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An Analysis of Fuel Region to Region Dancoff Factor with the Random Mixture Effects of Moderator and Fuel Pebbles

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1. Introduction

Dancoff factor is an entering probability of the neutron escaped from specific fuel kernel to another one without the interaction with moderators. In order to analytically evaluate Dancoff factor considering double-heterogeneous effect, inter-pebble and intra-pebble Dancoff factors should be calculated, respectively. Intra-pebble Dancoff factor related with the fuel kernels in one pebble was analyzed in the past study [1].

The fuel and moderator pebbles are randomly located in the pebble-type reactor. For the evaluation of inter-pebble Dancoff factor, a repetition of simple pebble structure is commonly assumed to simulate the complex geometry of pebble-type reactor. The evaluation using these structures can be underestimated because of the shadowing effects generated from the repetition of simple pebble structure. Fuel region to region Dancoff factor (FRDF) was defined as an entering probability of the neutron escaped from a specific fuel region to another one without any collision with moderator for a preliminary evaluation of inter-pebble Dancoff factor. To solve the underestimation problem of FRDF from the shadow effect, the specific pebble was assumed and FRDF was evaluated with the approximation method proposed in this study.

2. Methodology

The analytical method to calculate FRDF without random mixture effect was developed in the past study [2]. In the calculation of FRDF, the behind pebble of the target pebble with neutron traveling direction cannot be considered with the simple structures because of the shadowing effect. Therefore, FRDF with these structures is underestimated. An example of the shadowing effects is shown in Fig. 1.

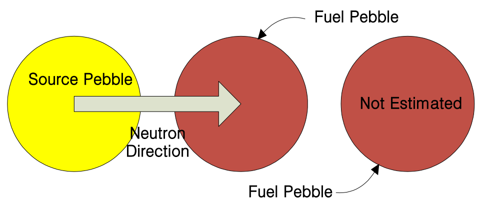

Fig. 1. The Shadowing Effect for the Calculation of FRDF

In this study, the analysis method to solve the shadowing effect problem is proposed with the assumption of specific pebble.

2.1 Assumption of Specific Pebble

The concept of specific pebble proposed in this study is used to apply the random mixture effect of fuel and moderator pebbles. As shown in Fig. 2, the specific pebble is regarded as the both fuel and moderator pebbles. Hence, the neutron has two calculation steps with having weights in a specific pebble. One is calculated as the fuel pebble while another is calculated as the moderator pebble. For the calculations of each step, the neutron weights of each calculation steps are equal to the F/M ratio in the reactor. Hence, a neutron in the specific pebble, which has 1:1 F/M ratio, has half weights of original value at each calculation step.

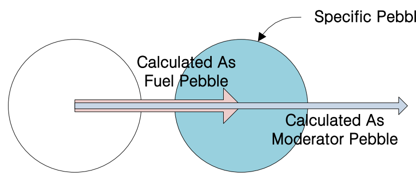

Fig. 2. The Calculations in a Specific Pebble

2.2 Calculation of FRDF with Random Mixture Effect of Fuel and Moderator Pebbles

It is supposed that the pebbles are piled up with BCC structure in pebble type reactor. All pebbles are assumed to be the specific pebble. The pebbles are numbered cubically from the source pebble as shown in Fig. 3. The pebbles with the same array number include all pebbles in the unit cube excepting the pebbles of subordinate arrays.

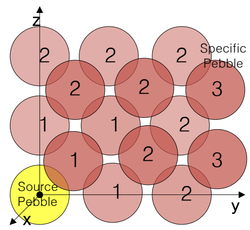

Fig. 3. Specific Pebble Arrangement with Array Number in BCC Structure

For the calculation of FRDF, the penetration distance of neutrons passing through the moderator region between the fuel regions should be properly estimated. The line equation with the specific direction from the source can be given by Eq. (1).

$$x = t \cdot \sin\phi \cdot \cos\theta = At \quad (1a)$$

$$y = t \cdot \sin\phi \cdot \sin\theta = Bt \quad (1b)$$

$$z = t \cdot \cos\phi = Ct \quad (1c)$$

The distance from pebble center point to the line is calculated to decide that a neutron penetrates some pebbles or not. The distance equation is given as the followings:

$$t_1 = (aA + bB + cC)/(A^2 + B^2 + C^2) \quad (2a)$$

$$d = \sqrt{(At_1 - a)^2 + (Bt_1 - b)^2 + (Ct_1 - c)^2} \quad (2b)$$

where,(a,b,c) = center point of a pebble,(x,y,z)
t_1*=t value of the distance from (a,b,c)point*
d=distance from line to center point of pebble

The neutron passes through the pebble where the distance, d, is shorter than the pebble radius. When the neutron passes the moderator, the attenuation distance with moderator is given as the following:

$$t'_1 = \frac{(aA+bB+cC) + \sqrt{(aA+bB+cC)^2 - (A^2+B^2+C^2)(a^2+b^2+c^2-R_p{}^2)}}{A^2+B^2+C^2} \quad (3a)$$

$$t'_2 = \frac{(aA+bB+cC) - \sqrt{(aA+bB+cC)^2 - (A^2+B^2+C^2)(a^2+b^2+c^2-R_p{}^2)}}{A^2+B^2+C^2} \quad (3b)$$

$$l = \sqrt{A^2(t'_1 - t'_2) + B^2(t'_1 - t'_2) + C^2(t'_1 - t'_2)} \quad (3c)$$

where, R_p = *fuel pebble radius*
t'_1, t'_2= *t values that the line meets the pebble surface*
l = *distance to pass through the pebble*

The distance between the surface of fuel region and fuel pebble on the line is given by Eq. (4).

$$t'' = \frac{(aA+bB+cC) - \sqrt{(aA+bB+cC)^2 - (A^2+B^2+C^2)(a^2+b^2+c^2-R_{fr}{}^2)}}{A^2+B^2+C^2} \quad (4a)$$

$$l' = \sqrt{A^2(t'' - t'_2) + B^2(t'' - t'_2) + C^2(t'' - t'_2)} \quad (4b)$$

where, R_{fr} = *fuel region radius*
t'' = *t value that the line meets the fuel region surface*
l' = *distance between fuel region and fuel pebble*

Using the attenuation distance the FRDF can be represented as the following:

$$P_{frr} = \sum w(\phi) \cdot w^n(p) \cdot e^{-\Sigma l_t} \quad (5a)$$

$$l_t = \sum_i l(i) + l' \quad (5b)$$

where, $w(\phi)$= *weight of Gauss-Legendre quadrature sets*
$w(p)$ = *weight from penetration of fuel region*
n = *number of fuel region penetrations*
l_t = *total distance to pass moderator from the source point to another fuel region*

3. Calculation Results and Discussion

FRDF with specific pebble was calculated with Matlab program. The calculations were pursued for array number 1 to 10, respectively. The radius of fuel region is 2.5cm and the pebble radius is 3cm with 0.61 packing fractions. The ratio of fuel and moderator pebble is 1:1. Gauss-Legendre quadrature sets are chosen to 128 orders. These calculations were compared with the past study [2]. The calculation results are shown in Table I.

Table I. Result of Fuel Region to Region Dancoff Factor

Array Number	Past Study Result [2]	MCNP5 Result [2]	This Study Result	Difference with Past Study
1	2.0425e-01	2.0538e-01	2.0242E-01	-1.830E-03
2	3.8339e-02	3.8200e-02	5.3622E-02	1.528E-02
3	2.2156e-03	2.2000e-03	5.3323E-03	3.117E-03
4	2.6177e-04	2.2740e-04	6.5865E-04	3.969E-04
5	4.3444e-05	-	4.7317E-05	3.873E-06
6	1.2117e-07	-	5.8429E-06	5.722E-06
7	0	-	5.3007E-07	5.301E-07
8	2.7169e-10	-	7.9357E-08	7.909E-08
9	0	-	5.8416E-09	5.842E-09
10	0	-	2.0898E-09	2.090E-09
Total	2.4511e-01	2.4610e-01	2.6209E-01	1.698E-02

FRDF reaches 0.2621 with the method proposed in this study. The result was estimated about 6.5% larger than the result of past study [2]. It means that the random mixture of fuel and moderator pebbles significantly affects to the calculation of FRDF. Therefore, the random mixture effect of moderator and fuel pebble should be included for the calculation of FRDF.

4. Conclusions

This study is for the evaluation of FRDF with the random mixture effect of fuel and moderator pebbles. The specific pebble is assumed for the application of the random mixture effect. The result was compared with the result of past study. The result shows that the random mixture effect should be considered for more accurate calculation of FRDF. In the future study, the inter-pebble Dancoff factor is evaluated with this method. Consequently, a novel methodology can be installed to deterministic computer code for pebble-type core which will be developed in future.

Acknowledgment

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