APPLICABILITY EVALUATION OF ENRICHED GADOLINIUM AS A BURNABLE ABSORBER IN ASSEMBLY LEVEL FOR BORON-FREE i-SMR CORE

Jinsun Kim, Bum Hee Cho Ser Gi Hong

KEPCO Nuclear Fuel Co., Ltd, 242, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, 305-353, Republic of Korea

Introduction

⟐Top requirement for boron free operation

- Innovative-Small Modular Reactor (i-SMR) considers boron-free operation as one of its top requirements.
- The boron-free core must control excess reactivity with only control rods and burnable absorber (BA).
- In order to secure shutdown margin and to improve the control rod operation strategy at the same time, it is important to maximize the ability to control excessive reactivity using BA.

⟐Enriched Gadolinia

- Gadolinia(Gd_2O_3) has a large absorption cross-section, therefore it is widely used to suppress excessive reactivity.
- The gadolinia depletes too rapidly, however, the residual poisoning effect at the end of the cycle is too small, which makes it difficult to control the infinite multiplication factor after the middle of cycle.
- it is difficult to control the power peaking factor because the internal power distribution of fuel assembly has severe fluctuation when the gadolinia pellets are depleted completely.

◆ Analysis method

- To avoid the fast burnout, a higher content of gadolinia can be used in a burnable absorber. However, as the gadolinia content increases, the thermal conductivity and the melting point of its mixture (UO_2-Gd_2O_3) are reduced.
- the effect of enriching ^{155}Gd and ^{157}Gd isotopes that have large thermal neutron absorption cross-section were evaluated from the natural Gd (i.g., 30% ^{155,157}Gd) up to 99%.

Methods and Result

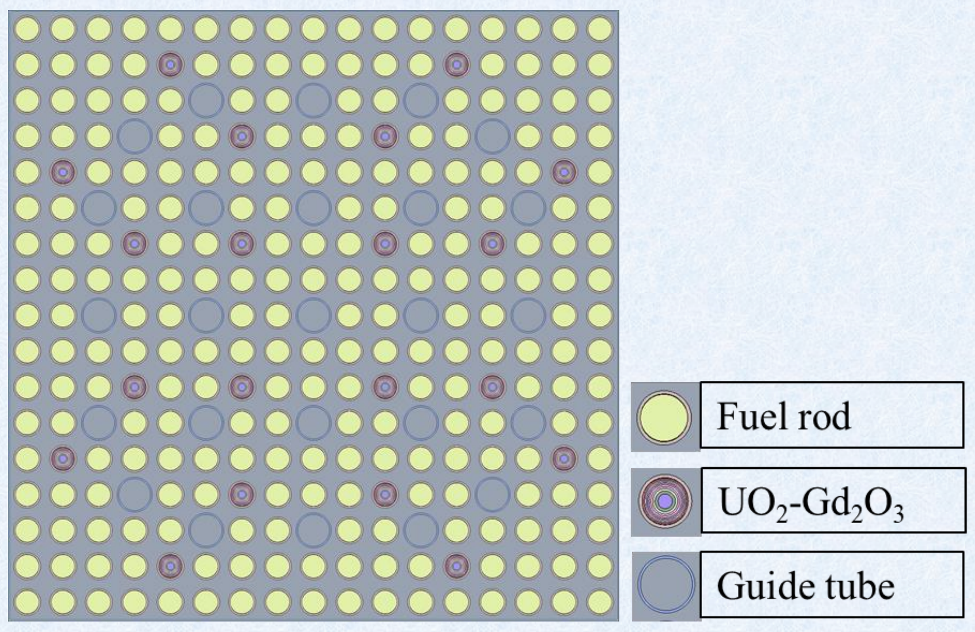

Fig 1. 17x17 fuel assembly configuration(4.0% ^{235}U enrichment, 20 Gd_2O_3 BA rods)

Parameter	Unit	Value
Reactor thermal power	MWt	540
Fuel assembly array		17x17
Fuel assembly height	cm	240
Number of fuel rods		264
Number of guide tubes		24
Fuel enrichment	wt%	4
Number of gadolinia rods	EA	20
Fuel rod		
Pellet outer diameter	inch	0.3225
Rod pitch	inch	0.4960
Cladding inner diameter	inch	0.3290
Cladding outer diameter	inch	0.3740
Guide tube inner diameter	inch	0.4420
Guide tube outer diameter	inch	0.4820
Cladding material		HANA

Table Ⅰ. i-SMR design and fuel assembly information

⟐ Computational Methods

- Assembly burnup calculations for two group cross section generation were calculated by KARMA (Kernel Analyzer by Ray-tracing Method for fuel Assembly).
- KARMA is a two-dimensional multi-group lattice transport code using 190 group and 47 group cross section library based on ENDF/B-VI.8.
- ASTRA code was used for 3D core calculation.
- ASTRA code is a 3D core depletion code and developed by KEPCO NF (KEPCO Nuclear Fuel) as a nuclear design code for the core design of pressurized water reactors (PWRs) based on the reactor physics technologies.

⟐ Parameter and Geometry Data

- Table Ⅰ shows the input parameters such as fuel assembly geometry, thermal power, uranium enrichment, and number of gadolinia rods considered in this work.
- Fig. 1 shows the WEC type 17x17 fuel assembly configuration used in the work. The burnable absorber (UO_2-Gd_2O_3) rods are located in 20 pin positions for control of the excess reactivity.

⟐ Results of Natural Gadolinia

- Fig. 2 compares the changes in infinite multiplication factor (k-inf) using natural isotopic ratio of gadolinium isotopes.
- The hold-down effect increases and k-inf value becomes more flatter as Gd_2O_3 content increases.

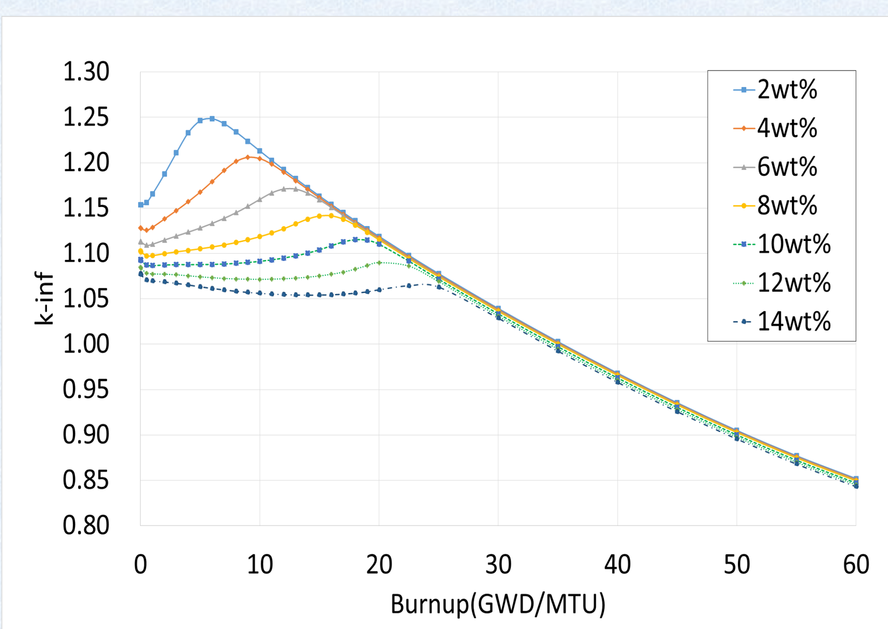

Fig. 2. Comparison of k-inf versus burnup (4.0% ^{235}U uranium enrichment, 20 BA rods) for various Gd_2O_3 contents

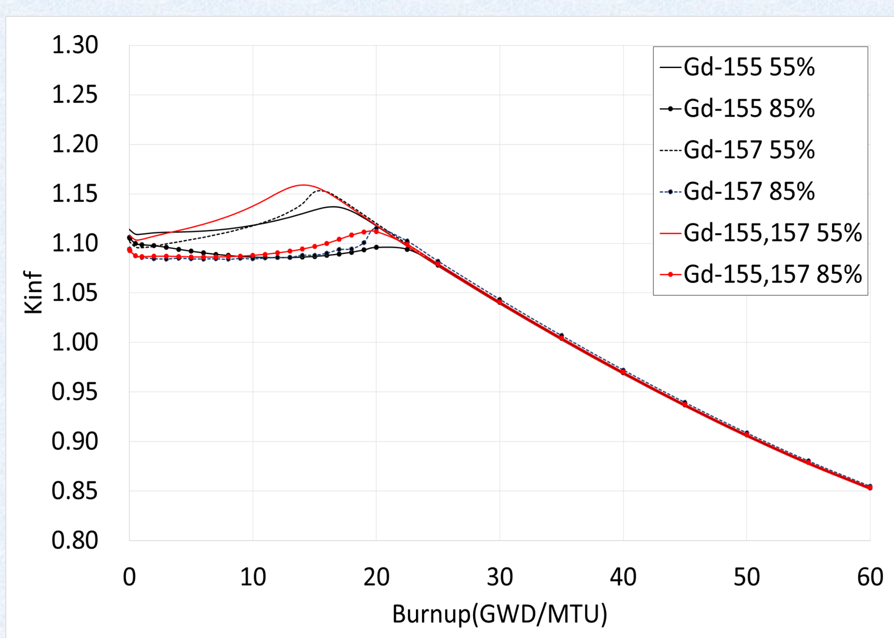

Fig. 3. Infinite neutron multiplication factor as a function of burnup considering the different isotope ratio of ^{155}Gd enriched only, ^{157}Gd enriched only, and ^{155,157}Gd enriched together (4.0% ^{235}U enrichment, 20 BA rods (4 wt% Gd2O3))

- Fig.3 shows the results of k-inf as a function of burnup considering the different isotope ratio of Gd including ^{155}Gd enriched only, ^{157}Gd enriched only, and ^{155,157}Gd enriched together.
- The proportional ratio of ^{155}Gd and ^{157}Gd simulated with red lines was used in this study since the dependency is negligible in terms of k-inf.

⟐Results of Enriched Gadolinia

- Fig. 4 shows the change in k-inf with various combinations of ^{155,157}Gd enrichments and Gd_2O_3 contents.
- The natural Gd case uses 12 wt% Gd_2O_3 content with the Gd burnout point of around 21.0 GWD/MTU, and the k-inf values of all the enriched cases stay around 1.07 until around 21.0 GWD/MTU.
- we can see that assemblies using high enriched ^{155,157}Gd have similar performance to that of high content Gd through the sensitivity evaluation of the enriched Gd.

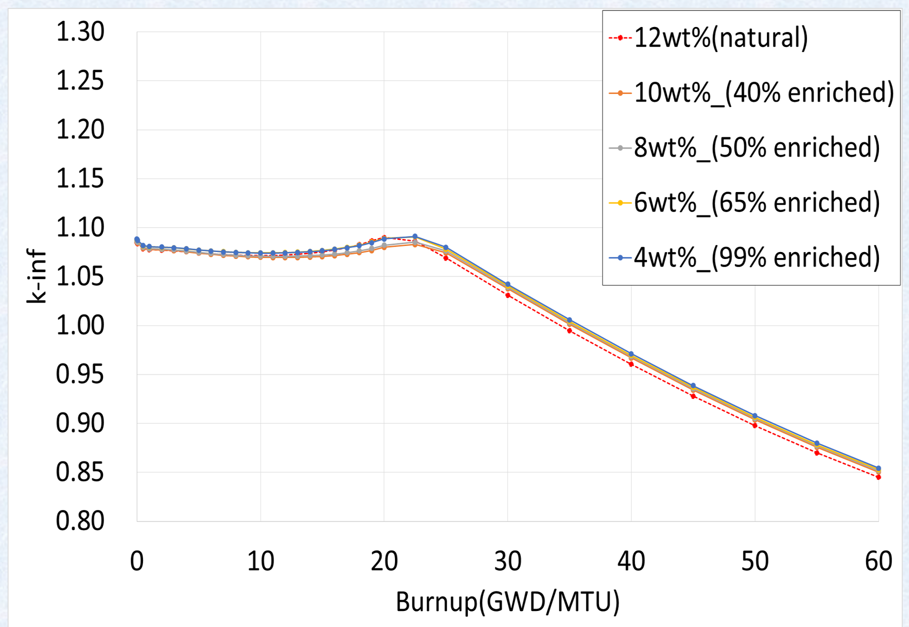

Fig 4. 17x17 fuel assembly configuration(4.0% ^{235}U enrichment, 20 Gd_2O_3 BA rods)

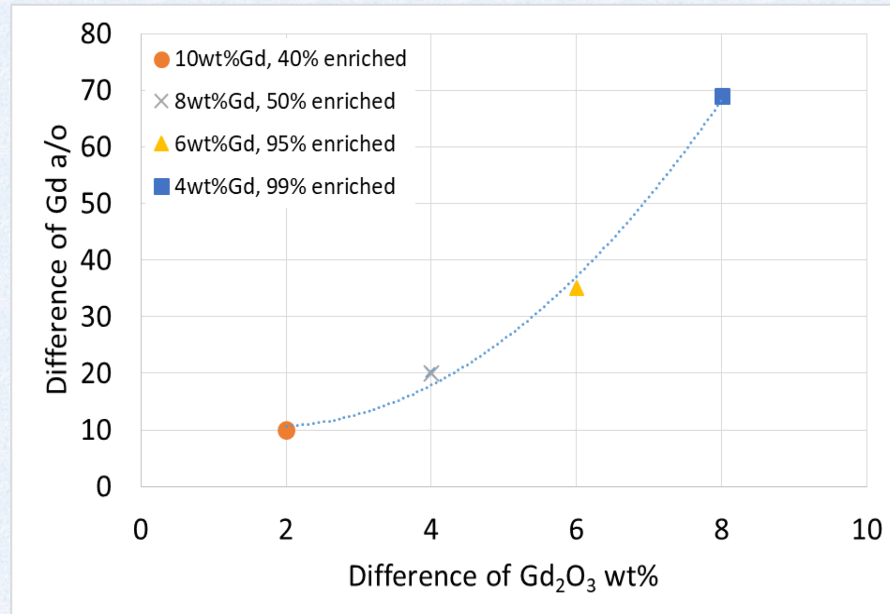

Fig. 5. Comparison of the enrichment difference between natural Gd and enriched Gd as a function of the difference in Gd_2O_3 (wt%) contents from 12 wt% Gd_2O_3 with natural Gd

- Fig. 5 shows the required Gd_2O_3 contents and enrichments of ^{155}Gd and ^{157}Gd to have the same burnout point as 12 wt% Gd_2O_3 with natural Gd.
- This figure shows that 10 wt% of Gd_2O_3 with the 40% enriched Gd is required to achieve the same performance of 12 wt% Gd_2O_3 with natural Gd.
- This graph can help the core designer to select the Gd enrichment of assembly for loading in the core. Since the uranium enrichment of UO_2-Gd_2O_3 decrease as the Gd_2O_3 content increase, it is possible to control the amount of uranium in the core and give an advantage to the cycle length.
- Fig. 6 shows the required enrichment of ^{155,157}Gd as a function of the Gd depletion point for each Gd_2O_3 content.
- To increase the Gd depletion time to 20,000 MWD/MTU, the cases using 4 wt%, 6 wt%, 8 wt%, and 10 wt% Gd_2O_3 contents require 90%, 60%, 45%, and 35% ^{155,157}Gd enrichments, respectively.
- This graph can help determine whether to increase the total amount of Gd_2O_3 content or increase the ^{155,157}Gd enrichments to change the cycle length of the core.

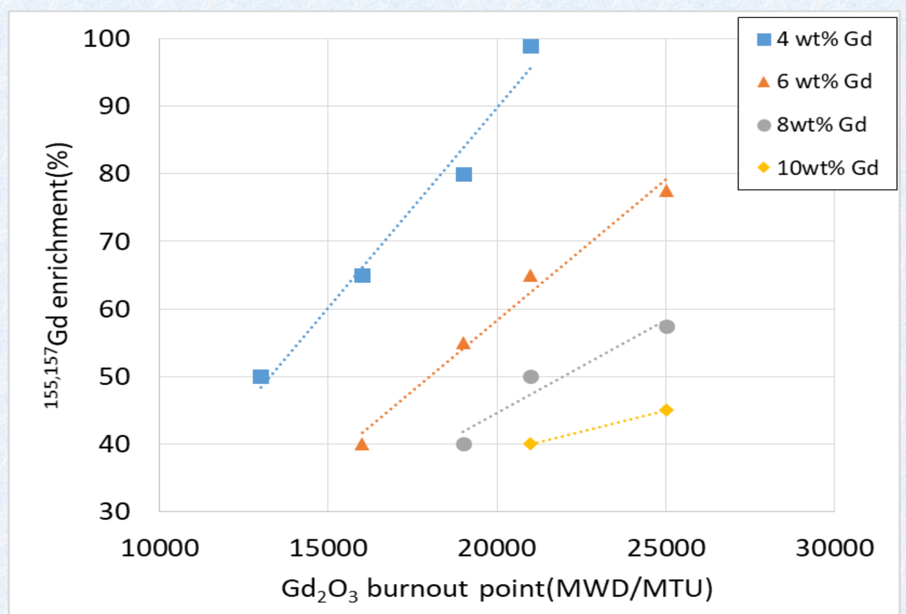

Fig. 6. Comparison of ^{155,157}Gd enrichment versus Gd bunrnout point versus Gd_2O_3 content (wt%)

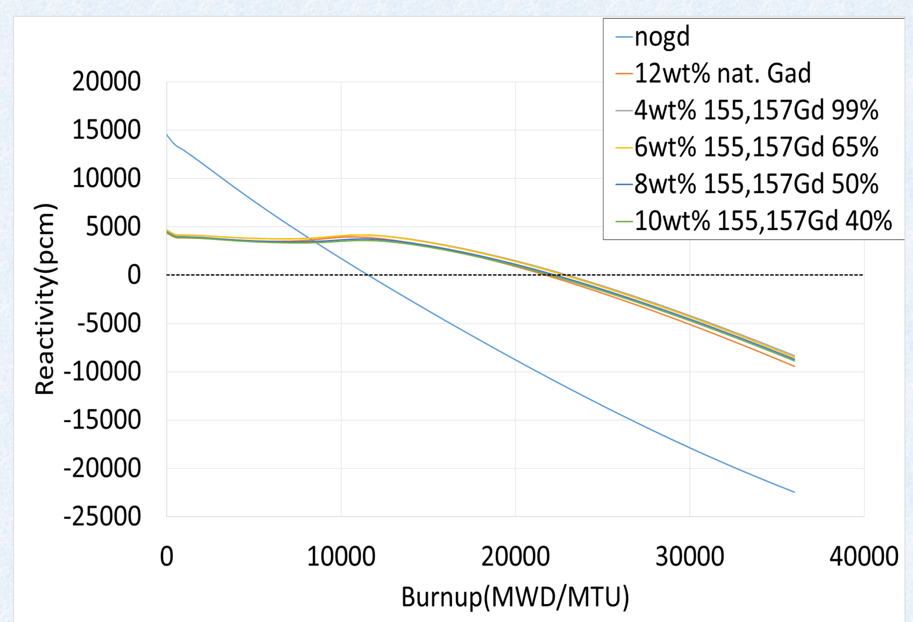

Fig. 7. The reactivity results of 3D core calculation using only one type assembly in the core as a function of burnup (69 Fuel assemblies)

- To verify the results, we analyzed the 3D core calculation. The i-SMR core has a reactor power rate of 540 MWt. It consists of 69 fuel assemblies with only one BA rods type.
- Fig.7 shows that the results of a core composed of assemblies with 12 wt% natural Gd have the similar reactivity as that of a core with a low-content, high enriched Gd assemblies.

Conclusions

- In the boron-free i-SMR core, the excess reactivity is controlled by control rods and BA rods.
- In order to achieve the longer cycle length under sufficiently controlled excess reactivity with only burnable absorbers, it is necessary to use higher Gd_2O_3 content, which leads to degradation of thermal conductivity.
- In this work, the use of enriched Gd in ^{155,157}Gd in the i-SMR core was suggested to achieve longer Gd burnout point, and its application was analyzed with fuel assembly depletion calculations.
- it was found that the long burnout point of Gd comparable to those of high Gd_2O_3 contents can be achieved with high Gd enrichments with low Gd_2O_3 contents.
- It can be also found that the burnout point increase when the content of Gd_2O_3 increases or the concentration of Gd increases at the same content.
- It can help the core designer to select the Gd enrichment of assembly in the core for the cycle length prediction.
- It can help determine whether to increase the total amount of Gd_2O_3 contents or increase the ^{155,157}Gd enrichments to change the cycle length of the core.