Investigation of Spatial Self-shielding Effects on Control Rod Worth for PGSFR

*Min Jae Lee, Jong Hyuck Won and Jae-Yong Lim
Korea Atomic Energy Research Institute (KAERI)
**Corresponding author: lmj@kaeri.re.kr*

1. Introduction

The Korea Atomic Energy Research Institute (KAERI) is developing a Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR), which is a 150MWe fast reactor with metallic fuels [1]. The reactor core design procedure for PGSFR follows ANL's modern neutronics code suites, such as MC^2-3/DIF3D/REBUS-3 [2, 3]. The multi-group cross section libraries are directly generated from MC^2-3 with homogeneous models. Meanwhile the neutron spectrum for group-collapsing is provided from a simple TWODANT R-Z model based on the ultra-fine energy group. However, this procedure cannot reflect the spatial self-shielding effects especially for the control rods. The calculated control rod worth based on a homogeneous model tends to overestimate the control rod worths, which leads to increased uncertainty in the reactor core design procedure. In order to improve the accuracy of calculated control rod worth, a heterogeneous model of control assembly is suggested and the improvement was assessed in this work.

2. Development of 1D Control Assembly Model

The heterogeneous control assembly model was developed based on the MC^2-3's 1D CPM capability for cylindrical geometry. In order to develop a 1D model from 3D heterogeneous control assembly, the radial boundary should be determined first. Fig. 1 shows the approach for finding the radial boundaries which is equivalent to a hexagonal lattice. The radial ring diameter is chosen to preserve the area of hexagon. The thickness of a ring is then calculated to preserve the inner area and out area as indicated by different colors in Fig. 1.

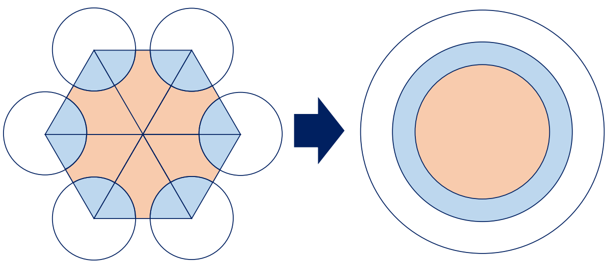

Fig. 1. Schematic diagram for finding radial boundary

The control assembly in PGSFR consists of 17 control rod pins as plotted in Fig. 2. There are double-layered ducts outside of the control rod pins. The heterogeneous model for the control assembly was developed by separating the B_4C pellets from the control rod pins, and sodium and other structure materials are homogenized. The geometry of 1D control assembly model is plotted in Fig. 3. By separating B_4C pellets, the increased neutron absorption will reduce the neutron flux in the pellets, which results in reduced absorption reactions compared to a homogeneous model.

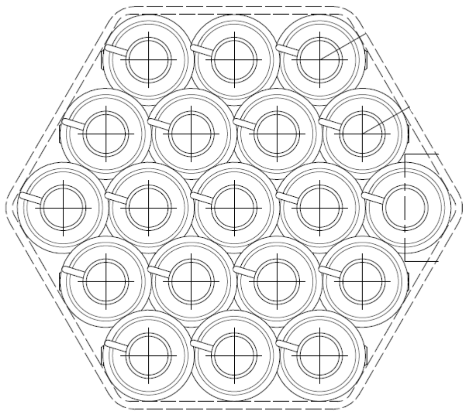

Fig. 2. Cross-sectional view of a control assembly

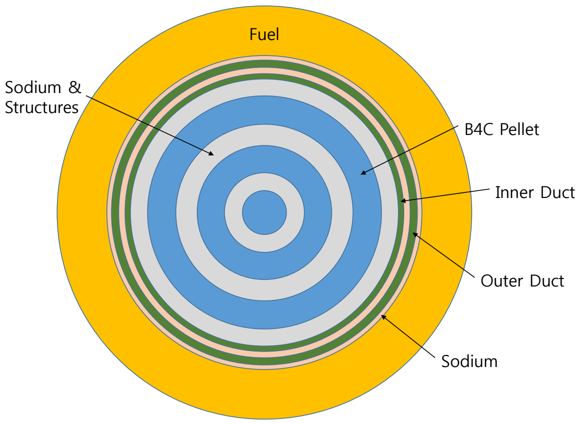

Fig. 3. 1D control assembly model for PGSFR

The MC^2-3 code requires fissionable isotopes to perform 1D CPM calculation, so a fuel region is included outside of the control assembly. The fuel region should be thick enough so that one can assume the control rod is inserted in an infinite reactor core. Note that, the fission neutrons coming into control assembly can be considered to have realistic energy spectrum, TWODANT R-Z procedure can be omitted.

3. Results of Control Rod Worth

The spatial self-shielding effects were examined by calculating the control rod worth with two different multi-group cross section sets; one from homogeneous control assembly model, and the other from the 1D model. For the Beginning Of Cycle (BOC) and the End Of Cycle (EOC) of the fresh PGSFR core, both primary and secondary control rod worth were calculated by the MC^2-3/DIF3D codes. Note that all the control primary and secondary control rod assemblies are moved together in the calculations. The core configuration of PGSFR is given in Fig. 4 and the calculated control rod worths were summarized in Tables I and II.

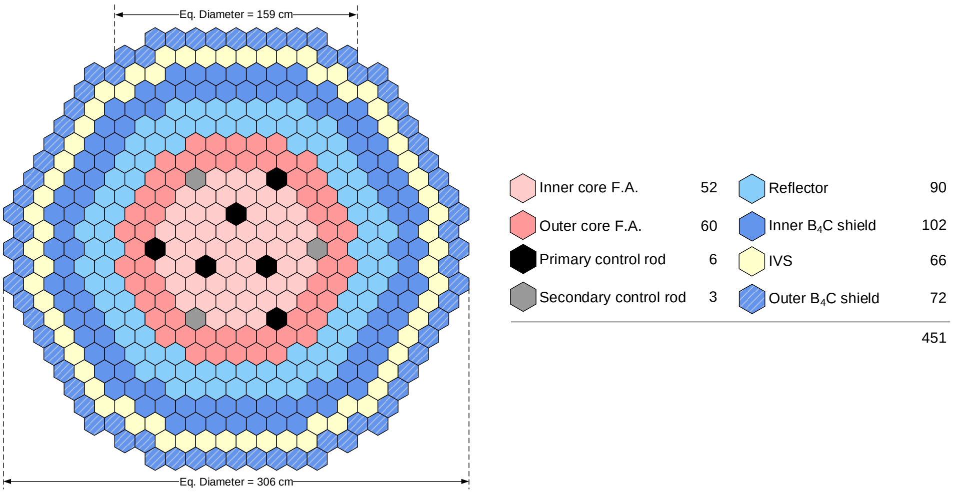

Fig. 4. PGSFR Core Loading Pattern

Table I: Primary Control Rod Worth

BOC				EOC			
CR position [cm]	Worth [pcm]			CR position [cm]	Worth [pcm]		
	0D	1D	Difference [%]		0D	1D	Difference [%]
97.04 (Bottom)	-13653	-12384	10.3	97.04 (Bottom)	-15381	-13927	10.4
108.435	-12693	-11507	10.3	111.544	-14017	-12690	10.5
119.830	-10844	-9845	10.2	126.048	-11266	-10235	10.1
131.225	-8314	-7573	9.8	140.552	-7787	-7113	9.5
142.619	-5685	-5195	9.4	155.056	-4590	-4209	9.1
154.014	-3407	-3117	9.3	169.560	-2159	-1980	9.0
165.214	-1697	-1551	9.4	177.560	-1193	-1094	9.0
176.414	-567	-518	9.5	186.427	-438	-402	8.9

Table II: Secondary Control Rod Worth

BOC				EOC			
CR position [cm]	Worth [pcm]			CR position [cm]	Worth [pcm]		
	0D	1D	Difference [%]		0D	1D	Difference [%]
97.04 (Bottom)	-4433	-3990	11.1	97.04 (Bottom)	-5240	-4701	11.5
108.435	-4153	-3734	11.2	111.544	-4826	-4326	11.6
119.830	-3645	-3274	11.3	126.048	-4033	-3613	11.6
131.225	-2926	-2626	11.4	140.552	-2950	-2644	11.6
142.619	-2102	-1885	11.5	155.056	-1821	-1633	11.6
154.014	-1310	-1173	11.7	169.560	-877	-785	11.6
165.214	-670	-599	11.9	177.560	-487	-436	11.7
176.414	-230	-205	12.1	186.427	-179	-161	11.6

According to the calculated control rod worths, the discrepancy between 0D and 1D model results are about 10 % for primary, and 12% for secondary. Since enriched B_4C pellets are loaded in the secondary control assembly, the spatial self-shielding effects turned out to be more important for secondary. For primary, the difference between 0D and 1D results tend to be increased when the control rod is inserted, but the opposite phenomenon was observed for secondary. The reason was not identified yet, however, the magnitude can be considered insignificant.

Additionally, the control rod worths of both primary and secondary were calculated by MCNP and they are given in Table III. The error of control rod worth turned out to be only about 1% when the 1D model is used. Therefore we conclude that the spatial self-shielding effects can be reasonably simulated by providing the 1D heterogeneous control assembly model.

Table III: Control rod worth at BOC (All Rods In)

CR Type	1D	MCNP	Difference [%]
Primary	-12383.6	-12260.3	1.0
Secondary	-3990.3	-3977.8	0.3

4. Conclusions

Only homogeneous models are used in the conventional PGSFR neutronics code system, the spatial self-shielding effects were hardly considered in the design procedure. Therefore, the control rod worth in PGSFR was slightly overestimated. In order to improve the accuracy of control rod worth, a 1D heterogeneous control assembly model was developed and the improvement was assessed. When the 1D heterogeneous model is used, the control rod worth was decreased by about 10% for primary, and 12% for secondary compared to homogeneous model cases. Compared to the MCNP calculation, the error of control rod worth by 1D model appeared about 1%, so quite accurate control rod worth can be achieved by the suggested 1D model.

ACKNOWLEDGEMENTS

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