Proceeding of the Korean Nuclear Society Spring Meeting
Cheju, Korea, May 1996

CASMO-3/MASTER Pin Power Benchmarking for the B&W Critical Experiments

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Abstract

A three-dimensional reactor core simulation code, MASTER has been developed as a part of ADONIS which is the Korean core design package in KAERI. CASMO-3 is used as a precedent lattice code for two-group microscopic cross sections and heterogeneous formfunctions.

The pin power reconstruction capability of CASMO-3/MASTER was evaluated for a validation and verification. Five B&W critical experiments were selected as benchmark problems. These problems included two experiments for CE-type and three for WH-type fuel assemblies. Two of them contained gadolinia rods as burnable absorber.

Comparisons of the calculated pin power distributions with the measured ones demonstrate that CASMO-3/MASTER can predict the pin power distributions as well as CASMO-3/SIMULATE-3.

I. Introduction

Korean core design package called ADONIS (Advanced Design and On-line Nuclear Information System) is under development in KAERI. MASTER (Multi-purpose Analyzer for Static and Transient Effects of Reactors) (Ref. 1) has been developed for core calculation as a part of ADONIS and CASMO-3 (Ref. 2) is supposed to be used as a lattice code.

All nuclear design codes should be validated and verified before the use for the nuclear design of operating reactors. Prediction capability should be evaluated in the validation and verification of the developed codes for various nuclear parameters - reactivities (boron concentration), pin-to-box factors, power distributions, rod worths and temperature coefficients, etc.. In this report the capability of pin power reconstruction of CASMO-3/MASTER was evaluated.

In MASTER the reconstruction of pin power distribution is performed by the method of successive smoothing with modified analytic solution(MSS-modified AS) and the modulation of heterogeneous formfunctions. CASMO-3/XFORM(Cross Section and Formfunction Formulator) (Ref. 3) was used to prepare the 2-group microscopic cross sections and heterogeneous formfunctions for MASTER.

Five B&W critical experiments(Ref. 4) were selected to evaluate the accuracy of the pin power prediction by CASMO-3/MASTER. To evaluate the prediction capability of CASMO-3/MASTER to the various fuel assemblies, 3 critical cores with small water holes and 2 with large water holes were selected and 2 of them contained UO_2+Gd_2O_3 burnable absorber rods. Critical cores were benchmarked by CASMO-3/MASTER to get the fission rate distributions in the central 15x15 or 16x16 fuel assemblies, which were compared with the measured values and the calculated values by CASMO-3/ SIMULATE-3.

II. B&W Critical Experiments

B&W critical experiments (Ref. 4) were conducted by DOE(U. S. Department Of Energy), Duke(Duke Power Company) and B&W(Babcock & Wilcox Company) in 1984 so as to verify the nuclear model for calculating the behavior of UO_2+Gd_2O_3 at the beginning-of-life condition in the PWR environment.

Five critical experiments for the fission rate distributions were selected in this calculation, and the core characteristics are shown in Table 1. Critical cores 1, 5, and 12 were composed of the WH-type fuels with the one-fuel-pin-size water holes, and critical cores 18 and 20 of CE-type fuels with the four-fuel-pin-size large water holes. Two of them (cores 5 and 20) included UO_2+Gd_2O_3 rods. In the selected B&W criticals there were 3 types of fuels which were 2.46w/o, 4.02w/o and 1.944w/o U^{235} fuel with 4w/o Gd_2O_3. The cladding for 2.46w/o U^{235} fuel and gadolinia rod was made of aluminum and SS304 for 4.02w/o U^{235} fuel. The critical cores were made to adjust the boron concentration when the moderator level was 145.0 cm and the temperature was 25 ^{o}C. Rhodium incore detector was placed in the central water hole. The fission rates distributions in the central fuel assemblies were measured three times at each configuration by gamma scanning. The normalized fission rates were calculated by averaging and normalizing three measured values.

III. CASMO-3/MASTER Modelling

Five B&W critical cores were benchmarked with a three-dimensional 2x2 mesh-per-node model using CASMO-3/MASTER. Because the critical cores were not composed of the complete fuel assemblies, the critical cores could not be exactly modelled in MASTER. Since our interest was the central 15x15 or 16x16 fuel assemblies and the formation of the peripheral fuel pins had almost no effect on the fission rate distribution of the central fuel assembly, we constructed the critical cores with the virtual quarter fuel assembly. B&W 1, 5 and 12 cores had the same core geometry and cores 18 and 20 were the same.

The assembly-homogenized microscopic cross sections and heterogenous formfunctions of fission rates for MASTER were prepared by CASMO-3/XFORM for each fuel assembly. The cross section of the radial reflector adopted from Reference 5 and that of the axial reflector from SAV79A (Ref. 6) design procedure were used. The cross section of the axial reflector had almost no effect on the radial fission rate distributions. The flow chart of CASMO-3/MASTER procedure is shown in Figure 1.

IV. Results and Analysis

The comparisons of measured and calculated fission rates are shown in Figures 2 to 6. The variances of the differences(S_d) between the measured and the calculated fission rates are shown in Table 2. Table 2 also shows the differences of peak pin values in fuel and gadolinia rods. Those values are compared with the values of CASMO-3/ SIMULATE-3 (Ref. 7).

The variances of CASMO-3/MASTER are less than 0.9% and 1.6% for the critical cores without and with gadolinia burnable absorber rods, respectively. The absolute differences of pin-to-box factors are less than 0.7% and 1.4% in the cores without and with gadolinia rods, respectively. Those values are comparable to the values of CASMO-3/ SIMULATE-3.

From the comparisons with the measurements, the several trends are found. The pin powers for the fuel pins adjacent to the gadolinia rods and the peripheral large water holes are underestimated in the calculation. The fission rates in gadolinia rods are underestimated. The fission rates in the fuel pins adjacent to the central water hole are overestimated. Those phenomena were also found in CASMO-3/SIMULATE-3, which demonstrate that those were originated from the heterogeneous formfunctions of CASMO-3.

V. Conclusions

All simulations of five critical cores show that the variances of pin power distributions and the maximum difference of pin-to-box factors in CASMO-3/MASTER are comparable to the values in CASMO-3/SIMULATE-3. Especially all the maximum differences of pin-to-box factors in CASMO-3/MASTER are less than the generic pin-to-box uncertainty of 2% in CASMO-3/SIMULATE-3. It is concluded that CASMO-3/MASTER procedure can predict the pin-to-box factors in other complicated core loadings with the similar accuracy.

References

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Table 1. B&W Critical Cores

Core	Core Description	2.46w/o pin #	4.02w/o pin #	Gd_2O_3 pin #	B_4C pin #	AgInCd pin #	Void pin #	1x1 water holes	2x2water holes	Boron ppm
1	15x15, 0-Gd	4808	0	0	0	0	0	153	-	1337.9
5	15x15, 12-Gd(A)	4780	0	28	0	0	0	153	-	1208.0
12	15x15, 0-Gd	3920	888	0	0	0	0	153	-	1899.3
18	16x16, 0-Gd	3676	944	0	0	0	0	-	45	1776.8
20	16x16, 16-Gd	3676	912	32	0	0	0	-	45	1499.0

Table 2. Summary of Pin Power Distributions

Cores	S_d (Meas.-Calc.)		Diff. in Peak Pin (Mea.-Cal.)/Mea.		Ave. Diff. in Gd Pin |Meas.-Calc.|	
	SIMULATE-3	MASTER	SIMULATE-3	MASTER	SIMULATE-3	MASTER
1	0.6%	0.6%	+0.1%	-0.2%	-	-
5	1.5%	1.6%	-1.1%	-1.4%	0.004	0.004
12	0.9%	0.9%	-0.5%	-0.2%	-	-
18	0.8%	0.8%	+0.8%	+0.7%	-	-
20	1.2%	1.5%	-1.3%	-1.4%	0.002	0.005

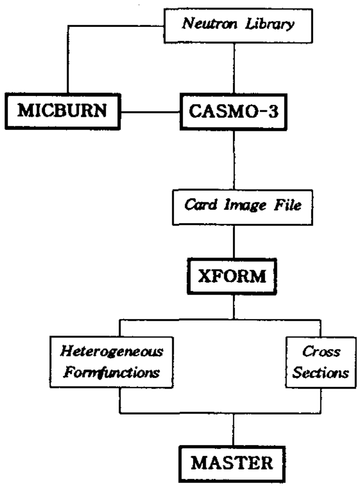

Figure 1. Flow Chart for Benchmark Calculation

0.000 0.000 0.000	- MEASURED FISSION RATE - CALCULATED FISSION RATE - MEAS. - CALC.						
1.018 1.040 -0.022	1.019 1.031 -0.012						
1.011 1.003 0.008	1.067 1.069 -0.002	0.000 0.000 0.000					
0.986 0.989 -0.003	1.012 1.015 -0.003	1.081 1.084 -0.003	1.053 1.059 -0.006				
0.981 0.984 -0.003	1.009 1.011 -0.002	1.091 1.085 0.006	1.104 1.106 -0.002	0.000 0.000 0.000			
0.997 0.982 0.015	1.057 1.051 0.006	0.000 0.000 0.000	1.086 1.087 -0.001	1.058 1.058 0.000	0.988 0.983 0.005		
0.966 0.963 0.003	0.999 0.983 0.016	1.033 1.040 -0.007	0.989 0.990 -0.001	0.966 0.962 0.004	0.938 0.943 -0.005	0.925 0.927 -0.002	
0.945 0.943 0.002	0.945 0.946 -0.001	0.953 0.951 0.002	0.945 0.945 0.000	0.934 0.934 0.000	0.923 0.924 -0.001	0.914 0.915 -0.001	0.903 0.906 -0.003

Figure 2. Fission Rates Comparison for B&W Core-01

0.000 0.000 0.000	- MEASURED FISSION RATE - CALCULATED FISSION RATE - MEAS. - CALC.						
1.005 1.031 -0.026	0.999 1.016 -0.017						
0.913 0.897 0.016	1.017 1.022 0.005	0.000 0.000 0.000					
0.177 0.178 -0.001	0.931 0.903 0.028	0.988 0.964 0.024	0.188 0.182 0.006				
0.932 0.917 0.015	1.007 1.002 0.005	1.087 1.078 0.009	1.049 1.027 0.022	0.000 0.000 0.000			
1.035 1.051 -0.016	1.124 1.131 -0.007	0.000 0.000 0.000	1.130 1.148 -0.018	1.047 1.016 0.031	0.195 0.190 0.005		
1.062 1.085 -0.023	1.093 1.109 -0.016	1.157 1.173 -0.016	1.087 1.100 -0.013	1.034 1.030 0.004	0.963 0.940 0.023	1.018 1.016 0.002	
1.071 1.099 -0.028	1.089 1.103 -0.014	1.099 1.107 -0.008	1.085 1.093 -0.008	1.069 1.070 -0.001	1.053 1.055 -0.002	1.059 1.061 -0.002	1.070 1.071 -0.001

Figure 3. Fission Rates Comparison for B&W Core-05

0.000 0.000 0.000	- MEASURED FISSION RATE - CALCULATED FISSION RATE - MEAS. - CALC.						
1.074 1.099 -0.025	1.067 1.076 -0.009						
1.040 1.033 0.007	1.125 1.126 -0.001	0.000 0.000 0.000					
1.006 1.010 -0.004	1.044 1.040 0.004	1.114 1.130 -0.016	1.083 1.080 0.003				
1.019 0.997 0.022	1.034 1.028 0.006	1.118 1.121 -0.003	1.138 1.140 -0.002	0.000 0.000 0.000			
1.000 0.985 0.015	1.075 1.081 0.006	0.000 0.000 0.000	1.102 1.110 0.008	1.071 1.068 0.003	0.957 0.963 0.006		
0.960 0.954 0.006	0.987 0.978 0.009	1.034 1.052 -0.018	0.979 0.976 0.003	0.939 0.936 0.003	0.900 0.909 -0.009	0.884 0.883 0.001	
0.924 0.919 0.005	0.927 0.921 0.006	0.941 0.923 0.018	0.907 0.912 -0.005	0.895 0.896 -0.001	0.883 0.877 0.006	0.857 0.858 -0.001	0.844 0.836 0.008

Figure 4. Fission Rates Comparison for B&W Core-12

0.000 0.000 0.000	- MEASURED FISSION RATE - CALCULATED FISSION RATE - MEAS. - CALC.						
1.205 1.218 -0.013	1.075 1.081 -0.006						
1.033 1.032 0.001	1.021 1.031 -0.010	1.066 1.079 -0.013					
0.996 0.999 -0.003	1.012 1.025 -0.013	1.227 1.216 0.011	0.000 0.000 0.000				
0.978 0.985 -0.007	1.010 1.012 -0.002	1.204 1.202 0.002	0.000 0.000 0.000	0.000 0.000 0.000			
0.959 0.967 -0.008	0.982 0.980 0.002	1.042 1.038 0.004	1.183 1.173 0.010	1.170 1.159 0.011	0.995 0.999 -0.004		
0.941 0.947 -0.006	0.946 0.949 -0.003	0.957 0.957 0.000	0.974 0.964 0.010	0.970 0.953 0.017	0.925 0.921 0.004	0.893 0.890 0.003	
0.910 0.923 -0.013	0.912 0.921 -0.009	0.928 0.919 0.009	0.924 0.913 0.011	0.909 0.902 0.007	0.886 0.884 0.002	0.866 0.863 0.003	0.833 0.841 -0.008

Figure 5. Fission Rates Comparison for B&W Core-18

0.000 0.000 0.000	- MEASURED FISSION RATE - CALCULATED FISSION RATE - MEAS. - CALC.						
1.279 1.301 -0.022	1.111 1.118 -0.007						
1.081 1.089 -0.008	1.011 1.000 0.011	0.170 0.165 0.005					
1.059 1.062 -0.003	1.058 1.063 -0.005	1.237 1.212 0.025	0.000 0.000 0.000				
1.044 1.059 -0.015	1.075 1.080 -0.005	1.268 1.288 -0.020	0.000 0.000 0.000	0.000 0.000 0.000			
1.043 1.049 -0.006	1.034 1.037 -0.003	1.073 1.046 0.027	1.283 1.265 0.018	1.280 1.276 0.004	1.077 1.080 -0.003		
1.017 1.039 -0.022	0.973 0.960 0.013	0.167 0.162 0.005	0.971 0.981 -0.010	1.044 1.041 0.003	0.961 0.943 0.018	0.159 0.154 0.005	
1.010 1.037 -0.027	0.980 1.003 -0.023	0.953 0.937 0.016	0.998 0.992 0.006	0.999 1.003 -0.004	0.978 0.965 0.013	0.900 0.889 0.011	0.930 0.921 0.009

Figure 6. Fission Rates Comparison for B&W Core-20