Effect of Transport Correction on the Multiplication Factor and Power Distribution in the OECD/NEA MHTGR-350 Benchmark using McCARD

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1. Introduction

Unlike many other multi-group benchmark problems, first-moment scattering matrices are provided in the MHTGR-350 benchmark [1]. To reflect this data, Transport Correction (TC) can be a way. Although directly using the anisotropic scattering data would be preferable to adjusting via TC, implementing direct anisotropic scattering is often restricted by code capabilities. This is precisely the case for the McCARD code. The benchmark problem was already solved before [2, 3] by using the McCARD and MCS codes. By taking a look into the calculation results, it is clear that the TC was done for both works.

At this point, a question arises regarding the quantitative discrepancy introduced by applying TC versus omitting it. The benchmark was solved twice with or without TC for three cases such as the reference, the rod out and the rod in. Then, we can extract the multiplication factor, rod worth and power distribution differences between two results.

These differences will be dependent on the reactor type. Considering the thermal neutron spectrum of a Very High Temperature Reactor (VHTR), similar to a typical Pressurized Water Reactor (PWR), the difference will be small compared with those of fast spectrum based on the qualitative expectation. But verifying quantitatively the exact amount of this gap will be meaningful for further research and development of nuclear engineering.

2. Benchmark Description

The benchmark is composed of three exercises including neutronics and thermal-hydraulics problems [4]. The neutronics only problem is considered in this study, namely exercise 1. Since the benchmark is well known, unnecessary details are omitted. Only radial and axial views are described for simplicity along with control rod worth calculation conditions and auxiliary information, are briefly described [1].

2.1 Radial and Axial Views

In Fig. 1, there is no symmetry for the axial direction as the thicknesses of the top and bottom reflectors differ. Also, control rod is parked at boundary between top reflector and active core 1 for the rod out case.

In Fig. 2, rotational symmetry can be applied for the azimuthal direction. However, because McCARD does not support rotational boundary condition, the full-core geometry is described in the McCARD input.

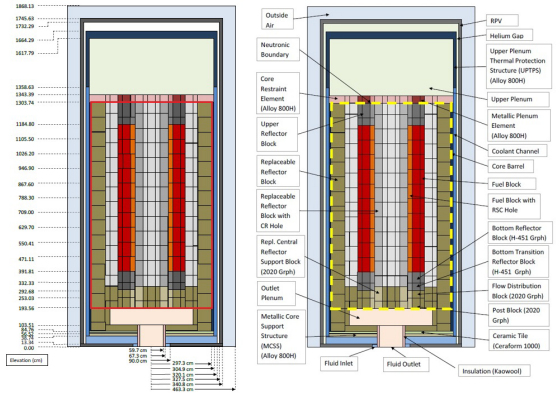


Fig. 1. Axial View of the MHTGR-350 Benchmark

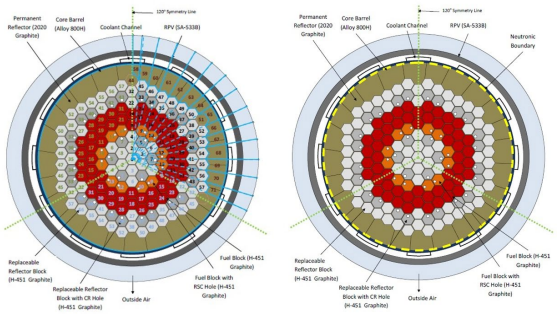


Fig. 2. Radial View of the MHTGR-350 Benchmark

2.2 Auxiliary Information

The control rod worth calculation is difference of reactivities of those at axial levels of 391.81 cm and 1184.8 cm in Fig. 1. The reference case has control rod position at the boundary between active core region 1 and 2, which is 1105.50 cm.

The block pitch (side-to-side length) is 36 cm. The active core region is marked with red in Fig. 2. The simplified cross-section includes 26 group total, fission, nu-fission cross sections, fission spectrums and diffusion coefficients. The 0th-moment and 1st-moment scattering matrices are also provided.

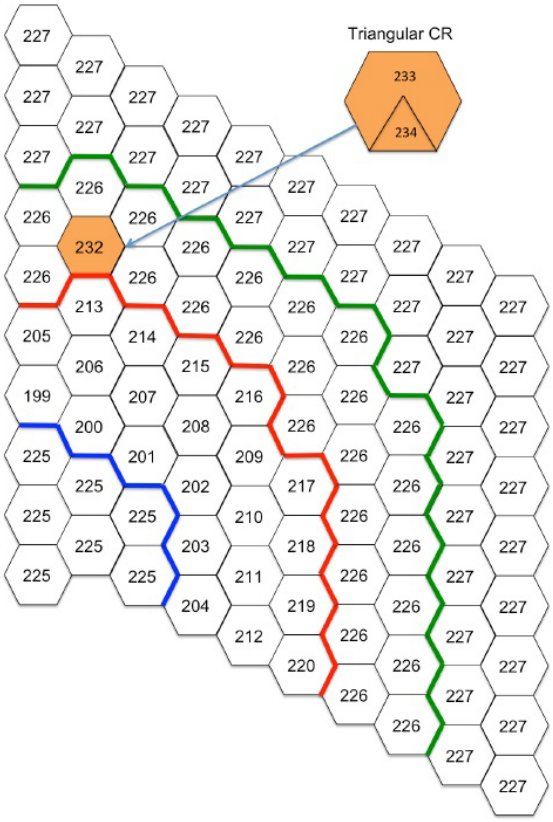


Fig. 3. Cross-Section Numbering for the Active Core Level 10

As shown in Fig. 3, the MHTGR-350 benchmark can proceed with two options for control rod geometry. One is hexagonal homogenized control rod block, another is control rod block containing triangular region which has two different homogenized regions. The first option is used in this study.

3. Transport Correction

It doesn't matter whether it's a row sum or a column sum in this benchmark for TC. Both calculations have almost no difference and it is internally measured. In this study the column sum result is shown. Bell-Hansen-Sandmeier (BHS) approximation [5] is adopted for the TC:

$$\Sigma_{s,gg'} = \Sigma_{s0,gg'} - \delta_{gg'} \sum_{g'}^{G} \Sigma_{s1,gg'}$$

To run McCARD, the MATXS format is required. During the TC adjustment for the MHTGR-350 benchmark, unphysical negative values may occur in the scattering or capture cross sections. To prevent these unphysical (negative capture and scattering cross sections) values, artificial background values were added consistently and adequately (making negative values to slightly positive) for every composition.

4. Numerical Results

McCARD simulation was done with 1 million particles, 300 inactive cycles and 800 active cycles to minimize the uncertainties of results. As presented in Table I, the Standard Deviation (S.D.) of the multiplication factor (k_eff) was within 2 pcm for all cases. The S.D. of power is below 0.1% for all regions and cases.

The validity of the result of the McCARD simulations done in this study is verified with official benchmark result book [6] and pre-existing studies referred already [2], [3]. In Table I through Table IV, note that case identification is based on the first paragraph in the section 2.2.

Table I: Multiplication Factor and Rod Worth

	Case	with TC (A)	w/o TC (B)	Diff. (B-A, pcm)
k_{eff} (S.D., pcm)	Ref.	1.06890 (2)	1.07151 (2)	261
	Rod Out	1.06958 (2)	1.07220 (2)	262
	Rod In	1.05994 (2)	1.06301 (2)	307
Rod Worth (pcm)		850	806	-44

Table II: Axial Power Distribution Errors

Case	Error (%)	
Ref.	RMS	0.98
	Max. Rel.	1.75
Rod Out	RMS	1.52
	Max. Rel	2.37
Rod In	RMS	1.54
	Max. Rel.	2.47

Table III: Radial Power Distribution Errors

Case	Error (%)	
Ref.	RMS	0.59
	Max. Rel.	0.93
Rod Out	RMS	0.58
	Max. Rel	0.95
Rod In	RMS	0.58
	Max. Rel.	0.91

Table IV: 3-D Power Distribution Errors

Case	Error (%)	
Ref.	RMS	1.17
	Max. Rel.	2.66
Rod Out	RMS	1.65

	Max. Rel	3.30
Rod In	RMS	1.67
	Max. Rel.	3.34

In Tables I through IV, the discrepancies generally increase with the structural and operational complexity of the problem (e.g., the Rod In case). Expectedly, the 3D spatial errors are larger than the 2D axial and radial errors, which are spatially integrated quantities.

5. Conclusions

Applying TC in this study significantly reduces the total and fast-group self-scattering cross sections. Consequently, neutrons experience fewer scattering events, leading to less frequent directional changes compared to the case without TC. The resulting preference for straight-line movement increases neutron leakage. This logic can explain the reduction of multiplication factor in Table I. Reduced self-scattering cross section makes down scattering frequently once scattering occurs.

It is clear that a certain directional power comparison with an integration can ignore the real amount of error from this study. (The contribution of the axial distribution is greater than that of the radial distribution by considering Tables II through IV.). So hopefully it is best to compare 3 dimensional power comparison rather than 2 dimensional power comparison.

Due to the thermal spectrum of the MHTGR-350, the overall effect of TC on reactivity is relatively minor and often neglected. But it is noted that significant amount of 3-dimensional power error along with marginal discrepancy of multiplication factor can appear considering this result. Also, it is clear that proper transport correction should be considered in the future in the VHTR analysis.

Acknowledgement

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