# Nuclear Criticality Analyses for Disposal Systems with Two Different Canisters

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## 1. Introduction

A deep geological disposal system has been adopted as an effective management solution of spent nuclear fuels (SNFs) in South Korea. The conceptual design of the system requires an accurate nuclear criticality analysis (NCA) considering burnup credit (BUC). The consideration of BUC has a significant effect on the reduction of the effective neutron multiplication factor ($k_{eff}$) of the system. Because the reactivity of the system reduces due to the depletion of fissile nuclides and the generation of neutron-absorbing fission products in SNFs. An NCA in BUC of a disposal system is performed according to the following steps:

① An assessment of the isotopic compositions in SNFs using a fuel depletion code and
② A calculation of the $k_{eff}$ value for the system using a nuclear criticality code.

The design requirement for an NCA of a disposal system is that the $k_{eff}$ value of the system should not exceed 0.95 [1-3]. The design concept of the KBS-3 disposal canister in the system was developed by the Finland Posiva and the Sweden SKB, whereas that of the STAD canister was developed by the United States Department of Energy.

The main objectives of this paper are

① to carry out the NCAs for the disposal system with one KBS-3 or STAD canister in BUC,
② to evaluate whether the $k_{eff}$ values meet the design requirement, $k_{eff} < 0.95$, and
③ to determine which system with two different canisters is more subcritical.

The type of SNFs in two disposal canister is the PLUS7 16x16 nuclear fuel of the most pressurized light water reactors (PWRs) in South Korea. The discharge burnups of the SNFs are categorized into two groups: the lower and higher burnup group. For the lower burnup group, the initial enrichment and discharge burnup are 4.0 wt. % U-235 and 45 GWD/MTU, respectively. For the higher burnup group, the enrichment and burnup are 4.5 wt. % U-235 and 55 GWD/MTU, respectively.

## 2. Analysis Processes and Results

### *2.1 Nuclear Reaction XS Libraries*

For step 1, new nuclear reaction cross section libraries for the PLUS7 16X16 nuclear fuel were generated to apply to the libraries of the fuel depletion code. Fig. 1 shows the geometry of PLUS7 nuclear fuel using the SCALE-TRITON code. The red, green and blue zones stand for the fuel rods, the zircaloy-4 cladding tubes, and $H_2O$ water, respectively.

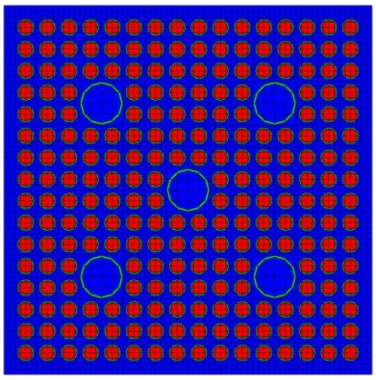


Fig. 1. Geometry of PLUS7 nuclear fuel.

The libraries were applied to the SCALE-ORIGEN code that assesses the isotopic compositions in SNFs due to the fuel depletion. The Evaluated Nuclear Data Files, Part B (ENDF/B)-VII 238-group XS library was applied to the nuclear criticality calculations in the STARBUCS code.

### *2.2 Axial Burnup Profile*

The PLUS7 SNFs were assumed to be discharged at the Hanbit PWR Unit 3. Two axial burnup profiles were selected corresponding to the lower and higher burnup SNF in Fig. 2 [1]. The y-axis represents the height percentage of the fuel. 0% is the bottom of the SNF and 100% the top. The x-axis stands for the ratio of the local discharge burnup to the average burnup. The blue and red dash line show the axial burnup distributions of the lower and higher burnup SNF, respectively. The zone from 10% to 90% of the SNF was greater than the average burnup, while the other was lesser.

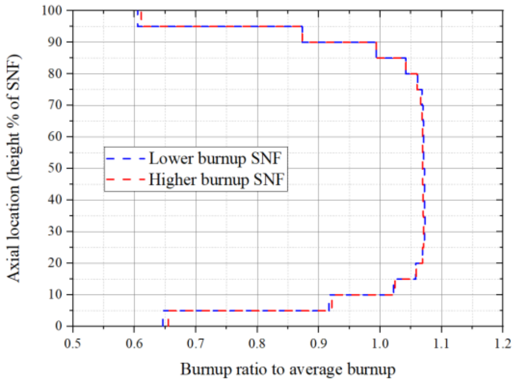


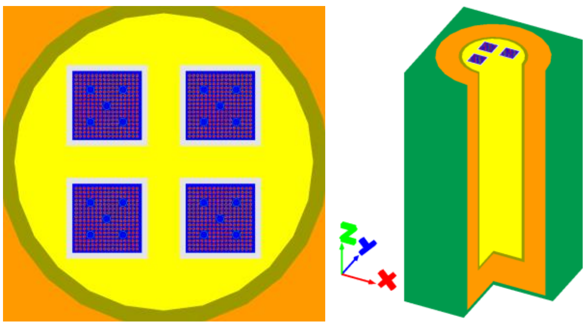

Fig. 2. Axial burnup profiles of lower & higher burnup SNF.

The nuclides selected for BUC were nine major actinides as follows: U-234, U-235, U-238, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, and Am-241 [1,2].

### *2.3 Disposal System Modeling*

Each of two disposal systems with the KBS-3 or STAD disposal canister was modeled. The deposition hole consisting of one disposal canister and the surrounding buffer were modeled. The host rock encompassing the deposition hole was also modeled.

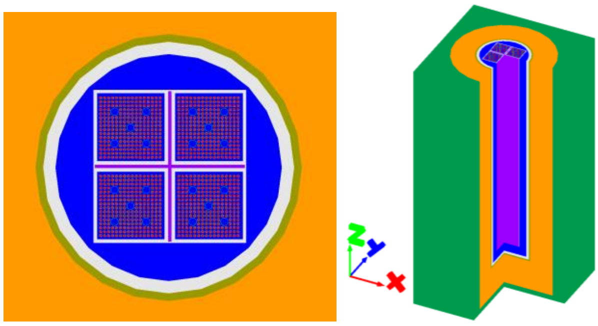
The KBS-3 canister consisted of four SNFs, four channels, the internal cast iron insert, the internal steel lid and the external copper shell and lid [3-5]. Fig. 3 shows (a) the radial and (b) the axial view of the geometry of the disposal system with the KBS-3 canister using the STARBUCS code. The red, blue, light gray, light yellow, dark yellow, orange, and green zones represent the fuel rod, $H_2O$ water, the steel channel, the cast iron insert, the copper shell, the buffer, and the host rock, respectively.



(a) Radial view (b) Axial view

Fig. 3. Geometry of KBS-3 canister.

The STAD disposal canister was composed of four SNFs, the basket assembly, the internal steel shell and lid, and the external copper shell and lid [6,7]. Fig. 4 shows (a) the radial and (b) the axial view of that with the STAD canister. The light gray and violet regions stand for the steel structure and the neutron absorber plate, respectively.



(a) Radial view (b) Axial view

Fig. 4. Geometry of STAD canister.

### *2.4 Analysis Results*

The NCAs in BUC were conducted with respect to two different disposal systems with one KBS-3 or STAD canister using the SCALE-STARBUCS code. Two burnup groups, the lower and higher, were applied to the PLUS7 SNFs. Three cooling times of the SNFs were assumed to be 40, 50, and 60 years. Fig. 5 and 6 show the $k_{eff}$ values of the disposal systems with the cooling times for lower and higher burnup SNFs, respectively.

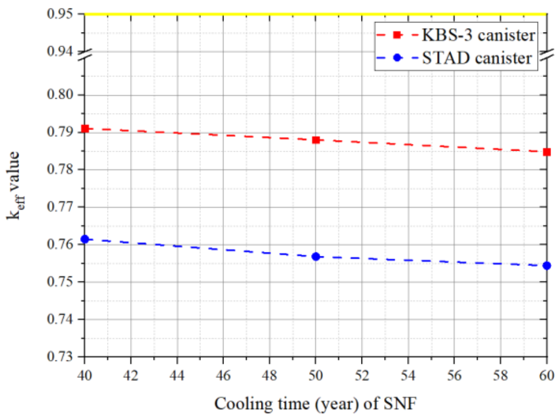



Fig. 5. $k_{eff}$ values for lower burnup SNFs.

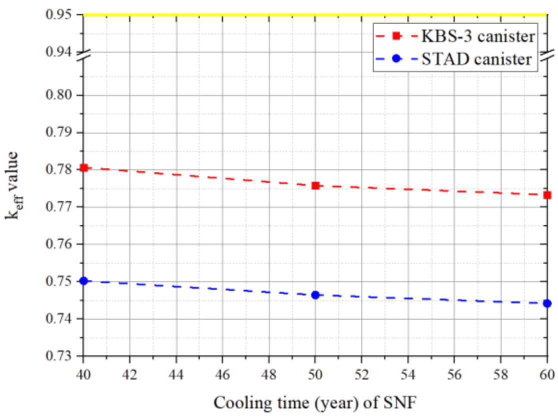



Fig. 6. $k_{eff}$ values for higher burnup SNFs.

In result, the $k_{eff}$ values for all cases met the design requirement, $k_{eff} < 0.95$. All values for the disposal systems of the higher burnup SNFs were lower than those of the lower. Because the inventories of the fissile nuclides such as U-235, Pu-239, and Pu-241 in the higher burnup SNFs were lesser than those in the lower. The $k_{eff}$ value reduced due to the radioactive decay of Pu-241 as the cooling time of the SNFs increased [1].

In addition, all $k_{eff}$ values for the disposal system with the STAD canister were lower than those with the KBS-3. In other words, the system with one STAD canister were more subcritical than that with the KBS-3. Because the neutron absorber plates in the STAD canister had a significant effect on the decrease of the thermal neutron flux and the corresponding $k_{eff}$ values although the distance between the SNFs in the STAD canister was much shorter than that of the KBS-3.

## 3. Conclusions

The NCAs in BUC were performed for the disposal systems with two different types of the disposal canisters: the KBS-3 and the STAD canister. New nuclear reaction cross section libraries for the PLUS7 fuel were generated using the TRITON code. The NCAs were carried out with the cooling times using the STARBUCS code. From the results, the following conclusions were drawn:

- For the lower burnup SNFs, the $k_{eff}$ values of the cooling times of 40, 50, and 60 years were assessed to be 0.79108, 0.78803, and 0.78484 for the disposal system of the KBS-3 canister, respectively. In addition, those were calculated to be 0.76149, 0.75683, and 0.75444 for the STAD canister, respectively.

- For the higher burnup SNFs, the $k_{eff}$ values for the cooling times of 40, 50, and 60 years were assessed to be 0.78067, 0.77581, and 0.77335 for the disposal system of the KBS-3 canister, respectively. In addition, those were calculated to be 0.75024, 0.74647, and 0.74420 for the STAD canister, respectively.

- Therefore, all $k_{eff}$ values met the design requirement, $k_{eff} < 0.95$. In other words, the disposal systems for all cases remained subcritical.

- All $k_{eff}$ values for the disposal system with the higher burnup SNFs were lower than those with the lower.

- All $k_{eff}$ values for the disposal system with the STAD canister were lower than those with the KBS-3.

## ACKNOWLEDGEMENTS

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