New Design of the Mobile Nuclear Fuel Assembly System for the Reactivity Control Purpose

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INTRODUCTION

- Growing demand for carbon neutrality and distributed power has increased interest in next-generation reactors with enhanced safety and flexibility.
- To ensure **redundancy** and **diversity** beyond conventional control systems, a **generally applicable active mitigation system** for reactivity suppression is proposed.
- An **i-SMR**(innovative Small Modular Reactor) core design was adopted as a reference model to evaluate **reactivity variations** caused by fuel assembly spacing.
- **Core reactivity** behavior was investigated to verify the feasibility and effectiveness of the proposed active criticality control concept.

METHODOLOGY

◆ Core Design Methodology

- Fig.1 illustrates the core loading pattern adopted in this study, while the detailed geometry and configuration of each fuel assembly type from A01 to A05 are presents in Fig.2.

Fig.1 Loading pattern of the i-SMR core

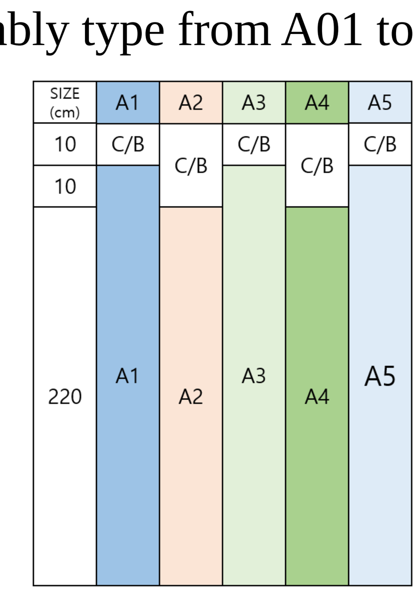

Fig.2 Axial configurations of the FAs

- The reactor core is designed to operate at 540 MWth with a 24-month refueling cycle, utilizing UO_2 as the fuel material in a 17x17 square pitch lattice configuration.
- The neutronic analysis was performed using the MCNP k-eigenvalue mode by tracking 60,000neutron histories per cycle, with k_{eff} estimated over 1100 active cycles out of a 1200 cycles to ensure a statistical uncertainty of less than 10 pcm.
- As shown in Fig.3 and 4 , the analysis focuses on the **Beginning of Cycle(BOC)** condition, which represents the most conservative state with the **greatest** $\boldsymbol{k_{eff}}$ due to the absence of fission products.

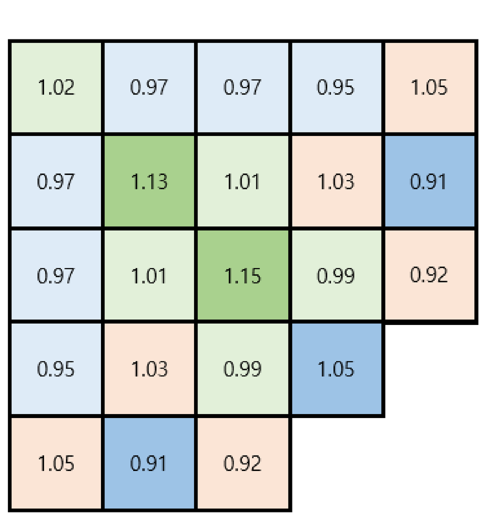

Fig.3 Radial power distribution

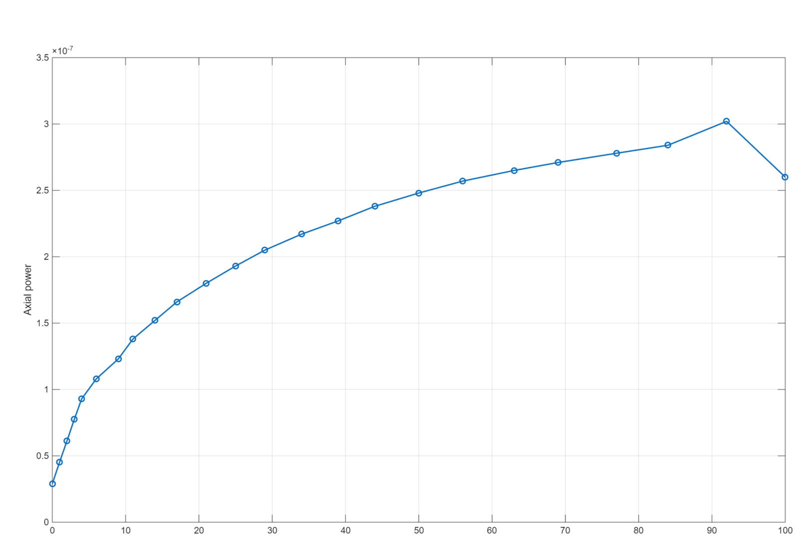

Fig.4 Axial power distribution

◆ Assembly Spacing-based Reactivity Reductions Concept

- The neutronic analysis was performed using the high-fidelity **MCNP code** with ENDF/B-based cross-section libraries.
- Fig5. shows that separating and relocating fuel assemblies under accident conditions creates additional moderator regions.
- This rearrangement induces negative reactivity and significantly reduces the effective multiplication factor.

Fig.5 Loading pattern implementing the assembly spacing based reactivity reduction concept

RESULTS

- The BOC k_{eff} was evaluated while systematically increasing the moderator gap, as shown in fig.6.
- According to Table.1, the reactivity begins to decrease from a **gap of 13cm**, indicating that this configuration can provide **sufficient margin** for safe reactor shutdown or power control.
- Up to a gap of 5cm, however, k_{eff} increases instead of decreases because the additional moderator slows excessively fast neutrons into a more favorable energy range for inducing fission.

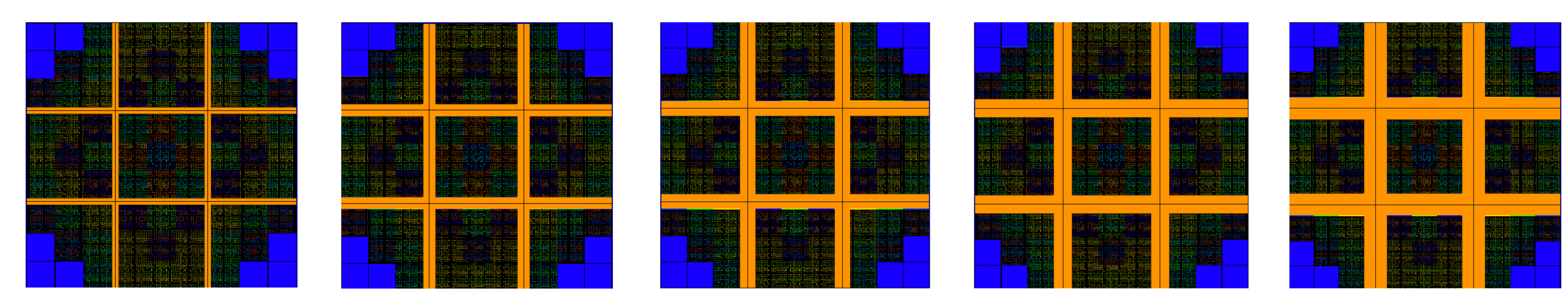

Fig.6 Cross-sectional views of the i-SMR core with various fuel assembly gaps (5, 10, 13, 15, and 20cm)

Gap	k_{eff}	ρ(pcm)	ρ($)
0cm	1.05283±0.00008	5017.9041	8.5571
5cm	1.06651±0.00008	6236.228	**10.9129**
10cm	1.00089±0.00008	88.9209	0.1037
13cm	0.97515±0.00009	-2548.3259	-3.7281
15cm	0.96466±0.00009	-3663.467	-5.2478
20cm	0.95301±0.00009	-4930.6933	-6.8895

Table.1 k_{eff} and Reactivity as a Function of Moderator Region Gap Size

CONCLUTIONS

- In this study, a concept of increasing the spacing between fuel assemblies under unintended reactivity insertion scenarios was proposed for the i-SMR core, and its reactivity effect was investigated through neutron transport simulations.
- The analysis showed that as **the spacing between fuel assemblies (FAs) increases** beyond a certain point, the introduction of additional moderator regions led to a **decrease in both the effective multiplication factor and reactivity**.
- These results suggest that the proposed core concept could be used as an additional control system **to suppress an increase in** $\boldsymbol{k_{eff}}$**.**
- However, **further improvements** are required in both mechanical design and reactor physics before practical implementation can be considered.
- Future work will focus on refining the design and analysis, as well as assessing the feasibility of this concept for real-world application.

ACKNOWLEDGEMENTS

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