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Irradiation Experiment Design Parameters for NBSR Fuel Conversion

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Preface

It has been proposed to convert the National Institute of Standards and Technology research reactor, known as the NBSR, from highly enriched uranium (HEU) fuel to low-enriched uranium (LEU) fuel. The motivation to convert the NBSR to LEU fuel is to reduce the risk of proliferation of special nuclear material. This report is a compilation of relevant information from recent studies related to the proposed conversion using a metal alloy of LEU with 10 w/o molybdenum. The objective is to inform the design of irradiation experiments that are being planned to qualify and/or license the fuel. This report provides relevant nominal dimensions of the proposed LEU fuel element, composition and dimensional tolerances, thermal-hydraulic operational parameters, and power densities and fission densities throughout fuel plates in fuel elements with the maximum local fission density and maximum local power density.

The motivation for Revision 1 of this report is to provide thermal-hydraulic information and more detailed power distributions not included in the original report as well as to clarify several issues that will help in the design and testing of the "Design Demonstration Element" (DDE). The NBSR DDE element will be irradiated under conditions as close as possible to those expected to be found in the NBSR under equilibrium fuel cycle conditions that are the norm for NBSR operation. In addition to the parameters found herein, there are drawings available with fuel element fabrication specifications.

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1 Introduction

This report is a compilation of results from studies of the conversion of the National Institute of Standards and Technology (NIST) research reactor, known as the NBSR, to low-enriched uranium (LEU) fuel from its current use of highly enriched uranium (HEU) fuel. The objective is to provide information useful for the Fuel Qualification (FQ) Pillar of the U.S. High Performance Research Reactor (USHPRR) Conversion Project, for the design of the NBSR Design Demonstration Experiment (NBSR DDE). The information that is expected to be useful is based on what was provided in a similar earlier report (Brown, 2014) and in a more recent report from another reactor being converted (Stillman, 2018). It consists of geometry and composition of fuel elements, thermal-hydraulic parameters, and information on power and fission density.

The information is relevant to an equilibrium LEU fuel cycle with the reactor operating in the same way in which the NBSR currently operates; namely, at 20 MW steady-state for a 38.5-day cycle. There will also be transition cores containing both LEU and HEU fuel. Preliminary analysis of those cores (Diamond, 2017) suggests that the equilibrium cycle will be the most limiting.

Section 2 provides the description of the fuel plates and the fuel elements. Section 3 provides information on the modeling of the reactor in order to obtain the power and fission densities of interest. Sections 4 and 5 explain these data with the actual tabulations found in Appendices A and B for power and fission density, respectively. Section 6 provides important parameters related to thermal-hydraulics. Key information is summarized and fuel element geometry and materials data are tabulated in Section 7. References are found in Section 8.

2 Geometry and Composition of the Fuel Elements

The NBSR is a high burn-up, 20 MW reactor described in detail in the safety analysis report (NIST, 2010). Moderation and cooling is provided by D_2O, which flows upward through the core from two concentric plena just below the lower grid plate. The NBSR is designed to have thermal neutrons stream through eight radial beam tubes and two cold neutron sources; the latter producing beams of neutrons at energies much lower than thermal energies. Toward this end there is an unfueled "gap" in the axial center of the fuel elements, which contains only moderator and structural materials. This gap minimizes fast neutron and gamma contamination of the thermal and cold streaming neutrons by being co-located axially with the beam tubes and cold neutron sources. The mid-plane gap is significant in terms of the NBSR peak local irradiation condition as the axial thermal flux always peaks in the mid-plane gap. Because the axial location of the thermal flux peak is fixed, the fuel that is directly adjacent to the gap experiences both the highest power density and the highest cumulative fission density in the NBSR core.

Another unique feature of the NBSR is the cadmium shim arms (control elements), which traverse the upper-half of the core in a semaphore fashion. During much of a reactor cycle, the shim arms act to suppress the flux in the upper half of the NBSR core. This flux "compression" shifts the peak local irradiation condition to the fuel in the lower half-element that is nearest to the mid-plane gap. A three-dimensional cut-away view of the NBSR vessel internals and reactor core is shown in Figure 2-1. The mid-plane gap (legend entry 5) and the shim arms (legend entry 2) are both visible in the figure.

Presently, the NBSR is fueled with highly enriched uranium (HEU) with a nominal ^{235}U enrichment of 93%. The fuel is U_3O_8 in an aluminum powder dispersion that is clad in aluminum alloy (Alloy 6061). Each fuel element is constructed of 17 fuel plates in each upper and lower half (34 plates per fuel element) and is constructed in the Materials Test Reactor (MTR) curved plate geometry.

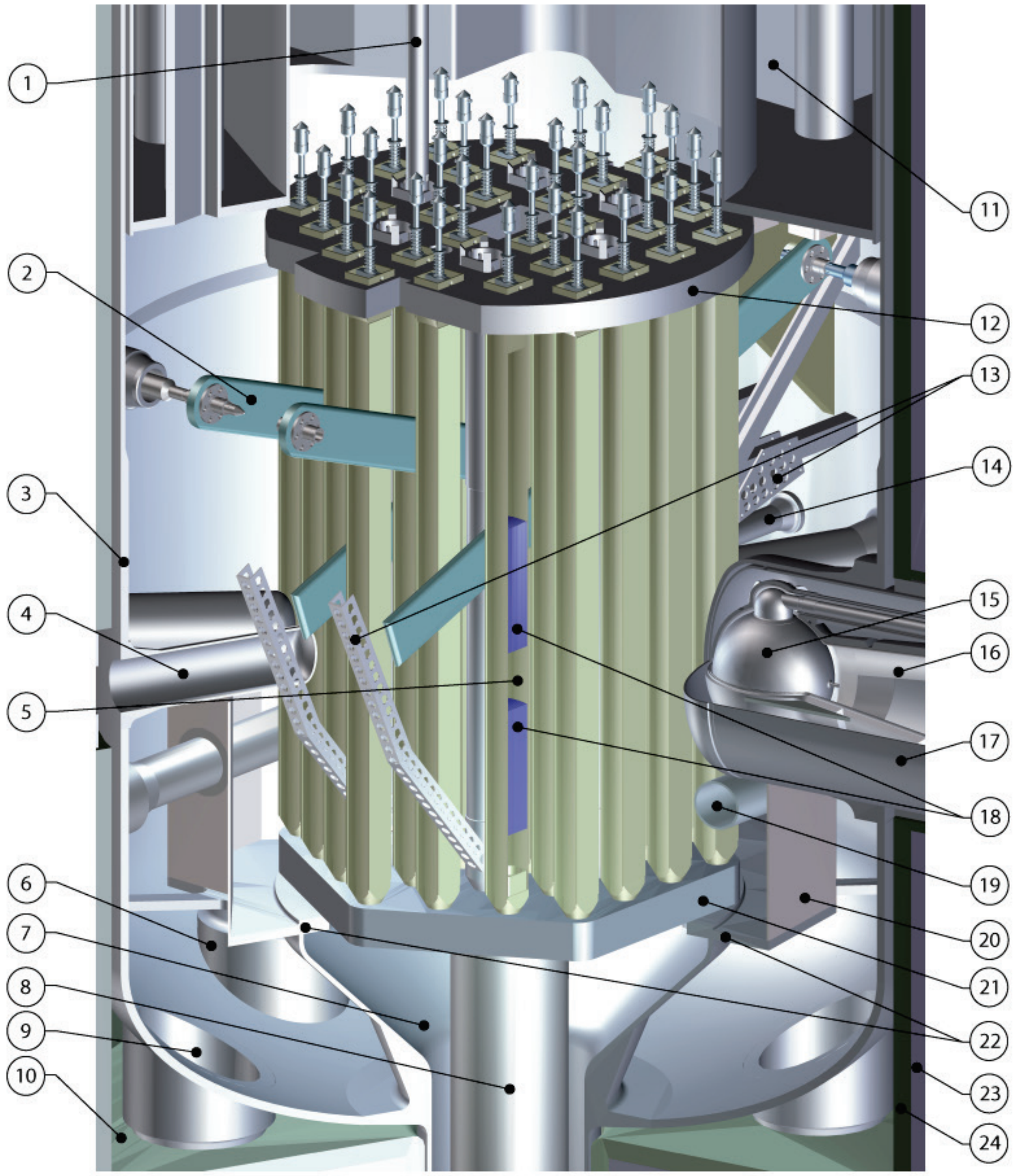
The conversion of the core to low-enriched uranium (LEU) fuel is explained in the conversion preliminary safety analysis report (Diamond, 2014). It will only require changing the interior of the fuel plates, that is, the fuel plate outer geometry and fuel element geometry will not change. Figure 2-2 shows a fuel element with the lower and upper fuel plates and midplane gap exposed.

Figure 2-3 is a cross-sectional view of the fuel plates in the fuel element showing the coolant flow channels and the effective coolant boundary. Outside that boundary there is heavy water moderator that is considered bypass flow. The modeling of the fuel element and coolant channel and bypass flow are discussed in Section 3 below.

The fuel proposed for the LEU reactor is monolithic U-10Mo (10 weight percent Mo alloyed with U) metal with a zirconium interlayer bonded on the outside to improve fuel behavior under irradiation. The same aluminum alloy cladding as used in the HEU fuel is on the outside of this foil[a]. Important data for the fuel, the plates and the fuel elements are given in Table 2-1 and

[a] A foil is defined as the combination of the fuel "core" (U-10Mo) and the Zr interlayer.

additional information is found in (Diamond, 2018). More information on the fuel including uncertainties in key parameters is also found in Section 7.



1	Poisoned Hold Down Tube (1 of 7)	13	Shim Arm Guide Extension # 3
2	Shim Arm #2	14	RT-3 Pneumatic Tube
3	Reactor Vessel	15	Cold Source Moderator Chamber
4	BT-2 Thimble	16	Cold Source Insulating Vacuum
5	Element Unfueled Gap	17	Cold Source D_2O Cooling Jacket
6	D_2O Outlet (1 of 2)	18	Fuel Plates, Upper and Lower Sections
7	D_2O Inlet - Outer Plenum	19	Through Tube (North)
8	D_2O Inlet – Inner Plenum	20	Heavy Water Holdup Pan
9	Fuel Transfer Chute Opening	21	Lower Grid Plate
10	CO_2 Filled Region	22	Outer Plenum Flange
11	Inner Reserve Tank	23	Steel (Thermal Shield)
12	Upper Grid Plate w/30 Elements	24	Lead (Thermal Shield)

Figure 2-1 NBSR Vessel Internals and Reactor Core (NIST, 2010)

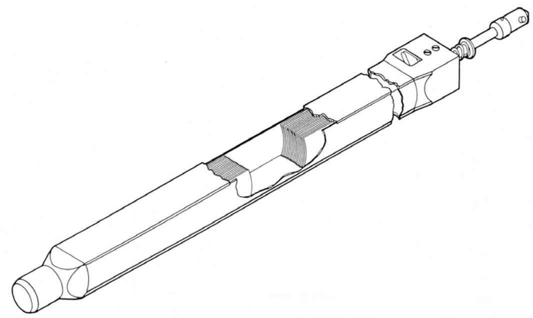


Figure 2-2 NBSR Fuel Element

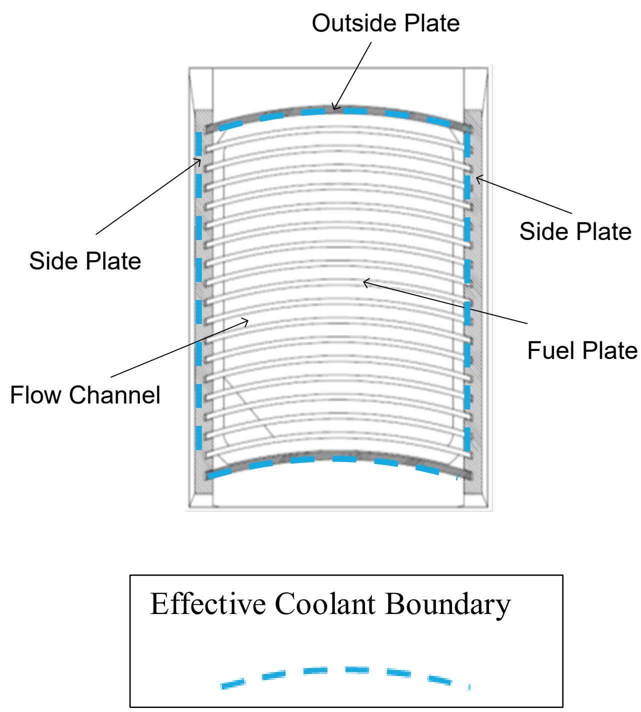


Figure 2-3 Cross Sectional View of NBSR Fuel Element

Table 2-1 LEU Fuel Plate/Element Information (Diamond, 2018)

Fuel element data	
^{235}U, grams	383
^{238}U, grams	1556
Mo, grams	215
Total grams	2154
Total fuel volume (cm^3)	125.9
Fuel plate data	
Fuel core density, g/cm^3	17.2
Nominal fuel core thickness, in (cm)	0.0085 (0.0216)
Nominal fuel foil thickness, in (cm)	0.0105 (0.0267)
Fuel width in plate, in (cm)	2.415 (6.134)
Fuel length in plate, in (cm)	11.0 (27.94)
Nominal cladding thickness, in (cm)	0.0198 (0.0503)
Plate length, in (cm)	13.0 (33.2)
Plate width, in (cm)	2.68 (6.81)
Plate thickness, in (cm)	0.0501 (0.127)
Fuel plate radius of curvature, in (cm)	5.50(14.0)

3 Modeling the NBSR Reactor

Figure 3-1 shows the labeling of the 30 fuel element positions for an equilibrium core. The thimble identifiers are bracketed (<>) and the regulating rod is identified as <RR>. In each position fuel elements are identified with two numbers and one letter. The letters are either E or W for the east or west side of the core. The fuel management scheme of the NBSR dictates that 16 fuel elements stay in the core for eight cycles and 14 fuel elements stay in the core for seven cycles. The first number at each position denotes how many cycles the element will be in the core (either eight or seven) and the second number denotes the cycle in which the fuel element resides. Therefore, at the beginning of a cycle, the 8-1 and 7-1 fuel elements are unirradiated fuel elements, whereas elements 8-8 and 7-7 are in their final cycles and will be removed after the cycle is over. After a cycle is finished the 8-8 and 7-7 fuel elements are removed and the 8-7 elements are moved into the 8-8 positions, the 7-6 elements are moved into the 7-7 positions, etc. A fuel element always stays in the east side or in the west side of the core. Unirradiated fuel is placed in the 8-1 and 7-1 positions**.**

	A	B	C	D	E	F	G	H	I	J	K	L	M
				COLD SOURCE									
1				8-1W		7-2W		7-2E		8-1E			
2			8-3W		7-5W		<>		7-5E		8-3E		
3		7-3W		<>		8-7W		8-7E		<>		7-3E	
4	7-1W		8-6W		7-7W		<>		7-7E		8-6E		7-1E
5		8-4W		<>		8-8W		8-8E		<>		8-4E	
6			7-4W		7-6W		<RR>		7-6E		7-4E		
7				8-2W		8-5W		8-5E		8-2E			

Figure 3-1 NBSR Fuel Management Scheme

Six fuel elements are in the inner core (positions E4, F3, F5, H3, H5, and I4), cooled by flow from the inner plenum, and twenty-four elements are in the outer core, cooled by flow from the outer plenum. The six inner elements are either in their seventh or eighth cycle.

Considering fuel elements at different spatial positions is equivalent to considering the time dependent change with burnup. The fuel element at position D1 is an element in its first cycle, at position D7 in its second cycle, …and the fuel element at position F5 in its last (eighth) cycle. This helps explain how fuel element data is selected for display as a function of cycle.

The reactivity of the NBSR is controlled with four cadmium shim arms that are rotated through the core in a semaphore fashion, and with a regulating rod, which is an aluminum cylinder that replaces water when moved into the core. The shim arms are located between rows two and three (see Figure 3-1) and rows five and six. Since they rotate from above the core, the power is generally higher in the bottom half-element relative to the top half-element.

For the conversion of the reactor to LEU fuel, an improved full-core model of the NBSR has been developed (the "current" model) for the neutronic and burn-up analysis (Kohut, 2019). The model utilizes MCNP6.2 (LANL, 2017) and includes a burn-up analysis of the fuel elements as they are moved through the core for either seven or eight 38.5-day fuel cycles. The NBSR model has been subjected to a variety of validation studies and is an evolution of the model utilized in the conversion PSAR (Diamond, 2014).

A planar view of the NBSR model at the core midplane is shown in Figure 3-2. The fuel elements are located on 17.7 cm (7.0 in) centers in the hexagonal array shown. The relatively large spacing contributes to the thermalization of the neutron flux and allows for the placement of the irradiation thimbles and the shim arms. The bypass water surrounding the fuel elements is 4% of the total flow. That flow is the result of the slight lifting of the fuel elements off the bottom grid plate due to water pressure. The bypass flow outside the fuel element remains outside the effective coolant boundary (Figure 2-3).

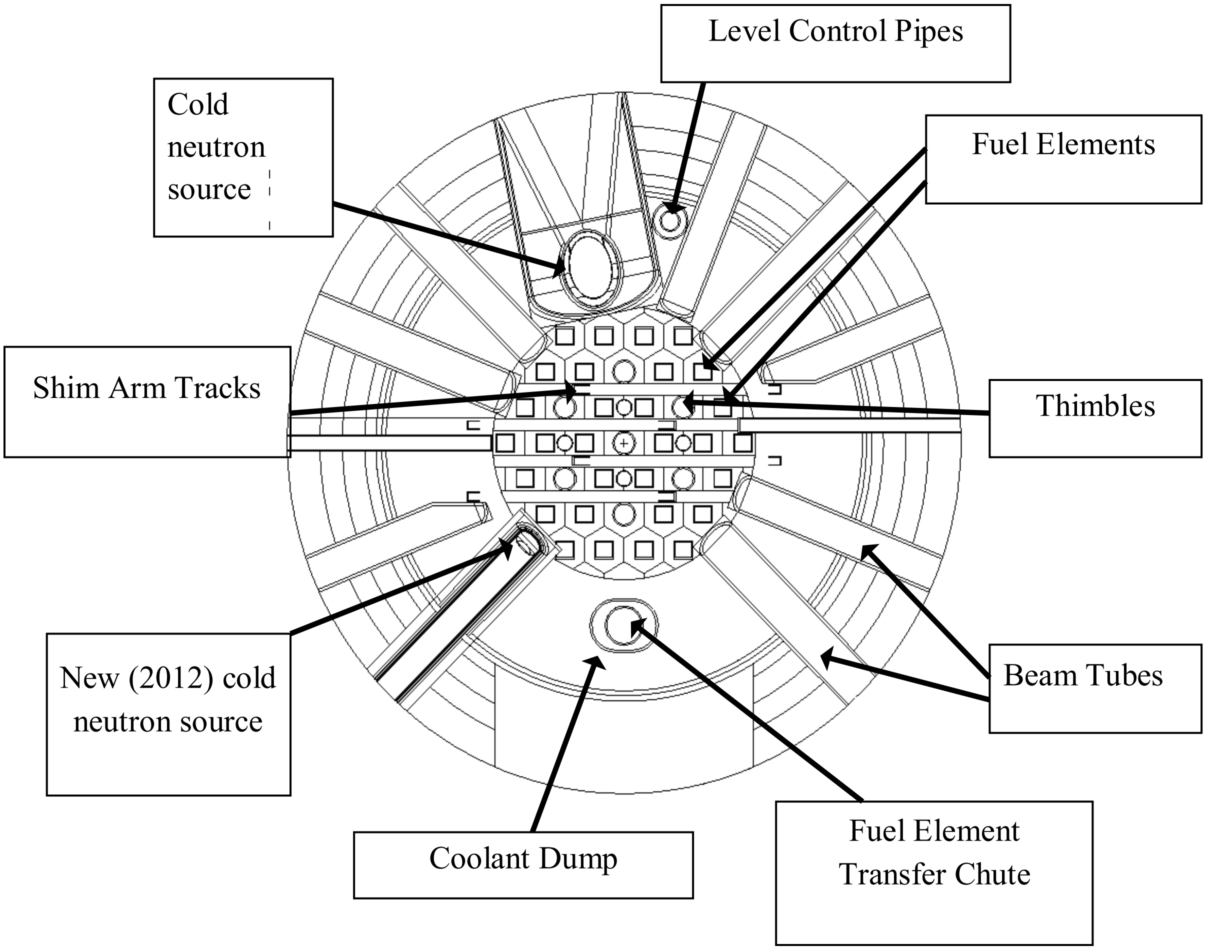


Figure 3-2 Planar View of the NBSR MCNP6 Model

To obtain detailed information on power density and fission density, each fuel plate in the model has power calculated on a 3x14 mesh (3 transverse or lateral meshes, and 14 axial meshes) with each mesh approximately 2x2 cm as shown on the right side of Figure 3-3. The figure also shows the 17 plates found at the top and bottom of the fuel element. The plates are modeled without curvature for simplification.[b] The power is calculated in each mesh and since there are 34 plates in each of the 30 fuel elements, there are a total of 30x34x3x14=42840 values of power calculated. The power distribution is calculated for the equilibrium fuel-cycle statepoints of interest; namely, startup (SU) at the very beginning of the cycle, beginning-of-cycle (BOC) after 1.5 days when the short-lived fission products (e.g., ^{135}Xe) have reached equilibrium, middle-of-cycle (MID) after another 17.5 days, and end-of-cycle (EOC) at the end of the 38.5-day fuel cycle that is normally used. Burnup is calculated for each interval (e.g., MID to EOC) with the shim arms at different positions representing the average position for criticality during that interval. At EOC all shim arms are fully withdrawn to a horizontal position.

[b] This assumption is used since the radius of curvature is 14 cm (not much curvature), the mean free path of thermal neutron in D_2O is 2.4 cm and the distance between plates (coolant channel thickness) is only 0.3 cm.

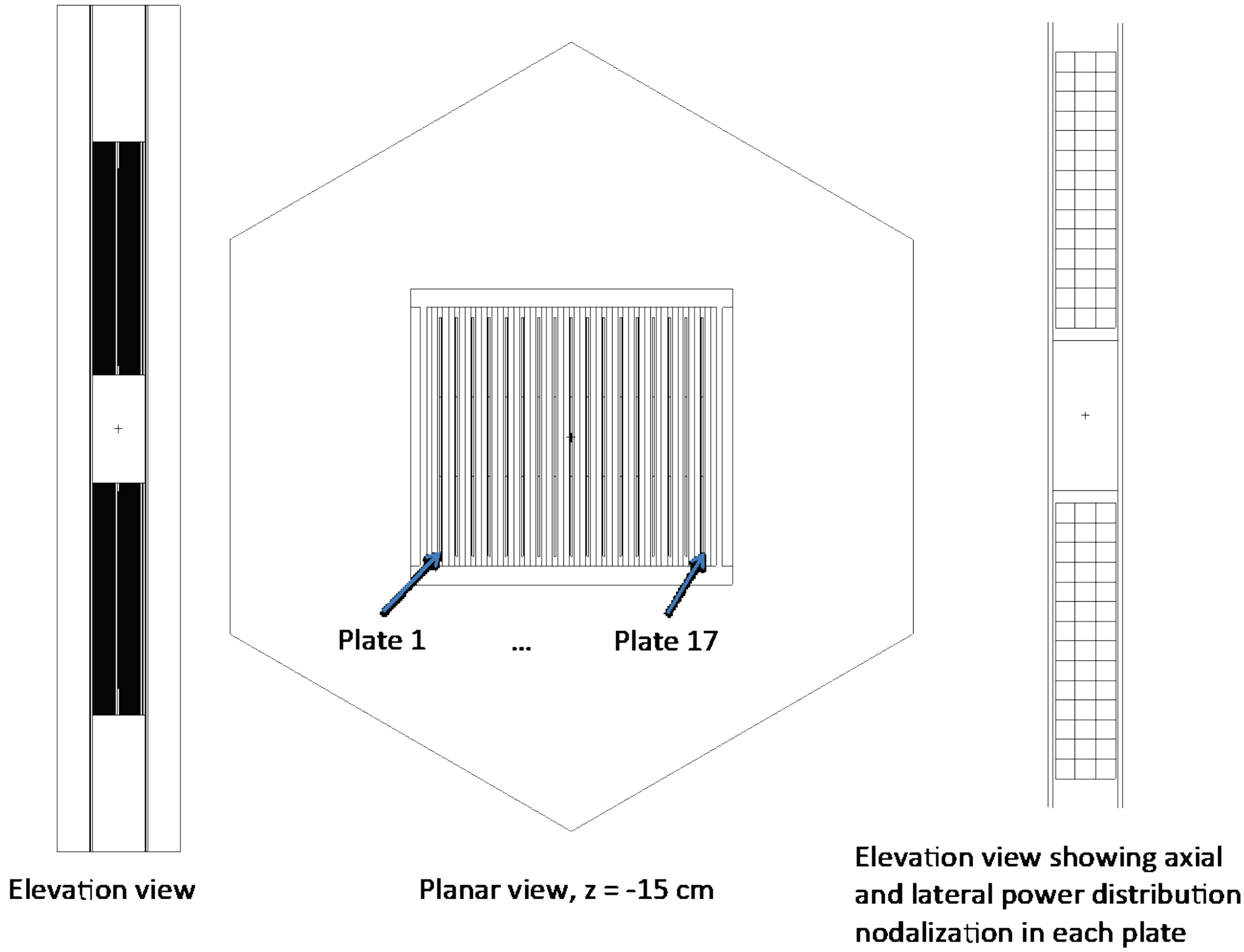


Figure 3-3 NBSR Fuel Element Geometry in the MCNP6.2 Model

The choice of the mesh size for the MCNP6.2 calculations is based on the observation that heat conduction in a fuel plate will result in a lateral heat flux profile (i.e., across the width of a fuel plate) that is flatter than the profile of the energy deposition due to fission (Cheng, 2010). The results of that study indicate the average surface energy flux (sum of energy deposition divided by the surface area of a mesh cell) for a 4 cm^2 mesh conservatively captures the maximum surface heat flux determined by solving the heat conduction problem for a fuel plate.

The choice of mesh size might also be selected to be comparable to the mesh size used for the measurement of fission density after irradiation tests used for fuel qualification. The blister temperature of fuel plates as a function of fission density is a key measurement used to determine the acceptance criterion for many postulated accidents. However, it is not clear what plate area is used when doing measurements of fission density (Meyer, 2017).

For thermal-hydraulic analyses, it is assumed that all fission energy is deposited directly in the cell that contains the fission. This assumption is conservative because in reality a fraction of the fission energy will be deposited directly in the cladding, coolant, moderator, and reactor structural material. A conservatively high estimate of the energy deposited in the fuel is 95% (Hanson, 2005).

Another assumption is that burnup is assumed to be uniform over zones that are much larger than the meshes used to obtain the power distribution. This is a pragmatic requirement because of the excessive running time for MCNP6.2 calculations when the number of composition zones are increased. The model used for relicensing the current NBSR and for the conversion PSAR used a single composition zone for each half-element. However, as explained below, the current model used to obtain the results herein has 15 composition zones in each half-element or a total of 900 zones in the core (Kohut, 2019).

Figure 3-4 shows the axial distribution of ten zones in a fuel element—five in the top half-element (zones AA to EE) and five in the bottom half-element (zones A to E). The use of more zones for the meshes facing the midplane gap is to eliminate the conservatism that results when the composition model does not change spatially, and burnup is underestimated where the flux/power is highest. This results in the power density (and hence, fission density) near the gap to be overestimated.

There are three zones to represent the different plates in a fuel element. The plates are aligned in the north-south direction. Due to the fact that the fuel elements are rotated arbitrarily 180 degrees each fuel cycle, it is not known after cycle 1 whether plate 1 or plate 17 is on the east side of the element or the west side, i.e., there cannot be a distinction between plates on either side of the fuel element (i.e., between plates 1 and 17 - Figure 3-3, plates 2 and 16, etc.) or between one side of a plate and the other side (i.e., between the two side edges shown in Figure 3-4). Since the highest power densities will be in the outside plates, the model lumps interior plates 3-15 together as one composition, plates 2 and 16 as another composition, and plates 1 and 17 as a third composition. Each top-bottom pair of fuel plates is divided into 10 axial composition zones as shown in Figure 3-4. With 30 fuel elements there are, therefore, 30 × 3 × 10 = 900 composition zones in the model.

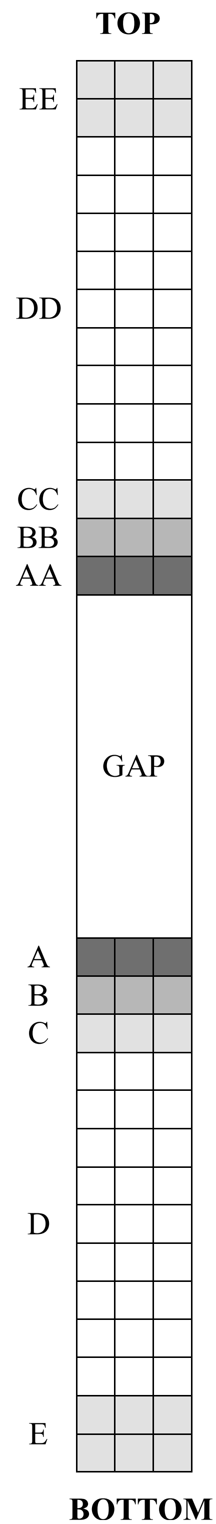


Figure 3-4 Axial Composition Zones and Power Meshes

4 Power Distribution

The design and planning of irradiation experiments for NBSR LEU fuel requires information on the prototypic power density and fission density in the fuel plates; especially the maximum values. The average power density in the NBSR is calculated based on the core power[c], the number of nodes in the core, and the volume of each node. The dimensions of each node (see Table 2-1) are (27.94/14) cm × (6.134/3) cm × 0.0216 cm = 0.08814 cm^3. In the proposed LEU U-10Mo fuel the average power density P_{avg} is the core thermal power/fuel core volume:

$$P_{avg} = (20\text{x}10^6\ \text{W})/(0.08814 \times 42840\ \text{cm}^3) = 5.30\ \text{kW/cm}^3$$

The maximum power density is obtained by searching the 42,840 meshes for the peak value. This is found at SU in a fresh fuel element at the outside of the core, namely, position A4 (see Figure 3-1), at the top of the bottom half-element. Table 4-1 gives the power density distribution in Plates 1 and 17[d] and shows the maximum value of 12.6 kW/cm^3. This corresponds to a heat flux of 136 W/cm^2 out of each side of the 0.0216 cm thick fuel core. Heat flux is used for the thermal analysis.

The fact that the maximum power density occurs at SU is the result of flux compression due to the position of the shim arms and the smaller burnup at SU relative to later in the cycle. Shim arms move out of the core during the fuel cycle. The calculations discussed herein are done assuming fresh shim arms and this contributes to the compression and adds conservatism to the power peaking during most cycles, when the shim arms are actually partially depleted.

Table 4-1 also shows that the power is higher in plate 17 (on the east side of the fuel element) relative to plate 1 (on the west side). This is due to the fact that plate 1 faces heavy water moderator at the edge of the core while plate 17 faces moderator and also two fuel elements; namely, B3 and B5 as seen in Figure 3-1. The asymmetry diminishes in interior plates. The differences in power between plates 2 and 16 are much less as shown in Table 4-2. For example, the difference at the hot spot between plates 1 and 17 relative to the average of the two is (12.58 - 10.21)/(12.58 + 10.21) or 10.4%, whereas for plates 2 and 16 it is only (11.05 - 10.58)/(11.05 + 10.58) or 2.2%.

The difference between plates 1 and 17 is less at a different location for fresh fuel. This is seen in Table 4-3 which shows the power density for fuel element D1, a fresh element with different surroundings than A4, as seen in Figure 3-1. For this fuel element, the difference at the hot spot between plates 1 and 17 is (9.67 - 8.67)/(9.67 + 8.67) or 5.4%.

The MCNP6.2 model does not rotate fuel-elements as they move through the core; fuel plates are always aligned in the same direction in every fuel element location; specifically with plate 1 to the left and plate 17 to the right. Hence, there can be calculated differences in the power distributions of plates 1 and 17 after their first cycle that in reality would be minimized as the fuel element is rotated 180° (in an undocumented manner) from cycle to cycle. Furthermore,

[c] The power removed by the primary coolant is 20 MW. An additional amount of power that is removed outside of the core via auxiliary systems (e.g., the thermal shield) and convection to the containment air is unknown.
[d] In the following discussion, the reference to plates means both in the top and bottom half-elements.

with more burnup but with the assumption of the same composition in plates to the left and right, the calculated differences are exaggerated since higher power meshes have higher burnup, which tends to reduce the higher power.

Table 4-1 Power Density (kW/cm^3) in Element A4 Plates 1 and 17

Plate 1

3.32	2.69	1.71
2.93	1.99	2.10
2.66	2.23	1.93
3.13	2.26	1.91
3.53	2.67	2.48
3.47	2.80	2.86
3.46	3.16	3.68
4.31	3.86	4.25
4.31	4.28	4.94
4.98	4.72	5.60
5.34	5.31	5.52
5.99	5.86	6.48
7.26	7.11	6.57
9.01	8.56	8.45

GAP

10.22	9.85	10.21
8.95	8.50	8.29
9.09	7.92	7.83
8.92	7.09	8.22
7.95	7.09	8.46
8.53	6.86	8.30
7.74	7.39	7.72
8.23	7.00	7.41
7.66	6.53	7.13
7.36	6.07	7.49
8.00	6.84	7.65
8.20	7.16	7.59
7.42	7.32	7.97
8.75	8.22	9.50

Plate 17

3.73	3.01	2.30
3.62	2.11	2.59
3.26	2.69	2.58
3.55	2.78	2.99
3.82	2.97	3.06
4.17	3.29	3.86
4.20	3.33	4.15
4.70	4.20	4.89
5.52	4.69	5.54
5.69	5.50	6.43
6.95	5.94	6.23
7.86	6.55	7.26
8.33	6.85	8.10
10.26	9.34	10.81

GAP

11.82	11.81	12.58
9.58	9.26	11.00
8.88	8.75	8.52
9.13	8.30	8.67
7.90	7.17	9.15
8.55	7.62	7.49
7.58	7.33	8.30
7.94	8.22	7.34
7.79	6.90	7.93
7.75	7.14	7.99
8.09	7.15	7.79
8.26	7.22	7.73
8.92	6.40	7.55
9.99	8.71	9.63

Table 4-2 Power Density (kW/cm^3) in Element A4 Plates 2 and 16

Plate 2

2.56	2.00	2.09
2.47	2.04	1.92
2.16	1.85	2.06
2.40	2.03	1.52
2.35	2.11	2.32
3.25	2.42	2.58
3.61	3.00	3.01
3.85	2.66	3.83
4.02	3.59	3.84
4.25	3.57	4.60
5.16	3.86	4.89
5.63	4.75	5.18
6.64	5.79	6.23
8.56	7.98	7.96

GAP

10.58	8.45	9.84
8.11	6.77	8.37
7.38	6.70	7.27
7.53	6.01	6.71
7.56	5.37	7.30
5.94	6.03	6.82
7.09	5.19	6.60
7.06	5.66	6.52
6.55	5.56	6.81
6.89	6.09	7.23
6.75	5.21	6.71
6.27	5.62	6.46
6.64	6.03	6.66
7.79	6.74	7.68

Plate 16

2.79	2.32	1.83
2.80	2.23	1.74
3.18	2.14	1.68
3.04	2.14	2.15
3.67	2.60	2.38
3.67	3.04	3.14
3.51	3.28	3.14
4.07	3.45	4.16
4.79	3.98	4.90
5.09	4.69	4.85
5.25	4.85	5.61
6.00	5.11	6.24
7.83	6.21	6.98
8.59	8.33	8.74

GAP

11.05	9.65	9.71
8.21	8.03	8.46
8.17	6.75	8.11
7.97	7.12	7.42
7.31	6.54	7.50
7.25	6.07	7.52
6.74	6.39	6.26
7.12	5.97	6.43
6.92	5.36	7.20
6.26	5.92	6.32
7.35	5.40	6.82
6.76	5.95	6.71
7.11	6.22	7.07
8.06	7.57	7.91

Table 4-3 Power Density (kW/cm^3) in Element D1 Plates 1 and 17

Plate 1

7.29	6.22	7.05
5.88	6.12	6.61
5.74	5.56	6.75
6.60	4.71	5.88
5.30	4.95	6.19
5.90	5.05	5.91
6.29	5.12	5.87
6.06	5.81	5.98
6.29	5.62	6.11
6.73	5.85	6.39
6.77	5.67	6.66
6.89	5.90	6.85
7.57	6.96	6.99
9.46	8.99	8.23

Plate 17

7.29	6.01	7.19
5.99	5.64	6.91
6.44	5.77	6.32
5.55	5.12	6.02
6.03	4.89	6.11
6.24	4.72	5.81
6.07	4.54	5.74
6.89	5.08	5.74
6.54	5.75	5.98
6.63	5.67	6.56
7.40	6.62	6.43
7.63	6.47	6.44
8.13	7.02	7.78
9.48	8.43	9.27

GAP (Plate 1)

8.67	7.99	8.15
7.06	7.43	6.95
7.58	6.07	6.76
7.65	6.52	6.34
6.96	6.26	6.58
6.61	5.45	5.95
6.71	5.39	6.10
6.91	6.25	6.22
6.86	5.08	5.49
6.12	5.54	5.89
6.46	5.15	6.24
6.89	5.45	6.34
6.63	5.58	6.11
7.61	6.28	6.97

GAP (Plate 17)

9.67	8.68	8.91
8.79	7.61	7.86
7.97	6.99	7.04
7.76	6.32	7.08
7.11	6.40	6.60
7.13	5.74	6.48
7.54	6.23	6.88
6.60	5.67	5.91
6.35	5.70	6.03
6.39	5.68	5.92
6.95	5.69	6.21
6.54	4.87	5.94
7.28	5.23	5.65
8.23	7.08	6.77

In Appendix A, more plate power distributions are given but they are presented taking into account that, in general, it is not possible to differentiate plate 1 from plate 17, 2 from 16, etc. after the first cycle. Hence, the results are given for averages of plates 1 and 17, 2 and 16, 3 and 15, 4 and 14, 5 and 13, 6 and 12, 7 and 11, 8 and 10, and for plate 9.

The power distributions in the appendix explicitly show the two outer transverse meshes even though it is known that the rotation of fuel elements will eliminate much of this asymmetry in plates that have undergone multiple cycles. Although only three points are given for the transverse power distribution, earlier analysis (Brown, 2014) has shown the smooth upwardly concave shape that is expected across the fuel plate.

The first set of results in Appendix A are for fresh fuel element A4. However, the more accurate details for A4 plates 1 and 17, and plates 2 and 16 at SU are given in the Figures 4-1 and 4-2 above. The results for plates 3-15 in A4 are averaged as explained above. Results are also given for a fuel element at SU at the center of the core, at position F3, at the beginning of its seventh cycle.[e] This is shown, because it is known that for those events that directly impact the inner plenum, such as the throttling of the valve feeding the inner plenum or a loss-of-coolant accident due to a pipe break impacting the inner plenum, the most limiting elements are in the inner core and will be those already having gone through six cycles (Diamond, 2014).

The third set of power densities shown in Appendix A are for the element at position F5—an 8-8 fuel element—at EOC before being discharged. This complements the results given in Appendix B (discussed below) for the fission density for fuel element F5, the element with the maximum local fission density.[f]

The results presented herein are with a composition model (900 composition zones) in the MCNP6.2 analysis that is far more detailed than the composition model (60 zones) that had been validated and used for the safety analysis submitted for license renewal of the HEU core (NIST, 2010). The effect of the composition model can be seen in Figure 4-1, which shows the calculated axial power distribution in the bottom half-element for the average of plates 1 and 17 and the two outer transverse meshes. The plot is for SU as an eight-cycle fuel element moves through the core—the index (D1, D7, etc.) indicates position in the core (as shown in Figure 3-1). In Figure 4-1 axial node 1 is next to the mid-plane water gap. Nodes 1, 2, and 3 all have different compositions (composition zones A, B, and C, respectively in Figure 3-4) for Cycles 2-8. At the beginning of the element's life (e.g., Cycles 1 and 2), the power density decreases from node 1 to node 3 due to the natural reduction of the neutron flux in the fuel plate moving away from the mid-plane water gap. However, near the end of the element life (e.g., Cycles 7 and 8), the power density increases from node 1 to node 3, because of the greater depletion of the fuel in the nodes closest to the mid-plane gap. The composition of the fuel material in node 4 is from composition zone D in Figure 3-4, which effectively averages the burnup of the fuel in nodes 4-12. Consequently, the burnup of the fuel material in node 4 of the neutronics model is underestimated, which results in an overprediction of the power density in that node for Cycles 2-8. This is particularly apparent for Cycles 5-8, which show a sharp rise in the calculated power density in node 4 relative to node 3.

[e] The corresponding fission density for this element is given in Appendix B. This element has an average burnup of 3.14×10^{21} fissions/cm^3 or 148 MWd.

[f] This element has an average burnup of 4.30×10^{21} fissions/cm^3 or 202 MWd.

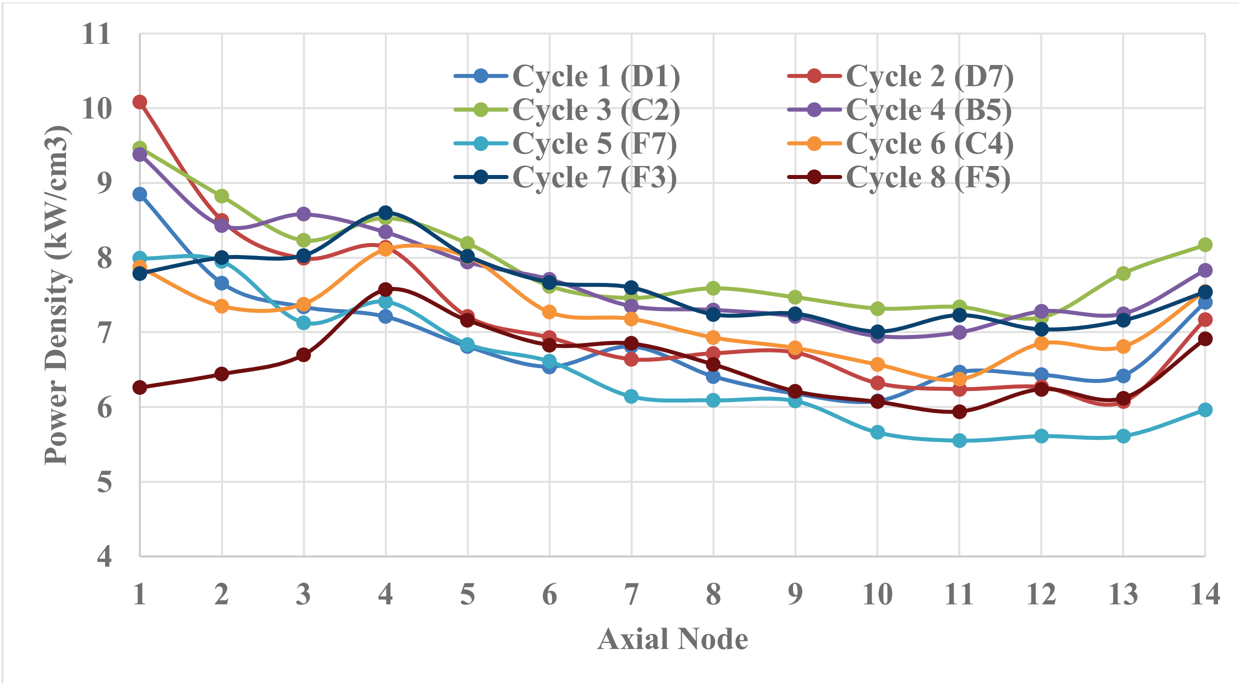


Figure 4-1 Axial Distribution of Power in Bottom Half-Element at SU along Outer Edge of Plates 1 and 17

5 Fission Density

The fission density is the integral of the fission rate (i.e., power) over time. To obtain the average fission density, note that the nominal fuel cycle length is 38.5 days, and two of the elements removed at the end of a cycle have been in the core for seven cycles and two have been in for eight cycles. Hence, the average time for a fuel element to be in the core is (7.5x38.5) = 288.75 days or 2.495×10^{7} seconds. The average fission rate density is obtained from the average power density knowing the average energy per fission. This number varies as the fissionable species in the fuel change with burnup. From the MCNP6.2 model, the value is 201.3 MeV/fission at the midpoint of the fuel cycle and this is assumed to be applicable in the analysis herein. Hence, the average fission rate density in the fuel is
$(5.30\times10^{3}$ W/cm$^{3})$ / [(201.3×10^{6} eV/fissions) (1.602×10^{-19} J/eV)] = 1.64×10^{14} fissions/s-cm^{3}.

The average fission density of all discharged fuel is then (1.64×10^{14} fissions/s-cm^{3}) × (2.50×10^{7} s) = 4.09×10^{21} fissions/cm^{3}. For the fuel elements that have been in the core for eight cycles, if it is assumed that they experience the average fission rate density, their average fission density at discharge would be (8/7.5) times the above value or 4.36×10^{21} fissions/cm^{3}.

The highest fission densities are in an 8-cycle fuel element before it is removed from the core and the maximum fission density within that element is expected to be at the edges, that is, in the outer transverse meshes, in the outer plates (plates 1 and 17), and facing the mid-plane water gap. The power peaks at these locations due to the additional moderator found there.

The fission density F^{i} in any mesh after one cycle (i) is calculated from:

$$F^{i} = \left(\frac{\kappa}{V}\right) \sum_{n} \bar{P}_n \Delta t_n$$

where

- $\bar{P}_n$ is the mesh power (MW)
- Δt_n is the time interval (days) for that power (explained below)
- κ is the conversion from MWd to fissions (2.679×10^{21} assuming 201.3 MeV/fission)
- V is the volume of a single mesh, 0.08814 cm^{3} (based on the ~2×2 cm mesh and assumed to be the appropriate size for assessing peak fission density)

The time steps used (n=1,3) are 1.5 days from SU to BOC, 17.5 days from BOC to MID, and 19.5 days from MID to EOC. The calculations to obtain the power for each of those intervals are done with different shim arm positions representing the average position for criticality during that interval. The fission density in a fuel element mesh as that element moves through eight fuel cycles is then the summation of F^{i} for i=1,8 cycles or, for the equilibrium core, at the fuel locations for an 8-1 element (position D1), an 8-2 element (position D7) an 8-3 element (position C2), … an 8-8 element (position F5). When calculating the fission density, the 180-degree symmetry is taken into account so that transverse regions 1 and 3 are averaged and plates 1 and 17 are averaged.

The spatial distribution of fission density in the 8-8 fuel element (position F5) being discharged is given in Appendix B. The maximum fission density is calculated to be 6.2×10^{21} fissions/cm^3. This occurs at both the top of the bottom half-element and the bottom of the top half-element (see Table B-1). The corresponding power density distribution is given in Appendix A (Table A-19 - Table A-27). The power is 4-5 kW/cm^3 at the locations where the fission density is highest. Appendix B also shows the fission density in the 8-7 fuel element (position F3) at SU (Table B-10 – Table B-18) corresponding to the power densities given in Appendix A for that element because of its importance as a limiting fuel element in certain accidents.

Figure 5-1 shows the axial distribution of fission density at EOC along the outer edge of the bottom half-element for the average of fuel plates 1 and 17. It is shown as the fuel element moves through the core. In this figure, axial node 1 is adjacent to the mid-plane water gap. The curves are much smoother than the power density curves due to the integration over time. It is observed that the calculated fission density at the end of Cycles 7 and 8 for axial node 4 is slightly larger than for node 3. This is due to an overprediction of the fission rate (power density) in axial node 4 due to the composition zoning employed in the MCNP6.2 model, as discussed at the end of Section 4.

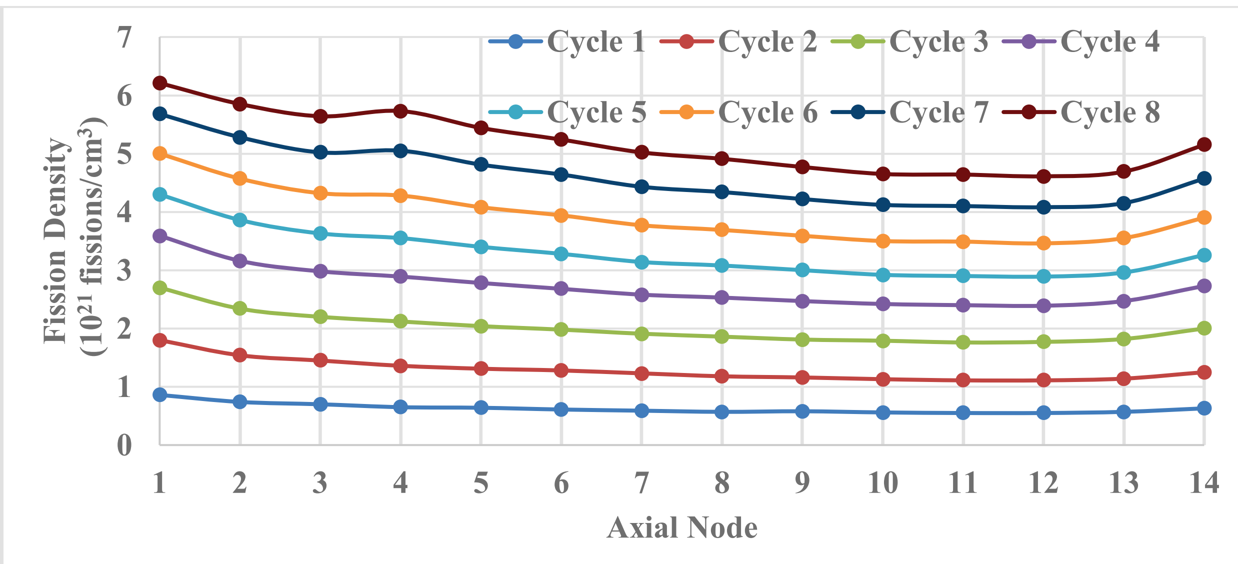


Figure 5-1 Axial Distribution of Fission Density in Bottom Half-Element along Outer Edge of Plates 1 and 17

6 Thermal-Hydraulic Parameters

There are six fuel elements with coolant from the inner plenum and 24 fuel elements with coolant from the outer plenum. The fuel element with the highest local power density is in the outer group—the hot spot peaking factor being 2.43 vs 2.40 in the inner group (Diamond, 2014), i.e., only ~1% difference. The element with the highest fission density reached is discharged from an inner group positon and the inner group has the highest flow rate and, hence, the more limiting condition.

The parameters of interest, for normal equilibrium operation at 20 MW, are given in Table 6-1. They are based on (Baek, 2014) and the analysis described therein. The data are for fuel elements in the inner group and take into account that 4% of total flow bypasses fuel element coolant channels. All coolant channel flow is within the effective coolant boundary shown in

Figure 2-3. Note that since the unfueled outside plates create an identical coolant channel to those on the inside, the data for coolant channels are 1/18th of fuel element values.

Table 6-1 Thermal Hydraulic Parameters for Inner LEU Fuel Elements

Parameter	Value
Fuel element coolant flowrate	368 gpm (0.02322 m^3/s)
Channel-averaged coolant flowrate	20.44 gpm (0.001290 m^3/s)
Channel-averaged inlet flow velocity	21.64 ft/s (6.595 m/s)
Coolant inlet temperature	100°F (37.8°C)
Flow area of single coolant channel	0.3031 in^2 (0.0001956 m^2)
Maximum cladding surface temperature	214°F (101°C)
Maximum fuel centerline temperature	233°F (112°C)

7 Summary of Key Results

Table 7-1 summarizes key parameters discussed in this report. Table 7-2 shows the geometry and material assumptions utilized in the safety analysis for the LEU core and supplements the data in Table 2-1. The source of the information is also given. Tolerances in the table are limiting values. Tolerances or uncertainties in geometric quantities for LEU fuel are generally the same as for the HEU fuel and are found on the drawings for LEU fuel elements (NCNR, 2020). For material quantities, for example, local fuel loading, the tolerance is expected to be as good as for HEU. However, these are preliminary evaluations and may be modified when more is known about fuel fabrication.

Table 7-1 Key Metrics

Parameter	Value
Average power density (kW/cm^3)	5.30
Maximum power density (kW/cm^3)	12.6
Average heat flux (W/cm^2)	57.2
Maximum heat flux (W/cm^2)	136
Fuel element coolant flowrate (m^3/s)	0.02322
Maximum cladding surface temperature (°C)	101
Average fission density (10^{21} fission/cm^3)	4.1
Maximum fission density (10^{21} fission/cm^3)	6.2

Table 7-2 Geometry and Material Assumptions

Parameter	LEU Analysis Assumes
Maximum channel width (at plate center)	116 ± 7 mil (same as HEU [1])
Average channel width	114 mil (same as HEU [2])
Minimum channel width for safety analysis	107.5 mil (same as HEU [2])
Plate thickness	50 mil (same as HEU [1])
Cladding thickness	19.8 mil [3]
Minimum cladding thickness	Bulk minclad 18 mil [3], not used
Cladding scratch maximum depth	< 2 mil (over fuel meat) [4], not used
Fuel meat	U-10Mo alloy with Mo 10 ± 1 w/o [4]
Fuel meat thickness	8.5 ± 1 mil [4]
U-235 enrichment	19.75 ± 0.20 w/o [4]
Average U-235 fuel loading (plate)	11.265 ± 0.24 g, (uncertainty based only on Mo and enrichment uncertainties in [4])
Bonding integrity	Debond characterization and tolerances to be determined
Local fuel homogeneousness	112% of nominal (same as HEU [1])
U-10Mo specific heat; U10Mo thermal conductivity	Values from [5] and [6]. Uncertainties are not available or not used.
References: 1. (NIST, 2010) 2. (Baek,2014) 3. (Diamond, 2018)	4. (INL, 2018) 5. (Rest, 2006) 6. (Burkes, 2010)

8 References

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APPENDIX A: POWER DENSITIES

The power densities in Tables A-1 to A-9 are for fuel element A4 at SU (fresh fuel).

Table A.1 Power Density (kW/cm^3) Fuel Element A4 (7-1W) Plates 1 and 17

TOP PLATE

3.52	2.85	2.01
3.28	2.05	2.34
2.96	2.46	2.25
3.34	2.52	2.45
3.68	2.82	2.77
3.82	3.05	3.36
3.83	3.24	3.91
4.50	4.03	4.57
4.91	4.48	5.24
5.34	5.11	6.02
6.14	5.63	5.87
6.92	6.20	6.87
7.80	6.98	7.33
9.63	8.95	9.63

Color Key
1.00
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BOTTOM PLATE

11.02	10.83	11.39
9.26	8.88	9.65
8.98	8.34	8.17
9.02	7.70	8.45
7.92	7.13	8.80
8.54	7.24	7.90
7.66	7.36	8.01
8.08	7.61	7.38
7.73	6.71	7.53
7.55	6.61	7.74
8.04	6.99	7.72
8.23	7.19	7.66
8.17	6.86	7.76
9.37	8.47	9.57

Table A.2 Power Density (kW/cm3) Fuel Element A4 (7-1W) Plates 2 and 16

TOP PLATE

2.68	2.16	1.96
2.64	2.13	1.83
2.67	1.99	1.87
2.72	2.08	1.84
3.01	2.35	2.35
3.46	2.73	2.86
3.56	3.14	3.07
3.96	3.06	3.99
4.41	3.79	4.37
4.67	4.13	4.72
5.21	4.36	5.25
5.81	4.93	5.71
7.23	6.00	6.61
8.58	8.15	8.35

BOTTOM PLATE

10.82	9.05	9.78
8.16	7.40	8.42
7.78	6.72	7.69
7.75	6.57	7.06
7.44	5.95	7.40
6.60	6.05	7.17
6.91	5.79	6.43
7.09	5.81	6.47
6.73	5.46	7.00
6.58	6.01	6.78
7.05	5.30	6.76
6.52	5.78	6.59
6.87	6.13	6.86
7.92	7.16	7.80

Table A.3 Power Density (kW/cm^3) Fuel Element A4 (7-1W) Plates 3 and 15

TOP PLATE

2.77	2.20	1.71
2.53	1.79	1.62
2.39	1.67	1.72
2.72	2.15	1.70
2.82	2.19	1.98
3.26	2.30	2.59
3.50	2.53	3.08
3.61	2.94	3.31
4.20	3.40	4.12
4.32	3.72	4.27
4.87	3.96	4.51
5.93	4.46	5.54
6.62	5.05	6.37
8.53	7.25	7.57

BOTTOM PLATE

9.29	8.26	8.98
8.03	6.10	7.71
7.15	5.67	6.84
6.60	5.94	6.64
6.63	5.36	6.55
6.30	5.48	6.18
6.49	5.25	6.30
6.24	5.45	6.43
6.16	5.06	6.19
5.87	5.09	5.89
6.17	4.86	5.78
6.15	5.05	6.14
6.29	5.33	6.28
7.66	7.01	7.46

Table A.4 Power Density (kW/cm^3) Fuel Element A4 (7-1W) Plates 4 and 14

TOP PLATE

2.54	1.87	1.84
2.27	1.56	1.47
2.26	1.70	1.65
2.45	1.76	1.45
2.78	1.86	2.06
2.95	2.28	2.34
2.84	2.49	2.75
3.28	2.81	3.25
3.66	2.99	3.70
3.86	3.47	4.19
4.45	3.60	4.48
4.94	4.28	4.95
5.98	4.66	6.10
7.79	6.31	7.59

BOTTOM PLATE

9.19	8.06	9.25
7.67	5.94	6.98
6.39	5.60	6.64
6.24	4.86	5.96
6.05	4.91	6.05
6.27	4.94	5.54
5.60	4.82	5.95
5.71	4.68	5.87
5.29	4.18	5.76
6.22	4.67	5.75
5.56	4.13	6.04
5.79	4.21	5.84
5.70	4.82	5.68
6.90	6.11	7.24

Table A.5 Power Density (kW/cm^3) Fuel Element A4 (7-1W) Plates 5 and 13

TOP PLATE

2.56	1.74	1.63
2.15	1.47	1.38
2.11	1.40	1.28
2.07	1.55	1.59
2.31	1.78	1.72
2.55	1.99	2.23
3.09	2.51	2.81
3.35	2.65	3.31
3.42	2.50	3.41
3.94	3.16	4.13
4.19	3.29	4.32
4.95	3.88	4.89
5.70	4.21	5.80
8.11	6.27	7.59

BOTTOM PLATE

8.95	7.50	8.16
6.37	5.49	6.63
6.24	4.93	5.82
6.57	4.44	5.77
6.03	4.64	5.79
5.57	4.58	5.44
5.60	4.33	5.25
5.23	4.01	5.33
5.63	4.28	5.38
5.74	4.20	5.41
5.08	4.18	5.47
5.54	3.96	5.57
6.11	4.26	5.52
7.06	5.98	7.19

Table A.6 Power Density (kW/cm^3) Fuel Element A4 (7-1W) Plates 6 and 12

TOP PLATE

2.39	1.79	1.65
2.13	1.47	1.37
2.26	1.35	1.67
2.21	1.35	1.43
2.16	1.82	1.88
2.61	1.97	2.13
2.90	1.96	2.70
3.22	2.42	2.81
3.63	2.80	3.30
3.87	2.66	3.72
3.96	3.24	4.15
4.87	3.51	4.65
5.55	4.43	5.49
7.52	6.49	7.57

BOTTOM PLATE

9.17	7.76	8.27
6.91	5.07	6.78
6.25	4.90	6.19
6.01	4.18	5.47
5.80	4.34	5.26
5.63	4.33	5.48
5.23	4.49	5.62
5.45	4.21	5.10
5.29	3.89	5.40
4.98	4.23	4.79
5.23	4.40	5.09
4.99	4.36	4.99
5.72	4.17	5.42
6.77	6.11	6.91

Table A.7 Power Density (kW/cm^3) Fuel Element A4 (7-1W) Plates 7 and 11

TOP PLATE

2.32	1.68	1.57
2.41	1.24	1.22
2.03	1.35	1.21
2.32	1.46	1.52
2.32	1.53	1.61
2.48	1.79	2.17
2.64	2.03	2.55
3.09	2.16	3.03
3.34	2.35	3.29
3.62	2.73	3.68
3.83	3.15	3.83
4.51	3.37	4.61
5.20	4.07	5.18
7.14	6.69	7.36

BOTTOM PLATE

8.61	7.35	8.39
6.39	5.24	6.35
6.25	4.47	5.88
5.72	4.15	5.44
5.73	4.45	5.36
5.17	3.73	5.39
5.54	4.23	5.08
5.03	4.38	5.30
4.98	3.67	4.79
5.19	3.79	5.16
5.21	4.03	5.16
5.20	3.88	5.02
5.91	4.24	5.21
6.60	6.01	6.62

Table A.8 Power Density (kW/cm^3) Fuel Element A4 (7-1W) Plates 8 and 10

TOP PLATE

2.36	1.65	1.40
2.00	1.66	1.21
2.08	1.22	1.06
1.92	1.44	1.47
2.29	1.62	1.81
2.46	1.74	2.07
2.90	1.96	2.32
3.05	2.19	2.68
3.41	2.53	3.36
3.80	2.77	3.52
4.21	2.95	3.96
4.44	3.39	4.12
5.18	3.87	5.59
7.31	6.48	6.72

BOTTOM PLATE

8.61	6.94	8.20
6.71	4.99	6.38
5.82	4.49	6.15
5.57	3.92	5.70
5.55	3.80	5.40
5.33	4.54	5.34
5.53	3.88	5.07
5.22	3.75	4.87
4.79	3.81	4.98
5.12	3.63	5.12
5.28	3.65	5.19
5.29	3.54	4.92
5.52	4.27	5.23
6.45	5.47	7.02

Table A.9 Power Density (kW/cm^3) Fuel Element A4 (7-1W) Plate 9

TOP PLATE

2.09	1.98	1.59
1.97	1.17	1.23
2.05	1.30	1.07
2.17	1.65	1.42
2.12	1.33	1.68
2.46	1.61	1.98
2.70	1.88	2.42
2.83	2.16	2.58
3.19	2.42	3.40
3.88	3.02	3.82
3.75	3.07	3.90
4.74	3.71	4.32
5.05	4.04	5.02
6.46	6.59	6.88

BOTTOM PLATE

8.72	7.43	8.53
6.71	5.02	5.93
5.85	4.42	6.01
5.00	4.03	5.44
5.54	3.74	5.49
5.28	4.60	5.45
5.23	3.71	5.03
4.90	4.10	4.96
4.90	3.60	5.11
4.83	3.62	4.99
4.25	3.29	5.39
5.37	3.41	4.71
5.21	4.11	5.55
6.75	5.77	6.38

The power densities in Tables A-10 to A-18 are for fuel element F3 at SU after six cycles.

Table A.10 Power Density (kW/cm^3) Fuel Element F3 (8-7W) Plates 1 and 17

TOP PLATE

3.80	3.75	3.92
3.72	3.54	4.21
4.16	4.23	4.27
4.55	4.20	4.65
5.08	4.53	5.31
5.24	4.94	5.28
5.56	4.89	5.88
6.17	5.30	6.32
6.34	6.01	6.06
6.93	6.36	6.59
7.39	6.93	7.14
7.22	6.19	6.71
7.19	6.61	7.71
7.08	6.75	7.70

Color Key
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00

BOTTOM PLATE

7.66	7.27	7.92
7.98	7.72	8.01
8.41	6.90	7.64
8.75	8.07	8.45
8.18	7.27	7.86
7.72	7.07	7.63
7.89	6.80	7.31
7.66	7.11	6.82
7.43	6.95	7.08
7.42	6.59	6.61
7.52	6.42	6.93
7.00	6.57	7.08
7.19	6.81	7.12
7.70	7.53	7.38

Table A.11 Power Density (kW/cm^3) Fuel Element F3 (8-7W) Plates 2 and 16

TOP PLATE

3.46	3.00	4.23
3.79	3.60	3.89
4.00	3.46	4.16
4.59	3.88	4.64
4.99	4.42	4.87
5.08	4.29	4.91
5.50	4.59	5.42
5.84	5.06	5.49
5.89	5.35	5.94
6.35	5.46	6.40
7.11	5.92	6.95
7.14	5.95	6.64
7.49	6.47	7.11
7.41	6.66	7.16

BOTTOM PLATE

7.62	7.42	7.66
7.69	7.18	7.63
7.56	7.54	8.01
8.04	7.60	8.26
7.81	7.13	7.86
7.30	6.47	7.42
7.35	6.94	7.44
7.21	6.06	7.16
7.11	6.18	7.14
6.93	5.84	6.96
6.65	6.14	6.16
6.75	5.81	6.55
7.42	6.27	6.30
7.68	7.17	7.51

Table A.12 Power Density (kW/cm^3) Fuel Element F3 (8-7W) Plates 3 and 15

TOP PLATE

3.63	3.57	3.78
3.77	3.68	4.47
4.05	3.61	4.44
4.63	4.28	4.93
4.82	4.62	5.01
5.18	4.73	5.04
5.99	5.04	5.76
5.87	4.89	6.27
5.77	5.53	6.33
6.67	5.94	6.71
7.47	6.13	7.19
7.81	6.32	7.44
7.73	7.39	7.77
8.22	7.32	7.91

BOTTOM PLATE

8.37	8.01	8.04
8.44	7.43	7.94
8.51	7.41	8.29
8.90	7.28	8.34
8.36	6.86	7.94
8.21	6.66	7.85
7.73	6.93	7.35
7.66	6.67	7.66
7.84	6.68	7.19
7.50	6.20	6.91
7.00	5.99	6.86
7.11	6.22	7.34
6.86	6.48	6.97
8.37	6.69	7.88

Table A.13 Power Density (kW/cm^3) Fuel Element F3 (8-7W) Plates 4 and 14

TOP PLATE

3.35	3.53	3.82
3.58	3.11	3.88
4.12	3.57	4.15
4.08	3.60	4.83
4.71	4.04	4.88
5.21	4.53	4.79
5.47	4.41	5.39
5.55	4.90	5.76
6.07	5.01	6.00
6.20	5.56	6.21
6.92	5.90	6.69
7.40	5.70	6.94
7.62	6.23	7.49
8.29	7.10	7.99

BOTTOM PLATE

8.24	7.79	8.34
8.49	7.23	7.68
8.10	6.99	7.79
8.62	7.29	8.07
7.89	6.23	7.76
7.52	6.28	7.50
7.56	6.17	7.06
6.82	5.92	7.28
7.30	5.90	6.77
6.37	5.92	6.65
6.84	5.27	6.50
6.40	5.53	6.36
6.97	5.70	6.61
7.60	6.56	7.47

Table A.14 Power Density (kW/cm^3) Fuel Element F3 (8-7W) Plates 5 and 13

TOP PLATE

3.36	3.54	3.89
3.41	3.14	3.45
4.08	3.60	4.05
4.03	3.54	3.98
4.53	3.79	4.89
4.67	4.04	4.87
5.32	4.01	5.34
5.78	4.64	5.70
5.82	4.50	5.45
6.07	5.34	6.30
6.64	5.73	6.43
6.89	5.79	6.66
7.23	6.35	6.95
7.64	6.97	6.94

BOTTOM PLATE

8.02	7.07	8.24
7.64	6.99	7.43
7.73	6.58	7.59
8.03	6.40	8.04
7.83	5.96	7.05
7.08	6.21	6.96
6.52	5.98	6.69
6.91	5.55	6.39
6.70	5.61	6.37
6.42	5.53	6.49
6.29	5.65	6.05
6.79	5.36	6.41
5.93	5.69	6.60
7.24	6.63	7.28

Table A.15 Power Density (kW/cm^3) Fuel Element F3 (8-7W) Plates 6 and 12

TOP PLATE

3.29	3.33	3.59
3.42	2.81	3.83
3.73	3.03	3.73
4.04	3.59	4.24
4.33	3.32	4.20
4.30	4.08	4.84
5.05	4.03	4.94
4.94	4.19	5.21
5.65	4.51	5.60
5.93	4.81	6.19
6.59	5.56	6.35
6.67	5.25	6.56
7.05	6.61	7.01
7.45	6.80	7.20

BOTTOM PLATE

7.90	7.35	7.64
7.75	6.91	7.75
7.63	6.38	7.35
7.96	6.30	7.48
7.37	5.66	6.85
7.45	5.58	6.41
7.28	5.65	6.71
7.13	5.68	6.64
6.64	5.67	5.78
6.62	5.15	6.36
6.19	5.31	6.02
6.29	5.10	5.97
6.44	5.13	6.06
7.17	6.46	6.91

Table A.16 Power Density (kW/cm^3) Fuel Element F3 (8-7W) Plates 7 and 11

TOP PLATE

3.50	3.04	3.77
3.47	2.93	3.40
3.86	3.34	3.84
3.88	3.25	4.21
4.25	3.47	4.07
4.75	3.83	4.60
4.46	3.91	5.12
5.24	3.81	4.79
5.37	4.41	5.60
5.85	4.61	6.08
6.50	5.58	6.26
6.47	5.34	6.59
7.17	6.17	6.41
7.36	6.84	7.51

BOTTOM PLATE

8.05	6.68	7.65
8.08	6.38	7.04
7.28	5.91	7.42
7.42	6.16	7.15
7.45	5.80	6.91
7.02	5.70	6.30
6.74	5.14	5.98
6.70	5.01	6.21
6.64	4.85	6.38
5.99	5.24	6.26
6.16	5.22	5.96
5.98	4.98	6.19
6.57	5.23	6.04
7.52	6.06	7.31

Table A.17 Power Density (kW/cm^3) Fuel Element F3 (8-7W) Plates 8 and 10

TOP PLATE

3.09	3.18	3.53
3.34	2.83	3.76
3.55	2.87	4.05
4.02	3.21	4.25
4.38	3.63	4.17
4.75	3.80	4.81
5.08	4.07	5.21
5.28	4.09	5.33
5.28	4.65	5.48
6.13	4.81	5.81
6.75	4.89	5.90
6.68	5.12	6.43
6.59	5.96	6.31
6.84	6.22	7.36

BOTTOM PLATE

7.91	7.44	7.28
7.64	6.48	7.45
7.50	6.02	7.35
7.43	6.18	7.23
7.20	5.54	6.60
7.13	5.67	6.65
6.55	5.22	6.38
6.28	5.35	6.11
6.20	4.83	6.46
5.86	4.96	5.86
5.93	4.91	6.21
6.43	5.12	5.81
6.13	4.99	6.27
7.14	6.34	6.95

Table A.18 Power Density (kW/cm^3) Fuel Element F3 (8-7W) Plate 9

TOP PLATE

3.27	2.91	3.11
2.99	2.98	3.51
3.34	2.98	4.41
4.36	3.32	4.55
4.26	3.26	4.04
4.47	3.70	4.34
4.92	3.69	4.94
5.23	4.05	5.36
5.73	4.49	5.81
6.15	4.61	5.93
6.44	5.09	6.30
6.74	5.58	6.00
7.41	6.09	5.99
6.96	6.00	7.52

BOTTOM PLATE

8.16	7.40	7.74
6.81	6.27	7.90
7.38	5.62	6.77
7.73	6.03	7.68
7.45	5.39	6.69
6.89	4.88	7.00
7.04	5.29	6.33
6.70	5.03	6.04
6.52	4.93	6.56
5.99	4.76	5.69
6.01	5.02	6.19
6.10	5.06	6.03
6.22	5.35	5.72
6.73	5.59	7.32

The power densities in Tables A-19 to A-27 are for fuel element F5 at EOC after eight cycles.

Table A.19 Power Density (kW/cm^3) Fuel Element F5 (8-8W) Plates 1 and 17

TOP PLATE

6.15	5.91	5.89
5.40	5.33	5.81
5.60	5.14	5.52
5.45	5.04	5.63
5.24	5.05	5.21
5.16	4.93	5.43
5.69	5.24	5.92
5.68	5.15	5.56
5.44	5.45	6.08
6.03	5.65	6.14
6.33	5.93	6.90
5.52	5.20	5.44
5.03	5.41	5.19
4.93	4.39	4.57

Color Key
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00

BOTTOM PLATE

4.42	4.32	4.75
4.97	4.52	4.84
5.20	4.56	5.55
6.23	5.48	6.10
5.58	5.27	5.74
5.46	5.28	5.48
5.11	5.02	5.47
4.70	4.51	5.11
4.76	4.46	4.65
4.28	4.53	4.55
4.69	4.63	4.58
4.28	3.95	5.08
4.31	4.24	4.67
4.62	4.80	5.20

Table A.20 Power Density (kW/cm^3) Fuel Element F5 (8-8W) Plates 2 and 16

TOP PLATE

5.85	5.46	5.84
5.44	5.05	5.42
5.20	4.96	5.44
5.28	4.73	5.40
4.82	4.73	5.43
5.13	4.63	5.31
5.29	4.96	5.44
5.13	5.26	5.62
5.35	5.31	5.85
5.96	5.48	6.16
6.57	5.50	6.56
5.43	4.93	5.54
5.18	4.82	5.36
4.46	4.64	5.07

BOTTOM PLATE

4.65	4.49	4.51
4.96	4.69	5.14
5.24	4.75	5.38
5.74	5.55	6.15
5.72	5.22	5.77
5.08	4.71	5.17
5.01	4.39	5.02
5.02	4.60	4.82
4.53	4.29	4.91
4.88	4.09	4.70
4.57	4.16	4.69
4.69	3.86	4.44
4.66	4.28	4.81
4.81	4.47	5.08

Table A.21 Power Density (kW/cm^3) Fuel Element F5 (8-8W) Plates 3 and 15

TOP PLATE

6.77	5.90	6.53
5.88	5.28	5.95
6.07	5.15	6.06
5.70	5.50	6.00
5.69	5.25	6.17
5.73	5.34	6.36
6.11	5.46	6.54
6.13	5.70	6.70
6.76	5.65	6.53
6.83	5.55	7.07
7.20	6.27	7.36
6.90	5.38	6.50
6.45	5.78	5.84
5.74	5.38	5.98

BOTTOM PLATE

5.20	5.12	5.56
5.43	5.24	5.80
6.32	5.43	6.57
6.47	6.01	6.89
6.06	5.57	6.48
5.79	4.90	6.09
5.76	5.16	5.41
5.45	5.11	5.93
5.30	5.02	5.76
5.68	4.91	5.52
5.37	4.59	5.14
5.04	4.54	5.12
5.03	4.55	5.29
5.07	5.08	5.56

Table A.22 Power Density (kW/cm^3) Fuel Element F5 (8-8W) Plates 4 and 14

TOP PLATE

6.63	5.73	6.82
5.73	5.05	5.90
5.76	5.17	5.55
5.36	4.77	5.55
5.40	4.94	5.48
5.90	5.13	5.84
5.70	5.27	6.04
5.58	5.05	6.23
6.26	5.69	6.33
6.45	5.93	6.46
7.03	6.39	6.82
6.26	5.65	6.65
6.05	5.45	6.03
5.29	5.21	5.88

BOTTOM PLATE

5.25	4.87	5.24
5.60	5.29	5.39
6.02	5.00	6.38
6.42	5.78	6.60
5.74	5.23	6.10
5.92	4.61	5.31
5.55	4.64	5.61
5.01	4.84	5.49
5.03	4.20	5.04
4.90	4.39	4.85
4.60	4.47	4.95
4.58	4.20	4.92
4.53	4.29	4.67
5.27	5.19	5.56

Table A.23 Power Density (kW/cm^3) Fuel Element F5 (8-8W) Plates 5 and 13

TOP PLATE

6.10	5.52	6.76
5.47	5.00	5.72
5.05	4.86	5.55
5.34	4.38	5.34
5.30	4.96	5.52
5.29	4.64	5.60
5.80	4.66	5.74
5.59	4.99	5.97
5.65	5.32	5.98
6.61	5.63	6.53
6.65	5.94	6.71
5.93	5.15	6.25
5.93	5.15	5.80
5.03	4.91	5.56

BOTTOM PLATE

5.08	4.85	5.10
5.47	4.88	5.77
5.83	5.12	6.19
6.26	5.39	6.39
5.63	4.71	6.00
5.23	4.41	5.32
5.05	4.54	4.95
4.84	4.10	4.94
4.62	4.14	5.00
4.57	3.68	4.91
4.49	4.04	4.63
4.98	3.93	4.99
4.32	3.92	4.78
5.40	4.76	4.78

Table A.24 Power Density (kW/cm^3) Fuel Element F5 (8-8W) Plates 6 and 12

TOP PLATE

6.11	5.34	5.70
5.32	4.54	5.80
5.29	4.66	5.34
5.79	4.73	5.22
5.08	4.30	5.43
5.26	4.48	5.46
5.90	4.77	5.94
5.66	4.98	5.78
5.79	5.11	6.07
6.13	4.87	6.32
6.62	5.29	6.41
6.43	5.03	6.02
5.70	5.24	6.02
5.33	4.81	5.56

BOTTOM PLATE

5.17	4.49	5.06
5.99	5.08	5.36
5.50	5.09	5.60
5.60	5.38	6.21
5.66	4.72	5.47
5.20	4.24	5.32
4.96	4.67	5.12
4.98	4.24	4.90
4.75	4.07	5.04
4.63	3.97	4.49
4.81	4.01	4.95
4.53	3.73	4.47
4.45	3.79	4.48
5.20	4.68	5.33

Table A.25 Power Density (kW/cm^3) Fuel Element F5 (8-8W) Plates 7 and 11

TOP PLATE

6.01	5.58	6.08
5.45	4.53	4.98
5.07	4.47	5.04
4.85	4.08	5.47
5.02	4.58	5.19
5.02	4.30	5.39
5.41	4.43	5.28
5.49	4.97	5.40
5.86	4.82	5.74
5.78	5.03	6.04
6.47	5.27	6.53
5.67	5.15	5.90
5.22	4.86	5.50
5.14	5.07	5.74

BOTTOM PLATE

5.05	4.80	5.12
5.40	4.76	5.37
5.83	4.61	5.59
6.12	5.30	6.21
5.43	4.74	5.69
5.10	4.30	5.38
4.89	4.39	5.20
5.03	3.62	4.88
4.81	4.18	4.99
4.31	3.76	4.70
4.32	4.05	4.80
4.25	3.67	4.67
4.63	3.69	4.72
4.64	4.46	4.94

Table A.26 Power Density (kW/cm^3) Fuel Element F5 (8-8W) Plates 8 and 10

TOP PLATE

6.07	5.49	6.24
5.11	4.66	5.43
5.51	4.01	5.50
4.92	4.39	5.23
5.02	4.28	4.97
4.85	4.84	5.11
5.38	4.39	5.38
5.50	4.61	5.63
5.08	4.82	5.54
6.06	4.84	6.07
6.09	5.68	6.29
5.60	5.26	6.01
5.66	4.96	5.50
5.23	4.92	5.30

BOTTOM PLATE

4.94	4.59	5.25
5.11	4.77	5.60
5.46	4.76	5.63
5.49	4.87	5.91
5.64	4.84	5.36
4.76	4.23	5.31
4.97	4.19	5.25
4.72	4.12	4.54
4.29	4.27	4.64
4.51	3.84	4.29
4.31	3.90	4.53
4.26	3.73	4.55
4.34	3.77	4.31
5.17	4.49	5.02

Table A.27 Power Density (kW/cm^3) Fuel Element F5 (8-8W) Plate 9

TOP PLATE

5.64	5.47	5.67
5.54	4.24	5.68
4.98	4.29	5.14
4.96	4.32	4.99
4.80	4.13	5.15
5.24	4.33	5.05
5.05	4.42	5.24
5.10	4.74	5.67
5.26	4.14	5.18
6.07	5.08	5.98
6.10	5.44	6.04
5.87	5.39	6.11
5.54	4.96	5.53
4.97	5.16	5.30

BOTTOM PLATE

5.21	5.24	5.52
5.23	4.58	5.33
5.33	4.81	6.06
5.43	4.94	5.85
5.45	4.12	5.87
4.44	3.75	5.29
4.49	4.06	5.15
4.61	4.02	4.72
4.62	4.21	4.92
4.73	3.79	4.54
4.33	3.46	4.92
4.34	3.71	4.90
4.33	3.16	4.12
4.48	4.60	5.14

APPENDIX B: FISSION DENSITIES

The fission densities in Tables B-1 to B-9 are for fuel element F5 at EOC (after eight cycles).

Table B.1 Fission Density (10^{21} fissions/cm^3) Fuel Element F5 (8-8W) Plates 1 and 17

TOP PLATE

5.10	4.73	5.07
4.70	4.23	4.64
4.69	4.15	4.58
4.66	4.18	4.60
4.75	4.23	4.70
4.89	4.34	4.76
4.93	4.42	4.90
5.06	4.54	4.98
5.32	4.70	5.19
5.49	4.91	5.39
5.74	5.17	5.69
5.70	5.07	5.52
5.95	5.33	5.80
6.29	5.82	6.17

Color Key
1.00
2.00
3.00
4.00
5.00
6.00
7.00

BOTTOM PLATE

6.29	5.80	6.13
5.89	5.39	5.81
5.69	5.12	5.59
5.80	5.15	5.66
5.48	4.93	5.40
5.27	4.72	5.22
5.07	4.59	4.98
4.96	4.42	4.87
4.78	4.32	4.76
4.67	4.22	4.63
4.63	4.18	4.64
4.61	4.20	4.60
4.71	4.24	4.68
5.15	4.80	5.14

Table B.2 Fission Density (10^{21} fissions/cm^3) Fuel Element F5 (8-8W) Plates 2 and 16

TOP PLATE

4.82	4.40	4.79
4.34	3.78	4.32
4.34	3.79	4.28
4.31	3.76	4.25
4.43	3.81	4.30
4.46	3.83	4.39
4.59	3.97	4.51
4.68	4.09	4.63
4.89	4.23	4.79
5.09	4.38	4.99
5.39	4.62	5.26
5.31	4.68	5.21
5.53	4.92	5.44
6.08	5.55	5.94

BOTTOM PLATE

6.05	5.54	5.87
5.55	4.94	5.42
5.36	4.64	5.23
5.35	4.68	5.30
5.11	4.42	5.01
4.92	4.22	4.81
4.75	4.08	4.65
4.58	3.98	4.57
4.45	3.88	4.41
4.35	3.81	4.33
4.33	3.74	4.26
4.30	3.73	4.22
4.35	3.83	4.30
4.86	4.48	4.86

Table B.3 Fission Density (10^{21} fissions/cm^3) Fuel Element F5 (8-8W) Plates 3 and 15

TOP PLATE

4.86	4.33	4.87
4.32	3.67	4.25
4.29	3.64	4.26
4.27	3.64	4.28
4.39	3.65	4.32
4.46	3.78	4.35
4.61	3.84	4.52
4.74	3.92	4.64
4.86	4.13	4.78
5.07	4.28	5.01
5.39	4.50	5.24
5.46	4.64	5.31
5.67	4.92	5.57
6.15	5.64	6.11

BOTTOM PLATE

6.27	5.62	6.10
5.71	4.93	5.59
5.43	4.62	5.37
5.44	4.55	5.32
5.10	4.28	5.02
4.87	4.13	4.80
4.67	3.96	4.68
4.57	3.84	4.50
4.43	3.76	4.44
4.36	3.66	4.32
4.24	3.61	4.23
4.32	3.63	4.25
4.29	3.70	4.35
4.89	4.44	4.96

Table B.4 Fission Density (10^{21} fissions/cm^3) Fuel Element F5 (8-8W) Plates 4 and 14

TOP PLATE

4.68	4.15	4.62
4.05	3.42	3.98
4.06	3.32	4.00
4.05	3.36	4.01
4.09	3.39	4.02
4.21	3.41	4.12
4.29	3.52	4.24
4.43	3.60	4.34
4.56	3.75	4.48
4.77	3.90	4.66
5.02	4.17	4.94
5.09	4.23	5.02
5.40	4.59	5.33
6.00	5.32	5.89

BOTTOM PLATE

6.04	5.32	5.87
5.43	4.62	5.31
5.13	4.23	5.04
5.07	4.18	4.98
4.82	3.92	4.72
4.60	3.76	4.54
4.42	3.65	4.37
4.28	3.54	4.23
4.14	3.43	4.13
4.06	3.35	4.04
4.01	3.32	4.03
4.02	3.34	4.00
4.02	3.43	4.04
4.63	4.19	4.70

Table B.5 Fission Density (10^{21} fissions/cm^3) Fuel Element F5 (8-8W) Plates 5 and 13

TOP PLATE

4.55	3.97	4.52
3.92	3.21	3.88
3.87	3.12	3.86
3.89	3.09	3.82
3.92	3.16	3.83
3.96	3.23	3.97
4.08	3.31	4.05
4.25	3.40	4.17
4.38	3.53	4.27
4.54	3.63	4.42
4.82	3.87	4.73
4.88	4.01	4.78
5.18	4.33	5.09
5.82	5.13	5.70

BOTTOM PLATE

5.84	5.16	5.70
5.24	4.31	5.13
4.94	4.01	4.88
4.80	3.89	4.75
4.61	3.68	4.50
4.43	3.52	4.30
4.21	3.40	4.14
4.09	3.30	4.01
3.99	3.20	3.95
3.85	3.17	3.88
3.83	3.08	3.81
3.83	3.09	3.81
3.92	3.22	3.87
4.55	3.98	4.57

Table B.6 Fission Density (10^{21} fissions/cm^3) Fuel Element F5 (8-8W) Plates 6 and 12

TOP PLATE

4.43	3.86	4.40
3.78	3.07	3.73
3.73	2.99	3.71
3.72	2.97	3.67
3.78	3.02	3.76
3.88	3.08	3.83
3.94	3.13	3.86
4.04	3.23	4.04
4.20	3.37	4.16
4.38	3.47	4.29
4.65	3.75	4.56
4.74	3.82	4.65
5.02	4.16	4.96
5.73	5.04	5.63

BOTTOM PLATE

5.75	5.02	5.59
5.03	4.15	4.97
4.71	3.84	4.65
4.66	3.72	4.61
4.43	3.52	4.32
4.23	3.34	4.15
4.07	3.26	4.02
3.93	3.16	3.92
3.86	3.04	3.83
3.75	3.00	3.72
3.74	2.95	3.68
3.69	2.97	3.71
3.75	3.06	3.79
4.46	3.88	4.46

Table B.7 Fission Density (10^{21} fissions/cm^3) Fuel Element F5 (8-8W) Plates 7 and 11

TOP PLATE

4.43	3.74	4.38
3.72	2.96	3.62
3.67	2.90	3.59
3.66	2.86	3.62
3.68	2.90	3.64
3.79	2.98	3.70
3.86	3.01	3.82
4.06	3.14	3.94
4.14	3.23	4.07
4.30	3.37	4.22
4.53	3.62	4.45
4.60	3.67	4.52
4.95	4.09	4.87
5.72	4.93	5.55

BOTTOM PLATE

5.65	4.97	5.57
4.97	4.05	4.85
4.64	3.70	4.55
4.59	3.56	4.47
4.32	3.39	4.24
4.16	3.25	4.09
3.99	3.13	3.97
3.89	3.06	3.83
3.78	2.98	3.72
3.67	2.93	3.67
3.61	2.86	3.61
3.62	2.87	3.66
3.70	3.01	3.68
4.40	3.81	4.44

Table B.8 Fission Density (10^{21} fissions/cm^3) Fuel Element F5 (8-8W) Plates 8 and 10

TOP PLATE

4.38	3.73	4.35
3.65	2.93	3.62
3.63	2.87	3.60
3.59	2.83	3.56
3.69	2.83	3.63
3.76	2.92	3.68
3.81	2.99	3.74
3.90	3.03	3.86
4.08	3.21	4.02
4.27	3.27	4.17
4.50	3.52	4.41
4.56	3.65	4.49
4.92	3.98	4.81
5.67	4.97	5.51

BOTTOM PLATE

5.61	4.94	5.49
4.90	4.02	4.84
4.62	3.65	4.50
4.46	3.50	4.41
4.23	3.37	4.23
4.10	3.17	4.03
3.96	3.08	3.86
3.80	2.95	3.82
3.72	2.88	3.68
3.64	2.84	3.58
3.59	2.77	3.58
3.59	2.85	3.55
3.66	2.93	3.64
4.39	3.80	4.37

Table B.9 Fission Density (10^{21} fissions/cm^3) Fuel Element F5 (8-8W) Plate 9

TOP PLATE

4.38	3.72	4.32
3.63	2.95	3.59
3.61	2.81	3.56
3.58	2.77	3.53
3.62	2.81	3.58
3.71	2.83	3.67
3.81	2.95	3.70
3.91	3.04	3.85
4.08	3.20	4.03
4.26	3.27	4.09
4.47	3.50	4.38
4.58	3.63	4.45
4.92	3.95	4.87
5.63	4.97	5.52

BOTTOM PLATE

5.58	4.96	5.55
4.92	4.00	4.78
4.58	3.67	4.53
4.48	3.51	4.37
4.21	3.24	4.18
4.07	3.16	3.99
3.91	3.04	3.87
3.78	2.94	3.75
3.71	2.94	3.69
3.65	2.85	3.64
3.58	2.78	3.51
3.60	2.79	3.64
3.62	2.90	3.64
4.34	3.72	4.34

The fission densities in Tables B-10 to B-18 are for fuel element F3 at SU after six cycles.

Table B.10 Fission Density (10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 1 and 17

TOP PLATE			Color Key	BOTTOM PLATE		
3.96	3.66	3.92	1.00	5.08	4.66	4.92
3.66	3.23	3.55	2.00	4.61	4.21	4.54
3.62	3.15	3.51	3.00	4.36	3.89	4.28
3.58	3.17	3.49	4.00	4.35	3.84	4.22
3.63	3.21	3.56	5.00	4.13	3.68	4.04
3.72	3.29	3.58	6.00	3.98	3.50	3.90
3.76	3.35	3.69		3.82	3.43	3.73
3.84	3.41	3.73		3.74	3.31	3.64
4.02	3.52	3.89		3.60	3.22	3.58
4.15	3.65	4.04		3.53	3.17	3.47
4.30	3.87	4.24		3.49	3.10	3.48
4.40	3.86	4.22		3.47	3.15	3.46
4.67	4.15	4.50		3.55	3.19	3.54
5.05	4.64	4.93		3.90	3.63	3.90

Table B.11 Fission Density (10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 2 and 16

TOP PLATE			BOTTOM PLATE		
3.70	3.37	3.66	4.80	4.36	4.66
3.30	2.84	3.26	4.27	3.78	4.17
3.29	2.82	3.23	4.05	3.46	3.92
3.26	2.80	3.20	3.95	3.42	3.89
3.34	2.83	3.22	3.79	3.23	3.71
3.35	2.84	3.25	3.65	3.09	3.55
3.43	2.93	3.33	3.50	2.99	3.43
3.48	3.01	3.42	3.40	2.93	3.39
3.64	3.11	3.52	3.31	2.84	3.26
3.77	3.21	3.68	3.22	2.80	3.21
4.00	3.37	3.85	3.22	2.74	3.14
4.03	3.47	3.90	3.18	2.73	3.12
4.28	3.75	4.16	3.25	2.80	3.18
4.83	4.37	4.69	3.63	3.34	3.65

Table B.12 Fission Density (10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 3 and 15

TOP PLATE

3.66	3.23	3.60
3.22	2.68	3.13
3.14	2.62	3.10
3.12	2.62	3.10
3.20	2.62	3.13
3.25	2.72	3.13
3.34	2.73	3.23
3.44	2.78	3.32
3.49	2.93	3.41
3.63	3.02	3.55
3.86	3.16	3.71
3.97	3.32	3.84
4.24	3.59	4.11
4.77	4.34	4.71

BOTTOM PLATE

4.85	4.31	4.70
4.26	3.63	4.16
3.94	3.29	3.89
3.88	3.18	3.78
3.66	3.02	3.57
3.50	2.92	3.42
3.34	2.80	3.34
3.29	2.71	3.22
3.19	2.67	3.17
3.13	2.59	3.07
3.03	2.56	3.01
3.11	2.56	3.04
3.11	2.66	3.15
3.56	3.22	3.63

Table B.13 Fission Density (10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 4 and 14

TOP PLATE

3.50	3.07	3.45
3.00	2.49	2.92
2.97	2.37	2.89
2.95	2.39	2.90
2.99	2.41	2.90
3.04	2.43	2.95
3.10	2.49	3.05
3.19	2.56	3.12
3.29	2.67	3.17
3.43	2.75	3.30
3.60	2.92	3.48
3.71	3.02	3.63
4.01	3.33	3.94
4.64	4.05	4.52

BOTTOM PLATE

4.64	4.06	4.53
4.03	3.37	3.92
3.71	3.00	3.64
3.59	2.92	3.54
3.44	2.74	3.34
3.30	2.64	3.23
3.15	2.58	3.10
3.06	2.50	3.02
2.95	2.41	2.96
2.92	2.36	2.88
2.88	2.34	2.89
2.86	2.35	2.83
2.90	2.46	2.91
3.39	3.04	3.44

Table B.14 Fission Density (10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 5 and 13

TOP PLATE

3.40	2.95	3.36
2.89	2.32	2.83
2.84	2.23	2.80
2.83	2.20	2.74
2.84	2.23	2.76
2.88	2.30	2.84
2.94	2.35	2.89
3.07	2.38	2.97
3.15	2.48	3.02
3.25	2.52	3.12
3.43	2.69	3.33
3.54	2.82	3.43
3.85	3.15	3.75
4.48	3.91	4.38

BOTTOM PLATE

4.51	3.94	4.37
3.87	3.14	3.79
3.58	2.84	3.50
3.41	2.69	3.34
3.30	2.55	3.18
3.16	2.45	3.05
3.00	2.39	2.94
2.91	2.31	2.84
2.84	2.24	2.80
2.75	2.23	2.76
2.73	2.15	2.70
2.73	2.17	2.71
2.83	2.27	2.78
3.32	2.85	3.32

Table B.15 Fission Density (10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 6 and 12

TOP PLATE

3.31	2.85	3.27
2.78	2.21	2.74
2.72	2.14	2.67
2.70	2.11	2.64
2.73	2.14	2.70
2.81	2.18	2.75
2.85	2.20	2.75
2.90	2.26	2.89
3.02	2.36	2.96
3.12	2.42	3.05
3.31	2.60	3.21
3.43	2.69	3.34
3.72	3.00	3.63
4.41	3.80	4.31

BOTTOM PLATE

4.43	3.82	4.28
3.73	3.00	3.65
3.39	2.72	3.32
3.28	2.58	3.26
3.15	2.45	3.08
3.01	2.34	2.94
2.90	2.29	2.86
2.79	2.21	2.80
2.77	2.11	2.73
2.70	2.10	2.64
2.67	2.06	2.64
2.62	2.07	2.63
2.70	2.15	2.72
3.25	2.79	3.25

Table B.16 Fission Density (10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 7 and 11

TOP PLATE

3.31	2.76	3.26
2.73	2.12	2.63
2.69	2.06	2.60
2.67	2.03	2.61
2.67	2.06	2.62
2.75	2.10	2.64
2.78	2.10	2.73
2.93	2.19	2.78
2.95	2.26	2.88
3.06	2.34	2.97
3.20	2.49	3.14
3.33	2.59	3.23
3.66	2.95	3.57
4.40	3.73	4.25

BOTTOM PLATE

4.35	3.78	4.29
3.67	2.91	3.58
3.34	2.59	3.25
3.25	2.45	3.13
3.07	2.34	3.00
2.96	2.27	2.90
2.84	2.17	2.83
2.77	2.13	2.71
2.69	2.07	2.65
2.62	2.04	2.60
2.58	2.01	2.59
2.56	2.01	2.62
2.65	2.13	2.64
3.18	2.74	3.23

Table B.17 Fission Density (10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 8 and 10

TOP PLATE

3.28	2.75	3.23
2.70	2.12	2.65
2.65	2.05	2.60
2.61	1.99	2.56
2.67	2.00	2.61
2.72	2.05	2.63
2.73	2.09	2.65
2.80	2.11	2.73
2.91	2.24	2.85
3.03	2.28	2.95
3.18	2.45	3.09
3.29	2.55	3.20
3.63	2.86	3.53
4.36	3.77	4.20

BOTTOM PLATE

4.30	3.74	4.22
3.62	2.88	3.54
3.32	2.56	3.22
3.14	2.41	3.09
3.00	2.34	2.97
2.91	2.20	2.85
2.82	2.15	2.71
2.73	2.06	2.70
2.66	2.01	2.62
2.60	1.98	2.53
2.57	1.94	2.54
2.56	1.98	2.51
2.62	2.06	2.62
3.18	2.72	3.19

Table B.18 Fission Density (10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plate 9

TOP PLATE

3.27	2.76	3.23
2.64	2.12	2.62
2.62	1.99	2.58
2.63	1.97	2.51
2.62	1.95	2.54
2.69	1.99	2.60
2.74	2.07	2.62
2.80	2.13	2.73
2.94	2.25	2.83
3.03	2.27	2.85
3.18	2.42	3.06
3.31	2.53	3.16
3.64	2.83	3.56
4.35	3.78	4.21

BOTTOM PLATE

4.32	3.79	4.27
3.62	2.89	3.51
3.30	2.57	3.27
3.16	2.41	3.07
3.00	2.22	2.95
2.91	2.21	2.81
2.81	2.11	2.76
2.68	2.04	2.66
2.65	2.04	2.61
2.59	2.00	2.58
2.56	1.94	2.51
2.57	1.93	2.59
2.60	2.04	2.59
3.15	2.68	3.14