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Benchmark Calculation for the Peach Bottom Unit 2 Cycles 1–3 Using the SCALE 6.3/Polaris–PARCS v3.4.2 Code Package



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December 2024

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Nuclear Energy and Fuel Cycle Division

**BENCHMARK CALCULATION FOR THE PEACH BOTTOM UNIT 2 CYCLES 1–3
USING THE SCALE 6.3/POLARIS–PARCS V3.4.2 CODE PACKAGE**

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December 2024

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ABBREVIATIONS

BOC	beginning of cycle
BWR	boiling water reactor
CR	control rod
ENDF	Evaluated Nuclear Data File
EOC	end of cycle
EPRI	Electric Power Research Institute
HFP	hot full power
HZP	hot zero power
Inc-718	Inconel-718
MC	Monte Carlo
ORNL	Oak Ridge National Laboratory
PB2	Peach Bottom Unit 2
RMS	root mean square
SS-304	stainless steel 304
SS-3161	stainless steel 3161
TIP	traverse in-core probe
TIPS	traverse in-core probe system
Zr-2	Zircaloy-2
Zr-4	Zircaloy-4

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ABSTRACT

In this study, benchmark calculations were performed for Peach Bottom Unit 2 cycles 1–3 to validate the SCALE 6.3/Polaris–PARCS v3.4.2 with the ENDF/B-VII.1 AMPX 56-group library by comparing the simulated results with the measured data. The benchmark results will be used to evaluate uncertainties of the SCALE/Polaris–PARCS code package for boiling water reactor physics analysis for key nuclear parameters such as reactivity and assembly power peaking factors. This report details plant and fuel design specifications and input data for SCALE/Polaris, GenPMAXS and PARCS. Additionally, detailed information is provided for all the input and output files produced for the benchmark calculations. The benchmark results were summarized such that they can be used to evaluate uncertainties with other benchmark results for key nuclear parameters.

1. INTRODUCTION

The Peach Bottom Unit 2 (PB2) is a General Electric Type 4 boiling water reactor (BWR) operated by Constellation Energy Generation that began operation at 3,293 MW_{th} using BWR 7 × 7 assemblies [1, 2]. PB2 has 43 traverse in-core probe (TIP) instrument assemblies. Detailed design data and measured data are provided in Electric Power Research Institute (EPRI) reports NP-563 [1] and NP-971 [2] for PB2.

In this study, the benchmark calculations for the PB2 benchmark problems were performed to validate the SCALE 6.3/Polaris [3, 4]–GenPMAXS v6.3.1 [5]–PARCS v3.4.2 [6] code package for BWR analysis with the Evaluated Nuclear Data File (ENDF)/B-VII.1 AMPX 56-group library [7]. The simulated benchmark results were compared with the measured data, and in future work, the benchmark results will be used to validate the SCALE 6.3/PARCS–GenPMAXS–PARCS v3.4.2 code package by evaluating uncertainties for key nuclear parameters such as reactivity and assembly power peaking factors.

Section 2 gives a brief overview of the Polaris–GenPMAXS–PARCS code package and provides the plant design data and measured data. Because the measured data were obtained for hot full power (HFP), the design data need to be thermally expanded to prepare input data for Polaris, GenPMAXS, and PARCS. However, to avoid unnecessary complication, the design data were not thermally expanded for this study because doing so would not have resulted in meaningful difference, and the dimensions do not need to be thermally expanded. In Section 3, the simulated benchmark results are summarized and compared with the measured data. In addition, Section 3 provides detailed information about the input and output files generated from the benchmark calculations. The summary and concluding remarks are presented in Section 4.

2. CODE PACKAGE AND DESIGN SPECIFICATION

2.1 PROCEDURE AND CODE PACKAGE

Benchmark calculations for PB2 cycles 1–3 were performed using the SCALE 6.3/Polaris–GenPMAXS v6.3.1–PARCS v3.4.2 code package with the ENDF/B-VII.1 AMPX 56-group library. The flowchart in Figure 2.1 illustrates how the Polaris–GenPMAXS–PARCS code package was used to simulate BWRs. The SCALE/Polaris code developed by Oak Ridge National Laboratory is a 2D lattice physics code used to generate two-group homogenized cross sections and pin power form factors for fuel assemblies and reflectors. Polaris depletion calculations were performed at the reference states with various branch calculations to cover all the probable states in a reactor. The GenPMAXS code developed by the University of Michigan prepares a cross section table set for each type of fuel assembly and reflector in which two-group macroscopic cross sections are tabulated as functions of burnup, moderator and fuel temperature, moderator density, and control rod insertion. Once cross section table sets were prepared for all types of fuel assemblies and radial and axial reflectors, whole-core nodal diffusion calculations were performed using the PARCS code. The PATHS thermal-hydraulics module was used for BWR physics analysis because it can treat two-phase flow [8].

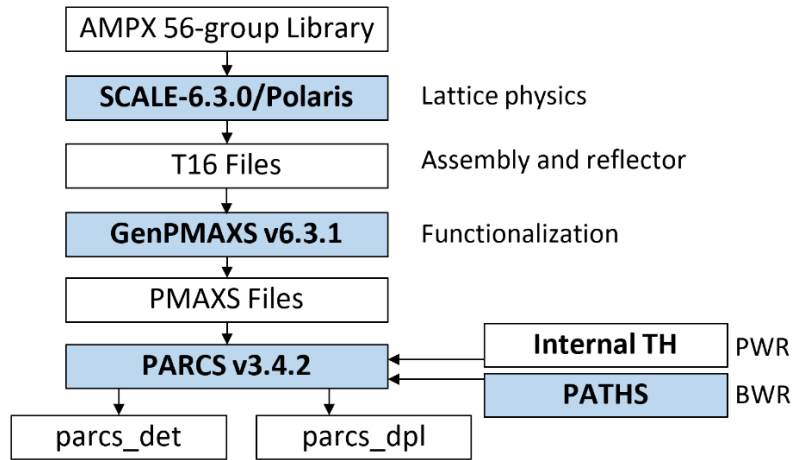


Figure 2.1. Flowchart of the Polaris–GenPMAXS–PARCS procedure.

Table 2.1 provides detailed information on the programs and data used in the benchmark calculations. The PATHS module is integrated with PARCS.

Table 2.1. Programs used in the benchmark calculations.

Program	File name	Version	md5sum ^a	Reference
SCALE/Polaris	scalerte	6.3.0	c30aa9d4841d51636ea08f2aa71cf1e5	[3, 4]
ENDF/B-VII.1 56-group library	scale.rev00.xn56g19v7.1	6.3.0	2a1ab889c81354758bd85b3c0593db7a	[7]
GenPMAXS	genpmaks-v6.3.1-linux2- intel-x64-release.x	6.3.1	5a0428587c6ba65e2028e6dc98d29488	[5]
PARCS	parcs-v342-linux2-intel- x64-release.x	3.4.2	fd005b709d0b597dd6910129d03fe8f5	[6]

^a Unix program to ensure file integrity

2.2 SPECIFICATIONS OF THE PB2 CORE

2.2.1 Design Data

PB2 is a General Electric Type 4 BWR operated by Constellation Energy Generation that began operation at 3,293 MW_{th} using BWR 7 × 7 assemblies [1, 2]. PB2 has 43 TIP instrument assemblies. Detailed design data and measured data are provided in EPRI reports NP-563 [1] and NP-971 [2] for PB2.

Table 2.2 provides the key design specifications of the PB2 core for cycles 1–3. Specifications of the PB2 active height, TIP instrument system, control blade, and radial and axial reflectors are described in Table 2.3. PB2 cycles 1–3 used seven types of fuel assemblies, which include axial variation with different ²³⁵U enrichments or burnable poisons. Therefore, cross section table sets were generated to consider the axial variation. Table 2.4 provides the fuel assembly types, some of which encompass subassembly types that designate axial variations. Figure 2.2–Figure 2.7 show the UO₂, gadolinia, and water rod configurations. Figure 2.8–Figure 2.10 illustrate the axial variations for the fuel assembly types 2, 3, and 6, respectively. More detailed information for each type of fuel assembly is provided in Table 2.5, which was used in preparing the Polaris inputs. Figure 2.11 and Figure 2.12 show fuel assembly and control rod configurations for the 7 × 7 and 8 × 8 fuel assemblies, respectively.

Figure 2.13 and Figure 2.14 illustrate the configurations of control rods, orifices, and TIP instruments. The layouts of fuel assemblies for PB2 cycles 1–3 (January, 1974 – September, 1978) are provided in Figure 2.15–Figure 2.17, which indicate fresh, once-burnt, and twice-burnt fuel assemblies. Fresh-assembly loading and shuffling patterns are illustrated in Figure 2.18–Figure 2.20, with which the PARCS input files were prepared. Table 2.6 provides the PARCS axial mesh configuration and subassembly type assignment for each type of fuel assembly.

Table 2.2. Specifications of the PB2 core.

Parameter	Design data		
	Cycle 1	Cycle 2	Cycle 3
Core thermal power (MW _{th})	3,293	3,293	3,293
Core total flow rate (Mlb/hr)	102.5	102.5	102.5
Core pressure (psia)	1,035	1,035	1,035
Reactor dome pressure (psia)	1,020	1,020	1,020
Steam flow rate (Mlb/hr)	13.381	13.381	13.381
Core inlet enthalpy (Btu/lb)	521.3	521.3	521.3
Average enthalpy rise across core (Btu/lb)	109.6	109.6	109.6
Total number of fuel assemblies	764	764	764
Total number of control elements	185	185	185
Total number of in-core flux monitors	43	43	43
Heat transfer surface area (m ²)	6,151.479	6,342.116	6,516.402
Average heat rate (W/cm)	230.971	215.551	206.365
Total U mass (ton)	144.4239	142.1559	141.9745
Lattice pitch (cm)	30.48	30.48	30.48
Fresh fuel assembly types	7×7, UO ₂ , type 1 7×7, UO ₂ , type 2 7×7, UO ₂ , type 3	8×8, UO ₂ , type 4 8×8, UO ₂ , type 5 8×8, UO ₂ , type 6	8×8, UO ₂ , type 7

Table 2.3. Specifications of the PB2 fuel assemblies, in-core detector, control blade, and reflectors.

Item	Material	Density (g/cm ³)	Subitem	Dimension
Fuel assembly	—	—	Active height (cm)	365.76
In-core detector	²³⁵ U	—	Virtual in gas	—
	Ar gas	8.31×10^{-3}	Outer radius (cm)	0.32258
	H ₂ O	—	Outer radius (cm)	0.35560
	SS-304 ^a	8.03	Outer radius (cm)	0.47625
	H ₂ O (47.87 wt %) A ₂ O ₃ (15.7 wt %) SS-304 (36.43 wt %)	1.3611	Outer radius (cm)	0.81280
	SS-304	8.03	Outer radius (cm)	0.88900
Control blade	—	—	Half thickness (cm)	0.39624
	—	—	Sheath thickness (cm)	0.14224
	—	—	Dead length (cm)	1.98501
	—	—	Wing tip curvature (cm)	0.39624
	—	—	Width of control section (cm)	10.02792
	—	—	Number of tubes	21
Control tubes	B ₄ C	1.7642	Outer radius (cm)	0.17526
	SS-304	8.03	Outer radius (cm)	0.23876
Radial reflector	H ₂ O	—	Coolant (cm)	20.195
	SS-3161 ^b	—	Shroud (cm)	5.08
	H ₂ O	—	Moderator (cm)	4.725
Top reflector	H ₂ O (24.33023 wt %) He (0.000809 wt %) Zr-2 ^c (32.83966 wt %) Zr-4 ^d (16.67851 wt %) SS-304 (26.15079 wt %)	1.925764	Zone 1 (cm) lower	30.48
	H ₂ O (41.76238 wt %) Zr-2 (26.66206 wt %) SS-304 (31.57556 wt %)	1.545993	Zone 2 (cm) upper	9.52
Bottom reflector	H ₂ O (21.25524 wt %) Zr-2 (10.76185 wt %) SS-304 (66.47959 wt %) INC-718 ^e (0.64007 wt %) B ₄ C (0.86324 wt %)	2.547030	Zone 1 (cm) upper	12.70
	H ₂ O (4.50458 wt %) SS-304 (95.09426 wt %) B ₄ C (0.40116 wt %)	5.480845	Zone 2 (cm) lower	10.0076

^a stainless steel 304

^b stainless steel 3161

^c Zircaloy-2

^d Zircaloy-4

^e Inconel-718

Table 2.4. Assembly types for the PB2 cycles 1–3.

Cycle	Assembly type	Axial type	Power density (W/g)	Fuel rods		²³⁵ U wt %	Gd ₂ O ₃ wt %	Number of rods	Density (g/cm ³)	Figure
				Type	Material					
1	1	1	21.98	1	UO ₂	1.33	—	31	10.34	2.2
				2	UO ₂	0.71	—	17	10.34	
				2S ^a	UO ₂	0.71	—	1	9.33	
	2	2A	23.5	1	UO ₂	2.93	—	26	10.32	2.3 2.8
				2	UO ₂	1.94	—	12	10.32	
				3	UO ₂	1.69	—	6	10.32	
				4	UO ₂	1.33	—	1	10.32	
				5A	UO ₂ + Gd ₂ O ₃	2.93	3.0	3	10.19	
				6	UO ₂	2.93	—	1	10.27	
				1	UO ₂	2.93	—	26	10.32	
		2B	23.5	2	UO ₂	1.94	—	12	10.32	2.3 2.8
				3	UO ₂	1.69	—	6	10.32	
				4	UO ₂	1.33	—	1	10.32	
				5A	UO ₂ + Gd ₂ O ₃	2.93	3.0	3	10.19	
				5B	UO ₂ + Gd ₂ O ₃	2.93	3.0	1	10.27	
				1	UO ₂	2.93	—	26	10.32	
				2	UO ₂	1.94	—	11	10.32	
		3	23.5	3	UO ₂	1.69	—	6	10.32	2.4 2.9
				4	UO ₂	1.33	—	1	10.32	
				5A, 6C ^a	UO ₂ + Gd ₂ O ₃	2.93	3.0	3	10.19	
				7	UO ₂	2.93	—	1	10.28	
				8	UO ₂	1.94	—	1	10.19	
				1	UO ₂	2.93	—	26	10.32	
			23.5	2	UO ₂	1.94	—	11	10.32	2.4 2.9
				3	UO ₂	1.69	—	6	10.32	
				4	UO ₂	1.33	—	1	10.32	
				5A, 6C	UO ₂ + Gd ₂ O ₃	2.93	3.0	3	10.19	
				8D	UO ₂ + Gd ₂ O ₃	1.94	4.0	1	10.28	
				7	UO ₂	2.93	—	1	10.28	
		3C	23.5	1	UO ₂	2.93	—	26	10.32	2.4 2.9
				2	UO ₂	1.94	—	11	10.32	
				3	UO ₂	1.69	—	6	10.32	
				4	UO ₂	1.33	—	1	10.32	
				5A, 6C	UO ₂ + Gd ₂ O ₃	2.93	3.0	3	10.19	
				8D	UO ₂ + Gd ₂ O ₃	1.94	4.0	1	10.28	
				7E	UO ₂ + Gd ₂ O ₃	2.93	4.0	1	10.28	
				1	UO ₂	3.01	—	39	10.32	2.5
2	4	4	23.5	2	UO ₂	2.22	—	14	10.32	
				3	UO ₂	1.87	—	4	10.32	
				4	UO ₂	1.45	—	1	10.32	
				5	UO ₂ + Gd ₂ O ₃	3.01	3.0	5	10.25	
				WR	H ₂ O	—	—	1	—	
				1	UO ₂	3.01	—	39	10.32	2.6
	5	5	23.5	2	UO ₂	2.22	—	14	10.32	
				3	UO ₂	1.87	—	4	10.32	
				4	UO ₂	1.45	—	1	10.32	
				5	UO ₂ + Gd ₂ O ₃	3.01	2.0	5	10.25	
				WR	H ₂ O	—	—	1	—	
				1	UO ₂	0.71	—	62	10.32	2.7 2.10
		6	23.6	WR	H ₂ O	—	—	2	—	
			23.6	1	UO ₂	3.01	—	38	10.32	2.7 2.10
				2	UO ₂	2.22	—	14	10.32	
				3	UO ₂	1.87	—	4	10.32	
				4	UO ₂	1.45	—	1	10.32	
				5	UO ₂ + Gd ₂ O ₃	3.01	2.0	5	10.25	
				WR	H ₂ O	—	—	2	—	
3	7	5	Same as type 4	—	—	—	—	—	—	—

^a Short rod was axially homogenized to conserve fuel mass.

Table 2.5. Assembly geometry specification for PB2 cycles 1–3.

Assembly type		Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Array		7 × 7	7 × 7	7 × 7	8 × 8	8 × 8	8 × 8	8 × 8
Narrow gap (cm)		0.4750	0.4750	0.4750	0.4242	0.4242	0.4242	0.4242
Wide gap (cm)		0.9525	0.9525	0.9525	0.9017	0.9017	0.9017	0.9017
Channel	Material	Zr-4	Zr-4	Zr-4	Zr-4	Zr-4	Zr-4	Zr-4
	Box thickness (cm)	0.2032	0.2032	0.2032	0.2540	0.2540	0.2540	0.2540
	Corner inner radius (cm)	0.9652	0.9652	0.9652	0.9652	0.9652	0.9652	0.9652
	Inner half width (cm)	6.7031	6.7031	6.7031	6.7031	6.7031	6.7031	6.7031
Pins	Number of fuel rods	49	45	44	58	58	57	58
	Number of gadolinia rods	0	4	5	5	5	5	5
	Number of water rods	0	0	0	1	1	2	1
	Total rods	49	49	49	64	64	64	64
	Pitch (cm)	1.875	1.875	1.875	1.6256	1.6256	1.6256	1.6256
Fuel	Outer radius (cm)	0.61849	0.60579	0.60579	0.52832	0.52832	0.52070	0.52832
Clad	Material	Zr-2	Zr-2	Zr-2	Zr-2	Zr-2	Zr-2	Zr-2
	Density (g/cm ³)	6.84699			6.87213			
	Mixture with spacer grids	Zr-2 (95.8085 wt %) Inc-718 (0.6691 wt %) Zr-4 (3.5224 wt %)			Zr-2 (95.458 wt %) Inc-718 (0.6489 wt %) Zr-4 (3.8931 wt %)			
	Inner radius (cm)	0.63373	0.62103	0.62103	0.53976	0.53976	0.53213	0.53976
	Outer radius (cm)	0.71501	0.71501	0.71501	0.62611	0.62611	0.61341	0.62611
Water rod	Inner radius (cm)	—	—	—	0.53975	0.53975	0.67437	0.53975
	Outer radius (cm)	—	—	—	0.62611	0.62611	0.75057	0.62611
PD ^a	Ratio	1.31083	1.31083	1.31083	1.29817	1.29817	1.32505	1.29817
Volume	Fuel (cm ²)	58.88590	56.49242	56.49242	55.24392	55.24392	52.81007	55.24392
	Gas (cm ²)	2.93773	2.87814	2.87814	2.41622	2.41622	2.34394	2.41622
	Cladding (cm ²)	16.87555	19.32862	19.32862	20.24365	20.24365	18.81798	20.24365
	Water rod (cm ²)	—	—	—	0.91524	0.91524	2.85743	0.91524
Clad	Perimeter (cm)	220.13448	220.13448	220.13448	251.77377	251.77377	248.39040	251.77377

^a PD: ratio of pin pitch to pin diameter

2	1	1	1	1	1	1
1	1	1	2	1	1	1
1	1	2	2	2	2	1
1	2	2	2	2	2	1
1	1	2	2S	2	2	1
1	1	2	2	2	1	1
1	1	1	1	1	1	1

Rod type	²³⁵ U wt %	Gd ₂ O ₃ wt %	# of rods	Comments
1	1.33	0	31	—
2	0.71	0	17	—
2S	0.71	0	1	short

Figure 2.2. Fuel assembly type 1.

4	3	3	2	2	2	3
3	2	1	1	1	1	2
3	1	5A	1	1	5A	1
2	1	1	1	1	1	1
2	1	1	1	5B	1	1
2	1	5A	1	1	1	2
3	2	1	1	1	2	2

Rod type	²³⁵ U wt %	Gd ₂ O ₃ wt %	# of rods
1	2.93	0	26
2	1.94	0	12
3	1.69	0	6
4	1.33	0	1
5A	2.93	3.0	3
6B	2.93	3.0	1

Figure 2.3. Fuel assembly type 2.

4	3	3	2	2	2	3
3	8D	1	1	1	1	2
3	1	1	1	1	5A	1
2	1	1	6C	1	1	1
2	1	1	1	1	1	1
2	1	5A	1	1	7E	2
3	2	1	1	1	2	2

Rod type	²³⁵ U wt %	Gd ₂ O ₃ wt %	# of rods
1	2.93	0	26
2	1.94	0	11
3	1.69	0	6
4	1.33	0	1
5A	2.93	3.0	2
6C	2.93	3.0	1
7E	2.93	4.0	1
8D	1.94	4.0	1

Figure 2.4. Fuel assembly type 3.

4	3	2	2	2	2	2	3
3	2	1	5	1	1	1	2
2	1	1	1	1	1	5	1
2	5	1	1	1	1	1	1
2	1	1	1	WS	1	1	1
2	1	1	1	1	1	1	1
2	1	5	1	1	1	5	1
3	2	1	1	1	1	1	2

Rod type	²³⁵ U wt %	Gd ₂ O ₃ wt %	# of rods	Comments
1	3.01	0	39	—
2	2.22	0	14	—
3	1.87	0	4	—
4	1.45	0	1	—
5	3.01	3.0	5	—
WS	—	0	1	Water rod

Figure 2.5. Fuel assembly type 4.

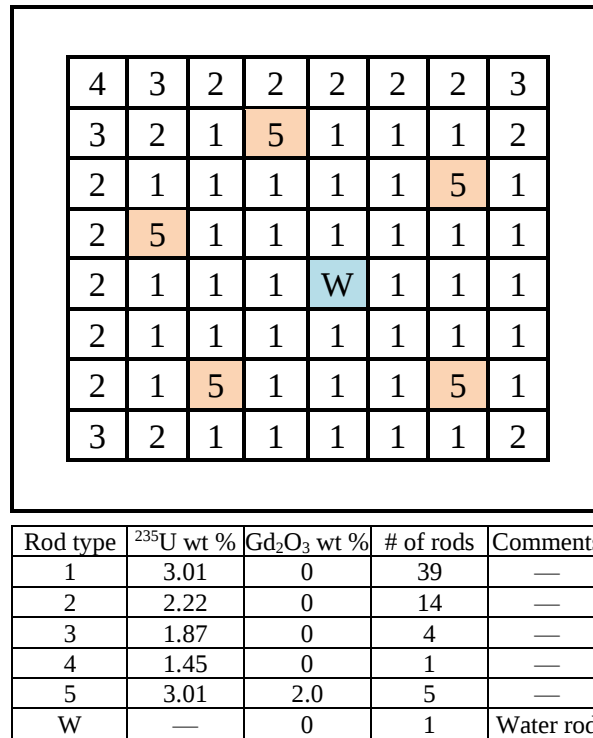


Figure 2.6. Fuel assembly type 5.

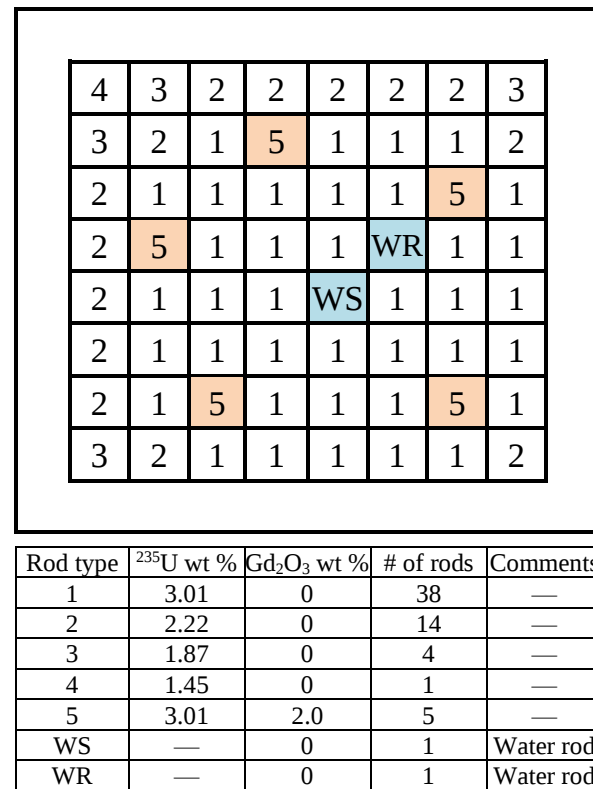


Figure 2.7. Fuel assembly type 6.

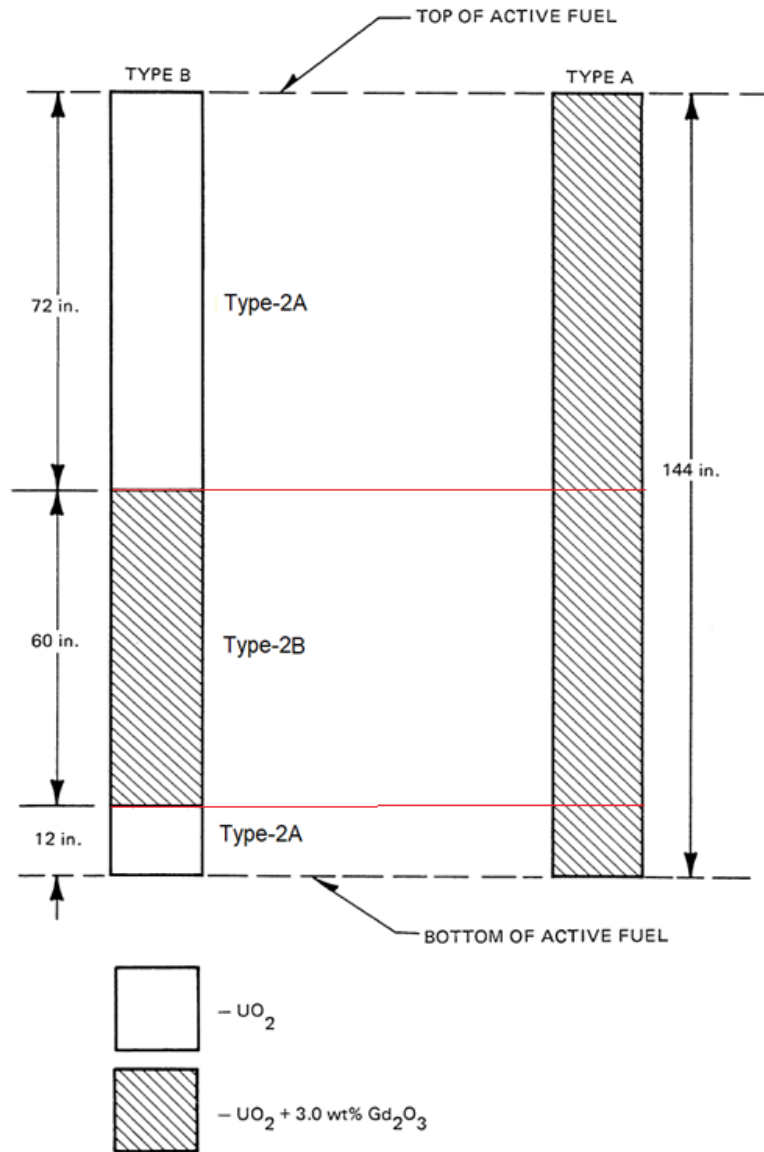
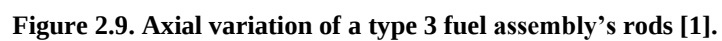


Figure 2.8. Axial variation of a type 2 fuel assembly's rods [1].



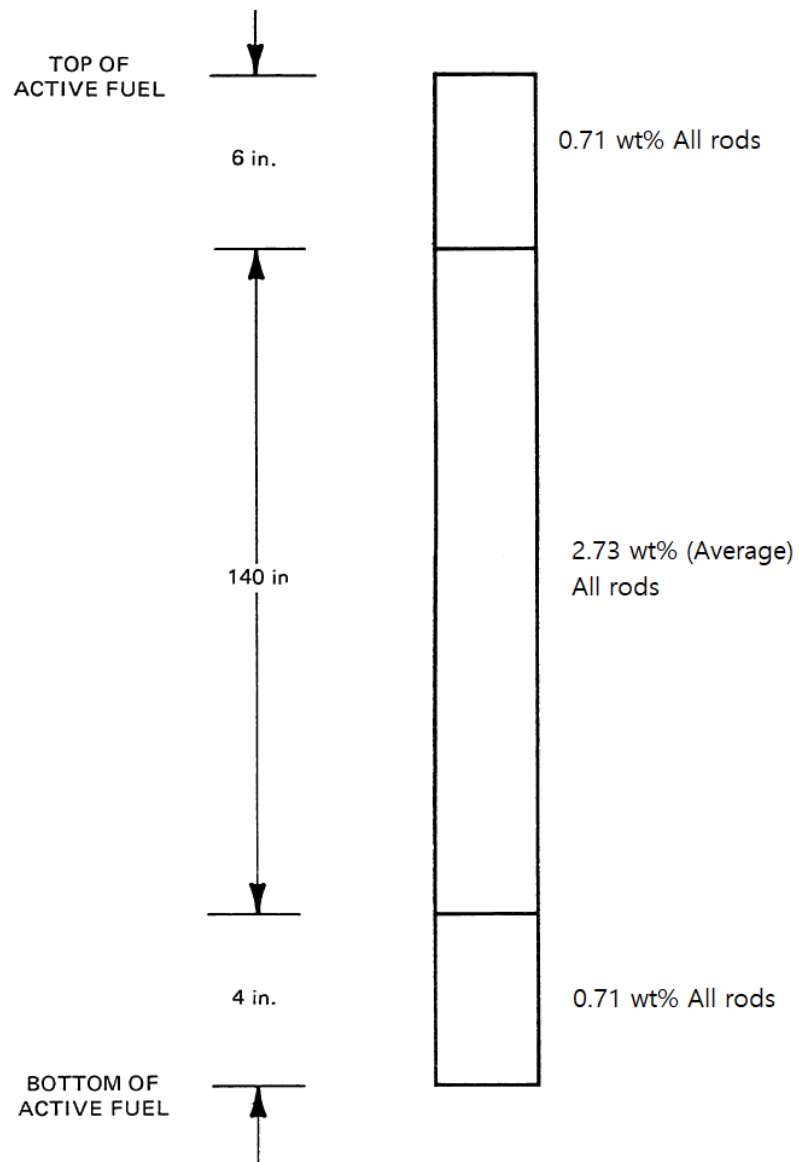


Figure 2.10. Axial variation of a type 6 fuel assembly's rods [1].

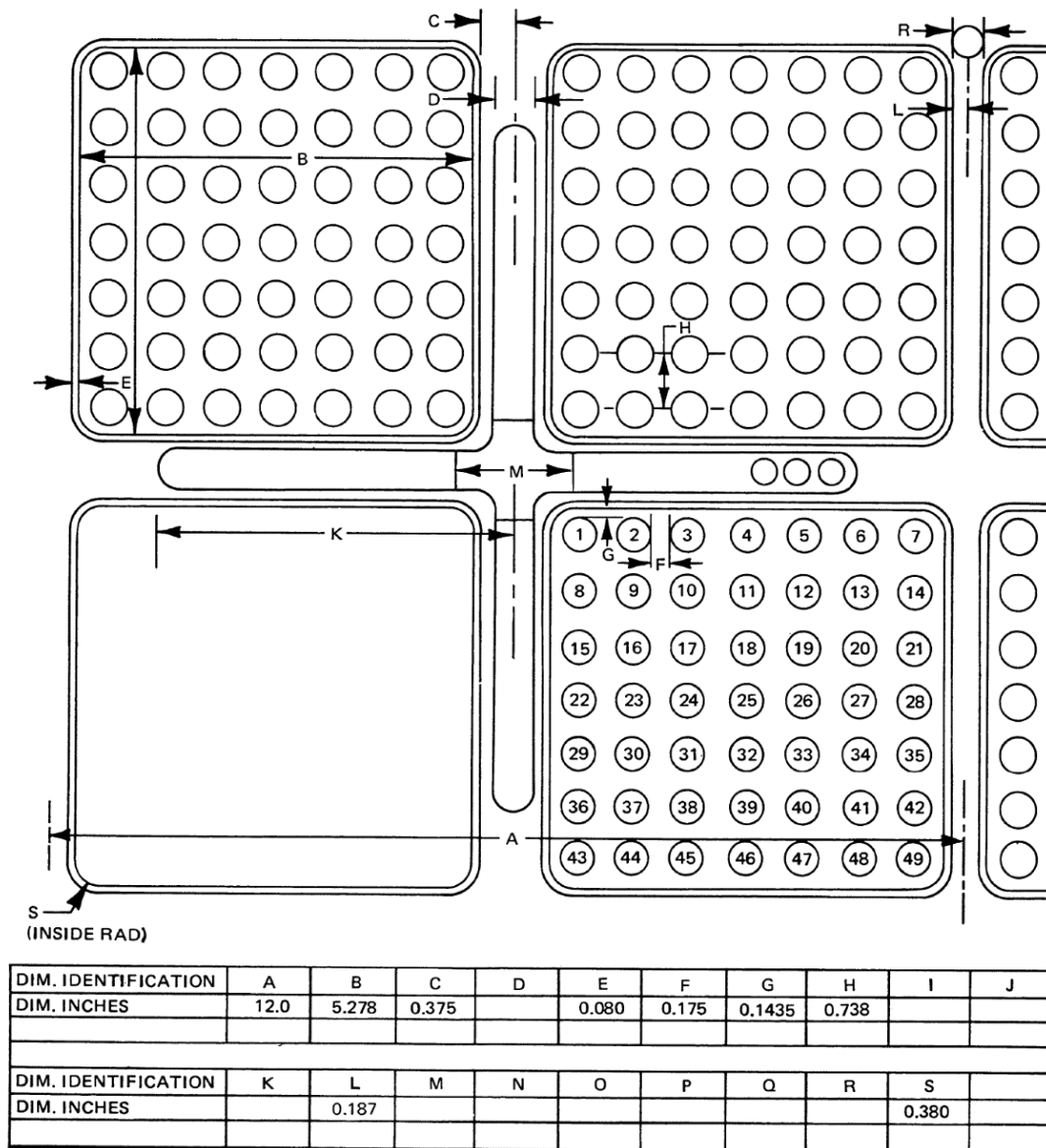


Figure 2.11. Assembly and control rod configuration for the 7 × 7 assembly [1].

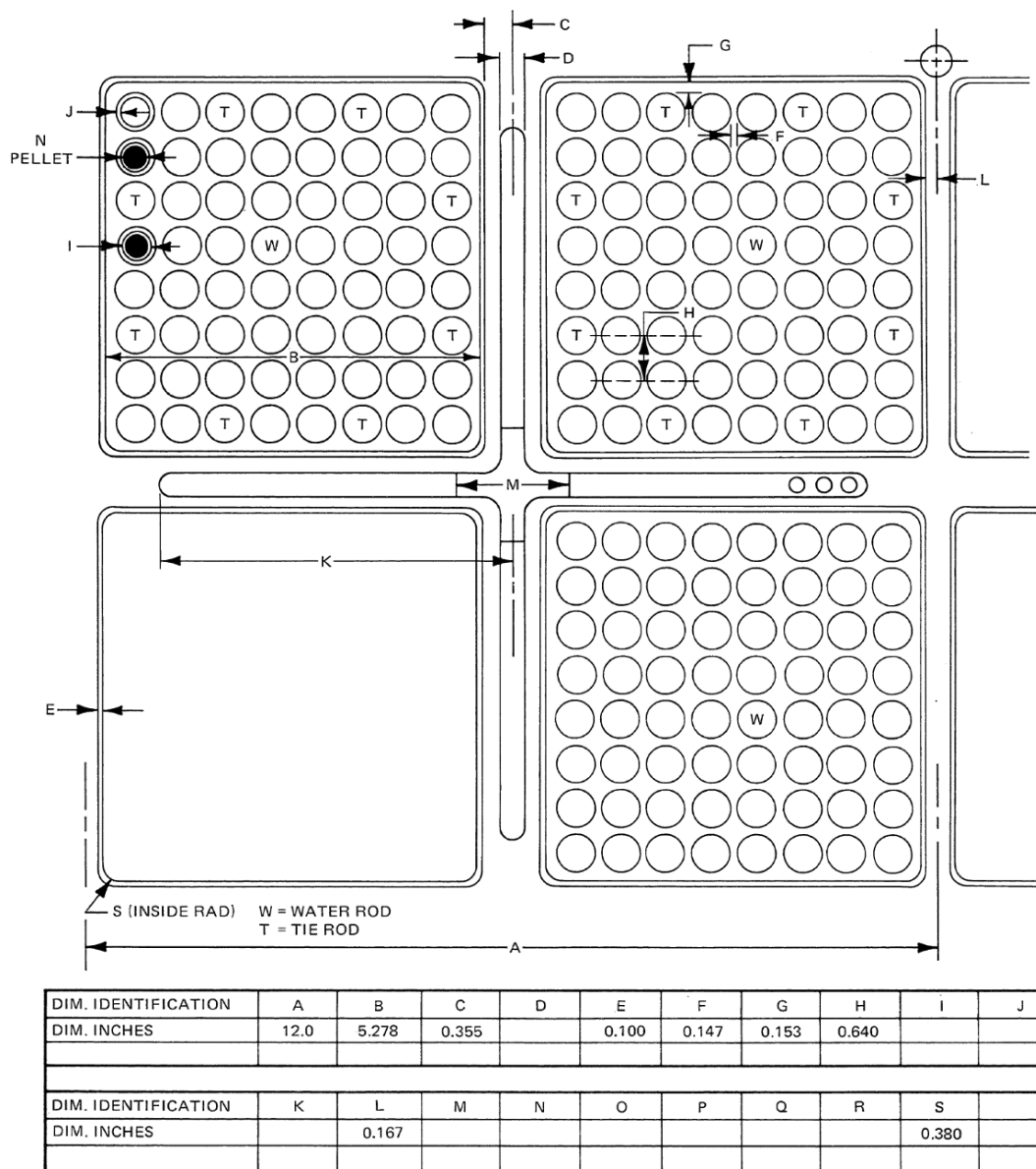
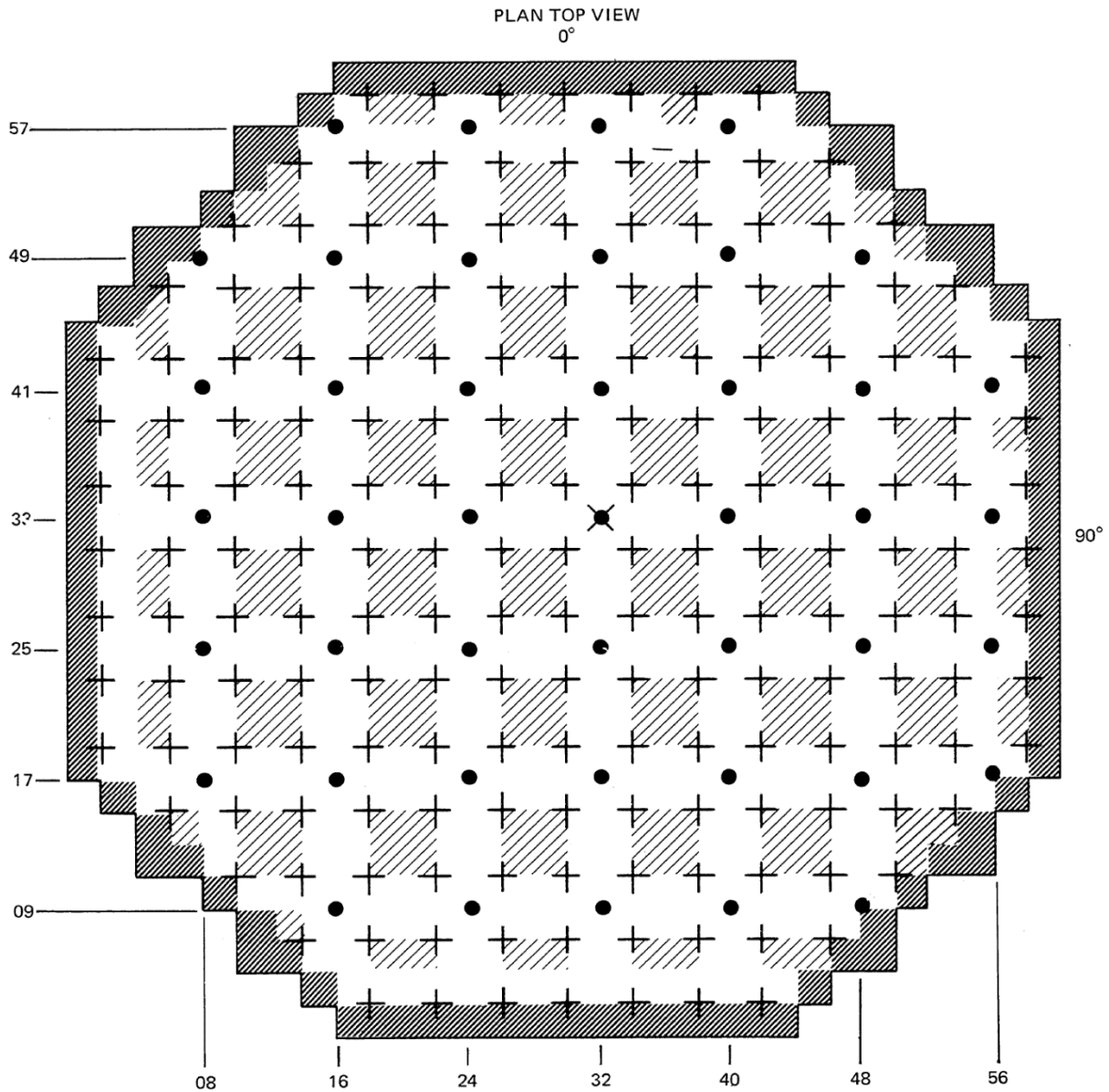


Figure 2.12. Assembly and control rod configuration for the 8 × 8 assembly [2].



- | | |
|---|--|
| <p>NUMBER OF FUEL ASSEMBLIES – 764</p> <p>+</p> <p>NUMBER OF CONTROL RODS – 185</p> <p>x</p> <p>NUMBER OF TIP INSTRUMENT ASSEMBLIES – 43</p> <p>x</p> <p>COMMON POSITION FOR ALL TIP MACHINES</p> | <p>□ FUEL BUNDLES WITH 2.211 in. ORIFICE DIAMETER – 672</p> <p>▨ FUEL BUNDLES WITH 1.469 in. ORIFICE DIAMETER – 92</p> <p>▩ TYPE 1 ASSEMBLIES WITH 2.211 in. ORIFICE AND RESTRICTED LOWER TIE PLATE – 168 (CYCLE 1 ONLY)</p> |
|---|--|

Figure 2.13. PB2 control rod, TIP, and orifice positions (cycles 1 and 2) [1].

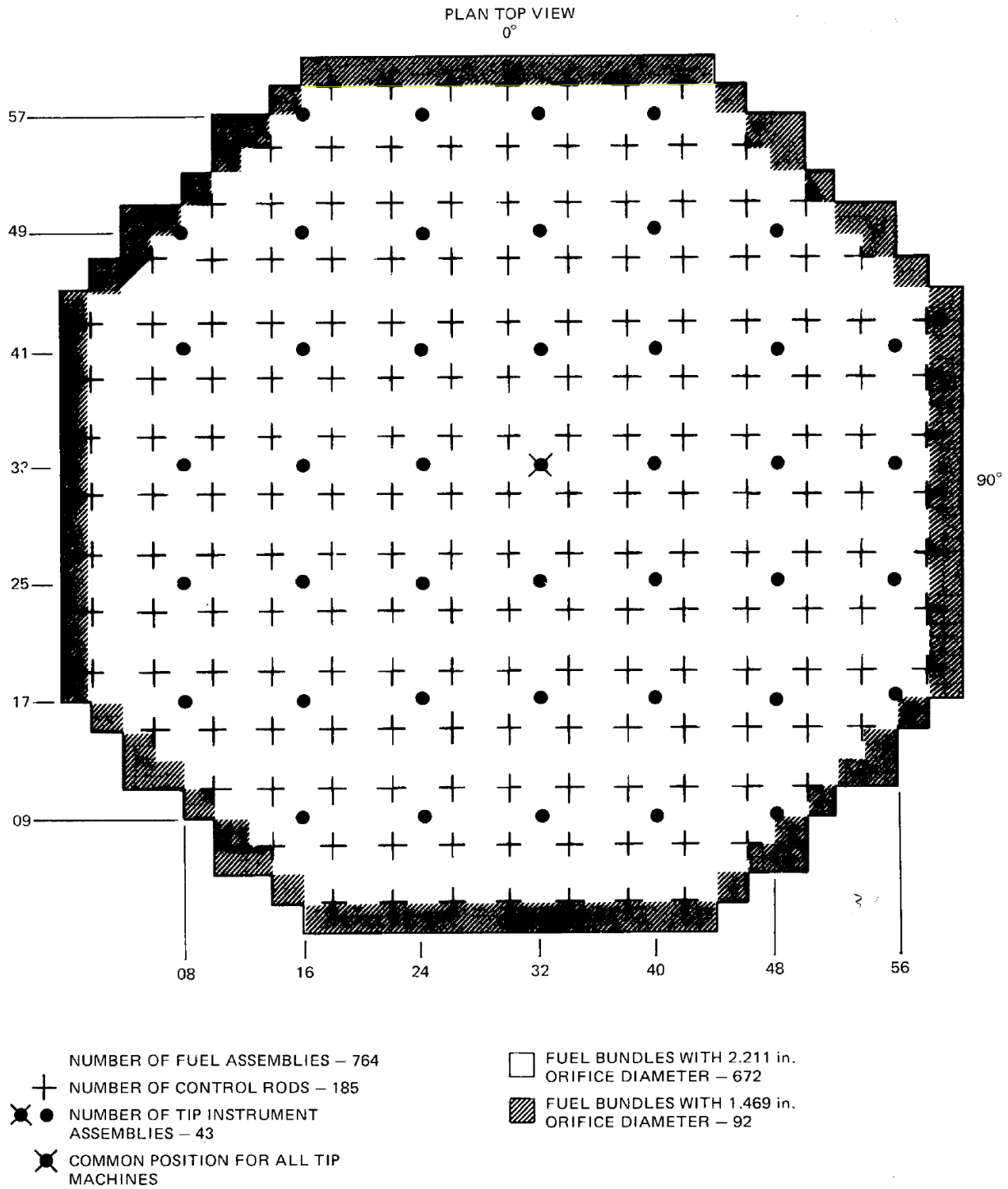
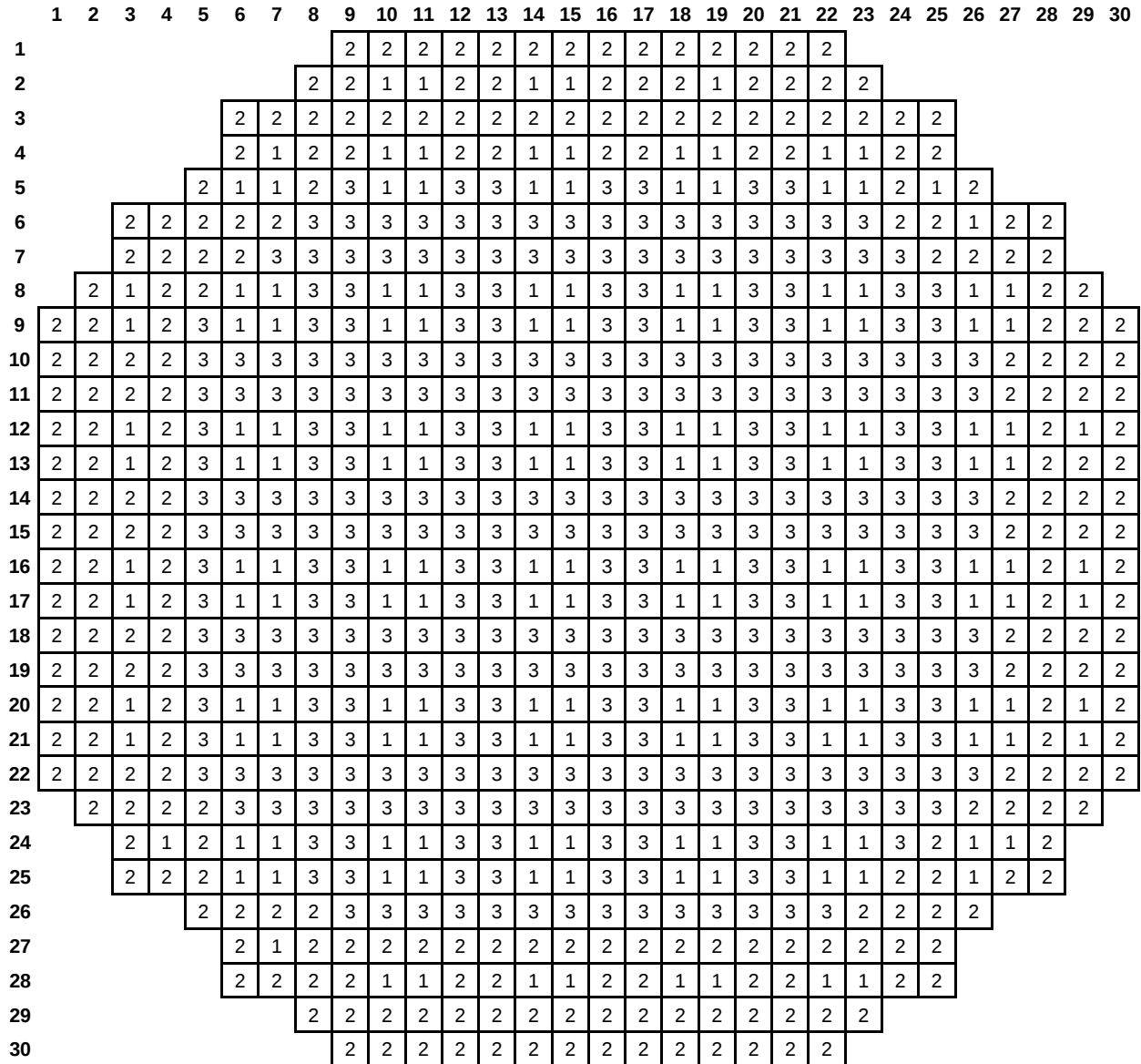


Figure 2.14. PB2 control rod, TIP, and orifice positions (cycle 3) [2].



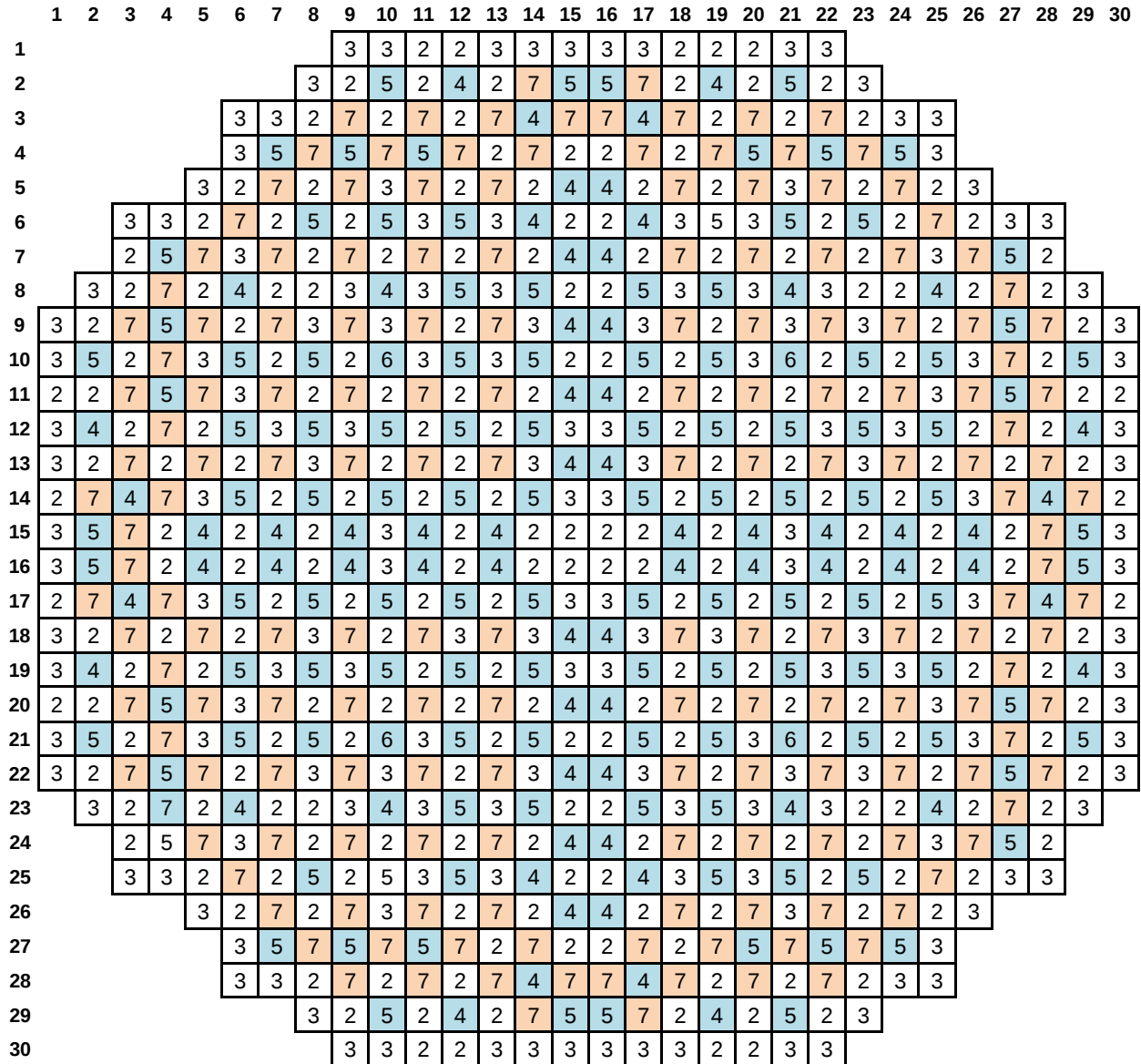
	# of assemblies	Description
Type 1	168	7×7 1.10 wt % ²³⁵ U
Type 2	263	7×7 2.50 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃
Type 3	333	7×7 2.50 wt % ²³⁵ U + 3.0/4.0 wt % Gd ₂ O ₃
Total	764	—

Figure 2.15. Layout of fuel assemblies in PB2 cycle 1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
1									3	2	2	2	2	2	2	2	2	2	2	2	2	3										
2								2	2	5	2	5	2	5	5	5	5	2	5	2	5	2	2									
3							2	3	3	5	2	5	2	5	2	2	2	2	5	2	5	2	5	3	3	2						
4							2	2	5	2	2	2	3	2	3	3	2	3	3	2	3	2	3	5	2	2						
5					3	2	5	2	5	3	5	3	5	3	4	4	3	5	3	5	3	5	3	5	2	3						
6			2	2	2	5	3	2	3	2	3	2	3	2	3	3	2	3	2	3	2	3	2	3	2	3	5	2	2	2		
7			2	2	5	3	6	3	5	3	5	3	4	3	3	2	3	4	3	5	3	5	2	6	3	5	2	3				
8		2	3	5	2	2	3	3	3	3	3	3	3	3	2	3	3	3	3	2	3	3	3	2	2	2	3	5	3	2		
9	3	2	5	2	5	3	5	3	4	3	4	3	4	3	4	4	3	4	3	4	3	4	3	4	3	5	3	5	3	5	2	3
10	2	5	2	2	3	2	3	2	3	2	3	3	3	2	3	3	3	3	3	3	3	3	3	2	3	2	3	2	2	5	2	
11	2	2	5	2	5	3	5	3	4	3	4	3	4	3	3	3	3	4	3	4	3	4	3	4	3	5	3	5	3	5	2	2
12	2	5	2	2	3	2	2	3	3	2	2	3	3	3	3	3	3	3	2	3	3	3	2	3	2	2	2	2	2	5	2	
13	2	2	5	2	5	3	4	3	4	3	4	3	4	3	4	4	3	4	3	4	3	4	3	4	3	5	3	5	2	2		
14	2	5	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	2	2	5	2	
15	2	5	2	2	4	2	3	2	4	3	3	3	4	3	3	3	3	4	3	3	3	4	3	3	3	4	3	2	5	2		
16	2	5	2	3	4	3	3	3	4	3	3	3	4	2	3	3	3	4	3	3	3	4	3	3	2	4	3	2	5	2		
17	2	5	2	2	3	3	3	3	3	2	3	3	3	3	2	3	3	3	3	3	3	3	3	3	2	3	3	3	2	5	2	
18	2	2	5	3	5	3	4	3	4	3	4	3	4	3	4	4	3	4	3	4	3	4	3	4	3	4	3	5	3	5	2	2
19	2	5	2	2	3	2	2	3	3	2	3	2	3	2	3	3	3	3	2	3	2	3	3	3	2	2	3	2	2	5	2	
20	2	2	5	2	5	3	5	3	4	3	4	3	4	3	2	3	3	4	3	4	3	4	3	5	3	5	3	5	3	5	2	2
21	2	5	2	2	3	2	3	2	3	3	3	3	3	2	3	3	3	3	2	3	2	3	2	3	2	3	2	3	2	2	5	2
22	3	2	5	2	5	3	5	3	4	3	4	3	4	3	4	4	3	4	3	4	3	4	3	4	3	5	3	5	2	5	2	2
23		2	3	5	2	2	3	2	3	3	3	3	3	2	3	2	2	3	3	3	3	3	2	3	2	2	5	2	2			
24			3	2	5	3	6	3	5	3	5	3	4	3	2	2	3	4	3	5	3	5	3	6	3	5	2	3				
25			2	2	2	5	3	2	3	2	3	2	3	3	3	3	3	2	2	3	2	3	2	3	5	2	2	2				
26					3	2	5	2	5	3	5	3	5	3	4	4	3	5	3	5	2	5	2	5	2	3						
27						2	2	5	2	2	2	2	2	2	3	2	3	2	2	2	2	2	2	5	2	2						
28						2	3	3	5	2	5	2	5	2	2	2	2	5	2	5	2	5	3	3	2							
29							2	2	5	2	5	2	5	5	5	5	5	2	5	2	5	2	2									
30									3	2	2	2	2	2	2	2	2	2	2	2	2	2	3									

	# of assemblies	Description	Remarks
Type 2	261	7×7 2.50 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	once-burned
Type 3	315	7×7 2.50 wt % ²³⁵ U + 3.0/4.0 wt % Gd ₂ O ₃	once-burned
Type 4	68	8×8 2.74 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	fresh
Type 5	116	8×8 2.74 wt % ²³⁵ U + 2.0 wt % Gd ₂ O ₃	fresh
Type 6	4	8×8 2.73 wt % ²³⁵ U + 2.0 wt % Gd ₂ O ₃	fresh
Total	764		

Figure 2.16. Layout of fuel assemblies in PB2 cycle 2.



	# of assemblies	Description	Remarks
Type 2	245	7×7 2.50 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	twice-burned
Type 3	159	7×7 2.50 wt % ²³⁵ U + 3.0/4.0 wt % Gd ₂ O ₃	twice-burned
Type 4	68	8×8 2.74 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	once-burned
Type 5	116	8×8 2.74 wt % ²³⁵ U + 2.0 wt % Gd ₂ O ₃	once-burned
Type 6	4	8×8 2.73 wt % ²³⁵ U + 2.0 wt % Gd ₂ O ₃	once-burned
Type 7	172	8×8 2.74 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	fresh
Total	764		

Figure 2.17. Layout of fuel assemblies in PB2 cycle 3.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1									367	241	362	237	358	233	354	229	350	225	347	221	343	216								
2								368	423	168	156	303	410	166	158	296	402	292	160	288	393	283	392							
3							213	337	210	334	206	331	202	328	198	325	194	322	190	319	186	316	182	314	178	375				
4							281	165	278	385	104	64	272	381	106	68	266	377	108	72	260	427	110	73	254	413				
5						309	151	23	173	762	141	27	502	567	145	31	575	561	152	35	586	555	124	39	170	40	175			
6			429	250	416	249	399	701	755	752	669	748	665	756	652	742	657	739	653	736	649	733	647	246	411	109	389	280		
7			315	179	306	171	530	576	527	549	524	541	521	499	554	544	515	536	512	509	489	501	529	574	307	172	336	209		
8		284	74	255	424	120	77	729	644	81	44	723	640	83	52	717	636	85	60	711	632	87	80	728	760	111	167	277	420	
9	344	217	34	183	556	121	14	503	486	128	20	493	480	132	3	504	474	136	7	496	485	127	4	583	761	142	24	205	365	240
10	394	285	430	258	650	734	633	709	628	705	624	702	620	699	616	696	612	693	608	690	627	704	643	726	753	750	384	275	419	366
11	348	222	320	187	559	588	513	511	472	498	448	469	445	461	681	453	439	464	447	467	483	510	523	539	570	581	330	201	361	236
12	396	289	69	261	654	99	59	712	609	94	47	687	604	95	55	442	600	97	49	686	623	118	58	722	668	113	63	271	157	302
13	351	226	30	191	562	139	19	538	475	133	13	466	438	138	17	460	437	137	11	459	479	150	10	550	566	146	28	197	357	232
14	404	293	378	264	658	740	637	715	613	694	601	679	598	677	597	676	596	675	603	684	619	698	639	720	664	744	380	269	408	299
15	355	230	326	195	565	577	519	546	478	506	443	455	433	454	432	452	436	458	441	470	477	589	517	542	564	573	324	193	353	228
16	406	297	65	267	662	116	50	718	617	92	53	682	591	88	56	671	595	100	57	680	615	91	54	716	660	115	67	265	159	295
17	359	234	26	199	568	144	6	535	481	129	9	463	434	122	33	456	435	140	15	462	473	135	12	534	560	154	32	189	164	224
18	414	300	382	270	666	746	641	721	621	700	605	685	592	672	593	673	594	674	599	678	611	692	635	714	656	738	376	263	400	291
19	363	238	332	203	571	585	525	543	484	495	449	471	440	468	444	457	446	465	450	492	451	494	491	507	558	584	318	185	346	220
20	415	304	61	273	670	114	42	724	625	90	45	688	602	98	51	683	606	96	43	689	607	93	41	745	661	117	71	259	161	287
21	369	242	22	207	763	147	2	551	487	155	5	500	476	134	1	508	482	130	18	497	488	126	16	533	518	123	36	181	162	215
22	426	256	386	276	757	754	759	727	629	706	610	691	614	695	618	697	622	758	626	703	630	707	631	708	648	732	425	257	391	282
23		243	338	211	308	547	531	578	490	505	514	532	516	540	520	548	522	537	526	545	528	572	552	580	553	169	313	177	342	
24			388	102	403	112	78	730	634	84	79	713	638	86	48	719	642	89	46	725	646	82	75	731	401	119	76	253		
25			340	214	310	153	37	582	557	143	25	590	563	148	29	579	569	131	8	587	764	149	21	174	311	125	312	245		
26				417	251	397	247	651	735	655	737	659	741	663	743	667	747	751	749	645	710	409	248	421	252					
27					176	38	180	317	184	321	188	323	192	327	196	329	200	333	204	335	208	339	212	341						
28					372	422	370	431	107	70	262	379	105	66	268	383	103	62	274	387	101	163	279	390						
29							218	345	219	349	223	352	227	356	231	360	235	364	239	371	244	373								
30								395	286	398	290	405	294	407	298	412	301	418	305	428	374									

	# of assemblies	Description
Type 1	PH001 – PH168	7×7 1.10 wt % ²³⁵ U
Type 2	PH169 – PH431	7×7 2.50 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃
Type 3	PH432 – PH764	7×7 2.50 wt % ²³⁵ U + 3.0/4.0 wt % Gd ₂ O ₃

Figure 2.18. Fresh assembly loading pattern PB2 cycle 1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30							
1										527	392	350	237	358	233	354	229	389	178	347	221	343	445														
2									404	368	3098	429	3099	367	3100	3101	3102	3103	375	3104	216	3105	420	355													
3								296	752	755	3106	206	3107	210	3108	303	325	194	254	3109	314	3110	182	3111	620	657	292										
4								396	250	3112	385	331	306	493	381	544	512	377	763	711	260	690	402	496	3113	359	413										
5								486	202	3114	173	3115	524	3116	502	3117	442	3213	3214	561	3118	586	3119	555	3120	574	3121	170	649								
6								179	351	416	3122	738	285	530	278	681	328	665	266	756	567	270	739	186	509	319	733	288	529	3123	198	407	353				
7								264	406	3124	560	9002	455	3126	549	3127	541	3215	669	554	316	515	3216	653	3128	489	3129	246	9004	728	3131	294	477				
8								423	734	3132	424	410	633	448	644	468	576	723	640	249	536	636	717	453	272	504	447	627	411	307	393	583	3133	753	365		
9								562	284	3134	183	3135	577	3136	503	3217	762	3218	748	3219	556	3220	3221	474	3222	736	3223	485	3224	647	3137	761	3138	523	3139	362	674
10								394	3140	222	334	513	226	482	427	709	320	499	702	701	430	616	696	722	693	608	510	550	629	275	726	172	750	205	408	3141	366
11								348	344	3142	187	3143	588	3144	511	3225	498	3226	472	3227	705	704	467	521	3228	464	3229	483	3230	760	3145	570	3146	539	3147	240	236
12								337	3148	217	261	654	293	378	712	609	255	258	624	438	735	630	501	603	600	269	433	459	623	197	581	271	384	330	277	3149	302
13								309	213	3150	191	3151	662	3231	457	3232	740	3233	694	3234	594	3235	3236	437	3237	490	3238	632	3239	668	3240	566	3152	643	3153	280	209
14								281	3154	310	538	267	687	565	715	613	637	475	677	598	546	460	672	441	650	720	645	573	698	764	673	201	744	380	419	3155	175
15								315	3156	297	195	3241	207	519	199	3242	506	443	591	3243	454	601	452	436	3244	479	534	470	3245	589	542	664	3246	564	193	3157	228
16								422	3158	234	724	3247	670	718	585	3248	682	469	547	3249	174	675	597	595	3250	458	680	615	3251	692	716	399	3252	461	265	3159	295
17								243	3160	242	332	568	517	727	535	481	326	559	605	434	520	401	456	465	435	599	596	660	553	635	171	686	676	745	346	3161	224
18								225	340	3162	525	3163	746	3253	495	3254	617	3255	505	3256	628	3257	3258	592	3259	488	3260	611	3261	558	3262	656	3164	507	3165	245	291
19								388	3166	256	203	571	300	382	543	484	211	700	180	440	248	697	518	497	658	318	710	425	494	491	584	189	376	707	244	3167	220
20								415	426	3168	273	3169	699	3170	551	3263	625	3264	602	3265	634	324	492	612	3266	528	3267	451	3268	661	3171	683	3172	731	3173	374	299
21								369	3174	289	304	439	386	759	403	487	432	582	500	476	262	610	508	719	638	339	607	311	580	230	708	185	533	259	181	3175	287
22								604	241	3176	276	3177	754	3178	730	3269	666	3270	578	3271	695	3272	3273	540	3274	587	3275	732	3276	552	3179	648	3180	387	3181	215	184
23								283	757	3182	308	338	531	397	691	688	655	471	516	327	619	329	274	537	526	545	450	572	313	631	219	169	3183	335	391		
24								478	363	3184	641	9003	514	3186	713	3187	532	3277	618	268	263	642	3278	751	3188	646	3189	758	9001	593	3191	341	622				
25								349	214	238	3192	706	370	557	352	444	431	563	449	590	749	689	196	360	725	231	626	400	685	3193	235	301	257				
26								621	223	3194	247	3195	659	3196	737	3197	741	3279	3280	480	3198	548	3199	383	3200	409	3201	421	614								
27								176	405	3202	317	357	321	188	323	192	671	379	606	200	333	204	212	208	3203	298	279										
28								371	651	667	3204	364	3205	345	3206	251	227	356	336	3207	177	3208	239	3209	446	569	361										
29								414	342	3210	395	3211	372	3212	3125	3185	3190	282	3130	390	3454	373	412														
30								522	286	398	232	417	218	290	418	312	252	253	305	428	747																

	# of assemblies	Description	Remarks
Type 2	PH169 – PH431	7×7 2.50 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	once-burned
Type 3	PH432 – PH764	7×7 2.50 wt % ²³⁵ U + 3.0/4.0 wt % Gd ₂ O ₃	once-burned
Type 4	LJ3213 – LJ3280	8×8 2.74 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	fresh
Type 5	LJ3098 – LJ3212, LJ3454	8×8 2.74 wt % ²³⁵ U + 2.0 wt % Gd ₂ O ₃	fresh
Type 6	9001 – 9004	8×8 2.73 wt % ²³⁵ U + 2.0 wt % Gd ₂ O ₃	fresh

Figure 2.19. Fresh assembly loading and shuffling patterns in PB2 cycle 2.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1									493	502	424	378	748	541	442	669	556	207	307	246	512	620								
2								576	368	3127	358	3275	392	3506	3117	3118	3523	343	3223	175	3128	420	509							
3						551	503	284	3507	315	3539	423	3540	3222	3541	6174	3225	6175	365	6176	407	3524	362	586	453					
4						738	3106	3508	3112	3542	3108	3543	179	3544	429	389	6177	292	6178	3109	6179	3113	3525	3139	690					
5					755	396	3509	350	3545	524	3546	285	3547	264	3213	3214	319	6180	393	6181	711	6182	178	3526	216	750				
6			633	560	367	3510	173	3116	337	3115	544	3100	554	3215	217	244	3216	717	3103	608	3120	347	3119	260	6183	413	647	726		
7			187	3124	3511	530	3548	351	3549	202	3550	410	3551	325	3219	3228	402	6184	198	6185	254	6186	229	6187	529	3527	3131	188		
8		511	404	3512	344	3217	422	237	448	3220	637	3101	546	3099	303	170	3102	550	3121	496	3237	728	221	209	3238	291	3528	355	760	
9	712	250	3513	3136	3552	281	3553	734	6120	752	6121	278	6122	467	3227	3221	447	6188	411	6189	445	6190	523	6191	236	6192	3137	3529	294	539
10	577	3144	309	6123	513	3135	210	3126	183	9002	574	3110	691	3114	430	186	3104	377	3147	753	9004	330	3129	314	3138	583	6193	302	3145	723
11	261	394	6124	3143	6125	624	6126	267	6127	427	6128	320	6129	206	3233	3229	288	6194	172	6195	381	6196	384	6197	720	6198	3146	6199	366	380
12	662	3231	406	6130	222	3154	562	3107	478	3142	255	3122	306	3111	722	622	3133	272	3123	316	3165	657	3153	674	3155	239	6200	359	3240	470
13	538	233	6131	296	6132	234	6133	605	6134	293	6135	399	6136	486	3235	3236	649	6201	385	6202	271	6203	702	6204	193	6205	353	6206	354	745
14	195	3514	3226	6137	682	3156	310	3166	328	3132	180	3140	174	3098	460	603	3105	269	3141	197	3149	275	3159	182	3157	542	6207	3239	3530	171
15	709	3150	6138	348	3241	416	3232	263	3242	687	3234	326	3243	249	213	280	313	3230	189	3244	573	3224	205	3245	251	3246	375	6208	3152	643
16	565	3151	6139	340	3247	256	3254	297	3248	757	3249	397	3255	248	417	282	311	3268	266	3250	716	3276	259	3251	184	3252	253	6209	3171	762
17	382	3515	3272	6140	718	3158	334	3148	403	3134	211	3174	401	3210	452	456	3454	208	3175	318	3201	387	3167	346	3161	635	6210	3261	3531	376
18	525	243	6141	371	6142	386	6143	715	6144	300	6145	683	6146	651	3257	3258	569	6211	446	6212	201	6213	597	6214	265	6215	361	6216	245	507
19	543	3253	405	6147	289	3160	604	3162	621	3168	324	3182	327	3204	689	614	3209	379	3193	383	3173	477	3164	527	3191	181	6217	298	3262	736
20	273	369	6148	3169	6149	535	6150	247	6151	317	6152	352	6153	304	3264	3267	364	6218	185	6219	339	6220	169	6221	491	6222	3172	6223	287	727
21	443	3170	415	6154	469	3177	242	3163	276	9003	449	3205	231	3211	262	274	3130	409	3208	686	9001	425	3199	177	3180	731	6224	295	3179	564
22	724	283	3516	3178	6155	176	6156	517	6157	522	6158	431	6159	492	3265	3266	450	6225	360	6226	747	6227	660	6228	220	6229	3189	3532	341	533
23		457	225	3517	426	3269	388	241	500	3279	688	3192	432	3212	238	419	3125	441	3185	534	3259	680	215	228	3260	240	3533	299	668	
24			203	3184	3518	531	6160	395	6161	223	6162	370	6163	331	3271	3256	212	6230	219	6231	235	6232	301	6233	580	3534	3181	204		
25			701	759	372	6164	322	3186	214	3195	471	3194	520	3270	345	421	3218	671	3190	497	3200	305	3198	335	6234	224	593	676		
26				641	398	3519	414	6165	667	6166	338	6167	227	3273	3280	226	6235	400	6236	719	6237	279	3535	374	582					
27					730	3176	3520	3202	6168	3206	6169	349	6170	312	390	6238	257	6239	3207	6240	3203	3536	3183	685						
28					713	514	232	3521	290	6171	363	6172	3277	6173	6241	3274	6242	391	6243	418	3537	412	552	631						
29						578	342	3187	218	3263	286	3522	3196	3197	3538	428	3278	252	3188	373	725									
30							681	610	321	308	584	444	623	526	548	581	333	196	732	626										

	# of assemblies	Description	Remarks
Type 1	PH001 – PH168	7×7 1.10 wt % ²³⁵ U	twice-burned
Type 2	PH169 – PH431	7×7 2.50 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	twice-burned
Type 3	PH432 – PH764	7×7 2.50 wt % ²³⁵ U + 3.0/4.0 wt % Gd ₂ O ₃	twice-burned
Type 4	LJ3213 – LJ3280	8×8 2.74 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	once-burned
Type 5	LJ3098 – LJ3212, LJ3454	8×8 2.74 wt % ²³⁵ U + 2.0 wt % Gd ₂ O ₃	once-burned
Type 6	9001 – 9004	8×8 2.73 wt % ²³⁵ U + 2.0 wt % Gd ₂ O ₃	once-burned
Type 7	LJ3506 – LJ3553, LJ6120 – LJ6243	8×8 2.74 wt % ²³⁵ U + 3.0 wt % Gd ₂ O ₃	fresh

Figure 2.20. Fresh assembly loading and shuffling patterns in PB2 cycle 3.

Table 2.6. PB2 core axial configurations.

No.	Mesh size (cm)	Fuel (cm)	Cross section assembly types						
			Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
40	10.16	—	R _{TOP} ^a	R _{TOP}	R _{TOP}	R _{TOP}	R _{TOP}	R _{TOP}	R _{TOP}
39	10.16	—	R _{TOP}	R _{TOP}	R _{TOP}	R _{TOP}	R _{TOP}	R _{TOP}	R _{TOP}
38	10.16	10.16	1	2A	3A	4	5	6B	4
37	10.16	10.16	1	2A	3A	4	5	6B	4
36	10.16	10.16	1	2A	3A	4	5	6B	4
35	10.16	10.16	1	2A	3A	4	5	6B	4
34	10.16	10.16	1	2A	3A	4	5	6B	4
33	10.16	10.16	1	2A	3A	4	5	6B	4
32	10.16	10.16	1	2A	3B	4	5	6B	4
31	10.16	10.16	1	2A	3B	4	5	6B	4
30	10.16	10.16	1	2A	3B	4	5	6B	4
29	10.16	10.16	1	2A	3B	4	5	6B	4
28	10.16	10.16	1	2A	3B	4	5	6B	4
27	10.16	10.16	1	2A	3B	4	5	6B	4
26	10.16	10.16	1	2A	3B	4	5	6B	4
25	10.16	10.16	1	2A	3B	4	5	6B	4
24	10.16	10.16	1	2A	3B	4	5	6B	4
23	10.16	10.16	1	2A	3C	4	5	6B	4
22	10.16	10.16	1	2A	3C	4	5	6B	4
21	10.16	10.16	1	2A	3C	4	5	6B	4
20	10.16	10.16	1	2B	3C	4	5	6B	4
19	10.16	10.16	1	2B	3C	4	5	6B	4
18	10.16	10.16	1	2B	3C	4	5	6B	4
17	10.16	10.16	1	2B	3C	4	5	6B	4
16	10.16	10.16	1	2B	3C	4	5	6B	4
15	10.16	10.16	1	2B	3C	4	5	6B	4
14	10.16	10.16	1	2B	3B	4	5	6B	4
13	10.16	10.16	1	2B	3B	4	5	6B	4
12	10.16	10.16	1	2B	3B	4	5	6B	4
11	10.16	10.16	1	2B	3B	4	5	6B	4
10	10.16	10.16	1	2B	3B	4	5	6B	4
9	10.16	10.16	1	2B	3B	4	5	6B	4
8	10.16	10.16	1	2B	3B	4	5	6B	4
7	10.16	10.16	1	2B	3B	4	5	6B	4
6	10.16	10.16	1	2B	3B	4	5	6B	4
5	10.16	10.16	1	2A	3A	4	5	6B	4
4	10.16	10.16	1	2A	3A	4	5	6B	4
3	10.16	10.16	1	2A	3A	4	5	6A	4
2	10.16	—	R _{BOT} ^b	R _{BOT}	R _{BOT}	R _{BOT}	R _{BOT}	R _{BOT}	R _{BOT}
1	10.16	—	R _{BOT}	R _{BOT}	R _{BOT}	R _{BOT}	R _{BOT}	R _{BOT}	R _{BOT}

^a Top reflector

^b Bottom reflector

2.2.2 Measured data

The measured data used in the present study were obtained from the publicly available PB2 cycles 1–3 operating histories. Figure 2.21–Figure 2.23 and Table 2.7 provide the operating histories for powers, flow rates, pressures, and inlet temperatures at burnups. The PARCS and PATHS inputs were prepared using this information. The EPRI reports do not clearly specify end of cycle (EOC) burnups. Therefore, core average burnups for reload cycles from the PARCS calculations may not be consistent with the core average burnups of the EPRI reports.

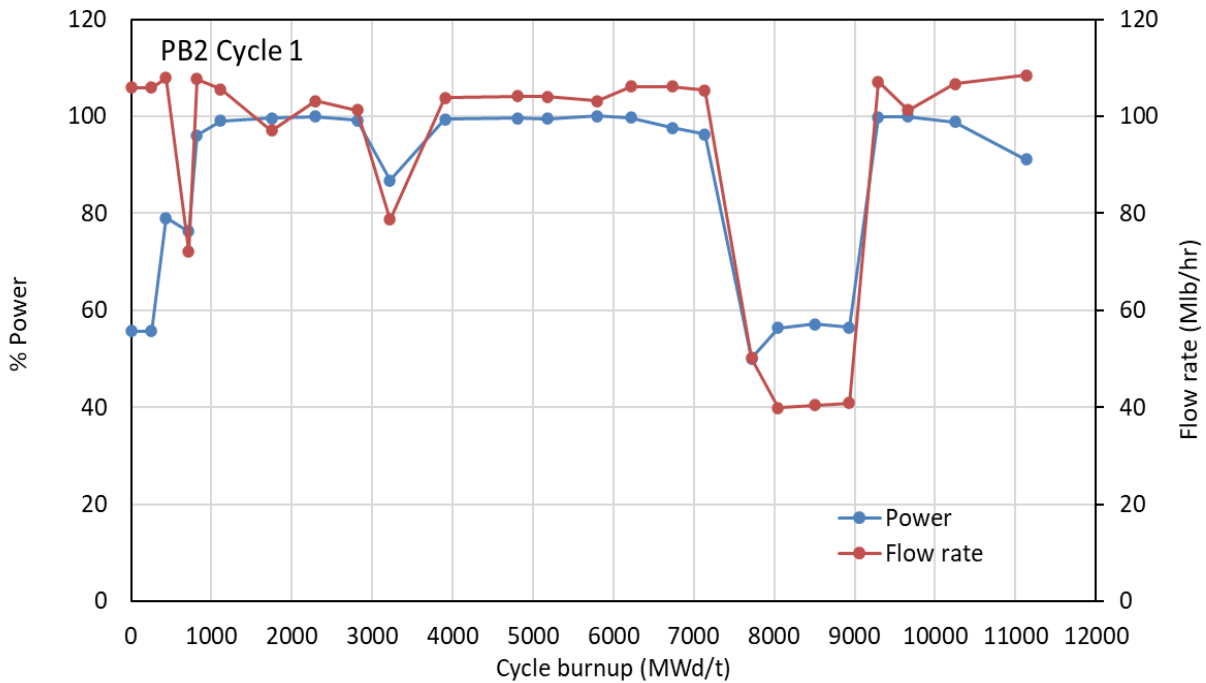


Figure 2.21. Power and flow rate history for PB2 cycle 1.

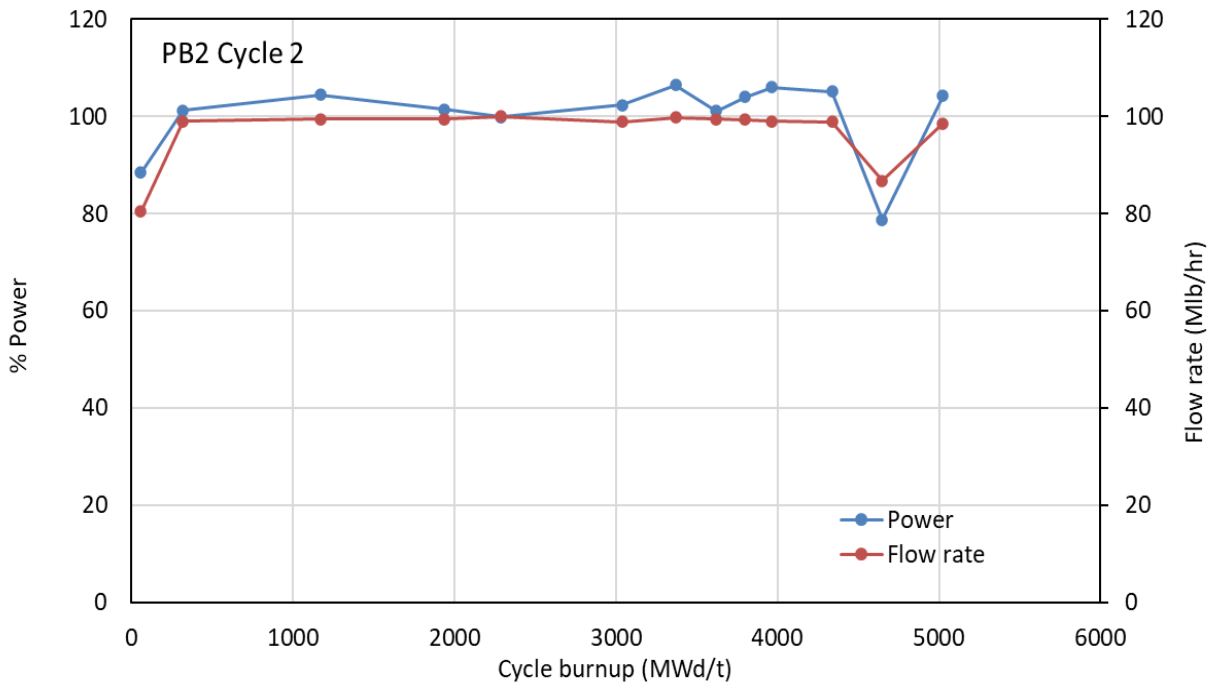


Figure 2.22. Power and flow rate history for PB2 cycle 2.

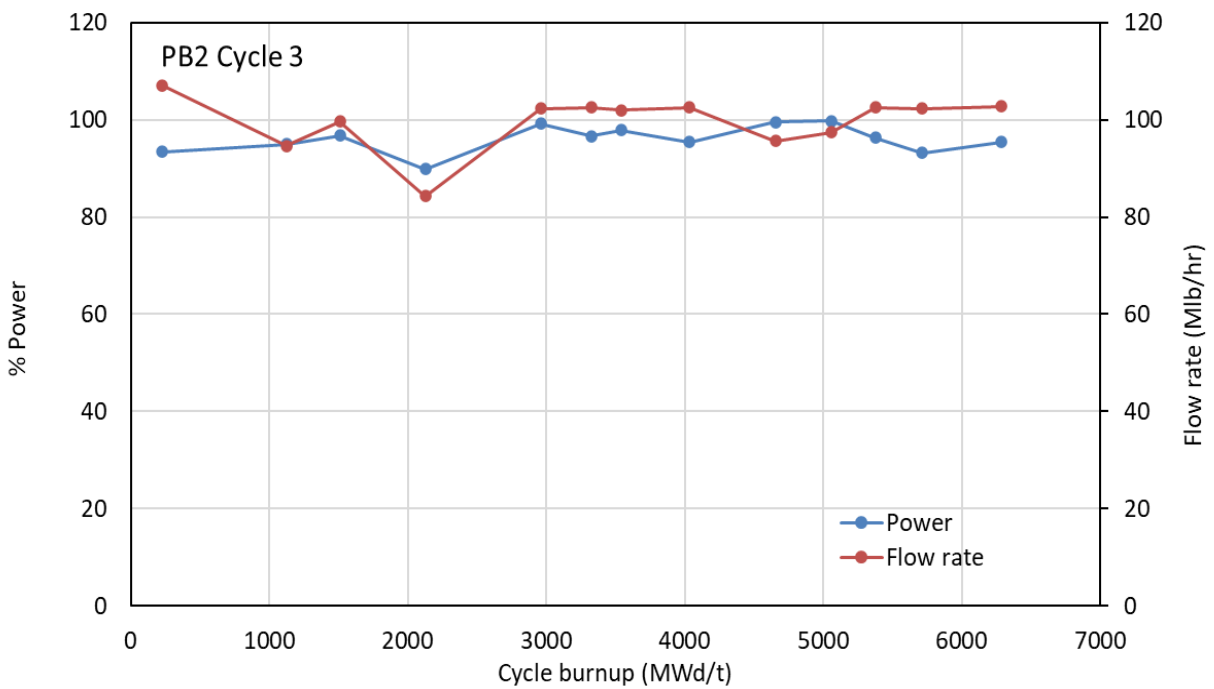


Figure 2.23. Power and flow rate history for PB2 cycle 3.

Table 2.7. PB2 operating history.

Cycle	Dataset	Exposure (MWd/t)		Power (MW)	D. Press (psi)	Flow (Mlb/h)	In. Sub. C. (Btu/lb)	Notches	Dome Press (MPa)	Inlet Subcool (kJ/kg)	Flow (%)	Total (kg/s)	Bypass (kg/s)
		Core	Cycle										
1		0.0	0.0	—	—	—	—	—	—	—	—	—	—
	1	253.5	253.5	1,835	973	105.9	14.20	910	6.709	33.007	103.32	13,343.18	2,182.77
	2	429.9	429.9	2,603	991	107.9	18.70	642	6.833	43.467	105.27	13,595.17	2,236.44
	3	714.3	714.3	2,513	1,007	72.1	28.40	488	6.943	66.014	70.34	9,084.45	1,303.50
	4	816.8	816.8	3,164	1,009	107.7	22.10	536	6.957	51.370	105.07	13,569.97	2,231.07
	5	1113.3	1113.3	3,261	1,017	105.6	22.80	586	7.012	52.997	103.02	13,305.38	2,174.73
	6	1747.2	1747.2	3,280	1,033	97.1	25.70	678	7.122	59.738	94.73	12,234.39	1,948.78
	7	2292.8	2292.8	3,292	1,015	103.1	23.80	984	6.998	55.322	100.59	12,990.38	2,107.93
	8	2816.4	2816.4	3,265	1,022	101.2	24.40	1,144	7.046	56.716	98.73	12,750.99	2,057.36
	9	3218.7	3218.7	2,856	1,016	78.7	31.20	1,440	7.005	72.523	76.78	9,916.03	1,471.06
	10	3904.4	3904.4	3,271	1,035	103.8	24.10	1,574	7.136	56.019	101.27	13,078.58	2,126.61
	11	4810.5	4810.5	3,280	1,027	104.1	23.90	1,712	7.081	55.554	101.56	13,116.38	2,134.62
	12	5177.6	5177.6	3,277	1,029	104.0	23.90	1,710	7.095	55.554	101.46	13,103.78	2,131.95
	13	5800.4	5800.4	3,293	1,033	103.1	24.20	1,660	7.122	56.252	100.59	12,990.38	2,107.93
	14	6217.0	6217.0	3,283	1,028	106.1	23.40	1,740	7.088	54.392	103.51	13,368.38	2,188.13
	15	6730.7	6730.7	3,215	1,025	106.1	22.90	1,728	7.067	53.230	103.51	13,368.38	2,188.13
	16	7132.0	7132.0	3,172	1,025	105.4	22.80	1,668	7.067	52.997	102.83	13,280.18	2,169.38
	17	7716.2	7716.2	1,649	986	50.1	29.70	1,706	6.798	69.036	48.88	6,312.49	759.44
	18	8046.9	8046.9	1,855	995	39.9	41.50	1,472	6.860	96.464	38.93	5,027.32	514.76
	19	8501.0	8501.0	1,882	1,014	40.4	42.10	1,330	6.991	97.859	39.41	5,090.31	526.64
	20	8928.7	8928.7	1,858	1,001	40.9	40.90	1,212	6.902	95.070	39.90	5,153.31	538.53
	21	9292.5	9292.5	3,285	1,023	107.1	22.00	908	7.053	51.138	104.49	13,494.37	855.33
	22	9662.9	9662.9	3,292	1,024	101.2	24.60	584	7.060	57.181	98.73	12,750.99	798.23
	23	10246.0	10246.0	3,255	1,025	106.7	22.10	494	7.067	51.370	104.10	13,443.97	851.45
	EOC1/24 ^a	11133.3	11133.3	3,001	1,014	108.4	24.70	400	6.991	57.414	105.76	13,658.17	867.94
2	BOC2 ^b	8789.8	0.0	—	—	—	—	—	—	—	—	—	—
	25	8846.0	56.2	2,650	1,017	88.4	24.70	1,432	7.012	57.414	86.24	11,138.21	847.56
	26	9109.5	319.7	3,262	1,013	101.2	23.91	1,200	6.984	55.577	98.73	12,750.99	997.78
	27	9959.4	1169.6	3,276	1,027	104.5	23.59	1,230	7.081	54.834	101.95	13,166.78	1,036.56
	28	10725.5	1935.7	3,275	1,022	101.5	24.30	1,198	7.046	56.484	99.02	12,788.78	1,001.30
	29	11078.2	2288.4	3,293	1,023	99.9	24.80	1,032	7.053	57.646	97.46	12,587.19	982.50
	30	11827.8	3038.0	3,256	1,021	102.3	23.70	986	7.040	55.089	99.80	12,889.58	1,010.70
	31	12158.5	3368.7	3,285	1,018	106.5	23.10	986	7.019	53.695	103.90	13,418.77	1,060.09
	32	12412.0	3622.2	3,276	1,019	101.1	24.40	948	7.026	56.716	98.63	12,738.39	996.60
	33	12588.4	3798.6	3,273	1,019	104.0	23.60	948	7.026	54.857	101.46	13,103.78	1,030.69
	34	12753.7	3963.9	3,260	1,018	106.0	23.00	948	7.019	53.462	103.41	13,355.78	1,054.20

Table 2.7. PB2 operating history (continued).

Cycle	Dataset	Exposure (MWd/t)		Power (MW)	D. Press (psi)	Flow (Mlb/h)	In. Sub. C. (Btu/lb)	Notches	Dome Press (MPa)	Inlet Subcool (kJ/kg)	Flow (%)	Total (kg/s)	Bypass (kg/s)
		Core	Cycle										
2	35	13128.5	4338.7	3,258	1,026	105.1	23.40	908	7.074	54.392	102.54	13,242.38	1,043.62
	36	13437.2	4647.3	2,858	1,026	78.8	29.80	824	7.074	69.268	76.88	9,928.63	735.15
	37	13812.0	5022.1	3,247	1,023	104.2	23.50	732	7.053	54.624	101.66	13,128.98	1,033.04
	EOC2	14109.6	5319.7	3,247	1,023	104.2	23.5	732	7.053	54.624	101.66	13,128.98	1,033.04
3	BOC3	9940.6	0.0	—	—	—	—	—	—	—	—	—	—
	38	10163.3	222.7	3,076	1,019	107.1	21.60	1,392	7.026	50.208	104.49	13,494.37	1,170.93
	39	11065.0	1124.4	3,127	1,015	94.6	25.20	1,066	6.998	58.576	92.29	11,919.40	1,003.26
	40	11450.8	1510.2	3,188	1,013	99.6	24.10	1,098	6.984	56.019	97.17	12,549.39	1,070.36
	41	12068.1	2127.5	2,958	1,010	84.3	28.20	1,064	6.964	65.549	82.24	10,621.62	864.89
	42	12901.4	2960.8	3,266	1,023	102.3	24.25	1,006	7.053	56.368	99.80	12,889.58	1,106.57
	43	13263.0	3322.4	3,182	1,023	102.6	23.67	1,006	7.053	55.020	100.10	12,927.38	1,110.60
	44	13481.3	3540.6	3,222	1,021	102.0	24.02	928	7.040	55.833	99.51	12,851.78	1,102.55
	45	13976.2	4035.6	3,144	1,015	102.5	23.31	928	6.998	54.183	100.00	12,914.78	1,109.26
	46	14594.6	4654.0	3,277	1,022	95.6	26.07	698	7.046	60.598	93.27	12,045.40	1,016.68
	47	14999.1	5058.5	3,286	1,027	97.4	25.82	664	7.081	60.017	95.02	12,272.19	1,040.84
	48	15318.8	5378.2	3,171	1,022	102.5	23.65	640	7.046	54.973	100.00	12,914.78	1,109.26
	49	15656.1	5715.5	3,070	1,023	102.3	26.88	820	7.053	62.481	99.80	12,889.58	1,106.57
	50	16223.8	6283.2	3,143	1,020	102.8	27.12	552	7.033	63.039	100.29	12,952.58	1,113.28
	ECO3	16726.5	6785.8	3,143	1,020	102.8	27.12	552	7.033	63.039	100.29	12,952.58	1,113.28

^a end of cycle

^b beginning of cycle

3. BENCHMARK CALCULATIONS AND RESULTS

3.1 BENCHMARK CALCULATIONS

3.1.1 Polaris Calculations

The SCALE 6.3/Polaris inputs were prepared using the data provided in Section 2 to process assembly-homogenized two-group cross sections for whole-core nodal diffusion calculations. To cover all the possible reactor states, the two-group cross sections were tabulated as functions of burnup, moderator and fuel temperatures, moderator density, and control rod insertion. Table 3.1 provides state information for six history cases. PB2 has seven Zr-4 spacer grids, including Inc-718 springs, which were considered in the Polaris lattice physics calculation. The spacer grids were integrated with the fuel cladding to simplify the models and thus minimize the number of Polaris calculations which might increase the differences between the measured data and calculation results in the TIP comparison.

To complete the functionalization of the cross section table sets, various branch calculations were performed at each burnup point for each history case. Table 3.2 provides the information for branch states for the assembly types. Table 3.3 provides the branch cases for reflectors for which no depletion calculation was performed. Figure 3.1 illustrates the Polaris models for the radial, top axial, and bottom axial reflectors.

Table 3.4 provides the Polaris input and output files for PB2 cycles 1–3. A sample file name with ‘cr0_v40.inp’ indicates

- cr0: control rod out,
- v40: 40% void fraction,
- inp: Polaris input.

Appendix A provides the Polaris inputs as follows:

- Appendix A.1: Polaris input for the fuel assembly type 1
- Appendix A.2: Polaris input for radial edge reflector
- Appendix A.3: Polaris input for axial top reflector
- Appendix A.4: Polaris input for axial bottom reflector

Table 3.1. History cases for each assembly type.

Case	File name	Coolant		Moderator		Temperature (K)					Rod-in
		Temp (K)	Density (g/cm ³)	Temp (K)	Density (g/cm ³)	Fuel	Clad	Gap	CR ^a	Channel	
A1	cr0_v00	560.29	0.7373	560.29	0.7373	948.45	637.92	793.19	560.29	560.29	no
A2	cr0_v40	"	0.4573	"	"	"	"	"	"	"	no
A3	cr0_v70	"	0.2473	"	"	"	"	"	"	"	no
A4	cr1_v00	"	0.7373	"	"	"	"	"	"	"	yes
A5	cr1_v40	"	0.4573	"	"	"	"	"	"	"	yes
A6	cr1_v70	"	0.2473	"	"	"	"	"	"	"	yes

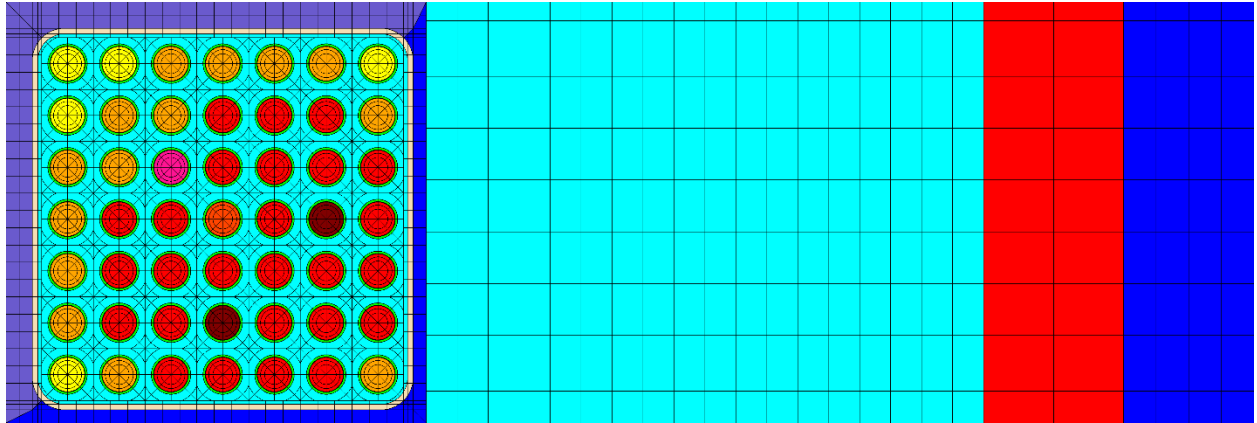
^a control rod

Table 3.2. Branch states for each assembly type.

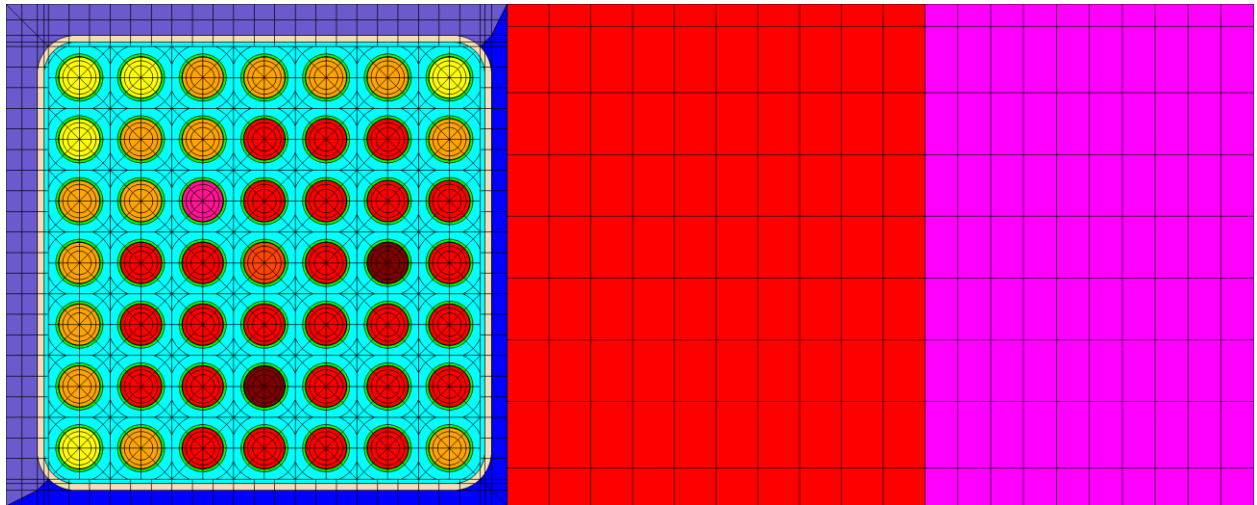
No.	Coolant		Moderator		Temperature (K)					Rod-in
	Density (g/cm ³)	Temperature (K)	Density (g/cm ³)	Temperature (K)	Fuel	Clad	Gap	CR	Channel	
1	0.7373	560.29	0.7373	560.29	948.45	637.92	793.19	560.29	560.29	no
2	0.4573	560.29	0.7373	560.29	948.45	637.92	793.19	560.29	560.29	no
3	0.2473	560.29	0.7373	560.29	948.45	637.92	793.19	560.29	560.29	no
4	0.7373	560.29	0.7373	560.29	948.45	637.92	793.19	560.29	560.29	yes
5	0.4573	560.29	0.7373	560.29	948.45	637.92	793.19	560.29	560.29	yes
6	0.2473	560.29	0.7373	560.29	948.45	637.92	793.19	560.29	560.29	yes
7	0.1073	560.29	0.7373	560.29	948.45	637.92	793.19	560.29	560.29	no
8	0.1073	560.29	0.7373	560.29	948.45	637.92	793.19	560.29	560.29	yes
9	0.7373	560.29	0.7373	560.29	500	548.23	524.12	560.29	560.29	no
10	0.4573	560.29	0.7373	560.29	500	548.23	524.12	560.29	560.29	no
11	0.2473	560.29	0.7373	560.29	500	548.23	524.12	560.29	560.29	no
12	0.1073	560.29	0.7373	560.29	500	548.23	524.12	560.29	560.29	no
13	0.7373	560.29	0.7373	560.29	500	548.23	524.12	560.29	560.29	yes
14	0.4573	560.29	0.7373	560.29	500	548.23	524.12	560.29	560.29	yes
15	0.2473	560.29	0.7373	560.29	500	548.23	524.12	560.29	560.29	yes
16	0.1073	560.29	0.7373	560.29	500	548.23	524.12	560.29	560.29	yes
17	0.7373	560.29	0.7373	560.29	1,500	748.23	1,124.12	560.29	560.29	no
18	0.4573	560.29	0.7373	560.29	1,500	748.23	1,124.12	560.29	560.29	no
19	0.2473	560.29	0.7373	560.29	1,500	748.23	1,124.12	560.29	560.29	no
20	0.1073	560.29	0.7373	560.29	1,500	748.23	1,124.12	560.29	560.29	no
21	0.7373	560.29	0.7373	560.29	1,500	748.23	1,124.12	560.29	560.29	yes
22	0.4573	560.29	0.7373	560.29	1,500	748.23	1,124.12	560.29	560.29	yes
23	0.2473	560.29	0.7373	560.29	1,500	748.23	1,124.12	560.29	560.29	yes
24	0.1073	560.29	0.7373	560.29	1,500	748.23	1,124.12	560.29	560.29	yes

Table 3.3. Branch states for reflectors.

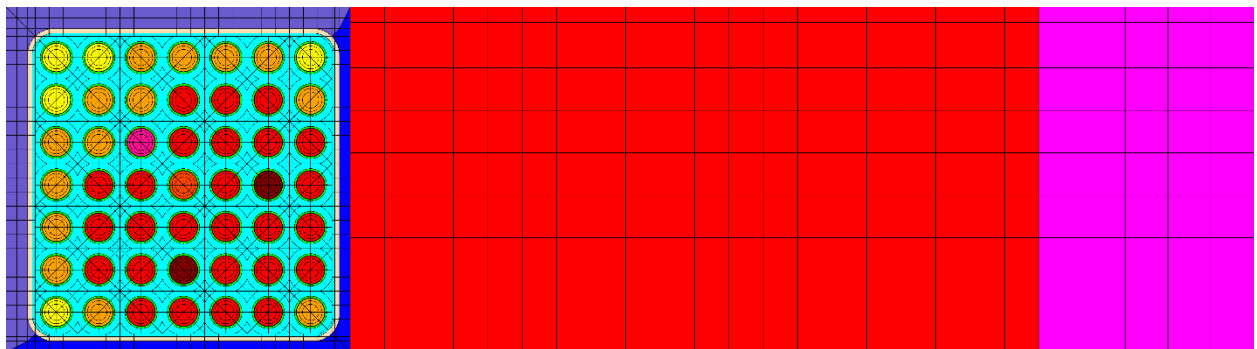
Case	Coolant		Moderator		Temperature (K)					Rod-in
	Temperature (K)	Density (g/cm ³)	Temperature (K)	Density (g/cm ³)	Fuel	Clad	Gap	CR	Channel	
Reference	560.29	0.4573	560.29	0.7373	948.45	560.29	560.29	560.29	560.29	no
1	560.29	0.7373	560.29	0.7373	948.45	560.29	560.29	560.29	560.29	no
2	560.29	0.2473	560.29	0.7373	948.45	560.29	560.29	560.29	560.29	no
3	560.29	0.1073	560.29	0.7373	948.45	560.29	560.29	560.29	560.29	no



(A) Radial reflector



(B) Bottom axial reflector



(C) Top axial reflector

Figure 3.1. Polaris models for reflectors.

Table 3.4. Polaris input and output files for PB2.

Assembly type	Directory	File name	Description
Type 1	./Polaris/type1	cr?_v??,*	Input, output, T16 cr? control rod cr0: out cr1: in v?? void percent v00: 0% void v40: 40% void v70: 70% void * File names inp: input file idc: IDC format input msg: message file out: output file png: geometry image file t16: few-group cross sections f71: ORIGIN concentration f33: ORIGIN library
Type 2A	./Polaris/type2a	cr?_v??,*	
Type 2B	./Polaris/type2b	cr?_v??,*	
Type 3A	./Polaris/type3a	cr?_v??,*	
Type 3B	./Polaris/type3b	cr?_v??,*	
Type 3C	./Polaris/type3c	cr?_v??,*	
Type 4	./Polaris/type4	cr?_v??,*	
Type 5	./Polaris/type5	cr?_v??,*	
Type 6A	./Polaris/type6a	cr?_v??,*	
Type 6B	./Polaris/type6b	cr?_v??,*	
Radial reflector	./Polaris/reflector	pb2_refl_rad.*	
Top reflector	./Polaris/reflector	pb2_refl_top.*	
Bottom reflector	./Polaris/reflector	pb2_refl_bot.*	

3.1.2 Cross Section Table Set Generation Using GenPMAXS

Appendix B provides the GenPMAXS inputs as follows:

- Appendix B.1: GenPMAXS input for the fuel assembly type 1
- Appendix B.2: GenPMAXS input for radial edge reflector
- Appendix B.3: GenPMAXS input for axial top reflector
- Appendix B.4: GenPMAXS input for axial bottom reflector

Table 3.5 provides the GenPMAXS input and output files. Various GenPMAXS input files can be used for various radial reflectors including edge, east, southeast, and south reflectors.

Table 3.5. GenPMAXS input and output files for PB2.

Assembly type	Directory	File name	Description
Type 1	./GenPMAXS	pb-type1,*	* inp: input files kinf: kinf summary out: output file PMAx: cross section table set
Type 2A	./GenPMAXS	pb-type2a,*	
Type 2B	./GenPMAXS	pb-type2b,*	
Type 3A	./GenPMAXS	pb-type3a,*	
Type 3B	./GenPMAXS	pb-type3b,*	
Type 3C	./GenPMAXS	pb-type3c,*	
Type 4	./GenPMAXS	pb-type4,*	
Type 5	./GenPMAXS	pb-type5,*	
Type 6A	./GenPMAXS	pb-type6a,*	
Type 6B	./GenPMAXS	pb-type6b,*	
Radial reflector	./GenPMAXS	pb2_refl_rad.*	
Top reflector	./GenPMAXS	pb2_refl_top.*	
Bottom reflector	./GenPMAXS	pb2_refl_bot.*	

3.1.3 Whole-Core Nodal Diffusion Calculations Using PARCS

Appendix C provides the PARCS inputs for the PB2 cycles 1–3 hot zero power (HZIP) and HFP calculations as follows:

- Appendix C.1: PARCS input for the cross section set “pb-pmaxfiles.back” file
- Appendix C.2: PARCS input for the cycle 1 assembly geometry “pb-cyc1.geom” file
- Appendix C.3: PATHS input for the cycle 1 “pb-cyc1.paths” file
- Appendix C.4: PARCS input for the HFP cycle 1
- Appendix C.5: PARCS input for the cycle 2 assembly geometry “pb-cyc2.geom” file
- Appendix C.6: PATHS input for the cycle 2 “pb-cyc2.paths” file
- Appendix C.7: PARCS input for the HZIP cycle 2 fuel shuffling
- Appendix C.8: PARCS input for the HFP cycle 2
- Appendix C.9: PARCS input for the cycle 3 assembly geometry “pb-cyc3.geom” file
- Appendix C.10: PATHS input for the cycle 3 “pb-cyc3.paths” file
- Appendix C.11: PARCS input for the HZIP cycle 3 fuel shuffling
- Appendix C.12: PARCS input for the HFP cycle 3

Table 3.6 provides the PARCS input and output files.

Table 3.6. PARCS input and output files for PB2.

Cycle	File name	Description
—	pb-pmaxfiles.back	Cross section table sets
1	pb-cyc1.geom	Geometry input
	pb-cyc1.paths	PATHS input
	depl-pb-cyc1.inp	PARCS input
	pb-cyc1.parc_out	Output
	pb-cyc1.parc_cyc-01	Restart file
	pb-cyc1.parc_det	Detector response
	pb-cyc1.parc_dpl	Summary
	./cy1_pinpower/pb-cyc1.parc_pin*	Pin powers
2	pb-cyc2.geom	Geometry input
	pb-cyc2.paths	PATHS input
	depl-pb-shuff-c1c2.inp	PARCS input for shuffling
	depl-pb-cyc2.inp	PARCS input
	pb-cyc2.parc_out	Output
	pb-cyc2.parc_cyc-02	Restart file
	pb-cyc2.parc_det	Detector response
	pb-cyc2.parc_dpl	Summary
	./cy2_pinpower/pb-cyc2.parc_pin*	Pin powers
3	pb-cyc3.geom	Geometry input
	pb-cyc3.paths	PATHS input
	depl-pb-shuff-c2c3.inp	PARCS input for shuffling
	depl-pb-cyc3.inp	PARCS input
	pb-cyc3.parc_out	Output
	pb-cyc3.parc_cyc-01	Restart file
	pb-cyc3.parc_det	Detector response
	pb-cyc3.parc_dpl	Summary
	./cy3_pinpower/pb-cyc3.parc_pin*	Pin powers

3.2 BENCHMARK RESULTS

Figure 3.2 illustrates the HFP multiplication factors as functions of burnup, and Table 3.7 shows the HFP multiplication factors, reactivity differences, and burnups at the operating critical conditions for PB2 which has significant reactivity biases for cycle 1, which may be typical in BWR simulations because of the BWR's very complicated operation history and many tests. However, the reactivities in PB2 cycles 2 and 3 are very close to criticality over whole burnups. A more detailed investigation is required of the significant reactivity bias of the Polaris-PARCS procedure for cycle 1, which may result from poor Xe modeling due to frequent reactor power change and shutdown or a poor thermal-hydraulics model neglecting bypass flow.

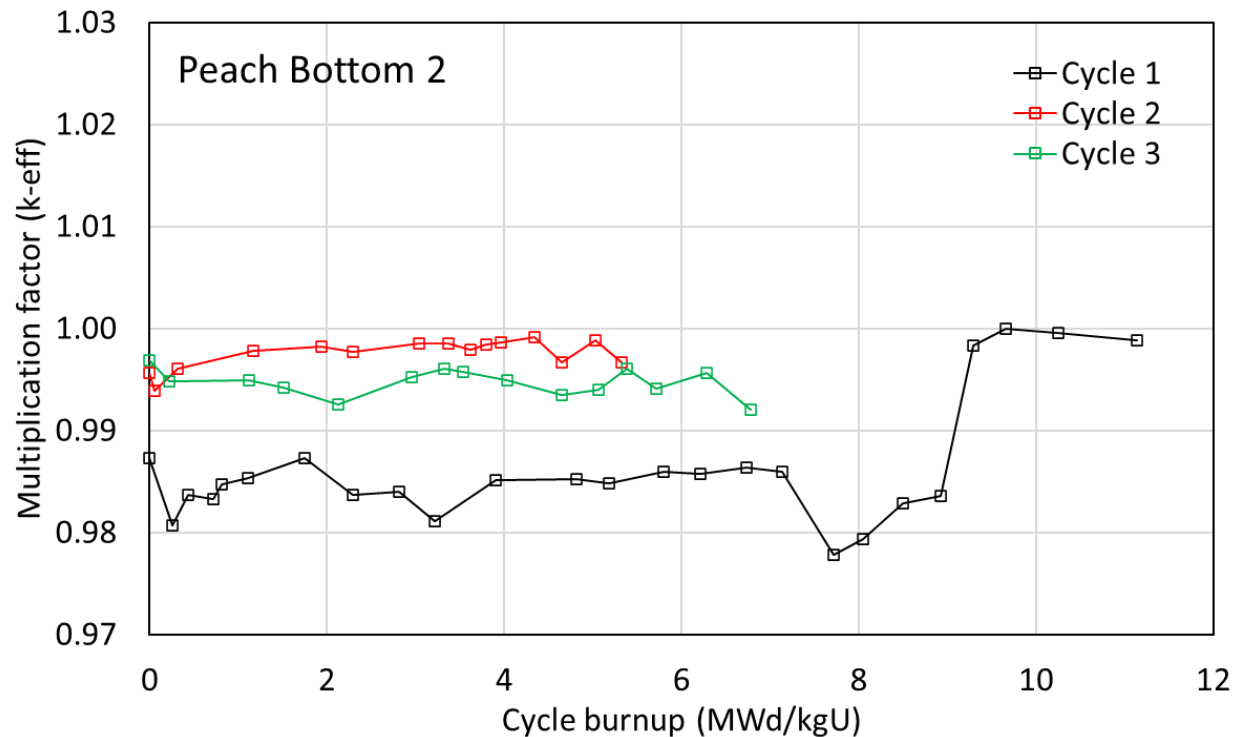


Figure 3.2. PB2 cycles 1–3 HFP reactivities.

Table 3.7. Comparison of the HFP reactivities.

No.	Cycle 1			Cycle 2				Cycle 3			
	Burnup (MWd/kgU)	k_{eff}	Δk_{eff} (pcm)	Burnup (MWd/kgU)		k_{eff}	Δk_{eff} (pcm)	Burnup (MWd/kgU)		k_{eff}	Δk_{eff} (pcm)
				Core	Cycle			Core	Cycle		
1	0.000	0.98729	-1271	8.656	0.000	0.99568	-432	9.835	0.000	0.99684	-316
2	0.254	0.98070	-1930	8.712	0.056	0.99388	-612	10.058	0.223	0.99486	-514
3	0.430	0.98367	-1633	8.976	0.320	0.99603	-397	10.959	1.124	0.99491	-509
4	0.714	0.98330	-1670	9.825	1.169	0.99782	-218	11.345	1.510	0.99423	-577
5	0.817	0.98468	-1532	10.592	1.936	0.99820	-180	11.963	2.128	0.99255	-745
6	1.113	0.98531	-1469	10.944	2.288	0.99769	-231	12.796	2.961	0.99525	-475
7	1.747	0.98725	-1275	11.694	3.038	0.99855	-145	13.157	3.322	0.99609	-391
8	2.293	0.98370	-1630	12.025	3.369	0.99857	-143	13.376	3.541	0.99575	-425
9	2.816	0.98396	-1604	12.278	3.622	0.99795	-205	13.871	4.036	0.99488	-512
10	3.219	0.98112	-1889	12.454	3.798	0.99844	-156	14.489	4.654	0.99344	-656
11	3.904	0.98513	-1487	12.620	3.964	0.99858	-142	14.894	5.059	0.99396	-604
12	4.810	0.98518	-1482	12.995	4.339	0.99913	-87	15.213	5.378	0.99603	-397
13	5.177	0.98479	-1521	13.303	4.647	0.99663	-337	15.551	5.716	0.99405	-596
14	5.800	0.98593	-1407	13.678	5.022	0.99886	-114	16.118	6.283	0.99559	-441
15	6.217	0.98576	-1424	13.976	5.320	0.99665	-335	16.621	6.786	0.99202	-798
16	6.731	0.98631	-1369	—	—	—	—	—	—	—	—
17	7.132	0.98597	-1403	—	—	—	—	—	—	—	—
18	7.716	0.97780	-2220	—	—	—	—	—	—	—	—
19	8.047	0.97936	-2064	—	—	—	—	—	—	—	—
20	8.501	0.98283	-1717	—	—	—	—	—	—	—	—
21	8.929	0.98357	-1643	—	—	—	—	—	—	—	—
22	9.292	0.99835	-165	—	—	—	—	—	—	—	—
23	9.663	1.00001	1	—	—	—	—	—	—	—	—
24	10.246	0.99960	-40	—	—	—	—	—	—	—	—
25	11.133	0.99882	-118	—	—	—	—	—	—	—	—

Figure 3.3 and Table 3.8 compare the TIP data between the measured data and calculated results for PB2. The figure and table include the TIP data comparisons for the 3D, axially integrated 2D radial, and radially integrated 1D axial distributions. The total 3D root mean square (RMS) error between the measured and calculated TIP data is 11.37%, the total radial 2D RMS error is 4.98%, and the total axial 1D RMS error is 9.31%. Overall, the RMS errors for the TIP comparisons are reasonable compared with other code packages. Appendix D provides the utility program used to compare the calculated flux map results with the measured data.

- Appendix D.1: Program source
- Appendix D.2: Cycle 1 input
- Appendix D.3: Cycle 2 input
- Appendix D.4: Cycle 3 input
- Appendix D.5: Cycle 1 TIP measured data
- Appendix D.6: Cycle 2 TIP measured data
- Appendix D.7: Cycle 3 TIP measured data

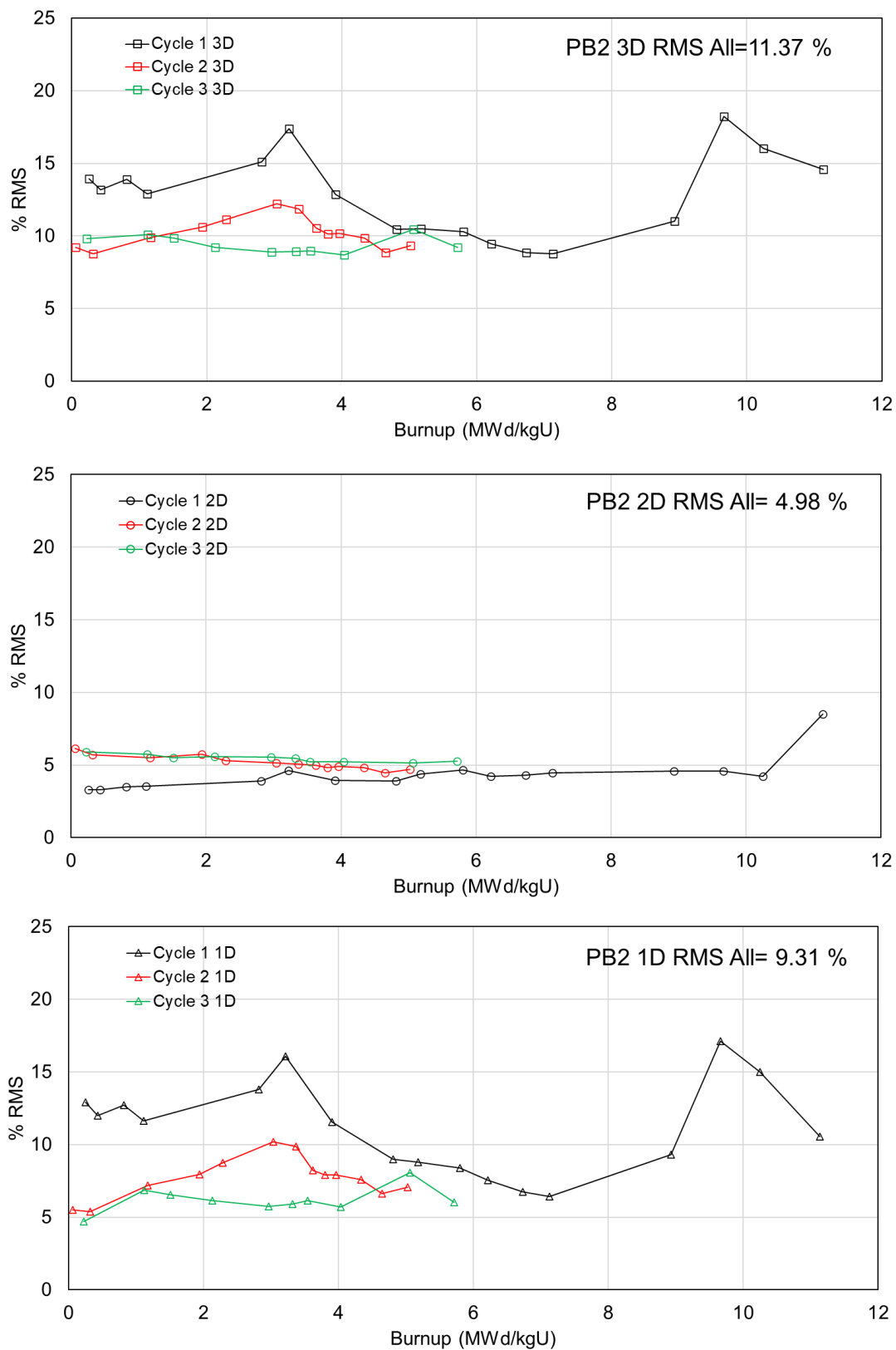


Figure 3.3. Comparison of the HFP TIP data for PB2.

Table 3.8. Comparison of the TIP data for PB2.

Cycle	Data point	Burnup (MWd/kgU)		PARCS point	3D		Radial		Axial	
		Cycle	Core		RMS (%)	Cases	RMS (%)	Cases	RMS (%)	Cases
1	1	0.254	0.254	2	13.93	1,032	3.30	43	12.92	24
	2	0.43	0.43	4	13.19	1,032	3.28	43	11.98	24
	4	0.817	0.817	8	13.89	1,032	3.51	43	12.73	24
	5	1.113	1.113	10	12.88	1,032	3.55	43	11.64	24
	8	2.816	2.816	16	15.11	1,032	3.91	43	13.78	24
	9	3.219	3.219	18	17.38	1,032	4.61	43	16.09	24
	10	3.904	3.904	20	12.85	1,032	3.95	43	11.57	24
	11	4.81	4.81	22	10.46	1,032	3.88	43	8.98	24
	12	5.177	5.177	24	10.49	1,032	4.39	43	8.80	24
	13	5.8	5.8	26	10.31	1,032	4.66	43	8.39	24
	14	6.217	6.217	28	9.44	1,032	4.21	43	7.55	24
	15	6.731	6.731	30	8.86	1,032	4.28	43	6.73	24
	16	7.132	7.132	32	8.76	1,032	4.46	43	6.44	24
	20	8.929	8.929	40	11.03	1,032	4.56	43	9.33	24
	22	9.663	9.663	44	18.21	1,032	4.58	43	17.11	24
	23	10.246	10.246	46	16.01	1,032	4.20	43	14.98	24
	24	11.133	11.133	48	14.57	1,032	8.51	43	10.54	24
2	25	0.056	8.712	2	9.23	1,032	6.15	43	5.49	24
	26	0.320	8.976	4	8.79	1,032	5.70	43	5.37	24
	27	1.169	9.825	6	9.90	1,032	5.50	43	7.19	24
	28	1.936	10.592	8	10.60	1,032	5.73	43	7.95	24
	29	2.288	10.944	10	11.13	1,032	5.32	43	8.75	24
	30	3.038	11.694	12	12.20	1,032	5.15	43	10.21	24
	31	3.369	12.025	14	11.87	1,032	5.08	43	9.89	24
	32	3.622	12.278	16	10.55	1,032	4.98	43	8.24	24
	33	3.798	12.454	18	10.13	1,032	4.83	43	7.91	24
	34	3.964	12.620	20	10.18	1,032	4.91	43	7.91	24
	35	4.339	12.995	22	9.86	1,032	4.81	43	7.60	24
	36	4.647	13.303	24	8.87	1,032	4.46	43	6.61	24
	37	5.022	13.678	26	9.34	1,032	4.70	43	7.08	24
3	38	0.223	10.058	2	9.81	1,032	5.89	43	4.72	24
	39	1.124	10.959	4	10.09	1,032	5.75	43	6.88	24
	40	1.51	11.345	6	9.84	1,032	5.52	43	6.54	24
	41	2.128	11.963	8	9.21	1,032	5.57	43	6.13	24
	42	2.961	12.796	10	8.90	1,032	5.54	43	5.76	24
	43	3.322	13.157	12	8.94	1,032	5.46	43	5.91	24
	44	3.541	13.376	14	8.98	1,032	5.21	43	6.15	24
	45	4.036	13.871	16	8.70	1,032	5.21	43	5.72	24
	47	5.059	14.894	20	10.44	1,032	5.15	43	8.05	24
	49	5.716	15.551	24	9.21	1,032	5.25	43	6.02	24
All	—	—	—	—	11.37	41,280	4.98	1,720	9.31	960

Figure 3.4 compares the 1D axial TIP data for PB2 cycle 2 at the burnups 8.7 and 13.7 MWd/kgU. The overall shapes of the 1D TIP data are consistent, but localized differences in the shapes may have been caused by neglect of the spacer grids in the Polaris-PARCS modeling. Detailed modeling for the seven spacer grids would improve the calculated axial TIP data shapes by improving the RMS errors.

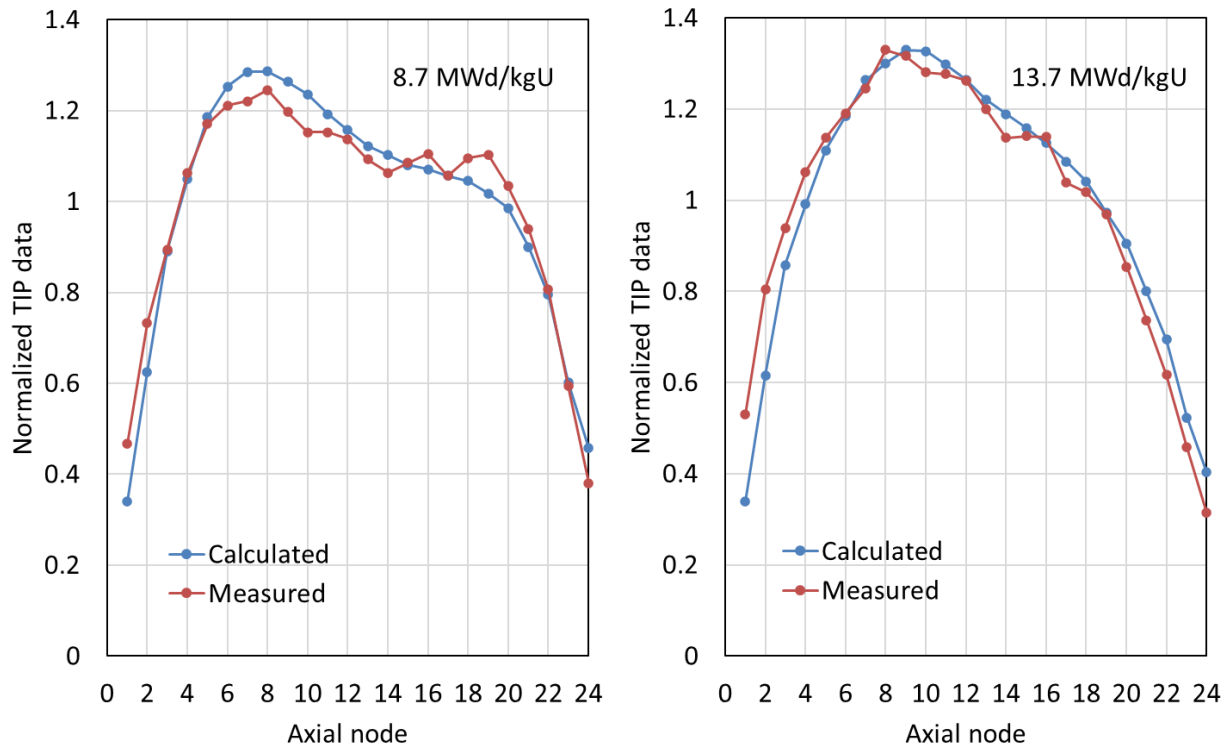


Figure 3.4. Axial 1D TIP comparison for PB2 cycle 2.

4. CONCLUSION

The benchmark calculations were performed for the PB2 cycles 1–3 using the SCALE 6.3/Polaris–PARCS v3.4.2 code package with the ENDF/B-VII.1 AMPX 56-group library. The benchmark results were compared with the measured data for the HFP reactivities and TIP data which are provided by the EPRI technical reports NP-563 and NP-961. The EPRI reports do not provide very detailed information for operational histories and design data such as top and bottom axial reflectors.

The benchmark results show relatively large reactivity biases for the initial cycle, good agreement for the reactivity of the reload cycles, and large discrepancies for the axial power distributions of all cycles. More detailed investigation is required to improve the Polaris-PARCS benchmark results for axial power distributions. This issue may come from poor axial reflector models, modeling approximation for Inc-718 spacer grids and poor two-phase T/H model.

The final goal of these benchmark calculations is to validate the SCALE/Polaris-GenPMAXS-PARCS code package with the ENDF/B-VII.1 AMPX 56-group library by assessing uncertainties for key nuclear reactor core simulation outputs, such as reactivity and assembly power peaking factors [9]. In addition, the Polaris-PARCS benchmark models, procedures and methodologies must be continuously improved based on this investigation.

5. REFERENCES

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APPENDIX A. SAMPLE OF POLARIS INPUT FILES

A.1 Polaris Input for the Fuel Assembly Type 1

```
=polaris
%-----
%   general options
%-----
title "PB Type 1"
lib   "scale.rev04.xn56v7.1"
opt PRINT XFile16=true
system BWR
%-----
%   geometry
%-----
geom BWR7x7: ASSM 7 1.875 FULL      % 7x7 assy, pin pitch, full symmetry
hgap 0.475 0.9525: MOD.1 MOD.2      % Narrow gap, wide gap
mesh MOD.1 : nd=2 nf=3              % Additional detail in bypass added at ORNL suggestion
mesh MOD.2 : nd=3 nf=3              % (see email from Matt Jessee, 7/20/17)
box 0.2032 0.9652 6.7 CAN.1        % box thickness, corner inner radius, inner half width
%-----
%   compositions and materials
%-----
% fuel comps
comp c_U133 UOX enr=1.33
comp c_U071 UOX enr=0.71

% fuel mats
mat FUEL.1 c_U133 dens=10.34
mat FUEL.2 c_U071 dens=10.34
mat FUEL.3 c_U071 dens= 9.33

% cladding comp - smear the spacer grids into the cladding material
% this was done consistent with the TRITON models (ML13042A450)
comp c_ZIRI : WT refdens=6.84699
               ZIRC4=3.5224
               INC718=0.6691
               ZIRC2=-100

% cladding mat
mat CLAD.1 c_ZIRI

% absorber mats - B4C, 70% TD
mat CNTL.2 B4C dens=1.7642

% channel box is Zry4
mat CAN.1 ZIRC4

% detector comps/mats
comp c_U235 : CONC 92235=1.0e-10
comp c_AL2O3 : FORM Al=2 O=3
comp c_DETMIX : WT WATER=47.87 c_AL2O3=15.7 SS304=-100
mat GAS.1 : Ar dens=8.31E-03
mat DET.1 : c_U235
mat DETMIX.1 : c_DETMIX 1.3611

%-----
%   pin definitions
%-----
% fuel pins
pin 1 : 0.61849 0.63373 0.71501 : FUEL.1 GAP.1 CLAD.1
pin 2 : 0.61849 0.63373 0.71501 : FUEL.2 GAP.1 CLAD.1
pin 3 : 0.61849 0.63373 0.71501 : FUEL.3 GAP.1 CLAD.1

% add rings according to ORNL recommendations
mesh FUEL.1 nr=3
mesh FUEL.2 nr=3
mesh FUEL.3 nr=3

mesh GAP ns=1 %gap is insignificant - don't need meshing there

% Self-shield fuel pin regions as single region, gad pins in multiregion
shield ALL=N FUEL.1=P FUEL.2=P FUEL.3=P

% control rod absorber pin
pin C : 0.17526 0.23876 : CNTL.2 STRUCT.1 MOD.2

% detector pin
pin D : 0.32258 0.35560 0.47625 0.81280 0.88900
```

```

: GAS      MOD.1  STRUCT DETMIX  STRUCT

%-----
%   pin maps
%-----
pinmap
2
1 1
1 1 2
1 2 2 3
1 1 2 2 2
1 1 2 2 2 1
1 1 1 1 1 1 1
%-----
%   control blade
%-----
control OEM : BLADE 0.39624 0.14224 1.98501
              wgcrrv=0.39624
              : C
              : 10.02792
              : 21
                  % half thickness, sheath thickness, dead length
                  % wing tip curvature
                  % pin C defined above
                  % width of controlled section of wing
                  % 21 control tubes per wing

%-----
%   states
%-----

power 21.98
bu 0.00000 0.00012 0.15714 0.46920 0.77820 1.08492 1.39005 1.69420 1.99793 2.30175
   2.60614 2.91158 3.21850 3.52733 3.83852 4.15248 4.46966 4.79050 5.11548 5.44507
   5.77980 6.12019 6.46685 6.82040 7.18152 7.55097 7.92959 8.31830 8.71814 9.13029
   9.55609 9.99709 10.4551 10.9322 11.4309 11.9543 12.5061 13.0909 13.7146 14.3849
   15.1122 15.9112 16.8035 17.8231 19.0300 20.5464 22.7041 25.5054 28.5054 31.5054
   34.5054 37.5054 40.5054 43.5054 46.5054 49.5054 52.5054 55.5054 58.5054 61.5054

det d_U235 : pin.D : R(n,FIS) GAS.1 DET.1
opt FG DetectorEdit=d_U235
%Set base temperature field to core average, use
% history and branching variables to perturb to appropriate
% value for calculations

state ALL : temp=560.29

MOD : temp=560.29 dens=0.7373

COOL : temp=560.29 dens=0.7373
CLAD.1 : temp=637.92
GAP.1 : temp=793.19
FUEL : temp=948.45

OEM : in=FALSE

read branch
%LABELS
add COOL : dens = 0.7373 0.4573 0.2473 0.7373 0.4573 0.2473 0.1073 0.1073 0.7373 0.4573 0.2473
0.1073 0.7373 0.4573 0.2473 0.1073 0.7373 0.4573 0.2473 0.1073 0.7373 0.4573 0.2473 0.1073
COOL : temp = 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29
560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29
CLAD.1 : temp = 637.92 637.92 637.92 637.92 637.92 637.92 637.92 637.92 637.92 637.92 637.92 637.92
548.23 548.23 548.23 548.23 548.23 548.23 548.23 548.23 548.23 548.23 548.23 548.23
GAP.1 : temp = 793.19 793.19 793.19 793.19 793.19 793.19 793.19 793.19 793.19 793.19 793.19 793.19
524.12 524.12 524.12 524.12 524.12 524.12 524.12 524.12 524.12 524.12 524.12 524.12
FUEL : temp = 948.45 948.45 948.45 948.45 948.45 948.45 948.45 948.45 948.45 948.45 948.45 948.45
500.00 500.00 500.00 500.00 500.00 500.00 500.00 500.00 500.00 500.00 500.00 500.00
MOD : dens = 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373
0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373 0.7373
MOD : temp = 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29
560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29
CNTL : temp = 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29
560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29
CAN : temp = 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29
560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29 560.29
OEM : in = FALSE FALSE FALSE TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE
FALSE TRUE TRUE TRUE TRUE FALSE FALSE FALSE FALSE TRUE TRUE TRUE TRUE TRUE
end branch

end

```

A.2 Polaris Input for Radial Reflector

```
=polaris
% -----
%   general options
% -----
title "PB2 7x7 lattice + radial reflector"
lib   "broad_lwr"
opt   PRINT XFile16=true
system BWR
% -----
%   compositions and materials
% -----
% fuel comps
comp c_U247a  UOX  enr=2.47
comp c_U170   UOX  enr=1.70
comp c_U120   UOX  enr=1.20
comp c_U247b  UOX  enr=2.47
comp c_U247c  UOX  enr=2.47
comp c_U247d  UOX  enr=2.47

% fuel mats - use stack density from EPRI reports
mat FUEL.1  c_U247a  dens=9.94
mat FUEL.2  c_U170   dens=9.94
mat FUEL.3  c_U120   dens=9.94
mat FUEL.4  c_U247b  dens=10.34
mat FUEL.5  c_U247c  dens=10.34
mat FUEL.6  c_U247d  dens=9.48

% cladding comp - smear the spacer grids into the cladding material
% this was done consistent with the TRITON models (ML13042A450)
comp c_ZIRI : WT refdens=6.84699
               ZIRC4=3.5224
               INC718=0.6691
               ZIRC2=-100

% cladding mat
mat CLAD.1  c_ZIRI

% channel box is Zry4
mat CAN.1   ZIRC4

% shroud
comp SS3161 : WT FE=68.7 CR=19.0 NI=11.3 MO=1.0
mat SHROUD.1 : SS3161 7.93

% -----
%   geometry
% -----
geom BWR7x7: ASSM 7  1.875  FULL      % 7x7 assy, pin pitch, full symmetry
hgap  0.475  0.9525: MOD.1  MOD.2    % Narrow gap, wide gap
mesh MOD.1 : nd=2  nf=3              % Additional detail in bypass added at ORNL suggestion
mesh MOD.2 : nd=3  nf=3              % (see email from Matt Jessee, 7/20/17)
box   0.2032 0.9652 6.7      CAN.1    % box thickness, corner inner radius, inner half width

% fuel pins
pin 1 : 0.61976 0.63373 0.71501 : FUEL.1 GAP.1 CLAD.1
pin 2 : 0.61976 0.63373 0.71501 : FUEL.2 GAP.1 CLAD.1
pin 3 : 0.61976 0.63373 0.71501 : FUEL.3 GAP.1 CLAD.1
pin 4 : 0.61849 0.63373 0.71501 : FUEL.4 GAP.1 CLAD.1
pin 5 : 0.61849 0.63373 0.71501 : FUEL.5 GAP.1 CLAD.1
pin 6 : 0.61976 0.63373 0.71501 : FUEL.6 GAP.1 CLAD.1

% add rings according to ORNL recommendations
mesh FUEL.1 nr=3
mesh FUEL.2 nr=3
mesh FUEL.3 nr=3
mesh FUEL.4 nr=3
mesh FUEL.5 nr=3
mesh FUEL.6 nr=3

shield ALL=N FUEL=P
pinmap
3
3 2
2 2 5
2 1 1 6
2 1 1 1 1
2 1 1 4 1 1
3 2 1 1 1 1 2
```

```

geom rad_ref : REFL 30.0
slab rad_ref : 20.195 5.080 4.725 : COOL.1 SHROUD.1 MOD.1 : 18 2 4 : 2 2 2
% -----
% states
% -----
state ALL : temp=560.29
FUEL : temp=948.45
COOL : temp=560.29 dens=0.4573
MOD : temp=560.29 dens=0.7373
rad_ref : in=yes
read branch
add ALL : temp=560.29 FUEL : temp=948.45 COOL : dens=0.7373 MOD : dens=0.7373
add ALL : temp=560.29 FUEL : temp=948.45 COOL : dens=0.2573 MOD : dens=0.7373
add ALL : temp=560.29 FUEL : temp=948.45 COOL : dens=0.1073 MOD : dens=0.7373
end branch

end

```

A.3 Polaris Input for Axial Top Reflector

```

=polaris
% -----
% general options
% -----
title "PB2 7x7 lattice + top reflector"
lib "broad_lwr"
opt PRINT XFile16=true
system BWR
% -----
% compositions and materials
% -----
% fuel comps
comp c_U247a UOX enr=2.47
comp c_U170 UOX enr=1.70
comp c_U120 UOX enr=1.20
comp c_U247b UOX enr=2.47
comp c_U247c UOX enr=2.47
comp c_U247d UOX enr=2.47

% fuel mats - use stack density from EPRI reports
mat FUEL.1 c_U247a dens=9.94
mat FUEL.2 c_U170 dens=9.94
mat FUEL.3 c_U120 dens=9.94
mat FUEL.4 c_U247b dens=10.34
mat FUEL.5 c_U247c dens=10.34
mat FUEL.6 c_U247d dens=9.48

% cladding comp - smear the spacer grids into the cladding material
% this was done consistent with the TRITON models (ML13042A450)
comp c_ZIRI : WT refdens=6.84699
ZIRC4=3.5224
INC718=0.6691
ZIRC2=-100

% cladding mat
mat CLAD.1 c_ZIRI

% channel box is Zry4
mat CAN.1 ZIRC4

% top reflectors
comp TOP1 : WT H2O=24.33023 HE=0.000809 ZIRC2=32.83966 ZIRC4=16.67851 SS304=26.15079
comp TOP2 : WT H2O=41.76238 ZIRC2=26.66206 SS304=31.57556
mat TOPREF.1 : TOP1 1.925764
mat TOPREF.2 : TOP2 1.545993

% -----
% geometry
% -----
geom BWR7x7: ASSM 7 1.875 FULL % 7x7 assy, pin pitch, full symmetry
hgap 0.475 0.9525: MOD.1 MOD.2 % Narrow gap, wide gap
mesh MOD.1 : nd=2 nf=3 % Additional detail in bypass added at ORNL suggestion
mesh MOD.2 : nd=3 nf=3 % (see email from Matt Jessee, 7/20/17)
box 0.2032 0.9652 6.7 CAN.1 % box thickness, corner inner radius, inner half width

% fuel pins
pin 1 : 0.61976 0.63373 0.71501 : FUEL.1 GAP.1 CLAD.1
pin 2 : 0.61976 0.63373 0.71501 : FUEL.2 GAP.1 CLAD.1
pin 3 : 0.61976 0.63373 0.71501 : FUEL.3 GAP.1 CLAD.1

```

```

pin 4 : 0.61849 0.63373 0.71501 : FUEL.4 GAP.1 CLAD.1
pin 5 : 0.61849 0.63373 0.71501 : FUEL.5 GAP.1 CLAD.1
pin 6 : 0.61976 0.63373 0.71501 : FUEL.6 GAP.1 CLAD.1

% add rings according to ORNL recommendations
mesh FUEL.1 nr=3
mesh FUEL.2 nr=3
mesh FUEL.3 nr=3
mesh FUEL.4 nr=3
mesh FUEL.5 nr=3
mesh FUEL.6 nr=3

shield ALL=N FUEL=P
pinmap
3
3 2
2 2 5
2 1 1 6
2 1 1 1 1
2 1 1 4 1 1
3 2 1 1 1 1 2
geom rad_ref : REFL 40.0
slab rad_ref : 30.48 9.52 : TOPREF.1 TOPREF.2 : 20 5 : 2 2
% -----
% states
% -----
state ALL : temp=560.29
FUEL : temp=948.45
COOL : temp=560.29 dens=0.4573
MOD : temp=560.29 dens=0.7373
rad_ref : in=yes
read branch
add ALL : temp=560.29 FUEL : temp=948.45 COOL : dens=0.7373 MOD : dens=0.7373
add ALL : temp=560.29 FUEL : temp=948.45 COOL : dens=0.2573 MOD : dens=0.7373
add ALL : temp=560.29 FUEL : temp=948.45 COOL : dens=0.1073 MOD : dens=0.7373
end branch

end

```

A.4 Polaris Input for Axial Bottom Reflector

```

=polaris
% -----
% general options
% -----
title "PB2 7x7 lattice + bottom reflector"
lib "broad_lwr"
opt PRINT XFile16=true
system BWR
% -----
% compositions and materials
% -----
% fuel comps
comp c_U247a UOX enr=2.47
comp c_U170 UOX enr=1.70
comp c_U120 UOX enr=1.20
comp c_U247b UOX enr=2.47
comp c_U247c UOX enr=2.47
comp c_U247d UOX enr=2.47

% fuel mats - use stack density from EPRI reports
mat FUEL.1 c_U247a dens=9.94
mat FUEL.2 c_U170 dens=9.94
mat FUEL.3 c_U120 dens=9.94
mat FUEL.4 c_U247b dens=10.34
mat FUEL.5 c_U247c dens=10.34
mat FUEL.6 c_U247d dens=9.48

% cladding comp - smear the spacer grids into the cladding material
% this was done consistent with the TRITON models (ML13042A450)
comp c_ZIRI : WT refdens=6.84699
ZIRC4=3.5224
INC718=0.6691
ZIRC2=-100

% cladding mat
mat CLAD.1 c_ZIRI

```

```

% channel box is Zry4
mat CAN.1 ZIRC4

% top reflectors
comp BOT1 : WT H2O=21.25524 ZIRC2=10.76185 SS304=66.47959 INC718=0.64007 B4C=0.86324
comp BOT2 : WT H2O=4.50458 SS304=95.09426 B4C=0.40116
mat BOTREF.1 : BOT1 2.547030
mat BOTREF.2 : BOT2 5.480845

% -----
% geometry
% -----
geom BWR7x7: ASSM 7 1.875 FULL % 7x7 assy, pin pitch, full symmetry
hgap 0.475 0.9525: MOD.1 MOD.2 % Narrow gap, wide gap
mesh MOD.1 : nd=2 nf=3 % Additional detail in bypass added at ORNL suggestion
mesh MOD.2 : nd=3 nf=3 % (see email from Matt Jessee, 7/20/17)
box 0.2032 0.9652 6.7 CAN.1 % box thickness, corner inner radius, inner half width

% fuel pins
pin 1 : 0.61976 0.63373 0.71501 : FUEL.1 GAP.1 CLAD.1
pin 2 : 0.61976 0.63373 0.71501 : FUEL.2 GAP.1 CLAD.1
pin 3 : 0.61976 0.63373 0.71501 : FUEL.3 GAP.1 CLAD.1
pin 4 : 0.61849 0.63373 0.71501 : FUEL.4 GAP.1 CLAD.1
pin 5 : 0.61849 0.63373 0.71501 : FUEL.5 GAP.1 CLAD.1
pin 6 : 0.61976 0.63373 0.71501 : FUEL.6 GAP.1 CLAD.1

% add rings according to ORNL recommendations
mesh FUEL.1 nr=3
mesh FUEL.2 nr=3
mesh FUEL.3 nr=3
mesh FUEL.4 nr=3
mesh FUEL.5 nr=3
mesh FUEL.6 nr=3

shield ALL=N FUEL=P
pinmap
3
3 2
2 2 5
2 1 1 6
2 1 1 1 1
2 1 1 4 1 1
3 2 1 1 1 1 2
geom rad_ref : REFL 22.7076
slab rad_ref : 12.70 10.0076 : BOTREF.1 BOTREF.2 : 10 10 : 2 2
% -----
% states
% -----
state ALL : temp=560.29
FUEL : temp=948.45
COOL : temp=560.29 dens=0.4573
MOD : temp=560.29 dens=0.7373
rad_ref : in=yes
read branch
add ALL : temp=560.29 FUEL : temp=948.45 COOL : dens=0.7373 MOD : dens=0.7373
add ALL : temp=560.29 FUEL : temp=948.45 COOL : dens=0.2573 MOD : dens=0.7373
add ALL : temp=560.29 FUEL : temp=948.45 COOL : dens=0.1073 MOD : dens=0.7373
end branch
end

```

APPENDIX B. SAMPLE OF GENPMAXS INPUT FILES

B.1 GenPMAXS Input for the Fuel Assembly Type 1

```
%JOB_TIT
'pb-type1.PMAX' T 3.31
%JOB_OPT
T T F F T F T T T F T T F
!ad,xe,de,jl,ch,Xd,iv,dt,yl,cd,gf,be,lb,dc
%DAT_SRC
8 6 1
%STA_VAR
3
CR DC TF
%HISTORY
6 2
HIST01 0.00000 0.73730 948.45
HIST02 0.00000 0.45730 948.45
HIST03 0.00000 0.24730 948.45
HIST04 1.00000 0.73730 948.45
HIST05 1.00000 0.45730 948.45
HIST06 1.00000 0.24730 948.45
%BRANCH
24 2
STAT01 0.00000 0.73730 948.45
STAT02 0.00000 0.45730 948.45
STAT03 0.00000 0.24730 948.45
STAT04 1.00000 0.73730 948.45
STAT05 1.00000 0.45730 948.45
STAT06 1.00000 0.24730 948.45
STAT07 0.00000 0.10730 948.45
STAT08 1.00000 0.10730 948.45
STAT09 0.00000 0.73730 500.00
STAT10 0.00000 0.45730 500.00
STAT11 0.00000 0.24730 500.00
STAT12 0.00000 0.10730 500.00
STAT13 1.00000 0.73730 500.00
STAT14 1.00000 0.45730 500.00
STAT15 1.00000 0.24730 500.00
STAT16 1.00000 0.10730 500.00
STAT17 0.00000 0.73730 1500.00
STAT18 0.00000 0.45730 1500.00
STAT19 0.00000 0.24730 1500.00
STAT20 0.00000 0.10730 1500.00
STAT21 1.00000 0.73730 1500.00
STAT22 1.00000 0.45730 1500.00
STAT23 1.00000 0.24730 1500.00
STAT24 1.00000 0.10730 1500.00
%BURNUP
1
BS1 60
0.000000E+00 1.200000E-04 1.571400E-01 4.692000E-01 7.782000E-01 1.084920E+00
1.390050E+00 1.694200E+00 1.997930E+00 2.301750E+00 2.606140E+00 2.911580E+00
3.218500E+00 3.527330E+00 3.838520E+00 4.152480E+00 4.469660E+00 4.790500E+00
5.115480E+00 5.445070E+00 5.779800E+00 6.120190E+00 6.466850E+00 6.820400E+00
7.181520E+00 7.550970E+00 7.929590E+00 8.318300E+00 8.718140E+00 9.130290E+00
9.556090E+00 9.997090E+00 1.045510E+01 1.093220E+01 1.143090E+01 1.195430E+01
1.250610E+01 1.309090E+01 1.371460E+01 1.438490E+01 1.511220E+01 1.591120E+01
1.680350E+01 1.782310E+01 1.903000E+01 2.054640E+01 2.270410E+01 2.550540E+01
2.850540E+01 3.150540E+01 3.450540E+01 3.750540E+01 4.050540E+01 4.350540E+01
4.650540E+01 4.950540E+01 5.250540E+01 5.550540E+01 5.850540E+01 6.150540E+01
HIST01 24*1
HIST02 24*1
HIST03 24*1
HIST04 24*1
HIST05 24*1
HIST06 24*1
%USERINP
1
PIN 1.87452 1.44018 1.44018 0
%DFREMAP
1
CDF 1 2 3 4
%FIL_CNT
1 './type1/cr0_v00.t16' 24 1
1 1 1 1 60 ! 0.00000 0.73730 948.45
2 1 2 1 60 ! 0.00000 0.45730 948.45
3 1 3 1 60 ! 0.00000 0.24730 948.45
4 1 4 1 60 ! 1.00000 0.73730 948.45
```

5	1	5	1	60	!	1.00000	0.45730	948.45
6	1	6	1	60	!	1.00000	0.24730	948.45
7	1	7	1	60	!	0.00000	0.10730	948.45
8	1	8	1	60	!	1.00000	0.10730	948.45
9	1	9	1	60	!	0.00000	0.73730	500.00
10	1	10	1	60	!	0.00000	0.45730	500.00
11	1	11	1	60	!	0.00000	0.24730	500.00
12	1	12	1	60	!	0.00000	0.10730	500.00
13	1	13	1	60	!	1.00000	0.73730	500.00
14	1	14	1	60	!	1.00000	0.45730	500.00
15	1	15	1	60	!	1.00000	0.24730	500.00
16	1	16	1	60	!	1.00000	0.10730	500.00
17	1	17	1	60	!	0.00000	0.73730	1500.00
18	1	18	1	60	!	0.00000	0.45730	1500.00
19	1	19	1	60	!	0.00000	0.24730	1500.00
20	1	20	1	60	!	0.00000	0.10730	1500.00
21	1	21	1	60	!	1.00000	0.73730	1500.00
22	1	22	1	60	!	1.00000	0.45730	1500.00
23	1	23	1	60	!	1.00000	0.24730	1500.00
24	1	24	1	60	!	1.00000	0.10730	1500.00
2	'./type1/cr0_v40.t16' 24 1							
1	2	2	1	60	!	0.00000	0.45730	948.45
2	2	1	1	60	!	0.00000	0.73730	948.45
3	2	3	1	60	!	0.00000	0.24730	948.45
4	2	4	1	60	!	1.00000	0.73730	948.45
5	2	5	1	60	!	1.00000	0.45730	948.45
6	2	6	1	60	!	1.00000	0.24730	948.45
7	2	7	1	60	!	0.00000	0.10730	948.45
8	2	8	1	60	!	1.00000	0.10730	948.45
9	2	9	1	60	!	0.00000	0.73730	500.00
10	2	10	1	60	!	0.00000	0.45730	500.00
11	2	11	1	60	!	0.00000	0.24730	500.00
12	2	12	1	60	!	0.00000	0.10730	500.00
13	2	13	1	60	!	1.00000	0.73730	500.00
14	2	14	1	60	!	1.00000	0.45730	500.00
15	2	15	1	60	!	1.00000	0.24730	500.00
16	2	16	1	60	!	1.00000	0.10730	500.00
17	2	17	1	60	!	0.00000	0.73730	1500.00
18	2	18	1	60	!	0.00000	0.45730	1500.00
19	2	19	1	60	!	0.00000	0.24730	1500.00
20	2	20	1	60	!	0.00000	0.10730	1500.00
21	2	21	1	60	!	1.00000	0.73730	1500.00
22	2	22	1	60	!	1.00000	0.45730	1500.00
23	2	23	1	60	!	1.00000	0.24730	1500.00
24	2	24	1	60	!	1.00000	0.10730	1500.00
3	'./type1/cr0_v70.t16' 24 1							
1	3	3	1	60	!	0.00000	0.24730	948.45
2	3	1	1	60	!	0.00000	0.73730	948.45
3	3	2	1	60	!	0.00000	0.45730	948.45
4	3	4	1	60	!	1.00000	0.73730	948.45
5	3	5	1	60	!	1.00000	0.45730	948.45
6	3	6	1	60	!	1.00000	0.24730	948.45
7	3	7	1	60	!	0.00000	0.10730	948.45
8	3	8	1	60	!	1.00000	0.10730	948.45
9	3	9	1	60	!	0.00000	0.73730	500.00
10	3	10	1	60	!	0.00000	0.45730	500.00
11	3	11	1	60	!	0.00000	0.24730	500.00
12	3	12	1	60	!	0.00000	0.10730	500.00
13	3	13	1	60	!	1.00000	0.73730	500.00
14	3	14	1	60	!	1.00000	0.45730	500.00
15	3	15	1	60	!	1.00000	0.24730	500.00
16	3	16	1	60	!	1.00000	0.10730	500.00
17	3	17	1	60	!	0.00000	0.73730	1500.00
18	3	18	1	60	!	0.00000	0.45730	1500.00
19	3	19	1	60	!	0.00000	0.24730	1500.00
20	3	20	1	60	!	0.00000	0.10730	1500.00
21	3	21	1	60	!	1.00000	0.73730	1500.00
22	3	22	1	60	!	1.00000	0.45730	1500.00
23	3	23	1	60	!	1.00000	0.24730	1500.00
24	3	24	1	60	!	1.00000	0.10730	1500.00
4	'./type1/cr1_v00.t16' 24 1							
1	4	4	1	60	!	1.00000	0.73730	948.45
2	4	1	1	60	!	0.00000	0.73730	948.45
3	4	2	1	60	!	0.00000	0.45730	948.45
4	4	3	1	60	!	0.00000	0.24730	948.45
5	4	5	1	60	!	1.00000	0.45730	948.45
6	4	6	1	60	!	1.00000	0.24730	948.45
7	4	7	1	60	!	0.00000	0.10730	948.45
8	4	8	1	60	!	1.00000	0.10730	948.45
9	4	9	1	60	!	0.00000	0.73730	500.00
10	4	10	1	60	!	0.00000	0.45730	500.00

```

11 4 11 1 60 ! 0.00000 0.24730 500.00
12 4 12 1 60 ! 0.00000 0.10730 500.00
13 4 13 1 60 ! 1.00000 0.73730 500.00
14 4 14 1 60 ! 1.00000 0.45730 500.00
15 4 15 1 60 ! 1.00000 0.24730 500.00
16 4 16 1 60 ! 1.00000 0.10730 500.00
17 4 17 1 60 ! 0.00000 0.73730 1500.00
18 4 18 1 60 ! 0.00000 0.45730 1500.00
19 4 19 1 60 ! 0.00000 0.24730 1500.00
20 4 20 1 60 ! 0.00000 0.10730 1500.00
21 4 21 1 60 ! 1.00000 0.73730 1500.00
22 4 22 1 60 ! 1.00000 0.45730 1500.00
23 4 23 1 60 ! 1.00000 0.24730 1500.00
24 4 24 1 60 ! 1.00000 0.10730 1500.00
5 './typel/crl_v40.t16' 24 1
1 5 5 1 60 ! 1.00000 0.45730 948.45
2 5 1 1 60 ! 0.00000 0.73730 948.45
3 5 2 1 60 ! 0.00000 0.45730 948.45
4 5 3 1 60 ! 0.00000 0.24730 948.45
5 5 4 1 60 ! 1.00000 0.73730 948.45
6 5 6 1 60 ! 1.00000 0.24730 948.45
7 5 7 1 60 ! 0.00000 0.10730 948.45
8 5 8 1 60 ! 1.00000 0.10730 948.45
9 5 9 1 60 ! 0.00000 0.73730 500.00
10 5 10 1 60 ! 0.00000 0.45730 500.00
11 5 11 1 60 ! 0.00000 0.24730 500.00
12 5 12 1 60 ! 0.00000 0.10730 500.00
13 5 13 1 60 ! 1.00000 0.73730 500.00
14 5 14 1 60 ! 1.00000 0.45730 500.00
15 5 15 1 60 ! 1.00000 0.24730 500.00
16 5 16 1 60 ! 1.00000 0.10730 500.00
17 5 17 1 60 ! 0.00000 0.73730 1500.00
18 5 18 1 60 ! 0.00000 0.45730 1500.00
19 5 19 1 60 ! 0.00000 0.24730 1500.00
20 5 20 1 60 ! 0.00000 0.10730 1500.00
21 5 21 1 60 ! 1.00000 0.73730 1500.00
22 5 22 1 60 ! 1.00000 0.45730 1500.00
23 5 23 1 60 ! 1.00000 0.24730 1500.00
24 5 24 1 60 ! 1.00000 0.10730 1500.00
6 './typel/crl_v70.t16' 24 1
1 6 6 1 60 ! 1.00000 0.24730 948.45
2 6 1 1 60 ! 0.00000 0.73730 948.45
3 6 2 1 60 ! 0.00000 0.45730 948.45
4 6 3 1 60 ! 0.00000 0.24730 948.45
5 6 4 1 60 ! 1.00000 0.73730 948.45
6 6 5 1 60 ! 1.00000 0.45730 948.45
7 6 7 1 60 ! 0.00000 0.10730 948.45
8 6 8 1 60 ! 1.00000 0.10730 948.45
9 6 9 1 60 ! 0.00000 0.73730 500.00
10 6 10 1 60 ! 0.00000 0.45730 500.00
11 6 11 1 60 ! 0.00000 0.24730 500.00
12 6 12 1 60 ! 0.00000 0.10730 500.00
13 6 13 1 60 ! 1.00000 0.73730 500.00
14 6 14 1 60 ! 1.00000 0.45730 500.00
15 6 15 1 60 ! 1.00000 0.24730 500.00
16 6 16 1 60 ! 1.00000 0.10730 500.00
17 6 17 1 60 ! 0.00000 0.73730 1500.00
18 6 18 1 60 ! 0.00000 0.45730 1500.00
19 6 19 1 60 ! 0.00000 0.24730 1500.00
20 6 20 1 60 ! 0.00000 0.10730 1500.00
21 6 21 1 60 ! 1.00000 0.73730 1500.00
22 6 22 1 60 ! 1.00000 0.45730 1500.00
23 6 23 1 60 ! 1.00000 0.24730 1500.00
24 6 24 1 60 ! 1.00000 0.10730 1500.00
%JOB_END

```

B.2 GenPMAXS Input for Radial Edge Reflector

```
%JOB_TIT
'refl_rad_diag.PMAX' T 3.0
%JOB_OPT
F F F F F F F F F F F F F F F
!adf,xes,ded,jlf,chi, chd,inv,det,yld,cdf,gff,bet,lam,dec,zdf
%DAT_SRC
8 1 0
%STA_VAR
3
CR DC DM
%HISTORY
1 1
HIST1 0 0.4573 0.7373
%BRANCH
4 1
HIST1 0 0.4573 0.7373
HIST2 0 0.7373 0.7373
HIST3 0 0.2573 0.7373
HIST4 0 0.1073 0.7373
%BURNUP
1
'NOBP' 1
0
HIST1 4*1
%FIL_CNT
1 ' ../Polaris/reflector/pb2_refl_rad.t16' 4 0
1 1 1 1 1
2 1 2 1 1
3 1 3 1 1
4 1 4 1 1
%JOB_END
```

B.3 GenPMAXS Input for Axial Top Reflector

```
%JOB_TIT
'refl_top.PMAX' T 3.0
%JOB_OPT
F F F F F F T F F F F F F F F
!adf,xes,ded,jlf,chi, chd,inv,det,yld,cdf,gff,bet,lam,dec,zdf
%DAT_SRC
8 1 0
%STA_VAR
3
CR DC DM
%HISTORY
1 1
HIST1 0 0.4573 0.7373
%BRANCH
4 1
HIST1 0 0.4573 0.7373
HIST2 0 0.7373 0.7373
HIST3 0 0.2573 0.7373
HIST4 0 0.1073 0.7373
%BURNUP
1
'NOBP' 1
0
HIST1 4*1
%FIL_CNT
1 ' ../Polaris/reflector/pb2_refl_top.t16' 4 0
1 1 1 1 1
2 1 2 1 1
3 1 3 1 1
4 1 4 1 1
%JOB_END
```

B.4 GenPMAXS Input for Axial Bottom Reflector

```
%JOB_TIT
'refl_bot.PMAX' T 3.0
%JOB_OPT
F F F F F F F F F F F F F F F
!adf,xes,ded,jlf,chi, chd,inv,det,yld,cdf,gff,bet,lam,dec,zdf
%DAT_SRC
```

```

      8 1 0
%STA_VAR
      3
      CR DC DM
%HISTORY
      1 1
      HIST1 0 0.7373 0.7373
%BRANCH
      1 1
      HIST1 0 0.7373 0.7373
%BURNUP
      1
      'NOBP' 1
              0
      HIST1 4*1
%FIL_CNT
      1 ' ../Polaris/reflector/pb2_refl_bot.t16' 1 0
      1 1 1 1 1
%JOB_END

```

APPENDIX C. PARCS INPUT FILES

C.1 PARCS Input for the Cross Section Set “pb-pmaxfiles.back” File

```

! Fuel XS
pmaxs_f 1      '..\GenPMAXS/pb2-type1.PMAX'      1 ! Cycle 1
pmaxs_f 2      '..\GenPMAXS/pb2-type2a.PMAX'     2 ! Cycle 1,2
pmaxs_f 3      '..\GenPMAXS/pb2-type2b.PMAX'     3 ! Cycle 1,2
pmaxs_f 4      '..\GenPMAXS/pb2-type2a.PMAX'     4 ! Cycle 1,2
pmaxs_f 5      '..\GenPMAXS/pb2-type3ac.PMAX'     5 ! Cycle 1,2
pmaxs_f 6      '..\GenPMAXS/pb2-type3d.PMAX'     6 ! Cycle 1,2
pmaxs_f 7      '..\GenPMAXS/pb2-type3e.PMAX'     7 ! Cycle 1,2
pmaxs_f 8      '..\GenPMAXS/pb2-type3d.PMAX'     8 ! Cycle 1,2
pmaxs_f 9      '..\GenPMAXS/pb2-type3ac.PMAX'     9 ! Cycle 1,2
pmaxs_f 10     '..\GenPMAXS/pb2-type4x7.PMAX'    10 ! Cycle 2,3
pmaxs_f 11     '..\GenPMAXS/pb2-type5.PMAX'      11 ! Cycle 2,3
pmaxs_f 12     '..\GenPMAXS/pb2-type6a.PMAX'     12 ! Cycle 2,3
pmaxs_f 13     '..\GenPMAXS/pb2-type6b.PMAX'     13 ! Cycle 2,3
pmaxs_f 14     '..\GenPMAXS/pb2-type4x7.PMAX'    14 ! Cycle 2,3

! Reflector XS
pmaxs_f 15     '..\GenPMAXS/refl_bot.PMAX'       15 ! Reflector Axial Bottom
pmaxs_f 16     '..\GenPMAXS/refl_rad_edge.PMAX'  16 ! Reflector Radial
pmaxs_f 17     '..\GenPMAXS/refl_top.PMAX'       17 ! Reflector Axial Top

! With radial discontinuity factors
pmaxs_f 18     '..\GenPMAXS/refl_rad_NW.PMAX'    18 ! Reflector Radial NW
pmaxs_f 19     '..\GenPMAXS/refl_rad_W.PMAX'     19 ! Reflector Radial W
pmaxs_f 20     '..\GenPMAXS/refl_rad_SW.PMAX'    20 ! Reflector Radial SW
pmaxs_f 21     '..\GenPMAXS/refl_rad_S.PMAX'     21 ! Reflector Radial S
pmaxs_f 22     '..\GenPMAXS/refl_rad_SE.PMAX'    22 ! Reflector Radial SE
pmaxs_f 23     '..\GenPMAXS/refl_rad_E.PMAX'     23 ! Reflector Radial E
pmaxs_f 24     '..\GenPMAXS/refl_rad_NE.PMAX'    24 ! Reflector Radial NE
pmaxs_f 25     '..\GenPMAXS/refl_rad_N.PMAX'     25 ! Reflector Radial N

```

C.2 PARCS Input for the Cycle 1 Assembly Geometry “pb-cyc1.geom” File

[illegible]

C.3 PATHS Input for the Cycle 1 “pb-cyc1.paths” File

C-3


```

bank_pos      -15
               48 48 48 48 48 48 48
               48 48 8 48 38 48 8 48 48
               48 48 48 48 48 48 48 48 48 48
               48 48 38 48 38 48 4 48 38 48 38 48 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 8 48 38 48 4 48 38 48 4 48 38 48 8 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 38 48 4 48 38 48 10 48 38 48 4 48 38 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 8 48 38 48 4 48 38 48 4 48 38 48 8 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 48 38 48 38 48 4 48 38 48 38 48 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 48 8 48 38 48 8 48 48
48 48 48 48 48 48 48

!-----
th_fdbk      T
int_th       T 1 'paths-pb-cycl.inp'
!-----
xe_sm        1 1
rot_adf      T
detector     T 3293.0 2
!-----
depletion    T 1.0e-3 F
! TREE,nset,adf,xes,ene,jlf,chi, chd,vel,det,yld,cdf,gff,bet,lam,dht
tree_xs      T 25 T T F F F F F T T F F T T F T
!_ugur       tree_xs T 25 T T T F F F T T F F T T F T
!-----
! input iteration planar adj
! edit table power pin reac
! print_opt  T F F
! fdbk flux planar
! rho precurs flux xe/sm T/H
! print_opt  F F F F
! ld pk rad pwr rad flux assy
! const data shape shape const
! print_opt  F F F F F
!*****
PARAM
nlupd_ss     3 5 1
n_iters      15 200
conv_ss      1.0e-5 1.0e-4 1.0e-3 0.001
wielandt     0.2 0.1 1.0
decusp       2
NODAL_KERN   NEMMG
cmfd         2
!*****
XSEC
group_spec   2 1
!*****
GEOM
file         './support/pb-cycl.geom'
!*****
FDBK
fa_powpit    4.3102 15.24
!*****
DEPL
satu_den     0.737 0.03753
bank_nr      185*1

time_stp     -0.2535
! inp_hst    'parcs.dep' 1 1
! inp_opt    F F F F ! ppm,crp,ths,xesm

hst_opt      T T F T F ! hcr, hdc, hpc, htf, htc
out_opt      T T F F F ! ppow,phst,pths,pxesm,pxss

file         './support/pb-pmaxfiles'
!*****
/
!*****
! DATASET 2
!*****
CNTL
core_power   79.05
bank_pos     -15
               48 48 48 48 48 48 48

```

```

48 48 38 48 34 48 38 48 48
48 48 48 48 48 48 48 48 48 48 48
48 48 38 48 34 48 14 48 34 48 38 48 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 38 48 34 48 12 48 38 48 12 48 34 48 38 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 34 48 14 48 38 48 14 48 38 48 14 48 34 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 38 48 34 48 12 48 38 48 12 48 34 48 38 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 48 38 48 34 48 14 48 34 48 38 48 48
48 48 48 48 48 48 48 48 48 48 48 48
48 48 38 48 34 48 38 48 48
48 48 48 48 48 48 48
48 48 48 48 48 48 48
48 48 48 48 48 48 48
!*****
TH
state_core      11358.73 1225.91 6.936E+06
!*****
DEPL
time_stp        -0.1764
!*****

/

!*****
! DATASET 3
!*****
CNTL
core_power      76.31
bank_pos        -15
48 48 48 48 48 48 48 48
48 42 48 40 48 40 48 42 48
48 48 48 48 48 48 48 48 48 48 48
48 48 48 38 48 32 48 32 48 38 48 48 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 48 38 48 14 48 40 48 40 48 14 48 38 48 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 48 30 48 38 48 16 48 16 48 38 48 30 48 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 48 38 48 14 48 40 48 40 48 14 48 38 48 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 48 48 38 48 32 48 32 48 38 48 48 48
48 48 48 48 48 48 48 48 48 48 48
48 42 48 40 48 40 48 42 48
48 48 48 48 48 48 48
!*****
TH
state_core      7780.95 1203.36 7.046E+06
!*****
DEPL
time_stp        -0.2844
!*****

/

!*****
! DATASET 4
!*****
CNTL
core_power      96.08
bank_pos        -15
48 48 48 48 48 48 48 48
48 48 30 48 40 48 30 48 48
48 48 48 48 48 48 48 48 48 48 48
48 48 40 48 38 48 38 48 38 48 40 48 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 30 48 38 48 14 48 38 48 14 48 38 48 30 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 40 48 38 48 38 48 16 48 38 48 38 48 40 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 30 48 38 48 14 48 38 48 14 48 38 48 30 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 48 40 48 38 48 38 48 38 48 40 48 48
48 48 48 48 48 48 48 48 48 48 48
48 48 30 48 40 48 30 48 48
48 48 48 48 48 48 48
!*****
TH
state_core      11338.90 1218.01 7.060E+06
!*****
DEPL

```

```

time_stp      -0.1025
!*****
/

!*****
! DATASET 5
!*****
CNTL
  core_power    99.03
  bank_pos      -15
                48 48 48 48 48 48 48
                48 48 32 48 40 48 32 48 48
                48 48 48 48 48 48 48 48 48 48
                48 48 40 48 34 48 28 48 38 48 40 48 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 32 48 38 48 12 48 38 48 12 48 34 48 32 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 40 48 28 48 38 48 14 48 38 48 28 48 40 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 32 48 34 48 12 48 38 48 12 48 38 48 32 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 48 40 48 38 48 28 48 34 48 40 48 48
                48 48 48 48 48 48 48 48 48 48 48
                48 48 32 48 40 48 32 48 48
                48 48 48 48 48 48 48
!*****
TH
  state_core    11130.64 1216.38 7.115E+06
!*****
DEPL
  time_stp      -0.2965
!*****
/

!*****
! DATASET 6
!*****
CNTL
  core_power    99.61
  bank_pos      -15
                48 48 48 48 48 48 48
                48 48 32 48 40 48 32 48 48
                48 48 48 48 48 48 48 48 48 48
                48 48 40 48 32 48 20 48 32 48 40 48 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 32 48 32 48 8 48 36 48 8 48 32 48 32 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 40 48 20 48 36 48 10 48 36 48 20 48 40 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 32 48 32 48 8 48 36 48 8 48 32 48 32 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 48 40 48 32 48 20 48 32 48 40 48 48
                48 48 48 48 48 48 48 48 48 48 48
                48 48 32 48 40 48 32 48 48
                48 48 48 48 48 48 48
!*****
TH
  state_core    10285.61 1209.64 7.226E+06
!*****
DEPL
  time_stp      -0.6338
!*****
/

!*****
! DATASET 7
!*****
CNTL
  core_power    99.97
  bank_pos      -15
                48 48 48 48 48 48 48
                48 42 48 26 48 26 48 42 48
                48 48 48 48 48 48 48 48 48 48 48
                48 34 48 30 48 8 48 8 48 30 48 34 48
                48 48 48 44 48 42 48 48 48 42 48 44 48 48 48
                48 48 32 48 8 48 28 48 28 48 8 48 32 48 48
                48 48 48 44 48 40 48 44 48 40 48 44 48 48 48
                48 48 14 48 32 48 6 48 6 48 32 48 14 48 48

```

```

48 48 48 44 48 40 48 44 48 40 48 44 48 48 48
48 48 32 48 8 48 28 48 28 48 8 48 32 48 48
48 48 48 44 48 42 48 48 48 42 48 44 48 48 48
48 34 48 30 48 8 48 8 48 30 48 34 48
48 48 48 48 48 48 48 48 48 48 48 48 48
48 42 48 26 48 26 48 42 48
48 48 48 48 48 48 48
!*****
TH
state_core      10882.45 1214.06 7.102E+06
!*****
DEPL
time_stp        -0.5456
!*****

/

!*****
! DATASET 8
!*****
CNTL
core_power      99.15
bank_pos        -15
48 48 48 48 48 48 48 48
48 38 48 26 48 26 48 38 48
48 48 48 48 48 48 48 48 48 48 48
48 34 48 20 48 6 48 6 48 20 48 34 48
48 48 48 38 48 42 48 48 48 42 48 38 48 48 48
48 48 26 48 4 48 24 48 24 48 4 48 26 48 48
48 48 48 44 48 40 48 40 48 40 48 44 48 48 48
48 48 10 48 32 48 6 48 6 48 32 48 10 48 48
48 48 48 44 48 40 48 40 48 40 48 44 48 48 48
48 48 26 48 4 48 24 48 24 48 4 48 26 48 48
48 48 48 38 48 42 48 48 48 42 48 38 48 48 48
48 34 48 20 48 6 48 6 48 20 48 34 48
48 48 48 48 48 48 48 48 48 48 48
48 38 48 26 48 26 48 38 48
48 48 48 48 48 48 48
!*****
TH
state_core      10693.63 1212.66 7.150E+06
!*****
DEPL
time_stp        -0.5236
!*****

/

!*****
! DATASET 9
!*****
CNTL
core_power      86.73
bank_pos        -15
48 48 48 48 48 48 48 48
48 48 20 48 14 48 20 48 48
48 48 40 48 44 48 44 48 40 48 48
48 48 14 48 18 48 8 48 18 48 14 48 48
48 48 40 48 48 48 38 48 38 48 48 40 48 48
48 20 48 18 48 4 48 22 48 4 48 18 48 20 48
48 48 44 48 38 48 36 48 36 48 38 48 44 48 48
48 14 48 8 48 22 48 8 48 22 48 8 48 14 48
48 48 44 48 38 48 36 48 36 48 38 48 44 48 48
48 20 48 18 48 4 48 22 48 4 48 18 48 20 48
48 48 40 48 48 48 38 48 38 48 48 40 48 48
48 48 14 48 18 48 8 48 18 48 14 48 48
48 48 40 48 44 48 44 48 40 48 48
48 48 20 48 14 48 20 48 48
48 48 48 48 48 48 48
!*****
TH
state_core      8444.98 1196.86 7.108E+06
!*****
DEPL
time_stp        -0.4023
!*****

/

!*****
! DATASET 10

```

```

!*****
CNTL
    core_power      99.33
    bank_pos        -15
                        48 48 48 48 48 48 48
                        48 48 30 48 14 48 30 48 48
                        48 48 36 48 38 48 38 48 36 48 48
                        48 48 14 48 12 48 8 48 12 48 14 48 48
                        48 48 36 48 36 48 38 48 38 48 36 48 36 48 48
                        48 30 48 12 48 6 48 12 48 6 48 12 48 30 48
                        48 48 38 48 38 48 34 48 34 48 38 48 38 48 48
                        48 14 48 8 48 12 48 10 48 12 48 8 48 14 48
                        48 48 38 48 38 48 34 48 34 48 38 48 38 48 48
                        48 30 48 12 48 6 48 12 48 6 48 12 48 30 48
                        48 48 36 48 36 48 38 48 38 48 36 48 36 48 48
                        48 48 14 48 12 48 8 48 12 48 14 48 48
                        48 48 36 48 38 48 38 48 36 48 48
                        48 48 30 48 14 48 30 48 48
                        48 48 48 48 48 48 48
!*****
TH
    state_core      10951.97 1213.36 7.239E+06
!*****
DEPL
    time_stp        -0.6856
!*****

/

!*****
! DATASET 11
!*****
CNTL
    core_power      99.61
    bank_pos        -15
                        48 48 48 48 48 48 48
                        48 38 48 28 48 28 48 38 48
                        48 36 48 16 48 6 48 16 48 36 48
                        48 48 48 30 48 38 48 38 48 30 48 48 48
                        48 36 48 8 48 6 48 16 48 6 48 8 48 36 48
                        48 48 24 48 36 48 34 48 34 48 36 48 24 48 48
                        48 32 48 6 48 10 48 12 48 10 48 6 48 32 48
                        48 48 10 48 36 48 36 48 36 48 36 48 10 48 48
                        48 32 48 6 48 10 48 12 48 10 48 6 48 32 48
                        48 48 24 48 36 48 34 48 34 48 36 48 24 48 48
                        48 36 48 8 48 6 48 16 48 6 48 8 48 36 48
                        48 48 48 30 48 38 48 38 48 30 48 48 48
                        48 36 48 16 48 6 48 16 48 36 48
                        48 38 48 28 48 28 48 38 48
                        48 48 48 48 48 48 48
!*****
TH
    state_core      10981.76 1213.82 7.184E+06
!*****
DEPL
    time_stp        -0.9061
!*****

/

!*****
! DATASET 12
!*****
CNTL
    core_power      99.51
    bank_pos        -15
                        48 48 48 48 48 48 48
                        48 48 24 48 14 48 24 48 48
                        48 48 36 48 38 48 38 48 36 48 48
                        48 48 12 48 10 48 6 48 10 48 12 48 48
                        48 48 36 48 32 48 34 48 34 48 32 48 36 48 48
                        48 24 48 10 48 6 48 10 48 6 48 10 48 24 48
                        48 48 38 48 34 48 34 48 34 48 34 48 38 48 48
                        48 14 48 6 48 10 48 10 48 10 48 6 48 14 48
                        48 48 38 48 34 48 34 48 34 48 34 48 38 48 48
                        48 24 48 10 48 6 48 10 48 6 48 10 48 24 48
                        48 48 36 48 32 48 34 48 34 48 32 48 36 48 48
                        48 48 12 48 10 48 6 48 10 48 12 48 48
                        48 48 36 48 38 48 38 48 36 48 48
                        48 48 24 48 14 48 24 48 48
                        48 48 48 48 48 48 48

```

```

!*****
TH
    state_core      10971.83 1213.82 7.198E+06
!*****
DEPL
    time_stp        -0.3671
!*****

/

!*****
! DATASET 13
!*****
CNTL
    core_power      100.0
    bank_pos        -15
                        48 48 48 48 48 48 48
                        48 48 24 48 14 48 24 48 48
                        48 48 36 48 38 48 38 48 36 48 48
                        48 48 12 48 10 48 8 48 10 48 12 48 48
                        48 48 36 48 34 48 38 48 38 48 34 48 36 48 48
                        48 24 48 10 48 6 48 10 48 6 48 10 48 24 48
                        48 48 38 48 38 48 34 48 34 48 38 48 38 48 48
                        48 14 48 8 48 10 48 12 48 10 48 8 48 14 48
                        48 48 38 48 38 48 34 48 34 48 38 48 38 48 48
                        48 24 48 10 48 6 48 10 48 6 48 10 48 24 48
                        48 48 36 48 34 48 38 48 38 48 34 48 36 48 48
                        48 48 12 48 10 48 8 48 10 48 12 48 48
                        48 48 36 48 38 48 38 48 36 48 48
                        48 48 24 48 14 48 24 48 48
                        48 48 48 48 48 48 48
!*****
TH
    state_core      10882.45 1213.13 7.226E+06
!*****
DEPL
    time_stp        -0.6228
!*****

/

!*****
! DATASET 14
!*****
CNTL
    core_power      99.70
    bank_pos        -15
                        48 48 48 48 48 48 48
                        48 38 48 28 48 28 48 38 48
                        48 36 48 14 48 8 48 14 48 36 48
                        48 48 48 28 48 38 48 38 48 28 48 48 48
                        48 36 48 8 48 8 48 18 48 8 48 8 48 36 48
                        48 48 20 48 36 48 34 48 34 48 36 48 20 48 48
                        48 30 48 6 48 8 48 12 48 8 48 6 48 30 48
                        48 48 10 48 38 48 36 48 36 48 38 48 10 48 48
                        48 30 48 6 48 8 48 12 48 8 48 6 48 30 48
                        48 48 20 48 36 48 34 48 34 48 36 48 20 48 48
                        48 36 48 8 48 8 48 18 48 8 48 8 48 36 48
                        48 48 48 28 48 38 48 38 48 28 48 48 48
                        48 36 48 14 48 8 48 14 48 36 48
                        48 38 48 28 48 28 48 38 48
                        48 48 48 48 48 48 48
!*****
TH
    state_core      11180.25 1214.99 7.191E+06
!*****
DEPL
    time_stp        -0.4167
!*****

/

!*****
! DATASET 15
!*****
CNTL
    core_power      97.63
    bank_pos        -15
                        48 48 48 48 48 48 48
                        48 38 48 28 48 28 48 38 48
                        48 36 48 14 48 8 48 14 48 36 48

```

```

48 48 48 28 48 38 48 38 48 28 48 48 48
48 36 48 10 48 8 48 18 48 8 48 10 48 36 48
48 48 20 48 36 48 34 48 34 48 36 48 20 48 48
48 30 48 6 48 8 48 12 48 8 48 6 48 30 48
48 48 12 48 38 48 36 48 36 48 38 48 12 48 48
48 30 48 6 48 8 48 12 48 8 48 6 48 30 48
48 48 20 48 36 48 34 48 34 48 36 48 20 48 48
48 36 48 10 48 8 48 18 48 8 48 10 48 36 48
48 48 48 28 48 38 48 38 48 28 48 48 48
48 36 48 14 48 8 48 14 48 36 48
48 38 48 28 48 28 48 38 48
48 48 48 48 48 48 48
! *****
TH
state_core      11180.25 1216.15 7.171E+06
! *****
DEPL
time_stp        -0.5137
! *****

/

! *****
! DATASET 16
! *****
CNTL
core_power      96.33
bank_pos        -15
48 48 48 48 48 48 48 48
48 38 48 30 48 30 48 38 48
48 36 48 14 48 8 48 14 48 36 48
48 48 48 32 48 38 48 38 48 32 48 48 48
48 36 48 12 48 8 48 20 48 8 48 12 48 36 48
48 48 20 48 36 48 36 48 36 48 36 48 20 48 48
48 32 48 6 48 8 48 12 48 8 48 6 48 32 48
48 48 14 48 40 48 36 48 36 48 40 48 14 48 48
48 32 48 6 48 8 48 12 48 8 48 6 48 32 48
48 48 20 48 36 48 36 48 36 48 36 48 20 48 48
48 36 48 12 48 8 48 20 48 8 48 12 48 36 48
48 48 48 32 48 38 48 38 48 32 48 48 48
48 36 48 14 48 8 48 14 48 36 48
48 38 48 30 48 30 48 38 48
48 48 48 48 48 48 48
! *****
TH
state_core      11110.79 1216.38 7.122E+06
! *****
DEPL
time_stp        -0.4012
! *****

/

! *****
! DATASET 17
! *****
CNTL
core_power      50.08
bank_pos        -15
48 48 48 48 48 48 48 48
48 48 12 48 12 48 12 48 48
48 48 40 48 44 48 44 48 40 48 48
48 48 8 48 8 48 4 48 8 48 8 48 48
48 48 40 48 44 48 40 48 40 48 44 48 40 48 48
48 12 48 8 48 0 48 4 48 0 48 8 48 12 48
48 48 44 48 40 48 40 48 40 48 40 48 44 48 48
48 12 48 4 48 4 48 6 48 4 48 4 48 12 48
48 48 44 48 40 48 40 48 40 48 40 48 44 48 48
48 12 48 8 48 0 48 4 48 0 48 8 48 12 48
48 48 40 48 44 48 40 48 40 48 44 48 40 48 48
48 48 8 48 8 48 4 48 8 48 8 48 48
48 48 40 48 44 48 44 48 40 48 48
48 48 12 48 12 48 12 48 48
48 48 48 48 48 48 48
! *****
TH
state_core      5553.05 1200.34 6.902E+06
! *****
DEPL
time_stp        -0.5842
! *****

```

```

/

! *****
! DATASET 18
! *****
CNTL
    core_power    56.33
    bank_pos      -15

        48 48 48 48 48 48 48
        48 48 16 48 22 48 16 48 48
        48 48 42 48 44 48 44 48 42 48 48
        48 48 20 48 10 48 6 48 10 48 20 48 48
        48 48 42 48 44 48 40 48 40 48 44 48 42 48 48
        48 16 48 10 48 8 48 12 48 8 48 10 48 16 48
        48 48 44 48 40 48 40 48 40 48 40 48 44 48 48
        48 22 48 6 48 12 48 16 48 12 48 6 48 22 48
        48 48 44 48 40 48 40 48 40 48 40 48 44 48 48
        48 16 48 10 48 8 48 12 48 8 48 10 48 16 48
        48 48 42 48 44 48 40 48 40 48 44 48 42 48 48
        48 48 20 48 10 48 6 48 10 48 20 48 48
        48 48 42 48 44 48 44 48 42 48 48
        48 48 16 48 22 48 16 48 48
        48 48 48 48 48 48 48

! *****
TH
    state_core    4512.56 1172.91 6.964E+06
! *****
DEPL
    time_stp      -0.3307
! *****

/

! *****
! DATASET 19
! *****
CNTL
    core_power    57.15
    bank_pos      -15

        48 48 48 48 48 48 48
        48 48 18 48 26 48 18 48 48
        48 48 44 48 44 48 44 48 44 48 48
        48 48 28 48 10 48 10 48 10 48 28 48 48
        48 48 44 48 44 48 44 48 44 48 44 48 48
        48 18 48 10 48 8 48 12 48 8 48 10 48 18 48
        48 48 44 48 44 48 42 48 42 48 44 48 44 48 48
        48 26 48 10 48 12 48 22 48 12 48 10 48 26 48
        48 48 44 48 44 48 42 48 42 48 44 48 44 48 48
        48 18 48 10 48 8 48 12 48 8 48 10 48 18 48
        48 48 44 48 44 48 44 48 44 48 44 48 44 48 48
        48 48 28 48 10 48 10 48 10 48 28 48 48
        48 48 44 48 44 48 44 48 44 48 44 48 48
        48 48 18 48 26 48 18 48 48
        48 48 48 48 48 48 48

! *****
TH
    state_core    4563.67 1171.52 7.095E+06
! *****
DEPL
    time_stp      -0.4542
! *****

/

! *****
! DATASET 20
! *****
CNTL
    core_power    56.42
    bank_pos      -15

        48 48 48 48 48 48 48
        48 48 48 38 48 38 48 48 48
        48 34 48 24 48 10 48 24 48 34 48
        48 48 48 46 48 48 48 48 46 48 48 48
        48 34 48 12 48 12 48 10 48 12 48 12 48 34 48
        48 48 48 48 42 48 42 48 42 48 42 48 48 48 48
        48 24 48 8 48 16 48 10 48 16 48 8 48 24 48
        48 48 48 48 48 48 44 48 44 48 48 48 48 48
        48 24 48 8 48 16 48 10 48 16 48 8 48 24 48
        48 48 48 48 42 48 42 48 42 48 42 48 48 48 48

```

```

48 34 48 12 48 12 48 10 48 12 48 12 48 34 48
48 48 48 46 48 48 48 48 48 46 48 48 48
48 34 48 24 48 10 48 24 48 34 48
48 48 48 38 48 38 48 48 48
48 48 48 48 48 48 48
!*****
TH
state_core      4614.78 1174.31 7.005E+06
!*****
DEPL
time_stp        -0.4277
!*****

/

!*****
! DATASET 21
!*****
CNTL
core_power      99.76
bank_pos        -15
48 48 48 48 48 48 48 48
48 48 48 38 48 38 48 48 48
48 38 48 32 48 20 48 32 48 38 48
48 48 48 48 48 48 48 48 48 48 48 48 48
48 36 48 30 48 12 48 32 48 12 48 30 48 36 48
48 48 48 48 44 48 44 48 44 48 44 48 48 48 48
48 32 48 12 48 20 48 18 48 20 48 12 48 32 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 32 48 12 48 20 48 18 48 20 48 12 48 32 48
48 48 48 48 44 48 44 48 44 48 44 48 48 48 48
48 36 48 30 48 12 48 32 48 12 48 30 48 36 48
48 48 48 48 48 48 48 48 48 48 48 48 48
48 38 48 32 48 20 48 32 48 38 48
48 48 48 38 48 38 48 48 48
48 48 48 48 48 48 48
!*****
TH
state_core      12639.04 1218.24 7.157E+06
!*****
DEPL
time_stp        -0.3638
!*****

/

!*****
! DATASET 22
!*****
CNTL
core_power      99.97
bank_pos        -15
48 48 48 48 48 48 48 48
48 48 48 44 48 44 48 48 48
48 42 48 36 48 34 48 36 48 42 48
48 48 48 48 48 48 48 48 48 48 48 48 48
48 42 48 38 48 18 48 40 48 18 48 38 48 42 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 38 48 20 48 34 48 18 48 34 48 20 48 38 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 38 48 20 48 34 48 18 48 34 48 20 48 38 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 42 48 38 48 18 48 40 48 18 48 38 48 42 48
48 48 48 48 48 48 48 48 48 48 48 48 48
48 42 48 36 48 34 48 36 48 42 48
48 48 48 44 48 44 48 48 48
48 48 48 48 48 48 48
!*****
TH
state_core      11952.76 1212.20 7.164E+06
!*****
DEPL
time_stp        -0.3704
!*****

/

!*****
! DATASET 23
!*****
CNTL

```

C.5 PARCS Input for the Cycle 2 Assembly Geometry “pb-cyc2.geom” File

C-14

C.7 PARCS Input for the HZP Cycle 2 Fuel Shuffling

C-18

C-19

```

0 0 0 414 342 -5 395 -5 372 -5 -5 -5 -5 282 -5 390 -5 373 412 0 0 0
0 0 0 522 286 398 232 417 218 290 418 312 252 253 305 428 747 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

```

```

! Multi-cycle schedule
!
!      itsq  itshufsq  itcyclesq
!      cycle_ind 1 0 1
!      cycle_ind 2 1 1
!      crit.(GWD/T) max itr
!      conv_ec 0.1 2
!*****

```

C.8 PARCS Input for the HFP Cycle 2

```

!*****
CASEID pb-cyc2
!*****
CNTL
  core_type      BWR
  core_power     80.47
!-----
  bank_pos       -15
                48 48 48 48 48 48 48
                48 48 40 48 40 48 40 48 48
                48 48 20 48 12 48 12 48 20 48 48
                48 48 42 48 38 48 36 48 38 48 42 48 48
                48 48 20 48 10 48 8 48 8 48 10 48 20 48 48
                48 40 48 38 48 44 48 48 48 44 48 38 48 40 48
                48 48 12 48 8 48 6 48 6 48 8 48 12 48 48
                48 40 48 36 48 48 48 32 48 48 48 36 48 40 48
                48 48 12 48 8 48 6 48 6 48 8 48 12 48 48
                48 40 48 38 48 44 48 48 48 44 48 38 48 40 48
                48 48 20 48 10 48 8 48 8 48 10 48 20 48 48
                48 48 42 48 38 48 36 48 38 48 42 48 48
                48 48 20 48 12 48 12 48 20 48 48
                48 48 40 48 40 48 40 48 48
                48 48 48 48 48 48 48
!-----
  th_fdbk        T
  int_th         T 1 'paths-pb-cyc2.inp'
!-----
  xe_sm          1 1
  rot_adf        T
  detector        T 3293.0 2
!-----
  depletion       T 1.0e-3 F
!      TREE,nset,adf,xes,ene,jlf,chi, chd,vel,det,yld,cdf,gff,bet,lam,dht
  tree_xs        T 25 T T F F F F F T T F F T T F T
!-----
  inp_opts        F T
!!      input iteration planar adj
!!      edit table power pin reac
!      print_opt T F F F
!!      fdbk flux planar
!!      rho precurs flux xe/sm T/H
!      print_opt F F F F
!!      1d pk rad pwr rad flux assy
!!      const data shape shape const
!      print_opt F F F F
!*****
PARAM
  nlupd_ss        3 5 1
  n_iters         15 200
  conv_ss         1.0e-5 1.0e-4 1.0e-3 0.001
  wielandt        0.2 0.1 1.0
  decusp          2
  nodal_kern      nemmg
  cmfd            2
!*****
XSEC
  group_spec      2 1
!*****
GEOM
  file            './support/pb-cyc2.geom'
!*****
FDBK
  fa_powpit       4.3102 15.24
!*****
DEPL
  satu_den        0.737 0.03753
  bank_nr         185*1

```

```

time_stp      -0.0562
inp_hst       'pb-shuff-clc2.parc5_cyc-02' 1 1
inp_opt       F F F F           ! ppm,crp,ths,xesm

hst_opt       T T F T F         ! hcr, hdc, hpc, htf, htc
out_opt       T T F F F         ! ppow,phst,pths,pxesm,pxss

file          './support/pb-pmaxfiles'

!*****

/

!*****
! DATASET 26
!*****
CNTL
  core_power   99.06
  bank_pos     -15
                48 48 48 48 48 48 48
                48 48 48 34 48 34 48 48 48
                48 38 48 38 48 42 48 38 48 38 48
                48 48 48 22 48 12 48 12 48 22 48 48 48
                48 38 48 38 48 38 48 40 48 38 48 38 48 38 48
                48 48 22 48 10 48 10 48 10 48 10 48 22 48 48
                48 40 48 40 48 48 48 44 48 48 48 40 48 40 48
                48 48 22 48 14 48 14 48 14 48 14 48 22 48 48
                48 40 48 40 48 48 48 44 48 48 48 40 48 40 48
                48 48 22 48 10 48 10 48 10 48 10 48 22 48 48
                48 38 48 38 48 38 48 40 48 38 48 38 48 38 48
                48 48 48 22 48 12 48 12 48 22 48 48 48
                48 38 48 38 48 42 48 38 48 38 48
                48 48 48 34 48 34 48 48 48
                48 48 48 48 48 48 48
!*****
TH
  state_core   11744.00 1213.80 7.088E+06
!*****
DEPL
  time_stp     -0.2635
!*****

/

!*****
! DATASET 27
!*****
CNTL
  core_power   99.48
  bank_pos     -15
                48 48 48 48 48 48 48
                48 48 38 48 40 48 38 48 48
                48 48 28 48 20 48 20 48 28 48 48
                48 48 40 48 40 48 38 48 40 48 40 48 48
                48 48 28 48 10 48 10 48 10 48 10 48 28 48 48
                48 38 48 40 48 48 48 48 48 48 48 40 48 38 48
                48 48 20 48 10 48 14 48 14 48 10 48 20 48 48
                48 40 48 38 48 48 48 42 48 48 48 38 48 40 48
                48 48 20 48 10 48 14 48 14 48 10 48 20 48 48
                48 38 48 40 48 48 48 48 48 48 48 40 48 38 48
                48 48 28 48 10 48 10 48 10 48 10 48 28 48 48
                48 48 40 48 40 48 38 48 40 48 40 48 48
                48 48 28 48 20 48 20 48 28 48 48
                48 48 38 48 40 48 38 48 48
                48 48 48 48 48 48 48
!*****
TH
  state_core   12120.71 1214.55 7.184E+06
!*****
DEPL
  time_stp     -0.8499
!*****

/

!*****
! DATASET 28
!*****
CNTL
  core_power   99.45
  bank_pos     -15
                48 48 48 48 48 48 48
                48 48 38 48 40 48 38 48 48
                48 48 28 48 18 48 18 48 28 48 48
                48 48 40 48 40 48 38 48 40 48 40 48 48
                48 48 28 48 10 48 14 48 14 48 10 48 28 48 48
                48 38 48 40 48 48 48 48 48 48 48 40 48 38 48
                48 48 18 48 14 48 18 48 18 48 14 48 18 48 48

```

```

48 40 48 38 48 48 48 42 48 48 48 38 48 40 48
48 48 18 48 14 48 18 48 18 48 14 48 18 48 48
48 38 48 40 48 48 48 48 48 48 48 40 48 38 48
48 48 28 48 10 48 14 48 14 48 10 48 28 48 48
48 48 40 48 40 48 38 48 40 48 40 48 48
48 48 28 48 18 48 18 48 28 48 48
48 48 38 48 40 48 38 48 48
48 48 48 48 48 48 48
!*****
TH
state_core      11778.25 1212.89 7.150E+06
!*****
DEPL
time_stp        -0.7661
!*****

/

!*****
! DATASET 29
!*****
CNTL
core_power      100.00
bank_pos        -15
48 48 48 48 48 48 48
48 42 48 36 48 36 48 42 48
48 34 48 26 48 12 48 26 48 34 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 36 48 18 48 12 48 32 48 12 48 18 48 36 48
48 48 40 48 48 48 48 48 48 48 48 40 48 48
48 32 48 10 48 30 48 12 48 30 48 10 48 32 48
48 48 48 48 44 48 48 48 48 44 48 48 48 48
48 32 48 10 48 30 48 12 48 30 48 10 48 32 48
48 48 40 48 48 48 48 48 48 48 48 40 48 48
48 36 48 18 48 12 48 32 48 12 48 18 48 36 48
48 48 48 48 48 48 48 48 48 48 48 48 48
48 34 48 26 48 12 48 26 48 34 48
48 42 48 36 48 36 48 42 48
48 48 48 48 48 48 48
!*****
TH
state_core      11595.59 1211.73 7.150E+06
!*****
DEPL
time_stp        -0.3527
!*****

/

!*****
! DATASET 30
!*****
CNTL
core_power      98.88
bank_pos        -15
48 48 48 48 48 48 48
48 48 28 48 36 48 28 48 48
48 48 40 48 44 48 44 48 40 48 48
48 48 36 48 12 48 10 48 12 48 36 48 48
48 48 40 48 48 48 48 48 48 48 48 40 48 48
48 28 48 12 48 28 48 28 48 28 48 12 48 28 48
48 48 44 48 48 48 48 48 48 48 48 44 48 48
48 36 48 10 48 28 48 14 48 28 48 10 48 36 48
48 48 44 48 48 48 48 48 48 48 48 44 48 48
48 28 48 12 48 28 48 28 48 28 48 12 48 28 48
48 48 40 48 48 48 48 48 48 48 48 40 48 48
48 48 36 48 12 48 10 48 12 48 36 48 48
48 48 40 48 44 48 44 48 40 48 48
48 48 28 48 36 48 28 48 48
48 48 48 48 48 48 48
!*****
TH
state_core      11869.57 1214.29 7.143E+06
!*****
DEPL
time_stp        -0.7496
!*****

/

!*****
! DATASET 31
!*****
CNTL
core_power      99.76
bank_pos        -15
48 48 48 48 48 48 48
48 48 28 48 36 48 28 48 48

```

```

48 48 40 48 44 48 44 48 40 48 48
48 48 36 48 12 48 10 48 12 48 36 48 48
48 48 40 48 48 48 48 48 48 48 48 40 48 48
48 28 48 12 48 28 48 28 48 28 48 12 48 28 48
48 48 44 48 48 48 48 48 48 48 48 44 48 48
48 36 48 10 48 28 48 14 48 28 48 10 48 36 48
48 48 44 48 48 48 48 48 48 48 48 44 48 48
48 28 48 12 48 28 48 28 48 28 48 12 48 28 48
48 48 40 48 48 48 48 48 48 48 48 40 48 48
48 48 36 48 12 48 10 48 12 48 36 48 48
48 48 40 48 44 48 44 48 40 48 48
48 48 28 48 36 48 28 48 48
48 48 48 48 48 48 48
!*****
TH
state_core      12349.01 1215.68 7.122E+06
!*****
DEPL
time_stp        -0.3307
!*****

/

!*****
! DATASET 32
!*****
CNTL
core_power      99.48
bank_pos        -15
48 48 48 48 48 48 48
48 36 48 32 48 32 48 36 48
48 44 48 44 48 44 48 44 48 44 48
48 38 48 16 48 26 48 26 48 16 48 38 48
48 40 48 44 48 44 48 48 48 44 48 44 48 40 48
48 48 28 48 8 48 36 48 36 48 8 48 28 48 48
48 38 48 48 48 48 48 48 48 48 48 48 38 48
48 48 28 48 36 48 6 48 6 48 36 48 28 48 48
48 38 48 48 48 48 48 48 48 48 48 48 38 48
48 48 28 48 8 48 36 48 36 48 8 48 28 48 48
48 40 48 44 48 44 48 48 48 44 48 44 48 40 48
48 38 48 16 48 26 48 26 48 16 48 38 48
48 44 48 44 48 44 48 44 48 44 48
48 36 48 32 48 32 48 36 48
48 48 48 48 48 48 48
!*****
TH
state_core      11732.59 1212.66 7.129E+06
!*****
DEPL
time_stp        -0.2535
!*****

/

!*****
! DATASET 33
!*****
CNTL
core_power      99.39
bank_pos        -15
48 48 48 48 48 48 48
48 36 48 32 48 32 48 36 48
48 44 48 44 48 44 48 44 48 44 48
48 38 48 16 48 26 48 26 48 16 48 38 48
48 40 48 44 48 44 48 48 48 44 48 44 48 40 48
48 48 28 48 8 48 36 48 36 48 8 48 28 48 48
48 38 48 48 48 48 48 48 48 48 48 48 38 48
48 48 28 48 36 48 6 48 6 48 36 48 28 48 48
48 38 48 48 48 48 48 48 48 48 48 48 38 48
48 48 28 48 8 48 36 48 36 48 8 48 28 48 48
48 40 48 44 48 44 48 48 48 44 48 44 48 40 48
48 38 48 16 48 26 48 26 48 16 48 38 48
48 44 48 44 48 44 48 44 48 44 48
48 36 48 32 48 32 48 36 48
48 48 48 48 48 48 48
!*****
TH
state_core      12063.63 1214.52 7.129E+06
!*****
DEPL
time_stp        -0.1764
!*****

/

!*****
! DATASET 34
!*****

```

```

CNTL
  core_power    99.00
  bank_pos      -15
                48 48 48 48 48 48 48
                48 36 48 32 48 32 48 36 48
                48 44 48 44 48 44 48 44 48 44 48
                48 38 48 16 48 26 48 26 48 16 48 38 48
                48 40 48 44 48 44 48 48 48 44 48 44 48 40 48
                48 48 28 48 8 48 36 48 36 48 8 48 28 48 48
                48 38 48 48 48 48 48 48 48 48 48 48 38 48
                48 48 28 48 36 48 6 48 6 48 36 48 28 48 48
                48 38 48 48 48 48 48 48 48 48 48 48 38 48
                48 48 28 48 8 48 36 48 36 48 8 48 28 48 48
                48 40 48 44 48 44 48 48 48 44 48 44 48 40 48
                48 38 48 16 48 26 48 26 48 16 48 38 48
                48 44 48 44 48 44 48 44 48 44 48
                48 36 48 32 48 32 48 36 48
                48 48 48 48 48 48 48
!*****
TH
  state_core    12291.93 1215.92 7.122E+06
!*****
DEPL
  time_stp      -0.1653
!*****

/

!*****
! DATASET 35
!*****
CNTL
  core_power    98.94
  bank_pos      -15
                48 48 48 48 48 48 48
                48 36 48 32 48 32 48 36 48
                48 44 48 44 48 44 48 44 48 44 48
                48 38 48 16 48 28 48 28 48 16 48 38 48
                48 40 48 44 48 44 48 48 48 44 48 44 48 40 48
                48 48 28 48 10 48 36 48 36 48 10 48 28 48 48
                48 38 48 48 48 48 48 48 48 48 48 48 38 48
                48 48 34 48 36 48 12 48 12 48 36 48 34 48 48
                48 38 48 48 48 48 48 48 48 48 48 48 38 48
                48 48 28 48 10 48 36 48 36 48 10 48 28 48 48
                48 40 48 44 48 44 48 48 48 44 48 44 48 40 48
                48 38 48 16 48 28 48 28 48 16 48 38 48
                48 44 48 44 48 44 48 44 48 44 48
                48 36 48 32 48 32 48 36 48
                48 48 48 48 48 48 48
!*****
TH
  state_core    12189.20 1214.99 7.177E+06
!*****
DEPL
  time_stp      -0.3748
!*****

/

!*****
! DATASET 36
!*****
CNTL
  core_power    86.79
  bank_pos      -15
                48 48 48 48 48 48 48
                48 48 38 48 40 48 38 48 48
                48 48 32 48 34 48 34 48 32 48 48
                48 48 42 48 44 48 48 48 44 48 42 48 48
                48 48 32 48 36 48 14 48 14 48 36 48 32 48 48
                48 38 48 44 48 48 48 48 48 48 44 48 38 48
                48 48 34 48 14 48 24 48 24 48 14 48 34 48 48
                48 40 48 48 48 48 48 48 48 48 48 48 40 48
                48 48 34 48 14 48 24 48 24 48 14 48 34 48 48
                48 38 48 44 48 48 48 48 48 48 44 48 38 48
                48 48 32 48 36 48 14 48 14 48 36 48 32 48 48
                48 48 42 48 44 48 48 48 44 48 42 48 48
                48 48 32 48 34 48 34 48 32 48 48
                48 48 38 48 40 48 38 48 48
                48 48 48 48 48 48 48
!*****
TH
  state_core    9186.38 1200.11 7.177E+06
!*****
DEPL
  time_stp      -0.3086
!*****

```



```
9 3 5 7 2 4 2 4 2 4 3 4 2 4 2 2 2 4 2 4 3 4 2 4 2 4 2 7 5 3 13 !17
9 2 7 4 7 3 5 2 5 2 5 2 5 2 5 3 3 5 2 5 2 5 2 5 3 7 4 7 2 13 !18
9 3 2 7 2 7 2 7 3 7 2 7 3 7 3 4 4 3 7 3 7 2 7 3 7 2 7 2 7 2 3 13 !19
9 3 4 2 7 2 5 3 5 3 5 2 5 2 5 3 3 5 2 5 2 5 3 5 2 7 2 4 3 13 !20
9 2 2 7 5 7 3 7 2 7 2 7 2 7 2 4 4 2 7 2 7 2 7 3 7 5 7 2 3 13 !21
9 3 5 2 7 3 5 2 5 2 6 3 5 2 5 2 2 2 5 2 5 3 6 2 5 2 5 3 7 2 5 3 13 !22
9 3 2 7 5 7 2 7 3 7 3 7 2 7 3 4 4 3 7 2 7 3 7 3 7 2 7 5 7 2 3 13 !23
16 10 3 2 7 2 4 2 2 3 4 3 5 3 5 2 2 5 3 5 3 4 3 2 2 4 2 7 2 3 12 16 !24
16 16 10 2 5 7 3 7 2 7 2 7 2 7 2 4 4 2 7 2 7 2 7 3 7 5 2 12 16 16 !25
0 16 9 3 3 2 7 2 5 2 5 3 5 3 4 2 2 4 3 5 3 5 2 5 2 7 2 3 3 13 16 0 !26
0 0 16 11 10 3 2 7 2 7 3 7 2 7 2 4 4 2 7 2 7 3 7 2 7 2 3 12 11 16 0 0 !27
0 0 0 16 16 10 3 5 7 5 7 5 7 2 7 2 2 7 2 7 5 7 5 7 5 3 12 16 16 0 0 !28
0 0 0 0 16 9 3 3 2 7 2 7 2 7 2 7 4 7 7 4 7 2 7 2 3 3 13 16 0 0 0 !29
0 0 0 0 0 16 11 10 3 2 5 2 4 2 7 5 5 7 2 4 2 5 2 3 12 11 16 0 0 0 !30
0 0 0 0 0 0 16 16 10 3 3 2 2 3 3 3 3 3 3 2 2 3 3 12 16 16 0 0 0 0 !31
0 0 0 0 0 0 0 16 16 11 11 11 11 11 11 11 11 11 11 11 16 16 0 0 0 0 0 0 !32
```

```
grid_x      32*15.240
neutmesh_x  32*1
grid_y      32*15.240
neutmesh_y  32*1
grid_z      2*10.16 36*10.16 2*10.16
boun_cond   2 2 2 2 2 2
```

```
assy_type    1 2*15 1*1 2*1 9*1 6*1 3*1 9*1 6*1 2*17 FUEL
assy_type    2 2*15 1*2 2*2 9*3 6*3 3*4 9*4 6*4 2*17 FUEL
assy_type    3 2*15 1*5 2*5 9*6 6*7 3*7 9*8 6*9 2*17 FUEL
assy_type    4 2*15 1*10 2*10 9*10 6*10 3*10 9*10 6*10 2*17 FUEL
assy_type    5 2*15 1*11 2*11 9*11 6*11 3*11 9*11 6*11 2*17 FUEL
assy_type    6 2*15 1*12 2*13 9*13 6*13 3*13 9*13 6*13 2*17 FUEL
assy_type    7 2*15 1*14 2*14 9*14 6*14 3*14 9*14 6*14 2*17 FUEL
assy_type    8 2*15 1*19 2*19 9*19 6*19 3*19 9*19 6*19 2*17 REFL !NW
assy_type    9 2*15 1*19 2*19 9*19 6*19 3*19 9*19 6*19 2*17 REFL !W
assy_type   10 2*15 1*20 2*20 9*20 6*20 3*20 9*20 6*20 2*17 REFL !SW
assy_type   11 2*15 1*21 2*21 9*21 6*21 3*21 9*21 6*21 2*17 REFL !S
assy_type   12 2*15 1*22 2*22 9*22 6*22 3*22 9*22 6*22 2*17 REFL !SE
assy_type   13 2*15 1*23 2*23 9*23 6*23 3*23 9*23 6*23 2*17 REFL !E
assy_type   14 2*15 1*24 2*24 9*24 6*24 3*24 9*24 6*24 2*17 REFL !NE
assy_type   15 2*15 1*25 2*25 9*25 6*25 3*25 9*25 6*25 2*17 REFL !N
assy_type   16 2*15 1*16 2*16 9*16 6*16 3*16 9*16 6*16 2*17 REFL
```

! assume stroke = absorber length = 143[in], 48 steps, 365.76[cm]/48 = 7.62[cm]

```
cr_axinfo    22.86 7.62 48 !fully inserted position and step size
```

```
bank_conf
```

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 1 2 2 3 3 4 4 5 5 6 6 7 7 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 8 8 9 9 10 10 11 11 12 12 13 13 14 14 15 15 16 16 0 0 0 0 0 0
0 0 0 0 0 0 8 8 9 9 10 10 11 11 12 12 13 13 14 14 15 15 16 16 0 0 0 0 0 0
0 0 0 0 17 17 18 18 19 19 20 20 21 21 22 22 23 23 24 24 25 25 26 26 27 27 0 0 0 0
0 0 0 0 17 17 18 18 19 19 20 20 21 21 22 22 23 23 24 24 25 25 26 26 27 27 0 0 0 0
0 0 0 28 28 29 29 30 30 31 31 32 32 33 33 34 34 35 35 36 36 37 37 38 38 39 39 40 40 0 0
0 0 0 28 28 29 29 30 30 31 31 32 32 33 33 34 34 35 35 36 36 37 37 38 38 39 39 40 40 0 0
0 41 41 42 42 43 43 44 44 45 45 46 46 47 47 48 48 49 49 50 50 51 51 52 52 53 53 54 54 55 55 0
0 41 41 42 42 43 43 44 44 45 45 46 46 47 47 48 48 49 49 50 50 51 51 52 52 53 53 54 54 55 55 0
0 56 56 57 57 58 58 59 59 60 60 61 61 62 62 63 63 64 64 65 65 66 66 67 67 68 68 69 69 70 70 0
0 56 56 57 57 58 58 59 59 60 60 61 61 62 62 63 63 64 64 65 65 66 66 67 67 68 68 69 69 70 70 0
0 71 71 72 72 73 73 74 74 75 75 76 76 77 77 78 78 79 79 80 80 81 81 82 82 83 83 84 84 85 85 0
0 71 71 72 72 73 73 74 74 75 75 76 76 77 77 78 78 79 79 80 80 81 81 82 82 83 83 84 84 85 85 0
0 86 86 87 87 88 88 89 89 90 90 91 91 92 92 93 93 94 94 95 95 96 96 97 97 98 98 99 99 100 100 0
0 86 86 87 87 88 88 89 89 90 90 91 91 92 92 93 93 94 94 95 95 96 96 97 97 98 98 99 99 100 100 0
0 101 101 102 102 103 103 104 104 105 105 106 106 107 107 108 108 109 109 110 110 111 111 112 112 113 113 114 114 115 115 0
0 101 101 102 102 103 103 104 104 105 105 106 106 107 107 108 108 109 109 110 110 111 111 112 112 113 113 114 114 115 115 0
0 116 116 117 117 118 118 119 119 120 120 121 121 122 122 123 123 124 124 125 125 126 126 127 127 128 128 129 129 130 130 0
0 116 116 117 117 118 118 119 119 120 120 121 121 122 122 123 123 124 124 125 125 126 126 127 127 128 128 129 129 130 130 0
0 131 131 132 132 133 133 134 134 135 135 136 136 137 137 138 138 139 139 140 140 141 141 142 142 143 143 144 144 145 145 0
0 131 131 132 132 133 133 134 134 135 135 136 136 137 137 138 138 139 139 140 140 141 141 142 142 143 143 144 144 145 145 0
0 0 0 146 146 147 147 148 148 149 149 150 150 151 151 152 152 153 153 154 154 155 155 156 156 157 157 158 158 0 0 0
0 0 0 146 146 147 147 148 148 149 149 150 150 151 151 152 152 153 153 154 154 155 155 156 156 157 157 158 158 0 0 0
0 0 0 0 159 159 160 160 161 161 162 162 163 163 164 164 165 165 166 166 167 167 168 168 169 169 0 0 0 0
0 0 0 0 170 170 171 171 172 172 173 173 174 174 175 175 176 176 177 177 178 178 0 0 0 0 0 0
0 0 0 0 170 170 171 171 172 172 173 173 174 174 175 175 176 176 177 177 178 178 0 0 0 0 0 0
0 0 0 0 0 179 179 180 180 181 181 182 182 183 183 184 184 185 185 0 0 0 0 0 0
0 0 0 0 0 179 179 180 180 181 181 182 182 183 183 184 184 185 185 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
adf_rot
```

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 0 0 0 0 0 0
0 0 0 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 0 0 0 0 0 0
0 0 0 0 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 0 0 0 0 0 0
0 0 0 0 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 0 0 0 0 0
0 0 0 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 0 0 0 0 0
0 0 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 0 0 0 0 0
0 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 0
0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 0
```


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```

4 2 2 1 2 1 2 1 2 1 2 1 1 1 1 2 1 2 1 2 1 2 1 2 1 2 2 4
4 2 2 2 1 2 1 2 1 2 1 2 1 1 1 2 1 2 1 2 1 2 1 2 2 2 4
4 1 2 1 2 1 2 1 2 1 2 1 2 2 1 2 1 2 1 2 1 2 1 2 1 2 4
4 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 4
4 1 2 2 2 1 2 1 2 1 2 1 2 2 1 2 1 2 1 2 1 2 1 2 2 1 4
4 2 1 2 1 2 1 2 1 3 1 2 1 2 1 2 1 3 1 2 1 2 1 2 1 2 4
4 1 2 2 2 1 2 1 2 1 2 1 2 2 1 2 1 2 1 2 1 2 1 2 2 1 4
4 1 2 1 2 1 1 1 2 1 2 1 2 1 2 1 2 1 2 1 1 2 1 2 1 4
4 2 2 1 2 1 2 1 2 1 2 1 2 2 1 2 1 2 1 2 1 2 1 2 2 4
4 4 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 4 4
4 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 4
4 2 2 2 2 2 2 1 2 1 2 1 2 2 2 2 2 2 2 2 2 2 4
4 4 1 2 1 2 1 2 1 2 1 2 2 2 2 2 2 2 2 2 1 4 4
4 1 2 1 2 1 2 1 2 1 2 1 2 2 2 2 2 1 2 1 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
!
chan_geom 1 0.0100225 0.0147335 4.57e-05 0.0187452 49 0.0071501 0.0061849 0.0009398 4600.00 0 0.0071501 !
7x7, type 2 & 3
chan_geom 2 0.0100105 0.0131830 4.57e-05 0.0162560 63 0.0062611 0.0052832 0.0008636 4600.00 1 0.0062611 !
8x8, type 4 & 5 & 7, one water rod
chan_geom 3 0.0102095 0.0135964 4.57e-05 0.0162560 62 0.0061341 0.0052070 0.0008128 4600.00 2 0.0075057 !
8x8, type 6, two water rods
chan_geom 4 0.0100225 0.0147335 4.57e-05 0.0187452 49 0.0071501 0.0061849 0.0009398 4600.00 0 0.0071501 !
7x7, type 2 & 3, with periph orifice
!
loss coefficients
ka_chan 1 33.16946 8.82098 0 0 0 1.15335 0 0 0 1.15335 0 0 0 1.15335 0 0 0 1.15335 0 0 0 1.15335 0 0 0 0
1.15335 0 0 0 1.15335 0 0 2.0
ka_chan 2 31.12837 8.27818 0 0 0 1.21265 0 0 0 1.21265 0 0 0 1.21265 0 0 0 1.21265 0 0 0 1.21265 0 0 0 0
1.21265 0 0 0 1.21265 0 0 1.8
ka_chan 3 31.12837 8.27818 0 0 0 1.21265 0 0 0 1.21265 0 0 0 1.21265 0 0 0 1.21265 0 0 0 1.21265 0 0 0 0
1.21265 0 0 0 1.21265 0 0 1.8
ka_chan 4 203.1175 8.82098 0 0 0 1.15335 0 0 0 1.15335 0 0 0 1.15335 0 0 0 1.15335 0 0 0 1.15335 0 0 0 0
1.15335 0 0 0 1.15335 0 0 2.0
.

```

C.11 PARCS Input for the HZP Cycle 3 Fuel Shuffling

```

|*****
CASEID pb-shuff-c2c3
|*****
CNTL
core_type BWR
!-----
th_fdbk F
!-----
rot_adf T
!-----
depletion T 1.0e-3 F
!
tree_xs TREE,nset,adf,xes,ene,jlf,chi,ehd,vel,det,yld,cdf,gff,bet,lam,dht
T 25 T F F F F F F F F F F F F F F
mult_cyc T
!-----
!
input iteration planar adj
! edit table power pin reac
! print_opt T F F
! fdbk flux planar
! rho precurs flux xe/sm T/H
! print_opt F F F
! ld pk rad pwr rad flux assy
! const data shape shape const
! print_opt F F F
|*****
PARAM
nlupd_ss 3 5 1
n_iters 15 5
conv_ss 1.0e-5 1.0e-4 1.0e-3 0.001
wielandt 0.2 0.1 1.0
decusp 2
nodal_kern nemmg
cmfd 2
|*****
XSEC
group_spec 2 1
|*****
GEOM
file './support/pb-cyc2.geom'
|*****
FDBK
fa_powpit 4.3102 15.24
|*****
TH
unif_th 0.4 600.0 300.0

```



```

0 0 0 730 79 -7 105 -7 109 -7 349 -7 312 390 -7 257 -7 110 -7 106 -7 86 685 0 0 0
0 0 713 514 232 -7 290 -7 363 -7 678 -7 -7 639 -7 391 -7 418 -7 412 552 631 0 0
0 0 0 578 342 90 218 166 286 -7 99 100 -7 428 679 252 91 373 725 0 0 0
0 0 0 681 610 321 308 584 444 623 526 548 581 333 196 732 626 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

! Multi-cycle schedule
!
!      itsq  itshufsq  itcyclesq
!      cycle_ind 1 0 1
!      cycle_ind 2 1 1
!      crit.(GWD/T) max itr
!      conv_ec 0.1 2
!*****
.

```

C.12 PARCS Input for the HFP Cycle 3

```

!*****
CASEID pb-cyc3
!*****
CNTL
  core_type      BWR
  core_power     93.41
!-----
  bank_pos      -15
                48 48 48 48 48 48 48
                48 48 48 48 48 48 48 48
                48 36 48 28 48 24 48 28 48 36 48
                48 26 48 14 48 12 48 12 48 14 48 26 48
                48 48 48 40 48 42 48 38 48 42 48 40 48 48 48
                48 48 10 48 14 48 6 48 6 48 14 48 10 48 48
                48 38 48 42 48 42 48 38 48 42 48 42 48 38 48
                48 48 18 48 8 48 14 48 14 48 8 48 18 48 48
                48 38 48 42 48 42 48 38 48 42 48 42 48 38 48
                48 48 10 48 14 48 6 48 6 48 14 48 10 48 48
                48 48 48 40 48 42 48 38 48 42 48 40 48 48 48
                48 26 48 14 48 12 48 12 48 14 48 26 48
                48 36 48 28 48 24 48 28 48 36 48
                48 48 48 48 48 48 48 48
                48 48 48 48 48 48 48
!-----
  th_fdbk      T
  int_th       T 1 'paths-pb-cyc3.inp'
!-----
  xe_sm        1 1
  rot_adf      T
  detector      T 3293.0 2
!-----
  depletion     T 1.0e-3 F
!      TREE,nset,adf,xes,ene,jlf,chi,chn,vel,det,yld,cdf,gff,bet,lam,dht
  tree_xs      T 25 T T F F F F F T T F F T T F T
!-----
!      input iteration planar adj
!      edit table power pin reac
!      print_opt T F F F
!      fdbk flux planar
!      rho precurs flux xe/sm T/H
!      print_opt F F F F
!      1d pk rad pwr rad flux assy
!      const data shape shape const
!      print_opt F F F F
!*****
PARAM
  nlupd_ss      3 5 1
  n_iters       15 200
  conv_ss       1.0e-5 1.0e-4 1.0e-3 0.001
  wielandt      0.2 0.1 1.0
  decusp        2
  nodal_kern     nemmg
  cmfd          2
!*****
XSEC
  group_spec    2 1
!*****
GEOM
  file          './support/pb-cyc3.geom'
!*****
FDBK
  fa_powpit     4.3102 15.24
!*****
DEPL
  satu_den      0.737 0.03753
  bank_nr       185*1
  time_stp      -0.2227

```

```

inp_hst      'pb-shuff-c2c3.parc_cyc-02' 1 1
inp_opt      F F F F                      ! ppm,crp,ths,xesm

hst_opt      T T F T F                    ! hcr, hdc, hpc, htf, htc
out_opt      T T F F F                    ! ppow,phst,pths,pxesm,pxss

file         './support/pb-pmaxfiles'

!*****

/

!*****
! DATASET 39
!*****
CNTL
  core_power  94.96
  bank_pos    -15
                48 48 48 48 48 48 48
                48 48 38 48 30 48 38 48 48
                48 48 40 48 48 48 48 48 40 48 48
                48 48 34 48 12 48 14 48 12 48 34 48 48
                48 48 40 48 48 48 48 48 48 48 48 40 48 48
                48 38 48 12 48 12 48 18 48 12 48 12 48 38 48
                48 48 48 48 48 32 48 32 48 48 48 48 48 48
                48 30 48 14 48 18 48 6 48 18 48 14 48 30 48
                48 48 48 48 48 32 48 32 48 48 48 48 48 48
                48 38 48 12 48 12 48 18 48 12 48 12 48 38 48
                48 48 40 48 48 48 48 48 48 48 48 40 48 48
                48 48 34 48 12 48 14 48 12 48 34 48 48
                48 48 40 48 48 48 48 48 40 48 48
                48 48 38 48 30 48 38 48 48
                48 48 48 48 48 48 48

!*****
TH
  state_core  10900.06 1210.80 7.102E+06
!*****
DEPL
  time_stp    -0.9017
!*****

/

!*****
! DATASET 40
!*****
CNTL
  core_power  96.81
  bank_pos    -15
                48 48 48 48 48 48 48
                48 48 38 48 30 48 38 48 48
                48 48 40 48 48 48 48 48 40 48 48
                48 48 28 48 12 48 14 48 12 48 28 48 48
                48 48 40 48 48 48 48 48 48 48 48 40 48 48
                48 38 48 12 48 12 48 16 48 12 48 12 48 38 48
                48 48 48 48 48 32 48 32 48 48 48 48 48 48
                48 30 48 14 48 16 48 6 48 16 48 14 48 30 48
                48 48 48 48 48 32 48 32 48 48 48 48 48 48
                48 38 48 12 48 12 48 16 48 12 48 12 48 38 48
                48 48 40 48 48 48 48 48 48 48 48 40 48 48
                48 48 28 48 12 48 14 48 12 48 28 48 48
                48 48 40 48 48 48 48 48 40 48 48
                48 48 38 48 30 48 38 48 48
                48 48 48 48 48 48 48

!*****
TH
  state_core  11462.11 1213.36 7.088E+06
!*****
DEPL
  time_stp    -0.3858
!*****

/

!*****
! DATASET 41
!*****
CNTL
  core_power  89.83
  bank_pos    -15
                48 48 48 48 48 48 48
                48 48 48 42 48 42 48 48 48
                48 32 48 20 48 22 48 20 48 32 48
                48 48 48 48 48 44 48 44 48 48 48 48 48
                48 38 48 14 48 32 48 10 48 32 48 14 48 38 48
                48 48 48 48 48 44 48 44 48 48 48 48 48 48
                48 34 48 12 48 12 48 14 48 12 48 12 48 34 48
                48 48 40 48 36 48 42 48 42 48 36 48 40 48 48

```

```

48 34 48 12 48 12 48 14 48 12 48 12 48 34 48
48 48 48 48 48 48 44 48 44 48 48 48 48 48 48
48 38 48 14 48 32 48 10 48 32 48 14 48 38 48
48 48 48 48 48 44 48 44 48 48 48 48 48
48 32 48 20 48 22 48 20 48 32 48
48 48 48 42 48 42 48 48 48
48 48 48 48 48 48 48

!*****
TH
state_core      9742.36 1203.83 7.067E+06
!*****
DEPL
time_stp        -0.6173
!*****

/

!*****
! DATASET 42
!*****
CNTL
core_power      99.18
bank_pos        -15
48 48 48 48 48 48 48
48 48 42 48 38 48 42 48 48
48 48 18 48 30 48 30 48 18 48 48
48 48 44 48 48 48 42 48 48 48 44 48 48
48 48 18 48 34 48 10 48 10 48 34 48 18 48 48
48 42 48 48 48 48 48 42 48 48 48 48 48 42 48
48 48 30 48 10 48 22 48 22 48 10 48 30 48 48
48 38 48 42 48 42 48 42 48 42 48 42 48 38 48
48 48 30 48 10 48 22 48 22 48 10 48 30 48 48
48 42 48 48 48 48 48 42 48 48 48 48 42 48
48 48 18 48 34 48 10 48 10 48 34 48 18 48 48
48 48 44 48 48 48 42 48 48 48 44 48 48
48 48 18 48 30 48 30 48 18 48 48
48 48 42 48 38 48 42 48 48
48 48 48 48 48 48 48

!*****
TH
state_core      11765.64 1213.01 7.157E+06
!*****
DEPL
time_stp        -0.8333
!*****

/

!*****
! DATASET 43
!*****
CNTL
core_power      96.63
bank_pos        -15
48 48 48 48 48 48 48
48 48 42 48 38 48 42 48 48
48 48 18 48 30 48 30 48 18 48 48
48 48 44 48 48 48 42 48 48 48 44 48 48
48 48 18 48 34 48 10 48 10 48 34 48 18 48 48
48 42 48 48 48 48 48 42 48 48 48 48 48 42 48
48 48 30 48 10 48 22 48 22 48 10 48 30 48 48
48 38 48 42 48 42 48 42 48 42 48 42 48 38 48
48 48 30 48 10 48 22 48 22 48 10 48 30 48 48
48 42 48 48 48 48 48 42 48 48 48 48 42 48
48 48 18 48 34 48 10 48 10 48 34 48 18 48 48
48 48 44 48 48 48 42 48 48 48 44 48 48
48 48 18 48 30 48 30 48 18 48 48
48 48 42 48 38 48 42 48 48
48 48 48 48 48 48 48

!*****
TH
state_core      11799.37 1214.36 7.157E+06
!*****
DEPL
time_stp        -0.3616
!*****

/

!*****
! DATASET 44
!*****
CNTL
core_power      97.48
bank_pos        -15
48 48 48 48 48 48 48
48 38 48 36 48 36 48 38 48
48 48 48 42 48 48 48 42 48 48 48

```

```

48 30 48 10 48 24 48 24 48 10 48 30 48
48 48 48 48 48 48 48 44 48 48 48 48 48 48
48 48 16 48 38 48 16 48 16 48 38 48 16 48 48
48 40 48 48 48 42 48 48 48 42 48 48 48 40 48
48 48 32 48 12 48 32 48 32 48 12 48 32 48 48
48 40 48 48 48 42 48 48 48 42 48 48 48 40 48
48 48 16 48 38 48 16 48 16 48 38 48 16 48 48
48 48 48 48 48 48 48 44 48 48 48 48 48 48
48 30 48 10 48 24 48 24 48 10 48 30 48
48 48 48 42 48 48 48 42 48 48 48
48 38 48 36 48 36 48 38 48
48 48 48 48 48 48 48

!*****
TH
state_core      11731.92 1213.55 7.143E+06
!*****
DEPL
time_stp        -0.2183
!*****

/

!*****
! DATASET 45
!*****
CNTL
core_power      95.48
bank_pos        -15

48 48 48 48 48 48 48 48
48 38 48 36 48 36 48 38 48
48 48 48 42 48 48 48 42 48 48 48
48 30 48 10 48 24 48 24 48 10 48 30 48
48 48 48 48 48 48 48 44 48 48 48 48 48 48
48 48 16 48 38 48 16 48 16 48 38 48 16 48 48
48 40 48 48 48 42 48 48 48 42 48 48 48 40 48
48 48 32 48 12 48 32 48 32 48 12 48 32 48 48
48 40 48 48 48 42 48 48 48 42 48 48 48 40 48
48 48 16 48 38 48 16 48 16 48 38 48 16 48 48
48 48 48 48 48 48 48 44 48 48 48 48 48 48
48 30 48 10 48 24 48 24 48 10 48 30 48
48 48 48 42 48 48 48 42 48 48 48
48 38 48 36 48 36 48 38 48
48 48 48 48 48 48 48

!*****
TH
state_core      11788.13 1215.20 7.102E+06
!*****
DEPL
time_stp        -0.4949
!*****

/

!*****
! DATASET 46
!*****
CNTL
core_power      99.51
bank_pos        -15

48 48 48 48 48 48 48 48
48 48 38 48 34 48 38 48 48
48 48 40 48 48 48 48 48 40 48 48
48 48 34 48 20 48 38 48 20 48 34 48 48
48 48 40 48 48 48 48 48 48 48 48 40 48 48
48 38 48 20 48 40 48 14 48 40 48 20 48 38 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 34 48 38 48 14 48 38 48 14 48 38 48 34 48
48 48 48 48 48 48 48 48 48 48 48 48 48 48
48 38 48 20 48 40 48 14 48 40 48 20 48 38 48
48 48 40 48 48 48 48 48 48 48 48 40 48 48
48 48 34 48 20 48 38 48 20 48 34 48 48
48 48 40 48 48 48 48 48 40 48 48
48 48 38 48 34 48 38 48 48
48 48 48 48 48 48 48

!*****
TH
state_core      11012.46 1208.78 7.150E+06
!*****
DEPL
time_stp        -0.6184
!*****

/

!*****
! DATASET 47
!*****
CNTL

```

```

core_power      99.79
bank_pos        -15

      48 48 48 48 48 48 48 48
      48 48 48 40 48 40 48 48 48
      48 38 48 30 48 38 48 30 48 38 48
      48 34 48 48 48 48 48 48 48 48 48 34 48
      48 48 48 12 48 34 48 26 48 34 48 12 48 48 48
      48 48 44 48 48 48 48 48 48 48 48 44 48 48
      48 30 48 42 48 28 48 44 48 28 48 42 48 30 48
      48 48 48 48 48 48 48 48 48 48 48 48 48 48
      48 30 48 42 48 28 48 44 48 28 48 42 48 30 48
      48 48 44 48 48 48 48 48 48 48 48 44 48 48
      48 48 48 12 48 34 48 26 48 34 48 12 48 48 48
      48 34 48 48 48 48 48 48 48 48 48 48 34 48
      48 38 48 30 48 38 48 30 48 38 48
      48 48 48 40 48 40 48 48 48
      48 48 48 48 48 48 48
!*****
TH
  state_core      11214.80 1209.36 7.184E+06
!*****
DEPL
  time_stp        -0.4045
!*****

/

!*****
! DATASET 48
!*****
CNTL
  core_power      96.30
  bank_pos        -15

      48 48 48 48 48 48 48 48
      48 48 48 40 48 40 48 48 48
      48 38 48 30 48 38 48 30 48 38 48
      48 34 48 48 48 48 48 48 48 48 48 34 48
      48 48 48 12 48 34 48 26 48 34 48 12 48 48 48
      48 48 44 48 48 48 48 48 48 48 48 44 48 48
      48 30 48 48 48 28 48 44 48 28 48 48 48 30 48
      48 48 48 48 48 48 48 48 48 48 48 48 48 48
      48 30 48 48 48 28 48 44 48 28 48 48 48 30 48
      48 48 44 48 48 48 48 48 48 48 48 44 48 48
      48 48 48 12 48 34 48 26 48 34 48 12 48 48 48
      48 34 48 48 48 48 48 48 48 48 48 48 34 48
      48 38 48 30 48 38 48 30 48 38 48
      48 48 48 40 48 40 48 48 48
      48 48 48 48 48 48 48
!*****
TH
  state_core      11788.13 1214.41 7.150E+06
!*****
DEPL
  time_stp        -0.3197
!*****

/

!*****
! DATASET 49
!*****
CNTL
  core_power      93.23
  bank_pos        -15

      48 48 48 48 48 48 48 48
      48 48 36 48 26 48 36 48 48
      48 48 40 48 48 48 48 48 40 48 48
      48 48 28 48 10 48 40 48 10 48 28 48 48
      48 48 40 48 48 48 48 48 48 48 48 40 48 48
      48 36 48 10 48 38 48 20 48 38 48 10 48 36 48
      48 48 48 48 48 48 48 48 48 48 48 48 48 48
      48 26 48 40 48 20 48 44 48 20 48 40 48 26 48
      48 48 48 48 48 48 48 48 48 48 48 48 48 48
      48 36 48 10 48 38 48 20 48 38 48 10 48 36 48
      48 48 40 48 48 48 48 48 48 48 48 40 48 48
      48 48 28 48 10 48 40 48 10 48 28 48 48
      48 48 40 48 48 48 48 48 48 40 48 48
      48 48 36 48 26 48 36 48 48
      48 48 48 48 48 48 48
!*****
TH
  state_core      11765.64 1206.90 7.157E+06
!*****
DEPL
  time_stp        -0.3373
!*****

/

```

```

!*****
! DATASET 50
!*****
CNTL
    core_power      95.44
    bank_pos        -15
                48 48 48 48 48 48 48
                40 48 38 48 34 48 38 48 40
                48 48 48 48 48 48 48 48 48 48
                40 48 36 48 22 48 42 48 22 48 36 48 40
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 38 48 22 48 42 48 36 48 42 48 22 48 38 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 34 48 42 48 36 48 48 48 36 48 42 48 34 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 38 48 22 48 42 48 36 48 42 48 22 48 38 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                40 48 36 48 22 48 42 48 22 48 36 48 40
                48 48 48 48 48 48 48 48 48 48 48 48
                40 48 38 48 34 48 38 48 40
                48 48 48 48 48 48 48
!*****
TH
    state_core      11821.85 1206.34 7.136E+06
!*****
DEPL
    time_stp        -0.5677
!*****

/

!*****
! EOC 3
!*****
CNTL
    core_power      95.44
    bank_pos        -15
                48 48 48 48 48 48 48
                40 48 38 48 34 48 38 48 40
                48 48 48 48 48 48 48 48 48 48
                40 48 36 48 22 48 42 48 22 48 36 48 40
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 38 48 22 48 42 48 36 48 42 48 22 48 38 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 34 48 42 48 36 48 48 48 36 48 42 48 34 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                48 38 48 22 48 42 48 36 48 42 48 22 48 38 48
                48 48 48 48 48 48 48 48 48 48 48 48 48 48
                40 48 36 48 22 48 42 48 22 48 36 48 40
                48 48 48 48 48 48 48 48 48 48 48 48
                40 48 38 48 34 48 38 48 40
                48 48 48 48 48 48 48
!*****
TH
    state_core      11821.85 1206.34 7.136E+06
!*****
DEPL
    time_stp        -0.5026
!*****

```

APPENDIX D. PROGRAM TO COMPARE TIPS DATA FOR BWR

D.1 Program Source

```
program CompareTips
!
implicit none
!
character(2) :: ss2
character(3) :: ss3
character(4) :: ss4
character(5) :: ss5
character(400) :: ssw
integer :: i,j,k,m,n,iorder,icase,ipic,idum
logical :: kr
real :: sum0,dum,rmsn,rmsr,rmsa,total(1000),sum1,sum2,sum3
character(30) :: file_tips,file_parcs_dpl,file_parcs_det
integer :: levels,tstrings,ncases,npoints,ntipdata
integer :: ndets,naxials
!tips data
type tips_type
integer :: icase,ibu_parcs
real :: power,burnup0,burnup,burnup_parcs
real,allocatable :: tipdata(:,::),tipradial(:,::),tipaxial(:,::),tipdiff(:,::)
logical,allocatable :: loctips(:,::)
character(7),allocatable :: tipname(:,::)
end type
type(tips_type),pointer :: tips(:,::),tips_parcs(:,::)
type(tips_type),pointer :: tip1,tip2
real,allocatable :: axialrms(:,::),axialave(:,::),axialmax(:,::)
!
!read input file
open(1,file='comparetips.in',status='old')
read(1,*) ss3,tstrings,levels !# of detectors, # of axials
read(1,*) ss3,file_tips !tips measured data
read(1,*) ss3,file_parcs_dpl !parcs *.dpl file
read(1,*) ss3,file_parcs_det !parcs *.det file
!
!read tips measured data
open(11,file=file_tips,status='old')
read(11,*)
read(11,*) ncases,ndets,naxials
if (ndets .ne. tstrings .or. naxials .ne. levels) then
write(6,*) "Error: ndets .ne. tstrings .or. naxials .ne. levels"
stop
endif
allocate(tips(ncases))
do i=1,ncases
allocate(tips(i)%tipdata(ndets,naxials))
allocate(tips(i)%tipname(ndets))
allocate(tips(i)%tipradial(ndets))
allocate(tips(i)%tipaxial(naxials))
allocate(tips(i)%tipdiff(ndets))
allocate(tips(i)%loctips(ndets))
read(11,*) ss4,tips(i)%icase,tips(i)%power,tips(i)%burnup0, &
tips(i)%burnup,tips(i)%burnup_parcs,tips(i)%ibu_parcs
read(11,*) (tips(i)%tipname(j),j=1,ndets)
do k=1,naxials
read(11,*) (tips(i)%tipdata(j,k),j=1,ndets)
enddo
enddo
close(11)
!
!read the PARCS output
open(12,file=file_parcs_dpl,status='old')
read(12,*) ; read(12,*) ; read(12,*) ; read(12,*) ;
read(12,*) ss2
if (ss2 .ne. 'PT') then
write(6,*) "Error: data structure is wrong!"
stop
endif
do i=1,1000
read(12,'(a400)',end=111) ssw
read(ssw,*,err=111) iorder
enddo
111 continue
npoints=iorder
allocate(tips_parcs(npoints))
rewind(12)
```

```

read(12,*); read(12,*); read(12,*); read(12,*); read(12,*)
do i=1,npoints
    read(12,'(a400)') ssw
    read(ssw(70:80),*) tips_parcs(i)%burnup_parcs
enddo
close(12)

!
!read the PARCS TIPS data axially reverse order
open(13,file=file_parcs_det,status='old')
read(13,*)
do i=1,npoints
    allocate(tips_parcs(i)%tipdata(ndets,naxials))
    allocate(tips_parcs(i)%tipname(ndets))
    allocate(tips_parcs(i)%tipradial(ndets))
    allocate(tips_parcs(i)%tipaxial(naxials))
    read(13,*) ss5,ss5,ss5,ss5,(tips_parcs(i)%tipname(j),j=1,ndets)
    do k=naxials,1,-1
        read(13,*) dum,idum,idum,idum,(tips_parcs(i)%tipdata(j,k),j=1,ndets)
    enddo
enddo
close(13)

!
! normalize psracs tip data
do i=1,npoints
    sum0=0.0
    do j=1,tstrings
        do k=1,levels
            sum0=sum0+tips_parcs(i)%tipdata(j,k)
        enddo
    enddo
    do j=1,tstrings
        do k=1,levels
            tips_parcs(i)%tipdata(j,k)=tips_parcs(i)%tipdata(j,k)/sum0*float(tstrings*levels)
        enddo
    enddo
enddo

!
!calculate average power shape information
!initialization
do i=1,npoints
    tips_parcs(i)%tipradial(:)=0.0
    tips_parcs(i)%tipaxial(:)=0.0
    total(i)=0.0
enddo
!calculate radial
do i=1,npoints
    do j=1,tstrings
        do k=1,levels
            tips_parcs(i)%tipradial(j)=tips_parcs(i)%tipradial(j)+tips_parcs(i)%tipdata(j,k)
            total(i)=total(i)+tips_parcs(i)%tipdata(j,k)
        enddo
    enddo
enddo
! normalize radial
do i=1,npoints
    do j=1,tstrings
        tips_parcs(i)%tipradial(j)=tips_parcs(i)%tipradial(j)/total(i)*float(tstrings)
    enddo
enddo

!
! calculate axial
do i=1,npoints
    do k=1,levels
        do j=1,tstrings
            tips_parcs(i)%tipaxial(k)=tips_parcs(i)%tipaxial(k)+tips_parcs(i)%tipdata(j,k)
        enddo
    enddo
enddo
! normalize axial
do i=1,npoints
    total(i)=0.0
enddo
do i=1,npoints
    do k=1,levels
        total(i)=total(i)+tips_parcs(i)%tipaxial(k)
    enddo
enddo
do i=1,npoints
    do k=1,levels
        tips_parcs(i)%tipaxial(k)=tips_parcs(i)%tipaxial(k)/total(i)*float(levels)
    enddo
enddo

```

```

enddo

! Loop over the measured cases =====
open(2,file='CompareTips.out',status='unknown')
open(3,file='CompareTips_detail.out',status='unknown')
open(4,file='CompareTips.sum',status='unknown')
allocate(axialrms(tstrings),axialave(tstrings),axialmax(tstrings))
do ica=1,ncases
  tip1=>tips(ica)
  !normalize measured tips data
  sum0=0.0
  do j=1,tstrings
    do k=1,levels
      sum0=sum0+tip1%tipdata(j,k)
    enddo
  enddo
  do j=1,tstrings
    do k=1,levels
      tip1%tipdata(j,k)=tip1%tipdata(j,k)/sum0*float(tstrings*levels)
    enddo
  enddo
  !calculate radial array with normalization
  tip1%tipradial(:)=0.0
  sum0=0.0
  do j=1,tstrings
    do k=1,levels
      tip1%tipradial(j)=tip1%tipradial(j)+tip1%tipdata(j,k)
      sum0=sum0+tip1%tipdata(j,k)
    enddo
  enddo
  tip1%tipradial(j)=tip1%tipradial(j)/sum0*float(tstrings)
  enddo
  !calculate axial array with normalization
  tip1%tipaxial(:)=0.0
  sum0=0.0
  do k=1,levels
    do j=1,tstrings
      tip1%tipaxial(k)=tip1%tipaxial(k)+tip1%tipdata(j,k)
      sum0=sum0+tip1%tipdata(j,k)
    enddo
  enddo
  do k=1,levels
    tip1%tipaxial(k)=tip1%tipaxial(k)/sum0*float(levels)
  enddo

!search for the corresponding parcs burnup point
ipic=tip1%ibu_parcs
tip2=>tips_parcs(ipic)
!check the consistency for detector names
kr=.false.
do j=1,tstrings
  if (tip1%tipname(j) .ne. tip2%tipname(j)) then
    write(6,*) "Error: TIP names are different!",j, &
      tips(ica)%tipname(j),tip2%tipname(j)
    stop
  endif
enddo
!compare
rmsn=0.0
rmsr=0.0
rmsa=0.0
do j=1,tstrings
  do k=1,levels
    rmsn=rmsn+(tip1%tipdata(j,k)-tip2%tipdata(j,k))**2
  enddo
  rmsr=rmsr+(tip1%tipradial(j)-tip2%tipradial(j))**2
  tip1%tipdiff(j)=(tip2%tipradial(j)-tip1%tipradial(j))*100.0
enddo

do k=1,levels
  rmsa=rmsa+(tip1%tipaxial(k)-tip2%tipaxial(k))**2
enddo

rmsn=sqrt(rmsn/float(tstrings*levels))*100.0
rmsr=sqrt(rmsr/float(tstrings))*100.0
rmsa=sqrt(rmsa/float(levels))*100.0
! print outputs

write(2,'(a6,i4,2x,70("-"))') '$CASE:',ica
write(2,*)

```

```

write(2,*) '@general information'
write(2, ' (2x,a37,f6.0) ') 'core exposure [mwd/short-ton]:      ', tip1%burnup0
write(2, ' (2x,a37,f6.3) ') 'core exposure [gwd/tonne]:        ', tip1%burnup
write(2, ' (2x,a37,f6.3) ') 'parcs core exposure [gwd/tonne]:   ', tip2%burnup_parcs
write(2, ' (2x,a37,i2) ') 'depletion point in parcs:          ', ipic
write(2, ' (2x,a37,i2) ') 'associated dataset:                ', tip1%icase
write(2, ' (2x,a37,f5.2) ') '3D nodal rms difference [%]:      ', rmsn
write(2, ' (2x,a37,f5.2) ') 'radial rms difference [%]:        ', rmsr
write(2, ' (2x,a37,f5.2) ') 'axial rms difference [%]:          ', rmsa
write(2,*)

if (icase == 1) write(4,*) "SUMMARY"
write(4, ' (i5,f9.3,3f8.2) ') icase, tip2%burnup_parcs, rmsn, rmsr, rmsa

write(2,*) '@axially integrated radial distribution'
write(2,*) ' tip name'
write(2,*) ' calculated'
write(2,*) ' measured'
write(2,*) ' difference(%)'
write(2,*) ' '
write(2, fmt=' (1x,6a10) ') ' ', (tip1%tipname(m), m=27, 31)
write(2, fmt=' (1a10,5f10.4) ') ' ', (tip2%tipradial(m), m=27, 31)
write(2, fmt=' (1a10,5f10.4) ') ' ', (tip1%tipradial(m), m=27, 31)
write(2, fmt=' (1a10,5f10.3) ') ' ', (tip1%tipdiff(m), m=27, 31)
!write(2,*)
write(2, fmt=' (1x,6a10) ') (tip1%tipname(m), m=21, 26)
write(2, fmt=' (6f10.4) ') (tip2%tipradial(m), m=21, 26)
write(2, fmt=' (6f10.4) ') (tip1%tipradial(m), m=21, 26)
write(2, fmt=' (6f10.3) ') (tip1%tipdiff(m), m=21, 26)
!write(2,*)
write(2, fmt=' (1x,6a10) ') (tip1%tipname(m), m=15, 20)
write(2, fmt=' (6f10.4) ') (tip2%tipradial(m), m=15, 20)
write(2, fmt=' (6f10.4) ') (tip1%tipradial(m), m=15, 20)
write(2, fmt=' (6f10.3) ') (tip1%tipdiff(m), m=15, 20)
!write(2,*)
write(2, fmt=' (1x,6a10) ') (tip1%tipname(m), m=9, 14)
write(2, fmt=' (6f10.4) ') (tip2%tipradial(m), m=9, 14)
write(2, fmt=' (6f10.4) ') (tip1%tipradial(m), m=9, 14)
write(2, fmt=' (6f10.3) ') (tip1%tipdiff(m), m=9, 14)
!write(2,*)
write(2, fmt=' (1x,6a10) ') ' ', (tip1%tipname(m), m=4, 8)
write(2, fmt=' (1a10,5f10.4) ') ' ', (tip2%tipradial(m), m=4, 8)
write(2, fmt=' (1a10,5f10.4) ') ' ', (tip1%tipradial(m), m=4, 8)
write(2, fmt=' (1a10,5f10.3) ') ' ', (tip1%tipdiff(m), m=4, 8)
!write(2,*)
write(2, fmt=' (1x,6a10) ') ' ', ' ', (tip1%tipname(m), m=1, 3), ' '
write(2, fmt=' (2a10,3f10.4,1a10) ') ' ', ' ', (tip2%tipradial(m), m=1, 3), ' '
write(2, fmt=' (2a10,3f10.4,1a10) ') ' ', ' ', (tip1%tipradial(m), m=1, 3), ' '
write(2, fmt=' (2a10,3f10.3,1a10) ') ' ', ' ', (tip1%tipdiff(m), m=1, 3), ' '
write(2,*) ' '
write(2,*) '@radially integrated axial distribution'
write(2,*)
sum0=sum(tip1%tipaxial(:))
sum1=sum(tip1%tipaxial(1:levels/2))
sum2=sum(tip2%tipaxial(:))
sum3=sum(tip2%tipaxial(1:levels/2))
write(2,*)
write(2, ' (" node calc. meas. diff.(%)") ')
do k=levels,1,-1
  write(2, ' (2x,i4,2f10.4,f10.2) ') k, tip2%tipaxial(k), tip1%tipaxial(k), &
    (tip2%tipaxial(k)-tip1%tipaxial(k))*100.0
enddo
write(2,*)
write(2, ' (6x,2f10.4,f10.2, " axial offset") ') 1.0-2.0*sum3/sum2, &
  1.0-2.0*sum1/sum0, -2.0*(sum3/sum2-sum1/sum0)*100.0
write(2,*)

!
write(3, ' (a6,i4,2x,70("-")) ') '$CASE:', icase
write(3,*)
write(3,*) '@general information'
write(3, ' (2x,a37,f6.0) ') 'core exposure [mwd/short-ton]:      ', tip1%burnup0
write(3, ' (2x,a37,f6.3) ') 'core exposure [gwd/tonne]:        ', tip1%burnup
write(3, ' (2x,a37,f6.3) ') 'parcs core exposure [gwd/tonne]:   ', tip2%burnup_parcs
write(3, ' (2x,a37,i2) ') 'depletion point in parcs:          ', ipic
write(3, ' (2x,a37,i2) ') 'associated dataset:                ', tip1%icase
write(3, ' (2x,a37,f5.2) ') '3D nodal rms difference [%]:      ', rmsn
write(3, ' (2x,a37,f5.2) ') 'radial rms difference [%]:        ', rmsr
write(3, ' (2x,a37,f5.2) ') 'axial rms difference [%]:          ', rmsa
write(3,*)
write(3, ' (2x,80a14) ') (tip1%tipname(j), j=1, tstrings)
axialrms(:)=0.0

```

```

axialave(:)=0.0
axialmax(:)=0.0
do k=1,levels
  do j=1,tstrings
    axialrms(j)=axialrms(j)+(tip1%tipdata(j,k)-tip2%tipdata(j,k))**2
    axialave(j)=axialave(j)+(tip2%tipdata(j,k)-tip1%tipdata(j,k))
    if (abs(tip2%tipdata(j,k)-tip1%tipdata(j,k)) > abs(axialmax(j))) then
      axialmax(j)=tip2%tipdata(j,k)-tip1%tipdata(j,k)
    endif
  enddo
enddo
tips(icasel)%loctips(:)=.true.
do j=1,tstrings
  axialrms(j)=sqrt(axialrms(j)/float(levels))
  axialave(j)=axialave(j)/float(levels)
  if (abs(axialmax(j)*100.0) > 30.0 .or. axialrms(j)*100.0 > 20.0) then
    tips(icasel)%loctips(j)=.false.
  endif
enddo
do k=1,levels
  write(3,'(i4,80(2f6.3,2x))') k,(tip1%tipdata(j,k),tip2%tipdata(j,k),j=1,tstrings)
enddo
write(3,*)
write(3,'(a4,80(6x,f6.2,2x))') " RMS", (axialrms(j)*100.0,j=1,tstrings)
write(3,'(a4,80(6x,f6.2,2x))') " AVE", (axialave(j)*100.0,j=1,tstrings)
write(3,'(a4,80(6x,f6.2,2x))') " MAX", (axialmax(j)*100.0,j=1,tstrings)
write(3,*)
!
!compare
rmsn=0.0
rmsr=0.0
rmsa=0.0
ntipdata=0
do j=1,tstrings
  if (.not.tips(icasel)%loctips(j)) cycle
  ntipdata=ntipdata+1
enddo
!Renormalization
!normalize measured tips data
sum0=0.0
do j=1,tstrings
  if (.not.tips(icasel)%loctips(j)) cycle
  do k=1,levels
    sum0=sum0+tip1%tipdata(j,k)
  enddo
enddo
do j=1,tstrings
  if (.not.tips(icasel)%loctips(j)) cycle
  do k=1,levels
    tip1%tipdata(j,k)=tip1%tipdata(j,k)/sum0*float(ntipdata*levels)
  enddo
enddo
!calculate radial array with normalization
sum0=0.0
tip1%tipradial(:)=0.0
do j=1,tstrings
  if (.not.tips(icasel)%loctips(j)) cycle
  do k=1,levels
    tip1%tipradial(j)=tip1%tipradial(j)+tip1%tipdata(j,k)
    sum0=sum0+tip1%tipdata(j,k)
  enddo
enddo
do j=1,tstrings
  if (.not.tips(icasel)%loctips(j)) cycle
  tip1%tipradial(j)=tip1%tipradial(j)/sum0*float(ntipdata)
enddo
!calculate axial array with normalization
tip1%tipaxial(:)=0.0
sum0=0.0
do k=1,levels
  do j=1,tstrings
    if (.not.tips(icasel)%loctips(j)) cycle
    tip1%tipaxial(k)=tip1%tipaxial(k)+tip1%tipdata(j,k)
    sum0=sum0+tip1%tipdata(j,k)
  enddo
enddo
do k=1,levels
  tip1%tipaxial(k)=tip1%tipaxial(k)/sum0*float(levels)
enddo
!normalize calculated tips data
sum0=0.0

```

```

do j=1,tstrings
  if (.not.tips(icas)%loctips(j)) cycle
  do k=1,levels
    sum0=sum0+tip2%tipdata(j,k)
  enddo
enddo
do j=1,tstrings
  if (.not.tips(icas)%loctips(j)) cycle
  do k=1,levels
    tip2%tipdata(j,k)=tip2%tipdata(j,k)/sum0*float(ntipdata*levels)
  enddo
enddo
!calculate radial array with normalization
sum0=0.0
tip2%tipradial(:)=0.0
do j=1,tstrings
  if (.not.tips(icas)%loctips(j)) cycle
  do k=1,levels
    tip2%tipradial(j)=tip2%tipradial(j)+tip2%tipdata(j,k)
    sum0=sum0+tip2%tipdata(j,k)
  enddo
enddo
do j=1,tstrings
  if (.not.tips(icas)%loctips(j)) cycle
  tip2%tipradial(j)=tip2%tipradial(j)/sum0*float(ntipdata)
enddo
!calculate axial array with normalization
tip2%tipaxial(:)=0.0
sum0=0.0
do k=1,levels
  do j=1,tstrings
    if (.not.tips(icas)%loctips(j)) cycle
    tip2%tipaxial(k)=tip2%tipaxial(k)+tip2%tipdata(j,k)
    sum0=sum0+tip2%tipdata(j,k)
  enddo
enddo
do k=1,levels
  tip2%tipaxial(k)=tip2%tipaxial(k)/sum0*float(levels)
enddo
!
do j=1,tstrings
  if (.not.tips(icas)%loctips(j)) cycle
  do k=1,levels
    rmsn=rmsn+(tip1%tipdata(j,k)-tip2%tipdata(j,k))**2
  enddo
  rmsr=rmsr+(tip1%tipradial(j)-tip2%tipradial(j))**2
  tip1%tipdiff(j)=(tip2%tipradial(j)-tip1%tipradial(j))*100.0
enddo
do k=1,levels
  rmsa=rmsa+(tip1%tipaxial(k)-tip2%tipaxial(k))**2
enddo

rmsn=sqrt(rmsn/float(tstrings*levels))*100.0
rmsr=sqrt(rmsr/float(tstrings))*100.0
rmsa=sqrt(rmsa/float(levels))*100.0
!
write(3,*) "Statistics with removing bad data"
write(3,'(2x,a37,f5.2)') '3D nodal rms difference [%]:',rmsn
write(3,'(2x,a37,f5.2)') 'radial rms difference [%]:',rmsr
write(3,'(2x,a37,f5.2)') 'axial rms difference [%]:',rmsa
write(3,'(2x,a37,i5)') 'Number of TIPS:',ntipdata,tstrings
write(3,*)
!
enddo
close(2)

write(6,*) 'Completed!!!'

end program CompareTips

```

D.2 Cycle 1 Input

```

DIM 43 24                !# of detectors, # of axials
TIP PB2C1_tips.det        !# of TIPS measure data
DPL pb-cycl.parc_dpl      !PARCS output summary
DET pb-cycl.parc_det       !PARCS TIPS calculated data

```

D.3 Cycle 2 Input

DIM	43 24	!# of detectors, # of axials
TIP	PB2C2_tips.det	!# of TIPS measure data
DPL	pb-cyc2.parcs_dpl	!PARCS output summary
DET	pb-cyc2.parcs_det	!PARCS TIPS calculated data

D.4 Cycle 3 Input

DIM	43 24	!# of detectors, # of axials
TIP	PB2C3_tips.det	!# of TIPS measure data
DPL	pb-cyc3.parcs_dpl	!PARCS output summary
DET	pb-cyc3.parcs_det	!PARCS TIPS calculated data

[illegible]

53.0 71.7 76.2 71.3 46.5 61.8 67.4 73.6 71.2 72.4 67.8 44.3 76.2 72.2 78.5 74.7 67.9 74.3 66.7 76.3 73.1 73.9 72.4 73.7 76.2 62.2 73.3 72.7 63.1 77.3 70.1 71.5 56.0 42.6 68.8 74.0 74.8 79.8 58.1 42.7 59.8 63.0 59.4
48.7 67.5 69.4 65.4 42.4 55.6 62.0 70.1 70.5 68.8 61.4 38.8 70.4 71.2 79.6 74.7 69.4 70.0 59.9 68.4 70.3 72.9 73.7 73.1 71.9 53.9 66.7 68.3 65.2 74.2 70.6 65.3 49.7 39.9 63.0 68.5 69.0 75.2 52.9 38.0 53.5 56.0 53.7
47.8 65.7 67.6 63.1 41.0 54.9 62.5 71.2 70.1 70.3 60.6 38.2 68.0 72.1 86.0 77.2 74.8 67.6 58.1 68.3 70.2 76.2 79.9 74.8 70.4 53.5 66.1 70.8 70.1 76.2 74.5 66.1 48.3 39.1 62.9 69.0 70.6 75.6 52.5 37.6 51.3 54.2 50.7
44.4 59.9 63.5 59.1 38.5 51.7 61.0 69.2 67.9 67.8 58.6 35.0 62.7 71.0 84.9 75.4 76.5 68.1 54.1 62.7 68.7 76.1 81.0 74.9 68.8 49.4 61.2 68.9 71.1 75.6 75.6 62.3 42.9 37.0 58.8 65.3 68.4 72.4 49.5 34.6 47.3 49.7 46.0
38.8 50.6 54.4 50.1 33.2 44.9 54.5 63.1 60.3 62.2 52.9 29.2 54.8 64.8 78.5 68.8 71.3 59.9 48.1 54.3 61.3 69.6 74.0 69.6 63.5 41.7 53.2 63.0 64.9 69.1 70.8 55.2 35.9 31.7 53.2 58.5 62.2 65.6 42.4 29.2 39.0 41.4 39.5
33.0 40.1 46.7 41.4 28.3 38.4 49.1 56.8 55.8 55.9 46.2 25.1 47.4 57.0 71.0 61.7 65.2 53.3 40.0 46.5 55.0 64.1 67.5 63.3 55.9 34.7 46.8 56.0 60.0 62.3 64.7 48.8 31.4 27.1 46.1 52.1 54.6 56.9 37.4 25.3 33.5 35.0 32.8
27.7 34.3 38.2 33.3 24.3 32.7 42.6 46.8 44.0 50.4 40.6 21.4 40.5 47.7 57.7 50.0 56.7 47.1 47.0 35.1 38.3 43.2 54.9 57.3 56.4 48.5 28.8 38.6 49.6 49.6 53.5 55.8 41.1 26.3 23.0 38.1 44.6 46.6 48.6 32.3 20.6 27.3 28.8 26.7
17.0 21.4 24.2 20.0 15.5 19.8 26.8 29.1 27.0 31.9 27.5 13.6 25.6 29.0 35.8 31.6 36.4 30.3 22.1 26.3 26.9 34.5 36.2 38.7 31.5 17.9 23.3 31.3 32.4 34.5 36.1 26.1 15.8 14.3 23.6 28.8 30.1 30.8 20.0 12.5 16.7 17.3 16.3
11.4 15.7 15.5 14.5 9.7 14.1 18.4 20.4 20.1 21.3 16.9 8.5 16.7 20.3 25.0 23.2 24.3 20.7 14.1 16.5 18.9 22.4 26.1 25.8 20.7 12.0 16.0 21.9 22.3 24.0 25.1 17.4 10.4 9.9 16.2 19.1 21.2 20.8 13.7 8.2 10.8 11.2 10.4
@set 5 41.5 1.111 1.111 1.111 10
D1609 D2409 D3209 D4009 D4809 D0817 D1617 D2417 D3217 D4017 D4817 D5617 D0825 D1625 D2425 D3225 D4025 D4825 D5625 D0833 D1633 D2433 D3233 D4033 D4833 D5633 D0841 D1641 D2441 D3241 D4041 D4841 D5641 D0849 D1649 D2449 D3249 D4049 D4849 D1657 D2457 D3257 D4057
41.5 39.8 37.5 40.4 25.5 38.8 42.4 46.9 47.4 39.3 33.4 18.7 35.2 46.4 50.0 51.1 42.5 36.4 17.7 38.6 43.1 44.4 47.3 37.4 35.7 21.4 37.0 40.4 40.7 43.3 42.8 40.0 21.7 26.3 38.3 36.7 39.5 38.6 31.8 18.6 19.0 21.1 20.6
56.5 54.9 53.6 54.6 40.4 55.5 63.3 66.9 64.9 61.3 55.8 29.5 51.4 63.4 69.2 70.2 63.8 56.9 28.7 55.4 60.7 63.6 67.5 59.7 54.8 32.3 53.1 61.1 59.4 62.7 64.2 59.2 31.2 40.5 58.3 54.4 56.9 59.3 49.5 27.6 28.5 32.6 30.8
64.8 64.6 65.3 64.0 47.8 63.5 77.3 77.8 73.7 71.8 70.3 35.5 61.3 70.9 79.5 82.7 74.9 69.1 35.3 68.5 71.3 74.2 78.0 71.5 65.6 41.4 62.7 73.9 68.5 72.4 74.9 70.5 35.9 48.5 72.2 64.5 67.6 71.4 60.8 32.3 33.9 41.6 36.2
74.9 74.4 82.1 72.8 56.7 75.7 92.1 90.0 80.6 85.9 86.1 42.5 73.0 80.5 88.4 93.1 87.9 85.5 43.9 83.2 79.1 86.9 87.8 85.6 77.7 54.4 74.9 89.1 77.8 85.2 86.8 82.2 42.8 57.0 87.7 75.4 79.1 85.9 78.5 39.0 42.1 55.0 44.1
72.8 78.0 88.1 76.3 61.1 77.4 99.0 93.6 82.0 88.5 95.0 46.1 76.4 80.5 88.7 95.7 88.4 94.5 50.2 90.2 80.3 90.4 87.6 92.0 80.2 64.4 78.0 96.1 79.3 89.7 88.0 85.1 47.7 61.2 91.4 77.6 62.5 92.7 84.5 42.5 47.7 65.7 48.1
70.1 74.4 88.3 73.4 61.3 75.3 96.6 93.9 78.7 89.0 96.1 47.6 77.8 79.0 82.9 92.8 86.2 94.6 55.0 87.8 78.0 89.2 86.6 91.7 79.3 68.3 77.4 99.4 76.0 88.3 86.6 85.2 51.0 60.2 89.9 77.0 81.1 95.8 85.1 43.5 51.2 69.3 51.8
67.7 76.5 85.5 76.2 57.7 73.0 89.2 90.6 74.6 85.1 89.4 47.2 76.4 79.1 77.5 79.9 79.3 88.5 57.5 86.1 73.7 83.0 77.6 85.8 74.9 70.3 76.1 93.6 70.7 81.6 78.7 84.3 56.2 58.1 84.2 78.7 76.2 92.6 79.1 47.4 56.1 71.2 56.6
65.4 75.5 81.6 75.6 57.4 71.0 82.0 80.0 64.9 83.0 83.5 48.3 78.9 73.6 66.6 74.3 70.9 76.6 74.3 70.9 82.5 64.4 83.1 65.7 74.2 66.0 80.1 71.7 71.5 86.0 63.6 74.1 71.9 80.9 59.6 54.6 77.9 75.8 72.0 86.2 75.2 45.4 60.8 71.3 61.6
60.5 73.0 75.9 75.9 51.4 63.9 70.3 69.6 60.5 72.9 70.3 46.8 77.1 66.6 58.1 64.5 53.8 71.7 66.9 77.6 58.2 62.2 54.9 67.8 64.8 67.2 74.6 72.5 54.8 64.5 61.6 71.9 61.5 50.6 67.2 69.4 65.0 74.5 67.4 44.2 63.0 67.9 63.6
55.3 69.9 72.9 71.6 48.3 62.1 62.6 62.1 60.1 67.8 64.1 45.0 74.9 62.4 53.6 57.1 59.0 60.4 66.8 75.5 57.5 56.1 50.6 62.4 64.5 64.4 71.0 67.0 49.8 58.2 56.4 68.2 60.0 46.6 62.2 65.0 65.1 71.1 60.3 44.4 62.2 65.9 63.1
55.2 72.2 75.7 75.5 47.2 61.9 62.0 63.1 63.5 65.4 61.3 46.6 76.5 62.2 53.9 56.2 52.3 65.2 70.2 75.7 61.9 55.0 48.9 59.8 66.8 68.1 72.4 64.2 50.1 58.4 54.4 67.9 61.7 45.2 62.6 67.4 67.0 69.8 58.3 44.7 65.1 68.2 63.6
54.9 73.5 76.8 73.3 48.1 63.5 60.4 63.7 65.1 64.7 60.2 45.4 78.9 64.5 53.2 56.5 52.2 65.8 69.2 77.1 64.3 55.4 48.1 59.3 70.5 68.8 72.9 65.1 49.7 58.8 54.5 67.5 62.3 45.0 62.0 67.0 68.9 69.5 58.0 44.5 64.8 65.9 65.0
53.1 70.0 75.1 71.0 46.8 61.7 59.6 62.5 64.1 64.8 59.2 45.4 76.1 63.4 55.0 56.6 52.2 65.0 69.0 75.2 63.5 54.7 48.9 60.0 70.2 66.6 70.6 64.8 49.8 58.9 54.7 65.9 58.2 43.9 60.8 66.9 68.0 69.4 57.4 43.0 63.9 67.9 62.0
52.6 73.3 76.0 73.9 44.9 60.6 59.9 67.6 71.9 65.5 58.3 44.2 76.6 68.4 62.2 63.4 54.7 65.7 66.8 76.1 69.2 60.5 54.9 61.3 72.0 65.3 71.6 65.1 53.8 64.4 58.3 67.2 57.1 42.9 64.6 69.9 71.7 70.3 56.4 43.3 62.3 65.6 60.2
53.7 73.3 77.2 74.5 44.9 61.8 65.7 72.3 76.2 72.4 64.4 42.9 76.6 72.9 68.8 69.4 62.7 71.7 66.2 78.4 74.8 66.9 61.6 68.0 77.6 63.2 72.5 71.6 57.8 71.1 64.1 71.0 55.8 43.4 67.6 73.8 77.3 75.9 58.1 41.6 60.0 63.7 57.8
52.4 71.7 75.6 70.5 44.3 60.3 67.2 73.0 75.9 72.9 64.7 42.4 77.2 74.5 72.5 73.6 67.1 75.7 64.3 76.1 76.8 72.1 67.5 74.4 80.6 60.6 71.6 72.8 63.0 73.6 67.6 72.6 52.6 42.3 68.3 76.1 78.4 78.9 57.6 41.5 58.9 62.2 55.6
46.5 65.7 70.3 64.3 40.0 55.3 62.6 70.1 71.3 68.7 61.9 37.5 70.4 72.0 73.3 65.5 69.9 59.2 70.6 72.9 70.6 69.6 72.6 74.2 54.6 64.6 67.9 61.1 70.6 67.3 67.5 46.0 38.9 62.4 71.1 71.7 73.1 51.4 37.6 51.5 55.7 49.6
43.6 60.4 66.2 61.9 38.5 53.3 60.9 69.4 72.4 69.0 58.6 35.8 66.6 73.6 78.7 75.3 69.2 69.3 56.4 67.5 72.9 74.3 75.6 73.1 73.0 52.9 63.1 67.9 63.1 74.6 71.7 65.8 45.5 38.5 61.6 69.4 70.9 72.0 50.5 36.5 50.1 52.6 48.6
42.8 58.3 61.2 57.3 36.3 49.1 58.6 68.3 68.8 67.3 56.7 33.3 62.7 71.7 79.4 72.3 69.2 61.8 66.3 53.6 61.9 70.5 74.1 77.0 74.3 70.2 47.5 58.7 67.5 66.8 73.6 72.6 63.0 42.1 35.6 57.9 67.0 69.6 68.0 48.1 33.7 46.2 48.7 44.8
36.6 49.6 52.9 48.5 31.4 42.7 53.3 61.9 60.8 61.8 50.7 28.4 54.3 63.1 72.8 66.3 69.8 60.5 46.7 53.9 61.6 68.1 71.9 68.1 62.8 40.8 51.8 60.8 63.0 67.1 67.7 54.2 35.1 30.2 51.0 59.4 59.9 61.0 41.5 28.2 38.2 43.3 37.3
31.9 43.2 45.0 42.0 26.7 36.7 47.5 56.0 55.2 55.1 44.3 23.8 46.6 58.0 65.0 61.1 63.9 51.5 38.8 45.0 55.4 61.8 65.5 61.4 55.7 34.8 44.1 54.5 58.1 59.1 61.1 48.1 30.6 26.1 44.4 52.6 54.8 53.9 35.7 24.0 32.2 35.5 34.0 31.7
26.1 33.4 37.3 37.8 22.9 30.3 40.9 46.6 44.3 28.2 38.5 20.0 39.6 46.3 52.0 50.1 56.6 46.2 32.9 37.4 44.3 57.2 53.8 55.7 48.5 27.9 36.9 47.4 57.4 50.9 53.7 40.5 24.7 21.9 37.2 43.9 46.4 45.3 30.4 19.6 26.9 28.3 26.1
15.9 21.1 22.8 18.8 15.1 18.8 25.9 28.4 27.5 30.5 26.5 12.6 24.9 28.6 33.6 30.9 35.7 29.5 21.1 23.2 27.8 33.3 34.1 36.5 31.3 17.1 22.1 30.0 31.0 32.7 33.9 25.8 15.2 13.5 22.3 27.9 28.9 28.2 18.8 12.0 16.5 17.1 15.6
10.8 14.9 15.1 14.8 9.6 12.0 17.8 20.2 20.6 20.0 16.8 7.9 16.2 19.6 23.4 22.7 24.0 19.7 13.0 15.8 19.2 22.8 24.2 24.3 20.2 11.5 14.6 20.3 21.8 23.8 23.3 23.6 18.1 10.6 8.8 15.0 17.8 21.3 18.5 13.0 7.1 10.8 11.2 10.0
@set 8 34.9 2.811 2.811 2.811 16
D1609 D2409 D3209 D4009 D4809 D0817 D1617 D2417 D3217 D4017 D4817 D5617 D0825 D1625 D2425 D3225 D4025 D4825 D5625 D0833 D1633 D2433 D3233 D4033 D4833 D5633 D0841 D1641 D2441 D3241 D4041 D4841 D5641 D0849 D1649 D2449 D3249 D4049 D4849 D1657 D2457 D3257 D4057
34.9 46.5 45.6 47.6 24.4 34.3 29.2 40.8 53.2 31.5 22.1 20.1 52.0 38.4 32.2 35.5 29.2 31.5 35.0 56.2 37.1 26.7 21.6 25.0 34.7 44.0 44.5 26.5 31.6 44.2 28.2 29.7 38.3 18.4 36.4 42.1 46.2 39.3 27.4 13.7 21.5 22.5 22.1
50.9 64.9 66.1 67.3 38.9 50.7 45.8 62.7 75.5 53.0 37.7 31.8 76.3 59.9 49.3 53.6 48.6 54.8 54.3 80.0 60.2 43.9 46.8 58.0 63.0 44.3 64.3 50.8 65.3 48.2 46.3 54.8 28.6 55.8 63.6 66.3 61.5 42.3 20.4 31.8 33.9 34.2
61.4 74.0 75.7 78.4 48.5 59.1 57.9 80.8 87.7 70.6 49.0 39.2 86.8 78.8 66.4 70.6 65.5 72.0 64.8 88.0 76.1 59.0 50.2 54.2 59.1 74.7 71.6 76.4 57.1 66.6 77.7 66.4 58.9 62.4 34.8 67.8 74.7 79.2 74.8 52.0 25.9 39.0 39.9 42.4
71.6 82.2 84.9 92.4 60.2 71.6 75.5 94.2 93.6 90.7 65.9 48.3 98.6 91.2 85.3 89.6 87.7 88.7 76.2 99.4 88.9 80.0 74.7 79.8 90.0 81.8 87.5 75.0 83.8 89.5 87.4 75.7 72.6 43.0 81.4 86.1 88.6 89.0 64.8 34.9 47.6 48.2 55.4
76.9 75.9 82.7 94.9 65.8 77.0 84.8 96.4 90.6 96.6 77.7 52.0 95.1 93.1 93.9 93.8 97.1 92.0 89.6 90.1 93.1 93.9 83.6 98.0 94.3 87.4 92.4 72.6 48.3 88.2 86.1 89.0 91.8 72.4 43.4 52.2 52.6 65.4
75.6 76.8 76.2 91.2 66.5 77.0 91.2 88.2 83.1 93.8 87.4 54.1 88.7 89.3 90.6 90.6 92.2 96.8 92.9 77.0 88.7 88.4 90.1 93.6 95.4 90.4 75.8 85.5 90.2 82.5 85.1 92.0 89.9 71.3 52.7 86.5 84.4 62.5 90.1 75.9 50.0 53.0 53.1 70.9
74.4 71.0 70.0 90.4 66.1 79.9 87.5 83.2 75.6 86.0 91.1 55.3 79.6 84.7 87.2 85.1 70.1 80.3 86.0 86.0 87.9 91.7 82.5 70.8 80.3 88.6 76.7 76.1 85.3 87.2 68.8 57.9 82.8 76.8 75.7 77.3 83.0 77.4 53.2 54.5 52.8 72.3
71.9 66.5 66.9 84.2 65.2 79.0 80.3 70.5 65.9 81.0 91.1 55.3 75.7 78.5 76.5 74.4 81.4 77.8 70.2 74.5 80.3 78.3 82.1 89.1 78.8 67.4 76.9 82.8 67.3 68.1 77.6 82.4 64.8 61.1 75.8 69.0 69.9 68.3 77.4 77.9 52.5 55.3 53.0 72.2
64.8 60.9 61.2 76.1 60.8 75.5 70.0 62.5 57.5 69.1 83.3 51.5 69.8 67.8 67.6 65.3 69.8 69.5 63.5 67.6 74.6 68.6 68.2 83.8 68.1 62.9 71.3 73.4 56.9 57.5 65.6 72.3 59.2 57.9 65.8 60.2 58.9 68.4 73.2 50.3 53.3 51.4 65.4
57.8 60.4 61.1 70.3 55.9 71.0 63.7 55.9 53.1 62.4 76.0 48.9 68.3 62.7 63.1 60.7 64.1 64.0 58.6 62.7 68.4 63.1 59.7 76.6 61.5 57.2 67.4 67.8 52.9 54.8 58.3 70.4 55.3 55.3 62.2 56.3 55.3 61.4 67.4 48.1 53.4 52.9 61.8
57.3 67.1 65.8 72.6 55.1 71.3 62.4 57.0 54.2 60.7 74.4 49.0 67.8 63.3 66.3 64.0 62.9 64.6 59.1 62.1 69.4 64.4 57.9 74.0 62.3 55.8 71.6 65.4 54.8 56.5 58.0 72.9 55.7 53.4 62.4 56.8 57.0 62.6 66.0 48.7 58.3 60.9 62.0
58.1 70.7 73.2 74.2 53.4 69.4 61.8 56.9 56.1 61.2 72.5 48.1 73.0 63.6 71.5 69.2 63.9 69.8 61.1 63.1 69.6 63.1 58.1 72.7 63.4 57.1 74.6 66.3 58.2 61.6 59.8 75.2 54.5 53.2 63.3 57.9 57.5 63.6 64.3 48.2 64.4 68.8 61.9
55.3 70.6 72.9 71.7 53.5 67.6 62.9 57.4 55.7 62.0 71.1 48.0 72.3 63.2 75.4 70.6 63.1 70.3 59.7 60.8 66.6 63.8 59.2 71.0 62.6 54.1 72.0 65.6 60.3 65.3 61.0 74.5 52.6 50.3 63.5 58.9 58.4 66.1 62.4 46.8 64.5 70.7 60.5
54.5 73.4 75.9 72.9 51.6 66.2 66.9 62.0 62.0 64.7 68.5 45.0 72.4 66.1 83.1 80.1 64.9 70.9 57.2 61.7 69.6 66.1 59.7 69.7 64.0 53.0 72.3 66.2 67.1 72.0 64.6 76.1 51.6 48.1 70.0 61.6 61.1 71.4 61.9 46.3 64.3 71.5 59.7
56.2 72.9 75.7 73.3 50.5 65.8 72.9 65.9 64.5 74.0 74.5 43.9 72.7 68.3 88.5 85.1 69.9 75.9 56.6 62.0 73.3 65.5 66.6 74.0 66.8 54.9 75.2 70.8 73.0 77.8 71.3 79.6 50.6 47.6 75.9 66.6 64.5 78.6 63.5 45.3 62.4 68.8 58.1
54.4 69.6 74.9 72.3 49.5 65.5 74.6 66.6 66.2 78.5 75.2 43.9 71.4 68.9 87.2 83.8 73.0 77.6 58.5 60.9 73.3 72.3 71.6 78.6 67.2 50.6 74.4 71.6 74.7 80.7 74.3 78.7 49.6 46.8 76.7 67.9 64.4 82.8 62.8 45.2 60.1 66.4 57.2
48.9 65.4 67.5 64.9 44.9 58.3 69.2 62.7 61.4 74.1 69.3 38.8 64.8 63.7 82.8 78.8 68.3 70.0 52.8 55.7 68.8 68.2 67.1 73.4 63.2 45.7 66.5 66.3 66.9 76.7 69.9 69.8 43.1 43.4 71.8 61.7 59.1 77.0 55.3 39.3 53.3 57.8 49.4
47.2 61.5 64.6 62.9 42.8 56.1 66.2 62.7 59.3 72.3 65.2 38.1 63.1 63.0 80.6 77.3 66.6 68.1 50.4 56.1 67.4 67.5 67.6 71.6 62.8 44.4 64.6 60.5 68.1 75.9 67.8 68.1 42.3 42.7 68.9 62.1 58.3 74.4 53.8 38.2 50.8 55.4 48.9
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36.9 46.7 47.9 48.5 35.2 55.3 47.1 46.1 49.3 44.2 61.3 26.6 47.1 43.3 44.5 47.9 45.0 39.4 30.7 45.3 43.7 42.8 48.4 44.3 44.5 39.9 34.0 48.8 43.6 41.3 42.4 41.3 45.3 35.6 53.5 45.2 44.9 42.3 43.7 48.6 20.9 31.3 34.7 37.8
49.8 60.4 59.7 63.3 46.8 67.8 58.5 60.3 64.7 56.4 74.3 35.0 57.8 55.5 59.4 61.6 58.9 50.4 39.7 56.5 58.3 57.1 59.6 59.9 52.0 44.4 61.2 56.1 52.9 54.6 53.2 56.6 46.5 64.1 59.5 58.7 56.6 56.6 59.9 30.7 41.8 44.9 52.5
60.8 65.7 66.7 75.5 56.3 74.6 67.4 73.0 77.2 66.0 80.3 43.2 65.8 65.3 69.0 72.0 70.5 58.9 48.1 60.9 69.1 60.9 71.5 74.3 59.3 52.8 68.9 67.5 62.4 63.6 64.0 64.8 57.1 67.7 67.5 70.8 71.1 66.3 67.8 42.1 50.4 52.4 65.9
70.3 68.2 71.2 83.3 66.7 79.2 70.9 83.0 85.0 71.4 82.0 51.1 71.2 73.3 78.3 81.7 82.2 63.2 54.9 64.6 78.1 78.6 83.2 84.2 64.4 57.9 76.1 76.5 70.5 70.7 74.7 69.2 67.4 67.8 77.0 78.5 82.0 71.6 74.1 52.2 55.4 56.0 76.5
76.1 69.7 71.5 85.3 72.1 81.2 73.1 88.3 91.8 75.7 82.6 58.2 73.4 79.2 89.7 92.0 88.4 65.5 59.8 65.7 83.2 85.8 91.8 90.6 67.4 61.1 80.7 84.0 78.2 79.7 82.7 71.5 72.9 67.9 85.1 81.8 85.7 75.8 78.7 58.5 59.4 60.4 80.8
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71.1 74.2 74.5 87.5 74.2 83.2 79.7 92.5 92.8 84.3 85.5 62.9 81.3 84.8 98.9 98.9 95.7 68.9 68.5 77.3 81.7 94.4 96.0 94.7 70.4 71.0 83.8 87.8 87.0 90.0 91.6 75.7 74.5 63.3 89.2 82.5 89.2 83.2 82.6 61.0 64.8 64.4 76.6
72.3 74.6 77.6 83.7 70.0 79.8 81.5 88.6 86.9 85.4 82.0 60.8 82.4 82.4 97.5 96.3 92.6 69.5 72.1 79.5 77.6 90.2 91.1 90.1 69.4 73.7 80.2 85.7 83.5 89.5 88.3 72.7 71.6 58.2 93.3 81.3 84.3 88.2 80.0 58.6 66.7 66.0 72.9
72.4 76.8 83.5 86.4 67.4 77.1 83.9 59.6 85.5 90.8 82.3 59.0 87.6 80.3 96.2 94.5 88.6 68.2 75.1 82.7 76.4 88.1 86.7 86.5 69.9 76.8 80.6 84.4 81.5 87.2 85.8 73.4 68.0 58.1 97.1 81.6 83.3 93.5 77.9 58.0 71.0 72.0 71.0
71.0 78.4 84.2 84.9 65.8 77.7 87.7 86.8 84.4 93.7 80.2 57.2 86.4 79.4 92.5 89.6 85.8 67.7 74.7 83.0 73.8 84.0 83.3 83.9 68.5 76.2 80.5 83.8 79.9 86.1 86.0 73.0 66.7 56.4 97.0 81.0 81.9 95.0 78.3 57.6 70.5 74.8 70.5
66.5 76.3 81.7 79.3 62.2 74.0 82.2 80.4 81.2 89.4 79.0 54.3 84.8 75.1 87.5 84.4 81.2 66.9 70.9 79.4 68.0 79.2 78.7 78.1 65.8 74.4 76.5 79.6 75.0 82.6 82.3 70.2 63.4 52.0 92.8 76.8 77.8 90.8 72.8 54.0 66.1 71.2 64.4
62.0 71.7 77.2 70.0 59.8 67.0 76.7 78.4 80.0 83.8 72.3 50.1 80.7 70.9 83.9 80.1 75.7 66.9 67.6 73.5 64.6 72.8 73.0 71.0 62.7 69.3 75.7 74.3 69.9 79.3 77.7 69.3 58.7 48.5 87.4 74.6 74.9 87.3 66.6 50.4 63.6 68.8 60.7
69.5 70.7 76.8 75.8 57.4 67.4 75.6 78.7 84.9 82.7 73.2 49.2 84.2 69.9 83.6 81.2 76.2 72.0 67.2 73.6 65.0 72.2 73.3 71.0 63.7 66.4 79.7 74.6 71.9 85.5 78.2 74.3 57.4 47.3 85.6 75.5 76.9 87.1 66.1 49.2 61.8 66.2 59.2
59.5 71.5 76.3 77.4 55.3 67.6 73.5 78.9 87.6 81.8 72.9 47.7 85.0 70.7 81.6 82.1 76.3 75.8 67.5 72.2 64.0 71.4 74.5 70.3 64.4 64.7 81.4 73.9 72.0 91.3 77.8 75.6 56.3 46.8 84.5 78.7 76.6 89.0 65.5 48.2 60.5 64.9 58.7
53.1 68.4 68.7 73.8 48.6 61.1 66.6 72.9 82.9 75.9 66.2 42.6 77.9 64.9 75.1 76.8 70.4 71.5 67.1 65.8 58.6 66.6 71.6 65.1 59.5 58.3 75.7 67.4 67.5 86.7 71.6 69.4 50.6 43.1 77.0 76.5 72.3 84.6 59.5 42.9 54.9 58.8 53.6
52.3 70.7 68.0 74.3 46.6 57.9 64.0 72.5 82.8 74.1 63.1 40.5 73.6 64.9 75.0 79.5 69.2 70.8 58.9 64.3 58.7 67.2 75.0 63.8 59.9 55.7 73.8 65.8 67.1 86.2 69.4 66.8 47.8 42.0 74.4 78.1 72.1 85.9 56

[illegible][illegible]

D-13

D.6 Cycle 2 TIP Measured Data

HE2 CYCLE-2

13 43 24 !cases, # of detectors, # of axials (opposite direction to FRACS)

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D1609 D2409 D3209 D4009 D4809 D0817 D1617 D2417 D3217 D4017 D4817 D5617 D0825 D1625 D2425 D3225 D4025 D4825 D5625 D0833 D1633 D2433 D3233 D4033 D4833 D5633 D0841 D1641 D2441 D3241 D4041 D4841 D5641 D0849 D1649 D2449 D3249 D4049 D4849 D1657 D2457 D3257 D4057
46.6 43.1 44.5 31.2 55.3 42.4 45.5 47.5 49.9 36.0 48.1 45.7 40.2 42.8 59.4 73.2 42.5 37.9 37.9 43.2 39.8 56.9 53.2 57.3 37.4 42.3 45.9 49.1 46.8 61.1 50.4 45.0 43.7 66.0 57.6 45.0 38.9 53.1 54.7 50.7 50.7 52.4 52.0
74.1 67.1 70.7 58.1 86.9 71.5 70.5 69.0 69.2 61.2 81.6 71.3 66.2 64.7 89.5 102.5 73.8 62.3 67.9 69.6 60.0 91.1 81.5 93.7 59.8 71.8 73.5 70.2 77.1 94.3 79.5 69.6 74.1 92.6 84.3 65.9 61.9 75.4 91.1 74.9 78.4 81.5 80.4
90.7 85.6 86.6 80.0 102.1 90.6 89.7 81.3 78.6 76.2 101.1 85.8 85.2 76.6 104.9 111.4 95.9 78.2 91.6 88.6 69.4 105.7 90.4 110.6 74.7 93.7 91.4 83.7 97.0 108.1 97.5 86.2 98.0 107.6 103.2 78.4 73.8 88.9 114.9 87.2 100.2 101.1 101.5
106.0 108.2 109.6 101.3 116.2 105.2 112.5 95.3 90.2 91.6 126.6 99.0 109.7 91.2 114.6 119.6 110.6 92.5 121.2 110.0 80.0 114.8 98.2 120.6 86.7 119.2 115.6 101.6 112.7 116.8 114.7 104.4 123.8 119.8 118.9 95.4 85.9 106.9 136.3 98.3 127.7 126.9 129.1
109.5 123.5 128.1 122.4 123.4 115.5 124.4 107.2 99.3 107.6 136.1 106.5 130.3 105.3 117.1 120.0 117.5 110.9 141.2 129.2 90.4 113.7 100.5 127.6 99.4 140.9 134.0 116.7 120.5 118.5 121.3 119.5 146.8 120.9 123.2 110.7 97.4 120.1 143.9 103.7 139.1 136.0 142.0
107.8 127.8 135.5 127.3 120.6 114.6 126.0 122.9 108.3 121.0 142.0 104.5 144.8 115.7 114.5 117.3 117.4 126.4 146.7 136.0 102.8 112.0 101.3 127.8 114.1 140.4 142.1 124.2 121.3 116.7 123.2 128.9 156.1 116.6 123.0 118.4 110.1 124.7 138.7 102.9 138.6 135.7 143.5
104.0 125.9 136.3 127.2 115.0 111.9 127.8 128.6 119.9 124.6 145.3 102.4 146.2 125.8 113.1 115.4 115.6 135.8 140.3 139.1 115.3 109.2 104.6 124.7 126.8 133.7 143.4 132.8 120.9 113.5 125.0 135.4 152.8 117.5 117.2 127.1 122.7 128.8 124.6 97.9 137.7 129.7 139.7
104.5 131.5 136.7 131.2 115.1 111.4 131.3 130.8 129.1 136.1 143.1 101.9 149.2 133.8 115.5 118.3 121.1 141.0 145.3 140.1 124.2 110.0 116.6 130.4 137.3 133.9 143.1 131.5 122.6 118.0 127.7 136.1 152.6 113.2 117.4 127.2 132.7 129.4 122.4 96.5 134.4 126.0 139.5
98.1 121.7 130.4 131.0 109.3 108.9 124.8 125.5 124.1 131.4 135.2 95.3 139.3 134.1 111.3 116.0 116.6 139.8 131.5 133.6 124.3 108.2 123.1 126.7 132.9 125.5 135.9 127.0 119.0 119.1 122.3 131.5 144.9 108.5 110.8 124.4 133.6 120.5 114.1 90.8 123.4 120.1 130.9
94.9 112.6 126.0 120.1 108.3 106.2 125.1 122.7 122.5 127.0 130.6 91.4 132.0 130.1 110.3 114.6 111.1 133.5 126.6 122.6 121.5 106.0 124.4 124.9 132.7 115.2 128.8 125.2 118.7 115.4 119.8 127.5 128.4 104.8 109.0 120.5 129.3 114.9 105.7 86.2 117.1 111.9 126.1
94.3 109.6 125.7 117.4 108.8 105.9 123.4 126.9 122.4 124.1 132.7 91.9 132.6 131.3 111.5 114.6 111.1 135.8 121.0 121.8 121.0 106.9 129.3 125.8 133.4 109.8 130.5 127.9 119.1 117.2 118.9 124.1 126.7 106.9 109.9 119.8 127.9 118.7 106.7 87.2 115.2 110.1 126.0
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98.7 105.3 114.3 116.6 108.7 108.8 124.1 114.0 111.3 122.8 129.4 87.2 123.4 120.9 103.9 104.5 106.2 125.3 114.5 113.5 107.7 101.8 121.5 119.6 114.9 99.8 126.8 117.3 111.6 113.9 111.8 125.5 121.4 101.5 110.0 112.1 119.7 114.9 110.1 82.8 104.4 97.8 118.8
99.6 99.8 108.7 115.6 106.9 108.4 120.4 110.4 110.4 114.0 131.9 84.3 115.7 115.8 99.6 104.2 99.6 119.2 105.9 108.9 102.7 94.9 110.5 111.2 111.2 94.5 127.2 115.7 103.6 105.8 109.2 128.3 114.1 104.2 120.2 112.0 112.8 123.2 105.5 84.9 103.0 93.7 117.5
108.7 102.2 113.5 125.3 110.0 118.7 125.6 109.6 107.9 116.7 138.7 87.2 118.3 116.6 98.7 101.4 100.9 122.0 108.3 108.4 102.0 93.9 109.7 109.6 109.8 96.1 127.3 116.7 104.4 105.7 106.6 137.9 116.6 105.4 128.4 115.4 116.5 125.2 111.7 84.7 101.1 92.5 118.7
113.0 106.3 115.4 132.6 112.7 125.4 132.9 110.3 111.3 118.8 144.6 89.9 117.5 118.5 99.1 100.9 101.1 123.3 107.6 112.0 104.1 94.5 106.8 109.5 110.3 96.2 142.9 115.6 106.0 106.3 109.1 141.4 117.4 103.6 131.3 118.0 118.9 129.7 117.1 87.2 101.4 96.3 119.3
106.5 100.6 110.8 132.4 106.1 120.5 124.9 108.2 105.8 115.5 135.2 82.6 115.2 112.9 92.8 95.2 97.2 121.0 100.5 106.5 98.7 88.9 98.6 103.9 107.2 90.5 136.8 115.4 102.2 99.8 103.7 139.1 109.7 99.3 127.5 115.5 124.9 110.8 82.2 96.0 89.8 112.9
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107.3 113.3 122.7 129.8 97.9 118.0 133.1 117.4 119.2 125.4 134.3 78.7 129.1 120.7 100.1 99.5 104.2 136.3 99.8 123.1 109.0 93.6 101.3 107.1 124.9 90.1 134.2 123.4 110.1 107.9 119.0 138.2 106.7 90.5 123.8 125.8 137.0 128.4 108.1 78.2 95.5 91.2 108.0
96.7 105.3 113.7 124.4 85.6 109.4 124.6 113.4 117.0 125.8 122.9 69.3 121.8 116.3 95.1 94.9 103.2 131.8 91.9 113.8 107.1 91.7 97.5 108.3 122.0 82.4 119.9 115.9 109.3 107.1 114.8 127.3 95.8 76.6 108.8 117.6 137.7 115.7 98.6 67.6 83.2 83.0 92.4
82.7 94.5 103.4 106.7 72.5 91.9 112.3 110.1 114.3 115.2 107.6 60.3 108.2 108.1 94.1 94.0 100.5 117.8 78.5 102.3 102.2 88.6 94.9 105.2 112.1 73.4 120.2 109.9 104.8 104.8 107.3 114.9 80.4 64.8 96.8 106.2 124.9 103.1 84.3 59.6 73.5 73.6 79.5
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67.3 63.0 66.3 69.7 54.8 57.5 55.5 54.0 58.1 50.1 76.9 42.3 55.6 57.9 76.2 77.2 70.1 55.6 54.8 59.9 56.5 83.0 82.0 81.3 56.7 59.8 64.0 58.2 52.3 56.6 54.1 58.3 53.8 75.7 69.1 62.1 62.0 66.8 65.9 71.5 74.5 70.3 93.4
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96.2 91.9 103.3 106.4 82.8 89.1 81.5 81.2 88.8 75.3 110.3 67.1 93.1 85.8 93.3 102.7 98.4 88.5 97.0 97.6 81.8 104.5 111.1 104.6 86.6 99.0 99.2 85.6 76.2 82.7 76.5 85.7 91.5 102.5 92.0 93.2 99.1 96.6 98.1 95.5 104.9 95.2 130.6
104.9 104.7 117.1 123.7 97.8 104.8 99.2 96.0 100.1 91.5 129.1 80.8 112.0 97.9 96.1 104.1 98.0 104.2 117.0 114.1 96.3 105.2 113.1 108.4 102.3 113.9 115.5 101.4 87.9 95.5 88.8 102.5 112.6 107.8 106.6 107.1 113.0 110.4 111.4 100.0 109.8 102.0 130.6
112.6 117.6 127.1 136.5 110.3 116.1 108.3 107.0 106.8 102.7 141.4 92.3 123.6 105.8 97.9 103.8 102.0 114.3 125.1 118.7 103.8 99.7 109.6 108.3 111.2 120.8 129.1 110.6 109.3 101.1 100.8 115.6 125.9 111.9 115.1 115.4 119.6 118.9 120.8 97.8 112.8 107.1 135.1
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115.6 140.7 151.7 139.7 120.7 126.8 127.4 119.1 115.4 123.1 150.5 101.4 131.6 122.0 99.3 105.3 101.7 125.6 128.3 123.7 109.0 97.0 110.9 110.4 116.3 116.9 137.5 122.6 111.9 112.8 117.7 131.2 138.5 115.4 118.5 128.3 129.9 129.2 126.3 97.3 128.9 122.2 133.0
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107.0 125.5 143.7 124.6 115.1 119.2 122.2 117.7 113.9 122.1 138.7 94.7 126.2 123.1 98.9 103.7 101.0 122.2 111.5 110.5 106.1 93.4 105.8 109.7 115.9 109.3 128.4 120.5 110.3 114.9 122.8 121.7 108.6 116.3 118.4 123.6 119.4 113.4 87.9 118.7 117.3 121.7
106.1 124.1 138.6 127.9 112.9 118.7 129.0 110.6 123.4 140.5 90.9 128.8 123.1 97.5 100.6 98.8 128.3 111.0 121.2 106.4 90.0 103.8 109.7 121.7 103.2 130.1 118.4 107.3 111.8 116.3 124.6 118.8 105.2 116.1 114.5 122.3 121.7 111.9 85.7 113.4 110.3 118.9
102.1 115.2 128.4 123.8 106.9 114.6 133.8 109.3 101.9 127.9 135.1 87.2 131.8 117.4 95.0 95.8 96.0 132.7 111.0 126.0 103.6 92.3 102.1 108.1 126.7 100.9 132.9 113.8 104.6 107.6 112.7 128.6 118.9 100.4 113.4 109.6 116.5 118.4 109.8 80.2 104.3 99.3 110.6
95.0 103.4 119.1 115.0 100.9 107.1 133.7 106.1 100.5 125.7 128.6 82.4 130.9 117.3 93.8 94.6 93.2 135.3 105.4 129.4 100.7 86.5 97.1 104.2 125.1 95.8 133.2 114.5 100.3 102.0 108.4 130.5 110.3 96.7 118.7 108.0 108.6 120.2 103.0 77.8 98.4 93.2 106.2
95.4 104.4 118.4 117.3 101.0 110.8 138.2 105.1 101.5 125.1 129.4 80.4 135.0 118.1 95.4 97.0 95.8 141.5 105.8 131.5 106.6 92.5 100.5 106.7 129.6 99.0 137.3 113.8 102.6 104.2 109.7 135.5 111.4 93.4 118.0 107.1 109.8 118.6 101.8 76.4 96.0 93.3 105.5
94.5 104.8 117.1 114.0 98.0 111.9 139.3 106.4 102.5 128.1 126.7 80.6 135.2 120.4 99.0 101.3 99.3 140.6 107.9 135.9 113.2 98.8 105.8 113.2 131.8 99.6 136.2 114.8 104.7 106.2 110.3 135.7 110.5 91.5 119.4 108.7 110.9 119.5 104.0 73.7 93.1 89.9 103.6
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D1609 D2409 D3209 D4009 D4809 D0817 D1617 D2417 D3217 D4017 D4817 D5617 D0825 D1625 D2425 D3225 D4025 D4825 D5625 D0833 D1633 D2433 D3233 D4033 D4833 D5633 D0841 D1641 D2441 D3241 D4041 D4841 D5641 D0849 D1649 D2449 D3249 D4049 D4849 D1657 D2457 D3257 D4057
40.8 38.5 42.0 28.7 54.5 40.6 43.7 48.5 49.2 37.9 44.4 52.6 57.7 49.7 45.1 48.9 41.6 46.3 45.6 51.5 51.3 50.1 43.1 41.7 47.4 45.3 46.0 51.1 42.5 40.0 59.6 48.5 49.0 45.4 51.9 48.4 46.5 56.0 55.8 50.3
70.5 59.9 61.1 51.7 78.9 69.0 65.8 72.9 78.4 68.0 73.7 71.4 57.0 67.9 74.7 80.2 74.5 71.4 79.0 62.2 68.6 70.6 76.7 74.8 73.2 71.7 65.6 71.0 70.9 70.8 77.9 69.2 68.9 80.1 70.2 71.4 70.1 77.8 81.1 67.5 79.1 81.4 77.2
82.2 70.6 71.2 67.9 86.5 83.1 81.5 85.6 86.8 81.9 88.8 79.8 69.4 81.2 82.2 88.9 85.7 85.8 94.2 75.3 76.9 81.9 87.5 84.7 79.0 89.0 77.7 85.9 84.1 80.7 88.4 86.7 85.8 87.8 82.0 84.7 80.2 90.0 98.6 76.0 89.5 92.2 89.0
90.1 82.3 83.1 76.6 95.4 92.2 100.3 99.3 93.9 97.1 104.7 84.9 82.1 93.3 90.1 99.5 94.3 99.6 106.0 90.8 84.2 90.7 97.1 92.6 89.0 101.0 86.9 98.4 94.2 86.4 100.1 98.8 99.0 93.8 95.5 98.3 87.9 104.2 107.8 84.8 103.5 104.9 103.8
94.4 93.8 95.1 87.9 95.1 96.7 111.4 104.1 95.9 104.9 110.2 85.3 92.2 98.3 96.5 106.5 97.2 106.3 113.1 104.6 88.7 98.1 106.5 95.6 94.5 109.9 96.6 109.3 99.3 90.3 106.4 109.1 109.8 92.1 100.4 104.0 94.3 110.7 116.3 86.0 110.5 109.0 113.6
94.2 104.4 108.0 99.7 95.3 97.6 120.1 108.4 95.3 114.2 113.7 84.7 105.2 102.9 102.7 114.5 100.1 113.5 118.0 111.2 89.8 105.7 115.6 99.3 100.5 112.2 112.0 118.8 102.8 91.8 114.6 113.8 118.4 92.4 103.7 107.6 99.2 116.4 111.0 86.3 111.6 103.5 117.9
97.1 110.6 120.0 107.6 95.8 98.2 126.3 112.0 98.8 122.6 124.5 86.4 118.9 105.3 111.6 122.4 102.3 122.5 113.2 119.0 92.4 110.4 126.6 103.7 107.8 108.0 123.8 128.2 102.5 94.5 120.9 122.1 119.0 95.9 109.3 116.1 104.8 124.7 103.9 83.7 112.6 109.0 121.9
104.5 124.1 132.5 122.7 99.4 110.8 141.9 118.6 103.8 129.5 133.6 86.3 130.5 114.0 118.9 129.5 106.6 137.0 112.5 127.3 97.1 119.8 135.2 108.1 120.8 110.7 138.8 135.3 108.7 101.6 128.3 134.8 120.9 95.6 117.1 129.0 122.4 133.1 106.8 86.1 113.3 110.3 122.4
104.7 127.2 128.0 107.7 97.7 113.9 137.5 115.0 103.7 129.0 132.2 83.4 135.9 113.6 116.6 127.5 105.0 135.6 107.1 126.4 96.5 119.0 134.3 109.7 119.3 108.1 136.2 130.9 109.7 102.3 125.0 133.3 118.6 96.4 118.2 129.0 124.9 130.0 103.5 85.6 108.4 104.8 121.6
104.8 120.8 126.9 124.8 95.9 113.0 134.5 111.4 103.3 125.5 127.5 81.9 129.9 111.3 112.8 124.1 102.3 130.3 105.4 123.2 94.7 114.8 133.3 108.9 120.4 101.2 133.3 129.0 106.8 105.4 123.3 129.6 111.7 95.8 114.4 123.1 126.5 120.4 100.4 81.1 107.0 96.6 111.9
101.5 117.0 127.5 119.2 98.8 111.3 134.5 114.1 101.3 127.3 129.6 79.6 128.8 114.6 114.8 124.5 102.8 131.8 105.1 123.1 96.1 114.4 133.3 110.4 122.4 95.7 133.9 128.3 106.8 104.7 123.0 130.3 106.1 95.4 117.2 123.1 123.5 121.4 96.0 81.0 100.8 95.9 111.7
99.1 113.7 124.3 120.3 98.8 108.0 132.6 112.6 102.4 126.7 127.0 77.9 126.8 114.6 114.0 127.2 102.4 130.8 102.5 122.8 96.7 114.7 132.8 111.3 117.7 94.9 128.9 124.2 109.8 104.7 121.6 126.4 108.5 93.3 116.6 120.8 125.0 116.7 98.5 80.6 98.0 91.9 110.3
92.6 108.3 117.2 116.4 91.8 107.2 124.3 107.8 99.1 118.6 119.9 73.4 121.9 108.3 109.1 116.8 100.9 121.9 96.8 114.4 92.2 111.2 127.5 110.3 111.6 89.5 112.0 127.5 109.9 105.4 116.4 120.8 102.4 88.2 107.2 113.3 120.5 110.3 93.1 74.8 89.1 84.9 101.1
84.8 97.6 109.1 108.8 88.2 99.0 118.4 106.1 100.1 109.9 113.9 69.0 109.6 106.0 106.4 113.7 98.6 115.9 89.7 105.9 91.4 103.6 116.5 108.2 106.4 82.3 115.5 110.2 103.4 102.6 110.2 112.8 93.0 85.1 103.6 110.1 113.9 103.1 86.2 70.9 85.7 80.0 97.5
84.3 95.5 109.1 104.9 89.2 100.0 117.8 107.8 106.0 108.6 110.5 67.0 107.1 110.3 107.2 112.5 103.8 114.9 89.5 104.8 96.4 105.0 114.5 114.9 106.9 82.8 111.8 110.9 109.6 110.3 111.7 113.1 92.9 81.3 102.4 111.7 113.4 101.1 86.5 69.8 84.1 77.7 95.6
83.2 95.7 107.5 104.0 83.3 99.7 115.1 111.1 111.8 107.2 106.7 66.1 107.9 113.6 107.6 112.8 108.0 113.9 89.4 103.1 103.0 105.3 110.3 121.8 104.8 81.8 110.5 109.3 114.4 116.1 112.3 113.4 88.9 79.1 99.3 107.2 113.2 99.8 85.7 69.1 80.7 77.2 92.8
75.7 84.4 95.1 98.3 76.4 91.6 104.0 113.4 102.5 99.0 97.4 61.8 96.3 105.9 96.3 100.8 102.1 101.5 79.2 94.2 105.9 90.7 102.4 113.5 94.1 75.5 98.6 97.3 109.9 110.4 101.1 101.8 84.1 71.5 89.5 95.4 105.7 90.2 79.5 62.4 72.4 69.2 83.9
74.2 83.2 92.5 89.0 74.8 87.9 100.8 103.0 103.2 96.2 95.5 60.0 95.2 104.6 96.2 99.5 101.0 99.4 77.4 91.5 95.9 94.6 98.5 111.2 95.1 72.4 96.1 96.4 109.5 108.4 99.2 101.4 79.7 69.2 89.4 92.2 102.1 88.7 75.9 61.4 72.3 69.0 81.9
72.0 80.8 87.6 88.7 70.1 84.7 95.0 96.7 98.3 93.5 91.8 56.2 91.0 98.0 90.9 93.9 97.2 95.7 74.0 86.2 90.5 90.8 94.8 94.8 110.5 89.4 68.2 90.1 91.9 104.1 104.9 93.6 98.1 75.8 64.3 94.6 88.9 99.2 84.9 74.5 56.9 67.1 65.8 78.1
64.5 71.7 76.7 81.8 60.6 76.4 83.2 84.7 85.0 82.8 79.8 49.3 81.0 85.6 80.1 81.4 84.7 84.4 64.7 75.0 80.2 81.3 84.0 91.2 78.6 61.8 79.6 79.4 92.4 93.8 82.0 86.7 67.5 54.4 74.0 76.9 91.4 74.0 68.6 49.5 58.1 57.4 65.7
56.2 61.2 66.6 69.4 52.7 63.1 71.5 72.7 76.5 72.3 70.4 43.7 70.8 72.8 70.2 70.8 74.2 72.9 55.9 63.8 69.2 69.7 72.2 79.5 68.6 52.4 67.4 69.5 78.3 79.2 71.6 73.6 57.5 47.6 65.2 66.7 77.5 64.2 57.9 42.8 50.9 50.6 55.8
46.5 50.9 59.6 61.4 52.3 55.7 64.9 65.5 58.2 62.5 37.0 63.9 59.2 56.5 61.9 60.3 57.6 42.9 57.1 56.5 65.6 63.6 56.2 43.9 63.1 59.5 64.5 65.5 71.3 57.9 60.4 50.7 36.2 51.0 52.6 70.1 51.2 49.2 37.1 38.8 40.3 46.9
35.7 40.6 40.2 47.4 28.0 39.7 43.0 44.4 43.9 45.8 41.6 23.7 45.6 45.7 43.9 42.0 48.3 44.6 31.7 40.5 44.4 44.7 48.3 50.4 43.8 33.5 41.4 42.7 51.2 55.2 45.2 47.6 36.9 25.2 38.9 39.9 52.8 39.6 39.9 24.3 28.0 28.3 30.3
21.7 26.0 27.6 33.9 18.8 25.4 29.7 33.2 32.3 36.9 31.2 31.6 16.7 28.3 29.9 32.3 34.4 32.3 31.3 19.1 26.4 29.6 30.2 34.2 35.0 33.6 20.6 26.2 32.3 33.3 36.6 29.9 29.9 20.8 18.0 28.2 32.3 33.1 32.3 26.0 14.7 18.6 20.2 18.6

D.7 Cycle 3 TIP Measured Data

HE2 CYCLE-3
10 43 24 !cases, # of detectors, # of axials (opposite direction to FRACS)
@eet 38 40.8 0.448 10.163 10.163 2
D1609 D2409 D3209 D4009 D4809 D0817 D1617 D2417 D3217 D4017 D4817 D5617 D0825 D1625 D2425 D3225 D4025 D4825 D5625 D0833 D1633 D2433 D3233 D4033 D4833 D5633 D0841 D1641 D2441 D3241 D4041 D4841 D5641 D0849 D1649 D2449 D3249 D4049 D4849 D1657 D2457 D3257 D4057
40.8 38.5 30.9 44.7 21.6 44.6 35.6 35.5 35.3 36.6 30.4 36.2 37.3 43.6 35.2 37.3 41.3 43.4 42.0 37.7 36.7 38.4 41.1 52.6 49.0 38.8 47.8 37.5 33.9 37.5 40.8 37.7 55.5 27.9 39.7 32.8 39.1 44.1 27.0 36.1 41.3 40.9 50.5
68.4 60.1 54.8 75.3 36.3 73.5 54.2 53.9 58.6 60.3 54.2 57.5 60.6 69.0 62.0 62.3 69.5 68.9 68.7 63.0 65.5 66.4 63.5 86.8 81.8 66.7 79.0 56.0 59.4 61.5 64.4 60.2 89.0 40.1 59.5 53.8 59.8 63.5 41.8 56.4 66.8 67.3 82.4
84.2 74.4 75.8 82.7 44.9 89.1 67.7 78.0 73.3 77.7 74.7 70.2 74.6 90.8 84.0 79.4 89.2 87.2 84.2 84.9 88.7 89.1 74.7 109.1 104.2 83.4 97.2 68.4 79.6 65 78.0 83.9 89.9 65.2 81.5 85.7 98.0
97.6 92.1 96.5 106.2 52.1 103.1 83.7 94.3 88.3 97.5 92.9 77.7 89.2 113.2 104.7 95.9 107.6 107.1 98.9 102.4 109.1 112.9 90.5 130.4 130.3 105.8 110.3 85.0 99.2 92.7 99.0 93.2 122.9 54.5 84.0 77.4 85.3 83.9 59.3 70.8 100.6 110.2 112.3
109.9 112.8 112.4 101.2 60.0 108.5 96.6 105.2 101.3 106.3 108.6 80.8 99.7 115.6 119.1 115.0 114.5 116.4 113.8 116.5 124.3 104.7 124.5 110.2 105.0 115.6 95.4 113.6 107.1 106.0 105.9 128.1 58.9 93.7 85.8 91.8 87.3 66.5 74.5 110.1 124.2 116.6
112.0 106.8 120.5 108.9 67.3 105.4 103.8 106.8 109.2 111.6 117.7 78.8 109.5 118.4 121.9 127.9 112.7 112.9 121.9 127.0 120.9 127.2 115.6 129.9 135.9 129.4 114.2 99.6 117.8 117.0 108.3 112.5 126.0 61.0 102.2 87.2 94.3 90.0 74.0 76.9 111.9 123.7 115.2
115.9 107.7 117.0 116.4 91.8 106.7 103.3 105.0 110.3 115.2 119.8 78.4 112.1 115.5 121.2 133.3 109.2 107.9 118.5 127.6 113.0 121.2 119.1 122.8 124.2 126.8 106.8 113.3 118.6 118.4 104.9 109.8 119.3 64.5 116.2 87.4 94.6 92.9 81.5 75.0 70.3 114.7 111.0
123.9 108.0 119.4 106.6 87.4 105.1 114.7 107.8 116.0 115.1 126.6 78.9 112.8 115.9 121.0 139.2 106.1 108.9 119.0 130.4 113.2 121.2 119.3 119.6 123.2 126.2 106.4 98.8 119.6 119.9 107.5 110.7 119.2 69.4 120.2 90.8 98.6 95.1 88.1 78.0 108.2 115.0 108.7
121.5 97.3 115.4

100.5 116.0 125.4 103.7 83.6 100.4 136.2 123.9 121.1 138.8 135.7 68.9 104.7 131.4 115.7 125.4 124.7 117.7 90.6 122.7 108.1 131.5 131.9 118.6 126.9 86.3 93.9 123.5 120.7 109.6 133.0 114.3 89.6 84.0 132.2 126.2 126.0 128.9 100.6 65.7 87.3 85.7 92.9
90.1 104.5 115.1 93.8 73.6 90.6 124.8 118.0 116.3 128.8 125.6 63.0 101.3 120.6 110.1 121.3 118.9 112.0 82.2 113.0 107.7 125.6 123.0 115.3 117.7 77.3 90.1 113.1 115.0 104.4 123.9 111.7 82.1 73.1 119.3 119.7 115.7 116.7 91.5 59.8 78.5 76.0 83.5
75.7 90.2 99.5 81.2 63.7 76.7 109.4 106.4 106.2 117.2 109.9 55.5 93.0 108.9 101.4 110.4 109.5 105.0 71.9 95.8 100.5 112.9 112.2 109.2 105.3 66.5 81.3 105.4 105.7 97.8 112.8 101.3 71.9 64.3 103.0 105.5 103.5 104.7 80.3 53.1 68.0 66.2 71.3
62.0 72.0 81.3 66.2 56.6 61.6 85.3 89.3 91.1 92.6 89.2 44.4 86.3 87.0 91.8 94.4 102.3 83.0 62.8 78.0 91.3 93.9 91.0 89.5 83.0 52.6 65.2 85.9 91.3 84.9 90.4 83.8 55.5 49.2 78.1 87.2 81.6 79.5 63.3 42.8 54.4 57.1 62.7
46.0 55.7 61.6 50.5 37.9 46.0 63.0 69.9 71.7 69.7 67.6 34.0 60.3 68.4 72.7 74.7 71.1 63.7 41.9 59.9 71.5 73.4 73.1 71.2 63.6 38.5 50.6 65.9 74.5 68.0 71.5 65.4 40.9 35.5 56.9 66.9 60.0 59.0 47.7 33.0 41.3 39.7 42.6
25.9 31.8 39.2 29.4 21.9 26.2 40.8 41.1 45.4 43.9 34.8 44.2 49.7 47.0 42.6 39.4 21.8 36.2 48.7 46.4 45.9 41.7 40.7 22.7 30.2 44.3 46.9 44.5 45.0 36.4 22.6 22.2 36.2 42.7 43.9 41.7 28.9 19.2 23.8 22.2 23.5
@set 39 59.8 1.348 11.063 11.063 4
D1609 D2409 D3209 D4009 D4809 D0817 D1617 D2417 D3217 D4017 D4817 D5617 D0825 D1625 D1625 D3225 D4025 D4825 D5625 D0833 D1633 D2433 D3233 D4033 D4833 D5633 D0841 D1641 D2441 D3241 D4041 D4841 D5641 D0849 D1649 D2449 D3249 D4049 D4849 D1657 D2457 D3257 D4057
59.8 76.2 72.5 52.7 46.5 60.0 78.5 91.4 94.5 80.8 51.6 44.7 70.4 91.7 55.5 54.2 81.5 92.9 55.2 82.0 76.8 47.5 45.8 94.4 99.8 61.9 55.2 83.8 75.2 89.1 96.6 63.0 57.3 55.8 65.3 83.5 105.1 75.7 64.4 41.2 54.7 56.3 52.4
97.4 113.2 120.2 87.6 76.8 99.2 112.8 135.5 143.3 122.9 90.1 71.6 108.1 130.0 88.1 84.8 119.2 130.2 90.3 130.0 122.3 75.4 65.8 137.0 141.5 100.0 88.4 111.0 119.3 130.2 136.3 98.2 91.8 85.5 97.7 125.8 150.5 108.9 96.8 65.9 85.4 90.6 83.0
119.6 130.1 147.8 107.8 93.1 122.7 126.2 145.8 153.9 137.5 118.1 89.1 124.2 135.8 101.8 96.2 129.3 136.8 108.9 147.0 140.0 87.3 71.0 144.3 151.6 118.7 107.3 118.0 134.0 137.1 145.0 115.7 109.0 100.2 118.5 139.3 156.4 125.6 112.1 78.9 97.1 108.4 96.4
142.8 146.6 156.9 131.0 102.2 145.4 137.9 151.6 155.2 148.3 137.6 101.9 139.2 143.5 104.5 102.8 131.3 145.7 124.9 155.8 135.8 91.8 75.0 142.6 152.4 130.1 130.9 125.7 136.5 137.9 144.1 133.8 129.3 112.1 142.9 144.9 153.4 143.0 125.4 91.5 112.1 121.5 114.3
151.6 146.9 154.6 148.1 108.0 159.3 134.6 141.0 138.7 144.0 153.8 107.3 139.8 131.9 103.8 100.2 120.0 136.4 134.2 154.4 132.5 90.9 75.0 132.2 148.7 128.8 146.6 120.1 131.5 128.2 134.0 144.8 143.6 113.3 152.9 139.9 137.8 146.9 127.7 95.7 118.6 119.7 123.7
152.5 142.1 142.5 155.8 106.3 155.7 131.0 128.1 120.9 136.7 160.2 105.9 142.4 118.8 97.7 97.6 108.2 126.3 139.1 145.3 119.0 88.8 76.1 119.9 132.6 123.3 154.4 111.2 123.0 114.6 121.2 139.9 151.6 114.4 154.2 132.2 123.7 141.3 124.5 93.9 122.1 112.4 132.8
142.4 133.8 128.3 145.0 102.3 148.0 134.4 109.6 105.3 129.3 158.0 102.0 134.1 103.9 91.8 96.3 97.4 117.0 135.4 131.7 103.0 87.9 80.9 106.8 118.5 113.3 153.0 104.3 108.3 98.3 110.0 134.9 143.9 114.1 152.9 114.3 111.1 135.3 125.4 90.3 116.5 102.5 131.5
140.0 132.0 125.9 143.4 102.3 145.0 142.8 106.6 100.9 126.0 162.5 101.7 132.1 102.3 97.7 105.0 96.4 115.3 137.7 130.1 94.9 96.2 92.8 102.6 115.9 113.0 143.4 100.0 103.7 95.6 103.5 131.4 143.0 111.6 156.5 108.3 104.8 131.8 131.3 91.1 116.6 100.6 128.6
130.9 121.5 126.0 134.9 97.6 132.3 136.6 99.6 90.8 117.3 154.6 95.3 122.4 97.3 98.9 110.7 90.2 105.9 127.8 129.4 90.6 102.3 101.8 98.2 107.9 114.1 135.7 95.3 98.9 90.9 97.2 122.7 132.2 104.0 146.3 104.6 100.9 121.6 122.4 85.8 110.3 101.1 118.0
121.0 113.0 120.3 121.6 93.2 123.0 126.8 96.1 85.8 109.2 148.5 89.1 115.1 93.4 102.1 118.1 88.3 101.4 121.2 130.5 84.5 100.8 107.3 94.4 102.5 109.3 118.5 89.0 95.7 85.4 93.4 113.2 122.4 100.4 135.3 96.8 94.0 113.6 113.8 79.4 101.4 103.7 109.7
115.1 110.0 120.7 115.7 93.9 117.8 124.8 95.8 83.4 109.4 142.5 87.0 112.0 94.8 105.1 121.0 86.9 99.8 114.2 129.0 82.9 107.0 115.6 96.1 102.9 117.2 109.9 91.4 96.9 86.7 95.5 110.5 121.0 96.0 133.2 94.1 94.1 109.3 110.4 77.2 101.3 105.9 107.3
111.5 109.4 123.1 113.3 87.1 111.2 123.4 96.7 83.6 107.9 138.0 82.7 113.7 93.4 108.9 124.5 89.3 99.3 115.6 129.4 85.6 110.7 116.4 98.8 102.8 110.2 109.1 89.5 99.1 89.7 92.6 107.9 116.4 91.4 127.4 94.0 94.0 105.0 104.3 73.9 99.3 101.9 104.2
104.7 104.7 119.2 106.3 82.2 81.9 104.8 115.2 94.2 81.9 103.8 128.5 77.5 107.5 93.6 108.9 129.5 87.5 95.4 109.5 125.2 85.8 112.0 115.4 98.1 101.2 103.9 101.2 84.4 97.9 90.7 90.7 104.3 108.3 86.0 119.9 90.4 92.0 100.2 96.4 70.5 91.6 96.6 95.6
96.9 97.9 111.2 97.2 77.3 96.9 110.6 91.8 80.8 100.1 121.3 71.3 99.4 92.9 108.0 128.5 88.1 93.9 102.9 113.6 83.7 112.9 118.4 103.3 99.4 97.9 93.5 85.0 96.4 92.1 90.8 99.0 100.0 82.5 114.9 87.6 89.5 98.3 88.9 64.7 86.8 90.3 92.1
97.9 100.0 112.6 97.8 76.2 97.7 113.3 96.7 90.2 104.8 123.8 68.9 101.5 97.4 116.3 143.6 96.1 96.3 101.2 116.8 91.5 124.3 125.8 116.5 103.4 99.7 95.6 88.4 105.6 106.2 97.6 101.0 99.6 79.8 112.9 92.4 93.1 101.0 89.9 63.8 87.7 91.2 91.4
95.8 102.4 112.6 98.9 77.0 96.6 116.5 103.9 99.6 110.2 125.6 69.4 104.2 106.1 124.0 156.9 105.5 100.6 103.2 116.5 100.1 139.5 134.1 132.9 111.5 97.0 95.5 94.0 115.6 121.0 103.6 103.6 100.6 78.8 114.4 97.2 100.9 103.0 90.8 64.2 86.7 90.5 91.2
98.5 97.4 109.4 92.5 71.1 89.4 104.4 104.1 101.7 108.7 120.4 64.9 96.7 106.9 126.4 156.7 107.8 99.0 93.9 109.5 104.7 140.8 128.5 135.1 112.5 89.0 89.8 94.0 117.8 124.0 104.4 100.0 92.6 73.5 107.7 94.7 102.1 101.1 85.0 59.8 79.5 83.7 84.2
86.2 100.8 109.0 91.9 70.6 89.1 117.3 115.8 115.1 119.8 121.4 65.7 99.9 120.1 137.8 164.8 120.9 110.3 93.0 110.5 116.0 149.2 135.4 142.4 122.7 89.3 90.8 107.5 130.8 134.3 120.1 106.5 91.8 73.1 110.8 104.6 111.7 110.3 86.4 60.4 79.6 83.1 85.0
88.5 99.5 110.3 90.5 69.8 85.8 116.8 123.6 122.6 126.1 120.8 63.1 100.4 126.3 144.8 166.3 130.2 115.6 88.8 109.9 126.3 149.4 135.8 145.1 127.3 85.6 90.4 113.1 140.9 136.7 128.2 110.0 88.2 68.4 108.6 109.6 114.5 111.0 83.3 57.7 78.2 79.6 81.9
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