Axial Depletion Behavior of Gd-155 and Gd-157 in an i-SMR Core Considering Coolant Temperature Gradients

Ji Hoon Lee[1], Jin Sun Kim[2], Gonghoon Bae[2], Seung Min Woo[1]*

[1]Department of Nuclear Engineering, Kyung Hee University, 1732, Gyeonggi-do, 17104, Republic of Korea
[2]KEPCO Nuclear Fuel Co. Ltd., Republic of Korea
*Corresponding author : woosm@khu.ac.kr

INTRODUCTION

- **i-SMR use relatively high gadolinium loading** to control excess reactivity without relying on soluble boron.
- Because **Gd-155 and Gd-157 absorption cross-sections are highly spectrum-dependent**, temperature-driven coolant density changes can produce **non-uniform depletion** of these isotopes.
- Therefore, this study investigates the **axial depletion behavior of Gd-155 and Gd-157**, focusing on **segment-wise burnout** to clarify how the axial moderation profile affects local burnable absorber depletion.

METHODOLOGY

◆ i-SMR(innovative Small Modular Reactor)

✓ Core, Steam Generator, Pressurizer, and Primary Coolant System are integrated into a **single Pressure Vessel.**

✓ Compact core geometry and strong thermal hydraulic coupling in i-SMR results in **axial and radial variations in neutron moderation and spectrum.**

✓ Compared to large pressurized water reactors, i-SMR typically operates with **shorter fuel assemblies and lower coolant flow rates**, leading to relatively **steep axial coolant temperature gradients**.

✓ **Gadolinium-bearing fuel is used in i-SMRs** to control excess reactivity and improve power distribution, but the depletion of Gd-155 and Gd-157 is highly sensitive to local neutron spectrum and moderation conditions.

◆ Core Modeling

✓ **69 fuel assemblies** categorized into four distinct types (**A01, A02, A04, and A05**).

✓ **Non-control rod condition.**

✓ Active core height of 240 cm discretized into **24 axial nodes at 10 cm intervals.**

✓ **Lower 210 cm consists of Gd_2O_3–UO_2 fuel**, while the **upper 30 cm consists of lower-enriched UO_2 fuel**.

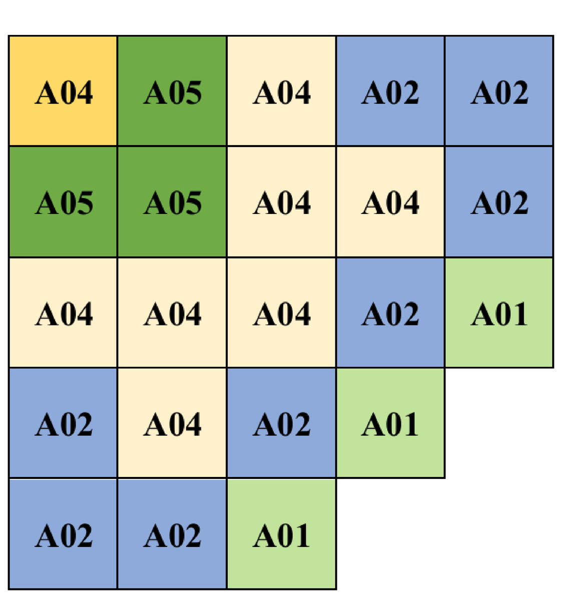

Fig. 1. i-SMR Radial Quarter-Core Loading Pattern

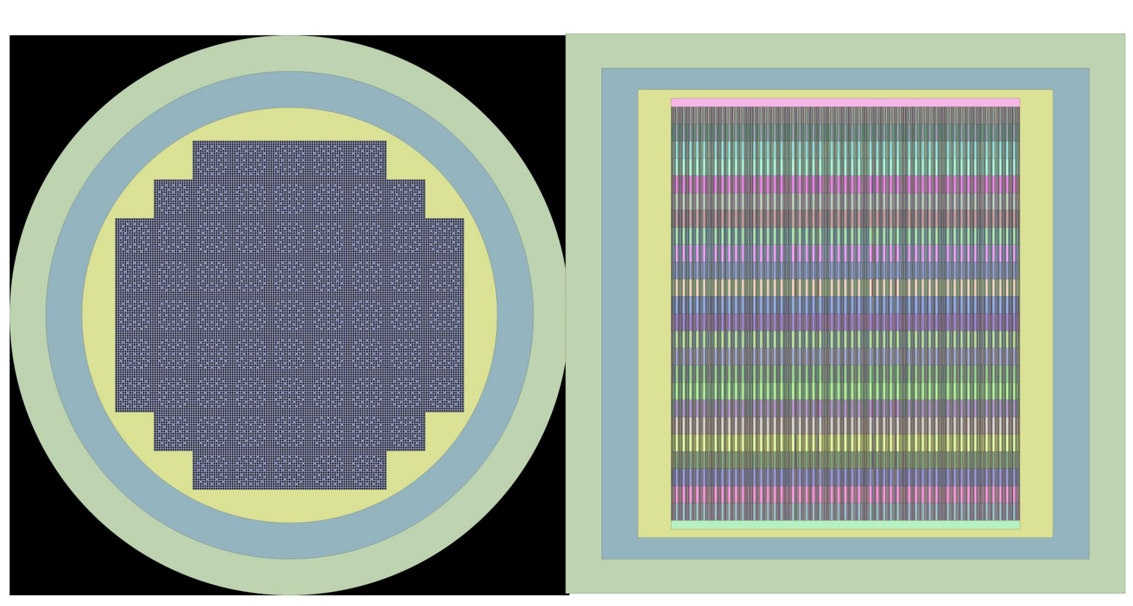

Fig. 2. i-SMR Core Radial and Axial View

◆ Coolant Temperature Distribution

✓ **Linear axial temperature gradient**.

✓ **Temperature rise (ΔT) of 35 K** was applied between the core inlet (lower core) and outlet (upper core).

✓ 35 K change induces a continuous **decrease in coolant density** toward the upper regions.

✓ Density 0.753g/cm^3 to 0.675g/cm^3.

Core Height (cm)	Coolant Temperature (K)
0-10 (1st floor)	559.88
10-20 (2nd floor)	561.34
20-30 (3rd floor)	562.80
30-40 (4th floor)	564.25
40-50 (5th floor)	565.71
50-60 (6th floor)	567.17
60-70 (7th floor)	568.63
70-80 (8th floor)	570.09
80-90 (9th floor)	571.55
90-100 (10th floor)	573.00
100-110 (11th floor)	574.46
110-120 (12th floor)	575.92
120-130 (13th floor)	577.38
130-140 (14th floor)	578.84
140-150 (15th floor)	580.30
150-160 (16th floor)	581.75
160-170 (17th floor)	583.21
170-180 (18th floor)	584.67
180-190 (19th floor)	586.13
190-200 (20th floor)	587.59
200-210 (21st floor)	589.05
210-220 (22nd floor)	590.50
220-230 (23rd floor)	591.96
230-240 (24th floor)	593.42

Table I. Assigned Coolant Temperature for each segment

RESULT

◆ k_{eff}

✓ Code: **Serpent 2**

✓ Library: **ENDF/B-VII.1**

✓ Burnup: 2 years / **20 MWD/kgU**

✓ Cycle: 5,000,000 nps / 100 active cycles / 40 inactive cycles

⇒ k_{eff} < 10 pcm

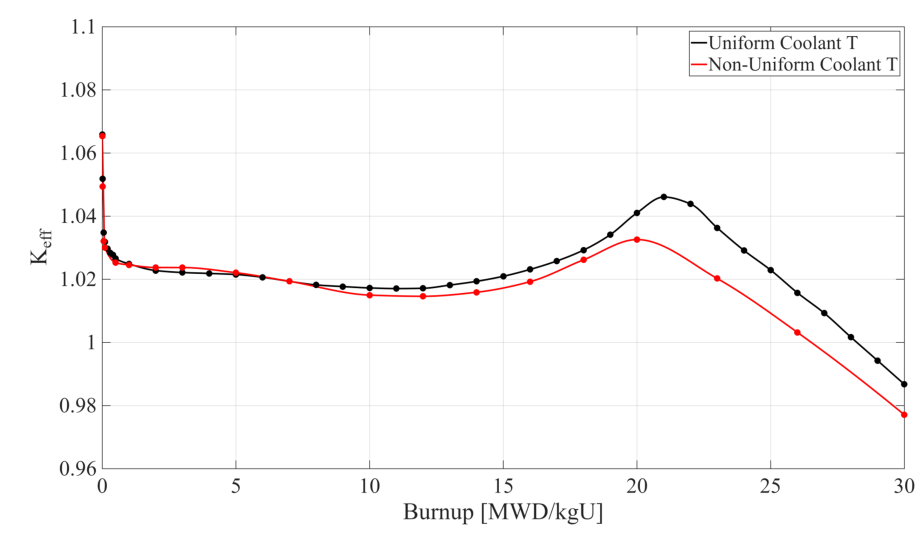

Fig. 3. k_{eff} change through depletion cycle

◆ Gadolinium Depletion

✓ The analysis was performed at the **1st, 5th, 9th, 13th, 17th, and 21st axial nodes** corresponding to the Gd-containing fuel layers.

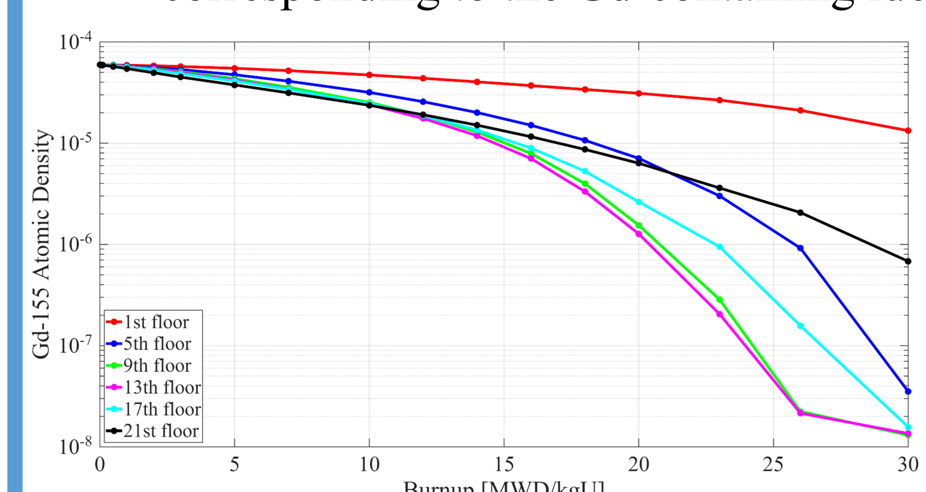

Fig. 4. Gd-155 Atomic Density changes through depletion cycle

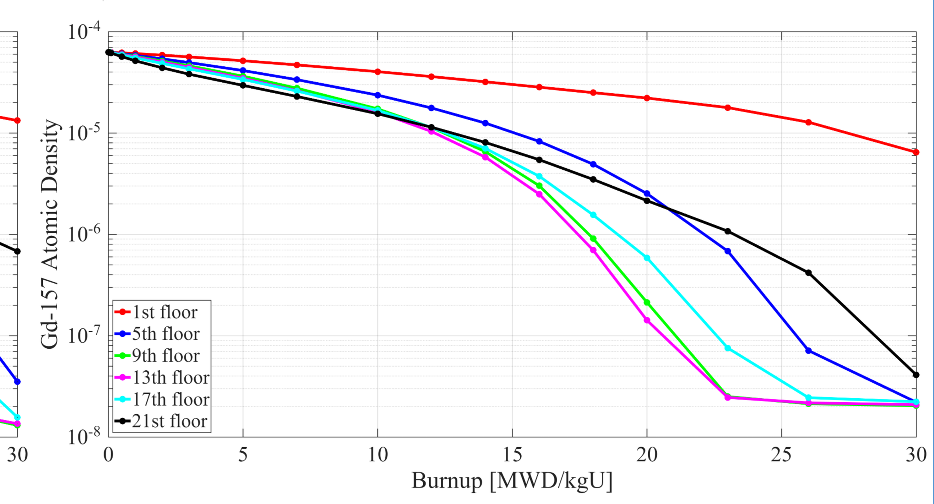

Fig. 5. Gd-157 Atomic Density changes through depletion cycle

✓ To further examine this behavior, the changes in the **overall gadolinium atomic density** was conducted.

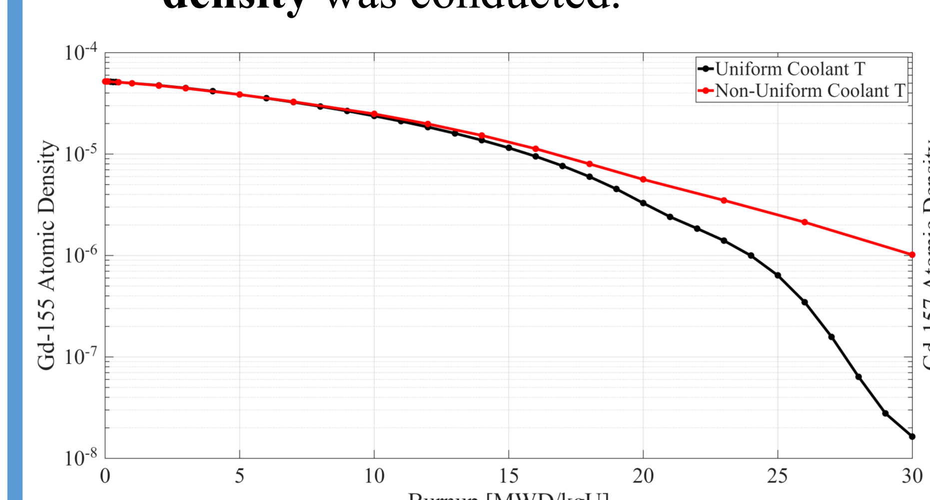

Fig. 6. Total Gd-155 Atomic Density changes through depletion cycle

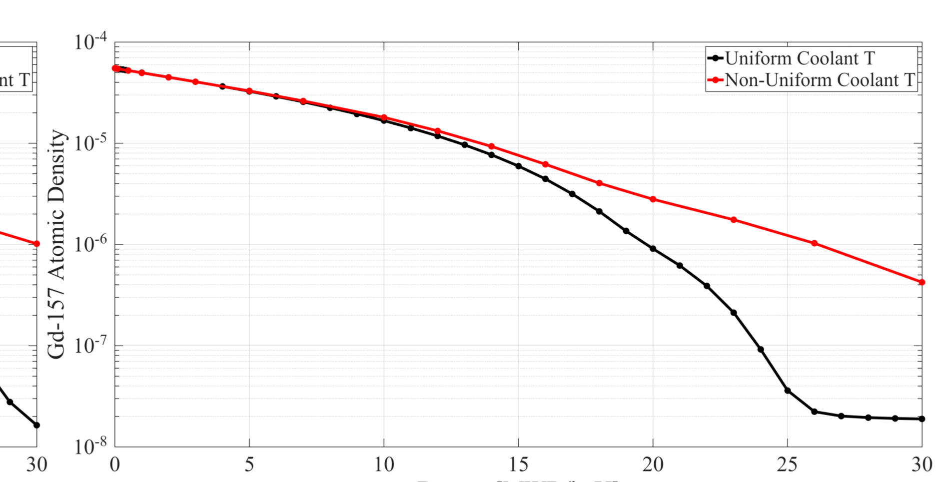

Fig. 7. Total Gd-157 Atomic Density changes through depletion cycle

◆ Axial Power Distribution

✓ Non-uniform depletion ⇒ **Axial power distribution change**.

✓ BOC: Lack of gadolinium fuel ⇒ **Tilted toward upper core.**

✓ MOC: Restores the local reactivity ⇒ **Cosine shape**.

✓ EOC: **Clearer cosine shape.**

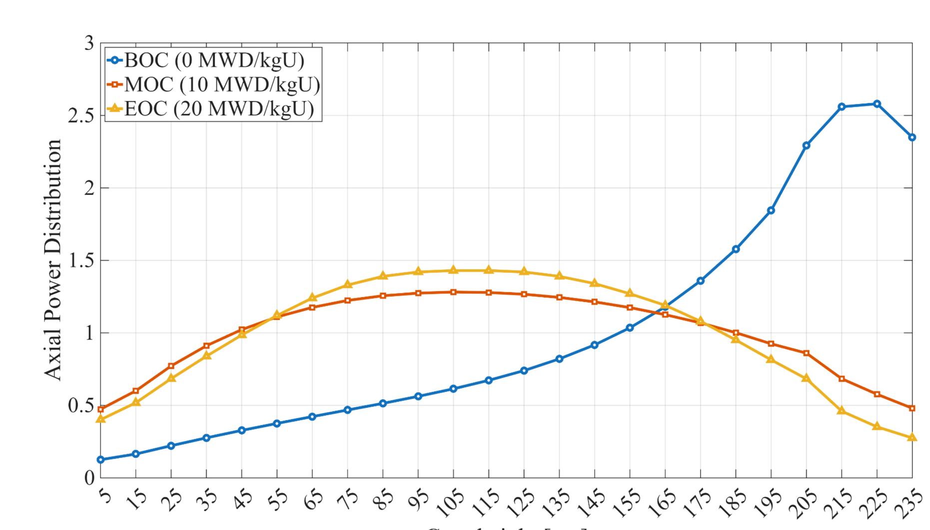

Fig. 8. BOC, MOC, EOC Axial Power Distribution

CONCLUSION

- **Axial coolant temperature gradient significantly affects the depletion of Gd-155 and Gd-157.**
- Compared with the uniform coolant temperature case, **the non-uniform case showed lower overall gadolinium depletion**, mainly because gadolinium in the lower axial region burned less.
- These findings highlight **the need to consider axial thermal-hydraulic conditions**, and future work will examine whether **reversing the fuel rod orientation** or **modifying the axial gadolinium loading pattern** can improve depletion balance.

ACKNOWLEDGMENT

- This work was supported by the Nuclear Safety Research Program through the Regulatory Research Management Agency for SMRs (RMAS) and the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. RS-2024-00509189).
- This work was supported by the Innovative Small Modular Reactor Development Agency grant funded by the Korea Government (MCEE) (No. RS-2024 00407975).

REFERENCE

- [1] Kim, J., Jung, T., & Yoon, J. "Reactor core design with practical gadolinia burnable absorbers for soluble boron-free operation in the innovative SMR." Nuclear Engineering and Technology, 56(8), 3144–3154 (2024).
- [2] Duderstadt, J. J., & Hamilton, L. J. Nuclear Reactor Analysis. Wiley (1976).
- [3] Leppänen, J., et al. "The Serpent Monte Carlo code: Status, development and applications in 2013." Annals of Nuclear Energy, 82, 142–150 (2015).
- [4] Wei, X., Zhu, Y., Yang, S., Xu, D., Jin, X. Modeling of the Gadolinium Fuel Tests with the Jasmine Fuel Performance Code. In: Liu, J., Jiao, Y. (eds) Proceedings of the 2023 Water Reactor Fuel Performance Meeting. WRFPM 2023. Springer Proceedings in Physics, vol 299. Springer, Singapore. https://doi.org/10.1007/978-981-99-7157-2_35. (2024).

사단법인 한국원자력학회
KOREAN NUCLEAR SOCIETY

2026 Spring CONFERENCE
May 6 – May 8 2026
Jeju, Korea

NUCLEAR NONPROLIFERATION LAB.
DEPT. OF NUCLEAR ENGINEERING
KYUNG HEE UNIVERSITY