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Criticality Safety Analysis (CSA) for the Shifted Fuel Assemblies in Spent Fuel Transportation Cask

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1. Introduction

The transportation of nuclear fuel must comply with internationally regulated safety standards, for which the casks used to transport the fuel must meet strict technical requirements. The NRC's regulatory requirement mentions subcriticality for arrangements and packaging that result in maximum neutron multiplication under normal and accidental transport conditions. [1]

Criticality Safety Analysis (CSA) is essential to prevent the potential safety issues that may arise during transportation of nuclear fuel. In particular, the placement of the spent nuclear fuel (SNF) assemblies may not be as designed, and the CSA needs to include the impacts in calculations. In addition, the placement of the nuclear fuel may not be as expected due to errors that may occur during transportation, and the CSA needs to take this into account too.

There is a standard review plan (SRP) for the transportation of SNF called "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel" (NUREG-2216). Section 6.3 of the reference says "The sum of the effective multiplication factor (k-eff), the two standard deviations (95% confidence level), and the bias correction should not exceed 0.95 to avoid proving unweighting by calculation."

This study additionally considers the effect of errors in the stacking position of aggregates on the criticality, a situation that may occur during transportation and storage. [2] Some CSAs have been performed to address potential safety with 350 misplaced or shifted assembly cases in a 24-SNF transport cask using KENO-VI (3-D Monte Carlo criticality computer code). [3]

2. Modeling and Case Studies

When transporting nuclear fuel, CSA of the transport cask is required to ensure the safety of nuclear fuel transportation.

First, the nuclear fuel composition and the neutron absorber of the transport cask must be analyzed. This is important to ensure that the nuclear fuel can be safely transported in the transport cask. In this study, a 5% enriched Westinghouse (WH) 17x17 nuclear fuel assembly was considered, and the nuclear fuel was considered as fresh nuclear fuel without considering burnup credit. A fully flooded condition with 100% water has been applied in the transport cask.

Second, considering the location and distribution of nuclear fuel, neutron absorbers and moderator in the transport cask, the nuclear criticality of the transport cask is analyzed. Table 1 shows the specification of a transport cask and B_4C+Aluminum was used as neutron absorber.

Table 1. Specification of a transport cask

Description	Material	Value
Neutron Absorber		
Thickness	B_4C+ Aluminum	0.46 cm
Width		19 cm
Basket		
Inner Width	SS-304	11 cm
Wall Thickness		0.5 cm
Canister		
Inner radius	SS-304	84 cm
Thickness		1 cm
Hight		393.16 cm
Cask		
Inner radius	Concrete	87 cm
Outer radius		166.8 cm
Height		452.12 cm

The KENO model of cask is shown in **Figure 1.** and the normal condition of the model (with all the nuclear fuel in the center) is shown as **Figure 2**.

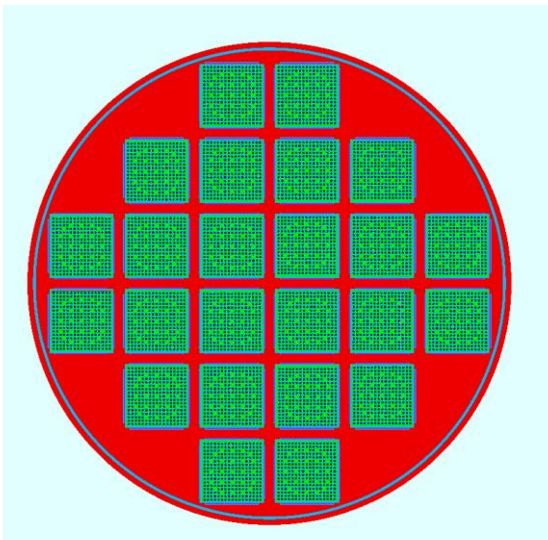

Figure 1. KENO Model of transport cask

Lastly, it is necessary to analyze the reliability of the criticality calculation results and evaluate the k-eff. So, the reliability of the criticality calculation results and the k-eff are evaluated based on the results of CSA of the transport cask,

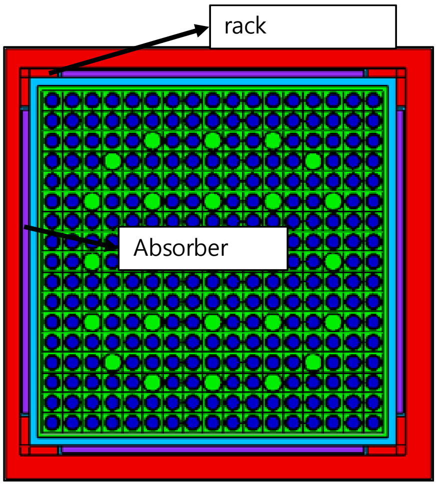

Figure 2. Cross section of center-position SNF

The CSAS6 program in SCALE 6.2.4 was used for the modeling and calculations and the ENDF/B-VII library was used. Criticality Safety Analysis Sequence with KENO-VI (CSAS6) is a three-dimensional Eigen Value Monte Carlo code

3. Results

To investigate the case where the SNF is shifted, 350 cases were created to create KENO-VI input and calculated. The 350 cases were randomly selected and applied to have a constant distribution at 0.1 cm intervals, considering a range of up to 0.29 cm in the inner space of the basket, where the centrally located assembly can move up, down, left and right.

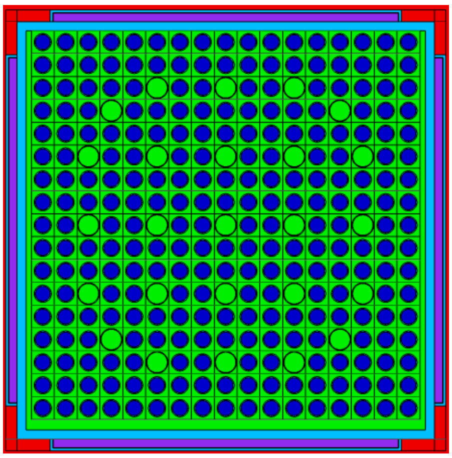

Figure 3. Cross section of shifted SNF

An example of a shifted SNF is shown as **Figure 3.** The green and red are water, the purple is the absorbent material composed of B_4C+Aluminum, and the blue is the basket made of SS304.

The results of the 350 cases and the k-eff with 95% confidence intervals for the cases where the SNF is fully shifted to the right, fully shifted to the left, and centered in the middle are shown as **Figure 4**, with 10000 particles per generation and 1000 generations.

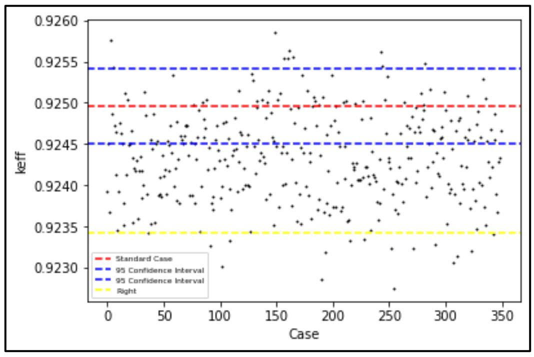

Figure 4. k-eff for centered SNF and other cases

The results show that the difference between the maximum and minimum values of k-eff is 310 pcm. In the case of all SNF shifted to the right, k-eff is less than "Centered" case's k-eff by 154 pcm. The difference from the centered case was a maximum of 89 pcm and a minimum of -221 pcm, which is over the valid range of 46 pcm.

4. Conclusion and Summary

Based on the conservative assumptions, every k-eff was below 0.95 at the 95% confidence interval. When the position of the SNF changes radically within the basket, it often falls outside the effective range of the k-eff in the case of a centered position. In addition, 100 case were tested in the direction of reducing the error range by increasing the number of neutrons per generation, k-eff was higher than when the SNF located in the center. Therefore, if the SNF is shifted, it is necessary to consider it when calculating the USL.

As a future work, some storage systems of SNF and reactor core will be evaluated using the results of this study.

Acknowledgement

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Reference

[1] Packaging and Transportation of Radioactive Material, NRC, 10 CFR Part 71
[2] Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material: Final Report, NUREG-2216
[3] SCALE Code System, Oak Ridge National Laboratory, April 2020