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Criticality Evaluations of Transportation Cask under Hypothetical Accident of Spent Nuclear Fuel

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1. Introduction

A transport cask for spent nuclear fuel (SNF) should be demonstrated by performing critical, shielding, thermal, and structural analyses to ensure safe transportations of SNF. However, it was reported that high burnup SNFs typically increased the fuel failure potential due to the degradation of fuel and cladding materials [1,2]. It is necessary that criticality analysis under hypothetical accident conditions by the high burnup SNFs should be conducted to verify the k-eff to meet the design basis of transport casks.

The purpose of this study is to investigate the results of potential fuel failures on the criticality for a transport cask. Criticality evaluations for fuel failure scenarios which the geometric structure or conditions of SNF assemblies and fuel rods are changed due to beyond design basis accidents are performed for KN-18 transport cask. KENO-VI Monte Carlo code was used to evaluate the criticality for those conditions of the cask [3].

2. Criticality Evaluations

KN-18 is a transport cask for CE type fuels. In this study, PLUS-7 fuel assembly with 5wt% concentration was selected. KN-18 cask body, neutron absorber and fuel baskets were also used as described in its safety analysis report. The acceptance criteria of criticality are described in the section 6-4 of NUREG-1617 [4].

2.1 Evaluation for normal condition

The k-effs of KENO-VI and MCNP6 calculation for normal condition are shown in Table I. 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 KN-18 transport cask of SNFs.

Table I: Calculated k-eff of normal condition

Code	k-eff	Std. dev.
KENO-VI	0.81385	0.00020
MCNP6	0.81265	0.00021

2.2 Evaluations for fuel failure scenarios

For the purpose of assessing the criticality under hypothetical accident conditions with high burnup SNFs, 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

2.2.1 Loss of single fuel rod

Criticalities of 32 scenarios were calculated for the number which means loss of designated fuel rod as shown in Fig. 1 and the results are depicted in Fig. 2 respectively.

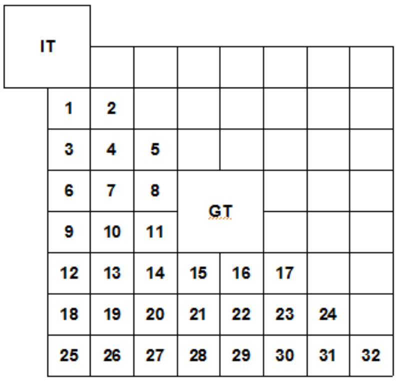

Fig. 1. Scenarios of loss of single fuel rod

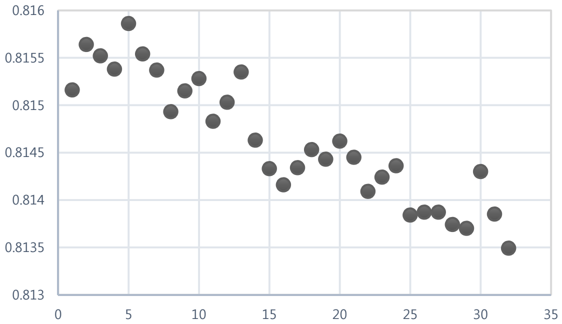

Fig. 2. K-effs for loss of single fuel rod

As shown in Fig.2, the calculated k-effs from 1st to 24th fuel rod loss are slightly increased compared with the k-eff of normal condition in Table I. This has an important meaning that fuel assemblies are designed to be under-moderated; however, when a single fuel rod is occurred to be lost from an assembly, the area being lost the rod is to become higher-moderated then makes the k-eff value being increased. These are because the removal of a rod both near the water hole in the middle of the fuel assembly and between fuel rods promotes k-eff value 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 the neutron absorber panels.

2.2.2 Loss of multiple fuel rods

Various criticality calculations were performed for the loss of multiple fuel rods. The removals of fuel rods both adjacent to the water holes of the assembly and between fuel rods were simulated sequentially as shown in Fig. 3. Firstly, the removals of fuel rod are carried out symmetrically for the each water hole. And secondly, the fuel rods are removed concentrically for each water hole. Finally, the removals of fuel rod are also carried out symmetrically and dispersedly for both adjacent and interjacent water holes respectively.

The results are shown in Fig 4. The k-effs are increased up to the point of 20 which means the number of removals of failed fuel rods and then are seemed to be decreased for the 1st case when the removals are carried out only around the water holes. Moreover, k-effs are gradually increased by removing the rods up to around 40 (about 17% of the entire fuel rods) and after that the k-effs are seemed to be saturated by removing additional rods from the fuel assembly for the 3rd case.

On the other hand, the k-effs are saturated to the point of the number of around 40 and then are sharply decreased for the 2nd case. This phenomena are very curious but it is assumed that the bulk of water around the water holes works as a neutron absorber.

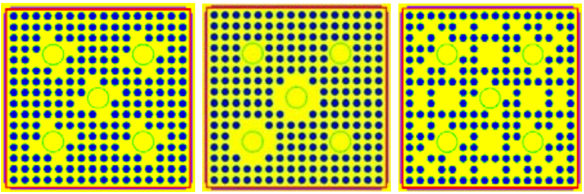
(1st case) (2nd case) (3rd case)

Fig. 3. Scenarios of loss of multiple fuel rods

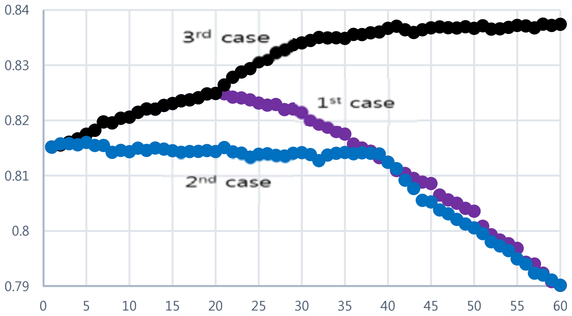

Fig. 4. K-effs for loss of multiple fuel rods

2.2.3 Loss of rod cladding

The fuel failures of loss of rod claddings were also analyzed by simply removing the cladding from all rods within the fuel assemblies. A total of twelve k-effs are calculated cumulatively for the fuel assemblies without cladding.

The material 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 Fig. 5.

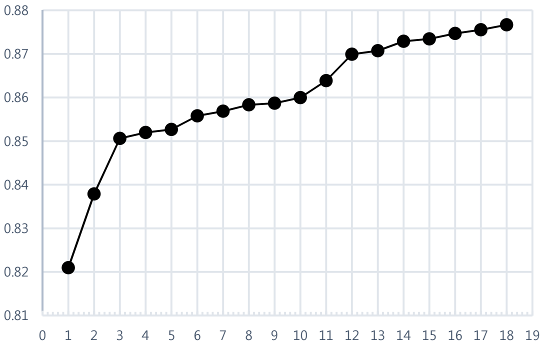

Fig. 5. K-effs for loss of rod claddings

3. Conclusion

Critical evaluations of the KN-18 transport cask were performed using the KENO-VI code. In case of normal condition, we compared MCNP6 code with the result for modeling verification and confirmed that the criticality was 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

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