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A Criticality Analysis of the Misloading Assemblies in the 32 Burnup Credit Cask

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1. Introduction

Recently, Korea Atomic Energy Environment Corporation performed the analysis of impact on criticality for 4 types of the misloading assemblies in cask with containing 24 spent fuel assemblies, which applied burnup credit concept.[1] The burnup credit for spent fuel cask has been applied to improve cask loading capacities considering spent nuclear burnup and increasing reactivity margin. According to the Nuclear Regulatory Commission (NRC) report, the previous studies have performed on the cases of misloading about 4 spent fuel assemblies in the center of GBC-32 cask.[2] Recently, NRC Interim Staff Guidance (ISG)-8 has proposed a recommendation that the criticality of cask needs to satisfy the margin of subcriticality even when misloaded. [3] The misloading concept means that fuel assembly, which is underburned than other assemblies, can affect the criticality in the cask. Single and multiple misleading concepts are taken into considerations based on the burnup distribution from the loading curve.

In this paper, the misleading criticality analysis has been done extending possible misloaded cases up to 16 fuel assemblies in the center region for the GBC-32 cask. Axial burnup distribution is assumed to be uniform and the inventories of fuel assemblies are obtained from the ORIGEN-ARP[3] which is one module of the SCALE 6.1. The criticality analysis are performed the typical 3D Monte Carlo code such ase KENO-VI[4] with the ENDF/B-VII.0 library.

2. Analysis

Due to the GBC-32(Generic burnup credit) cask has been applied in the various cases including misloaded assemblies,[2] this study takes the reference cask as GBC-32. Misloaded analysis are referred to the NRC report to reduce the risk of critical or super critical state by increasing number of possible misloaded assemblies. To begin with the analysis on criticality change, the criticality calculation is done with parameters in Table 1. And it is obtained 29 compositions of the spent nuclear fuel (SNF) nuclides from ORIGEN-ARP calculation given as shown in Table 2.[2] The initial fuel composition is given in Table 3, which is consistent with Ref. 1.

Table 1 Parameters for cask misleading criticality analysis

Burn up (MWD/MTU)	45,000
Enrichment (wt%)	4.89
Cooling Time (years)	5
Fuel Type	WH 17x17

The spent nuclear fuel(SNF) composition was calculated with Origen Arp which is a module of Scale 6.1.[3] The calculation of 0% and 90% burnup composition was done similarly in addition.

Table 2 SNF nuclides for the misloading analysis

^{109}Ag	^{241}Am	^{243}Am	^{133}Cs	^{151}Eu
^{153}Eu	^{155}Gd	^{95}Mo	^{143}Nd	^{145}Nd
^{237}Np	^{16}O	^{238}Pu	^{239}Pu	^{240}Pu
^{241}Pu	^{242}Pu	^{103}Rh	^{101}Ru	^{147}Sm
^{149}Sm	^{150}Sm	^{151}Sm	^{152}Sm	^{99}Tc
^{234}U	^{235}U	^{236}U	^{238}U	

Table 3. composition of 0% burnup fuel

Nuclide	Weight Percent(%)
U-234	0.043521
U-235	4.89
U-236	0.022494
U-238	95.04399

Before calculating the criticality of the cask, it is necessary to define possible misloaded cases. To figure out the misloaded cases, it is estimated possible misloaded cases extending 16 fuel assemblies in the central region of the GBC-32 cask. Table 4 provides various misloaded cases as a function of number of mislaoded fuel assemblies. The chosen cases have no overlapping in the arrangement and the rotational symmetric condition is assumed.

Table 4. Number of cases based on the number of misloading assemblies (MA)

Number of MA	Number of Cases	Number of MA	Number of Cases
1	4	9	25740
2	30	10	18018
3	140	11	9828
4	4095	12	4095
5	9828	13	140
6	18018	14	30
7	25740	15	4
8	28957	16	1

For the criticality analysis with KENO VI, the number of generation (GEN) was set as 150, the neutrons per generation (NPG) as 10,000 for ensuring accurate k-eff values. The standard deviation of k-eff is about 0.01. Fig. 1 depicts the most significant misleading cases based on the previous reports and the severe unburned case is assumed to be the fresh fuel loading.

The sensitivity of criticality due to misloading assembly(MA) has been carried out and the analysis results with 90% and 0% burnup is given in this paper. It is assumed that the axial burnup distribution is uniform.

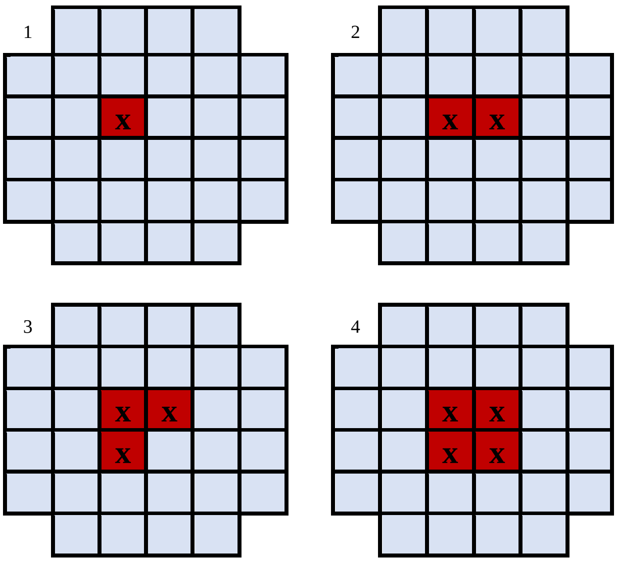

Figure 1. Expected arrangement with high criticality

3. Result

Prior to detailed analysis, when the 100% burnup assembly was normally loaded into the cask, the criticality was about 0.86039. The sensitivity analysis was performed for the reactivity effect of various burnup when one fuel assembly (FA) is misloaded. Calculated average value of criticality ($k_{average}$) was 0.894734 and compared with the calculated criticality of 0% to 100% burnup composed assembly ($k_{specific}$). The result of comparison is shown in Figure 2.

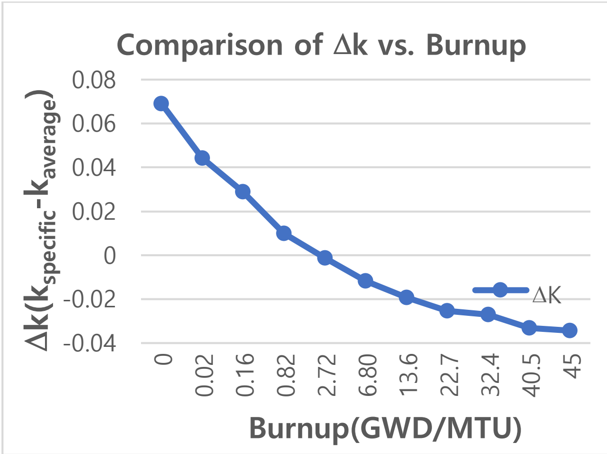

Fig 2. Reactivity for various changes

Fig. 2 represents the reactivity change as a function of burnup of the GBC-32 cask without misleading cases. As shown in Fig. 2, Δk increases when the fuel assembly is less depleted and the deviation between the fresh and the burnt case of 4 GWD/MTU is about 0.1.

The misleading analyses with various misloaded cases have carried out with 90% burnup and the results provided as shown in Fig. 3. The k-eff is chosen the maximum value from the various misloaded cases for the given MA number.

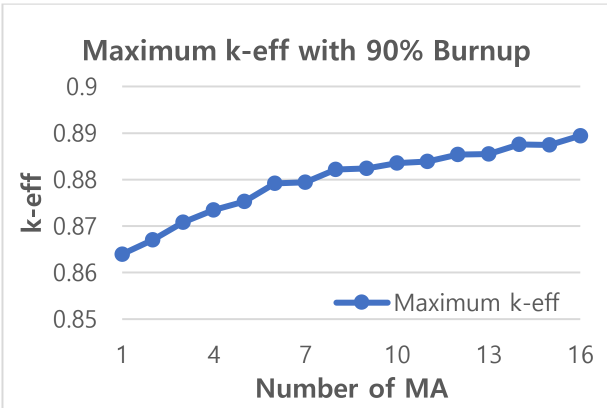

Fig 3. Maximum k-eff when 90% burnt assemblies misloaded

The maximum value of all the k-eff value was less than 0.9, when the MA composed of 90% burnup. The difference in the k-eff value between 1 misloading case and 16 misloading case is about 0.02. In addition, there is no much difference compared to the case with no MA. Therefore, 90% burnup composed MA have a low probability may lead an insignificant effect on the reactivity change in the cask.

In addition, the analysis of the case of spent fuel with 0% burnup misloading case was perfomred. The nuclear fuel assembly with a 0% burnup is equal to a fresh fuel assembly with a weight percentage of 4.89%. Thus, the composition of the fuel assembly is taken from the fresh state in Table 3. The results are provided in Fig. 4 and the k-eff value increases as the number of fuel assemblies of 0% burnup increases. The reactivity difference becomes larger when compared with those of the spent fuel with 90% burnup in Fig. 3.

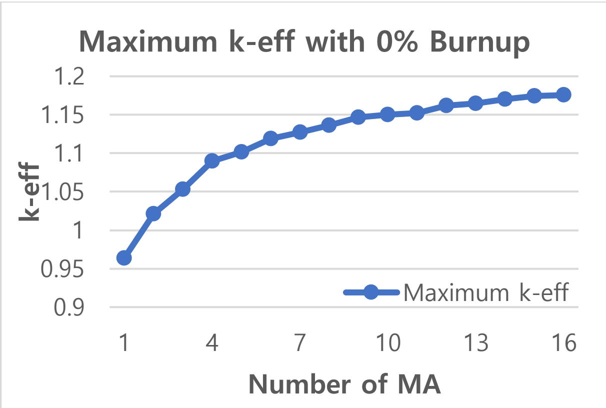

Fig 4. Maximum k-eff when 0% burnt assemblies misloaded

As can be seen from the Fig. 4, even though only one of 90% burnup composed fuel assembly is misloaded, the k-eff value is 0.96385, which exceeds 0.95. Thus, it is not necessary to analyze the other cases at all in this condition of fuel loading. It may be meaning to determine number of misloaded fuel assemblies to exceed 0.95 of k-eff from various misloaded analysis. To oder to estimate the limit condition, the criticality analysis is proceeded with 0% burnup. As shown in Fig. 4, the maximum k-eff value exceeds 1.0 even though with 3 of 0% burnup. For the more detailed analysis, the significant configurations with 2 and 3 cases of 0% burnup are chosen from the results and Fig. 5 shows the most significnat petterns for sensitivity analysis.

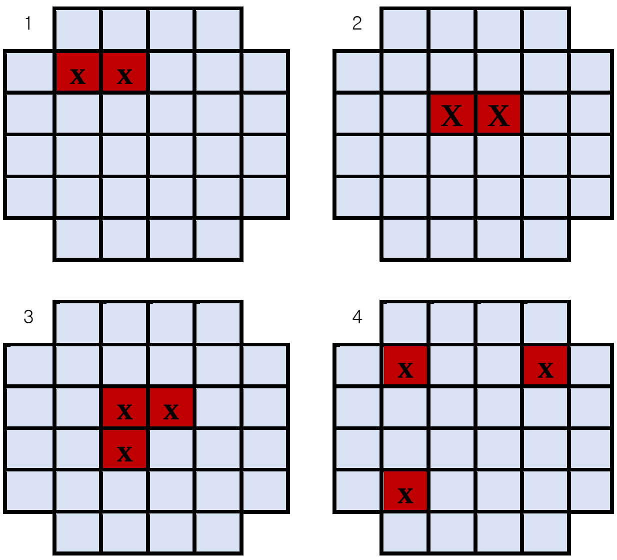

Fig. 5. Typical array with k-eff value above 1.0

For the latter case, too many patterns were found, and Figure 6 is only few patterns of arrangement that of subcritical state.

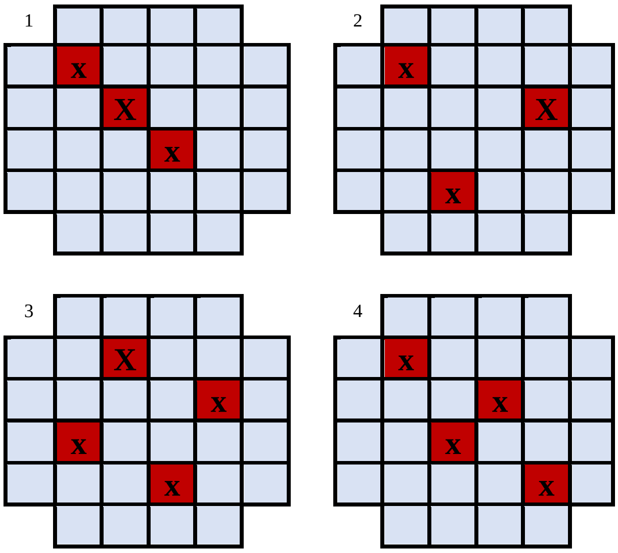

Fig 6. Typical array with k-eff value below 1.0

Comparing the patterns shown in Fig. 5 and 6 for the 3 MA case, the arrangement may affect k-eff and it may not exist in the central region ash shown in the 4th case in Fig. 4. Thus more detail investigation is undergoing and reliable quantification results will be provided.

4. Conclusion

The misloading critical analysis for the GBC-32 Cask has been performed with extending 16 misloading cases. The possible misleading criticality analysis of the spent fuel assemblies has done with Monte Carlo analysis considering burnup dependent compositions. In the case of 90% burnup, the criticality was not over 0.9 even even if 16 assemblies were misloaded. On the other hand, the criticality exceeded 0.95 even though only one spent fuel assembly was misloaded which is composed of 0% burnup. As a conclusion, from the preliminary analysis for multiple misleading cases, it is necessary to investigate on various spatial dependent cases with burnup state. The loading curve is essential to provide burnup profiles for the desired cask and lots of burnup measurement of spent nuclear fuel is necessary for the sufficiently reliable burnup credit cask design. And It is expected that the misloading analysis may be helpful to provide reliable basic data for the future spent fuel management. Extending the this works, more detail misleading analysis should be carried out by considering uncertainty analysis for bias and bias uncertainty of criticality with various design parameters of the spent nuclear fuel cask.

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