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Feasibility Study on Deploying Micro Modular Reactors (MMR) in Korea for Remote Area

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1. Introduction

The remote regions in Korea, including military bases currently depend heavily on KEPCO's commercial power grid and diesel generators, making it difficult to secure a stable power supply.

Due to Korea's geographical characteristics, numerous islands are scattered along the coastline, and more than 70% of the land consists of mountainous terrain. As a result, ensuring a stable power supply in remote and mountainous regions poses significant economic and technical challenges.

In reality, out of 472 inhabited islands, more than 100 islands rely on self-generation for electricity supply. For example, Baek-Ryeong Island, the northernmost island of South Korea, operates a total of eight diesel generators, providing a power generation capacity of 15,000 kW [1]. Beyond Korea's mainland, The King Sejong Station, a scientific research station in Antarctica, runs three main generators capable of producing 275kW of electricity.

This challenge is not limited to the civilian sector but is also evident in the military. Republic of Korea (ROK) Army is undergoing a reduction in military personnel, leading to significant changes in National Defense policies. In response, the Ministry of National Defense has established the "Defense Innovation 4.0 Master Plan" to proactively address future challenges. This plan is expected to result in a sharp increase in energy demand for military operations [2]. However, the military bases in Korea located in the remote region do not have a clear pathway to secure power supply during wartime and emergency situation other than relying on the diesel generator.

Table 1. Limitations of Conventional Power Source

Source	Disadvantages
Commercial Grid	- Limited Mobility and Scalability - High Costs in Remote Areas : Power Lines - Impact of Climate Change
Diesel Generator	- Low Fuel Economics - Environmental Impact : GHG emissions - Noise and Smoke

The disadvantages of conventional power grid, as shown in Table 1, introduce problems in both military and civilian sector. Therefore, securing a stable, independent, and reliable energy source is crucial for successful mission execution and civilian use.

This paper analyzes the introduction of Micro Modular Reactor (MMR) as a new power source to address the increasing energy demand and reduce its heavy reliance on the existing power grid in remote regions, which has several limitations. Additionally, various international cases were reviewed to outline the design, performance, and development plan of an MMR optimized for South Korea.

2. Necessity & Advantages of MMR

The Micro Modular Reactor (MMR) is a small reactor with a capacity ranging from 1 to 20 MWe, offering excellent mobility and safety, making it an ideal power source for remote locations. To ensure ease of deployment and feasibility in remote, mountainous, and island regions, five key requirements were identified and evaluated. Considering these requirements for a new power supply, the main advantages of MMR are presented in Table 2.

Table 2. Main advantages of MMR

Key Requirements	MMR Advantages
High Power Output	- Output of 1 to 20Mwe matches the demand profile of isolated or off-grid applications
Resilience to Supply Chain Risks	-Operates independently of external power grids -Operates for over few years without external fuel supply
Operational Compatibility	-Transportable -Enable Quick Deployment
Flexibility in Design	-Allow tailored deployments -Power output can be adjusted
Safety and Reliability	-Passive Safety System -Minimal operational personnel

Considering these characteristics and advantages, MMR appears to be a viable power supply solution that not only meets increasing electricity but also enables flexible response under various circumstances.

3. MMR Optimized for South Korea

This paper analyzes the detailed contents by dividing them into two categories for the introduction of MMR in Korea.

3.1. Fields for MMR Utilization

To envision how MMR can operate in Korea, Project Pele in the US can be auseful example [3]. A task force analysis conducted in 2016 revealed that 70–90% of the supplies delivered to forward bases and expeditionary forces during the Iraq and Afghanistan wars consisted of fuel and water. However, this type of support paradoxically provided the enemy with opportunities to attack convoys and launch IED (Improvised Explosive Device) attacks, leading to a loss of combat capability. To minimize these losses, MMR was developed with the aim of providing power support to FOBs (Forward Operating Bases), ROBs (Remote Operating Bases), and expeditionary bases.

It is also necessary to analyze the operation of MMR from an economic perspective. According to the techno-economic evaluation conducted by Idaho National Laboratory, as shown in Table 3 and Figure 1 below, the NOAK (Nth-of-a-kind) cost of MMR is relatively high when compared to wholesale electricity prices.

Table 3. FOAK Cost & NOAK Cost of MMR [4]

	FOAK Cost	NOAK Cost
Operating Cost ($/Mwh)	171	54
LCOE	470	136

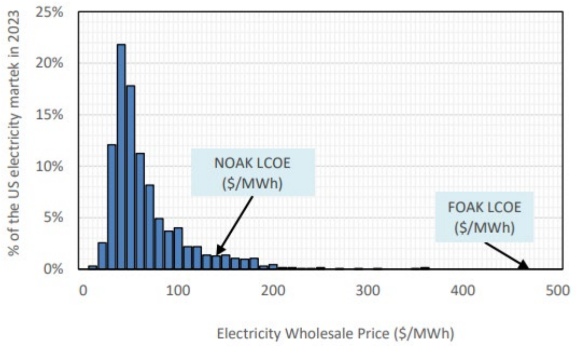

Figure 1. LCOE (Levelized Cost of Electricity of the MMR FOAK (First-of-a-kind) and NOAK compared to the wholesale electricity price (in 2023)

Considering the objectives of Project Pele and the Levelized Cost of Electricity (LCOE) of MMR compared to wholesale electricity prices, the use of MMR can be classified into three categories.

The first is remote island and mountainous regions where stable commercial power supply is limited**.** As mentioned in the introduction, more than 100 islands rely on self-generation without any auxiliary power source, making it difficult to respond effectively in emergency situations. In particular, these remote areas are highly susceptible to environmental and climatic variability, which compromises the stability of power supply. Therefore, additional power infrastructure must be established to ensure the safety and survival of local residents.

The second category is the use in remote locations such as Antarctica and space installations. As mentioned in the introduction, the King Sejong Station relies solely on generators for power, making it one of the most vulnerable locations in terms of stable electricity supply. Although backup generators are available for emergency situations, the extreme climate and harsh environmental conditions of Antarctica pose inherent risks to maintaining a stable power supply Thanks to MMR's low maintenance requirements and long fuel cycle, it is expected to be more economically viable than relying exclusively on diesel generators in off-grid environments [5].

The final category is military applications. The ROK Army is expected to face limitations in utilizing conventional power grids in emergency situation due to issues such as facility destruction, unstable power networks, and differences in frequency and voltage. It is anticipated that using MMR to support power networks would enable a more stable power supply without diminishing military capability. Additionally, ROK military units deployed in Lebanon, South Sudan, and Somalia rely on self-sustained generators due to the limited availability of stable electricity in these regions. In this context**,** MMR could serve as an ideal power source for deployment operations**.**

3.2. Specification of MMR

According to the latest information on the Pele Project, in September 2023, the U.S. Department of Defense awarded an additional contract to X-energy to proceed with the enhanced engineering design of a MMR called Xe-Mobile. Additionally, the transportable nuclear reactor being developed by BWXT aims to transport the fully assembled reactor to Idaho National Laboratory by 2026 [6]. The specifications of the MMRs being developed by companies associated with the Pele Project can be found in Table 4.

Table 4. Project Pele MMR Specification [7]

Company / Model	Output (MWe)	Reactor Type	Fuel Cycle (Years)	Fuel Type
BWXT / BANR	1 to 5	HTGR	2 to 5	TRSIO
Xenergy / Xe-Mobile	2 to 7	HTGR	More than 3	TRSIO

The difference in capacity ultimately translates to variations in size, making this classification more practical for real-world applications. Small MMR would be ideal for extreme environments where mobility and ease of deployment are crucial, while medium-sized MMR would be more suitable for stable power supply in remote islands, mountainous regions, or large-scale facilities.

In military applications, determining the required power capacity is challenging due to limitations in assessing the exact electricity needs of different unit echelons, making it difficult to define precise figures. The average population of island regions is 1,762.8, and South Korea's per capita electricity consumption last year was 10,637 kWh [8]. Based on this, considering peak power usage with a 1.5 multiplier, an appropriate power capacity for island regions would be 3 MWe. Additionally, Antarctic research stations currently operate three 275 kW diesel generators, suggesting that a suitable capacity would be approximately 1 MWe.

Given these considerations, the optimal classification for MMR output would be 1 MWe for small-scale units and 3 MWe for medium-scale units, allowing for flexible and efficient deployment depending on the specific power needs

High Temperature Gas-cooled Reactors (HTGRs) and TRISO fuel, though distinct in type, have proven to be a compatible and promising combination - as demonstrated in the Pele Project. While HTGR is a feasible and commercially viable reactor design, TRISO fuel has also shown maturity and robustness. However, additional reactor types and fuel options are being actively researched. The technologies being developed in the US include SFR (Sodium-cooled Fast Reactor), MSR (Molten Salt Reactor), and Heat Pipe reactors. The characteristics and advantages of each core system are summarized in Table 5.

Table 5. Reactor Specifications by Type [9]

Reactor Type	Fuel Type	Advantages / Disadvantages
HTGR	TRISO	- Hydrogen production and Heat Supply (High Temperature)
		-TRISO is Difficult to reprocess -High Temperature increases Risk
Heat Pipe		-Versatile Application -Advantageous for miniaturization
		-Enclosed system limits maintenance
SFR	U-PU-Zr Alloy	-Excellent Heat Transfer -Fast Neutrons enhance Fuel Efficiency & Waste Reduction
		-High Reactiveness of Sodium -Complex due to High Temperature and Pressure
MSR	Mix T, U, P And Minor actinides With F or C	-Nuclear Fuel acts as a Heat Transfer medium -Solidifies immediately upon leakage -Enable Fuel Circulation with an Extended Cycle
		-Difficult to miniaturize -Technology difficulties

4. Summary and Further Works

This paper assesses the introduction of MMR as a new power grid solution for remote area while addressing various issues arising from increasing electricity demand and the heavy reliance on conventional power grids and diesel generators. Based on international case studies, this study evaluates an MMR optimized for Korea, identifying fields for MMR deployment, detailing its specifications, and discussing its future development.

While the benefits of introducing a new power grid and MMR are evident, there remain several unresolved challenges. Despite long-term R&D efforts that have led to securing key technologies for the next-generation reactors, the commercialization process has been hindered by the lack of site selection and business models. Additionally, the timely establishment of a safety regulatory framework and strategic international cooperation remain critical areas that require further attention.

Through thorough preparation and government-led implementation, the introduction of MMR should resolve current issues faced by both civilian and military sectors.

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