Analysis of the Effects on a Core Reactivity by a PWR Radial Reflector

Kyung-Hoon Lee, Jae-Seung Song, Sang-Yoon Park, Chung-Chan Lee
Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong-gu, Daejeon, 305-353, lkh@kaeri.re.kr

1. Introduction

A commercial PWR core is usually constructed with the fuel assemblies enclosed by a radial reflector, which includes a baffle and water. In the design procedure for a PWR analysis, the effective cross section for the reflector can be generated by applying a heterogeneity factor based on a simplified equivalence theory and some approximations.[1] However, since the reflector for a small-sized PWR such as a SMART is filled with a mixture of steel and water, the removal cross section of the steel reflector is less than that of the water reflector. Therefore, the conventional method for a water reflector may no longer be valid for a steel reflector.

In this paper the effective reflector cross sections for the SMART core with various reflectors were generated by using the method[2] which is generalized through an elimination of the approximations. Also, we analyze the effects on a core reactivity due to the material type of those reflectors.

2. Methods

2.1 Analytic Method

Analytic heterogeneity factor can be derived from a 1-dimensional spectral geometry as shown in Figure 1.

Fuel Assembly	Homogenized Reflector

x=0 x=u

Figure 1. The 1-dimensional spectral geometry

The 1-dimensional 2-group diffusion equation at the interface of a core and a reflector can be written as follows:

$$\frac{D_1}{f_1}\frac{\partial^2\phi_1(x)}{\partial x^2}-\frac{\Sigma_{a1}+\Sigma_r}{f_1}\phi_1(x)=0 \tag{1a}$$

$$\frac{D_2}{f_2}\frac{\partial^2\phi_2(x)}{\partial x^2}-\frac{\Sigma_{a2}}{f_2}\phi_2(x)+\frac{\Sigma_r}{f_1}\phi_1(x)=0 \tag{1b}$$

where f_g is the heterogeneity factor of group g.

Solving Eq. (1) with a boundary condition at $x=u$, we can obtain the analytic solutions as follows:

$$\phi_1(x)=A_1(\sinh\omega_1 x-\coth\omega_1 u\,\cosh\omega_1 x) \tag{2a}$$

$$\phi_2(x)=KA_1(\sinh\omega_1 x-\coth\omega_1 u\,\cosh\omega_1 x)+A_2(\sinh\omega_2 x-\coth\omega_2 u\,\cosh\omega_2 x) \tag{2b}$$

where $\omega_1=\sqrt{\frac{\Sigma_{a1}+\Sigma_r}{D_1}}$, $\omega_2=\sqrt{\frac{\Sigma_{a2}}{D_2}}$,

$$K=\frac{f_2\Sigma_r}{f_1 D_2(\omega_2^2-\omega_1^2)}.$$

Applying a net current definition at the interface, we can obtain f_g as follows:

$$f_1=\frac{D_1\hat{\phi}_1\omega_1 T_1}{\hat{J}_1} \tag{3a}$$

$$f_2=\frac{D_2\hat{\phi}_2}{\frac{\Sigma_r\hat{J}_1}{D_1(\omega_2-\omega_1)}\left(\frac{1}{\omega_1T_1}-\frac{1}{\omega_2T_2}\right)+\frac{\hat{J}_2}{\omega_2T_2}} \tag{3b}$$

where $\hat{\phi}_g$ is a surface flux at the interface,

$T_1=\tanh\omega_1 u$, $T_2=\tanh\omega_2 u$.

Therefore, by dividing a homogenized cross section by this heterogeneity factor, we can determine an effective reflector cross section.

2.2 Response Matrix Method

Heterogeneity factor in the former method is derived directly, whereas the one in the response matrix method is estimated by a determination of the group-wise diffusion constants from a response matrix which is obtained from a pair of surface fluxes and net currents.

The response matrix between the surface fluxes and net currents can be defined at an interface as follows:

$$\Phi=\mathbf{R}J \tag{4}$$

Rewriting Eq. (3), $\mathbf{R}$ is denoted as follows:

$$\mathbf{R}=\begin{bmatrix}\frac{f_1}{D_1\omega_1T_1} & 0\\ \frac{f_2\Sigma_r}{D_1D_2}\frac{\omega_2T_2-\omega_1T_1}{\omega_1\omega_2T_1T_2} & \frac{f_2}{D_2\omega_2T_2}\end{bmatrix} \tag{5}$$

From Eqs. (4) and (5), the response matrix for two fuel assemblies (A and B) with different characteristics such as an enrichment variation can be expressed as follows:

$$\begin{bmatrix}r_{11} & 0\\ r_{21} & r_{22}\end{bmatrix}=\begin{bmatrix}\hat{\phi}_1^A & \hat{\phi}_1^B\\ \hat{\phi}_2^A & \hat{\phi}_2^B\end{bmatrix}\begin{bmatrix}\hat{J}_1^A & \hat{J}_1^B\\ \hat{J}_2^A & \hat{J}_2^B\end{bmatrix}^{-1} \tag{6}$$

If f_1 is set to be unity due to no source term at the reflector region, we can compute D_g as follows:

$$D_1\sqrt{\frac{\Sigma_{a,1}^A+\Sigma_r^A}{D_1}}\tanh\left(u\sqrt{\frac{\Sigma_{a,1}^A+\Sigma_r^A}{D_1}}\right)=\frac{1}{r_{11}} \tag{7a}$$

$$D_2=\frac{\Sigma_{a,2}^A}{\omega_1^2+\frac{r_{22}}{r_{21}}\frac{\Sigma_r^A}{D_1}\left(\frac{\sqrt{\frac{\Sigma_{a,2}^A}{D_2}}\tanh\left(\sqrt{\frac{\Sigma_{a,2}^A}{D_2}}u\right)}{\omega_1\tanh\omega_1 u}-1\right)} \tag{7b}$$

Finally, using D_2 obtained from Eq. (7), we can calculate f_2 as follows:

$$f_2 = r_{22} D_2 \omega_2 \tanh \omega_2 u \quad (8)$$

3. Calculations

3.1 Radial Reflector Cross Section for the SMART Core

The SMART core as shown in Figure 2 is surrounded by two types of reflectors. Reflector 'R2' is adjacent to fuel assemblies 'A0' and 'B3', reflector 'R3' is contiguous with fuel assemblies 'B3' and 'B4'.

A2	A1	B6	A2	B4	R3
	A2	A3	B6	B3	R3
		B6	B4	A0	R2
			A0	R2	R2
				R2	

Figure 2. The SMART core (1/8 symmetry)

The homogenized cross sections, the surface fluxes, and the net currents at the interface of each fuel assembly at a core periphery and reflector were calculated by the CASMO-3[3] code with a 40 group library. The effective reflector cross section is generated by using the response matrix method with the CASMO-3 results.

Since the radial reflector for the SMART core is filled with a mixture of a steel and water, we additionally established a steel reflector and a water reflector, respectively.

Table 1 provides the effective cross sections for the reflector 'R2'. This table shows that the removal cross section of the water reflector is about 5 times larger than one of the steel reflector. It was shown that the reflector cross section is considerably changed by the material type of the reflectors.

Table 1. A comparison of effective cross sections for R2

	Case-1 (Steel)	Case-2 (Steel+Water)	Case-3 (Water)
Σ_{a1}	3.98037E-03	2.54443E-03	1.65065E-03
Σ_{a2}	4.19279E-02	6.46928E-02	2.33221E-01
Σ_{tr1}	4.11167E-01	3.34322E-01	4.43204E-01
Σ_{tr2}	1.25392E+00	1.35941E+00	1.79562E+00
Σ_{r}	4.51292E-03	2.41048E-02	2.74991E-02

3.2 Effects on Core Reactivity

Using the newly generated reflector cross sections, the effects on a core reactivity due to the material type of the reflectors were evaluated through 3-dimensional core calculation by the MASTER[4] code.

Figures 3 and 4 show the critical boron concentration and the nuclear power peaking factor for the SMART core with various reflectors. Cycle lengths of Case-1 and Case-2 are 864 EFPD and 803 EFPD, respectively, which are 16 ~ 77 days larger than the cycle length of Case-3 (787 EFPD). Maximum peaking factor of Case-1 and Case-2 are 1.9733 and 2.1205, respectively, which are lower than the peaking factor of Case-3 (2.1678).

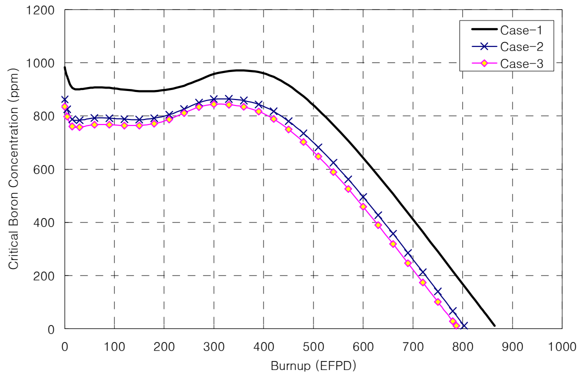

Figure 3. A comparison of critical boron concentration

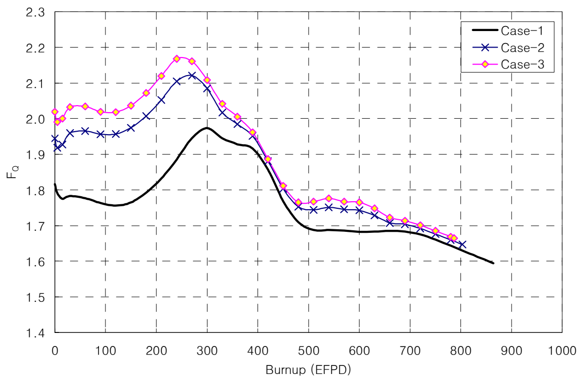

Figure 4. A comparison of nuclear power peaking factor

5. Conclusion

We have generated new radial reflector cross sections for the SMART core analysis. The response matrix method without any approximations was adopted in obtaining the effective reflector cross section. The results show that it is required to use the steel reflector for the PWR core design.

REFERENCES

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