EPRI CORETRAN-01 BENCHMARK RESULTS

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ABSTRACT

EPRI CORETRAN-01, a three-dimensional neutronic and thermal-hydraulic simulation code for use in reactor analysis, has been benchmarked against Northern States Power's Prairie Island and Monticello reactors through twelve cycles of operation. The two Prairie Island reactors are Westinghouse two loop units with an asymmetric 14x14 lattice design utilizing up to 8 w/o Gadolinium while Monticello is a General Electric 484 bundle BWR. All reactor cases were executed in full core utilizing 24 axial nodes per assembly in the fuel with one additional reflector node above, below and around the perimeter of the core. Cross section sets used in this benchmark effort were generated by EPRI CPM-3, Studsvik CASMO-3 and Studsvik CASMO-4 to allow for separation of the lattice calculation effect from the nodal simulation method. Cases exercised the depletion – shuffle – depletion sequence through four cycles for each unit using plant data to follow actual operations. Flux map calculations were performed for comparison to corresponding measurement statepoints. Additionally, startup physics testing cases were used to predict cycle physics parameters for comparison to existing plant methods and measurements.

These benchmark results agreed well with both current analysis methods and plant measurements indicating that CORETRAN-01 may be appropriate for steady-state physics calculations of both the Prairie Island and Monticello reactors. Additional plant specific validation work will need to be conducted in order to fully assess the adequacy of CORETRAN-01 for use in a full production environment. No attempt was made to apply CORETRAN-01's kinetics capability to analyzing transients for these plants, but the steady state results encourage further investigation.

1. INTRODUCTION

EPRI and Northern States Power are working in a coordinated effort to benchmark CORETRAN-01 and obtain USNRC approval for its application to reload design and safety analysis activities. Since Northern States Power has been doing their own reload design work for many years, quite a large collection of data exists which can be used in benchmarking efforts for both PWRs and BWRs. As a starting point, twelve cycles of the Prairie Island and Monticello reactors were chosen for comparison. The current approved methods for Prairie Island utilize EPRI CASMO-2E and N3P, a custom derivative of EPRI NODE-P, while the Monticello methods utilize Studsvik CASMO-3 and SIMULATE-3. Additionally, Northern States Power is currently evaluating the accuracy of the Studsvik CASMO-4/SIMULATE-3 package for possible future use with Prairie Island. This method change for Prairie Island is being driven by fuel design considerations which will soon eclipse the capability of the existing code set.

With the Studsvik CASMO/SIMULATE package already being used for Monticello and under active consideration for Prairie Island, it was decided to compare the EPRI CPM/CORETRAN package results to Studsvik's as well as to plant measured data. Also, it was recognized early on that by feeding CASMO cross sections to CORETRAN, in addition to the normal CPM-3 data, could allow for isolation of the unique nodal code solution technique benefits from the corresponding lattice code's contribution. For Monticello, this meant using CASMO-3 lattice data and, for Prairie Island, using CASMO-4 as input to a CORETRAN calculation.

2. BENCHMARK APPROACH

Cases have been executed for all three units to explore the accuracy of models using CPM/CORETRAN, CASMO/SIMULATE and CASMO/CORETRAN over the depletion – shuffle – depletion sequence through four cycles per unit. So far the results have been encouraging with CORETRAN performing quite well. In the interest of space and reader attention, only the Prairie Island Unit 1 (P1) results will be discussed in any detail since they are representative of the benchmark work as a whole.

As mentioned before, NSP has performed their own benchmark comparison of the CASMO-4/SIMULATE-3 package to plant data for possible use as part of a revised Prairie Island Reload Safety Evaluation (RSE) Topical submittal. To take advantage of their work and use it as part of our analysis, we converted their SIMULATE cases into equivalent CORETRAN inputs for use in our benchmark effort. This allowed for the highest degree of agreement between nodal code inputs and modeling approaches. In fact, no effort was made at all to change NSP's modeling approach when running the CORETRAN cases. We simply accepted their inputs 'as is' and only tweaked values when necessary because equivalent input options didn't exist in CORETRAN for setting up a case in exactly the same manner. Also, both nodal simulation codes were initialized with the same history data for all assemblies in the first 'burn-in' cycle for each unit to further minimize deviations in input.

The two Prairie Island reactors are Westinghouse two loop PWRs with an asymmetric 14x14 lattice design utilizing up to 8 w/o Gadolinium. The reloads chosen by NSP for use in their work were unit 1 cycles 16 through 19 and unit 2 cycles 15 through 18. Because of lattice asymmetry, enrichments and burnable poison loadings in a typical cycle, NSP has been modeling assemblies as 2x2x24 nodes for many years. Consequently, all of their SIMULATE case were setup with this same nodalization. Interestingly enough, CASMO-4 will only generate assembly average cross sections (i.e., 1x1) for use by SIMULATE. However, CPM-3 generates both assembly average and quarter assembly (i.e., 2x2) data for use in CORETRAN at the user's discretion.

For the first wave of benchmark cases, CASMO-4 cross sections were fed to CORETRAN and the depletion – shuffle – depletion sequence was executed for the 'burn-in' cycle and three subsequent reloads. This of course allows for comparison of the nodal solution technique's effect on the benchmark. Next, the CASMO-4 data was replaced with CPM-3 and the process repeated to differentiate the lattice physics code's contribution. Finally, results from both series of cross section inputs were compared to NSP's benchmark using CASMO/SIMULATE as well as to the plant measured data. What follows is a somewhat self-explanatory graphical and tabular collection of these results showing the high degree of agreement among the code combinations.

3. BENCHMARK RESULTS

Radial power distributions from SIMULATE and CORETRAN were compared for P1 cycle 16 through 19 at BOC, MOC and EOC. The largest deviations were observed at BOC for the P1 cycle 16, the 'burn-in' cycle. Tables I through III reflect the BOC data and error comparison. Table IV shows the EOC error comparison. It should be noted that the differences observed in P116 at BOC are gone within 0.5 GWd/MTU and remain that way through the rest of the cycles. Table V shows the BOC comparison for P1 cycle 17 after the first shuffle.

Table I. P1Cycle 16 Radial Relative Power - BOC

Exposure = 0.000

CORETRAN

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1						0.2578	0.3241	0.2558					
2				0.3665	1.0377	1.0981	1.1016	1.0979	1.0381	0.3657			
3			0.3926	1.1078	1.3159	1.2192	1.0727	1.2212	1.3182	1.1089	0.3935		
4		0.3651	1.1063	1.0432	1.1940	1.1314	1.3540	1.1332	1.1996	1.0458	1.1104	0.3675	
5		1.0359	1.3144	1.1963	1.1117	1.3550	1.1295	1.3592	1.1153	1.1969	1.3180	1.0399	
6	0.2555	1.0964	1.2194	1.1306	1.3542	1.1480	1.1161	1.1540	1.3595	1.1344	1.2223	1.1007	0.2584
7	0.3237	1.1001	1.0717	1.3517	1.1266	1.1104	1.0854	1.1200	1.1319	1.3565	1.0750	1.1034	0.3247
8	0.2574	1.0974	1.2187	1.1307	1.3539	1.1477	1.1146	1.1527	1.3594	1.1344	1.2230	1.0996	0.2562
9		1.0371	1.3145	1.1938	1.1123	1.3557	1.1286	1.3572	1.1150	1.1997	1.3181	1.0389	
10		0.3666	1.1079	1.0439	1.1973	1.1314	1.3532	1.1322	1.1960	1.0457	1.1091	0.3661	
11			0.3928	1.1070	1.3162	1.2196	1.0719	1.2195	1.3173	1.1096	0.3934		
12				0.3651	1.0366	1.0967	1.1009	1.0981	1.0384	0.3669			
13						0.2556	0.3239	0.2575					

Table II. P1Cycle 16 Radial Relative Power - BOC

Exposure = 0.000

SIMULATE

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1						0.241	0.305	0.239					
2				0.345	0.958	1.029	1.041	1.029	0.959	0.345			
3			0.371	1.047	1.261	1.213	1.081	1.216	1.266	1.050	0.373		
4		0.343	1.046	1.044	1.222	1.172	1.382	1.175	1.230	1.049	1.052	0.346	
5		0.956	1.261	1.225	1.172	1.416	1.210	1.421	1.177	1.228	1.268	0.962	
6	0.238	1.026	1.212	1.170	1.415	1.249	1.232	1.258	1.423	1.177	1.219	1.033	0.242
7	0.304	1.038	1.078	1.379	1.206	1.225	1.203	1.237	1.214	1.387	1.085	1.045	0.306
8	0.240	1.028	1.212	1.171	1.415	1.250	1.231	1.257	1.424	1.178	1.220	1.033	0.240
9		0.957	1.262	1.223	1.173	1.418	1.210	1.421	1.178	1.232	1.269	0.962	
10		0.345	1.049	1.046	1.228	1.174	1.383	1.175	1.228	1.050	1.053	0.346	
11			0.372	1.049	1.264	1.216	1.082	1.217	1.267	1.053	0.373		
12				0.344	0.959	1.030	1.042	1.032	0.962	0.347			
13						0.239	0.305	0.241					

Table III. P1Cycle 16 Radial Relative Power - BOC

Exposure = 0.000

(CORETRAN – SIMULATE)/SIMULATE

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1						6.97%	6.26%	7.03%					
2				6.23%	8.32%	6.72%	5.82%	6.70%	8.25%	6.00%			
3			5.82%	5.81%	4.35%	0.51%	-0.77%	0.43%	4.12%	5.61%	5.50%		
4		6.44%	5.76%	-0.08%	-2.29%	-3.46%	-2.03%	-3.56%	-2.47%	-0.31%	5.55%	6.21%	
5		8.36%	4.23%	-2.34%	-5.15%	-4.31%	-6.65%	-4.35%	-5.24%	-2.53%	3.94%	8.10%	
6	7.35%	6.86%	0.61%	-3.37%	-4.30%	-8.09%	-9.41%	-8.27%	-4.46%	-3.62%	0.27%	6.55%	6.78%
7	6.48%	5.98%	-0.58%	-1.98%	-6.58%	-9.36%	-9.78%	-9.46%	-6.76%	-2.20%	-0.92%	5.59%	6.11%
8	7.25%	6.75%	0.55%	-3.44%	-4.32%	-8.18%	-9.46%	-8.30%	-4.54%	-3.70%	0.25%	6.45%	6.75%
9		8.37%	4.16%	-2.39%	-5.17%	-4.39%	-6.73%	-4.49%	-5.35%	-2.62%	3.87%	7.99%	
10		6.26%	5.61%	-0.20%	-2.50%	-3.63%	-2.15%	-3.64%	-2.61%	-0.41%	5.33%	5.81%	
11			5.59%	5.53%	4.13%	0.30%	-0.93%	0.21%	3.97%	5.38%	5.47%		
12				6.13%	8.09%	6.48%	5.65%	6.41%	7.94%	5.73%			
13						6.95%	6.20%	6.85%					

Table IV. P1Cycle 16 Radial Relative Power - EOC

Exposure = 18.011

(CORETRAN – SIMULATE)/SIMULATE

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1						0.34%	0.31%	0.51%					
2				-0.16%	0.23%	0.10%	0.02%	0.05%	0.26%	-0.27%			
3			-0.29%	-0.17%	-0.05%	-0.04%	-0.10%	-0.01%	-0.07%	-0.26%	-0.51%		
4		-0.24%	-0.25%	-0.70%	-0.11%	-0.25%	0.46%	-0.27%	-0.13%	-0.73%	-0.30%	-0.20%	
5		0.26%	-0.06%	-0.11%	-0.51%	0.53%	-0.42%	0.54%	-0.52%	-0.13%	-0.08%	0.18%	
6	0.43%	0.02%	0.00%	-0.26%	0.52%	0.19%	0.56%	0.18%	0.50%	-0.28%	0.02%	0.04%	0.24%
7	0.25%	0.00%	-0.07%	0.48%	-0.44%	0.56%	0.28%	0.56%	-0.44%	0.52%	0.00%	-0.02%	0.02%
8	0.19%	0.06%	-0.04%	-0.25%	0.51%	0.18%	0.52%	0.25%	0.50%	-0.19%	-0.03%	-0.01%	0.16%
9		0.20%	-0.06%	-0.10%	-0.59%	0.54%	-0.42%	0.52%	-0.50%	-0.13%	-0.08%	0.14%	
10		-0.18%	-0.28%	-0.79%	-0.11%	-0.26%	0.54%	-0.26%	-0.12%	-0.70%	-0.28%	-0.27%	
11			-0.49%	-0.24%	-0.05%	0.00%	-0.02%	-0.05%	-0.07%	-0.28%	-0.51%		
12				-0.24%	0.17%	0.05%	0.02%	0.01%	0.21%	-0.40%			
13						0.24%	0.08%	0.24%					

Table V. P1Cycle 17 Radial Relative Power - BOC

Exposure = 0.000

(CORETRAN – SIMULATE)/SIMULATE

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1						-3.97%	-3.98%	-3.98%					
2				-4.08%	-0.73%	-0.19%	-0.21%	-0.25%	-0.79%	-4.16%			
3			-4.30%	-0.93%	0.47%	1.14%	1.51%	1.07%	0.35%	-1.05%	-4.59%		
4		-4.30%	-0.95%	0.21%	0.27%	1.35%	1.60%	1.32%	0.28%	0.08%	-1.17%	-4.39%	
5		-0.75%	0.43%	0.38%	0.40%	0.34%	1.57%	0.29%	0.30%	0.16%	0.26%	-0.97%	
6	-4.12%	-0.43%	1.08%	1.46%	0.34%	1.11%	0.94%	1.03%	0.33%	1.35%	0.90%	-0.62%	-4.39%
7	-4.07%	-0.38%	1.44%	1.61%	1.48%	1.03%	0.55%	1.02%	1.46%	1.49%	1.34%	-0.57%	-4.45%
8	-4.07%	-0.41%	1.02%	1.47%	0.34%	1.02%	0.95%	0.98%	0.29%	1.32%	0.83%	-0.68%	-4.41%
9		-0.81%	0.39%	0.30%	0.38%	0.26%	1.50%	0.28%	0.30%	0.10%	0.16%	-1.11%	
10		-4.39%	-1.07%	0.10%	0.15%	1.21%	1.49%	1.22%	0.08%	-0.02%	-1.26%	-4.70%	
11			-4.51%	-1.09%	0.26%	0.98%	1.37%	0.93%	0.14%	-1.23%	-4.76%		
12				-4.34%	-0.98%	-0.41%	-0.33%	-0.47%	-1.05%	-4.49%			
13						-4.24%	-4.15%	-4.16%					

This trend is also observed in the boron letdown curves where good agreement is reached by the first GWd/MTU. After shuffling into the next cycle, similar results were found. This is illustrated in Figures 1 and 2 below.

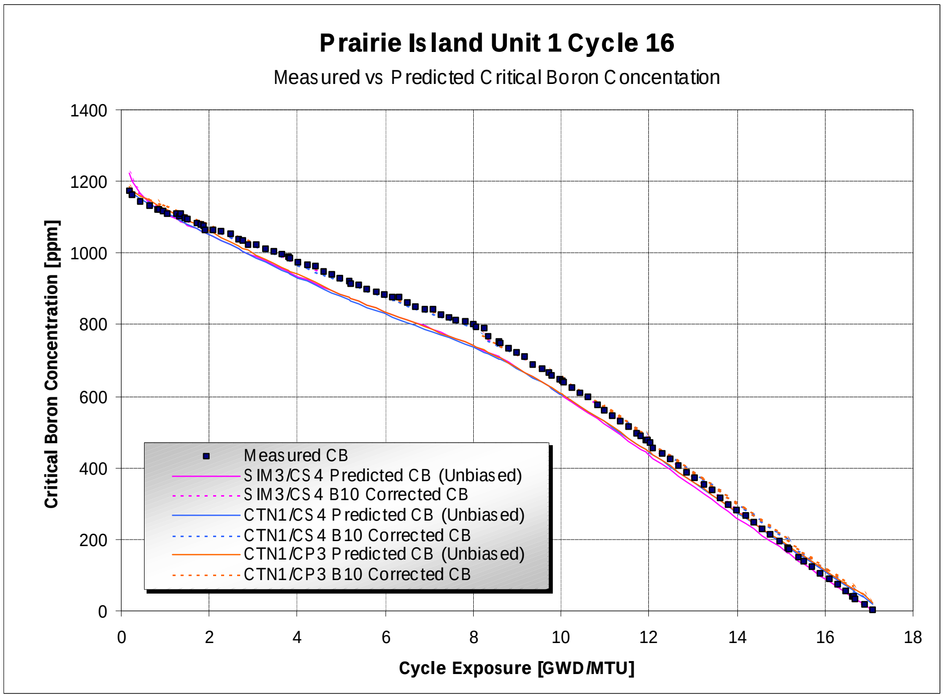

Figure 1. P1Cycle 16 Boron Letdown

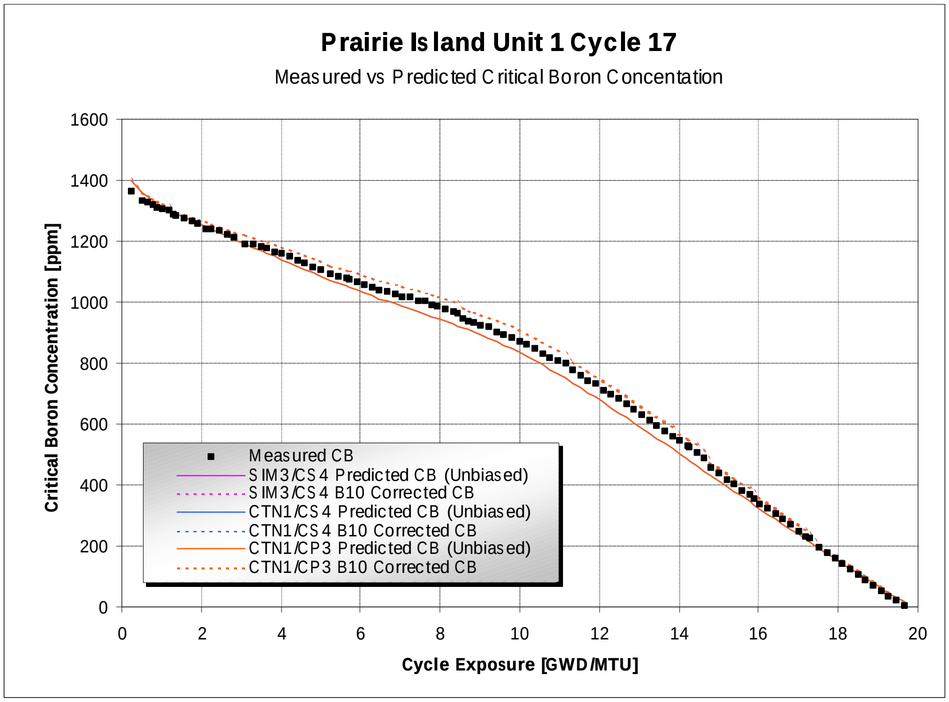

Figure 2. P1Cycle 17 Boron Letdown

Both of these figures show all possible code combinations and, as can be readily observed, they are barely distinguishable from one another. The degree of agreement found in cycle 17 is repeated in subsequent cycles as well during the depletion-shuffle-depletion sequence.

Another illustration of good general core wide behavior through a cycle can be seen in the average axial power shapes at BOC, MOC and EOC. These are represented in Figure 3 through 5 below for P1 17.

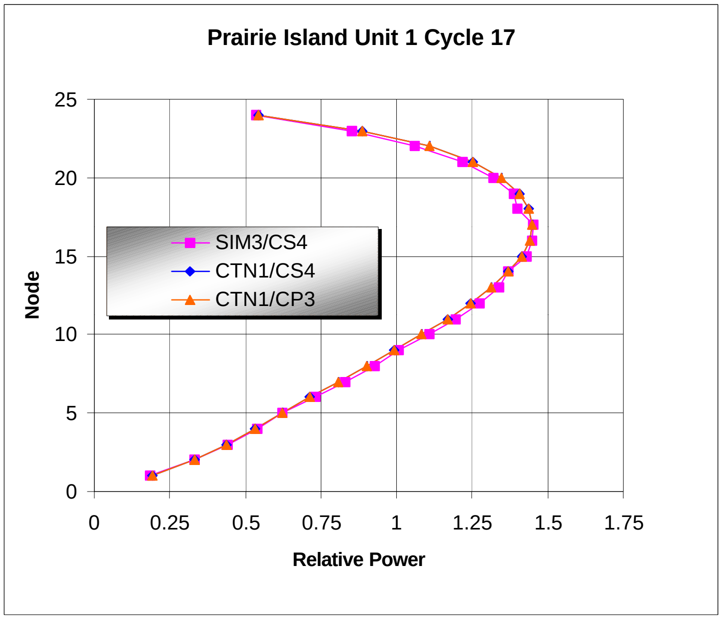

Figure 3. P1Cycle 17 Average Axial Relative Power - BOC

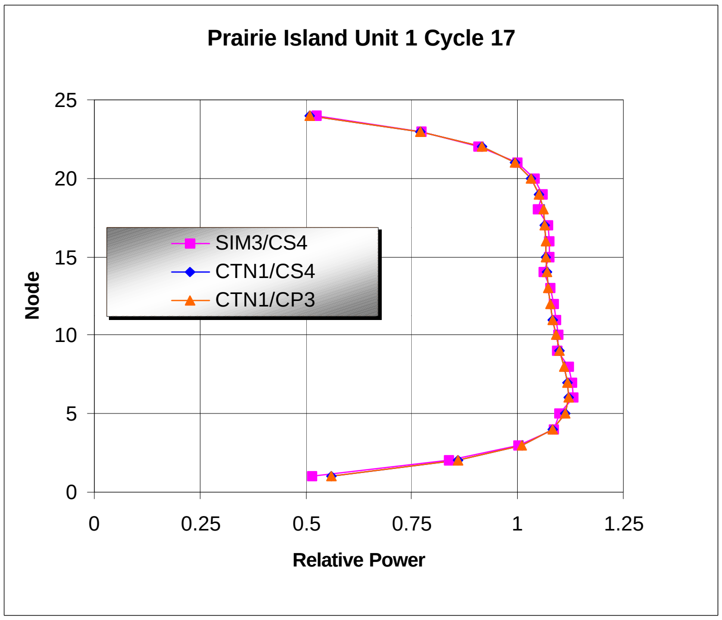

Figure 4. P1Cycle 17 Average Axial Relative Power - MOC

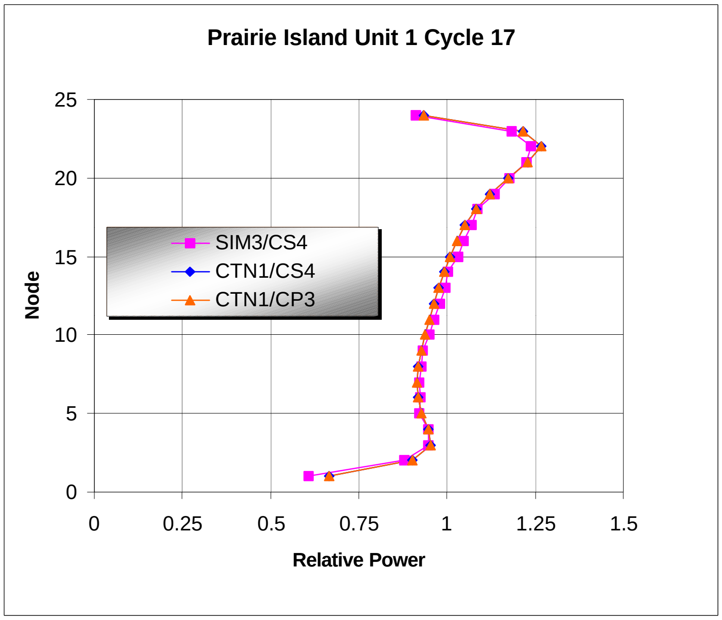

Figure 5. P1Cycle 17 Average Axial Relative Power - EOC

More detailed core wide comparisons were made to plant measured flux map data at about twenty-one statepoints per cycle in the monitored assemblies. Representative integral reaction rate results are shown in Tables VI through VIII for P1 17 at BOC, MOC and EOC statepoints. Again, good agreement was observed among the code sets to the plant measurements throughout the remaining benchmark cycles.

Table VI. P1Cycle 17 Flux Map Integral Reaction Rates - BOC

Chn	Thm	(I,J)	Plant Measured	SIM3/CS4 Predicted	CTN1/CS4 Predicted	CTN1/CP3 Predicted	SIM3/CS4 % Error	CTN1/CS4 % Error	CTN1/CP3 % Error
G 6	1	(7, 6)	0.88078	0.91583	0.91056	0.91053	3.98%	3.38%	3.38%
I 5	2	(9, 5)	1.27570	1.31300	1.30404	1.30400	2.92%	2.22%	2.22%
M 7	3	(13, 7)	0.50939	0.50754	0.51815	0.51842	-0.36%	1.72%	1.77%
G 9	4	(7, 9)	1.12731	1.15267	1.14469	1.14465	2.25%	1.54%	1.54%
C 8	5	(3, 8)	1.29443	1.29490	1.28585	1.28315	0.04%	-0.66%	-0.87%
J10	6	(10,10)	1.29753	1.30631	1.29773	1.29759	0.68%	0.02%	0.00%
E 6	7	(5, 6)	1.14673	1.16312	1.15558	1.15551	1.43%	0.77%	0.77%
G 2	8	(7, 2)	1.09215	1.06076	1.05391	1.05394	-2.87%	-3.50%	-3.50%
B 6	9	(2, 6)	1.05330	1.03247	1.05148	1.05152	-1.98%	-0.17%	-0.17%
F 5	10	(6, 5)	1.16154	1.16368	1.15661	1.15604	0.18%	-0.42%	-0.47%
D 7	11	(4, 7)	0.00000	na	na	na	na	na	na
G13	12	(7,13)	0.49162	0.49481	0.49228	0.49214	0.65%	0.14%	0.11%
I 7	13	(9, 7)	1.10168	1.12848	1.12271	1.12267	2.43%	1.91%	1.91%
E 2	14	(5, 2)	0.00000	na	na	na	na	na	na
E10	15	(5,10)	1.31724	1.29152	1.28491	1.28496	-1.95%	-2.45%	-2.45%
L 4	16	(12, 4)	0.55812	0.53980	0.53684	0.53687	-3.28%	-3.81%	-3.81%
L 9	17	(12, 9)	1.04583	0.97410	0.96841	0.96842	-6.86%	-7.40%	-7.40%
H10	18	(8,10)	0.00000	na	na	na	na	na	na
K 7	19	(11, 7)	1.28720	1.31164	1.33715	1.33709	1.90%	3.88%	3.88%
C11	20	(3,11)	0.56733	0.56298	0.57479	0.57492	-0.77%	1.31%	1.34%
G 4	21	(7, 4)	1.23214	1.23744	1.25775	1.25751	0.43%	2.08%	2.06%
H 8	22	(8, 8)	0.98751	1.02963	1.02233	1.02230	4.27%	3.53%	3.52%
D 5	23	(4, 5)	1.29700	1.32563	1.31564	1.31560	2.21%	1.44%	1.43%
J 3	24	(10, 3)	1.02621	1.00934	1.02736	1.02742	-1.64%	0.11%	0.12%
J12	25	(10,12)	0.58860	0.57557	0.58824	0.58828	-2.21%	-0.06%	-0.05%
F12	26	(6,12)	1.10791	1.06233	1.08175	1.08177	-4.11%	-2.36%	-2.36%
H 1	27	(8, 1)	0.40779	0.40649	0.40350	0.40381	-0.32%	-1.05%	-0.98%
G11	28	(7,11)	1.31784	1.31147	1.30318	1.30338	-0.48%	-1.11%	-1.10%
C 3	29	(3, 3)	0.50697	0.51023	0.50739	0.50723	0.64%	0.08%	0.05%
H 3	30	(8, 3)	1.29913	1.29498	1.28679	1.28709	-0.32%	-0.95%	-0.93%
K 4	31	(11, 4)	1.00485	0.98845	0.98295	0.98301	-1.63%	-2.18%	-2.17%
F 8	32	(6, 8)	0.99413	1.01581	1.01016	1.01011	2.18%	1.61%	1.61%
C 9	33	(3, 9)	1.21352	1.19552	1.18887	1.18894	-1.48%	-2.03%	-2.03%
J 8	34	(10, 8)	1.22603	1.25138	1.24442	1.24437	2.07%	1.50%	1.50%
A 8	35	(1, 8)	0.39795	0.39584	0.39364	0.39383	-0.53%	-1.08%	-1.04%
I11	36	(9,11)	1.21291	1.20281	1.19612	1.19623	-0.83%	-1.38%	-1.38%

Table VII. P1Cycle 17 Flux Map Integral Reaction Rates - MOC

Chn	Thm	(I,J)	Plant Measured	SIM3/CS4 Predicted	CTN1/CS4 Predicted	CTN1/CP3 Predicted	SIM3/CS4 % Error	CTN1/CS4 % Error	CTN1/CP3 % Error
G 6	1	(7, 6)	0.97963	0.98866	0.98772	0.98759	0.92%	0.83%	0.81%
I 5	2	(9, 5)	1.25475	1.27038	1.26918	1.26909	1.25%	1.15%	1.14%
M 7	3	(13, 7)	0.53212	0.51872	0.51822	0.51826	-2.52%	-2.61%	-2.60%
G 9	4	(7, 9)	1.22208	1.23549	1.23432	1.23422	1.10%	1.00%	0.99%
C 8	5	(3, 8)	1.23000	1.22242	1.22126	1.22142	-0.62%	-0.71%	-0.70%
J10	6	(10,10)	1.16767	1.17368	1.17256	1.17237	0.51%	0.42%	0.40%
E 6	7	(5, 6)	1.19265	1.19513	1.19400	1.19350	0.21%	0.11%	0.07%
G 2	8	(7, 2)	1.01496	1.00587	1.00492	1.00502	-0.90%	-0.99%	-0.98%
B 6	9	(2, 6)	0.99609	0.99905	1.01821	1.01788	0.30%	2.22%	2.19%
F 5	10	(6, 5)	1.19267	1.19550	1.19437	1.19393	0.24%	0.14%	0.11%
D 7	11	(4, 7)	0.00000	na	na	na	na	na	na
G13	12	(7,13)	0.54047	0.53045	0.52995	0.53000	-1.85%	-1.95%	-1.94%
I 7	13	(9, 7)	1.23873	1.26380	1.26260	1.26254	2.02%	1.93%	1.92%
E 2	14	(5, 2)	0.84953	0.85356	0.85182	0.85162	0.47%	0.27%	0.25%
E10	15	(5,10)	1.20140	1.21948	1.21832	1.21826	1.50%	1.41%	1.40%
L 4	16	(12, 4)	0.53689	0.53034	0.52985	0.52992	-1.22%	-1.31%	-1.30%
L 9	17	(12, 9)	0.00000	na	na	na	na	na	na
H10	18	(8,10)	0.00000	na	na	na	na	na	na
K 7	19	(11, 7)	1.25469	1.25791	1.28355	1.28315	0.26%	2.30%	2.27%
C11	20	(3,11)	0.00000	na	na	na	na	na	na
G 4	21	(7, 4)	1.21208	1.21703	1.21588	1.21563	0.41%	0.31%	0.29%
H 8	22	(8, 8)	1.10064	1.11004	1.10898	1.10885	0.85%	0.76%	0.75%
D 5	23	(4, 5)	1.22686	1.22251	1.22134	1.22162	-0.35%	-0.45%	-0.43%
J 3	24	(10, 3)	0.93704	0.93456	0.93367	0.93402	-0.26%	-0.36%	-0.32%
J12	25	(10,12)	0.59138	0.57720	0.57657	0.57660	-2.40%	-2.51%	-2.50%
F12	26	(6,12)	1.01869	0.99965	0.99870	0.99875	-1.87%	-1.96%	-1.96%
H 1	27	(8, 1)	0.42346	0.41447	0.41408	0.41412	-2.12%	-2.22%	-2.20%
G11	28	(7,11)	1.23198	1.22815	1.22699	1.22731	-0.31%	-0.40%	-0.38%
C 3	29	(3, 3)	0.50820	0.50312	0.50264	0.50274	-1.00%	-1.09%	-1.07%
H 3	30	(8, 3)	1.23519	1.22271	1.22155	1.22165	-1.01%	-1.10%	-1.10%
K 4	31	(11, 4)	0.93061	0.93137	0.93049	0.92932	0.08%	-0.01%	-0.14%
F 8	32	(6, 8)	1.14741	1.14146	1.13949	1.13971	-0.52%	-0.69%	-0.67%
C 9	33	(3, 9)	1.17089	1.16235	1.16125	1.16138	-0.73%	-0.82%	-0.81%
J 8	34	(10, 8)	1.28121	1.29115	1.28918	1.28905	0.78%	0.62%	0.61%
A 8	35	(1, 8)	0.42111	0.41356	0.41317	0.41322	-1.79%	-1.89%	-1.87%
I11	36	(9,11)	1.15475	1.16667	1.16556	1.16547	1.03%	0.94%	0.93%

Table VIII. P1Cycle 17 Flux Map Integral Reaction Rates - EOC

Chn	Thm	(I,J)	Plant Measured	SIM3/CS4 Predicted	CTN1/CS4 Predicted	CTN1/CP3 Predicted	SIM3/CS4 % Error	CTN1/CS4 % Error	CTN1/CP3 % Error
G 6	1	(7, 6)	1.04063	1.04136	1.03969	1.03797	0.07%	-0.09%	-0.26%
I 5	2	(9, 5)	1.23161	1.23790	1.23843	1.23823	0.51%	0.55%	0.54%
M 7	3	(13, 7)	0.60159	0.58797	0.58772	0.58775	-2.26%	-2.31%	-2.30%
G 9	4	(7, 9)	1.21059	1.22434	1.22488	1.22478	1.14%	1.18%	1.17%
C 8	5	(3, 8)	1.20567	1.21111	1.21163	1.21141	0.45%	0.49%	0.48%
J10	6	(10,10)	1.15903	1.16614	1.16664	1.16648	0.61%	0.66%	0.64%
E 6	7	(5, 6)	1.12935	1.13807	1.13855	1.13842	0.77%	0.81%	0.80%
G 2	8	(7, 2)	0.99916	1.00023	1.00066	0.99977	0.11%	0.15%	0.06%
B 6	9	(2, 6)	0.96553	0.97883	0.99078	0.99071	1.38%	2.62%	2.61%
F 5	10	(6, 5)	1.13277	1.13844	1.13893	1.13872	0.50%	0.54%	0.53%
D 7	11	(4, 7)	0.00000	na	na	na	na	na	na
G13	12	(7,13)	0.58534	0.57822	0.57795	0.57803	-1.22%	-1.26%	-1.25%
I 7	13	(9, 7)	1.22897	1.24421	1.24364	1.24356	1.24%	1.19%	1.19%
E 2	14	(5, 2)	0.00000	na	na	na	na	na	na
E10	15	(5,10)	1.17537	1.19586	1.19532	1.19526	1.74%	1.70%	1.69%
L 4	16	(12, 4)	0.57247	0.56014	0.55989	0.55993	-2.15%	-2.20%	-2.19%
L 9	17	(12, 9)	0.00000	na	na	na	na	na	na
H10	18	(8,10)	0.00000	na	na	na	na	na	na
K 7	19	(11, 7)	1.23302	1.23447	1.25302	1.25216	0.12%	1.62%	1.55%
C11	20	(3,11)	0.00000	na	na	na	na	na	na
G 4	21	(7, 4)	1.13360	1.14407	1.14340	1.14329	0.92%	0.86%	0.86%
H 8	22	(8, 8)	1.12491	1.13018	1.12952	1.12928	0.47%	0.41%	0.39%
D 5	23	(4, 5)	1.20868	1.19623	1.19554	1.19563	-1.03%	-1.09%	-1.08%
J 3	24	(10, 3)	0.91798	0.91791	0.91737	0.92966	-0.01%	-0.07%	1.27%
J12	25	(10,12)	0.61713	0.60178	0.60116	0.60119	-2.49%	-2.59%	-2.58%
F12	26	(6,12)	1.01069	0.99856	0.99832	0.99840	-1.20%	-1.22%	-1.22%
H 1	27	(8, 1)	0.50637	0.46150	0.46124	0.46125	-8.86%	-8.91%	-8.91%
G11	28	(7,11)	1.21616	1.21201	1.21040	1.21068	-0.34%	-0.47%	-0.45%
C 3	29	(3, 3)	0.55801	0.55100	0.55021	0.55029	-1.26%	-1.40%	-1.38%
H 3	30	(8, 3)	1.24059	1.23070	1.22770	1.22783	-0.80%	-1.04%	-1.03%
K 4	31	(11, 4)	0.91152	0.91622	0.91501	0.91483	0.52%	0.38%	0.36%
F 8	32	(6, 8)	1.16322	1.15050	1.14734	1.14745	-1.09%	-1.36%	-1.36%
C 9	33	(3, 9)	1.10625	1.11370	1.11222	1.11208	0.67%	0.54%	0.53%
J 8	34	(10, 8)	1.24946	1.25317	1.25023	1.24989	0.30%	0.06%	0.03%
A 8	35	(1, 8)	0.46258	0.46056	0.45995	0.46017	-0.44%	-0.57%	-0.52%
I11	36	(9,11)	1.09796	1.11933	1.11784	1.11779	1.95%	1.81%	1.81%

Finally as part of startup physics test comparisons, measured and predicted control rod worth for the reference bank was compared. Representative examples for P1 17 are shown in Figures 6 and 7 below.

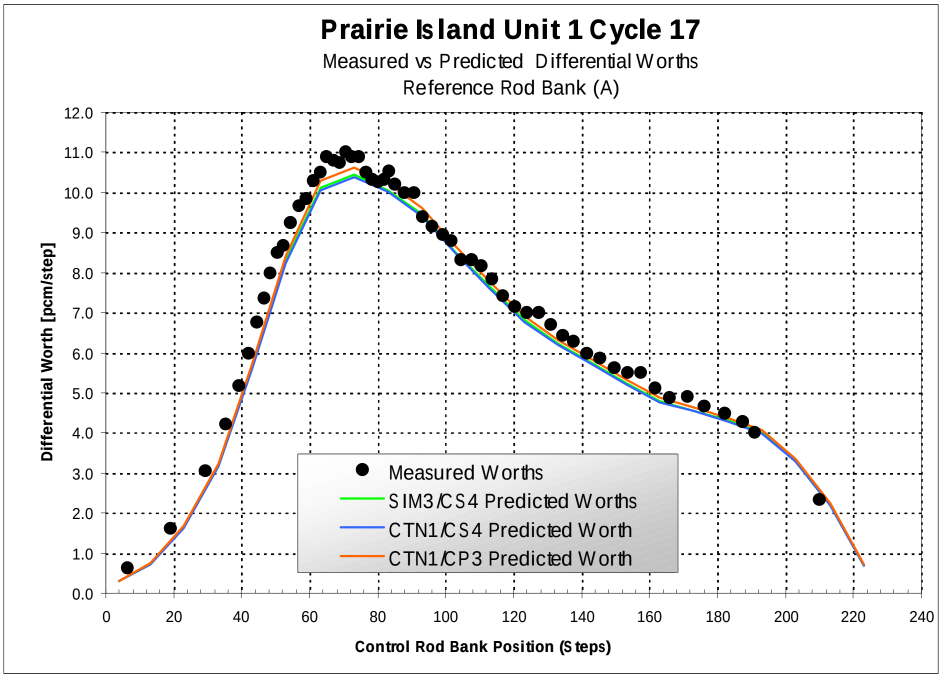

Figure 6. P1Cycle 17 Differential Control Rod Worth

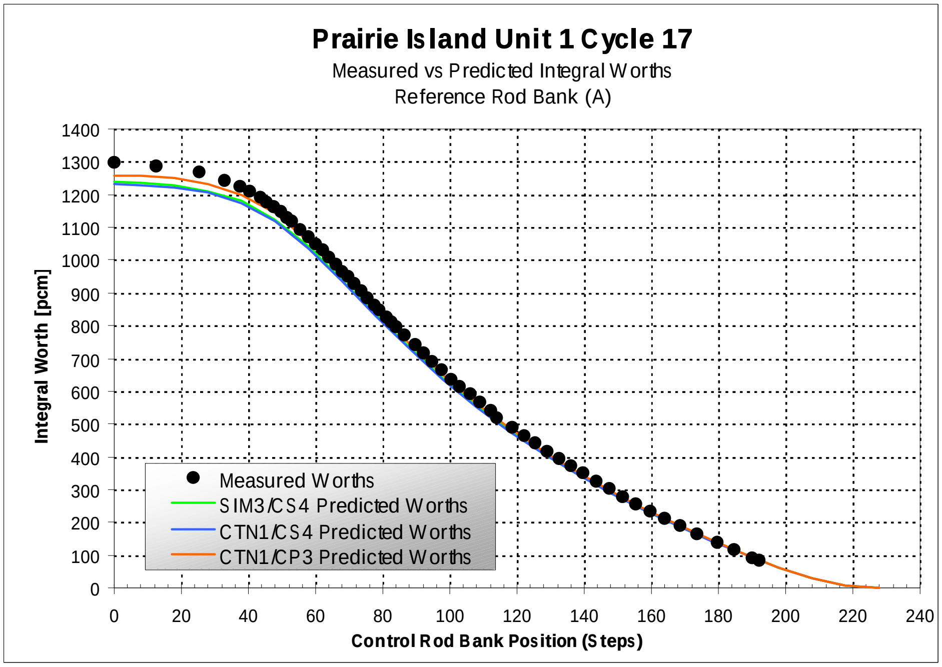

Figure 7. P1Cycle 17 Integral Control Rod Worth

Again, the similarity in results is readily apparent in these figures. Comparable results were also found for other startup physics parameters and the remaining benchmark cycles as well.

While the results presented here come primarily from P1 16 and 17, it should be stresses again that this is representative of the entire benchmark effort. P2 cycles 15 through 18 demonstrated the same general behavior as P1 cycles 16 through 19. In addition, Monticello results for cycles 16 through 19 were of the same quality as Prairie Island.

CONCLUSION

These benchmark results agree well with both current analysis methods and plant measurements indicating that CORETRAN-01 may be appropriate for steady-state physics calculations of both the Prairie Island and Monticello reactors. Before submittal to the USNRC, additional plant specific validation work will need to be conducted to fully assess CORETRAN-01's adequacy as part of an approved reload safety evaluation methodology. No attempt was made to apply CORETRAN-01's kinetics capability to analyzing transients for these plants, but the steady state results encourage further investigation.

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