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Verification and Validation of MASTER Code for Steady-State and Transient Benchmark Core Calculations

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1. Introduction

For the verification and validation of the MASTER code [1], the steady-state and transient PWR benchmark problems are simulated. It is performed as a part of licensing the DeCART2D/MASTER code system for SMART core design. This work focuses on the verification of MASTER methodology and errors from the group constant homogenization performed in the DeCART2D code are exclusive. MASTER is designed to analyze the steady-state and transient core behaviors. The reliability, accuracy, stability and efficiency of MASTER can be verified by simulating the benchmark sets based on well-defined problems with a complete set of input data, such as core configurations, group constants and core conditions, and a unique solution.

The IAEA PWR benchmark sets [2] of 2-dimensional and 3-dimensional are performed to verify the performance of the steady-state calculations. To verify the performance of the transient calculation, NEACRP 3-D LWR transient benchmark [3], which simulated the control rod ejection from the core, is performed.

2. Benchmark Problem Specifications

2.1 IAEA PWR Benchmark Problem

The IAEA PWR benchmark problem offers a steady-state core power distribution test and is widely used to test the accuracy of the diffusion theory solution. This problem is a simplified three-dimensional or two-dimensional, two-group core consisting of a two-zone core containing 177 fuel assemblies, each having a width of 20cm. The core is surrounded by 20cm of water reflector. The active core height is 340cm. The nine fully-inserted controls rods and four partially-inserted control rods exist in the core and they make the accurate calculation of flux distribution. The reactor core has an octant symmetry and a vacuum boundary condition. The two-dimensional test problem is chosen as the middle plane of the three-dimensional problem.

2.2 NEACRP 3-D LWR Transient Benchmark Problem

The NEACRP 3-D LWR transient benchmark problem is the one of the NEACRP standard problems of PWR core safety analysis about the rod ejection accident. This problem is used to assess the discrepancies between the 3-D space-time kinetics codes in transient calculations. The transients are initiated from hot zero power (2775W) and hot full power (2775MW) for three different rod ejection configurations. The cases are denoted by A1, B1, C1 for HZP and A2, B2, C2 for HFP. The reactor core consists of 157 fuel assemblies each having a width of 21.606cm and is surrounded by same width of reflectors. The active core height is 367.3cm including top and bottom reflectors having a thickness of 30cm. The four types CAs, which are labeled with symbols -, C, B, A and X which correspond to insertion lengths of 228, 200, 150, 100 and 0 steps. The time for CA ejection is 100 ms for all cases independent of the initial insertion depth. After ejection has occurred no reactor scram will be considered.

3. Results

3.1 IAEA PWR Benchmark Problem

MASTER steady-state calculations are performed with 4 boxes per one assembly radially and with axially 17 nodes. The reference solution of two-dimensional test problem is a 10/3cm nodal calculation obtained by Wagner [2], which is spatially converged. The reference solution of three-dimensional test problem is obtained by finite difference solution using the VENTURE code [2], which involving 1.25cm radial meshes. The calculation results are compared for k-effective and axially averaged radial assembly power distributions.

Table I shows the comparison results of k-effective for two- and three-dimensional benchmark problems. The differences between MASTER and reference solutions are 0.00002 and 0.00007, respectively. This results show good agreement.

Table I. Comparison Results of k-effective for the IAEA PWR Problem

Case	Reference (a)	MASTER (b)	Diff (b-a)
2-D	1.02959	1.02961	+0.00002
3-D	1.02903	1.02910	+0.00007

Figure 1 and Figure 2 are the comparison results of MASTER radial power distributions with the reference solutions, respectively. It can be seen from this figures that the largest discrepancies are 0.77% and 1.21% for each problem. These results also show good agreement because the assembly having a largest percent error are located in low power assemblies adjacent to the reflector. Therefore, MASTER performs correctly for solving the steady-state problems.

0.7456 -0.15	1.3097 -0.28	1.4537 -0.20	1.2107 -0.22	0.6100 -0.03	0.9351 -0.10	0.9343 0.05	0.7549 0.12
	1.4351 -0.19	1.4799 -0.19	1.3149 -0.13	1.0697 -0.16	1.0361 0.01	0.9504 0.07	0.7358 0.15
		1.4694 -0.16	1.3451 -0.13	1.1792 -0.07	1.0705 0.03	0.9752 0.05	0.6921 0.53
			1.1929 -0.08	0.9670 -0.09	0.9064 0.12	0.8461 0.37	
				0.4706 0.15	0.6856 0.06	0.5972 0.59	
	Ref. Diff.(%)				0.5849 0.77		

Figure 1. Normalized Assembly Power and Errors for the 2-D IAEA PWR Problem

0.7290 -0.40	1.2810 -0.67	1.4220 -0.54	1.1930 -0.50	0.6100 -0.02	0.9530 -0.13	0.9590 0.20	0.7770 0.41
	1.3970 -0.58	1.4320 -0.59	1.2910 -0.47	1.0720 -0.41	1.0550 -0.06	0.9760 0.12	0.7570 0.46
		1.3680 -0.46	1.3110 -0.40	1.1810 -0.25	1.0890 0.01	1.0000 0.16	0.7110 0.87
			1.1780 -0.28	0.9720 -0.25	0.9230 0.15	0.8660 0.62	
				0.4760 0.23	0.7000 0.16	0.6110 0.90	
	Ref. Diff.(%)				0.5970 1.21		

Figure 2. Normalized Assembly Power and Errors for the 3-D IAEA PWR Problem

3.2 NEACRP 3-D LWR Transient Benchmark Problem

In the most rod ejection accident, which causes the super-prompt critical, the behavior of core power appears in the form of a pulse. This is because the rapid power increase is controlled by the immediate Doppler feedback effect. The major evaluation parameters for rod ejection accidents are the time of peak power, power at the peak time and the area of pulse (core power integral). For the initial steady-state, critical boron concentration and axially averaged radial power distribution are evaluated. For the transient, core power versus time and core power integral during 5 seconds for all cases are evaluated. MASTER steady-state calculations are performed with 4 boxes per one assembly radially. MASTER results are compared with reference solutions that are obtained from PARCS 4 nodes per assembly calculation.

Table II. CBC at initial steady-state (unit : ppm)

Case	MASTER (a)	PARCS (b)	Diff. (a-b)
A1	561.36	561.26	0.10
A2	1154.09	1154.37	-0.28
B1	1248.09	1248.21	-0.12
B2	1182.56	1182.87	-0.31
C1	1128.41	1128.64	-0.23
C2	1154.09	1154.38	-0.29

Table II shows the comparison results of critical boron concentrations at initial steady-state. For all cases, the differences are quite small which are within 1 ppm.

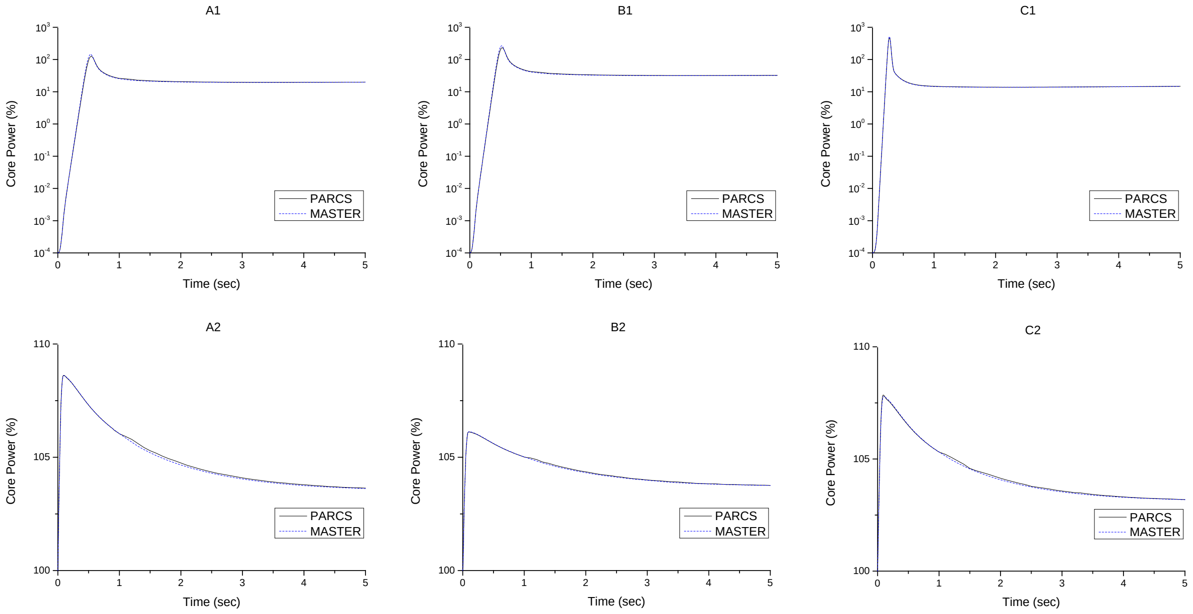

Figure 3. Core Power Behavior versus time for NEACRP Transient Calculation

Table III shows the maximum differences and RMS errors of radial power distribution at initial state. The maximum difference between MASTER and reference solution is 0.50% for Case A1 and the maximum RMS error is 0.16% for Case A1.

Table IV show the core power integral for 5 seconds. In case of rod ejection at hot full power, the difference is slightly larger than that at hot zero power. However, the maximum difference is smaller than 2%. Figure 3 represents the core power behavior versus time after rod ejection accident. It can be seen that MASTER predicts reactor power behavior and reactor peak power accurately.

Table III. Radial Power Distribution Error (unit : %)

Case	Max Diff.	RMS
A1	0.49	0.16
A2	0.18	0.08
B1	0.20	0.09
B2	0.17	0.08
C1	0.35	0.12
C2	0.18	0.09

Table IV. Core Power Integral during 5 sec (unit : %)

Case	MASTER (a)	PARCS (b)	Diff. (a-b)
A1	114.04	113.71	0.33
A2	522.97	524.56	-1.59
B1	188.11	188.08	0.03
B2	522.59	521.99	0.60
C1	97.93	97.11	0.82
C2	520.09	521.57	-1.48

4. Conclusion

The verification of the MASTER code is performed via benchmark comparisons for steady-state and transient core conditions. Benchmark calculations include comparisons with reference solutions of IAEA PWR and NEACRP 3-D LWR problems. The MASTER results are almost identical with reference solutions of all test problems. It is concluded that MASTER is correctly working for solving steady-state and transient benchmark problems. Also, this study will be extended to comparisons with experiment measurement data to validated that DeCART2D/MASTER code system can be sufficiently applied to SMART core design.

ACKNOWLEDGMENT

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