DeCART Solution for VERA Benchmark Problems from 5 to 9

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1. Introduction

The VERA benchmark [1] is a good problem for the evaluation of the code uncertainties in the aspects of eigenvalue, power distribution, control rod worth and reactivity coefficients systematically because it contains the problems from pin cell to whole core depletion at hot full power (HFP) state. In KAERI, this benchmark is used to estimate the code system uncertainties of DeCART2D/MASTER [2,3]. This benchmark was also solved by the nTER code [4] which is a descendant code of DeCART [5] focusing on the rectangular commercial reactors but equips the massive parallel computation, and the results for the problems from 1 to 4 were published. In this paper, the solutions for the remaining problems from 5 to 9 are presented. The last problem 10 which aims to demonstrate the depletion capability for reload core is not solved due to the lack of problem information such as material composition and assembly configuration, etc. In the comparison, some results of nTRACER [6] are also compared.

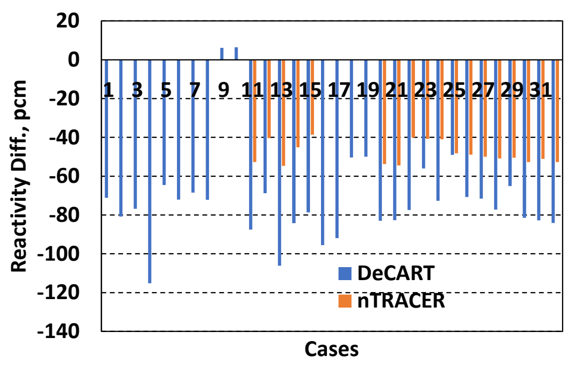
2. Calculations and Results

In solving the benchmark problems, the ray options of 0.02 cm spacing, 32 azimuthal angles, and 2 polar angles are used. In addition, the P2 anisotropic scattering calculation using the multi-group library based on ENDF/B-VII.1 is performed.

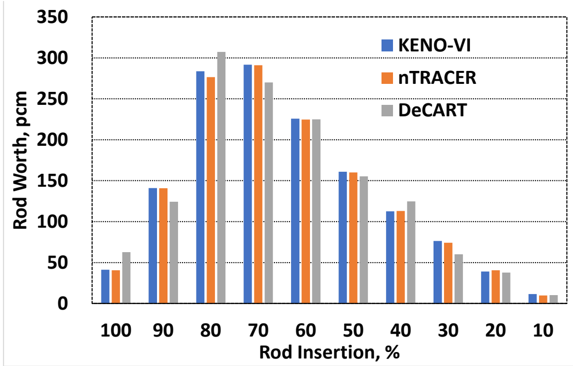
2.1 Problem5: Physical Reactor Zero Power Physics Tests Problem

This problem demonstrates the DeCART capability to predict the eigenvalue and core reactivity coefficients without thermal-hydraulic feedback or depletion for a full reactor model consistent with typical nuclear core analysis. The reference solution are given from the KENO-VI calculation. In DeCART calculation, the 24 planes model including 4 bottom reflector and 4 top reflector planes.

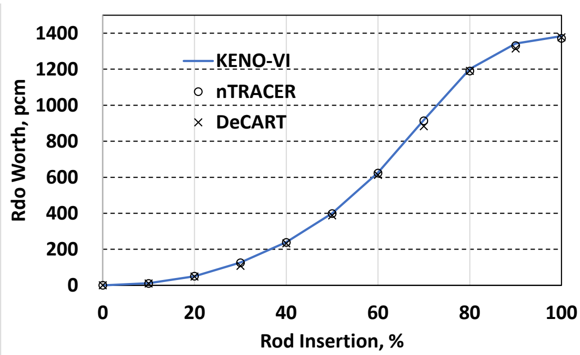
The calculation results are given in Fig. 1. In the eigenvalue comparison, while nTRACER shows good agreement with KENO-VI of about 50 pcm over all the problems, DeCART shows a llitle bit fluctuation of about 100 pcm in eigenvalue difference. Almost the same eigenvalue error of nTRACER in over all the problems is mainly due to the exact 58 axial plane model corresponding to the control rod position to remove the rod cusping effect, and it results in the accurate estimation of the control rod worth. DeCART shows a good agreement in the integral rod worth but a little bit larger error in the differential rod worth than the nTRACER code. In the radial assembly power distributions, DeCART shows good agreement showing less than 2.0 % error. In the axial power distribution, DeCART shows similar power shape as KENO. In the comparison for the isothermal temperature coefficient (ITC), all codes estimate similar reactivity coefficient.



(a) Eigenvalue Error



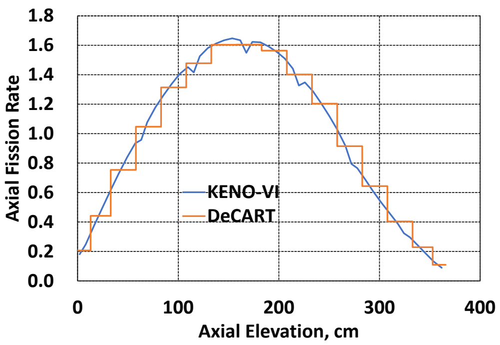
(b) Differential Rod Worth Comparison for D Bank



(c) Integral Rod Worth Comparison for D Bank

0.9487					
-1.67					
0.9193	0.9973		KENO-VI, Power		
-1.64	-1.88		DeCART, Err., %		
1.0181	0.9083	1.0648			
-1.74	-1.52	-1.54			
0.9850	1.0819	1.0412	1.1615		
-1.06	-1.28	-0.96	-0.84		
1.0647	1.0471	1.1746	1.0850	1.2368	
-0.51	-0.50	-0.64	-0.17	0.28	
1.0480	1.1619	1.1520	1.1508	0.8969	0.9126
0.12	-0.10	0.16	0.13	0.46	0.75
1.0841	1.0652	1.1039	1.0496	0.9452	0.6296
0.58	0.97	0.65	1.04	1.05	0.70
0.7931	0.9071	0.8046	0.6590		
1.60	1.68	1.59	1.34		

(d) Radial Power Error for Initial Condition



(e) Axial Power Comparison for Initial Condition

Code	ITC, pcm/K
KENO-VI	5.74
nTRACER	5.80
DeCART	5.71

(f) ITC Comparison for ARO Condition

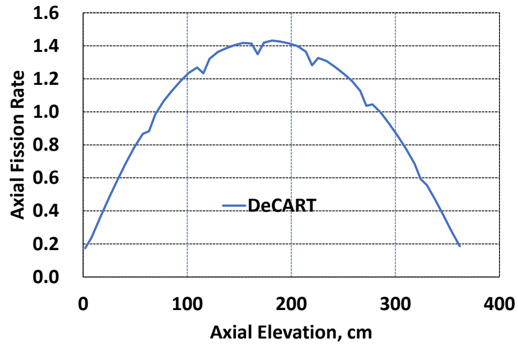
Fig. 1. Solution comparisons for problem 5.

2.2 Problem 6: 3D HFP Assembly Problem

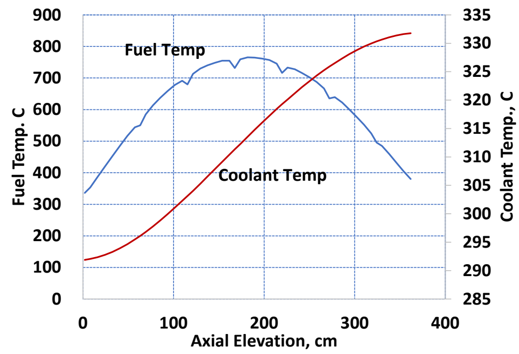
This problem demonstrates the DeCART capability for a coupled multi-physics iterative solution in an operating reactor condition. The geometry is a single PWR fuel assembly identical to Problem 3. However, this assembly is at typical full power and nominal flow conditions, requiring the additional capability of thermal-hydraulic (T-H) feedback to the neutronics in both the fuel and coolant properties.

In this calculation, the 57 plane model which divides the spacer grid region explicitly is used. The coolant temperature rise from inlet to outlet is fixed to 40 °C, and the mass flow rate is determined in the code to meet the coolant temperature rise. The coolant properties are obtained by solving the assembly-wise closed lumped channel model and using steam table in the code. The fuel temperature is determined by solving the pin-wise conduction equation and using the fuel and cladding property in the code. The reference solution for this problem is not given in the benchmark book. Therefore, in this section, the feasibility of the DeCART solution is discussed rather than the comparison with other code.

Fig. 2 shows the DeCART solution for Problem 6. One can see that DeCART shows reasonable axial power shape and axial temperature distribution.



(a) Axial Power Distribution



(b) Axial Temperature Distribution

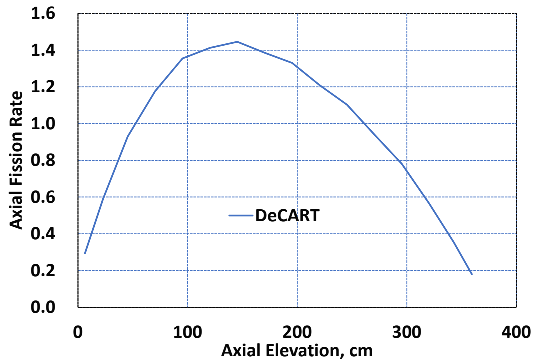
Fig. 2. DeCART Solution for problem 6.

2.3 Problem 7: 3D HFP BOC Physical Reactor

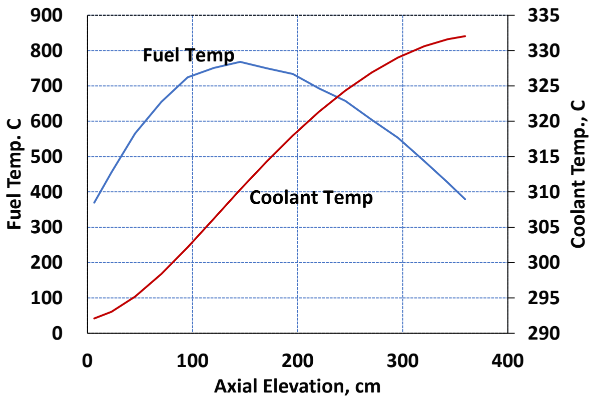
This problem demonstrates the DeCART capability for a coupled multi-physics iterative solution in an operating reactor condition. The geometry is the Watts Bar Cycle 1 core identical to Problem 5. However, this core is at typical full power and nominal flow conditions, requiring the additional capability of thermal-hydraulic feedback to the neutronics in both the fuel and coolant properties.

In this calculation, the 24 plane model which smears the spacer grid in the axial thick plane is used. The coolant temperature rise from inlet to outlet is fixed to 40 °C, and the mass flow rate is determined in the code to meet the coolant temperature rise as in problem 6. The fuel and coolant properties in this problem are obtained as the same way as in problem 6. The reference solution for this problem is not given as problem 6. Therefore, in this section also, the feasibility of the DeCART solution is discussed.

Fig. 3 shows the DeCART solution for Problem 7. One can see that DeCART shows reasonable axial power shape and axial temperature distribution.



(a) Axial Power Distribution



(b) Axial Temperature Distribution

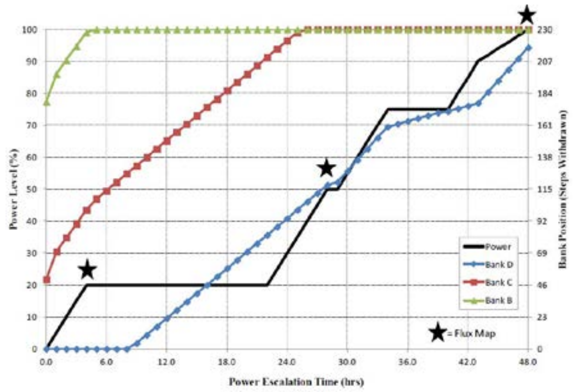
Fig. 3. DeCART Solution for problem.7.

2.4 Problem 8: Physical Reactor Startup Flux Maps Problem

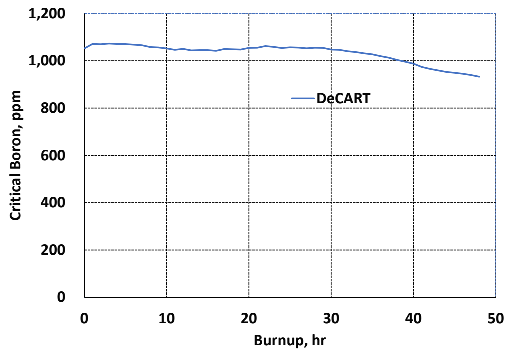
This problem demonstrates the DeCART startup follow capability in an operating reactor condition. The geometry is the Watts Bar Cycle 1 core identical to Problem 5. However, rather than executing a single state point at BOC HFP equilibrium conditions, the code must provide for time-dependent simulation of a power escalation procedure, and include predictions of the incore instrumentation response at various points during the startup. As with Problem 7, thermal-hydraulic feedback to the neutronics is required.

In the DeCART calculation, the coolant temperature rise from inlet to outlet is set to vary linearly according to the core power level from 0 °C at zero power to 40 °C at full power condition, and the mass flow rate is determined in the code to meet the condition of coolant temperature rise. Also, while the coolant temperature is determined using the assembly lumped model, the fuel temperature is calculated for each pin rod by solving the conduction equation. For time-dependent simulation of a power escalation procedure, the depletion calculation is performed with 1 hour depletion step.

The calculation result of critical boron concentration is given in Fig. 4. For this problem, no reference solution exists at this time. Therefore, the comparison with other results can be done in the future. The DeCART result looks good showing reasonable shape.



(a) Reactor Startup Sequence



(b) Critical Boron Concentration

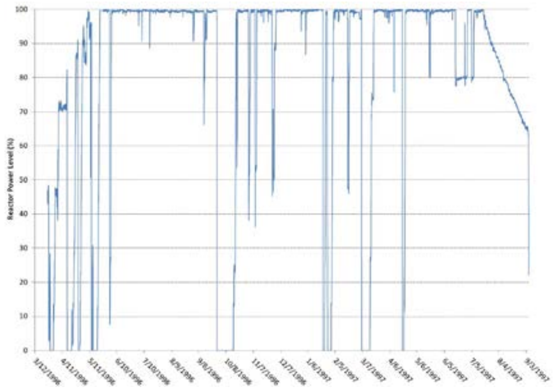
Fig. 4. DeCART Solution for problem 8.

2.5 Problem 9: Physical Reactor Depletion Problem

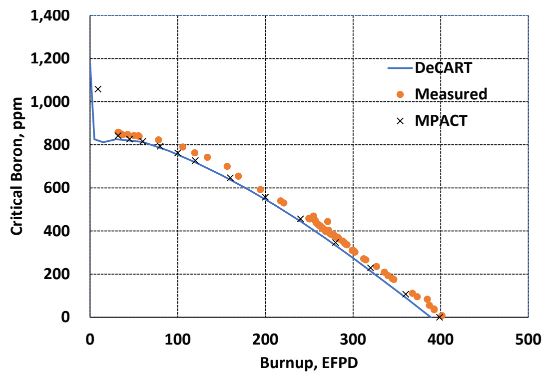
This problem demonstrates the DeCART depletion capability in an operating reactor condition. The geometry is the Watts Bar Cycle 1 core identical to Problem 5. Like the previous problem, time dependent of the reactor at operating conditions in pseudo-steady state is a major requirement. However, this problem increases the required time scale to the length of a typical 18 month fuel cycle. Fig. 5(a) shows the core power history during the cycle length. According to the core power history, the D bank position and the coolant inlet condition is also varied.

In the DeCART depletion calculation, the core power is fixed to the full power condition, and the D bank position to 215 steps. Also the core inlet temperature and temperature rise from inlet to outlet are fixed to 291.85 °C and 40 °C, and the mass flow rate is determined in the code to meet the coolant temperature rise. The node-wise coolant and fuel temperature are calculated as the previous problems.

The calculation result of the critical boron concentration (CBC) is given in Fig. 5(b). For this problem, the measured CBC is given in the benchmark book with the measured state. Among the measured data, the CBCs for the power state over 90 % of full power are selected and displayed in the Figure. DeCART shows about 30 ~ 40 ppm lower CBCs which are general in the other codes such as MPACT [7,8]. Therefore it can be concluded that the DeCART model and the DeCART results are reasonable.



(a) Core Power History



(b) Critical Boron Concentration

Fig. 5. Solution comparisons for problem 9.

3. Conclusions

In this paper, the VERA benchmark from problem 5 to 9 were solved by DeCART. The results in this paper with the results published already from problem 1 to 4 showed that DeCART contained the capability to solve the benchmark problems for the initial core at the various states including full power condition and depletion problem. However, the problem 10, the reload core depletion problem, was not solved due to the lack of problem information such as material composition and assembly configuration, etc. Therefore, in the future, the capability to solve the reload core needs to be verified.

ACKNOWLEDGMENT

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