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Sensitivity Analysis of MHTGR-350 Single Block Problem with DeCART2D/CAPP Code System

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1. Introduction

The expectation of Very High Temperature Gas-Cooled Reactor (VHTR) is based on three key factors: its inherent safety, high thermal efficiency and applicability to the hydrogen production process. However, due to the distinctive characteristics of VHTR including a high operating temperature and double heterogeneity from TRISO fuel particles, the core analysis code systems for VHTR have been developed [1-2].

In this regard, Korea Atomic Energy Research Institute (KAERI) has developed and improved DeCART2D/CAPP code system [2]. However, for this code system to be applicable to a range of reactor designs, it is necessary to verify its applicability to a range of core parameter changes.

In this study, a numerical calculation for a single fuel block of the MHTGR-350 design is performed using the DeCART2D/CAPP code system and compared with the McCARD Monte-Carlo code. Furthermore, a sensitivity analysis is performed for uranium enrichment, packing fraction and cross section library.

2. Computational Methodology

2.1 DeCART2D/CAPP Code System

DeCART2D is a multi-group neutron transport code for two-dimensional cores that has been improved for prismatic VHTR cores [3]. The code generates homogenized group constant (HGC) files, which are subsequently edited by PXSGEN into the few group cross section files that can be read by CAPP. The CAPP code is a three-dimensional neutron diffusion solver based on the finite element method [4]. The procedure for the two-step reactor analysis code system is illustrated in Figure 1.

2.2 McCARD capability for double heterogeneity geometry

DeCART2D/CAPP calculation result is verified by a Monte-Carlo based neutron transport code, McCARD. McCARD has the function, FCEL card, which can sample randomly distributed TRISO fuel particles within a fuel compact [5], so that no additional treatment for double heterogeneity is required. Consequently, it can be used as a realistic reference value [6].

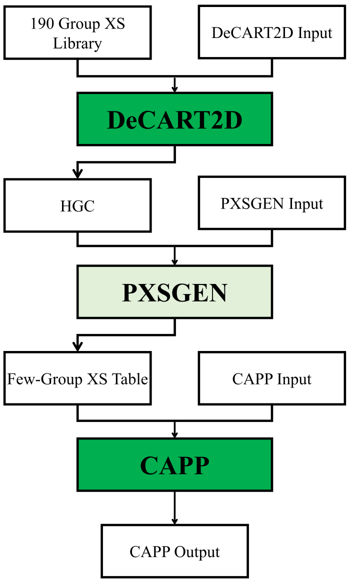

Figure 1. DeCART2D/CAPP code system [4]

3. MHTGR-350 Single Block Benchmark

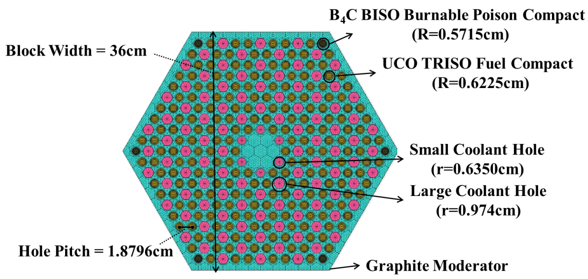

Figure 2. Configuration of MHTGR-350 fuel block [7]

In this study, a single fuel block of MHTGR-350, designed by General Atomics (GA) has been modeled in this study [7]. Cylindrical fuel compacts and burnable poison compacts are inserted into the holes of the hexagonal block which is composed of graphite moderator. The fuel compacts are composed of UCO TRISO particles, while the burnable poison compacts comprise B_4C BISO particles. Additionally, the block has coolant holes which provide the passages for helium gas. The dimensions of the block, including 36 cm of block width and 1.876 cm of hole pitch are modeled in this study. The configuration of the single block is illustrated in Figure 2. The operating conditions, including fuel temperature, moderator temperature and coolant temperature are set to 1000K. In order to perform a two-dimensional block calculation, reflective boundary conditions are applied on all sides of the block. For the purpose of the reference depletion calculation, 35% packing fraction of fuel compacts with 15.5w/o of UCO TRISO particles are utilized. Depletion calculation is performed using DeCART2D, CAPP and McCARD. 5,000 histories per cycle with 500 active cycles and 200 inactive cycles are used for McCARD calculation. The burnup steps were calculated at intervals of 0, 0.01, 0.1, 0.2, 0.5, 1.0 MWd/KgU, from 1 to 10 MWd/KgU in increments of 0.5 MWd/KgU and from 10 to 80 MWd/KgU in increments of 1 MWd/KgU.

4. Numerical Result and Discussion

4.1 Burnup Calculation

The multiplication factors in depletion calculations are performed by McCARD, DeCART2D and CAPP. Figure 3 compares the numerical results obtained from McCARD, DeCART2D and CAPP with their differences. DeCART2D and CAPP results fit well in this reference case where the differences are less than 33.8 pcm. McCARD overestimates the multiplication factors than DeCART2D within 372.6 pcm. Compared to McCARD with CAPP, McCARD overestimates the multiplication factors within 341.8 pcm.

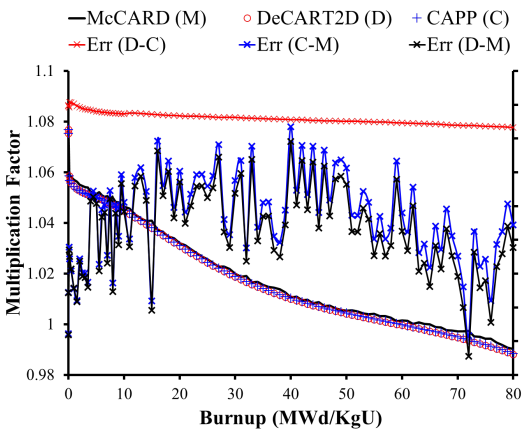

Figure 3. Burnup calculation for single fuel block

4.2 Sensitivity Analysis

For the sensitivity analysis, the calculations are performed using DeCART2D, CAPP and McCARD. 1,000 histories per cycle with 500 active cycles and 100 inactive cycles are used for McCARD calculation. The burnup steps were calculated at intervals of 0, 1, 5, 10, 20, 40, 70 EFPD, and from 100 to 1200 EFPD in increments of 100 EFPD.

Figure 4 shows the representative case of the sensitivity analysis for uranium enrichment. It is observed that the multiplication factors increase during the depletion calculation when the uranium enrichment is 10w/o. In this case, sufficient amounts of U-238 lead to the increase of Pu production during the depletion calculation, which subsequently leads to an increase in the multiplication factor during depletion calculation. It is noted that the slope of multiplication factors along the burnup becomes steeper as the uranium enrichment increases.

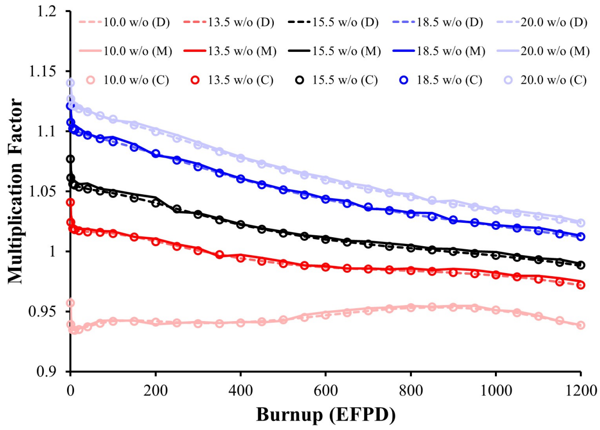

Figure 4. Sensitivity analysis for uranium enrichment

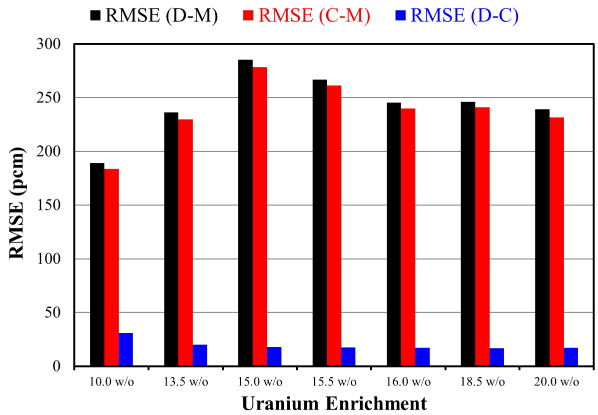

Figure 5. RMS error of sensitivity analysis for uranium enrichment

Figure 5 and Table 1 compared the root mean square (RMS) errors among McCARD, DeCART2D and CAPP results. The RMS errors between DeCART2D and CAPP at 10w/o are calculated from 16.6 pcm to 30.9 pcm. The RMS errors between McCARD and DeCART2D are calculated up to 285.3 pcm. It is also observed that the RMS errors between McCARD and CAPP are calculated up to 278.4 pcm. The maximum RMS error between McCARD is calculated both at 15.0 w/o of uranium enrichment.

Table 1. RMS difference in reactivity for sensitivity analysis of uranium enrichment

Uranium Enrichment	RMS Difference in Reactivity [pcm]		
	(M-D)	(D-C)	(C-M)
10.0 w/o	189	31	184
13.5 w/o	236	20	230
15.0 w/o	285	18	278
15.5 w/o	267	17	261
16.0 w/o	245	17	240
18.5 w/o	246	17	241
20.0 w/o	239	17	232

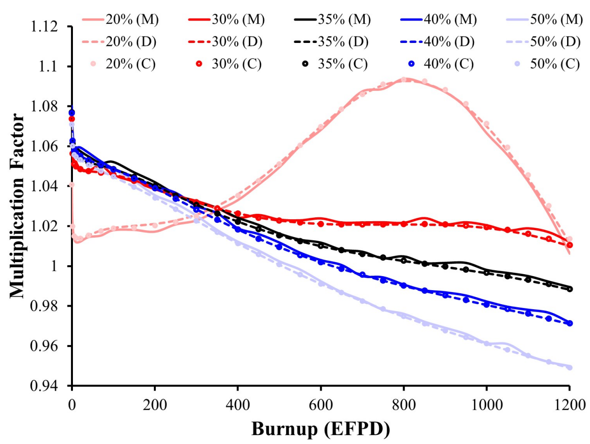

Figure 6. Sensitivity analysis for packing fraction

Figure 6 shows the representative case of the sensitivity analysis for packing fraction. It is clearly seen that the large reactivity swing arose when the packing fraction is 20%. It should be noted that this sensitivity analysis is performed with consistent thermal power. Consequently, the higher flux level is required with the lower packing fraction to achieve an equivalent power level, which leads burnable poison to burnt out at the early stage of burnup steps. After the burnable poison all burnt out, the multiplication factor increases drastically. On the other hand, as the packing fraction increases, the burnup reactivity swing gets smaller. Figure 7 and Table 2 show a comparison of the RMS errors among McCARD, DeCART2D and CAPP. As a consequence of the considerable reactivity swing, the numerical results lack sufficient reliability at low packing fractions. It is worth noting that the library system of DeCART2D/CAPP is not suitable for 10% and 15% packing fractions. However, as the packing fraction increases, the RMS errors decrease to a similar level as that observed in the reference case.

4.3 Effect on the Evaluated Nuclear Data Library

The nuclear reaction cross section is the most crucial factor in determining the accuracy of nuclear core design parameters. The most widely used evaluated nuclear data library is currently ENDF/B-VII.1, which has been utilized in the previous section. Figure 8 presents the multiplication factors with ENDF/B-VII.1 and ENDF/B-VIII.0, which is the up-to-date version of ENDF/B evaluated nuclear data library. As burnup proceeds, it can be observed that the multiplication factor in ENDF/B-VIII.0 decreases more rapidly. A similar behavior can be observed in light water reactor (LWR) burnup analyses as well [8].

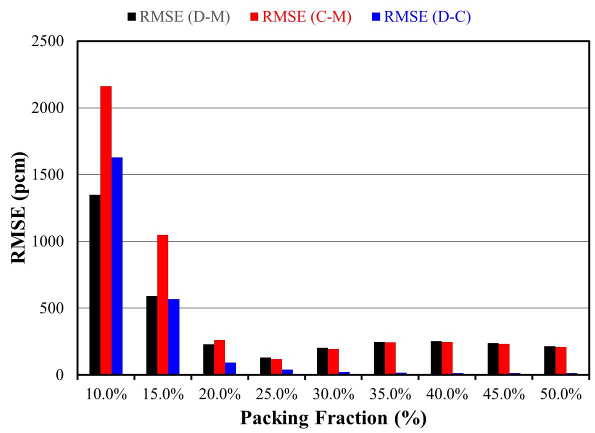

Figure 7. RMS error of sensitivity analysis for packing fraction

Table 2. RMS difference in reactivity for sensitivity analysis of packing fraction

Packing Fraction	RMS Difference in Reactivity [pcm]		
	(M-D)	(D-C)	(C-M)
0.1	1372	1628	2164
0.15	603	568	1048
0.2	234	94	262
0.25	133	39	120
0.3	209	23	194
0.35	253	17	245
0.4	257	15	248
0.45	244	15	233
0.5	219	15	210

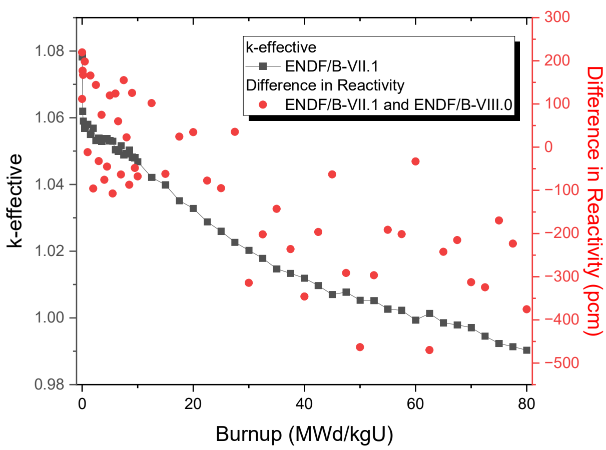

Figure 8. Comparison between multiplication factors with ENDF/B-VII.1 and ENDF/B-VIII.0 libraries

5. Conclusion

In this study, sensitivity analyses for a single fuel block of MHTGR-350 were performed by DeCART2D, CAPP and McCARD to evaluate the impact of uranium enrichment and packing fraction. In the reference case using the design core parameters from MHTGR-350 specification, there was no significant difference compared to the McCARD reference; however, substantial differences arose in core parameter results with large design core parameter variations. The sensitivity in the depletion analyses due to the evaluated nuclear data libraries was also assessed to be quite significant. As the next works, the core benchmark problem for MHTGR-350 or the other VHTR systems will be conducted using the DeCART2D/CAPP code system and McCARD.

ACKNOWLEDGEMENT

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