Preliminary Study of Thorium Fueled Gas Cooled Micro Modular Reactor

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1. Introduction

Small Modular Reactors (SMRs) are safer and more cost-effective reactors as an alternative to conventional large nuclear power plants. While SMRs have gained attention for their enhanced safety features and potential to reduce construction costs compared to traditional nuclear facilities, Micro Modular Reactors (MMRs) take this concept a step further by minimizing their physical footprint and offering increased flexibility in deployment. The distinctive feature of MMRs lies in their compact size, which enables them to be deployed in diverse settings, including urban areas, industrial zones, and remote regions. [1]

In this paper, thorium fueled gas cooled MMR core design will be proposed. The main objective of this study is to introduce a conceptual framework for the feasibility of incorporating thorium fuel within the design of MMR. Thorium, with its inherent safety characteristics and potential to address nuclear waste concerns, has emerged as a promising candidate for advancing nuclear energy technologies. In this work, all the neutronic calculations are performed by using the KENO-VI code in SCALE6.2.4, a continuous-energy Monte Carlo code [2], with the ENDF/B-VII.1 neutron data library.

2. Design Specification

Thorium is a fertile material that, on its own, does not occur fission. Thus, it requires neutron to capture and convert it to fissile material, 233U. Thorium may be used to produce 233U, by undergoing neutron capture followed by beta decay. Due to the thorium atom requires two neutrons to be able to occur fission, therefore a better neutron economy must be devised when using thorium fuel. [3]

One of the advantages of the thorium-uranium fuel cycle lies in the lower-production of high activity long lived waste. The lower atomic weight of thorium compared to 238U means that Thorium needs absorption of many more neutrons to form the heavy isotopes. [4]

The MMR proposed in this paper has minimized its size and utilized thorium as fuel with 233U. The design parameters have shown in Table 1. criticality and depletion calculation has been performed with KENO-VI of SCALE 6.2.4 with the reference input as shown in Figure 1. One of the advantages of this reactor is that it doesn't have to consider proliferation resistance. Because it is a fast reactor, ^{232}Th causes a fission reaction in fast region.

Table 1. Design Parameter of Micro Modular Reactor

Design Parameters	Specification
Fuel Composition	(Th+^{233}U)Al
Reactor Power	10MW$_{th}$
Coolant Material	He
Clad Material	Zr-4
Reflector Material	Graphite
Fuel Rod Radius	0.45 cm
Assembly Pitch Size	2.5 cm
^{233}U Enrichment	45 wt%
^{10}B Enrichment(Control Rods)	90 wt%
Core Radius	25 cm
Active Core Height	40 cm

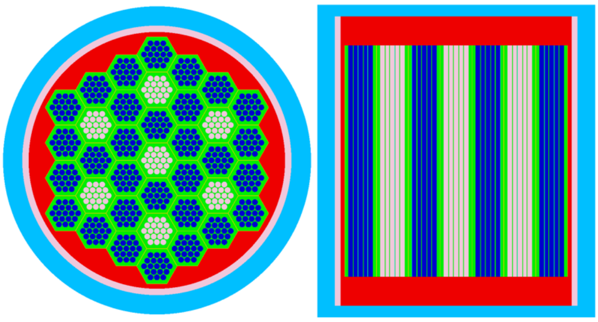

Figure 1. X-Y and Y-Z Cross-sectional View of Reactor

In addition, calculations have also been performed to ensure critical safety. Critical safety was confirmed in the All Control Rods In (ARI) state. Seven control rod Assemblies were used to accomplished subcriticality in the ARI state. The material of the control rod is B4C. The x-y cross-sectional view of All Control Rods Out (ARO) and ARI states have shown in Figure 2. In addition, fuel rod assembly and control rod assembly have shown in Figure 3.

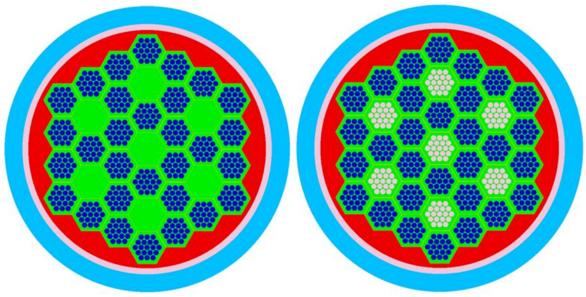

Figure 2. X-Y Cross-sectional View of ARO and ARI

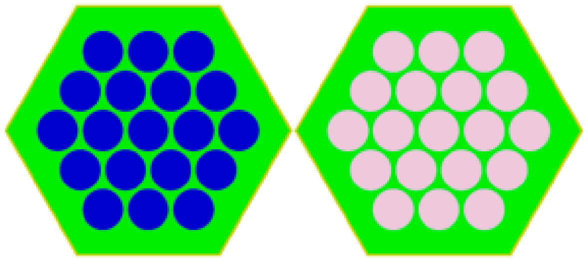

Figure 3. X-Y Cross-sectional View of Fuel Rod Assembly and Control Rod Assembly

3. Result Analysis

To sum up Chapter 2, the detailed core design is the fuel with (Th+233U) composition with 45 wt% enrichment of 233U. In addition, helium has been utilized as coolant material, the fuel rod radius has been designed as 0.45 cm, and the pitch size has been designed as 0.5 cm. In ARO, the keff is 1.2362. In ARI, the keff is 0.9632, which satisfies the subcritical. The critical calculation results are shown in Table 2

Table 2. Calculation Result with Control Rods

Conditions	k_{eff}	std
All Control Rod Out	1.2362	0.0019
All Control Rod In	0.9632	0.0015

The gas cooled fast reactor has been designed with optimized parameters as Table 1. And it is necessary tocalculate out the neutron spectrum of the optimized gas cooled fast reactor. Thus, the neutron spectrum had been calculated as shown in Figure 3 with utilizing the CDS parameter which save fission distribution as a mesh tally in KENO-VI code.

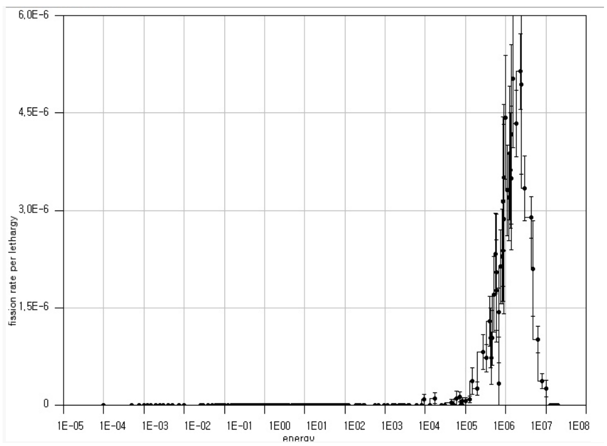

Figure 3. Gas Cooled MMR Neutron Spectrum

As shown in Figure 3, the neutron spectrum of gas cooled fast reactor is showing the peak around the 1MeV. This means that the designed reactor is a fast reactor. The depletion calculation had been performed with KENO-VI code. The NPS has been set for 10000, and skipped cycles has been set as 50 cycles, and active cycles for 150. The depletion calculation has been performed with power of 10 MWth. As a result, the designed reactor is expected to have a lifespan of 40 years. The results have shown as Figure 4.

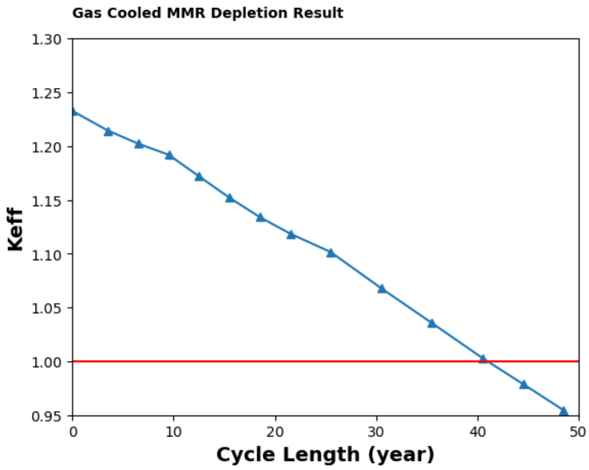

Figure 4. Gas Cooled MMR Depletion Result

4. Conclusion

This study presented a thorium-fueled gas cooledMMR core design, focusing on its small size and extended fuel cycle length. The calculation results haveshowed that the proposed MMR design, featuring(Th+233U)Al fuel composition with 45 wt% enrichment of 233U, impressive criticality performance. Also, since keff is subcritical in ARI state, critical safety was confirmed.

The neutron spectrum of reactor has shown that design achieved its intended purpose, with the neutron spectrum peaking around 1 MeV. The depletion calculations, conducted over a period of approximately 40 years at 10 MWth power, showed the long-term performance potential of the reactor.

Critical performance and critical safety have been verified, but further studies are needed to control the initially high excess reactivity.

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