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2-DIMENSIONAL PWR AND BWR WHOLE CORE BENCHMARK PROBLEMS

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ABSTRACT

Because of the recent advancements in computer technology, it is now possible to solve much larger and more complicated reactor problems. To efficiently solve these problems, many new methods and reactor codes are in development; however, most available benchmark problems are small scale, possessing only a few fuel assemblies, or are homogenized at the pin-cell or fuel assembly level. There is a need for newer benchmark problems to thoroughly test codes and methods that are designed to handle larger problems. In order to adequately validate these new codes, benchmark problems are necessary which are large-scale, highly heterogeneous, and representative of realistic reactor designs. Both a PWR and a BWR benchmark problem are presented in this paper. They are both 2-dimensional, whole-core models, with heterogeneity at the core and assembly level. Few-group cross-sections are produced by performing assembly calculations with the lattice depletion code HELIOS, and the problems were solved at the core level using MCNP5. Full descriptions of the benchmark problems are presented, including geometry, materials, and cross-sections. Results are presented for the eigenvalues and pin fission densities.

Key Words: Reactor Benchmarks

1. INTRODUCTION

As new computer codes are developed for solving the transport equation in reactor problems, it is essential for methods developers to have at their disposal effective and robust computational benchmarks. In order to validate computational methods and reactor codes that may be used for real-world reactor problems, the benchmark configurations must be representative of realistic reactor designs, which implies that they must be large-scale and highly heterogeneous, both at the assembly and the core levels.

Until recent years, benchmark problems have had to be kept relatively simple, composed of only a small number of assemblies. In addition, the complexity of reactor systems required a

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significant amount of homogenization in order to make the core-level problem tractable for older computer systems. The dramatic increase in computational ability that has occurred in recent years, however, has allowed for an increase in the complexity of problems that can be solved. Whole-core problems can now be solved in a reasonable amount of time, and new methods are constantly in development to improve these solutions.

The available benchmark problems for testing these new methods and codes are still smaller scale, however, and most advanced methods are still not tested on large scale problems. This represents a significant gap in the resources available for programmers and engineers in the nuclear industry. The present work is intended to provide full-core, heterogeneous benchmark problem descriptions to test the capabilities of new computational techniques for solving reactor problems. A Pressurized Water Reactor (PWR) problem and a Boiling Water Reactor (BWR) problem are presented in this paper. The PWR model is a 15x15 assembly core design with fuel assemblies based on the C5G7 assembly [1]; the BWR model is a 19x19 assembly design with assemblies based on a GE9 bundle [2].

2. PWR BENCHMARK PROBLEM

2.1. Benchmark Description

The PWR benchmark problem is composed of square assemblies, laid out in a manner consistent with pressurized water reactors, based upon a 2-loop Westinghouse PWR design [3]. The Westinghouse design does not include MOX assemblies, and the core layout is adjusted to include those assemblies in a checkerboard fashion. The design of the fuel assemblies is from the C5G7 fuel assemblies used in NEA MOX benchmark [1], and the isotopic composition of most materials is from earlier work on the C5G7 assembly [4].

The PWR benchmark consists of two different assembly designs: Uranium Oxide (UO2) and Mixed Oxide (MOX). The UO2 assembly is composed of only one type of fuel, and the MOX assembly is composed of three different enrichments of transuranic isotopes. The isotopic concentration of each material is presented in Appendix A. Control is maintained in the reactor by means of boron control rods which are inserted into 24 guide tubes in the fuel assemblies. In most PWR reactors, additional burnable poison is mixed in the moderator, however this was not performed in this problem for simplicity.

2.1.1. Core layout

The core is composed of 121 square fuel assemblies of length 21.42 cm, surrounded by assemblies of moderator, and then vacuum. The problem is simplified via implementing 1/8th symmetry, laid out as in Figure 1. Due to the presence of control rods in several assemblies, there are 4 distinct assembly types in the PWR problem: Uncontrolled UO2 (UO2), Controlled UO2 (UO2-C), Uncontrolled MOX (MOX), and Controlled MOX (MOX-C). The left and right side of the simplified model are treated with specular reflective boundary conditions.

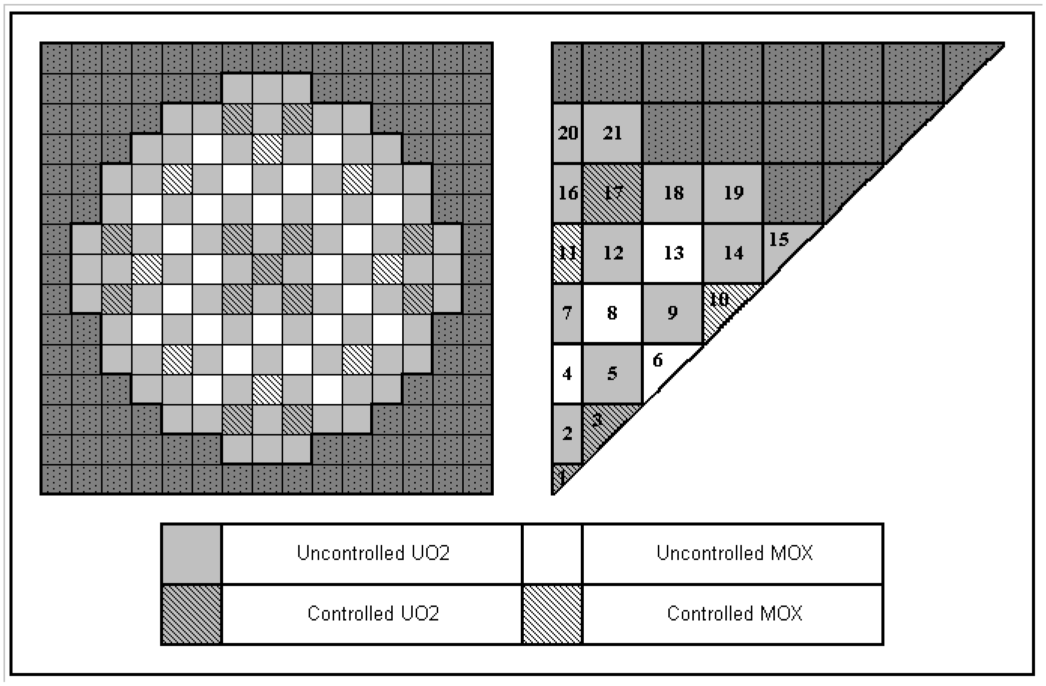


Figure 1: PWR Core Layout

The state parameters for the PWR core, used primarily in cross-section generation, are based on several different sources. See Table I for complete state parameters.

Table I. PWR State parameters

Number of Fuel Assemblies	121
Specific Power Level [3]	34.8 W/g
Fuel Temperature [5]	900 K
Moderator / Structure Temperature	600 K
Number of Control Rods / Guide Tubes	24 per Assembly
Assembly Pitch	21.42 cm

2.1.2. Assembly configuration

Both primary types of assembly used in this problem are based on the C5G7 model; however, that model used a simplistic pin cell to generate homogenized cross-sections. Each assembly consists of a 17x17 square lattice of pin cells, with 24 guide tubes/control rods evenly spaced throughout, and one central guide tube, as in Figure 2. In order to test codes for realistic reactor problems, spatial homogenization is not necessarily desired; thus, in the current PWR problem, each pin cell is composed of a square, 1.26 cm in width, filled with moderator. Centered in the pin cell is a circular pin of fuel, surrounded by zirconium cladding.

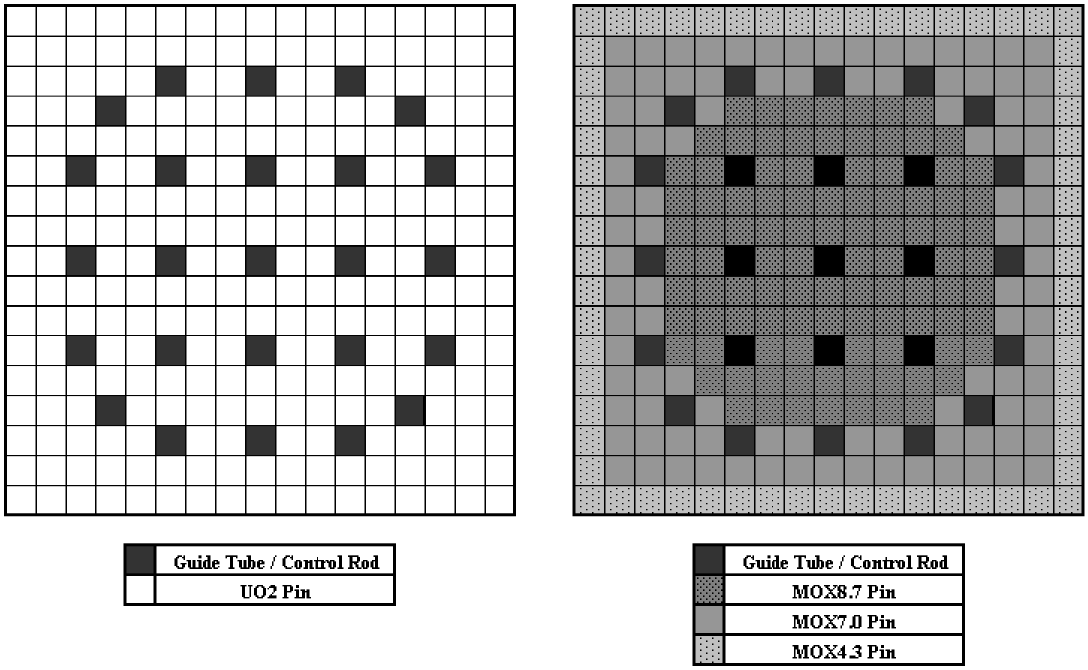


Figure 2: PWR Fuel Assemblies (UO2 Left, MOX Right)

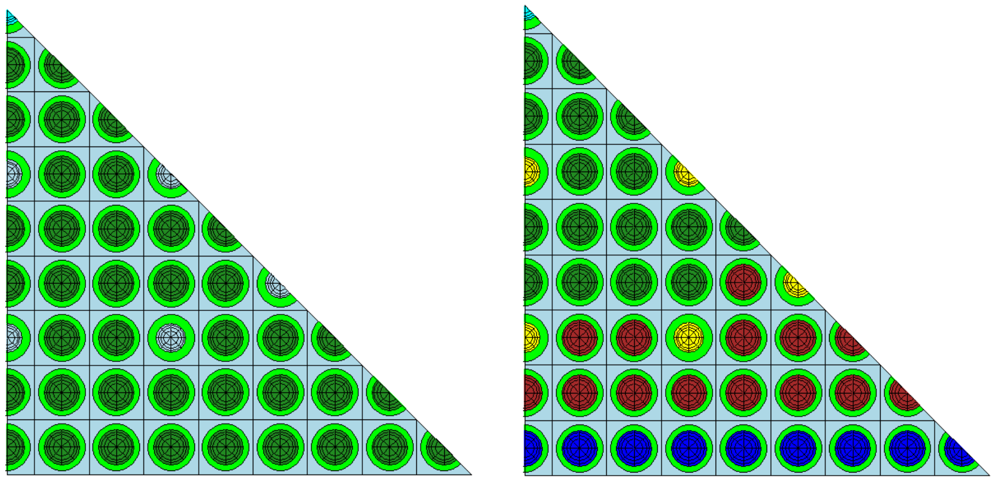
The guide tubes are composed of an annular region of zirconium, filled with moderator in the uncontrolled case and with natural boron (19.8at% B-10, 80.2at% B-11) in the controlled case. The UO_2 assemblies consist of a single type of fuel, but the MOX assemblies consist of 3 different enrichments of MOX fuel. To simulate the effects of a fission chamber in the central tube, a small amount of U-235 is added to the moderator in the center guide tube. Material compositions for each region are in Appendix A. Geometric parameters for the PWR assemblies are presented in Table II.

Table II. PWR Assembly Parameters

Number of Fuel Pins / Assembly	264
Fuel Pin Radius	0.4095 cm
Fuel Pin Clad Radius	0.54 cm
Guide Tube / Control Rod Radius	0.34 cm
Guide Tube / Control Rod Clad Radius	0.54 cm
Pin Pitch	1.26 cm

2.2. Cross Section Generation

The PWR problem was treated with a standard 2-level nodal approach, whereby 47-group transport calculations are performed for the single assemblies. These calculations are used to generate 2-group cross sections for each material region. These are then used to solve the whole core. In this paper, the single assembly calculations were performed by modeling the single assembly types with the lattice depletion code HELIOS [6]. The assemblies were modeled using 1/8th symmetry and specular reflective boundary conditions on all sides (see Figure 3).



(a) (b)

Figure 3: UO2 (a) and MOX-C (b) Cross-Section Generation Models

HELIOS was used to generate cross sections using typical PWR 2,4, and 8 group structures[5], presented in Table III. The 2-group cross sections are presented in Appendix B; however, for brevity, higher group structures are not presented in this paper.

Table III. Energy Group Structure

2-Group	4-Group	8-Group	Lower Energy Bound (eV)
1	1	1	2.2313E+06
		2	8.2085E+05
		3	9.1188E+03
	2	4	1.3007E+02
		5	3.9279E+00
	3	6	6.2506E-01
2	4	7	1.4572E-01
		8	1.0000E-04

2.3. Reference Calculations

The problem was run on a 160-core computer cluster with 1 billion neutron histories, using the multi-group option and the cross section library presented in Appendix B; nominally 250,000 particles were simulated in each cycle, with 4000 cycles run (200 inactive for source convergence). Tallies were made for the average energy-integrated fission density in all fission producing pins and the average absorption density for the control pins. All tallies passed the MCNP statistical checks. Due to the large number of fuel pins present in each assembly of the PWR model, the only results presented are the assembly average fission density for each assembly, as well as peaking effects in each assembly. The results of the calculation are presented in Table IV, wherein assembly indices correspond to the layout from Figure 1. The presented fission densities are produced by normalizing the 1/8th symmetry tally result $\overline{f_i}$ to the number of fission producing assemblies in the entire core (121) as in Eq. 1.

$$F_i = \frac{\overline{f_i} \cdot 121}{8 \cdot \sum_i \overline{f_i}} \tag{1}$$

Results are also presented for the average absorption rate of the control pins in each controlled assembly as a fraction of the average assembly fission density in the core as in Eq. 2

$$A_i = \frac{\overline{a}_i}{\overline{\overline{F}}} \tag{2}$$

Because the reactor is composed of a very large number of fuel pins (31,944), presenting results for each pin is neither practical nor particularly instructive. It is often desired, however, to gain a measure of understanding of the peaking effect within a reactor assembly. For this reason, the ratio of peak pin fission density to the assembly average is presented for each assembly. In order to gain a thorough understanding of the statistical uncertainty present in the pin fission density distribution, three separate methods are used to provide aggregate uncertainty estimates [1]. In Eqs. 3-5, e_n is the percent uncertainty of the fission density f_n.

$$AVG = \frac{\sum_N |e_n|}{N} \tag{3}$$

$$RMS = \sqrt{\frac{\sum_N e_n^2}{N}} \tag{4}$$

$$MRE = \frac{\sum_N |e_n| \cdot f_n}{N \cdot f_{avg}} \tag{5}$$

Table IV. PWR Reference Results

Eigenvalue Results						
Eigenvalue		1.00294		%Unc[2]	0.002	
Fuel Assembly Average Results						
Assy Index	Avg Fiss. Density	% Unc		Assy Index	Avg Fiss. Density	% Unc
1	1.32696	0.02		11	0.64198	0.03
2	1.26056	0.01		12	0.63137	0.01
3	1.17479	0.01		13	0.57631	0.02
4	1.01979	0.02		14	0.49659	0.01
5	0.96942	0.01		15	0.51684	0.02
6	0.86092	0.01		16	0.52751	0.02
7	0.79443	0.02		17	0.50436	0.01
8	0.79185	0.02		18	0.49815	0.01
9	0.68828	0.01		19	0.48004	0.02
10	0.58829	0.03		20	0.37138	0.02
				21	0.40517	0.02
Control Rate Average Results						
Assy Index	Avg Abs. Rate	% Unc		Assy Index	Avg Abs. Rate	% Unc
1	0.22712	0.02		11	0.11089	0.02
3	0.20272	0.01		17	0.08605	0.01
10	0.10187	0.02				

Local Peaking Factors / Pin Fission Density Uncertainty Results					
Assy Index	Local Fiss Density Peaking	Average % Unc	RMS % Unc	MRE % Unc	Max % Unc
1	1.02771	0.06846	0.06949	0.06852	0.10
2	1.08897	0.06270	0.06318	0.06267	0.09
3	1.08125	0.06406	0.06461	0.06398	0.09
4	1.22886	0.09537	0.09602	0.09516	0.14
5	1.17396	0.06936	0.06940	0.06927	0.07
6	1.31093	0.10399	0.10459	0.10383	0.15
7	1.14716	0.07774	0.07833	0.07765	0.11
8	1.21958	0.10299	0.10310	0.10271	0.11
9	1.16497	0.08049	0.08055	0.08036	0.09
10	1.27656	0.12210	0.12305	0.12175	0.18
11	1.19484	0.11691	0.11767	0.11667	0.17
12	1.13076	0.08424	0.08439	0.08404	0.09
13	1.26072	0.12141	0.12155	0.12095	0.13
14	1.12269	0.09697	0.09712	0.09683	0.11
15	1.86015	0.11014	0.11089	0.10959	0.16

[2] % Unc is defined as (one relative standard uncertainty)*100.

16	1.10408	0.09854	0.09927	0.09830	0.14
17	1.16021	0.09576	0.09593	0.09533	0.11
18	1.51717	0.10159	0.10170	0.10149	0.11
19	1.77503	0.10928	0.10943	0.10877	0.12
20	1.18888	0.12518	0.12636	0.12451	0.19
21	1.68720	0.11898	0.11931	0.11778	0.13

3. BWR BENCHMARK PROBLEM

3.1. Benchmark Description

The BWR benchmark problem is composed of square assemblies, laid out in a geometry that is typical of boiling water reactor models, based upon the HAFAS core layout [7]. The HAFAS problem is only loosely heterogeneous, and does not present a benchmark problem that is realistic in geometry or scope. To improve upon this, the overall layout of the HAFAS core is used, but the assemblies are taken from work done on a GE9-based lattice [2], which is where the isotopic composition of most materials originates.

The BWR benchmark consists of a checkerboard layout of fresh (0 GWd/TU) and depleted (17 GWd/TU). One of the most important effects present in a BWR is coolant voiding in the reactor, and this is modeled by using voided coolant in the interior of fuel assemblies that are near the center of the reactor. As is characteristic of BWR assemblies, there is a complicated layout of fuel types within the assembly. Each assembly contains 12 different types of fuel, laid out as in Figure 4. The isotopic concentration of each material is presented in Appendix A. Control is maintained in the reactor by means of control blades[8] which are inserted in the larger gap between bundles of fuel assemblies. The control blades are composed of 72 control tubes in a steel sheath.

3.1.1. Core layout

The core is composed of 308 square fuel assemblies of length 15.24 cm, surrounded by assemblies of moderator, and then vacuum. The problem is simplified via implementing 1/8th symmetry, laid out as in Figure 4. Due to the presence of control blades in several assemblies, there are 8 distinct assembly types in the BWR problem:

1. Fresh, 00% Voiding (F00)
2. Fresh, 40% Voiding (F40)
3. Fresh, 70% Voiding (F70)
4. Fresh, Controlled (FC)
5. Depleted, 00% Voiding (D00)
6. Depleted, 40% Voiding (D40)
7. Depleted, 70% Voiding (D70)
8. Depleted, Controlled (DC)

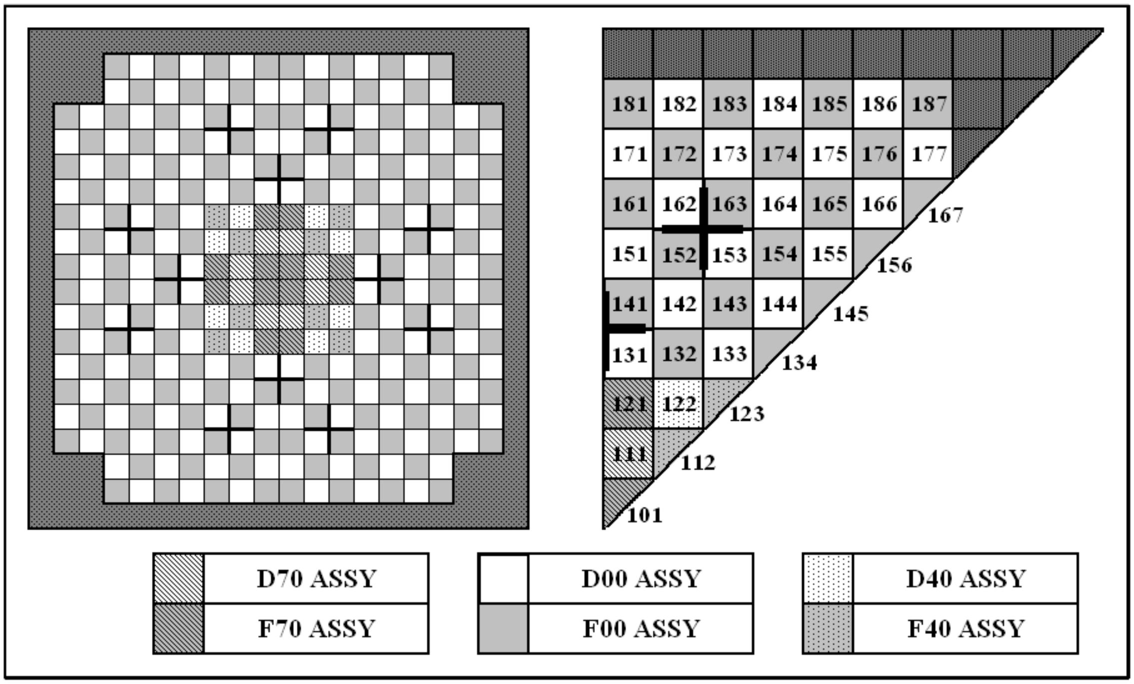


Figure 4: BWR Core Layout

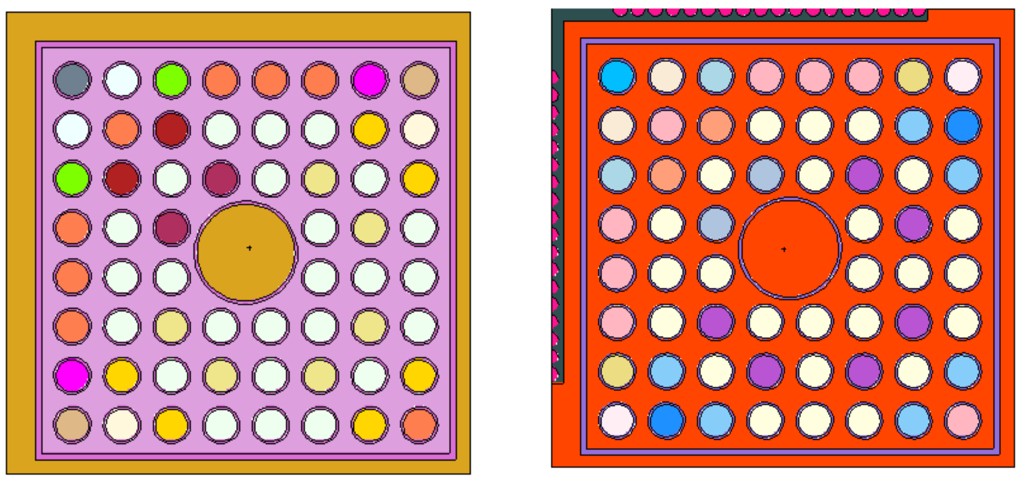
The state parameters for the BWR core, used primarily in cross-section generation, are based on the RACER model [2]. See Table I for complete state parameters.

Table V. BWR State parameters

Number of Fuel Assemblies		308
Specific Power Level [9]		25.6 W/g
Fuel Temperature		833 K
Moderator / Structure Temperature		600 K
Number of Control Rods \ Guide Tubes		16 Blades
Assembly Width		15.24 cm
Control Blade Specifications [8]	Sheath Half-Span	12.3825 cm
	Sheath Center-Cross Standoff	1.98501 cm
	Sheath Thickness	0.79248 cm
	Sheath Material	Stainless Steel 304
	Number of Control Tubes	72
	Control Tube Material	B4C
	Control Tube Radius	0.23876 cm
	Control Tube Pitch	0.57764 cm

3.1.2. Assembly configuration

All the assembly types in the BWR problem are composed of the same geometry and fuel layout; all that is varied between them is the burn-up and void parameters, as well as the presence of control blades. The basic geometry is from the RACER assembly, but that work was not focused on a whole-core problem, and the HAFAS that the core is based on was not focused at providing realistic assembly geometry. Each assembly is an 8x8 square lattice of fuel pin cells laid out as in Figure 5. Layout of specific fuels is present in Section 3.2.



(a) (b)

Figure 5: BWR Assembly Layout for an (a) uncontrolled case and a (b) controlled case.

For each type of assembly, the materials (atom densities) for most regions are the same. Void is handled by using different atom densities for the moderator (except the central water channel and inter-assembly gap, which are always 0% void). Burn-up is handled during cross-section generation by use of the HELIOS code. Table VI contains detailed specifications for the assembly geometry.

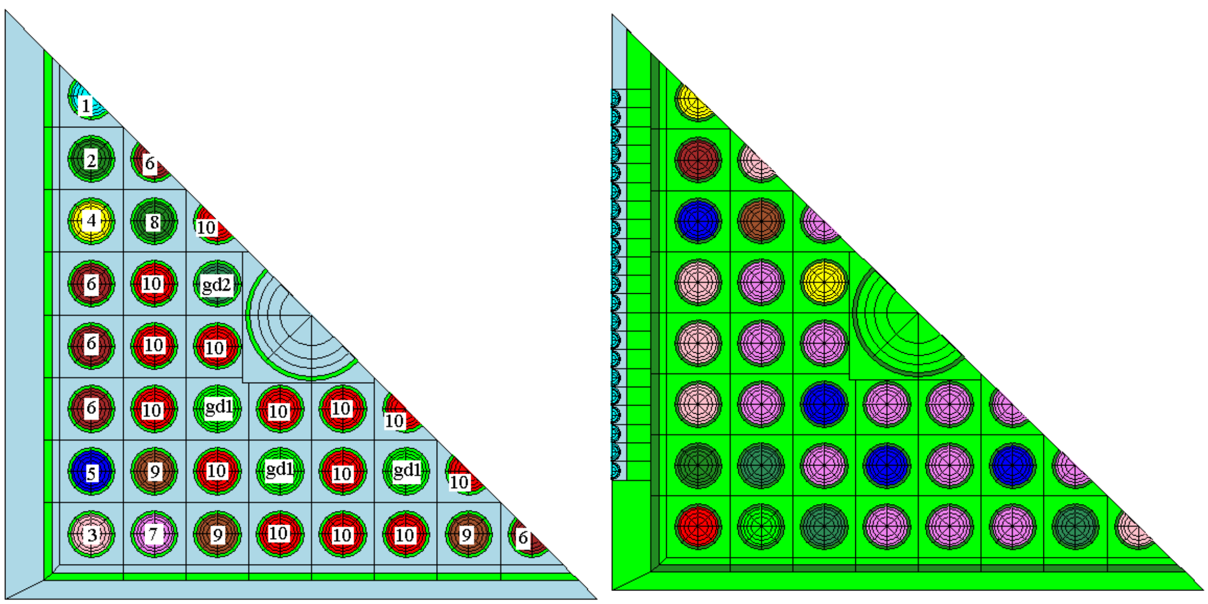
Table VI. BWR Assembly Parameters

Number of Fuel Pins	60	Pin Pitch	1.6256 cm
Fuel Pin Radius	0.53213 cm	Large Water Gap Thickness	0.9525 cm
Fuel Pin Clad Radius	0.61341 cm	Small Water Gap Thickness	0.47498 cm
Central Water Tube Radius	1.6002 cm	Zr Assembly Casing Thickness	0.2032 cm
Central Water Tube Clad Radius	1.7018 cm		

It is apparent in Figure 5 and in Table VI that the assembly casing is not centered in the assembly cell. The assemblies are oriented in the core such that they are always in groups of 4 with narrow gaps in between, and the control blades move through the large gaps. The presence of the control blades in the core design uniquely determines the orientation of all assemblies in the core.

3.2. Cross Section Generation

The BWR problem was also treated with a standard 2-level nodal approach, with 47-group transport calculations performed for the eight single assembly types. These calculations were used to generate 2-group cross sections for each material region. These were then used to solve the whole core. As in the PWR case, these calculations were performed by modeling the single assembly types with HELIOS. The assemblies were modeled using 1/8th symmetry and specular reflective boundary conditions on all sides (see Figure 6).



(a) **(b)**

Figure6: BWR HELIOS Cross Section Generation Model
(a) Uncontrolled, (b) Controlled

Cross sections were generated using the same 2, 4, and 8 group structures as in the PWR, presented in Table III. The 2-group BWR cross sections are presented in Appendix C; again, for brevity, higher group structures are not presented in this paper.

3.3. Reference Calculations

The BWR core was run on a 96-core computer cluster with 1 billion neutron histories, using the multi-group option and the cross section library presented in Appendix C; nominally 250,000 particles were simulated in each cycle, with 4000 cycles run (200 inactive for source convergence). Tallies were made for the average energy-integrated fission density in all fission producing pins. All tallies passed the MCNP statistical checks. Due to the large number of fuel pins present in the core, as in the PWR case, the only results presented are the assembly average fission density for each assembly, as well as peaking effects in each assembly. The results of the calculation are presented in Table VII, wherein assembly indices correspond to the layout from Figure 4. The results presented are the same as in the PWR case, with the same normalization method and uncertainty estimates.

Table VII. BWR Reference Results

Eigenvalue Results						
Eigenvalue		0.99489		%UNC[3]	0.002	
Fuel Assembly Average Results						
Assy Index	Avg Fiss. Density	% UNC		Assy Index	Avg Fiss. Density	% UNC
111	1.02196	0.02		161	0.62061	0.01
112	1.34195	0.01		162	0.37847	0.01
121	0.99394	0.02		163	0.66273	0.02
122	1.21898	0.01		164	1.01436	0.01
123	1.41874	0.01		165	1.34715	0.01
131	0.75637	0.01		166	1.17865	0.01
132	1.40328	0.02		167	1.04240	0.02
133	1.53810	0.02		171	0.48538	0.01
134	1.86461	0.01		172	0.53081	0.01
141	0.57001	0.02		173	0.58837	0.02
142	0.98303	0.03		174	0.86111	0.01
143	1.43169	0.01		175	0.88907	0.01
144	1.55414	0.01		176	0.91827	0.01
145	1.74780	0.02		177	0.66543	0.02
151	0.62053	0.01		181	0.36989	0.02
152	0.53749	0.02		182	0.34913	0.03
153	0.72079	0.01		183	0.45284	0.02
154	1.40754	0.01		184	0.48517	0.01
155	1.47734	0.02		185	0.58575	0.01
156	1.59401	0.03		186	0.48040	0.02
				187	0.39175	0.02

Local Peaking Factors / Pin Fission Density Uncertainty Results					
Assy Index	Local Fiss Density Peaking	Average % Unc	RMS % Unc	MRE % Unc	Max % Unc
111	1.12309	0.08183	0.08201	0.08178	0.09000
112	1.34546	0.08152	0.08332	0.08364	0.12000
121	1.29017	0.08000	0.08068	0.08155	0.09000
122	1.16601	0.07900	0.07933	0.07866	0.09000
123	1.30659	0.08000	0.08213	0.08034	0.13000
131	1.59914	0.10850	0.10963	0.10449	0.15000
132	1.38098	0.08017	0.08100	0.08136	0.10000
133	1.14240	0.07500	0.07517	0.07514	0.08000

[3] % Unc is defined as (one relative standard uncertainty)*100.

134	1.28548	0.07636	0.07804	0.07851	0.12000
141	1.80313	0.12250	0.12417	0.12219	0.15000
142	1.28102	0.09367	0.09432	0.09237	0.11000
143	1.43043	0.07967	0.08048	0.08072	0.10000
144	1.17519	0.07417	0.07440	0.07393	0.08000
145	1.26082	0.07970	0.08174	0.08066	0.13000
151	1.18093	0.11733	0.11756	0.11736	0.13000
152	1.84875	0.12717	0.12931	0.12562	0.16000
153	1.82387	0.11417	0.11564	0.10842	0.16000
154	1.42272	0.08033	0.08120	0.08140	0.10000
155	1.15070	0.07667	0.07681	0.07674	0.08000
156	1.33327	0.08212	0.08365	0.08392	0.12000
161	1.29243	0.12167	0.12291	0.12383	0.15000
162	1.45633	0.15267	0.15337	0.14980	0.18000
163	1.92049	0.11467	0.11662	0.11323	0.16000
164	1.25474	0.09233	0.09292	0.09132	0.11000
165	1.34134	0.08217	0.08312	0.08354	0.10000
166	1.21748	0.08517	0.08551	0.08485	0.10000
167	1.41708	0.10333	0.10636	0.10246	0.17000
171	1.20724	0.13333	0.13354	0.13335	0.15000
172	1.27956	0.13000	0.13107	0.13269	0.16000
173	1.31825	0.12117	0.12133	0.12118	0.13000
174	1.49190	0.10317	0.10430	0.10492	0.13000
175	1.26355	0.09867	0.09888	0.09847	0.11000
176	1.51099	0.09917	0.10002	0.10143	0.12000
177	1.35119	0.11500	0.11550	0.11373	0.13000
181	1.46082	0.16033	0.16243	0.16060	0.21000
182	1.28796	0.15850	0.15961	0.15628	0.19000
183	1.55691	0.14367	0.14552	0.14388	0.18000
184	1.33177	0.13450	0.13563	0.13199	0.16000
185	1.53840	0.12717	0.12907	0.12655	0.17000
186	1.37548	0.13567	0.13672	0.13298	0.16000
187	1.56220	0.15850	0.16145	0.15463	0.22000

4. CONCLUSIONS

In this paper, two whole-core two-dimensional benchmark problems have been developed. One is typical of a BWR core based on the HAFAS model with GE9 fuel bundles. The other is typical of a PWR with MOX and UO_2 fuel assemblies based on the C5G7 benchmark problem and a core layout that is based on a 2-loop Westinghouse design. The results presented are intended to serve as a method for validating new codes and methods, using the cross-sections presented in this paper. These cross sections have been developed using standard methods and industry codes. They should be sufficient for the validation of a transport method. Further cross sections have been developed for other group structures, and both benchmark problems are in the process of being extended to three dimensional configuration.

5. ACKNOWLEDGEMENTS

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APPENDIX A: Material Compositions

BWR Material Number Densities (10^24 at/cm^3)

Nuclide	Fuel 01	Fuel 02	Fuel 03	Fuel 04	Fuel 05
U-234	3.1503E-06	4.0177E-06	4.4514E-06	4.8851E-06	5.3189E-06
U-235	3.6369E-04	4.5461E-04	5.0007E-04	5.4553E-04	5.9099E-04
U-238	2.2081E-02	2.1991E-02	2.1945E-02	2.1900E-02	2.1854E-02
O	4.4896E-02	4.4898E-02	4.4899E-02	4.4900E-02	4.4901E-02

	Fuel 06	Fuel 07	Fuel 08	Fuel 09	Fuel 10
U-234	5.7526E-06	6.1863E-06	7.4874E-06	7.9211E-06	8.2406E-06
U-235	6.3645E-04	6.8190E-04	8.1828E-04	8.6374E-04	8.9783E-04
U-238	2.1809E-02	2.1764E-02	2.1628E-02	2.1582E-02	2.1548E-02
O	4.4902E-02	4.4903E-02	4.4907E-02	4.4908E-02	4.4908E-02

	Fuel 11 (gd1)	Fuel 12 (gd2)		H	O-16
U-234	7.8127E-06	7.0985E-06	Water at 600 K, No Void		
U-235	8.5120E-04	7.7578E-04		4.9316E-02	2.4658E-02
U-238	2.0429E-02	2.0504E-02	Water at 600 K, 40% Void		
O	4.4558E-02	4.4556E-02		3.0588E-02	1.5294E-02
Gd-154	2.8746E-05	2.8746E-05	Water at 600 K, 70% Void		
Gd-155	1.9550E-04	1.9550E-04		1.6542E-02	8.2712E-03
Gd-156	2.7045E-04	2.7045E-04	Zirconium Cladding		
Gd-157	2.0677E-04	2.0677E-04		Nat Zr	4.3239E-02
Gd-158	3.2819E-04	3.2819E-04			
Gd-160	2.9121E-04	2.9121E-04			

Stainless Steel (wt %), 8.03 g/cm^3

Nat Fe	70.351	Nat. Cr	19.152	Nat. Ni	8.483	Nat. Mn	2.014

PWR Material Number Densities (10^24 at/cm^3)

	MOX 4.3% Inner	MOX 7.0% Middle	MOX 8.7% Outer	UO2	Moderator	Center Tube	Zr Clad
U-235	5.00E-05	5.00E-05	5.00E-05	8.65E-04		1.00E-08	
U-238	2.21E-02	2.21E-02	2.21E-02	2.23E-02			
Pu-238	1.50E-05	2.40E-05	3.00E-05				
Pu-239	5.80E-04	9.30E-04	1.16E-03				
Pu-240	2.40E-04	3.90E-04	4.90E-04				
Pu-241	9.80E-05	1.52E-04	1.90E-04				
Pu-242	5.40E-05	8.40E-05	1.05E-04				
Am-241	1.30E-05	2.00E-05	2.50E-05				
O	4.63E-02	4.63E-02	4.63E-02	4.62E-02			
H2O					3.35E-02	3.35E-02	
Nat B						2.78E-05	
Nat Zr							4.30E-02

Control Material in guide tubes is composed of Natural Boron (19.8% B-10, 80.2% B-11 by number)

APPENDIX B: PWR Macroscopic Cross Sections

Controlled UO2 Assembly								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Moderator	g1	1.29631E-01	9.84635E-05	-	-	g1	3.02536E-01	2.28650E-03
	g2	5.15357E-01	3.25954E-03	-	-	g2	9.04664E-03	7.62723E-01
Zr Clad	g1	2.96310E-01	1.92397E-03	-	-	g1	3.31730E-01	1.75563E-03
	g2	2.75943E-01	3.45009E-03	-	-	g2	1.88926E-04	2.73206E-01
Center Tube	g1	1.30444E-01	3.10528E-04	8.11686E-08	1.98323E-07	g1	3.03738E-01	2.12040E-03
	g2	5.40408E-01	1.29818E-02	2.40427E-06	5.85151E-06	g2	9.34638E-03	7.77483E-01
UO2	g1	3.89886E-01	2.52426E-02	8.00406E-03	2.01444E-02	g1	4.06058E-01	3.97919E-03
	g2	6.57948E-01	2.62557E-01	1.90221E-01	4.62963E-01	g2	5.39801E-04	4.00209E-01
Control Tube	g1	1.44125E-02	1.92397E-03	-	-	g1	4.99075E-03	4.96400E-05
	g2	4.52495E-01	3.45009E-03	-	-	g2	1.94780E-05	6.12523E-03
Uncontrolled UO2 Assembly								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Moderator	g1	1.28965E-01	1.00356E-04	-	-	g1	3.00428E-01	2.10585E-03
	g2	5.25973E-01	3.33891E-03	-	-	g2	9.27199E-03	7.72970E-01
Zr Clad	g1	2.94760E-01	1.90051E-03	-	-	g1	3.30502E-01	1.60545E-03
	g2	2.76086E-01	3.54400E-03	-	-	g2	1.97829E-04	2.73401E-01
Center Tube	g1	1.29626E-01	3.13642E-04	8.08780E-08	1.97638E-07	g1	3.01288E-01	1.98398E-03
	g2	5.47684E-01	1.31873E-02	2.44687E-06	5.95519E-06	g2	9.51298E-03	7.84383E-01
UO2	g1	3.88178E-01	2.52597E-02	8.05974E-03	2.03004E-02	g1	4.04593E-01	3.67897E-03
	g2	6.64494E-01	2.68861E-01	1.95156E-01	4.74971E-01	g2	5.61796E-04	4.00647E-01
Guide Tube	g1	1.29233E-01	1.90051E-03	-	-	g1	3.01032E-01	1.98690E-03
	g2	5.38084E-01	3.54400E-03	-	-	g2	9.43337E-03	7.84512E-01
Controlled MOX Assembly								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Moderator	g1	1.26587E-01	8.35467E-05	-	-	g1	2.99539E-01	4.13410E-03
	g2	4.81155E-01	2.99884E-03	-	-	g2	5.48968E-03	7.28052E-01
Zr Clad	g1	2.96237E-01	1.93861E-03	-	-	g1	3.32788E-01	3.43195E-03
	g2	2.75588E-01	3.19332E-03	-	-	g2	8.23235E-05	2.71448E-01
Center Tube	g1	1.26359E-01	2.36151E-04	6.96481E-08	1.70351E-07	g1	2.98400E-01	3.75175E-03
	g2	5.01315E-01	1.18658E-02	2.15569E-06	5.24652E-06	g2	5.52271E-03	7.39257E-01
MOX8.7	g1	4.06507E-01	3.58288E-02	1.14166E-02	3.29391E-02	g1	4.15603E-01	9.91168E-03
	g2	1.76150E+00	1.36389E+00	7.70455E-01	2.21078E+00	g2	1.83469E-04	3.96476E-01

MOX7.0	g1	4.02387E-01	3.34123E-02	9.89347E-03	2.84674E-02	g1	4.12825E-01	9.11694E-03
	g2	1.52835E+00	1.13381E+00	6.39841E-01	1.83519E+00	g2	2.08244E-04	3.94181E-01
MOX4.3	g1	3.92926E-01	2.79809E-02	7.21733E-03	2.06410E-02	g1	4.07556E-01	8.18040E-03
	g2	1.15186E+00	7.61853E-01	4.27054E-01	1.22334E+00	g2	2.28498E-04	3.90556E-01
Guide Tube	g1	1.17388E-02	1.93861E-03	-	-	g1	4.95711E-03	9.07140E-05
	g2	4.16246E-01	3.19332E-03	-	-	g2	8.11419E-06	6.06855E-03
Uncontrolled MOX Assembly								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Moderator	g1	1.26392E-01	8.57752E-05	-	-	g1	2.98712E-01	3.98608E-03
	g2	4.87406E-01	3.04569E-03	-	-	g2	5.74617E-03	7.34138E-01
Zr Clad	g1	2.95169E-01	1.92791E-03	-	-	g1	3.31775E-01	3.27659E-03
	g2	2.75680E-01	3.25377E-03	-	-	g2	8.89930E-05	2.71632E-01
Center Tube	g1	1.26162E-01	2.40812E-04	7.01451E-08	1.71569E-07	g1	2.97620E-01	3.72329E-03
	g2	5.03462E-01	1.19262E-02	2.16779E-06	5.27596E-06	g2	5.71263E-03	7.41278E-01
MOX8.7	g1	4.06405E-01	3.66025E-02	1.15940E-02	3.34525E-02	g1	4.14833E-01	9.48830E-03
	g2	1.77245E+00	1.37477E+00	7.78203E-01	2.23319E+00	g2	1.99836E-04	3.96964E-01
MOX7.0	g1	4.02152E-01	3.40277E-02	1.00267E-02	2.88518E-02	g1	4.12087E-01	8.76708E-03
	g2	1.53624E+00	1.14162E+00	6.45376E-01	1.85119E+00	g2	2.23714E-04	3.94608E-01
MOX4.3	g1	3.92149E-01	2.81939E-02	7.28304E-03	2.08296E-02	g1	4.06771E-01	8.08220E-03
	g2	1.15112E+00	7.61079E-01	4.26973E-01	1.22313E+00	g2	2.38985E-04	3.90692E-01
Guide Tube	g1	1.26500E-01	1.92791E-03	-	-	g1	2.98788E-01	3.62200E-03
	g2	4.98523E-01	3.25377E-03	-	-	g2	5.95916E-03	7.45057E-01

APPENDIX C: BWR Macroscopic Cross Sections

Uncontrolled BWR Assembly (0 MWd/TU, 0% Void)								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Water, No Void	g1	2.77725E-01	3.38697E-04	-	-	g1	6.32366E-01	1.38344E-03
	g2	1.41684E+00	9.27581E-03	-	-	g2	3.22384E-02	1.95192E+00
Zr Clad	g1	2.75815E-01	1.75357E-03	-	-	g1	3.10944E-01	3.91447E-04
	g2	2.79226E-01	4.60415E-03	-	-	g2	3.58035E-04	2.76672E-01
Fuel 1	g1	3.57847E-01	2.57937E-02	6.13908E-03	1.60349E-02	g1	3.75343E-01	7.64567E-04
	g2	5.52136E-01	1.67750E-01	1.08788E-01	2.64767E-01	g2	9.55812E-04	3.92018E-01
Fuel 2	g1	3.53974E-01	2.55389E-02	6.80896E-03	1.76979E-02	g1	3.72739E-01	8.34132E-04
	g2	5.82929E-01	1.98224E-01	1.34082E-01	3.26330E-01	g2	8.94817E-04	3.92276E-01
Fuel 3	g1	3.56768E-01	2.67203E-02	7.19534E-03	1.86279E-02	g1	3.74023E-01	8.83124E-04
	g2	5.98221E-01	2.13346E-01	1.46627E-01	3.56862E-01	g2	8.97957E-04	3.92401E-01
Fuel 4	g1	3.52892E-01	2.60877E-02	7.47316E-03	1.93363E-02	g1	3.71625E-01	8.97113E-04
	g2	6.13386E-01	2.28335E-01	1.59053E-01	3.87103E-01	g2	8.59174E-04	3.92567E-01
Fuel 5	g1	3.53158E-01	2.66078E-02	7.83219E-03	2.02185E-02	g1	3.71437E-01	9.27645E-04
	g2	6.28551E-01	2.43321E-01	1.71459E-01	4.17297E-01	g2	8.53831E-04	3.92720E-01
Fuel 6	g1	3.53166E-01	2.68325E-02	8.12580E-03	2.09317E-02	g1	3.71319E-01	9.66653E-04
	g2	6.43209E-01	2.57801E-01	1.83525E-01	4.46664E-01	g2	8.38520E-04	3.92859E-01
Fuel 7	g1	3.53709E-01	2.73520E-02	8.47806E-03	2.17955E-02	g1	3.71362E-01	1.03784E-03
	g2	6.56773E-01	2.71224E-01	1.94827E-01	4.74170E-01	g2	8.32246E-04	3.92936E-01
Fuel 8	g1	3.50943E-01	2.75402E-02	9.32435E-03	2.38890E-02	g1	3.69199E-01	1.12773E-03
	g2	6.99278E-01	3.13187E-01	2.29839E-01	5.59381E-01	g2	7.89085E-04	3.93398E-01
Fuel 9	g1	3.53914E-01	2.86994E-02	9.72932E-03	2.48604E-02	g1	3.70570E-01	1.18276E-03
	g2	7.13507E-01	3.27225E-01	2.41536E-01	5.87851E-01	g2	7.98763E-04	3.93532E-01
Fuel 10	g1	3.55304E-01	2.90252E-02	9.95070E-03	2.53899E-02	g1	3.71386E-01	1.35571E-03
	g2	7.19110E-01	3.32826E-01	2.46917E-01	6.00945E-01	g2	7.90091E-04	3.93370E-01
Fuel 11 (gd1)	g1	3.71593E-01	4.03605E-02	9.41603E-03	2.39632E-02	g1	3.75039E-01	4.86289E-03
	g2	3.83844E+00	3.43846E+00	1.40255E-01	3.41352E-01	g2	7.80841E-04	4.03720E-01
Fuel 12 (gd2)	g1	3.73555E-01	4.07657E-02	8.97714E-03	2.28822E-02	g1	3.76185E-01	4.62325E-03
	g2	3.96572E+00	3.56521E+00	1.29433E-01	3.15013E-01	g2	8.11233E-04	4.04496E-01
Uncontrolled BWR Assembly (0 MWd/TU, 40% Void)								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Water, No	g1	2.85520E-01	3.43445E-04	-	-	g1	6.50982E-01	1.36969E-03

Void	g2	1.42648E+00	9.34675E-03	-	-	g2	3.41028E-02	1.96100E+00
Water, 40% Void	g1	1.70193E-01	1.96757E-04	-	-	g1	3.88691E-01	1.16351E-03
	g2	8.48426E-01	5.52773E-03	-	-	g2	1.82161E-02	1.18167E+00
Zr Clad	g1	2.77602E-01	2.79106E-01	-	-	g1	3.12898E-01	4.76693E-04
	g2	2.79106E-01	4.52573E-03	-	-	g2	3.39761E-04	2.76548E-01
Fuel 1	g1	3.60309E-01	2.54546E-02	6.00170E-03	1.56433E-02	g1	3.77589E-01	9.14958E-04
	g2	5.49411E-01	1.65222E-01	1.06999E-01	2.60414E-01	g2	3.77589E-01	3.91675E-01
Fuel 2	g1	3.56183E-01	2.50617E-02	6.66854E-03	1.72988E-02	g1	3.74861E-01	9.99284E-04
	g2	5.79271E-01	1.94789E-01	1.31576E-01	3.20229E-01	g2	8.75095E-04	3.91894E-01
Fuel 3	g1	3.59357E-01	2.63255E-02	7.03993E-03	1.81897E-02	g1	3.76433E-01	1.05960E-03
	g2	5.94285E-01	2.09630E-01	1.43883E-01	3.50183E-01	g2	8.70344E-04	3.92010E-01
Fuel 4	g1	3.55050E-01	2.55848E-02	7.32653E-03	1.89218E-02	g1	3.73728E-01	1.07230E-03
	g2	6.09003E-01	2.24182E-01	1.55950E-01	3.79551E-01	g2	8.40058E-04	3.92167E-01
Fuel 5	g1	3.55455E-01	2.61014E-02	7.67518E-03	1.97766E-02	g1	3.73670E-01	1.10881E-03
	g2	6.23897E-01	2.38894E-01	1.68121E-01	4.09173E-01	g2	8.30833E-04	3.92317E-01
Fuel 6	g1	3.55292E-01	2.62759E-02	7.96488E-03	2.04812E-02	g1	3.73470E-01	1.15511E-03
	g2	6.38026E-01	2.52857E-01	1.79773E-01	4.37531E-01	g2	8.16018E-04	3.92439E-01
Fuel 7	g1	3.56050E-01	2.67801E-02	8.30406E-03	2.13103E-02	g1	3.73691E-01	1.25252E-03
	g2	6.50513E-01	2.65232E-01	1.90285E-01	4.63115E-01	g2	8.05943E-04	3.92460E-01
Fuel 8	g1	3.52744E-01	2.68123E-02	9.15325E-03	2.34121E-02	g1	3.71170E-01	1.35408E-03
	g2	6.91027E-01	3.05241E-01	2.23715E-01	5.44477E-01	g2	7.71546E-04	3.92875E-01
Fuel 9	g1	3.55969E-01	2.79821E-02	9.52430E-03	2.42992E-02	g1	3.72800E-01	1.42807E-03
	g2	7.05129E-01	3.19138E-01	2.35294E-01	5.72658E-01	g2	7.69765E-04	3.93011E-01
Fuel 10	g1	3.56648E-01	2.81135E-02	9.71245E-03	2.47518E-02	g1	3.73188E-01	1.63311E-03
	g2	7.09364E-01	3.23407E-01	2.39631E-01	5.83212E-01	g2	7.57170E-04	3.92770E-01
Fuel 11 (gd1)	g1	3.70628E-01	3.86583E-02	9.13045E-03	2.32267E-02	g1	3.75748E-01	5.34854E-03
	g2	3.51497E+00	3.11705E+00	1.36469E-01	3.32138E-01	g2	7.36057E-04	4.01163E-01
Fuel 12 (gd2)	g1	3.72665E-01	3.92479E-02	8.73599E-03	2.22581E-02	g1	3.76794E-01	5.05106E-03
	g2	3.67301E+00	3.27437E+00	1.26338E-01	3.07480E-01	g2	7.71166E-04	4.02194E-01
Uncontrolled BWR Assembly (0 MWd/TU, 70% Void)								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Water, No Void	g1	2.86147E-01	3.29635E-04	-	-	g1	6.54244E-01	1.61688E-03
	g2	1.40643E+00	9.19741E-03	-	-	g2	3.26677E-02	1.94176E+00
Water, 70% Void	g1	9.20104E-02	1.01547E-04	-	-	g1	2.10653E-01	7.52045E-04
	g2	4.48156E-01	2.90997E-03	-	-	g2	9.33716E-03	6.28834E-01

Zr Clad	g1	2.79684E-01	1.78244E-03	-	-	g1	3.15170E-01	5.78201E-04
	g2	2.78963E-01	4.43241E-03	-	-	g2	3.19709E-04	2.76399E-01
Fuel 1	g1	3.62681E-01	2.49826E-02	5.84490E-03	1.52025E-02	g1	3.79896E-01	1.08825E-03
	g2	5.46377E-01	1.62407E-01	1.05009E-01	2.55572E-01	g2	9.01519E-04	3.91289E-01
Fuel 2	g1	3.58156E-01	2.44118E-02	6.50183E-03	1.68339E-02	g1	3.76955E-01	1.18930E-03
	g2	5.75189E-01	1.90955E-01	1.28782E-01	3.13431E-01	g2	8.47675E-04	3.91463E-01
Fuel 3	g1	3.61484E-01	2.57185E-02	6.85400E-03	1.76785E-02	g1	3.78695E-01	1.26213E-03
	g2	5.89945E-01	2.05532E-01	1.40858E-01	3.42819E-01	g2	8.33359E-04	3.91572E-01
Fuel 4	g1	3.56892E-01	2.48887E-02	7.14982E-03	1.84320E-02	g1	3.75758E-01	1.27301E-03
	g2	6.04141E-01	2.19575E-01	1.52511E-01	3.71180E-01	g2	8.13859E-04	3.91720E-01
Fuel 5	g1	3.57329E-01	2.53731E-02	7.48145E-03	1.92451E-02	g1	3.75775E-01	1.31563E-03
	g2	6.18827E-01	2.34070E-01	1.64485E-01	4.00323E-01	g2	7.99054E-04	3.91869E-01
Fuel 6	g1	3.56945E-01	2.54843E-02	7.76415E-03	1.99335E-02	g1	3.75443E-01	1.36949E-03
	g2	6.32370E-01	2.47459E-01	1.75677E-01	4.27563E-01	g2	7.85729E-04	3.91971E-01
Fuel 7	g1	3.57780E-01	2.59396E-02	8.08238E-03	2.07095E-02	g1	3.75794E-01	1.49745E-03
	g2	6.43589E-01	2.58605E-01	1.85261E-01	4.50888E-01	g2	7.70300E-04	3.91924E-01
Fuel 8	g1	3.53985E-01	2.58406E-02	8.93986E-03	2.28319E-02	g1	3.72894E-01	1.60677E-03
	g2	6.81881E-01	2.96438E-01	2.16929E-01	5.27961E-01	g2	7.47845E-04	3.92290E-01
Fuel 9	g1	3.57303E-01	2.69568E-02	9.25662E-03	2.35862E-02	g1	3.74733E-01	1.70520E-03
	g2	6.95966E-01	3.10294E-01	2.28466E-01	5.56042E-01	g2	7.32139E-04	3.92421E-01
Fuel 10	g1	3.57256E-01	2.69050E-02	9.41715E-03	2.39753E-02	g1	3.74777E-01	1.93736E-03
	g2	6.98927E-01	3.13322E-01	2.31817E-01	5.64196E-01	g2	7.18201E-04	3.92118E-01
Fuel 11 (gd1)	g1	3.69283E-01	3.66952E-02	8.80560E-03	2.23925E-02	g1	3.76350E-01	5.82055E-03
	g2	3.22539E+00	2.82932E+00	1.32962E-01	3.23602E-01	g2	6.89092E-04	3.98835E-01
Fuel 12 (gd2)	g1	3.71553E-01	3.75455E-02	8.46915E-03	2.15676E-02	g1	3.77356E-01	5.46127E-03
	g2	3.40730E+00	3.01035E+00	1.23472E-01	3.00506E-01	g2	7.31026E-04	4.00087E-01
Uncontrolled BWR Assembly (17 GWd/TU, 0% Void)								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Water, No Void	g1	2.77732E-01	3.43107E-04	-	-	g1	6.33083E-01	1.31525E-03
	g2	1.42731E+00	9.35348E-03	-	-	g2	3.19844E-02	1.96188E+00
Zr Clad	g1	2.75803E-01	1.76162E-03	-	-	g1	3.10627E-01	3.77864E-04
	g2	2.79267E-01	4.63045E-03	-	-	g2	3.57790E-04	2.76699E-01
Fuel 1	g1	3.64424E-01	3.12221E-02	4.74642E-03	1.30440E-02	g1	3.75907E-01	7.28672E-04
	g2	5.65220E-01	1.83287E-01	9.03643E-02	2.45166E-01	g2	9.34494E-04	3.89569E-01
Fuel 2	g1	3.59951E-01	2.99905E-02	5.12467E-03	1.39698E-02	g1	3.73518E-01	7.83314E-04

	g2	5.83852E-01	2.01773E-01	1.04722E-01	2.80210E-01	g2	8.74791E-04	3.89666E-01
Fuel 3	g1	3.62962E-01	3.12325E-02	5.34245E-03	1.45014E-02	g1	3.74898E-01	8.30717E-04
	g2	5.96592E-01	2.14489E-01	1.13980E-01	3.03753E-01	g2	8.83958E-04	3.89643E-01
Fuel 4	g1	3.58594E-01	3.00071E-02	5.52021E-03	1.49398E-02	g1	3.72534E-01	8.33137E-04
	g2	6.04361E-01	2.22149E-01	1.20319E-01	3.18591E-01	g2	8.43553E-04	3.89754E-01
Fuel 5	g1	3.58946E-01	3.03831E-02	5.71784E-03	1.54261E-02	g1	3.72497E-01	8.61144E-04
	g2	6.14565E-01	2.32313E-01	1.27892E-01	3.37370E-01	g2	8.41082E-04	3.89767E-01
Fuel 6	g1	3.58419E-01	3.02843E-02	5.93417E-03	1.59478E-02	g1	3.72205E-01	8.92829E-04
	g2	6.26288E-01	2.43915E-01	1.37099E-01	3.59920E-01	g2	8.24445E-04	3.89860E-01
Fuel 7	g1	3.58864E-01	3.06353E-02	6.23542E-03	1.66895E-02	g1	3.72296E-01	9.60118E-04
	g2	6.41108E-01	2.58605E-01	1.48704E-01	3.88777E-01	g2	8.18722E-04	3.89927E-01
Fuel 8	g1	3.54784E-01	2.99464E-02	6.88708E-03	1.82833E-02	g1	3.69725E-01	1.02165E-03
	g2	6.73855E-01	2.90961E-01	1.74959E-01	4.52210E-01	g2	7.71911E-04	3.90265E-01
Fuel 9	g1	3.57614E-01	3.11108E-02	7.17187E-03	1.89789E-02	g1	3.70992E-01	1.08332E-03
	g2	6.88388E-01	3.05419E-01	1.85755E-01	4.79522E-01	g2	7.82507E-04	3.90281E-01
Fuel 10	g1	3.57492E-01	3.10921E-02	7.63964E-03	2.01223E-02	g1	3.70940E-01	1.23063E-03
	g2	7.08918E-01	3.25662E-01	2.03307E-01	5.22941E-01	g2	7.67502E-04	3.90427E-01
Fuel 11 (gd1)	g1	3.61268E-01	3.41864E-02	8.84952E-03	2.30046E-02	g1	3.71519E-01	2.33501E-03
	g2	1.22565E+00	8.47082E-01	2.27433E-01	5.87053E-01	g2	7.57572E-04	3.84661E-01
Fuel 12 (gd2)	g1	3.62662E-01	3.44478E-02	8.43578E-03	2.20012E-02	g1	3.72354E-01	2.08562E-03
	g2	1.18642E+00	8.08276E-01	2.13574E-01	5.53148E-01	g2	7.89150E-04	3.84482E-01
Uncontrolled BWR Assembly (17 GWd/TU, 40% Void)								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Water, No Void	g1	2.85687E-01	3.47908E-04	-	-	g1	6.51865E-01	1.35816E-03
	g2	1.43057E+00	9.37695E-03	-	-	g2	3.40055E-02	1.96486E+00
Water, 40% Void	g1	1.69950E-01	1.98021E-04	-	-	g1	3.88903E-01	1.12517E-03
	g2	8.58217E-01	5.60023E-03	-	-	g2	1.77601E-02	1.19095E+00
Zr Clad	g1	2.77510E-01	1.77423E-03	-	-	g1	3.12583E-01	4.72715E-04
	g2	2.79148E-01	4.55245E-03	-	-	g2	3.35421E-04	2.76566E-01
Fuel 1	g1	3.66594E-01	3.09768E-02	4.74613E-03	1.30385E-02	g1	3.77881E-01	9.03713E-04
	g2	5.77564E-01	1.95879E-01	9.81688E-02	2.67549E-01	g2	8.97608E-04	3.89152E-01
Fuel 2	g1	3.61774E-01	2.95298E-02	5.12312E-03	1.39561E-02	g1	3.75358E-01	9.74979E-04
	g2	5.95901E-01	2.14063E-01	1.12463E-01	3.02312E-01	g2	8.41169E-04	3.89240E-01
Fuel 3	g1	9.74979E-04	3.08723E-02	5.36603E-03	1.45540E-02	g1	3.76950E-01	1.03556E-03
	g2	3.89240E-01	2.29107E-01	1.23321E-01	3.30233E-01	g2	8.42438E-04	3.89221E-01

Fuel 4	g1	3.60413E-01	2.95295E-02	5.52001E-03	1.49284E-02	g1	3.74381E-01	1.03542E-03
	g2	6.16683E-01	2.34704E-01	1.28236E-01	3.41199E-01	g2	8.10833E-04	3.89325E-01
Fuel 5	g1	3.60845E-01	2.98852E-02	5.72630E-03	1.54355E-02	g1	3.74446E-01	1.07089E-03
	g2	6.27777E-01	2.45746E-01	1.36458E-01	3.61699E-01	g2	8.04770E-04	3.89344E-01
Fuel 6	g1	3.60168E-01	2.97385E-02	5.94318E-03	1.59583E-02	g1	3.74066E-01	1.10997E-03
	g2	6.39264E-01	2.57113E-01	1.45509E-01	3.83847E-01	g2	7.88912E-04	3.89426E-01
Fuel 7	g1	3.60665E-01	3.00467E-02	6.27398E-03	1.67733E-02	g1	3.74257E-01	1.20868E-03
	g2	6.56005E-01	2.73709E-01	1.58661E-01	4.16749E-01	g2	7.78612E-04	3.89479E-01
Fuel 8	g1	3.56407E-01	2.92179E-02	6.89262E-03	1.82780E-02	g1	3.71595E-01	1.28034E-03
	g2	6.85426E-01	3.02773E-01	1.82545E-01	4.73944E-01	g2	7.41927E-04	3.89775E-01
Fuel 9	g1	3.59292E-01	3.04061E-02	7.21159E-03	1.90626E-02	g1	3.72952E-01	1.36578E-03
	g2	7.03305E-01	3.20529E-01	1.95780E-01	5.07723E-01	g2	7.41860E-04	3.89813E-01
Fuel 10	g1	3.58778E-01	3.02639E-02	7.64803E-03	2.01298E-02	g1	3.72769E-01	1.54482E-03
	g2	7.22170E-01	3.39152E-01	2.11954E-01	5.47818E-01	g2	7.25904E-04	3.89885E-01
Fuel 11 (gd1)	g1	3.61647E-01	3.30970E-02	8.65650E-03	2.25308E-02	g1	3.72768E-01	2.82809E-03
	g2	1.21439E+00	8.36222E-01	2.31250E-01	6.00897E-01	g2	7.09662E-04	3.83779E-01
Fuel 12 (gd2)	g1	3.63237E-01	3.35630E-02	8.27244E-03	2.16084E-02	g1	3.73576E-01	2.47756E-03
	g2	1.17468E+00	7.96925E-01	2.18711E-01	5.70392E-01	g2	7.45794E-04	3.83697E-01
Uncontrolled BWR Assembly (17 GWd/TU, 70% Void)								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Water, No Void	g1	2.86045E-01	3.32627E-04	-	-	g1	6.54784E-01	1.63944E-03
	g2	1.40944E+00	9.21952E-03	-	-	g2	3.23061E-02	1.94457E+00
Water, 70% Void	g1	9.17974E-02	1.01652E-04			g1	2.10708E-01	7.49876E-04
	g2	4.53700E-01	2.95094E-03	-	-	g2	8.98030E-03	6.34058E-01
Zr Clad	g1	2.79499E-01	1.78807E-03	-	-	g1	3.14845E-01	5.88595E-04
	g2	2.79006E-01	4.45980E-03			g2	3.11447E-04	2.76404E-01
Fuel 1	g1	3.68511E-01	3.05524E-02	4.76220E-03	1.30784E-02	g1	3.79816E-01	1.11209E-03
	g2	5.92304E-01	2.10879E-01	1.07528E-01	2.94286E-01	g2	8.53852E-04	3.88691E-01
Fuel 2	g1	3.63218E-01	2.88420E-02	5.12804E-03	1.39611E-02	g1	3.77090E-01	1.20387E-03
	g2	6.09758E-01	2.28175E-01	1.21383E-01	3.27715E-01	g2	8.00347E-04	3.88763E-01
Fuel 3	g1	1.20387E-03	3.02660E-02	5.39923E-03	1.46361E-02	g1	3.78820E-01	1.28008E-03
	g2	3.88763E-01	2.46123E-01	1.34184E-01	3.60995E-01	g2	7.92717E-04	3.88748E-01
Fuel 4	g1	3.61784E-01	2.87992E-02	5.52159E-03	1.49234E-02	g1	3.76094E-01	1.27651E-03
	g2	6.30615E-01	2.48887E-01	1.37186E-01	3.66718E-01	g2	7.71235E-04	3.88841E-01
Fuel 5	g1	3.62179E-01	2.91145E-02	5.73561E-03	1.54502E-02	g1	3.76185E-01	1.32033E-03

	g2	6.42792E-01	2.60989E-01	1.46175E-01	3.89259E-01	g2	7.60219E-04	3.88874E-01
Fuel 6	g1	3.61354E-01	2.89030E-02	5.94522E-03	1.59537E-02	g1	3.75741E-01	1.36806E-03
	g2	6.53648E-01	2.71732E-01	1.54794E-01	4.10265E-01	g2	7.45985E-04	3.88942E-01
Fuel 7	g1	3.61842E-01	2.91473E-02	6.29865E-03	1.68247E-02	g1	3.76006E-01	1.50754E-03
	g2	6.72211E-01	2.90144E-01	1.69390E-01	4.47000E-01	g2	7.30445E-04	3.88962E-01
Fuel 8	g1	3.57307E-01	2.81641E-02	6.86803E-03	1.81987E-02	g1	3.73142E-01	1.58567E-03
	g2	6.96603E-01	3.14229E-01	1.89719E-01	4.94774E-01	g2	7.05592E-04	3.89200E-01
Fuel 9	g1	3.60225E-01	2.93407E-02	7.21510E-03	1.90573E-02	g1	3.74644E-01	1.70336E-03
	g2	7.18549E-01	3.35992E-01	2.05856E-01	5.36303E-01	g2	6.93246E-04	3.89266E-01
Fuel 10	g1	3.59272E-01	2.90593E-02	7.60088E-03	1.99988E-02	g1	3.74195E-01	1.91215E-03
	g2	7.34661E-01	3.51919E-01	2.19839E-01	5.70923E-01	g2	6.77790E-04	3.89254E-01
Fuel 11 (gd1)	g1	3.61421E-01	3.16402E-02	8.40962E-03	2.19185E-02	g1	3.73837E-01	3.38173E-03
	g2	1.20213E+00	8.24357E-01	2.33897E-01	6.11475E-01	g2	6.57030E-04	3.82836E-01
Fuel 12 (gd2)	g1	3.63231E-01	3.23438E-02	3.23438E-02	2.11113E-02	g1	3.74594E-01	2.90647E-03
	g2	1.16174E+00	7.84399E-01	7.84399E-01	5.85666E-01	g2	6.99186E-04	3.82867E-01
Controlled BWR Assembly (0 MWd/TU, 0% Void)								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Water, No Void	g1	2.78452E-01	3.38730E-04	-	-	g1	6.34518E-01	1.69105E-03
	g2	1.38966E+00	9.07358E-03	-	-	g2	3.21568E-02	1.92590E+00
Zr Clad	g1	2.78244E-01	1.79019E-03	-	-	g1	3.12583E-01	4.89278E-04
	g2	2.79072E-01	4.50430E-03	-	-	g2	3.59809E-04	2.76523E-01
B4C	g1	1.13705E-02	8.26778E-03	-	-	g1	3.35729E-03	1.16450E-05
	g2	3.09650E-01	3.05554E-01	-	-	g2	2.48511E-05	4.34735E-03
SS304	g1	5.64491E-01	5.36495E-03	-	-	g1	5.94530E-01	2.13999E-03
	g2	1.00690E+00	1.40458E-01	-	-	g2	1.54060E-03	8.76174E-01
Fuel 1	g1	3.69087E-01	2.67635E-02	5.92868E-03	1.53620E-02	g1	3.83227E-01	1.11401E-03
	g2	5.45925E-01	1.61937E-01	1.05055E-01	2.55683E-01	g2	9.79871E-04	3.91280E-01
Fuel 2	g1	3.65425E-01	2.67691E-02	6.69671E-03	1.72782E-02	g1	3.80506E-01	1.16946E-03
	g2	5.76081E-01	1.91743E-01	1.29763E-01	3.15816E-01	g2	9.35162E-04	3.91581E-01
Fuel 3	g1	3.63960E-01	2.76558E-02	7.17968E-03	1.85016E-02	g1	3.78695E-01	1.00331E-03
	g2	5.95816E-01	2.11071E-01	1.44966E-01	3.52819E-01	g2	9.44156E-04	3.92154E-01
Fuel 4	g1	3.64010E-01	2.73935E-02	7.42674E-03	1.90855E-02	g1	3.79065E-01	1.23854E-03
	g2	6.05419E-01	2.20738E-01	1.53849E-01	3.74439E-01	g2	9.01480E-04	3.91865E-01
Fuel 5	g1	3.61192E-01	2.76263E-02	7.83282E-03	2.01208E-02	g1	3.76714E-01	1.11953E-03
	g2	6.23891E-01	2.38870E-01	1.68263E-01	4.09519E-01	g2	8.94098E-04	3.92322E-01

Fuel 6	g1	3.62422E-01	2.80091E-02	8.13741E-03	2.08468E-02	g1	3.77433E-01	1.24170E-03
	g2	6.36090E-01	2.50977E-01	1.78690E-01	4.34896E-01	g2	8.77488E-04	3.92295E-01
Fuel 7	g1	3.60257E-01	2.82920E-02	8.52640E-03	2.18339E-02	g1	3.75556E-01	1.12875E-03
	g2	6.54703E-01	2.69245E-01	1.93224E-01	4.70267E-01	g2	8.75558E-04	3.92756E-01
Fuel 8	g1	3.60871E-01	2.90516E-02	9.47438E-03	2.41407E-02	g1	3.75494E-01	1.40774E-03
	g2	6.91117E-01	3.05297E-01	2.24116E-01	5.45453E-01	g2	8.44285E-04	3.92853E-01
Fuel 9	g1	3.59448E-01	2.95376E-02	9.81452E-03	2.50013E-02	g1	3.74089E-01	1.26654E-03
	g2	7.11280E-01	3.25082E-01	2.39665E-01	5.83297E-01	g2	8.33820E-04	3.93373E-01
Fuel 10	g1	3.61206E-01	2.99410E-02	1.00559E-02	2.55766E-02	g1	3.75094E-01	1.46408E-03
	g2	7.16138E-01	3.29959E-01	2.44506E-01	5.95077E-01	g2	8.26596E-04	3.93151E-01
Fuel 11 (gd1)	g1	3.77536E-01	4.16657E-02	9.50789E-03	2.41281E-02	g1	3.78520E-01	4.98951E-03
	g2	3.75875E+00	3.35930E+00	1.39281E-01	3.38982E-01	g2	8.14635E-04	4.03061E-01
Fuel 12 (gd2)	g1	3.81495E-01	4.26297E-02	9.10627E-03	2.31204E-02	g1	3.80695E-01	4.92463E-03
	g2	3.77938E+00	3.38010E+00	1.27342E-01	3.09925E-01	g2	8.58824E-04	4.02956E-01
Controlled BWR Assembly (17 GWd/TU, 0% Void)								
Material		Σtr	Σa	Σf	υΣf	Σgg'	g1	g2
Water, No Void	g1	2.78048E-01	3.41794E-04	-	-	g1	6.34435E-01	1.62895E-03
	g2	1.40081E+00	9.15626E-03	-	-	g2	3.16606E-02	1.93649E+00
Zr Clad	g1	2.78136E-01	1.79579E-03	-	-	g1	3.12265E-01	4.80165E-04
	g2	2.79113E-01	4.53080E-03	-	-	g2	3.56678E-04	2.76545E-01
B4C	g1	1.13509E-02	8.25013E-03	-	-	g1	3.35582E-03	1.17132E-05
	g2	3.10570E-01	3.06473E-01	-	-	g2	2.44170E-05	4.34808E-03
SS304	g1	5.65025E-01	5.36823E-03	-	-	g1	5.95250E-01	2.16603E-03
	g2	1.00723E+00	1.40759E-01	-	-	g2	1.51879E-03	8.76173E-01
Fuel 1	g1	3.73558E-01	3.16721E-02	5.05112E-03	1.37103E-02	g1	3.82789E-01	1.15592E-03
	g2	5.94180E-01	2.12126E-01	1.13935E-01	3.06990E-01	g2	9.31617E-04	3.89281E-01
Fuel 2	g1	3.69836E-01	3.10064E-02	5.47675E-03	1.47621E-02	g1	3.80458E-01	1.19432E-03
	g2	6.12072E-01	2.29870E-01	1.27696E-01	3.40238E-01	g2	8.91199E-04	3.89395E-01
Fuel 3	g1	3.70420E-01	3.25677E-02	5.33297E-03	1.44439E-02	g1	3.79525E-01	9.62922E-04
	g2	6.04905E-01	2.22948E-01	1.19345E-01	3.19174E-01	g2	9.22351E-04	3.89370E-01
Fuel 4	g1	3.68455E-01	3.12414E-02	5.93410E-03	1.58904E-02	g1	3.79266E-01	1.24271E-03
	g2	6.33197E-01	2.50849E-01	1.43757E-01	3.79720E-01	g2	8.64459E-04	3.89497E-01
Fuel 5	g1	3.66899E-01	3.16575E-02	5.86462E-03	1.57445E-02	g1	3.77617E-01	1.07376E-03
	g2	6.29773E-01	2.47566E-01	1.39207E-01	3.67868E-01	g2	8.70595E-04	3.89518E-01
Fuel 6	g1	3.67007E-01	3.15899E-02	6.26264E-03	1.67066E-02	g1	3.77846E-01	1.20739E-03

	g2	6.48527E-01	2.66110E-01	1.54575E-01	4.06027E-01	g2	8.48216E-04	3.89600E-01
Fuel 7	g1	3.65804E-01	3.19777E-02	6.17208E-03	1.65054E-02	g1	3.76506E-01	1.06020E-03
	g2	6.44914E-01	2.62633E-01	1.50034E-01	3.94171E-01	g2	8.56487E-04	3.89607E-01
Fuel 8	g1	3.64455E-01	3.16784E-02	7.27895E-03	1.91920E-02	g1	3.75817E-01	1.36479E-03
	g2	6.94329E-01	3.11392E-01	1.91236E-01	4.95154E-01	g2	8.12964E-04	3.89977E-01
Fuel 9	g1	3.63922E-01	3.23464E-02	7.08406E-03	1.87397E-02	g1	3.74797E-01	1.17118E-03
	g2	6.89497E-01	3.06809E-01	1.84537E-01	4.78750E-01	g2	8.15674E-04	3.89914E-01
Fuel 10	g1	3.63778E-01	3.23318E-02	7.61266E-03	2.00344E-02	g1	3.74803E-01	1.34958E-03
	g2	7.12126E-01	3.29119E-01	2.03807E-01	5.26599E-01	g2	7.99239E-04	3.90064E-01
Fuel 11 (gd1)	g1	3.66688E-01	3.53072E-02	8.85216E-03	2.30063E-02	g1	3.74733E-01	2.39633E-03
	g2	1.19802E+00	8.19820E-01	2.30158E-01	5.96744E-01	g2	7.85664E-04	3.84228E-01
Fuel 12 (gd2)	g1	3.70092E-01	3.60584E-02	8.54946E-03	2.22604E-02	g1	3.76707E-01	2.35252E-03
	g2	1.17577E+00	7.97901E-01	2.17546E-01	5.66239E-01	g2	8.28366E-04	3.83935E-01