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A Spectrum Correction Method for Fuel Assembly Rehomogenization

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ABSTRACT

To overcome the limitation of existing homogenization methods based on the single assembly calculation with zero current boundary condition, we propose a new rehomogenization method, named spectrum correction method (SCM), consisting of the multigroup energy spectrum approximation by spectrum correction and the condensed two-group heterogeneous single assembly calculations with non-zero current boundary condition. In SCM, the spectrum shifting phenomena caused by current across assembly interfaces are considered by the spectrum correction at group condensation stage at first. Then, heterogeneous single assembly calculations with two-group cross sections condensed by using corrected multigroup energy spectrum are performed to obtain rehomogenized nodal diffusion parameters, i.e., assembly-wise homogenized cross sections and discontinuity factors. To evaluate the performance of SCM, it was applied to the analytic function expansion nodal (AFEN) method and several test problems were solved. The results show that SCM can reduce the errors significantly both in multiplication factors and assembly averaged power distributions.

I. INTRODUCTION

Various nodal diffusion methods have been developed and widely used for the reactor core analysis and design due to its rapidity and low computational burden with acceptable accuracy. These methods are fundamentally relied on the nodal equivalence between the global heterogeneous solution and the global homogeneous solution for

each node, which is typically fuel assembly. Thus, it is required to generate equivalent nodal diffusion parameters, known as homogenization procedure, for the perfect reproduction of the heterogeneous solution by the nodal diffusion calculation. However, it is well known that even though we can derive exact mathematical expressions for ideal homogenized parameters, there are some problems for applications to practical problems. However, there have been many efforts to develop practical homogenization methods. Among these, generalized equivalence theory (GET) [1] with single assembly homogenization method is a most popular one and has been used widely for nodal diffusion calculations. In this method, the heterogeneous solution required for the calculation of homogenized diffusion parameters is approximated by the solution of single assembly calculations with zero current boundary conditions.

The method based on single assembly homogenization shows relatively good performance if the current effect at interfaces of the fuel assembly are negligible. But, if rapid flux gradients at interfaces of fuel assembly are involved, then it leads to very poor results of nodal diffusion calculation. This comes mainly from two main limitations of the existing single assembly homogenization methods. The first one is that multigroup neutron flux distribution used in group condensation and spatial homogenization cannot be a representative one for global heterogeneous system due to the use of unrealistic zero current boundary condition for single assembly calculation. The other one is that even though we have information on the interface currents in condensed group structure for each assembly coming from the nodal diffusion calculation, it is very difficult to consider this effect at the single assembly level calculation.

To remedy the limitations above, we propose a new rehomogenization method based on the spectrum correction. There have been some approaches which also attempt to reflect the spectrum effect, that is the discrepancy in spectrum between the global heterogeneous calculation and single assembly calculations caused by interface currents, in the sense of spectrum correction. [2][3] However, these methods focused mainly on searching direct empirical correlations between homogenized two-group cross sections (or two-group cross section distribution within assembly) and various spectral states of fuel assemblies, possibly those of the global heterogeneous system. Thus, these methods require many lattice level calculations in advance. In addition, even though it can be done easily and is minor, it is also required to modify existing nodal diffusion code for its practical application. Also, discontinuity factors are not updated in these methods.

Unlike these methods, we improve multigroup energy spectrum from that of single assembly calculation via spectrum correction using results of the prior nodal diffusion

calculation. With resulting corrected spectrum, group condensation is done for pin-wise heterogeneous two-group cross sections. Then, heterogeneous two-group single assembly problems with non-zero current boundary conditions are solved to obtain the two-group flux distribution required for spatial homogenization. Finally, one-node nodal diffusion calculations are done to update discontinuity factors. From these procedures, we can obtain rehomogenized nodal diffusion parameters including updated discontinuity factors. It should be also noted that SCM requires neither any additional lattice level calculations nor modification of nodal diffusion code for its practical application.

II. SPECTRUM CORRECTION METHOD FOR REHOMOGENIZATION

II.1 The Spectrum Effect in Single Assembly Homogenization Method

From the nodal equivalence theory, expressions for ideal homogenization parameters are

$$\Sigma_{\alpha H}^{hom,i} = \frac{\sum_{g\in H}\int_{V_i}\Sigma_{\alpha g}^{het,i}\phi_g^{het}(\vec{r})d\vec{r}}{\sum_{g\in H}\int_{V_i}\phi_g^{hom}(\vec{r})d\vec{r}}, \quad \begin{matrix} H = F,T \\ \alpha = t, f, g' \end{matrix} \tag{1}$$

$$D_H^{hom,i} = \frac{\sum_{g\in H} -\int_{S_k^i}\vec{J}_g^{het}(\vec{r})\cdot d\vec{S}}{\sum_{g\in H}\int_{S_k^i}\nabla\phi_g^{hom}(\vec{r})\cdot d\vec{S}}, \quad \begin{matrix} H = F,T \\ k = 1,2,\ldots,K \text{ surfaces of the node} \end{matrix} \tag{2}$$

where *i* is assembly index, *F* and *T* are macro group index for fast and thermal groups, respectively. Eq.(1) includes two procedures of group condensation and spatial homogenization, and can be split into the following two equations :

$$\Sigma_{\alpha H}^{het,i} = \frac{\sum_{g\in H}\Sigma_{\alpha g}^{het,i}\phi_g^{het}(\vec{r})}{\sum_{g\in H}\phi_g^{hom}(\vec{r})} \tag{3}$$

$$\Sigma_{\alpha H}^{hom,i} = \frac{\int_{V_i}\Sigma_{\alpha H}^{het,i}\phi_H^{het}(\vec{r})d\vec{r}}{\int_{V_i}\phi_H^{hom}(\vec{r})d\vec{r}} \tag{4}$$

where

$$\phi_H^{het}(\vec{r}) = \sum_{g\in H}\phi_g^{het}(\vec{r}), \quad \phi_H^{het}(\vec{r}) = \sum_{g\in H}\phi_g^{het}(\vec{r}).$$

In single assembly homogenization method, Eq.(1) is approximated by

$$\Sigma_{\alpha H}^{hom,i} = \frac{\sum_{g\in H}\int_{V_i}\Sigma_{\alpha g}^{het,i}\phi_g^{SA}(\vec{r})d\vec{r}}{\sum_{g\in H}\int_{V_i}\phi_g^{SA}(\vec{r})d\vec{r}} \ . \tag{5}$$

where $\phi_g^{SA}(\vec{r})$ is a solution of single assembly calculation. Discontinuity factors are also calculated using the results of single assembly calculation as

$$DF_H^i = \frac{\sum_{g\in H}\tilde{\phi}_g^{het}\Big|_{S_k^i}}{\sum_{g\in H}\tilde{\phi}_g^{hom}\Big|_{S_k^i}} \approx \frac{\sum_{g\in H}\tilde{\phi}_g^{SA}\Big|_{S_k^i}}{\sum_{g\in H}\bar{\phi}_g^{SA}} \ , \tag{6}$$

where $\tilde{\phi}_g$ and $\bar{\phi}_g$ are surface average and volume average fluxes, respectively. By introducing discontinuity factors we may choose diffusion coefficients arbitrarily. Then, we can solve the nodal diffusion equation with these homogenized nodal diffusion parameters.

As mentioned already, this homogenization method works relatively well in the conventional pressurized water reactor (PWR) analysis in which the flux distribution is usually smooth. But if advanced design features (such as mixed oxide (MOX) fuel, extensive use of burnable absorber, material zoning inside fuel assembly, and so on) are introduced it causes poor results in nodal diffusion calculation. [4]

To illustrate the spectrum effect, we solved a sample problem consisting of UO_2 and MOX assembly using the existing single assembly homogenization method and the nodal diffusion code AFEN. [5] Each assembly contains 17 fuel pins and pin-wise averaged flux distribution was compared. Figure 1 shows the configuration of the sample problem and Figure 2 shows the results of reconstructed flux distribution from the AFEN calculation. The reference solution was obtained by 45-group VENTURE calculation. As shown in Figure 2, maximum errors of thermal flux of each assembly occur near the assembly interface. This can be explained well by spectrum parameters, especially by the spectrum index (SI) defined as

$$\Gamma(\vec{r}) = \frac{\sum_{g\in F}\phi(\vec{r})}{\sum_{g\in T}\phi(\vec{r})} \ . \tag{7}$$

Figure 3 gives the SI distribution of the reference and SA calculations. From Figure 3, we observe that as the discrepancy in SI between the reference and single assembly calculations increases, larger errors in thermal flux occur. Thus, we have to consider this spectrum effect caused by interface currents during the homogenization procedures to achieve accurate results by nodal diffusion calculation.

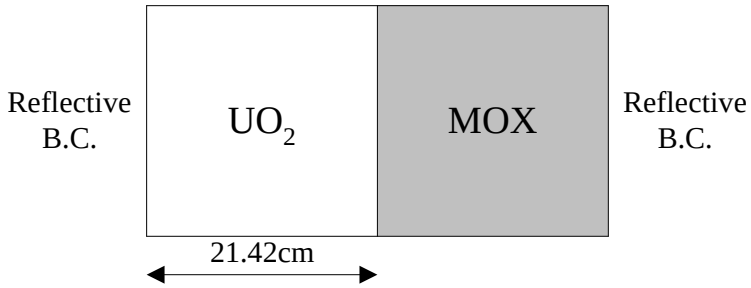


Figure 1. Configuration of a sample two-assembly problem.

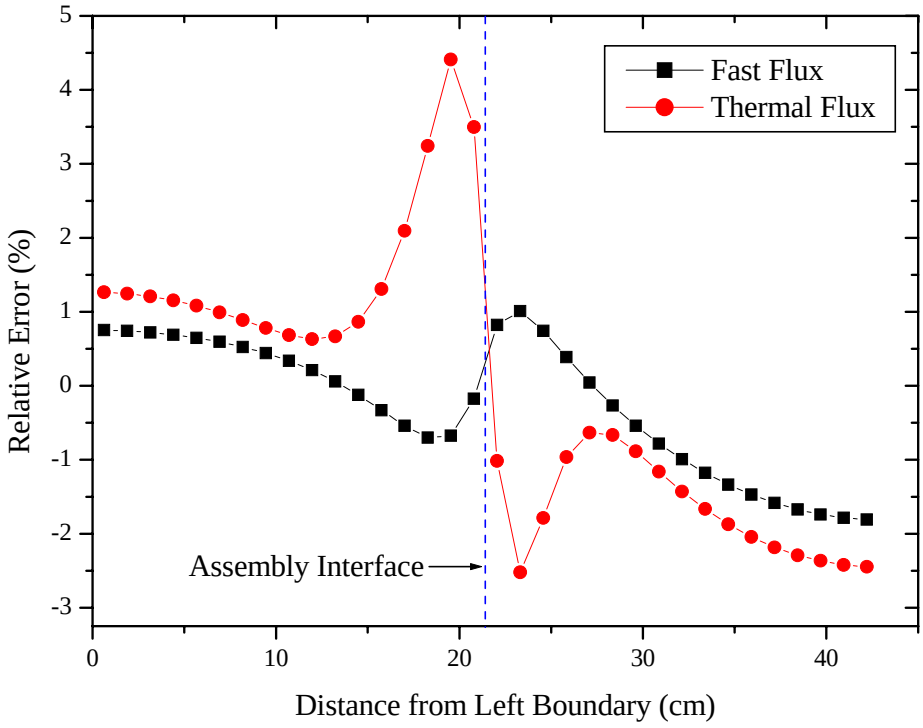


Figure 2. Results of the sample problem : flux distribution.

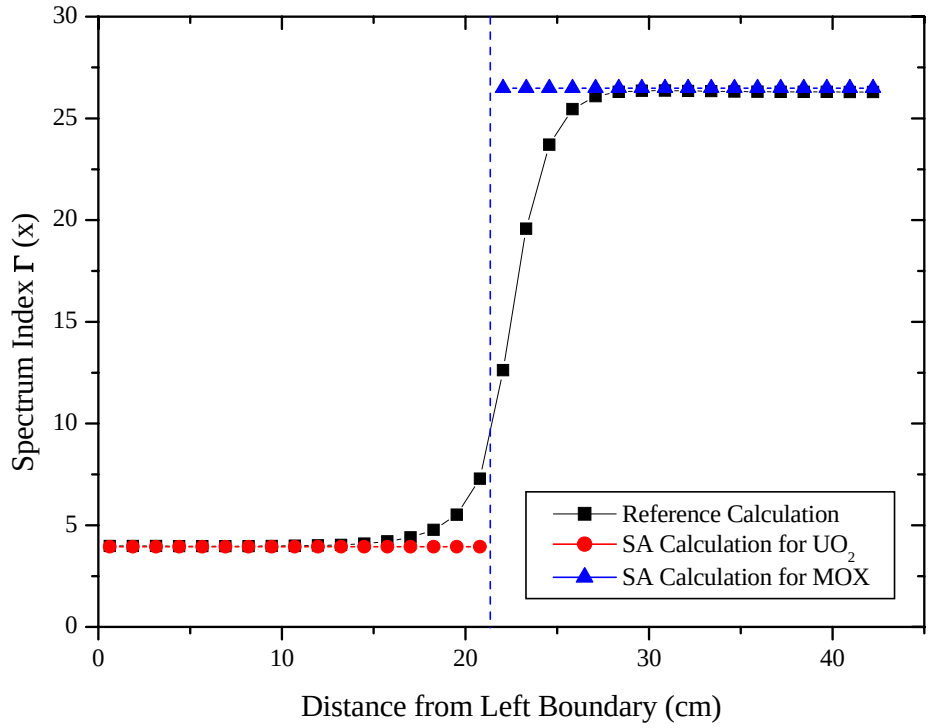


Figure 3. Spectrum index distributions.

II.2 Spectrum Correction

The basic idea of SCM is that if we have approximated distribution of SI for global heterogeneous solution, we can approximate the multigroup energy spectrum by corrections on the spectrum obtained by single assembly calculation and resulting corrected spectrum could be representative of the global heterogeneous system. Once we solve a nodal diffusion problem, then we can obtain the knowledge about the multiplication factor, flux distribution, SI distribution, and boundary conditions at assembly interfaces. Thus, the prior nodal diffusion calculation can provide required data for fuel assembly rehomogenization.

At first, the multigroup flux is separated into magnitude function f and energy spectrum φ_g.

$$\phi_g(\vec{r}) = f(\vec{r})\varphi_g(\vec{r}) , \tag{8}$$

where

$$f(\vec{r}) = \sum_g^G \phi_g(\vec{r}) , \qquad \sum_g^G \varphi_g(\vec{r}) = 1 .$$

Substituting Eq.(8) into Eq.(3), we have

$$\Sigma_{\alpha H}^{het,i} = \frac{f^{het}(\vec{r}) \sum_{g \in H} \Sigma_{\alpha g}^{het,i} \varphi_g^{het}(\vec{r})}{f^{hom}(\vec{r}) \sum_{g \in H} \varphi_g^{hom}(\vec{r})} \ . \tag{9}$$

If we assume

$$f^{het}(\vec{r}) = f^{hom}(\vec{r}) \ , \tag{10}$$

Eq.(9) becomes

$$\Sigma_{\alpha H}^{het,i} = \frac{\sum_{g \in H} \Sigma_{\alpha g}^{het,i} \varphi_g^{het}(\vec{r})}{\sum_{g \in H} \varphi_g^{hom}(\vec{r})} \ . \tag{11}$$

By spectrum correction, instead of evaluating multigroup flux, only energy spectrum is calculated to obtain spectrum corrected cross sections using Eq.(11). Then, the flux distribution required for spatial homogenization is obtained by two-group heterogeneous single assembly calculations.

Leakage Correction

It is well known fact that the effect of interface currents vanishes within a few mean free paths in diffusion theory. But, the region located far from the interface is also affected by interface currents and its effect is not negligible if heterogeneity inside the fuel assembly is considered. As shown in Figure 3, SI is almost constant at these regions and energy spectrum for these regions can be characterized by the types of material because change in energy spectrum within these regions is negligible for a given type of material. In these regions, the discrepancy of energy spectrum between the reference and single assembly calculations can be explained by the different resulting multiplication factors, and can be corrected by adjusting the uniform leakage rate. So, we named this correction procedure “leakage correction”.

For a constant SI region, the leakage term in multigroup neutron diffusion equation can be expressed as

$$-D_g^m \nabla^2 \varphi_g = D_g^m B_m^2 \ , \tag{12}$$

where *m* is material index. Therefore, the energy spectrum in the constant SI region can be found by searching material buckling B_m, which satisfies the following equation :

$$D_g^m B_m^2 + \Sigma_{ag}^m \varphi_{g,m}^B + \sum_{g' \neq g}^{G} \Sigma_{g'g}^m \varphi_{g,m}^B = \frac{\chi_g}{k_{eff}^{NC}} \sum_{g'}^{G} \nu \Sigma_{fg'}^m \varphi_{g',m}^B + \sum_{g' \neq g}^{G} \Sigma_{gg'}^m \varphi_{g',m}^B \tag{13}$$

Using $\varphi_{g,m}^{B}$ obtained by solving Eq.(13), leakage correction is done as follows :

$$\varphi_{g,m}^{LC} = \varphi_{g,m}^{SA} \frac{\varphi_{g,m}^{B}}{\varphi_{g,m}^{\infty}} \tag{14}$$

where $\varphi_{g,m}^{SA}$ and $\varphi_{g,m}^{\infty}$ are the energy spectrum given by single assembly calculation and the one which satisfies Eq.(13) when B_m is equal to zero, respectively. In Eq.(13), multiplication factor of the global heterogeneous system is approximated by k_{eff}^{NC} which comes from the prior nodal diffusion calculation. If the fuel assembly is homogeneous, $\varphi_{g,m}^{\infty}$ is the same with $\varphi_{g,m}^{SA}$, and $\varphi_{g,m}^{B}$ becomes leakage corrected energy spectrum.

External Spectrum Source Correction

After leakage corrections for all types of material, the effect of external spectrum source is considered and final corrected energy spectrum distribution $\varphi_g^C(\vec{r})$ is evaluated for all regions. During this correction, the spectral condition of the global heterogeneous system is reflected by SI distribution, $\Gamma^{NC}(\vec{r})$, calculated by the prior nodal diffusion solution. More precisely, the following condition is imposed on the external spectrum source correction.

$$\frac{\sum_{g\in F}\varphi_g^C(\vec{r})}{\sum_{g\in T}\varphi_g^C(\vec{r})} = \frac{\varphi_F^C(\vec{r})}{\varphi_T^C(\vec{r})} = \Gamma^{NC}(\vec{r}) \tag{15}$$

Using leakage corrected spectra, the final corrected energy spectrum is given by

$$\varphi_g^C(\vec{r}) = \bar{\varphi}_{g,m}^{LC} - a(\vec{\Gamma}^{NC}) w_{g,m}(\bar{\varphi}_{g,m}^{LC} - \bar{\varphi}_{g,m'}^{LC}) \ , \tag{16}$$

where a, and $w_{g,m}$ are correction factor and weight, respectively. m and m' are material index and external spectrum source index at position $\vec{r}$, respectively. In Eq.(16), bar denotes that its summed value over all energy groups is normalized to unity. If we define normalized weight as

$$\bar{w}_{g,m} = w_{g,m} \frac{\sum_{g\in H}(\bar{\varphi}_{g,m}^{LC} - \bar{\varphi}_{g,m'}^{LC})}{\sum_{g\in H} w_{g,m}(\bar{\varphi}_{g,m}^{LC} - \bar{\varphi}_{g,m'}^{LC})} \ , \tag{17}$$

and use this normalized weight instead of $w_{g,m}$, then sum of corrected energy spectrum over all energy groups becomes unity. Then, Eq.(16) can be expressed as

$$\bar{\varphi}_g^C(\vec{r}) = \bar{\varphi}_{g,m}^{LC} - a(\vec{\Gamma}^{NC})\bar{w}_{g,m}(\bar{\varphi}_{g,m}^{LC} - \bar{\varphi}_{g,m'}^{LC}) \ . \tag{18}$$

If we use Eq.(18) for correction, the correction factor a can be expressed in the following simple form, by summing Eq.(18) over macro group structure with the condition given in Eq.(15) :

$$a(\Gamma^{NC}) = \frac{\bar{\varphi}_{F,m}^{LC} - \bar{\varphi}_F^C(\vec{r})}{\bar{\varphi}_{F,m}^{LC} - \bar{\varphi}_{F,m'}^{LC}} = \frac{\bar{\varphi}_{T,m}^{LC} - \bar{\varphi}_T^C(\vec{r})}{\bar{\varphi}_{T,m}^{LC} - \bar{\varphi}_{T,m'}^{LC}} \tag{19}$$

Now, a remaining problem is the determination of weight for more effective spectrum correction. Figure 4 shows the 40'th group energy spectrum of the previous sample problem as a function of SI. As shown in the figure, energy spectrum within each assembly is almost linear to SI except in the very near proximity of the interface. If we do not use weight in Eq.(18), corrected energy spectrum will be determined along the dotted line in Figure 4. Thus, the optimal weight for external spectrum source correction can be expressed as

$$w_{g,m}^{opt} = \frac{\dfrac{\bar{\varphi}_g^{het}(\Gamma_{m,r1}^{het}) - \bar{\varphi}_g^{het}(\Gamma_{m,r2}^{het})}{\Gamma_{m,r1}^{het} - \Gamma_{m,r2}^{het}}}{\dfrac{\bar{\varphi}_{g,m}^{LC} - \bar{\varphi}_{g,m'}^{LC}}{\Gamma_m^{LC} - \Gamma_{m'}^{LC}}} \ , \tag{20}$$

where

$$\Gamma_m^{LC} = \frac{\sum_{g\in F} \bar{\varphi}_{g,m}^{LC}}{\sum_{g\in T} \bar{\varphi}_{g,m}^{LC}} \ , \qquad \Gamma_{m'}^{LC} = \frac{\sum_{g\in F} \bar{\varphi}_{g,m'}^{LC}}{\sum_{g\in T} \bar{\varphi}_{g,m'}^{LC}} \ ,$$

and *r1* and *r2* denote positions within uniform medium of material *m*. However, we cannot use optimal weight in practical situations because it requires knowledge of the global heterogeneous solution.

From the investigation on various cases, it was observed that the following equation gives most accurate corrected energy spectrum :

$$w_{g,m} = \frac{D_g^m}{\dfrac{2D_g^m D_g^{m'}}{D_g^m + D_g^{m'}}} \ . \tag{21}$$

Thus, weights calculated by Eq.(21) are used for numerical tests.

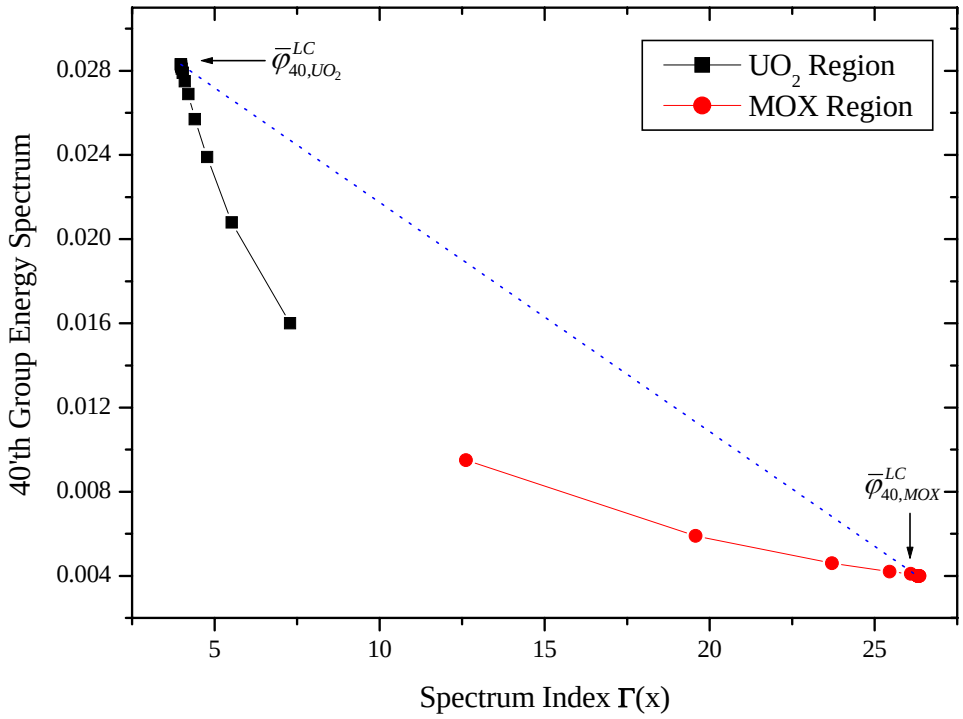


Figure 4. Energy spectrum distribution as a function of SI.

Group Condensation with Corrected Energy Spectrum

By spectrum correction, we can obtain multigroup energy spectra for all regions. With this energy spectrum distribution, group condensation is performed to evaluate spectrum corrected two-group pin-wise heterogeneous cross sections, in which the spectrum effect is reflected, by following equation :

$$\Sigma^{C,ij}_{\alpha H} = \frac{\sum_{g\in H}\int_{V_j}\Sigma^{het,i}_{\alpha g}\bar{\varphi}^{C}_{g}(\vec{r})d\vec{r}}{\sum_{g\in H}\int_{V_j}\bar{\varphi}^{C}_{g}(\vec{r})d\vec{r}}\ , \tag{22}$$

where j is pin index.

By definition of group condensed diffusion coefficient given by Eq.(2), it is obvious that diffusion coefficient must be condensed by current not by energy spectrum. Therefore, we use the following equation for evaluating condensed diffusion coefficient :

$$D^{C,ij}_{H} = \frac{\left|\sum_{g\in H}\hat{J}^{C,ij}_{g}\right|}{\left|\sum_{g\in H}\frac{\hat{J}^{C,ij}_{g}}{D^{het,i}_{g}}\right|}\ , \tag{23}$$

where

$$\hat{J}_g^{C,ij} = \frac{\sum_k \int_{S_k^j} \vec{J}_g^{C,i}(\vec{r}) \cdot d\vec{S}}{\sum_k S_k^j} = \frac{\int_{V_j} -D_g^{het,i} \nabla^2 \overline{\varphi}_g^C(\vec{r}) d\vec{r}}{\sum_k S_k^j} \quad . \tag{24}$$

From multigroup diffusion equation, the numerator in Eq.(24) can be calculated by

$$\int_{V_j} -D_g^{het,i} \nabla^2 \overline{\varphi}_g^C(\vec{r}) d\vec{r} = \int_{V_j} \left(\frac{\chi_g}{k_{eff}^{NC}} \sum_{g'}^{G} \nu \Sigma_{fg'}^{het,i} \overline{\varphi}_{g'}^C(\vec{r}) + \sum_{g' \neq g}^{G} \Sigma_{gg'}^{het,i} \overline{\varphi}_{g'}^C(\vec{r}) \right.$$
$$\left. - \Sigma_{ag}^{het,i} \overline{\varphi}_g^C(\vec{r}) - \sum_{g' \neq g}^{G} \Sigma_{g'g}^{het,i} \overline{\varphi}_g^C(\vec{r}) \right) d\vec{r} \quad . \tag{25}$$

II.3 Generation of Rehomogenized Assembly Parameters

In SCM, flux distributions required for spatial homogenization is obtained by two-group, heterogeneous, single assembly calculations with spectrum corrected cross sections and albedo boundary conditions. We performed these calculations via fine mesh FDM solution method. Albedo boundary conditions for each assembly are provided by the prior nodal diffusion calculation and defined as

$$\alpha_H^{i,k} = \frac{J_H^{NC}\big|_{S_k^i}}{\phi_H^{NC}\big|_{S_k^i}} \quad . \tag{26}$$

Once these calculations are done, rehomogenized cross sections can be obtained by Eq.(4) using the two-group heterogeneous flux distribution. Finally, to update discontinuity factors, homogeneous one-node calculations for each assembly are performed with rehomogenized cross sections by nodal solution method, which should be the same with that used for global homogeneous calculation.

III. NUMERICAL TESTS AND RESULTS

We applied this rehomogenization method to the AFEN code and test problems were solved to evaluate its performance. All test problems are pin-wise homogenous. Table I gives data for pins and fuel assemblies. Lattice configurations are given in Figure 5.

Pin-wise homogeneous 45 group cross section data were generated by the transport theory code HELIOS. [6] All heterogeneous multigroup calculations for reference solution and single assembly homogenization were done by VENTURE with 45 group cross sections and 6×6 mesh division per pin. Rehomogenization of fuel assembly was carried out using the results of AFEN calculation with homogenized diffusion parameters by single assembly homogenization method, called AFEN-SA. From AFEN-SA calculation, the detailed pin-wise data were reconstructed by a form function method.

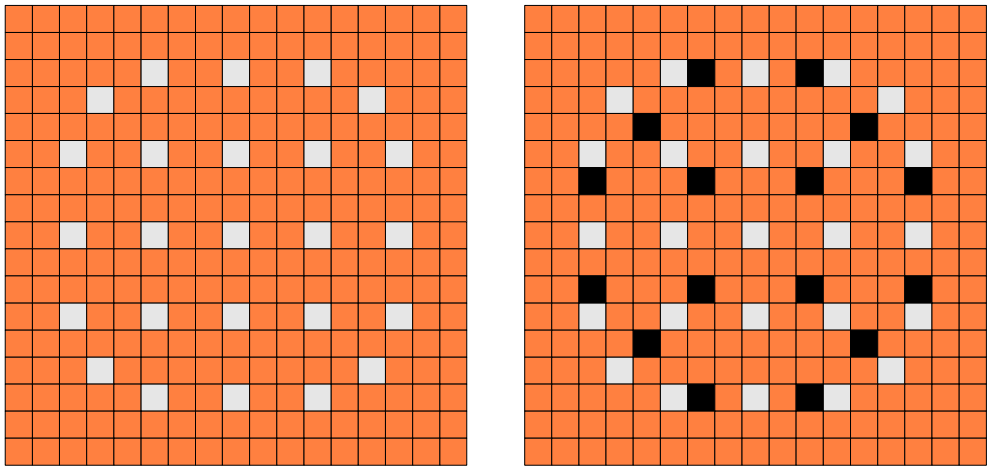
Figures 6 and 7 show the configuration of the problems and results of test problems 1 and 2. To induce large amount of interface currents, problems including burnable absorber (BA) loaded assembly and MOX assembly were configured. Figures 6 and 7 show that rehomogenization method based the spectrum correction method reduces the errors significantly both in multiplication factor and assembly averaged power.

Test problems 3 and 4 are small core problems. The homogenized diffusion parameters of reflector region were generated by two-assembly calculation consisting of peripheral fuel assembly and reflector. In SCM, rehomogenization of reflector region was not considered.

The configuration and results are given in Figures 8 and 9. In test problem 3, the error in multiplication factor by AFEN-SCM is over 0.1% but the error is reduced by a factor of 3 compared with the result of AFEN-SA. The large error of AFEN-SCM in assembly averaged power is also found in test problem 4 at peripheral assembly. However, we find that AFEN-SCM gives much better results than AFEN-SA.

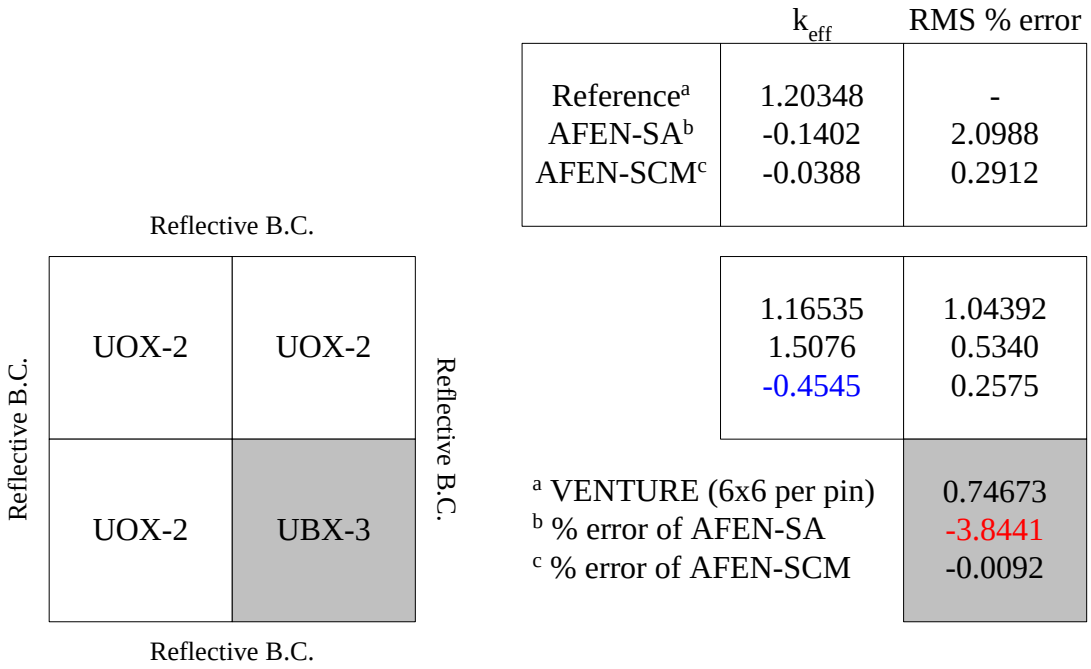
Table I. Data for Pin and Fuel Assembly

- Lattice : 17×17	- Assembly Pitch : 21.42 cm
- Pin Pitch : 1.26 cm	- Number of Waterhole : 25
- Type of Pin : UO_2 : 2.0 wt%, 3.0 wt%, 4.0 wt% MOX : 7.0 wt% BA (gadolinia) Waterhole Reflector	- Types of Assembly UOX-2 (2.0 wt% UO_2) UOX-3 (3.0 wt% UO_2) UOX-4 (4.0 wt% UO_2) MOX-2 (7.0 wt% MOX) UBX-3 (3.0 wt% UO_2, BA)



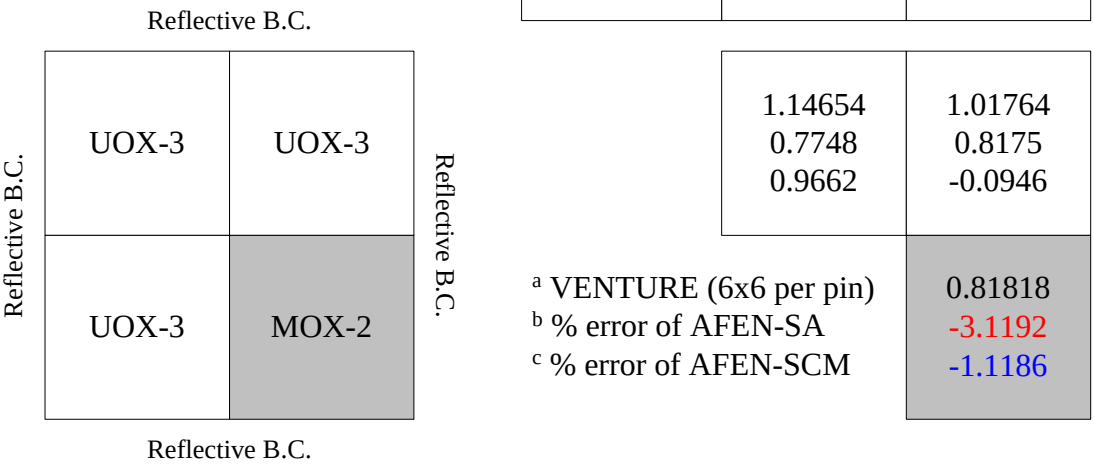
(a) Fuel assembly without BA (b) Fuel assembly with BA

Figure 5. Lattice configuration of fuel assemblies.



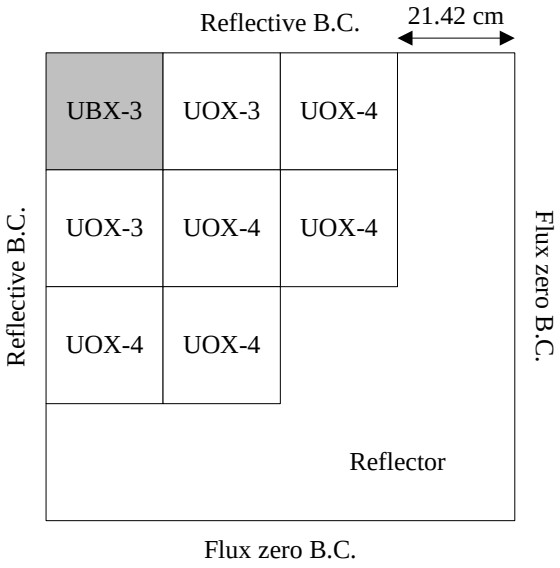
	k_{eff}	RMS % error
Reference[a]	1.20348	-
AFEN-SA[b]	-0.1402	2.0988
AFEN-SCM[c]	-0.0388	0.2912
	1.16535	1.04392
	1.5076	0.5340
	-0.4545	0.2575
[a] VENTURE (6x6 per pin)		0.74673
[b] % error of AFEN-SA		-3.8441
[c] % error of AFEN-SCM		-0.0092

Figure 6. Configuration and result of test problem 1.



	k_{eff}	RMS % error
Reference[a]	1.30874	-
AFEN-SA[b]	0.1881	1.7078
AFEN-SCM[c]	-0.0027	0.7421
	1.14654	1.01764
	0.7748	0.8175
	0.9662	-0.0946
[a] VENTURE (6x6 per pin)		0.81818
[b] % error of AFEN-SA		-3.1192
[c] % error of AFEN-SCM		-1.1186

Figure 7. Configuration and result of test problem 2.

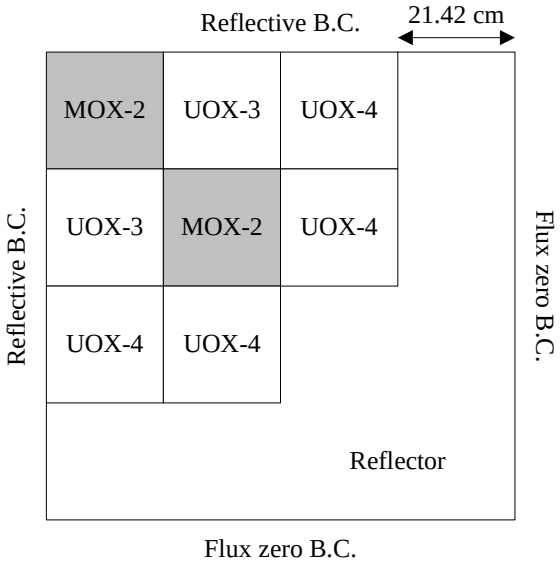


	k_{eff}	RMS % error
Reference[a]	1.24639	-
AFEN-SA[b]	0.3275	1.9874
AFEN-SCM[c]	-0.1090	0.5832

0.72190	1.14690	1.01819
-4.6445	0.9534	0.4954
0.0138	0.1012	-0.2642

[a] VENTURE (6x6 per pin)	1.23011	0.85891
[b] % error of AFEN-SA	2.0153	-1.3520
[c] % error of AFEN-SCM	-0.9965	0.8852

Figure 8. Configuration and result of test problem 3.



	k_{eff}	RMS % error
Reference[a]	1.23272	-
AFEN-SA[b]	0.5566	2.8860
AFEN-SCM[c]	-0.0587	1.2741

1.17426	1.15251	1.02453
-2.9333	3.9637	0.7542
-0.0649	-0.9899	-0.1664

[a] VENTURE (6x6 per pin)	1.00251	0.73458
[b] % error of AFEN-SA	-3.8986	-2.2666
[c] % error of AFEN-SCM	-0.6686	2.2927

Figure 9. Configuration and result of test problem 4.

IV. CONCLUSIONS

To obtain more accurate results by nodal diffusion calculation, we proposed a new rehomogenization method, named spectrum correction method, based on multigroup energy spectrum correction and two-group heterogeneous single assembly calculation with non-zero current boundary condition. SCM does not require additional lattice level calculation and it can be directly applied to existing nodal diffusion calculation scheme without any difficulties.

To evaluate its performance, we applied SCM to the AFEN method and solved several test problems. The results of numerical tests show that SCM gives much better results than existing homogenization methods using single assembly calculation with zero current boundary condition and can significantly reduce the error of nodal diffusion calculation both in multiplication factor and assembly averaged power. From the results, we can ascertain that the spectrum effect caused by interface currents can be successfully taken into account by SCM.

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