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Improvement of SPH Factor Calculation in Fuel Lattice

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1. Introduction

The SPH method is widely used as homogenization method. Conventional SPH method can be used with reflective boundary condition, but cannot be used in the case with leakage. So, we are developing an improved SPH method in the case with leakage. We call this improved SPH method the Leakage Dependent SPH method.

2. Theory

The SPH factor is derived to preserve the cell (or region) integrated or averaged reaction rates between heterogeneous and homogeneous calculations. The g-group cell reaction rates of x type(x = fission, capture, scattering) are calculated by the heterogeneous calculation as

$$R_x = \sum_i \phi_i^g V_i \Sigma_x^g \quad (1)$$

The summation is performed over the regions included in a cell.

In the homogeneous calculation, the flux-weighted homogeneous cross section $\overline{\Sigma}_x^g$ is multiplied by the SPH factor f to preserve the reaction rates.

$$f^g \overline{\Sigma}_x^g \overline{\phi}^g V = R_x^g \quad (2)$$

In Eq.(2), $\overline{\phi}^g$ is the cell (or region) averaged heterogeneous flux. Usually the SPH factor f^g is obtained as follows. First $\overline{\Sigma}_x^{(n)g}$ is obtained by iteratively calculating homogeneous flux $\phi^{(n-1)g}$ in terms of cross section $\overline{\Sigma}_x^{(n)g}$

$$\overline{\Sigma}_x^{(n)g} = R_x^g / \phi^{(n-1)g} V \quad (3)$$

and f^g is derived by

$$f^g = \overline{\Sigma}_x^{(n)g} / \overline{\Sigma}_x^g = \overline{\phi}_I{}^g \Big/ \phi_I^{(n-1)g} \quad (4)$$

Furthermore $\phi^{(n-1)g}$ is normalized by the condition which is obtained from Eq.(5).

$$\sum_{\text{All Cells}} \phi^{(n-1)g} V = \sum_{\text{All Cells}} \overline{\phi}^g V \quad (5)$$

In the homogeneous calculation to obtain $\phi^{(n-1)g}$, one has to preserve the neutron leakage because the integrated reaction rates cannot be preserved without the preservation of neutron leakage. When the albedo is utilized, the neutron leakage can be written as

$$J_{net} = (1-\beta) J_{out} \quad (6)$$

where J_{in} is the incoming current . The above J_{net} must be preserved in the homogeneous calculation. So β must be modified to β^* to satisfy

$$J_{net} = (1-\beta) J_{out} = (1-\beta^*) \overline{J}_{out} \quad (7)$$

which $\overline{J}_{in}$ is the homogeneous calculation .
Therefore we calculate β^* in each iteration by

$$\beta^* = 1 - (1-\beta) \frac{J_{out}}{\overline{J}_{out}} \quad (8)$$

β^* is iteratively updated from homogeneous calculations with $\overline{\Sigma}_x^{(n)g}$. So, it is dependent on the iteration n, and we denote it as $\beta^{(n)*}$.

We call this method the Leakage Dependent SPH Method.

3. Calculation Geometry

Calculation geometry is shown in Figure 1. This mini core consists of 4x4 UO2 assembly and 4x4 MOX assembly. Outer boundary condition is reflective. The heterogeneous cross-section of C5G7MOX benchmark is used.

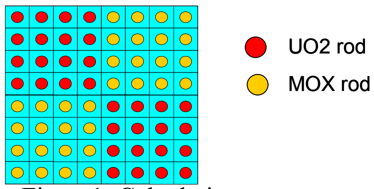

Figure1. Calculation geometry

4. Calculation Flow

Heterogeneous assembly calculation
with reflective boundary condition

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Homogeneous cross section

↓

Homogeneous Core Calculation

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Calculate albedo

↓

Heterogeneous assembly calculation with albedo

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Homogeneous assembly calculation with albedo

SPH factors

Homogeneous cross section

Homogeneous Core Calculation

5. Results

We calculated homogeneous cross section by two methods. Method 1 is the conventional SPH method, and Method 2 is the Leakage Dependent SPH method. Figure 2 and 3 show the difference of the cell production rate distribution from reference result for the core calculation with the conventional SPH method and the core calculation with the Leakage Dependent SPH method. The reference result is obtained by whole core heterogeneous core calculation. From this result, we found that the result of core calculation with Leakage Dependent SPH method is in good agreement with reference.

0.8	0.7	0.3	−1.4	2.7	−2.1	−2.6	−2.6
0.7	0.6	0.2	−1.6	2.8	−2.1	−2.7	−2.6
0.3	0.2	−0.3	−2.3	3.0	−1.8	−2.1	−2.1
−1.4	−1.6	−2.3	−3.8	5.2	3.0	2.8	2.7
2.7	2.8	3.0	5.2	−3.8	−2.3	−1.6	−1.4
−2.1	−2.1	−1.8	3.0	−2.3	−0.3	0.2	0.3
−2.6	−2.7	−2.1	2.8	−1.6	0.2	0.6	0.7
−2.6	−2.6	−2.1	2.7	−1.4	0.3	0.7	0.8

Figure2 Difference of cell production rate between core calculation with conventional SPH method and reference

0.5	0.5	0.4	−0.5	0.6	−0.6	−0.6	−0.6
0.5	0.5	0.4	−0.5	0.5	−0.6	−0.6	−0.6
0.4	0.4	0.3	−0.4	0.4	−0.6	−0.6	−0.6
−0.5	−0.5	−0.4	−0.5	0.3	0.3	0.5	0.6
0.6	0.5	0.4	0.3	−0.5	−0.4	−0.5	−0.5
−0.6	−0.6	−0.6	0.4	−0.4	0.3	0.4	0.4
−0.6	−0.6	−0.6	0.5	−0.5	0.4	0.5	0.5
−0.6	−0.6	−0.6	0.6	−0.5	0.4	0.5	0.5

Figure3 Difference of cell production rate between core calculation with Leakage Dependent SPH method and reference

6. Conclusion

We developed the Leakage Dependent SPH method to preserve the reaction rates between heterogeneous and homogeneous calculations in non-reflective boundary condition. We confirmed this method works well in the mini core calculation including UO2 and MOX assemblies.