SHORT NOTE

Application of BWR Simulator to Neutronics Calculation Tool in Fast Reactors

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Many calculation tools of neutronics for the light water reactors which take a short computing time have been developed\(^{(1)(2)}\). FLARE\(^{(1)}\) is one of such codes and widely used as a three-dimensional boiling water reactor (BWR) simulator. Shortness of its calculation time is due to the one-energy-group approximation and effective use of adjustable parameters. Great success in adopting it to BWRs suggests applicability of its model to a fast breeder reactor (FBR).

It is the purpose of this note to give an algorithm in a finite difference form for developing an efficient two-dimensional neutron diffusion code and demonstrate it by applying the obtained algorithm to solve the neutronics properties of an actual LMFBR core.

In the calculation, the hexagonal geometry is used in which one mesh point is allocated for each assembly as is shown in Fig. 1.

![Hexagonal geometry](image)

Fig. 1 Hexagonal geometry

Based on the neutron diffusion equation, the neutron balance for assembly \(i\) leads to the following set of equations:

\[
S_i = \frac{k_{o\infty} \sum_j S_j W_{ij}}{\lambda - k_{o\infty} W_{ii}},
\]

\[
\lambda = \frac{\sum_i S_i - \sum_j \sum_i S_i W_{ij} (n_i - \alpha_i)}{\sum_i A_i},
\]

\[
S_i = k_{o\infty} A_i,
\]

where

- \(\lambda\): Effective multiplication factor
- \(S_i\): Number of neutrons produced in assembly \(i\) in unit time
- \(A_i\): Member of neutrons absorbed in assembly \(i\) in unit time
- \(k_{o\infty}\): Infinite multiplication factor of assembly \(i\)
- \(W_{ij}\): Probability that neutron produced in assembly \(i\) is absorbed in assembly \(j\)
- \(\alpha_i\): Albedo of assembly \(i\) which is placed at external boundary (see Fig. 1(b))
- \(n_i\): Number of external mesh points adjacent to assembly \(i\) at external boundary (see Fig. 1(b); in this case \(n_i = 2\)).

The summations in the denominator and in the first term of the numerator of Eq. (2) are taken for all assemblies, while the summation \(i\) in the second term of the numerator is taken for those assemblies allocated at the reactor core boundary. The quantity \(W_{ij}\) is expressed as a linear combination of the diffusion and transport kernels, and is written as

\[
W_{ij} = \frac{2}{3k_{o\infty}} \left[ g \frac{M_{ij}^3}{\epsilon} + (1 - g) \frac{M_{ij}^1}{\epsilon} \right],
\]

\[
W_{ii} = 1 - \sum_j W_{ij}.
\]

The \(M_{ij}^1\) and \(k_{o\infty}\) are provided as follows:

\[
M_{ij}^1 = \frac{2D_i D_j}{\sum_a (D_i + D_j)},
\]

\[
k_{o\infty} = \frac{\nu \sum_f}{\sum_a},
\]

where

- \(M_{ij}\): Neutron migration length between assembly \(i\) and assembly \(j\)
- \(D_i\): Neutron diffusion coefficient in assembly \(i\)
- \(\Sigma_a\): Macroscopic neutron absorption cross section in assembly \(i\)

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$\Sigma_{fi}$: Macroscopic neutron fission cross section in assembly $i$

$\nu_i$: Number of neutron produced per one fission in assembly $i$

$h$: Distance between adjacent mesh points

$g$: Mixing parameter of diffusion and transport kernels.

For control rod channels the $\gamma$ and the migration area $M_{CR}^2$ are regarded as new parameters. For the assemblies that are placed at the external boundary, $W_{ij}$ is replaced by

$$W_{ij} = 1 - \left( \sum_{j=1}^{n_i} W_{ij} + W_{ij}(n_i - \alpha_i) \right).$$

As shown later, the introduction of $\alpha_i$ with a small value at the core-blanket boundary improves the accuracy of power distribution. Thus, Eq. (8) is also used for the assemblies placed at the core-blanket boundary with $n_i = 0$, although the neutron balance comes to be not reserved there. To distinguish the two-kinds of $\alpha_i$, the former is denoted as $(\alpha_1)_i$, the latter $(\alpha_2)_i$. In carrying out Eq. (2), $\alpha_2$ is of course set at zero. To take into account the effect of neutron leakage in the axial direction, a parameter $\beta$ is introduced as the axial albedo. The quantity $S_i$ obtained from the above equations is converted into the power output $P_i$ for each assembly as follows:

$$P_i = S_i / \nu_i.$$  

Using the above mentioned algorithm a new two-dimensional hexagonal diffusion code was made. Some numerical results obtained by the code are shown for a 300 MWt LMFBR. The state of the core is clean core. Figure 2 shows the dependence of $k_{eff} (= \lambda)$ on four parameters, i.e., $\alpha_1$, $\beta$, $g$ and $\gamma$. It is seen that the sensitivity of these parameters (except for $\alpha_1$) on $k_{eff}$ is large. By comparing the reference calculation results which are obtained, for example, by CITATION code[5], it is possible to estimate the values of these parameters.

The effect of albedo $\alpha_1$ on the power distribution is not large. The albedo $\alpha_1$ is estimated to be in the range of 0.0~0.07 and $\beta$ in the range of 0.97~1.0. The effect of a mixing parameter $g$ on the radial power distribution is small as shown in Fig. 3(a). Proper value of $g$ is in the range of 0.9~1.0, which shows the applicability of the diffusion kernel for the LMFBR considered. The dependence of the radial power distribution on $\gamma$ and $M_{CR}^2$ is shown in Fig. 3(b). The pattern of the radial power distribution varies significantly with the values of $\gamma$ and $M_{CR}^2$. The desirable value of $\gamma$ is in the range of $-0.3$~$-0.2$ and $M_{CR}^2$ in the range of 130~10,000. The desirable value of $\gamma$ is approximately $-0.3$ and $M_{CR}^2$ 130 for channels of control rods fully inserted into the core, and $\gamma$ $0.2$ and $M_{CR}^2$ 10,000 for channels of control rod fully withdrawn, respectively. Figure 4 shows the radial power distribution obtained from the present method, which is compared with that obtained by the six-group CITATION calculation.

The power distribution is in good agreement. The effective multiplication factor $k_{eff}$ also agrees within 0.5% in both calculations. The six-group diffusion calculation by CITATION takes about 200 sec for one diffusion
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Fig. 4 Comparison between power distributions obtained from six-group CITATION calculation (Upper values) and from present method (Lower values). The present code, however, requires only about 10 sec to calculate the keff and the power distribution. It is concluded therefore that the FLARE model can be applied to the FBR neutronics calculation, provided that the parameters are properly chosen in advance as shown in this note.

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**REFERENCES**