Criticality Effect according to Fuel Assembly Deformation

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1. Introduction

Criticality analysis is performed to show that a spent fuel is under the sub-criticality condition. The objective of this analysis is to evaluate the effect of criticality due to fuel deformation when a fuel assembly is dropped into the empty spent fuel storage rack. Therefore, we need to know in advance how much fuel deformation occurs at the fuel assembly drop. Information of fuel deformation is cited from Reference 1 that we published in 2017 [1]. Figure 1 shows the deformed shape of the fuel assembly and Figure 2 shows the final displacement of the fuel rod pitch due to fuel assembly drop.

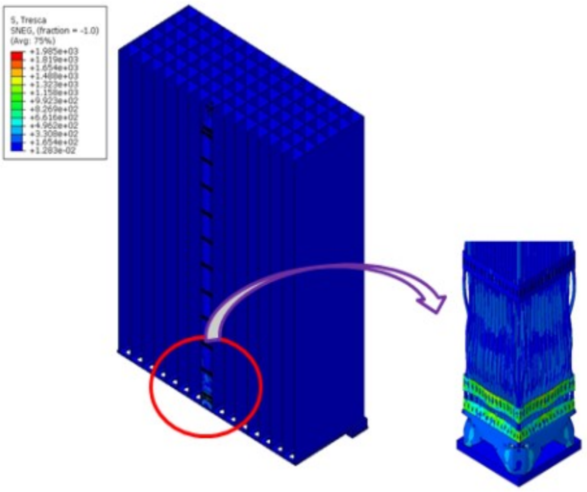


Figure 1-1. Fuel Assembly deformation due to drop [1]

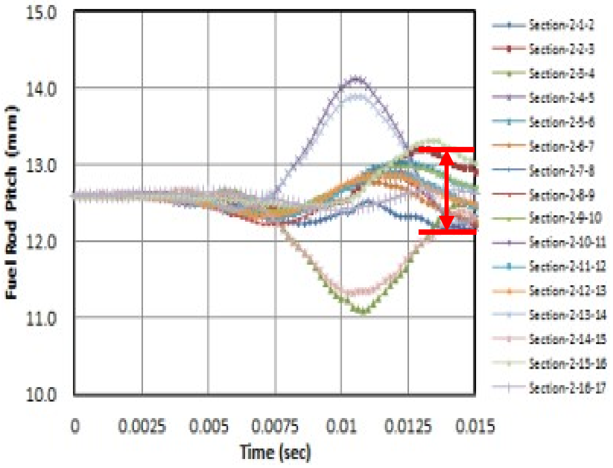


Figure 1-2. Fuel rod pitch vs. Time after contact between fuel assembly & bottom [1]

Therefore, we applied the pitch range from 12.1mm to 13.2mm based on the result of Figure 2 in order to evaluate the critical effect of the displacement of the fuel rod. This interpretation will be significant, as fuel rod displacement can occur when fuel assembly falls into the empty storage rack or an earthquake occurs. Figure 1-3 shows the definition of fuel rod pitch.

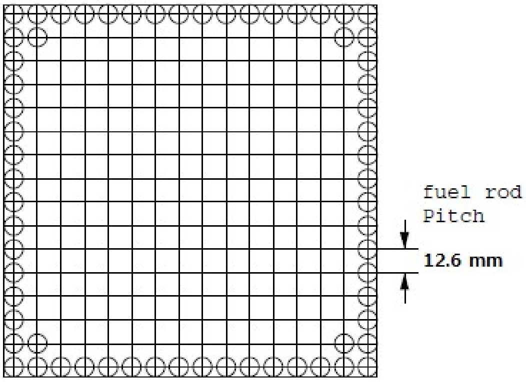


Figure 1-3. Fuel Rod Pitch

2. Modeling Approach and Assumption

SCALE(**S**tandardized **C**omputer **A**nalyses for **L**icensing **E**valuation) is used for the criticality analysis. The SCALE computer software system developed at Oak Ridge National Laboratory is widely used and accepted around the world for criticality safety analysis [2]. The well-known KENO-VI three-dimensional Monte Carlo criticality computer code is one of the primary criticality safety analysis tools in SCALE. Scale was originally created under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC), and it continues to be supported by the NRC, as well as the U.S. Department of Energy (DOE).

The geometric mechanical models for spent fuel storage rack with 6x6 array were constructed for the criticality analysis like figure 2-2. This paper considers V5H with 17x17 array that is the most conservative fuel type in criticality analysis. Variables of fuel rod pitches are 12.1, 12.3, 12.6, 12.9 and 13.2mm respectively. Fuel rod pitch of V5H is 12.6mm in normal condition. Figure 2-3 is the fuel assembly models with the minimum (12.1mm) and maximum fuel rod pitch (13.2mm). Calculations are performed to determine k_{eff} at the fully flooded moderator and at the temperature of 20℃. All of spent fuel assemblies is assumed as the enrichment is 5.0wt% and burnup is 46,000 MWD/MTU. Spent fuel storage rack consists of neutron absorber boral and stainless steel cell.

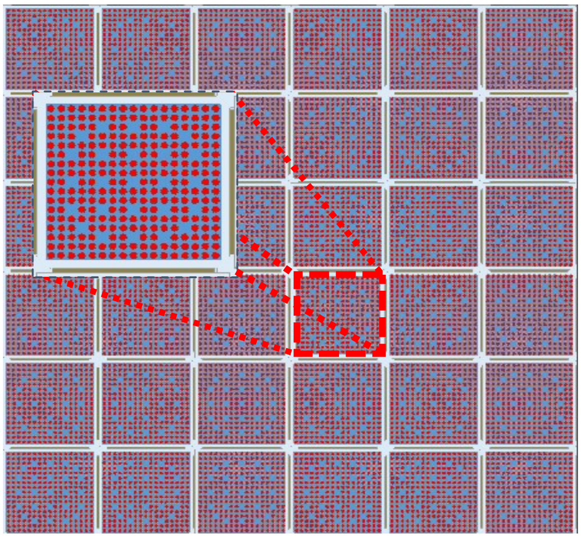
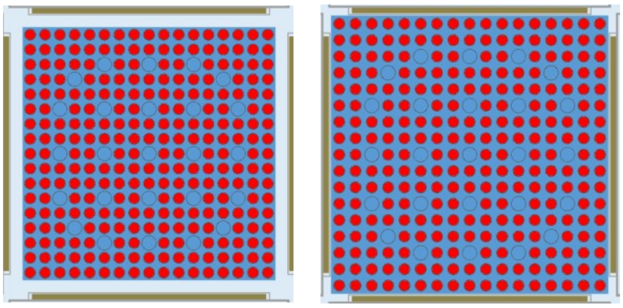


Figure 2-2.Geometric mechanical models for spent fuel storage rack with 6x6 array and a deformed fuel assembly



(a) 12.1 mm

(b) 13.2 mm

Figure 2-3 fuel assembly models with the minimum (12.1mm) and maximum (13.2mm) fuel rod pitch

3. Analysis Result

Calculation was performed by varying the fuel rod pitch of V5H fuel from 12.1mm to 13.2mm, and the effect of criticality was evaluated according to the size of the fuel rod pitch. The range of the applied fuel rod pitch is the minimum and maximum values derived from the results in figures 1-2 and the fuel rod pitch of the V5H is 12.6 mm under normal conditions.

Table 3-1 shows that k_{eff} increases gradually as the size of the fuel rod pitch increases. That is why the spacing between the fuel rods increases, which increases the amount of moderator and ultimately increases neutron moderation.

Table 3-2 shows that k_{eff} exceeded USL (Upper Safety Limit) of spent fuel pool when the fuel rod pitch is 12.9 mm. So, additional criticality analysis was performed considering the boron concentration in the coolant. As the result, critical safety is secured according to the variation of fuel rod pitch in case that the boron concentration is over 100ppm. For reference, boron concentration can be applied in case of accident analysis of domestic spent fuel storage pool for license [3]. The minimum boron concentration in KHNP nuclear power plants is above 2,000ppm.

Fuel rod Pitches (mm)	12.1	12.3	12.6	12.9	13.2
k-eff	0.93418	0.93514	0.93567	0.93624	0.93635

Table 3-1. k_{eff} vs. fuel rod pitches

Boron (ppm)	Fuel Rod Pitch(mm)				
	12.1	12.3	12.6	12.9	13.2
0	0.93418	0.93514	0.93567	0.93624	0.93635
100	0.92366	0.92425	0.92483	0.92499	0.92576
200	0.91349	0.91295	0.91399	0.91451	0.91496
USL : 0.93590					

Table 3-2. k_{eff} vs. fuel rod pitches according to boron concentration

4. Conclusions

The paper evaluates the critical safety of fuel assemblies when fuel assemblies fall into the empty spent fuel storage racks. The displacement of the fuel rod pitch due to the fuel assembly drop can be changed from a minimum of 12.1 mm to a maximum of 13.2 mm. And k_{eff} increases, as the fuel rod pitch increases. Also, k_{eff} exceeds USL of spent fuel pool when the fuel rod pitch is 12.9mm. For the criticality safety, additional analysis was carried out considering the boron concentration. As the result, the critical safety was secured if the boron concentration is above 100 ppm in spent fuel pool.

REFERENCES

[1] Kiyoung Kim, Development of evaluation technology on the long-term integrity of PWR spent nuclear fuel wet storage. KHNP 2017-50003339-전-0482TM, 2017.

[2] A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design. ORNL/TM-2005/39 Version 6.1.

[3] Hanbit Unit 1&2 Final Safety Analysis Report, KHNP.