DeCART Benchmark Calculation for LWR Next Generation Fuels

Jin-Young Cho[a] Kang-Seog Kim[a] Chung-Chan Lee[a] Han-Gyu Joo [b]
a Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong-gu, Daejon, 305-353 Korea, jyoung@kaeri.re.kr
b Seoul National University, San 56-1, Sillim-dong, Kwanak-gu, Seoul, Korea

1. Introduction

DeCART (Deterministic Core Analysis based on Ray Tracing)[1] is a three-dimensional whole-core transport code capable of a direct core calculation at power generating conditions. Recently, a depletion capability has been implemented into the DeCART code to predict the depleted composition in the fuel. The representative depletion methods include the exponential matrix method and the linearization method. While most of the transport lattice codes adopt the linearization method for a better efficiency in the computing time, the Monte Carlo depletion codes adopt the exponential matrix method. The drawback of the linearization method is in its fixed formulation which causes difficulties in the modification of the depletion chains and the programming itself. The drawback of the exponential matrix method is the relatively expensive computing time. However, the computing time for a depletion calculation is quite small when compared with that for the main transport calculation. Therefore, the DeCART code adopts the exponential matrix method of ORIGEN-2[2] for the depletion calculation. In this paper, some features of the depletion method implemented in DeCART are described first, and next the depletion capability is examined by solving a LWR next generation fuel benchmark problem [3].

2. Methods and Results

2.1 Depletion Features

ORIGEN-2 performs the depletion calculation using its own one group cross section library and decay constant file, and it treats more isotopes than the DeCART multi-group library. The one group cross section included in the library is not correct, and the isotopes treated in the ORIGEN-2 code are not consistent with those in the DeCART code. Therefore, to implement the ORIGEN-2 code into the DeCART code, a one-group cross section generation and a substitution are required. DeCART generates the one-group cross section by condensing the multi-group cross section using the multi-group spectrum at every uniform cross section region and replaces the original incorrect ORIGEN-2 one-group cross section. For the non-resident isotopes at the local region, DeCART does not perform the group condensation and uses the original ORIGEN-2 cross section. Regarding the isotope treatment, the mapping routine between the DeCART and ORIGEN-2 isotope identifiers is established. For the non-resident isotopes, DeCART ignores the isotope number density transferred from ORIGEN-2.

DeCART performs the depletion calculations two times to obtain an accurate depleted composition, first by using the scalar fluxes and cross sections at the previous time point (predictor), and a second time by using those at the current time point (corrector). The final depleted compositions are obtained simply by averaging the predicted and corrected compositions. This predictor-corrector method is applied to all the burnup steps. For the accurate fission products number densities, the predictor only depletion calculation is performed at the burnup of 0.01 MWD/kgHM without the eigenvalue calculation.

In the macroscopic multi-group cross section preparation, DeCART ignores some isotopes which have a negligible effect on the macroscopic cross section resulting from the trivial number density or microscopic cross section. However, those isotopes are not just ignored in the depletion calculation. Before the main transport calculation, DeCART first determines the critical number densities for all the isotopes.

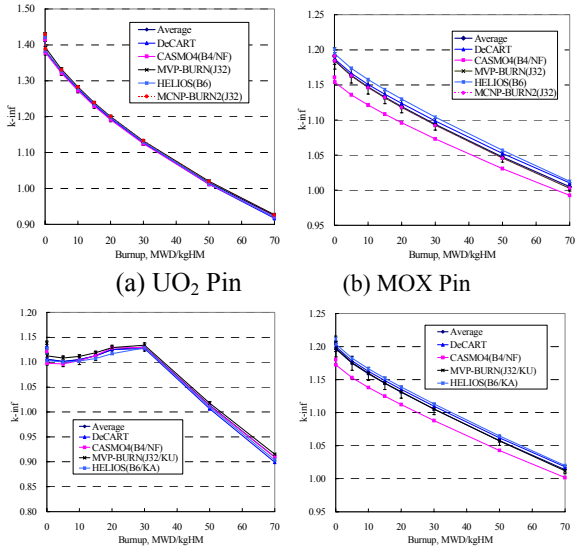
The DeCART code uses the exponential matrix method of ORIGEN-2 and its libraries. The depletion chains are greatly simplified through lumping a process for the short lived nuclides and removing the meaningless nuclides in the reactor physics analysis. The transmutation matrix is established with the neutron reaction, decay and fission product in the form of a first order differential equation. The solution of this differential equation is a form of an exponential matrix in which the exponential matrix can not be solved easily. Therefore, the exponential matrix is solved by dividing the nuclides into long-lived and short-lived ones. The exponential matrix of long-lived nuclides is solved easily by the Taylor series expansion. Then, the short-lived number densities are obtained by the iteration method.

2.2 Benchmark Results

To examine the depletion capability implemented into the DeCART code, a LWR next generation fuel benchmark problem is solved. This problem is from 'The working Party on Reactor Physics for LWR Next Generation Fuels in the Research Committee on Reactor Physics' which is organized by the Japan Atomic Energy Research Institute. Three different geometries are included in this benchmark problem: the

fuel pin, the PWR fuel assembly and the BWR fuel assembly. Since DeCART is not capable of handling the geometry of a BWR fuel assembly, the BWR assembly problems are excluded from our calculations. The UO_2 and MOX fuels are loaded in this benchmark problem.

The results of the DeCART calculations are compared with those obtained from Ref. [4] where all the participant results are loaded. As shown in Fig. 1, DeCART shows a good agreement with the averaged k-infinite of all the participants. Especially, at the fuel burnup of less than 40 MWD/kgHM, DeCART shows a less than 150 pcm difference in the UO_2 loaded problems, and a less than 500 pcm difference in the MOX loaded problems. However, at the fuel burnup of greater than 40 MWD/kgHM, DeCART shows a little larger difference of a maximum 1000 pcm. This difference is kept when using a very small burnup step size over all the burnup space, but reduced when applying a predictor alone depletion scheme, which means that the DeCART code performs adequately.



(a) UO_2 Pin (b) MOX Pin

(c) UO_2 Assembly (d) MOX Assembly

Figure 1. k_∞ comparison

Table 1 shows the reactivity comparisons between the DeCART code and the participant averaged value. Doppler reactivity is obtained by increasing the fuel temperature from the operating condition of 900 K to 1800 K, and the total reactivity by decreasing all the temperatures of the fuel, cladding, and coolant to 300 K. Void1 and void2 reactivity are obtained by increasing the 0 % void of the operating condition to 40 % and 70 %, respectively. For this comparison, DeCART performs the branch calculations at each burnup step. DeCART shows a good agreement with the averaged values for the Doppler and total reactivity showing less than 100 pcm Δρ. However, in the void2 reactivity for the MOX assembly, DeCART shows a little larger difference of a maximum 400 pcm Δρ.

Table 1. Reactivity Comparison, %

Burnup, MWD/kgHM	Doppler[1]		Total[2]		Void1[3]		Void2[4]	
	Ag.[5]	D[6]	Ag.[5]	D[6]	Ag.[5]	D[6]	Ag.[5]	D[6]
	UO_2 Pin							
0.0	-1.45	-1.40	4.97	4.87	-2.13	-2.11	-6.06	-6.00
0.1	-1.45	-1.43	4.69	4.63	-1.99	-2.00	-5.69	-5.66
5.0	-1.52	-1.50	5.20	5.16	-2.16	-2.15	-6.13	-6.06
10.0	-1.63	-1.64	5.79	5.78	-2.41	-2.38	-6.75	-6.66
15.0	-1.76	-1.78	6.34	6.35	-2.62	-2.59	-7.30	-7.22
20.0	-1.89	-1.92	6.82	6.85	-2.82	-2.80	-7.86	-7.75
30.0	-2.13	-2.17	7.65	7.70	-3.23	-3.20	-8.94	-8.84
50.0	-2.50	-2.55	8.94	9.02	-4.08	-4.05	-11.25	-11.19
70.0	-2.79	-2.84	9.80	9.88	-4.93	-4.94	-13.67	-13.68
	MOX Pin							
0	-1.81	-1.86	4.84	4.74	-0.72	-0.63	-1.07	-0.81
0.1	-1.80	-1.85	4.50	4.44	-0.62	-0.55	-0.84	-0.61
5	-1.80	-1.85	4.38	4.33	-0.59	-0.51	-0.76	-0.51
10	-1.81	-1.86	4.41	4.38	-0.61	-0.53	-0.79	-0.54
15	-1.82	-1.88	4.51	4.48	-0.66	-0.57	-0.87	-0.62
20	-1.83	-1.89	4.63	4.61	-0.70	-0.61	-0.99	-0.72
30	-1.86	-1.92	4.90	4.88	-0.81	-0.71	-1.21	-0.94
50	-1.94	-2.00	5.46	5.48	-1.07	-0.95	-1.79	-1.46
70	-2.04	-2.09	6.07	6.10	-1.35	-1.21	-2.43	-2.07
	UO2 Assembly				MOX Assembly			
	Doppler		Total		Doppler		Total	
0	-1.69	-1.68	6.89	6.81	-1.78	-1.79	5.26	5.08
0.1	-1.68	-1.70	6.32	6.39	-1.77	-1.78	4.88	4.77
5	-1.66	-1.70	5.71	5.79	-1.77	-1.78	4.80	4.68
10	-1.69	-1.76	5.46	5.53	-1.79	-1.79	4.85	4.75
15	-1.78	-1.82	5.32	5.38	-1.79	-1.81	4.96	4.87
20	-1.82	-1.86	5.27	5.32	-1.81	-1.82	5.08	5.01
30	-1.99	-2.03	6.46	6.58	-1.84	-1.86	5.36	5.30
50	-2.34	-2.39	7.47	7.64	-1.94	-1.93	5.94	5.92
70	-2.62	-2.66	7.71	7.91	-2.01	-2.03	6.58	6.56

1) Doppler Reactivity, T_f from 900 K to 1800 K
2) Total Temperature Reactivity, from hot to cold state
3) Void Reactivity, from 0 % to 40 % void
4) Void Reactivity, from 0 % to 70 % void
5) Participant Average
6) DeCART

3. Conclusion

A depletion capability was implemented into the DeCART code based on the exponential matrix method of ORIGEN-2 and examined by solving a LWR next generation fuel benchmark problem. The computational results for the benchmark problem showed that the depletion capability was successfully implemented into the DeCART code.

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