Criticality Evaluation of GBC-32 Cask with HBN #3 Fuels in PWR Burnup Credit

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1. Introduction

In Korea, the current criticality safety analysis for dry storage casks assumes the only fresh nuclear fuel assemblies with the maximum enrichment in a dry storage cask for conservatism. However, the large conservatism leads to the significant increase of casks required. Thus, an application of burnup credit is able to increase the capacity in casks.

In this paper, the criticality evaluation for burnup credit was performed for the GBC-32 cask with the fuel assemblies discharged after HBN #3 Cycle 6 by SCALE6.1/STARBUCS and MCNP6 with the axial burnup distributions and average discharge burnups evaluated using DeCART and MASTER codes.

2. Methods and Results

2.1 Geometry and Materials

The fuel assembly design applied in the GBC-32 cask is the PLUS7 16x16 fuel assemblies at zero burnup. The design of the cask accommodates 32 fuel assemblies. For simplicity, the fuel assemblies are centered in the storage cells and the assembly upper and lower hardware are modeled as water. The design data for the fuel assemblies in Cycle 6 of HBN#3 is listed in Table I. The configuration of the fuel assemblies is shown in Fig. 1. The DSC (Dry Storage Cask) of GBC-32 loaded with the PLUS7 16x16 fuel assemblies was modeled by STARBUCS in a full scale. Cross-sectional view of the cask is shown in Fig. 2.

Table I: Design data for the fuel assemblies in Cycle 6

Fuel Type	Enrichment (wt. %)	Fuel Rods/FA	Burnable Absorber Rods/FA	Burnable Absorber (wt. %)
G0	4.10	184	0	0.0
G1	4.11	176	8	6.0
G2	4.12	172	12	6.0
H0	4.52	184	0	0.0
H1	4.50	176	8	6.0
H2	4.50	172	12	6.0
J0	4.48	184	0	0.0
J1	4.48	176	8	6.0
J2	4.48	172	12	6.0

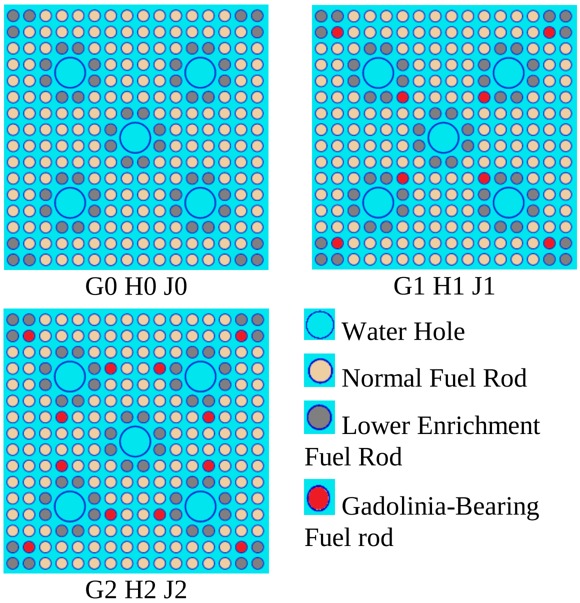

Fig. 1. Configuration of the fuel assemblies in HBN#3 Cycle6.

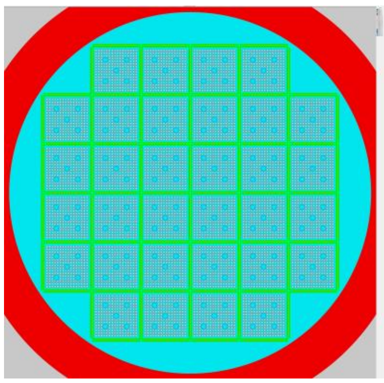

Fig. 2. Radial cross section of the GBC-32 dry storage cask.

2.2 Axial Burnup Distributions

The axial burnup distributions and average discharge burnups were evaluated using DeCART and MASTER codes through the cycle-by-cycle reload core analyses from the initial core to the cycle 6 core. The active fuel length of the fuel assemblies is divided into 20 equal-length axial regions to facilitate the variation in axial isotopic composition due to the axial burnup distribution. The loading pattern of the fuel assemblies in the reactor core of Cycle 6 is shown in Fig. 3. The reference normalized axial burnup distributions [1] and the normalized axial burnup distributions for 20 fuel assemblies of Cycle 6 are shown in Fig. 4. The average discharge burnups for 20 NFAs of Cycle 6 are listed in Table II.

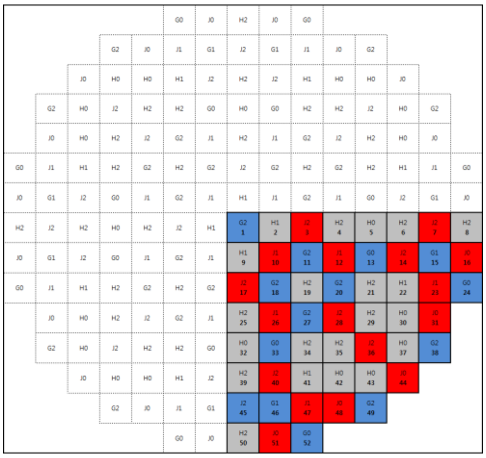

Fig. 3. Loading pattern in the reactor core of Cycle 6.

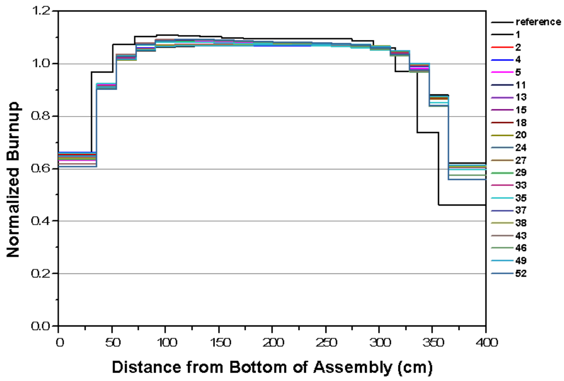

Fig. 4. Normalized axial burnup distributions for the reference [1] and 20 NFAs of Cycle 6.

Table II: Average burnups for 20 fuel assemblies

Fuel Index	Enrichment (wt. %)	Burnup (GWD/MTU)
1	4.11	51.90
2	4.50	41.06
4	4.50	41.12
5	4.52	33.92
11	4.12	50.13
13	4.10	48.27
15	4.11	39.66
18	4.12	50.14
20	4.12	42.60
24	4.10	33.16
27	4.12	42.58
29	4.50	40.09
33	4.10	48.40
35	4.50	40.06
37	4.52	31.54
38	4.12	39.31
43	4.52	31.51
46	4.11	39.64
49	4.12	41.76
52	4.10	33.17

2.3 Results and Evaluations

k_{eff} values were calculated for the GBC-32 cask specified in previous subsection as a function of the cooling time for the PLUS7 16x16 fuel assemblies discharged at the end of Cycle 6 by using STARBUCS and MCNP 6 codes. The k_{eff} values were calculated for 3 cooling times of 0, 20, and 30 years and plotted in Figs. 5, 6, and 7, where the black square and red circle denote the results calculated by STARBUCS code for the uniform and non-uniform axial burnup distributions, respectively, and the blue triangle and green inverted triangle denote the results calculated by MCNP 6 code for the uniform and non-uniform axial burnup distributions, respectively.

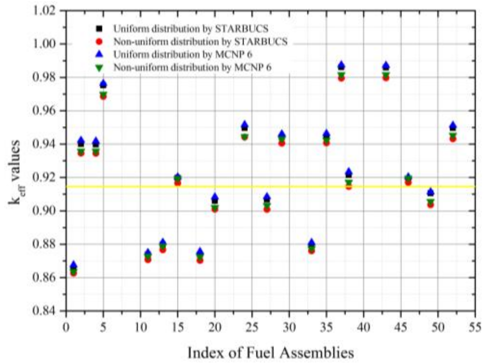

Fig. 5. k_{eff} values for the cask with various fuel assemblies for the cooling time of 0 year.

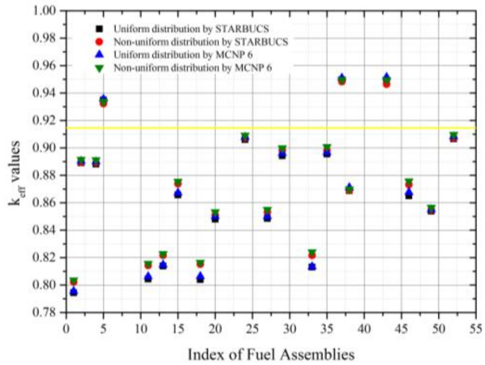

Fig. 6. k_{eff} values for the cask with various fuel assemblies for the cooling time of 20 years.

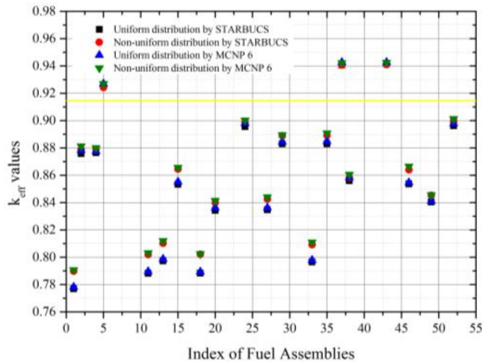

Fig. 7. k_{eff} values for the cask with various fuel assemblies for the cooling time of 30 years.

An upper criticality safety limit for the GBC-32 cask was set to be 0.9146 by using the bias uncertainties given in Refs. 2 and 3 and the yellow line denotes the upper criticality safety limit. Therefore, Fig. 5 indicates that 12 discharged fuel assemblies for the cooling time of 0 year were not allowed to be stored in the cask because the estimated k_{eff} values exceeds 0.9146. Figs. 6 and 7 indicate that most of the discharged fuel assemblies except for 3 discharged fuel assemblies were allowed to be stored for the cooling times of 20 and 30 years.

In addition, the end effects (pcm) were calculated for 3 cooling times of 0, 20, and 30 years and plotted in Figs. 8, 9, and 10, where the black square and red circle denote the results calculated by STARBUCS and MCNP 6 code, respectively.

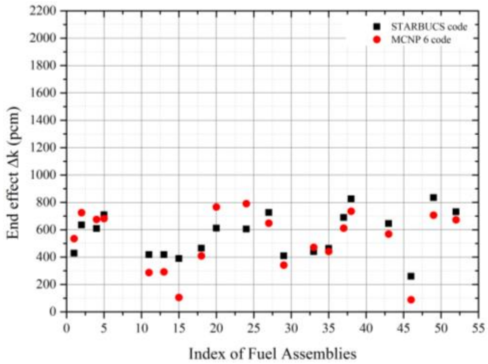

Fig. 8. End effects (pcm) of various fuel assemblies for the cooling time of 0 year.

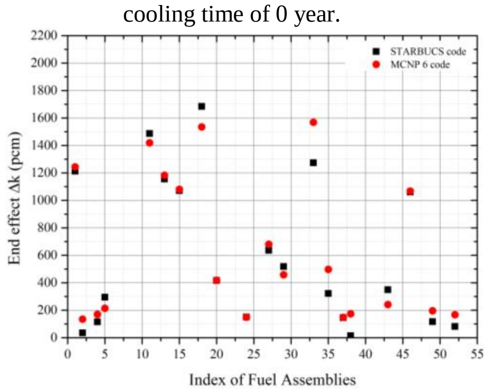

Fig. 9. End effects (pcm) of various fuel assemblies for the cooling time of 20 years.

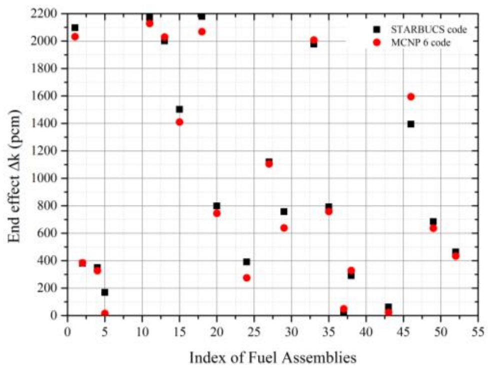

Fig. 10. End effects (pcm) of various fuel assemblies for the cooling time of 30 years.

The end effect is defined as the difference between the k-effs obtained with uniform and non-uniform axial burnup distributions. As shown in these figures, the end effects increased as the cooling time increases. The maximums values of the end effect are 834.93 pcm, 1685 pcm, and 2179 pcm for the cooling times of 0, 20 years, and 30 years, respectively. The positive end effects means that the criticality analyses with uniform axial burnup give more conservative results than the ones with the non-uniform axial burnup distributions. Also these figures show that the end effects evaluated with STARBUCS have good agreements with those evaluated with MCNP6.

3. Conclusions

The criticality evaluation for burnup credit was performed for the GBC-32 cask with the fuel assemblies discharged after HBN #3 Cycle 6 by STARBUCS and MCNP6 codes with the axial burnup distributions and average discharge burnups evaluated using DeCART and MASTER codes. k_{eff} values and end effects were calculated for 3 cooling times of 0, 20, and 30 years. From the results calculated in these conditions, the following conclusions are drawn.

(1) 12 discharged fuel assemblies for the cooling time of 0 year were not allowed to be stored in the cask because the estimated k_{eff} values exceeds 0.9146.
(2) Most of the discharged fuel assemblies except for 3 discharged fuel assemblies were allowed to be stored for the cooling times of 20 and 30 years.
(3) The end effects increased as the cooling time increases, within the maximums of 834.93 pcm for the cooling time of 0 year, 1684.45 pcm for 20 years, and 2178.92 pcm for 30 years.
(4) The criticalities and the end effects evaluated with STARBUCS have good agreements with those evaluated with MCNP6.

REFERENCES

[1] J. C. Wagner, M. D. DeHart, and C. V. Parks, "Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses," NUREG/CR-6801, ORNL/TM-2001/273, 2003.

[2] U.S. NRC, "Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks," Interim Staff Guidance (ISG)-8 Revision 3, 2012.

[3] J. M. Scaglione, D. E. Mueller, J. C. Wagner, W. J. Marchall, "An Approach for Validating Actinide and Fission Product Burnup Credit Criticality Safety Analyses – Criticality (k_{eff}) Predictions," NUREG/CR-7109, ORNL/TM-2011/514, 2012.