nice passive safety features as well as being extremely proliferation proof. The technology of molten salt reactors is of interest to those seeking a long-term solution to the nuclear waste problem of legacy systems in the U.S. It is thought that a molten salt reactor operating on liquid fuel could be powered using spent nuclear fuel from LWR facilities with minimal reprocessing. Lead and sodium are both poor neutron moderators and therefore well positioned for fast reactor operations.

Licensing presents a major near term hurdle for liquid metal and liquid salt reactors. They are still very much in the research stages of production and have some material challenges to overcome. There is still research to be done in the development of materials that are corrosion resistant as well as studying the effects of radiation on these materials at high temperatures.

SMR Applications of Advanced Reactor Technology

Advanced reactor technology research is progressing despite licensing challenges. Much of the research done in developing these reactors will help the industry as a whole. The materials research, fuel development, and modeling methods used in advanced reactor design will improve current designs. The research for advanced reactor technology is not limited to reactors generating less than 300 MWe. The research is focused on developing advanced designs beyond the LWR concept. Many of the reactor concepts developed could be applied to a community needing an SMR. Currently there are a number of advanced reactor designs of interest. DoE is working on its Next Generation Nuclear Plant (NGNP), which is based off an Areava design for an HTGR. [37] Other gas-cooled designs include the General Atomics Gas Turbine-Modular Helium Reactor (GT-MHR) and the Pebble Bed Modular Reactor.[35] GE Hitachi is perusing a modular sodium cooled reactor called PRISM.[38] Toshiba is working on a sodium reactor called 4S. The 4S reactor is a fast reactor designed to operate for 30 years without refueling.[39] At Oak Ridge National Lab, a team is working to modify the Fluoride Salt Cooled High Temperature Reactor (FHR) into a small version called the SM-AHTR.[40] While advanced reactor technology is not yet technologically ready for commercialization, the research gains made are tremendous for the industry.

Description of SMRs Considered

The following analysis compares four SMR designs. The designs studied are

1. Babcock and Wilcox mPower LWR
2. NuScale LWR
3. GE Hitachi Nuclear Energy PRISM
4. Toshiba 4S

The following paragraphs provide a brief description of the reactor design. Highlighted features include the reactor output, coolant methods, safety measures, and refuel intervals.

Light Water SMRs

The two best-known SMRs thought to be ready for commercial production are Babcock and Wilcox's mPower reactor and NuScale Power's SMR design. These reactor designs gained notoriety as leaders in the field by receiving significant funding support from the Department of Energy to develop small reactor technology. Both reactors utilize LWR technology. Westinghouse is also developing a LWR SMR design called W-SMR. Recent reports however indicate that Westinghouse plans to reprioritize its efforts away from SMR technology to focus on its AP1000 large commercial PWR. The Westinghouse change in strategy comes after twice failing to receive funding support from the Department of Energy to promote SMR technology.[41]

MPower

B&W's mPower reactor is a small, light water reactor that integrates the latest passive safety features into proven reactor concepts. The reactor vessel contains the core, the control rod drive mechanism, the steam generator and the pressurizer. The core is fueled by low enriched uranium that is similar in configuration to today's large scale reactors. Core reactivity is maintained through the use of control rods. The control rod drive mechanisms are located in the lower vessel and below the pressure boundary, which exists between the core in the lower vessel and the steam generator in the upper the vessel. This reduces the risk of control rod ejection. Additionally the control rods have the passive safety feature of gravity activation in the event of loss of power. Figure 18 shows the location of key components within the mPower reactor.

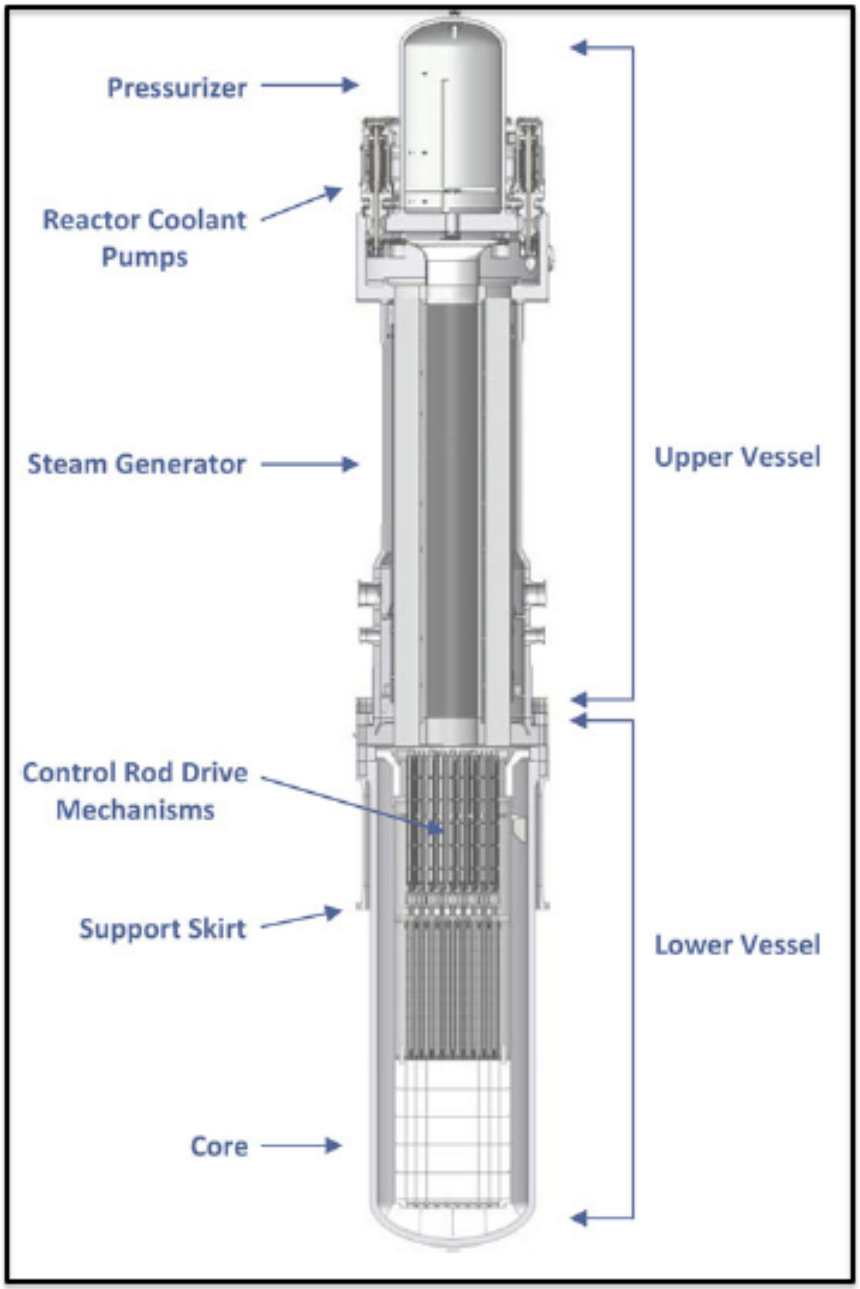

Figure 18: Babcock and Wilcox mPower SMR[42]

Light water reactors require constant cooling and thus it is paramount in an emergency situation that the core remains covered in water. Due to the one-vessel integrated design of the mPower reactor, all reactor coolant stays within the vessel. Figure 19 shows the primary and secondary coolant loops of the mPower reactor. There are small penetrations in the reactor vessel to provide for coolant sampling and letdown but they are located well above the core. This design, coupled with a large water inventory inside the vessel, allows for the core to remain covered in the event of an accident. There are additional tanks within the containment building holding enough water to provide cooling for a minimum of 7 days. The core utilizes gravity and natural circulation for cooling which aids in removing decay heat without the use of emergency diesel generators. Finally, the containment building itself is located below ground and is resistant to both flooding and seismic events.

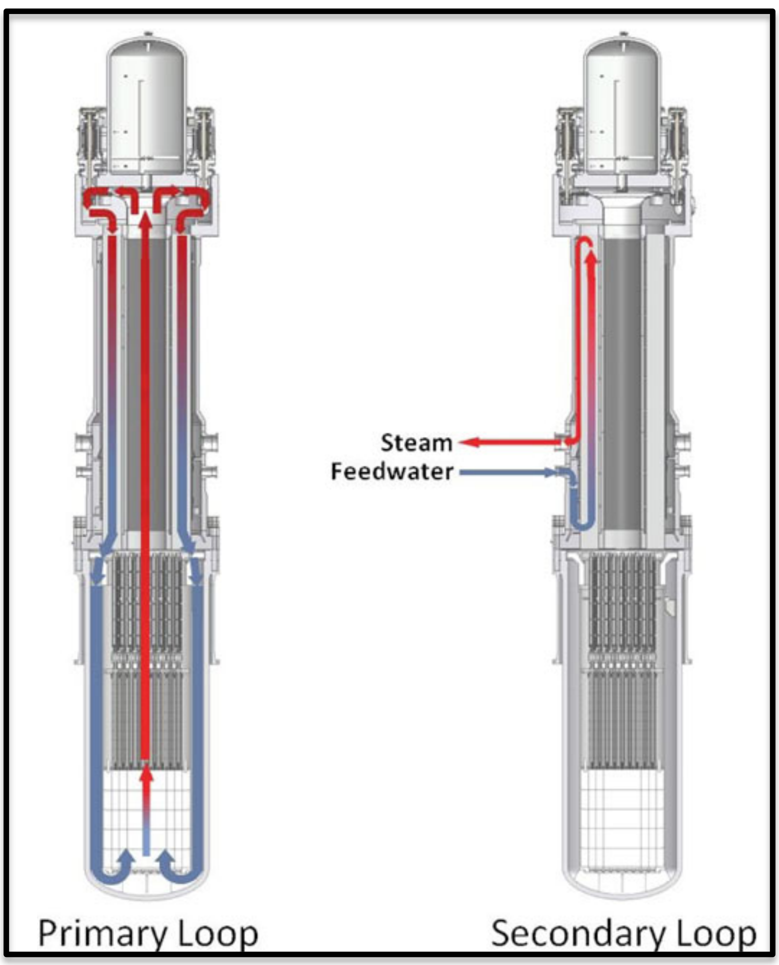

Figure 19: B&W Coolant Flow Diagram[42]

The B&W mPower reactor produces 155 MWe (530MWth) for each module. At a height of 83 feet and a diameter of 13 feet, the modules are very small compared to their commercial, large-scale brethren. They are modular in construction. Movements of the major reactor components can be done via rail or road. The mPower reactor has a refueling interval of 4 years. The containment building also has a spent fuel pool for cooling used fuel until it can be transferred to dry cask storage or a geologic repository. B&W significantly reduced the size of the reactor facility. A two-module facility sits on only 40 acres. Table 5 lists some key design characteristics of the mPower reactor.

Table 5: mPower SMR LWR Design Characteristics[43]

Feature	mPower
Thermal Output (MWth)	530
Electrical Output (MWe)	155
Vessel Size	Diameter: 13 ft.
	Height: 83 ft.
Vessel Weight	628 Tons w/o fuel
	716 Tons w/ fuel
Fuel Enrichment	< 5% U235
Fuel Shape	17x17 fuel pin array
	95 in active length
	69 bundles
Refueling Interval	4 years
Coolant outlet Temp	320 °C
Land Requirements	40 Acres (2-pack)

The Tennessee Valley Authority plans to use B&W's mPower reactor to power is SMR reactor facility under development at Clinch River Tennessee. This will be the first SMR reactor facility to undergo licensing, development and implementation is thought to be a pilot project for the SMR proof of concept. [42]

NuScale

The NuScale reactor is also a small light water reactor utilizing the latest in active and passive design features to produce a safe, scalable power solution. Similar to the mPower design, the NuScale reactor uses a standard light water reactor fuel bundle (17X17 configuration) enriched at just under 5% U235. Within the NuScale reactor vessel lies

the core, the control rod drive mechanisms, two steam generators and the pressurizer. The NuScale reactor utilizes natural circulation to move heated coolant water from the core, up through the steam generator and then returns it to the core. As the heated coolant water rises through the steam generator, it conducts heat to the secondary coolant loop within the steam generator. It then condenses and falls back to the bottom of the vessel with the aid of gravity and is once again heated by the core.

The reactor utilizes two passive heat removal features in the event of an emergency. The reactor vessel sits in a reactor pool. The decay heat removal system (DHRS) removes heat by routing coolant from the two steam generators to condensers submerged in the reactor pool. Rather than sending steam to a generator for power production, the steam transfers heat to the pool to aid in decay heat removal. Figure 20 illustrates the DHRS integrated onto a NuScale reactor.

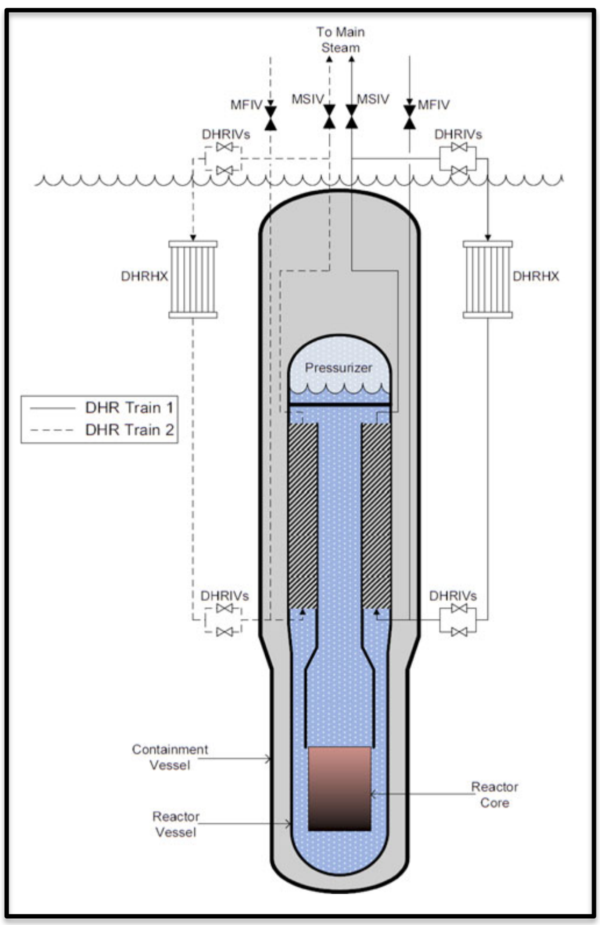

Figure 20: NuScale DHRS[36]

The second passive heat removal feature is the emergency core systems (ECCS). It recirculates primary coolant within the reactor vessel. As heated primary coolant rises to the top of the vessel, vents open at the top and allow the heated water to escape (as steam) from internal section of the reactor vessel. The steam condenses on the inside of the exterior wall the reactor vessel and falls to the bottom. As the coolant level on the exterior portions of the vessel rises, it aids in cooling the rector from the outside. Once the external water level reaches the top of the vessel, vents at the bottom of the reactor open allowing the water to circulate through the internal portions of the core and out the top of the vessel in one loop. Figure 21 illustrates the movement of emergency cooling utilizing the ECCS.

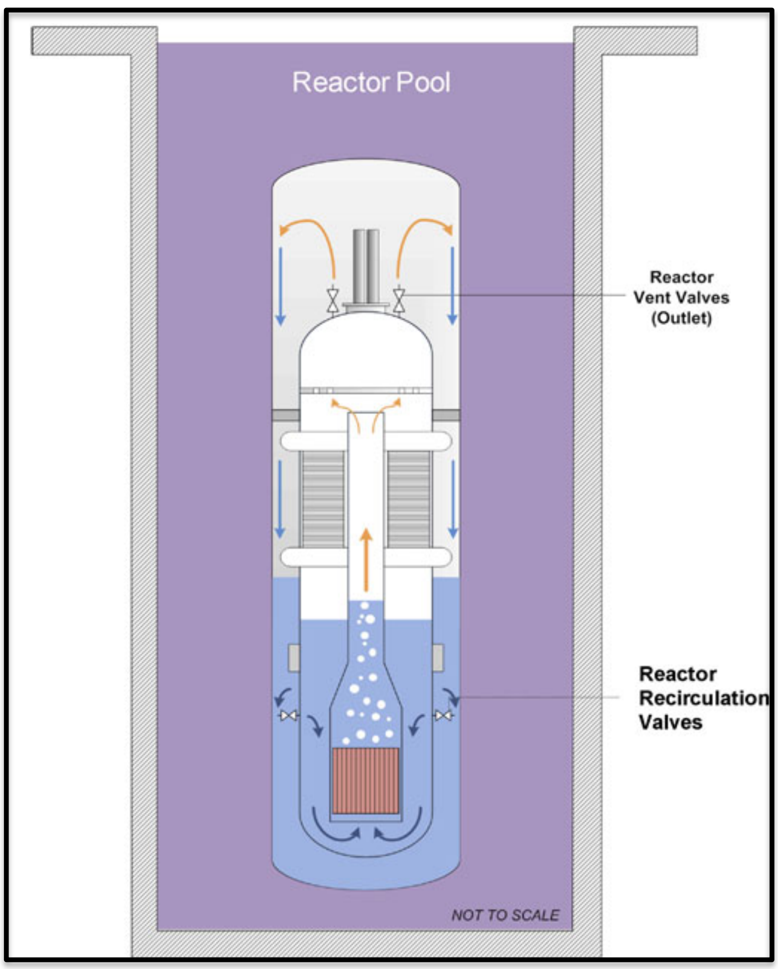

Figure 21: NuScale ECCS[36]

The NuScale reactor has a power output of 45 MWe (160 MWth). The reactor vessel is small compared to conventional plants with a single module weighting 650 tons and standing 80 feet high. It is modular in construction and can be shipped via rail, road or barge. The physical size of the reactor facility is very small. A reactor facility containing 12 modules (540 MWe production) sits on a facility that is only 44 acres.

Due to the power output of the NuScale plants, they are very adaptable to the needs of a community. Configurations of up to 12 modules can be linked to support the specific needs of a community. Table 6 illustrates some of the key characteristics of a NuScale Module.

Table 6: NuScale Reactor Characteristic Summary[44]

Feature	NuScale
Thermal Output (MWth)	160
Electrical Output (MWe)	45
Vessel Size	Diameter: 15 ft.
	Height: 80 ft.
Vessel Weight	650 tons as shipped
Fuel Enrichment	Standard LWR fuel (<5% U235)
Fuel Shape	17x17 fuel rod assembly
	78 in length
Refueling Interval	24 months
Coolant outlet Temp	
Land Requirements	44 Acres (12 Module)

A NuScale reactor has a 24-month refuel interval. The unique design of the NuScale reactor facility allows for simultaneous refuel and power production operations. Figure 22 illustrates the layout of a 12 module NuScale reactor facility with refueling bay and spent fuel pool.[36]

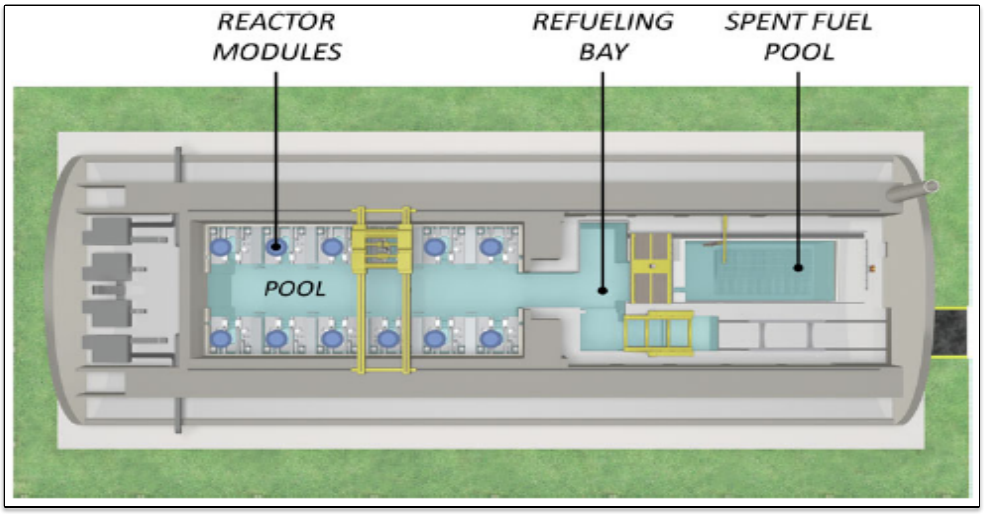

Figure 22: 12 Module NuScale Reactor Facility Layout[36]

To refuel a module, it is physically removed from the reactor bay and placed in the refueling bay. There, it is isolated from the operating reactor modules. In the refuel bay it undergoes refuel and maintenance operations. The integrated, continuous refuel cycle of the NuScale facility reduces the impact of refuel operations on the plant operator. Rather than occasionally shutting down to conduct large scale refuel operations, the operator utilizes a small specially trained team that focuses only on continuous refuel operations.

Liquid Metal

PRISM

The PRISM reactor is a sodium fast reactor (SFR). GE Hitachi Nuclear Energy, as part of the Global Nuclear Energy Partnership (GNEP), is developing it as a solution to spent nuclear fuel challenges. The goal of the GNEP is to develop an Advanced Recycling Center (ARC) to reprocess used nuclear fuel. The PRISM reactor is a central component of the recycle process, as it would operate on the recycled fuel.

The PRISM core has metallic fuel. The fuel is formed within the recycling center. The composition of the fuel and its configuration within the core will change depending on the mission of the PRISM reactor. PRISM missions could include the recycle of actinides, breeding fuel or consuming highly enriched fuel from nuclear weapons. The PRISM is intended to be a solution to many different nuclear fuel cycle challenges. The primary mission of the PRISM is intended to be spent fuel recycle.

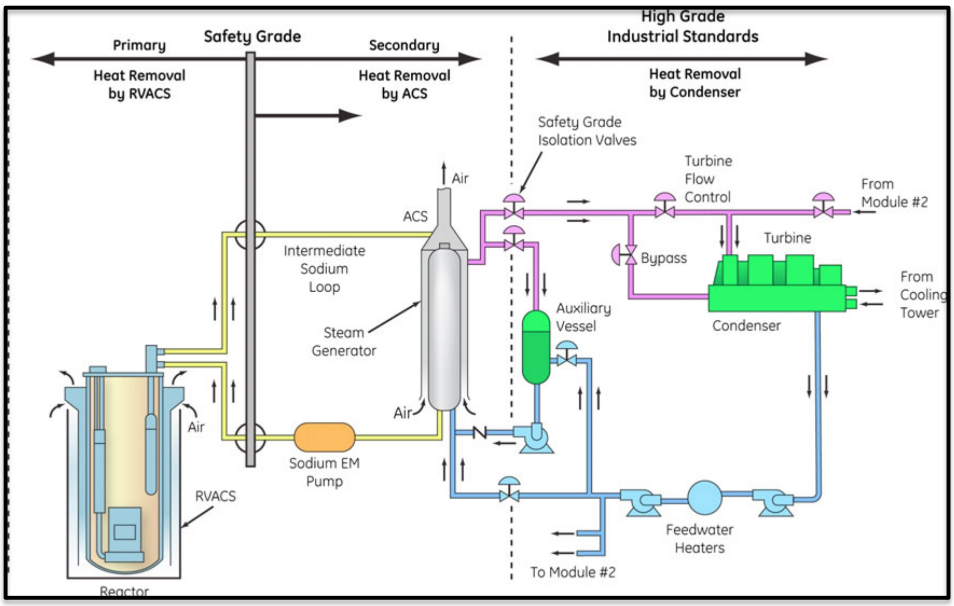

Figure 23: PRISM Coolant Loops and Balance of Plant[38]

The PRISM has three independent coolant loops as seen in Figure 23. The primary coolant loop uses sodium to cool the core and transfers heat to an intermediate sodium coolant loop. Heat transfer between the loops occurs within the containment vessel. The intermediate loop acts as an interface to the power generation portion of the plant. It transfers heat to tertiary coolant loop containing water. This loop is then used to make steam and provide power. There are a number of leak detection and isolation systems used to prevent the incursion and mixing of coolant or air between the loops.

The PRISM has a power output of 311 MWe, which is slightly higher than the ANS definition of an SMR. The ARC design calls for the operation of six PRISM modules. By having six modules the ARC has maximum flexibility. It has multiple fuel recycle

platforms, each configurable for the type of spent fuel in need of processing. Each PRISM can be configured to support and different fuel recycling mission and they can be operated simultaneously. While its design is not intended for use as a stand-alone facility, it does present a viable design concept for building a small scale SFR.[38]

4S

The Super-Safe, Small, and Simple (4S) sodium cooled reactor is being designed by Toshiba Corporation and the Central Research Institute of Electric Power Industry (CRIEPI). Its intended purpose is to support extremely remote locations and operate continuously without refuel for 30 years. Because the reactor is intended for use in remote locations, it is design to operate with very little maintenance and supervision. The reactor has an output of 10 MWe (30 MWth). It is modular in construction and can be transported by barge. Due to its small size, single fuel load and minimal operating costs, this reactor is very economical. The reduced cost of the reactor make it a possible candidate to provide long term power to small, remote locations.

The 4S is a sodium fast reactor that uses metallic fuel consisting of 18% enriched U235. The fuel is formed into metallic fuel pins. These pins are typically one of the lifetime limiting factors of a reactor. The cladding on fuel pins is susceptible to thermal creep. The 4S fuel pins mitigate this with thick cladding as well as a central gas plenum within the pin. This gas plenum is what enables the reactor to have a much longer lifetime than the typical reactor. Figure 24 illustrates the location of the glass plenum within the metallic fuel pin.

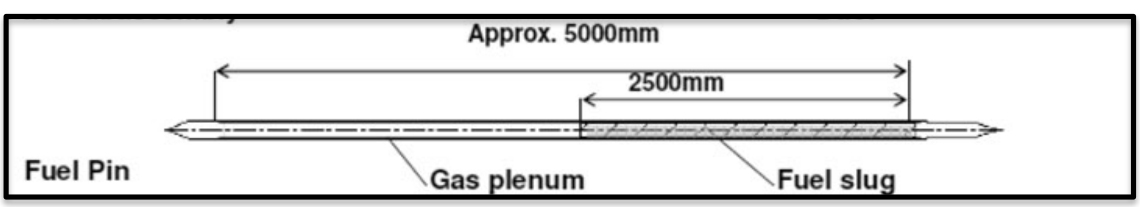

Figure 24: 4S Fuel Pin Configuration with Gas Plenum[39]

Reactivity is controlled through the combined use of a reflector and a fixed central absorber. By balancing the position of these features, the reactive can be controlled with

course movements for startup and shutdown as well as fine movements to balance burn up. There is also a shutdown rod in the center of the core that can be used for emergency shutdown. Either the removal of the reflector or the insertion of the shutdown rod is capable of providing the necessary negative reactivity to shut the core down on its own.

The 4S uses a three-coolant loop system similar to the PRISM reactor. The primary sodium loop is used to cool the core and is internal to the core vessel. The intermediate loop transfers heat from the core using sodium to the tertiary loop containing water. The tertiary loop is used to produce steam and makes electricity. All loops have leak detection and isolation features.

The 4S has several passive heat removal systems. The Intermediate Reactor Auxiliary Cooling systems (IRACS) uses air to cool the intermediate loop. Heat is removed from the core using the primary to intermediate loop interface. The IRACS then uses air, instead of water from the tertiary loop, to cool the intermediate loop. This air moves via natural circulation and vents excess heat into the atmosphere. It is an emergency system and is only intended for accident scenarios. The IRACS interfaces between the intermediate and tertiary loops. Figure 25 shows the location of the IRACS.

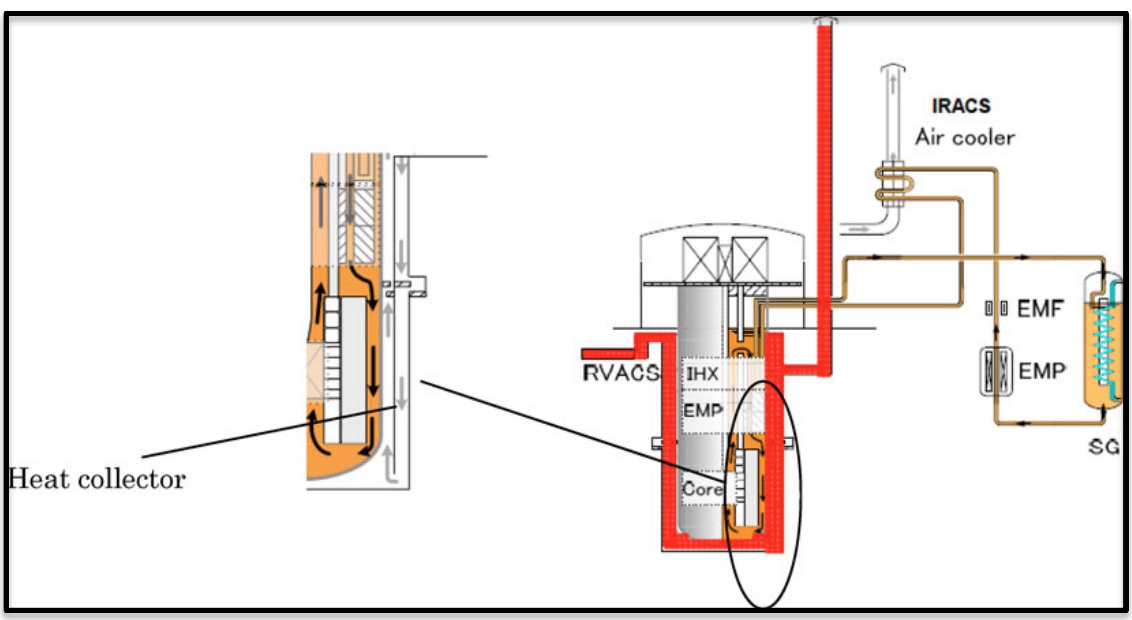

Figure 25: 4S Passive Reactor Safety Systems IRACS and RVACS[39]

The Reactor Vessel Auxiliary Cooling System (RVACS) removes heat by transferring directly it from the reactor vessel. The reactor vessel is surrounded by cylindrical heat collector, which is filed with air. Ambient air circulates within the collector providing decay heat transfer and removal from the reactor vessel. The heat from the heat collector is discharged via exhaust stacks. Figure 25 shows the RVACS location within the plant as well as a close-up of RVACS air circulation within the cylindrical heat collector. Both systems operating alone provide enough cooling to keep with fuel within material safety standards.[39]

Assessment of SMRs using Evaluation Criteria

I assessed each reactor design by rank ordering each design based on 9 assessment criteria. The following paragraphs define the assessment criteria. The full analysis of each reactor and its score for each criterion is found in Appendix B.

1. Safety
2. Power Output
3. Physical Size
4. Refueling Cycle
5. Licensing
6. Public Acceptance
7. Fuel Cost
8. Maturity of Technology
9. Process Heat Applications

Safety

Safety considerations are paramount when choosing an SMR design. Many reactors utilize both passive and active safety features. Having maximum passive safety features in the design is optimal. Advanced reactor designs maximize massive safety features. Some reactor designs are more prone than others to certain types of accidents. For example, LWR operate at high pressures to keep their coolant from boiling. High-pressure operations make LWR more prone to loss of pressure accidents than their liquid metal counterparts operating at low pressures. Companies conduct probabilistic risk analysis on their designs as they seek to license them. Those designs, which have complete or are near-complete analysis are preferable over those that are still testing their

designs. If a reactor has a functioning prototype with a proven safety history, this is also advantageous.

Power Output

The amount of power produced by the reactor must meet the needs of the Department of Defense. Furthermore, it must be able to meet both electrical generation needs and have the capacity for utilization in process heat applications. Many designs match desired output needs by increasing or decreasing the number of individual modules. An increase in modules leads to an increase in overall cost as well as facility complexity. A balance needs to be achieved by using the correct number of modules to meet installation needs.

Physical Size

The size of the reactor facility is very important. Military installations can be vast expanses of training grounds or restricted access, fenced locations nestled in the heart of a population center. Encroaching on civilian land would be both unpopular and expensive for the Department of Defense. Siting within the perimeter of a current installation would potentially reduce the amount of land available for training. Minimizing the size impact of the reactor on installation military operations is extremely important.

Refueling Cycle

The refuel cycle of the reactor is important to installation operations. If the reactor provides sole power for the installation, it is important that an alternate supply of power is available for the base during refuel outages. This is of particular importance if the reactor must be taken offline for extended periods.

Licensing

The NRC's current licensing framework is structured by the assumption that the projects to be supported for development are large, stationary light water reactors. Many of the regulatory requirements for developers are driven by these assumptions. With the increasing interest in SMR applications and technology, the NRC is working to adjust its regulatory framework to support a more flexible design. The NRC developed several new offices to aid in the licensing of SMRs. The NRC staff is hoping to review SMR designs and find generic resolutions to policy, regulatory and key technical issues related to these designs. In addition, there are issues that arise specific to each application.

Issues such as how to handle the licensing of a process heat application, the licensing of a single or multi-module facility, and the appropriate size of the emergency planning zone (EPZ) all will require the development of a new regulatory framework. As designs drift further from the standard LWR reactor, the NRC must continue to ensure the safety of the public while promoting innovation and flexibility. Large deviations from the traditional LWR design include the use of TRISO fuel particles, fuel enrichments greater than 5%, and alternative choices for primary coolant methods.[35] The American Nuclear Society position statement 25 which covers SMRs encourages the NRC to

"enable timely adoption of SMR designs by assisting in the identification and resolution of generic SMR licensing issues as well as by establishing the most efficient and effective licensing approaches"[33]

TVA's Clinch River Project is of extreme importance to the nuclear industry in United States. As energy providers to look consider using nuclear SMR technology as an option to modernize their fleet, there are many attractive economical and environmental characteristics. The nuclear industry is highly regulated. Developers are fearful to commit large capital investments into a technology that has a history of high regulation when that regulatory framework is still in development. An open, honest dialogue between the site developer, the reactor manufacturer and the NRC will result in reductions in ambiguity and the establishment of SMR licensing precedent for years to follow.

Pubic Acceptance

DoD installations work closely with the communities that surround them to build cohesive relationships. The communities surrounding an installation, which chooses to install a nuclear power source, will face many questions about the safety of the facility and its impact on the community. DoD should strive to pick a reactor that will be readily accepted by the public. Forecasting public concerns and being prepared to counter those concerns with demonstrated, safe technology will increase the likelihood of public acceptance for a nuclear powered military installation.

Fuel Costs

The expense of nuclear fuel and its transportation is a factor is reactor selection. Fuel costs are influenced by manufacturing difficulty, resource availability and the refuel cycle. Increased refuel intervals increases the cost of operation for the facility. A unique fuel design, like TRISO fuel, will be costly if not yet produced on a commercial scale. Additionally, a reactor requiring refuel often will have increased fuel burdens. The installation will often shift operations to accommodate the transportation fuel to the facility. Given the sensitive nature of nuclear fuel, transportation operations will require special protocols and procedures.

Maturity of Technology

DoD needs a solution to its energy security challenges as soon as possible. There are many innovative reactor designs that exist either on paper or are still in the initial stages of testing. Many reactors were developed in the middle of the 20th century but have not been operated in recent years. These designs are viable but still need extensive testing. Designs with more maturity will be easier to for DoD to implement quickly.

Process Heat Applications

Being able to use nuclear heat for applications other than electricity gives DoD flexibility in developing future energy solutions. A military installation nuclear reactor should have the capacity to support both electricity production and process heat applications.

The Small Modular Reactor For DoD

Advanced reactor technology offers the greatest long-term potential for the Department of Defense. The passive safety features of liquid metal or salt cooled reactors make them a vastly superior design to the standard LWR design. They have great potential for use as a nuclear waste solution as well as being used for power applications. They offer excellent resistance to proliferation. HTGRs offer the most potential for process heat applications. These reactors can reach extremely high temperatures, which could be useful in producing hydrogen on an industrial scale. If hydrogen fuel technology continues to advance, these reactors could play a key role in helping the defense industry wean itself from its annual $16 billion fuel bill.[6]

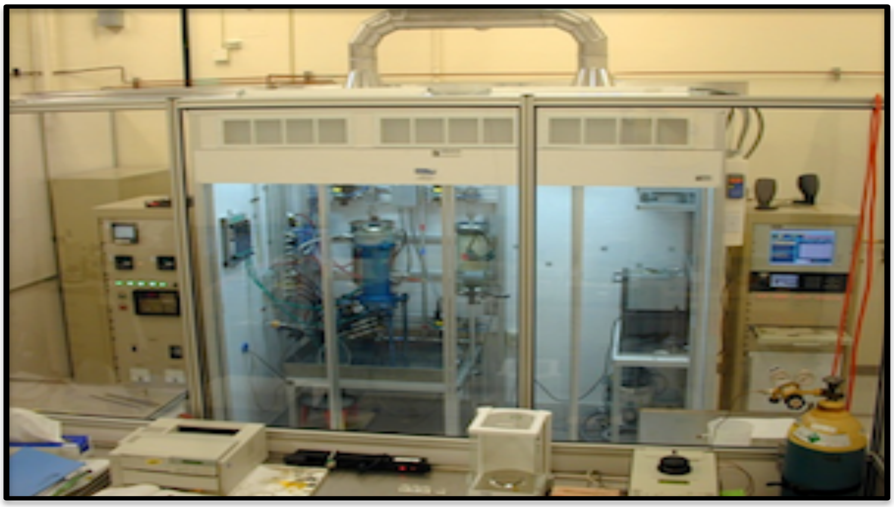

Figure 26: Coated Particle Fuel Development Lab at ORNL

Most advanced reactor technology is still in the development and testing stages. Many reactors have further research needed in materials development, fuel enhancement, and modern modeling techniques. As these advanced designs are optimized, they must undergo extremely rigorous probabilistic risk analysis in order to satisfy the safety requirements of the U.S. nuclear industry. Work is being done across the country in DoE labs as well as at universities to find solutions to these challenges. Figure 26 shows the Coated Particle Fuel Lab at ORNL which works on developing improved solid fuel designs for advanced reactors.[45]

International organizations are also aggressively working on advanced reactor technologies. In his 2011 testament before the U.S. Senate, Joe Calvin, then president of the ANS, noted

"The nuclear supply infrastructure has become thoroughly internationalized in the last three decades…it is clearly preferable to have U.S. involvement in the global nuclear marketplace, rather than ceding the territory to non-US suppliers that may not always share our approach toward safety and nonproliferation."[46]

The research conducted will be used to support the licensing and construction of prototype and test facilities. Once researchers construct a prototype and the NRC develops a regulatory framework, the designs will be more attractive to commercial developers and investors.

However, the Department of Defense needs a solution to its energy security vulnerabilities now. As the defense industry becomes more technical and energy dependent, installations require a continuous source of power to conduct even the most basic of military operations. The rising threat from cyber security attacks as well as natural disasters make military installations increasingly vulnerable. Even a simple, physical attack could cripple a military installation if targeting its electrical supply lines. DoD is aggressively seeking solutions to reduce its energy demand by spending almost $1 billion annually on reduction initiatives. While these efforts are somewhat effective, simply turning off more lights, unplugging coffee pots and changing climate control settings fail to match the rising real energy consumption of the armed forces.

The military becomes more reliant on technology daily. Gone are the days of a military signal corps using flags and smoke to pass messages. Today, commanders at even the lowest level carry smartphones and provide daily status reports via automated reporting systems. The signal corps long since retired its flags and replaced them with Joint Network Nodes capable of establishing communication and Internet links in remote, austere locations. A private on a remote hilltop in Afghanistan can send an enemy status report to his headquarters at Bagram Airfield as easily and often as a college student checks social media. Resupply requests, movement orders and personnel evaluations, are all delivered electronically. Meetings are conducted in person as well as via video teleconference linking commanders in locations all across the world.

Figure 27: Joint Network Node[47]

Without a steady supply of power, military operations come to an abrupt stop. Implementation of SMR technology today, prior to full commercialization, provides DoD an immediate, reliable power supply.

While advanced reactor technology is attractive because of its potential, small modular light water reactors are expected to be in commercial operation in the very near future. In February 2013, TVA and B&W signed an agreement to pursue licensing an SMR facility at Clinch River. With DoE financial support of $452 million in funding over five years, 50% of the licensing and design costs will be funded by DoE. DoE hopes to have the mPower design certified by the NRC by 2015 and a commercial demonstration of SMRs by 2022.[48] The progress shown by TVA, B&W and NuScale in partnership with DoE and the NRC shows promise for the world of small modular reactors. SMRs can bring safe, reliable, clean power to American in a scalable format to fit the needs of each community. They are ideal suited to fit the varied needs of the Department of Defense as it seeks to eliminate its energy Achilles heel.

Indeed SMRs might also be at least part of the solution to DoD's energy security problem. However, in speaking with an official from the Army Office for Installations, Energy and Environment it is clear that DoD does not want to be a prototype validator for a new energy technology. Rather, DoD prefers to leave such innovation to its partners in DoE.[49] This does not mean however, that the Defense Department is not open to new ideas. The Defense Department routinely applies new technology in unique ways as it adapts technology for military use. In applying nuclear technology to power its installations, the Department of Defense must be very conscious of public opinion. Military installations already receive a great deal of public scrutiny due to the unique nature of the operations conducted on installations. Military installations do their best to coexist tranquilly with their neighbors and the military often conducts more disruptive maneuvers at installations far removed from civilian population sectors. When implementing a new energy strategy on its installations that capitalized on the benefits of nuclear power, the military would need to carefully select its reactor choice. A reactor

design that has the full support of DoE, the NRC and is in use in a commercial facility will be far more publically acceptable than an advanced, prototype design.

Appendix B contains an assessment of each SMR considered for use in an energy solution for the Department of Defense. Table 7 from that Appendix is below. The table contains the decision assessment rankings used for selecting the SMR. The assessment evaluation takes into consideration the unique purpose and constraints associated with using a nuclear reactor to power a DoD installation. Each reactor is rank ordered from one to four with a score of one being given to the reactor design that is most apt to meeting the needs of DoD given the individual criterion. The criteria are equally weighted. The reactor with the lowest score is best suited for a DoD energy security solution.

Table 7: SMR Assessment Criteria Rating

Reactor	mPower	NuScale	PRISM	4S
Safety	3	2	4	1
Power Output	1	2	3	4
Physical Size	2	3	4	1
Refueling Cycle	2	3	4	1
Licensing	1	2	4	3
Public Acceptance	1	2	4	3
Fuel Costs	1	2	4	3
Maturity of Technology	1	2	4	3
Process Heat Applications	1	3	2	4
Score	**13**	**21**	**33**	**23**

The mPower reactor is the best available SMR design for the Department of Defense. The amount of energy needed on a military base to secure its installation energy future is not enormous. Most installations have all their electricity needs met by a reactor that produces less than 100 MWe. A single mPower reactor produces 130 MWe while a NuSclae module produces 45 MWe. The power capacity of an mPower facility gives installations maximum flexibility on how they operate the reactor. If running at full capacity, the installation can sell unused, excess power to a local utility. It can operate at reduced capacity and decrease its burn rate, which will extend its lifetime. When operating at 90% capacity, the reactor does not require refuel for 4 years. Due to the military application of the facility, designers could present a modified design that uses a fuel with a higher level of enrichment so as to further increase time between refueling. Naval vessels run on highly enriched fuel allowing them extremely long operation intervals between refueling.

NuScale technology is capable of increasing power output by increasing the number of modules in the facility. This would allow DoD some flexibility in how it sited the reactors on each installation. NuScale modules require frequent refueling at 24 months. Their multi-module approach does offer the capability of conducting refuel operations without shutting down the entire facility. A frequent refuel interval will produce more waste than an mPower facility requiring on-site storage in either spent fuel pools or dry casks. This is not ideal for a military installation on which space is precious commodity. Designers could look at the effects of increasing the level of fuel enrichment on a NuScale design as well to see if the refuel interval could be increased.

With its current design, an mPower SMR is perfectly suited to meet the Department of Defenses installation energy needs and any future demand increases. As DoE, TVA, B&W and the NRC validate the mPower design and put it into application at Clinch River, DoD should look closely at how to apply the reactor facility to military use. The following paragraphs present how an mPower reactor would be applied for us on a military installation.

Chapter 8: m²Power: A Military Modular Reactor to Meet DoD's Needs

A modular military reactor provides a sustainable solution to DoD's energy security vulnerabilities. An m²Power reactor is a B&W mPower reactor modified to serve the needs of a military installation. In examining the impact of an m²Power reactor on a military installation, there are multiple considerations. Many of these factors are the same as used when analyzing the impact of renewable energy sources on installations. Some considerations are

- Power Output
- Process Heat Applications
- Physical Size
- Mission Impact
- Environment
- Security
- Reactor Accident Impact on Military Operations
- Military Accident Impact on Reactor Operations
- Manning and Management
- Transportation
- Waste Management

The following paragraphs examine each of these considerations and the impact of an SMR operating on a military installation.

Power Output

Military installations are in essence small cities. They have their own fire protection and police force. Most have a hospital or medical facility. There are full time residents who live in military housing on the installation. Some residents are single and live in soldier barracks while others are families living in duplexes or single-family homes. The vast

majority of the buildings are used to support or sustain military operations. These buildings range from office buildings, to mechanical support facilities to physical fitness centers. There are also a number of small businesses on a military installation such as fast food restaurants, grocery stores and gas stations.

The power demands of the installation are proportionally related to its size and geographic location. Figure 28 shows the MW usage of some military installations previously discussed.

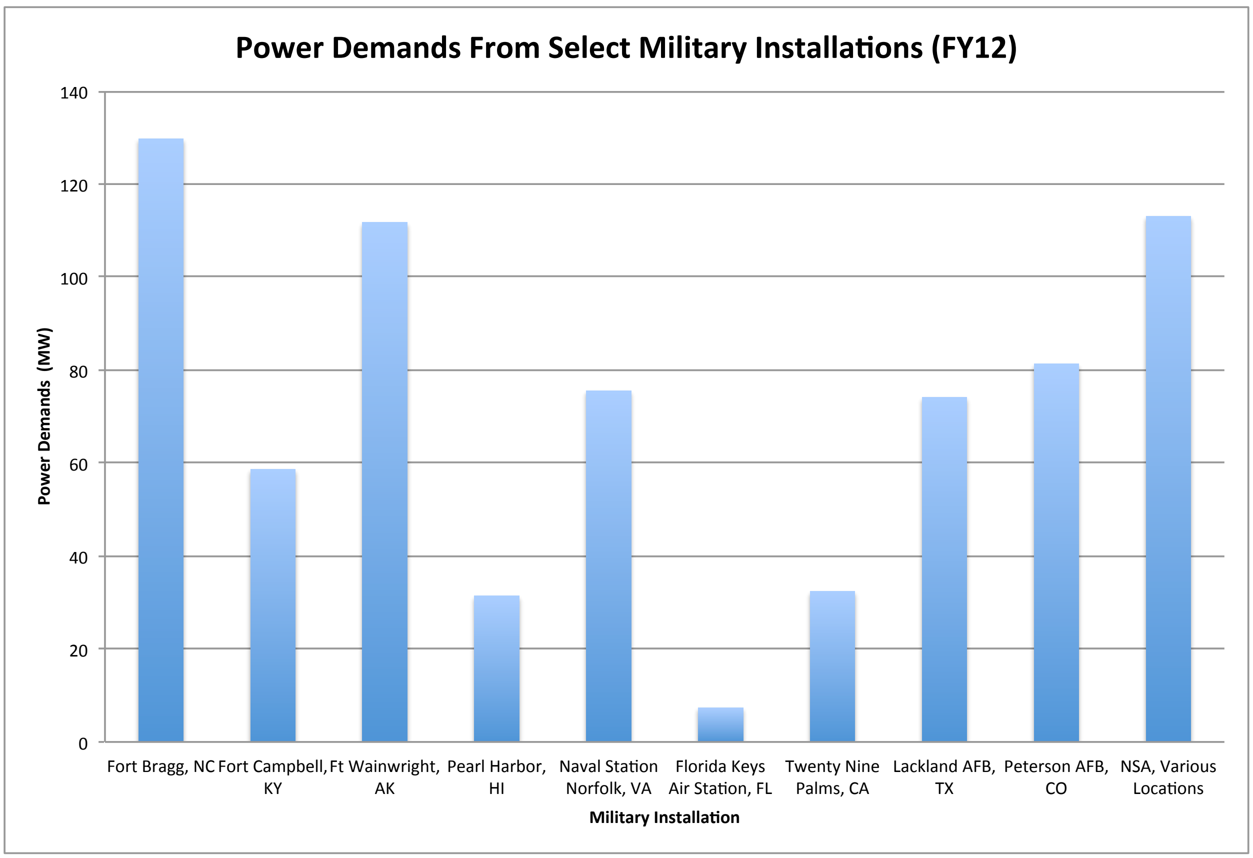

Figure 28: Select Installation Power Demands (MW) FY 2012 [4]

The installation consuming power at the largest rate is FT Bragg, NC. It consumed power at an annual rate of approximately 130 MW in 2012. Fort Bragg is operational a very large military installation. It houses the headquarters of some of the largest components of the military. It has approximately 57,000 military personnel, 11,000 civilians and 23,000 family members making a small city with a population just under 100,000

personnel. It is one of the largest military complexes in the world.[50] Its high power demands are possibly attributed to the amount of personnel operating daily at the installation. Other installations with high power needs can be found in extreme climates. Fort Wainwright Alaska and Peterson Air Force Base, Colorado both have high power demands at 112 MW and 81 MW respectively.[7]

These figures represent the highest energy demands for installations in the military. Thus, it is possible to use a reactor smaller than a conventional power facility to support an installation. Installations within DoD could be support by a reactor producing 150 MWe such as the mPower reactor. Many have consumption levels less than 100 MW. Installations with less electoral demand could put excess energy toward process heat applications or the military could sell the energy back to a local utility. The size and type of energy demands on a military installation make them ideally suited for the use of an m^2Power reactor.

Process Heat Applications

In recent years, the need for process heat in industrial applications rose significantly. In 2012, the IAEA released the results of a study about the use of nuclear power in process heat applications. The study focused on the use of high temperature gas reactors. The goal was to determine if nuclear power could be used in the process heat applications requiring the highest thermal energies. One of the most environmentally significant of these applications is the production of hydrogen, which requires a reactor output coolant temperature greater than 700^{o}C. Hydrogen is thought to be considered an viable possible alternative to fossil fuels in vehicles as well as being an excellent large scale energy storage medium.

Another useful application of thermal energy is in nuclear desalination. Nuclear desalination is a low temperature reaction occurring at coolant output temperatures from 100 ^{o}C to 140 ^{o}C. Other desalination processes use fossil fuels to provide thermal energy and have significant greenhouse gas emissions and costs associated with pollution

[7] The energy to power conversion rate is based on a 24-hour day, 365-day year and a production capacity of 90%.

control. Desalination technology is used in countries with limited access to fresh water but access to salt water sources.

District heating is useful in providing heat to communities existing in extremely cold climates. District heating uses reactor output coolant temperatures of 80 °C to 150 °C. District heating is most effective in small communities where the produced heat does not have to travel long distances (less than 5 km). A small community district heat network is sustainable with 10-50 MW(th).

Other applications of nuclear generated process heat include oil recovery and the production of chemicals. Oil recovery operations using nuclear produced steam appears to be most successful in extraction of oil from sand. A CANDU cogeneration facility could be useful in extracting oil from Canadian oil sands and providing electricity when oil production is low. Chemical industries use process heat for a wide variety of applications, which require the splitting of hydrocarbons. This is a key step in the production of gas and hydrogen. Figure 29 illustrates a wide variety of industrial process heat applications and the output coolant temperatures needed to conduct these applications. [51]

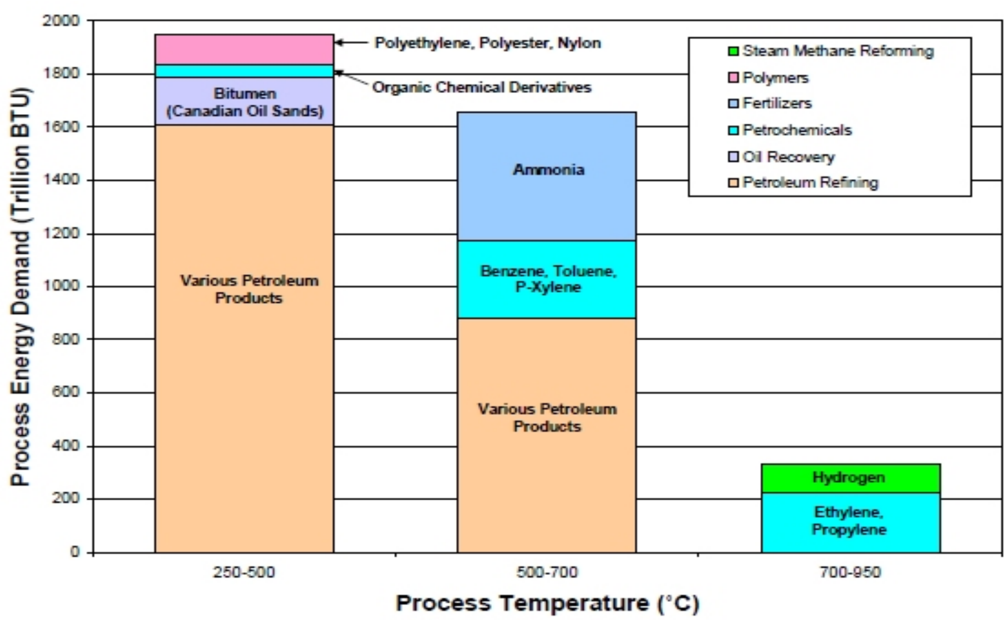

Figure 29: Chemical Production Process Heat Requirements [52]

It is unlikely that the military will use process heat in a chemical production method. The military itself produces very little of its own supplies. It relies heavily on an extensive supply chain, which runs continuously to provide the products necessary to meet its needs. The military supply system is almost entirely devoted to procurement rather than production. While an m^2Power reactor will not reach the temperatures needed to produce most chemicals or hydrogen, in future years, advanced SMRs will be able to reach the desired outputs. Should hydrogen become a viable alternative to petroleum for vehicle and aircraft operations, the military might want to consider internally producing it. By establishing the policies and procedures for reactor operations early, the military would be positioned to capitalize on the industrial production of hydrogen giving it operational energy independence.

Process heat applications of an m^2Power reactor could be useful to a military installation based on environmental considerations. Some of the largest energy consuming installations in DoD reside in extremely cold climates. Energy created by an m^2Power reactor could be used in a cogeneration capacity on installations located in these extreme climates. Fort Wainwright Alaska has average low temperatures below freezing for more than half the year. [53]It is a relatively small installation with only about 3400 acres (13.8 km^2) owned by the federal government. [54] Depending on the allocation of that property, it is likely that the central living and work facilities on the installation are in close proximity to each other. This type of installation would be ideal for the use of an electricity and district heating cogeneration m^2Power reactor.

In addition, military retains within its assets water purification equipment. This equipment depends on an existing supply of water. Efforts are being made to find technology that could use desalination technology to aid in supporting the project of forces into arid climates. A theoretical small, portable nuclear reactor could provide foreword-deployed forces with the power needed to run electrical equipment as well desalinate water. While an m^2Power facility is to a large to be considered truly mobile by military standards, using reactor technology on permanent installations in arid locations could help an installation becoming entirely Net Zero. Not only could the facility

provide electricity, it could also provide water for installation use. Using an m^{2}Power reactor in this capacity reduces two major sustainment vulnerabilities for the installation.

Physical Size

Conventional nuclear power plants occupy enormous amounts of physical space. Southern Company's nuclear power plant, Vogtle Unit 1 and 2, sits on a 3200-acre site 34 miles southeast of Augusta Ga. That is an incredible expanse of land used to support a single facility that is designed to produced over 2400 MW of power.[55] It is unrealistic to expect a plant of this to operate on a military installation. By comparison, TVA's is planning to use a 1200-acre site for its Clinch River project. At Clinch River, TVA will be prepared to install multiple small modular reactors, each with an output of about 180 MW.[56] B&W claims that a two-pack m^{2}Power reactor could occupy a site the size of 40 acres (.16 km^2). This is an incredibly small footprint and is advantageous to a military installation that might be limited on size by geological or man-made boundaries. A single SMR could occupy an even smaller footprint.

The size of the geographic footprint of the reactor facility plays a large role in both installation and reactor selection. Some installations occupy vast expanses of land and are far removed from civilian populations. Fort Irwin California is home to the National Training Center in Southern California. It is an expansive reservation of land used to conduct large scale military exercises. It is far removed from any metropolitan area. By contrast, Joint Base Lewis-McCord (JBLM) is an installation that is nestled in the I-5 corridor just south of Tacoma, WA and less than an hour from Seattle. While the potential for SMR site development could exist at Ft. Irwin in the California desert, it is unlikely that even a reactor facility as small as .16 km^2 would be suitable for at Joint Base Lewis-McCord due to the population density. Due to its physical size constraints, JBLM conducts much of its large-scale maneuver and weapons training at a remote facility near Yakima WA. The Yakima training center would be more suited, due to its size and location, for the use of an m^{2}Power reactor facility.

Another consideration when locating an SMR on a military installation is the impact of the exclusion zone.[57] The NRC requires that all reactors have a defined exclusion zone

and low-population zone. An exclusion area means that the licensee has *"the authority to determine all activities including exclusion or removal of personnel or property from the area."* This does not, however, prohibit movement within the zone. The NRC clearly states that the area may be traversed by highway, rail or water as long as they do not interfere with plant operations.[58] If the facility is location on an installation, then installation commander will have complete authority over exclusion zone authorization. In addition, military installation occupants are familiar with locations on installations that have limited or restricted access. These areas are usually well marked, monitored and at times physically guarded. Controlling access in and around the facility should not impact training or operations as long as the site chosen allows for maximum flexibility of tenet units.

The low population zone is an area containing residents where the

"total number and density of which are such that there is a reasonable probability that appropriate protective measures could be taken in their behalf in the event of a serious accident."

In the case of a low-population zone, there are no defined numeric guidelines.[58] Christofer Mowry, the president of B&W mPower, claims the size and passive safety features of the mPower r reactor can reduce such a zone to as small as half a mile.[59] Much of the size depends on how quickly an area can responds to an accident. In the case of a military installation, on post residents and employees are routinely subject to emergency planning and security drills. Incorporating nuclear accident scenario planning would follow already established similar protocols. In addition, timeliness of the response will be greatly improved over a commercial plant because the communication structure of the military is streamlined through a single command channel. In a commercial facility, reactor operators must coordinate with multiple state and local agencies for support. Military installation occupants are already trained and familiar with mass information distribution processes.

Mission Impact

The impact on mission performance is the most important factor when selecting a military installation for the use of SMR technology. As with other forms of renewable energy, the SMR cannot detract from the organizations ability to train and conduct its mission. Much of the mission impact of an SMR can be mitigated through procedural changes. For example, an installation with high levels of rotary wing or fixed wing air traffic might have to modify approach and departure corridors to avoid over flight of an SMR facility. This is not at all unusual for aircraft pilots as they commonly directed to avoid over flight of facilities. Alternatively they could be allowed to overly the facility but only above certain altitudes.

Figure 30: Considerations for reactor placement; military helicopter training [60]

Using an SMR to power a geographically large, remote training center like Ft. Irwin is ideal. Much of the FT Irwin reservation is an open maneuver facility that allows freedom of movement for tanks, personnel carriers and vehicles. These vehicles would simply need to avoid the SMR facility. These types of restrictions are familiar to military planners and have little impact on mission execution. In fact, at times they represent real-

world scenarios where an invading force might chose to avoid an area so as to preserve historical or religious significance. In Operation Iraqi Freedom, many mosques were restricted targets because they were of religious significance to the local population.

Additionally the facility could add to an aspect of military training that is not currently emphasized. The potential for conflict with a nuclear powered or nuclear-armed country is possible for the US Military. While it would be unwise to use an existing, operating facility as a location for conducting military training, there is some value from having to include it in operational planning. By forcing military planners to incorporate real, rather than simulated, nuclear facility impacts into the mission development process, the scenarios used for training will be a more realistic simulation of the potential future conflicts.

To develop a reactor site on an installation, developers must interface closely with their military partners. The developers must have a full and complete understanding of the installation operations. They must ensure that the military is aware of all possible impacts on performance. Finally, site developers must understand that on a military installation, the base commander holds the final decision authority. He or she will consider many factors when siting a reactor facility. Developers must be open and understanding of his or her concerns.

Environment

The environmental conditions impacting a military installation will be a key factor in site selection. The military gains the most economical benefit by selecting an installation that not only has a high electrical energy demand but also has an overall high energy consumption due to environmental factors. Extreme weather conditions are commonly found at military installations. Locations like Ft Wainwright Alaska and Ft Drum New York are known for being very cold. Alternatively, the Twenty-Nine Palms, CA or Ft. Bliss Texas record some of the highest temperatures at military installations. Installations in extreme cold climates could benefit from the district heating capabilities of an SMR cogeneration facility. Installations having high power demands for heating or cooling

which is located the end of transmission lines might find it more cost effective to simply produce their own power. The environment will shape which installations are good candidates for SMR technology in a similar way that it shapes siting for commercial reactor locations. Environmental risks to SMRs are similar to the risks to commercial reactors. Installations prone to high seismic activity should be avoided. Facilities threated by high tidal swells or hurricane activity must mitigate these risks with severe weather plans, increased facility hardening and back-up systems. Many of the same tools used to analyze environmental risks to commercial reactors will apply to the placement of SMRs.

Security

"Nuclear power plants continue to be among the best-protected private sector facilities in the Nation." –NRC[58]

NRC regulation 10 CFR Part 73 governs the physical protection requirements of plants and materials. The NRC requires the use of an extensive security network to ensure the safeguards of our nations nuclear facilities. It states that facilities are

"well-protected by physical barriers, armed guards, intrusion detection systems, area surveillance systems, access controls, and access authorization requirements for employees working inside the plants."[58]

Siting it on a military installation would enhance reactor security. Military installations are limited access. They have access control points at all locations. Figure 31 shows an access control point at Ft. Campbell, KY.[61]

Figure 31: Military Installation Access Control Point

Installations are surrounded by physical barrier systems. Manned security patrols operate 24 hours a day year round. Individual units on the installations each have their own security patrols, which operate after business hours to ensure basic physical security measures are in place. The military provides continuous security on its installation due to the concentration of weapons, equipment and ammunition stored on site. Personnel are trained in the detection of unusual behavior as well as how to report and respond to threats. Installations conduct annual drills emphasizing force protection and each origination has planned measures to take in the event of a threat or attack on the installation. Individual buildings on the installation have limited access due to the nature of the building, which require identification checks, badging, and other security protocols. Members of the armed services are familiar with operating in a security centric environment.

Facility security could be provided by armed service members or outside contractors. It is not unusual for DoD to use contracted security on its installations. Many installations have contracted gate security officers and police forces. Using a contracted security force would allow for guards to receive specialize training on reactor specific threats. The use of contractors would also be much less costly to the Defense Department, which would not have to train and develop a specialized force of reactor security personnel. The interface between reactor security personnel and installation security forces would be similar to the procedures used on installations with contracted gate security forces.

Reactor Accident Impact on Military Operations

The impact of a reactor accident on the installation will be the one of the most important concerns to an installation commander. Of primary concern to the commander will be the physical impact on installation personnel. Additionally, he or she will need to know how an incident will impact military operations.

Clear and complete reactor accident analysis is integral to all forms of nuclear reactor development. It will be no different when siting a reactor on a military installation. The NRC mandates the study of effects of a reactor incident on the local population. The

most important metric in this analysis is the possible dose given to the population. In addition, an installation commander will need to know the evacuation requirements. He or she will want to know if and when reentry onto the installation is possible. The military will not allow for a scenario that renders the base and all its equipment unusable for a long period of time.

Safety features on the m^{2}Power reactor significantly reduce the likely hood of accidents. As the design completes the NRC certification process, probabilistic risk analysis will validate these features. All nuclear processes adhere to the double contingency principle meaning that no single event should be cause for failure. The industry applies “defense in depth” to all designs requiring multiple redundancies for systems. Many reactor systems employ passive features that cause the reactor to dissipate heat or shut down with no action from the operator. Additionally, reactors contain active controls that trigger immediate shutdowns in the event of abnormal or questionable conditions. Accidents are mitigated through routine and extensive training. Training teaches operators how to respond to recognize and prevent an accident. The nuclear industry is the safest power industry in America due in part to the extensive training undergone by operators. Military personnel conduct training on a daily basis. Some events are at the individual level while others can include thousands of personnel and pieces of equipment. The military is exceptional at planning, resourcing and conducting training. The incorporation of a nuclear training program on a military installation would be nested within the overall training plans for the base.

Military Accident Impact on Reactor Operations

Unique to the challenges facing SMR site selection on a military installation is the potential impact military munitions accidents on the reactor. Risks associated with the impact of a military accident must be closely examined. This will be one of the largest and probably most publically discussed risks associated with military reactor power.

The NRC mandates the examination of the potential hazards from military facilities in 10 CFR 100.21(e).

"Military facilities must be evaluated and site characteristics established such that potential hazards from such routes and facilities will pose no undue risk to the type of facility proposed to be located at the site."[58]

The type of accident presenting the highest risk will be installation dependent. A naval air station is more likely to have an aircraft accident. A heavy maneuver division of the Army is more likely to have a weapons malfunction or range fire. This level of risk analysis is not an insurmountable challenge. The Navy has procedures that allow for the operation of aircraft, the loading of munitions and movement of other vessels in and around its nuclear powered equipment. It conducts operations safely and without incident because it has established the procedures and training to ensure safety. Army personnel operate large weapons systems in careful, controlled environments. Thorough planning and analysis of the effects are part of every operation using weapons systems. The simplest mitigation technique for large weapons systems is geographically isolating the firing locations. Many weapons in the military's arsenal can only be fired at certain, controlled locations. Some weapons training is even done via simulation.

Figure 32: Paladin Weapon System[62]

Many geographically large, remote installations are used weapons ranges. Systems fired here cannot be close proximity to dense population centers. The location also makes the

installation an ideal candidate for SMR power. A reactor would need to be located not only outside the direct impact areas of these ranges but also outside the area where malfunctioning systems could impact. Impact planning is done routinely by the military. Impact experts understand the effects of their weapons functioning both properly and when they malfunction. The effects of ranges are integrated into all development planning on military installations. A unique consideration would be the seismic effects on the reactor systems caused by the impact of locally fired large caliber weapons. While the impact areas would be far from the reactor site, there would be a potential for system disruption from the repeated impacts of these systems. The effect of these systems requires further study.

The NRC also mandates an examination of the impact of airports, dams and significant transportation networks near the SMR site. The m^{2}Power concept houses reactor facilities below ground, which significantly minimizes the effects of an aircraft impact on the facility. Much of the risk associated with these features can also be mitigated using procedural modifications. Site selection on the installation will be the most important factor in risk mitigation. Developers and military personnel will need to closely interface in order to minimize the risk. Site developers must have a complete understanding of the military mission on the installation and work to minimize impacts while maximizing gain for the

Manning and Management

Running the SMR facility requires a staff of highly trained personnel. The Department of Defense could opt train its own reactor operators as it did with the Army Nuclear Power Program (Appendix A). m^{2}Power reactors offer a wide range of opportunities for the current force of DoD service members serving in a nuclear related field. It would create the opportunity for the application of their skills in a joint billet. DoD may consider using naval reactor personnel as operators for the facility by rotating them through shore assignments.[57] This would provide naval personnel an opportunity to widen their technological expertise and become trained on the latest development in nuclear reactor systems. Shore rotations would also provide naval personnel an assignment that serves as

a respite from deployments. Additionally, other military branches have nuclear non-proliferation experts within their ranks. The Army employs officers in the field called Functional Area 52, which is nuclear nonproliferation. These officers could benefit from assignments with a military reactor team. Not only could they improve their understanding of the nuclear power industry, they would be able to apply their non-proliferation expertise to the facility. Health physics and radiation safety officers within the branches of service could gain valuable interdisciplinary experience by rotating through assignments at an m^{2}Power facility.

The Department of Defense could also contract reactor operation personnel from commercial organizations operating in the United States. By doing this, DoD saves money on personnel costs and ensures that facility is maintained and operated by a staff that is already familiar with the industry. Commercial nuclear power generation companies understand the licensing and training requirements unique to the nuclear industry. They have established protocols and procedures to ensure regulatory compliance. While the military has service members trained in the some fields of the nuclear industry, their expertise is not in land based plant operations. A contract team brings a level of operational experience and expertise to the program that would take many years to grown internally within the military.

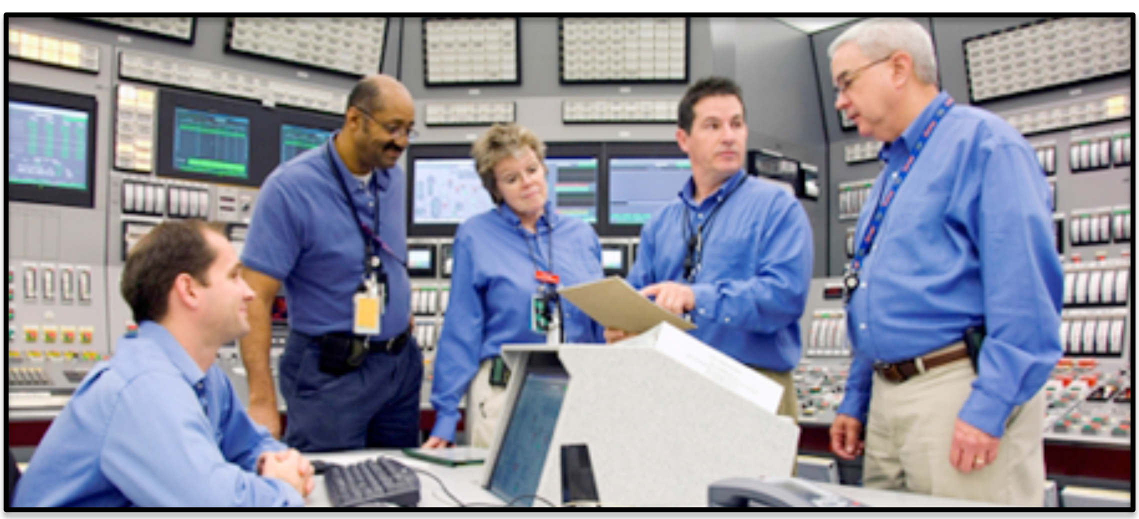

Figure 33: Nuclear Energy Workers From Duke Energy[63]

Contract development would need to consider the complexity of nuclear power plant management when setting contract timelines. The contract would need to offer the awarded company stability in its position. The management and operation of a complex reactor facility requires an extensive investment in the hiring and training of personnel. A company cannot afford to invest such a commitment unless the contact guarantees operation of the facility for an extended period of time. To ensure contract performance, DoD could place military representatives imbedded in the operations and management of the facility. This is achievable by rotating military officers within the nuclear fields through the facility for short-term assignments. These personnel could not only aid in the operation of the reactor but also act as military technical advisors to the installation commander. These officers have the military expertise needed to understand the impact of a reactor on installation operations. They would be able to provide honest and open evaluations of the work conducted by the contracted reactor operator and aid in the procurement of further resources for the facility.

Contract discussions must also involve the delineation of liability. The installation commander is responsible for all actives on the base. The reactor operator however, should be held liable for accidents caused by mismanagement or operational errors. Responsibility for shutdown, decommissioning, cleanup and disposal of the facility would be that of the Defense Department. Discussions about liability and responsibilities must be included in the reactor development plan.

Transportation

Military installations are well equipped to handle the transportation requirements of moving nuclear fuel and equipment. Installations are usually accessible by both highway and railroad. Military units use rail facilities to load and unload military equipment for transportation to support operations all over the world. Installations are equipped with loading yards for trucks to upload and download cargo. They have specialized equipment designed to move and lift heavy equipment from the trucks. Some installations are equipped with runways capable of supporting the worlds largest transport planes.

Military planners are familiar with transporting equipment that is unusual in size and sensitive in nature.

Figure 34: Fuel Casks Being Shipped By Rail[30]

Accident considerations must be examined when analyzing the transportation of fuel to the SMR facility. Much of the impact of this kind of accident can be mitigate through route selection. Fuel transportation will require increased security to it would be ideal to conduct the operation during a period of low activity on the installation. Any lifting or delicate movement of nuclear fuel casks should be done as near to the reactor facility as possible. Nuclear fuel shipping casks are very robust but in the event of an accident, the installation needs to have a procedure in place ensure the incident site is secure until clean up is complete. Military personnel are familiar with the movement of sensitive equipment. They will be able to develop movement protocols for nuclear materials into their standing operating procedures.

Spent Fuel Management

Currently in the United States, spent nuclear fuel is being stored on site at commercial facilities. In August of 2013, the D.C. Circuit Court of Appeals ordered the NRC to resume work on the geological repository Yucca Mountain. [64] There is still much debate about the repository and funding the project. Until the debate surrounding the America's geological repository results in a solution, spent fuel will continue to be stored on site at reactor facilities.

January 2012, The Blue Ribbon Commission released the results of its study on managing nuclear waste in the United States. It recommends the consolidated storage of spent nuclear fuel rather than the current method which stores fuel on site at reactors all across the country.[30] It is conceivable that a storage consolation plan could be developed in future years. Additionally, the possibility of another geologically repository besides Yucca Mountain is likely.

Figure 35: Dry Cask Storage for Spent Fuel[30]

For a single reactor project, DoD will more than likely store the spent fuel on site. As it develops multiple reactors, DoD might consider developing its own consolidated spent fuel storage location. As advanced reactor technology improves, spent DoD m^2Power fuel might prove useful as fuel source for new reactor designs. A consolidated storage location for all DoD fuel would be ideal for siting an advanced reactor like PRISM, which could be used to recycle nuclear fuel. The technology has many years to mature but it is in planning now that DoD prepares for the future.

Chapter 9: Implementation Strategy Building From a Proven Concept

Taking a conceptual design from graph paper to reality is one of the hardest tasks in engineering. Even known technology takes years to develop, resource, plan, and construct. In choosing the m^2Power reactor, DoD's use of a tested reactor technology rather than starting from the conceptual beginning speeds its implementation. The m^2Power reactor utilizes technology that has extensive testing, evaluation and proof of concept in the basic design of LWR technology. The application of LWR technology to smaller reactors is a new aspect of the design, which needs validation. DoD capitalizes on the research being done B&W, TVA, the NRC and the Department of Energy in that it will not need to recreate the their efforts. Those organizations will use their time, resources and expertise to test, validate and improve the mPower design and SMR commercial power concept.

The Technology Readiness Level (TRL) is a tool that helps DoD evaluate, rank and prioritize the developmental needs of the m^2Power reactor.[65] Table 8 summarizes the TRLs for the m^2Power reactor.[66] The table compares the TRL posture of the Clinch River Project and a DoD m^2Power reactor. DoD benefits from the use of previous research and development from the Clinch River program. The table shows the TRL levels for a m^2Power reactor used for electrical and cogeneration purposes. The analysis is color coded to indicate the progress made toward accomplishing each TRL.

DoD benefits significantly from the work being done on the Clinch River Project as it not only validates the technology but also helps establish the SMR regulatory framework with the NRC. DoD would need to conduct assessments independent of the Clinch River project beginning at TRL 7 as it moved the reactor into an operational environment. At that point, the impacts of siting a reactor on a military installation would need special consideration by both the NRC and the armed services. A full analysis of the TRL assessment can be found in Appendix C.

Table 8: Technology Readiness Assessment for mPower use on DoD Installation

DoD Technology Readiness Levels				
TRL	**Definition**	**Clinch River Project**	**DoD Power**	**DoD CHP**
1	Basic principles observed and reported	Complete	B&W Work, Complete	Complete
2	Technology concept and/or application formulated	Complete	B&W Work, Complete	Past Analysis Review/Update
3	Analytical and experimental critical function and/or characteristic proof of concept	Complete	B&W Work, Complete	Past Analysis Review/Update
4	Component and/or breadboard validation in a laboratory environment	Complete	B&W Work, Complete	
5	Component and/or breadboard validation in a relevant environment	Complete	B&W Work, Complete	
6	System/subsystem model or prototype demonstration in a relevant environment	Operating Since July 2012, In Progress		
7	System prototype demonstration in an operational environment.	In-Progress		
8	Actual system completed and qualified through test and demonstration.	In-Progress		
9	Actual system proven through successful mission operations.	In-Progress		

The Collaborative Team

One of the most challenge aspects of project management is the development and control of the collaborative team. It is important to keep each team member fully engaged. Tasks and responsibilities must be divided in such a manner that best capitalizes on the collective expertise. It is incredibly challenging to provide oversight of large numbers of contracts and ensure that each contractor provides high quality work. [65] The Department of Defense runs some of the largest project management operations in the world. Projects range from simple lawn care operations to troop food preparation in chow halls to the development, testing and fielding new fighter jets.

In the collaborative team for the development of an SMR, DoD will need to extend contractual relationships into the nuclear industry. The Department of Defense has contractual relationships with reactor manufacturers supporting nuclear navy operations as well as government organizations. Defense personnel work closely with DoE and the NNSA to manage the nuclear fuel supplies for naval vessels. The protocols and relationships defined to support the nuclear navy will be helpful in defining a framework of procedures for land based reactor operations. During the early years of Army Nuclear Power Program, there was confusion around the overall control of the project. The first reactor, SM-1 at Ft. Belvoir VA, was developed in a disjointed manner that loosely aligned the Atomic Energy Commission, the Army Corps of Engineers and the reactor contractor. The result was overlapping responsibilities as well as gaps in task completion. The Army learned from this project and streamlined all operations under the Army Corps of Engineers for further reactor projects. Having a single project management office for the development of an m^{2}Power reactor will aid in streamlining the collaborative efforts of the team.

Program Organization

A land based m^{2}Power project would be a Department of Defense level operation. DoD would need to establish a centralized program office to manage the collaborative team as no such structure exists within the organization today. The m^{2}Power Nuclear Program Office would be the office responsible for the overall project management of siting,

licensing and constructing an m^{2}Power facility. Figure 35 shows a simplified organizational chart that illustrates just a few of collaborative team members under to m^{2}Power Nuclear Program Office. As the project grows, this organizational chart will increase in complexity.

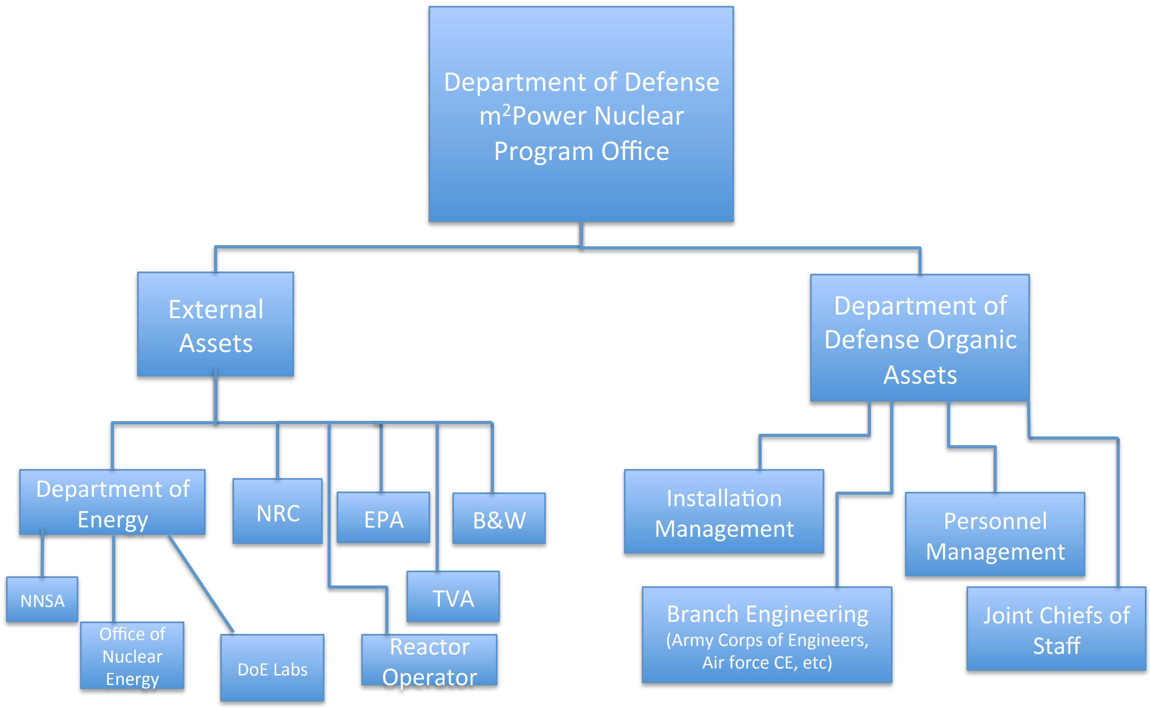

Figure 36: Nuclear Power Program Office Oragnaztional Chart

The expertise in land reactor operations exists outside the Department of Defense. Coordination with these experts is vital to the success of the project. There will be extensive coordination with other government agencies. Defense officials will need to coordinate closely with Department of Energy as it is the government leader in the development of energy systems and is at the forefront of SMR development. The NNSA will need to be included as DoD develops a fuel cycle plan for sustaining the reactor. DoE laboratories play a key role in the research of new energy technology. While there is no need for the development of new technology in an m^{2}Power reactor, the impacts of putting a nuclear reactor on a military installation need further study. DoE employs the experts capable of making independent, unbiased analysis of siting SMRs on military

installations. DoE laboratories will also be able to aid the Department of Defense in finding the most environmentally suited installation for siting a m^{2}Power reactor.

The NRC will want to examine licensing changes associated with putting the reactor on a military installation. The Environmental Protection Agency (EPA) will need to be included in the assessment of environmental impacts of the reactor on the military installation environment as well as that of the surrounding comminutes. Military installations already have unique environmental impacts to their surroundings. Evaluations of environmental impacts from the installations would need to be updated to include nuclear operations.

Defense officials will play a pivotal role in assessing which installations are suited for nuclear power. The Joint Chiefs of Staff understand the missions of each of their installations and would be best suited to analyze the impact of nuclear reactor technology on their base. Personnel management is controlled at the individual branch level. Joint military personnel analysis would need to be conducted at interdepartmental levels in order to best understand the talents of the nuclear personnel within each branch. From this assessment, the m^{2}Power Nuclear Program Office could develop a manning methodology that utilizes current DoD personnel and provides opportunities to enhance organic nuclear professional development without sacrificing mission performance within the branches. Each branch of the military handles construction projects through their own organizations. The Army uses the Army Corps of engineers. The Air Force utilizes Air Force civil engineers. Once an installation is determined to be a suitable prototype installation for the first m^{2}Power facility, the program office will work closely with those engineers as well as the installation management commanders.

Non-governmental organizations will also work with the m^{2}Power Nuclear Program Office. Reactor designers from B&W will need to re-validate design criteria taking into considerations any impact from military installation siting. The reactor operator chosen to run the facility will need to not only be aware of reactor operations but also understand its interface with the military installation it services. The NRC analysis will need to come

from the m^{2}Power reactor team so an expert on licensing SMRs will be needed. This could possibly be internal to B&W or perhaps come from one of the TVA experts on the Clinch River Project.

Financing Considerations

Financing the costs of large projects is a complicated process. DoD funds many of its acquisition projects through direct appropriation of funds over a given number of years. A project of this size would require large amounts of funding but it is not on a scale unfamiliar to DoD. Additionally, much of the expense which goes into developing "first of a kind" technology has already been covered by DoE as it works in collaboration with B&W and TVA. DoD would need to source funding for military specific site assessments. Funding is available under current budgets for renewable energy projects. Funding for any reactor modification to meet military installation needs could be jointly shared through the Departments of Energy and Defense.

Construction and operation costs could be handled in a similar manner as current renewable energy projects. Conservation and renewable energy performance contracts allow developers to be paid from the savings or revenues made through conservation or energy generation. In a similar way, a developer undertaking the m^{2}Power project could be paid by the power generated for the military. Because nuclear facilities have extremely long life spans, a utility company would be guaranteed an excellent source of long term revenue once initial expenses are repaid. Additionally, the provider would be alleviated of all fuel procurement, storage and decommissioning costs, as DoD would assume these responsibilities. This kind of arrangement drastically reduces the overhead cost for the developer. Finally, if the base fails to use all this power generated, a utility company could be further incentivized through having the latitude to sell excess power to other customers.

Chapter 10: Conclusion and Summary

In an effort to improve its energy security, DoD has linked energy security to its efforts to reduce climate change. Many of the measures undertaken by the Department are performing well. DoD investments on conservation efforts have resulted in a much more efficient use of facility energy on its installations. New buildings begin construction with a target goal of being functional as well as being energy efficient. Old buildings receive many upgrades, which help minimize the waste of heating or cooling resources. The Department is actively monitoring its real property to try and identify areas where energy waste can be minimized.

Despite the increases in energy efficiency, DoD is failing to secure its future. By focusing solely on a limited definition of renewable technology, DoD power production does not provide it with a sustainable power source. The current renewable energy sources used by DoD are inefficient, low production methods that are susceptible to seasonal fluctuations. Renewable technologies do not produce the power outputs needed to sustain the large, technology driven operations of a modern military. These sources leave an installation tethered to an external civilian power network.

By looking to the nuclear industry, the Department of Defense finds a renewable, sustainable solution to its energy security. Nuclear fuel is the most powerful source of energy on the planet. It emits no harmful greenhouse gases. It has a proven history of reliability within the United States commercial and defense sectors. It can be recycled into new fuel for existing facilities. Nuclear energy offers DoD a sustainable energy source that not only meets its large energy demand, but also preserves America's natural and man-made resources for many generations. As in the middle of the 20th century, DoD must make a technological leap in order to fulfill its security mission for the citizens it serves.

The B&W mPower reactor is currently the most technologically adaptable reactor for use on a military installation. It produces the power output needed to sustain all installation energy needs. It produces abundant electrical power. It can also be used for

cogeneration to produce power or process heat. Process heat applications include base heating or water procurement. The mPower timeline to commercialization makes it a solution DoD can recognize in the near future.

In applying the m^2Power reactor to a military installation there are some unique considerations that differentiate it from the commercial product. The most important consideration is the impact of the reactor on the mission of the installation. A support system such as a power facility, water treatment plan or garbage disposal plant cannot interfere with base operations. The commander of an installation must have the freedom to execute military training with minimal interference from the facility. The size of an m^2Power facility make it ideally suited for reduced impact on military installation operations. Placement of the m^2Power facility on the installation will be dictated by how it impacts military operations. Commanders will have a reliable source of power with minimal intrusion. Additionally, the installation offers added security for the power facility by utilizing established military security protocols. Many installations are in remote locations that present a viable option for national spent fuel consolidation program. The military has many nuclear trained personnel who can aid in the operation and management of an m^2Power facility.

The Babcock and Wilcox mPower small modular nuclear reactor offers the Department of Defense the technical paradigm shift needed to secure its installation energy future. By looking at the current energy strategy of the Department of Defense, it is clear that DoD does not have a sustainable energy solution. While its reduction initiatives are effectively optimizing energy demand, its production measures are woefully lacking in output. A shift to sustainable, nuclear power secures DoD's energy future. With a careful understanding of military operations, the placement of an m^2Power facility on an installation will provide it sustainable, clean energy for many years. To confront the advanced threats facing the Nation today, the Department of Defense needs a robust, technical response. Nuclear energy provided a revolutionary change in the Cold War of the 20th century and is postured to provide that same change in the conflicts of the 21st century.

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Appendices

Appendix A: Army Nuclear Power Program

The Army first investigated using nuclear power to provide electricity and heat to military installations in the 1950s. Observing success within the Navy and its campaign to power submarines with nuclear power, Army leadership wondered if this new technology could be useful to power some of their remote out stations or even be made into a portable power source. An initial studied conducted by Dr. Lawrence Hafstad of the AEC working at ORNL concluded that it was feasible for a small scale nuclear reactor to be used to power a military installation.

The Army Nuclear Power Program began in 1953 with a joint partnership between the Army Corps of Engineers and Atomic Energy Commission. Heading the program was Col. James B. Lampert. Much of the initial work in establishing the program revolved around the allocation of responsibility for cost of construction. The AEC and DOD created a detailed contract that outlined which portions of a proposed plant would be funding by each department. Eventually the decision was made that the AEC would construct the nuclear power portion of the plant and the Army Corps of Engineers would construct the traditional power generation station. There were specific contractual provisions about the fuel transfers and costs associated with fabrication and reprocessing. On July 21, 1954 the final proposed joint funding contract was approved and by December the program had contracted ALCO (American Locomotive Company) to construct the plant.

The Army Nuclear Power division quickly realized that it would need a prototype reactor site from which they could test the technology and train personnel before it started putting reactors in remote locations. The first reactor built was SM-1 at Ft. Belvoir VA. The reactor was a 10MWth pressurized water reactor. SM-1 had 38 fuel elements and 7 control rods. On April 8, 1957 it achieved criticality. It began its 700-hour load testing on June 2, 1957 and successfully operated at varying loads form 10% to 100% being shut down for only 7 hours and 28 minutes to install testing instrumentation. The facility became fully operational in 1958 and ran for 16 years without accident. While

constructing SM-1, the Army Nuclear Power division realized that significant training was required for individuals to work on these sites. SM-1 became not only the prototype reactor but also the training facility. Individuals selected to work in power production underwent training from the University of Virginia, Pennsylvania State and University of California Berkley. They received instruction from equipment manufactures as well. Men were chosen from the Army Signal Corps and the Army Corps of Engineers. They were expected to have a master's degree in nuclear engineering or some closely related field.

While the project in VA was underway, the Col Lampert began planning and developing the first remote power station at Ft. Greely, AK. This station had extreme environmental temperature variations as well as the challenge of being very remote. The purpose of this station would be to test the feasibility of using a reactor in arctic conditions. After a long and challenging funding validation process SM-1A was approved for development in Alaska. Learning from the challenges of the SM-1 contact, this project was entirely managed by the Army Corps of Engineers. The Corps of Engineers contacted Kiewit Construction to build the reactor facility. SM-1A was different from its predecessor in hat it was a true combined heat and power facility. Half of the energy it created was used to generate steam for power generation and the other half was used for installation heating. Additionally, the cooling water for this location came from deep wells rather than a river such as SM-1's use of the Potomac. Plagued by delays and faulty instrumentation, SM-1A went critical on March 13, 1962. Over the next two years of testing, the plant faced many minor challenges resulting in a difficult testing process. On August 9, 1964, SM-1A became fully operational and went on to set the record for continuous operations by a military reactor facility of 2750 hours. SM-1A proved that reactor technology could be used in remote and austere locations to provided combined heat and power to an installation.

The Army Nuclear Reactor Program reached its peak in early 1960s. At the height of the program, there were a number of reactors operating independently in remote locations. PM-2A was located at Camp Century in the inland of Greenland. This plant was unique

in that it was designed to be portable. Many portions of it were shipped via air straight into Camp Century while the nuclear power portion was moved via ship. After installation in 1962, the plant ran for a few short months. Due to a reduction in the mission at Camp Century, it was no longer needed and subsequently disassembled and shipped back to the United States. It demonstrated not only functionality in an austere environment but showed that the reactor system was truly portable. Other portable reactors included PM-1, which ran a radar site in Sundance Wyoming. PM-1 provided heat and power to the radar facility operated by NORAD. PM-3A operated at a Naval land station in McMurdo Sound Antarctica. Despite the logistical and environmental challenges associated with operation in Antarctica, this reactor facility successfully provided power to 150 personnel for 11 years. It was decommissioned in 1972.

Other innovative designs came from the program. The Army Transportation Corps explored the idea of the Military Compact Reactor (MCR) that could power a vehicle or a train. The ML-1 project was a portable gas cooled reactor that could be loaded on a truck or barge or train and sent forward with deployed troops. ML-1 was actually built and operated in Idaho and was unique to the military because it was the first gas-cooled reactor. MH-1A was a floating nuclear reactor mounted on a barge named *Sturgis.* The *Sturgis* was specially built and designed to carry the reactor. MH-1A went critical on January 24, 1967 while docked at Ft Belvoir. It was operated by an engineer detachment and provided power to the base. The state department eventually entered into a contract with the State of Panama to use the *Sturgis* to power the Panama Canal Zone. The boat was towed to Panama in 1968 and moored with the hydroelectric station. Once hooked into the station, the boat provided power to the Canal Zone for 8 years. The *Sturgis* was returned to the United States in 1977 following negations concerning about ownership of the Canal Zone. It was decommissioned and put into anchorage in 1978.

The first signs of program decline following an accident at reactor facility SL-1 located in Idaho. This was the first boiling water reactor used by the military. After testing, SL-1 operated successfully for two years and was used to conduct training for military crews on a boiling water plant. On December 23, 1960, the facility was shutdown for routine maintenance. During maintenance, it is theorized that one of the reactor operators moved

a central control rod too quickly causing prompt criticality, instantaneous superheating of the core water and vaporization to steam. The massive pressure caused an explosion and killed three operators. No radioactive material leaked from the facility. Many lessons were learned about operating procedures and BWR design following the accident. Nevertheless, the accident was a significant blemish on the record of the nuclear power program.

Despite running many successful reactors and demonstrating their functionality in remote in austere locations, funding constraints at the end of the 1960s caused a reexamination of the Army Nuclear Power Program. In the late 60s, the Vietnam War began to significantly affect DoD's budget. Military leaders looked for places to make cuts in spending. Analysis of the Army Nuclear Power Program showed that it was not cost effective to build such expensive projects in support of remote locations, many of which only had operating missions of a few years. The Army sought to define the requirements for the program but in light of the competing costs of the Vietnam war it was determined that remote stations could still be powered more cheaply by diesel fuel. SM-1 never produced electricity at a rate that was cheaper than the base could have purchased it from the local utility. Thus the Army cut funding to the research and development portion of the Army Nuclear Program. By 1975 all reactors had been deactivated with the exception of the *Sturgis* and the program had transitioned to the Engineer Power Group focused on storing and maintaining non-tactical generators on installations. The group restructured again in 1977 and assumed responsibility of installation maintenance and remote power procurement. By the 1980s, the Engineer Power Group had turned its focus entirely to the maintenance of installation facilities such as the maintenance and repair of real property, construction, fire prevention systems and environmental controls.[67]

Appendix B: SMR Design Assessments

mPower

B.1 Safety: The mPower reactor incorporates the latest passive and active safety features into its small, LWR design. Of primary consideration is potential damaged caused by a loss of coolant scenario. The mPower reactor reduces the risk of this accident by keeping all coolant within a single vessel. The reactor facility contains on-site storage of supplemental water than can provide cooling for a minimum of 7 days. Many of the reactor controls have passive redundancies in the event of a power loss. The facility itself is seismically hardened as well as resistant to flooding. The LWR technology is proven and well tested. Designers' depth of knowledge and practical experience with these types of reactors allows for a much more complete understanding of potential accident scenarios than then more experimental reactor designs.

B.2 Power Output*:* The mPower reactor has a power output of 155 MWe or 530 MWth. This size of reactor adequately meets the needs of a DoD installation with one module. There is enough energy generated to be both a source of electricity as well as being used for process heat applications like district heating.

B.3 Physical Size*:* A two-module facility with a spent fuel storage pond occupies a 40-acre site. The anticipated exclusion zone is less than a mile.

B.4 Refueling Cycle*:* The mPower reactor runs for 4 years at 95% capacity before requiring refuel. A two-module system could operate on offset refueling intervals so as to always provide constant power to an installation. Two modules would generate an excess amount of power for a typical installation. A one-module facility could be operated at less than 95% to increase refueling intervals. An installation could use civilian power during times of refueling. Potentially this could be at no cost if DoD could earn credit by supplying the civilian provider with excess power during times of normal operations. Modifications to the fuel configuration could also increase the time between refuel operations.

B.5 Licensing*:* The mPower reactor closely resembles the LWR models used by the NRC under its current regulatory framework. TVA plants to use the mPower reactor at its new SMR facility under development at Clinch River. TVA's Clinch River project is presenting the NRC with its first SMR licensing test. In evaluating the Clinch River project, the NRC must not only license a new reactor design but also it must also look at the project from a new perspective. TVA is planning to install mPower modules, which currently are still in need of design certification from the NRC. The siting of the mPower units and how they will be implemented over time require not only forethought on the part of TVA, but also require flexibility in regulation from the NRC to make the project economical. It is unreasonable for TVA to have to readdress all regulatory requirements for every additional mPower module they add to the site. TVA must forecast facility impacts on the environment and conduct accident analysis assuming the facility is operating at its largest planned capacity. The NRC should be flexible and allow TVA to implement its mPower installation timeline freely as long as it stays within its forecast capacity.

B.6 Public Acceptance*:* The LWR design is the reactor design most easily accepted by the public. It is not a large divergence from currently used reactor technology and mPower can boast of many new safety features that differentiate it from the more troubled reactors like Fukushima. Additionally, mPower has an edge over other SMR technologies as TVA constructs a first of its kind facility using mPower near future at Clinch River. An operating reactor facility will provide the public comfort by knowing that other commercial manufactures are using it and the military installation is not being used to test new technology.

B.7 Fuel Cost: The mPower reactor uses standard LWR fuel. No special fabrication facilities are needed to provide fuel for the reactor. Current fuel cycle processes would be capable of sustaining this reactor.

B.8 Maturity of Technology: LWR technology is the most widely used reactor technology. mPower incorporates many new safety features and design changes however

the basic technology remains unchanged. Due to the mature nature of the technology, LWR designs are the quickest to be implemented for military use. They require very little further testing of reactor components or systems. mPower has a test reactor, which it operates, and might soon have the first commercial designs used for power production.

B.6 Process Heat Applications: The mPower reactor produces thermal energy at temperatures high enough to provide district heating as well as nuclear desalination. It could be used for limited chemical production applications as well. The single reactor produces enough energy to be used as a cogeneration facility to combine electrical production as well as some process heat applications.[42]

NuScale

B.1 Safety: The NuScale reactor takes advantage of natural circulation to sustain coolant flow within its system. Natural circulation is advantageous as it operates both actively and passively. It has a number of redundant decay heat removal systems (DHRS and ECCS) as well as being situated within a pond of cooling water. The reactor facility is located below ground and is hardened against natural disasters. The NuScale design incorporates spent fuel storage cooling into its plant safety analysis. The spent fuel pool has a cooling capacity with the water volume necessary to accommodate high or low density fuel racks. It has an additional water supply that can be activated by reactor personnel in safe locations. The NuScale design incorporates an active refuel operation. Refueling operations are conducted at the same time the facility produces power. While this is economical advantageous, it does induce risk in the form of operational and process errors. These errors are compounded in severity as the other reactor modules could be operating at the time of an accident. Extensive risk analysis is needed to identify the risks during refuel operations as well as the adoption of strict refuel procedures and protocols. Many of the NuScale safety features are in direct response to the Fukushima accident. These features allow designs to directly answer Fukushima safety questions from critics as well as comply with new NRC guidance.

***B.2 Power Output**:* The NuScale reactor outputs 45 MWe or 160 MWth. The reactor output is small but it intended to be operated in a multi-module facility. A DoD installation would need 2-3 reactors to meet its basic electrical needs. If it wanted to conduct process heat applications, it would need additional modules. The small output of the modules allows DoD to tailor each facility to the installation.

***B.3 Physical Size**:* A 12-module facility with a spent fuel storage pond occupies a 44-acre site. The anticipated exclusion zone is much smaller than current commercial reactors.

***B.4 Refueling Cycle**:* The NuScale module requires refueling every 2 years. For a 12 module facility, this means refueling a module every 2 months. Facility operators would undergo refuel operations on a constant schedule. For a facility with fewer modules, the refueling intervals would be easier to offset. For DoD, a 3 to 4 module facility would require one module refueled every 6 months. During times of refuel, consideration must be given to the reduced power capacity of the facility. It may be necessary to increase the number of modules to account for refuel outages.

***B.5 Licensing**:* NuScale is part of a DoE partnership to enhance the use of SMR technology. NuScale began its pre-application in 2008 and is expected to have design certification from the NRC in 2015. [68]While it is slightly behind mPower on the licensing timeline, it benefits from the development of regulatory framework that is developing around mPower. The reactor technology is not drastically different than a LWR so licensing questions will revolve mostly around the SMR framework and individual technologies.

***B.6 Public Acceptance**:* The LWR design is the reactor design most easily accepted by the public. It is not a large divergence from currently used reactor technology and mPower can boast of many new safety features that differentiate it from the more troubled reactors like Fukushima. NuScale has safety features that can are designed to be in direct response to the Fukushima accident. These features will aid developers by

increasing public confidence in the design as they point out its key safety differences from the troubled reactor. Additionally, similar SMR technology is being implemented commercially at Clinch River. An operating commercial reactor with a similar design will provide the public comfort by knowing that the military installation is not being used to test new, unproven technology.

B.7 Fuel Cost: The NuScale reactor uses standard LWR fuel. No special fabrication facilities are needed to provide fuel for the reactor. Current fuel cycle processes would be capable of sustaining this reactor.

B.8 Maturity of Technology: LWR technology is the most widely used reactor technology. NuScale incorporates many new safety features and design changes however the basic technology remains unchanged. Due to the mature nature of the technology, LWR designs are the quickest to be implemented for military use. They require very little further testing of reactor components or systems. NuSclae has a prototype reactor used to test systems and controls of the individual module. They have yet to develop a full NuScale power generation facility.

B.6 Process Heat Applications: The NuScale rector could be used for both district heating and nuclear desalination. It is unlikely that it could be used for cogeneration while operating as a single module. Working in an array of modules, NuScale technology could be used to power a cogeneration facility.[36]

PRISM

B.1 Safety: The use of sodium as a coolant provides both safety advantages and disadvantages. Sodium coolant is operated under low pressure, which eliminates the loss of pressure accident within the core. Sodium's reactivity with water is risk unique to SFR. Reactor designers mitigate this risk by using intermediate cooling loops to separate core coolant from steam production. Leaks within sodium reactors can pose potential dangers as the coolant reacts with air or water. Sodium cooled reactors have been operated and many have experienced small leaks which were easily contained. There is a history of leak detection and isolation controls for the operation of SFR. The PRISM

incorporates decay heat removal systems to passively remove heat from the core during normal or emergency shutdown. The Auxiliary Cooling System (ACS) removes heat from the vessel by using forced or natural circulation to pass air along the exterior of the reactor vessel. The Reactor Vessel Auxiliary Cooling System (RVACS) adds additional cooling air to the ACS using passive systems only. Additionally, the RVACS provides protection to the reactor vessel in event of failure to a heat removal system as decay heat is transferred through the vessel to the surrounding containment. The PRISM reactors are designed to be operated in a variety of configurations. The lack of uniformity presents an operational risk, as there is an increased potential for human induced errors, especially while simultaneously operating a number of PRISM reactors in different configurations.

B.2 Power Output: The PRISM outputs 311 MWe or 840 MWth. This is more than enough to meet the needs of a DoD installation. If operated as part of a waste management solution, it could provide power for the waste reprocessing as well as installation power. Excess power could be sold to a local utility.

B.3 Physical Size: PRISM reactors are part of the ARC solution to nuclear waste. The anticipated ARC facility will be very large and is unlikely to be situated on a military compound.

B.4 Refueling Cycle: The PRISM refuel cycle is 12- 24 months depending on fuel configuration for the mission of the PRISM. The intent of the ARC facility is nuclear fuel reduction through re-use within a PRISM module. Thus, increased refueling intervals aid ARC operators by providing increased opportunities to burn used nuclear fuel.

B.5 Licensing: The PRISM reactor diverges greatly from the LWR framework used by the NRC. As an advanced reactor, there are many questions concerning the development of a licensing framework.

B.6 Public Acceptance*:* The benefits of the sodium cooled, nuclear waste fueled PRISM present an attractive solution to the Nation's nuclear waste challenges. Using a reactor with the capacity to run on spent fuel would be certain to have strong public appeal. The public might be concerned about the use of advanced reactor technology since it the project would be a first of its kind development. The public would be more likely to accept the project if it was located far from population centers on a remote military installation. This kind of implementation is likely to have strong approval as it not only presents a viable solution to nuclear waste disposal but it also keeps the reactor out of major population centers. The public is likely to approve of its placement on a military installation as these facilities already have established security protocols.

B.7 Fuel Cost: The PRISM reactor requires specific fuel in order to operate. It is indented to be coupled to a fuel-recycling center, which would accept and process nuclear waste. The recycling center would then repackage the waste into useable fuel for the PRISM reactor. Fuel manufacturing for the PRISM would be expensive however if coupled to a solution to the disposal of nuclear waste, might be an acceptable cost. Funding for a project of this scale requires cooperation of many departments within the government and is unlikely to be conducted solely by the Department of Defense.

B.8 Maturity of Technology: Sodium cooled reactors have an extensive history of testing and operation. They are not currently used in the United States. The PRISM has a number to technological advances that require further testing and evaluation. A large component of this design is evaluating the fuel-recycling center. This reactor is considered advanced and is still in the research and development stages of implementation.

B.6 Process Heat Applications: While the PRISM reactor attains temperatures that could be used for process heat applications, its primary purpose is nuclear fuel recycling. It could be used however for nuclear desalination or district heating. A fuel recycling facility located in a remote location could find some use in the application of excess

energy. Process heat applications of thermal energy could be used for life support systems of the facility staff. [38]

4S

B.1 Safety: The 4S reactor has the same advantages and disadvantages as the PRISM reactor due to using sodium as a coolant. The 4S reactor incorporates a number of passive decay heat removal systems such as the IRACS and RVACS. The 4S reactor is intended to be a stand-alone, minimum maintenance reactor. By reducing the number of reactivity changes, reducing maintenance outages and eliminating refuel operations, the reactor has a reduced risk of procedural induced accidents (human error). This operational approach does increase the risk from material failure induced accidents, as there is a reduced level of scheduled maintenance on the facility. Proper risk analysis needs to be done to define material failure times. The maintenance checks must then be conducted within appropriate time standards to prevent failures.

B.2 Power Output*:* The 4S reactor produces 10 MWe. This output will not sustain a large DoD installation. There are small, remote outstations however that could be sustained on 10 MWe.

B.3 Physical Size*:* The 4S reactor is very small and intended for remote locations. It is well suited to fit in confined spaces, as it requires no storage for spent fuel. Increasing the number of 4S modules would increase the land requirements however these modules are not intended to be operated collectively.

B.4 Refueling Cycle*:* The 4S reactor has no refuel option. It runs for 30 years continuously and is then replaced. This significantly reduces fuel and operating costs.

B.5 Licensing*:* The 4S reactor diverges greatly from the LWR framework used by the NRC. As an advanced reactor, there are many questions concerning the development of a licensing framework.

B.6 Public Acceptance: The 4S reactor is much smaller and longer lived than other SMR designs. These characteristics make it uniquely suited for certain situations. The public is likely to approve of a remote power, long-term power source like the 4S reactor if it is clearly tied to a solution for a challenging problem. Most ideally it would be suited for providing power to locations within third world countries to sustain medical and foreign aid operations. These locations face challenging security situations so its anti-proliferation design features aid the reactor. Additionally the reactor requires very little active control so it does not need the typical large, well trained, expensive staff found in a commercial facility. The public is likely to accept this reactor abroad and could be used by the military on small installations outside the United States. It could also be used at small remote sites within the US. Within the country, the public might be concerned about the minimal staffing requirements as well as the first of its kind technology.

B.7 Fuel Cost: The 4s reactor uses a uniquely designed fuel pin with a glass plenum running along het center axis of the pin. It is a unique design and would require specialized fabrication. While this would be more costly than standard LWR fuel, it is also a one-time expense. The reactor runs for 30 years without the need for refueling. The longevity of the fuel cycle offsets the expense of the fuel.

B.8 Maturity of Technology: Sodium cooled reactors have an extensive history of testing and operation. They are not currently used in the United States. The 4S reactor has a number to technological advances that require further testing and evaluation. Further research is needed for both material and fuel pin design. This reactor is considered advanced and is still in the research and development stages of implementation.

B.6 Process Heat Applications: The 4S reactor does not produced enough energy to provide both process heat and electricity. It is possible it could be used for process heat applications in stand-alone facilities on a small scale.[39]

Reactor Assessment

The reactors are ranked on a scale of 1 through 4. A score of 1 is given the reactor with the best characteristics to meet the design consideration. All characteristics are equally

weighted. Each subsequent reactor is ranked numerically. The reactor with the lowest total score is the one that meets the current design needs of the Department of Defense for providing installation energy security. This assessment shows that the mPower reactor is most suited for powering a DoD installation.

Reactor	mPower	NuScale	PRISM	4S
Safety	3	2	4	1
Power Output	1	2	3	4
Physical Size	2	3	4	1
Refueling Cycle	2	3	4	1
Licensing	1	2	4	3
Public Acceptance	1	2	4	3
Fuel Costs	1	2	4	3
Maturity of Technology	1	2	4	3
Process Heat Applications	1	3	2	4
Score	**13**	**21**	**33**	**23**

Appendix C: Technology Readiness Assessment for DoD Power Reactor and Combined Heat and Power Facility

This table was prepared using the 2011 Department of Defense Technology Readiness Level Assessment Guidebook.[66]

DoD Technology Readiness Levels					
TRL	**Definition**	**Description**	**Clinch River Project**	**DoD Power**	**DoD CHP**
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.	No changes to basic science from LWR concepts **Complete**	No action needed **Complete**	No action needed **Complete**
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Development of improved safety features, both passive and active. Small, self contained reactor conceptualized **Complete**	No action needed **Complete**	No action needed for reactor technology. Analysis of cogeneration demands/applications **Past Analysis Review/ Update**
3	Analytical and experimental critical function and/or characteristic proof of concept	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative	Analysis and modeling of passive safety features and controls unique to mPower reactor. Simulations of balance of plant **Complete**	No action needed **Complete**	No action need on new reactor design. Analysis of cogeneration options/balance of plant utilizing lessons learned from Army Nuclear Power Program **Past Analysis Review/ Update**
4	Component and/or breadboard validation in a laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	Individual safety system development, testing and modeling. Laboratory models of controls and safety features **Complete**	No action needed **Complete**	No action needed for reactor technology. Cogeneration technology components tested (controls, valves, load shedding, distribution)
5	Component and/or breadboard validation in a relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components	Newly development components tested in controlled reactor environment or test facility. **Complete**	No action needed **Complete**	Cogeneration technology applied to existing test reactor facility. Reactor/process heat interface validated
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's laboratory environment or in a simulated operational environment demonstrated readiness. Examples include testing a prototype in a high-fidelity	Reactor prototype built and operated in controlled environment. B&W Integrated System Test Facility (fully operational July 2012) **In-Progress**	No action needed	Existing prototype facility coupled to process heat application. Verification of reactor/process heat interface. Validation of all reactor control/safety features. Process heat output confirmed
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an air-craft, in a vehicle, or in space).	Reactor prototype built and operated in facility similar to commercial application. No simulated conditions. Reactor runs at varying loads continuously for determined test period	No action needed for technology, Analysis of installation siting choices and military impacts on NRC licensing	Reactor prototype facility coupled to process heat application. Verification of all outputs (power and process heat) at varying loads.
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to deter-mine if it meets design specifications.	NRC validation and design certification complete **In-Progress**	DoD, Army Corps of Engineers and NRC analysis and validation of impacts on license for military application.	NRC licensing of cogeneration design and process heat application license
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	Successful build and operation of Clinch River Project **In-Progress**	mPower facility installed on pilot installation. Validation of systems, protocols, management and operation	Successful build and operation of military installation CHP facility. Incorporation of process heat produced for installation use

Vita

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