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Criticality Analysis for the New Fuel Transport Container

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1. Introduction

The new fuel assemblies are transported using the transport container from the fabrication facility to the nuclear power plant. The fresh fuel transport container shall be designed according to the MEST regulations [1] and/or the IAEA safety requirements [2]. To ensure the criticality safety guided in the regulations, criticality analysis was performed for the new fuel transport container loaded with two PLUS7 fuel assemblies. The Monte Carlo method computer codes of SCALE4.4 [3] and MCNP4b [4] are used on the evaluating the k-eff of the system.

2. Methods and Results

The new fuel transport container (Figure 1) comprises outer shell, frame, and cover. Two fuel assemblies are loaded in the fuel assembly support frame (reverse T shape) and fuel cover (rectangular beams). To control the reactivity, four (4) Borated Aluminum plates are attached inside of the support frame. The fuel covers which are opened for loading and unloading protect the fuel assemblies and limit the bulge of fuel pitch against the external damage. The fuel assembly support frame is suspended in the outer shell by means of rubber shock absorbers which are not shown in the figure.

The calculation model of the criticality analysis is the new fuel transport container loaded with two PLUS7 fuel assemblies. It is assumed that the maximum enrichment of U-235 and stack density of the PLUS7 fuel is 5.0 wt% and 10.313 g/cm^3, respectively.

The affecting factors for criticality safety are;
(1) the distance between the fuel assemblies,
(2) the neutron absorber plates inserted between the fuel assemblies,
(3) the fuel pin pitch could be bulged by the accidental drop of the container, and
(4) the moderator density which causes the maximum neutron multiplication.

The nominal conditions assumed on the analyses are, (1) two PLUS7 fuels are loaded, (2) four neutron absorber plates (Borated Aluminum plate) are attached, (3) the inside and outside of the transport container is filled with pure water, and (4) transport containers are packed infinitely (reflective boundary condition applied).

The criticality calculations were performed to investigate the effect of the design parameters which affect on the reactivity. The separation distance between two fuel assemblies of 5.2 cm is assumed to be intact under all conditions.

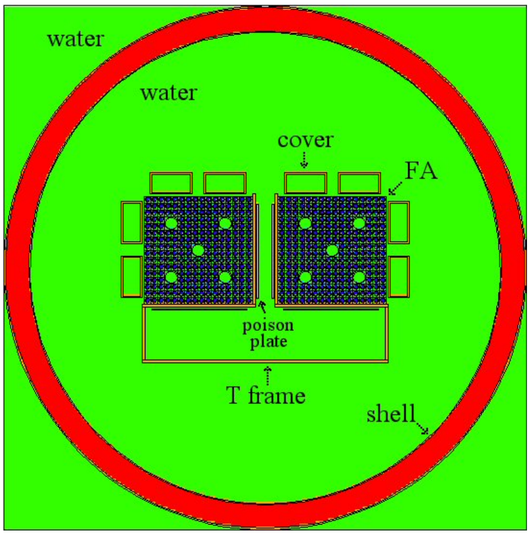

Figure 1. Nominal model of new fuel transport container

To meet the criticality safety requirements, the k-eff, including all biases and uncertainties at a 95 percent confidence level, shall not exceed 0.95 under all credible normal, abnormal, and accident conditions and events. The bias of the calculation methods of SCALE4.4 and MCNP4b was evaluated by the critical benchmark calculations on the various critical experiments [5] and the uncertainties due to the mechanical tolerances and/or design parameter variation for the new fuel transport container were estimated based on Reference 6. It can be seen from References 5 and 6 that applied calculation methods are suitable for the new fuel transport container analysis and the total bias and uncertainties would not exceed 2% Δk. In this analysis, the calculated k-eff of 0.92 was conservatively chosen as the criticality safety limit.

2.1 Neutron Absorber Plate

In this analysis, the effect of the neutron absorber plates was investigated. For nominal condition model as shown in Figure 1, four neutron absorber plates are placed between and under the fuel assemblies. For two neutron absorber plates model, the absorber plates under the fuel assemblies are eliminated. And for no neutron absorber plate model, all absorber plates are eliminated. The results are listed in the Table 1. From the results it can be seen that two absorber plates between fuel assemblies are essential to criticality safety, however, two absorber plates under fuel assemblies could be eliminated.

Table 1. k-eff vs. number of neutron absorber plates

No. of neutron absorber plates	k-eff	
	SCALE4.4	MCNP4b
4	0.85679±0.00038	0.85752±0.00111
2	0.87803±0.00046	0.87924±0.00113
0	0.92978±0.00038	0.93143±0.00115

2.2 Fuel Pin Pitch Bulge

The fuel assembly would bulge due to accidental drop of transport container. In this analysis, it is assumed that the fuel assembly is confined within the T frame and cover and the T frame and cover are not deformed. Then, the maximum fuel pin pitch bulge is determined, the fuel pin pitch can be bulged up to +0.02 cm maximum. The results of this model are listed in the Table 2. It can be seen that as the fuel pin pitch bulge, the k-eff of the fuel transport container becomes higher. However, the nuclear criticality safety is maintained by the fuel cover which limits the maximum bulge of fuel pin.

Table 2. k-eff vs. bulge of fuel pin pitch

Fuel pin pitch bulge	k-eff	
	SCALE4.4	MCNP4b
nominal	0.85679±0.00038	0.85752±0.00111
+0.01 cm	0.86174±0.00040	0.86231±0.00115
+0.02 cm	0.86864±0.00040	0.86763±0.00113

2.3 Moderator Density

In this analysis; the water density is varied from 0.001 g/cm^3 to 1.000 g/cm^3 to see the optimum moderating effects which cause the maximum reactivity and the results are graphed in Figure 2. The result shows that for the new fuel transport container, the optimum moderator density causing most reactive condition is full density water.

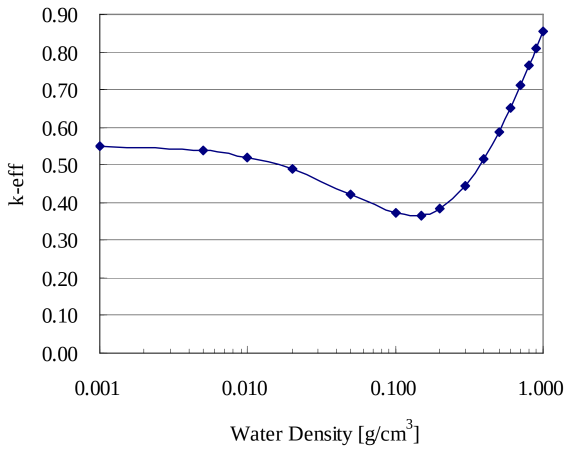

Figure 2. k-eff vs. water density

3. Conclusions

The analysis results represent that the given new fuel transport container model satisfies the criticality safety requirement. In addition to the separation distance between fuel assemblies, the number of neutron absorber plates, bulge of fuel assemblies due to accident, and fuel flooding of the container affect the criticality safety of the fresh fuel transport container.

REFERENCES

[1] The Ministry of Education, Science and Technology Notice No. 2008-69, "Regulations for the Package and Transport of Radioactive Material."

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[3] "SCALE 4.4 : Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers," C00545/MNYCP00, Oak Ridge National Laboratory, 1998.

[4] J. F. Briesmeister, "MCNP-A General Monte Carlo N-Particle Transport Code Version 4B," Los Alamos National Laboratory, LA-12625-M, March 1997.

[5] "Comparison of Criticality Benchmark Calculations on the UO_2 and MOX Fuel Arrays Using ENDF/B-V and ENDF/B-VI Data," PHYSOR 2000, Pittsburgh, USA, May 2000.

[6] Topical Report, "Criticality Analysis Method for High Density Fuel Storage Rack," DOOSAN and KOPEC, March 2007.