Assessment and Improvement of DeCART Depletion Calculation for VHTR Fuel Elements

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1. Introduction

It has been an issue that the HELIOS code overestimate the k_{inf} value compared to the McCARD code during depletion calculation for VHTR fuel elements[1,2]. Recently, DeCART code was developed and its cross-section library was generated by using the KAERI multi-group cross section library generation programs(GREDIT,MERIT,SUBDATA.LIBGEN)[3] for the analysis of block type VHTR cores. It was observed that DeCART code also overestimate the k_{inf} value compared to the McCARD code during depletion calculation for VHTR fuel elements.

In this paper, the depletion calculation of DeCART code was assessed by comparing the results with those of McCARD code and the cross-section library was improved.

2. Methods and Results

There are many sources of error such as double heterogeneity treatment, spatial discretization, angular discretization, neutron energy discretization including resonance treatment, and nuclide chain model in DeCART depletion calculation for VHTR fuel elements. The first three sources of error can be eliminated by introducing a homogeneous fuel element with reflective boundary conditions. Table 1 shows the composition of the homogeneous VHTR fuel element used in this study.

Table 1. Composition of a homogeneous fuel element.

Nuclide	Number Density [#/barn-cm]	Nuclide	Number Density [#/barn-cm]
U-235	3.21161E-04	Nat. Si	8.06328E-04
U-238	2.32544E-03	Graphite	1.19841E-01
O-16	5.29319E-03		

Two compositions of the burnt VHTR fuel element, composition 1 and composition 2, were obtained by performing depletion calculation for the homogeneous fuel element till 150[GWD/T] with McCARD code and DeCART code, respectively. With the two compositions, the effect of nuclide chain model and the effect of neutron energy discretization on k_{inf} were analyzed.

2.1 The Effect of Nuclide Chain Model

The number densities of the two compositions are affected mainly by the nuclide chain model of the two codes. The effect of nuclide chain model can be evaluated by comparing the k_{inf} values evaluated with a code for the two compositions. Table 2 compares the k_{inf} values for the two compositions evaluated with the two codes. Each code gives similar k_{inf} values for the two compositions while the two codes give very different k_{inf} values for the same compositions, which means that nuclide chain model is not the major cause of the discrepancy between the two codes in depletion calculation for the VHTR fuel elements.

Table 2. k_{inf} values for the burnt fuel element.

	McCARD	DeCART	Δk [pcm]
Comp. 1	0.81142±4pcm	0.82217	+1075
Comp. 2	0.81080±4pcm	0.82161	+1081
Δk [pcm]	-62	-56	

Although the k_{inf} values for the two compositions evaluated by a code are similar, there is a possibility that large errors related to some nuclides are canceled out. To investigate the effects of each nuclide, the number density of each nuclide in composition 1 is replaced with that of composition 2 one by one. Table 3 shows the effect of each replacement evaluated with DeCART code. The sums of the positive and the negative discrepancy are -479pcm and +401pcm, respectively and they cancel out to give a small discrepancy in table 2. In spite of the fact that the k_{inf} values for the two compositions evaluated by a code are similar and the nuclide chain model is not the major cause of the discrepancy between the two codes in depletion calculation, nuclide chain model has a potential for a large discrepancy between the two codes because the apparently small discrepancy in the k_{inf} values is achieved by an error cancelation.

Table 3. Effect of number density replacement.

Nuclide Replaced	Δk [pcm]	Nuclide Replaced	Δk [pcm]
Pu-241	-122	Pu-240	+74
Pu-239	-118	Sm-151	+50
U-235	-81	Xe-135	+37
U-238	-38	Cd-113	+36
Ag-109	-53	Eu-154	+28
Am-242m	-36	Eu-155	+28
⋮	⋮	⋮	⋮
Sum	-479	Sum	+401

2.2 The Effect of Neutron Energy Discretization

The multi-group cross-sections of the nuclides are affected mainly by the neutron energy discretization

including resonance treatment. The effect of multi-group cross-sections of a nuclide can be evaluated by comparing the nuclide worth evaluated with the two codes for a composition. Table 4 compares the nuclide worth evaluated with the two codes for composition 1. The nuclide worth was evaluated by removing the nuclide from composition 1. It should be noted that the fission product nuclides in Table 4 are treated as non-resonant nuclides in DeCART code as well as in HELIOS code though they have resonances while the actinides in Table 4 are treated as resonant nuclides in DeCART code. The errors in the nuclide worth for the fission products can be improved by treating them as resonant nuclides in DeCART code. The resonance data for the fission product nuclides in Table 4 were generated and the cross-section library was updated by adding the resonance data for the nuclides. Table 5 shows that the nuclide worth for the fission products is much improved by treating them as resonant nuclides.

Table 4. Nuclide worth for composition 1.

Nuclide	Nuclide Worth Δk [pcm]		
	McCARD	DeCART	Difference
Actinides			
Pu-239	+13040	+13263	+223
Pu-241	+6461	+6531	+70
U-235	+4413	+4482	+69
Pu-240	-16582	-16646	-64
Pu-242	-1364	-1403	-39
⋮	⋮	⋮	⋮
Fission Products			
Sm-152	-496	-297	+199
Pm-147	-467	-377	+90
Ag-109	-403	-321	+82
Nd-145	-383	-320	+63
Sm-147	-133	-112	+21
Eu-153	-439	-425	+14
⋮	⋮	⋮	⋮

Table 5. Nuclide worth with the new library

Nuclide	Nuclide Worth Δk [pcm]		
	McCARD	DeCART	Difference
Sm-152	-496	-493	+3
Pm-147	-467	-463	+4
Ag-109	-403	-395	+8
Nd-145	-383	-358	+25
Sm-147	-133	-133	0
Eu-153	-439	-441	-2

2.3 Depletion Calculation with the Improved Library

Figure 1 and Figure 2 compares the k_{inf} values during depletion calculation for homogeneous fuel element and PMR200 fuel cell modeled by RPT method. The discrepancy was improved by 588pcm and 552pcm $\Delta\rho$ at 150[GWD/T] for the homogeneous fuel element and the PMR200 fuel cell, respectively.

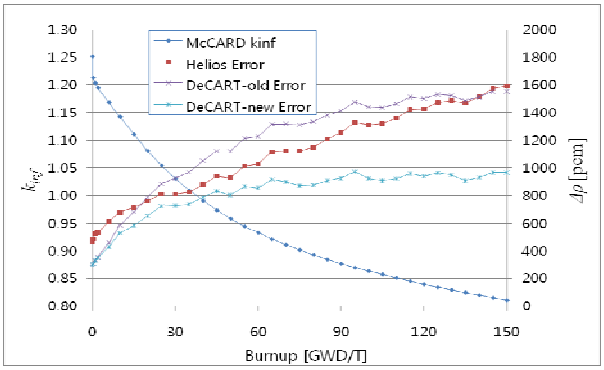

Figure 1. Depletion results for the homogeneous fuel

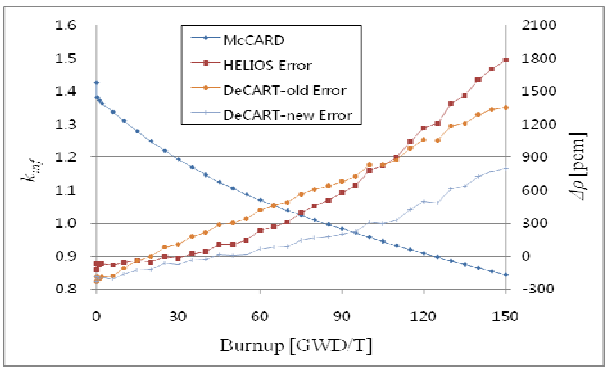

Figure 2. Depletion results for the PMR200 fuel cell

3. Conclusions

The DeCART depletion calculation was assessed and improved. The error in the cross-sections of some fission products was one of the sources for the large discrepancy between the k_{inf} values evaluated with the two codes for burnt fuel elements. The worth for the fission product nuclides was improved by treating them as resonant nuclides. The error in the cross-sections of some actinides was another source for the large discrepancy. The nuclide chain model did not affect much on the k_{inf} value during the depletion calculation performed in this study but it is a potential source of relatively large error because there are some error cancelations between relatively large errors.

The cross-sections of the actinides and the nuclide chain model should be investigated more closely to improve the depletion calculation of DeCART code.

REFERENCES

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[3]] K. S. Kim et al., "Improvements on MERIT 1.1 and SUBDATA 1.1 and a New Procedure for Resonance Integral Adjustment," Trans. of KNS Autumn Meeting, Gyeongju, Korea, Oct. 29-30.