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Benchmark Calculation for BEAVRS Cycles 1 and 2 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 BEAVRS Cycles 1 and 2 Using
the SCALE 6.3/POLARIS-PARCS V3.4.2 Code Package**

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December 2024

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ABBREVIATIONS

BEAVRS	Benchmark for Evaluation and Validation of Reactor Simulations
BOC	beginning of cycle
BA	burnable absorber
CR	control rod
EFPD	effective full power day
ENDF	Evaluated Nuclear Data File
EOC	end of cycle
FTC	fuel temperature coefficient
F_q	total nuclear hot channel factor
$F_{\Delta H}^N$	enthalpy rise hot channel factor
F_{xy}	total planar radial peaking factor (3D)
F_r	radial nuclear hot channel factor (axially integrated)
HFP	hot full power
HZP	hot zero power
Inc-718	Inconel-718
ITC	isothermal temperature coefficient
LWR	light-water reactor
MC	Monte Carlo
MG	multigroup
MOC	middle of cycle
ORNL	Oak Ridge National Laboratory
PWR	pressurized water reactor
RMS	root mean square
SS-304	Stainless steel 304
Zr-4	Zircaloy-4

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ABSTRACT

This study performed the benchmark calculation for BEAVRS to validate the SCALE 6.3/Polaris–PARCS v3.4.2 code package with the ENDF/B-VII.1 56-group library, comparing the simulated results with the measured data. The benchmark results will be used in evaluating uncertainties of the SCALE/Polaris–PARCS code package for pressurized water reactor physics analysis for key nuclear parameters such as reactivity, control bank worth, temperature coefficients, and pin and assembly power peaking factors. This report details plant and fuel design specifications and input data for SCALE/Polaris as well as GenPMAXS and PARCS. Additionally, detailed information is provided for all the input and output files produced for the benchmark calculations. The benchmark results are summarized herein so that they can be used in evaluating uncertainties for key nuclear parameters with other benchmark results.

1. INTRODUCTION

Benchmark for Evaluation And Validation of Reactor Simulations (BEAVRS) [1] is a multi-cycle full-core pressurized water reactor (PWR) depletion benchmark based on two operational cycles of a commercial nuclear power plant. BEAVRS provides a detailed description of fuel assemblies, burnable absorbers, in-core fission detectors, core loading patterns, and numerous in-vessel components. The benchmark also provides measured reactor data for hot zero power (HZP) physics tests, boron letdown curves, and 3D in-core flux maps from 58 instrumented assemblies.

This study performed the benchmark calculations for the BEAVRS benchmark problems to validate the SCALE 6.3/Polaris [2, 3]–GenPMAXS v6.3.1 [4]–PARCS v3.4.2 [5] code package for PWR analysis with the ENDF/B-VII.1 AMPX 56-group library [6]. The simulated benchmark results were compared to the measured data, and then they will be used in the validation of the SCALE 6.3/PARCS–GenPMAXS–PARCS v3.4.2 code package by evaluating uncertainties for key nuclear parameters such as reactivity, control bank work, temperature coefficients, and pin and assembly power peaking factors.

Section 2 provides a brief overview of the Polaris–GenPMAXS-PARCS code package as well as detailed information for the plant design data and measured data. Because the measured data were obtained for HZP and hot full power (HFP), the design data were thermally expanded to prepare input data for Polaris, GenPMAXS, and PARCS. In Section 3, the simulated benchmark results are summarized and compared to the measured data. In addition, detailed information is provided for the input and output files generated from the benchmark calculations. Section 4 discusses the pending issues in Polaris and PARCS. The summary and concluding remarks are presented in Section 5.

2. CODE PACKAGE AND DESIGN SPECIFICATION

2.1 PROCEDURE AND CODE PACKAGE

Benchmark calculations for BEAVRS cycles 1 and 2 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. Figure 2.1 illustrates the flowchart of the Polaris–GenPMAXS–PARCS code package to simulate PWRs. SCALE/Polaris, developed by Oak Ridge National Laboratory, is a 2D lattice physics code to generate 2-group homogenized cross sections and pin power form factors for fuel assemblies and reflectors. The 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 library for each type of fuel assembly and reflector: 2-group macroscopic cross sections are functionalized with respect to burnup, boron concentration, moderator and fuel temperatures, moderator density, and control rod insertion. Once cross section libraries are prepared for all types of fuel assemblies and radial and axial reflectors, whole-core nodal diffusion calculations are performed using the PARCS code, also developed by the University of Michigan. Typically, a simplified internal thermal hydraulics model can be used for the PWR physics analysis. However, a sensitivity analysis is required to compare the PARCS results with the simplified internal thermal hydraulics model and PATHS [7].

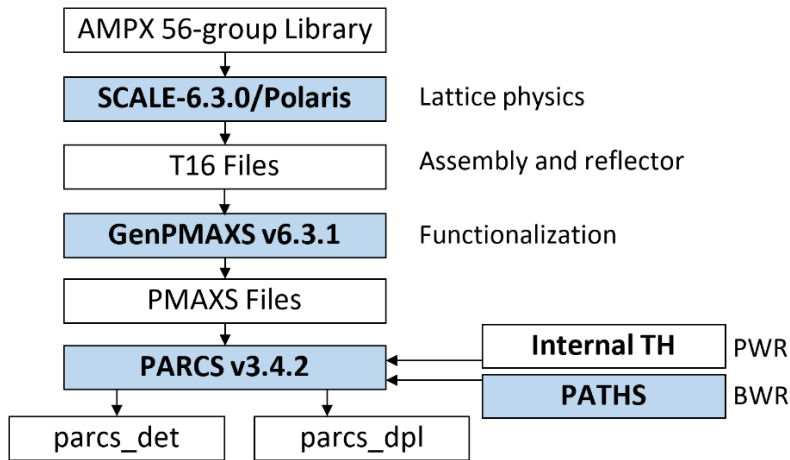


Figure 2.1. Flowchart of the Polaris–GenPMAXS–PARCS procedure.

The SCALE 6.3/Polaris, GenPMAXS v6.3.1 and PARCS v3.4.2 with the ENDF/B-VII.1 AMPX 56-group library were used in these benchmark calculations. Table 2.1 provides detailed information on the programs and data used in the benchmark calculations.

Table 2.1. Programs used in the benchmark calculations.

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

2.2 SPECIFICATION OF THE BEAVRS CORE

2.2.1 Design Data

BEAVRS [1] is a multi-cycle, full-core PWR depletion benchmark based on two operational cycles of a commercial nuclear power plant. BEAVRS provides a detailed description of fuel assemblies, burnable absorbers, in-core fission detectors, core loading patterns, and numerous in-vessel components. The benchmark also provides measured reactor data for HZP physics tests, boron letdown curves, and 3D in-core flux maps from 58 instrumented assemblies.

Table 2.2 provides key design specifications of the BEAVRS core for cycles 1 and 2. Table 2.3 provides specifications of the BEAVRS fuel assemblies and radial and axial reflectors. Because the plant measured data are for the HZP and HFP conditions, the geometry and composition specifications were thermally expanded at the HZP temperature using the thermal expansion coefficients provided in Table 2.4. A sensitivity calculation was performed to investigate the impact of thermal expansion, which shows some differences in reactivity and TIP comparison. These thermally expanded data were used in the Polaris, GenPMAXS, and PARCS inputs. The thermally expanded dimension (l_T) at temperature T can be calculated using

$$l_T = l_{25} \times (1.0 + \Delta T \times \varepsilon), \quad (2.1)$$

where ΔT is the temperature difference between 25 °C and actual temperature (T), and ε denotes the thermal expansion coefficient.

Table 2.2. Specifications of the BEAVRS core [1].

Parameter	Design data	Hot dimension
Core power	3411 MWth	
Operating pressure	2250 psia (15.51 MPa)	
Core flow rate	61.5×10^6 kg/hr (5% bypass)	
Inlet temperature	292.89 °C	
Number of fuel assemblies	193	
Region 1 (cycle-1)	1.60 w/o ^{235}U	
Region 2 (cycle-1)	2.40 w/o ^{235}U	
Region 3 (cycle-1)	3.10 w/o ^{235}U	
Region 4A (cycle-2)	3.20 w/o ^{235}U	
Region 4B (cycle-2)	3.40 w/o ^{235}U	
Total heavy metal mass (cycle-1)	81.8 MT	
Pin lattice configuration	17×17	
Active fuel length	365.76 cm	367.6833 cm
Number of fuel rods	264	
Number of grid spacers	8 (6 Zircaloy, 2 Inconel-718)	
Assembly pitch	21.50364 cm	21.60912 cm
Pin pitch	1.25984 cm	1.26198 cm
Fuel pellet radius	0.39218 cm	0.39424 cm
Cladding inner/outer radius	0.40005/0.45720 cm	0.40073/0.45798 cm
Number of control banks	57	
Control rod material (upper)	B ₄ C	
Control rod material (lower)	AgInCd	
Number of burnable poison rods	1266	
Burnable poison material	Borosilicate glass, 12.5 w/o B ₂ O ₃	

Table 2.3. Specifications of the BEAVRS fuel assemblies and reflectors [1].

Item	Material	Density (g/cm ³)	Sub-item (unit)	Thermal exp. Coeff. (°C ⁻¹)	Dimension	
					Cold	Hot
Active height	UO ₂		(cm)	1.052E-05	365.76	367.6833
Assembly pitch	SS-304		(cm)	1.730E-05	21.50364	21.60912
Pin pitch	Zr-4	6.55	(cm)	6.000E-06	1.25984	1.26198
Assembly gap			(cm)		0.04318	0.07770
Fuel	UO ₂		Outer radius (cm)	1.052E-05	0.39218	0.39424
Clad	Zr-4	6.55	Inner radius (cm)	6.000E-06	0.40005	0.40073
			Outer radius (cm)	6.000E-06	0.45720	0.45798
Instrument tube	Zr-4	6.55	Inner radius(cm)	6.000E-06	0.56134	0.56229
			Outer radius(cm)	6.000E-06	0.60198	0.60300
Guide tube	Zr-4	6.55	Inner radius(cm)	6.000E-06	0.56134	0.56229
			Outer radius(cm)	6.000E-06	0.60198	0.60300
Spacer grid (top/bottom)	Inc-718	8.2	Inc-718 weight (g)		390.136	
	SS-304 (sleeve)	8.03	SS-304 weight (g)		91.0329	
			Height (cm)		3.358	
			Volume (g/cm ³)		58.9142	
Spacer grid (intermediate)	Zr-4	6.55	Zr-4 weight (g)		1169.23	
			Height (cm)		5.715	
			Volume (cm ³)		178.5084	
Radial reflector	SS-304	8.03	Water gap (cm)		0.1627	
			Baffle thick. (cm)		2.2225	
			Water		-	
Top reflector	Zr-4(29*), SS-304(55), H ₂ O(16)		Plenum		8.556	
	Zr-4(23), SS-304(45), Inc-718(20), H ₂ O(12)		Plenum + Grid		3.866	
	Zr-4(29), SS-304(55), H ₂ O(16)		Plenum		3.578	
	Zr-4(88), H ₂ O(12)		Plug		1.670	
	Zr-4(7), H ₂ O(93)		Nozzle + Gap		2.129	
	SS-304(76), H ₂ O(24)		Top nozzle		8.827	
Bottom reflector	SS-304(93), H ₂ O(7)		Support plate		7.600	
	Zr-4(44), Inc-718(21), H ₂ O(35)		Gap		5.898	
	SS-304(80), H ₂ O(20)		Bottom nozzle		6.053	
	SS-304(91), H ₂ O(20)		Support plate		5.000	
	Zr-4(44), Inc-718(21), H ₂ O(35)		Gap		20.000	

* weight%

Table 2.4. Thermal expansion coefficients.

Material	Thermal expansion coefficient (°C ⁻¹)	Reference
Zircaloy-4	6.0E-6	https://www.azom.com/article.aspx?ArticleID=7644
SS-304	17.3E-6	http://esmat.esa.int/Services/Preferred_Lists/Materials_Lists/a62.htm
UO ₂	10.52E-6	J. Chem. Phys. 30, 1524 (1959) https://doi.org/10.1063/1.1730230
Inconel-718	13.0E-6	https://www.espimetals.com/index.php/technical-data/91-inconel-718

The following rules were used in obtaining thermally expanded dimensions.

- Eq. (2.1) was used for x, y, and radial expansions.
- Hot pin pitch was determined by expanding the Zircaloy-4 (Zr-4) spacer grid material.
- Hot assembly pitch was determined by expanding the SS-304 bottom plate material.

- Active height was determined by expanding UO₂. When expanding UO₂, the total UO₂ mass should be conserved.
- Thermal expansion was not applied to spacer grids, control rod materials, and burnable poison materials because they will not change moderator volume.

Table 2.5 lists the cold and hot atomic number densities for UO₂ fuel, provided by conserving total uranium mass per each fuel assembly. The hot atomic number densities were used in the Polaris calculations to generate assembly-homogenized 2-group cross sections for nodal diffusion calculations. Table 2.6 provides atomic number densities for structure materials such as Zr-4, Inc-718, and SS-304 and burnable absorber (BA) and control rod materials. Thermal expansion was applied only for UO₂ and Zr-4 claddings. Figure 2.2 illustrates fuel assembly configurations with various loadings of BAs.

Table 2.5. Atomic number densities for UO₂ fuels.

Fuel type	²³⁵ U wt %		Density (g/cm ³)		Mass (kgU)	Nuclide	ID	Atomic number density (#/barn-cm)	
	Nominal	As-built	cold	hot				Cold	Hot
1.60_bp00	1.60	1.610	10.31341	10.15233	424.1647	²³³ U	92233	1.00000E-10	9.84389E-11
						²³⁴ U	92234	3.01310E-06	2.96606E-06
						²³⁵ U	92235	3.75030E-04	3.69175E-04
						²³⁸ U	92238	2.26250E-02	2.22718E-02
						¹⁶ O	8016	4.58950E-02	4.51785E-02
						¹⁷ O	8017	1.74820E-05	1.72091E-05
						¹⁸ O	8018	9.43130E-05	9.28407E-05
2.40_bp00	2.40	2.400	10.29748	10.13666	423.5052	²³³ U	92233	1.00000E-10	9.84389E-11
						²³⁴ U	92234	4.48420E-06	4.41420E-06
						²³⁵ U	92235	5.58140E-04	5.49427E-04
						²³⁸ U	92238	2.24070E-02	2.20572E-02
						¹⁶ O	8016	4.58280E-02	4.51126E-02
						¹⁷ O	8017	1.74570E-05	1.71845E-05
						¹⁸ O	8018	9.41760E-05	9.27058E-05
3.10_bp00	3.10	3.102	10.30166	10.14068	423.6682	²³³ U	92233	1.00000E-10	9.84389E-11
						²³⁴ U	92234	5.79870E-06	5.70818E-06
						²³⁵ U	92235	7.21750E-04	7.10483E-04
						²³⁸ U	92238	2.22530E-02	2.19056E-02
						¹⁶ O	8016	4.58500E-02	4.51342E-02
						¹⁷ O	8017	1.74660E-05	1.71933E-05
						¹⁸ O	8018	9.42220E-05	9.27511E-05
3.20_bp00	3.20	3.195	10.34115	10.1797	425.2990	²³³ U	92233	1.00000E-10	9.84389E-11
						²³⁴ U	92234	5.99590E-06	5.90230E-06
						²³⁵ U	92235	7.46290E-04	7.34640E-04
						²³⁸ U	92238	2.23170E-02	2.19686E-02
						¹⁶ O	8016	4.60260E-02	4.53075E-02
						¹⁷ O	8017	1.75330E-05	1.72593E-05
						¹⁸ O	8018	9.45840E-05	9.31075E-05
3.40_bp00	3.195	3.406	10.35917	10.19752	426.0419	²³³ U	92233	1.00000E-10	9.84389E-11
						²³⁴ U	92234	6.40180E-06	6.30186E-06
						²³⁵ U	92235	7.96810E-04	7.84371E-04
						²³⁸ U	92238	2.23070E-02	2.19588E-02
						¹⁶ O	8016	4.61080E-02	4.53882E-02
						¹⁷ O	8017	1.75640E-05	1.72898E-05
						¹⁸ O	8018	9.47510E-05	9.32719E-05

Table 2.6. Atomic number densities for structure materials (1/2).

Material	Density (g/cm ³)		Nuclide	Nuclide ID	Atomic number density (#/barn-cm)	
	cold	hot			Cold	Hot
Zr-4	6.55	6.51657	¹⁶ O	8016	3.07430E-04	3.05866E-04
			¹⁷ O	8017	1.17110E-07	1.16514E-07
			¹⁸ O	8018	6.31760E-07	6.28547E-07
			⁵⁰ Cr	24050	3.29620E-06	3.27943E-06
			⁵² Cr	24052	6.35640E-05	6.32407E-05
			⁵³ Cr	24053	7.20760E-06	7.17094E-06
			⁵⁴ Cr	24054	1.79410E-06	1.78497E-06
			⁵⁴ Fe	26054	8.66990E-06	8.62580E-06
			⁵⁶ Fe	26056	1.36100E-04	1.35408E-04
			⁵⁷ Fe	26057	3.14310E-06	3.12711E-06
			⁵⁸ Fe	26058	4.18290E-07	4.16162E-07
			⁹⁰ Zr	40090	2.18270E-02	2.17160E-02
			⁹¹ Zr	40091	4.76000E-03	4.73579E-03
			⁹² Zr	40092	7.27580E-03	7.23879E-03
			⁹⁴ Zr	40094	7.37340E-03	7.33590E-03
			⁹⁶ Zr	40096	1.18790E-03	1.18186E-03
			¹¹² Sn	50112	4.67350E-06	4.64973E-06
			¹¹⁴ Sn	50114	3.17990E-06	3.16373E-06
			¹¹⁵ Sn	50115	1.63810E-06	1.62977E-06
			¹¹⁶ Sn	50116	7.00550E-05	6.96987E-05
¹¹⁷ Sn	50117	3.70030E-05	3.68148E-05			
¹¹⁸ Sn	50118	1.16690E-04	1.16096E-04			
¹¹⁹ Sn	50119	4.13870E-05	4.11765E-05			
¹²⁰ Sn	50120	1.56970E-04	1.56172E-04			
¹²² Sn	50122	2.23080E-05	2.21945E-05			
¹²⁴ Sn	50124	2.78970E-05	2.77551E-05			
Inconel 718	8.2	Inconel 718	⁵⁰ Cr	24050	7.8239e-04	
			⁵² Cr	24052	1.5088e-02	
			⁵³ Cr	24053	1.7108e-03	
			⁵⁴ Cr	24054	4.2586e-04	
			⁵⁴ Fe	26054	1.4797e-03	
			⁵⁶ Fe	26056	2.3229e-02	
			⁵⁷ Fe	26057	5.3645e-04	
			⁵⁸ Fe	26058	7.1392e-05	
			⁵⁵ Mn	25055	7.8201e-04	
			⁵⁸ Ni	28058	2.9320e-02	
			⁶⁰ Ni	28060	1.1294e-02	
			⁶¹ Ni	28061	4.9094e-04	
			⁶² Ni	28062	1.5653e-03	
			⁶⁴ Ni	28064	3.9864e-04	
			²⁸ Si	14028	5.6757e-04	
²⁹ Si	14029	2.8820e-05				
³⁰ Si	14030	1.8998e-05				
Borosilicate glass	2.26		²⁷ Al	13027	1.7352e-03	
			¹⁰ B	5010	9.6506e-04	
			¹¹ B	5011	3.9189e-03	
			¹⁶ O	8016	4.6514e-02	
			¹⁷ O	8017	1.7671e-05	
			¹⁸ O	8018	9.3268e-05	
			²⁸ Si	14028	1.6926e-02	
			²⁹ Si	14029	8.5944e-04	
³⁰ Si	14030	5.6654e-04				

Table 2.6. Atomic number densities for structure materials (2/2).

Material	Density (g/cm ³)		Nuclide	Nuclide ID	Atomic number density (#/barn-cm)	
	cold	hot			Cold	Hot
AgInCd	10.16		¹⁰⁷ Ag	47107	2.3523e-02	
			¹⁰⁹ Ag	47109	2.1854e-02	
			¹⁰⁶ Cd	48106	3.3882e-05	
			¹⁰⁸ Cd	48108	2.4166e-05	
			¹¹⁰ Cd	48110	3.3936e-04	
			¹¹¹ Cd	48111	3.4821e-04	
			¹¹² Cd	48112	6.5611e-04	
			¹¹³ Cd	48113	3.3275e-04	
			¹¹⁴ Cd	48114	7.8252e-04	
			¹¹⁶ Cd	48116	2.0443e-04	
			¹¹³ In	49113	3.4219e-04	
¹¹⁵ In	49115	7.6511e-03				
B ₄ C	1.76		¹⁰ B	5010	1.5206e-02	
			¹¹ B	5011	6.1514e-02	
			¹² C	6012	1.8972e-02	
			¹³ C	6013	2.1252e-04	
SS 304	8.03		⁵⁰ Cr	24050	7.6778e-04	
			⁵² Cr	24052	1.4806e-02	
			⁵³ Cr	24053	1.6789e-03	
			⁵⁴ Cr	24054	4.1791e-04	
			⁵⁴ Fe	26054	3.4620e-03	
			⁵⁶ Fe	26056	5.4345e-02	
			⁵⁷ Fe	26057	1.2551e-03	
			⁵⁸ Fe	26058	1.6703e-04	
			⁵⁵ Mn	25055	1.7604e-03	
			⁵⁸ Ni	28058	5.6089e-03	
			⁶⁰ Ni	28060	2.1605e-03	
			⁶¹ Ni	28061	9.3917e-05	
			⁶² Ni	28062	2.9945e-04	
			⁶⁴ Ni	28064	7.6261e-05	
			²⁸ Si	14028	9.5281e-04	
²⁹ Si	14029	4.8381e-05				
³⁰ Si	14030	3.1893e-05				



Figure 2.2. Fuel assembly configurations with burnable absorbers (B) and guide (G) and instrument (I) tubes.

Figure 2.3 provides the cycle 1 fuel assembly and BA loading patterns. Three ^{235}U enrichments, UO_2 fuels, and five types of BA patterns were used in various combinations for a total of nine types of fuel assemblies. Figure 2.4 illustrates the cycle 2 loading patterns with fresh assembly loadings with 3.2 and 3.4 wt% ^{235}U fuels and shuffling of once-burned fuel assemblies. Control and shutdown bank positions are provided in Figure 2.5. BEAVRS includes the ^{235}U fission chambers as in-core detectors, and their locations in the core are provided in Figure 2.6. Table 2.8 provides the fuel assembly types and numbers loaded in cycles 1 and 2. The BEAVRS axial configuration for fuel, spacer grids, and reflectors are shown in Table 2.9.

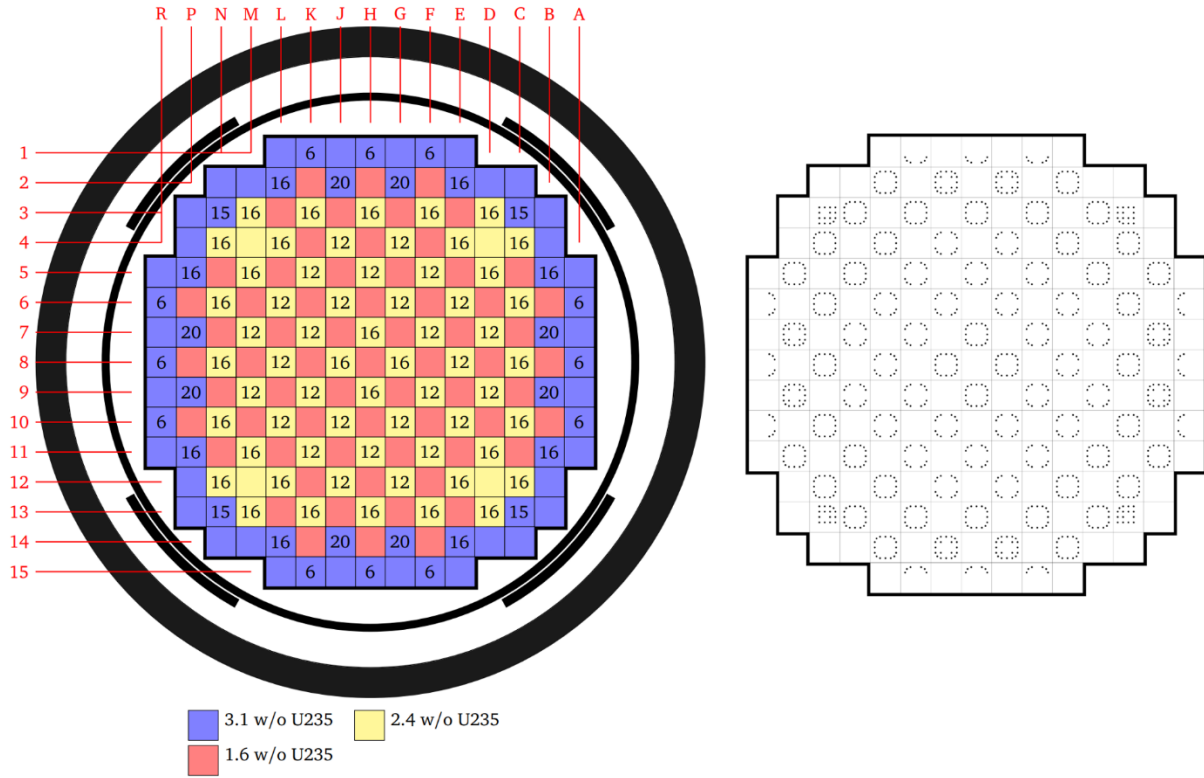


Figure 2.3. Layout of fuel assemblies and burnable poisons in BEAVRS cycle 1.

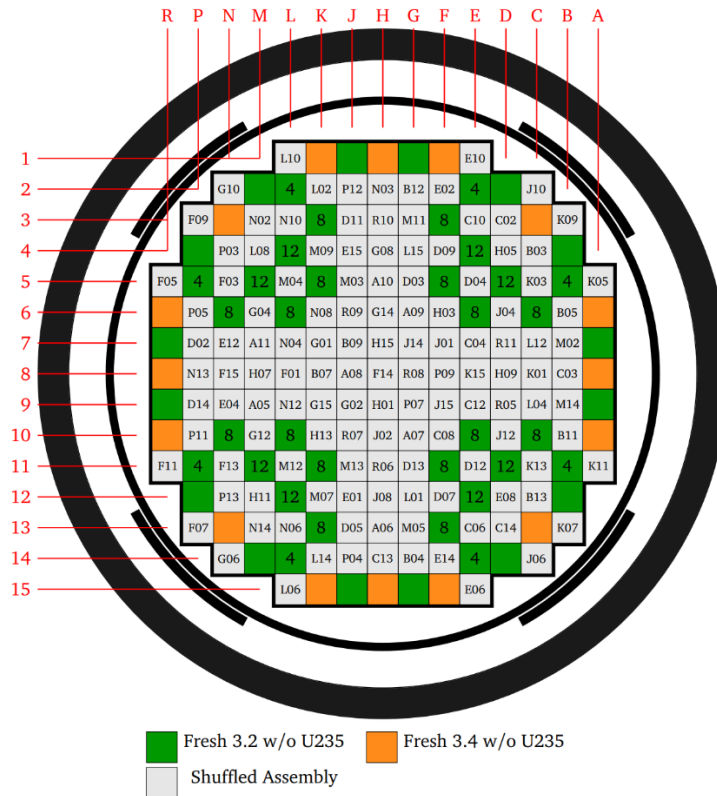


Figure 2.4. Fresh assembly loading and shuffling patterns in BEAVRS cycle 2.

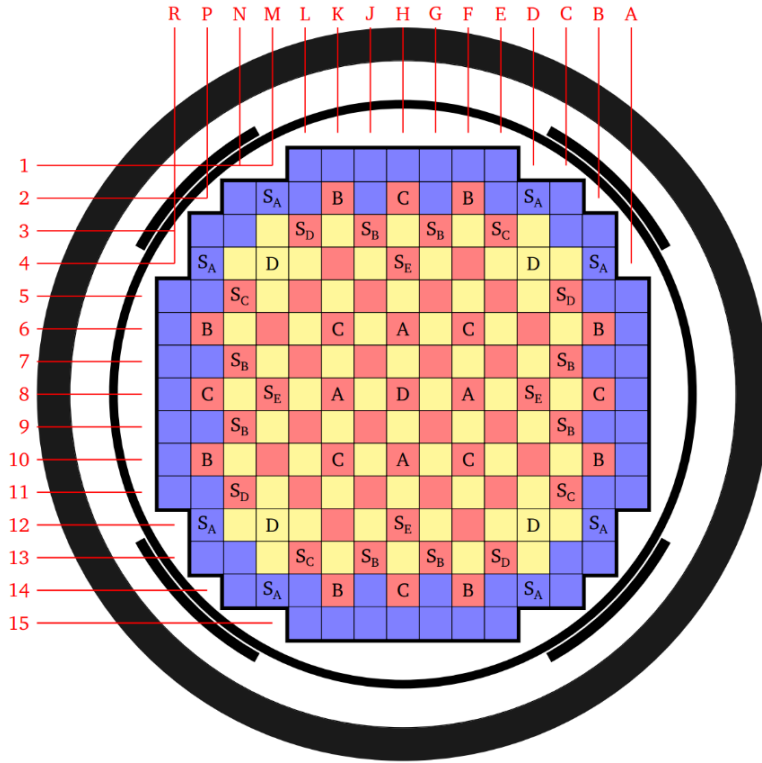


Figure 2.5. BEAVRS control rod and shutdown bank positions.

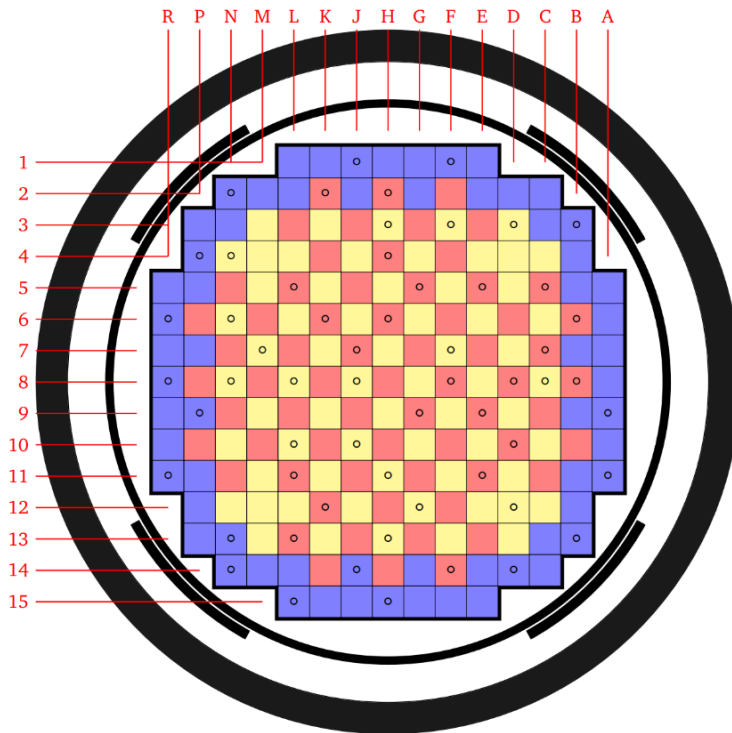


Figure 2.6. BEAVRS core instrumentation locations.

Table 2.7. Fuel assembly types.

Cycle	Type	²³⁵ U wt%	Number of burnable absorbers	Number of feeds
1	1.60_bp00	1.60	0	65
	2.40_bp00	2.40	0	4
	2.40_bp12	2.40	12	28
	2.40_bp16	2.40	16	32
	3.10_bp00	3.10	0	32
	3.10_bp06	3.10	6	12
	3.10_bp15	3.10	15	4
	3.10_bp16	3.10	16	8
	3.10_bp20	3.10	20	8
2	3.20_bp00	3.20	0	16
	3.20_bp04	3.20	4	8
	3.20_bp08	3.20	8	32
	3.20_bp12	3.20	12	8
	3.40_bp00	3.40	0	16

Table 2.8. BEAVRS core axial configurations.

No.	Axial materials	Cold (cm)	Reflector and Grid	SG* height (cm)	Hot (cm)	Distance (cm)	# of meshes	
1	Water	460.000	Highest Extent		461.923	28.124	1	
2	Nozzle/support plate SS	431.876	Top of Upper Nozzle		433.799	8.827		
3	Water	423.049	Bottom of Upper Nozzle		424.972	3.345		
4	Zircaloy pin	419.704	Top of Fuel Rod		421.627	2.540		
5	Fuel rod plenum pincell	417.164	Top of Fuel Rod Plenum		419.087	2.000		
6	Fuel rod plenum pincell w/ Grid	415.164	Grid 8 Top	3.358	417.087	3.358		
7	Fuel rod plenum pincell	411.806	Grid 8 Bottom		413.729	9.298		
8	Fuel rod pincell	402.508	Top of Active Fuel		404.431	37.917		3
9	Fuel rod pincell w/ Grid	364.725	Grid 7 Top	5.715	366.514	5.715		1
10	Fuel rod pincell	359.010	Grid 7 Bottom		360.799	46.738		3
11	Fuel rod pincell w/ Grid	312.528	Grid 6 Top	5.715	314.061	5.715		1
12	Fuel rod pincell	306.813	Grid 6 Bottom		308.346	46.738		3
13	Fuel rod pincell w/ Grid	260.331	Grid 5 Top	5.715	261.608	5.715		1
14	Fuel rod pincell	254.616	Grid 5 Bottom		255.893	46.738		3
15	Fuel rod pincell w/ Grid	208.134	Grid 4 Top	5.715	209.155	5.715		1
16	Fuel rod pincell	202.419	Grid 4 Bottom		203.440	46.738	3	
17	Fuel rod pincell w/ Grid	155.937	Grid 3 Top	5.715	156.702	5.715	1	
18	Fuel rod pincell	150.222	Grid 3 Bottom		150.987	46.738	3	
19	Fuel rod pincell w/ Grid	103.740	Grid 2 Top	5.715	104.249	5.715	1	
20	Fuel rod pincell	98.025	Grid 2 Bottom		98.534	57.815	4	
21	Fuel rod pincell w/ Grid	40.520	Grid 1 Top	3.358	40.719	3.358	1	
22	Fuel rod pincell	37.162	Grid 1 Bottom		37.361	0.613		
23	Zircaloy pin	36.748	Bottom of Active Fuel		36.748	1.748		
24	Nozzle/support plate SS	35.000	Bottom of Fuel Rod		35.000	15.000	1	
25	Water	20.000	Bottom of Support Plate		20.000	20.000		
		0.000	Lowest Extent		0.000	total	31	

* spacer grid

2.2.2 Measured Data

The measured data used in the current study were obtained from the publicly available BEAVRS cycles 1 and 2 HZP physics test data and operating history, which includes a critical boron history and in-core detector responses. The measured data are available at <https://github.com/mit-crpg/BEAVRS/>. Figures 2.7 and 2.8 illustrate the power histories and detector maps.

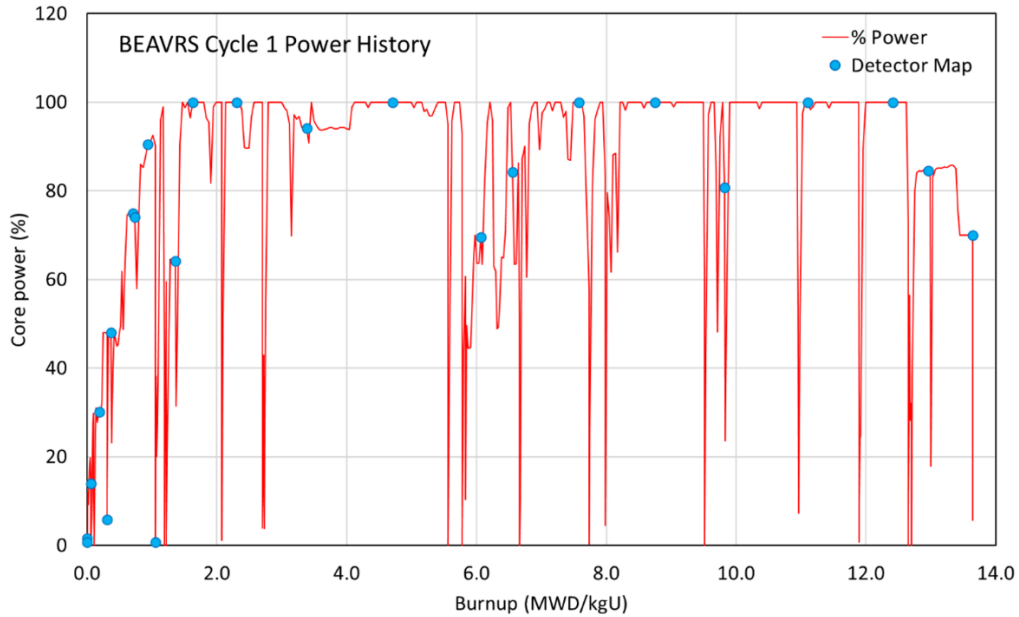


Figure 2.7. Power history and detector maps for BEAVRS cycle 1.

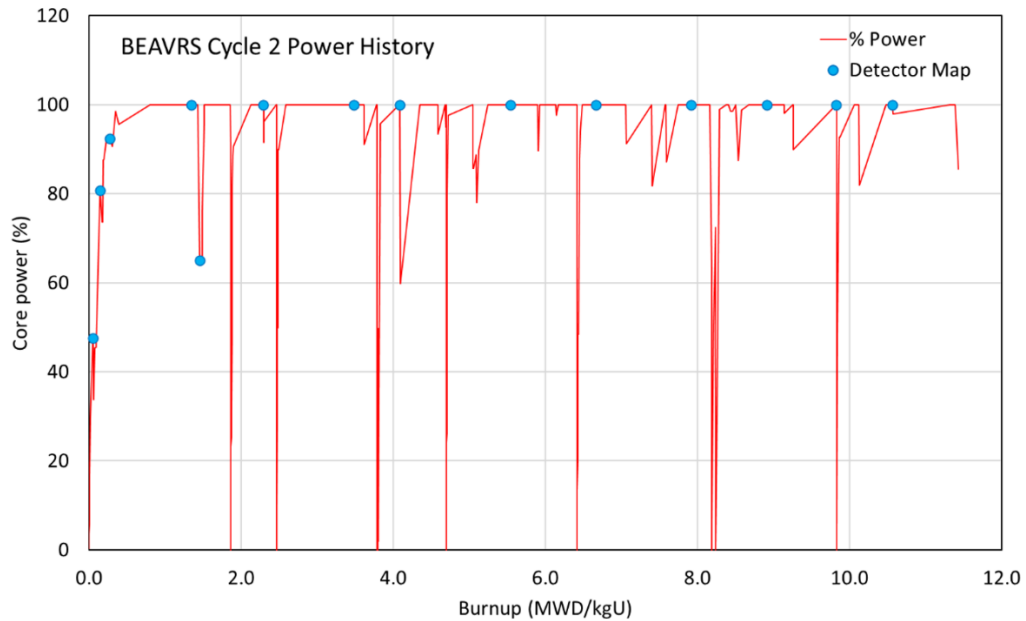


Figure 2.8. Power history and detector maps for BEAVRS cycle 2.

3. BENCHMARK CALCULATIONS AND RESULTS

3.1 BENCHMARK CALCULATION

3.1.1 Polaris Calculations

The SCALE 6.3/Polaris inputs were prepared using the data provided in Section 2 to process assembly-homogenized 2-group cross sections for whole-core nodal diffusion calculations. To cover all the possible reactor states, the 2-group cross sections were tabulated as a function of burnup, moderator and fuel temperatures, moderator density, soluble boron concentration, and control rod insertion. Table 3.1 provides state information for 7 reference cases. Another 7 reference cases are for spacer grid assemblies. There are two types of spacer grids in BEAVRS—including Zr-4 (6 intermediates) and Inc-718 (2 top and bottom)—that should be considered in the Polaris lattice physics calculation. Six intermediate Zr-4 and one bottom Inc-718 spacer grids are included in the active fuel zone. Therefore, three sets of cross section table sets should be provided for each assembly. Because there is only one Inc-718 spacer grid, it was treated as the Zr-4 spacer grid for simplicity. This should be updated in later calculations to achieve more accurate simulation results. The Inc-718 spacer grid occupies less volume, resulting in more water and more neutron absorption compared to the Zr-4 spacer grid, which helps improve the simulated axial power distribution.

To complete the functionalization of the cross section table sets, various branch calculations should be performed at each burnup point for each reference case. Tables 3.2 and 3.3 provide the information for branch states for assemblies without and with BAs, respectively. Because the Pyrex burnable absorbers are located at the guide tubes, branch cases 28–36 for the assemblies without BAs are not included in the assemblies with BAs. Table 3.4 provides the branch cases for reflectors for which no depletion calculation was performed. Figure 3.1 illustrates the Polaris models for radial and top and bottom axial reflectors.

Appendices A.1–A.4 provide the Polaris inputs for the fuel assembly 2.40_bp12 (A.1) and radial (A.2), axial top (A.3), and bottom (A.4) reflectors. Table 3.5 provides the Polaris input and output files for BEAVRS cycles 1 and 2. A sample file name with ‘beavrs_1.60_bp00_cr1_dc60_p0500_tf0800.inp’ indicates

- beavrs: BEAVRS benchmark problem,
- 1.60: 1.60 ²³⁵U wt%,
- bp00: no burnable poison,
- dc60: 0.60811 g/cm³ moderator density,
- p0500: 500 ppm,
- tf0800: 800K fuel temperature, and
- inp: Polaris input.

Table 3.5 includes the actual states for ²³⁵U wt%, burnable poisons, moderator densities, soluble boron concentrations, and fuel temperatures, and the Polaris file types.

Table 3.1. Reference cases for each assembly type.

History	History name	Control rod in	Moderator temperature (K)	Density (g/cm³)	Soluble boron (ppm)	Fuel temperature (K)	Spacer grid
A1	CR0-HDC-MPC-MTF	no	550	0.76971	500	800	no
A2	CR0-LDC-MPC-MTF	no	615	0.60811	500	800	no
A3	CR0-MDC-HPC-MTF	no	585	0.70045	1500	800	no
A4	CR0-MDC-LPC-MTF	no	585	0.70045	0	800	no
A5	CR0-MDC-MPC-HTF	no	585	0.70045	500	1600	no
A6	CR0-MDC-MPC-LTF	no	585	0.70045	500	560	no
A7	CR0-MDC-MPC-MTF	no	585	0.70045	500	800	no
A8	CR1-MDC-MPC-MTF	yes	585	0.70045	500	800	no
B1	CR0-HDC-MPC-MTF	no	550	0.76971	500	800	yes
B2	CR0-LDC-MPC-MTF	no	615	0.60811	500	800	yes
B3	CR0-MDC-HPC-MTF	no	585	0.70045	1500	800	yes
B4	CR0-MDC-LPC-MTF	no	585	0.70045	0	800	yes
B5	CR0-MDC-MPC-HTF	no	585	0.70045	500	1600	yes
B6	CR0-MDC-MPC-LTF	no	585	0.70045	500	560	yes
B7	CR0-MDC-MPC-MTF	no	585	0.70045	500	800	yes
B8	CR1-MDC-MPC-MTF	yes	585	0.70045	500	800	yes

Table 3.2. Branch states for assembly types without BAs.

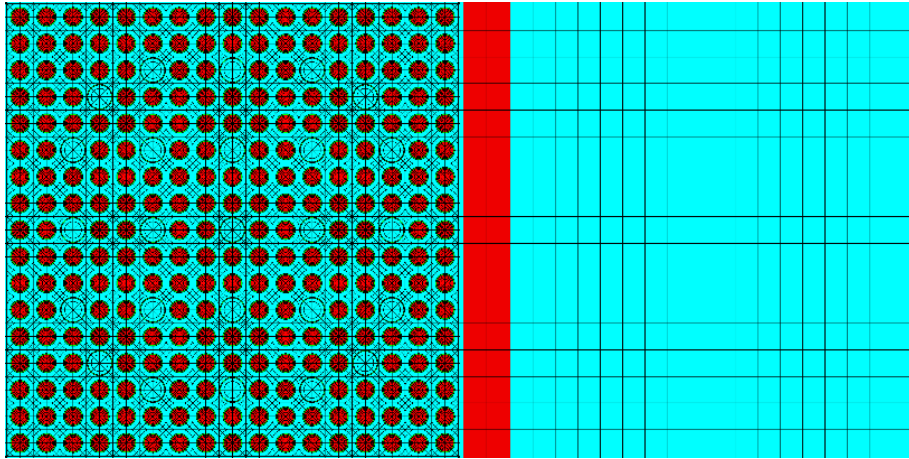
Case	Control bank		All	Moderator		Fuel	Reference
	B	A	Temperature (K)	Density (g/cm ³)	Soluble boron (ppm)	Temperature (K)	
1	false	false	615.0	0.60811	0.1	560.0	
2	false	false	615.0	0.60811	500	560.0	
3	false	false	615.0	0.60811	1500	560.0	
4	false	false	585.0	0.70045	0.1	560.0	
5	false	false	585.0	0.70045	500	560.0	A6
6	false	false	585.0	0.70045	1500	560.0	
7	false	false	550.0	0.76971	0.1	560.0	
8	false	false	550.0	0.76971	500	560.0	
9	false	false	550.0	0.76971	1500	560.0	
10	false	false	615.0	0.60811	0.1	800.0	
11	false	false	615.0	0.60811	500	800.0	A2, B2
12	false	false	615.0	0.60811	1500	800.0	
13	false	false	585.0	0.70045	0.1	800.0	A4, B4
14	false	false	585.0	0.70045	500	800.0	A7, B7
15	false	false	585.0	0.70045	1500	800.0	A3, B3
16	false	false	550.0	0.76971	0.1	800.0	
17	false	false	550.0	0.76971	500	800.0	A1, B1
18	false	false	550.0	0.76971	1500	800.0	
19	false	false	615.0	0.60811	0.1	1600.0	
20	false	false	615.0	0.60811	500	1600.0	
21	false	false	615.0	0.60811	1500	1600.0	
22	false	false	585.0	0.70045	0.1	1600.0	
23	false	false	585.0	0.70045	500	1600.0	A5, B5
24	false	false	585.0	0.70045	1500	1600.0	
25	false	false	550.0	0.76971	0.1	1600.0	
26	false	false	550.0	0.76971	500	1600.0	
27	false	false	550.0	0.76971	1500	1600.0	
28	true	false	615.0	0.60811	0.1	800.0	
29	true	false	615.0	0.60811	500	800.0	
30	true	false	615.0	0.60811	1500	800.0	
31	true	false	585.0	0.70045	0.1	800.0	
32	true	false	585.0	0.70045	500	800.0	A8, B8
33	true	false	585.0	0.70045	1500	800.0	
34	true	false	550.0	0.76971	0.1	800.0	
35	true	false	550.0	0.76971	500	800.0	
36	true	false	550.0	0.76971	1500	800.0	
37	false	true	615.0	0.60811	0.1	800.0	
38	false	true	615.0	0.60811	500	800.0	
39	false	true	615.0	0.60811	1500	800.0	
40	false	true	585.0	0.70045	0.1	800.0	
41	false	true	585.0	0.70045	500	800.0	
42	false	true	585.0	0.70045	1500	800.0	
43	false	true	550.0	0.76971	0.1	800.0	
44	false	true	550.0	0.76971	500	800.0	
45	false	true	550.0	0.76971	1500	800.0	

Table 3.3. Branch states for assembly types with BAs.

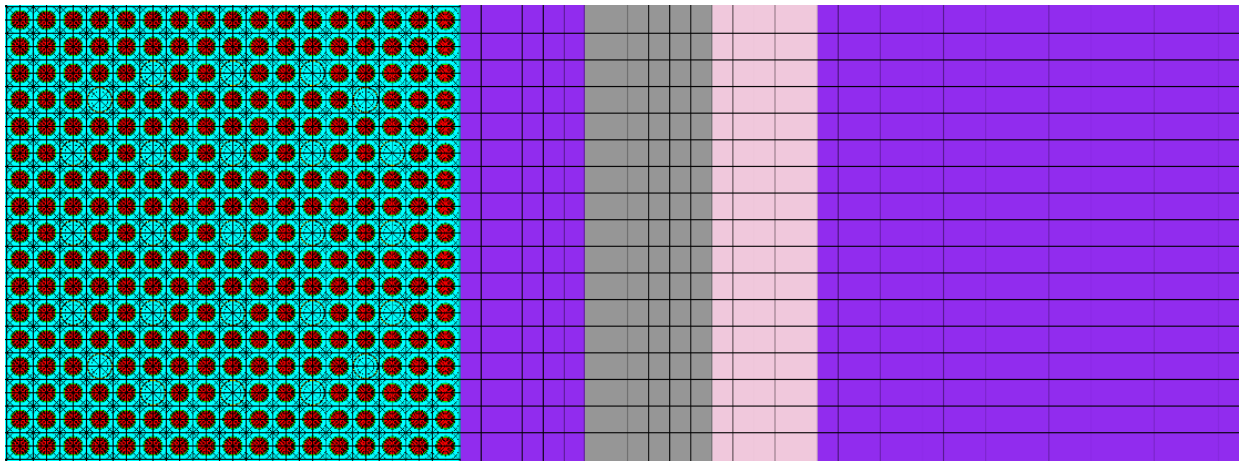
Case	Control bank		All	Moderator		Fuel	Remark
	BA	Rod	Temperature (K)	Density (g/cm ³)	Soluble boron (ppm)	Temperature (K)	
1	false	–	615.0	0.60811	0.1	560.0	
2	false	–	615.0	0.60811	500	560.0	
3	false	–	615.0	0.60811	1500	560.0	
4	false	–	585.0	0.70045	0.1	560.0	
5	false	–	585.0	0.70045	500	560.0	A6
6	false	–	585.0	0.70045	1500	560.0	
7	false	–	550.0	0.76971	0.1	560.0	
8	false	–	550.0	0.76971	500	560.0	
9	false	–	550.0	0.76971	1500	560.0	
10	false	–	615.0	0.60811	0.1	800.0	
11	false	–	615.0	0.60811	500	800.0	A2, B2
12	false	–	615.0	0.60811	1500	800.0	
13	false	–	585.0	0.70045	0.1	800.0	A4, B4
14	false	–	585.0	0.70045	500	800.0	A7, B7
15	false	–	585.0	0.70045	1500	800.0	A3, B3
16	false	–	550.0	0.76971	0.1	800.0	
17	false	–	550.0	0.76971	500	800.0	A1, B1
18	false	–	550.0	0.76971	1500	800.0	
19	false	–	615.0	0.60811	0.1	1600.0	
20	false	–	615.0	0.60811	500	1600.0	
21	false	–	615.0	0.60811	1500	1600.0	
22	false	–	585.0	0.70045	0.1	1600.0	
23	false	–	585.0	0.70045	500	1600.0	A5, B5
24	false	–	585.0	0.70045	1500	1600.0	
25	false	–	550.0	0.76971	0.1	1600.0	
26	false	–	550.0	0.76971	500	1600.0	
27	false	–	550.0	0.76971	1500	1600.0	
28	true	–	615.0	0.60811	0.1	800.0	
29	true	–	615.0	0.60811	500	800.0	
30	true	–	615.0	0.60811	1500	800.0	
31	true	–	585.0	0.70045	0.1	800.0	
32	true	–	585.0	0.70045	500	800.0	A8, B8
33	true	–	585.0	0.70045	1500	800.0	
34	true	–	550.0	0.76971	0.1	800.0	
35	true	–	550.0	0.76971	500	800.0	
36	true	–	550.0	0.76971	1500	800.0	

Table 3.4. Branch states for reflectors.

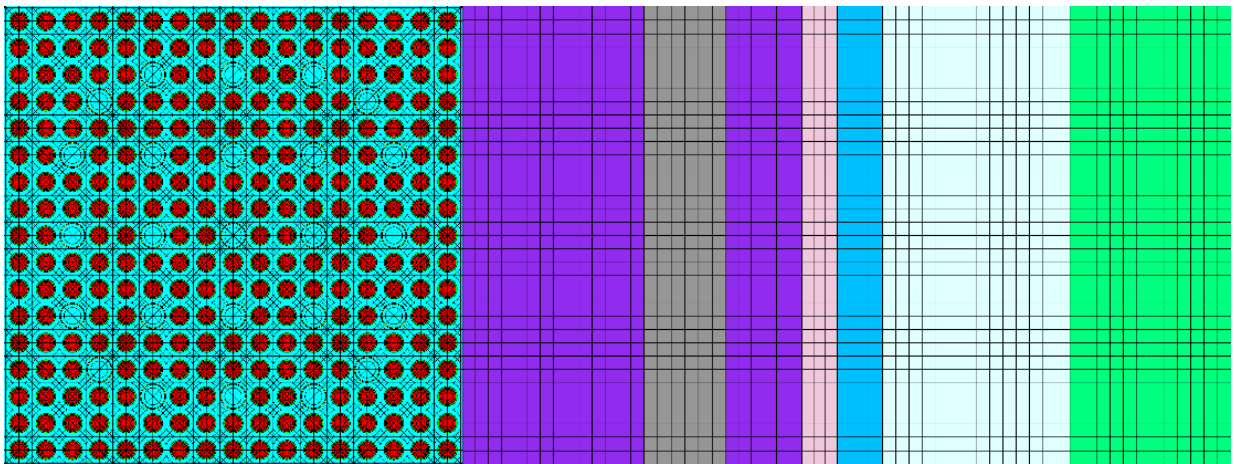
Case	Control bank		All	Moderator		Fuel
	BA	Rod	Temperature (K)	Density (g/cm ³)	Soluble boron (ppm)	Temperature (K)
Reference	false	false	550.0	0.76971	600	800.0
1	false	false	550.0	0.76971	0	800.0
1	false	false	550.0	0.76971	1800	800.0
2	false	false	580.0	0.70045	600	800.0



(A) Radial reflector



(B) Bottom axial reflector



(C) Top axial reflector

Figure 3.1. Polaris models for reflectors.

Table 3.5. Polaris input and output files for BEAVRS.

Assembly type	Dir	File name	Description
1.60_bp00	./bare	beavrs_1.60_bp00_cr?_dc??_p????_tf????.*	Dir
2.40_bp00	./bare	beavrs_2.40_bp00_cr?_dc??_p????_tf????.*	./bare: no spacer grid
2.40_bp12	./bare	beavrs_2.40_bp12_cr?_dc??_p????_tf????.*	./zirc: Zr-4 spacer grid
2.40_bp16	./bare	beavrs_2.40_bp16_cr?_dc??_p????_tf????.*	./refl: reflector
3.10_bp00	./bare	beavrs_3.10_bp00_cr?_dc??_p????_tf????.*	Input, output, T16 cr?: Control rod cr0: out cr1: in dc?? moderator density dc60: 0.60811 dc70: 0.70045 dc77: 0.76971 p???? boron concentration p0000: 0 ppm p0500: 500 ppm p1500: 1500 ppm tf???? Fuel temperature tf0560: 560 K tf0800: 800 K tf1600: 1600 K * File names inp: input file idc: idc format input msg: message file out: output file png: geometry image t16: few-group cross sections f71: ORIGEN concentration f33: ORIGEN library
3.10_bp06	./bare	beavrs_3.10_bp06_cr?_dc??_p????_tf????.*	
3.10_bp15	./bare	beavrs_3.10_bp15_cr?_dc??_p????_tf????.*	
3.10_bp16	./bare	beavrs_3.10_bp16_cr?_dc??_p????_tf????.*	
3.10_bp20	./bare	beavrs_3.10_bp20_cr?_dc??_p????_tf????.*	
3.20_bp00	./bare	beavrs_3.20_bp00_cr?_dc??_p????_tf????.*	
3.20_bp04	./bare	beavrs_3.20_bp04_cr?_dc??_p????_tf????.*	
3.20_bp08	./bare	beavrs_3.20_bp08_cr?_dc??_p????_tf????.*	
3.20_bp12	./bare	beavrs_3.20_bp12_cr?_dc??_p????_tf????.*	
3.40_bp00	./bare	beavrs_3.40_bp00_cr?_dc??_p????_tf????.*	
1.60_bp00	./zirc	beavrs_1.60_bp00_cr?_dc??_p????_tf????.*	
2.40_bp00	./zirc	beavrs_2.40_bp00_cr?_dc??_p????_tf????.*	
2.40_bp12	./zirc	beavrs_2.40_bp12_cr?_dc??_p????_tf????.*	
2.40_bp16	./zirc	beavrs_2.40_bp16_cr?_dc??_p????_tf????.*	
3.10_bp00	./zirc	beavrs_3.10_bp00_cr?_dc??_p????_tf????.*	
3.10_bp06	./zirc	beavrs_3.10_bp06_cr?_dc??_p????_tf????.*	
3.10_bp15	./zirc	beavrs_3.10_bp15_cr?_dc??_p????_tf????.*	
3.10_bp16	./zirc	beavrs_3.10_bp16_cr?_dc??_p????_tf????.*	
3.10_bp20	./zirc	beavrs_3.10_bp20_cr?_dc??_p????_tf????.*	
3.20_bp00	./zirc	beavrs_3.20_bp00_cr?_dc??_p????_tf????.*	
3.20_bp04	./zirc	beavrs_3.20_bp04_cr?_dc??_p????_tf????.*	
3.20_bp08	./zirc	beavrs_3.20_bp08_cr?_dc??_p????_tf????.*	
3.20_bp12	./zirc	beavrs_3.20_bp12_cr?_dc??_p????_tf????.*	
3.40_bp00	./zirc	beavrs_3.40_bp00_cr?_dc??_p????_tf????.*	
Radial reflector	./refl	beavrs_refl_rad.*	
Top reflector	./refl	beavrs_refl_top.*	
Bottom reflector	./refl	beavrs_refl_bot.*	

3.1.2 Cross Section Table-set Generation Using GenPMAXS

Appendices B.1–B.4 provide the GenPMAXS inputs for the fuel assembly 2.40_bp12 and radial edge, axial top, and bottom reflectors.

- B.1 GenPMAXS input for the fuel assembly 2.40_bp12
- B.2 GenPMAXS input for radial edge reflector
- B.3 GenPMAXS input for axial top reflector
- B.4 GenPMAXS input for axial bottom reflector

Table 3.6 provides the GenPMAXS input and output files. There can be various GenPMAXS input files for various radial reflectors, including edge, east, southeast, and south reflectors.

Table 3.6. GenPMAXS input and output files for BEAVRS.

Assembly type	Dir	Filename	Description
1.60_bp00	./bare	1.60_bp00.*	Dir ./bare: no spacer grid ./zirc: Zr-4 spacer grid * inp_pmx: input files kinf: kinf summary out: output file PMAX: cross section table set
2.40_bp00	./bare	2.40_bp00.*	
2.40_bp12	./bare	2.40_bp12.*	
2.40_bp16	./bare	2.40_bp16.*	
3.10_bp00	./bare	3.10_bp00.*	
3.10_bp06	./bare	3.10_bp06.*	
3.10_bp15	./bare	3.10_bp15.*	
3.10_bp16	./bare	3.10_bp16.*	
3.10_bp20	./bare	3.10_bp20.*	
3.20_bp00	./bare	3.20_bp00.*	
3.20_bp04	./bare	3.20_bp04.*	
3.20_bp08	./bare	3.20_bp08.*	
3.20_bp12	./bare	3.20_bp12.*	
3.40_bp00	./bare	3.40_bp00.*	
1.60_bp00	./zirc	1.60_bp00.*	
2.40_bp00	./zirc	2.40_bp00.*	
2.40_bp12	./zirc	2.40_bp12.*	
2.40_bp16	./zirc	2.40_bp16.*	
3.10_bp00	./zirc	3.10_bp00.*	
3.10_bp06	./zirc	3.10_bp06.*	
3.10_bp15	./zirc	3.10_bp15.*	
3.10_bp16	./zirc	3.10_bp16.*	
3.10_bp20	./zirc	3.10_bp20.*	
3.20_bp00	./zirc	3.20_bp00.*	
3.20_bp04	./zirc	3.20_bp04.*	
3.20_bp08	./zirc	3.20_bp08.*	
3.20_bp12	./zirc	3.20_bp12.*	
3.40_bp00	./zirc	3.40_bp00.*	
Radial reflector diagonal	./bare	refl_rad_diag.*	
Radial reflector edge	./bare	refl_rad_edge.*	
Radial reflector east	./bare	refl_rad_E.*	
Radial reflector south east	./bare	refl_rad_SE.*	
Radial reflector south	./bare	refl_rad_S.*	
Top reflector	./bare	refl_top.*	
Bottom reflector	./bare	refl_bot.*	

3.1.3 Whole-Core Nodal Diffusion Calculations Using PARCS

Appendices C.1–C.6 provides the PARCS inputs for BEAVRS cycles 1 and 2 HZP and HFP calculations.

- C.1 PARCS input for the cross section set ‘pmax.dir’ file
- C.2 PARCS input for the assembly geometry ‘depl_assm.geom’ file
- C.3 PARCS input for the in-core detector map ‘depl_detect.geom’ file
- C.4 PARCS input for HFP cycle 1
- C.5 PARCS input for the HZP cycle 2 fuel shuffling
- C.6 PARCS input for HFP cycle 2

Table 3.7 provides the PARCS input and output files.

Table 3.7. PARCS input and output files for BEAVRS.

Cycle	Condition	File name	Description
All		depl_assm.geom	Assembly geometry
		depl_detect.geom	Detector
		pmax.dir	Cross section table sets
1	HZIP	beavrs_c1_hzp_01_ARO_keff.*	
		beavrs_c1_hzp_02_ARO_ITC1.*	
		beavrs_c1_hzp_02_ARO_ITC2.*	
		beavrs_c1_hzp_02_ARO_ppm.*	
		beavrs_c1_hzp_03_Din_keff.*	
		beavrs_c1_hzp_04_Din_ppm.*	
		beavrs_c1_hzp_04_Din_ppm_ITC1.*	
		beavrs_c1_hzp_04_Din_ppm_ITC2.*	
		beavrs_c1_hzp_05_CinD_keff.*	
		beavrs_c1_hzp_06_CDin_ppm.*	
		beavrs_c1_hzp_06_CDin_ppm_ITC1.*	
		beavrs_c1_hzp_06_CDin_ppm_ITC2.*	
		beavrs_c1_hzp_07_BinCD_keff.*	
		beavrs_c1_hzp_08_BCDin_ppm.*	
		beavrs_c1_hzp_09_AinBCD_keff.*	
		beavrs_c1_hzp_10_ABCDin_ppm.*	
	beavrs_c1_hzp_11_SEinABCD_keff.*		
	beavrs_c1_hzp_12_SEABCDin_ppm.*		
	beavrs_c1_hzp_13_SDinSEABCD_keff.*		
	beavrs_c1_hzp_14_SDSEABCDin_ppm.*		
	beavrs_c1_hzp_15_ScinSDSEABCD_keff.*		
	beavrs_c1_hzp_16_SCSSEABCDin_ppm.*		
	HFP	beavrs_c1.inp	PARCS input
		BEAVRS_cycle1_hfp.parc_out	output
		BEAVRS_cycle1_hfp.parc_cyc-01	Restart file
		BEAVRS_cycle1_hfp.parc_det	Detector response
		BEAVRS_cycle1_hfp.parc_dpl	Summary
		./cy1_pinpower/BEAVRS_cycle1_hfp.parc_pin*	Pin powers
2	HZIP	beavrs_c1_c2_shuf.inp	PARCS input
		BEAVRS_cycle2_hzp_BOC.parc_out	output
		BEAVRS_cycle2_hzp_BOC.parc_cyc-02	Restart file
		BEAVRS_cycle2_hzp_BOC.parc_det	Detector response
		BEAVRS_cycle2_hzp_BOC.parc_dpl	Summary
		./cy2_hzp_pinpower/BEAVRS_cycle2_hzp.parc_pin*	Pin powers
	HFP	beavrs_c2.inp	PARCS input
		BEAVRS_cycle2_hfp.parc_out	output
		BEAVRS_cycle2_hfp.parc_cyc-01	Restart file
		BEAVRS_cycle2_hfp.parc_det	Detector response
		BEAVRS_cycle2_hfp.parc_dpl	Summary
		./cy2_pinpower/BEAVRS_cycle2_hfp.parc_pin*	Pin powers

3.2 BENCHMARK RESULTS

3.2.1 HZP Physics Tests

Table 3.8 compares the control bank worths, critical boron concentrations, and isothermal thermal temperature coefficients (ITCs) between the measured data and the calculated results in the BEAVRS cycle 1 HZP physics tests.

Figure 3.2 compares the calculated flux maps with the measured flux maps at the cycle 1 HZP beginning of cycle (BOC). The simulated flux maps are consistent with the measured flux maps, except for the B12, B13, C13, C14, and D14 assemblies in red. This large flux map differences may be a result of poor reflector cross sections. However, because there is almost no assembly power tilt over the core, it may not result from the reflector cross sections. The assembly C14 includes asymmetric BA loadings, as shown in Figure 2.3. Because PARCS does not support 2×2 nodes per assembly, the asymmetric assembly cannot be correctly treated which might result in the issue. The 2×2 node capability with different cross section table set assignments should be incorporated. In conjunction with the 2×2 node capability a 2×2 node-based assembly burnups should be considered in shuffling scheme with assembly rotation.

Table 3.8. Comparison of the control bank worth and ITC for the BEAVRS cycle 1.

Cycle	Case	Critical boron (ppm)		Control bank worth (pcm)				ITC (pcm/°F)			
		Meas.	Calc.	Meas. [M]	Calc. [C]	Difference		Meas. [M]	Calc. [C]	Difference	
						C-M	% ^a			C-M	% ^a
1	ARO	975	957.8					-1.75	-2.03	-0.28	16.0
	D with ARO	902	896	788	793.5	5.5	0.7	-4.65	-3.49	1.16	-24.9
	C with D in	810	794.7	1203	1275.7	72.7	6.0	-8.01	-8.27	-0.26	3.2
	B with D+C in		703	1171	1213.3	42.3	3.6				
	A with D+C+B in	686	655	548	614.5	66.5	12.1				
	SE with D+C+B+A in		612.5	461	525.6	64.6	14.0				
	SD with D+C+B+A+SE in		551.7	772	755.6	-16.4	-2.1				
	SC with D+C+B+A+SE+SD in	508	463.7	1099	1111.7	12.7	1.2				

^a (C-M)/M (%)

—	0.779	1.065	0.940	1.147	0.935	1.264	0.778
0.949	0.789	1.072	0.937	1.154	0.943	1.268	0.770
—	1.00	0.65	-0.32	0.71	0.78	0.37	-0.81
	1.011	0.897	1.143	0.974	1.168	0.873	0.815
	1.025	0.907	1.150	0.968	1.195	0.876	0.790
	1.35	0.96	0.67	-0.63	2.73	0.28	-2.51
	0.897	1.138	0.968	1.212	0.984	1.242	0.728
	0.907	1.146	0.983	1.205	0.977	1.260	0.717
	0.96	0.85	1.52	-0.74	-0.69	1.77	-1.14
	1.143	0.968	1.249	—	1.307	—	0.584
	1.150	0.983	1.257	1.072	1.344	0.923	0.568
	0.68	1.52	0.85	—	3.73	—	-1.64
	0.974	1.212	—	1.343	1.196	0.958	
	0.968	1.205	1.072	1.337	1.199	0.910	
	-0.63	-0.74	—	-0.64	0.31	-4.78	
	1.168	0.984	1.307	1.196	0.852	0.702	
	1.195	0.977	1.344	1.199	0.934	0.649	
	2.73	-0.69	3.73	0.32	8.17	-5.27	
	0.873	1.242	—	0.958	0.702		
	0.876	1.260	0.923	0.910	0.649		
	0.28	1.77	—	-4.78	-5.27		
	0.815	0.728	0.584	Measured			
	0.790	0.717	0.568	Calculated			
	-2.51	-1.14	-1.63	% difference			

Figure 3.2. BEAVRS cycle 1 HZP normalized detector response comparison.

3.2.2 HFP Results

Comparison of the HFP critical boron concentrations is illustrated in Figure 3.3 and Table 3.9. Figure 3.4 illustrates the boron worths as a function burnup which are used in converting the differences of critical boron concentrations between measurement and simulation into reactivity differences. Since boron worths are changing smoothly as burnup increases, boron worths were obtained only for the selected burnup points. The enthalpy rise hot channel factors ($F_{\Delta H}^N$) for the BEAVRS cycles 1 and 2 are provided in Figure 3.5; these factors satisfy the limit of 1.435 considering 8% uncertainty.

The measured detector maps were selected only for 100% power at this time. This will be improved in the next benchmark calculations. Figure 3.6 and Table 3.10 provide comparisons of the calculated flux maps with the measured flux maps for the 3D, axially integrated 2D radial, and radially integrated 1D axial distributions. Appendix D provides the utility program to compare the calculated flux map results with the measured data.

- D.1 Program source
- D.2 Cycle 1 input
- D.3 Cycle 2 input
- D.4 Cycle 1 flux map measured data
- D.5 Cycle 2 flux map measured data

The total 3D, 2D, and 1D root mean square (RMS) errors between the measured and calculated flux maps for BEAVRS are 4.87%, 1.51%, and 3.85%, respectively. Figure 3.7 compares the 1D axial flux maps at burnups of 1.63 and 7.57 MWD/kgU for BEAVRS cycle 1, which indicates some axial power tilt, probably resulting from poor axial reflector cross sections or no consideration of control rod existence in the top reflector. Typically, it is much easier to resolve the axial reflector issue than the radial reflector

issue. These comparisons will be used to statistically assess the uncertainties of the SCALE/Polaris–PARCS code package for various key nuclear parameters, including reactivity, control bank worths, ITCs, and 2D and 3D pin and assembly powers.

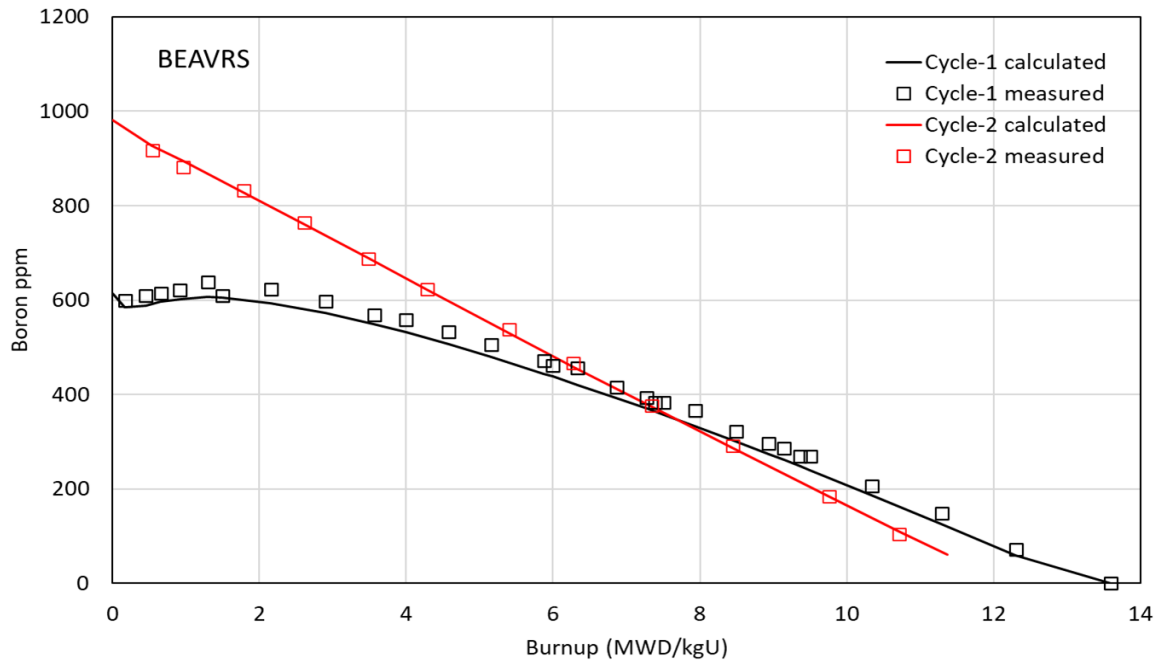


Figure 3.3. BEAVRS cycles 1 and 2 HFP boron letdown comparison.

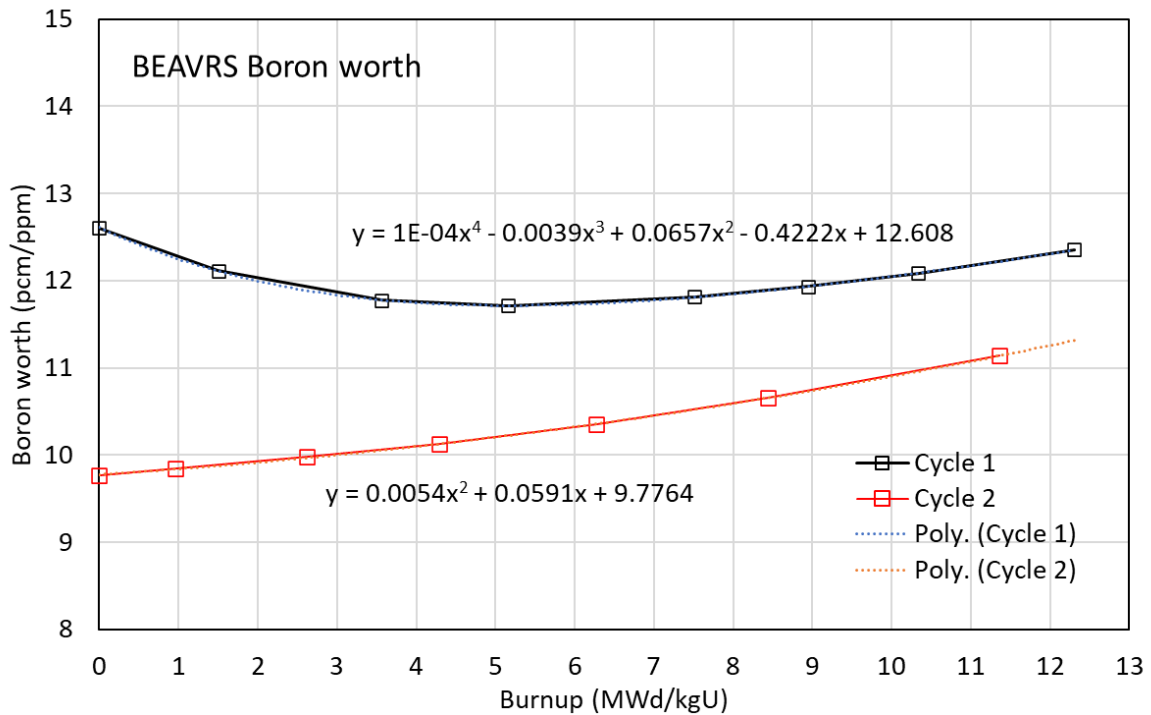


Figure 3.4. Boron worths as a function of burnup for BEAVRS cycles 1–2.

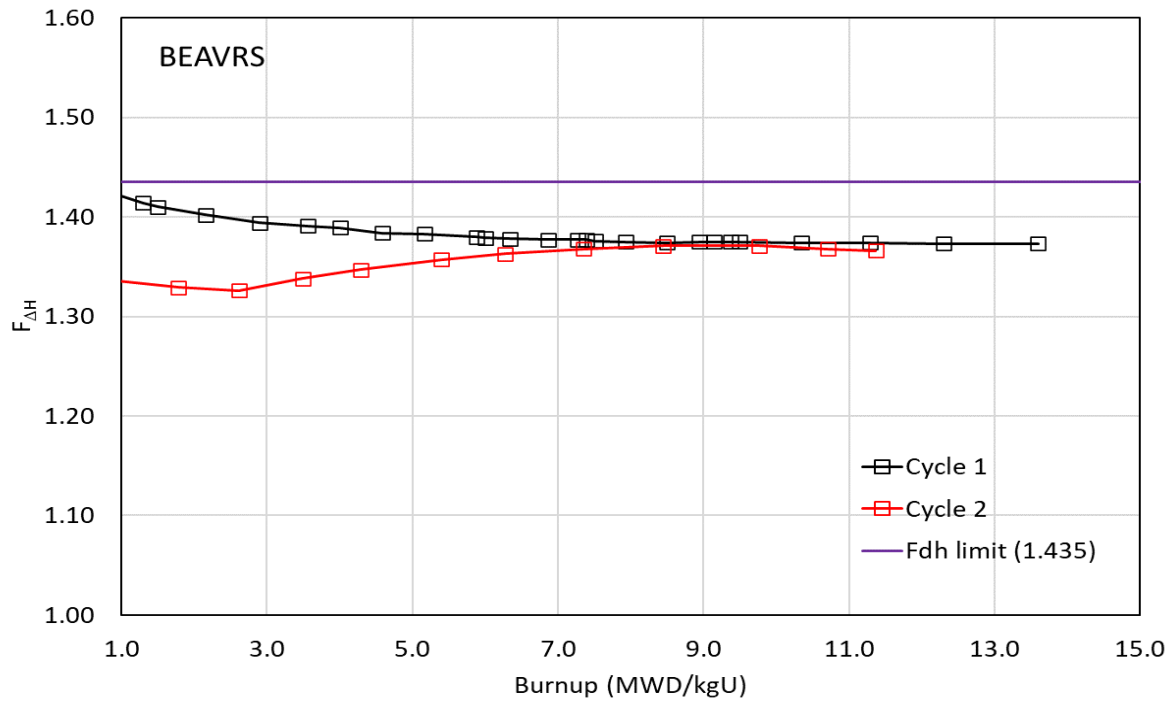


Figure 3.5. Enthalpy rise hot channel factors for the BEAVRS cycles 1 and 2.

Table 3.9. Comparison of the critical boron concentrations.

Cycle 1						Cycle 2					
Burnup		Critical boron (ppm)			$\Delta\rho$ (pcm)	Burnup		Critical boron (ppm)			$\Delta\rho$ (pcm)
MWd/kgU	EFPD ^a	Measured [M]	Calculated [C]	[C-M]		MWd/kgU	EFPD	Measured [M]	Calculated [C]	[C-M]	
0.000	0	–	614	–		0	0	–	981	–	
0.170	4	599	585	–14	–172	0.544	13	918	926	8	79
0.453	11	610	589	–21	–261	0.963	23	882	894	12	122
0.659	16	614	597	–17	–214	1.786	43	832	828	–4	–38
0.921	22	621	602	–19	–228	2.616	63	764	760	–4	–44
1.296	31	638	606	–32	–387	3.489	84	687	688	1	8
1.499	36	610	606	–4	–51	4.285	103	623	622	–1	–8
2.157	52	623	594	–30	–353	5.399	129	538	531	–7	–75
2.898	69	598	573	–25	–294	6.272	150	466	460	–6	–66
3.564	85	569	549	–20	–238	7.348	176	376	373	–3	–29
3.999	96	559	531	–28	–325	8.444	202	292	286	–6	–60
4.580	110	533	506	–27	–318	9.766	234	184	183	–1	–7
5.159	124	506	479	–27	–315	10.712	257	104	110	6	71
5.874	141	471	444	–27	–315	EOC	272.7	–	60	–	
5.998	144	461	438	–23	–271						
6.337	152	457	420	–37	–430						
6.862	164	415	393	–22	–264						
7.274	174	394	370	–24	–282						
7.390	177	384	364	–20	–240						
7.510	180	384	357	–27	–320						
7.930	190	367	333	–34	–403						
8.490	204	322	301	–22	–256						
8.941	214	296	274	–22	–265						
9.148	219	286	261	–25	–295						
9.370	225	270	248	–22	–266						
9.501	228	270	240	–30	–364						
10.338	248	207	187	–20	–237						
11.293	271	149	126	–23	–279						
12.305	295	72	60	–12	–154						
13.598	326	0	0	0	0						
EOC	327.2										

^a Effective full power day

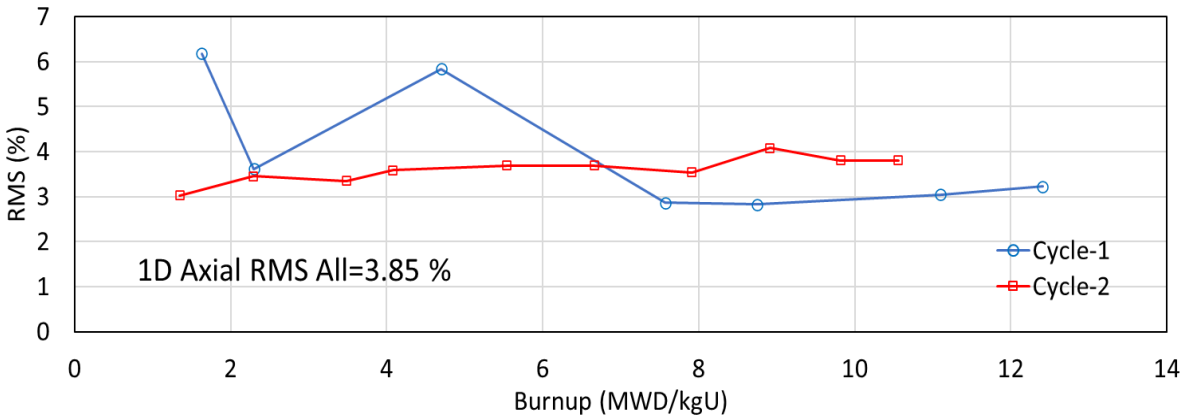
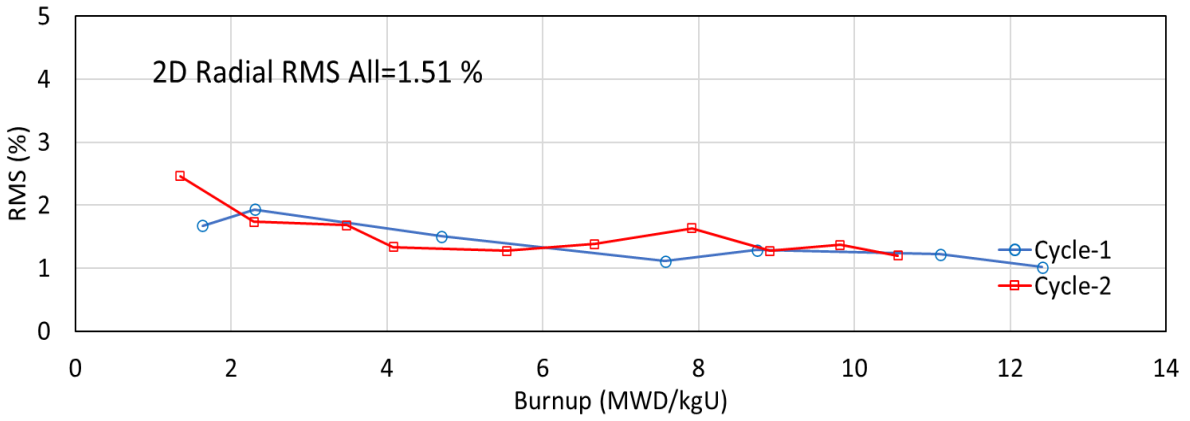
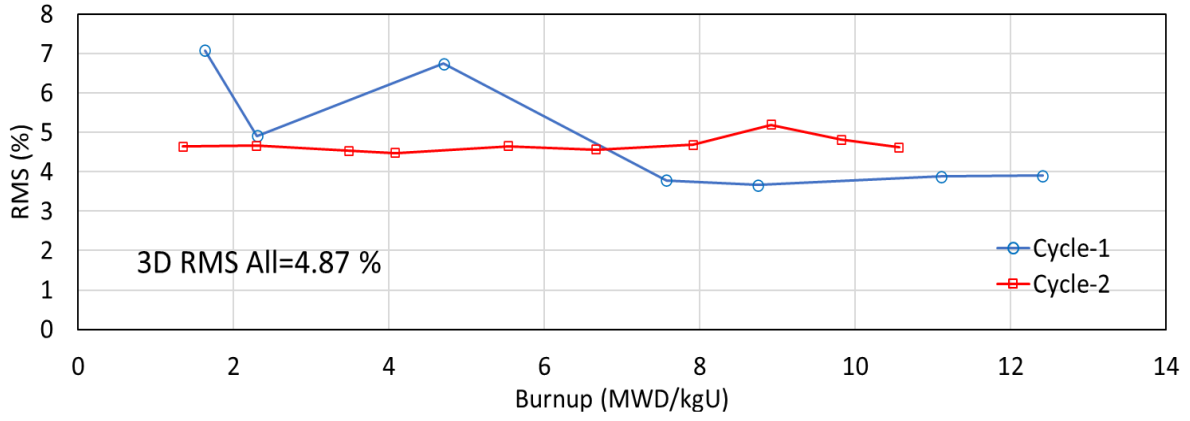


Figure 3.6. Comparison of the HFP flux maps for BEAVRS.

Table 3.10. Comparison of the detector responses for BEAVRS.

Cycle	Data point (days)	Burnup (MWd/kgU)	PARCS point	3D		Radial		Axial	
				RMS (%)	Cases	RMS (%)	Cases	RMS (%)	Cases
1	169	1.630	7	7.080	1566	1.676	54	6.180	29
	187	2.300	8	4.911	1450	1.932	50	3.616	29
	251	4.700	12	6.739	1537	1.502	53	5.838	29
	368	7.570	20	3.786	1363	1.110	47	2.862	29
	403	8.750	23	3.662	1421	1.290	49	2.826	29
	468	11.100	28	3.882	1363	1.221	47	3.050	29
	504	12.410	29	3.904	1392	1.020	48	3.226	29
2	35	1.346	4	4.639	1334	2.460	46	3.028	29
	65	2.292	6	4.656	1363	1.733	47	3.454	29
	93	3.483	7	4.528	1334	1.685	46	3.352	29
	126	4.083	8	4.479	1450	1.334	50	3.590	29
	156	5.536	9	4.648	1537	1.275	53	3.691	29
	191	6.666	11	4.566	1595	1.382	55	3.695	29
	220	7.912	13	4.682	1537	1.636	53	3.545	29
	251	8.915	15	5.194	1595	1.276	55	4.086	29
	266	9.818	16	4.817	1595	1.369	55	3.802	29
	296	10.561	17	4.614	1566	1.202	54	3.806	29
All				4.866	24998	1.508	862	3.850	493

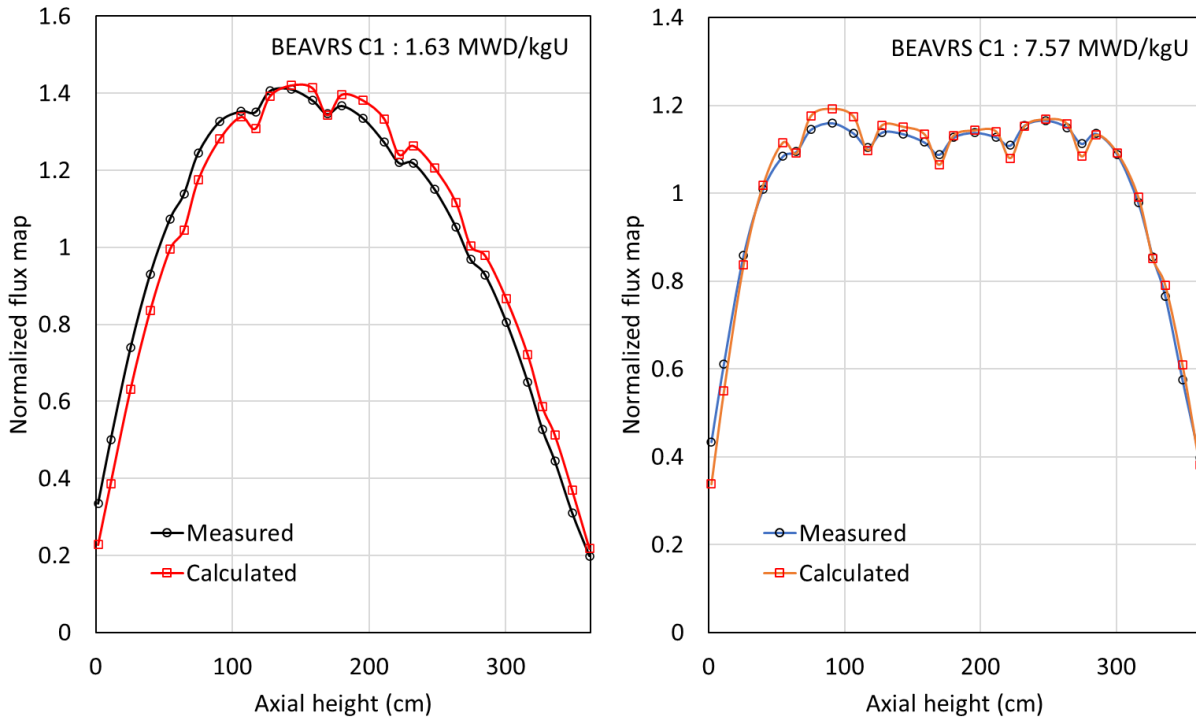


Figure 3.7. Axial 1D flux map comparison for BEAVRS cycle 1.

4. CONCLUSION

The benchmark calculations for BEAVRS cycles 1 and 2 were performed using the SCALE 6.3/Polaris–GenPMAXS–PARCS v3.4.2 code package with the ENDF/B-VII.1 AMPX 56-group library which has been used in confirmatory analysis by US Nuclear Regulatory Commission. The benchmark results were compared with the measured data for the HZP physics test, including control rod worths and ITC and the HFP critical boron concentrations and in-core detector flux maps. The benchmark results such as critical boron concentration, control rod worth and ITC for the HZP physics test show very good agreement with the measured data. The simulated HFP critical boron concentrations are consistent with the measured critical boron concentrations within a maximum error of 37 ppm (430 pcm). The RMS errors for the flux map comparison are 4.87% for 3D fluxes, 1.51% for axially integrated 2D fluxes and 3.85% for radially integrated 1D fluxes, which indicates very good agreement between simulation and measurement. The simulated axial flux shapes can be improved by enhancing effective axial reflector cross sections and explicitly considering Inconel spacer grids.

The final goal of this benchmark calculation is to validate the SCALE/Polaris–GenPMAXS–PARCS code package with the ENDF/B-VII.1 AMPX 56-group libraries by assessing uncertainties for key nuclear parameters such as reactivity, temperature reactivity coefficients, control rod worth, and pin and assembly power peaking factors. [8] The benchmark results for BEAVRS cycles 1 and 2 will be used in the statistical analysis together with the benchmark results for Watts Bar Unit 1, Surry Unit 1 and Turkey Point Unit 3.

5. REFERENCES

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APPENDIX A. SAMPLE OF POLARIS INPUT FILES

A.1 Polaris input for the fuel assembly 2.40_bp12

```
=polaris
title "BEAVRS 2.40 w/o 12 BP"
lib "broad_lwr"

opt KEFF RaySpacing=0.04
opt PRINT XFile16=true
system PWR

% pin pitch = 1.26198cm
% lattice pitch = 21.60912 cm
% assembly width = 21.45372 cm
% gap = 0.07770 cm

geom assembly: ASSM 17 1.26198 SE
hgap 0.0777 % seg fault with spec

% materials and compositions
%%COMPOSITIONS FROM BEAVRS DOCUMENTATION

comp uo2 : CONC refdens=10.13666
92233 = 9.8439E-11
92234 = 4.4142E-06
92235 = 5.4943E-04
92238 = 2.2057E-02
8016 = 4.5113E-02
8017 = 1.7184E-05
8018 = 9.2706E-05

comp air : CONC refdens=0.000616
6012 = 6.7565e-09
6013 = 7.3076e-11
8016 = 5.2864e-06
8017 = 2.0137e-09
8018 = 1.0863e-08
7014 = 1.9681e-05
7015 = 7.1900e-08
18036 = 7.9414e-10
18038 = 1.4915e-10
18040 = 2.3506e-07

comp poison : CONC refdens=2.260000
5010 = 9.6506e-04
5011 = 3.9189e-03
8016 = 4.6511e-02
8017 = 1.7717e-05
8018 = 9.5581e-05
13027 = 1.7352e-03
14028 = 1.6924e-02
14029 = 8.5977e-04
14030 = 5.6743e-04

comp AgInCd : CONC refdens=10.160000
47107 = 2.3523e-02
47109 = 2.1854e-02
49113 = 3.4291e-04
49115 = 7.6504e-03
48106 = 3.4019e-05
48108 = 2.4221e-05
48110 = 3.3991e-04
48111 = 3.4835e-04
48112 = 6.5669e-04
48113 = 3.3257e-04
48114 = 7.8188e-04
48116 = 2.0384e-04

comp B4C : CONC refdens=1.76
5010 = 1.5203e-02
5011 = 6.1504e-02
6012 = 1.8972e-02
6013 = 2.1253e-04

comp Heg : CONC refdens=0.001598
2004 = 2.4044e-04
```

```

comp stnstl : CONC refdens=8.03
14028 = 9.5274e-04
14029 = 4.8400e-05
14030 = 3.1943e-05
24050 = 7.6778e-04
24052 = 1.4806e-02
24053 = 1.6789e-03
24054 = 4.1791e-04
25055 = 1.7604e-03
26054 = 3.4620e-03
26056 = 5.4345e-02
26057 = 1.2551e-03
26058 = 1.6703e-04
28058 = 5.6089e-03
28060 = 2.1605e-03
28061 = 9.3917e-05
28062 = 2.9945e-04
28064 = 7.6261e-05

comp cladding : CONC refdens=6.55
8016 = 3.0587E-04
8017 = 1.1651E-07
8018 = 6.2855E-07
24050 = 3.2794E-06
24052 = 6.3241E-05
24053 = 7.1709E-06
24054 = 1.7850E-06
26054 = 8.6258E-06
26056 = 1.3541E-04
26057 = 3.1271E-06
26058 = 4.1616E-07
40090 = 2.1716E-02
40091 = 4.7358E-03
40092 = 7.2388E-03
40094 = 7.3359E-03
40096 = 1.1819E-03
50112 = 4.6497E-06
50114 = 3.1637E-06
50115 = 1.6298E-06
50116 = 6.9699E-05
50117 = 3.6815E-05
50118 = 1.1610E-04
50119 = 4.1176E-05
50120 = 1.5617E-04
50122 = 2.2195E-05
50124 = 2.7755E-05

mat FUEL.1 : uo2      temp=615.0
mat CLAD.1 : cladding temp=615.0
mat AIR.1  : air      temp=615.0
mat COOL.1 : WATER    temp=615.0 dens=0.60811 : boron=500
mat HE.1   : Heg      temp=615.0
mat BP.1   : poison   temp=615.0
mat CR.1   : B4C      temp=615.0
mat CR.2   : AgInCd   temp=615.0
mat SS.1   : stnstl   temp=615.0

deplete ALL=false FUEL=true BP=true
shield ALL=N FUEL=P CR=P BP=P

% definition of pin types

comp c_u235 : CONC 92235=1.0e-15
mat DET.1 : c_u235
pin D : 0.4 : COOL.2
det d_u235 : pin.D at=pin.I : R(n,FIS) COOL.2 DET.1
opt FG DetectorEedit=d_u235

pin F : 0.39424 0.40073 0.49752
      : FUEL.1 HE.1 CLAD.1
pin I : 0.43688 0.48387 0.56229 0.60300
      : AIR.1 CLAD.1 COOL.1 CLAD.1
pin G : 0.56229 0.60300
      : COOL.1 CLAD.1

pinmap
I
F F
F F F
G F F G
F F F F F

```

```

      F F F F F G
      G F F G F F F
      F F F F F F F F
      F F F F F F F F F

% define the Pyrex

pin P : 0.21400   0.23051   0.24130   0.42672   0.43688   0.48387   0.56229   0.60300
      : AIR.1     SS.1     AIR.1     BP.1     AIR.1     SS.1     COOL.1   CLAD.1

control BankP : RODLET

-
--
---
----
-----
----- P
----- P
-----
-----
-----

% begin burnup and branch cases
power 41.7045
bu 0 0.1 0.5 1 2 4 6 8 10 12.5 15 17.5
    20 25 30 35 40 45 50 55 60

state ALL : temp=615.0 : FUEL : temp=800.0 : COOL : boron=500 : COOL : dens=0.60811 : BankP :
in=false

% reference history internal burnup steps through 50 GWD/MTU

read branch
add BankP : in= false ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 0.1 FUEL : temp= 560.0
add BankP : in= false ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 500 FUEL : temp= 560.0
add BankP : in= false ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 1500 FUEL : temp= 560.0
add BankP : in= false ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 0.1 FUEL : temp= 560.0
add BankP : in= false ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 500 FUEL : temp= 560.0
add BankP : in= false ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 1500 FUEL : temp= 560.0
add BankP : in= false ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 0.1 FUEL : temp= 560.0
add BankP : in= false ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 500 FUEL : temp= 560.0
add BankP : in= false ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 1500 FUEL : temp= 560.0
add BankP : in= false ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 0.1 FUEL : temp= 800.0
% add BankP : in= false ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 500 FUEL : temp= 800.0
add BankP : in= false ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 1500 FUEL : temp= 800.0
add BankP : in= false ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 0.1 FUEL : temp= 800.0
add BankP : in= false ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 500 FUEL : temp= 800.0
add BankP : in= false ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 1500 FUEL : temp= 800.0
add BankP : in= false ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 0.1 FUEL : temp= 800.0
add BankP : in= false ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 500 FUEL : temp= 800.0
add BankP : in= false ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 1500 FUEL : temp= 800.0
add BankP : in= false ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 0.1 FUEL : temp= 1600.0
add BankP : in= false ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 500 FUEL : temp= 1600.0
add BankP : in= false ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 1500 FUEL : temp= 1600.0
add BankP : in= false ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 0.1 FUEL : temp= 1600.0
add BankP : in= false ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 500 FUEL : temp= 1600.0
add BankP : in= false ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 1500 FUEL : temp= 1600.0
add BankP : in= false ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 0.1 FUEL : temp= 1600.0
add BankP : in= false ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 500 FUEL : temp= 1600.0
add BankP : in= false ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 1500 FUEL : temp= 1600.0
add BankP : in= true ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 0.1 FUEL : temp= 800.0
add BankP : in= true ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 500 FUEL : temp= 800.0
add BankP : in= true ALL : temp= 615.0 COOL.1 : dens= 0.60811 COOL.1 : boron= 1500 FUEL : temp= 800.0
add BankP : in= true ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 0.1 FUEL : temp= 800.0
add BankP : in= true ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 500 FUEL : temp= 800.0
add BankP : in= true ALL : temp= 585.0 COOL.1 : dens= 0.70045 COOL.1 : boron= 1500 FUEL : temp= 800.0
add BankP : in= true ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 0.1 FUEL : temp= 800.0
add BankP : in= true ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 500 FUEL : temp= 800.0
add BankP : in= true ALL : temp= 550.0 COOL.1 : dens= 0.76971 COOL.1 : boron= 1500 FUEL : temp= 800.0
end branch

% opt FG AdjointMode="INFMED"
% opt PRINT XFile16=true
% opt RUN CheckOnly=false

End

```

A.2 Polaris input for radial reflector

```
=polaris
% -----
%   general options
% -----
title "WEC 17x17 lattice"
lib   "broad_lwr"
opt   PRINT XFile16=true
system PWR
% -----
%   compositions and materials
% -----
comp uox_e310 : CONC refdens=10.14068
92233 = 9.8439E-11
92234 = 5.7082E-06
92235 = 7.1048E-04
92238 = 2.1906E-02
 8016 = 4.5134E-02
 8017 = 1.7193E-05
 8018 = 9.2751E-05
comp cladding : CONC refdens=6.51657
 8016 = 3.0587E-04
 8017 = 1.1651E-07
 8018 = 6.2855E-07
24050 = 3.2794E-06
24052 = 6.3241E-05
24053 = 7.1709E-06
24054 = 1.7850E-06
26054 = 8.6258E-06
26056 = 1.3541E-04
26057 = 3.1271E-06
26058 = 4.1616E-07
40090 = 2.1716E-02
40091 = 4.7358E-03
40092 = 7.2388E-03
40094 = 7.3359E-03
40096 = 1.1819E-03
50112 = 4.6497E-06
50114 = 3.1637E-06
50115 = 1.6298E-06
50116 = 6.9699E-05
50117 = 3.6815E-05
50118 = 1.1610E-04
50119 = 4.1176E-05
50120 = 1.5617E-04
50122 = 2.2195E-05
50124 = 2.7755E-05
comp stnstl : CONC refdens=8.03
14028 = 9.5274e-04
14029 = 4.8400e-05
14030 = 3.1943e-05
24050 = 7.6778e-04
24052 = 1.4806e-02
24053 = 1.6789e-03
24054 = 4.1791e-04
25055 = 1.7604e-03
26054 = 3.4620e-03
26056 = 5.4345e-02
26057 = 1.2551e-03
26058 = 1.6703e-04
28058 = 5.6089e-03
28060 = 2.1605e-03
28061 = 9.3917e-05
28062 = 2.9945e-04
28064 = 7.6261e-05
mat FUEL.1 : uox_e310 temp=800
mat CLAD.1 : cladding temp=550
mat BAFFLE.1 : stnstl temp=565
mat COOL.1 : WATER temp=565 dens=0.76971 : boron=600
% -----
%   geometry
% -----
geom W17 : ASSM 17 1.26198
hgap 0.0777
pin F : 0.39424 0.40073 0.45798 : FUEL.1 GAP CLAD.1
pin I : 0.56229 0.60300 : COOL.1 CLAD.1
pin G : 0.56229 0.60300 : COOL.1 CLAD.1
mesh GAP : ns=1
mesh FUEL : nr=4
shield ALL=N FUEL=P
```

```

pinmap
  I
  F F
  F F F
  G F F G
  F F F F F
  F F F F F G
  G F F G F F F
  F F F F F F F F
  F F F F F F F F F
geom rad_ref : REFL 21.60912
slab rad_ref : 0.1627 2.2225 19.22392 : COOL.1 BAFFLE.1 COOL.1 : 1 2 18 : 2 2 2
% -----
%   states
% -----
state ALL : temp=550 FUEL : temp=800 COOL : dens=0.76971 boron=600 rad_ref : in=yes
read branch
  add COOL : boron=0
  add COOL : boron=1800
  add ALL : temp=585 FUEL : temp=800 COOL : boron=600 dens=0.70045
end branch

end

```

A.3 Polaris input for axial top reflector

```

=polaris
% -----
%   general options
% -----
title "WEC 17x17 spacer_000/2.1-CR0-MDC-MPC-MTF lattice"
lib  "broad_lwr"
opt  PRINT XFile16=true
system PWR
% -----
%   geometry
% -----
geom W17 : ASSM 17 1.26198 FULL
hgap 0.0777
% -----
%   compositions and materials
% -----
comp c_uox : UOX 2.11
mat FUEL.1 : c_uox 10.257
% -----
%   pins definitions
% -----
pin F : 0.39424 0.40073 0.45798 : FUEL.1 GAP CLAD
pin I : 0.56229 0.60300          : COOL.1 TUBE
pin G : 0.56229 0.60300          : COOL.1 TUBE
mesh GAP : ns=1
mesh FUEL : nr=4
shield ALL=N FUEL=P
% -----
%   maps
% -----
pinmap
I
F F
F F F
G F F G
F F F F F
F F F F F G
G F F G F F F
F F F F F F F F
F F F F F F F F
% -----
%   reflector
% -----
geom top_refl_lpc : REFL 36.226
geom top_refl_mpc : REFL 36.226
geom top_refl_hpc : REFL 36.226
geom top_refl_mdc : REFL 36.226
slab top_refl_lpc : 8.556 3.866 3.578 1.67 2.129 8.827 7.6
                   : PLE.1 PLE_GRID.1 PLE.1 PLUG.1 NOZ_GAP.1 TOP_NOZ.1 TOP_CP.1
                   : 14 6 6 3 3 14 12
                   : 34 34 34 34 34 34 34
slab top_refl_mpc : 8.556 3.866 3.578 1.67 2.129 8.827 7.6
                   : PLE.2 PLE_GRID.2 PLE.2 PLUG.2 NOZ_GAP.2 TOP_NOZ.2 TOP_CP.2
                   : 14 6 6 3 3 14 12
                   : 34 34 34 34 34 34 34
slab top_refl_hpc : 8.556 3.866 3.578 1.67 2.129 8.827 7.6
                   : PLE.3 PLE_GRID.3 PLE.3 PLUG.3 NOZ_GAP.3 TOP_NOZ.3 TOP_CP.3
                   : 14 6 6 3 3 14 12
                   : 34 34 34 34 34 34 34
slab top_refl_mdc : 8.556 3.866 3.578 1.67 2.129 8.827 7.6
                   : PLE.4 PLE_GRID.4 PLE.4 PLUG.4 NOZ_GAP.4 TOP_NOZ.4 TOP_CP.4
                   : 14 6 6 3 3 14 12
                   : 34 34 34 34 34 34 34
mat PLE.1 : c_ple_lpc 2.25
mat PLE_GRID.1 : c_ple_grid_lpc 2.78
mat PLUG.1 : c_plug_lpc 3.07
mat NOZ_GAP.1 : c_noz_gap_lpc 0.66
mat TOP_NOZ.1 : c_top_noz_lpc 2.02
mat TOP_CP.1 : c_top_cp_lpc 4.27

mat PLE.2 : c_ple_mpc 2.25
mat PLE_GRID.2 : c_ple_grid_mpc 2.78
mat PLUG.2 : c_plug_mpc 3.07
mat NOZ_GAP.2 : c_noz_gap_mpc 0.66
mat TOP_NOZ.2 : c_top_noz_mpc 2.02
mat TOP_CP.2 : c_top_cp_mpc 4.27

mat PLE.3 : c_ple_hpc 2.25
mat PLE_GRID.3 : c_ple_grid_hpc 2.78

```

```

mat PLUG.3 : c_plug_hpc 3.07
mat NOZ_GAP.3 : c_noz_gap_hpc 0.66
mat TOP_NOZ.3 : c_top_noz_hpc 2.02
mat TOP_CP.3 : c_top_cp_hpc 4.27

mat PLE.4 : c_ple_mdc 2.31
mat PLE_GRID.4 : c_ple_grid_mdc 2.83
mat PLUG.4 : c_plug_mdc 3.12
mat NOZ_GAP.4 : c_noz_gap_mdc 0.75
mat TOP_NOZ.4 : c_top_noz_mdc 2.10
mat TOP_CP.4 : c_top_cp_mdc 4.32

comp c_cool_lpc : LW 0
comp c_ple_lpc : WT ZIRC4=29 SS304=55 c_cool_lpc=-100
comp c_ple_grid_lpc : WT ZIRC4=23 SS304=45 INC718=20 c_cool_lpc=-100
comp c_plug_lpc : WT ZIRC4=88 c_cool_lpc=-100
comp c_noz_gap_lpc : WT ZIRC4=8 c_cool_lpc=-100
comp c_top_noz_lpc : WT SS304=76 c_cool_lpc=-100
comp c_top_cp_lpc : WT SS304=93 c_cool_lpc=-100

comp c_cool_mpc : LW 600
comp c_ple_mpc : WT ZIRC4=29 SS304=55 c_cool_mpc=-100
comp c_ple_grid_mpc : WT ZIRC4=23 SS304=45 INC718=20 c_cool_mpc=-100
comp c_plug_mpc : WT ZIRC4=88 c_cool_mpc=-100
comp c_noz_gap_mpc : WT ZIRC4=8 c_cool_mpc=-100
comp c_top_noz_mpc : WT SS304=76 c_cool_mpc=-100
comp c_top_cp_mpc : WT SS304=93 c_cool_mpc=-100

comp c_cool_hpc : LW 1800
comp c_ple_hpc : WT ZIRC4=29 SS304=55 c_cool_hpc=-100
comp c_ple_grid_hpc : WT ZIRC4=23 SS304=45 INC718=20 c_cool_hpc=-100
comp c_plug_hpc : WT ZIRC4=88 c_cool_hpc=-100
comp c_noz_gap_hpc : WT ZIRC4=8 c_cool_hpc=-100
comp c_top_noz_hpc : WT SS304=76 c_cool_hpc=-100
comp c_top_cp_hpc : WT SS304=93 c_cool_hpc=-100

comp c_cool_mdc : LW 600
comp c_ple_mdc : WT ZIRC4=28 SS304=54 c_cool_mdc=-100
comp c_ple_grid_mdc : WT ZIRC4=23 SS304=44 INC718=20 c_cool_mdc=-100
comp c_plug_mdc : WT ZIRC4=87 c_cool_mdc=-100
comp c_noz_gap_mdc : WT ZIRC4=7 c_cool_mdc=-100
comp c_top_noz_mdc : WT SS304=73 c_cool_mdc=-100
comp c_top_cp_mdc : WT SS304=92 c_cool_mdc=-100

opt ESSM RaySpacing=0.0425
opt KEFF RaySpacing=0.046
% -----
% states
% -----
state ALL : temp=615
FUEL : temp=800
COOL : dens=0.60811 boron=600
top_refl_mpc : in=yes
top_refl_lpc : in=no
top_refl_hpc : in=no
top_refl_mdc : in=no
read branch
add COOL : boron=0
top_refl_mpc : in=no
top_refl_lpc : in=yes
top_refl_hpc : in=no
top_refl_mdc : in=no

add COOL : boron=1800
top_refl_mpc : in=no
top_refl_lpc : in=no
top_refl_hpc : in=yes
top_refl_mdc : in=no

add ALL : temp=585
FUEL : temp=800
COOL : boron=600 dens=0.70045
top_refl_mpc : in=no
top_refl_lpc : in=no
top_refl_hpc : in=no
top_refl_mdc : in=yes
end branch
end

```

A.4 Polaris input for axial bottom reflector

```

=polaris
% -----
%   general options
% -----
title 'BEAVRS 310 w/ 0 BP base'
lib  "broad_lwr"
opt  PRINT XFile16=true
system PWR
% -----
%   geometry
% -----
geom W17 : ASSM 17 1.26198 FULL
hgap 0.0777
% -----
%   compositions and materials
% -----
comp uox_e310 : CONC refdens=10.14068
92233 = 9.8439E-11
92234 = 5.7082E-06
92235 = 7.1048E-04
92238 = 2.1906E-02
8016 = 4.5134E-02
8017 = 1.7193E-05
8018 = 9.2751E-05
mat FUEL.1 : uox_e310
% -----
%   pins definitions
% -----
pin F : 0.39424 0.40073 0.45798 : FUEL.1 GAP CLAD
pin I : 0.56229 0.60300          : COOL.1 TUBE
pin G : 0.56229 0.60300          : COOL.1 TUBE
mesh GAP : ns=1
mesh FUEL : nr=4
shield ALL=N FUEL=P
% -----
%   maps
% -----
pinmap
I
F F
F F F
G F F G
F F F F F
F F F F F G
G F F G F F F
F F F F F F F F
F F F F F F F F
% -----
%   reflector
% -----
geom bot_refl_lpc : REFL 36.951
geom bot_refl_mpc : REFL 36.951
geom bot_refl_hpc : REFL 36.951
geom bot_refl_mdc : REFL 36.951

slab bot_refl_lpc : 5.898 6.053 5.000 20.0 : BOT_GAP.1 BOT_NOZ.1 BOT_CP.1 BOT_GAP.1 : 6 6 5 20 : 2 2 2 2
slab bot_refl_mpc : 5.898 6.053 5.000 20.0 : BOT_GAP.2 BOT_NOZ.2 BOT_CP.2 BOT_GAP.2 : 6 6 5 20 : 2 2 2 2
slab bot_refl_hpc : 5.898 6.053 5.000 20.0 : BOT_GAP.3 BOT_NOZ.3 BOT_CP.3 BOT_GAP.3 : 6 6 5 20 : 2 2 2 2
slab bot_refl_mdc : 5.898 6.053 5.000 20.0 : BOT_GAP.4 BOT_NOZ.4 BOT_CP.4 BOT_GAP.4 : 6 6 5 20 : 2 2 2 2

mat BOT_GAP.1 : c_bot_gap_lpc 1.82
mat BOT_NOZ.1 : c_bot_noz_lpc 2.79
mat BOT_CP.1 : c_bot_cp_lpc 4.35

mat BOT_GAP.2 : c_bot_gap_mpc 1.82
mat BOT_NOZ.2 : c_bot_noz_mpc 2.79
mat BOT_CP.2 : c_bot_cp_mpc 4.35

mat BOT_GAP.3 : c_bot_gap_hpc 1.82
mat BOT_NOZ.3 : c_bot_noz_hpc 2.79
mat BOT_CP.3 : c_bot_cp_hpc 4.35

mat BOT_GAP.4 : c_bot_gap_mdc 1.76
mat BOT_NOZ.4 : c_bot_noz_mdc 2.74
mat BOT_CP.4 : c_bot_cp_mdc 4.32

comp c_cool_lpc : LW 0
comp c_bot_gap_lpc : WT ZIRC4=44 INC718=21 c_cool_lpc=-100
comp c_bot_noz_lpc : WT SS304=80 c_cool_lpc=-100

```

```

comp c_bot_cp_lpc : WT SS304=91 c_cool_lpc=-100

comp c_cool_mpc : LW 600
comp c_bot_gap_mpc : WT ZIRC4=44 INC718=21 c_cool_mpc=-100
comp c_bot_noz_mpc : WT SS304=80 c_cool_mpc=-100
comp c_bot_cp_mpc : WT SS304=91 c_cool_mpc=-100

comp c_cool_hpc : LW 1800
comp c_bot_gap_hpc : WT ZIRC4=44 INC718=21 c_cool_hpc=-100
comp c_bot_noz_hpc : WT SS304=80 c_cool_hpc=-100
comp c_bot_cp_hpc : WT SS304=91 c_cool_hpc=-100

comp c_cool_mdc : LW 600
comp c_bot_gap_mdc : WT ZIRC4=46 INC718=21 c_cool_mdc=-100
comp c_bot_noz_mdc : WT SS304=82 c_cool_mdc=-100
comp c_bot_cp_mdc : WT SS304=92 c_cool_mdc=-100

opt ESSM RaySpacing=0.045
opt KEFF RaySpacing=.066
% -----
%   states
% -----
state ALL : temp=550
  FUEL : temp=800
  COOL : dens=0.76971 boron=600
  bot_refl_mpc : in=yes
  bot_refl_lpc : in=no
  bot_refl_hpc : in=no
  bot_refl_mdc : in=no
read branch
  add      COOL : boron=0
  bot_refl_mpc : in=no
  bot_refl_lpc : in=yes
  bot_refl_hpc : in=no
  bot_refl_mdc : in=no

  add      COOL : boron=1800
  bot_refl_mpc : in=no
  bot_refl_lpc : in=no
  bot_refl_hpc : in=yes
  bot_refl_mdc : in=no

  add      ALL : temp=585
  FUEL : temp=800
  COOL : boron=600 dens=0.70045
  bot_refl_mpc : in=no
  bot_refl_lpc : in=no
  bot_refl_hpc : in=no
  bot_refl_mdc : in=yes
end branch
end

```

APPENDIX B. SAMPLE OF GENPMAXS INPUT FILES

B.1 GenPMAXS input for the fuel assembly 2.40_bp12

```

%JOB_TIT
'2.40_bp12.PMAX' T 3.0
%JOB_OPT
T T F F T F F T T F T F F F F
!adf,xes,ded,jlf,chi, chd,inv,det,yld,cdf,gff,bet,lam,dec,zdf
%DAT_SRC
8 8 1
%STA_VAR
4
CR DC PC TF
%HISTORY
8 4
HIST01 0.00000 0.60811 500.0 800.0
HIST02 0.00000 0.70045 0.0 800.0
HIST03 0.00000 0.70045 500.0 565.0
HIST04 0.00000 0.70045 500.0 800.0
HIST05 0.00000 0.70045 500.0 1400.0
HIST06 0.00000 0.70045 1500.0 800.0
HIST07 0.00000 0.76971 500.0 800.0
HIST08 1.00000 0.70045 500.0 800.0
%BRANCH
36 14
BLCK01 0.00000 0.60811 0.5 565.0
BLCK02 0.00000 0.60811 500.0 565.0
BLCK03 0.00000 0.60811 1500.0 565.0
BLCK04 0.00000 0.70045 0.5 565.0
BLCK05 0.00000 0.70045 500.0 565.0
BLCK06 0.00000 0.70045 1500.0 565.0
BLCK07 0.00000 0.76971 0.5 565.0
BLCK08 0.00000 0.76971 500.0 565.0
BLCK09 0.00000 0.76971 1500.0 565.0
BLCK10 0.00000 0.60811 0.5 800.0
BLCK11 0.00000 0.60811 500.0 800.0
BLCK12 0.00000 0.60811 1500.0 800.0
BLCK13 0.00000 0.70045 0.5 800.0
BLCK14 0.00000 0.70045 500.0 800.0
BLCK15 0.00000 0.70045 1500.0 800.0
BLCK16 0.00000 0.76971 0.5 800.0
BLCK17 0.00000 0.76971 500.0 800.0
BLCK18 0.00000 0.76971 1500.0 800.0
BLCK19 0.00000 0.60811 0.5 1600.0
BLCK20 0.00000 0.60811 500.0 1600.0
BLCK21 0.00000 0.60811 1500.0 1600.0
BLCK22 0.00000 0.70045 0.5 1600.0
BLCK23 0.00000 0.70045 500.0 1600.0
BLCK24 0.00000 0.70045 1500.0 1600.0
BLCK25 0.00000 0.76971 0.5 1600.0
BLCK26 0.00000 0.76971 500.0 1600.0
BLCK27 0.00000 0.76971 1500.0 1600.0
BLCK28 1.00000 0.60811 0.5 800.0
BLCK29 1.00000 0.60811 500.0 800.0
BLCK30 1.00000 0.60811 1500.0 800.0
BLCK31 1.00000 0.70045 0.5 800.0
BLCK32 1.00000 0.70045 500.0 800.0
BLCK33 1.00000 0.70045 1500.0 800.0
BLCK34 1.00000 0.76971 0.5 800.0
BLCK35 1.00000 0.76971 500.0 800.0
BLCK36 1.00000 0.76971 1500.0 800.0
%BURNUP
1
BS1 21
0.000 0.100 0.500 1.000 2.000
4.000 6.000 8.000 10.000 12.500
15.000 17.500 20.000 25.000 30.000
35.000 40.000 45.000 50.000 55.000
60.000
HIST01 36*1
HIST02 36*1
HIST03 36*1
HIST04 36*1
HIST05 36*1
HIST06 36*1
HIST07 36*1
HIST08 36*1
%USERINP

```

```

1
PIN 1.26198 0.07770 0.07770 0
%FIL_CNT
1 './2.40_bp12/beavrs_2.40_bp12_cr0_dc60_p0500_tf0800.t16' 36 1
  1 1 11 1 21 !
  2 1 1 1 21 !
  3 1 2 1 21 !
  4 1 3 1 21 !
  5 1 4 1 21 !
  6 1 5 1 21 !
  7 1 6 1 21 !
  8 1 7 1 21 !
  9 1 8 1 21 !
 10 1 9 1 21 !
 11 1 10 1 21 !
 12 1 12 1 21 !
 13 1 13 1 21 !
 14 1 14 1 21 !
 15 1 15 1 21 !
 16 1 16 1 21 !
 17 1 17 1 21 !
 18 1 18 1 21 !
 19 1 19 1 21 !
 20 1 20 1 21 !
 21 1 21 1 21 !
 22 1 22 1 21 !
 23 1 23 1 21 !
 24 1 24 1 21 !
 25 1 25 1 21 !
 26 1 26 1 21 !
 27 1 27 1 21 !
 28 1 28 1 21 !
 29 1 29 1 21 !
 30 1 30 1 21 !
 31 1 31 1 21 !
 32 1 32 1 21 !
 33 1 33 1 21 !
 34 1 34 1 21 !
 35 1 35 1 21 !
 36 1 36 1 21 !
2 './2.40_bp12/beavrs_2.40_bp12_cr0_dc70_p0000_tf0800.t16' 36 1
  1 2 13 1 21 !
  2 2 1 1 21 !
  3 2 2 1 21 !
  4 2 3 1 21 !
  5 2 4 1 21 !
  6 2 5 1 21 !
  7 2 6 1 21 !
  8 2 7 1 21 !
  9 2 8 1 21 !
 10 2 9 1 21 !
 11 2 10 1 21 !
 12 2 11 1 21 !
 13 2 12 1 21 !
 14 2 14 1 21 !
 15 2 15 1 21 !
 16 2 16 1 21 !
 17 2 17 1 21 !
 18 2 18 1 21 !
 19 2 19 1 21 !
 20 2 20 1 21 !
 21 2 21 1 21 !
 22 2 22 1 21 !
 23 2 23 1 21 !
 24 2 24 1 21 !
 25 2 25 1 21 !
 26 2 26 1 21 !
 27 2 27 1 21 !
 28 2 28 1 21 !
 29 2 29 1 21 !
 30 2 30 1 21 !
 31 2 31 1 21 !
 32 2 32 1 21 !
 33 2 33 1 21 !
 34 2 34 1 21 !
 35 2 35 1 21 !
 36 2 36 1 21 !
3 './2.40_bp12/beavrs_2.40_bp12_cr0_dc70_p0500_tf0560.t16' 36 1
  1 3 5 1 21 !
  2 3 1 1 21 !
  3 3 2 1 21 !

```

```

4 3 3 1 21 !
5 3 4 1 21 !
6 3 6 1 21 !
7 3 7 1 21 !
8 3 8 1 21 !
9 3 9 1 21 !
10 3 10 1 21 !
11 3 11 1 21 !
12 3 12 1 21 !
13 3 13 1 21 !
14 3 14 1 21 !
15 3 15 1 21 !
16 3 16 1 21 !
17 3 17 1 21 !
18 3 18 1 21 !
19 3 19 1 21 !
20 3 20 1 21 !
21 3 21 1 21 !
22 3 22 1 21 !
23 3 23 1 21 !
24 3 24 1 21 !
25 3 25 1 21 !
26 3 26 1 21 !
27 3 27 1 21 !
28 3 28 1 21 !
29 3 29 1 21 !
30 3 30 1 21 !
31 3 31 1 21 !
32 3 32 1 21 !
33 3 33 1 21 !
34 3 34 1 21 !
35 3 35 1 21 !
36 3 36 1 21 !
4 './2.40_bp12/beavrs_2.40_bp12_cr0_dc70_p0500_tf0800.t16' 36 1
1 4 14 1 21 !
2 4 1 1 21 !
3 4 2 1 21 !
4 4 3 1 21 !
5 4 4 1 21 !
6 4 5 1 21 !
7 4 6 1 21 !
8 4 7 1 21 !
9 4 8 1 21 !
10 4 9 1 21 !
11 4 10 1 21 !
12 4 11 1 21 !
13 4 12 1 21 !
14 4 13 1 21 !
15 4 15 1 21 !
16 4 16 1 21 !
17 4 17 1 21 !
18 4 18 1 21 !
19 4 19 1 21 !
20 4 20 1 21 !
21 4 21 1 21 !
22 4 22 1 21 !
23 4 23 1 21 !
24 4 24 1 21 !
25 4 25 1 21 !
26 4 26 1 21 !
27 4 27 1 21 !
28 4 28 1 21 !
29 4 29 1 21 !
30 4 30 1 21 !
31 4 31 1 21 !
32 4 32 1 21 !
33 4 33 1 21 !
34 4 34 1 21 !
35 4 35 1 21 !
36 4 36 1 21 !
5 './2.40_bp12/beavrs_2.40_bp12_cr0_dc70_p0500_tf1600.t16' 36 1
1 5 23 1 21 !
2 5 1 1 21 !
3 5 2 1 21 !
4 5 3 1 21 !
5 5 4 1 21 !
6 5 5 1 21 !
7 5 6 1 21 !
8 5 7 1 21 !
9 5 8 1 21 !
10 5 9 1 21 !

```

```

11 5 10 1 21 !
12 5 11 1 21 !
13 5 12 1 21 !
14 5 13 1 21 !
15 5 14 1 21 !
16 5 15 1 21 !
17 5 16 1 21 !
18 5 17 1 21 !
19 5 18 1 21 !
20 5 19 1 21 !
21 5 20 1 21 !
22 5 21 1 21 !
23 5 22 1 21 !
24 5 24 1 21 !
25 5 25 1 21 !
26 5 26 1 21 !
27 5 27 1 21 !
28 5 28 1 21 !
29 5 29 1 21 !
30 5 30 1 21 !
31 5 31 1 21 !
32 5 32 1 21 !
33 5 33 1 21 !
34 5 34 1 21 !
35 5 35 1 21 !
36 5 36 1 21 !
6 './2.40_bp12/beavrs_2.40_bp12_cr0_dc70_p1500_tf0800.t16' 36 1
  1 6 15 1 21 !
  2 6 1 1 21 !
  3 6 2 1 21 !
  4 6 3 1 21 !
  5 6 4 1 21 !
  6 6 5 1 21 !
  7 6 6 1 21 !
  8 6 7 1 21 !
  9 6 8 1 21 !
 10 6 9 1 21 !
 11 6 10 1 21 !
 12 6 11 1 21 !
 13 6 12 1 21 !
 14 6 13 1 21 !
 15 6 14 1 21 !
 16 6 16 1 21 !
 17 6 17 1 21 !
 18 6 18 1 21 !
 19 6 19 1 21 !
 20 6 20 1 21 !
 21 6 21 1 21 !
 22 6 22 1 21 !
 23 6 23 1 21 !
 24 6 24 1 21 !
 25 6 25 1 21 !
 26 6 26 1 21 !
 27 6 27 1 21 !
 28 6 28 1 21 !
 29 6 29 1 21 !
 30 6 30 1 21 !
 31 6 31 1 21 !
 32 6 32 1 21 !
 33 6 33 1 21 !
 34 6 34 1 21 !
 35 6 35 1 21 !
 36 6 36 1 21 !
7 './2.40_bp12/beavrs_2.40_bp12_cr0_dc77_p0500_tf0800.t16' 36 1
  1 7 17 1 21 !
  2 7 1 1 21 !
  3 7 2 1 21 !
  4 7 3 1 21 !
  5 7 4 1 21 !
  6 7 5 1 21 !
  7 7 6 1 21 !
  8 7 7 1 21 !
  9 7 8 1 21 !
 10 7 9 1 21 !
 11 7 10 1 21 !
 12 7 11 1 21 !
 13 7 12 1 21 !
 14 7 13 1 21 !
 15 7 14 1 21 !
 16 7 15 1 21 !
 17 7 16 1 21 !

```

```

18 7 18 1 21 !
19 7 19 1 21 !
20 7 20 1 21 !
21 7 21 1 21 !
22 7 22 1 21 !
23 7 23 1 21 !
24 7 24 1 21 !
25 7 25 1 21 !
26 7 26 1 21 !
27 7 27 1 21 !
28 7 28 1 21 !
29 7 29 1 21 !
30 7 30 1 21 !
31 7 31 1 21 !
32 7 32 1 21 !
33 7 33 1 21 !
34 7 34 1 21 !
35 7 35 1 21 !
36 7 36 1 21 !
8  './2.40_bp12/beavrs_2.40_bp12_cri_dc70_p0500_tf0800.t16' 36 1
  1 8 32 1 21 !
  2 8 1 1 21 !
  3 8 2 1 21 !
  4 8 3 1 21 !
  5 8 4 1 21 !
  6 8 5 1 21 !
  7 8 6 1 21 !
  8 8 7 1 21 !
  9 8 8 1 21 !
 10 8 9 1 21 !
 11 8 10 1 21 !
 12 8 11 1 21 !
 13 8 12 1 21 !
 14 8 13 1 21 !
 15 8 14 1 21 !
 16 8 15 1 21 !
 17 8 16 1 21 !
 18 8 17 1 21 !
 19 8 18 1 21 !
 20 8 19 1 21 !
 21 8 20 1 21 !
 22 8 21 1 21 !
 23 8 22 1 21 !
 24 8 23 1 21 !
 25 8 24 1 21 !
 26 8 25 1 21 !
 27 8 26 1 21 !
 28 8 27 1 21 !
 29 8 28 1 21 !
 30 8 29 1 21 !
 31 8 30 1 21 !
 32 8 31 1 21 !
 33 8 33 1 21 !
 34 8 34 1 21 !
 35 8 35 1 21 !
 36 8 36 1 21 !
%JOB_END

```

B.2 GenPMAXS input for radial edge reflector

```
%JOB_TIT
'refl_rad_edge.PMAX' T 3.0
%JOB_OPT
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 PC
%HISTORY
1 1
'CR0-HDC-MPC' 0 0.76971 600
%BRANCH
4 1
'CR0-HDC-MPC' 0 0.76971 600
'CR0-HDC-LPC' 0 0.76971 0
'CR0-HDC-HPC' 0 0.76971 1800
'CR0-MDC-MPC' 0 0.70045 600
%BURNUP
1
'NOBP' 1
0
'CR0-MDC-MPC' 4*1
%FIL_CNT
1 './reflector/beavrs_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 PC
%HISTORY
1 1
'CR0-LDC-MPC' 0 0.60811 600
%BRANCH
4 1
'CR0-LDC-MPC' 0 0.60811 600
'CR0-LDC-LPC' 0 0.60811 0
'CR0-LDC-HPC' 0 0.60811 1800
'CR0-MDC-MPC' 0 0.70045 600
%BURNUP
1
'NOBP' 1
0
'CR0-LDC-MPC' 4*1
%FIL_CNT
1 './reflector/beavrs_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 PC
%HISTORY
1 1
'CR0-HDC-MPC' 0 0.76971 600
%BRANCH
4 1
'CR0-HDC-MPC' 0 0.76971 600
'CR0-HDC-LPC' 0 0.76971 0
'CR0-HDC-HPC' 0 0.76971 1800
'CR0-MDC-MPC' 0 0.70045 600
%BURNUP
1
'NOBP' 1
0
'CR0-MDC-MPC' 4*1
%FIL_CNT
1 './reflector/beavrs_refl_bot.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
```

APPENDIX C. PARCS INPUT FILES

C.1 PARCS input for the cross section set 'pmax.dir' file

```

!
!*****
!          Index          PMAXS File Name          Br_struct
!*****
!          PMAXS_F      1      'xs/refl/refl_bot.PMAX'          1
!          PMAXS_F      2      'xs/refl/refl_top.PMAX'          2
!*****
!          PMAXS_F      3      'xs/refl/refl_rad_S.PMAX'          3
!          PMAXS_F      4      'xs/refl/refl_rad_SE.PMAX'          4
!          PMAXS_F      5      'xs/refl/refl_rad_E.PMAX'          5
!          PMAXS_F      6      'xs/refl/refl_rad_edge.PMAX'          6
!          PMAXS_F      7      'xs/refl/refl_rad_diag.PMAX'          7
!*****
!          PMAXS_F      8      'xs/spacer_000/1.60_bp00.PMAX'          8
!          PMAXS_F      9      'xs/spacer_230/1.60_bp00.PMAX'          9
!          PMAXS_F     10      'xs/spacer_000/2.40_bp00.PMAX'         10
!          PMAXS_F     11      'xs/spacer_230/2.40_bp00.PMAX'         11
!          PMAXS_F     12      'xs/spacer_000/2.40_bp12.PMAX'         12
!          PMAXS_F     13      'xs/spacer_230/2.40_bp12.PMAX'         13
!          PMAXS_F     14      'xs/spacer_000/2.40_bp16.PMAX'         14
!          PMAXS_F     15      'xs/spacer_230/2.40_bp16.PMAX'         15
!          PMAXS_F     16      'xs/spacer_000/3.10_bp00.PMAX'         16
!          PMAXS_F     17      'xs/spacer_230/3.10_bp00.PMAX'         17
!          PMAXS_F     18      'xs/spacer_000/3.10_bp06.PMAX'         18
!          PMAXS_F     19      'xs/spacer_230/3.10_bp06.PMAX'         19
!          PMAXS_F     20      'xs/spacer_000/3.10_bp15.PMAX'         20
!          PMAXS_F     21      'xs/spacer_230/3.10_bp15.PMAX'         21
!          PMAXS_F     22      'xs/spacer_000/3.10_bp16.PMAX'         22
!          PMAXS_F     23      'xs/spacer_230/3.10_bp16.PMAX'         23
!          PMAXS_F     24      'xs/spacer_000/3.10_bp20.PMAX'         24
!          PMAXS_F     25      'xs/spacer_230/3.10_bp20.PMAX'         25
!          PMAXS_F     26      'xs/spacer_000/3.20_bp00.PMAX'         26
!          PMAXS_F     27      'xs/spacer_230/3.20_bp00.PMAX'         27
!          PMAXS_F     28      'xs/spacer_000/3.20_bp04.PMAX'         28
!          PMAXS_F     29      'xs/spacer_230/3.20_bp04.PMAX'         29
!          PMAXS_F     30      'xs/spacer_000/3.20_bp08.PMAX'         30
!          PMAXS_F     31      'xs/spacer_230/3.20_bp08.PMAX'         31
!          PMAXS_F     32      'xs/spacer_000/3.20_bp12.PMAX'         32
!          PMAXS_F     33      'xs/spacer_230/3.20_bp12.PMAX'         33
!          PMAXS_F     34      'xs/spacer_000/3.40_bp00.PMAX'         34
!          PMAXS_F     35      'xs/spacer_230/3.40_bp00.PMAX'         35
!*****
!*****

```

C.2 PARCS input for the assembly geometry 'depl_assm.geom' file

```

grid_x      1*10.80456 8*21.60912
neutmesh_x  1*1 8*1
grid_y      1*10.80456 8*21.60912
neutmesh_y  1*1 8*1

!
!          Refl SG Fuel Fuel Fuel Fuel SG Fuel Fuel Fuel SG Fuel Fuel Fuel SG Fuel Fuel Fuel SG Fuel Fuel Fuel
!          SG Fuel Fuel Fuel SG Fuel Fuel Fuel Refl
!          grid_z      30.00 3.97 14.45 14.45 14.45 14.45 5.71 15.58 15.58 15.58 5.72 15.58 15.58 15.58 5.71 15.58 15.58 15.58 5.72 15.58 15.58 15.58
!          5.72 15.58 15.58 15.58 5.72 12.64 12.64 12.64 30.00

!          boun_cond      0 2 0 2 2 2

!          assy_type      4 1*1 29*3 1*2 REFL ! S - 1-sided refl
!          assy_type      5 1*1 29*4 1*2 REFL ! SE - 2-sided refl
!          assy_type      6 1*1 29*5 1*2 REFL ! E - 1-sided refl
!          assy_type      7 1*1 29*6 1*2 REFL ! island node on edge
!          assy_type      8 1*1 29*7 1*2 REFL ! island node on diagonal

!
!          R S F S F S F S F S F S F S F R
!          assy_type      10 1*1 1*9 4*8 1*9 3*8 1*9 3*8 1*9 3*8 1*9 3*8 1*9 3*8 1*9 3*8 1*2 FUEL ! 1.6wt%
!          assy_type      20 1*1 1*11 4*10 1*11 3*10 1*11 3*10 1*11 3*10 1*11 3*10 1*11 3*10 1*11 3*10 1*2 FUEL ! 2.4wt%
!          assy_type      21 1*1 1*13 4*12 1*13 3*12 1*13 3*12 1*13 3*12 1*13 3*12 1*13 3*12 1*13 3*12 1*2 FUEL ! 2.4wt%-bp12
!          assy_type      22 1*1 1*15 4*14 1*15 3*14 1*15 3*14 1*15 3*14 1*15 3*14 1*15 3*14 1*15 3*14 1*2 FUEL ! 2.4wt%-bp16
!          assy_type      30 1*1 1*17 4*16 1*17 3*16 1*17 3*16 1*17 3*16 1*17 3*16 1*17 3*16 1*17 3*16 1*2 FUEL ! 3.1wt%
!          assy_type      31 1*1 1*19 4*18 1*19 3*18 1*19 3*18 1*19 3*18 1*19 3*18 1*19 3*18 1*19 3*18 1*2 FUEL ! 3.1wt%-bp06
!          assy_type      32 1*1 1*21 4*20 1*21 3*20 1*21 3*20 1*21 3*20 1*21 3*20 1*21 3*20 1*21 3*20 1*2 FUEL ! 3.1wt%-bp15
!          assy_type      33 1*1 1*23 4*22 1*23 3*22 1*23 3*22 1*23 3*22 1*23 3*22 1*23 3*22 1*23 3*22 1*2 FUEL ! 3.1wt%-bp16
!          assy_type      34 1*1 1*25 4*24 1*25 3*24 1*25 3*24 1*25 3*24 1*25 3*24 1*25 3*24 1*25 3*24 1*2 FUEL ! 3.1wt%-bp20
!          assy_type      40 1*1 1*27 4*26 1*27 3*26 1*27 3*26 1*27 3*26 1*27 3*26 1*27 3*26 1*27 3*26 1*2 FUEL ! 3.2wt%
!          assy_type      41 1*1 1*29 4*28 1*29 3*28 1*29 3*28 1*29 3*28 1*29 3*28 1*29 3*28 1*29 3*28 1*2 FUEL ! 3.2wt%-bp04
!          assy_type      42 1*1 1*31 4*30 1*31 3*30 1*31 3*30 1*31 3*30 1*31 3*30 1*31 3*30 1*31 3*30 1*2 FUEL ! 3.2wt%-bp08

```

```

assy_type 43 1*1 1*33 4*32 1*33 3*32 1*33 3*32 1*33 3*32 1*33 3*32 1*33 3*32 1*33 3*32 1*2 FUEL ! 3.2wt%-bp12
assy_type 50 1*1 1*35 4*34 1*35 3*34 1*35 3*34 1*35 3*34 1*35 3*34 1*35 3*34 1*35 3*34 1*2 FUEL ! 3.4wt%

```

```

PINCAL_IOC
 1 2 3 4 5 6 7 8 0
 1 2 3 4 5 6 7 8 0
 9 10 11 12 13 14 15 16 0
17 18 19 20 21 22 23 24 0
25 26 27 28 29 30 31 32 0
33 34 35 36 37 38 39 0 0
40 41 42 43 44 45 46 0
47 48 49 50 51 52 0 0
53 54 55 56 0 0 0
 0 0 0 0 0

```

C.3 PARCS input for the in-core detector map 'depl_detect.geom' file

```

grid_x      1*10.80456 8*21.60912
DET_XY_LOC  56
 1 2 3 4 5 6 7 8 0
 9 10 11 12 13 14 15 16 0
17 18 19 20 21 22 23 24 0
25 26 27 28 29 30 31 32 0
33 34 35 36 37 38 39 0 0
40 41 42 43 44 45 46 0
47 48 49 50 51 52 0 0
53 54 55 56 0 0 0
 0 0 0 0 0

DET_Z_LOC   30 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 31

DET_Z_WEI   1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

DET_NAME
1 D01
2 D02
3 D03
4 D04
5 D05
6 D06
7 D07
8 D08
9 D09
10 D10
11 D11
12 D12
13 D13
14 D14
15 D15
16 D16
17 D17
18 D18
19 D19
20 D20
21 D21
22 D22
23 D23
24 D24
25 D25
26 D26
27 D27
28 D28
29 D29
30 D30
31 D31
32 D32
33 D33
34 D34
35 D35
36 D36
37 D37
38 D38
39 D39
40 D40
41 D41
42 D42
43 D43
44 D44
45 D45

```

46 D46
 47 D47
 48 D48
 49 D49
 50 D50
 51 D51
 52 D52
 53 D53
 54 D54
 55 D55
 56 D56

C.4 PARCS input for the HFP cycle-1

```

!*****
CASEID BEAVRS_cycle1_hfp
!*****
CNTL
  core_type      PWR
!
  int_th         T -1
  xe_sm          1 1
!
  core_power     100.0
!
  bank_pos       A(1) B(2) C(3) D(4) SA(5) SB(6) SC(7) SD(8) SE(9) BP(10)
                400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
!
  ppm            700.0
  search         ppm 1.0 1000.0
!
  mult_cyc       T
  detector       T 250.0 2
!-----
  depletion      T 1.0e-4 T
!
  TREE_XS        TREE,nset,adf,xes,ene,jlf,chi, chd,vel,det,yld,cdf,gff,bet,lam,dht
                T 35 T T F F F F F T T F T F F F
!
  PLOT_OPTS      pow flux th prec xesm pin
                0 0 0 0 0 2
  PIN_POWER      T
!*****
PARAM
  nlupd_ss       3 5 1
  n_iters_ss     15 200
  conv_ss        1.0e-6 1.0e-5 5.0e-5
  cnv_th_ss      0.001
  wielandt       0.3 10.0 1.0
  decusp         2
  cmfd           2
!*****
! CYCLE-1
!   A   B16  A   B12  A   B16  A   C06
!   B16  A   B12  A   B12  A   C20  C
!   A   B12  A   B12  A   B16  A   C06
!   B12  A   B12  A   B16  A   C16  C
!   A   B12  A   B16  B   B16  C
!   B16  A   B16  A   B16  C15  C
!   A   C20  A   C16  C   C
!   C06  C   C06  C
!
!   A   (10) : 1.6W/O 00-BP
!   B   (20) : 2.4W/O 00-BP
!   B12 (21) : 2.4W/O 12-BP
!   B16 (22) : 2.4W/O 16-BP
!   C   (30) : 3.1W/O 00-BP
!   C06 (31) : 3.1W/O 06-BP
!   C15 (32) : 3.1W/O 15-BP
!   C16 (33) : 3.1W/O 16-BP
!   C20 (34) : 3.1W/O 20-BP
! CYCLE-2
!   D   (40) : 3.2W/O 00-BP
!   D04 (41) : 3.2W/O 04-BP
!   D08 (42) : 3.2W/O 08-BP
!   D12 (43) : 3.2W/O 12-BP
!   E   (50) : 3.4W/O 00-BP

GEOM
  geo_dim       9 9 31 1 1
  rad_conf      !nasyx,nasyy,nz,nzbr,nztr

```

```

10 22 10 21 10 22 10 31 6
22 10 21 10 21 10 34 30 6
10 21 10 21 10 22 10 31 6
21 10 21 10 22 10 33 30 6
10 21 10 22 20 22 30 5 7
22 10 22 10 22 32 30 6 0
10 34 10 33 30 30 5 8 0
31 30 31 30 5 4 8 0 0
4 4 4 4 7 0 0 0 0

file './depl_assm.geom'

crb_def      2
              1 0 2 1 0    1.87 101.60 260.225 500.0    ! Four Types
              2 0 1 0    1.90 371.25 500.0    ! Control Rod: None AIC B4C None
crb_type     1 1 1 1 1 1 1 1 2    ! Pyrex Rods None Pyrx None

cr_axinfo    33.958 1.58708    ! All adjustments for BP, WABA done with crb definitions

! A(1) B(2) C(3) D(4) SA(5) SB(6) SC(7) SD(8) SE(9) BP(10)
bank_conf
  4 10 1 10 9 10 3 10 0
 10 0 10 0 10 6 10 0 0
  1 10 3 10 0 10 2 10 0
 10 0 10 0 10 7 10 0 0
  9 10 0 10 4 10 5 0 0
 10 6 10 8 10 10 0 0
  3 10 2 10 5 0 0 0
 10 0 10 0 0 0 0 0
  0 0 0 0 0

file './depl_detect.geom'

!*****
FDBK
  fa_powpit    17.673575 21.60912    ! assembly power(Mw) and pitch(cm)    3411MW/193 assm
!*****
TH
  unif_th      0.74300 600.0 293.33    ! cool den, ftemp(C), ctemp(C)

!
  flow_cond    293.33 88.500    ! tin,cmfrfa(Kg/sec)
  n_pingt     264 25    ! npin,ngt
  pin_dim     3.9424 4.5798 0.5725 0.603    ! pelletrad,cladrad,cladthick,rgt(mm)
  hgap       8000.0    ! hgap(w/M^2-C)
  n_ring      8    ! number of meshes in pellet
!*****
DEPL
!   INP_HST     'shuf-cycl2-2.dep' 1 2
!   INP_OPT     F F F T
!
  HST_OPT     T T T T F    ! LHCR, LHDC, LHPC, LHTF, LHTC
  OUT_OPT     T T T T F    ! PPOW, PHST, PTHS, PXESM, PXSS
!   HCR_BPRA   T
!
file './pmax.dir'

!*****
MCYCLE
bank_def 1 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 2 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 3 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 4 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 5 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 6 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 7 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 8 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 9 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 10 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 11 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 12 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 13 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 14 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 15 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 16 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 17 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 18 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 19 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 20 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 21 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 22 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 23 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0

```

```

bank_def 24 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 25 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 26 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 27 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 28 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 29 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def 30 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0

cycle_def 1
! bpra_pos 0 0 0 0 0 0 0 0 0 1
depl_step -0.170 -0.283 -0.206 -0.262 -0.375 -0.203 -0.658 -0.741 -0.666 -0.435 -0.581
-0.579 -0.715 -0.124 -0.339 -0.525 -0.412 -0.116 -0.120 -0.420 -0.560 -0.451 -0.207 -0.222 -0.131
-0.837 -0.955 -1.012 -1.293
bank_seq 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
power_lev 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0
100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0
100.0 100.0 100.0 100.0 100.0
inlet_ent 30*-566.48
flow_rate 30*88.5

LOCATION
1 2 3 4 5 6 7 8 0
9 10 11 12 13 14 15 16 0
17 18 19 20 21 22 23 24 0
25 26 27 28 29 30 31 32 0
33 34 35 36 37 38 39 0 0
40 41 42 43 44 45 46 0
47 48 49 50 51 52 0 0
53 54 55 56 0 0 0
0 0 0 0 0

SHUF_MAP 1 1 ! shuf index, shuf mode: 1-individual; 2-batch
1 2 3 4 5 6 7 8 0
9 10 11 12 13 14 15 16 0
17 18 19 20 21 22 23 24 0
25 26 27 28 29 30 31 32 0
33 34 35 36 37 38 39 0 0
40 41 42 43 44 45 46 0
47 48 49 50 51 52 0 0
53 54 55 56 0 0 0
0 0 0 0 0

CYCLE_IND 1 0 1
!
CONV_EC 0.1 1 ! convergence criterion (GWD/T), max number of iteration
!*****
.

```

C.5 PARCS input for the HZP cycle 2 fuel shuffling

```

!*****
CASEID BEAVERS_cycle2_hzp_BOC
!*****
CNTL
core_type PWR
!
int_th F -1
xe_sm 3 3
!
core_power 1.0
! A(1) B(2) C(3) D(4) SA(5) SB(6) SC(7) SD(8) SE(9) BP(9)
bank_pos 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0
!
! ppm 500.0
! search ppm 1.0 2500.0
!
mult_cyc T
detector T 250.0 2
!-----
depletion T 1.0e-4 F
! TREE,nset,adf,xes,ene,jlf,chi, chd,vel,det,yld,cdf,gff,bet,lam,dht
TREE_XS T 35 T T F F F F F T T F T F F F
! pow flux th prec xesm pin
PLOT_OPTS 0 0 0 0 0 2
PIN_POWER T
!*****
PARAM

```

```

nlupd_ss      3 5 1
n_iters_ss    15 200
conv_ss       1.0e-6 1.0e-5 5.0e-5
cnv_th_ss     0.001
wielandt     0.3 10.0 1.0
decusp        2
cmfd          2
!*****
GEOM
geo_dim       9 9 31 1 1          !nasyx,nasyy,nz,nzbr,nztr
rad_conf
10 22 10 21 10 22 10 31 6
22 10 21 10 21 10 34 30 6
10 21 10 21 10 22 10 31 6
21 10 21 10 22 10 33 30 6
10 21 10 22 20 22 30 5 7
22 10 22 10 22 32 30 6 0
10 34 10 33 30 30 5 8 0
31 30 31 30 5 4 8 0 0
4 4 4 4 7 0 0 0 0

file './depl_assm.geom'

crb_def       2
1 0 2 1 0     1.87 101.60 260.225 500.0 ! Four Types
2 0 1 0       1.90 371.25 500.0         ! Control Rod: None AIC B4C None
! Pyrex Rods None Pyrx None
crb_type      1 1 1 1 1 1 1 1 1 2

cr_axinfo     33.958 1.58708 ! All adjustments for BP, WABA done with crb definitions

! A(1) B(2) C(3) D(4) SA(5) SB(6) SC(7) SD(8) SE(9) BP(10)
bank_conf
4 10 1 10 9 10 3 10 0
10 0 10 0 10 6 10 0 0
1 10 3 10 0 10 2 10 0
10 0 10 0 10 7 10 0 0
9 10 0 10 4 10 5 0 0
10 6 10 8 10 10 0 0
3 10 2 10 5 0 0 0
10 0 10 0 0 0 0
0 0 0 0 0

file './depl_detect.geom'

!*****
FDBK
fa_powpit     17.673575 21.60912 ! assembly power(Mw) and pitch(cm) 3411MW/193 assm =
!*****
TH
unif_th       0.74300 600.0 293.33 ! cool den, ftemp(C), ctemp(C)
!
flow_cond     293.33 88.500 ! tin,cmfrfa(Kg/sec)
n_pingt       264 25 ! npin,ngt
pin_dim       3.9424 4.5798 0.5725 0.603 ! pelletrad,cladrad,cladthick,rgt(mm)
hgap          8000.0 ! hgap(w/M^2-C)
n_ring        8 ! number of meshes in pellet
!*****
DEPL
INP_HST       'BEAVRS_cycle1_hfp.parcs_cyc-01' 1 30
INP_OPT       F F F T
!
HST_OPT       T T T T F ! LHCR, LHDC, LHPC, LHTF, LHTC
OUT_OPT       T T T T F ! PPOW, PHST, PTHS, PXESM, PXSS
HCR_BPRA     T
!
file './pmax.dir'

!*****
MCYCLE
bank_def      1 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0
!
cycle_def     1
depl_step     0.0001
power_lev     2*0.001
bank_seq      2*1
bpra_pos      9*0
!
cycle_def     2
depl_step     0.0001
power_lev     2*0.001
bank_seq      2*1

```

```

!      bpra_pos      9*0

LOCATION      0
H-08 G-08 F-08 E-08 D-08 C-08 B-08 A-08      0
H-09 G-09 F-09 E-09 D-09 C-09 B-09 A-09      0
H-10 G-10 F-10 E-10 D-10 C-10 B-10 A-10      0
H-11 G-11 F-11 E-11 D-11 C-11 B-11 A-11      0
H-12 G-12 F-12 E-12 D-12 C-12 B-12      0 0
H-13 G-13 F-13 E-13 D-13 C-13 B-13      0
H-14 G-14 F-14 E-14 D-14 C-14      0 0
H-15 G-15 F-15 E-15      0 0 0
      0 0 0 0 0

SHUF_MAP 1 1      ! shuf index, shuf mode: 1-individual; 2-batch
F-14 H-15 G-14 A-10 H-09 F-15 C-13 -50 0
A-08 B-09 A-09 C-12 A-11 E-12 B-12 -40 0
G-14 G-15 C-08 -42 D-09 -42 B-11 -50 0
A-10 D-13 -42 D-12 -43 C-10 -41 E-10 0
H-09 E-15 G-12 -43 E-08 B-13 -40 0 0
F-15 D-11 -42 F-13 C-14 -50 F-09 0
C-13 D-14 E-14 -41 -40 G-10 0 0
-50 -40 -50 F-11 0 0 0
      0 0 0 0 0

CYCLE_IND 1 0 1
CYCLE_IND 2 1 2
!
CONV_EC 0.1 2      ! convergence criterion (GWD/T), max number of iteration
!*****
.

```

C.6 PARCS input for the HFP cycle-2

```

!*****
CASEID BEAVRS_cycle2_hfp
!*****
CNTL
  core_type      PWR
!
  int_th         T -1
  xe_sm          1 1
!
  core_power     100.0
  A(1) B(2) C(3) D(4) SA(5) SB(6) SC(7) SD(8) SE(9) BP(10)
!
  bank_pos       400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
!
  ppm            1285.0
  search         ppm 1.0 1500.0
!
  mult_cyc       T
  detector        T 250.0 2
!-----
  depletion      T 1.0e-4 T
!
  TREE_XS        T 35 T T F F F F T T F T F F F
!
  pow flux th prec xesm pin
PLOT_OPTS       0 0 0 0 0 2
PIN_POWER       T
!*****
PARAM
  nlupd_ss       3 5 1
  n_iters_ss     15 200
  conv_ss        1.0e-6 1.0e-5 5.0e-5
  cnv_th_ss      0.001
  wielandt       0.3 10.0 1.0
  decusp         2
  cmfd           2
!*****
GEOM
  geo_dim        9 9 31 1 1      !nasyx,nasyy,nz,nzbr,nztr
  rad_conf
  10 31 34 31 22 31 32 50 6
  31 34 30 22 30 22 30 40 6
  34 30 22 42 21 42 33 50 6
  31 22 42 20 43 22 41 21 6
  22 30 21 43 21 30 40 5 7
  31 22 42 22 30 50 21 6 0
  32 30 33 41 40 21 5 8 0
  50 40 50 21 5 4 8 0 0
  4 4 4 4 7 0 0 0 0

```

```

! 10 30 30 30 20 30 30 50 6
! 30 30 30 20 30 20 30 40 6
! 30 30 20 42 20 42 30 50 6
! 30 20 42 20 43 20 41 20 6
! 20 30 20 43 20 30 40 5 7
! 30 20 42 20 30 50 20 6 0
! 30 30 30 41 40 20 5 8 0
! 50 40 50 20 5 4 8 0 0
! 4 4 4 4 7 0 0 0 0

file './depl_assm.geom'

crb_def      2
              1 0 2 1 0    1.87 101.60 260.225 500.0 ! Four Types
              2 0 1 0    1.90 371.25 500.0 ! Control Rod: None AIC B4C None
crb_type     1 1 1 1 1 1 1 1 2 ! Pyrex Rods None Pyrx None

cr_axinfo   33.958 1.58708 ! All adjustments for BP, WABA done with crb definitions

! A(1) B(2) C(3) D(4) SA(5) SB(6) SC(7) SD(8) SE(9) BP(10)
bank_conf
  4 0 1 0 9 0 3 0 0
  0 0 0 0 0 6 0 0 0
  1 0 3 10 0 10 2 0 0
  0 0 10 0 10 7 10 0 0
  9 0 0 10 4 0 5 0 0
  0 6 10 8 0 0 0 0
  3 0 2 10 5 0 0 0
  0 0 0 0 0 0 0
  0 0 0 0 0

file './depl_detect.geom'

!*****
FDBK
fa_powpit   17.673575 21.60912 ! assembly power(Mw) and pitch(cm) 3411MW/193 assm =
!*****
TH
unif_th     0.74300 600.0 293.33 ! cool den, ftemp(C), ctemp(C)

!
flow_cond   293.33 88.500 ! tin,cmfrfa(Kg/sec)
n_pingt    264 25 ! npin,ngt
pin_dim     3.9424 4.5798 0.5725 0.603 ! pelletrad,cladrad,cladthick,rgt(mm)
hgap        8000.0 ! hgap(w/M^2-C)
n_ring      8 ! number of meshes in pellet
!*****
DEPL
INP_HST     'BEAVRS_cycle2_hzp_BOC.parcs_cyc-02' 1 2
INP_OPT     F F F F

!
HST_OPT     T T T T F ! LHCR, LHDC, LHPC, LHTF, LHTC
OUT_OPT     T T T T F ! PPOW, PHST, PTHS, PXESM, PXSS
HCR_BPRA    T

!
file './pmax.dir'

!*****
MCYCLE
bank_def    1 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    1 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    2 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    3 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    4 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    5 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    6 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    7 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    8 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    9 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    10 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    11 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    12 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0
bank_def    13 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 400.0 0.0

cycle_def   1 !14 steps
! bpra_pos 0 0 0 0 0 0 0 0 1 1
depl_step   -0.544 -0.419 -0.823 -0.830 -0.873 -0.796 -1.114 -0.873 -1.076 -1.096 -1.322
-0.946 -0.654
bank_seq    1 2 3 4 5 6 7 8 9 10 11
12 13
power_lev   100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0
100.0 100.0 100.0

```

```

inlet_ent    14*-566.48
flow_rate    14*85.93

LOCATION
  1  2  3  4  5  6  7  8  0
  9 10 11 12 13 14 15 16 0
 17 18 19 20 21 22 23 24 0
 25 26 27 28 29 30 31 32 0
 33 34 35 36 37 38 39  0 0
 40 41 42 43 44 45 46  0
 47 48 49 50 51 52  0 0
 53 54 55 56  0  0  0
  0  0  0  0  0

SHUF_MAP    1  1          ! shuf index, shuf mode: 1-individual; 2-batch
  1  2  3  4  5  6  7  8  0
  9 10 11 12 13 14 15 16 0
 17 18 19 20 21 22 23 24 0
 25 26 27 28 29 30 31 32 0
 33 34 35 36 37 38 39  0 0
 40 41 42 43 44 45 46  0
 47 48 49 50 51 52  0 0
 53 54 55 56  0  0  0
  0  0  0  0  0

CYCLE_IND   1  0  1
!
CONV_EC     0.1  1          ! convergence criterion (GWD/T), max number of iteration
!*****
.

```

APPENDIX D. PROGRAM TO COMPARE FLUX MAPS FOR PWR

D.1 Program source

```
program DetectorResponse
! This is for the PWR detector response
implicit none
!
character(10) :: ss10
character(100) :: ctitle, file1, file2
character(400) :: ssw
integer :: nmeasure, nburn, naxial, ndets, nassembly, nxa, nya, numdet
integer :: i, j, k, nx, nid, ix, j1, j2, k2, idparcs, kid
integer, allocatable :: nidmeasure(:), numx(:), mapaxial(:, :), mapradial(:)
character(3), allocatable :: cDET(:), mDET(:), config(:, :)
real, allocatable :: weight(:), axialmesh(:)
real :: tempr, sumfa, totsum, sum0, sum1, sum2, sum3, diff, diff2, zpoint, x1, x2, y1, y2, yout
real :: mao, cao, dz
logical :: kr
!
type meas_type
integer :: nid, ndets, naxial, ndets_active
real :: burnup, efpd
character(3), allocatable :: mDET(:)
real, allocatable :: axialmesh(:)
real, allocatable :: mpownodal(:, :), mpowradial(:), mpowaxial(:)
real, allocatable :: mpownodal2(:, :), mpowradial2(:), mpowaxial2(:)
real, allocatable :: cpownodal(:, :), cpowradial(:), cpowaxial(:)
logical, allocatable :: ldata(:)
end type
type(meas_type), allocatable :: measdata(:)
!
type calc_type
character(3), allocatable :: cDET(:)
real, allocatable :: pownodal(:, :), axialmesh(:)
end type
type(calc_type), allocatable :: calcddata(:)
real :: rms_all, rms_radial, rms_axial
real :: max_all, max_radial, max_axial, min_all, min_radial, min_axial
!
! read input file
open(1, file='DetRes.in', status='old')
open(21, file='DetRes.out', status='unknown')
read(1, *) !%TITLE
read(1, *) ctitle
read(1, *) !%MEASURED
read(1, *) ss10, file1
read(1, *) ss10, nmeasure, ndets
allocate(nidmeasure(nmeasure))
read(1, *) (nidmeasure(i), i=1, nmeasure)
read(1, *) !%CALCULATED
read(1, *) ss10, file2
read(1, *) ss10, nburn, naxial, nassembly
allocate(axialmesh(0:naxial))
axialmesh(0)=0.0
do i=1, naxial
read(1, *) axialmesh(i)
enddo
read(1, *) !%INDEX
allocate(mDET(ndets), cDET(ndets), weight(ndets))
do i=1, ndets
read(1, *) ix, mDET(i), cDET(i) !Detector names in meas. and calc.
enddo
read(1, *) !%CORE
read(1, *) nxa, nya
allocate(config(nxa, nya))
do j=1, nya
read(1, *) (config(i, j), i=1, nxa)
enddo
!
! read calculated data
open(3, file=file2, status='old')
read(3, *)
allocate(calcddata(nburn))
do i=1, nburn
allocate(calcddata(i) %cDET(nassembly))
allocate(calcddata(i) %pownodal(naxial, nassembly))
read(3, *) ss10, ss10, ss10, ss10, (calcddata(i) %cDET(k), k=1, nassembly)
```

```

do j=naxial,1,-1
  read(3,*) tempr,tempr,tempr,tempr,(calcddata(i)%pownodal(j,k),k=1,nassembly)
enddo
enddo
!
!
read measured data
open(2,file=file1,status='old')
allocate(measdata(nmeasure))
read(2,*) ssl0,nx
if (nx .ne. nmeasure) then
  write(6,*) "Error: # of cases do not match in the measured data"
  stop
endif
do i=1,nmeasure
  idparcs=nidmeasure(i)

  read(2,*) measdata(i)%nid,measdata(i)%ndets,measdata(i)%naxial
  read(2,*)
  read(2,*) measdata(i)%burnup, measdata(i)%efpd
  allocate(measdata(i)%mDET(measdata(i)%ndets))
  allocate(measdata(i)%mpownodal(measdata(i)%naxial,measdata(i)%ndets))
  allocate(measdata(i)%axialmesh(measdata(i)%naxial))
  read(2,*) ssl0,(measdata(i)%mDET(k),k=1,measdata(i)%ndets)
  do j=1,measdata(i)%naxial
    read(2,*) measdata(i)%axialmesh(j),(measdata(i)%mpownodal(j,k),k=1,measdata(i)%ndets)
  enddo
  read(2,*,end=200)
  continue
  !sum over radial & axial and normalize
  allocate(measdata(i)%mpowradial(measdata(i)%ndets))
  allocate(measdata(i)%ldata(measdata(i)%ndets))
  allocate(measdata(i)%mpowaxial(measdata(i)%naxial))
  measdata(i)%mpowradial(:)=0.0
  measdata(i)%mpowaxial(:)=0.0
  sum0=0.0
  do j=1,measdata(i)%naxial
    do k=1,measdata(i)%ndets
      measdata(i)%mpowradial(k)=measdata(i)%mpowradial(k)+measdata(i)%mpownodal(j,k)
      measdata(i)%mpowaxial(j)=measdata(i)%mpowaxial(j)+measdata(i)%mpownodal(j,k)
      sum0=sum0+measdata(i)%mpownodal(j,k)
    enddo
  enddo
  !Sort out the detectors without data
  measdata(i)%ldata(:)=.false.
  numdet=0
  do k=1,measdata(i)%ndets
    if (measdata(i)%mpowradial(k) > 1.0e-5) then
      measdata(i)%ldata(k)=.true.
      numdet=numdet+1
    endif
  enddo
  measdata(i)%ndets_active=numdet
  !normalization
  do k=1,measdata(i)%ndets
    measdata(i)%mpowradial(k)=measdata(i)%mpowradial(k)/sum0*float(numdet)
  enddo
  do j=1,measdata(i)%naxial
    measdata(i)%mpowaxial(j)=measdata(i)%mpowaxial(j)/sum0*float(measdata(i)%naxial)
  enddo
  do j=1,measdata(i)%naxial
    do k=1,measdata(i)%ndets
      measdata(i)%mpownodal(j,k)=measdata(i)%mpownodal(j,k)/sum0*float(numdet*measdata(i)%naxial)
    enddo
  enddo
  !
  !convert the calculated data into the measured format
  allocate(measdata(i)%cpownodal(naxial,measdata(i)%ndets))
  allocate(measdata(i)%cpowradial(measdata(i)%ndets))
  allocate(measdata(i)%cpowaxial(naxial))
  allocate(measdata(i)%mpownodal2(naxial,measdata(i)%ndets))
  allocate(measdata(i)%mpowradial2(measdata(i)%ndets))
  allocate(measdata(i)%mpowaxial2(naxial))
  allocate(mapradial(measdata(i)%ndets))
  allocate(mapaxial(naxial,2))
  !axial mesh mapping
  mapaxial(:,:)=0
  do j=1,naxial
    zpoint=0.5*(axialmesh(j-1)+axialmesh(j))
    do j2=1,measdata(i)%naxial-1
      if ((zpoint-measdata(i)%axialmesh(j2))*(zpoint-measdata(i)%axialmesh(j2+1)) < 0.0) then
        nid=j2
      endif
    enddo
  enddo
enddo

```

```

        !write(6,*) j,j2,measdata(i)%axialmesh(j),axialmesh(j2),axialmesh(j2+1)
        exit
    elseif ((zpoint-measdata(i)%axialmesh(j2))*(zpoint-measdata(i)%axialmesh(j2+1)) == 0.0) then
        if (zpoint == measdata(i)%axialmesh(j2)) then
            nid=j2
        else
            nid=j2+1
        endif
        exit
    endif
enddo
if (nid > measdata(i)%naxial) nid=nid-1
mapaxial(j,1)=nid
mapaxial(j,2)=nid+1
enddo
!radial mesh mapping
mapradial(:)=0
do k=1,measdata(i)%ndets
    if (.not.measdata(i)%ldata(k)) cycle
    kr=.false.
    do k2=1,ndets
        if (measdata(i)%mDET(k) == mDET(k2)) then
            !write(6,*) k,mDET(k2)," ",cDET(k2)
            kr=.true.
            kid=k2
            exit
        endif
    enddo
    if (.not.kr) then
        write(6,*) "Error: there is no matching detector #1!"
    endif
    kr=.false.
    do k2=1,nassembly
        if (calcddata(idparcs)%cDET(k2) == cDET(kid)) then
            kr=.true.
            mapradial(k)=k2
            exit
        endif
    enddo
    if (.not.kr) then
        write(6,*) "Error: there is no matching detector #2!"
    endif
enddo
!Data re-assignment for the calculated
measdata(i)%cpownodal(:,:)=0.0
do j=1,naxial
    do k=1,measdata(i)%ndets
        if (.not.measdata(i)%ldata(k)) cycle
        k2=mapradial(k)
        measdata(i)%cpownodal(j,k)=calcddata(idparcs)%pownodal(j,k2)
    enddo
enddo
measdata(i)%cpowradial(:)=0.0
measdata(i)%cpowaxial(:)=0.0
sum0=0.0
do j=1,naxial
    do k=1,measdata(i)%ndets
        measdata(i)%cpowradial(k)=measdata(i)%cpowradial(k)+measdata(i)%cpownodal(j,k)
        measdata(i)%cpowaxial(j)=measdata(i)%cpowaxial(j)+measdata(i)%cpownodal(j,k)
        sum0=sum0+measdata(i)%cpownodal(j,k)
    enddo
enddo
!normalization
do k=1,measdata(i)%ndets
    measdata(i)%cpowradial(k)=measdata(i)%cpowradial(k)/sum0*float(measdata(i)%ndets_active)
enddo
do j=1,naxial
    measdata(i)%cpowaxial(j)=measdata(i)%cpowaxial(j)/sum0*float(naxial)
enddo
do j=1,naxial
    do k=1,measdata(i)%ndets
        measdata(i)%cpownodal(j,k)=measdata(i)%cpownodal(j,k)/sum0*float(measdata(i)%ndets_active*naxial)
    enddo
enddo
!Data re-assignment for the measured
measdata(i)%mpownodal2(:,:)=0.0
do j=1,naxial
    zpoint=0.5*(axialmesh(j-1)+axialmesh(j))
    j1=mapaxial(j,1)
    j2=mapaxial(j,2)
    x1=measdata(i)%axialmesh(j1)

```

```

x2=measdata(i)%axialmesh(j2)
do k=1,measdata(i)%ndets
  if (.not.measdata(i)%ldata(k)) cycle
  y1=measdata(i)%mpownodal(j1,k)
  y2=measdata(i)%mpownodal(j2,k)
  if (j1 == j2) then
    yout=measdata(i)%mpownodal(j1,k)
  else
    yout=(y2-y1)*zpoint/(x2-x1)+(y1*x2-y2*x1)/(x2-x1)
  endif
  measdata(i)%mpownodal2(j,k)=yout
enddo
enddo
measdata(i)%mpowradial2(:)=0.0
measdata(i)%mpowaxial2(:)=0.0
sum0=0.0
do j=1,naxial
  do k=1,measdata(i)%ndets
    measdata(i)%mpowradial2(k)=measdata(i)%mpowradial2(k)+measdata(i)%mpownodal2(j,k)
    measdata(i)%mpowaxial2(j)=measdata(i)%mpowaxial2(j)+measdata(i)%mpownodal2(j,k)
    sum0=sum0+measdata(i)%mpownodal2(j,k)
  enddo
enddo
!normalization
do k=1,measdata(i)%ndets
  measdata(i)%mpowradial2(k)=measdata(i)%mpowradial2(k)/sum0*float(measdata(i)%ndets_active)
enddo
do j=1,naxial
  measdata(i)%mpowaxial2(j)=measdata(i)%mpowaxial2(j)/sum0*float(naxial)
enddo
do j=1,naxial
  do k=1,measdata(i)%ndets
    measdata(i)%mpownodal2(j,k)=measdata(i)%mpownodal2(j,k)/sum0*float(measdata(i)%ndets_active*naxial)
  enddo
enddo
!
!Data processing for %RMSs
rms_all=0.0
rms_radial=0.0
rms_axial=0.0
max_all=0.0
max_radial=0.0
max_axial=0.0
min_all=0.0
min_radial=0.0
min_axial=0.0
do j=1,naxial
  do k=1,measdata(i)%ndets
    if (.not.measdata(i)%ldata(k)) cycle
    diff=measdata(i)%cpownodal(j,k)-measdata(i)%mpownodal2(j,k)
    diff2=diff**2
    rms_all=rms_all+diff2
    if (diff > max_all) max_all=diff
    if (diff < min_all) min_all=diff
  enddo
enddo
rms_all=sqrt(rms_all/float(measdata(i)%ndets_active*naxial))*100.0
do k=1,measdata(i)%ndets
  if (.not.measdata(i)%ldata(k)) cycle
  diff=measdata(i)%cpowradial(k)-measdata(i)%mpowradial2(k)
  diff2=diff**2
  rms_radial=rms_radial+diff2
  if (diff > max_radial) max_radial=diff
  if (diff < min_radial) min_radial=diff
enddo
rms_radial=sqrt(rms_radial/float(measdata(i)%ndets_active))*100.0
do j=1,naxial
  diff=measdata(i)%cpowaxial(j)-measdata(i)%mpowaxial2(j)
  diff2=diff**2
  rms_axial=rms_axial+diff2
  if (diff > max_axial) max_axial=diff
  if (diff < min_axial) min_axial=diff
enddo
rms_axial=sqrt(rms_axial/float(naxial))*100.0
mao=0.0
cao=0.0
sum1=0.0
sum2=0.0
zpoint=0.5*axialmesh(naxial)
do j=1,naxial
  dz=axialmesh(j)-axialmesh(j-1)

```

```

sum1=sum1+measdata(i)%mpowaxial2(j)*dz
sum2=sum2+measdata(i)%cpowaxial(j)*dz
if (zpoint > axialmesh(j)) then
  mao=mao+measdata(i)%mpowaxial2(j)*dz
  cao=cao+measdata(i)%cpowaxial(j)*dz
elseif (zpoint < axialmesh(j-1)) then
  cycle
elseif (zpoint > axialmesh(j-1) .and. zpoint < axialmesh(j) ) then
  dz=abs(zpoint-axialmesh(j-1))
  mao=mao+measdata(i)%mpowaxial2(j)*dz
  cao=cao+measdata(i)%cpowaxial(j)*dz
endif
enddo
mao=(sum1-2.0*mao)/sum1*100.0
cao=(sum2-2.0*cao)/sum2*100.0
!
if (i==1) write(21,*) ctitle
write(21,*)
write(21,('@Case =          ',i5)) i
write(21,('Burnup(MWD/kgU)',f10.3)) measdata(i)%burnup
write(21,('% RMS for 3D          ',f10.3,i5)) rms_all,measdata(i)%ndets_active*naxial
write(21,('% RMS for radial',f10.3,i5)) rms_radial,measdata(i)%ndets_active
write(21,('% RMS for axial ',f10.3,i5)) rms_axial,naxial
!write(21,('% axial offsets ',2f10.3)) mao,cao
write(21,*)
do j=1,naxial
  diff=(measdata(i)%cpowaxial(j)-measdata(i)%mpowaxial2(j))*100.0
  zpoint=0.5*(axialmesh(j-1)+axialmesh(j))
  write(21,(i5,4f10.3)) j,zpoint,measdata(i)%mpowaxial2(j),measdata(i)%cpowaxial(j),diff
enddo
!
  deallocate(mapaxial)
  deallocate(mapradial)
enddo
100 continue
!
  close(21)
!
  stop
end

```

D.2 Cycle-1 input

```

%TITLE
'BEAVRS cycle-1'
%MEASURED
file BEAVRS_cyl.dat
dim 7 58 !# of parc burnup points, # of detectors
7 8 12 20 23 28 29
%CALCULATED
file BEAVRS_cycle1_hfp.parc_det
dim 30 29 56 4 !# of burnups / # of axials / # of assemblies / symmetry (1:full, 4:quarter
3.97 !1 3.97 bottom to top
18.42 !2 14.45
32.87 !3 14.45
47.32 !4 14.45
61.77 !5 14.45
67.48 !6 5.71
83.06 !7 15.58
98.64 !8 15.58
114.22 !9 15.58
119.94 !10 5.72
135.52 !11 15.58
151.10 !12 15.58
166.68 !13 15.58
172.39 !14 5.71
187.97 !15 15.58
203.55 !16 15.58
219.13 !17 15.58
224.85 !18 5.72
240.43 !19 15.58
256.01 !20 15.58
271.59 !21 15.58
277.31 !22 5.72
292.89 !23 15.58
308.47 !24 15.58
324.05 !25 15.58
329.77 !26 5.72
342.41 !27 12.64

```

355.05 !28 12.64
 367.69 !29 12.64

```
%INDEX 58
 1 J01 D54 ! 1 For WBN1
 2 F01 D55 ! 2
 3 N02 D52 ! 3
 4 K02 D49 ! 4
 5 H02 D47 ! 5
 6 H03 D40 ! 6
 7 F03 D42 ! 7
 8 D03 D44 ! 8
 9 B03 D46 ! 9
10 P04 D39 ! 10
11 N04 D38 ! 11
12 H04 D33 ! 12
13 L05 D28 ! 13
14 G05 D26 ! 14
15 E05 D28 ! 15
16 C05 D30 ! 16
17 R06 D24 ! 17
18 N06 D22 ! 18
19 K06 D19 ! 19
20 H06 D17 ! 20
21 B06 D23 ! 21
22 M07 D13 ! 22
23 J07 D10 ! 23
24 F07 D11 ! 24
25 C07 D14 ! 25
26 R08 D08 ! 26
27 N08 D06 ! 27
28 L08 D04 ! 28
29 J08 D02 ! 29
30 F08 D03 ! 30
31 D08 D05 ! 31
32 C08 D06 ! 32
33 B08 D07 ! 33
34 P09 D15 ! 34
35 G09 D10 ! 35
36 E09 D12 ! 36
37 A09 D16 ! 37
38 L10 D20 ! 38
39 J10 D18 ! 39
40 D10 D21 ! 40
41 R11 D32 ! 41
42 L11 D28 ! 42
43 H11 D25 ! 43
44 E11 D28 ! 44
45 A11 D32 ! 45
46 K12 D35 ! 46
47 G12 D34 ! 47
48 D12 D37 ! 48
49 N13 D45 ! 49
50 L13 D43 ! 50
51 H13 D40 ! 51
52 B13 D46 ! 52
53 N14 D52 ! 53
54 J14 D48 ! 54
55 F14 D49 ! 55
56 D14 D51 ! 56
57 L15 D56 ! 57
58 H15 D53 ! 58
```

```
%CORE
15 15
 0 0 0 0 0 0 1 0 0 2 0 0 0 0 0
 0 0 3 0 0 4 0 5 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 6 0 7 0 8 0 9 0
 0 10 11 0 0 0 0 12 0 0 0 0 0 0 0
 0 0 0 0 13 0 0 0 14 0 15 0 16 0 0
17 0 18 0 0 19 0 20 0 0 0 0 0 21 0
 0 0 0 22 0 0 23 0 0 24 0 0 25 0 0
26 0 27 0 28 0 29 0 0 30 0 31 32 33 0
 0 34 0 0 0 0 0 35 0 36 0 0 0 37
 0 0 0 0 38 0 39 0 0 0 0 40 0 0 0
41 0 0 0 42 0 0 43 0 0 44 0 0 0 45
 0 0 0 0 46 0 0 47 0 0 48 0 0 0
 0 0 49 0 50 0 0 51 0 0 0 0 52 0
 0 0 53 0 0 0 54 0 0 55 0 56 0 0 0
 0 0 0 0 57 0 0 58 0 0 0 0 0 0
```

%END

D.3 Cycle-2 input

```

%TITLE
'BEAVRS cycle-2'
%MEASURED
file BEAVRS_cy2.dat
dim 10 58 !# of parc burnup points, # of detectors
  4 6 7 8 9 11 13 15 16 17
%CALCULATED
file BEAVRS_cycle2_hfp.parc_det
dim 18 29 56 4 !# of burnups / # of axials / # of assemblies / symmetry (1:full, 4:quarter
  3.97 !1 3.97 bottom to top
  18.42 !2 14.45
  32.87 !3 14.45
  47.32 !4 14.45
  61.77 !5 14.45
  67.48 !6 5.71
  83.06 !7 15.58
  98.64 !8 15.58
 114.22 !9 15.58
 119.94 !10 5.72
 135.52 !11 15.58
 151.10 !12 15.58
 166.68 !13 15.58
 172.39 !14 5.71
 187.97 !15 15.58
 203.55 !16 15.58
 219.13 !17 15.58
 224.85 !18 5.72
 240.43 !19 15.58
 256.01 !20 15.58
 271.59 !21 15.58
 277.31 !22 5.72
 292.89 !23 15.58
 308.47 !24 15.58
 324.05 !25 15.58
 329.77 !26 5.72
 342.41 !27 12.64
 355.05 !28 12.64
 367.69 !29 12.64
%INDEX 58
  1 J01 D54 ! 1 For WBN1
  2 F01 D55 ! 2
  3 N02 D52 ! 3
  4 K02 D49 ! 4
  5 H02 D47 ! 5
  6 H03 D40 ! 6
  7 F03 D42 ! 7
  8 D03 D44 ! 8
  9 B03 D46 ! 9
 10 P04 D39 ! 10
 11 N04 D38 ! 11
 12 H04 D33 ! 12
 13 L05 D28 ! 13
 14 G05 D26 ! 14
 15 E05 D28 ! 15
 16 C05 D30 ! 16
 17 R06 D24 ! 17
 18 N06 D22 ! 18
 19 K06 D19 ! 19
 20 H06 D17 ! 20
 21 B06 D23 ! 21
 22 M07 D13 ! 22
 23 J07 D10 ! 23
 24 F07 D11 ! 24
 25 C07 D14 ! 25
 26 R08 D08 ! 26
 27 N08 D06 ! 27
 28 L08 D04 ! 28
 29 J08 D02 ! 29
 30 F08 D03 ! 30
 31 D08 D05 ! 31
 32 C08 D06 ! 32
 33 B08 D07 ! 33
 34 P09 D15 ! 34
 35 G09 D10 ! 35
 36 E09 D12 ! 36
 37 A09 D16 ! 37
 38 L10 D20 ! 38
 39 J10 D18 ! 39

```

```

40 D10 D21 ! 40
41 R11 D32 ! 41
42 L11 D28 ! 42
43 H11 D25 ! 43
44 E11 D28 ! 44
45 A11 D32 ! 45
46 K12 D35 ! 46
47 G12 D34 ! 47
48 D12 D37 ! 48
49 N13 D45 ! 49
50 L13 D43 ! 50
51 H13 D40 ! 51
52 B13 D46 ! 52
53 N14 D52 ! 53
54 J14 D48 ! 54
55 F14 D49 ! 55
56 D14 D51 ! 56
57 L15 D56 ! 57
58 H15 D53 ! 58

```

```
%CORE
```

```

15 15
0 0 0 0 0 0 1 0 0 2 0 0 0 0 0
0 0 3 0 0 4 0 5 0 0 0 0 0 0 0
0 0 0 0 0 0 0 6 0 7 0 8 0 9 0
0 10 11 0 0 0 0 12 0 0 0 0 0 0
0 0 0 0 13 0 0 0 14 0 15 0 16 0
17 0 18 0 0 19 0 20 0 0 0 0 0 21 0
0 0 0 22 0 0 23 0 0 24 0 0 25 0
26 0 27 0 28 0 29 0 0 30 0 31 32 33 0
0 34 0 0 0 0 0 0 35 0 36 0 0 0 37
0 0 0 0 38 0 39 0 0 0 0 40 0 0
41 0 0 0 42 0 0 43 0 0 44 0 0 0 45
0 0 0 0 0 46 0 0 47 0 0 48 0 0
0 0 49 0 50 0 0 51 0 0 0 0 52 0
0 0 53 0 0 0 54 0 0 55 0 56 0 0
0 0 0 0 57 0 0 58 0 0 0 0 0 0

```

```
%END
```