Assessment of DeCART for Numerical Benchmark Problems Based on the Compact Nuclear Power Source Critical Experiments

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1. Introduction

DeCART[1] is a 3-dimensional whole-core code based on the synthesis of 2-D radial MOC (Method Of Characteristics) transport and 1-D axial nodal diffusion methods. This code has been applied to the PWR physics analysis. Recently its' geometry treatment capability has been extended to deal with the hexagonal meshes for the VHTR (Very High Temperature gas-cooled Reactor) physics analysis,[2] which requires a verification of the applicability to the VHTR fuels.

The Argonne national laboratory has developed the numerical benchmark problems based on the Compact Nuclear Power Source (CNPS) experiments[3] conducted at the Los Alamos National Laboratory (LANL) in the late 1980s in order to support the validation and verification work for the VHTR physics codes.[4] Development of the numerical benchmarks was required from a lack of experimental information on the design data uncertainties and the inconsistency in the design data from different sources. Two- and three-dimensional numerical benchmarks based on the CNPS experiment are specified for the verification of the VHTR physics.

In this study the DeCART code was assessed by performing the CNPS benchmark calculations and comparing the results with the MCNP[5] ones.

2. Methods and Results

2.1 Numerical CNPS Benchmarks

The CNPS reactor was designed to produce 20 KWe continuously for 20 years and to use a TRISO particle fuel and a graphite moderator. The fuel compact consists of low-enriched (19.9%) uranium graphite fuel in a TRISO form and a graphite matrix. The packing fraction of a fuel particle in a fuel compact is 0.601, which is composed of five layers including a $UC_{0.3}O_{1.7}$ kernel. Diameter of the fuel compact is 1.245 cm, and the corresponding pin pitch in the form of a square cell is 4.713 cm. The CNPS benchmarks include two core configurations as shown in Figures 1 and 2. The CNPS-184 core includes 184 fuel pins, 12 empty heat pipe channels and 5 empty control rod channels, and the CNPS-492 core includes 492 fuel pins, three control rods and one shim rod which are partly inserted. The active core height is 108.46 cm, aluminum plate is 6 cm from the bottom of the core, and the bottom and top graphite reflectors are 21.7 cm and 17.84 cm, respectively. B_4C control rods are inserted from the bottom up to 62.459 cm, and a B_4C shim rod is inserted from the top by 48.06 cm. Two-dimensional benchmark configurations were established by axially homogenizing the active core excluding the axial reflectors.

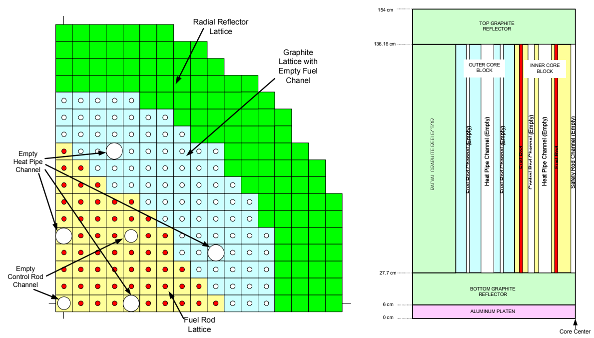

Figure 1. Core configuration of CNPS-184

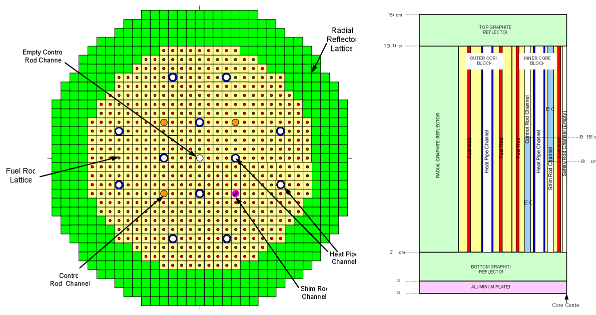

Figure 2. Core configuration of CNPS-492

2.2 DeCART

A whole core transport code DeCART has been developed as a core neutronics simulator that accomplishes the method of characteristics (MOC) based whole core 3-D transport calculations with an explicit representation of the local heterogeneity. This code generates sub-pin level power distributions by representing a local heterogeneity explicitly without a homogenization, by using a multi-group cross section library directly without a group condensation and incorporating a pin-wise thermal hydraulic feedback. In DeCART, the coarse mesh finite difference (CMFD) formulation is employed as the means of coupling 2-D MOC and 1-D nodal solutions as well as accelerating the MOC solutions. DeCART code includes a standalone thermal hydraulic calculation module. Sub-pin level thermal hydraulic feedback effect can be considered in predicting the pin-wise power distributions through this module. And the MOC based transient capability has also been implemented in DeCART and verified.

2.3 Computation Results

The CNPS benchmark problems were analyzed by the DeCART code, and the results were compared with those of the MCNP calculations. Table 1 shows the comparison of the multiplication factors for the CNPS fuel pins. The DeCART results are very consistent with those of MCNP to within the maximum errors of 190 pcm and 300 pcm when using the 190 group and 47 group libraries, respectively.

Table 1. Comparison of the multiplication factors for pin

Case	Temp. (K)	MCNP		DeCART	
		DH	RPT	47-g	190-g
Homo	300	1.74324		1.74716	1.74287
	600	1.71753		1.72461	1.72008
	900	1.69726		1.70589	1.70166
Hetero	300	1.79319	1.79212	-	1.79318
	600	1.77564	1.77509	-	1.77887
	900	1.76038	1.76010	-	1.76629

Standard deviation < 0.00030

Table 2. Comparison of the multiplication factors for CNPS

Core	Code	Fuel	Temperature (K)		
			300	600	900
184 2D	MCNP*	Hetero.	1.19742	1.16923	1.14468
	MCNP*	Homo.	1.19558	1.16859	1.14302
	MCNP*	RPT[6]	1.19751	1.16924	1.14459
	DeCART(a)	Homo.	1.18890	1.16346	1.13927
	DeCART(b)	Homo.	1.19638	1.17076	1.14605
184 3D	MCNP*	Hetero.	1.00546	0.97557	0.94871
	MCNP*	Homo.	1.00589	0.97493	0.94786
	MCNP*	RPT	1.00661	0.97586	0.94867
	DeCART(b)	Homo.	1.00500	0.97582	0.94974
492 2D	MCNP*	Hetero.	1.12030	1.09057	1.06413
	MCNP*	Homo.	1.11928	1.08877	1.06335
	DeCART(a)	Homo.	1.10709	1.07953	1.05468
	DeCART(b)	Homo.	1.11364	1.08603	1.06064
492 3D	MCNP*	Hetero.	1.00518	0.97667	0.95322
	MCNP*	Homo.	1.00510	0.97603	0.95032
	DeCART(b)	Homo.	-	-	-

*Standard deviation < 0.00049
(a) 190-group library (b) 47-group library

Table 2 provides a comparison of the multiplication factors for the CNPS-184 and 492 cores. The DeCART results with the 47 group library are closer to the MCNP results in all the cases. Figure 3 shows a comparison of the pin power distributions, in which the maximum error is 1.84.

0.000 - -	0.981 -0.49 -1.10	0.952 0.15 -0.38	0.937 0.08 -0.45	0.000 - -	0.913 0.40 0.07	0.913 0.78 0.67	0.957 0.58 0.78	1.064 -0.54 0.03	1.218 -0.95 -0.13
0.978 -0.16 -0.78	0.965 0.05 -0.47	0.951 -0.23 -0.76	0.929 0.51 0.08	0.922 0.42 -0.02	0.910 1.12 0.90	0.932 0.50 0.50	0.999 0.05 0.35	1.135 -1.14 -0.52	
0.951 0.21 -0.31	0.950 -0.06 -0.58	0.933 0.89 0.35	0.937 -0.44 -0.87	0.924 0.76 0.44	0.939 0.40 0.29	0.980 1.36 1.56	1.114 -0.39 0.06		
0.936 0.22 -0.32	0.927 0.71 0.28	0.933 0.00 -0.42	0.934 0.92 0.59	0.958 0.77 0.56	0.985 0.63 0.73	1.090 -0.30 -0.02			
0.000 - -	0.922 0.40 -0.04	0.930 0.14 -0.18	0.958 0.70 0.49	0.000 - -	1.066 0.35 0.54	1.211 -0.65 -0.16			
0.912 0.59 0.26	0.929 -1.01 -1.22	0.939 0.41 0.30	0.991 -0.01 0.09	1.067 0.28 0.46	1.204 -0.80 -0.38				
0.926 -0.70 -0.81	0.935 0.17 0.17	1.000 -0.72 -0.52	1.092 -0.45 -0.17	1.212 -0.73 -0.23					
0.963 0.00 0.21	1.003 -0.35 -0.05	1.120 -0.90 -0.45							
1.068 -0.91 -0.35	1.139 -1.45 -0.84						MCNP DeCART 47-g DeCART 190-g		
1.229 -1.84 -1.03									

Figure 3. Comparison of the pin power distributions for the CNPS 184 core

3. Conclusion

We performed DeCART calculations for the CNPS numerical benchmark problems. The computation results showed that the DeCART results with the 47 and 190 group libraries were very consistent with those of MCNP. Although many more benchmark calculations are required, the DeCART code can predict the eigenvalue and the power distribution accurately for the VHTR cores.

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