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Uncertainty Analysis Results for MHTGR-350 Benchmark 3D Cores

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has developed a sensitivity and uncertainty analysis code based on the Generalized Perturbation Theory (GPT) [1], MUSAD (Modules of Uncertainty and Sensitivity Analysis for DeCART) [2,3]. The code is used in the lattice physics analysis step of the two-step uncertainty analysis procedure [4]. It can provide sensitivities and uncertainties for general responses in connection with the DeCART (Deterministic Core Analysis based on Ray Tracing) [5] code and also generates randomly sampled few-group cross section sets for the CAPP (Core Analyzer for Pebble and Prism type VHTRs) [6] code which is a core simulation code for block type HTGR cores.

In this study, the DeCART/MUSAD/CAPP code system was applied to uncertainty analysis for the MHTGR-350 Exercise II-2 3D core benchmark proposed by the HTGR UAM [7] and the uncertainties for the neutronic parameters such as the k_{eff}, the axial offset, the power distribution, and the control rod worth were evaluated. Moreover, this paper presents the comparisons of the uncertainty for the benchmark problems based on the two covariance data originated from ENDF/B-VII.1 and ENDF/B-VIII.0.

2. Methods and Results

2.1 Uncertainty analysis code system

The MUSAD code can evaluate sensitivities and uncertainties for general responses. The uncertainty for an eigenvalue of the neutron transport equation and the few-group cross section are calculated based on the eigenvalue perturbation theory and GPT, respectively. Furthermore, the code can generate randomly sampled few-group cross section sets for the stochastic analysis of the core parameter uncertainty in the 3-D core simulation step.

The TANUA (Tools for Automatic Neutronics Uncertainty Analysis) was developed for assisting the uncertainty analysis based on the random sampling method. It consists of four modules, merge of covariance matrix for nuclides, preprocessing of the few-group cross section sets, automatic generation of CAPP input files and automatic execution, and post-processing of CAPP outputs. The tools help the analysis between MUSAD and CAPP for efficiently processing randomly sampled files without cumbersome work.

Figure 1 shows the procedure of the code system.

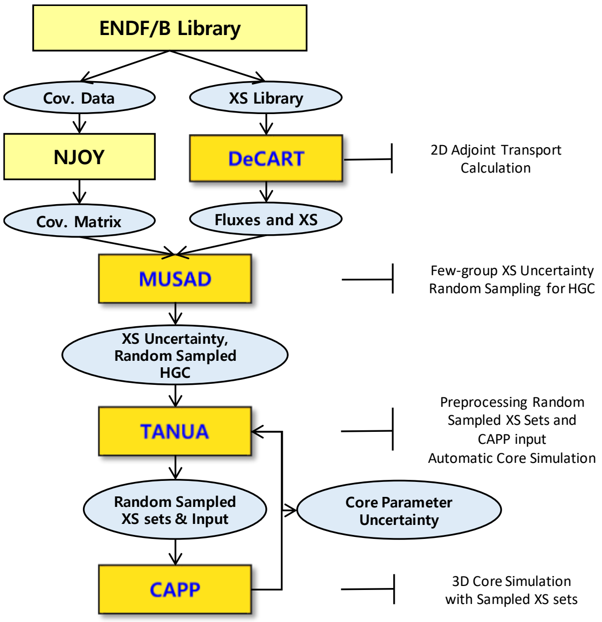

Fig. 1. Uncertainty Analysis Code System for HTGR

2.2 MHTGR-350 Exercise ii-2 Benchmark Analysis Results

HTGR UAM proposed Exercise II-2 problem for 3-D full core neutronics calculations. It is noted that the core problem involves steady-state neutronics calculations at HFP (Hot Full Power) condition without any temperature feedback. It consists of two problems, Exercise II-2a and II-2b. The first one is composed of the fresh fuel block which is identical to Exercise I-2a given for Phase I. It consists of the fuel pin model, Exercise I-1b, which has a DH fuel compact with randomly dispersed UCO TRISO particles as shown in Figure 2. Figure 3 shows the radial configuration of the Exercise II-2a 1/6 core. For the detailed specification of the benchmark, the reports [7] can be referred to.

The Exercise II-2b is composed of the fresh fuel block, F, and the burnt fuel block, B, which is identical to Exercise I-2b given for Phase I. Figure 4 presents the radial configuration of the 1/3 core with a control block. The 3-D core has axially 4 bottom reflector layers, 10 identical fuel layers, and 2 top reflector layers. It has a reflector block with a control rod partially inserted in position ‘C’ shown in Figure 4.

The core parameter uncertainties for MHTGR-350 Exercise II-2a and II-2b were quantified using DeCART/MUSAD/CAPP code system. In this calculation, 7 major isotopes (^{235}U, ^{236}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{12}C), and 4 cross section types (capture, fission, ν, scattering) with a 10-group structure were used and the number of few-group cross section sets was determined as 600 from the previous case study [8]. The code system used the 190-group cross sections originated from ENDF/B-VII.1 and the covariance data processed from ENDF/B-VII.1 and ENDF/B-VIII.0. Because the covariance data is relative value, the effect by the different version between the cross section library and the covariance data is very small.

Table I shows the k_{inf} uncertainty for Exercise I-2b based on the two covariance data. The reference values are obtained by the Monte Carlo code, McCARD [9]. It reveals that there are significant differences between two covariance data versions. The contribution by uranium nuclides in the new covariance data be lower to that based on the previous version. However, the contribution by the ^{239}Pu capture-capture cross section increases to 320% in the new version. Thus, the total uncertainty increase to 153% in the new covariance data.

Table II provides the uncertainties of the k_{eff} and axial power offset for the 3-D core problem, Exercise II-2a. It is clear that the uncertainty of k_{eff} significantly decreases in the ENDF/B-VIII.0 covariance data. In the case of the axial power offset, its uncertainty is relatively large because the absolute value is very small. It is attributed to the axially symmetric power distribution in the no temperature feedback problem. Figure 5 shows the relative power distribution and their uncertainties for the Exercise II-2a. The uncertainties based on the new covariance data is slightly higher than those based on the old version, because of the slight increase of the contribution by the ^{235}U fission-fission cross section.

Table III shows the core parameter uncertainties for the Exercise II-2b which consists of the fresh and burnt fuel block. The difference of the k_{eff} uncertainty between two covariance data versions is not large, if compared with the Exercise II-2a result. The decreased contributions in the fresh fuel block are cancelled out the increased ones in the burnt fuel block, Exercise I-2b. The axial power offset is slightly higher due to the partially inserted control rod and its uncertainty is lower by 1.53%. Figure 6 shows the radial power distribution and their uncertainties based on two covariance data for the problem. The increase in the new covariance data is much higher due to the effect of the ^{235}Pu fission-fission cross section, if compared with the Exercise II-2a.

3. Conclusions

In this study, the uncertainty analysis on the MHTGR-350 Exercise II-2 3D core benchmark proposed by the HTGR UAM was performed based on the ENDF/B-VII.1 and ENDF/B-VIII.0 covariance data.

The calculation results reveal that there are significant differences in the major contributors, U and Pu nuclides between two covariance data. Thus, the total k_{eff} uncertainty decreases from 731 pcm to 548 pcm in the Exercise II-2a with the fresh fuel blocks. On the contrary, in the case of the Exercise II-2b, the difference of the total k_{eff} uncertainty between two covariance data versions is not large, because the decreased contributions in the fresh fuel block are cancelled out the increased ones in the burnt fuel block.

From this study, it is expected that the DeCART/MUSAD/CAPP code system can be well applied to the uncertainty analysis of various HTGR systems.

ACKNOWLEDGMENTS

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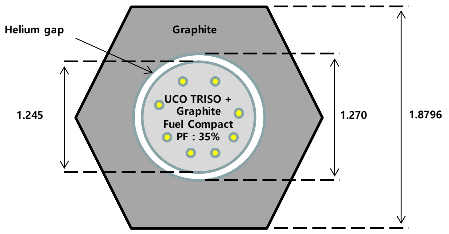

Fig. 2. Exercise I-1b configuration

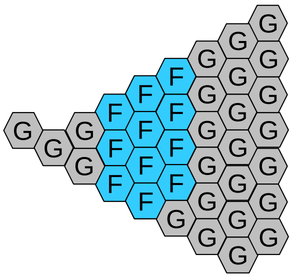

Fig. 3. Exercise II-2a configuration

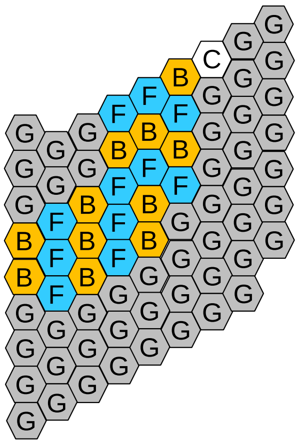

Fig. 4. Exercise II-2b configuration

Table. I: Exercise I-2b k_{inf} uncertainty

Contributor	Ex. I-2b ($\Delta k/k$ (%))		
	McCARD	DeCART2D/MUSAD	
	E7.1	E7.1	E8.0
^{235}U ν-ν	0.253	0.257	0.190
^{235}U cap-cap	0.076	0.076	0.030
^{235}U fis-cap	0.035	0.035	0.016
^{235}U fis-fis	0.049	0.049	0.057
^{238}U ν-ν	0.008	0.007	0.007
^{238}U cap-cap	0.288	0.289	0.194
C sct-sct	0.121	0.198	0.272
^{239}Pu cap-cap	0.192	0.189	0.605
^{239}Pu fis-cap	0.129	0.128	0.143
^{239}Pu fis-fis	0.154	0.154	0.312
^{240}Pu cap-cap	0.041	0.041	0.222
^{241}Pu fis-fis	0.096	0.096	0.096
^{236}U cap-cap	0.069	0.069	0.069
Total	0.542	0.564	0.862

Table. II: Exercise II-2a uncertainty

Cov.Data	ENDF/B-VII.1		ENDF/B-VIII.0	
Code	DeCART2D/MUSAD/CAPP			
Parameter	k_{eff}	Axial Offset (%)	k_{eff}	Axial Offset (%)
Value	1.05994	-0.012	1.06001	-0.012
Uncertainty (%)	0.731	4.52	0.548	4.45

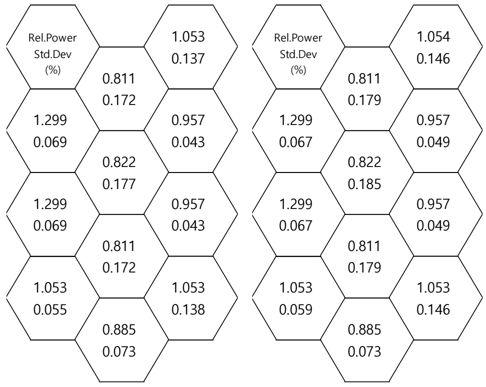

Fig. 5. Exercise II-2a relative power distribution and their uncertainties

Table. III: Exercise II-2b uncertainty

Cov.Data	ENDF/B-VII.1			ENDF/B-VIII.0		
Code	DeCART2D/MUSAD/CAPP					
Parameter	k_{eff}	Axial Offset (%)	CRW (pcm)	k_{eff}	Axial Offset (%)	CRW (pcm)
Value	1.04104	-0.108	81	1.04075	-0.108	81
Uncertainty (%)	0.695	1.53	1.19	0.760	1.59	1.41

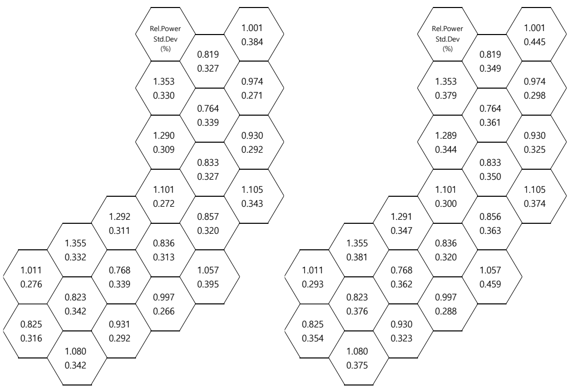

Fig. 6. Exercise II-2b relative power distribution and their uncertainties