STYLIZED WHOLE-CORE BENCHMARK OF THE INTEGRAL INHERENTLY SAFE LIGHT WATER REACTOR (I²S-LWR) CONCEPT

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ABSTRACT

The Integral, Inherently Safe Light Water Reactor (I²S-LWR) is a pressurized water reactor (PWR) concept under development by a multi-institutional team led by Georgia Tech. The core is similar in size to small 2-loop PWRs while having the power level of current large reactors (~1000 MWe) but using uranium silicide fuel and advanced stainless steel cladding. A stylized benchmark specification of the I²S-LWR core has been developed in order to test whole-core neutronics codes and methods. For simplification the core was split into 57 distinct material regions for cross section generation. Cross sections were generated using the lattice physics code HELIOS version 1.10 in both 8 and 47 groups. Monte Carlo solutions, including eigenvalue and pin fission densities, were generated for the 8 group library using MCNP5. Due to space limitations in this paper, the full cross section library and normalized pin fission density results are provided in the journal's electronic repository.

Keywords: PWR benchmark problems, neutronics, whole-core transport

1. Introduction

The Integral, Inherently Safe light water reactor (I²S-LWR) [1] is a new pressurized water reactor concept that leverages the enhanced safety of small modular reactors while maintaining the same power level (~1000 MWe) of current reactors. Enhanced safety is obtained through an integral primary circuit, which provides inherent safety features, and a new fuel/clad system with enhanced accident tolerance. The size of the core is similar to that of 2-loop PWR designs while having the power of a 4-loop design. Due to its smaller size, the I²S-LWR operates at a higher power density than current commercial reactors. In order to facilitate the higher power density, a new 19x19 assembly was developed [2]. The I²S-LWR also has a stainless steel neutron reflector to decrease neutron leakage.

In order to test codes and methods it is important to have robust computational benchmarks that are representative of operational reactors. These benchmarks should be large and heterogeneous on both the assembly and core level in order to capture the physics of new and current reactor designs. In order to be useable, these benchmarks must also be simple enough to allow for easy

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implementation and testing. The I²S-LWR core concept was stylized in order to be converted into a benchmark that is useable while maintaining some of the physics of the problem.

This benchmark problem is based on the original I²S-LWR equilibrium core (enrichment, reloading patterns, geometry, etc.), developed by Westinghouse [2,3]. Using the original equilibrium core design, the lattice depletion code HELIOS version 1.10 [4] was used to generate nuclear data for each unique assembly region. These assembly regions differ with fuel enrichment and in the number of pins with Integral Fuel Burnable Absorber (IFBA). The nuclear data generated from HELIOS were then used in PARCS [5] to re-generate the equilibrium core initially developed by Westinghouse. The PARCS equilibrium core solutions [6] (temperature, burnup, boron concentrations, etc.) were then simplified into 57 unique regions to specify state parameters for the stylized I²S-LWR benchmark specification.

For each of the 57 unique regions of the I²S-LWR benchmark, 47 and 8 group cross sections were generated for each unique material in a unique pin cell using HELIOS version 1.10. The cross section generation used each region's state parameters (temperatures, densities, isotopic concentrations) in the equilibrium core solution generated by PARCS as they changed throughout the cycle. Cross sections representative of 10 days into the equilibrium cycle were then used in the stochastic radiation transport code MCNP5 [7] to generate whole-core solutions for both core eigenvalue and pin powers. Eigenvalue results are presented for both 47 and 8 group solutions. It was found that the 8 group results were similar to the 47 group results. For this reason, region averaged fission densities are presented only for the 8 group solution. Due to space limitations, a selected set of pin fission densities are presented. The detailed 8 group pin fission density results as well as the 8 group cross sections can be found in the journal's online repository.

2. Core specification

The layout of the I²S-LWR core is consistent with those of 2-loop PWRs. The core is made up of 121 assemblies laid out in a 13 x 13 Cartesian grid. The core uses a 19x19 pin fuel assembly design in order to enable a higher power density. The design includes silicide fuel (U₃Si₂) which is denser than uranium oxide fuels and allows for a greater uranium loading within the core. The fuel cladding is an advanced stainless steel (APMT), used to provide a greater accident tolerance though at the expense of neutron utilization. Some core parameters are presented in Table 1, and the isotopic composition used for the APMT steel is located in Table 2. Four unique assembly types are present in the design which vary in their enrichment as well as in the number of pins with integral fuel burnable absorber (IFBA) coating. The four assembly types are as follows: 4.45% enriched fuel with 85 IFBA pins, 4.45% with 156 IFBA, 4.65% with 84 IFBA, and 4.65% with 100 IFBA. The I²S-LWR concept uses a three batch reloading scheme with a very low leakage pattern. The low leakage loading pattern can be seen in Figure 1 with a more detailed quarter core depiction in Figure 4.

Figure 1. Radial core loading pattern with the burnup of fuel assemblies noted. Fresh fuel assemblies are labeled FD (feed).

Table 1. P^2S -LWR core parameters.

Parameter	Value
Number of fuel assemblies	121
Specific power level	39.1 W/g
Fuel Density	11.56 g/cm ³
Cladding Density (APMT)	7.25 g/cm ³
Assembly pitch	23.1 Cm
IFBA loading	2.505 mg ¹⁰ B/in

Table 2. APMT cladding composition.

Material	Wt %
Chromium	22.00
Aluminum	5.80
Carbon	0.03
Silicon	0.40
Manganese	0.20
Iron	71.57

Axially, the fuel assemblies are divided into 5 unique regions, referred to as the top blanket, bottom blanket, top cutback, bottom cutback and central fuel region with IFBA. Figure 2 shows the axial layout of an assembly with dimensions. The top and bottom of the assembly are composed of a blanket region that has reduced fuel enrichment to decrease neutron leakage. The center of the assembly is composed of the fuel region where IFBA coating is present. The cutback regions between the center fuel region and blanket regions of the assembly have the same fuel compositions as the center fuel regions but have no IFBA coating (the IFBA coating is cut back in these regions).

Figure 2. Axial fuel assembly layout. Dashed lines indicate the discretization used in the simplified model.

The steel neutron reflector at the periphery of the core has been simplified for the I²S-LWR benchmark description. For the axial regions, a composition of 30% steel and 70% moderator by volume was assumed, while for the radial region a composition of 70% steel and 30% moderator by volume was used. The axial regions are located directly above and below the fuel assemblies

and extend 30 cm, while the radial reflector is assumed to extend one extra assembly spacing from the periphery of the core. The extent of the radial reflector can be seen in Figure 9.

3. Assembly specification

The I²S-LWR uses a new 19x19 pin assembly design. The assembly has 336 fuel pins and 25 guide/instrument tubes as laid out in Figure 3. Figure 3 also depicts the location of pins which have been coated with IFBA for each assembly type. Some notable features of this assembly design are its silicide (U₃Si₂) fuel, that is fabricated into an annular pellet, and that an advanced stainless steel (APMT) is used for the cladding. Table 3 summarizes the geometric parameters of the assembly. It should be noted that the thickness of the IFBA coating was chosen based on the limitations on the size of regions in HELIOS version 1.10, while preserving the linear ¹⁰B loading. Development of the I²S-LWR concept is ongoing, and thus its final core design may differ in details from the one described here. Still, this benchmark problem is useful for modeling the physics of the reactor and for numerical benchmarking of codes and methods for this novel reactor design, in particular its annular fuel is expected to be challenging to model for reactor physics codes.

Table 3. I²S-LWR benchmark assembly parameters.

Parameter	Value (cm)
Pin cell pitch	1.21056
Fuel pin cladding outer radius	0.45720
Fuel pin cladding inner radius	0.41656
Fuel pellet radius	0.40132
Fuel pellet inner void radius	0.12700
IFBA thickness	0.00150
Guide tube outer radius	0.55270
Guide tube inner radius	0.51537

Figure 3. Pin layouts for the I^2S -LWR assemblies. Each square cell represents one pin cell of the 19x19 assembly.

4. Methodology

The cross sections for the I^2S -LWR benchmark problem were generated through a multi-step procedure by simplifying the equilibrium cycle model. Equilibrium cycle state parameters throughout the entire cycle were generated using the PARCS neutronics code [6]. These parameters include thermohydraulic data, burnup data, and the soluble boron letdown curve throughout the cycle. The cross sections generated for this benchmark fully describe the heterogeneous core at 10 days into its equilibrium cycle, with all of the relevant state parameters built into the cross sections.

The fully detailed 3-batch I^2S -LWR equilibrium cycle loading pattern can be found in Figure 4. A map of the assembly-averaged burnups and the full cycle boron letdown curve can be found in Figures 5 and 7.

4.65% 84 IFBA 3x burned	4.45% 84 IFBA 1x burned	4.65% 100 IFBA 0x burned	4.45% 84 IFBA 2x burned	4.65% 84 IFBA 1x burned	4.65% 84 IFBA 0x burned	4.65% 84 IFBA 2x burned
4.45% 84 IFBA 1x burned	4.65% 100 IFBA 2x burned	4.45% 156 IFBA 1x burned	4.65% 84 IFBA 1x burned	4.45% 156 IFBA 0x burned	4.65% 84 IFBA 0x burned	4.45% 84 IFBA 2x burned
4.65% 100 IFBA 0x burned	4.45% 156 IFBA 1x burned	4.45% 84 IFBA 1x burned	4.45% 84 IFBA 1x burned	4.45% 84 IFBA 0x burned	4.45% 156 IFBA 2x burned	
4.45% 84 IFBA 2x burned	4.65% 84 IFBA 1x burned	4.45% 84 IFBA 1x burned	4.65% 100 IFBA 1x burned	4.45% 84 IFBA 0x burned	4.65% 84 IFBA 2x burned	
4.65% 84 IFBA 1x burned	4.45% 156 IFBA 0x burned	4.45% 84 IFBA 0x burned	4.45% 84 IFBA 0x burned	4.45% 84 IFBA 2x burned		
4.65% 84 IFBA 0x burned	4.65% 84 IFBA 0x burned	4.45% 156 IFBA 2x burned	4.65% 84 IFBA 2x burned			
4.65% 84 IFBA 2x burned	4.45% 84 IFBA 2x burned					

Key:

% U-235
IFBA pins
Times burned

Figure 4. Quarter-core representation of the I^2S -LWR core loading pattern. The top-left assembly is located at the center of the core.

The detailed core results cannot be used directly in the creation of a benchmark without simplification, as this would result in an intractably large problem with separate cross sections for each assembly in the core and for each of the 24 axial regions (from the equilibrium cycle calculation) of that assembly. Instead, some simplifications must be employed. The end result of these simplifications is that the benchmark problem is divided into 7 axial layers and 12 unique assembly types for a total of 54 unique fuel regions and 3 unique reflector regions. The simplification process will be described in more detail in the next section.

Once the total number of unique regions of the reactor was identified from the equilibrium cycle model, final macroscopic cross sections were recalculated using HELIOS version 1.10. Recalculation of the cross sections was necessary in order to capture the exact (simplified) state parameters from the equilibrium cycle calculation in the cross sections. Each of the 54 unique fuel regions of the core was depleted across multiple cycles using the state parameters at each time step.

5. Simplifications

Several simplifications were made to the core specification in order to result in a more tractable and useful benchmark problem. Where possible, the simplifications were made to cause minimal impact on the ability of the benchmark to preserve the physics of the I^2S -LWR core. The first simplification is that the benchmark is specified at 10 days into the equilibrium cycle. Picking a point in the equilibrium cycle establishes a baseline for the benchmark. The use of data from 10 days into the equilibrium cycle allows for equilibrium (or near-equilibrium) buildup of xenon and samarium in the core, allowing for the benchmark to be more readily duplicated with other depletion tools. The same methodology as described in this paper could just as easily be used to describe the benchmark at any other point in the equilibrium cycle.

Additionally, the single 3x burned assembly located at the center of the core (refer to Figure 1) has been replaced by a 2x burned assembly in this benchmark. This change significantly reduces the total number of cross sections required to describe the benchmark problem with only a minimal change in the physics of the core. The single 3x burned assembly is treated as twice burned, and the other assemblies that have been twice-burned have slightly-increased burnup values in order to conserve core burnup. Except for the 3x burned assembly, all assemblies with the same number of cycles burned and the same assembly type have had their state parameters averaged together. The simplification of assembly averaged burnup values is summarized by Figure 5. Figure 5 shows that this simplification of the assembly burnup values introduces only a 10% error in burnup in the center assembly.

Figure 5. Quarter-core depiction showing the effect of simplification of assembly-averaged burnup values of the beginning-of-cycle I^2S -LWR. The total core burnup is conserved in this simplification.

This benchmark problem was simplified by reducing the number of unique regions in the core while aiming to minimize the changes to the physics of the core. The first step of this process was to average all thermohydraulic properties from the equilibrium cycle model into axial layers. These axial layers were then collapsed from 24 layers to 7: one each for the top and bottom fuel blankets, one each for the top and bottom cutback regions, and three for the fuel regions with IFBA (marked ‘top’, ‘mid’, and ‘bot’). The dashed lines in Figure 2 show the relative sizes and positions of these axial regions. The use of three axial regions in the IFBA-fuel region is sufficient to capture the changing temperatures in that region without adding unnecessarily to the size of the cross section library. Dividing the thermohydraulic properties of the core into axial layers has the additional simplifying effect of reducing the number of cross sections needed for blanket and cutback regions of each assembly. This is because the geometry of the blanket region is identical for all four assembly types, meaning that with averaged thermohydraulic properties, all of the fuel blankets with the same burnup also have the same cross sections. This effect also reduces the number of cross sections needed for cutback regions by half.

All regions having the same thermohydraulic parameters, the same composition, and having been cycled through the core the same number of times have had their burnup values averaged together. For example, all regions that can be described as regions that have been burned once and that are the top third of the IFBA fuel region of a 4.45% enriched assembly with 156 IFBA pins are treated as having the same materials. This is reasonable because after applying the above simplifications for thermohydraulic parameters, the only difference between these regions are their burnup values, which are necessarily very similar. The effect of this change in assembly burnup can be seen in Figure 5. This simplification results in a maximum assembly-averaged burnup deviation between the equilibrium core calculation and the benchmark model of 10% and an average assembly-averaged burnup deviation of 5%, while reducing the size of the final cross section library by over 75%. The end result is that the benchmark description contains 54 unique fuel regions and 3 unique reflector regions. A list of each of the 57 total unique regions of the core, as well as the important parameters for each of those regions can be found in Table 4.

The design of the neutron reflector in the I²S-LWR concept has not been finalized as of the drafting of this paper. The basic design will be solid steel with axial cooling channels. In lieu of a finalized reflector design, a simplified design is assumed based on a best-estimate of 70% steel by volume radially, and the axial regions above and below the core are assumed to have 30% steel by volume. A description of the cross section generation procedure for the reflector model can be found in the following section. Thermohydraulic state parameters for the axial reflector cross sections were chosen to be identical to their nearest blanket regions, and the radial reflector uses state parameters from the reactor centerline.

6. Cross section generation

Multi-group cross sections for the I²S-LWR benchmark problem were generated for each of the 57 unique regions of the reactor described in Table 4 for both 47 and 8 energy groups using the 2-D transport lattice depletion code HELIOS version 1.10. The 54 regions containing fuel were modeled in HELIOS as shown in Figure 6. The geometry of each assembly was modeled exactly, including the center void of each pin and a 0.0015cm thick IFBA layer on appropriate pins.

Calculations for each region were performed using the temperatures and coolant densities found in Table 4. Depletion calculations were performed while updating the moderator boron concentration at each step to match the average boron concentration over each depletion step as obtained from the boron letdown curve of the equilibrium cycle. The equilibrium cycle boron letdown curve can be found in Figure 7[6]. Each region was depleted up to the burnup values found in Table 4.

Figure 6. 1/8th symmetry depiction of an I^2S -LWR fuel assembly as modeled in HELIOS. Fuel pins are modeled explicitly.

Table 4. Summary of the 57 unique regions modeled in the I^2S -LWR benchmark problem.

Region	Thermodynamic properties			Burnup (BOC + 10 days) [MWd/tU]		
	Coolant Temp. [K]	Coolant Density [g/cm ³]	Fuel Temp. [K]	0x burned	1x burned	2x burned
Blanket Top	596.9	0.665	648.0	174	5932	12447
Axial Reflector Top	596.9	0.665	-		-	
Blanket Bot	552.8	0.765	602.0	176	6281	12511
Axial Reflector Bot.	552.8	0.765	-		-	
4.45% Cutback Top	596.1	0.668	703.6	341	12185	24269
4.45% Cutback Bot.	553.9	0.763	669.0	393	15026	27653
4.65% Cutback Top	596.1	0.668	703.6	351	11993	25071
4.65% Cutback Bot.	553.9	0.763	669.0	412	14519	29362
4.45%, 84IFBA Top	589.7	0.686	748.9	486	17374	34548
4.45%, 84IFBA Mid	576.3	0.719	754.7	522	19190	36979

4.45%, 84IFBA Bot.	561.8	0.749	721.6	518	19314	36608
4.45%, 156IFBA Top	589.7	0.686	748.9	523	20074	36850
4.45%, 156IFBA Mid	576.3	0.719	754.7	562	22390	39341
4.45%, 156IFBA Bot.	561.8	0.749	721.6	557	22726	38903
4.65%, 84IFBA Top	589.7	0.686	748.9	514	17336	36769
4.65%, 84IFBA Mid	576.3	0.719	754.7	560	19345	39928
4.65%, 84IFBA Bot.	561.8	0.749	721.6	560	19592	39864
4.65%, 100IFBA Top	589.7	0.686	748.9	517	19718	36439
4.65%, 100IFBA Mid	576.3	0.719	754.7	547	20587	38639
4.65%, 100IFBA Bot.	561.8	0.749	721.6	538	20041	38053
Radial Reflector	576.3	0.719	-	-	-	-

Macroscopic cross sections were generated for each material inside the unique pin cells for each assembly region. For example, in one assembly region, all of the unique material cross sections for pin cells with IFBA pins are averaged together (flux weighted) to result in cross sections for fuel, IFBA, cladding, and coolant materials. For fuel pin cells without IFBA, cross sections are reported for fuel, cladding, and moderator. Guide tube cells have cross sections for both moderator and the cladding. Including reflector cross sections, there are a total of 417 materials in the I²S benchmark problem.

Figure 7. Boron letdown curve over the equilibrium cycle.

To generate the multi-group flux-averaged cross sections for the three reflector regions, HELIOS was used to model the fuel-reflector system shown in Figure 8. This model employs a full

assembly thick reflector next to a 4.65% enriched assembly with 100 IFBA pins. Reflected boundary conditions on all but the right side were used. The same geometric model was used for both the axial and radial reflector cross section calculations.

Figure 8. HELIOS model used for the I^2S -LWR reflector cross section calculations.

7. Results / discussion

To generate a reference solution to the I^2S -LWR model, the core was modeled in MCNP5 with $1/8^{\text{th}}$ symmetry using the 8 group cross sections as described in the previous sections. In order to provide a more detailed fission density distribution, each of the fuel regions with IFBA were further divided into 5 equal-length axial layers for tallying results. In all, there are 19 axial layers where fission density results are provided. A depiction of the MCNP model can be seen in Figure 9. The calculation was run with 13,000 inactive cycles with 1,000,000 particles per cycle for source convergence. Then fission density and eigenvalue results were calculated with 6,000 active cycles with 1,000,000 particles per cycle. The active cycles took approximately 200 hours on a 96 CPU cluster.

The eigenvalue results for the 47 and 8 group calculations can be found in Table 5. It was found that the 8 group results were similar to the results of the 47 group calculation, differing in the eigenvalue by only 17 pcm and in region-averaged fission densities by 3% on average. For simplicity, only the 8 group solutions and cross sections are presented.

Figure 9. MCNP core model (shown with 1/8th symmetry). Blue/gray regions indicate reflector.

Table 5. Eigenvalue results and standard deviation from the MCNP solution to the P^2S -LWR benchmark problem.

Group Structure	Eigenvalue	Standard Deviation
47g	1.01586	0.00001
8g	1.01603	0.00001

The fission density distribution of the core can be found in Figure 10. The assembly region pin fission densities can be found in Table 6 with the associated standard deviation as reported by MCNP in Table 7. The assembly-averaged fission density results are normalized to 2,299 -- the number of assembly regions in the core. In these tables the assembly indices refer to Figure 9 with the core levels as described in the simplification section. Selected pin fission density results and their associated standard deviation (which is multiplied by 100) are presented in Figures 11-14. These pin fission density results are normalized to 48,279, the number of pin regions in the core. The assembly regions selected for pin fission density results represent the regions with the highest and lowest fission density as well as a couple other select locations. A detailed pin fission density distribution as well as the 8 group cross sections used for this calculation can be found in the journal's online repository. Readers should be cautioned that although the MCNP results passed all statistical checks, the uncertainties reported often underestimate the actual uncertainty, especially in large reactor problems. There are specifically issues with guaranteeing that the fission source has been converged in large reactor problems with a dominance ratio close

to 1. Further analysis of the Monte Carlo convergence for the I^2S core is presented in a companion paper (reference 8). Due to these issues, Monte Carlo solutions are only provided for the reader's convenience as a point of comparison and as a demonstration of pin fission density and bundle-averaged fission density distributions.

Figure 10. Normalized 8 group pin fission density results for the I^2S -LWR benchmark.

Table 6. Assembly region 8-group normalized fission densities.

Assembly	1	2	3	4	5	6	7	8	9	10	11
Top Blanket	0.297	3.713	0.354	0.504	0.459	0.480	0.452	0.515	0.513	0.464	0.551
Top Cutback	0.597	7.838	0.716	1.182	0.976	1.030	0.899	1.122	1.107	1.028	1.196
Top Fuel 5	0.892	1.230	1.071	1.739	1.500	1.660	1.332	1.734	1.758	1.589	1.778
Top Fuel 4	0.972	1.338	1.168	1.865	1.633	1.830	1.421	1.861	1.913	1.725	1.851
Top Fuel 3	1.005	1.379	1.205	1.918	1.683	1.891	1.455	1.909	1.970	1.778	1.878
Top Fuel 2	0.985	1.351	1.182	1.884	1.656	1.866	1.430	1.882	1.950	1.763	1.850
Top Fuel 1	0.910	1.258	1.100	1.769	1.553	1.758	1.349	1.780	1.854	1.690	1.767
Middle Fuel 5	0.788	1.131	0.978	1.653	1.410	1.616	1.224	1.648	1.735	1.615	1.668
Middle Fuel 4	0.699	1.012	0.876	1.497	1.276	1.471	1.118	1.510	1.601	1.501	1.553
Middle Fuel 3	0.640	9.288	0.806	1.384	1.181	1.370	1.042	1.410	1.500	1.411	1.465
Middle Fuel 2	0.597	8.716	0.758	1.304	1.116	1.302	0.990	1.341	1.431	1.351	1.402
Middle Fuel 1	0.569	8.327	0.725	1.254	1.073	1.259	0.956	1.299	1.394	1.323	1.367
Bottom Fuel 5	0.555	8.246	0.717	1.257	1.070	1.266	0.957	1.309	1.415	1.359	1.389
Bottom Fuel 4	0.534	7.968	0.694	1.224	1.043	1.241	0.939	1.287	1.396	1.346	1.379
Bottom Fuel 3	0.511	7.663	0.670	1.186	1.011	1.206	0.919	1.260	1.366	1.320	1.366
Bottom Fuel 2	0.485	7.279	0.637	1.134	0.967	1.153	0.895	1.223	1.318	1.274	1.358
Bottom Fuel 1	0.442	6.712	0.584	1.077	0.898	1.056	0.861	1.170	1.236	1.196	1.363
Bottom Cutback	0.304	4.422	0.399	0.781	0.612	0.677	0.613	0.806	0.814	0.799	0.988
Bottom Blanket	0.154	2.089	0.200	0.325	0.289	0.316	0.312	0.370	0.377	0.357	0.454
	12	13	14	15	16	17	18	19	20	21	
Top Blanket	0.598	0.514	0.365	0.152	0.487	0.427	0.229	0.122	0.159	0.124	
Top Cutback	1.355	1.187	0.848	0.312	1.155	1.001	0.455	0.244	0.322	0.248	
Top Fuel 5	1.793	1.724	1.261	0.461	1.677	1.425	0.638	0.353	0.460	0.357	
Top Fuel 4	1.842	1.807	1.340	0.492	1.728	1.459	0.661	0.372	0.477	0.370	
Top Fuel 3	1.870	1.845	1.377	0.506	1.745	1.473	0.670	0.380	0.481	0.374	
Top Fuel 2	1.845	1.825	1.366	0.503	1.719	1.452	0.662	0.377	0.474	0.368	
Top Fuel 1	1.766	1.754	1.313	0.481	1.657	1.399	0.635	0.359	0.454	0.352	
Middle Fuel 5	1.710	1.707	1.279	0.446	1.629	1.372	0.590	0.329	0.420	0.327	
Middle Fuel 4	1.596	1.594	1.196	0.416	1.537	1.292	0.551	0.305	0.393	0.306	
Middle Fuel 3	1.504	1.503	1.128	0.393	1.457	1.225	0.521	0.288	0.373	0.290	
Middle Fuel 2	1.439	1.439	1.081	0.376	1.398	1.175	0.499	0.276	0.358	0.278	
Middle Fuel 1	1.403	1.406	1.058	0.368	1.369	1.151	0.488	0.269	0.350	0.272	
Bottom Fuel 5	1.433	1.441	1.087	0.371	1.414	1.183	0.493	0.269	0.354	0.275	
Bottom Fuel 4	1.422	1.430	1.078	0.367	1.412	1.181	0.489	0.266	0.352	0.274	
Bottom Fuel 3	1.406	1.409	1.060	0.361	1.408	1.174	0.484	0.262	0.352	0.273	
Bottom Fuel 2	1.393	1.383	1.031	0.350	1.410	1.176	0.480	0.259	0.353	0.273	
Bottom Fuel 1	1.420	1.368	0.998	0.336	1.436	1.206	0.483	0.251	0.356	0.275	
Bottom Cutback	1.179	1.022	0.720	0.238	1.082	0.927	0.367	0.184	0.265	0.202	
Bottom Blanket	0.508	0.432	0.302	0.118	0.446	0.385	0.187	0.093	0.134	0.103	

Table 7. Assembly region 8-group normalized fission density standard deviations.

Assembly	1	2	3	4	5	6	7	8	9	10	11
Top Blanket	1.82E-04	1.00E-04	9.73E-05	1.16E-04	7.82E-05	1.14E-04	1.09E-04	8.29E-05	8.29E-05	1.12E-04	1.22E-04
Top Cutback	2.93E-04	1.68E-04	1.58E-04	2.15E-04	1.32E-04	1.94E-04	1.74E-04	1.44E-04	1.41E-04	1.96E-04	2.11E-04
Top Fuel 5	3.50E-04	2.11E-04	1.89E-04	2.58E-04	1.63E-04	2.47E-04	2.09E-04	1.79E-04	1.77E-04	2.42E-04	2.56E-04
Top Fuel 4	3.65E-04	2.20E-04	1.97E-04	2.65E-04	1.70E-04	2.58E-04	2.14E-04	1.85E-04	1.87E-04	2.51E-04	2.61E-04
Top Fuel 3	3.70E-04	2.23E-04	2.00E-04	2.70E-04	1.73E-04	2.62E-04	2.17E-04	1.88E-04	1.86E-04	2.56E-04	2.64E-04
Top Fuel 2	3.66E-04	2.21E-04	1.98E-04	2.67E-04	1.71E-04	2.61E-04	2.15E-04	1.87E-04	1.87E-04	2.55E-04	2.61E-04
Top Fuel 1	3.52E-04	2.13E-04	1.91E-04	2.60E-04	1.66E-04	2.52E-04	2.10E-04	1.81E-04	1.83E-04	2.49E-04	2.56E-04
Middle Fuel 5	3.26E-04	2.03E-04	1.80E-04	2.56E-04	1.59E-04	2.44E-04	2.00E-04	1.75E-04	1.79E-04	2.46E-04	2.50E-04
Middle Fuel 4	3.08E-04	1.92E-04	1.70E-04	2.44E-04	1.51E-04	2.33E-04	1.91E-04	1.68E-04	1.71E-04	2.38E-04	2.41E-04
Middle Fuel 3	2.95E-04	1.84E-04	1.63E-04	2.34E-04	1.45E-04	2.25E-04	1.84E-04	1.62E-04	1.65E-04	2.30E-04	2.35E-04
Middle Fuel 2	2.85E-04	1.78E-04	1.59E-04	2.26E-04	1.41E-04	2.19E-04	1.79E-04	1.58E-04	1.62E-04	2.25E-04	2.29E-04
Middle Fuel 1	2.78E-04	1.75E-04	1.55E-04	2.23E-04	1.38E-04	2.15E-04	1.76E-04	1.55E-04	1.60E-04	2.23E-04	2.27E-04
Bottom Fuel 5	2.75E-04	1.75E-04	1.55E-04	2.27E-04	1.40E-04	2.18E-04	1.77E-04	1.58E-04	1.62E-04	2.28E-04	2.31E-04
Bottom Fuel 4	2.71E-04	1.73E-04	1.53E-04	2.23E-04	1.38E-04	2.16E-04	1.75E-04	1.57E-04	1.61E-04	2.27E-04	2.31E-04
Bottom Fuel 3	2.64E-04	1.69E-04	1.50E-04	2.21E-04	1.36E-04	2.13E-04	1.73E-04	1.55E-04	1.59E-04	2.26E-04	2.29E-04
Bottom Fuel 2	2.57E-04	1.65E-04	1.46E-04	2.15E-04	1.33E-04	2.08E-04	1.72E-04	1.52E-04	1.57E-04	2.22E-04	2.29E-04
Bottom Fuel 1	2.45E-04	1.58E-04	1.40E-04	2.10E-04	1.28E-04	1.99E-04	1.68E-04	1.49E-04	1.52E-04	2.15E-04	2.29E-04
Bottom Cutback	2.11E-04	1.31E-04	1.19E-04	1.84E-04	1.08E-04	1.62E-04	1.46E-04	1.26E-04	1.25E-04	1.79E-04	1.99E-04
Bottom Blanket	1.34E-04	7.81E-05	7.53E-05	9.86E-05	6.46E-05	9.65E-05	9.37E-05	7.32E-05	7.39E-05	1.03E-04	1.15E-04
	12	13	14	15	16	17	18	19	20	21	
Top Blanket	8.95E-05	8.29E-05	6.99E-05	6.40E-05	1.15E-04	7.55E-05	5.49E-05	4.00E-05	6.50E-05	4.04E-05	
Top Cutback	1.60E-04	1.50E-04	1.27E-04	1.03E-04	2.13E-04	1.40E-04	8.76E-05	6.47E-05	1.06E-04	6.45E-05	
Top Fuel 5	1.79E-04	1.79E-04	1.53E-04	1.23E-04	2.54E-04	1.65E-04	1.01E-04	7.60E-05	1.23E-04	7.59E-05	
Top Fuel 4	1.82E-04	1.83E-04	1.58E-04	1.27E-04	2.58E-04	1.67E-04	1.03E-04	7.80E-05	1.25E-04	7.74E-05	
Top Fuel 3	1.84E-04	1.85E-04	1.60E-04	1.29E-04	2.60E-04	1.68E-04	1.04E-04	7.89E-05	1.26E-04	7.77E-05	
Top Fuel 2	1.82E-04	1.84E-04	1.59E-04	1.29E-04	2.57E-04	1.67E-04	1.03E-04	7.86E-05	1.25E-04	7.73E-05	
Top Fuel 1	1.77E-04	1.81E-04	1.56E-04	1.26E-04	2.52E-04	1.63E-04	1.01E-04	7.67E-05	1.22E-04	7.54E-05	
Middle Fuel 5	1.78E-04	1.81E-04	1.57E-04	1.21E-04	2.56E-04	1.65E-04	9.69E-05	7.30E-05	1.17E-04	7.25E-05	
Middle Fuel 4	1.73E-04	1.76E-04	1.52E-04	1.17E-04	2.47E-04	1.60E-04	9.38E-05	7.05E-05	1.14E-04	7.02E-05	
Middle Fuel 3	1.67E-04	1.70E-04	1.47E-04	1.13E-04	2.42E-04	1.56E-04	9.11E-05	6.84E-05	1.10E-04	6.83E-05	
Middle Fuel 2	1.64E-04	1.67E-04	1.45E-04	1.11E-04	2.36E-04	1.52E-04	8.91E-05	6.69E-05	1.08E-04	6.69E-05	
Middle Fuel 1	1.62E-04	1.64E-04	1.43E-04	1.10E-04	2.33E-04	1.51E-04	8.81E-05	6.60E-05	1.07E-04	6.63E-05	
Bottom Fuel 5	1.66E-04	1.69E-04	1.47E-04	1.11E-04	2.41E-04	1.56E-04	8.89E-05	6.63E-05	1.08E-04	6.69E-05	
Bottom Fuel 4	1.65E-04	1.69E-04	1.47E-04	1.10E-04	2.41E-04	1.56E-04	8.85E-05	6.59E-05	1.08E-04	6.68E-05	
Bottom Fuel 3	1.64E-04	1.68E-04	1.45E-04	1.09E-04	2.41E-04	1.55E-04	8.82E-05	6.54E-05	1.07E-04	6.67E-05	
Bottom Fuel 2	1.64E-04	1.66E-04	1.43E-04	1.08E-04	2.41E-04	1.55E-04	8.79E-05	6.51E-05	1.08E-04	6.67E-05	
Bottom Fuel 1	1.65E-04	1.65E-04	1.41E-04	1.05E-04	2.43E-04	1.57E-04	8.81E-05	6.41E-05	1.08E-04	6.69E-05	
Bottom Cutback	1.57E-04	1.47E-04	1.23E-04	9.16E-05	2.17E-04	1.42E-04	7.99E-05	5.70E-05	9.71E-05	5.92E-05	
Bottom Blanket	8.71E-05	8.02E-05	6.70E-05	5.79E-05	1.16E-04	7.56E-05	5.11E-05	3.60E-05	6.15E-05	3.79E-05	

1.835	1.859	1.891	1.921	1.947	1.966	1.956	1.959	1.973	1.984	1.985	1.980	2.004	2.016	2.011	2.003	1.979	1.955	1.942
0.330	0.335	0.340	0.346	0.350	0.334	0.333	0.333	0.335	0.337	0.337	0.337	0.341	0.343	0.342	0.341	0.336	0.332	0.350
1.810	1.816	1.857	1.910	1.955	2.024	1.956	1.920	1.963	2.041	1.975	1.945	1.991	2.078	2.016	1.973	1.934	1.910	1.909
0.326	0.327	0.334	0.344	0.352	0.344	0.333	0.326	0.334	0.347	0.336	0.331	0.338	0.353	0.343	0.335	0.329	0.325	0.344
1.810	1.832	1.907	2.039	2.082		2.032	1.935	2.026		2.038	1.955	2.068		2.138	2.096	1.980	1.907	1.911
0.326	0.330	0.343	0.347	0.354		0.345	0.329	0.344		0.346	0.332	0.352		0.364	0.356	0.337	0.324	0.344
1.833	1.863	2.018		2.109	2.091	1.973	1.920	1.962	2.061	1.972	1.939	2.007	2.134	2.165		2.090	1.946	1.924
0.330	0.335	0.363		0.359	0.355	0.335	0.326	0.333	0.350	0.335	0.330	0.341	0.363	0.368		0.355	0.331	0.327
1.854	1.908	2.050	2.100	2.048	2.072	1.972	1.912	1.957	2.049	1.962	1.935	1.996	2.113	2.098	2.165	2.124	1.983	1.944
0.334	0.343	0.348	0.357	0.348	0.352	0.335	0.344	0.333	0.348	0.334	0.329	0.339	0.359	0.357	0.368	0.361	0.337	0.330
1.867	1.967		2.072	2.066		2.026	1.921	2.015		2.024	1.935	2.058		2.123	2.137		2.049	1.956
0.336	0.354		0.352	0.351		0.344	0.327	0.343		0.344	0.329	0.350		0.361	0.363		0.348	0.333
1.857	1.897	1.999	1.952	1.959	2.015	1.935	1.893	1.934	2.018	1.943	1.911	1.962	2.059	1.999	2.003	2.060	1.971	1.936
0.334	0.342	0.360	0.332	0.333	0.343	0.329	0.341	0.329	0.343	0.330	0.325	0.333	0.350	0.340	0.341	0.350	0.335	0.329
1.844	1.858	1.893	1.893	1.901	1.914	1.892	1.876	1.893	1.921	1.901	1.891	1.917	1.955	1.944	1.938	1.944	1.923	1.920
0.332	0.335	0.341	0.341	0.342	0.325	0.341	0.338	0.341	0.327	0.342	0.340	0.326	0.332	0.331	0.329	0.331	0.327	0.346
1.860	1.894	1.987	1.931	1.940	2.004	1.925	1.887	1.924	2.004	1.932	1.902	1.948	2.041	1.977	1.979	2.029	1.954	1.927
0.335	0.341	0.358	0.348	0.349	0.341	0.327	0.340	0.327	0.341	0.348	0.342	0.331	0.347	0.336	0.336	0.345	0.332	0.328
1.881	1.982		2.025	2.028		2.006	1.910	2.006		2.002	1.919	2.026		2.063	2.066		2.032	1.934
0.339	0.357		0.344	0.345		0.341	0.325	0.341		0.340	0.326	0.344		0.351	0.351		0.345	0.329
1.871	1.910	1.994	1.942	1.953	2.006	1.928	1.892	1.929	2.002	1.933	1.907	1.947	2.033	1.979	1.976	2.036	1.954	1.930
0.337	0.344	0.339	0.330	0.332	0.341	0.328	0.341	0.328	0.340	0.329	0.343	0.331	0.346	0.336	0.336	0.346	0.332	0.328
1.877	1.885	1.914	1.916	1.918	1.926	1.901	1.887	1.897	1.925	1.902	1.894	1.912	1.944	1.935	1.935	1.943	1.921	1.923
0.338	0.339	0.345	0.345	0.345	0.327	0.342	0.340	0.323	0.327	0.323	0.322	0.325	0.330	0.329	0.329	0.330	0.327	0.346
1.891	1.929	2.030	1.974	1.973	2.034	1.949	1.904	1.939	2.016	1.937	1.908	1.960	2.052	1.989	1.991	2.056	1.959	1.931
0.340	0.347	0.345	0.336	0.335	0.346	0.331	0.343	0.330	0.343	0.329	0.324	0.333	0.349	0.338	0.338	0.350	0.333	0.348
1.919	2.012		2.105	2.094		2.038	1.933	2.021		2.021	1.944	2.051		2.105	2.125		2.043	1.941
0.345	0.342		0.358	0.356		0.346	0.329	0.344		0.344	0.330	0.349		0.358	0.361		0.347	0.330
1.912	1.956	2.106	2.137	2.078	2.097	1.991	1.930	1.964	2.049	1.972	1.931	1.992	2.106	2.081	2.147	2.112	1.969	1.926
0.344	0.333	0.358	0.363	0.353	0.356	0.338	0.328	0.334	0.348	0.335	0.328	0.339	0.358	0.354	0.365	0.359	0.335	0.347
1.895	1.927	2.075		2.144	2.115	1.998	1.933	1.969	2.061	1.972	1.932	1.990	2.121	2.142		2.079	1.925	1.904
0.341	0.347	0.353		0.364	0.359	0.340	0.329	0.335	0.350	0.335	0.328	0.338	0.361	0.364		0.353	0.327	0.343
1.885	1.890	1.960	2.075	2.117		2.053	1.950	2.032		2.034	1.942	2.045		2.106	2.071	1.948	1.887	1.876
0.339	0.340	0.333	0.353	0.360		0.349	0.331	0.345		0.346	0.330	0.348		0.358	0.352	0.331	0.340	0.338
1.888	1.879	1.898	1.943	1.984	2.048	1.966	1.923	1.953	2.026	1.948	1.918	1.963	2.035	1.964	1.924	1.880	1.851	1.861
0.340	0.338	0.342	0.330	0.337	0.348	0.334	0.327	0.332	0.344	0.331	0.326	0.334	0.346	0.334	0.327	0.338	0.333	0.335
1.913	1.903	1.910	1.933	1.950	1.964	1.945	1.931	1.935	1.948	1.930	1.922	1.929	1.940	1.923	1.906	1.879	1.866	1.873
0.344	0.343	0.344	0.348	0.332	0.334	0.331	0.328	0.329	0.331	0.347	0.346	0.347	0.330	0.346	0.343	0.338	0.336	0.337

Figure 11. Normalized pin fission densities (bold) and standard deviations (std * 100) for assembly index: 9, axial layer: top fuel 3.

0.018	0.020	0.021	0.023	0.025	0.027	0.028	0.031	0.033	0.035	0.036	0.038	0.040	0.042	0.044	0.046	0.047	0.049	0.052
0.029	0.030	0.030	0.032	0.034	0.035	0.035	0.038	0.038	0.040	0.040	0.041	0.043	0.044	0.045	0.046	0.046	0.046	0.048
0.020	0.022	0.024	0.027	0.029	0.033	0.033	0.034	0.037	0.041	0.042	0.043	0.046	0.050	0.051	0.052	0.054	0.055	0.058
0.030	0.032	0.033	0.035	0.036	0.039	0.039	0.039	0.041	0.045	0.044	0.044	0.047	0.048	0.049	0.049	0.050	0.050	0.052
0.023	0.025	0.029	0.032	0.035		0.039	0.039	0.044		0.048	0.049	0.054		0.061	0.062	0.061	0.062	0.064
0.032	0.034	0.037	0.039	0.042		0.043	0.043	0.046		0.048	0.048	0.051		0.055	0.054	0.053	0.054	0.055
0.026	0.029	0.033		0.039	0.042	0.042	0.044	0.047	0.051	0.051	0.054	0.058	0.063	0.068		0.071	0.069	0.071
0.035	0.037	0.040		0.043	0.045	0.044	0.045	0.046	0.049	0.049	0.050	0.052	0.055	0.058		0.059	0.056	0.057
0.029	0.032	0.038	0.040	0.041	0.046	0.047	0.048	0.052	0.057	0.057	0.059	0.063	0.070	0.072	0.077	0.079	0.078	0.080
0.036	0.039	0.043	0.044	0.044	0.047	0.047	0.047	0.049	0.052	0.051	0.053	0.054	0.059	0.059	0.061	0.062	0.060	0.061
0.032	0.037		0.045	0.048		0.053	0.053	0.059		0.065	0.066	0.072		0.080	0.084		0.088	0.088
0.038	0.042		0.047	0.049		0.050	0.049	0.053		0.055	0.055	0.058		0.062	0.064		0.065	0.063
0.035	0.039	0.044	0.046	0.048	0.054	0.056	0.058	0.061	0.067	0.069	0.072	0.075	0.082	0.083	0.086	0.093	0.092	0.095
0.040	0.042	0.045	0.047	0.047	0.051	0.051	0.052	0.053	0.056	0.057	0.057	0.058	0.062	0.062	0.063	0.067	0.065	0.067
0.040	0.044	0.046	0.051	0.054	0.056	0.060	0.063	0.067	0.072	0.074	0.076	0.081	0.086	0.089	0.093	0.096	0.098	0.102
0.043	0.045	0.046	0.049	0.050	0.051	0.053	0.053	0.055	0.057	0.057	0.059	0.061	0.063	0.064	0.065	0.066	0.067	0.068
0.043	0.048	0.054	0.056	0.060	0.066	0.066	0.068	0.075	0.082	0.083	0.084	0.090	0.098	0.099	0.101	0.108	0.108	0.112
0.044	0.047	0.052	0.052	0.053	0.057	0.055	0.055	0.059	0.063	0.063	0.063	0.065	0.068	0.069	0.069	0.071	0.071	0.073
0.048	0.055		0.063	0.068		0.074	0.076	0.084		0.092	0.093	0.099		0.111	0.114		0.122	0.120
0.047	0.051		0.055	0.058		0.059	0.059	0.064		0.066	0.066	0.068		0.073	0.074		0.076	0.074
0.052	0.058	0.064	0.067	0.072	0.079	0.079	0.082	0.088	0.094	0.096	0.099	0.105	0.114	0.115	0.119	0.127	0.127	0.129
0.049	0.053	0.055	0.055	0.058	0.061	0.061	0.061	0.063	0.067	0.066	0.066	0.069	0.073	0.073	0.075	0.077	0.076	0.077
0.057	0.063	0.069	0.072	0.076	0.082	0.085	0.090	0.094	0.099	0.103	0.106	0.112	0.119	0.121	0.127	0.133	0.134	0.139
0.050	0.053	0.056	0.058	0.058	0.061	0.062	0.064	0.066	0.068	0.069	0.069	0.072	0.074	0.075	0.076	0.078	0.078	0.081
0.063	0.070	0.078	0.081	0.086	0.093	0.095	0.098	0.104	0.112	0.113	0.117	0.123	0.133	0.135	0.138	0.148	0.147	0.150
0.053	0.057	0.061	0.061	0.063	0.066	0.066	0.067	0.070	0.073	0.072	0.074	0.076	0.080	0.079	0.080	0.085	0.082	0.082
0.069	0.079		0.093	0.098		0.107	0.108	0.117		0.127	0.129	0.139		0.151	0.158		0.162	0.163
0.055	0.062		0.067	0.069		0.071	0.071	0.075		0.077	0.078	0.080		0.085	0.087		0.087	0.086
0.076	0.084	0.096	0.103	0.105	0.112	0.114	0.115	0.123	0.134	0.135	0.137	0.147	0.159	0.163	0.171	0.174	0.170	0.172
0.059	0.063	0.068	0.071	0.071	0.073	0.073	0.073	0.075	0.080	0.080	0.080	0.084	0.088	0.088	0.091	0.091	0.088	0.089
0.083	0.091	0.101		0.119	0.123	0.122	0.124	0.133	0.145	0.146	0.147	0.157	0.173	0.180		0.185	0.180	0.185
0.061	0.065	0.070		0.076	0.077	0.075	0.076	0.078	0.084	0.083	0.081	0.085	0.092	0.094		0.094	0.092	0.092
0.088	0.096	0.106	0.119	0.127		0.135	0.135	0.148		0.163	0.160	0.173		0.189	0.192	0.189	0.188	0.196
0.064	0.066	0.070	0.076	0.079		0.081	0.078	0.084		0.088	0.086	0.090		0.094	0.096	0.094	0.092	0.096
0.096	0.104	0.113	0.121	0.130	0.140	0.142	0.147	0.156	0.169	0.168	0.171	0.180	0.194	0.193	0.196	0.200	0.203	0.211
0.066	0.069	0.072	0.075	0.078	0.081	0.081	0.083	0.086	0.089	0.088	0.089	0.092	0.097	0.094	0.096	0.096	0.096	0.099
0.108	0.117	0.126	0.133	0.141	0.150	0.154	0.162	0.171	0.179	0.184	0.187	0.195	0.204	0.208	0.213	0.216	0.225	0.231
0.070	0.074	0.077	0.080	0.082	0.084	0.085	0.088	0.089	0.091	0.092	0.094	0.096	0.098	0.100	0.100	0.100	0.101	0.104

Figure 12. Fission densities and standard deviations ($std * 100$) for assembly index: 19, axial layer: bottom blanket.

0.445	0.464	0.485	0.512	0.540	0.563	0.578	0.594	0.616	0.635	0.644	0.657	0.674	0.699	0.700	0.701	0.711	0.712	0.733
0.169	0.172	0.175	0.179	0.184	0.192	0.191	0.196	0.197	0.203	0.206	0.204	0.209	0.210	0.210	0.210	0.213	0.214	0.220
0.477	0.504	0.533	0.567	0.602	0.645	0.638	0.645	0.676	0.720	0.709	0.712	0.739	0.786	0.778	0.770	0.770	0.769	0.786
0.177	0.181	0.181	0.193	0.199	0.206	0.204	0.200	0.210	0.216	0.213	0.214	0.222	0.228	0.226	0.223	0.223	0.223	0.220
0.510	0.545	0.592	0.654	0.688		0.711	0.704	0.753		0.790	0.776	0.828		0.884	0.881	0.846	0.830	0.842
0.178	0.185	0.195	0.209	0.213		0.220	0.211	0.226		0.229	0.225	0.232		0.248	0.247	0.237	0.232	0.236
0.553	0.595	0.664		0.745	0.758	0.740	0.744	0.777	0.825	0.811	0.814	0.858	0.923	0.950		0.946	0.895	0.899
0.188	0.196	0.213		0.223	0.228	0.222	0.216	0.225	0.231	0.227	0.228	0.240	0.249	0.256		0.256	0.242	0.243
0.592	0.643	0.722	0.760	0.764	0.803	0.781	0.790	0.823	0.874	0.855	0.859	0.894	0.967	0.972	1.017	1.014	0.959	0.957
0.195	0.206	0.224	0.228	0.222	0.233	0.226	0.221	0.230	0.245	0.231	0.232	0.241	0.261	0.253	0.264	0.264	0.249	0.249
0.630	0.699		0.790	0.818		0.846	0.827	0.886		0.925	0.906	0.968		1.029	1.049		1.039	1.005
0.202	0.217		0.229	0.237		0.237	0.231	0.239		0.250	0.245	0.252		0.268	0.262		0.260	0.251
0.659	0.712	0.773	0.788	0.813	0.858	0.848	0.853	0.888	0.945	0.929	0.932	0.969	1.031	1.019	1.030	1.070	1.042	1.042
0.204	0.214	0.224	0.228	0.228	0.240	0.229	0.230	0.240	0.255	0.241	0.242	0.252	0.258	0.255	0.257	0.267	0.260	0.261
0.690	0.731	0.779	0.805	0.833	0.861	0.872	0.883	0.909	0.943	0.952	0.964	0.988	1.023	1.031	1.043	1.064	1.065	1.073
0.214	0.212	0.226	0.225	0.233	0.232	0.235	0.238	0.236	0.245	0.247	0.251	0.247	0.256	0.258	0.261	0.266	0.266	0.268
0.726	0.777	0.844	0.856	0.885	0.937	0.922	0.927	0.964	1.021	1.010	1.008	1.044	1.103	1.091	1.102	1.145	1.116	1.107
0.211	0.225	0.236	0.240	0.239	0.253	0.240	0.241	0.251	0.265	0.252	0.252	0.261	0.276	0.262	0.265	0.275	0.268	0.266
0.766	0.841		0.932	0.962		0.997	0.975	1.042		1.079	1.058	1.122		1.173	1.189		1.189	1.160
0.222	0.236		0.252	0.250		0.259	0.253	0.260		0.270	0.264	0.269		0.282	0.285		0.285	0.278
0.795	0.849	0.917	0.925	0.959	1.013	0.998	0.998	1.046	1.097	1.078	1.079	1.117	1.177	1.162	1.174	1.221	1.180	1.181
0.223	0.238	0.248	0.241	0.249	0.263	0.259	0.249	0.261	0.274	0.259	0.259	0.268	0.283	0.279	0.270	0.281	0.272	0.272
0.829	0.873	0.919	0.951	0.980	1.011	1.017	1.029	1.059	1.090	1.099	1.107	1.136	1.167	1.176	1.187	1.204	1.200	1.214
0.232	0.236	0.239	0.247	0.255	0.253	0.254	0.257	0.254	0.262	0.264	0.266	0.273	0.268	0.271	0.273	0.277	0.276	0.279
0.871	0.927	1.002	1.016	1.043	1.096	1.072	1.077	1.114	1.173	1.151	1.147	1.184	1.258	1.232	1.247	1.297	1.249	1.243
0.235	0.241	0.260	0.254	0.261	0.274	0.257	0.258	0.267	0.282	0.276	0.275	0.272	0.289	0.283	0.287	0.298	0.287	0.286
0.908	1.007		1.109	1.136		1.156	1.123	1.187		1.228	1.192	1.271		1.331	1.355		1.330	1.283
0.236	0.262		0.277	0.273		0.277	0.270	0.285		0.282	0.274	0.292		0.306	0.298		0.293	0.295
0.945	1.005	1.114	1.158	1.164	1.198	1.160	1.148	1.190	1.254	1.217	1.216	1.262	1.347	1.349	1.400	1.391	1.313	1.293
0.246	0.251	0.279	0.278	0.279	0.287	0.278	0.276	0.274	0.288	0.280	0.280	0.290	0.296	0.297	0.308	0.306	0.289	0.285
0.962	1.021	1.122		1.232	1.239	1.189	1.183	1.222	1.283	1.252	1.244	1.292	1.386	1.411		1.392	1.307	1.302
0.250	0.255	0.269		0.296	0.285	0.274	0.272	0.281	0.295	0.288	0.286	0.284	0.305	0.310		0.306	0.287	0.287
0.990	1.032	1.102	1.191	1.247		1.254	1.218	1.283		1.316	1.277	1.351		1.414	1.401	1.333	1.302	1.308
0.247	0.258	0.265	0.286	0.287		0.288	0.280	0.295		0.303	0.281	0.297		0.311	0.308	0.293	0.286	0.288
1.030	1.060	1.107	1.150	1.206	1.259	1.236	1.228	1.262	1.322	1.295	1.281	1.314	1.381	1.352	1.328	1.312	1.307	1.319
0.258	0.254	0.266	0.276	0.277	0.290	0.284	0.283	0.290	0.291	0.285	0.282	0.289	0.304	0.298	0.292	0.289	0.287	0.290
1.090	1.116	1.141	1.174	1.212	1.240	1.244	1.260	1.280	1.305	1.305	1.313	1.333	1.348	1.341	1.345	1.334	1.330	1.337
0.262	0.268	0.274	0.270	0.279	0.285	0.286	0.290	0.282	0.287	0.287	0.289	0.293	0.297	0.295	0.296	0.293	0.293	0.294

Figure 13. Fission densities and standard deviations ($std * 100$) for assembly index: 17, axial layer: top cutback.

0.619	0.614	0.609	0.612	0.616	0.619	0.611	0.606	0.607	0.610
0.254	0.190	0.183	0.184	0.185	0.186	0.183	0.182	0.188	0.256
	0.601	0.600	0.606	0.615	0.628	0.607	0.589	0.600	0.622
	0.253	0.186	0.182	0.184	0.189	0.182	0.177	0.186	0.261
		0.613	0.646	0.645		0.621	0.580	0.608	
		0.258	0.200	0.193		0.186	0.174	0.188	
				0.646	0.640	0.592	0.572	0.583	0.608
				0.200	0.192	0.178	0.177	0.181	0.262
				0.623	0.622	0.581	0.561	0.576	0.597
				0.262	0.199	0.180	0.174	0.184	0.257
						0.594	0.552	0.578	
						0.190	0.171	0.185	
						0.562	0.542	0.553	0.575
						0.247	0.179	0.183	0.253
							0.537	0.539	0.545
							0.242	0.189	0.251
								0.542	0.562
								0.260	0.281

Figure 14. Fission densities and standard deviations ($std * 100$) for assembly index: 1, axial layer: middle fuel 2.

8. Summary and conclusion

The I2S-LWR concept has been stylized and used to create a benchmark to test new and existing codes and methods. This benchmark represents a simplified version of the equilibrium cycle core at a time of 10 days into the cycle. The core geometry has been fully described and the 8 group cross sections developed using the lattice physics code HELIOS are provided online. A MCNP5 solution to the benchmark description has been provided for the reader's convenience as a point of comparison and as a demonstration of pin fission density and bundle-averaged fission density distributions. Eigenvalue, average assembly region pin fission density, and selected pin fission density results are presented with the entire pin fission density distribution provided in the journal's online repository. Users are cautioned when using these results as the MCNP uncertainties underestimate the real uncertainty significantly.

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