Criticality possibility study in the event of an accident while transporting spent nuclear fuel container

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Keywords: Criticality, Spent fuel, Absorber,

1. Introduction

The transportation of spent nuclear fuel (SNF) is a crucial aspect of nuclear energy management, requiring careful attention to safety, technical intricacies, and regulatory compliance. Among the numerous considerations involved, managing the risk of criticality incidents during transport stands out as a primary concern. Criticality, the self-sustaining nuclear chain reaction, poses significant safety hazards, necessitating rigorous planning, robust engineering, and stringent regulation.

Nuclear energy plays a vital role in meeting global energy demands while reducing carbon emissions. As such, safe SNF transport is increasingly crucial, demanding a deep understanding of criticality risks and effective risk management strategies.

SNF transport presents unique challenges due to its complex radioactive composition, including fissile materials like uranium and plutonium. Understanding factors influencing criticality, such as neutron moderation and absorption, is essential for developing effective safety measures. Regulatory bodies impose strict standards on transport cask design, testing, and certification, emphasizing prevention and response capabilities.

This paper aims to select scenarios where criticality is possible by configuring various accident scenarios expected to occur

2. Method

2.1 Source Term

Standard review Plant for Transportation Packages for Spent Fuel and Radioactive Material [1] recommends that axial burnup should be considered in the criticality assessment of spent fuel transportation vessels. Therefore, in this study, axial burnup was applied to spent fuel by referring to NUREG-6801[2], as there is no burnup history of a specific power plant. Also, the spent fuel initial conditions are enrichment 4.5 wt%, burnup 55,000 MWD/MTU, 3 cycles, specific power 40 MW/MTU and 5 years of cooling time.

2.2 Scenarios

Each scenario is shown in Table 1 and illustrated in the Figure.1 to 8

Table 1 Accident Classification

Accident Case		Fresh	SNF	Inner Space	
				Water	Helium
A	Absorbers completely lost	O	-	O	-
		O	-	-	O
B	Move the baskets centers	O	-	O	-
C	Move the fuel and basket Centers	O	-	O	-
		O	-	-	O
D	Move the entire assembly down	O	-	O	-
E	Move the Fuel Baskets Centers	-	O	O	-
F	Move the Fuel and Basket Centers	-	O	O	-
G	Move the entire assembly down	-	O	O	-
H	Absorbers completely lost	-	O	O	-

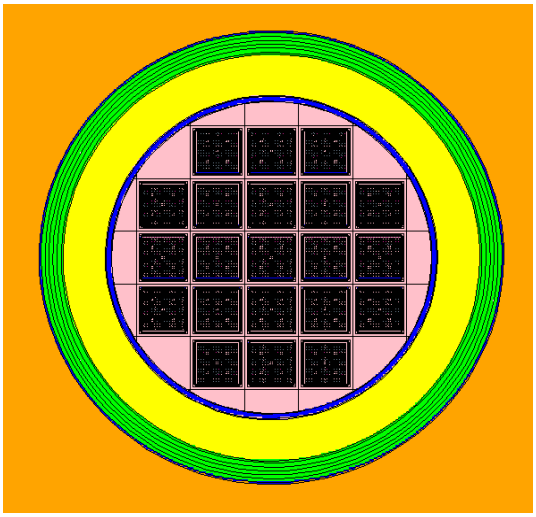

Figure 1. Scenrio A: absorbers completely lost

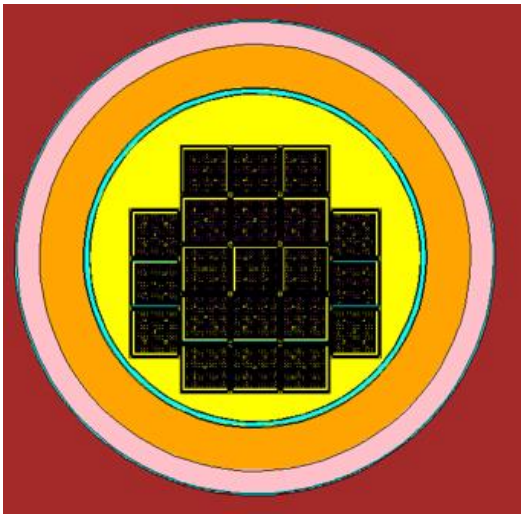

Figure 2. Scenrio B: Move the basket centers

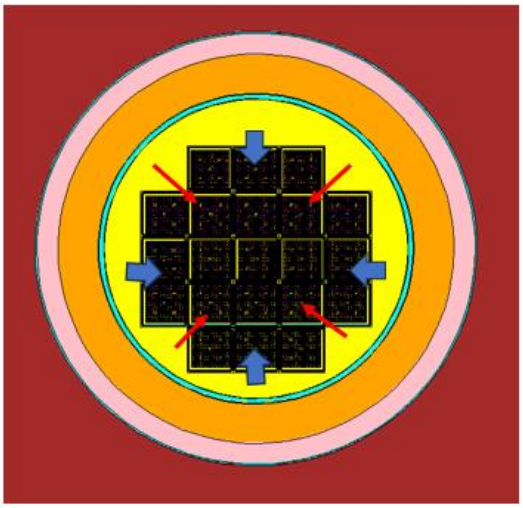

Figure 3. Scenrio C: Move the fuel and basket centers

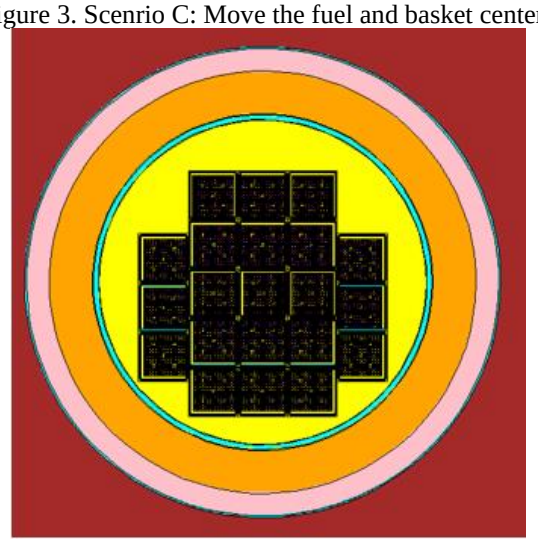

Figure 4. Scenrio D: Move the entire assembly down

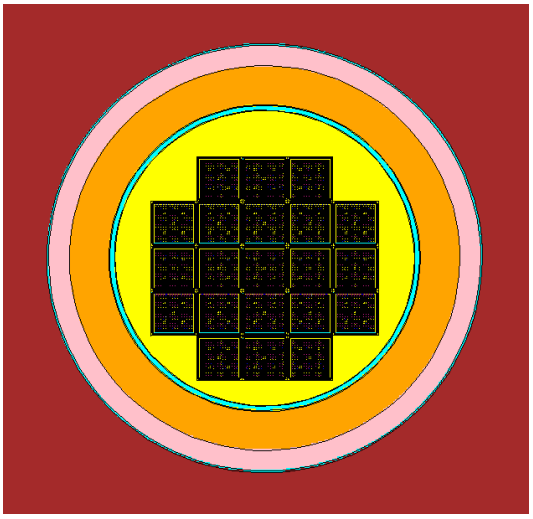

Figure 5. Move the Fuel Baskets Centers

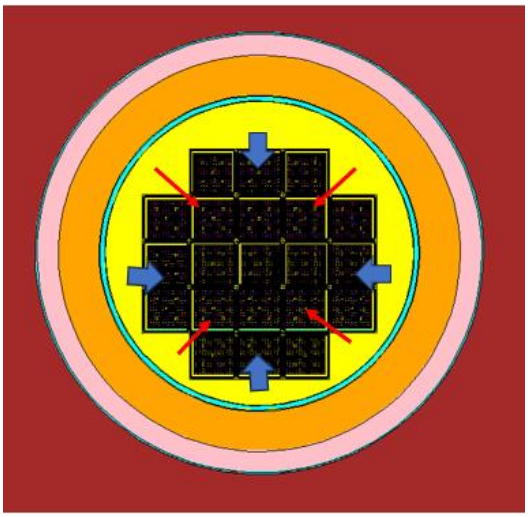

Figure 6. Scenrio F: Move the Fuel and Basket Centers

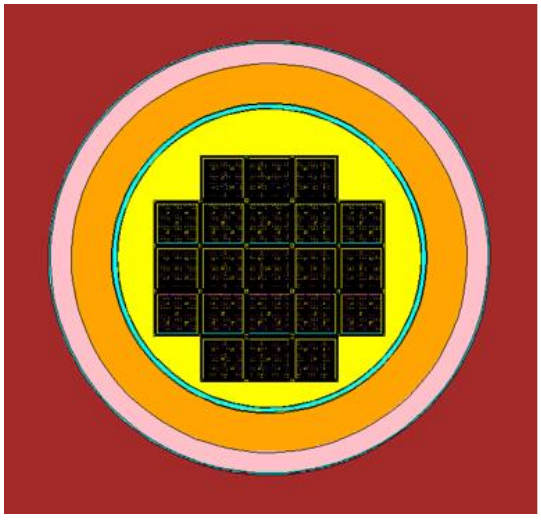

Figure 7. Scenrio G: Move the entire assembly down

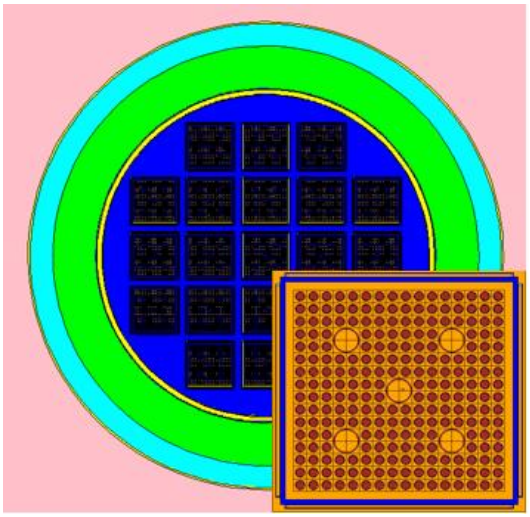

Figure 8. Scenrio H: Absorbers completely lost

3. Results

Table 2 shows the criticality test results for each accident scenario.

Table 2 The Results of Criticality test

Accident Case		K_{eff}
A	Absorbers completely lost	1.02763
		0.38283
B	Move the baskets centers	1.02890
C	Move the fuel and basket Centers	1.03405
		0.35183
D	Move the entire assembly down	1.03262
E	Move the Fuel Baskets Centers	0.71555
F	Move the Fuel and Basket Centers	0.71809
G	Move the entire assembly down	0.71777
H	Absorbers completely lost	0.73754

4. Conclusions and Future work

4.1 Conclusions

Based on the results of simulated tests, it has been observed that spent nuclear fuel maintains a subcritical state even under various accident conditions. However, due to significant uncertainties associated with spent nuclear fuel, evaluations of criticality for spent nuclear fuel containers recommended to utilize fresh fuel, as per 10 CFR 71. In the event of an accident-causing submersion of the spent nuclear fuel container, leading to the potential movement of internal nuclear fuel or loss of neutron absorber material, it has been determined through computational modeling tests that this could escalate to a supercritical state. To mitigate such potential criticality, reinforcement of neutron absorber material to enhance durability is essential. Additionally, materials capable of absorbing shocks between support grids, rendering assembly movement difficult, should be inserted. Moreover, thorough waterproofing measures are necessary to prevent water ingress between sealed threads**.**

4.2 Future work

This study is based on very conservative assumptions. The next study will add a sensitivity analysis to every part of the study for a more detailed evaluation.

Acknowledgement

This paper is a result of The Human Resources Development Project for HLW Management hosted by KORAD.

REFERENCE

[1] US. NRC. 2019, Standard Review Plan for Spent Fuel Transportation, NUREG-2216.
[2] ORNL. 2003 Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses, NUREG/CR-6801.
[3] NRC, 2024.03.22, 10 CFR 71.47 - Packaging and Transportation of Radioactive Material.