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Multi-group Discontinuity Factors of Control Assembly in Sodium-Cooled Fast Reactor Analysis

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1. Introduction

In previous work [1], a Monte Carlo-deterministic hybrid method has been investigated for the analysis of a sodium-cooled fast reactor (SFR). It was shown that the hybrid method could be successfully applied to a 3-D, TRU-bearing, and unrodded burner SFR.

In Ref. 2, the hybrid method was applied to a heavily rodded SFR core for 9-group cross sections. For a better modeling of the self-shielding effects and analysis, RZ-embedded RZ (RRZ) was proposed and the nodal equivalence theory was introduced to improve the accuracy of the hybrid method. Consequently, application of the discontinuity factor (DF) in the control assembly of the SFR results in a largely improved accuracy. To apply the nodal equivalence theory, a simple cylindrical spectral geometry was used to determine the DFs of the control assembly region. In this work, the DF of the control assembly region is further characterized for 9- and 24-group models.

2. Monte Carlo Cross Section Generation

In the previous study on the hybrid method [1], the multi-group cross sections were generated by transforming the reactor into a simple RZ geometry through a simple volume-weighted smearing process. This is shown in Fig. 1 for a 300 MWe SFR problem considered in Refs. 1&2.

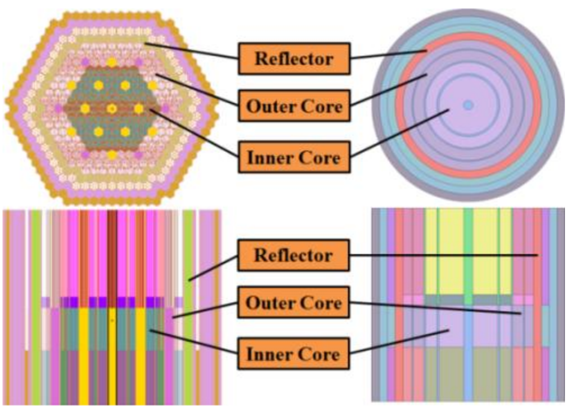

Figure.1 300 MWe SFR TRU burner core

Ref. 2 introduced the RRZ model to the homogenized core in order to better consider the self-shielding effect of the control rods for the heavily rodded core. The rodded RRZ model is depicted in Fig. 2, where each control assembly is modeled with an embedded RZ geometry.

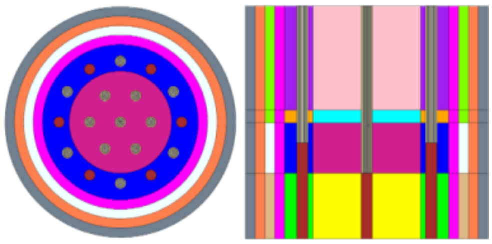
Figure.2 RRZ simplified model

3. Discontinuity Factor for Control Assembly

As shown Fig. 2, all the control assemblies in the inner core region are fully inserted with half of the remaining control assemblies inserted 30 cm from the top of the core to make the reactor near critical.

As discussed in Ref. 2, a relatively large error in the rodded RRZ core was observed in the standard diffusion analysis due to overestimation of the control rod worth. In order to overcome these limitations in the control assembly, a unique application of the well-known nodal equivalence theory was proposed in Ref. 2 and a simple cylindrical spectral geometry, shown in Fig. 3, was used to determine the DF values. It was shown that the accuracy of control assembly modeling can strongly affect the whole core analysis in Ref. 2.

In this paper, we verify the effect of the DFs on core analysis and the sensitivity of the DFs to the spectral geometry model. The spectral geometry problem in Fig. 3 is analyzed by using MCNP5 (50,000 histories per cycle, 100 inactive and 1,000 active cycles) to get the reference solution. Then, fixed-source group-wise diffusion equations are solved to find the DFs of the control assembly region on the interface. In this study, 3 values of fuel radius (R_f) are considered to determine the DFs.

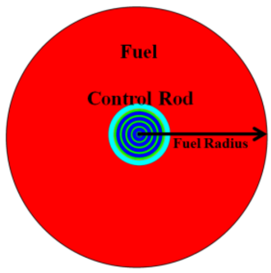

Figure.3 Spectral geometry to determine discontinuity factors of control assembly

3. Numerical Results and Analysis

In this study, 9- and 24-group cross sections, including high-order scattering cross sections, were generated using MCNP5 for the RRZ model in Fig. 2. For all MCNP5 calculations, the ENDF/B-VII.0 library was used. The reference solution was also obtained with MCNP5 (100,000 histories per cycle, total 3,000 cycles). The calculated group-wise DFs for the spectral geometry are shown on Table I. It is clear that DFs are not sensitive to the size of the spectral geometry.

Table I. Discontinuity factors of control assembly

Energy Group	DF for several fuel region radius (R_f) 25cm	50cm	100cm
1	1.132	1.118	1.138
2	1.092	1.089	1.084
3	1.090	1.080	1.080
4	1.096	1.091	1.084
5	1.092	1.085	1.087
6	1.155	1.152	1.153
7	1.232	1.233	1.233
8	1.168	1.170	1.178
9	1.070	1.073	1.070
10	1.138	1.140	1.140
11	1.186	1.192	1.192
12	1.050	1.055	1.047
13	1.148	1.156	1.153
14	1.030	1.041	1.038
15	1.066	1.077	1.083
16	1.031	1.043	1.034
17	1.177	1.189	1.189
18	1.072	1.090	1.084
19	1.021	1.036	1.029
20	1.220	1.235	1.222
21	1.050	1.072	1.063
22	2.068	2.075	2.059
23	2.199	2.182	2.245
24	3.320	3.492	3.493

Using the MCNP5 9- and 24-group cross sections and the DF values in Table I, the whole core 3-D analysis was done with the DIF3D code for the rodded SFR problem. The results are summarized in Table II and Fig. 4.

Table II. Estimation of the k-eff

Code	R_f	k_{eff}	Error (pcm)
MCNP5	Reference	1.00570±0.00003	0
Hybrid (9G)	Non-DF	0.99489	-617.58
Hybrid (9G)	25cm	1.00554	-16.21
Conventional diffusion(24G)	--	0.986165	-1942.43
Hybrid (24G)	Non-DF	0.996650	-899.87
Hybrid (24G)	25cm	1.00310	-258.75
Hybrid (24G)	50cm	1.00332	-236.53
Hybrid (24G)	100cm	1.00326	-242.58

Table II indicates that introduction of DFs greatly improves the k-eff prediction for the rodded SFR problem, and the solution is not sensitive to the size of the spectral geometry. It is also noted that 9-group model provides a much better accuracy than 24-group one.

Due to the limited space, Fig. 4 compares only three results obtained with the DF-based schemes. From Fig. 4, one can note that the power profiles are rather comparable for both 9- and 24-group models if the DF information is utilized. Meanwhile, the maximum error in the power distribution is -1.76% in the case of the conventional diffusion theory method. Also, it is mentioned that the maximum power error in the hybrid method without DFs is -5.95% for the 9-group model and -5.51% for the 24-group one.

Based on the above results, it is clear that the application of nodal equivalence to the control assembly cross section works well not only for 9-group but also for 24-group models in the SFR core analysis. One can also note that the DF of control assembly does not strongly depend on the spectral geometry and the necessary DF values can be adequately determined by using appropriate spectral geometry for DF.

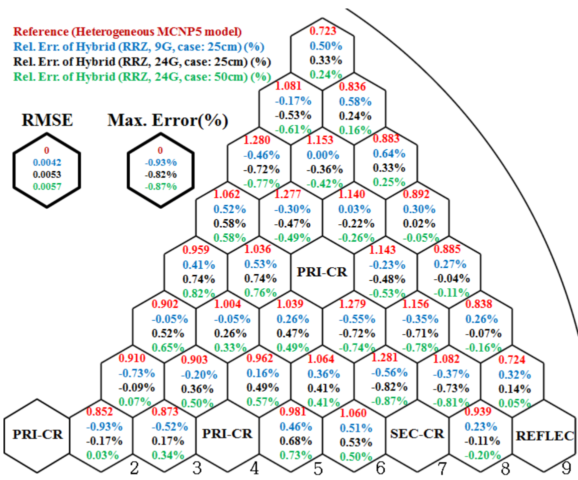

Figure.4 Comparison of assembly power distribution

4. Conclusion

Conventional nodal equivalence theory using DF correction of the control assembly cross sections has shown good performance in a heavily rodded SFR core. In addition, it is shown that the DF values are not sensitive to the size of the spectral geometry to determine the DF in SFR core analysis.

REFERENCES

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