Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

Time-Average Calculation using FEM in a CANDU Reactor

Eun Hyun Ryu[a]*, Hyung Jin Shim[b], Joo Hwan Park[a], Yong Man Song[a], Lee Chung Chan[a]
[a]*Korea Atomic Energy Research Institue, 1045 Daedeok-daero, Yuseong-gu, Daejon, 305-353, Korea*
[b]*Seoul National University, 599 Gwanak-ro, Gwanak-gu, Seoul, 151-744, Korea*
**ryueh@kaeri.re.kr*

1. Introduction

To get a much accurate result and to be sure about the calculated reactor physics value, new code system which is appropriate to the CANDU reactor and has high fidelity is required. This study here is to understand and analyze the existing code system, WIMS-RFSP. Because the FEM codes used here can calculate multiplication factor, group flux, channel power easily with cross section data from WIMS and geometrical data from GMSH, the results of FEM are good examples to compare with RFSP results. With the comparison process itself and numerical experiments, it is expected that the basis of new code system become abundant. Time-average module is mainly discussed with regular process in RFSP.

2. Time-Average Calculation

Time-average calculation is to seek an equilibrium core state in a mathematical point of view. Because of complexity in refueling process, the time-averaged cross section is generated to neglect daily refueling process. Finally, with several repeated calculation, it is assumed that a certain equilibrium state exists and we can reach to that state.

2.1 Time Averaged Macroscopic Cross Section

The amount of irradiation depends on the both neutron flux and irradiation time.

$$\omega_{out,jk} = \omega_{in,jk} + \hat{\phi}_{jk} \cdot T_j \qquad (1)$$

Note that index j and k are channel number and axial position respectively. $\omega_{in,jk}$ and $\omega_{out,jk}$ are fuel irradiation in a bundle when it enters and exits position jk in Eqn. (1). T_j is refueling time. Time averaging is to preserve the average reaction rate at that position, so

$$\Sigma_{i,jk}(t.av.) = \frac{\frac{1}{T_j}\int_0^{T_j} \Sigma_i\left(\omega(t)\right)\hat{\phi}_{jk}\,dt}{\frac{1}{T_j}\int_0^{T_j} \hat{\phi}_{jk}\,dt} \qquad (2)$$

Equating $d\omega = \hat{\phi}dt$ to Eqn. (2), Eqn. (2) can be written over irradiation instead of over time.

$$\Sigma_{i,jk}(t.av.) = \frac{1}{\left(\omega_{out,jk} - \omega_{in,jk}\right)} \int_{\omega_{in,jk}}^{\omega_{out,jk}} \Sigma_i(\omega)\,d\omega \qquad (3)$$

The macroscopic cross section with irradiation is already given by WIMS[2], inlet and outlet irradiation is a function of exit irradiation as in Eqn. (5)[4]. Assigned exit irradiation in this study is conventional value.[4]

$$\omega_{in,jk} = \begin{cases} 0 & \text{for } 1 \le k \le 8 \\ \omega_{out,j(k-8)} & 9 \le k \le 12 \end{cases} \qquad (4)$$

$$T_j = \frac{8 \cdot \omega_{exit,j}}{\sum_{k=1}^{12} \hat{\phi}_{jk}} \qquad (5)$$

2.2 Calculation Flow

Time-average calculation needs initial guess of average flux and exit irradiation for each bundle. When convergence of axial flux shape is confirmed, then iteration stops[4]. But in this study, flux iteration procedure is done only once.

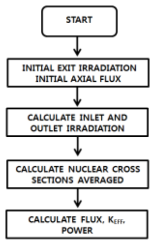

Fig. 1. Time-average calculation flow chart

3. FEM Geometry and Reactivity Devices

3.1 Principles of Reflecting Incremental Cross Section of Reactivity Devices

The basic lattice properties are come from the WIMS calculation, and incremental cross section can be obtained by DRAGON, MULTICELL and PPV[1]. In this study, previously obtained 1.5 group cross section form of PPV is converted to 2 group form[3]. And in reflecting incremental cross section process, we can impose the principle of superposition and volume weighting. Within the boundaries of the volume representing a device[4],

$$\Sigma_i(combination) = \Sigma_i(basic\ \ fuel) + \Sigma_i(device\ \ 1) + \Sigma_i(device\ \ 2) + \ldots \qquad (6)$$

And for the homogenization of the properties within a node[4],

$$\Sigma_i(node) = \frac{\sum_{n=1}^{R}\{V_n \Sigma_i(subregion)\}}{\sum_{n=1}^{R} V_n} \qquad (7)$$

3.2 Cross Sectional Area of FEM Geometry

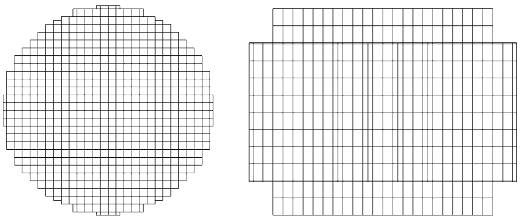

Fig. 2. Cross Sections of FEM geometry for x-y Direction and x-z Direction

4. Numerical Results

Two cases are considered in this study. First case is that a core without any reactivity devices and second case is that a core with vertical reactivity devices. In second case, horizontal reactivity devices and liquid zone controller is excluded because of lack of current calculation capability of FEM backup utility.

Table I: FEM Mesh Data

Nodes	Elements	Average Volume	Element Pitch
40,283	233,806	1041.2cm^3	11.3cm

Table II: RFSP Mesh Data

	Dimension of Mesh	Mesh Spacing	Element Pitch
X	30	25.523cm	23.5cm
Y	30	25.523cm	
Z	30	19.812cm	

Table III: k_{eff} results

	Case 1	Case 2
RFSP	1.03568	1.01675
FEM P_1	1.02013	1.00111
FEM SP_3	1.02014	1.00113

Table IV: Cutting Plane Designation

Plane 1	Plane 2
x=382.85	z=297.18

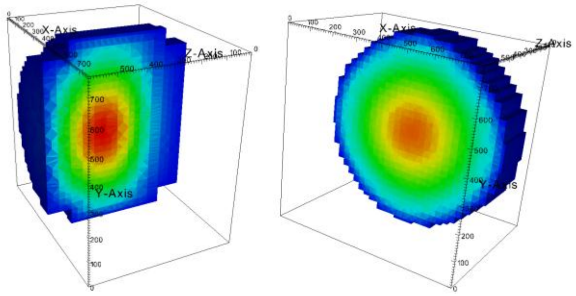

Fig. 3. Thermal flux distribution of case 1 with cutting plane 1 and 2

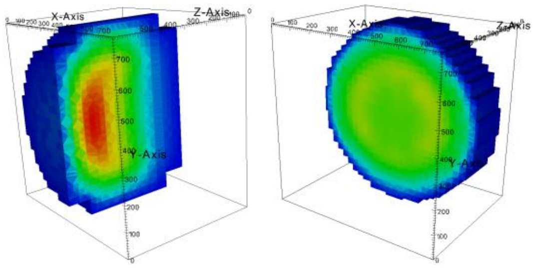

Fig. 4. Thermal flux distribution of case 2 with cutting plane 1 and 2

5. Conclusions

Although the element pitch of RFSP[3] is much bigger than that of FEM, difference between k_{eff} of RFSP and k_{eff} of FEM seems large for both cases. Because that the consistency of cross section production process is not confirmed elaborately, further analysis is required. Because of the large size of the core, the transport effect in CANDU reactor is negligible as expected. The thermal flux distribution is positive z-directional skewed due to the one directional refueling scheme, not bi-directional refueling scheme in this study. Including reactivity devices gives a flattened flux distribution as we can see in Fig.3. and Fig.4..

Confirming cross section production process, sophisticated works for reflecting all kind of reactivity devices and z-directional integrated channel power comparison are required in the future. Criticality search with LZC and reflecting bi-directional fueling scheme are also required.

REFERENCES

[1] Gyu Hong Roh, Chang Joon Jeong, Hang Bok Choi, Assessment of CANDU physics codes using experimental data-II: CANDU core physics measurement, KAERI/TR-1971/2001, Korea Atomic Energy Research Institute, 2001.

[2] Won Young Kim, Hae Sun Jung, Jun Ho Bae, Joo Hwan Park, Fuel Management Study on a CANDU-6 Reactor Using WIMS-IST/DRAGON-IST/RFSP-IST,KAERI/TR-4199/2010, Korea Atomic Energy Research Institue, 2010.

[3] P. Schwanke, RFSP-IST Version REL_3-04: Users' Manual, 2006.

[4] W. Shen, RFSP-IST Version REL_3-04: Theory Manual, 2006.