A Criticality Evaluation of the GBC-32 Dry Storage Cask in PWR Burnup Credit

Hyoungju Yoon [a], Kwangheon Park [a*], Ser Gi Hong [a]
[a]*Nuclear Engr. Department, Kyung Hee Univ., 1732 Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do 446-701, Republic of Korea*
[*]*Corresponding author: kpark@khu.ac.kr*

1. Introduction

The capability of on-site storage of used nuclear fuels (UNFs) generated in the domestic nuclear power plants is project to reach the limit from 2024, including re-racking and on-site transportation of UNFs. As an alternative of this awkward situation, it is necessary to utilize a dry storage system (DSS) for storage of UNFs and perform the accurate safety evaluations of the DSS. The current criticality safety evaluation assumes the only unirradiated fresh fuels with the maximum enrichment in a dry storage cask (DSC) for conservatism without consideration of the depletion of fissile nuclides and the generation of neutron-absorbing fission products. However, the large conservatism leads to the significant increase of the storage casks required. Thus, the application of burnup credit which takes credit for the reduction of reactivity resulted from fuel depletion can increase the capacity in storage casks. On the other hand, the burnup credit application introduces lots of complexity into a criticality safety analysis such as the accurate estimation of the isotopic inventories and the burnup of UNFs and the validation of the criticality calculation. In this work, the criticality evaluation considering burnup credit was performed for Generic 32 PWR-assembly Burnup Credit (GBC-32) cask [1] with the STARBUCS sequence of SCALE 6.1.

2. Methods and Results

In this section, SCALE 6.1/STARBUCS used to model the DSC of GBC-32 was described and the detailed modeling such as the geometry and compositions of the materials are specified. Then, k_{eff} values versus burnup and cooling time for four initial enrichments were evaluated and compared.

2.1 Regulatory Requirement

The criticality evaluation ensures that UNFs contained into the DSS remains subcritical under normal, off-normal, and accident conditions during dry storage. A subcritical condition is maintained by fulfilling the following acceptance criteria [2]:

- The effective neutron multiplication factor, k_{eff}, should not exceed 0.95 under all credible normal, off-normal, and accident conditions.
- DSS must be designed to remain subcritical unless at least two unlikely independent events occur.
- Criticality safety of the practicable design should be established on the basis of favorable geometry, permanently fixed neutron-absorbing materials of which degradation cannot occur over the life of the facility, or both.
- Criticality safety of the cask should not rely on credit for more than 75% of the neutron poison material in fixed neutron absorbers.

2.2 Computational Tool

STARBUCS (**ST**andardized **A**nalysis of **R**eactivity for **Bu**rnup **C**redit using **S**CALE) is the very useful computational tool to assist in performing criticality safety evaluations of DSCs with consideration of burnup credit [3]. STARBUCS automatically generates spatial region-dependent nuclide compositions in UNFs and applies k_{eff} values in a three-dimensional Monte Carlo neutron transport calculation for criticality evaluation. STARBUCS also can perform iterations on the initial enrichment to determine the initial enrichment below which the PWR UNFs may be loaded in a cask for a specified burnup and an upper safety limit. With this capability, STARBUCS assists the generation of burnup loading curves for criticality safety analyses. In particular, STARBUCS performs the depletion calculation using the ORIGEN-ARP and prepares ORIGEN-ARP libraries to reduce the computing time compared with the equivalent calculations using the SCALE depletion method with two-dimensional transport methods. The ORIGEN-ARP libraries may be prepared with TRITON by considering the assembly design and operating conditions.

2.3 Main Input Settings

In this subsection, the geometry, materials, axial burnup distribution, either major actinides only or minor actinides and major fission products relevant to burnup credit, etc. were modeled on the DSC of GBC-32 with Westinghouse PWR 17X17 optimized fuel assemblies (OFAs) [1].

2.3.1 Geometry and Materials [1]

The fuel assembly design applied in the cask is the Westinghouse PWR 17X17 OFAs 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 physical

specifications of the fuel assembly and the cask are listed in Table I and II, respectively. The material compositions of the unirradiated fuel assemblies with the various initial enrichments and the cask are listed in Table III and IV, respectively. The DSC of GBC-32 loaded with Westinghouse PWR 17X17 OFAs was modeled by SCALE 6.1/STARBUCS in a full scale. Cross-sectional view of the cask is shown in Fig. 1 and a three-dimensional cutaway view of the fuel assembly is shown in Fig. 2.

Table I: PWR fuel assembly specifications [1]

Parameter	cm
Fuel outside radius	0.39220
Cladding inside radius	0.40005
Cladding outside radius	0.45720
Cladding radial thickness	0.05715
Rod half pitch	0.62990
Guide tube/thimble inside radius	0.56135
Guide tube/thimble outside radius	0.60200
Thimble radial thickness	0.04065
Instrument tube inside radius	0.56135
Instrument tube outside radius	0.60200
Instrument tube radial thickness	0.04065
Active fuel length	365.76
Array size	17 x 17
Number of fuel rods	264
Number of guide tubes/thimbles	24
Number of instrument tubes	1

Table II: GBC-32 cask specifications [1]

Parameter	cm
Cell inside radius	11.00
Cell outside radius	11.75
Cell wall thickness	0.75
Boral panel thickness	0.2565
Boral center thickness	0.2057
Boral Al plate thickness	0.0254
Cell half pitch	11.87825
Boral panel width	19.05
Cell height	365.76
Boral panel height	365.76
Cask inside radius	87.5
Cask outside radius	107.5
Cask radial thickness	20.0
Base plate thickness	30.0
Cask lid thickness	30.0
Cask inside height	410.76
Active fuel height	365.76
Bottom assembly hardware thickness	15.0
Top assembly hardware thickness	30.0

Table III: PWR fuel assembly material compositions [1]

Isotope	Atom density (atoms/b-cm)	Weight percent
Cladding (ρ = 6.40 g/cm^3)		
Zirconium (Zr)	0.0423	100.0
Total	0.0423	100.0
UO_2, 2 wt. % ^{235}U enrichment (ρ = 10.5216 g/cm^3)		
Oxygen (O)	4.686E-02	11.8519
U-234	3.905E-06	0.0144
U-235	4.745E-04	1.7630
U-236	2.173E-06	0.0081
U-238	2.295E-02	86.3626
Total	7.029E-02	100.0
UO_2, 3 wt. % ^{235}U enrichment (ρ = 10.5216 g/cm^3)		
Oxygen (O)	4.686E-02	11.8532
U-234	6.058E-06	0.0224
U-235	7.117E-04	2.6444
U-236	3.260E-06	0.0122
U-238	2.271E-02	85.4678
Total	7.030E-02	100.0
UO_2, 4 wt. % ^{235}U enrichment (ρ = 10.5216 g/cm^3)		
Oxygen (O)	4.687E-02	11.8545
U-234	8.274E-06	0.0306
U-235	9.489E-04	3.5258
U-236	4.346E-06	0.0162
U-238	2.247E-02	84.5728
Total	7.030E-02	100.0
UO_2, 5 wt. % ^{235}U enrichment (ρ = 10.5216 g/cm^3)		
Oxygen (O)	4.687E-02	11.8558
U-234	1.054E-05	0.0390
U-235	1.186E-03	4.4072
U-236	5.433E-06	0.0203
U-238	2.224E-02	83.6777
Total	7.031E-02	100.0

Table IV: GBC-32 cask material compositions [1]

Isotope	Atom density (atoms/b-cm)	Weight percent
Water (ρ = 0.9983 g/cm^3)		
Hydrogen (H)	0.06674	11.19
Oxygen (O)	0.03337	88.81
Total	0.10011	100.0
Stainless steel 304 (ρ = 7.92 g/cm^3)		
Chromium (Cr)	0.01743	19.0
Manganese (Mn)	0.00174	2.0
Iron (Fe)	0.05936	69.5
Nickel (Ni)	0.00772	9.5
Total	0.08625	100.0
Boral panel Aluminum cladding (ρ = 2.699 g/cm^3)		
Aluminum (Al)	0.0602	100.0
Total	0.0602	100.0
Boral panel central layer (0.0225 g B-10/cm^2)		
Boron-10 (B-10)	6.5794E-03	4.13
Boron-11 (B-11)	2.7260E-02	18.81
Carbon (C)	8.4547E-03	6.37
Aluminum (Al)	4.1795E-02	70.69
Total	8.4089E-02	100.0

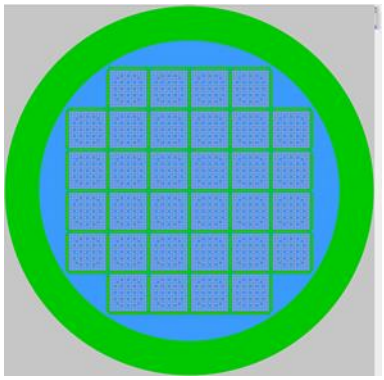


Fig. 1. Radial cross section of the GBC -32 dry storage cask.

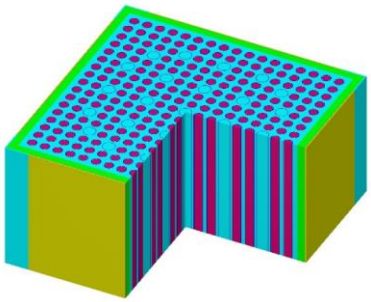


Fig. 2. 3-D cutaway view of the fuel assembly.

2.3.2 Axial Burnup Distribution [1]

The active fuel length of the fuel assemblies is divided into 18 equal-length axial regions to facilitate the variation in axial isotopic compositions due to the axial burnup distribution. The specifications of the axial burnup distribution of the fuel assembly are listed in Table V, and this distribution is related to PWR fuel assembly with average-assembly discharge burnup greater than 30,000 MWD/MTU.

Table V: Specification of axial burnup distribution [1]

Upper bound of axial region, measured from bottom of active fuel (cm)	Normalized burnup
20.32	0.652
40.64	0.967
60.95	1.074
81.27	1.103
101.61	1.108
121.93	1.106
142.28	1.102
162.60	1.097
182.88	1.094
203.20	1.094
223.52	1.095
243.83	1.096
264.15	1.095
284.49	1.086
304.81	1.059
325.12	0.971
345.44	0.738
365.76	0.462

2.3.3 Nuclide sets for burnup credit

The criticality safety evaluation to apply burnup credit is based on three different nuclide sets for burnup credit: (1) major actinide only, (2) actinides and fission products, (3) minor actinides and fission products. The assembly-average burnup was covered up to 60,000 MWD/MTU and cooled out-of-reactor cooling time ranges between 1 and 40 years [1,4]. The three nuclide sets used for the estimation of an effect on burnup credit are listed in Table VI.

Table VI: Two Nuclide sets [1]

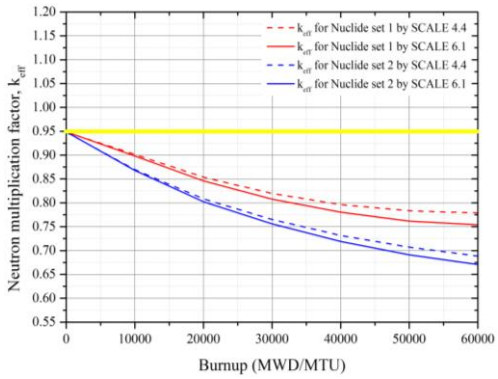
Nuclide set 1: Major actinides-only				
U-234	U-235	U-238	Pu-238	Pu-239
Pu-240	Pu-241	Pu-242	Am-241	O
Nuclide set 2: Actinides and fission products				
U-234	U-235	U-236	U-238	Pu-238
Pu-239	Pu-240	Pu-241	Pu-242	Am-241
Am-243	Np-237	Mo-95	Tc-99	Ru-101
Rh-103	Ag-109	Cs-133	Sm-147	Sm-149
Sm-150	Sm-151	Sm-152	Nd-143	Nd-145
Eu-151	Eu-153	Gd-155	O	
Nuclide set 3: Minor actinides and fission products				
Mo-95	Tc-99	Ru-101	Rh-103	Ag-109
Cs-133	Sm-147	Sm-149	Sm-150	Sm-151
Sm-152	Nd-143	Nd-145	Eu-151	Eu-153
Gd-155	U-236	Am-243	Np-237	O

2.4 Results and Evaluations

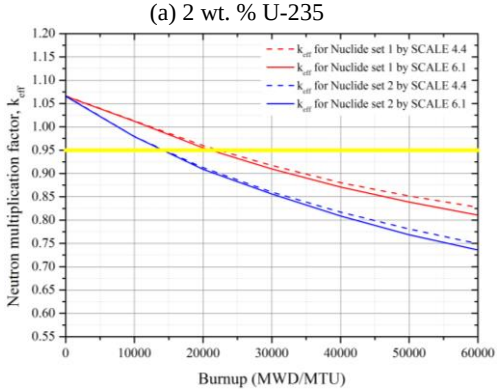
k_{eff} values were calculated for the GBC-32 cask specified in previous subsection as a function of burnup and cooling time for four initial enrichments of 2, 3, 4, and 5 wt. % ^{235}U. The burnup for the calculations ranges from 0 to 60,000 MWD/MTU, in increments of 10,000 MWD/MTU, and the five cooling times of 0, 5, 10, 20, and 40 years were considered.

The evolutions of k_{eff} values in the cask as a function of burnup using the nuclide set 1 and 2 for the cooling times of 0 and 40 year and the initial enrichments of 2, 3, 4, and 5 wt. % ^{235}U were compared in Fig. 3 and 4, where the red and blue lines denote the results calculated by applying the nuclide set 1 and 2, respectively, the dotted and solid lines denote the results calculated by SCALE 4.4a [1] and our results by SCALE 6.1, respectively. Differences (%) between k_{eff} values calculated by SCALE 4.4a [1] and SCALE 6.1 were listed in Table VII. In this work, the following three observations were made in Fig. 3 and 4 and Table VII: (1) the level of agreement between our results calculated by SCALE 6.1 and the results calculated by SCALE 4.4a [1] was very good within the maximum difference of 3.17%, (2) most of k_{eff} values calculated by SCALE 6.1 were smaller than those calculated by SCALE 4.4a [1] and differences between k_{eff} values calculated by SCALE 4.4a [1] and SCALE 6.1 became larger as the initial enrichment decreases, and (3) the 32

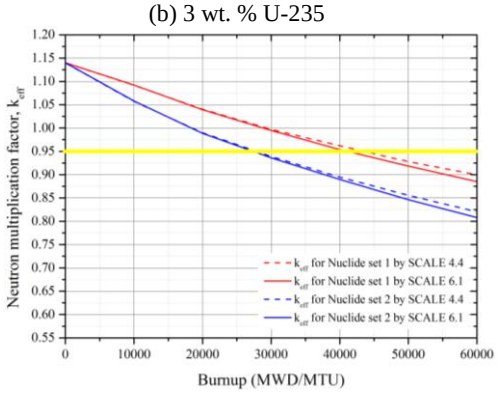
UNFs with the burnup and initial enrichments below the yellow line are allowed to be stored in the cask because the effective neutron multiplication factor, k_{eff}, should not exceed 0.95 on the regulatory requirement. For example, the 32 UNFs with the nuclide set 1, 30,000 MWD/MTU, 0 year cooling time, and initial enrichments of 4 wt. % ^{235}U in Fig. 3(c) were not allowed to be stored in the cask because k_{eff} exceeded 0.95 for both SCALE versions, while the 32 UNFs with the nuclide set 2 for the same conditions were allowed because k_{eff} did not exceed 0.95.



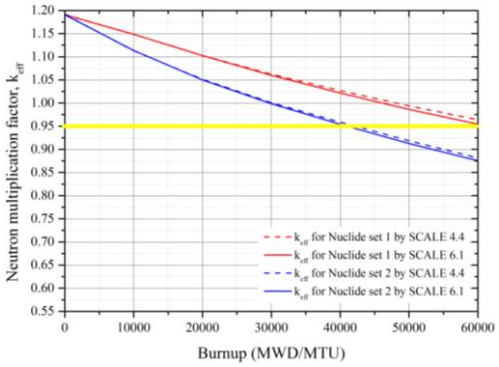
(a) 2 wt. % U-235



(b) 3 wt. % U-235

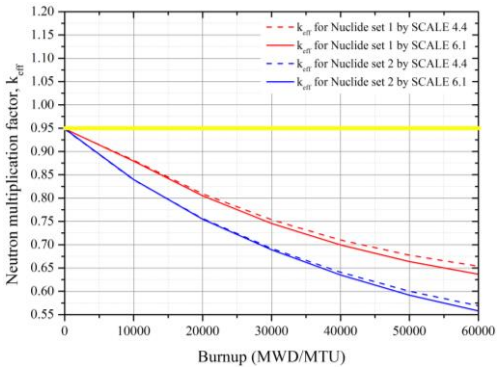


(c) 4 wt. % U-235

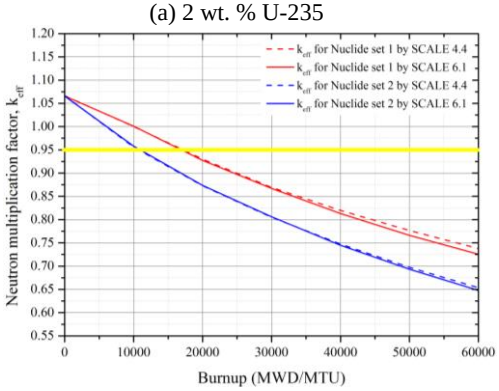


(d) 5 wt. % U-235

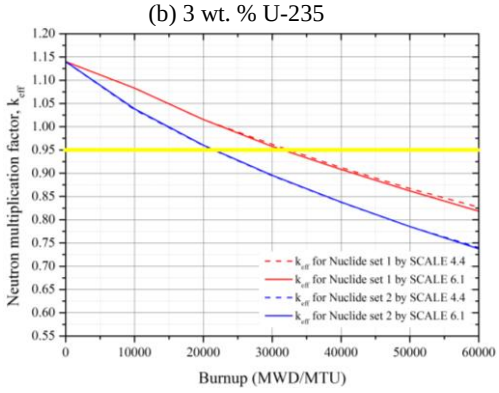
Fig. 3. Values of k_{eff} in the cask as a function of burnup using the nuclide set 1 and 2 for 0 year cooling time and the initial enrichments of (a) 2 wt. % ^{235}U, (b) 3 wt. % ^{235}U, (c) 4 wt. % ^{235}U, (d) 5 wt. % ^{235}U.



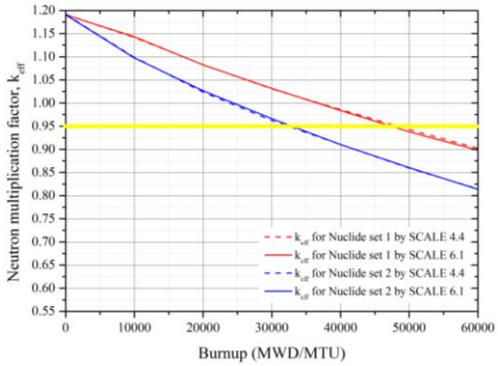
(a) 2 wt. % U-235



(b) 3 wt. % U-235



(c) 4 wt. % U-235



(d) 5 wt. % U-235

Fig. 4. Values of k_{eff} in the cask as a function of burnup using the nuclide set 1 and 2 for 40 year cooling time and the initial enrichments of (a) 2 wt. % ^{235}U, (b) 3 wt. % ^{235}U, (c) 4 wt. % ^{235}U, (d) 5 wt. % ^{235}U.

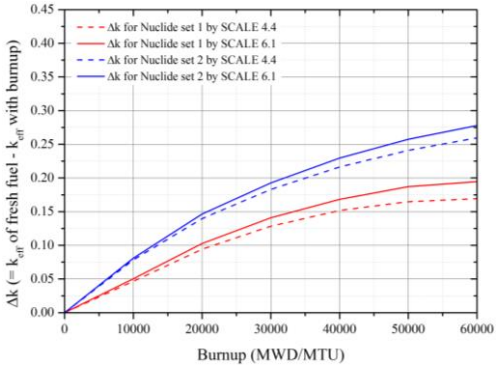
Table VII: Differences (%) between k_{eff} values calculated by SCALE 4.4 and SCALE 6.1

Cooling time	0 year		40 year	
Burnup (MWD/MTU)	Nuclide set 1	Nuclide set 2	Nuclide set 1	Nuclide set 2
Initial enrichments of 2 wt. % ^{235}U				
0	0.06	0.06	0.06	0.06
10,000	0.36	0.20	0.22	0.07
20,000	0.93	0.77	0.54	0.22
30,000	1.46	1.21	1.09	0.39
40,000	2.01	1.73	1.49	0.92
50,000	2.77	2.25	2.06	1.37
60,000	3.17	2.58	2.65	1.96
Initial enrichments of 3 wt. % ^{235}U				
0	0.06	0.06	0.06	0.06
10,000	0.09	0.01	0.06	0.22
20,000	0.50	0.38	0.29	0.10
30,000	0.85	0.49	0.26	0.12
40,000	1.08	1.00	0.83	0.35
50,000	1.52	1.58	1.35	0.56
60,000	1.99	1.83	1.67	0.90
Initial enrichments of 4 wt. % ^{235}U				
0	0.04	0.04	0.04	0.04
10,000	0.06	0.08	0.00	0.14
20,000	0.11	0.11	0.00	0.07
30,000	0.25	0.31	0.46	0.08
40,000	0.86	0.58	0.41	0.06
50,000	1.02	1.10	0.58	0.00
60,000	1.62	1.48	1.02	0.32
Initial enrichments of 5 wt. % ^{235}U				
0	0.05	0.05	0.05	0.05
10,000	0.01	0.05	0.12	0.11
20,000	0.04	0.13	0.03	0.28
30,000	0.23	0.23	0.05	0.40
40,000	0.53	0.51	0.17	0.02
50,000	0.79	0.61	0.52	0.14
60,000	0.99	0.68	0.48	0.12

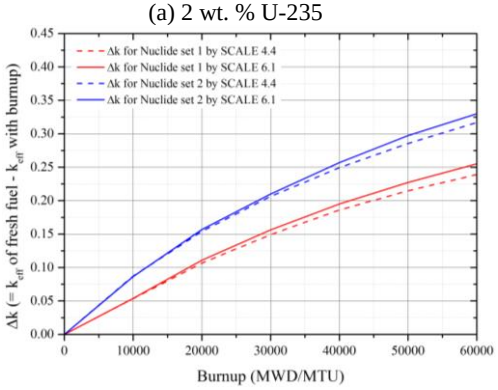
The evolutions of Δk values in the cask as a function of burnup using the nuclide set 1 and 2 for the cooling times of 0 and 40 year and the initial enrichments of 2, 3, 4, and 5 wt. % ^{235}U were compared in Fig. 5 and 6, where Δk is k_{eff} reduction compared to unirradiated fuel due to the presence of the nuclide set 1 or 2 as expressed in Eq. (1), and the red, blue, dotted, and solid lines are same meanings as those in Fig. 3 and 4.

$$\Delta k = k_{eff}^{initial} - k_{eff}\left(Burnup, t_{Cooling}, Enrich., Nuclideset\right) \quad (1)$$

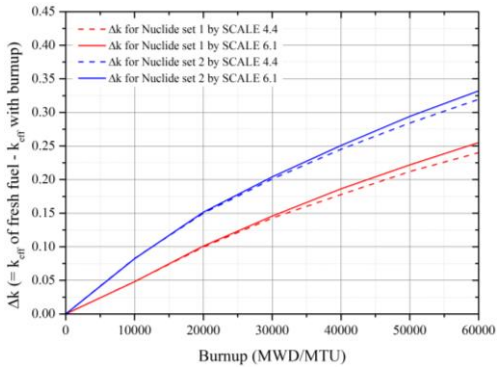
In this work, the following three observations were made in Fig. 5 and 6: (1) Δk values in the cask increased exponentially as the burnup increases because some actinides and fission products, such as the nuclide set 2, generated due to fuel burnup played a significant role as neutron absorbers and the yield of those increased as the burnup increases, and (2) Δk values applied for the nuclide set 2 became larger than those applied for the nuclide set 1 as the burnup increases because the actinides and fission products for the nuclide set 2 included all those (as neutron absorbers) for the nuclide set 1 and 3.



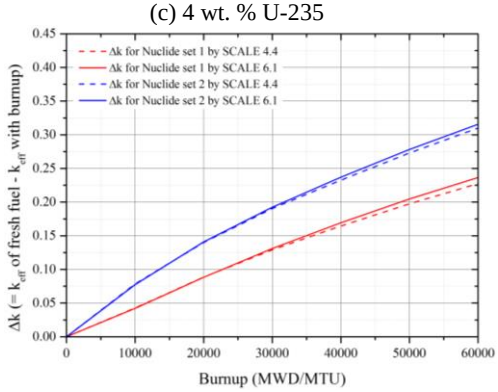
(a) 2 wt. % U-235



(b) 3 wt. % U-235

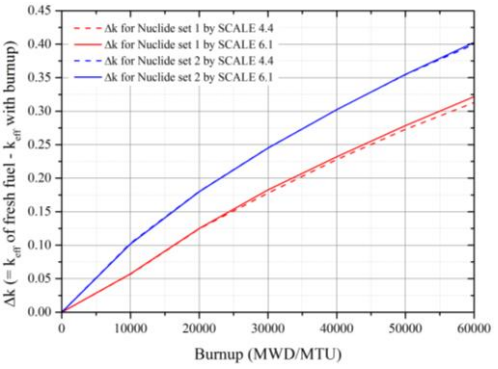


(c) 4 wt. % U-235

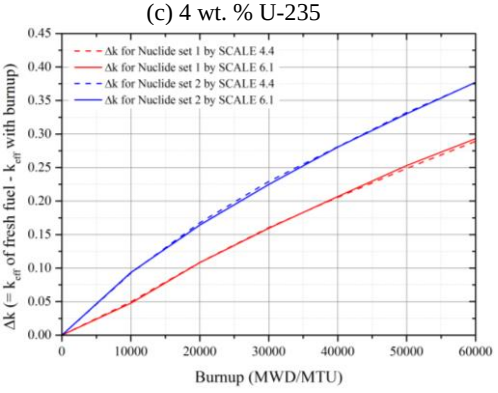


(d) 5 wt. % U-235

Fig. 5. Values of Δk in the cask as a function of burnup using the nuclide set 1 and 2 for 0 year cooling time and the initial enrichments of (a) 2 wt. % ^{235}U, (b) 3 wt. % ^{235}U, (c) 4 wt. % ^{235}U, (d) 5 wt. % ^{235}U.

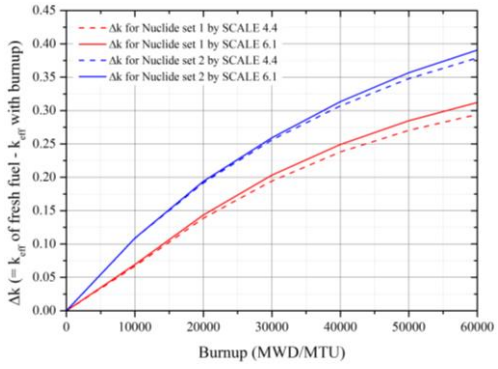


(c) 4 wt. % U-235

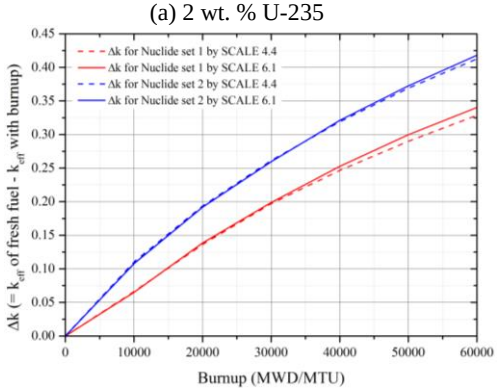


(d) 5 wt. % U-235

Fig. 6. Values of Δk in the cask as a function of burnup using the nuclide set 1 and 2 for 40 year cooling time and the initial enrichments of (a) 2 wt. % ^{235}U, (b) 3 wt. % ^{235}U, (c) 4 wt. % ^{235}U, (d) 5 wt. % ^{235}U.

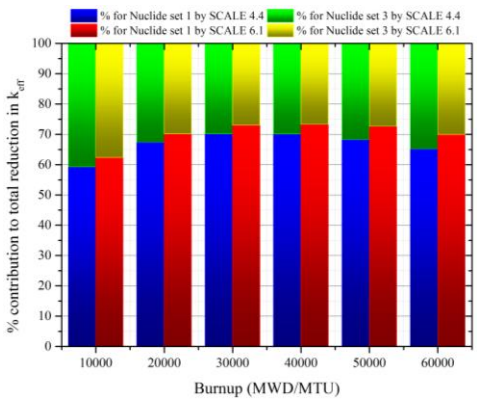


(a) 2 wt. % U-235

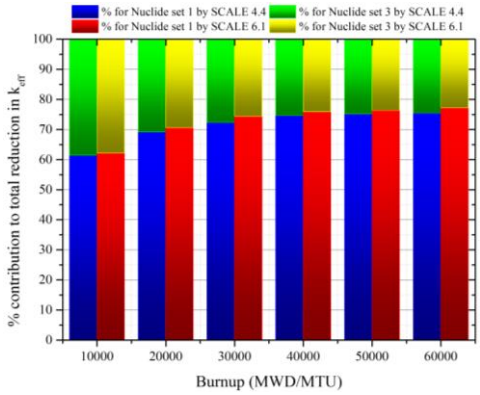


(b) 3 wt. % U-235

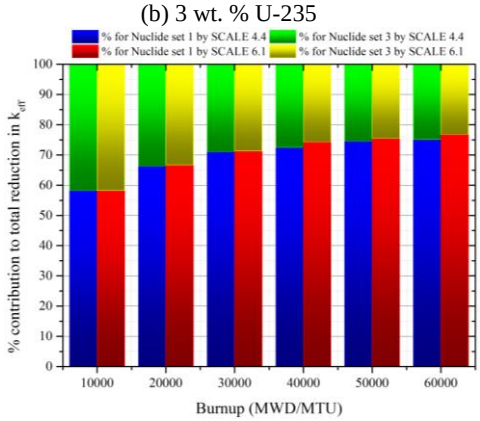
The graphs of the contributions for the nuclide set 1 and 3 to total reduction in k_{eff} in the cask as a function of burnup for the cooling times of 0 and 40 year and the initial enrichments of 2, 3, 4, and 5 wt. % ^{235}U were plotted in Fig. 7 and 8, where the blue and green bars denote the results calculated by applying the nuclide set 1 and 3 to SCALE 4.4a [1], respectively, the red and yellow bars denote the results calculated by applying the nuclide set 1 and 3 to SCALE 6.1, respectively. Fig. 7 and 8 shows that the major actinides of the nuclide set 1 contributed more significantly to total reduction in k_{eff} than the minor actinides and fission products of the nuclide set 3 in the cask as the burnup increases.



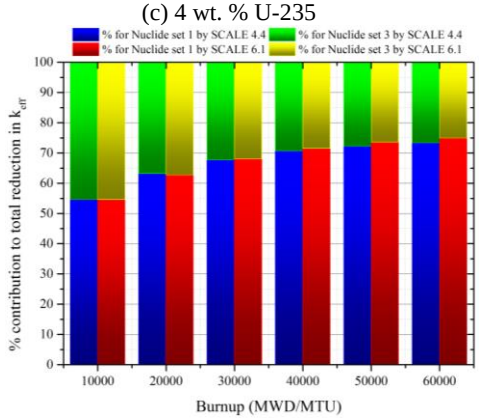
(a) 2 wt. % U-235



(b) 3 wt. % U-235

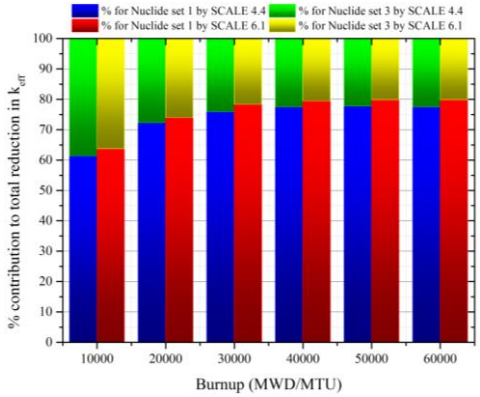


(c) 4 wt. % U-235

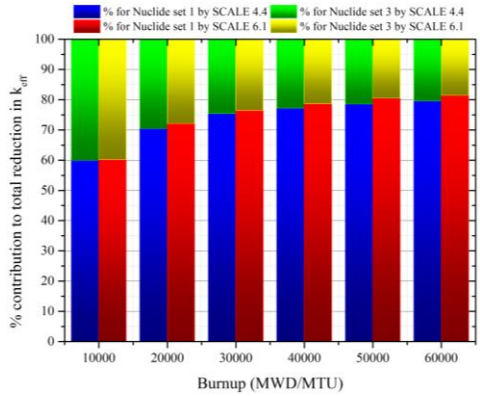


(d) 5 wt. % U-235

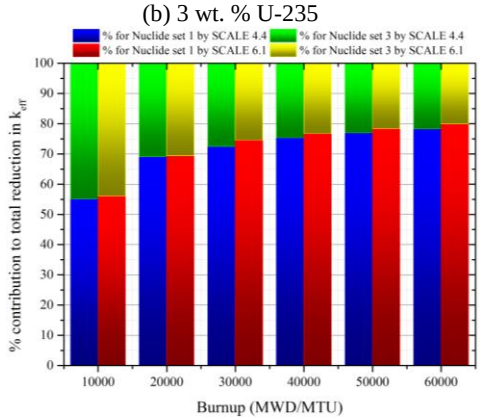
Fig. 7. Comparison of the contributions for the nuclide set 1 and 3 to total reduction in k_{eff} in the cask as a function of burnup for 0 year cooling time and the initial enrichments of (a) 2 wt. % ^{235}U, (b) 3 wt. % ^{235}U, (c) 4 wt. % ^{235}U, (d) 5 wt. % ^{235}U.



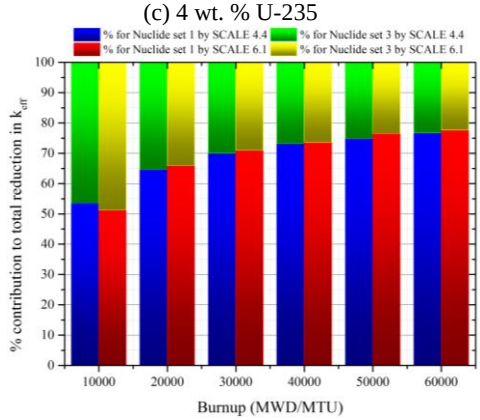
(a) 2 wt. % U-235



(b) 3 wt. % U-235



(c) 4 wt. % U-235

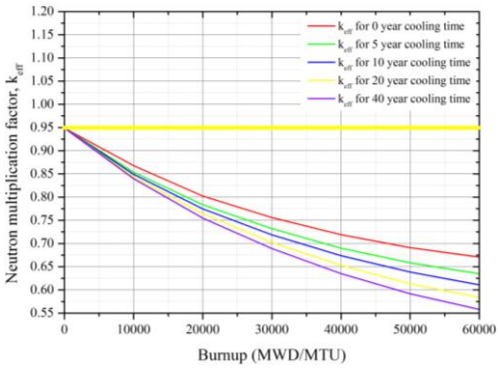


(d) 5 wt. % U-235

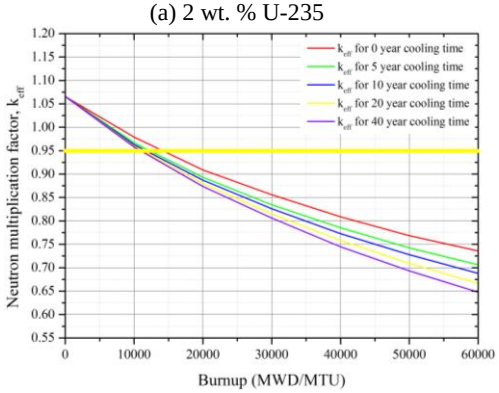
Fig. 8. Comparison of the contributions for the nuclide set 1 and 3 to total reduction in k_{eff} in the cask as a function of burnup for 40 year cooling time and the initial enrichments of (a) 2 wt. % ^{235}U, (b) 3 wt. % ^{235}U, (c) 4 wt. % ^{235}U, (d) 5 wt. % ^{235}U.

The graphs of k_{eff} values in the cask as a function of burnup using five cooling times for the nuclide set 2 and the initial enrichments of 2, 3, 4, and 5 wt. % ^{235}U by SCALE 6.1 were plotted in Fig. 9, where the red, green, blue, yellow, and violet lines denote the results calculated for the cooling times of 0, 5, 10, 20, and 40 years, respectively. The graphs of Δk values in the cask as a function of burnup using five cooling times for the nuclide set 2 and the initial enrichments of 2, 3, 4, and 5 wt. % ^{235}U by SCALE 6.1 were plotted in Fig. 10, where Δk is same indicates as Fig. 5 and 6, and the red, green, blue, yellow, and violet lines are same meanings as those in Fig. 9. Fig. 9 and 10 show that Δk values in

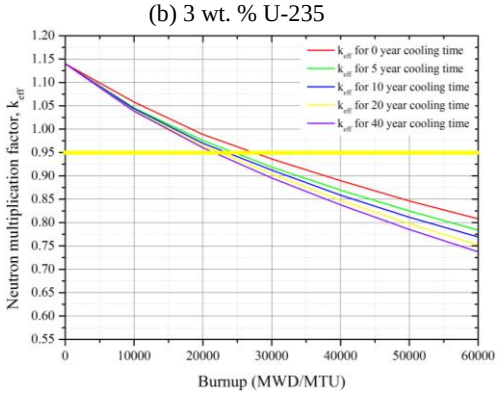
the cask increased and k_{eff} values decreased as the cooling time increases up to 40 years because the yield of actinides and fission products as neutron absorbers increased as the cooling time increases.



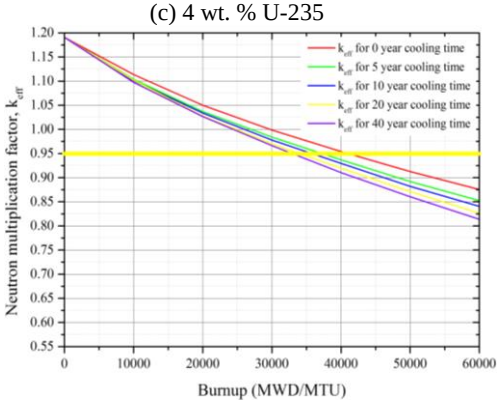
(a) 2 wt. % U-235



(b) 3 wt. % U-235

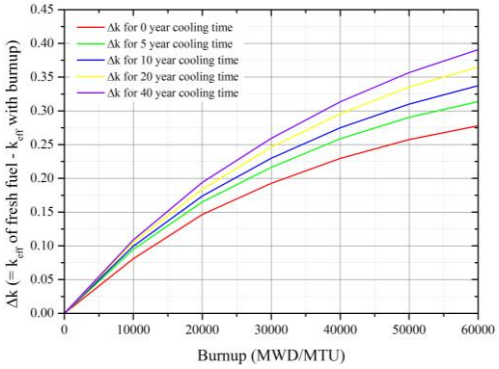


(c) 4 wt. % U-235

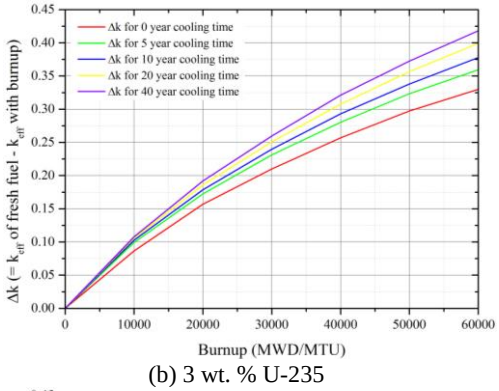


(d) 5 wt. % U-235

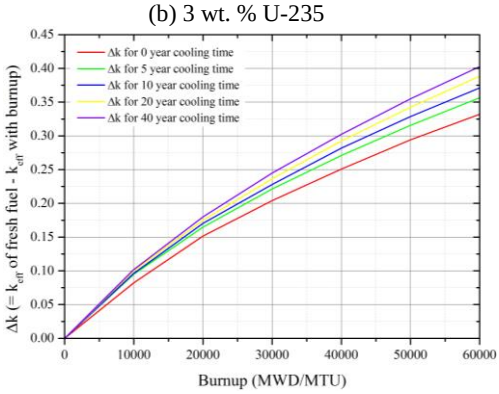
Fig. 9. Values of k_{eff} in the cask as a function of burnup using five cooling times for the nuclide set 2 and the initial enrichments of (a) 2 wt. % ^{235}U, (b) 3 wt. % ^{235}U, (c) 4 wt. % ^{235}U, (d) 5 wt. % ^{235}U.



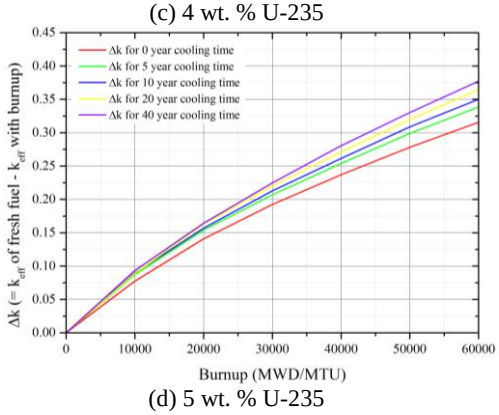
(a) 2 wt. % U-235



(b) 3 wt. % U-235



(c) 4 wt. % U-235



(d) 5 wt. % U-235

Fig. 10. Values of Δk in the cask as a function of burnup using five cooling times for the nuclide set 2 and the initial enrichments of (a) 2 wt. % ^{235}U, (b) 3 wt. % ^{235}U, (c) 4 wt. % ^{235}U, (d) 5 wt. % ^{235}U.

3. Conclusions

The criticality evaluation with an effect of burnup credit was performed for the DSC of GBC-32 by using SCALE 6.1/STARBUCS. k_{eff} values were calculated as a function of burnup and cooling time for four initial enrichments of 2, 3, 4, and 5 wt. % ^{235}U. The values were calculated for the burnup range of 0 to 60,000 MWD/MTU, in increments of 10,000 MWD/MTU, and for five cooling times of 0, 5, 10, 20, and 40 years. From the results calculated in these conditions, the following conclusions are drawn.

(1) The level of agreement between our results calculated by SCALE 6.1 and results calculated by SCALE 4.4a [1] was very good within the maximum difference of 3.17% in Table VII.

(2) The current criticality safety evaluation assumes the only unirradiated fresh fuels in the cask and the k_{eff} value is equivalent to that calculated for the burnup of 0 MWD/MTU and the cooling time of 0 year. In Fig. 3, the 32 UNFs with 0 MWD/MTU and 0 year cooling time for the initial enrichments of 3, 4, and 5 wt. % ^{235}U except for 2 wt. % ^{235}U were not allowed to be stored in the cask because k_{eff} exceeded 0.95. However, for the criticality evaluation considering burnup credit, it showed that the some 32 UNFs for the initial enrichments of 3, 4, and 5 wt. % ^{235}U were also allowed to be stored in the cask because k_{eff} did not exceed 0.95. In particular, the 32 UNFs with a high initial enrichment for high burnup took significant credit required to be stored in the cask.

(3) As the initial enrichment increases, the conditions for burnup and cooling time of allowable 32 UNFs to be stored in the cask were more restrictive.

(4) The major actinides of the nuclide set 1 contributed more sensitively to total reduction in k_{eff} than the minor actinides and fission products of the nuclide set 3 in the cask as the burnup increases in Fig. 7 and 8.

(5) As the cooling time increases up to 40 years in Fig. 9, k_{eff} values decreased in the cask because the yield of actinides and fission products as neutron absorbers increased as the cooling time increases.

REFERENCES

[1] J. C. Wagner, "Computational Benchmark for Estimation of Reactivity Margin from Fission Products and Minor Actinides in PWR Burnup Credit", NUREG/CR-6747, ORNL/TM-2000/306, 2001.

[2] Office of Nuclear Material Safety and Safeguards, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility", NUREG-1536 Revision 1, 2010.

[3] G. Radulescu and I. C. Gauld, "STARBUCS: A Scale Control Module for Automated Criticality Safety Analyses Using Burnup Credit", ORNL/TM-2005/39 Version 6.1, Section C10, 2011.

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