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Application of the Reactivity Coefficient Method for the Nuclear Design Calculations

M. Kromar, A. Trkov
Jožef Stefan Institute
Jamova 39, Ljubljana, Slovenia
E-mail: *marjan.kromar@ijs.si*
andrej.trkov@ijs.si

ABSTRACT – *The CORD-2 package has been extended with the possibility of a cycle specific neutron macroscopic cross section library as an additional option to the standard sequence of calculation. The cross section library is generated with the standard calculational procedure at three specific operating conditions (hot full power, hot zero power and cold zero power) and at several cycle burnup steps. Nodal cross sections at any other operating conditions are obtained by modification of the cross sections with the reactivity coefficient method and suitable interpolation.*

1. Introduction

The CORD-2 package[1] developed at our institute has been verified for design calculations of PWR cores. Since the system was designed to be flexible and as accurate as possible, it does not rely on macroscopic cross sections library. Instead, the concept of an isotopic composition library was adopted. For each problem to be solved, only cell isotopic composition is retrieved from a precomputed library. Everything else (cell cross sections determination, assembly cross section homogenization, global diffusion calculation) is performed on case by case basis. In this standard sequence of calculation, Xenon and power feedback effects are mainly calculated by the WIMS[2] code. Only small local perturbations to accurately account for thermohydroulic and neutronic coupling are covered by reactivity coefficient method (RCM)[3] applied in the diffusion code GNOMER[4].

The concept proved to be successful for typical design calculations of reload cores, where only relatively limited number of cases need to be examined. However, for some specific problems, such as loading pattern determination, 3-D dynamic and kinetic problems, efficiency of the system is not sufficient to be practical. Since the recently refined reactivity coefficient method[3] proved to be sufficiently accurate, the implementation of a cycle specific cross section library was investigated.

The macroscopic cross section library is generated with the standard calculational procedure at three specific operating conditions (HFP - Hot Full Power, HZP - Hot Zero Power and CZP - Cold Zero Power) and at several cycle burnup steps. Nodal cross sections at any other operating conditions are obtained by modification of the cross sections with the reactivity coefficient method and suitable interpolation.

2. Cross section verification

Accuracy of the concept was tested on several cases which normally arise during the process of the nuclear design. Results of calculations (marked as RCM) are compared with results based on the standard sequence of calculations with CORD-2 package (marked as CORD-2) in a typical Krško NPP reload cycle.

2.1 Zero power conditions

Comparison of the critical boron concentrations for the All Rods Out (ARO) and All Rods In (ARI) configuration at the Beginning, Middle and End Of Cycle (BOC, MOC, EOC) conditions are shown in Tables 1 and 2. Temperature was varied over the entire CZP-HZP range. Maximal difference for the ARO condition is 9 ppm and 22 ppm for the ARI case. Observed differences are within the accuracy of the CORD-2 package and lie well within standard 50 ppm review criteria.

Table 1: Comparison of the ARO critical boron concentrations at BOC, MOC and EOC.

	BOC			MOC			EOC		
T [deg.C]	CORD-2 [ppm]	RCM [ppm]	DIFF. [ppm]	CORD-2 [ppm]	RCM [ppm]	DIFF. [ppm]	CORD-2 [ppm]	RCM [ppm]	DIFF. [ppm]
21	2110	2110	0	1650	1650	0	1234	1233	-1
60	2117	2123	6	1650	1656	6	1226	1232	6
93	2127	2135	8	1649	1658	9	1216	1225	9
149	2150	2157	7	1647	1653	6	1192	1196	4
177	2163	2168	5	1643	1645	2	1174	1172	-2
204	2170	2173	3	1631	1630	-1	1144	1140	-4
260	2169	2172	3	1569	1570	1	1034	1033	-1
292	2137	2137	0	1482	1482	0	905	904	-1

Table 2: Comparison of the ARI critical boron concentrations at BOC, MOC and EOC.

T	BOC			MOC			EOC		
	CORD-2	RCM	DIFF.	CORD-2	RCM	DIFF.	CORD-2	RCM	DIFF.
[deg.C]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]
21	1370	1365	-5	912	912	0	528	533	5
60	1349	1354	5	883	893	10	492	508	16
93	1327	1334	7	850	863	13	452	471	19
149	1275	1278	3	774	780	6	356	369	13
177	1240	1237	-3	724	723	-1	293	299	6
204	1192	1185	-7	656	652	-4	210	215	5
260	1031	1028	-3	438	442	4	-49	-32	17
292	858	853	-5	214	221	7	-309	-287	22

Comparison of the isothermal temperature defect (Tables 3 and 4) shows similar behavior. Maximal difference is 120 pcm for the ARO case and 132 pcm for the ARI condition. All four tables also implicitly show acceptable discrepancies in boron reactivity coefficient and control rod worths.

Table 3: Comparison of the ARO isothermal temperature defect at BOC, MOC and EOC.

T	BOC			MOC			EOC		
	CORD-2	RCM	DIFF.	CORD-2	RCM	DIFF.	CORD-2	RCM	DIFF.
[deg.C]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]
21	210	205	-5	1591	1597	6	3391	3410	19
60	245	293	48	1548	1618	70	3224	3323	99
93	288	358	70	1499	1591	92	3038	3158	120
149	393	451	58	1391	1447	56	2628	2688	60
177	440	475	35	1309	1327	18	2371	2377	6
204	439	461	22	1157	1156	-1	2022	2004	-18
260	291	313	22	610	625	15	983	995	12
292	0	0	0	0	0	0	0	0	0

Table 4: Comparison of the ARI isothermal temperature defect at BOC, MOC and EOC.

T	BOC			MOC			EOC		
	CORD-2	RCM	DIFF.	CORD-2	RCM	DIFF.	CORD-2	RCM	DIFF.
[deg.C]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]	[pcm]
21	1686	1681	-5	2975	2973	-2	4678	4693	15
60	1617	1678	61	2832	2909	77	4417	4525	108
93	1550	1635	85	2678	2779	101	4133	4265	132
149	1417	1475	58	2347	2401	54	3517	3574	57
177	1327	1350	23	2137	2143	6	3141	3138	-3
204	1169	1175	6	1838	1822	-16	2657	2628	-29
260	614	633	19	912	924	12	1265	1277	12
292	0	0	0	0	0	0	0	0	0

2.2 At power conditions

Comparison of the total power defect is presented on Table 5. Differences are even smaller than in no power case.

Table 5: Comparison of the total power defect at BOC, MOC and EOC.

P [%]	BOC CORD-2 [pcm]	BOC RCM [pcm]	BOC DIFF. [pcm]	MOC CORD-2 [pcm]	MOC RCM [pcm]	MOC DIFF. [pcm]	EOC CORD-2 [pcm]	EOC RCM [pcm]	EOC DIFF. [pcm]
100	-1953	-1963	-10	-2402	-2415	-13	-2971	-3015	-44
75	-1513	-1522	-9	-1839	-1855	-16	-2264	-2308	-44
50	-1045	-1053	-8	-1273	-1290	-17	-1562	-1605	-43
25	-544	-550	-6	-667	-685	-19	-823	-850	-28
0	0	0	0	0	0	0	0	0	0

Results of the HFP control rod worth calculations are shown in Table 6. Even for a such extreme case as total insertion of control rods at HFP, agreement is excellent.

Table 6: Comparison of the HFP control rod worths at BOC, MOC and EOC.

Control bank	BOC CORD-2 [pcm]	BOC RCM [pcm]	BOC DIFF. [pcm]	MOC CORD-2 [pcm]	MOC RCM [pcm]	MOC DIFF. [pcm]	EOC CORD-2 [pcm]	EOC RCM [pcm]	EOC DIFF. [pcm]
D	753	751	-2	797	796	-1	817	816	-1
C	1238	1239	1	1224	1225	1	1266	1266	0
B	944	950	6	1030	1034	4	1078	1083	5
A	1566	1569	3	1826	1828	2	1860	1859	-1
S	3855	3872	17	3924	3933	9	4012	4002	-10

Power distributions for the core at 75 % nominal power are presented in Figures 1 and 2. Differences are smaller than 0.25 % in average assembly powers and less than 0.5 % in average axial distribution.

1.0862 1.0853 -0.09				CORD-2 RCM DIFF. [%]
0.9538 0.9526 -0.12	1.1578 1.1570 -0.08			
1.2983 1.2982 -0.01	1.0672 1.0668 -0.04	1.0997 1.0995 -0.02		
0.9099 0.9107 0.08	1.0914 1.0902 -0.12	1.3450 1.3456 0.06	1.1358 1.1362 0.04	
1.0885 1.0862 -0.23	1.2883 1.2887 0.04	1.3036 1.3044 0.08	1.1449 1.1456 0.07	0.4505 0.4506 0.01
1.2361 1.2364 0.03	1.1441 1.1445 0.04	1.0000 1.0007 0.07	0.4229 0.4229 0.00	
0.3951 0.3941 -0.10	0.3191 0.3191 0.00			

Figure 1: Comparison of the assemblywise power at the 75 % core power level, BOC.

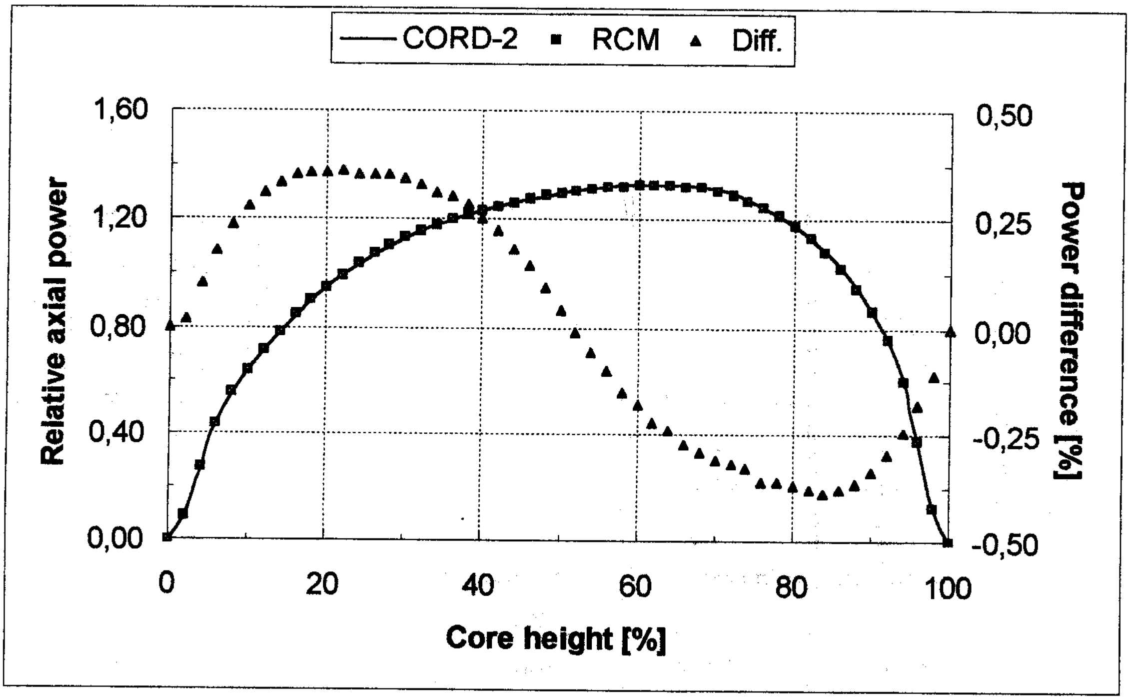

Figure 2: Comparison of the relative average axial power at the 75 % core power level, BOC.

3. Conclusion

Concept of the cycle dependent nodal macroscopic cross section library, incorporated as an option into the CORD-2 package, was found to be sufficiently accurate for the design calculations. Since the cross section library requires only standard sequence of calculation at three different operating conditions, the concept enables faster core design process and offers substantial savings in CPU time.

References

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