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Irradiation Experiment Design Parameters for NBSR Fuel Conversion

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Abstract

It has been proposed to convert the National Institute of Standards and Technology research reactor, known as the NBSR, from high-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. This report provides relevant dimensions of the fuel elements, and average and maximum fission rate densities and fission densities. The latter profiles are given for different plates to show the variation throughout the core. A summary of the methodology to obtain these results is presented. Fuel element tolerance assumptions and hot channel factors used in the safety analysis are also given.

Table of Contents

List of Figures

List of Tables

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. The objective is to provide information useful for the fuel plate irradiation experiment design team at Idaho National Laboratory. 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 and information on power and fission density.

Section 2 provides the description of the fuel plates and the fuel element. 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. Key information such as fuel element geometry and materials, and hot channel factors are summarized in Section 6 along with related uncertainties. References are found in Section 7.

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). The 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 with several unique features that enable low-energy and thermal neutrons to stream through eight radial beam tubes and two cold neutron sources. These features include an unfueled “gap” in the axial center of the fuel elements, which contains only moderator and structural materials. This gap, which acts to minimize contamination of the streaming low-energy neutrons, is co-located with the beam tubes at the core axial mid-plane. The mid-plane gap is very significant in terms of the NBSR peak local irradiation condition. 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 fission rate density and the highest cumulative fission density in the NBSR core.

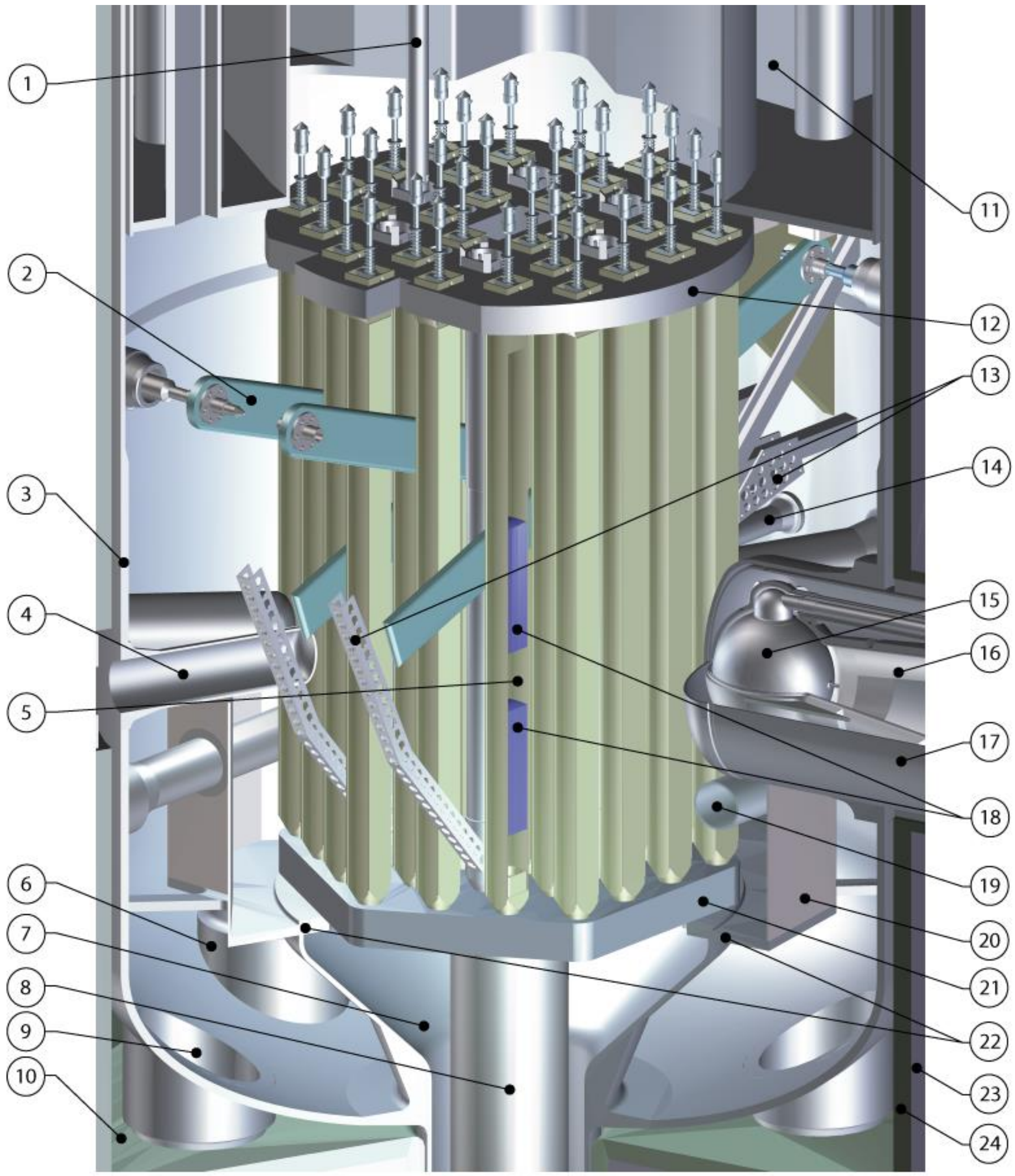
Another unique feature of the NBSR is the cadmium shim arms (control elements), which traverse the upper-half of the core in a semaphore fashion. During much of a reactor cycle, the shim arms act to suppress the flux in the upper half of the NBSR core. This flux “compression” shifts the peak local irradiation 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. Due to the combined impact of the mid-plane gap and the shim arms, the maximum cumulative fission density in the NBSR fuel approaches 100% burn-up of fissile nuclides, primarily ^{235}U and ^{239}Pu.

Presently, the NBSR is fueled with high-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 change the interior of the fuel plates, that is, the fuel plate and fuel element geometry will not change. Figure 2-2 shows a fuel element with the lower and upper fuel plates exposed along with the physical gap around the midplane. Figure 2-3 shows a cross sectional view of a fuel element.

The fuel for the LEU reactor is U10Mo (10 weight percent Mo alloyed with U) metal with a zirconium diffusion barrier layer 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 additional information is found in (Diamond, 2018). More information on the fuel including uncertainties in key parameters is also found in Section 6.

[a] A foil is defined as the combination of the fuel “core” (U10Mo) and the Zr interlayer.



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

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

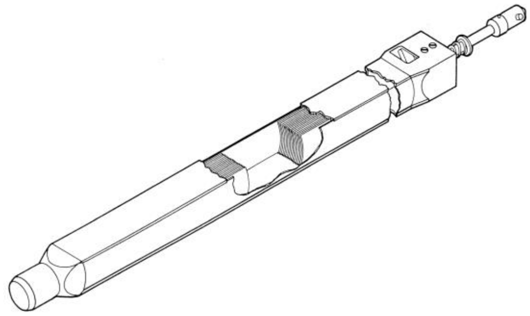


Figure 2-2 NBSR Fuel Element

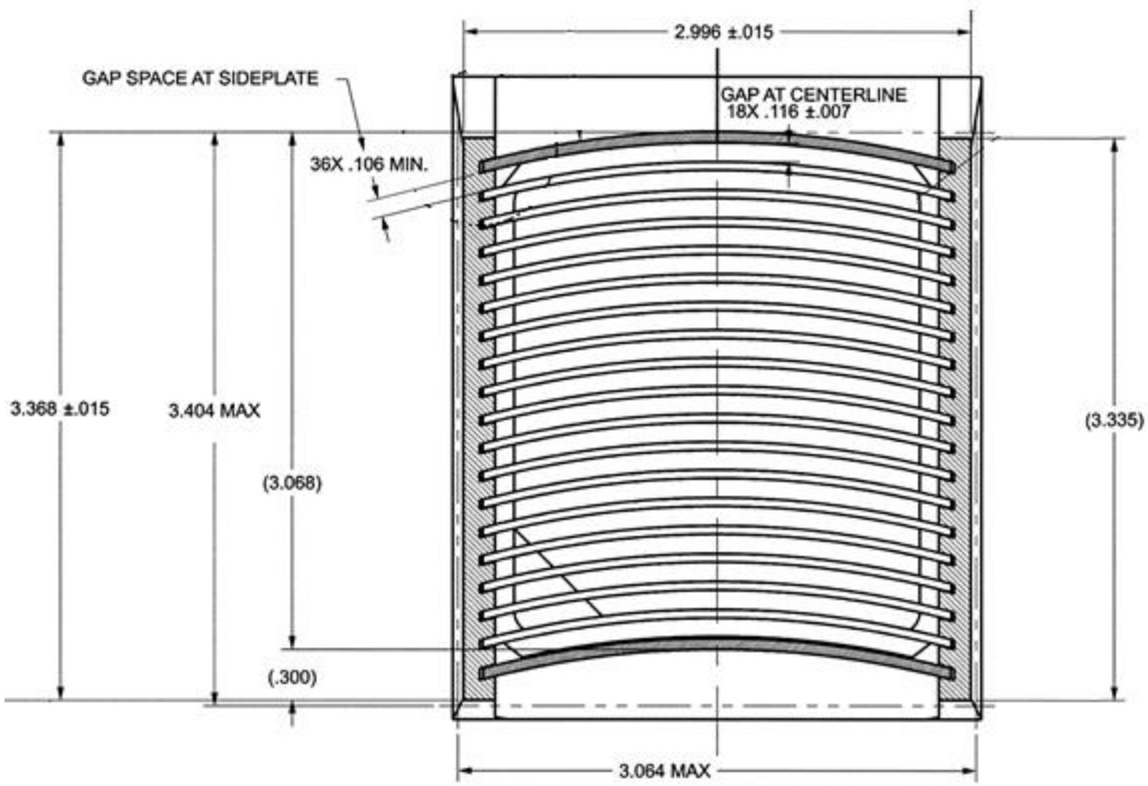


Figure 2-3 Cross Sectional View of Fuel Element (Dimensions in Inches)

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 clad thickness, in (cm)	0.0198 (0.0503)
Bulk minclad thickness, in (cm)	0.018 (0.046)
Point minclad thickness, in (cm)	0.011 (0.028)
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

There are 30 fuel elements in the NBSR core. Six fuel elements are located in the inner core, cooled by flow from the inner plenum, and twenty-four elements in the outer core, cooled by flow from the outer plenum.

Figure 3-1 shows the labeling of 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 noting that a fuel element always stays in the east side or in the 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 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 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. Unirradiated fuel is placed in the 8-1 and 7-1 positions.

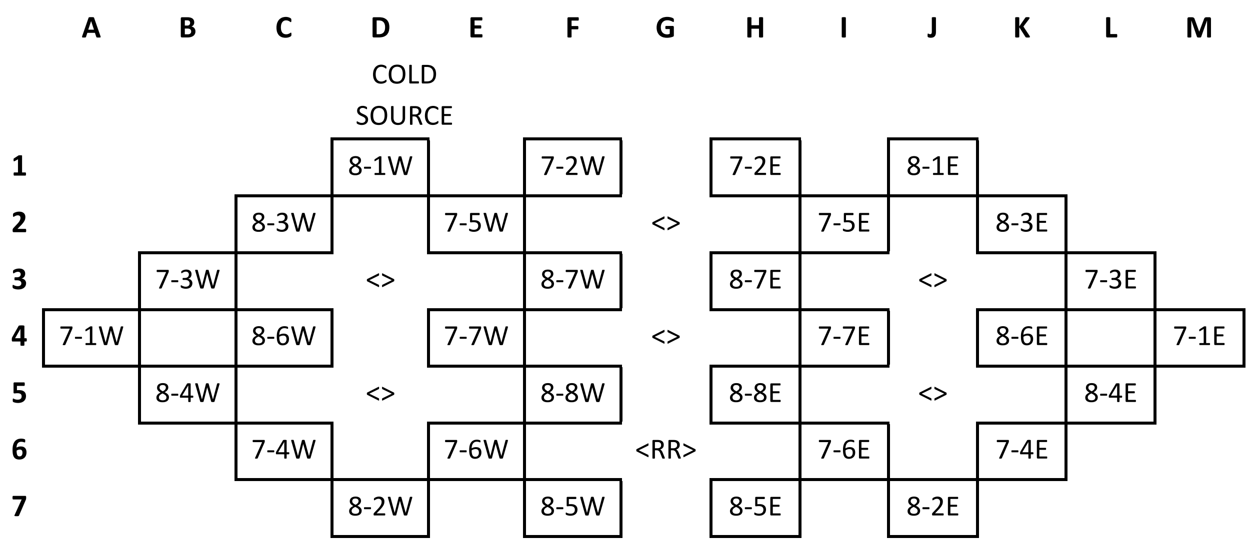


Figure 3-1. NBSR Fuel Management Scheme

By looking at fuel elements at different spatial positions one has 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 in 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 "present" model) for the neutronic and burn-up analysis (Kohut, 2019). The model utilizes MCNP6.2 (LANL, 2020) 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. The original model has been utilized to design two cold neutron sources. A planar view of the NBSR model at the core midplane is shown in Figure 3-2

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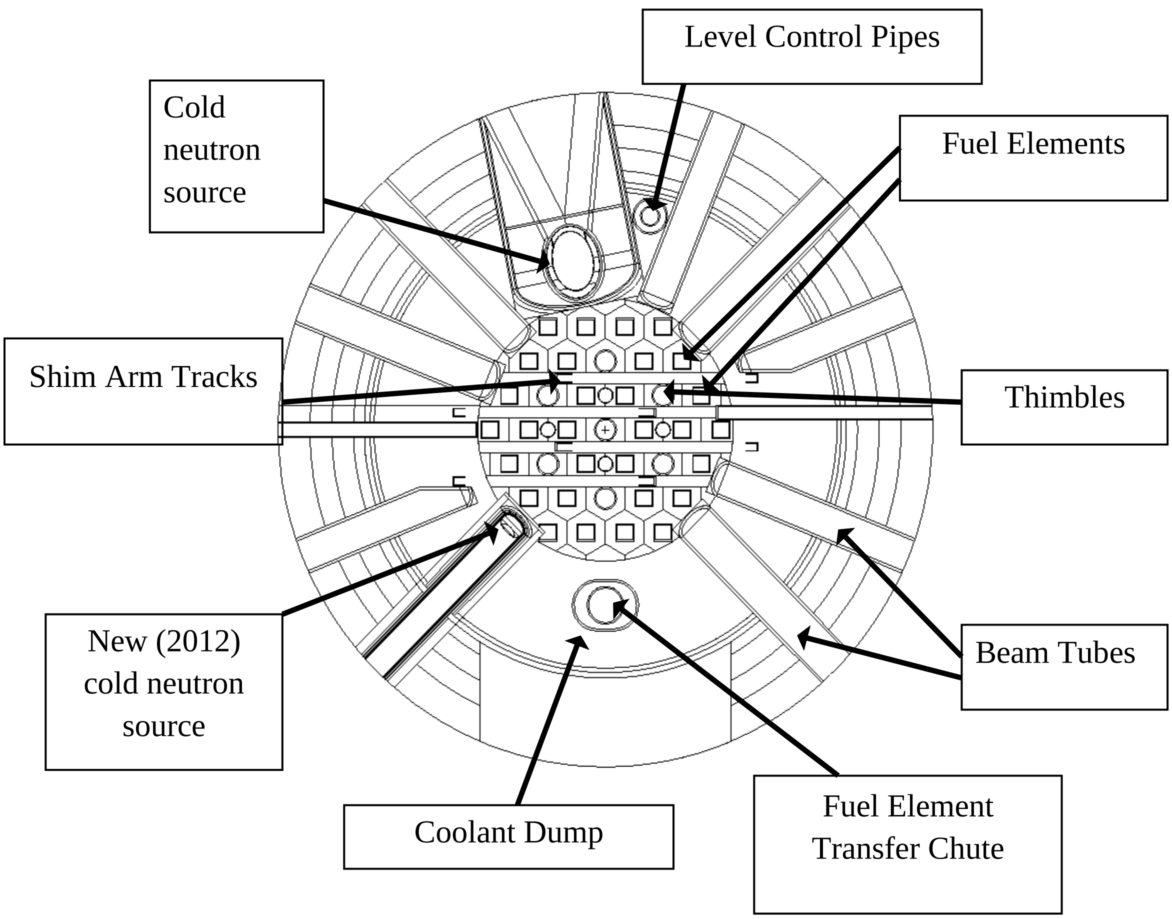

Figure 3-2. Planar View of the NBSR MCNP6 Model

To obtain detailed information on fission rate (power) density and fission density, each fuel plate in the model has 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. 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 statepoints of interest; namely, startup (SU) at the 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. At each point in time, the shim arms are at another position as they move to their limiting withdrawn position (horizontal) at EOC.

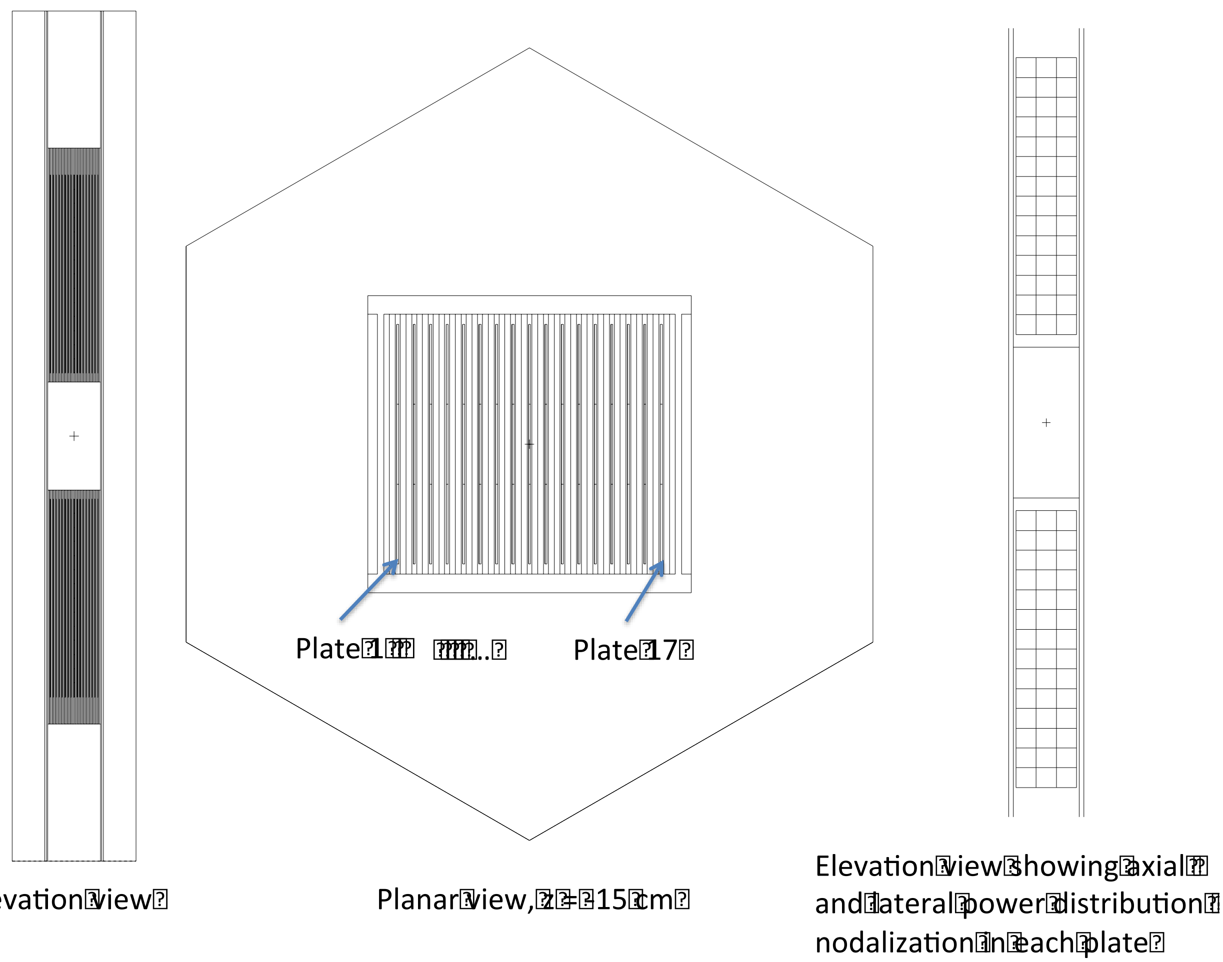

Figure 3-3. NBSR Fuel Element Geometry in the MCNP6.2 Model

The choice of 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 these studies 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. 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).

It is assumed that all fission energy is deposited directly in the fuel and within 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 conservative 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 current model uses 30 composition zones in each fuel element. The transverse meshes at any axial level are treated as a single composition. In the axial direction there are ten different compositions and the 17 plates in each half-element are lumped into three sets of plates.

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. Due to the fact that the fuel elements are rotated arbitrarily 180 degrees each fuel cycle, 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). The MCNP6.2 model does not rotate fuel-elements as they move through the core. Hence, the post-processing of MCNP6.2 calculations takes this into account by averaging results for the symmetric plates (e.g., 1 and 17). It is also the reason that the three zones are set up to represent plates 1 and 17 as a single zone, plates 2 and 16 as a single zone, and plates 3-15 as a single zone. With 30 fuel elements there are 30x3x10=900 composition zones in the model.

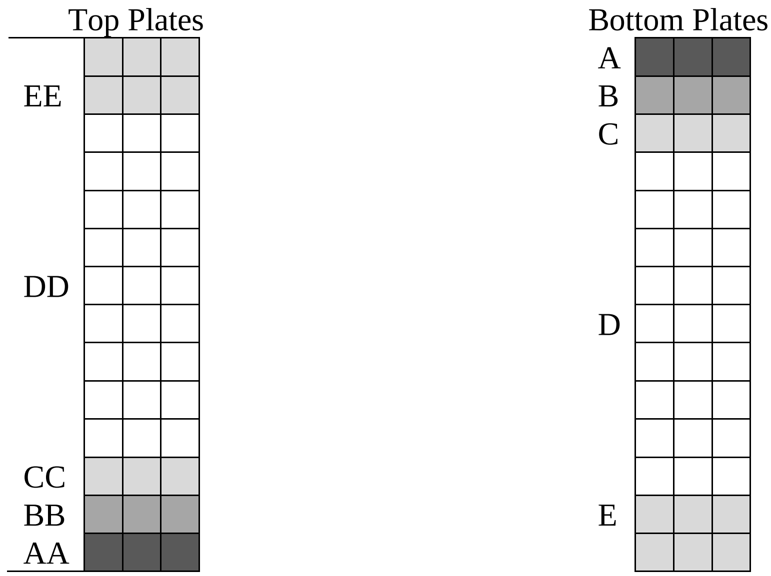

Figure 3-4. Axial Distribution of Composition Zones

4 Power Distribution

The design and planning of future irradiation experiments for NBSR fuel requires information on the expected fission rate density and fission density in the fuel plates; especially the maximum values. The average fission rate density in the NBSR is calculated based on the core power, the number of nodes in the core, and the volume of each node. The dimensions of each node are (see Table 1) (27.94/14) cm x (6.134/3) cm x 0.0216 cm = 0.08814 cm^3. In the proposed LEU U10Mo fuel the average power density P_{avg} is the core thermal power/fuel core volume.

$$P_{avg} = (20x10^6 \text{ W})/(0.08814x42840 \text{ cm}^3) = 5.30 \text{ kW/cm}^3$$

To convert power to a fission rate density one needs to know 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

$$P' = P_{avg}/[(201.3x10^6 \text{ eV/fission})(1.602x10^{-19} \text{ J/eV})] = 1.64x10^{14} \text{ fissions/s-cm}^3$$

The maximum power density is obtained by searching the 42840 meshes for the peak value. This is found at SU in a fresh fuel element at the outside of the core, namely, A4 (Figure 3-1), at the top of the bottom half. The value is 11.2 kW/cm^3 based on averaging the two outer (transverse) meshes as explained in Section 3. This corresponds to a heat flux of 121 W/cm^2 out of each side of the 0.0216 cm thick fuel core. Heat flux is used for the thermal analysis.

The corresponding power distribution throughout this fuel element is found in Appendix A for all plates taking into account that there should be no difference between plates 1 and 17, 2 and 16, etc. These results show the two outer transverse nodes explicitly rather than averaging them. It is seen how asymmetries in the core affect the calculated power distribution in the transverse direction even though it is known that the rotation of fuel elements will eliminate much of this asymmetry. 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 fact that the maximum power density occurs at SU is the result of flux compression due to the position of the shim arms. Shim arms move out of the core during the fuel cycle. The calculations discussed herein are done assuming fresh shim arms which contributes to this compression and adds conservatism to the power peaking.

Appendix A provides the results for two additional fuel elements. One is at SU for a fuel element that is at the center of the core, namely, at position F3 at the beginning of its eighth cycle. The other is for the 8-8 fuel element at EOC before being discharged (fuel element F5 at EOC). This complements the results given in Appendix B for the fission density for that fuel element.

The results presented herein are with a composition model (900 composition zones) 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. Nevertheless, it still results in a discontinuous composition distribution which leads to axial power distributions that are also seemingly discontinuous—although a correct calculation. This can be seen in Figure 4-1 which shows the 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, etc.) indicating position in the core (Figure 3-1). Axial position 1 is next to the mid-plane gap so positions 1, 2, and 3 all have different compositions (Figure 3-4). However, the composition in position 4 is from averaging the burnup from position 4-12 where generally, the power is low and hence burnup at position 4 is underestimated leading to the increase in power at that location as the fuel element goes through eight cycles.

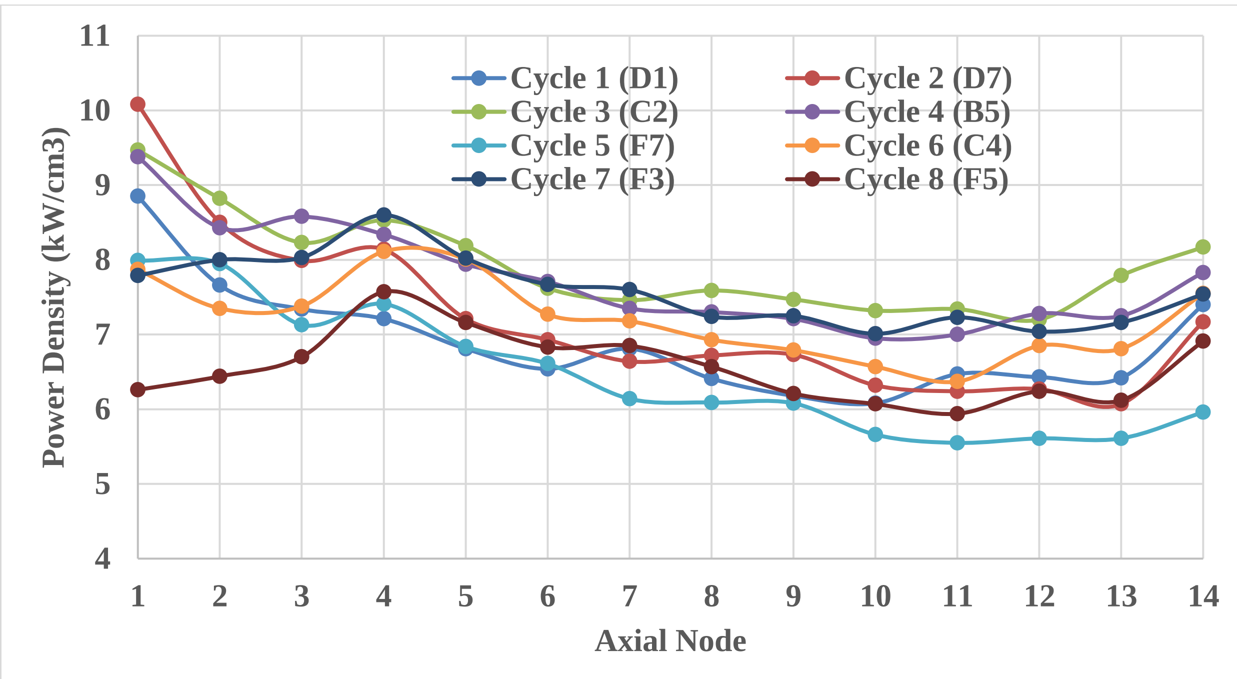

Figure 4-1. Axial Distribution of Power at SU along Outer Edge

5 Fission Density

The fission density is the integral of the fission rate (power) over time. Since 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 days and two have been in for eight days, 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. Hence, the average fission density of all discharged fuel is (1.64×10^{14} fissions/s-cm^3) x (2.49×10^{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 before an 8-cycle fuel element is removed from the core and the maximum fission density is expected at the top of the bottom half-element (Diamond, 2019). The largest fission density F^i in any one fuel element after one cycle (i) is calculated from:

$$F^i = (\frac{\kappa}{V}) \sum_n \bar{P}_n \Delta t_n$$

where

- $\bar{P}_n$ is the average mesh power (MW) in the two outer transverse meshes at the top of the two outermost plates (plates 1 and 17) in the bottom half-element (the location of peak power)
- 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, 0.088814 cm^3 (based on the ~2x2 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. The largest fission density as one fuel element moves through eight fuel cycles is then the summation of F^i for i=1,8 cycles for that element, or for the equilibrium core, at the fuel locations for an 8-1 element (D-1), an 8-2 element (D-7) an 8-3 element (C-2), … an 8-8 element (F-5).

The maximum fission density is calculated to be 6.2×10^{21} fissions/cm3. The spatial distribution of fission density in the 8-8 fuel element being discharged is given in Appendix B. The corresponding power density distribution is given in Appendix A. The power is ~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 (F3) at SU corresponding to one of the power densities given in Appendix A.

Figure 5-1 shows the axial distribution of fission density at EOC as a fuel element moves through the core. The curves are much smoother than the power density curves due to the integration over time.

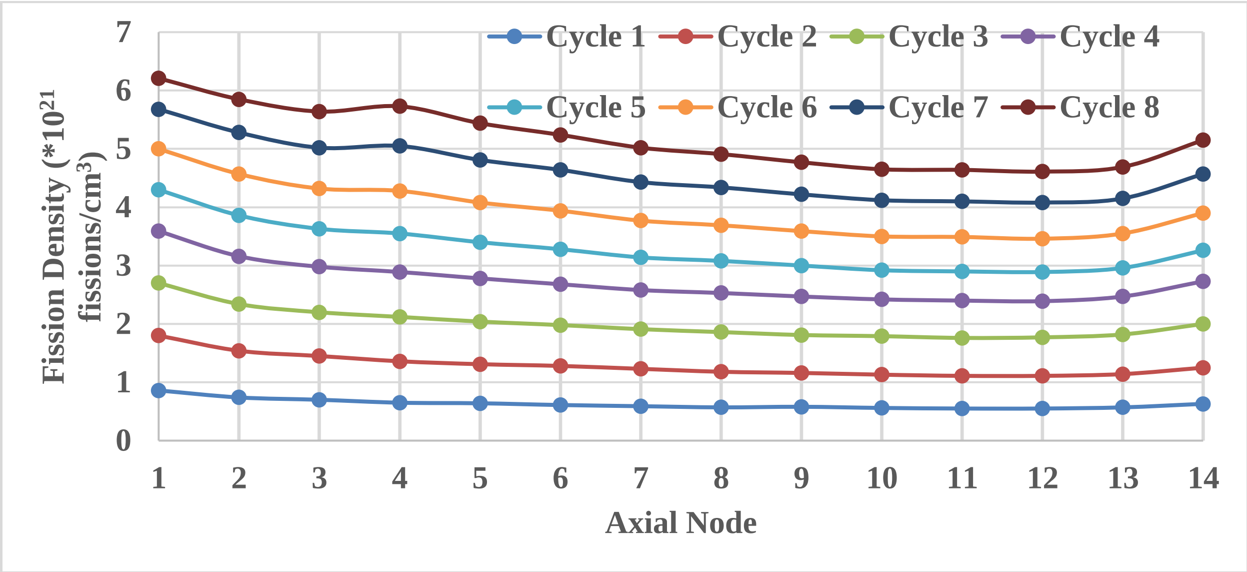

Figure 5-1. Axial Distribution of Fission Density along Outer Edge of Plate 1

6 Summary of Key Results

Table 6-1 summarizes some key parameters discussed in this report. Table 6-2 shows the geometry and material assumptions utilized in the safety analysis (SA) for both the HEU and the LEU cores. The source of the information is also given. Tolerances in the table are limiting values. Table 6-3 shows the hot channel factors (HCFs or standard deviations) utilized in the statistical hot channel analysis. Tolerances or uncertainties in geometric quantities for LEU fuel can be assumed to be the same as for the HEU fuel. For material quantities, for example, local fuel loading, the tolerance is expected to be as good as for HEU. However, these are subjective evaluations and may be modified when more is known about fuel fabrication.

Table 6-1 Key Metrics

Parameter	Value
Average fission rate density (10^{14} fission/cm^3-s)	1.64
Peak fission rate density (10^{14} fission/cm^3-s)	3.47
Average heat flux (W/cm^2)	57.2
Peak heat flux (W/cm^2)	121
Average fission density (10^{21} fission/cm^3)	4.09
Peak fission density (10^{21} fission/cm^3)	6.2
Fuel meat temperature (K)	< 390

Table 6-2 Geometry and Material Assumptions

Parameter	HEU Specification	LEU Analysis Assumes
Maximum channel width (at plate center)	116 ± 7 mil [1]	116 ± 7 mil (same as HEU)
Average channel width	114 mil [2]	114 mil [2]
Minimum channel width for SA	107.5 mil [2]	107.5 mil [2]
Plate thickness	50 mil [1]	50.1 mil [3]
Clad thickness	15 mil [1]	19.8 mil [3]
Minimum clad thickness	10.5 mil, not used in SA [1]	Bulk minclad 18 mil [3], not used in SA
Clad scratch maximum depth	< 5 mil (over fuel meat), not used in SA	< 2 mil (over fuel meat) [4], not used in SA
Fuel meat	U_3O_8 dispersion in Al	U10Mo alloy with Mo 10 ± 1 w/o [4]
Fuel meat thickness	20 mil	8.5 ± 1 mil [4]
U-235 enrichment	93 ± 1 w/o [1]	19.75 ± 0.20 w/o [4]
Average U-235 fuel loading (plate)	10.294 ± 0.2 g [1]	11.265 ± 0.24 g, based on Mo and enrichment uncertainties [4]
Bonding integrity	Fuel is subjected to blister test at 482 ± 11°C for at least one hour.	Debond characterization and tolerances to be determined
Local fuel homo-geneity	112% of nominal [1]	112% of nominal (same as HEU)
Fission density limit	$<3.1\text{x}10^{21}$ fission/cm^3 (100% U-235 burnup)	$6.2\text{x}10^{21}$ fission/cm^3
U-10Mo specific heat; U10Mo thermal conductivity	Not applicable	Values from [5] and [6]. Uncertainties are not available or used in SA.

References:
1. (NIST, 2010)
2. (Baek,2014)
3. (Diamond, 2018)
4. (INL, 2018)
5. (Rest, 2006)
6. (Burkes, 2010)

Table 6-3 Hot Channel Factors and References to Underlying Tolerances (Diamond, 2014)

Source of Uncertainty	Normalized Variable Identification	HEU		LEU	
		Standard Deviation[1]	Source	Standard Deviation	Source
Reactor Power Measurement	F_1	0.025	Table 3.2-1 of (NBS, 1980)	0.025	Same as HEU
Power Density Calculation	F_2	0.040	Table 3.2-1 of (NBS, 1980) / Engineering judgment	0.040	Same as HEU
Channel Dimensional Tolerance (local)	F_3	0.042	NBSR Dwg # E-04-016 in (NIST, 2010b)	0.042	Fuel element assembly assumed same as HEU
Channel Dimensional Tolerance (average)	F_4	0.035	Dwg # E-04-016 in (NIST, 2010b)	0.035	Fuel element assembly assumed same as HEU
Velocity Distribution Measurement	F_5	0.025	Table 3.2-1 of (NBS, 1980)	0.025	Same as HEU
Primary Flow Rate Measurement	F_6	0.022	(Gazit, 2002)	0.022	Same as HEU
Fuel Loading Tolerance (local)	F_7	0.069	(NIST, 2010b)	0.069	Monolithic fuel more uniform; bound by HEU value
Fuel Loading Tolerance (average)	F_8	0.0112	(NIST, 2010b)	0.0123	Uncertainties in Mo and enrichment (INL, 2018)
Critical Heat Flux Correlation	F_9	0.202	Sudo-Kaminaga correlation (Kaminaga, 1998)	0.202	Same as HEU
OFI Heat Flux Correlation	F_{10}	0.153	Saha-Zuber correlation (Saha, 1974)	0.153	Same as HEU

[1]Uncertainty limits represent 1 σ standard deviation assuming a normal distribution. When the referenced uncertainties were given as lower and upper limits, the range was assumed to represent a $\sqrt{12}\sigma$ value.

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A POWER DENSITIES

The following power densities are for fuel element A4 and F3 at SU and F5 at EOC.

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

Color Key
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00

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

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/cm^3) 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

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	1.00
5.08	4.53	5.31	2.00
5.24	4.94	5.28	3.00
5.56	4.89	5.88	4.00
6.17	5.30	6.32	5.00
6.34	6.01	6.06	6.00
6.93	6.36	6.59	7.00
7.39	6.93	7.14	8.00
7.22	6.19	6.71	
7.19	6.61	7.71	
7.08	6.75	7.70	

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

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

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

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

1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00

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

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

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 115

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

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

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

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

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

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

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

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

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

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

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

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

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

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

B FISSION DENSITIES

The following fission densities are for fuel element F5 at EOC and F3 at SU.

Table B-1 Fission Density ($x10^{21}$ 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

2
3
4
5
6
7

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 ($x10^{21}$ 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 ($x10^{21}$ 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 ($x10^{21}$ 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 ($x10^{21}$ 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 ($x10^{21}$ 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 ($x10^{21}$ 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 ($x10^{21}$ 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 (x10^{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

Table B-10 Fission Density (x10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 1 and 17

3.96	3.66	3.92	1
3.66	3.23	3.55	2
3.62	3.15	3.51	3
3.58	3.17	3.49	4
3.63	3.21	3.56	5
3.72	3.29	3.58	6
3.76	3.35	3.69	
3.84	3.41	3.73	
4.02	3.52	3.89	
4.15	3.65	4.04	
4.30	3.87	4.24	
4.40	3.86	4.22	
4.67	4.15	4.50	
5.05	4.64	4.93	

5.08	4.66	4.92
4.61	4.21	4.54
4.36	3.89	4.28
4.35	3.84	4.22
4.13	3.68	4.04
3.98	3.50	3.90
3.82	3.43	3.73
3.74	3.31	3.64
3.60	3.22	3.58
3.53	3.17	3.47
3.49	3.10	3.48
3.47	3.15	3.46
3.55	3.19	3.54
3.90	3.63	3.90

Table B-11 Fission Density (x10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 2 and 16

3.70	3.37	3.66
3.30	2.84	3.26
3.29	2.82	3.23
3.26	2.80	3.20
3.34	2.83	3.22
3.35	2.84	3.25
3.43	2.93	3.33
3.48	3.01	3.42
3.64	3.11	3.52
3.77	3.21	3.68
4.00	3.37	3.85
4.03	3.47	3.90
4.28	3.75	4.16
4.83	4.37	4.69

4.80	4.36	4.66
4.27	3.78	4.17
4.05	3.46	3.92
3.95	3.42	3.89
3.79	3.23	3.71
3.65	3.09	3.55
3.50	2.99	3.43
3.40	2.93	3.39
3.31	2.84	3.26
3.22	2.80	3.21
3.22	2.74	3.14
3.18	2.73	3.12
3.25	2.80	3.18
3.63	3.34	3.65

Table B-12 Fission Density (x10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 3 and 15

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

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 (x10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 4 and 14

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

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 (x10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 5 and 13

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

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 (x10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 6 and 12

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

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 (x10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 7 and 11

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

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 (x10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plates 8 and 10

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

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 (x10^{21} fissions/cm^3) Fuel Element F3 (8-7W) Plate 9

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

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