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Evaluation on Required ^{10}B Enrichment of Neutron Absorber Panels Depending on Discharged Burnup

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1. Introduction

As part of increasing the capacity factor of a commercial nuclear power plant, the longer cycle operation technique is being developed. Due to the longer cycle operation, the number of fresh fuel assembly is more than refueling assembly. Therefore the once-burned assemblies having very low burnup (~26 GWD/MTU) are discharged. Fig. 1 shows a minimum discharged burnup of a fuel for store in a spent fuel pool in accordance with initial enrichment of the fuel. An acceptable criterion of criticality in a spent fuel pool is 0.95. Because of the lower discharge burnup caused by the longer cycle operation, however, re-criticality can occur in the spent fuel pool. In this paper, as one of the solutions, changing the boron enrichment of neutron absorber panel is conducted to prevent exceeding the criterion.

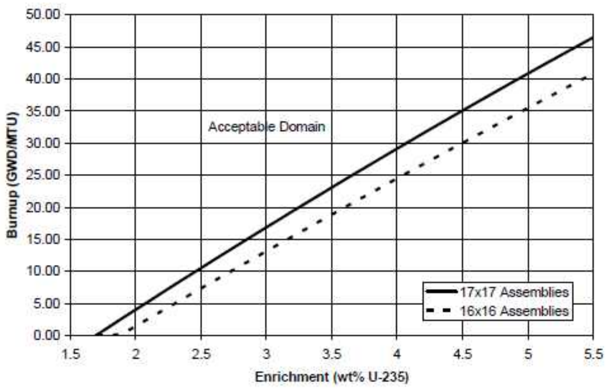

Fig. 1. Minimum required fuel assembly burnup as a function of nominal initial enrichment to permit storage in region 2(Hanul Unit 3/4)[1]

2. Methods and Results

The evaluation model is spent fuel storage racks containing the spent fuels that are applied with burnup-credit. ^{10}B enrichment of Neutron absorber panels attached to the steel walls is changed and criticality analysis is performed.

2.1 Applying Burnup Credit

Up to recently, criticality analysis of a spent fuel pool had been assumed that fresh fuels are inserted in order to have conservative design. But amount of spent fuels were gathered and storage space became not enough, the spent fuel storage rack was densely redesigned to accommodate more spent fuel. This design uses compositions of spent fuels as applying burnup-credit, and excessively conservative design property is reduced. Burnup-credit is applied using the OREGEN-ARP code that can get compositions of spent fuels by 4.95 wt% uranium enriched UO_2 fuel burnup. As shown in Table 1, the number of nuclide used to apply burnup-credit are 28; 12 of actinides, 15 of fission products, 1 of light element.

Table 1.Nuclides for burnup-credit [2]

Actinide (12)	U-234, 235, 236, 238; Np-237; Pu-238, 239, 240, 241, 242; Am-241, 243
Fission Product (15)	Mo-95; Tc-99; Ru-101; Rh-103; Ag-109; Cs-133; Sm-147, 149, 150, 151, 152; Nd-143, 145; Eu-153; Gd-155
Light Element	O-16

2.2 Preparations for Criticality Analysis

2.2.1 Validation of the Monte-Carlo Codes

115 of critical experiments in Reference [3] are selected for this study because these are most similar with characteristics of the commercial PWR's spent fuel storage racks.

Upper safety limits(USL) of each Monte-Carlo code are given in Table 2. USL is maximum criticality value from code calculation to assure that real criticality is below the criterion.

K_L is gotten by bias and bias uncertainty, Δ_{SM} is safety margin that the spent fuel pool should have, Δ_{AOA} is a value that is needed whenever area of applicability (AOA) is expanded. The AOAs of uranium enrichment and fuel diameter used in the experiments are 2.35~4.31 wt.% and 1.27~1.415cm respectively. Actually, these values are different with those of the fuels in the spent fuel pools, therefore the AOAs expand by 1~5wt.% of the enrichment and 0.775~1.415cm of the fuel diameter. Δ_{AOA} is decided by tendencies of Bias and Bias uncertainty in accordance with changing the value of these parameters.

Table 2. Upper safety limits of each Monte-Carlo code

Code name	$K_L - \Delta_{SM} - \Delta_{AOA}$	USL
KENO-Va	0.9922-0.05-0.0011-0.007	0.9344
MCNP5	0.9898-0.05-0.0006-0.004	0.9349
SERPENT	0.9935-0.05-0.0007-0.004	0.9385

2.2.2 Composition of SF according to discharge Burnup

Composition of a spent fuel is analyzed to predict trend of criticality. In Fig. 2, the amounts of fissile nuclides and parasitic absorber(fertile + fission product) are changed linearly as a fuel is burned. However, the effects of changing the amounts of these nuclides are simultaneously concerned in criticality. Therefore, Criticality can be predicted to change exponentially along with burnup by using the correlation mass change ratio, Fissile/Δ (Fertile+FP).

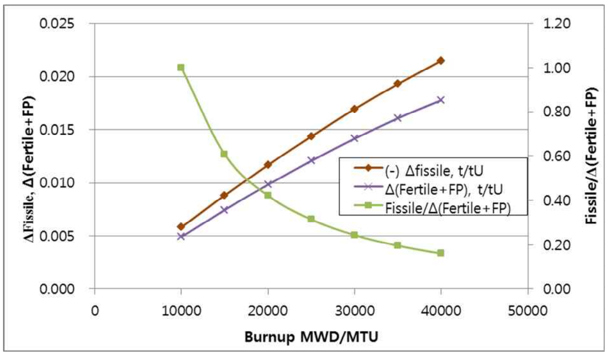

Fig. 2. Mass change of Fissile and (Fertile+FP) in 1 ton of UO_2 fuel and nomalized Fssile/Δ(Fertile+FP)

2.3 Criticality Analysis to Search for Boron Enrichment

2.3.1 Geometric Model

The dense storage rack model of the spent fuel pool region 2 in the Hanul unit 5/6 is shown in Fig. 3. The array is similar to a checkerboard, and the neutron absorber plate is attached at the exterior steel wall. Specification of the storage rack for the design is indicated in Table 3.

Fig. 4 represents the spent fuel storage rack designed by MCNP5. The spent fuels are inserted inside of the racks and also in the space surrounded by them. Two lacks and two spaces are designed and the four edges of the whole design are applied with periodic boundary condition due to the shape of the array.

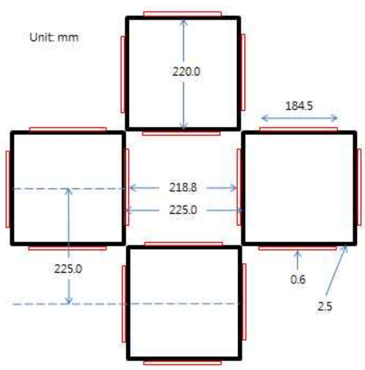

Fig. 3. A two-dimensional representation of the region 2 rack (Hanul unit 5/6)

Table 3. Specifications of spent fuel storage rack region2 (Hanul unit 5/6)

List	value
Storage cell	
Material	SS-304
Thickness (cm)	0.25
Cell pitch (cm)	22.5
Neutron Absorber	
Material	BORAL
Boron density (g $^{10}B/cm^2$)	0.03(minimum)
Thickness (cm)	0.25
Width (cm)	18.4
Sheath	
Material	SS-304
Thickness (cm)	0.06

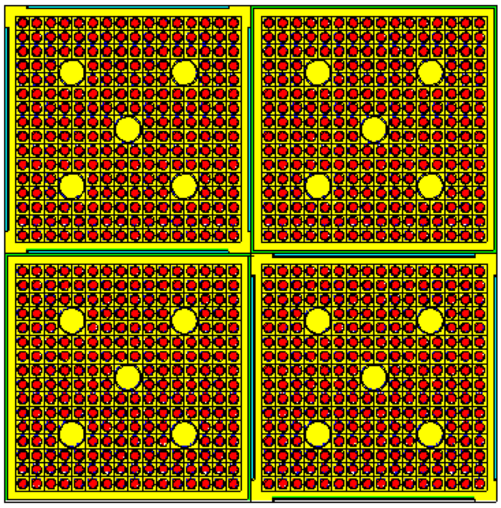

Fig. 4. The two-dimensional geometry designed by MCNP5

2.3.2 Boron Enrichment in accordance with Burnup

Analyzed condition is as follows; uranium enrichment of fresh fuel is 4.95 percent, and discharged burnup ranges between from 10GWD/MTU to 40GWD/MTU. In these conditions, boron enrichment satisfying USL is searched. The result is the same as the Fig.5. If discharged burnup decrease to 25GWD/MTU, even though ^{10}B enrichment is 100wt.%, USL is unsatisfied. Minimum burnup satisfying with USL is 28GWD/MTU on the premise that ^{10}B enrichment is 80wt.%. The reason why ^{10}B enrichment increase exponentially according as burnup decrease is that the criticality changes exponentially as shown in the Fig.2.

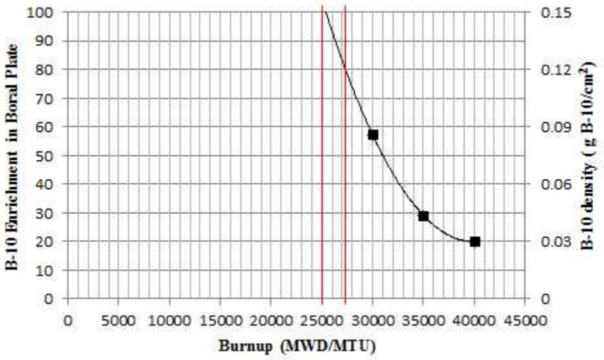

Fig. 5. Required ^{10}B enrichment/density of boral plate by discharged burnup

3. Conclusions

Disadvantage of longer cycle operation development is the decrease of discharged burnup. That is driving spent fuel pool to have re-criticality. In this study, ^{10}B enrichment of neutron absorber plate in spent fuel storage rack is increased in order to prevent re-criticality.

However, the result shows that minimum burnup satisfying USL is 28GWD/MTU at 80wt.% of ^{10}B. It is impossible that criticality of the spent fuel pool including once-burned assemblies(~26 GWD/MTU) is satisfied with the criterion by only increasing boron enrichment.

To store the lower burnup assemblies in spent fuel pool, any other methods increasing the amount of neutron absorbers should be researched.

REFERENCES

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[2] KOPEC, Conceptual Cask Design with Burnup-Credit, 2003

[3] International Handbook of Evaluated Criticality Safety Benchmark Experiments, OECD-NEA, NSC, 2012