PHYSOR 2002, Seoul, Korea, October 7-10,2002

Two-dimensional Baffle/Reflector Constants Based on Transport Equivalent Diffusion Parameters

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ABSTRACT

In order to improve the calculation accuracy of PWR core power distribution by nodal code, a two-dimensional homogenization method based on transport equivalent diffusion parameters was developed. The method was verified against the benchmark calculation of an actual PWR.

1. INTROUDUCTION

For nodal calculations, Baffle/Reflector homogenization constants (B/R constants) have to be generated. the baffle/reflector region is usually represented by two regions, which are called flat edges and corner edges. B/R constants are generated using an equivalent one-dimensional model for each region. However, errors of 3～4% appear for fuel assemblies along core corner with one-dimensional B/R constants. Therefore, in order to improve the accuracy of power distribution calculation, a method for calculating two-dimensional B/R constants that reflects the geometrical configuration has been developed, in which the geometrical configuration outside the core is treated explicitly using a two-group fine-mesh diffusion code. In order to take account of transport effect, a method for calculating transport equivalent diffusion parameters of materials in the reflector region were also developed. By incorporating these diffusion parameters into the calculation of 2-D B/R constants, the high calculation accuracy for core power distribution was obtained.

2. METHOD

The B/R constants should be determined in order that the neutron current from the core can be calculated exactly considering the complex geometry of the reflector region. For this purpose, two methods were developed. The first one is the method for calculating two-dimensional B/R constants based on a two-dimensional diffusion calculation. The second one is the method for calculating the two-group transport equivalent diffusion parameters of the materials contained in the reflector region. By applying the transport equivalent diffusion parameters to the two-dimensional diffusion calculation where the core, the baffle plate and the water reflector etc. are modeled as they are, the two-dimensional B/R constants reflecting the complicated geometry of the reflector region were calculated.

2.1 Two-dimensional baffle/reflector constants based on the diffusion theory

The general solution of the diffusion equation for a node having uniform nuclear constants within the node can be written as

$$\Psi_{\omega}(\vec{r}) = \sum_{n=1}^{4} F_n e^{i\omega \vec{\mathbf{k}}_n \vec{\mathbf{r}}} \quad , \tag{1}$$

$$\phi_1(\vec{r}) = \Psi_{\mu}(\vec{r}) \qquad \phi_2(\vec{r}) = \alpha\ \Psi_{\mu}(\vec{r}) + \Psi_{\nu}(\vec{r}), \tag{2}$$

$$\mu^2 = \frac{\Sigma_{a1} + \Sigma_r}{D_1},\ \ \nu^2 = \frac{\Sigma_{a2}}{D_2},\ \ \alpha = \frac{\Sigma_r}{\Sigma_{a2} - D_2\mu^2} \quad , \tag{3}$$

where ***k*** is the unit vector and perpendicular to the node surface. By imposing surface averaged neutron currents from the two-dimensional diffusion calculation in the geometry shown in Fig.1, we can determine the coefficients F_n. From the surface averaged fluxes for each node, we can determine neutron flux discontinuity factors**[1]** ,**[2]** and then two-dimensional B/R constants**[3]**.

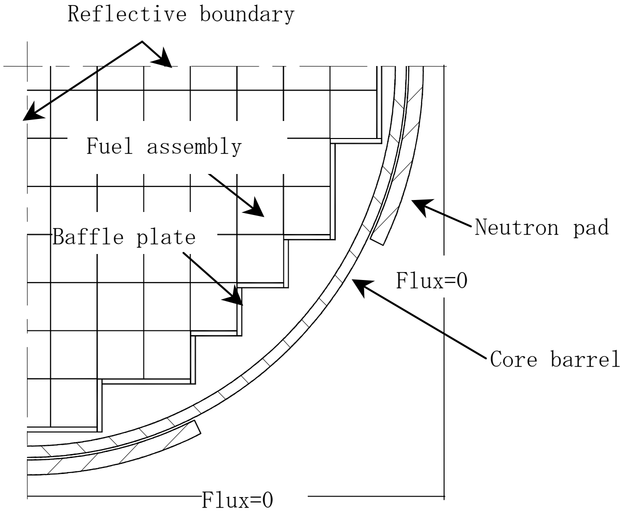

Fig. 1 Two-dimensional core model for B/R constants

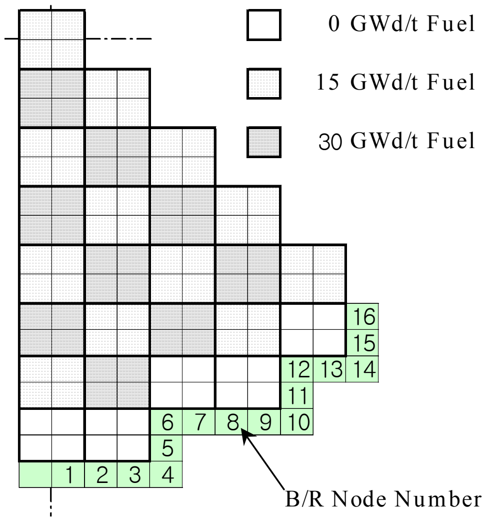

Fig. 2 Fuel loading pattern of 3-loop core

The comparison in assembly power is shown in Fig. 3. The figure shows that, the two-dimensional

B/R constants give more accurate prediction of assembly power than one-dimensional B/R constants; a maximum error of 3.81% for one-dimensional B/R constants is dramatically reduced to 0.5%.

To check the applicability of the B/R constants to a different type of fuel loading pattern, once-burnt fuel assemblies with 15GWd/t burnup were placed next to the baffle plate along core corner. Assemblies in the inner core were shuffled to achieve an acceptable power peaking and the low-leakage loading pattern was established. The one- and two-dimensional B/R constants generated for the loading pattern shown in Fig.2 were again used for this core. Using the two- dimensional B/R constants, a maximum error of only 0.48% was found, in contrast with 2.68% error obtained by using the one-dimensional B/R constants. This tendency of assembly error is similar to that seen in Fig.3. In other words, the B/R constants are quite independent of fuel loading pattern. Further investigation confirmed that the two dimensional discontinuity factors of baffle/reflector nodes for the low-leakage core at 0 ppm boron concentration were consistent with those for the core shown in Fig.2. Accordingly, a set of B/R constants tabulated as parameters of boron concentration and moderator temperature can be used for the same kind of fuel assembly, for instance, uranium fuel.

1.232 −2.19 0.31				
1.045 −2.12 0.30	1.220 −2.05 0.29			
1.208 −1.90 0.27	1.024 −1.76 0.25	1.182 −1.52 0.22		
1.005 −1.49 0.20	1.172 −1.37 0.19	0.981 −1.02 0.15	1.115 −0.45 0.09	
1.141 −1.00 0.12	0.967 −0.83 0.10	1.111 −0.36 0.06	0.911 0.38 0.00	0.998 1.50 −0.05
0.932 −0.43 −0.01	1.088 −0.18 −0.01	0.922 0.33 −0.06	0.997 1.40 −0.08	0.852 3.81 −0.29
1.058 0.13 −0.18	0.844 0.66 −0.09	1.062 1.88 −0.22	0.806 2.85 −0.33	
0.995 0.25 −0.50	0.783 1.28 −0.46			

Heterogeneous B/R (ref.)
$(P_{1D\ B/R} - P_{ref.})*100/\ P_{ref.}$
$(P_{2D\ B/R} - P_{ref.})*100/\ P_{ref.}$

Maximum error:
1D B/R: 3.81%
2D B/R: −0.50%

Fig. 3 Comparison in assembly power at 0ppm boron concentration.

If transport effect is incorporated into this model, the calculation accuracy for core power distribution will be greatly improved. The method for calculating transport equivalent diffusion parameters for such purpose will be described in the next sub-section.

2.2 Transport equivalent diffusion parameters

The transport equivalent two-group diffusion constants were defined as the set of the diffusion coefficients and cross-sections that makes zero or minimize the difference of the diffusion and transport currents on the reflector boundaries.

$$D_1 = \frac{1}{\kappa_1}\sqrt{\alpha\ \beta}\ ,\ \kappa_1 = \frac{1}{T}\cosh^{-1}\left(\frac{\beta+\alpha}{\beta-\alpha}\right),\ \alpha=\frac{J_1^{\ell,Trns} - J_1^{r,trns}}{\phi_1^{\ell}+\phi_1^{r}}\ ,\ \beta=\frac{J_1^{\ell,Trns} + J_1^{r,Trns}}{\phi_1^{\ell}-\phi_1^{r}}, \qquad (4)$$

$$W = \left(\frac{J_2^{\ell,Diff} - J_2^{\ell,Trns}}{J_2^{\ell,Trns}}\right)^2 + \left(\frac{J_2^{r,Diff} - J_2^{r,Trns}}{J_2^{r,Trns}}\right)^2, \qquad (5)$$

where J_g is the total currents and ϕ_g is the fluxes based on the transport partial currents j^{tr}:

$$\phi_g^r = 2\left(j_g^{tr,r+} + j_g^{tr,r-}\right), \qquad \phi_g^\ell = 2\left(j_g^{tr,\ell+} + j_g^{tr,\ell-}\right), \qquad (6)$$

$$J_g^r = \left(j_g^{tr,r+} - j_g^{tr,r-}\right), \qquad J_g^\ell = \left(j_g^{tr,\ell+} - j_g^{tr,\ell-}\right). \qquad (7)$$

By imposing the boundary currents J_g and fluxes ϕ_g and minimizing W, diffusion parameters can be obtained[**4**],[**5**]. The transport partial currents required for the above equations are calculated by a transport theory code, MCNP4B for instance, in one-dimensional core model.

3. ANALYSIS of A PWR CORE and RESULTS

The validity of the two-dimensional B/R constants was confirmed by comparing power distribution and critical boron concentration with the measurement data of an actual plant. A three-loop plant with thermal power of 2,652MWt was selected as a benchmark analysis. This core has a large corner part of the B/R region and is suitable for verification of the two-dimensional B/R constants developed by this research work.

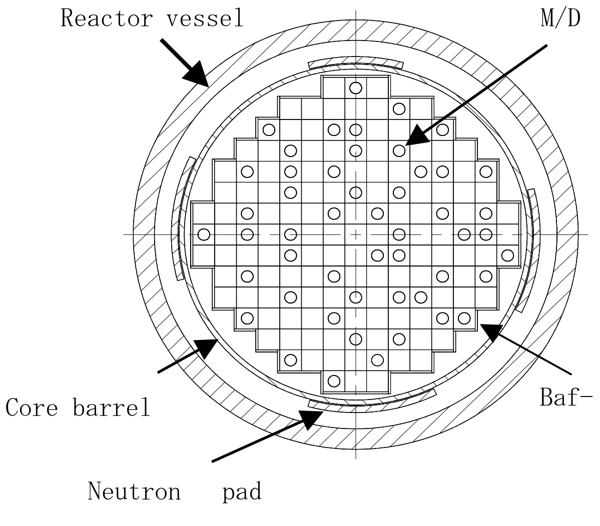

Fig. 4 Plan view of a 3-loop core

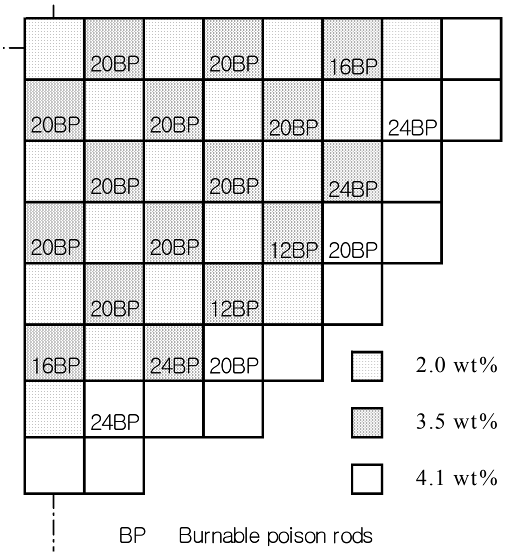

Fig. 5 Core loading pattern of the first cycle

The nuclear data of the preliminary version of JENDL-3.3**[6]** were used in the calculation of fuel constants, and ENDF/B-VI was used for B/R constants according to the study of the iron reflector**[7]**. For the core calculation, the three-dimensional nodal code ANC**[8]** was used, which is based on the diffusion theory. The reaction rate data, which were measured by Movable Detectors (M/D) at all control rods out conditions (ARO), were processed with the INFANT code**[9]** and the resultant assembly power distribution were compared with the calculated one. Figures 2 and 3 show comparisons in assembly power at the hot zero power conditions (HZP) and hot full power conditions (HFP) for the first cycle (CY1). The calculated assembly power agrees well with the measured one on the core periphery and for almost all the area inside the core and the error of the whole core is 1.2% for HZP and 1.3% for HFP, respectively.

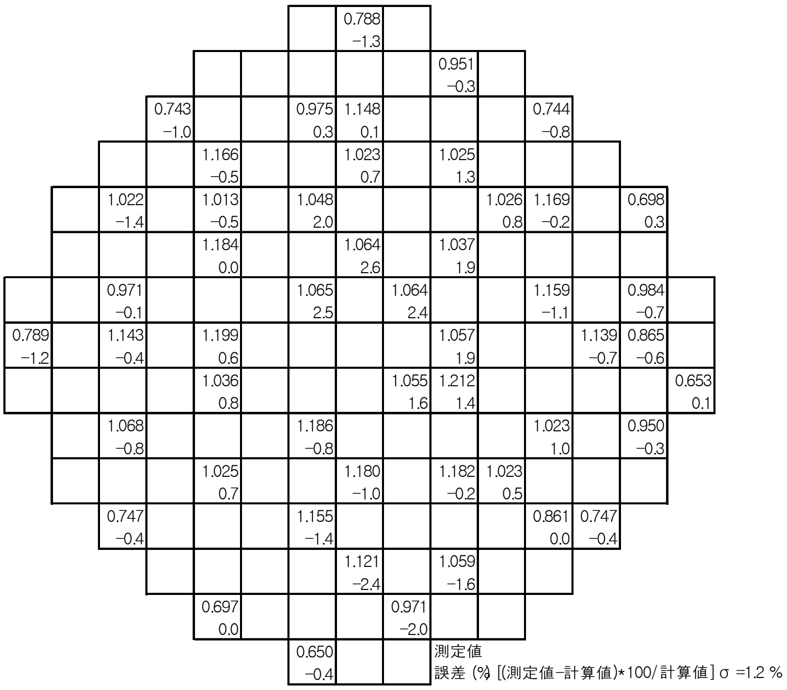

Fig. 6 **Comparison of assembly power**
(CY1, 0MWd/t, HZP, ARO)

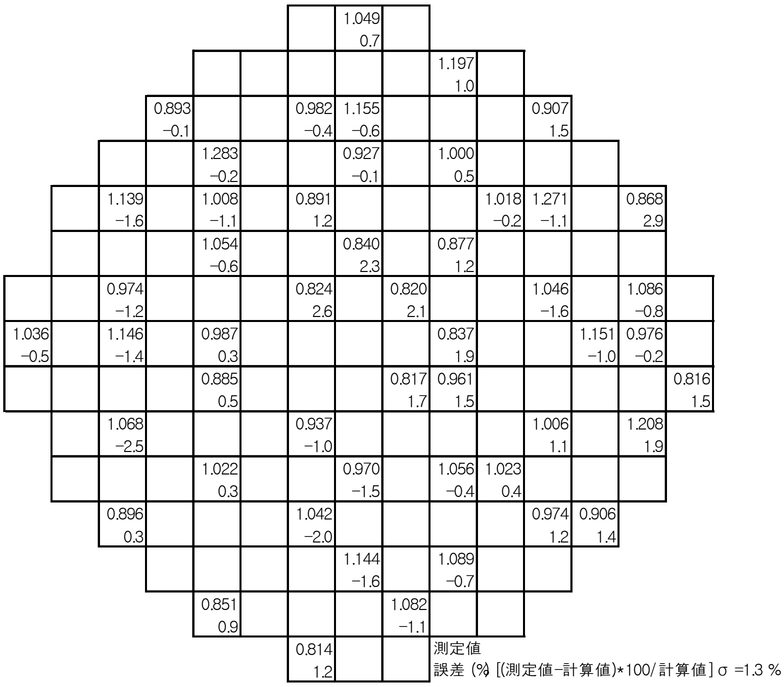

Fig. 7 **Comparison of assembly power**
(CY1, 8900MWd/t, HFP, ARO)

Table 1 shows the comparison between the measured and calculated boron concentrations of the first and third cycles at HZP for the cases of ARO and the control bank D fully inserted. The difference of the calculated and measured critical boron concentration is only 17ppm.

Figure 8 shows the comparison between the measured and calculated critical boron concentration at hot full power operation for the first cycle. The prediction error of critical boron concentration is smaller than 15ppm. These results show that two-dimensional B/R constants based on the transport equivalent diffusion parameters enables us to evaluate neutron leakage from the core correctly and then predict critical boron concentration with high accuracy.

Table 1 Comparison of critical boron concentrations at HZP

Control rod	Cycle 1		Cycle 3	
	Meas. (ppm)	Cal. (ppm)	Meas. (ppm)	Cal. (ppm)
ARO*	1729	1714(15) ***	1726	1728(-2)
D**	1604	1591(13)	1564	1567(-3)

* All control rods out

** Control bank D inserted

*** The value in the parenthesis represents error : (Mea.-Cal.)

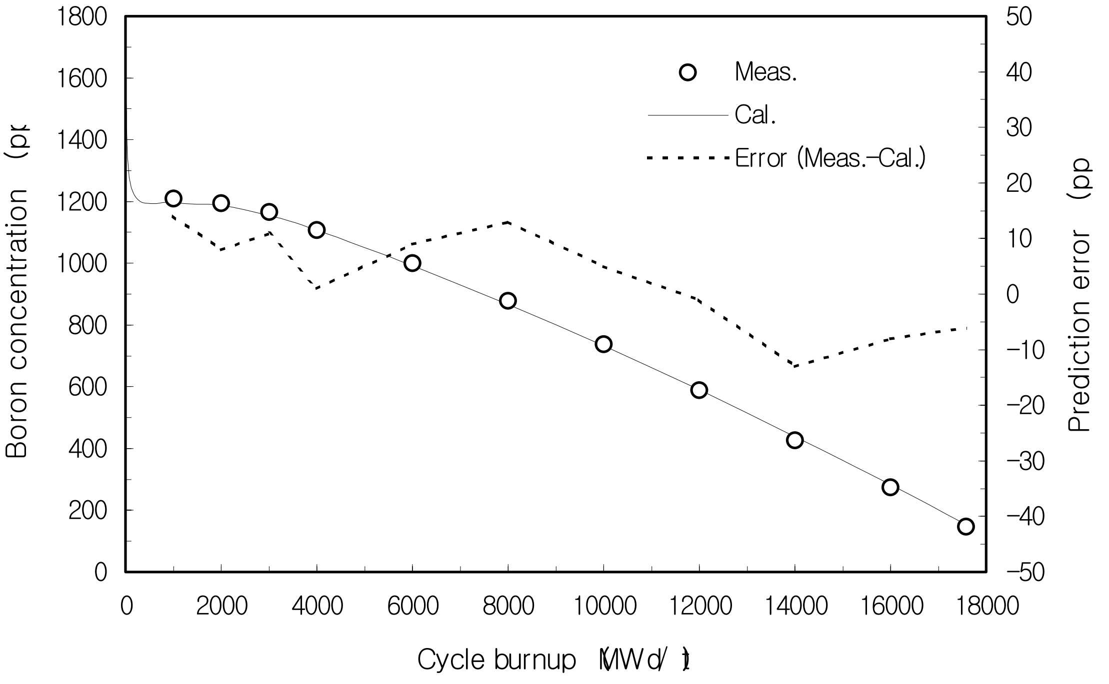

Fig. 8 Critical boron concentration vs. burnup for the first cycle (HFP, ARO)

4.CONCLUSION

The characteristics of the core, especially, the radial power distribution depend largely on the treatment of the radial reflector region. In order to improve PWR core power calculation with the nodal method, a method for calculating the two-dimensional B/R constants was developed by applying the transport equivalent diffusion parameters of the water gap, baffle plate, water reflector, core barrel and neutron pad to the two-dimensional diffusion calculation. The power distribution and the critical boron concentration of the actual 3-loop core were calculated with high accuracy using the B/R constants. This shows that the two-dimensional B/R constants based on the transport equivalent diffusion parameters enable high accurate prediction of power distribution and critical boron concentration of PWR cores.

ACKNOWLEDGEMENTS

One of the authors (Y.T.) would like to thank Mrs. Yoko Hitosugi, Mr. Hideyuki Noda, and Mr. Kazuhiro Tani of Engineering Development Co., Ltd. for their help in the analysis. He is also grateful to Nuclear Data Center of JAERI for the use of the latest version of JENDL.

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