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Improvement of the DeCART2D/CAPP Code System for Prismatic VHTR Cores

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1. Introduction

Very High Temperature Reactor (VHTR), one of the Gen-IV reactor type, is drawing an interest due to its highly passive safety and efficient heat utilization. It is a thermal reactor, but the characteristics of VHTR are different from those of conventional light water reactors. Hence it is necessary to develop a reactor analysis tool for VHTR cores.

The CAPP code has been developed at Korea Atomic Energy Research Institute (KAERI) for the analysis of VHTR cores [1-4]. It is a three-dimensional reactor physics analysis code including a neutron diffusion equation solver based on the finite element method. It also has a simplified thermal fluid equation solver and a nuclide decay chain solver. Each solver was verified in the previous works [1-4].

To utilize the CAPP code, a homogenized few-group cross section set is required. First the HELIOS code [5] was used for the lattice calculation. The depletion calculation showed that the HELIOS/CAPP code system is accurate for single block calculation, but it has limitation for 2-D or 3-D core problems. In recent years, the DeCART2D code [6], instead of the HELIOS code, was applied to the two-step calculation procedure [7].

This paper presents the DeCART2D/CAPP code system for two- and three-dimensional prismatic VHTR cores. The code system is tested on a PMR-200 core problem [8], with encouraging results.

2. DeCART2D/CAPP Code System

Figure 1 shows the two-step reactor analysis code system for VHTRs developed at KAERI. This code system uses the DeCART2D code instead of the HELIOS code, which was used to generate the multi-group cross section data in the previous studies. PXS_GEN is a program that reads the HGC (homogenized group constants) file generated by the DeCART2D code and edits the cross section data to generate cross section table files used in the CAPP code. The CAPP code performs core calculation with the provided cross section table files.

This code system has some differences from those of the light water reactors. One is the problem domain for the lattice calculation. A prismatic VHTR has large flux gradient. Hence a single assembly block calculation with the reflective boundary condition cannot give a reliable homogenized group constant set. To generate an accurate homogenized group constant set, a two-dimensional core is the problem domain of the lattice calculation by the DeCART2D code.

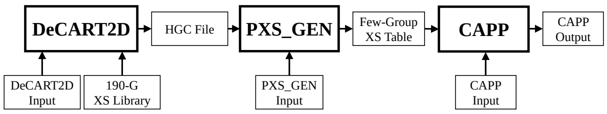


Fig. 1. DeCART2D/CAPP two step reactor analysis code system [7].

In a prismatic VHTR core, the variation of flux distribution within a single assembly block is large. It induces large changes of power, burnup, and nuclide number densities within a single assembly block. The CAPP code divides a single block into six triangular prisms to consider such aspects. However, the DeCART2D code generates assembly-wise homogenized group constants. This homogenized group constants preserve the assembly-wise averaged reaction rate, but does not preserve the reaction rates over each triangular prisms.

To overcome the problem, the CAPP code uses triangular prism-wise different nuclide number densities. In the neutron diffusion calculation, the averaged nuclide number densities are used for each assembly block so that the assembly-wise and the whole core reaction rates are preserved. On the other hand, the micro depletion calculation uses independent nuclide number densities for each triangular prism so that the burnup and the nuclide number density distributions are preserved.

3. Numerical Results

To test the DeCART2D/CAPP code system, two- and three-dimensional PMR200 cores are considered. The reference calculations are performed by the McCARD code [9].

3.1. PMR200 2-D Core Model

Figure 2 is a two-dimensional core configuration of PMR200. The detailed specification of the reactor core is described in [8]. To simplify the problem, the control rod holes and the reversed shutdown system channels are omitted. The temperature of fuel and moderator is set to 1000K. Two cases were considered for the calculation; burnable absorber loaded or not.

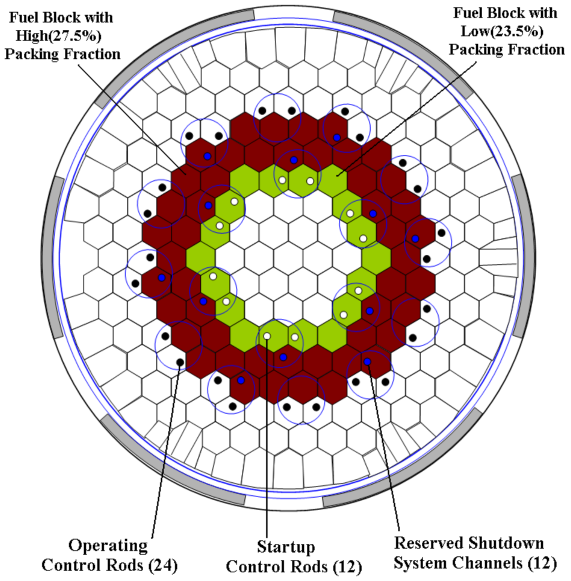


Fig. 2. PMR200 2-D Core Model [8].

Figure 3 compares the multiplication factor during the two-dimensional core depletion calculation for no burnable absorber case. The DeCART2D code underestimates the multiplication factor from 124 pcm to 365 pcm to the McCARD code. The CAPP code overestimates the multiplication factor from 86 pcm to 159 pcm compared to the DeCART2D code. Finally the difference between the CAPP code and the McCARD code is less than 300 pcm due to the error cancellation.

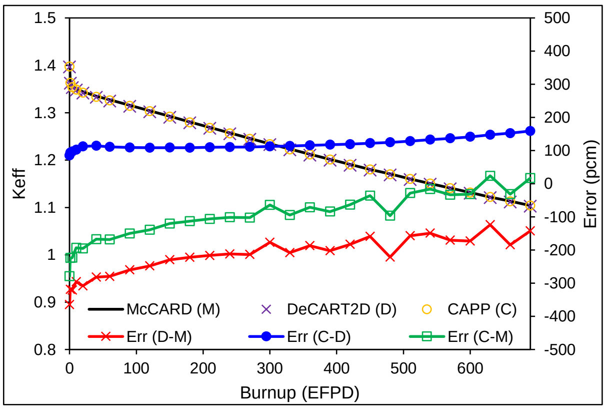


Fig. 3. Multiplication factor during the 2-D core depletion calculation; no burnable absorber case.

Figure 4 compares the multiplication factor for burnable absorber case. Compared to the previous case, the difference between the McCARD code and the DeCART2D code is reduced. But the difference between the CAPP code and the DeCART2D code increases. Even though such an aspect, the error of the CAPP code is less than 340 pcm during the depletion calculation.

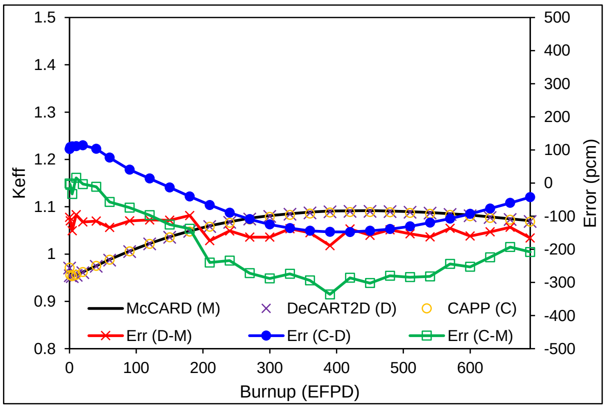
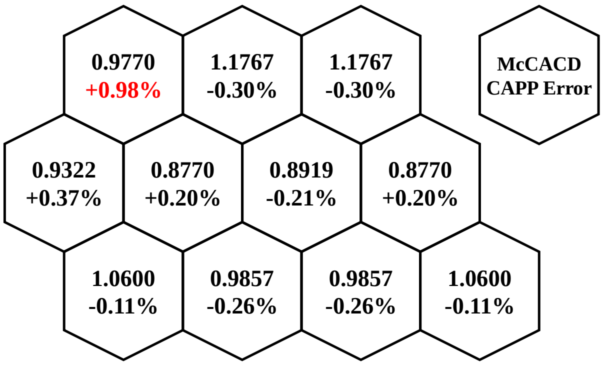
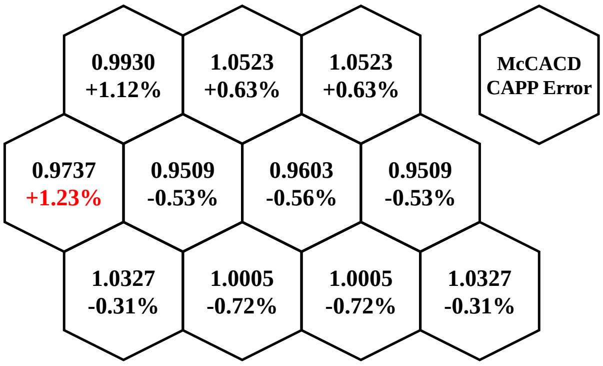


Fig. 4. Multiplication factor during the 2-D core depletion calculation; burnable absorber case.

Figure 5 shows the radial power distribution for burnable absorber case. The maximum assembly block power density errors are 0.98% at BOC and 1.23% at EOC. The increment of power density error is small during the depletion calculation. No burnable absorber case also shows similar level of errors.



(a) BOC (at 0 EFPD)



(b) EOC (at 690 EFPD)

Fig. 5. Radial power distribution for PMR200 2-D core; burnable absorber case.

3.2. PMR200 3-D Core Model

A PMR200 core has six fuel block layers with the same radial configuration. Each height of fuel block layers is 79.3 cm. In a fuel block layer, the height of fuel zone is 75 cm and two 2.15 cm non-fueled zones are on the top and bottom of the fuel zone. There are top and bottom graphite reflector layers with the thickness of 120 cm/160 cm, respectively.

Figure 6 compares the multiplication factor during the three-dimensional core depletion calculation for no burnable absorber case. The DeCART2D/CAPP code system overestimates the multiplication factor from 232 pcm to 399 pcm.

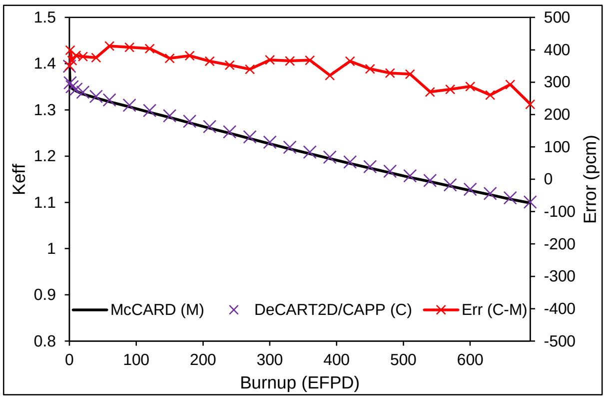


Fig. 6. Multiplication factor during the 3-D core depletion calculation; no burnable absorber case.

Figure 7 compares the multiplication factor for burnable absorber case. The difference between the DeCART2D/CAPP code system and the McCARD code decreases as the depletion proceeds. The maximum error of the multiplication factor is less than 450 pcm.

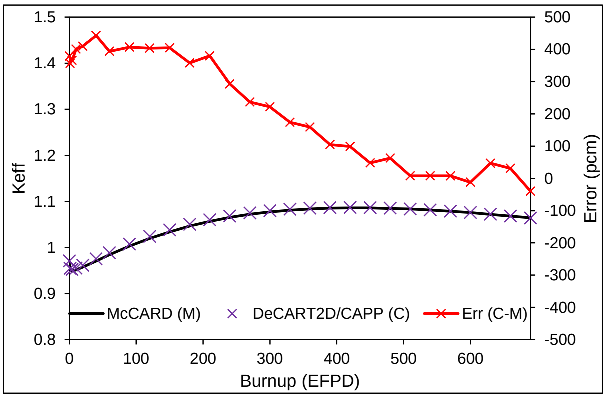


Fig. 7. Multiplication factor during the 3-D core depletion calculation; burnable absorber case.

Figure 8 shows the radial power distribution for burnable absorber case. The maximum assembly block power density errors are 1.11% at BOC and 0.51% at EOC. No burnable absorber case also shows similar level of errors.

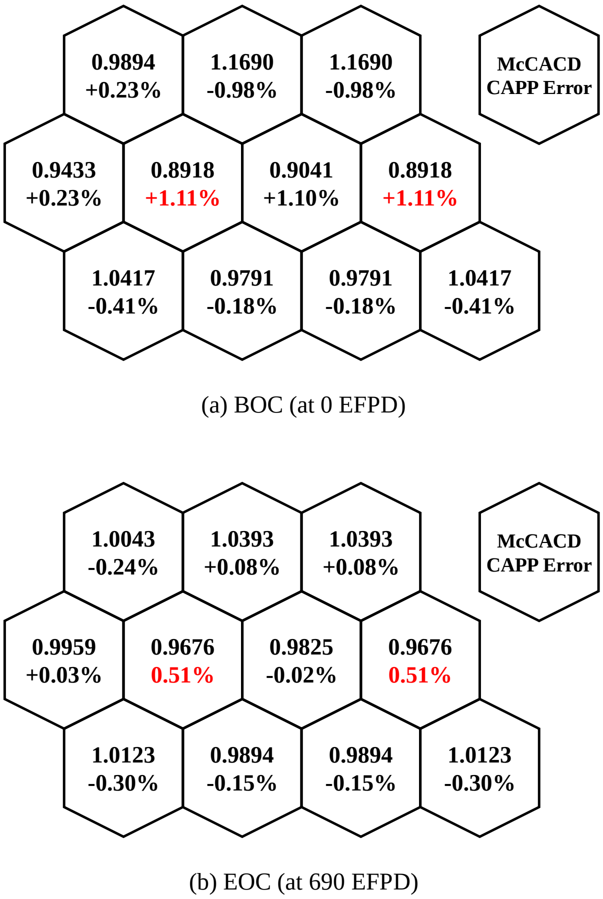


Fig. 8. Radial power distribution for PMR200 3-D core; burnable absorber case.

3. Conclusions

In this paper, the DeCART2D/CAPP reactor analysis code system is presented and the verification is performed with the PMR200 core configurations. In the two-dimensional core model, it is verified that the DeCART2D/CAPP code system works properly. In the three-dimensional core model, the maximum multiplication factor error is less than 450 pcm and the error of assembly block power density is small during the depletion calculation.

In the future work, the improvement of the two-step code system for VHTR cores will be studied to increase the accuracy. Especially, the cause of the error for the burnable absorber case in the two step calculation will be investigated.

Acknowledgments

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REFERENCES

[1] H. C. Lee, C. K. Jo, and J. M. Noh, "Development of CAPP Code Based on the Finite Element Method for Analysis of VHTR Cores," Proceedings of the 4th International Topic Meeting on High Temperature Reactor Technology (HTR2008), Washington, DC, USA, September 28–October 1, 2008.

[2] H. C. Lee, C. K. Jo, and J. M. Noh, "Development of the CAPP Code for the Analysis of Block Type VHTRs," Transactions of the Korean Nuclear Society Spring Meeting, Taebaek, Korea, May, 26–27, 2011.

[3] H. C. Lee, T. Y. Han, C. K. Jo, and J. M. Noh, "Development of the HELIOS/CAPP Code System for the Analysis of Block type VHTR cores," Proc. PHYSOR 2012, Knoxville, Tennessee, USA, April 15–20, 2012.

[4] H. C. Lee, T. Y. Han, C. K. Jo, and J. M. Noh, "Development of the HELIOS/CAPP code system for the analysis of pebble type VHTR cores," Annals of Nuclear Energy, Vol. 71, pp. 130–144, 2014.

[5] R.J. Stamml'er et al., HELIOS Methods, Studsvik Scanpower, 1998.

[6] J. Y. Cho et al., DeCART2D User's Manual, KAERI/TR-5116/2013, KAERI, 2013.

[7] C. J. Jeong, T. Y. Han, H. C. Lee, and J. M. Noh, "Preliminary Verification Calculation of DeCART/CAPP System by HTTR Core Analysis," Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, October, 24–25, 2013.

[8] H. C. Lee et al., "Decay Heat Analysis of VHTR Cores by Monte Carlo Core Depletion Calculation," Annals of Nuclear Energy, Vol. 37, pp. 1356–1368, 2010.

[9] H. J. Shim et al., "McCARD: Monte Carlo Code for Advanced Reactor Design and Analysis," Nuclear Engineering and Technology, Vol. 44, pp. 161–176, 2012.