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Criticality Evaluation of Fuel Failure Scenarios using KENO-VI

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1. Introduction

A spent fuel transport cask should be demonstrated by performing critical, shielding, thermal, and structural analyzes to ensure safe transport of nuclear fuel. However, it was reported that high burnup spent fuels ranged 60 to 80 GWd/MTU increase the fuel failure potential due to the degradation of fuel and cladding materials [1]. It is necessary that criticality analysis under hypothetical accident conditions should be conducted to verify the k-eff to meet the criticality design basis of a transport cask.

The purpose of this study is to investigate the results of potential fuel failure on the criticality for a transport cask. Criticality evaluations for fuel failure scenarios in which the geometric structure or conditions of spent fuel assemblies and fuel rods are changed due to beyond design basis accidents are performed for KN-18 transport cask. KENO-VI was used to evaluate the criticality for those conditions of the cask [2].

2. Criticality Evaluations

KN-18 is a transport cask for 16×16 CE type fuels. In this study, Plus7 fuel assemblies with 5wt% concentration were selected and KN-18 cask body, neutron absorber and fuel baskets were used as described in its safety analysis report.

Criticality assessments for normal condition which is assumed to be flooded state were conducted using KENO-VI as well as MCNP6 for the code to code validation. The acceptance criticality criteria are described in the section 6-4 of NUREG-1617 [3].

2.1 Evaluation for normal condition

The KENO-VI modeling of the cask in the radial direction including the fuel assemblies is shown in Fig. 1. METAMIC as a neutron absorber is installed outside the nuclear fuel assembly.

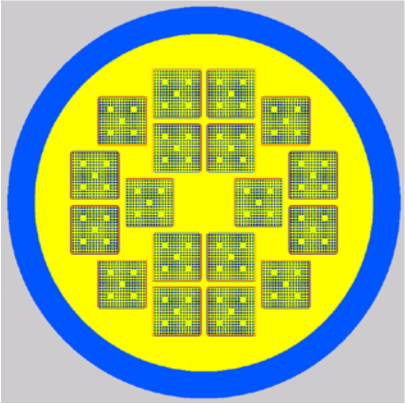


Fig. 1. Criticality Modeling of KN-18 Cask

The effective multiplication factor from the KENO-VI and MCNP6 calculation is shown in Table 1. The k-eff values are so close to each other that the KENO-VI modeling is validated for being utilized as the criticality evaluation tool in this study for spent fuel transport cask.

Table 1. Calculated k-eff of normal condition

Code	K-eff	Std. dev.
KENO-VI	0.81384	0.00019
MCNP6	0.81335	0.00020

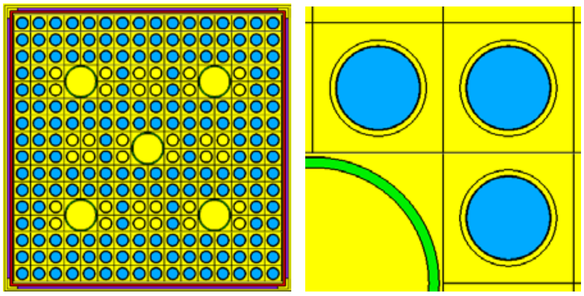
2.2 Evaluations for fuel failure scenarios

It has been grown particular concerns when high burnup spent fuels had been analyzed under hypothetical accident conditions. For the purpose of assessing the criticality under those circumstances, several assumptions were made as internal and external structures within the cask, the basket structures with neutron absorbers, especially fuel assemblies, are maintained as their original states.

In addition, fuel failure scenarios are assumed to be within the scope of severe accidents. Three cases which are unlikely to occur are chosen as the accident scenarios.

○ Loss of a single fuel rod
○ Loss of multiple fuel rods
○ Loss of rod cladding

The fuel assembly modellings based on those scenarios are depicted as shown in Figure 2.



(Loss of fuel rods) (Loss of cladding)

Fig. 2. KENO-VI modeling of fuel failures

As shown in table 2, the calculated k-eff and standard deviations from the first and second scenarios are slightly increased compared with the normal condition consequences. This has an important meaning that fuel assemblies are designed to be under-moderated; however, when single fuel rod is occurred to be lost from an assembly, the area being lost a rod is to become higher-moderated then makes the k-effective value being increased.

Those are because the removal of a rod near from the water hole and from the middle of the fuel assembly promotes k-eff values to be increased due to the moderation growth. On the other hand, the removal of a rod from the edge of the fuel assembly decreases the k-eff slightly because of the increased moderation near from the neutron absorber panels.

Table 2. Calculated k-eff for loss of a single rod

Position of losing rod	K-eff	Std. Dev.
Near the water hole	0.81540	0.00022
In the middle of fuel assembly	0.81519	0.00020
Edge of the fuel assembly	0.81376	0.00020

Various criticality calculations were performed for the purpose of impact when the losses of multiple fuel rods scenario happen. The removals of fuel rods adjacent to the water hole and from the middle of the assembly were simulated sequentially, and the results are shown in Fig 2.

The k-effs are increased gradually by removing the rods up to around 20 (about 10% of the entire fuel rods) adjacent to the water hole, and after that the k-effs are sharply increased by removing additional about 20 rods in the middle of the fuel assembly consecutively (total rods up to 40, about 17% of the entire fuel rods).

The fuel failure of loss of fuel rod cladding was also analyzed by simply removing the cladding from all rods within the fuel assembly.

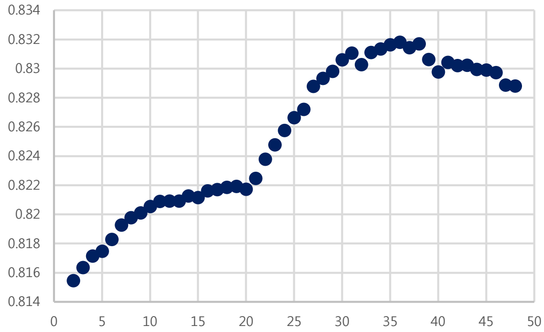


Fig. 2. k-eff for loss of rods near the water hole and in the middle of the fuel assembly

The space formerly filled with rod cladding was replaced with water. This provides extra moderating conditions to the under-moderated fuel system then increases the k-eff values by a substantial amount as shown in table 3.

Table 3. Calculated k-eff for loss of rod cladding

K-eff	Std. Dev.
0.87198	0.00019

3. Conclusion

Critical evaluations of the KN-18 transport cask were performed using the KENO-VI code. In case of normal condition, we compare MCNP6 code with the result for modeling verification and confirm that the criticality is within the statistical error range.

Criticality evaluations were performed for three types of fuel failure scenarios; loss of a single fuel rod, loss of multiple fuel rods, and loss of rod cladding. And the results show that the criticality of loss of cladding material accidents was much higher than other scenarios. Fortunately, this is also within the acceptance criteria of NUREG-1617.

REFERENCES

[1] K.R. Elam, J.C. Wagner, C.V. Parks, "Effects of Fuel Failure on Criticality Safety and Radiation Dose for Spent Fuel Casks," NUREG/CR-6835, ORNL, Sept. 2003

[2] "KENO-VI: A General Quadratic Version of the KENO Program", ORNL/TM-2005/39, June, 2011.

[3] NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," March 2000, U.S. Nuclear Regulatory Commission