An Evaluation of Criticality Margin by an Application of Parallelogram Lattice Arrangement in the Nuclear Fuel Storage Rack

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1. Introduction

The criticality evaluation in the nuclear fuel storage rack is essentially required for the prevention of the criticality accident. The square lattice structure of the storage rack is commonly used because it has a simple structure for the storage of the numerous fuel assemblies as well as the good mechanical strength. For the design of the fuel storage rack, the boron plate is commonly used for the criticality reduction. In this study, an arrangement method with the parallelogram lattice structure is proposed for the reduction of the boron concentration or the rack pitch. The criticality margins by the application of the parallelogram lattice were evaluated with MCNP5 code [1]. From the result, the reduction of the boron concentrated in the borated-Al plate was evaluated.

2. Parallelogram Lattice Structure

The parallelogram lattice structure is shown as figure 1. The centers of the racks on the first line are located at the middles of the racks on the second line. The structure is repeated in the fuel storage region. The rack pitch on the each line is equal. The length between the lines is same with the rack pitch. Therefore, the length A is the same as the length B. And, the length C is $\sqrt{3/2}$ times longer than the length A.

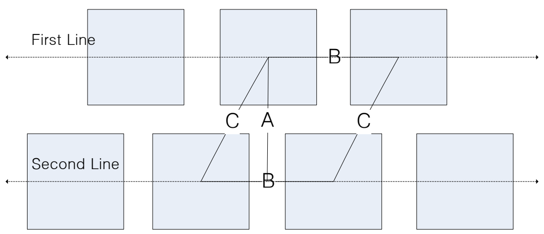

Fig. 1. Parallelogram Lattice Structure

Figure 2 shows the flux distribution for the condition given in Table I. The flux distribution for a fuel assembly surrounded by the light water was calculated with the MCNP5 code. The fuel assembly specification used for the flux evaluation was arbitrarily assumed in this study. As shown in Figure 2, the flux in the moderator region has the circular distribution. Therefore, if the length C is increased, the reactivity can be reduced. Hence, it is expected that the application of the parallelogram structure can reduce the criticality in having the same storage capacity with the square lattice structure for the infinite arrangement case.

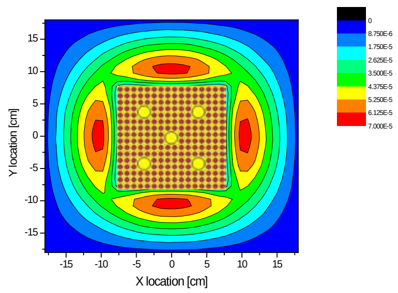

Fig. 2. Distribution of Relative Thermal Flux (<1eV) for a Fuel Assembly

Table I. Specification of the Fuel Assembly

Enrichment of UO2 [w/o]	5
UO2 Density [g/cm3]	10.2
Radius of the Fuel Pellet [cm]	0.4
Material of the Cladding	Zirlo
Inner Radius of the Cladding [cm]	0.42
Outer Radius of the Cladding [cm]	0.46
Inner Radius of the Guide Tube [cm]	1.1
Outer Radius of the Guide Tube [cm]	1.2
Assembly Pitch [cm]	20
Effective Height [cm]	∞
Type of Assembly	16x16

3. Evaluation of the Criticality Margin

The criticality margin in this study is defined as a multiplication factor difference when the parallelogram lattice structure is applied in the nuclear fuel storage rack. The criticality margin is given in equation (1). $k_{squa}(p,a)$ is the multiplication factor calculated by the square lattice structure and $k_{para}(p,a)$ is the multiplication factor calculated when the parallelogram lattice structure is applied. Where, p is a pitch of the rack and a is the boron concentration in the borated-Al plate.

$$\Delta k(p,a) = k_{squa}(p,a) - k_{para}(p,a) \quad (1)$$

At first, the multiplication factors with the square lattice structure were evaluated by using the MCNP5 code. Also, the calculations by using the parallelogram lattice structure were pursued. The modeling geometries for the two structures with MCNP5 code are shown in figure 3. From the both results, the criticality margin was calculated by using the equation (1). The calculation result of the criticality margin without the neutron absorber is given in section 3.1 and the calculation result with the neutron absorber is given in section 3.2. The rack and absorber specifications are given in Table II. The criticality calculations were pursued with ENDF/B-VI cross-section library and used SAB2002 thermal cross-section library.

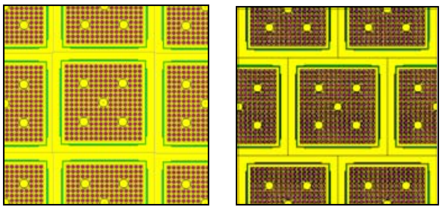

Fig. 3. Geometries of Square Lattice Structure (Left) and Parallelogram Lattice Structure (Right)

Table II. Specification of Rack [2]

Material of Rack	SS-304
Thickness of Rack [cm]	0.25
Inner Length of Rack [cm]	0.4
Outer Length of Rack [cm]	22
Material of Neutron Absorber	B_4C-Al
Thickness of Neutron Absorber [cm]	0.2
Wide of Neutron Absorber [cm]	18.0
Neutron Absorber Height [cm]	∞
Thickness of the Neutron Absorber Cover [cm]	0.06

3.1 Result of Criticality Margin without Neutron Absorber

The result of criticality margin calculation is given in figure 4 without the neutron absorber. The maximum criticality margin in the result was 0.00682 at 29.5cm of the rack pitch. The criticality margin was increased until 29.5cm rack pitch because the small pitch cannot give them enough length of C to reduce the multiplication factor. From the 29.5cm rack pitch, the criticality margin is reduced. The reason is that the pitch is long enough; hence, the length of C cannot sufficiently affect the multiplication factor.

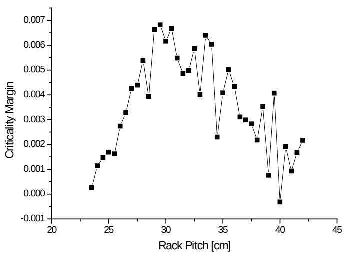

Fig. 4. Criticality Margin without Neutron Absorber

3.2 Result of Criticality Margin with Neutron Absorber

The result of criticality margin calculation is given in table III as the changes of the rack pitch and the boron concentration. The average criticality margin in all cases was 0.005. The pitch of spent fuel rack for the fuel assemblies discharged is 27cm in APR1400 [2]. When the pitch of the rack was 27cm, the multiplication factor with the square lattice structure was 0.923 ±0.00066. With the parallelogram lattice structure, the multiplication factor at 26.4% boron atom ratio was 0.922 ±0.00065. Therefore, it shows that the application of the parallelogram lattice structure in the condition can reduce the boron concentration about 12% than that of the 30.0% Borated-Al case.

Table III. Criticality Margin with Neutron Absorber

Pitch [cm]	30.0% B_4C	29.4% B_4C	28.8% B_4C	28.2% B_4C	27.6% B_4C	27% B_4C	26.4% B_4C	25.8% B_4C
23.5	0.007	0.006	0.005	0.007	0.006	0.006	0.007	0.007
24	0.007	0.007	0.007	0.005	0.008	0.007	0.006	0.008
24.5	0.007	0.007	0.007	0.008	0.007	0.006	0.006	0.006
25	0.007	0.006	0.006	0.007	0.006	0.004	0.006	0.006
25.5	0.007	0.007	0.007	0.007	0.006	0.004	0.006	0.005
26	0.006	0.006	0.006	0.004	0.005	0.006	0.007	0.005
26.5	0.004	0.004	0.005	0.005	0.005	0.006	0.004	0.008
27	0.005	0.006	0.005	0.005	0.007	0.004	0.005	0.005
27.5	0.005	0.005	0.004	0.004	0.005	0.005	0.002	0.004
28	0.005	0.005	0.006	0.005	0.005	0.006	0.003	0.004
28.5	0.003	0.003	0.003	0.003	0.004	0.004	0.003	0.002
29	0.002	0.003	0.003	0.004	0.003	0.004	0.006	0.005
29.5	0.004	0.002	0.005	0.004	0.004	0.002	0.004	0.005
30	0.005	0.002	0.003	0.003	0.003	0.005	0.002	0.005
Average	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005

4. Conclusions

An arrangement method for the storage of spent nuclear fuel, which is used the parallelogram lattice structure, is proposed in this study. The criticality with the parallelogram lattice structure in the spent fuel storage rack was evaluated with the changes of the rack pitch and the boron content by percentage. The results were compared with the result of the criticality, which is evaluated with square lattice structure. The results show that the criticality in spent fuel storage rack can be reduced by the application of the parallelogram lattice structure. In the case of the 27cm pitch with the neutron absorber, the arrangement method can reduce the boron concentration about 12% than that of the 30.0% Borated-Al case. Therefore, it is expected that the parallelogram lattice structure can be utilized in the design of the spent fuel storage rack for the reduction of the boron concentration.

Acknowledgment

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