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A Review of U.S. Microreactor Projects: Historical Development and Future Prospects

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1. Introduction

A microreactor is a small nuclear reactor that can operate as part of the electric grid independently, or as a part of a microgrid to generate up to 20 MWe that can be used to generate electricity and provide heat for industrial applications. Most of these small reactors are designed to be transportable and many could be hauled by a semi tractor-trailer. Microreactors are 100 to 1,000 times smaller than conventional nuclear reactors [1].

The U.S. has shown significant interests in microreactors due to their potential to provide reliable power in remote or isolated locations and to reduce dependence on fossil fuels. This interest is driven by both climate considerations and strategic need [2]. Since the 1950s, the U.S. has been engaged in various projects aimed at deploying small nuclear reactors to military bases to meet the energy requirements.

In 2011, the U.S. acknowledged in an official document that while small reactors with outputs up to 300 MWe could support its missions, their output was too excessive compared to the power demand of U.S. military bases. Consequently, the concept of a microreactor with a 10 MWe output emerged as a more suitable solution, addressing both operational and strategic energy requirements effectively [3].

This study provides a brief review of the historical development and current status of U.S. microreactor projects and explores future implementation prospects. It examines key microreactor initiatives chronologically, assessing how they have addressed the energy needs of military bases and remote locations. Additionally, the research discusses the potential deployment of microreactors within the Republic of Korea (ROK), proposing strategic approaches to meet future energy demands.

2. Historical and Contemporary Microreactor Projects

In this section provide a chronological review of major microreactor projects undertaken by the U.S., specifically focusing on those aimed at utilizing microreactors as a power source for military bases.

2.1 Army Nuclear Power Program (Feb. 1954 – Nov. 1976)

Established in 1954, the Army Nuclear Power Program (ANPP) was a collaborative initiative between the U.S. Army Corps of Engineers (USACE) and the Atomic Energy Commission (AEC). The program's primary objective was to develop small, rugged, and transportable nuclear power plants (NPPs) that could provide both heat and electricity for remote military installations.

In 1957 the ANPP succeeded in developing its first prototype reactor at Ft. Belvoir, Virginia. Over the next two decades, the program designed, built, and operated a total of eight reactors, both within the U.S. and internationally. Although the ANPP was discontinued in 1976, it significantly advanced the field of nuclear power through innovations in detailed reactor designs (e.g., Pressurized Water Reactor (PWRs), Boiling Water Reactors (BWRs)), containment and control systems, and radiation protection and safety protocols [4,5].

Table1. Major Achievements by Reactor Type in the ANPP [5]

Reactor	Reactor Type	Major Achievements
SM-1	PWR	First Closed-Cycle NPP. First Use of Stainless Steel as Fuel Element Cladding. First NPP to Supply Electricity to a Commercial Power Grid.
SL-1	BWR	First Operational BWR.
PM-2A	PWR	First Portable Prepackaged Modular NPP.
ML-1	PWR	First Land Transportable NPP. First Nuclear Closed-Loop (Brayton) Gas Turbine Cycle.
PM-3A	PWR	First Use of Nuclear Power for Desalination.
SM-1A	PWR	First Use of Nuclear Heat Source to Strengthen Reactor Vessels. First Replacement of a Steam Generator. First Pressure Suppression System.
MH-1A	PWR	First Floating NPP.

2.2 Project Pele (Jan. 2020 - Present)

In 2016, the Defense Science Board (DSB) identified significant and growing energy challenges, projecting a substantial increase in energy use on the battlefield over the coming decades. This increase necessitated a comprehensive re-evaluation of the U.S. energy logistics. The DSB's study emphasized the need for long-term energy solutions that support technical superiority and meet the demands of new warfighting systems, such as directed-energy lasers, railguns, and UAVs, which require reliable, high-density energy sources. The DSB concluded that nuclear energy could offer a viable solution, leading to the initiation of Project Pele [6,7].

To ensure safety and efficiency, Project Pele has adopted advanced Tri-structural Isotropic (TRISO) encapsulated nuclear fuel. This technology is particularly suited for mobile microreactors, offering robust safety features and efficient energy production. It represents a significant advancement in nuclear reactor design for military applications [6].

Table2. Project Pele Technical Requirements [8,9]

Characteristics	Value
Output	1 – 5 MWe
Reactor type	HTGR (High Temperature Gas Reactor)
Fuel	TRISO (using HALEU)
Life	Able to generate threshold power for>3years without refueling
Start-up	Time from arrival of unit to reaching full electric power less than 72 hours
Wrap-up	Time for planned shutdown, cool down, disconnect, prepared transport, and safe transport less than 7 days
Size	All components should fit in ISO 688 certified 20' or 40' CONEX boxes<40 tons (to be delivered vis train, truck, or cargo plane)

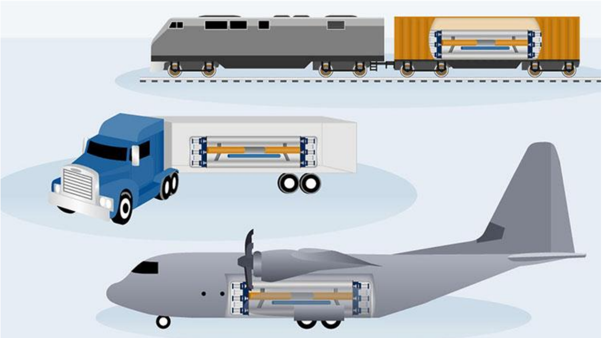

Fig. 1. Conceptual Transportation for Microreactors [10]

Currently, Project Pele is under development with efforts focused on achieving a prototype demonstration by late 2025. The project aims to develop and demonstrate mobile microreactor technology to provide a compact, high-density energy source that meets the increasing energy demands of advanced military systems and enhances operational capabilities on the battlefield [2].

2.3 Microreactor Pilot Program at Eielson AFB (Oct. 2021 - Present)

In October 2021, The Department of the Air Force (DAF) selected Eielson Air Force Base (AFB) in Alaska, as the site to pilot its first microreactor. The program is scheduled to conduct a pre-operational test in 2026, with the goal of concluding the pilot phase and beginning commercial operations by 2027. Eielson AFB was chosen due to its resilient power needs for mission assurance, limited access to clean energy, existing energy infrastructure, and compatible climate. The selection allows the Air Force to address both power and heating requirements at the base like Eielson AFB, while ensuring the microreactor operates reliably in extreme climates and integrates seamlessly with existing infrastructure.

However, the purpose of the Eielson micro-reactor is notably different from the prototype mobile micro-reactor being constructed under Project Pele. As explained in a 2020 request for information about micro-reactors, the U.S. is interested in both fixed-site and mobile micro-reactors, while the Eielson project is focused on the use of fixed-site applications [11,12].

3. Summary and Discussion

The U.S. has predicted a significant increase in energy demands for military operations over the coming decades, alongside efforts to reduce greenhouse has (GHG) emissions. The historical and ongoing microreactor projects of the U.S. highlight the necessity of deploying NPPs at military bases to meet the escalating power demands driven by evolving battlefield environments and paradigms. These projects also demonstrate that the design requirements for microreactors may vary based on the operational characteristics, regional location, climate conditions, and specific purposes of the deploying units. The U.S. microreactor pilot programs aim to validate the feasibility of microreactors for future energy needs and to set objectives for their commercial operation.

At present, the ROK faces a critical demographic challenge due to a declining birth rate, which is projected to have severe implications for future defense policies [13]. In response, the ROK is focusing on integrating technologically advanced systems in defense area, ultimately leading to the need for reliable energy sources to address rising energy demands. Moreover, aligning with global carbon reduction efforts necessitates consideration of nuclear energy. In the light of the U.S. experiences, the differences in power usage based on operational, geographical, and climatic characteristics of the ROK should be first analyzed to forecast future power demands in order to derive the optimal pathway for deploying microreactors.

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