Reaction Rate Distribution Measurements in ZPPR-15

Nuclear Science and Engineering Division

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ABSTRACT

Small metal foils were irradiated in ZPPR-15 to measure distributions for $^{239}\text{Pu}(n,f)$, $^{235}\text{U}(n,f)$, $^{238}\text{U}(n,f)$, $^{238}\text{U}(n,\gamma)$, $^{115}\text{In}(n,n')$ and $^{115}\text{In}(n,\gamma)$ reaction rates in ZPPR-15. The measured data were reported as basic reaction rate distributions for individual foils, cell-averaged reaction rate distributions and spectral indices or reaction rate ratios. All of the measured data were analyzed and tabulated in such a manner that the data can be readily compared with computed values.

The published uncertainties for ZPPR-15 the reaction rate measurements include the statistical uncertainties in the measurements, reproducibility uncertainty and small uncertainties related to corrections for items such as foil compositions and post-irradiation decay between reactor shutdown and foil measurement. There are additional uncertainty components related to detector calibration that are not included in the published uncertainties. A full uncertainty analysis was performed for each foil measurement and for quantities derived from the basic foil measurements. The significant uncertainties were quantified, and a total uncertainty was derived for each measured value.

The ZPPR-15 experimental records were used to create detailed as-built Monte Carlo models for the foil reaction rate measurements in ZPPR-15 loadings 123, 134 and 203 and for the fission chamber measurements of ^{237}Np and ^{242}Pu fission rates in ZPPR-15 loading 141. Because there were many foils distributed in the ZPPR-15 assembly and because an individual foil occupies a negligible volume in the ZPPR-15 assembly, direct Monte Carlo calculations of the measured foil reaction rates would require an impractical computational effort. The as-built Monte Carlo models and related files were prepared for conversion to deterministic models that can be calculated with realistic computational effort.

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1 Introduction

Reaction rate distributions were measured in ZPPR-15 by irradiating small metal foils at selected locations in the core, blanket and radial reflector of the assembly. These measurements were used to characterize the neutron flux and neutron spectrum in the assembly. $^{239}\text{Pu}(n,f)$, $^{235}\text{U}(n,f)$, $^{238}\text{U}(n,f)$ and $^{238}\text{U}(n,\gamma)$ distributions were the common ZPPR foil measurements although the ZPPR material inventory included small numbers of foils of other types for special measurements. Foils were irradiated in ZPPR-15B and ZPPR-15D to measure reaction rate distributions along the X-axis and Y-axis. In addition, foils were used to measure axial reaction rate distributions at three matrix locations in ZPPR-15D.

Reference 1 provides a general description of the Zero Power Plutonium Reactor (ZPPR) facility, equipment and materials. That discussion will not be repeated here.

2 Foil Reaction Rate Measurements in ZPPR-15

Four types of metal irradiation foils were used in the ZPPR-15 measurements. $^{235}\text{U}(n,f)$ reactions were measured with ^{235}U foils. The ^{235}U foils were 12.7 mm in diameter and 0.112 mm thick. $^{238}\text{U}(n,f)$ and $^{238}\text{U}(n,\gamma)$ reactions were measured with ^{238}U foils. The diameter and thickness of the ^{238}U foils were 12.7 mm and 0.140 mm, respectively. ^{235}U foils and ^{238}U foils were coated with Kel-F (a paint-like coating material) to prevent corrosion and then were covered on the top and bottom with 0.0025 mm aluminum disks. The aluminum disks protected the foils during handling and use.

^{239}Pu foils were used to measure $^{239}\text{Pu}(n,f)$ reactions. The diameter and thickness of the ^{239}Pu foils were 10.8 mm and 0.127 mm, respectively, and the nominal plutonium mass in a foil was ~150 mg. The ^{239}Pu foils were clad in 0.025 mm aluminum but were not coated.

In addition to the uranium foils and plutonium foils, indium foils were used to measure $^{115}\text{In}(n,\gamma)$ and $^{115}\text{In}(n,n')$ reactions in the ZPPR-15B shield experiments. The diameter and thickness of the indium foils were 12.7 mm and 0.25 mm, respectively. Available documents do not indicate whether the indium foils were clad or coated.

The ^{239}Pu foils were not pure ^{239}Pu . Likewise, ^{235}U foils were not pure ^{235}U , and ^{238}U foils were not pure ^{238}U . The isotopic compositions of the different types of foils were known, and the experimenters corrected for other isotopes in the foils when deriving the foil reaction rates from the raw measurement data.

The measurements were performed by placing 1 – 3 foils into holes in thin stainless steel or aluminum holders which were inserted between plates in drawers at selected locations in half 1 of ZPPR-15B and ZPPR-15D. The foil holders provided fixed positions for the foils in the drawers. The foils were irradiated, removed from the reactor and counted to determine reaction rates.

The foils in the holders were centered at the mid-height of the drawer. The axial positions of the foils from the interface between half 1 and half 2 were 63.1 mm for ^{235}U foils, 77.0 mm for ^{238}U foils, 90.8 mm for ^{239}Pu foils and 90.8 mm for indium foils.

The measured foil data were presented in two forms in the ZPPR reports. It was not practical to place foils everywhere in the core, blanket and reflector of a ZPPR assembly because the supply of foils was limited and because it would not be economically feasible to load, unload

and count that many foils. A second consideration is that it was not possible to calculate accurate reaction rates for many individual foils at their exact locations in the assembly during the 1970s and 1980s when ZPPR operated due to the computer and software limitations in that period.

The standard ZPPR practice was to place foils between specific columns of plates in many drawers in the core, blanket and reflector of an assembly. These foils were referred to as mapping foils. The mapping foils provided detailed reaction rate distributions throughout an assembly. Because reaction rates in individual foils could not be computed accurately, the experimenters converted the mapping foil data to cell-averaged reaction rates that could be computed with the available computing resources.

Although it was not practical to place many foils in every drawer location of interest, it was possible to place multiple foils in drawers at a few selected locations. The experimenters used the reaction rates determined from these more detailed measurements to compute average reaction rates in representative drawer environments for reaction types of interest. These average reaction rates were called cell factors. The cell factors were used to relate the reaction rate measured by an individual mapping foil to the average reaction rate in the unit cell, i.e., drawer, containing the mapping foil.

Cell factors were measured for various representative drawer environments in the assembly including environments at the boundaries between different regions such as the core-blanket interface. When ZPPR operated, cell factors were measured in the cell environments of interest. The general consensus today is that modern computers and codes make it possible to compute cell factors that will be more accurate than the cell factors measured in the 1970s and 1980s.

In ZPPR-15B, the foil measurements were performed in loadings 123 and 134 as part of the ZPPR-15B shield experiment. Figures 2.1 and 2.2 show the matrix maps for half 1 and half 2, respectively, of ZPPR-15B loading 123 (ZPPR-15B L123). Figure 2.3 and 2.4 show the matrix maps for half 1 and half 2, respectively, of ZPPR-15B loading 134 (ZPPR-15B L134). Note that a matrix map shows the drawer master loaded in each matrix tube (see Ref. 1 for details regarding drawer masters and matrix maps). The projection on one side in Figures 2.1 through 2.4 was a simulated radial shield constructed to obtain reaction rate measurements in a shield environment. The available plate inventory and the 77 x 77 size of the ZPPR matrix limited the simulated shield to one side of the core.

The rows in the 77 x 77 ZPPR matrix were numbered from 111 to 187 in half 1, the stationary half, and from 211 to 287 in half 2, the movable half. Rows 111 and 211 were at the top of the matrix; rows 187 and 287 were at the bottom of the matrix. The columns in the ZPPR matrix were numbered from 11 to 87 in both halves, but the order of the columns was reversed in half 2. An observer standing between the two halves and facing half 1 would see column 11 of half 1 on the left. Column 11 of half 2 would be over the observer's left shoulder. If the observer turns around and faces half 2, the observer would see column 87 on the left and column 11 on the right. These are the views shown in the matrix maps presented below. The reverse order of the columns in half 2 allowed the column numbers to align when the matrix halves were brought together. The standard ZPPR convention for specifying matrix locations is that 145-33 refers to row 45, column 33 in half 1 while 245-33 refers to row 45, column 33 in half 2. In this manner, the matrix location 145-33 would be directly aligned with matrix location 245-33 when the matrix halves touch. The Z-axis was parallel to the long axis or length of the matrix tubes

with positive Z values in half 1. This numbering convention provided a standard right-handed coordinate system.

Figure 2.1 ZPPR-15B Loading 123 – Half 1

The small numbers in the cells are abbreviations for the drawer master identifiers. For example, “101” is the abbreviation for “15-0-101,” the full identifier for that drawer master (see Ref. 1). Light blue cells are the radial reflector, and dark blue cells are the radial blanket. Empty cells outside the radial reflector are empty matrix tubes.

White cells containing numbers are core drawer masters containing a single Pu-U-Mo fuel column (SCF), and green cells inside the radial blanket are core drawer masters containing two Pu-U-Mo fuel columns (DCF). Brown cells inside the radial blanket are matrix tubes containing a control rod and a narrow core drawer. Orange cells scattered throughout the matrix are drawers containing a detector. The remaining colors on one side of each ZPPR-15B matrix map denote components of the simulated radial shield.

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Figure 2.2 ZPPR-15B Loading 123 - Half 2

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Figure 2.3 ZPPR-15B Loading 134 - Half 1

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Figure 2.4 ZPPR-15B Loading 134 – Half 2.

Reaction rate distributions were measured in ZPPR-15D loading 203 (ZPPR-15D L203). Figures 2.5 and 2.6 show the matrix maps for half 1 and half 2, respectively of ZPPR-15D L203. The colors in the cells in Figures 2.5 and 2.6 have the same meaning as the description for Figures 2.1 through 2.4 with one exception. The salmon-colored cells in Figures 2.5 and 2.6 contain columns of HEU fuel in place of Pu-U-Mo fuel.

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Figure 2.5 ZPPR-15D Loading 203 – Half 1

Figure 2.6 ZPPR-15D Loading 203 – Half 2

Uncertainty components and total uncertainties in this document are relative uncertainties expressed in percent unless noted otherwise for a specific case or table. If M is the measured value, σ_a is the absolute uncertainty for M and σ_r is the relative uncertainty for M , then σ_a and σ_r are related by

$$\sigma_r = \sigma_a / M$$

3 Basic Mapping Foil Reaction Rates in ZPPR-15

Mapping foils were placed at many locations in the ZPPR-15 core and blanket. These foils provide the basic data for normalized reaction rate distributions, absolute reaction rate

distributions, cell-averaged reaction rate distributions and reaction rate ratio or spectral index distributions.

The mapping foil data can be used to provide normalized reaction rate distributions or profiles in the assembly. The mapping foil data can also be converted to absolute reaction rates relative to a specific reactor power. Section 3.1 discusses the uncertainties for the basic mapping foil data and for reaction rate distributions normalized to some value such as the maximum measured foil value. Uncertainties related to the absolute reaction rates are discussed in Section 4.1.

3.1 Mapping Foil Reaction Rate Uncertainties

In addition to basic counting statistics, there are a number of other uncertainty components that determine the total uncertainty for foil measurements in ZPPR, and the relevant uncertainties depend upon whether the quantity of interest is a relative reaction rate, an absolute reaction rate, a cell-averaged reaction rate or a spectral index (reaction rate ratio for foils of different types).

The published uncertainties for the mapping foils include several uncertainties in addition to the actual counting statistics for the foil. These additional uncertainties are a) a 0.3% reproducibility uncertainty related to foil positioning in the counting system, b) uncertainties related to corrections for other isotopes in the foils, c) uncertainty related to correction for decay during the irradiation period, d) uncertainty related to correction for decay during the elapsed time between the end of irradiation and the foil counting and e) uncertainty related to any dead time corrections for the counting system.

The 0.3% reproducibility uncertainty refers to the fact that it was not possible to place every foil at exactly the same position in the counting system to an arbitrary degree of precision. Tests in which the operation of placing a foil in the counting system, counting it and then removing it was repeated multiple times showed that the effect of non-reproducibility in foil positioning on the measured count rate was 0.3%.

In addition to the published uncertainties for the mapping foils, there is a 0.1% uncertainty in the foil mass and an approximately 0.8% uncertainty related to the discrete channel boundaries for integration of the peak in the ZPPR counting system (see IRPhEP benchmark ZPPR-LMFR-EXP-002, Section 2.7.1.1 in Ref. 2). The uncertainty regarding discrete channel boundaries arises from the fact that other fission product gamma peaks overlap the gamma peaks of ^{239}Np , ^{133}I , ^{97}Nb , ^{132}I and $^{97\text{m}}\text{Nb}$ that were measured in the counting system.

There are also small uncertainties related to half-lives, fission yields, etc., but those uncertainties are negligible compared to the counting statistics, 0.3% reproducibility uncertainty and 0.8% channel boundary uncertainty.

The ^{238}U fission rate was measured with solid state track recorders (SSTRs) rather than ^{238}U foils in locations outside of the core and blanket in L134. Special ^{238}U foils were used in the SSTR measurements. These foils had a thickness of 0.25 mm, a diameter of 9.5 mm and a ^{235}U fraction of $3.0 \pm 0.1 \times 10^{-6}$ whereas standard ^{238}U foils had a ^{235}U fraction of 0.0022. Packets of ^{238}U foils and mica were wrapped in aluminum foil, placed in drawers and irradiated. After irradiation, the fission fragment tracks were counted visually to determine the number of fission tracks per unit area. Although the reports are not clear regarding the function of the mica, it seems likely that the mica served as the recording medium and that the tracks in the mica were

counted to determine the fission rate. It seems unlikely that it would have been possible to count tracks in the ^{238}U foils.

Power was reduced for the SSTR irradiation. The SSTR data were converted to units of fissions/atom-watt-second using the integral power measured by the ZPPR ex-core detectors. Comparison of activation foils and SSTR data in a previous core indicated that SSTRs measure a 10% lower fission rate than foils. The SSTR data were adjusted to match the foil data by the experimenters before the data were published.

For the SSTR data, there are the standard statistical uncertainties in counting tracks plus three additional uncertainties. The first of these is a 3% random uncertainty for reproducibility in counting tracks. The second is a 2.5% systematic uncertainty for adjustment of SSTR data to match the irradiation foil data. The third is a 2% uncertainty for the foil calibration. All of these uncertainties are one-sigma values.

Tables 3.1 – 3.15 show the basic mapping foil data with the total uncertainties listed. The uncertainty listed for each reaction rate in Tables 3.1 – 3.15 is the total uncertainty expressed in percent.

For all cases in Tables 3.1 – 3.15 except $^{238}\text{U}(\text{n},\text{f})$ reaction rates outside the radial blanket in L134, the total uncertainty shown combines the published uncertainty, 0.1% uncertainty in the foil mass and 0.8% uncertainty related to discrete channel boundaries for integration of the peak in the ZPPR counting system.

For $^{238}\text{U}(\text{n},\text{f})$ reaction rates outside of the radial blanket in L134, the total uncertainty shown combines the published uncertainty, the 3% reproducibility uncertainty for counting tracks, the 2.5% uncertainty for adjusting the SSTR data to foil data and the 2% uncertainty for foil calibration.

The uncertainties listed in Tables 3.1 – 3.15 must be combined correctly if the reaction rates are normalized to a specific measured value such as the largest value in the table. It is not valid to simply divide all of the measured values and uncertainties in the table by a selected reference value from that table because that selected reference value is itself uncertain. The correct procedure for determining the uncertainty for a normalized ratio is the following (see Ref. 3, Section V.E):

1. Consider x with uncertainty σ_x , y with uncertainty σ_y , and the desired ratio $R = x/y$.
2. Define $S_x = \sigma_x/x$, $S_y = \sigma_y/y$, and $S_R = \sigma_R/R$.
3. Then $S_R = \sqrt{(S_x)^2 + (S_y)^2}$

S_R is the correct relative uncertainty for any ratio such as normalization in which S_x and S_y are independent. In the present case, S_R is an approximation because there are correlations for some of the corrections. However, the uncertainties for those corrections are small compared to the counting statistics, 0.3% reproducibility uncertainty and 0.8% uncertainty for the discrete channel boundaries discussed above, so accounting for these correlations would not significantly affect S_R .

In Tables 3.1 – 3.15, the example x and y used here correspond to measured reaction rates taken from column 7. The total uncertainties in column 8 of Tables 3.1 – 3.15 correspond to S_x and S_y .

3.2 Mapping Foil Reaction Rate Distributions in ZPPR-15

Foils were irradiated in ZPPR-15B L123, ZPPR-15B L134 and ZPPR-15D L203. The usable interior width in a drawer was 2 in. The ZPPR staff divided this space into sixteen $1/8^{\text{th}}$ inch columns for reporting purposes. These drawer columns were labeled with letters A – P with A on the left as the observer faces the drawer. The two letters shown in the “Location” columns of the tables below are the drawer columns that either contain or bound the foil location. For example, JK means the foil was placed between columns J and K in the drawer. The columns labeled “Row” and “Column” in the tables below are the row and column of the ZPPR matrix containing the foil. All foils were placed in half 1 of the matrix.

The X-, Y- and Z-coordinates shown in all tables are the coordinates of the foil location relative to an origin at the lower left corner of the interface between matrix halves. $Z = 0.0$ is at the interface, and the positive Z-axis is the axis of the matrix tubes in half 1. $X = 0.0$ is at the left side of column 11 in half 1, and $Y = 0.0$ is at the bottom of row 187. Consequently, the origin corresponds to the position at the lower left corner of the interface between half 1 and half 2 for an observer facing half 1. All dimensions in all tables are in centimeter units.

Note that the Z-coordinates in all tables in this report are relative to the interiors of the drawers. They do not include the 0.030 in (0.762 mm) front plate of each drawer.

The reactions in Tables 3.1 – 3.15 were normalized to a power of one watt by the ZPPR staff. Note that two shield configurations were constructed in ZPPR-15B. “SSNA” in ZPPR-15B L123 is the stainless steel – sodium shield configuration. “BCNA” in ZPPR-15B L134 is the boron carbide – sodium shield configuration.

Table 3.1 ²³⁵U(n,f) Distribution in ZPPR-15B L123 – SSNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁵ U(n,f)	σ _{total} , %
159	17	HI	35.9042	157.4063	6.3100	0.274	1.36
159	18	HI	41.4287	157.4063	6.3100	0.443	1.05
159	19	HI	46.9532	157.4063	6.3100	0.619	1.03
159	20	HI	52.4777	157.4063	6.3100	0.798	1.02
159	21	FG	57.3672	157.4063	6.3100	1.140	0.96
159	22	FG	62.8917	157.4063	6.3100	1.755	0.96
159	23	FG	68.4162	157.4063	6.3100	2.468	0.94
159	24	FG	73.9407	157.4063	6.3100	3.289	0.91
159	25	FG	79.4652	157.4063	6.3100	4.151	0.90
159	26	FG	84.9897	157.4063	6.3100	4.905	0.90
159	27	FG	90.5142	157.4063	6.3100	5.373	0.90
159	28	FG	96.0387	157.4063	6.3100	5.071	0.91
159	29	JK	102.8332	157.4063	6.3100	4.144	0.95
159	30	JK	108.3577	157.4063	6.3100	4.760	0.93
159	31	JK	113.8822	157.4063	6.3100	6.071	0.95
159	32	II	118.9304	157.4063	6.3100	7.587	0.91
159	33	IJ	124.6137	157.4063	6.3100	9.249	0.98
159	34	II	129.9794	157.4063	6.3100	10.477	0.90
159	35	IJ	135.6627	157.4063	6.3100	12.011	0.92
159	36	II	141.0284	157.4063	6.3100	12.796	0.89
159	37	IJ	146.7117	157.4063	6.3100	13.771	0.89
159	38	IJ	152.2362	157.4063	6.3100	14.350	0.90
159	40	IJ	163.2852	157.4063	6.3100	15.386	0.89
159	42	IJ	174.3342	157.4063	6.3100	15.970	0.89
159	44	IJ	185.3832	157.4063	6.3100	16.225	0.89
159	46	IJ	196.4322	157.4063	6.3100	16.340	0.89
159	48	IJ	207.4812	157.4063	6.3100	16.498	0.89
159	49	GH	212.3707	157.4063	6.3100	16.546	0.89
159	51	GH	223.4197	157.4063	6.3100	16.464	0.90
159	53	GH	234.4687	157.4063	6.3100	16.125	0.89
159	55	GH	245.5177	157.4063	6.3100	16.003	0.89
159	57	GH	256.5667	157.4063	6.3100	15.455	0.89
159	59	GH	267.6157	157.4063	6.3100	14.551	0.90
159	60	GH	273.1402	157.4063	6.3100	13.884	0.90
159	61	HH	278.8234	157.4063	6.3100	12.866	0.89
159	62	GH	284.1892	157.4063	6.3100	11.868	0.91
159	63	HH	289.8724	157.4063	6.3100	10.596	0.90
159	64	GH	295.2382	157.4063	6.3100	9.304	0.90
159	65	HH	300.9214	157.4063	6.3100	7.677	0.91
159	66	FG	305.9697	157.4063	6.3100	6.130	0.92
159	67	FG	311.4942	157.4063	6.3100	4.836	0.95
159	68	FG	317.0187	157.4063	6.3100	4.152	0.95
159	69	HI	323.1782	157.4063	6.3100	5.076	0.92
159	70	HI	328.7027	157.4063	6.3100	5.362	0.91
159	71	HI	334.2272	157.4063	6.3100	4.911	0.93
159	72	HI	339.7517	157.4063	6.3100	4.028	0.92
159	73	HI	345.2762	157.4063	6.3100	3.149	0.94
159	74	HI	350.8007	157.4063	6.3100	2.259	0.97
159	75	HI	356.3252	157.4063	6.3100	1.477	0.97
159	76	HI	361.8497	157.4063	6.3100	0.829	1.01

a. Data are in units of 10⁻¹⁸ reactions/atom-watt second.

Table 3.2 $^{238}\text{U}(\text{n},\text{f})$ Distribution in ZPPR-15B L123 – SSNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$^{238}\text{U}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
159	30	JK	108.3577	157.4063	7.7000	0.0391	1.73
159	32	II	118.9304	157.4063	7.7000	0.1867	1.00
159	33	IJ	124.6137	157.4063	7.7000	0.2683	0.96
159	34	II	129.9794	157.4063	7.7000	0.2868	0.96
159	35	IJ	135.6627	157.4063	7.7000	0.3520	0.95
159	36	II	141.0284	157.4063	7.7000	0.3425	0.95
159	49	GH	212.3707	157.4063	7.7000	0.3627	0.95
159	63	HH	289.8724	157.4063	7.7000	0.2880	0.96
159	64	GH	295.2382	157.4063	7.7000	0.2680	0.96
159	65	HH	300.9214	157.4063	7.7000	0.1855	1.00
159	66	FG	305.9697	157.4063	7.7000	0.0915	1.19
159	67	FG	311.4942	157.4063	7.7000	0.0388	1.74
159	68	FG	317.0187	157.4063	7.7000	0.0190	2.75

a. Data are in units of 10^{-18} reactions/atom-watt second.

Table 3.3 $^{238}\text{U}(\text{n},\gamma)$ Distribution in ZPPR-15B L123 – SSNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$^{238}\text{U}(\text{n},\gamma)$	$\sigma_{\text{total}}, \%$
159	30	JK	108.3577	157.4063	7.7000	0.5803	0.91
159	32	II	118.9304	157.4063	7.7000	0.9952	0.91
159	33	IJ	124.6137	157.4063	7.7000	1.2135	0.91
159	34	II	129.9794	157.4063	7.7000	1.3595	0.90
159	35	IJ	135.6627	157.4063	7.7000	1.5609	0.90
159	36	II	141.0284	157.4063	7.7000	1.6601	0.90
159	49	GH	212.3707	157.4063	7.7000	2.2786	0.90
159	63	HH	289.8724	157.4063	7.7000	1.3641	0.90
159	64	GH	295.2382	157.4063	7.7000	1.2207	0.90
159	65	HH	300.9214	157.4063	7.7000	1.0016	0.91
159	66	FG	305.9697	157.4063	7.7000	0.7534	0.91
159	67	FG	311.4942	157.4063	7.7000	0.5897	0.92
159	68	FG	317.0187	157.4063	7.7000	0.4792	0.92

a. Data are in units of 10^{-18} reactions/atom-watt second.

Table 3.4 $^{115}\text{In}(n,n')$ Distribution in ZPPR-15B L123 – SSNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$\text{In}(n,n')$	$\sigma_{\text{total}}, \%$
159	18	HI	41.4287	157.4063	9.0800	0.0019	36.85
159	19	HI	46.9532	157.4063	9.0800	0.0030	43.34
159	20	HI	52.4777	157.4063	9.0800	0.0049	26.54
159	21	FG	57.3672	157.4063	9.0800	0.0027	40.75
159	22	FG	62.8917	157.4063	9.0800	0.0065	24.63
159	23	FG	68.4162	157.4063	9.0800	0.0078	24.37
159	24	FG	73.9407	157.4063	9.0800	0.0158	15.84
159	25	FG	79.4652	157.4063	9.0800	0.0332	9.07
159	26	FG	84.9897	157.4063	9.0800	0.0590	6.32
159	27	FG	90.5142	157.4063	9.0800	0.1180	3.81
159	28	FG	96.0387	157.4063	9.0800	0.2370	1.36
159	30	JK	108.3577	157.4063	9.0800	1.1800	1.09
159	32	II	118.9304	157.4063	9.0800	5.1500	1.09
159	37	IJ	146.7117	157.4063	9.0800	9.9200	1.06
159	49	GH	212.3707	157.4063	9.0800	10.0000	0.96
159	65	HH	300.9214	157.4063	9.0800	5.1700	1.41
159	67	FG	311.4942	157.4063	9.0800	1.1950	1.42
159	70	HI	328.7027	157.4063	9.0800	0.1260	3.89
159	73	HI	345.2762	157.4063	9.0800	0.0164	12.83
159	76	HI	361.8497	157.4063	9.0800	0.0018	72.23

a. The indium reaction rates are relative reaction rates based on 10.0 for the measured rate in matrix position 159-49.

Table 3.5 $^{115}\text{In}(n,\gamma)$ Distribution in ZPPR-15B L123 – SSNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	In(n, γ)	σ_{total} , %
159	18	HI	41.4287	157.4063	9.0800	0.740	2.06
159	19	HI	46.9532	157.4063	9.0800	0.880	1.22
159	20	HI	52.4777	157.4063	9.0800	1.370	1.67
159	21	FG	57.3672	157.4063	9.0800	1.540	1.17
159	22	FG	62.8917	157.4063	9.0800	3.060	1.27
159	23	FG	68.4162	157.4063	9.0800	4.170	1.13
159	24	FG	73.9407	157.4063	9.0800	5.370	1.09
159	25	FG	79.4652	157.4063	9.0800	6.290	1.12
159	26	FG	84.9897	157.4063	9.0800	6.940	1.15
159	27	FG	90.5142	157.4063	9.0800	6.780	1.08
159	28	FG	96.0387	157.4063	9.0800	5.410	1.09
159	30	JK	108.3577	157.4063	9.0800	3.470	1.14
159	32	II	118.9304	157.4063	9.0800	4.540	1.15
159	37	IJ	146.7117	157.4063	9.0800	8.100	1.17
159	49	GH	212.3707	157.4063	9.0800	10.000	0.96
159	65	HH	300.9214	157.4063	9.0800	4.580	1.14
159	67	FG	311.4942	157.4063	9.0800	3.500	1.18
159	70	HI	328.7027	157.4063	9.0800	6.830	1.12
159	73	HI	345.2762	157.4063	9.0800	5.120	1.15
159	76	HI	361.8497	157.4063	9.0800	1.250	1.19

a. The indium reaction rates are relative reaction rates based on 10.0 for the measured rate in matrix position 159-49.

Table 3.6 $^{239}\text{Pu}(n,f)$ Distribution in ZPPR-15B L134 – BCNA – X-Y Plane^a

Row	Column	Location	X	Y	Z	$^{239}\text{Pu}(n,f)$	σ_{total} , %
159	51	GH	223.4197	157.4063	9.0800	16.222	0.91
159	53	GH	234.4687	157.4063	9.0800	15.962	0.90
159	55	GH	245.5177	157.4063	9.0800	15.701	0.90
159	57	GH	256.5667	157.4063	9.0800	15.331	0.90
159	59	GH	267.6157	157.4063	9.0800	14.598	0.90
159	60	GH	273.1402	157.4063	9.0800	14.154	0.91
159	61	HH	278.8234	157.4063	9.0800	13.220	0.91
159	62	GH	284.1892	157.4063	9.0800	12.361	0.91
159	63	HH	289.8724	157.4063	9.0800	10.934	0.92
159	64	GH	295.2382	157.4063	9.0800	9.639	0.92
159	65	HH	300.9214	157.4063	9.0800	7.813	0.94

a. Data are in units of 10^{-18} reactions/atom-watt second.

Table 3.7 ²³⁵U(n,f) Distribution in ZPPR-15B L134 – BCNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁵ U(n,f)	σ _{total} , %
159	17	HI	35.9042	157.4063	6.3100	0.013	3.18
159	18	HI	41.4287	157.4063	6.3100	0.018	2.36
159	19	HI	46.9532	157.4063	6.3100	0.021	2.07
159	20	HI	52.4777	157.4063	6.3100	0.023	1.92
159	21	FG	57.3672	157.4063	6.3100	0.023	1.92
159	22	FG	62.8917	157.4063	6.3100	0.044	2.41
159	23	FG	68.4162	157.4063	6.3100	0.095	1.33
159	24	FG	73.9407	157.4063	6.3100	0.210	0.94
159	25	FG	79.4652	157.4063	6.3100	0.496	0.90
159	26	FG	84.9897	157.4063	6.3100	1.956	0.88
159	27	FG	90.5142	157.4063	6.3100	3.443	0.92
159	28	FG	96.0387	157.4063	6.3100	3.979	0.90
159	29	JK	102.8332	157.4063	6.3100	3.786	0.92
159	30	JK	108.3577	157.4063	6.3100	4.590	0.90
159	31	JK	113.8822	157.4063	6.3100	5.944	0.89
159	32	II	118.9304	157.4063	6.3100	7.528	0.89
159	33	IJ	124.6137	157.4063	6.3100	9.247	0.90
159	34	II	129.9794	157.4063	6.3100	10.545	0.92
159	35	IJ	135.6627	157.4063	6.3100	11.856	0.89
159	36	II	141.0284	157.4063	6.3100	12.708	0.89
159	37	IJ	146.7117	157.4063	6.3100	13.751	0.89
159	38	IJ	152.2362	157.4063	6.3100	14.385	0.89
159	40	IJ	163.2852	157.4063	6.3100	15.382	0.89
159	42	IJ	174.3342	157.4063	6.3100	15.904	0.88
159	44	IJ	185.3832	157.4063	6.3100	16.069	0.91
159	46	IJ	196.4322	157.4063	6.3100	16.390	0.88
159	48	IJ	207.4812	157.4063	6.3100	16.414	0.88
159	49	GH	212.3707	157.4063	6.3100	16.450	0.88
159	51	GH	223.4197	157.4063	6.3100	16.353	0.90
159	53	GH	234.4687	157.4063	6.3100	16.205	0.88
159	55	GH	245.5177	157.4063	6.3100	15.990	0.88
159	57	GH	256.5667	157.4063	6.3100	15.414	0.88
159	59	GH	267.6157	157.4063	6.3100	14.511	0.88
159	60	GH	273.1402	157.4063	6.3100	13.804	0.89
159	61	HH	278.8234	157.4063	6.3100	12.845	0.89
159	62	GH	284.1892	157.4063	6.3100	11.897	0.88
159	63	HH	289.8724	157.4063	6.3100	10.556	0.89
159	64	GH	295.2382	157.4063	6.3100	9.269	0.90
159	65	HH	300.9214	157.4063	6.3100	7.662	0.89
159	66	FG	305.9697	157.4063	6.3100	6.104	0.91
159	67	FG	311.4942	157.4063	6.3100	4.827	0.92
159	68	FG	317.0187	157.4063	6.3100	4.132	0.94

a. Data are in units of 10⁻¹⁸ reactions/atom-watt second.

Table 3.8 $^{238}\text{U}(\text{n},\text{f})$ Distribution in ZPPR-15B L134 – BCNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$^{238}\text{U}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
159	19	HI	46.9532	157.4063	7.7000	0.0000255	6.15
159	21	HI	58.0022	157.4063	7.7000	0.0000551	5.26
159	22	HI	63.5267	157.4063	7.7000	0.0001078	4.92
159	23	HI	69.0512	157.4063	7.7000	0.0002137	4.91
159	24	HI	74.5757	157.4063	7.7000	0.0004160	4.89
159	25	HI	80.1002	157.4063	7.7000	0.0008380	4.89
159	26	HI	85.6247	157.4063	7.7000	0.0019350	4.92
159	27	HI	91.1492	157.4063	7.7000	0.0038990	4.54
159	29	JK	102.8332	157.4063	7.7000	0.0183300	3.16
159	30	JK	108.3577	157.4063	7.7000	0.0384000	2.48
159	31	JK	113.8822	157.4063	7.7000	0.0909000	1.28
159	32	II	118.9304	157.4063	7.7000	0.1860000	1.03
159	33	IJ	124.6137	157.4063	7.7000	0.2683000	1.00
159	34	II	129.9794	157.4063	7.7000	0.2857000	1.00
159	35	IJ	135.6627	157.4063	7.7000	0.3517000	0.97
159	36	II	141.0284	157.4063	7.7000	0.3408000	0.96
159	49	GH	212.3707	157.4063	7.7000	0.3586000	0.95
159	63	HH	289.8724	157.4063	7.7000	0.2838000	1.00
159	64	GH	295.2382	157.4063	7.7000	0.2679000	1.00
159	65	HH	300.9214	157.4063	7.7000	0.1859000	1.00
159	66	FG	305.9697	157.4063	7.7000	0.0908000	1.19
159	67	FG	311.4942	157.4063	7.7000	0.0398000	1.71
159	68	FG	317.0187	157.4063	7.7000	0.0186800	2.85
258	70	HI	328.7027	162.9308	7.7000	0.0040470	4.60
258	72	HI	339.7517	162.9308	7.7000	0.0008860	4.93
258	74	HI	350.8007	162.9308	7.7000	0.0002301	4.88
258	76	HI	361.8497	162.9308	7.7000	0.0000639	6.78

a. Data are in units of 10^{-18} reactions/atom-watt second.

As mentioned, the ^{238}U fission rate was measured with solid state track recorders (SSTRs) rather than ^{238}U foils in locations outside of the core and blanket in L134. Special ^{238}U foils were used in the SSTR measurements. The SSTR data were converted to units of fissions/atom-watt-second using the integral power measured by the ex-core detectors.

The SSTRs were in ZPPR matrix columns 19 – 27 and 70 -76 which are identifiable in Table 3.8 as those results with significantly higher total uncertainties than those at the center of the core.

Table 3.9 $^{238}\text{U}(\text{n},\gamma)$ Distribution in ZPPR-15B L134 – BCNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$^{238}\text{U}(\text{n},\gamma)$	$\sigma_{\text{total}}, \%$
159	29	JK	102.8332	157.4063	7.7000	0.4479000	0.94
159	30	JK	108.3577	157.4063	7.7000	0.5694000	0.95
159	31	JK	113.8822	157.4063	7.7000	0.7361000	0.93
159	32	II	118.9304	157.4063	7.7000	0.9935000	0.91
159	33	IJ	124.6137	157.4063	7.7000	1.2123000	0.93
159	34	II	129.9794	157.4063	7.7000	1.3575000	0.93
159	35	IJ	135.6627	157.4063	7.7000	1.5653000	0.92
159	36	II	141.0284	157.4063	7.7000	1.6528000	0.91
159	49	GH	212.3707	157.4063	7.7000	2.2818000	0.92
159	63	HH	289.8724	157.4063	7.7000	1.3706000	0.92
159	64	GH	295.2382	157.4063	7.7000	1.2288000	0.92
159	65	HH	300.9214	157.4063	7.7000	1.0050000	0.92
159	66	FG	305.9697	157.4063	7.7000	0.7595000	0.93
159	67	FG	311.4942	157.4063	7.7000	0.5887000	0.93
159	68	FG	317.0187	157.4063	7.7000	0.4817000	0.93

a. Data are in units of 10^{-18} reactions/atom-watt second.

Table 3.10 $^{115}\text{In}(\text{n},\text{n}')$ Distribution in ZPPR-15B L134 – BCNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$^{115}\text{In}(\text{n},\text{n}')$	$\sigma_{\text{total}}, \%$
159	17	HI	35.9042	157.4063	9.0800	0.00062	45.17
159	18	HI	41.4287	157.4063	9.0800	0.00059	38.99
159	19	HI	46.9532	157.4063	9.0800	0.00057	40.36
159	20	HI	52.4777	157.4063	9.0800	0.00078	37.19
159	21	FG	57.3672	157.4063	9.0800	0.00154	20.79
159	22	FG	62.8917	157.4063	9.0800	0.00366	12.05
159	23	FG	68.4162	157.4063	9.0800	0.00635	9.64
159	24	FG	73.9407	157.4063	9.0800	0.01220	9.05
159	25	FG	79.4652	157.4063	9.0800	0.02560	6.30
159	26	FG	84.9897	157.4063	9.0800	0.05410	4.69
159	27	FG	90.5142	157.4063	9.0800	0.11540	3.31
159	28	FG	96.0387	157.4063	9.0800	0.23650	2.38
159	30	JK	108.3577	157.4063	9.0800	1.15900	1.35
159	32	II	118.9304	157.4063	9.0800	5.13600	1.02
159	49	GH	212.3707	157.4063	9.0800	10.00000	0.89
159	68	FG	317.0187	157.4063	9.0800	0.58570	1.72

a. The indium reaction rates are relative reaction rates based on 10.0 for the measured rate in matrix position 159-49.

Table 3.11 $^{115}\text{In}(n,\gamma)$ Distribution in ZPPR-15B L134 – BCNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$\text{In}(n,\gamma)$	$\sigma_{\text{total}}, \%$
159	17	HI	35.9042	157.4063	9.0800	0.0091	6.64
159	18	HI	41.4287	157.4063	9.0800	0.0124	7.30
159	19	HI	46.9532	157.4063	9.0800	0.0153	5.29
159	20	HI	52.4777	157.4063	9.0800	0.0157	7.05
159	21	FG	57.3672	157.4063	9.0800	0.0154	5.26
159	22	FG	62.8917	157.4063	9.0800	0.0335	3.67
159	23	FG	68.4162	157.4063	9.0800	0.0694	2.99
159	24	FG	73.9407	157.4063	9.0800	0.1466	2.65
159	25	FG	79.4652	157.4063	9.0800	0.3437	1.92
159	26	FG	84.9897	157.4063	9.0800	1.7490	1.18
159	27	FG	90.5142	157.4063	9.0800	3.1190	1.05
159	28	FG	96.0387	157.4063	9.0800	3.3350	1.04
159	30	JK	108.3577	157.4063	9.0800	3.0540	1.22
159	32	II	118.9304	157.4063	9.0800	4.4410	1.04
159	49	GH	212.3707	157.4063	9.0800	10.0000	0.83
159	68	FG	317.0187	157.4063	9.0800	3.6200	1.24

- a. The indium reaction rates are relative reaction rates based on 10.0 for the measured rate in matrix position 159-49.

Table 3.12 ²³⁹Pu(n,f) Distribution in ZPPR-15D L203^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁹ Pu(n,f)	σ _{total} , %
152	49	HI	212.6882	196.0778	9.0800	1.482	1.05
153	49	HI	212.6882	190.5533	9.0800	1.489	1.05
154	49	HI	212.6882	185.0288	9.0800	1.482	1.05
155	49	HI	212.6882	179.5043	9.0800	1.475	1.05
156	49	HI	212.6882	173.9798	9.0800	1.500	1.05
157	49	HI	212.6882	168.4553	9.0800	1.456	1.15
158	49	HI	212.6882	162.9308	9.0800	1.480	1.10
159	50	HI	218.2127	157.4063	9.0800	1.459	1.10
159	51	HI	223.7372	157.4063	9.0800	1.482	1.05
159	52	HI	229.2617	157.4063	9.0800	1.495	1.05
159	53	HI	234.7862	157.4063	9.0800	1.498	1.05
159	54	HI	240.3107	157.4063	9.0800	1.503	1.09
159	55	HI	245.8352	157.4063	9.0800	1.468	1.06
159	56	HI	251.3597	157.4063	9.0800	1.517	1.08
159	57	HI	256.8842	157.4063	9.0800	1.501	1.05
159	58	HI	262.4087	157.4063	9.0800	1.419	1.12
159	59	HI	267.9332	157.4063	9.0800	1.390	1.08
159	61	CC	277.2359	157.4063	9.0800	1.250	1.08
159	62	HI	284.5067	157.4063	9.0800	1.167	1.12
159	63	CC	288.2849	157.4063	9.0800	1.046	1.11
159	65	CC	299.3339	157.4063	9.0800	0.745	1.34
159	66	FG	305.9697	157.4063	9.0800	0.573	1.32
159	67	FG	311.4942	157.4063	9.0800	0.440	1.39
159	68	FG	317.0187	157.4063	9.0800	0.384	1.53
159	49	HH	212.5294	156.0223	7.7000	1.501	1.05
159	49	HH	212.5294	156.0223	12.7800	1.451	1.06
159	49	HH	212.5294	156.0223	17.8600	1.371	1.04
159	49	HH	212.5294	156.0223	25.4800	1.246	1.08
159	49	HH	212.5294	156.0223	33.1000	1.090	1.15
159	49	HH	212.5294	156.0223	38.1800	0.954	1.16
159	49	HH	212.5294	156.0223	43.2600	0.826	1.17
159	60	HI	273.4577	156.0223	7.7000	1.337	1.05
159	60	HI	273.4577	156.0223	12.7800	1.277	1.02
159	60	HI	273.4577	156.0223	17.8600	1.234	1.14
159	60	HI	273.4577	156.0223	25.4800	1.113	1.08
159	60	HI	273.4577	156.0223	33.1000	0.952	1.16
159	60	HI	273.4577	156.0223	38.1800	0.841	1.16
159	60	HI	273.4577	156.0223	43.2600	0.700	1.18
159	64	HH	295.3969	156.0223	7.7000	0.913	1.11
159	64	HH	295.3969	156.0223	12.7800	0.879	1.13
159	64	HH	295.3969	156.0223	17.8600	0.845	1.24
159	64	HH	295.3969	156.0223	25.4800	0.745	1.24
159	64	HH	295.3969	156.0223	33.1000	0.648	1.23
159	64	HH	295.3969	156.0223	38.1800	0.565	1.33
159	64	HH	295.3969	156.0223	43.2600	0.477	1.32

a. Data are in units of 10⁻¹⁷ reactions/atom-watt second.

Various ZPPR staff members processed the measured foil data and wrote the report sections documenting the foil measurements. The measured values and associated normalizations listed in this document are the measured values and associated normalizations presented in the original ZPPR reports.

Table 3.13 ²³⁵U(n,f) Distribution in ZPPR-15D L203^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁵ U(n,f)	σ _{total} , %
159	29	JK	102.8332	157.4063	6.3100	0.3940	1.11
159	30	JK	108.3577	157.4063	6.3100	0.4500	1.05
159	31	JK	113.8822	157.4063	6.3100	0.5580	1.08
159	32	NN	120.5179	157.4063	6.3100	0.6950	1.08
159	33	HI	124.2962	157.4063	6.3100	0.8120	1.01
159	34	NN	131.5669	157.4063	6.3100	0.9580	0.96
159	35	HI	135.3452	157.4063	6.3100	1.0560	0.93
159	36	NN	142.6159	157.4063	6.3100	1.1560	1.01
159	37	HI	146.3942	157.4063	6.3100	1.2210	0.94
159	38	HI	151.9187	157.4063	6.3100	1.2930	0.97
159	39	HI	157.4432	157.4063	6.3100	1.3540	0.96
159	40	HI	162.9677	157.4063	6.3100	1.3980	0.95
159	41	HI	168.4922	157.4063	6.3100	1.4230	0.94
159	42	HI	174.0167	157.4063	6.3100	1.4350	0.94
159	43	HI	179.5412	157.4063	6.3100	1.4420	0.94
159	44	HI	185.0657	157.4063	6.3100	1.4470	0.94
159	45	HI	190.5902	157.4063	6.3100	1.4460	0.94
159	46	HI	196.1147	157.4063	6.3100	1.4480	0.94
159	47	HI	201.6392	157.4063	6.3100	1.4530	0.94
159	48	HI	207.1637	157.4063	6.3100	1.4310	0.94
131	49	HI	212.6882	312.0923	6.3100	0.0810	1.47
132	49	HI	212.6882	306.5678	6.3100	0.1480	1.57
133	49	HI	212.6882	301.0433	6.3100	0.2220	1.21
134	49	HI	212.6882	295.5188	6.3100	0.3080	1.04
135	49	HI	212.6882	289.9943	6.3100	0.4010	1.10
136	49	HI	212.6882	284.4698	6.3100	0.4850	1.02
137	49	HI	212.6882	278.9453	6.3100	0.5360	0.98
138	49	HI	212.6882	273.4208	6.3100	0.5010	1.00
139	49	FG	212.0532	267.8963	6.3100	0.4000	1.10
140	49	FG	212.0532	262.3718	6.3100	0.4520	1.04
141	49	FG	212.0532	256.8473	6.3100	0.5540	1.08
142	49	CC	210.9419	251.3228	6.3100	0.6890	0.99
143	49	HI	212.6882	245.7983	6.3100	0.8170	0.94
144	49	CC	210.9419	240.2738	6.3100	0.9350	0.97
145	49	HI	212.6882	234.7493	6.3100	1.0490	0.94
146	49	CC	210.9419	229.2248	6.3100	1.1480	0.96
147	49	HI	212.6882	223.7003	6.3100	1.2330	0.99
148	49	HI	212.6882	218.1758	6.3100	1.2930	0.97
149	49	HI	212.6882	212.6513	6.3100	1.3470	0.96
150	49	HI	212.6882	207.1268	6.3100	1.3910	0.95
151	49	HI	212.6882	201.6023	6.3100	1.4070	0.95
152	49	HI	212.6882	196.0778	6.3100	1.4280	0.94
153	49	HI	212.6882	190.5533	6.3100	1.4370	0.94
154	49	HI	212.6882	185.0288	6.3100	1.4250	0.94
155	49	HI	212.6882	179.5043	6.3100	1.4450	0.94
156	49	HI	212.6882	173.9798	6.3100	1.4390	0.94
157	49	HI	212.6882	168.4553	6.3100	1.4490	0.94

158	49	HI	212.6882	162.9308	6.3100	1.4330	0.94
160	49	HI	212.6882	151.8818	6.3100	1.4420	0.94
161	49	HI	212.6882	146.3573	6.3100	1.4430	0.98
162	49	HI	212.6882	140.8328	6.3100	1.3890	0.91
163	49	HI	212.6882	135.3083	6.3100	1.4440	0.98
164	49	HI	212.6882	129.7838	6.3100	1.4350	0.98
165	49	HI	212.6882	124.2593	6.3100	1.4260	0.94
166	49	HI	212.6882	118.7348	6.3100	1.4020	0.95
167	49	HI	212.6882	113.2103	6.3100	1.3740	0.99
168	49	HI	212.6882	107.6858	6.3100	1.3540	0.96
169	49	HI	212.6882	102.1613	6.3100	1.2880	0.93
170	49	HI	212.6882	96.6368	6.3100	1.2140	0.95
171	49	CC	210.9419	91.1123	6.3100	1.1430	0.96
172	49	HI	212.6882	85.5878	6.3100	1.0470	0.94
173	49	CC	210.9419	80.0633	6.3100	0.9300	0.97
174	49	HI	212.6882	74.5388	6.3100	0.8150	1.01
175	49	CC	210.9419	69.0143	6.3100	0.6850	1.00
176	49	FG	212.0532	63.4898	6.3100	0.5530	0.97
177	49	FG	212.0532	57.9653	6.3100	0.4520	1.04
178	49	FG	212.0532	52.4408	6.3100	0.4010	1.10
159	50	HI	218.2127	157.4063	6.3100	1.4450	0.91
159	51	HI	223.7372	157.4063	6.3100	1.4350	0.91
159	52	HI	229.2617	157.4063	6.3100	1.4380	0.94
159	53	HI	234.7862	157.4063	6.3100	1.4560	0.94
159	54	HI	240.3107	157.4063	6.3100	1.4410	0.98
159	55	HI	245.8352	157.4063	6.3100	1.4290	0.91
159	56	HI	251.3597	157.4063	6.3100	1.4260	0.91
159	57	HI	256.8842	157.4063	6.3100	1.4020	0.91
159	58	HI	262.4087	157.4063	6.3100	1.3540	0.92
159	59	HI	267.9332	157.4063	6.3100	1.2920	0.93
159	61	CC	277.2359	157.4063	6.3100	1.1550	0.92
159	62	HI	284.5067	157.4063	6.3100	1.0490	0.94
159	63	CC	288.2849	157.4063	6.3100	0.9550	0.96
159	65	CC	299.3339	157.4063	6.3100	0.6940	0.99
159	66	FG	305.9697	157.4063	6.3100	0.5590	0.97
159	67	FG	311.4942	157.4063	6.3100	0.4490	1.05
159	68	FG	317.0187	157.4063	6.3100	0.3930	1.11
159	69	HI	323.1782	157.4063	6.3100	0.4840	1.15
159	70	HI	328.7027	157.4063	6.3100	0.5150	1.12
159	71	HI	334.2272	157.4063	6.3100	0.4750	1.02
159	72	HI	339.7517	157.4063	6.3100	0.3920	1.11
159	73	HI	345.2762	157.4063	6.3100	0.2990	1.05
159	74	HI	350.8007	157.4063	6.3100	0.2180	1.22
159	75	HI	356.3252	157.4063	6.3100	0.1480	1.57
159	76	HI	361.8497	157.4063	6.3100	0.0810	1.47
159	49	HH	212.5294	158.7903	7.7000	1.4330	0.91
159	49	HH	212.5294	158.7903	12.7800	1.3880	0.91
159	49	HH	212.5294	158.7903	17.8600	1.3390	0.92
159	49	HH	212.5294	158.7903	25.4800	1.1960	0.95
159	49	HH	212.5294	158.7903	33.1000	1.0560	0.93
159	49	HH	212.5294	158.7903	38.1800	0.9280	0.97
159	49	HH	212.5294	158.7903	43.2600	0.8090	0.95
159	49	GH	212.3707	158.7903	48.3400	0.6990	0.99
159	49	GH	212.3707	158.7903	53.4200	0.5820	0.96
159	49	GH	212.3707	158.7903	63.5800	0.3870	1.12

159	49	GH	212.3707	158.7903	73.7400	0.2830	1.07
159	60	HI	273.4577	158.7903	7.7000	1.2170	0.90
159	60	HI	273.4577	158.7903	12.7800	1.1740	0.95
159	60	HI	273.4577	158.7903	17.8600	1.1220	0.92
159	60	HI	273.4577	158.7903	25.4800	1.0210	0.94
159	60	HI	273.4577	158.7903	33.1000	0.8810	0.93
159	60	HI	273.4577	158.7903	38.1800	0.7840	0.95
159	60	HI	273.4577	158.7903	43.2600	0.6650	1.01
159	60	GH	273.1402	158.7903	48.3400	0.5730	0.96
159	60	GH	273.1402	158.7903	53.4200	0.4770	1.02
159	60	GH	273.1402	158.7903	63.5800	0.3140	1.03
159	60	GH	273.1402	158.7903	73.7400	0.2210	1.21
159	64	HH	295.3969	158.7903	7.7000	0.8170	0.94
159	64	HH	295.3969	158.7903	12.7800	0.7830	0.95
159	64	HH	295.3969	158.7903	17.8600	0.7530	0.97
159	64	HH	295.3969	158.7903	25.4800	0.6740	0.92
159	64	HH	295.3969	158.7903	33.1000	0.5820	0.96
159	64	HH	295.3969	158.7903	38.1800	0.5150	0.99
159	64	HH	295.3969	158.7903	43.2600	0.4410	1.05
159	64	GH	295.2382	158.7903	48.3400	0.3710	0.97
159	64	GH	295.2382	158.7903	53.4200	0.3080	1.26
159	64	GH	295.2382	158.7903	63.5800	0.2030	1.27
159	64	GH	295.2382	158.7903	73.7400	0.1470	1.05

a. Data are in units of 10⁻¹⁷ reactions/atom-watt second.

Table 3.14 ²³⁸U(n,f) Distribution in ZPPR-15D L203^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁸ U(n,f)	σ _{total} , %
139	49	FG	212.0532	267.8963	7.7000	0.0020	5.06
140	49	FG	212.0532	262.3718	7.7000	0.0038	5.32
141	49	FG	212.0532	256.8473	7.7000	0.0083	2.54
142	49	CC	210.9419	251.3228	7.7000	0.0210	2.07
143	49	HI	212.6882	245.7983	7.7000	0.0317	1.50
144	49	CC	210.9419	240.2738	7.7000	0.0339	1.43
145	49	HI	212.6882	234.7493	7.7000	0.0417	1.25
146	49	CC	210.9419	229.2248	7.7000	0.0397	1.50
147	49	HI	212.6882	223.7003	7.7000	0.0365	1.59
148	49	HI	212.6882	218.1758	7.7000	0.0370	1.35
149	49	HI	212.6882	212.6513	7.7000	0.0379	1.33
150	49	HI	212.6882	207.1268	7.7000	0.0475	1.33
151	49	HI	212.6882	201.6023	7.7000	0.0477	1.32
152	49	HI	212.6882	196.0778	7.7000	0.0385	1.32
153	49	HI	212.6882	190.5533	7.7000	0.0364	1.36
154	49	HI	212.6882	185.0288	7.7000	0.0360	1.37
155	49	HI	212.6882	179.5043	7.7000	0.0363	1.37
156	49	HI	212.6882	173.9798	7.7000	0.0358	1.38
157	49	HI	212.6882	168.4553	7.7000	0.0358	1.38
158	49	HI	212.6882	162.9308	7.7000	0.0357	1.38
159	50	HI	218.2127	157.4063	7.7000	0.0358	1.38
159	51	HI	223.7372	157.4063	7.7000	0.0355	1.62
159	52	HI	229.2617	157.4063	7.7000	0.0362	1.37
159	53	HI	234.7862	157.4063	7.7000	0.0365	1.36
159	54	HI	240.3107	157.4063	7.7000	0.0371	1.57
159	55	HI	245.8352	157.4063	7.7000	0.0387	1.52
159	56	HI	251.3597	157.4063	7.7000	0.0483	1.31
159	57	HI	256.8842	157.4063	7.7000	0.0476	1.32
159	58	HI	262.4087	157.4063	7.7000	0.0392	1.51
159	59	HI	267.9332	157.4063	7.7000	0.0374	1.34
159	61	CC	277.2359	157.4063	7.7000	0.0377	1.33
159	62	HI	284.5067	157.4063	7.7000	0.0416	1.45
159	63	CC	288.2849	157.4063	7.7000	0.0338	1.43
159	65	CC	299.3339	157.4063	7.7000	0.0224	1.56
159	66	FG	305.9697	157.4063	7.7000	0.0085	2.49
159	67	FG	311.4942	157.4063	7.7000	0.0040	5.06
159	68	FG	317.0187	157.4063	7.7000	0.0022	9.13
159	49	HH	212.5294	157.4063	7.7000	0.0354	1.39
159	49	HH	212.5294	157.4063	12.7800	0.0343	1.42
159	49	HH	212.5294	157.4063	17.8600	0.0331	1.45
159	49	HH	212.5294	157.4063	25.4800	0.0295	1.58
159	49	HH	212.5294	157.4063	33.1000	0.0255	1.43
159	49	HH	212.5294	157.4063	38.1800	0.0224	1.56
159	49	HH	212.5294	157.4063	43.2600	0.0172	1.92
159	49	GH	212.3707	157.4063	48.3400	0.0074	2.82
159	49	GH	212.3707	157.4063	53.4200	0.0038	5.32
159	49	GH	212.3707	157.4063	63.5800	0.0013	7.73
159	49	GH	212.3707	157.4063	73.7400	0.0006	16.69
159	60	HI	273.4577	157.4063	7.7000	0.0370	1.35
159	60	HI	273.4577	157.4063	12.7800	0.0359	1.38
159	60	HI	273.4577	157.4063	17.8600	0.0338	1.43
159	60	HI	273.4577	157.4063	25.4800	0.0311	1.52

159	60	HI	273.4577	157.4063	33.1000	0.0259	1.41
159	60	HI	273.4577	157.4063	38.1800	0.0216	1.61
159	60	HI	273.4577	157.4063	43.2600	0.0175	1.89
159	60	GH	273.1402	157.4063	48.3400	0.0080	2.63
159	60	GH	273.1402	157.4063	53.4200	0.0040	5.06
159	60	GH	273.1402	157.4063	63.5800	0.0012	16.69
159	60	GH	273.1402	157.4063	73.7400	0.0008	12.53
159	64	HH	295.3969	157.4063	7.7000	0.0318	1.49
159	64	HH	295.3969	157.4063	12.7800	0.0309	1.53
159	64	HH	295.3969	157.4063	17.8600	0.0289	1.60
159	64	HH	295.3969	157.4063	25.4800	0.0262	1.40
159	64	HH	295.3969	157.4063	33.1000	0.0221	1.58
159	64	HH	295.3969	157.4063	38.1800	0.0190	1.77
159	64	HH	295.3969	157.4063	43.2600	0.0150	1.56
159	64	GH	295.2382	157.4063	48.3400	0.0057	3.60
159	64	GH	295.2382	157.4063	53.4200	0.0029	3.54
159	64	GH	295.2382	157.4063	63.5800	0.0010	10.03
159	64	GH	295.2382	157.4063	73.7400	0.0008	25.01

a. Data are in units of 10^{-17} reactions/atom-watt second.

Table 3.15 ²³⁸U(n,γ) Distribution in ZPPR-15D L203^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁸ U(n,γ)	σ _{total} , %
139	49	FG	212.0532	267.8963	7.7000	0.0457	1.04
140	49	FG	212.0532	262.3718	7.7000	0.0552	1.08
141	49	FG	212.0532	256.8473	7.7000	0.0685	1.00
142	49	CC	210.9419	251.3228	7.7000	0.0894	0.98
143	49	HI	212.6882	245.7983	7.7000	0.1043	0.99
144	49	CC	210.9419	240.2738	7.7000	0.1199	0.95
145	49	HI	212.6882	234.7493	7.7000	0.1338	0.96
146	49	CC	210.9419	229.2248	7.7000	0.1460	0.97
147	49	HI	212.6882	223.7003	7.7000	0.1543	0.96
148	49	HI	212.6882	218.1758	7.7000	0.1642	0.94
149	49	HI	212.6882	212.6513	7.7000	0.1711	0.96
150	49	HI	212.6882	207.1268	7.7000	0.1819	0.95
151	49	HI	212.6882	201.6023	7.7000	0.1871	0.97
152	49	HI	212.6882	196.0778	7.7000	0.1960	0.95
153	49	HI	212.6882	190.5533	7.7000	0.2000	0.95
154	49	HI	212.6882	185.0288	7.7000	0.2016	0.95
155	49	HI	212.6882	179.5043	7.7000	0.2024	0.95
156	49	HI	212.6882	173.9798	7.7000	0.2032	0.97
157	49	HI	212.6882	168.4553	7.7000	0.2031	0.94
158	49	HI	212.6882	162.9308	7.7000	0.2048	0.94
159	50	HI	218.2127	157.4063	7.7000	0.2039	0.94
159	51	HI	223.7372	157.4063	7.7000	0.2040	0.94
159	52	HI	229.2617	157.4063	7.7000	0.2039	0.94
159	53	HI	234.7862	157.4063	7.7000	0.2027	0.95
159	54	HI	240.3107	157.4063	7.7000	0.2028	0.97
159	55	HI	245.8352	157.4063	7.7000	0.1976	0.95
159	56	HI	251.3597	157.4063	7.7000	0.1892	0.94
159	57	HI	256.8842	157.4063	7.7000	0.1836	0.97
159	58	HI	262.4087	157.4063	7.7000	0.1737	0.96
159	59	HI	267.9332	157.4063	7.7000	0.1660	0.94
159	61	CC	277.2359	157.4063	7.7000	0.1487	0.97
159	62	HI	284.5067	157.4063	7.7000	0.1345	0.96
159	63	CC	288.2849	157.4063	7.7000	0.1205	0.99
159	65	CC	299.3339	157.4063	7.7000	0.0907	0.98
159	66	FG	305.9697	157.4063	7.7000	0.0683	1.00
159	67	FG	311.4942	157.4063	7.7000	0.0551	1.08
159	68	FG	317.0187	157.4063	7.7000	0.0451	1.05
159	49	HH	212.5294	157.4063	7.7000	0.2031	0.94
159	49	HH	212.5294	157.4063	12.7800	0.1983	0.95
159	49	HH	212.5294	157.4063	17.8600	0.1886	0.96
159	49	HH	212.5294	157.4063	25.4800	0.1713	0.93
159	49	HH	212.5294	157.4063	33.1000	0.1504	0.97
159	49	HH	212.5294	157.4063	38.1800	0.1354	0.96
159	49	HH	212.5294	157.4063	43.2600	0.1189	0.95
159	49	GH	212.3707	157.4063	48.3400	0.0979	0.95
159	49	GH	212.3707	157.4063	53.4200	0.0836	1.00
159	49	GH	212.3707	157.4063	63.5800	0.0582	1.06
159	49	GH	212.3707	157.4063	73.7400	0.0421	1.08
159	60	HI	273.4577	157.4063	7.7000	0.1544	0.96
159	60	HI	273.4577	157.4063	12.7800	0.1497	0.97
159	60	HI	273.4577	157.4063	17.8600	0.1428	0.94
159	60	HI	273.4577	157.4063	25.4800	0.1294	0.97

159	60	HI	273.4577	157.4063	33.1000	0.1132	0.96
159	60	HI	273.4577	157.4063	38.1800	0.1014	1.00
159	60	HI	273.4577	157.4063	43.2600	0.0876	0.99
159	60	GH	273.1402	157.4063	48.3400	0.0782	1.03
159	60	GH	273.1402	157.4063	53.4200	0.0666	1.01
159	60	GH	273.1402	157.4063	63.5800	0.0462	1.04
159	60	GH	273.1402	157.4063	73.7400	0.0329	1.01
159	64	HH	295.3969	157.4063	7.7000	0.1036	0.99
159	64	HH	295.3969	157.4063	12.7800	0.1009	0.95
159	64	HH	295.3969	157.4063	17.8600	0.0958	0.96
159	64	HH	295.3969	157.4063	25.4800	0.0866	0.99
159	64	HH	295.3969	157.4063	33.1000	0.0752	0.97
159	64	HH	295.3969	157.4063	38.1800	0.0675	1.00
159	64	HH	295.3969	157.4063	43.2600	0.0589	1.05
159	64	GH	295.2382	157.4063	48.3400	0.0504	1.00
159	64	GH	295.2382	157.4063	53.4200	0.0437	1.06
159	64	GH	295.2382	157.4063	63.5800	0.0293	1.06
159	64	GH	295.2382	157.4063	73.7400	0.0220	1.22

a. Data are in units of 10^{-17} reactions/atom-watt second.

4 Absolute Foil Reaction Rates in ZPPR-15

The uncertainty analysis in Section 3.1 applies to relative or normalized reaction rate distributions and ratios such as the ratio of the measured foil reaction rate at each location to the maximum measured foil reaction rate. For calculations of relative or normalized distributions and ratios, the units in which the measured reaction rates are reported do not matter because they cancel out in ratios. Likewise, uncertainties in calibration of the counting system do not matter for relative distributions or ratios of foils of the same type.

The basic foil data for the ^{235}U , ^{238}U and ^{239}Pu foils for ZPPR-15B were reported in units of 10^{-18} reactions per atom-watt second and in units of 10^{-17} reactions per atom-watt second in ZPPR-15D, which indicates that they were intended to be absolute reaction rates. Conversion of the basic mapping foil data to absolute reaction rates requires relating the measured mapping foil reaction rates to a specific reactor power and introduces additional uncertainties related to calibration of the detector system.

4.1 Absolute Foil Reaction Rate Uncertainties

Determining absolute foil reaction rates required calibration of the detector system used to count the foils. The ZPPR staff measured a calibration factor to relate the number of counts recorded in the gamma counting system to the number of reactions required to produce those counts. If C_γ is the number of counts recorded in the detector system for a reaction and N is the number of reactions that occurred to produce C_γ counts in the detector system, then the calibration factor, ϵ_γ , was defined as

$$\epsilon_\gamma = (C_\gamma)_{\text{calib}} / (N)_{\text{calib}}$$

according to Ref. 4.

For calculations of absolute reaction rates, uncertainties related to detector calibration and the calibration factor must be added to the uncertainties listed in Section 3.1 for the basic mapping foil data. The following is a summary of a description of reaction rate calibration techniques at ZPPR by S. B. Brumbach and D. W. Maddison of the ZPPR staff [4].

Foil masses were measured, and the uncertainty in the measured masses was less than 0.1%. The foil mass uncertainty was neglected for calibration purposes because it is small compared to other sources of uncertainty for detector calibration. Uncertainties in the foil material isotopics were neglected for the same reason.

Back-to-back (BTB) fission chambers were used for the calibration measurements. The BTB chambers were a fundamental component of the detector calibration process. Fissionable and fissile materials were electroplated onto small stainless steel substrate disks (15.88 mm diameter, 0.08 mm thick) which were placed in the BTB chambers. Deposit masses were ~ 100 μg for ^{235}U and ^{239}Pu and ~ 250 μg for ^{238}U .

The primary deposit standards were ^{235}U deposits. A weighed amount of ^{235}U was dissolved, and a known amount of the resulting solution was used for the electroplating process. After electroplating, the mass of ^{235}U remaining in the solution was measured to establish the mass of ^{235}U deposited on the substrate. Mass values could also be verified by irradiating pairs of

deposits in a BTB chamber and comparing count rate ratios to mass ratios to verify mass values. Dissolving one of the deposits and determining its mass by isotope dilution mass spectrometry provided additional mass verification. The uncertainty in the mass of the reference ^{235}U deposit was 1.2%.

After the mass standard for the reference ^{235}U deposit was established, masses of other fissile deposits were determined relative to the reference ^{235}U deposit in the BTB fission chamber measurements in the Argonne Fast Source Reactor (AFSR) thermal column. Use of the AFSR thermal column for establishing the mass values required knowledge of thermal cross sections and g-factors for ^{235}U and ^{239}Pu . A 1% correction with a 0.4% uncertainty was applied to observed BTB count rates for fission fragment pulses lost below a predetermined bias level.

The mass of the ^{239}Pu deposit used in the reaction rate calibration was determined by the AFSR thermal column BTB chamber method. The components of the uncertainty in the ^{239}Pu deposit mass are: 1) 0.1% for counting statistics in the BTB chamber, 2) 0.42% for the ^{239}Pu cross section, 3) 0.28% for the ^{239}Pu g-factor, 4) 0.31% for the ^{235}U cross section, 5) 0.16% for the ^{235}U g-factor, 6) 1.2% for the ^{235}U reference deposit mass and 7) 0.4% for the BTB fission chamber correction. The total uncertainty for the ^{239}Pu deposit mass was 1.4%.

The masses of other ^{235}U deposits were also determined by irradiation in the thermal column with the reference ^{235}U deposit. The uncertainty components for one of these ^{235}U deposits are: 1) 0.05% for counting statistics in the BTB chamber, 2) 1.2% for the reference ^{235}U deposit mass and 3) 0.4% for the BTB fission chamber correction. The total uncertainty for any ^{235}U deposit mass except the reference deposit was 1.3%.

Deposits used to calibrate the ^{238}U fission rate were made of natural uranium. The natural uranium deposit was irradiated in the AFSR thermal column with a reference ^{235}U deposit. This irradiation allowed the ^{235}U mass and, consequently, the ^{238}U mass in the natural uranium deposit to be determined. The components of the uncertainty in the ^{238}U mass in the natural uranium deposit are: 1) 0.3% for counting statistics in the BTB chamber, 2) 0.8% for the isotopic composition of the deposit, 3) 1.2% for the mass of the reference ^{235}U deposit and 4) 0.4% for the BTB fission chamber correction. The total uncertainty in the ^{238}U deposit mass in the natural uranium deposit was 1.5%.

A BTB fission chamber was a thin-walled aluminum hemisphere with a diameter of approximately 3.56 cm. The fissile deposit substrate disks were mounted back-to-back on a lip in the center of the chamber. One or two irradiation foils could be centered between the backs of the deposits for a given measurement.

A fundamental assumption in the BTB chamber irradiations was that both deposits experience the same neutron flux and spectrum, but the chambers were irradiated in reactor environments where flux gradients existed. Ideally, the deposits were perpendicular to the direction of the flux gradient during irradiation, but that was not possible in some cases because orientation of the chamber was restricted by cables and gas tubes protruding from the back of the chamber. In addition, neutron fission and capture in foils placed between the substrate disks could in principle introduce a gradient. Effects of flux gradients could be determined by measuring count rates, rotating the BTB chamber 180° to face the opposite direction and obtaining another count rate. If the count rate ratios from the two orientations were different, an average value could be used. The wires and gas tubes projecting from the back of the BTB chamber were

symmetric about the axial centerline of the chamber (see Ref. 4, Fig. 1), so rotating the BTB chamber 180° did not introduce any asymmetry related to the wires and gas tubes.

Effects of flux gradients and self-shielding in a BTB chamber with a ^{239}Pu foil between the substrate disks were measured in several ZPPR environments. No statistically significant variations in the calibration constants were found, so no self-shielding corrections were applied to BTB chamber measurements during ZPPR irradiation when ^{239}Pu or ^{235}U foils were placed in the chambers. The situation with respect to ^{238}U foils was less clear, but no corrections were applied to BTB chamber data for the effects of any of the foils on any of the deposits.

The deposits in the BTB chambers provided reference values for calibrating foils that were placed in the chambers. The BTB chamber contained a ^{235}U foil, ^{235}U deposit, ^{239}Pu foil and ^{239}Pu deposit for the irradiation.

The largest single uncertainty for the calibration foils resulted from counting statistics. This uncertainty was approximately 0.5% for ^{239}Pu fission, 0.4% for ^{235}U fission, 1% for ^{238}U fission and 0.5% for ^{238}U capture. The other significant uncertainty for the calibration foils was the 0.3% reproducibility uncertainty discussed earlier when the calibration foils were placed in the detector and counted.

Several minor corrections were made to the count rates in the calibration foils. Uncertainties related to these corrections were not propagated because either the uncertainties were negligible or else the uncertainties appeared in a ratio and, consequently, cancelled out.

The components of the uncertainty for the absolute ^{239}Pu fission rate foil calibration are: 1) 0.5% uncertainty for counting statistics, 2) 0.3% reproducibility uncertainty and 3) 1.4% ^{239}Pu deposit mass uncertainty. The total uncertainty in the absolute ^{239}Pu fission rate foil calibration was 1.5%.

The components of the uncertainty for the absolute ^{235}U fission rate foil calibration are: 1) 0.4% uncertainty for counting statistics, 2) 0.3% reproducibility uncertainty and 3) 1.3% ^{235}U deposit mass uncertainty. The total uncertainty in the ^{235}U fission rate foil calibration factor was 1.4%.

Absolute ^{238}U fission rate calibration required simultaneous irradiation of a depleted uranium foil, natural uranium deposit and ^{235}U deposit in a BTB chamber. The components of the uncertainty for the absolute ^{238}U fission rate foil calibration are: 1) 1.5% for the ^{238}U deposit mass uncertainty, 2) 0.3% for the reproducibility uncertainty, 3) 1% for gamma counting statistics for the foil and 4) 0.7% uncertainty for fission chamber counts due to ^{238}U fission. The total uncertainty in the ^{238}U fission rate foil calibration factor was 2.0%.

Absolute ^{238}U capture rate calibration involved simultaneous irradiation of a ^{239}Pu deposit and ^{238}U foil in a BTB chamber in the AFSR thermal column. The components of the uncertainty for the absolute ^{238}U capture rate foil calibration are: 1) 1.4% for the ^{239}Pu deposit mass, 2) 0.5% uncertainty for counting statistics for ^{238}U capture, 0.3% reproducibility uncertainty, 4) 0.6% for the ^{238}U capture cross section and 5) 0.2% for the ^{238}U g-factor. The total uncertainty in the ^{238}U capture rate foil calibration factor was 1.6%.

Table 4.1 shows the total uncertainties for the ^{239}Pu , ^{235}U and ^{238}U calibration factors.

Table 4.1 Total Uncertainties for the ^{239}Pu , ^{235}U and ^{238}U Calibration Factors

Calibration Factor	Total Uncertainty, %
$^{239}\text{Pu}(\text{n,f})$	1.5
$^{235}\text{U}(\text{n,f})$	1.4
$^{238}\text{U}(\text{n,f})$	2.0
$^{238}\text{U}(\text{n},\gamma)$	1.6

4.2 Absolute Foil Reaction Rate Distributions in ZPPR-15

Section 3.2 listed the measured mapping foil reaction rates and total mapping foil uncertainties for the foil irradiations in the ZPPR-15 loadings 123, 134 and 203. Section 4.1 showed that additional uncertainties apply to absolute reaction rates.

Tables 4.2 – 4.12 show the absolute reaction rates and associated total uncertainties for the ZPPR-15 foil measurements. The uncertainty listed for each reaction rate in Tables 4.2 – 4.12 is the relative total uncertainty, i.e., the total uncertainty divided by the measured value, expressed in percent. It was not possible to determine absolute reaction rates for the indium foils because there were no calibration standards for the indium foils.

Table 4.2 ²³⁵U(n,f) Absolute Reaction Rate Distribution in ZPPR-15B L123 – SSNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁵ U(n,f)	σ _{total} , %
159	17	HI	35.9042	157.4063	6.3100	0.274	1.95
159	18	HI	41.4287	157.4063	6.3100	0.443	1.75
159	19	HI	46.9532	157.4063	6.3100	0.619	1.74
159	20	HI	52.4777	157.4063	6.3100	0.798	1.73
159	21	FG	57.3672	157.4063	6.3100	1.140	1.70
159	22	FG	62.8917	157.4063	6.3100	1.755	1.69
159	23	FG	68.4162	157.4063	6.3100	2.468	1.69
159	24	FG	73.9407	157.4063	6.3100	3.289	1.67
159	25	FG	79.4652	157.4063	6.3100	4.151	1.67
159	26	FG	84.9897	157.4063	6.3100	4.905	1.67
159	27	FG	90.5142	157.4063	6.3100	5.373	1.66
159	28	FG	96.0387	157.4063	6.3100	5.071	1.67
159	29	JK	102.8332	157.4063	6.3100	4.144	1.69
159	30	JK	108.3577	157.4063	6.3100	4.760	1.68
159	31	JK	113.8822	157.4063	6.3100	6.071	1.69
159	32	II	118.9304	157.4063	6.3100	7.587	1.67
159	33	IJ	124.6137	157.4063	6.3100	9.249	1.71
159	34	II	129.9794	157.4063	6.3100	10.477	1.66
159	35	IJ	135.6627	157.4063	6.3100	12.011	1.67
159	36	II	141.0284	157.4063	6.3100	12.796	1.66
159	37	IJ	146.7117	157.4063	6.3100	13.771	1.66
159	38	IJ	152.2362	157.4063	6.3100	14.350	1.66
159	40	IJ	163.2852	157.4063	6.3100	15.386	1.66
159	42	IJ	174.3342	157.4063	6.3100	15.970	1.66
159	44	IJ	185.3832	157.4063	6.3100	16.225	1.66
159	46	IJ	196.4322	157.4063	6.3100	16.340	1.66
159	48	IJ	207.4812	157.4063	6.3100	16.498	1.66
159	49	GH	212.3707	157.4063	6.3100	16.546	1.66
159	51	GH	223.4197	157.4063	6.3100	16.464	1.66
159	53	GH	234.4687	157.4063	6.3100	16.125	1.66
159	55	GH	245.5177	157.4063	6.3100	16.003	1.66
159	57	GH	256.5667	157.4063	6.3100	15.455	1.66
159	59	GH	267.6157	157.4063	6.3100	14.551	1.66
159	60	GH	273.1402	157.4063	6.3100	13.884	1.66
159	61	HH	278.8234	157.4063	6.3100	12.866	1.66
159	62	GH	284.1892	157.4063	6.3100	11.868	1.67
159	63	HH	289.8724	157.4063	6.3100	10.596	1.67
159	64	GH	295.2382	157.4063	6.3100	9.304	1.66
159	65	HH	300.9214	157.4063	6.3100	7.677	1.67
159	66	FG	305.9697	157.4063	6.3100	6.130	1.67
159	67	FG	311.4942	157.4063	6.3100	4.836	1.69
159	68	FG	317.0187	157.4063	6.3100	4.152	1.69
159	69	HI	323.1782	157.4063	6.3100	5.076	1.68
159	70	HI	328.7027	157.4063	6.3100	5.362	1.67
159	71	HI	334.2272	157.4063	6.3100	4.911	1.68
159	72	HI	339.7517	157.4063	6.3100	4.028	1.68
159	73	HI	345.2762	157.4063	6.3100	3.149	1.68
159	74	HI	350.8007	157.4063	6.3100	2.259	1.70
159	75	HI	356.3252	157.4063	6.3100	1.477	1.70
159	76	HI	361.8497	157.4063	6.3100	0.829	1.72

a. Data are in units of 10⁻¹⁸ reactions/atom-watt second.

Table 4.3 $^{238}\text{U}(n,f)$ Absolute Reaction Rate Distribution in ZPPR-15B L123 – SSNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$^{238}\text{U}(n,f)$	$\sigma_{\text{total}}, \%$
159	30	JK	108.3577	157.4063	7.7000	0.0391	2.65
159	32	II	118.9304	157.4063	7.7000	0.1867	2.24
159	33	IJ	124.6137	157.4063	7.7000	0.2683	2.22
159	34	II	129.9794	157.4063	7.7000	0.2868	2.22
159	35	IJ	135.6627	157.4063	7.7000	0.3520	2.22
159	36	II	141.0284	157.4063	7.7000	0.3425	2.21
159	49	GH	212.3707	157.4063	7.7000	0.3627	2.21
159	63	HH	289.8724	157.4063	7.7000	0.2880	2.22
159	64	GH	295.2382	157.4063	7.7000	0.2680	2.22
159	65	HH	300.9214	157.4063	7.7000	0.1855	2.24
159	66	FG	305.9697	157.4063	7.7000	0.0915	2.33
159	67	FG	311.4942	157.4063	7.7000	0.0388	2.65
159	68	FG	317.0187	157.4063	7.7000	0.0190	3.40

a. Data are in units of 10^{-18} reactions/atom-watt second.

Table 4.4 $^{238}\text{U}(n,\gamma)$ Absolute Reaction Rate Distribution in ZPPR-15B L123 – SSNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$^{238}\text{U}(n,\gamma)$	$\sigma_{\text{total}}, \%$
159	30	JK	108.3577	157.4063	7.7000	0.5803	1.84
159	32	II	118.9304	157.4063	7.7000	0.9952	1.84
159	33	IJ	124.6137	157.4063	7.7000	1.2135	1.84
159	34	II	129.9794	157.4063	7.7000	1.3595	1.84
159	35	IJ	135.6627	157.4063	7.7000	1.5609	1.84
159	36	II	141.0284	157.4063	7.7000	1.6601	1.84
159	49	GH	212.3707	157.4063	7.7000	2.2786	1.84
159	63	HH	289.8724	157.4063	7.7000	1.3641	1.84
159	64	GH	295.2382	157.4063	7.7000	1.2207	1.84
159	65	HH	300.9214	157.4063	7.7000	1.0016	1.84
159	66	FG	305.9697	157.4063	7.7000	0.7534	1.84
159	67	FG	311.4942	157.4063	7.7000	0.5897	1.85
159	68	FG	317.0187	157.4063	7.7000	0.4792	1.84

a. Data are in units of 10^{-18} reactions/atom-watt second.

Table 4.5 $^{239}\text{Pu}(\text{n},\text{f})$ Absolute Reaction Rate Distribution in ZPPR-15B L134 - BCNA - X-Y Plane^a

Row	Column	Location	X	Y	Z	$^{239}\text{Pu}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
159	51	GH	223.4197	157.4063	9.0800	16.222	1.75
159	53	GH	234.4687	157.4063	9.0800	15.962	1.75
159	55	GH	245.5177	157.4063	9.0800	15.701	1.75
159	57	GH	256.5667	157.4063	9.0800	15.331	1.75
159	59	GH	267.6157	157.4063	9.0800	14.598	1.75
159	60	GH	273.1402	157.4063	9.0800	14.154	1.75
159	61	HH	278.8234	157.4063	9.0800	13.220	1.76
159	62	GH	284.1892	157.4063	9.0800	12.361	1.76
159	63	HH	289.8724	157.4063	9.0800	10.934	1.76
159	64	GH	295.2382	157.4063	9.0800	9.639	1.76
159	65	HH	300.9214	157.4063	9.0800	7.813	1.77

a. Data are in units of 10^{-18} reactions/atom-watt second.

Table 4.6 ²³⁵U(n,f) Absolute Reaction Rate Distribution in ZPPR-15B L134 – BCNA – X-Y Plane^a.

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁵ U(n,f)	σ _{total} , %
159	17	HI	35.9042	157.4063	6.3100	0.013	3.48
159	18	HI	41.4287	157.4063	6.3100	0.018	2.75
159	19	HI	46.9532	157.4063	6.3100	0.021	2.50
159	20	HI	52.4777	157.4063	6.3100	0.023	2.37
159	21	FG	57.3672	157.4063	6.3100	0.023	2.37
159	22	FG	62.8917	157.4063	6.3100	0.044	2.79
159	23	FG	68.4162	157.4063	6.3100	0.095	1.93
159	24	FG	73.9407	157.4063	6.3100	0.210	1.68
159	25	FG	79.4652	157.4063	6.3100	0.496	1.67
159	26	FG	84.9897	157.4063	6.3100	1.956	1.65
159	27	FG	90.5142	157.4063	6.3100	3.443	1.67
159	28	FG	96.0387	157.4063	6.3100	3.979	1.66
159	29	JK	102.8332	157.4063	6.3100	3.786	1.68
159	30	JK	108.3577	157.4063	6.3100	4.590	1.66
159	31	JK	113.8822	157.4063	6.3100	5.944	1.66
159	32	II	118.9304	157.4063	6.3100	7.528	1.66
159	33	IJ	124.6137	157.4063	6.3100	9.247	1.66
159	34	II	129.9794	157.4063	6.3100	10.545	1.67
159	35	IJ	135.6627	157.4063	6.3100	11.856	1.66
159	36	II	141.0284	157.4063	6.3100	12.708	1.66
159	37	IJ	146.7117	157.4063	6.3100	13.751	1.66
159	38	IJ	152.2362	157.4063	6.3100	14.385	1.66
159	40	IJ	163.2852	157.4063	6.3100	15.382	1.66
159	42	IJ	174.3342	157.4063	6.3100	15.904	1.65
159	44	IJ	185.3832	157.4063	6.3100	16.069	1.67
159	46	IJ	196.4322	157.4063	6.3100	16.390	1.66
159	48	IJ	207.4812	157.4063	6.3100	16.414	1.66
159	49	GH	212.3707	157.4063	6.3100	16.450	1.65
159	51	GH	223.4197	157.4063	6.3100	16.353	1.66
159	53	GH	234.4687	157.4063	6.3100	16.205	1.65
159	55	GH	245.5177	157.4063	6.3100	15.990	1.65
159	57	GH	256.5667	157.4063	6.3100	15.414	1.66
159	59	GH	267.6157	157.4063	6.3100	14.511	1.65
159	60	GH	273.1402	157.4063	6.3100	13.804	1.66
159	61	HH	278.8234	157.4063	6.3100	12.845	1.66
159	62	GH	284.1892	157.4063	6.3100	11.897	1.66
159	63	HH	289.8724	157.4063	6.3100	10.556	1.66
159	64	GH	295.2382	157.4063	6.3100	9.269	1.67
159	65	HH	300.9214	157.4063	6.3100	7.662	1.66
159	66	FG	305.9697	157.4063	6.3100	6.104	1.67
159	67	FG	311.4942	157.4063	6.3100	4.827	1.67
159	68	FG	317.0187	157.4063	6.3100	4.132	1.69

a. Data are in units of 10⁻¹⁸ reactions/atom-watt second.

Table 4.7 ²³⁸U(n,f) Absolute Reaction Rate Distribution in ZPPR-15B L134 – BCNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁸ U(n,f)	σ _{total} , %
159	19	HI	46.9532	157.4063	7.7000	0.0000255	6.47
159	21	HI	58.0022	157.4063	7.7000	0.0000551	5.63
159	22	HI	63.5267	157.4063	7.7000	0.0001078	5.31
159	23	HI	69.0512	157.4063	7.7000	0.0002137	5.30
159	24	HI	74.5757	157.4063	7.7000	0.0004160	5.28
159	25	HI	80.1002	157.4063	7.7000	0.0008380	5.28
159	26	HI	85.6247	157.4063	7.7000	0.0019350	5.31
159	27	HI	91.1492	157.4063	7.7000	0.0038990	4.96
159	29	JK	102.8332	157.4063	7.7000	0.0183300	3.74
159	30	JK	108.3577	157.4063	7.7000	0.0384000	3.18
159	31	JK	113.8822	157.4063	7.7000	0.0909000	2.37
159	32	II	118.9304	157.4063	7.7000	0.1860000	2.25
159	33	IJ	124.6137	157.4063	7.7000	0.2683000	2.24
159	34	II	129.9794	157.4063	7.7000	0.2857000	2.24
159	35	IJ	135.6627	157.4063	7.7000	0.3517000	2.22
159	36	II	141.0284	157.4063	7.7000	0.3408000	2.22
159	49	GH	212.3707	157.4063	7.7000	0.3586000	2.21
159	63	HH	289.8724	157.4063	7.7000	0.2838000	2.24
159	64	GH	295.2382	157.4063	7.7000	0.2679000	2.24
159	65	HH	300.9214	157.4063	7.7000	0.1859000	2.24
159	66	FG	305.9697	157.4063	7.7000	0.0908000	2.33
159	67	FG	311.4942	157.4063	7.7000	0.0398000	2.63
159	68	FG	317.0187	157.4063	7.7000	0.0186800	3.48
258	70	HI	328.7027	162.9308	7.7000	0.0040470	5.02
258	72	HI	339.7517	162.9308	7.7000	0.0008860	5.32
258	74	HI	350.8007	162.9308	7.7000	0.0002301	5.27
258	76	HI	361.8497	162.9308	7.7000	0.0000639	7.07

a. Data are in units of 10⁻¹⁸ reactions/atom-watt second.

Table 4.8 ²³⁸U(n,γ) Absolute Reaction Rate Distribution in ZPPR-15B L134 – BCNA – X-Y Plane^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁸ U(n,γ)	σ _{total} , %
159	29	JK	102.8332	157.4063	7.7000	0.4479	1.86
159	30	JK	108.3577	157.4063	7.7000	0.5694	1.86
159	31	JK	113.8822	157.4063	7.7000	0.7361	1.85
159	32	II	118.9304	157.4063	7.7000	0.9935	1.84
159	33	IJ	124.6137	157.4063	7.7000	1.2123	1.85
159	34	II	129.9794	157.4063	7.7000	1.3575	1.85
159	35	IJ	135.6627	157.4063	7.7000	1.5653	1.84
159	36	II	141.0284	157.4063	7.7000	1.6528	1.84
159	49	GH	212.3707	157.4063	7.7000	2.2818	1.85
159	63	HH	289.8724	157.4063	7.7000	1.3706	1.84
159	64	GH	295.2382	157.4063	7.7000	1.2288	1.84
159	65	HH	300.9214	157.4063	7.7000	1.0050	1.84
159	66	FG	305.9697	157.4063	7.7000	0.7595	1.85
159	67	FG	311.4942	157.4063	7.7000	0.5887	1.85
159	68	FG	317.0187	157.4063	7.7000	0.4817	1.85

a. Data are in units of 10⁻¹⁸ reactions/atom-watt second.

Table 4.9 ²³⁹Pu(n,f) Absolute Reaction Rate Distribution in ZPPR-15D L203^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁹ Pu(n,f)	σ _{total} , %
152	49	HI	212.6882	196.0778	9.0800	1.482	1.83
153	49	HI	212.6882	190.5533	9.0800	1.489	1.83
154	49	HI	212.6882	185.0288	9.0800	1.482	1.83
155	49	HI	212.6882	179.5043	9.0800	1.475	1.83
156	49	HI	212.6882	173.9798	9.0800	1.500	1.83
157	49	HI	212.6882	168.4553	9.0800	1.456	1.89
158	49	HI	212.6882	162.9308	9.0800	1.480	1.86
159	50	HI	218.2127	157.4063	9.0800	1.459	1.86
159	51	HI	223.7372	157.4063	9.0800	1.482	1.83
159	52	HI	229.2617	157.4063	9.0800	1.495	1.83
159	53	HI	234.7862	157.4063	9.0800	1.498	1.83
159	54	HI	240.3107	157.4063	9.0800	1.503	1.85
159	55	HI	245.8352	157.4063	9.0800	1.468	1.83
159	56	HI	251.3597	157.4063	9.0800	1.517	1.85
159	57	HI	256.8842	157.4063	9.0800	1.501	1.83
159	58	HI	262.4087	157.4063	9.0800	1.419	1.87
159	59	HI	267.9332	157.4063	9.0800	1.390	1.85
159	61	CC	277.2359	157.4063	9.0800	1.250	1.85
159	62	HI	284.5067	157.4063	9.0800	1.167	1.87
159	63	CC	288.2849	157.4063	9.0800	1.046	1.87
159	65	CC	299.3339	157.4063	9.0800	0.745	2.01
159	66	FG	305.9697	157.4063	9.0800	0.573	2.00
159	67	FG	311.4942	157.4063	9.0800	0.440	2.05
159	68	FG	317.0187	157.4063	9.0800	0.384	2.14
159	49	HH	212.5294	156.0223	7.7000	1.501	1.83
159	49	HH	212.5294	156.0223	12.7800	1.451	1.84
159	49	HH	212.5294	156.0223	17.8600	1.371	1.83
159	49	HH	212.5294	156.0223	25.4800	1.246	1.85
159	49	HH	212.5294	156.0223	33.1000	1.090	1.89
159	49	HH	212.5294	156.0223	38.1800	0.954	1.90
159	49	HH	212.5294	156.0223	43.2600	0.826	1.90
159	60	HI	273.4577	156.0223	7.7000	1.337	1.83
159	60	HI	273.4577	156.0223	12.7800	1.277	1.81
159	60	HI	273.4577	156.0223	17.8600	1.234	1.89
159	60	HI	273.4577	156.0223	25.4800	1.113	1.85
159	60	HI	273.4577	156.0223	33.1000	0.952	1.90
159	60	HI	273.4577	156.0223	38.1800	0.841	1.90
159	60	HI	273.4577	156.0223	43.2600	0.700	1.91
159	64	HH	295.3969	156.0223	7.7000	0.913	1.87
159	64	HH	295.3969	156.0223	12.7800	0.879	1.88
159	64	HH	295.3969	156.0223	17.8600	0.845	1.95
159	64	HH	295.3969	156.0223	25.4800	0.745	1.94
159	64	HH	295.3969	156.0223	33.1000	0.648	1.94
159	64	HH	295.3969	156.0223	38.1800	0.565	2.01
159	64	HH	295.3969	156.0223	43.2600	0.477	2.00

a. Data are in units of 10⁻¹⁷ reactions/atom-watt second.

Table 4.10 ²³⁵U(n,f) Absolute Reaction Rate Distribution in ZPPR-15D L203^a

Row	Column	Location	X, cm	Y, cm	Z, cm	²³⁵ U(n,f)	σ _{total} , %
159	29	JK	102.8332	157.4063	6.3100	0.394	1.79
159	30	JK	108.3577	157.4063	6.3100	0.450	1.75
159	31	JK	113.8822	157.4063	6.3100	0.558	1.77
159	32	NN	120.5179	157.4063	6.3100	0.695	1.77
159	33	HI	124.2962	157.4063	6.3100	0.812	1.73
159	34	NN	131.5669	157.4063	6.3100	0.958	1.70
159	35	HI	135.3452	157.4063	6.3100	1.056	1.68
159	36	NN	142.6159	157.4063	6.3100	1.156	1.73
159	37	HI	146.3942	157.4063	6.3100	1.221	1.69
159	38	HI	151.9187	157.4063	6.3100	1.293	1.70
159	39	HI	157.4432	157.4063	6.3100	1.354	1.70
159	40	HI	162.9677	157.4063	6.3100	1.398	1.69
159	41	HI	168.4922	157.4063	6.3100	1.423	1.69
159	42	HI	174.0167	157.4063	6.3100	1.435	1.69
159	43	HI	179.5412	157.4063	6.3100	1.442	1.69
159	44	HI	185.0657	157.4063	6.3100	1.447	1.69
159	45	HI	190.5902	157.4063	6.3100	1.446	1.69
159	46	HI	196.1147	157.4063	6.3100	1.448	1.69
159	47	HI	201.6392	157.4063	6.3100	1.453	1.69
159	48	HI	207.1637	157.4063	6.3100	1.431	1.69
131	49	HI	212.6882	312.0923	6.3100	0.081	2.03
132	49	HI	212.6882	306.5678	6.3100	0.148	2.11
133	49	HI	212.6882	301.0433	6.3100	0.222	1.85
134	49	HI	212.6882	295.5188	6.3100	0.308	1.74
135	49	HI	212.6882	289.9943	6.3100	0.401	1.78
136	49	HI	212.6882	284.4698	6.3100	0.485	1.73
137	49	HI	212.6882	278.9453	6.3100	0.536	1.71
138	49	HI	212.6882	273.4208	6.3100	0.501	1.72
139	49	FG	212.0532	267.8963	6.3100	0.400	1.78
140	49	FG	212.0532	262.3718	6.3100	0.452	1.75
141	49	FG	212.0532	256.8473	6.3100	0.554	1.77
142	49	CC	210.9419	251.3228	6.3100	0.689	1.72
143	49	HI	212.6882	245.7983	6.3100	0.817	1.69
144	49	CC	210.9419	240.2738	6.3100	0.935	1.70
145	49	HI	212.6882	234.7493	6.3100	1.049	1.68
146	49	CC	210.9419	229.2248	6.3100	1.148	1.70
147	49	HI	212.6882	223.7003	6.3100	1.233	1.71
148	49	HI	212.6882	218.1758	6.3100	1.293	1.70
149	49	HI	212.6882	212.6513	6.3100	1.347	1.70
150	49	HI	212.6882	207.1268	6.3100	1.391	1.69
151	49	HI	212.6882	201.6023	6.3100	1.407	1.69
152	49	HI	212.6882	196.0778	6.3100	1.428	1.69
153	49	HI	212.6882	190.5533	6.3100	1.437	1.69
154	49	HI	212.6882	185.0288	6.3100	1.425	1.69
155	49	HI	212.6882	179.5043	6.3100	1.445	1.69
156	49	HI	212.6882	173.9798	6.3100	1.439	1.69
157	49	HI	212.6882	168.4553	6.3100	1.449	1.69
158	49	HI	212.6882	162.9308	6.3100	1.433	1.69
160	49	HI	212.6882	151.8818	6.3100	1.442	1.69
161	49	HI	212.6882	146.3573	6.3100	1.443	1.71
162	49	HI	212.6882	140.8328	6.3100	1.389	1.67
163	49	HI	212.6882	135.3083	6.3100	1.444	1.71

164	49	HI	212.6882	129.7838	6.3100	1.435	1.71
165	49	HI	212.6882	124.2593	6.3100	1.426	1.69
166	49	HI	212.6882	118.7348	6.3100	1.402	1.69
167	49	HI	212.6882	113.2103	6.3100	1.374	1.72
168	49	HI	212.6882	107.6858	6.3100	1.354	1.70
169	49	HI	212.6882	102.1613	6.3100	1.288	1.68
170	49	HI	212.6882	96.6368	6.3100	1.214	1.69
171	49	CC	210.9419	91.1123	6.3100	1.143	1.70
172	49	HI	212.6882	85.5878	6.3100	1.047	1.68
173	49	CC	210.9419	80.0633	6.3100	0.930	1.70
174	49	HI	212.6882	74.5388	6.3100	0.815	1.73
175	49	CC	210.9419	69.0143	6.3100	0.685	1.72
176	49	FG	212.0532	63.4898	6.3100	0.553	1.70
177	49	FG	212.0532	57.9653	6.3100	0.452	1.75
178	49	FG	212.0532	52.4408	6.3100	0.401	1.78
159	50	HI	218.2127	157.4063	6.3100	1.445	1.67
159	51	HI	223.7372	157.4063	6.3100	1.435	1.67
159	52	HI	229.2617	157.4063	6.3100	1.438	1.69
159	53	HI	234.7862	157.4063	6.3100	1.456	1.69
159	54	HI	240.3107	157.4063	6.3100	1.441	1.71
159	55	HI	245.8352	157.4063	6.3100	1.429	1.67
159	56	HI	251.3597	157.4063	6.3100	1.426	1.67
159	57	HI	256.8842	157.4063	6.3100	1.402	1.67
159	58	HI	262.4087	157.4063	6.3100	1.354	1.68
159	59	HI	267.9332	157.4063	6.3100	1.292	1.68
159	61	CC	277.2359	157.4063	6.3100	1.155	1.67
159	62	HI	284.5067	157.4063	6.3100	1.049	1.68
159	63	CC	288.2849	157.4063	6.3100	0.955	1.70
159	65	CC	299.3339	157.4063	6.3100	0.694	1.72
159	66	FG	305.9697	157.4063	6.3100	0.559	1.70
159	67	FG	311.4942	157.4063	6.3100	0.449	1.75
159	68	FG	317.0187	157.4063	6.3100	0.393	1.79
159	69	HI	323.1782	157.4063	6.3100	0.484	1.81
159	70	HI	328.7027	157.4063	6.3100	0.515	1.79
159	71	HI	334.2272	157.4063	6.3100	0.475	1.73
159	72	HI	339.7517	157.4063	6.3100	0.392	1.79
159	73	HI	345.2762	157.4063	6.3100	0.299	1.75
159	74	HI	350.8007	157.4063	6.3100	0.218	1.86
159	75	HI	356.3252	157.4063	6.3100	0.148	2.11
159	76	HI	361.8497	157.4063	6.3100	0.081	2.03
159	49	HH	212.5294	158.7903	7.7000	1.433	1.67
159	49	HH	212.5294	158.7903	12.7800	1.388	1.67
159	49	HH	212.5294	158.7903	17.8600	1.339	1.68
159	49	HH	212.5294	158.7903	25.4800	1.196	1.69
159	49	HH	212.5294	158.7903	33.1000	1.056	1.68
159	49	HH	212.5294	158.7903	38.1800	0.928	1.70
159	49	HH	212.5294	158.7903	43.2600	0.809	1.69
159	49	GH	212.3707	158.7903	48.3400	0.699	1.71
159	49	GH	212.3707	158.7903	53.4200	0.582	1.70
159	49	GH	212.3707	158.7903	63.5800	0.387	1.79
159	49	GH	212.3707	158.7903	73.7400	0.283	1.76
159	60	HI	273.4577	158.7903	7.7000	1.217	1.67
159	60	HI	273.4577	158.7903	12.7800	1.174	1.69
159	60	HI	273.4577	158.7903	17.8600	1.122	1.68
159	60	HI	273.4577	158.7903	25.4800	1.021	1.69

159	60	HI	273.4577	158.7903	33.1000	0.881	1.68
159	60	HI	273.4577	158.7903	38.1800	0.784	1.69
159	60	HI	273.4577	158.7903	43.2600	0.665	1.72
159	60	GH	273.1402	158.7903	48.3400	0.573	1.70
159	60	GH	273.1402	158.7903	53.4200	0.477	1.73
159	60	GH	273.1402	158.7903	63.5800	0.314	1.74
159	60	GH	273.1402	158.7903	73.7400	0.221	1.85
159	64	HH	295.3969	158.7903	7.7000	0.817	1.69
159	64	HH	295.3969	158.7903	12.7800	0.783	1.69
159	64	HH	295.3969	158.7903	17.8600	0.753	1.70
159	64	HH	295.3969	158.7903	25.4800	0.674	1.68
159	64	HH	295.3969	158.7903	33.1000	0.582	1.70
159	64	HH	295.3969	158.7903	38.1800	0.515	1.72
159	64	HH	295.3969	158.7903	43.2600	0.441	1.75
159	64	GH	295.2382	158.7903	48.3400	0.371	1.70
159	64	GH	295.2382	158.7903	53.4200	0.308	1.89
159	64	GH	295.2382	158.7903	63.5800	0.203	1.89
159	64	GH	295.2382	158.7903	73.7400	0.147	1.75

a. Data are in units of 10^{-17} reactions/atom-watt second.

Table 4.11 $^{238}\text{U}(\text{n},\text{f})$ Absolute Reaction Rate Distribution in ZPPR-15D L203^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$^{238}\text{U}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
139	49	FG	212.0532	267.8963	7.7000	0.0020	5.45
140	49	FG	212.0532	262.3718	7.7000	0.0038	5.69
141	49	FG	212.0532	256.8473	7.7000	0.0083	3.23
142	49	CC	210.9419	251.3228	7.7000	0.0210	2.88
143	49	HI	212.6882	245.7983	7.7000	0.0317	2.50
144	49	CC	210.9419	240.2738	7.7000	0.0339	2.46
145	49	HI	212.6882	234.7493	7.7000	0.0417	2.36
146	49	CC	210.9419	229.2248	7.7000	0.0397	2.50
147	49	HI	212.6882	223.7003	7.7000	0.0365	2.55
148	49	HI	212.6882	218.1758	7.7000	0.0370	2.41
149	49	HI	212.6882	212.6513	7.7000	0.0379	2.40
150	49	HI	212.6882	207.1268	7.7000	0.0475	2.40
151	49	HI	212.6882	201.6023	7.7000	0.0477	2.40
152	49	HI	212.6882	196.0778	7.7000	0.0385	2.39
153	49	HI	212.6882	190.5533	7.7000	0.0364	2.42
154	49	HI	212.6882	185.0288	7.7000	0.0360	2.43
155	49	HI	212.6882	179.5043	7.7000	0.0363	2.42
156	49	HI	212.6882	173.9798	7.7000	0.0358	2.43
157	49	HI	212.6882	168.4553	7.7000	0.0358	2.43
158	49	HI	212.6882	162.9308	7.7000	0.0357	2.43
159	50	HI	218.2127	157.4063	7.7000	0.0358	2.43
159	51	HI	223.7372	157.4063	7.7000	0.0355	2.58
159	52	HI	229.2617	157.4063	7.7000	0.0362	2.42
159	53	HI	234.7862	157.4063	7.7000	0.0365	2.42
159	54	HI	240.3107	157.4063	7.7000	0.0371	2.54
159	55	HI	245.8352	157.4063	7.7000	0.0387	2.51
159	56	HI	251.3597	157.4063	7.7000	0.0483	2.39
159	57	HI	256.8842	157.4063	7.7000	0.0476	2.40
159	58	HI	262.4087	157.4063	7.7000	0.0392	2.51
159	59	HI	267.9332	157.4063	7.7000	0.0374	2.41
159	61	CC	277.2359	157.4063	7.7000	0.0377	2.40
159	62	HI	284.5067	157.4063	7.7000	0.0416	2.47
159	63	CC	288.2849	157.4063	7.7000	0.0338	2.46

159	65	CC	299.3339	157.4063	7.7000	0.0224	2.54
159	66	FG	305.9697	157.4063	7.7000	0.0085	3.19
159	67	FG	311.4942	157.4063	7.7000	0.0040	5.45
159	68	FG	317.0187	157.4063	7.7000	0.0022	9.34
159	49	HH	212.5294	157.4063	7.7000	0.0354	2.43
159	49	HH	212.5294	157.4063	12.7800	0.0343	2.45
159	49	HH	212.5294	157.4063	17.8600	0.0331	2.47
159	49	HH	212.5294	157.4063	25.4800	0.0295	2.55
159	49	HH	212.5294	157.4063	33.1000	0.0255	2.46
159	49	HH	212.5294	157.4063	38.1800	0.0224	2.54
159	49	HH	212.5294	157.4063	43.2600	0.0172	2.77
159	49	GH	212.3707	157.4063	48.3400	0.0074	3.46
159	49	GH	212.3707	157.4063	53.4200	0.0038	5.69
159	49	GH	212.3707	157.4063	63.5800	0.0013	7.99
159	49	GH	212.3707	157.4063	73.7400	0.0006	16.81
159	60	HI	273.4577	157.4063	7.7000	0.0370	2.41
159	60	HI	273.4577	157.4063	12.7800	0.0359	2.43
159	60	HI	273.4577	157.4063	17.8600	0.0338	2.46
159	60	HI	273.4577	157.4063	25.4800	0.0311	2.51
159	60	HI	273.4577	157.4063	33.1000	0.0259	2.45
159	60	HI	273.4577	157.4063	38.1800	0.0216	2.56
159	60	HI	273.4577	157.4063	43.2600	0.0175	2.75
159	60	GH	273.1402	157.4063	48.3400	0.0080	3.30
159	60	GH	273.1402	157.4063	53.4200	0.0040	5.45
159	60	GH	273.1402	157.4063	63.5800	0.0012	16.81
159	60	GH	273.1402	157.4063	73.7400	0.0008	12.68
159	64	HH	295.3969	157.4063	7.7000	0.0318	2.50
159	64	HH	295.3969	157.4063	12.7800	0.0309	2.52
159	64	HH	295.3969	157.4063	17.8600	0.0289	2.56
159	64	HH	295.3969	157.4063	25.4800	0.0262	2.44
159	64	HH	295.3969	157.4063	33.1000	0.0221	2.55
159	64	HH	295.3969	157.4063	38.1800	0.0190	2.67
159	64	HH	295.3969	157.4063	43.2600	0.0150	2.54
159	64	GH	295.2382	157.4063	48.3400	0.0057	4.12
159	64	GH	295.2382	157.4063	53.4200	0.0029	4.07
159	64	GH	295.2382	157.4063	63.5800	0.0010	10.23
159	64	GH	295.2382	157.4063	73.7400	0.0008	25.09

a. Data are in units of 10^{-17} reactions/atom-watt second.

Table 4.12 $^{238}\text{U}(n,\gamma)$ Absolute Reaction Rate Distribution in ZPPR-15D L203^a

Row	Column	Location	X, cm	Y, cm	Z, cm	$^{238}\text{U}(n,\gamma)$	σ_{total} , %
139	49	FG	212.0532	267.8963	7.7000	0.0457	1.91
140	49	FG	212.0532	262.3718	7.7000	0.0552	1.93
141	49	FG	212.0532	256.8473	7.7000	0.0685	1.88
142	49	CC	210.9419	251.3228	7.7000	0.0894	1.88
143	49	HI	212.6882	245.7983	7.7000	0.1043	1.88
144	49	CC	210.9419	240.2738	7.7000	0.1199	1.86
145	49	HI	212.6882	234.7493	7.7000	0.1338	1.87
146	49	CC	210.9419	229.2248	7.7000	0.1460	1.87
147	49	HI	212.6882	223.7003	7.7000	0.1543	1.87
148	49	HI	212.6882	218.1758	7.7000	0.1642	1.86
149	49	HI	212.6882	212.6513	7.7000	0.1711	1.87
150	49	HI	212.6882	207.1268	7.7000	0.1819	1.86
151	49	HI	212.6882	201.6023	7.7000	0.1871	1.87
152	49	HI	212.6882	196.0778	7.7000	0.1960	1.86
153	49	HI	212.6882	190.5533	7.7000	0.2000	1.86
154	49	HI	212.6882	185.0288	7.7000	0.2016	1.86
155	49	HI	212.6882	179.5043	7.7000	0.2024	1.86
156	49	HI	212.6882	173.9798	7.7000	0.2032	1.87
157	49	HI	212.6882	168.4553	7.7000	0.2031	1.86
158	49	HI	212.6882	162.9308	7.7000	0.2048	1.86
159	50	HI	218.2127	157.4063	7.7000	0.2039	1.86
159	51	HI	223.7372	157.4063	7.7000	0.2040	1.86
159	52	HI	229.2617	157.4063	7.7000	0.2039	1.86
159	53	HI	234.7862	157.4063	7.7000	0.2027	1.86
159	54	HI	240.3107	157.4063	7.7000	0.2028	1.87
159	55	HI	245.8352	157.4063	7.7000	0.1976	1.86
159	56	HI	251.3597	157.4063	7.7000	0.1892	1.85
159	57	HI	256.8842	157.4063	7.7000	0.1836	1.87
159	58	HI	262.4087	157.4063	7.7000	0.1737	1.87
159	59	HI	267.9332	157.4063	7.7000	0.1660	1.86
159	61	CC	277.2359	157.4063	7.7000	0.1487	1.87
159	62	HI	284.5067	157.4063	7.7000	0.1345	1.87
159	63	CC	288.2849	157.4063	7.7000	0.1205	1.88
159	65	CC	299.3339	157.4063	7.7000	0.0907	1.87
159	66	FG	305.9697	157.4063	7.7000	0.0683	1.88
159	67	FG	311.4942	157.4063	7.7000	0.0551	1.93
159	68	FG	317.0187	157.4063	7.7000	0.0451	1.91
159	49	HH	212.5294	157.4063	7.7000	0.2031	1.86
159	49	HH	212.5294	157.4063	12.7800	0.1983	1.86
159	49	HH	212.5294	157.4063	17.8600	0.1886	1.87
159	49	HH	212.5294	157.4063	25.4800	0.1713	1.85
159	49	HH	212.5294	157.4063	33.1000	0.1504	1.87
159	49	HH	212.5294	157.4063	38.1800	0.1354	1.86
159	49	HH	212.5294	157.4063	43.2600	0.1189	1.86
159	49	GH	212.3707	157.4063	48.3400	0.0979	1.86
159	49	GH	212.3707	157.4063	53.4200	0.0836	1.89
159	49	GH	212.3707	157.4063	63.5800	0.0582	1.92
159	49	GH	212.3707	157.4063	73.7400	0.0421	1.93
159	60	HI	273.4577	157.4063	7.7000	0.1544	1.87
159	60	HI	273.4577	157.4063	12.7800	0.1497	1.87
159	60	HI	273.4577	157.4063	17.8600	0.1428	1.86
159	60	HI	273.4577	157.4063	25.4800	0.1294	1.87

159	60	HI	273.4577	157.4063	33.1000	0.1132	1.87
159	60	HI	273.4577	157.4063	38.1800	0.1014	1.89
159	60	HI	273.4577	157.4063	43.2600	0.0876	1.88
159	60	GH	273.1402	157.4063	48.3400	0.0782	1.90
159	60	GH	273.1402	157.4063	53.4200	0.0666	1.89
159	60	GH	273.1402	157.4063	63.5800	0.0462	1.91
159	60	GH	273.1402	157.4063	73.7400	0.0329	1.89
159	64	HH	295.3969	157.4063	7.7000	0.1036	1.88
159	64	HH	295.3969	157.4063	12.7800	0.1009	1.86
159	64	HH	295.3969	157.4063	17.8600	0.0958	1.87
159	64	HH	295.3969	157.4063	25.4800	0.0866	1.88
159	64	HH	295.3969	157.4063	33.1000	0.0752	1.87
159	64	HH	295.3969	157.4063	38.1800	0.0675	1.89
159	64	HH	295.3969	157.4063	43.2600	0.0589	1.92
159	64	GH	295.2382	157.4063	48.3400	0.0504	1.89
159	64	GH	295.2382	157.4063	53.4200	0.0437	1.92
159	64	GH	295.2382	157.4063	63.5800	0.0293	1.92
159	64	GH	295.2382	157.4063	73.7400	0.0220	2.01

a. Data are in units of 10^{-17} reactions/atom-watt second.

5 Cell-Averaged Reaction Rates in ZPPR-15

A mapping foil was placed between two specific columns of plates in a drawer such that the reaction rate measured in that foil was affected by the adjacent plates. It was not practical to compute reaction rates for many individual mapping foils at their exact locations when ZPPR-15 was built. The standard practice at ZPPR was to convert the mapping foil data to cell-averaged reaction rates that could be computed with computers and software available at that time [5]. In this context, a cell consisted of the drawer, plates and surrounding matrix tube at the desired location.

Although it was not practical to place multiple foils in every drawer of interest, it was possible to place multiple foils in selected drawers to measure intra-drawer reaction rate distributions in a limited number of drawer types in representative cell environments. A cell factor was measured by placing foils between various columns of plates in a drawer to determine an average reaction rate for the unit cell represented by that drawer and its neighbors. The ratio of the average reaction rate in the unit cell to the measured reaction rate for the mapping foil at the specific location of interest in the cell was the cell factor. For example, for the $^{239}\text{Pu}(n,f)$ reaction, ^{239}Pu mapping foils were placed adjacent to Pu-U-Mo fuel plates in drawers at many core locations. At selected core locations representing typical unit cells, multiple ^{239}Pu foils were placed between many of the plate columns in the drawer. The average $^{239}\text{Pu}(n,f)$ reaction rate measured in the unit cell divided by the $^{239}\text{Pu}(n,f)$ reaction rate for the ^{239}Pu mapping foil adjacent to the Pu-U-Mo plate in the unit cell was the $^{239}\text{Pu}(n,f)$ cell factor for the cell.

The measured cell factor was applicable to any drawer master in the same unit cell configuration, i.e., a drawer master with similar plate columns (ignoring differences in the plate lengths resulting from the finite plate inventory) and with similar neighboring drawers. Cell factors were measured for various combinations of drawer types in the core, radial blanket, axial blanket and at the boundary between different regions such as the core-radial blanket interface.

Multiplying the reaction rate in the mapping foil by the appropriate cell factor for the mapping foil location converted the mapping foil reaction rate at a specific point in the cell to an average reaction rate for the cell, i.e., to a cell-averaged reaction rate that could be computed with the computing resources available in the 1980s. Cell-averaged reaction rates were determined for the relevant reactions ($^{239}\text{Pu}(n,f)$, $^{235}\text{U}(n,f)$, $^{238}\text{U}(n,f)$ or $^{238}\text{U}(n,\gamma)$) in ZPPR-15.

5.1 Cell-Averaged Reaction Rate Uncertainties

The total uncertainty for a cell-averaged reaction rate includes a component from the mapping foil data and a component from the determination of the relevant cell factor. The following discussion is a summary of an analysis of uncertainties in cell-averaged reaction rates by S. B. Brumbach and J. M. Gasidlo of the ZPPR staff [5].

There are three uncertainty components for the determination of cell factors for absolute fission and capture rates. First, determining cell factors required measuring and/or calculating reaction rates inside Pu-U-Mo fuel plates and depleted uranium (DU) metal plates (see Ref. 5, Section IV). The plates used at ZPPR were solid, so special procedures were required to determine in-plate reaction rates. There are systematic uncertainties related to determining the in-plate

reaction rates. Table 5.1 shows the systematic uncertainties for determination of in-plate reaction rates for the Pu-U-Mo and depleted uranium metal plates.

The uncertainties for the depleted uranium plates in Table 5.1 are due to uncertainties in isotopic composition and loss of fission products. Pu-U-Mo plates and HEU plates were canned, so it was not possible to measure in-plate reaction rates for these materials directly. The uncertainties for Pu-U-Mo plates in Table 5.1 arise from applying the results of the Stanford-Robinson experiment and measurements with half-thickness fuel plates.

Table 5.1 Uncertainties in Determination of In-Plate Reaction Rates

Reaction	Pu-U-Mo	DU metal
	σ , %	σ , %
$^{239}\text{Pu}(n,f)$	0.5	
$^{235}\text{U}(n,f)$	0.5	0.5
$^{238}\text{U}(n,f)$	1.5	0.2
$^{238}\text{U}(n,\gamma)$	1.0	0.0

In practice, the approximations involved in determining in-plate reaction rates do not have a large effect on the total uncertainty for cell-averaged reaction rates because the total uncertainty for the cell-averaged reaction rates is dominated by the mapping foil uncertainty and the calibration factor uncertainty.

The second cell factor uncertainty component results from the counting statistics and foil positioning uncertainty in the cell factor measurement that varied for different cell factors and measurement configurations. The exact nature of the contents of neighboring drawers affected the measured reaction rates in foils in the cell of interest. For example, SC denotes a single column fuel drawer, DC denotes a double fuel column drawer and RB denotes a radial blanket drawer. If the middle drawer is the cell for which a cell factor is being measured, then SC-SC-SC, DC-SC-DC, SC-SC-RB, and DC-SC-RB are four different environments for the center SC drawer. Each of these environments produces different reaction rates in the center SC drawer. Consequently, it was necessary to measure cell factors for various environments and configurations in ZPPR-15. In the present context, environment refers to the unit cell for which the cell factor is being measured and the adjacent drawers on both sides of the unit cell of interest.

Tables 5.2 – 5.9 give the measured cell factors for ZPPR-15B and ZPPR-15D. Column 1 in each of these tables gives the measured cell factor, column 2 gives the reported uncertainty for the cell factor and column 3 gives the relative uncertainty for the cell factor. Note that the relative uncertainty in column 3 is the reported uncertainty divided by the cell factor. This relative uncertainty is not expressed in percent.

Column 4 in Tables 5.2 – 5.9 gives the applicable cell environment. The entries in column 4 correspond to the following:

- SC – single fuel column drawer,
- DC – double fuel column drawer,
- Sym Zr – drawer with symmetric Zr column(s),

Asym Zr – drawer with asymmetric Zr column(s),

RB – radial blanket,

AB – axial blanket,

RR – radial reflector.

The three-digit numbers in column 4 for the ZPPR-15D cell factors list the drawer masters or range of drawer masters for which the cell factor is applicable. Finally, column 5 lists the axial region over which the cell factor is applicable. In some cases, the entry in column 5 refers to an actual range to which the cell factor applies such as 0.0 mm – 381.8 mm. “All” indicates that the cell factor applies over the entire axial range. If there is a single number in column 5, then the cell factor applies to that axial position.

Table 5.2 ZPPR-15B – $^{239}\text{Pu}(n,f)$ Cell Factors

$^{239}\text{Pu}(n,f)$ Cell Factor	σ	σ_{relative}	Environment	Z, mm
0.9988	0.0041	0.0041	SC, Sym Zr	0 - 381.8
0.9988	0.0041	0.0041	SC, Asym Zr	0 - 381.8
1.0020	0.0039	0.0039	SC/DC-SC-DC	0 - 381.8
1.0056	0.0050	0.0050	SC-DC-SC	0 - 381.8
1.0000	0.0100	0.0100	DC-RB-RB	All
1.0000	0.0100	0.0100	RB-RB-RB	All
1.0000	0.0100	0.0100	RB-RB-RR	All
0.9988	0.0041	0.0041	SC, Sym Zr	432.6
0.9995	0.0067	0.0067	SC/DC-SC-DC	432.6
1.0000	0.0100	0.0100	AB	470.7
1.0000	0.0100	0.0100	AB	483.4
1.0000	0.0100	0.0100	AB	496.1
1.0000	0.0100	0.0100	AB	521.5
1.0000	0.0100	0.0100	AB	534.2
1.0000	0.0100	0.0100	AB	546.9
1.0000	0.0100	0.0100	AB	635.8
1.0000	0.0100	0.0100	AB	737.4

Table 5.3 ZPPR-15B – $^{235}\text{U}(\text{n},\text{f})$ Cell Factors

$^{235}\text{U}(\text{n},\text{f})$ Cell Factor	σ	σ_{relative}	Environment	Z, mm
0.9962	0.0038	0.0038	SC, Sym Zr	0 - 381.8
0.9962	0.0038	0.0038	SC, Asym Zr	0 - 381.8
1.0012	0.0039	0.0039	SC/DC-SC-DC	0 - 381.8
1.0062	0.0042	0.0042	SC-DC-SC	0 - 381.8
1.0000	0.0100	0.0100	DC-RB-RB	All
1.0000	0.0100	0.0100	RB-RB-RB	All
1.0000	0.0100	0.0100	RB-RB-RR	All
0.9962	0.0038	0.0038	SC, Sym Zr	432.6
1.0003	0.0043	0.0043	SC/DC-SC-DC	432.6
1.0000	0.0100	0.0100	AB	470.7
1.0000	0.0100	0.0100	AB	483.4
1.0000	0.0100	0.0100	AB	496.1
1.0000	0.0100	0.0100	AB	521.5
1.0000	0.0100	0.0100	AB	534.2
1.0000	0.0100	0.0100	AB	546.9
1.0000	0.0100	0.0100	AB	635.8
1.0000	0.0100	0.0100	AB	737.4

Table 5.4 ZPPR-15B – ²³⁸U(n,f) Cell Factors

²³⁸ U(n,f) Cell Factor	σ	σ _{relative}	Environment	Z, mm
0.9328	0.0076	0.0081	SC, Sym Zr	0 - 381.8
0.9240	0.0109	0.0118	SC, Asym Zr	0 - 381.8
0.9414	0.0089	0.0095	SC/DC-SC-DC	0 - 381.8
1.0056	0.0112	0.0111	SC-DC-SC	0 - 381.8
1.0290	0.0250	0.0243	DC-RB-RB	All
1.0290	0.0250	0.0243	RB-RB-RB	All
1.0290	0.0250	0.0243	RB-RB-RR	All
0.9079	0.0154	0.0170	SC, Sym Zr	432.6
0.9158	0.0065	0.0071	SC/DC-SC-DC	432.6
0.9160	0.0400	0.0437	AB	470.7
0.9230	0.0370	0.0401	AB	483.4
0.9290	0.0430	0.0463	AB	496.1
0.9430	0.0530	0.0562	AB	521.5
0.9500	0.0590	0.0621	AB	534.2
0.9560	0.0550	0.0575	AB	546.9
1.0040	0.0310	0.0309	AB	635.8
1.0600	0.1400	0.1321	AB	737.4

Table 5.5 ZPPR-15B – ²³⁸U(n,γ) Cell Factors.

²³⁸ U(n,γ) Cell Factor	σ	σ _{relative}	Environment	Z, mm
0.9279	0.0053	0.0057	SC, Sym Zr	0 - 381.8
0.9378	0.0053	0.0057	SC, Asym Zr	0 - 381.8
0.9393	0.0040	0.0043	SC/DC-SC-DC	0 - 381.8
0.9542	0.0049	0.0051	SC-DC-SC	0 - 381.8
1.0119	0.0060	0.0059	DC-RB-RB	All
1.0178	0.0042	0.0041	RB-RB-RB	All
1.0279	0.0043	0.0042	RB-RB-RR	All
0.9158	0.0098	0.0107	SC, Sym Zr	432.6
0.9271	0.0050	0.0054	SC/DC-SC-DC	432.6
0.9080	0.0074	0.0081	AB	470.7
0.8979	0.0054	0.0060	AB	483.4
0.8904	0.0064	0.0072	AB	496.1
0.8803	0.0065	0.0074	AB	521.5
0.8778	0.0055	0.0063	AB	534.2
0.8753	0.0065	0.0074	AB	546.9
0.8641	0.0036	0.0042	AB	635.8
0.7982	0.0076	0.0095	AB	737.4

Table 5.6 ZPPR-15D – ²³⁹Pu(n,f) Cell Factors

²³⁹ Pu(n,f) Cell Factor	σ	σ _{relative}	Environment	Z, mm
1.0000	0.0100	0.0100	901-904	0 - 381.8
1.0000	0.0100	0.0100	905-914	0 - 381.8
1.0000	0.0100	0.0100	915-920	0 - 381.8
1.0000	0.0100	0.0100	158-162,64	0 - 381.8
1.0000	0.0100	0.0100	158-61,63,65	0 - 381.8
1.0000	0.0100	0.0100	143,145-49	0 - 381.8
1.0000	0.0100	0.0100	142,144,146-49	0 - 381.8
1.0000	0.0080	0.0080	DC-RB-RB	All
1.0000	0.0080	0.0080	RB-RB-RB	All
1.0000	0.0080	0.0080	RB-RB-RR	All
1.0000	0.0100	0.0100	901-904	432.6
1.0000	0.0100	0.0100	905-914	432.6
1.0000	0.0100	0.0100	923-924,927-928	432.6
1.0000	0.0100	0.0100	AB	483.4
1.0000	0.0100	0.0100	AB	534.2
1.0000	0.0100	0.0100	AB	635.8
1.0000	0.0100	0.0100	AB	737.4

Table 5.7 ZPPR-15D – ²³⁵U(n,f) Cell Factors

²³⁵ U(n,f) Cell Factor	σ	σ _{relative}	Environment	Z, mm
1.0000	0.0048	0.0048	901-904	0 - 381.8
1.0000	0.0070	0.0070	905-914	0 - 381.8
0.9990	0.0048	0.0048	915-920	0 - 381.8
0.9984	0.0045	0.0045	158-162,64	0 - 381.8
1.0000	0.0040	0.0040	158-61,63,65	0 - 381.8
0.9984	0.0045	0.0045	143,145-49	0 - 381.8
1.0000	0.0040	0.0040	142,144,146-49	0 - 381.8
1.0000	0.0080	0.0080	DC-RB-RB	All
1.0000	0.0080	0.0080	RB-RB-RB	All
1.0000	0.0080	0.0080	RB-RB-RR	All
1.0000	0.0083	0.0083	901-904	432.6
1.0000	0.0090	0.0090	905-914	432.6
0.9980	0.0051	0.0051	923-924,927-928	432.6
1.0000	0.0100	0.0100	AB	483.4
1.0000	0.0100	0.0100	AB	534.2
1.0000	0.0100	0.0100	AB	635.8
1.0000	0.0100	0.0100	AB	737.4

Table 5.8 ZPPR-15D – ²³⁸U(n,f) Cell Factors

²³⁸ U(n,f) Cell Factor	σ	σ _{relative}	Environment	Z, mm
0.7846	0.0114	0.0145	901-904	0 - 381.8
0.8717	0.0182	0.0209	905-914	0 - 381.8
0.7465	0.0127	0.0170	915-920	0 - 381.8
0.7742	0.0077	0.0099	158-162,64	0 - 381.8
0.8694	0.0080	0.0092	158-61,63,65	0 - 381.8
0.7628	0.0082	0.0107	143,145-49	0 - 381.8
0.8613	0.0064	0.0074	142,144,146-49	0 - 381.8
1.0290	0.0250	0.0243	DC-RB-RB	All
1.0290	0.0250	0.0243	RB-RB-RB	All
1.0290	0.0250	0.0243	RB-RB-RR	All
0.7504	0.0154	0.0205	901-904	432.6
0.8376	0.0182	0.0217	905-914	432.6
0.7247	0.0083	0.0115	923-924,927-928	432.6
0.9230	0.0370	0.0401	AB	483.4
0.9500	0.0590	0.0621	AB	534.2
1.0040	0.0310	0.0309	AB	635.8
1.0600	0.1400	0.1321	AB	737.4

Table 5.9 ZPPR-15D – ²³⁸U(n,γ) Cell Factors

²³⁸ U(n,γ) Cell Factor	σ	σ _{relative}	Environment	Z, mm
0.8954	0.0053	0.0059	901-904	0 - 381.8
0.9745	0.0130	0.0133	905-914	0 - 381.8
0.9319	0.0057	0.0061	915-920	0 - 381.8
0.9502	0.0051	0.0054	158-162,64	0 - 381.8
0.9482	0.0060	0.0063	158-61,63,65	0 - 381.8
0.9502	0.0051	0.0054	143,145-49	0 - 381.8
0.9482	0.0060	0.0063	142,144,146-49	0 - 381.8
1.0119	0.0060	0.0059	DC-RB-RB	All
1.0178	0.0042	0.0041	RB-RB-RB	All
1.0279	0.0043	0.0042	RB-RB-RR	All
0.8823	0.0086	0.0097	901-904	432.6
0.9583	0.0143	0.0149	905-914	432.6
0.9363	0.0053	0.0057	923-924,927-928	432.6
0.8979	0.0054	0.0060	AB	483.4
0.8778	0.0055	0.0063	AB	534.2
0.8641	0.0036	0.0042	AB	635.8
0.7982	0.0076	0.0095	AB	737.4

The third uncertainty component for the cell factor determination is the appropriate uncertainty for detector calibration for absolute reaction rate measurements.

The uncertainty in the determination of in-plate reaction rates, counting statistics for the relevant cell factor in Tables 5.2 – 5.9 and the relevant detector calibration uncertainty must be added in quadrature with the mapping foil uncertainty to determine the total uncertainty for the cell-averaged reaction rate that corresponds to the selected mapping foil.

Tables 5.10 – 5.20 shows the cell-averaged reaction rates, components of the total uncertainty and total uncertainty for the cell-averaged reaction rates measured in ZPPR-15B and ZPPR-15D. The component uncertainties are included in these tables to show their relative contributions to the total uncertainties for the cell-averaged reaction rates. Columns 1 and 2 show the row and column where the drawer or cell was located. Column 3 is the cell-averaged reaction rate. Column 4 is the mapping foil uncertainty, and column 5 is the uncertainty for the cell factor measurement. Column 6 is the uncertainty in the in-plate reaction rate, and column 7 is the detector calibration uncertainty. The component uncertainties in columns 4 – 7 are

added in quadrature to produce the total uncertainties shown in column 8 in Tables 5.10 – 5.20. All uncertainties in Tables 5.10 -5.20 are relative uncertainties expressed in percent.

Table 5.10 Cell-Averaged $^{235}\text{U}(\text{n},\text{f})$ in ZPPR-15B L123 and Uncertainty Components

Row	Column	$^{235}\text{U}(\text{n},\text{f})$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	17	0.0274	1.36	1.00	0.50	1.40	2.25
159	18	0.0443	1.05	1.00	0.50	1.40	2.08
159	19	0.0619	1.03	1.00	0.50	1.40	2.07
159	20	0.0798	1.02	1.00	0.50	1.40	2.06
159	21	0.140	0.96	1.00	0.50	1.40	2.03
159	22	0.176	0.96	1.00	0.50	1.40	2.03
159	23	0.247	0.94	1.00	0.50	1.40	2.02
159	24	0.329	0.91	1.00	0.50	1.40	2.01
159	25	0.415	0.90	1.00	0.50	1.40	2.01
159	26	0.491	0.90	1.00	0.50	1.40	2.01
159	27	0.537	0.90	1.00	0.50	1.40	2.00
159	28	0.507	0.91	1.00	0.50	1.40	2.01
159	29	0.414	0.95	1.00	0.50	1.40	2.03
159	30	0.476	0.93	1.00	0.50	1.40	2.02
159	31	0.607	0.95	1.00	0.50	1.40	2.03
159	32	0.764	0.91	0.50	0.50	1.40	1.81
159	33	0.926	0.98	0.50	0.50	1.40	1.85
159	34	1.054	0.90	0.50	0.50	1.40	1.81
159	35	1.202	0.92	0.50	0.50	1.40	1.82
159	36	1.288	0.89	0.50	0.50	1.40	1.80
159	37	1.372	0.89	0.50	0.50	1.40	1.80
159	38	1.429	0.90	0.50	0.50	1.40	1.81
159	40	1.533	0.89	0.50	0.50	1.40	1.80
159	42	1.591	0.89	0.50	0.50	1.40	1.80
159	44	1.616	0.89	0.50	0.50	1.40	1.80
159	46	1.628	0.89	0.50	0.50	1.40	1.81
159	48	1.643	0.89	0.50	0.50	1.40	1.80
159	49	1.648	0.89	0.50	0.50	1.40	1.80
159	51	1.640	0.90	0.50	0.50	1.40	1.81
159	53	1.606	0.89	0.50	0.50	1.40	1.80
159	55	1.594	0.89	0.50	0.50	1.40	1.81
159	57	1.540	0.89	0.50	0.50	1.40	1.80
159	59	1.450	0.90	0.50	0.50	1.40	1.81
159	60	1.383	0.90	0.50	0.50	1.40	1.81
159	61	1.295	0.89	0.50	0.50	1.40	1.80
159	62	1.188	0.91	0.50	0.50	1.40	1.81
159	63	1.066	0.90	0.50	0.50	1.40	1.81
159	64	0.932	0.90	0.50	0.50	1.40	1.81
159	65	0.773	0.91	0.50	0.50	1.40	1.81
159	66	0.613	0.92	1.00	0.50	1.40	2.01
159	67	0.484	0.95	1.00	0.50	1.40	2.03
159	68	0.415	0.95	1.00	0.50	1.40	2.03
159	69	0.508	0.92	1.00	0.50	1.40	2.02
159	70	0.536	0.91	1.00	0.50	1.40	2.01
159	71	0.491	0.93	1.00	0.50	1.40	2.02
159	72	0.403	0.92	1.00	0.50	1.40	2.01
159	73	0.315	0.94	1.00	0.50	1.40	2.02
159	74	0.226	0.97	1.00	0.50	1.40	2.04
159	75	0.148	0.97	1.00	0.50	1.40	2.04
159	76	0.083	1.01	1.00	0.50	1.40	2.06

Table 5.11 Cell-Averaged $^{238}\text{U}(\text{n},\text{f})$ in ZPPR-15B L123 and Uncertainty Components.

Row	Column	$^{238}\text{U}(\text{n},\text{f})$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	30	0.00402	1.73	2.43	0.50	2.00	3.63
159	32	0.02123	1.00	1.00	1.50	2.00	2.87
159	33	0.02526	0.96	1.00	1.50	2.00	2.86
159	34	0.03262	0.96	1.00	1.50	2.00	2.86
159	35	0.03314	0.95	1.00	1.50	2.00	2.86
159	36	0.03895	0.95	1.00	1.50	2.00	2.85
159	49	0.03383	0.95	1.00	1.50	2.00	2.85
159	63	0.03275	0.96	1.00	1.50	2.00	2.86
159	64	0.02523	0.96	1.00	1.50	2.00	2.86
159	65	0.02109	1.00	1.00	1.50	2.00	2.87
159	66	0.00941	1.19	2.43	0.50	2.00	3.40
159	67	0.00399	1.74	2.43	0.50	2.00	3.63
159	68	0.00195	2.75	2.43	0.50	2.00	4.21

Table 5.12 Cell-Averaged $^{238}\text{U}(\text{n},\gamma)$ in ZPPR-15B L123 and Uncertainty Components

Row	Column	$^{238}\text{U}(\text{n},\gamma)$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	30	0.0591	0.91	0.60	0.50	1.60	2.00
159	32	0.0955	0.91	0.55	1.00	1.60	2.16
159	33	0.1140	0.91	0.55	1.00	1.60	2.16
159	34	0.1304	0.90	0.55	1.00	1.60	2.16
159	35	0.1466	0.90	0.55	1.00	1.60	2.16
159	36	0.1593	0.90	0.55	1.00	1.60	2.16
159	49	0.2114	0.90	0.55	1.00	1.60	2.16
159	63	0.1304	0.90	0.55	1.00	1.60	2.16
159	64	0.1147	0.90	0.55	1.00	1.60	2.16
159	65	0.0961	0.91	0.55	1.00	1.60	2.17
159	66	0.0762	0.91	0.60	0.50	1.60	2.00
159	67	0.0600	0.92	0.60	0.50	1.60	2.00
159	68	0.0493	0.92	0.60	0.50	1.60	2.00

Table 5.13 Cell-Averaged $^{239}\text{Pu}(n,f)$ in ZPPR-15B L134 and Uncertainty Components

Row	Column	$^{239}\text{Pu}(n,f)$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	51	1.620	0.91	0.50	0.50	1.50	1.89
159	53	1.594	0.90	0.50	0.50	1.50	1.89
159	55	1.568	0.90	0.50	0.50	1.50	1.89
159	57	1.531	0.90	0.50	0.50	1.50	1.89
159	59	1.458	0.90	0.50	0.50	1.50	1.89
159	60	1.414	0.91	0.50	0.50	1.50	1.89
159	61	1.340	0.91	0.50	0.50	1.50	1.89
159	62	1.239	0.91	0.50	0.50	1.50	1.89
159	63	1.108	0.92	0.50	0.50	1.50	1.90
159	64	0.966	0.92	0.50	0.50	1.50	1.90
159	65	0.792	0.94	0.50	0.50	1.50	1.90

Table 5.14 Cell-Averaged $^{235}\text{U}(\text{n},\text{f})$ in ZPPR-15B L134 and Uncertainty Components

Row	Column	$^{235}\text{U}(\text{n},\text{f})$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	17	0.00126	3.18	1.00	0.50	1.40	3.65
159	18	0.00178	2.36	1.00	0.50	1.40	2.97
159	19	0.00207	2.07	1.00	0.50	1.40	2.74
159	20	0.00225	1.92	1.00	0.50	1.40	2.62
159	21	0.00226	1.92	1.00	0.50	1.40	2.62
159	22	0.00436	2.41	1.00	0.50	1.40	3.00
159	23	0.00953	1.33	1.00	0.50	1.40	2.23
159	24	0.021	0.94	1.00	0.50	1.40	2.02
159	25	0.0496	0.90	1.00	0.50	1.40	2.01
159	26	0.196	0.88	1.00	0.50	1.40	2.00
159	27	0.344	0.92	1.00	0.50	1.40	2.01
159	28	0.398	0.90	1.00	0.50	1.40	2.01
159	29	0.379	0.92	1.00	0.50	1.40	2.02
159	30	0.459	0.90	1.00	0.50	1.40	2.00
159	31	0.594	0.89	1.00	0.50	1.40	2.00
159	32	0.758	0.89	0.50	0.50	1.40	1.80
159	33	0.926	0.90	0.50	0.50	1.40	1.81
159	34	1.061	0.92	0.50	0.50	1.40	1.82
159	35	1.187	0.89	0.50	0.50	1.40	1.80
159	36	1.279	0.89	0.50	0.50	1.40	1.80
159	37	1.370	0.89	0.50	0.50	1.40	1.80
159	38	1.433	0.89	0.50	0.50	1.40	1.80
159	40	1.532	0.89	0.50	0.50	1.40	1.80
159	42	1.584	0.88	0.50	0.50	1.40	1.80
159	44	1.601	0.91	0.50	0.50	1.40	1.81
159	46	1.633	0.88	0.50	0.50	1.40	1.80
159	48	1.635	0.88	0.50	0.50	1.40	1.80
159	49	1.639	0.88	0.50	0.50	1.40	1.80
159	51	1.629	0.90	0.50	0.50	1.40	1.81
159	53	1.614	0.88	0.50	0.50	1.40	1.80
159	55	1.593	0.88	0.50	0.50	1.40	1.80
159	57	1.535	0.88	0.50	0.50	1.40	1.80
159	59	1.446	0.88	0.50	0.50	1.40	1.80
159	60	1.375	0.89	0.50	0.50	1.40	1.80
159	61	1.293	0.89	0.50	0.50	1.40	1.80
159	62	1.191	0.88	0.50	0.50	1.40	1.80
159	63	1.062	0.89	0.50	0.50	1.40	1.80
159	64	0.928	0.90	0.50	0.50	1.40	1.81
159	65	0.771	0.89	0.50	0.50	1.40	1.80
159	66	0.610	0.91	1.00	0.50	1.40	2.01
159	67	0.483	0.92	1.00	0.50	1.40	2.01
159	68	0.413	0.94	1.00	0.50	1.40	2.02

Table 5.15 Cell-Averaged $^{238}\text{U}(\text{n},\text{f})$ in ZPPR-15B L134 and Uncertainty Components

Row	Column	$^{238}\text{U}(\text{n},\text{f})$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	19	2.25E-06	6.15	2.43	0.50	2.00	6.93
159	21	5.51E-06	5.26	2.43	0.50	2.00	6.15
159	22	1.08E-05	4.92	2.43	0.50	2.00	5.86
159	23	2.14E-05	4.91	2.43	0.50	2.00	5.85
159	24	4.16E-05	4.89	2.43	0.50	2.00	5.84
159	25	8.38E-05	4.89	2.43	0.50	2.00	5.83
159	26	0.000194	4.92	2.43	0.50	2.00	5.86
159	27	0.00039	4.54	2.43	0.50	2.00	5.54
159	29	0.001887	3.16	2.43	0.50	2.00	4.49
159	30	0.003951	2.48	2.43	0.50	2.00	4.04
159	31	0.009349	1.28	2.43	0.50	2.00	3.43
159	32	0.02116	1.03	1.00	1.50	2.00	2.88
159	33	0.02526	1.00	1.00	1.50	2.00	2.87
159	34	0.0325	1.00	1.00	1.50	2.00	2.87
159	35	0.03311	0.97	1.00	1.50	2.00	2.86
159	36	0.03876	0.96	1.00	1.50	2.00	2.86
159	49	0.03345	0.95	1.00	1.50	2.00	2.86
159	63	0.03228	1.00	1.00	1.50	2.00	2.87
159	64	0.0252	1.00	1.00	1.50	2.00	2.87
159	65	0.02115	1.00	1.00	1.50	2.00	2.87
159	66	0.009345	1.19	2.43	0.50	2.00	3.40
159	67	0.00409	1.71	2.43	0.50	2.00	3.62
159	68	0.001922	2.85	2.43	0.50	2.00	4.27
159	70	0.000405	4.60	2.43	0.50	2.00	5.60
159	72	8.86E-05	4.93	2.43	0.50	2.00	5.87
159	74	2.30E-05	4.88	2.43	0.50	2.00	5.83
159	76	6.39E-06	6.78	2.43	0.50	2.00	7.49

Table 5.16 Cell-Averaged $^{238}\text{U}(n,\gamma)$ in ZPPR-15B L134 and Uncertainty Components

Row	Column	$^{238}\text{U}(n,\gamma)$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	29	0.04604	0.94	0.55	0.50	1.60	2.00
159	30	0.05795	0.95	0.55	0.50	1.60	2.01
159	31	0.07449	0.93	0.55	0.50	1.60	1.99
159	32	0.09532	0.91	0.55	1.00	1.60	2.17
159	33	0.1139	0.93	0.55	1.00	1.60	2.18
159	34	0.1302	0.93	0.55	1.00	1.60	2.17
159	35	0.1470	0.92	0.55	1.00	1.60	2.17
159	36	0.1586	0.91	0.55	1.00	1.60	2.17
159	49	0.2117	0.92	0.55	1.00	1.60	2.17
159	63	0.1315	0.92	0.55	1.00	1.60	2.17
159	64	0.1154	0.92	0.55	1.00	1.60	2.17
159	65	0.09642	0.92	0.55	1.00	1.60	2.17
159	66	0.07685	0.93	0.55	0.50	1.60	1.99
159	67	0.05992	0.93	0.55	0.50	1.60	1.99
159	68	0.04951	0.93	0.55	0.50	1.60	1.99

Table 5.17 Cell-Averaged $^{239}\text{Pu}(n,f)$ in ZPPR-15D L203 and Uncertainty Components

Row	Column	$^{239}\text{Pu}(n,f)$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	49	1.501	1.05	1.00	0.50	1.50	2.14
159	50	1.459	1.10	1.00	0.50	1.50	2.17
159	51	1.482	1.05	1.00	0.50	1.50	2.15
159	52	1.495	1.05	1.00	0.50	1.50	2.14
159	53	1.498	1.05	1.00	0.50	1.50	2.14
159	54	1.503	1.09	1.00	0.50	1.50	2.16
159	55	1.468	1.06	1.00	0.50	1.50	2.15
159	56	1.517	1.08	1.00	0.50	1.50	2.16
159	57	1.501	1.05	1.00	0.50	1.50	2.14
159	58	1.419	1.12	1.00	0.50	1.50	2.18
159	59	1.390	1.08	1.00	0.50	1.50	2.16
159	60	1.337	1.05	1.00	0.50	1.50	2.15
159	61	1.250	1.08	1.00	0.50	1.50	2.16
159	62	1.167	1.12	1.00	0.50	1.50	2.18
159	63	1.046	1.11	1.00	0.50	1.50	2.18
159	64	0.913	1.11	1.00	0.50	1.50	2.18
159	65	0.745	1.34	1.00	0.50	1.50	2.30
159	66	0.574	1.32	0.80	0.50	1.50	2.21
159	67	0.440	1.39	0.80	0.50	1.50	2.25
159	68	0.384	1.53	0.80	0.50	1.50	2.34
152	49	1.482	1.05	1.00	0.50	1.50	2.15
153	49	1.489	1.05	1.00	0.50	1.50	2.15
154	49	1.482	1.05	1.00	0.50	1.50	2.15
155	49	1.475	1.05	1.00	0.50	1.50	2.15
156	49	1.500	1.05	1.00	0.50	1.50	2.14
157	49	1.455	1.15	1.00	0.50	1.50	2.20
158	49	1.480	1.10	1.00	0.50	1.50	2.17
159	49	1.501	1.05	1.00	0.50	1.50	2.14
159	49	1.451	1.06	1.00	0.50	1.50	2.15
159	49	1.371	1.04	1.00	0.50	1.50	2.14
159	49	1.246	1.08	1.00	0.50	1.50	2.16
159	49	1.090	1.15	1.00	0.50	1.50	2.20
159	49	0.954	1.16	1.00	0.50	1.50	2.20
159	49	0.826	1.17	1.00	0.50	1.50	2.21
159	60	1.337	1.05	1.00	0.50	1.50	2.15
159	60	1.277	1.02	1.00	0.50	1.50	2.13
159	60	1.234	1.14	1.00	0.50	1.50	2.19
159	60	1.113	1.08	1.00	0.50	1.50	2.16
159	60	0.952	1.16	1.00	0.50	1.50	2.20
159	60	0.841	1.16	1.00	0.50	1.50	2.20
159	60	0.700	1.18	1.00	0.50	1.50	2.21
159	64	0.913	1.11	1.00	0.50	1.50	2.18
159	64	0.879	1.13	1.00	0.50	1.50	2.19
159	64	0.845	1.24	1.00	0.50	1.50	2.25
159	64	0.745	1.24	1.00	0.50	1.50	2.24
159	64	0.648	1.23	1.00	0.50	1.50	2.24
159	64	0.565	1.33	1.00	0.50	1.50	2.30
159	64	0.477	1.32	1.00	0.50	1.50	2.29

Table 5.18 Cell-Averaged $^{235}\text{U}(\text{n},\text{f})$ in ZPPR-15D L203 and Uncertainty Components.

Row	Column	$^{235}\text{U}(\text{n},\text{f})$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	30	0.450	1.05	0.80	0.20	1.40	1.93
159	31	0.558	1.08	0.80	0.20	1.40	1.95
159	32	0.695	1.08	0.50	0.20	1.40	1.85
159	33	0.811	1.01	0.50	0.20	1.40	1.81
159	34	0.958	0.96	0.50	0.20	1.40	1.78
159	35	1.054	0.93	0.50	0.20	1.40	1.77
159	36	1.156	1.01	0.50	0.20	1.40	1.81
159	37	1.221	0.94	0.50	0.20	1.40	1.77
159	38	1.293	0.97	0.50	0.20	1.40	1.79
159	39	1.354	0.96	0.50	0.20	1.40	1.78
159	40	1.397	0.95	0.50	0.20	1.40	1.78
159	41	1.421	0.94	0.50	0.20	1.40	1.77
159	42	1.435	0.94	0.50	0.20	1.40	1.77
159	43	1.442	0.94	0.50	0.20	1.40	1.77
159	44	1.447	0.94	0.50	0.20	1.40	1.77
159	45	1.446	0.94	0.50	0.20	1.40	1.77
159	46	1.448	0.94	0.50	0.20	1.40	1.77
159	47	1.453	0.94	0.50	0.20	1.40	1.77
159	48	1.431	0.94	0.50	0.20	1.40	1.77
159	49	1.433	0.91	0.50	0.20	1.40	1.75
159	50	1.445	0.91	0.50	0.20	1.40	1.75
159	51	1.435	0.91	0.50	0.20	1.40	1.75
159	52	1.438	0.94	0.50	0.20	1.40	1.77
159	53	1.456	0.94	0.50	0.20	1.40	1.77
159	54	1.441	0.98	0.50	0.20	1.40	1.79
159	55	1.429	0.91	0.50	0.20	1.40	1.75
159	56	1.424	0.91	0.50	0.20	1.40	1.75
159	57	1.400	0.91	0.50	0.20	1.40	1.76
159	58	1.354	0.92	0.50	0.20	1.40	1.76
159	59	1.292	0.93	0.50	0.20	1.40	1.77
159	60	1.217	0.90	0.50	0.20	1.40	1.75
159	61	1.155	0.92	0.50	0.20	1.40	1.76
159	62	1.047	0.94	0.50	0.20	1.40	1.77
159	63	0.955	0.96	0.50	0.20	1.40	1.78
159	64	0.816	0.94	0.50	0.20	1.40	1.77
159	65	0.694	0.99	0.50	0.20	1.40	1.80
159	66	0.559	0.97	0.80	0.20	1.40	1.89
159	67	0.449	1.05	0.80	0.20	1.40	1.93
159	68	0.393	1.11	0.80	0.20	1.40	1.97
139	49	0.400	1.10	0.80	0.20	1.40	1.96
140	49	0.452	1.04	0.80	0.20	1.40	1.93
141	49	0.554	1.08	0.80	0.20	1.40	1.95
142	49	0.689	0.99	0.50	0.20	1.40	1.80
143	49	0.816	0.94	0.50	0.20	1.40	1.77
144	49	0.935	0.97	0.50	0.20	1.40	1.78
145	49	1.047	0.94	0.50	0.20	1.40	1.77
146	49	1.148	0.96	0.50	0.20	1.40	1.78
147	49	1.233	0.99	0.50	0.20	1.40	1.80
148	49	1.293	0.97	0.50	0.20	1.40	1.79
149	49	1.347	0.96	0.50	0.20	1.40	1.78
150	49	1.390	0.95	0.50	0.20	1.40	1.78
151	49	1.406	0.95	0.50	0.20	1.40	1.77

152	49	1.428	0.94	0.50	0.20	1.40	1.77
153	49	1.437	0.94	0.50	0.20	1.40	1.77
154	49	1.425	0.94	0.50	0.20	1.40	1.77
155	49	1.445	0.94	0.50	0.20	1.40	1.77
156	49	1.439	0.94	0.50	0.20	1.40	1.77
157	49	1.449	0.94	0.50	0.20	1.40	1.77
158	49	1.433	0.94	0.50	0.20	1.40	1.77
159	49	1.433	0.91	0.50	0.20	1.40	1.75
160	49	1.442	0.94	0.50	0.20	1.40	1.77
161	49	1.443	0.98	0.50	0.20	1.40	1.79
162	49	1.389	0.91	0.50	0.20	1.40	1.76
163	49	1.444	0.98	0.50	0.20	1.40	1.79
164	49	1.435	0.98	0.50	0.20	1.40	1.79
165	49	1.426	0.94	0.50	0.20	1.40	1.77
166	49	1.401	0.95	0.50	0.20	1.40	1.77
167	49	1.372	0.99	0.50	0.20	1.40	1.80
168	49	1.354	0.96	0.50	0.20	1.40	1.78
169	49	1.288	0.93	0.50	0.20	1.40	1.77
170	49	1.215	0.95	0.50	0.20	1.40	1.77
171	49	1.143	0.96	0.50	0.20	1.40	1.78
172	49	1.045	0.94	0.50	0.20	1.40	1.77
173	49	0.930	0.97	0.50	0.20	1.40	1.79
174	49	0.813	1.01	0.50	0.20	1.40	1.81
175	49	0.685	1.00	0.50	0.20	1.40	1.80
176	49	0.553	0.97	0.80	0.20	1.40	1.89
177	49	0.452	1.04	0.80	0.20	1.40	1.93
178	49	0.401	1.10	0.80	0.20	1.40	1.96
159	49	1.433	0.91	0.50	0.20	1.40	1.75
159	49	1.388	0.91	0.50	0.20	1.40	1.76
159	49	1.339	0.92	0.50	0.20	1.40	1.76
159	49	1.197	0.95	0.50	0.20	1.40	1.78
159	49	1.056	0.93	0.50	0.20	1.40	1.77
159	49	0.928	0.97	0.50	0.20	1.40	1.79
159	49	0.809	0.95	0.50	0.20	1.40	1.77
159	49	0.699	0.99	1.00	0.20	1.40	1.99
159	49	0.582	0.96	1.00	0.20	1.40	1.98
159	49	0.387	1.12	1.00	0.20	1.40	2.06
159	49	0.283	1.07	1.00	0.20	1.40	2.04
159	60	1.217	0.90	0.50	0.20	1.40	1.75
159	60	1.174	0.95	0.50	0.20	1.40	1.78
159	60	1.122	0.92	0.50	0.20	1.40	1.76
159	60	1.021	0.94	0.50	0.20	1.40	1.77
159	60	0.881	0.93	0.50	0.20	1.40	1.76
159	60	0.784	0.95	0.50	0.20	1.40	1.78
159	60	0.665	1.01	0.50	0.20	1.40	1.81
159	60	0.573	0.96	1.00	0.20	1.40	1.98
159	60	0.477	1.02	1.00	0.20	1.40	2.01
159	60	0.314	1.03	1.00	0.20	1.40	2.01
159	60	0.221	1.21	1.00	0.20	1.40	2.11
159	64	0.816	0.94	0.50	0.20	1.40	1.77
159	64	0.782	0.95	0.50	0.20	1.40	1.78
159	64	0.752	0.97	0.50	0.20	1.40	1.78
159	64	0.673	0.92	0.50	0.20	1.40	1.76
159	64	0.581	0.96	0.50	0.20	1.40	1.78
159	64	0.515	0.99	0.50	0.20	1.40	1.80

159	64	0.440	1.05	0.50	0.20	1.40	1.83
159	64	0.372	0.97	1.00	0.20	1.40	1.99
159	64	0.308	1.26	1.00	0.20	1.40	2.14
159	64	0.203	1.27	1.00	0.20	1.40	2.15
159	64	0.147	1.05	1.00	0.20	1.40	2.03

Table 5.19 Cell-Averaged $^{238}\text{U}(\text{n},\text{f})$ in ZPPR-15D L203 and Uncertainty Components							
Row	Column	$^{238}\text{U}(\text{n},\text{f})$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	49	0.02775	1.39	1.70	0.50	2.00	3.01
159	50	0.02805	1.38	1.70	0.50	2.00	3.01
159	51	0.02782	1.62	1.70	0.50	2.00	3.13
159	52	0.02843	1.37	1.70	0.50	2.00	3.00
159	53	0.02863	1.36	1.70	0.50	2.00	3.00
159	54	0.02915	1.57	1.70	0.50	2.00	3.10
159	55	0.03033	1.52	1.70	0.50	2.00	3.08
159	56	0.03602	1.31	1.70	0.50	2.00	2.98
159	57	0.03555	1.32	1.70	0.50	2.00	2.98
159	58	0.03417	1.51	1.70	0.50	2.00	3.07
159	59	0.03261	1.34	1.70	0.50	2.00	2.99
159	60	0.03226	1.35	1.70	0.50	2.00	2.99
159	61	0.03275	1.33	1.70	0.50	2.00	2.99
159	62	0.03223	1.45	1.70	0.50	2.00	3.04
159	63	0.02937	1.43	1.70	0.50	2.00	3.03
159	64	0.02462	1.49	1.70	0.50	2.00	3.06
159	65	0.01952	1.56	1.70	0.50	2.00	3.10
159	66	0.00899	2.49	2.40	0.50	2.00	4.02
159	67	0.00417	5.06	2.40	0.50	2.00	5.97
159	68	0.00225	9.13	2.40	0.50	2.00	9.66
139	49	0.00207	5.06	2.40	0.50	2.00	5.97
140	49	0.00395	5.32	2.40	0.50	2.00	6.19
141	49	0.00852	2.54	2.40	0.50	2.00	4.06
142	49	0.01810	2.07	1.70	0.50	2.00	3.38
143	49	0.02418	1.50	1.70	0.50	2.00	3.06
144	49	0.02916	1.43	1.70	0.50	2.00	3.03
145	49	0.03182	1.25	1.70	0.50	2.00	2.95
146	49	0.03416	1.50	1.70	0.50	2.00	3.06
147	49	0.03185	1.59	1.70	0.50	2.00	3.11
148	49	0.03226	1.35	1.70	0.50	2.00	2.99
149	49	0.03308	1.33	1.70	0.50	2.00	2.98
150	49	0.03543	1.33	1.70	0.50	2.00	2.98
151	49	0.03559	1.32	1.70	0.50	2.00	2.98
152	49	0.03018	1.32	1.70	0.50	2.00	2.98
153	49	0.02859	1.36	1.70	0.50	2.00	3.00
154	49	0.02825	1.37	1.70	0.50	2.00	3.00
155	49	0.02852	1.37	1.70	0.50	2.00	3.00
156	49	0.02808	1.38	1.70	0.50	2.00	3.01
157	49	0.02811	1.38	1.70	0.50	2.00	3.01
158	49	0.02803	1.38	1.70	0.50	2.00	3.01
159	49	0.02775	1.39	1.70	0.50	2.00	3.01
159	49	0.02692	1.42	1.70	0.50	2.00	3.02
159	49	0.02594	1.45	1.70	0.50	2.00	3.04
159	49	0.02318	1.58	1.70	0.50	2.00	3.10
159	49	0.02001	1.43	1.70	0.50	2.00	3.03
159	49	0.01756	1.56	1.70	0.50	2.00	3.10

159	49	0.01291	1.92	1.70	0.50	2.00	3.29
159	49	0.00684	2.82	5.00	0.50	2.00	6.10
159	49	0.00363	5.32	5.00	0.50	2.00	7.59
159	49	0.00129	7.73	5.00	0.50	2.00	9.44
159	49	0.00066	16.69	5.00	0.50	2.00	17.54
159	60	0.03226	1.35	1.70	0.50	2.00	2.99
159	60	0.03130	1.38	1.70	0.50	2.00	3.01
159	60	0.02950	1.43	1.70	0.50	2.00	3.03
159	60	0.02712	1.52	1.70	0.50	2.00	3.07
159	60	0.02257	1.41	1.70	0.50	2.00	3.02
159	60	0.01887	1.61	1.70	0.50	2.00	3.12
159	60	0.01462	1.89	1.70	0.50	2.00	3.28
159	60	0.00741	2.63	5.00	0.50	2.00	6.01
159	60	0.00384	5.06	5.00	0.50	2.00	7.41
159	60	0.00121	16.69	5.00	0.50	2.00	17.54
159	60	0.00081	12.53	5.00	0.50	2.00	13.64
159	64	0.02462	1.49	1.70	0.50	2.00	3.06
159	64	0.02395	1.53	1.70	0.50	2.00	3.08
159	64	0.02235	1.60	1.70	0.50	2.00	3.12
159	64	0.02030	1.40	1.70	0.50	2.00	3.02
159	64	0.01707	1.58	1.70	0.50	2.00	3.10
159	64	0.01475	1.77	1.70	0.50	2.00	3.21
159	64	0.01089	1.56	1.70	0.50	2.00	3.09
159	64	0.00527	3.60	5.00	0.50	2.00	6.50
159	64	0.00271	3.54	5.00	0.50	2.00	6.46
159	64	0.00097	10.03	5.00	0.50	2.00	11.40
159	64	0.00082	25.01	5.00	0.50	2.00	25.59

Table 5.20 Cell-Averaged $^{238}\text{U}(n,\gamma)$ in ZPPR-15D L203 and Uncertainty Components

Row	Column	$^{238}\text{U}(n,\gamma)$	$\sigma_{\text{map foil, \%}}$	$\sigma_{\text{cell factor, \%}}$	$\sigma_{\text{in plate, \%}}$	$\sigma_{\text{calib, \%}}$	$\sigma_{\text{total, \%}}$
159	49	0.1818	0.94	0.75	0.50	1.60	2.07
159	50	0.1825	0.94	0.75	0.50	1.60	2.06
159	51	0.1827	0.94	0.75	0.50	1.60	2.06
159	52	0.1826	0.94	0.75	0.50	1.60	2.06
159	53	0.1815	0.95	0.75	0.50	1.60	2.07
159	54	0.1816	0.97	0.75	0.50	1.60	2.08
159	55	0.1769	0.95	0.75	0.50	1.60	2.07
159	56	0.1763	0.94	0.75	0.50	1.60	2.06
159	57	0.1711	0.97	0.75	0.50	1.60	2.08
159	58	0.1692	0.96	0.75	0.50	1.60	2.07
159	59	0.1617	0.94	0.75	0.50	1.60	2.06
159	60	0.1505	0.96	0.75	0.50	1.60	2.07
159	61	0.1410	0.97	0.75	0.50	1.60	2.08
159	62	0.1278	0.96	0.75	0.50	1.60	2.07
159	63	0.1143	0.99	0.75	0.50	1.60	2.09
159	64	0.0985	0.99	0.75	0.50	1.60	2.09
159	65	0.0860	0.98	0.75	0.50	1.60	2.08
159	66	0.0691	1.00	0.60	0.50	1.60	2.04
159	67	0.0561	1.08	0.60	0.50	1.60	2.08
159	68	0.0464	1.05	0.60	0.50	1.60	2.06
139	49	0.0469	1.04	0.60	0.50	1.60	2.06
140	49	0.0562	1.08	0.60	0.50	1.60	2.08
141	49	0.0693	1.00	0.60	0.50	1.60	2.04
142	49	0.0848	0.98	0.75	0.50	1.60	2.08
143	49	0.0991	0.99	0.75	0.50	1.60	2.09
144	49	0.1137	0.95	0.75	0.50	1.60	2.07
145	49	0.1272	0.96	0.75	0.50	1.60	2.07
146	49	0.1384	0.97	0.75	0.50	1.60	2.08
147	49	0.1504	0.96	0.75	0.50	1.60	2.07
148	49	0.1600	0.94	0.75	0.50	1.60	2.06
149	49	0.1668	0.96	0.75	0.50	1.60	2.07
150	49	0.1695	0.95	0.75	0.50	1.60	2.07
151	49	0.1744	0.97	0.75	0.50	1.60	2.08
152	49	0.1755	0.95	0.75	0.50	1.60	2.07
153	49	0.1791	0.95	0.75	0.50	1.60	2.07
154	49	0.1805	0.95	0.75	0.50	1.60	2.07
155	49	0.1812	0.95	0.75	0.50	1.60	2.07
156	49	0.1819	0.97	0.75	0.50	1.60	2.08
157	49	0.1818	0.94	0.75	0.50	1.60	2.07

158	49	0.1834	0.94	0.75	0.50	1.60	2.06
159	49	0.1818	0.94	0.75	0.50	1.60	2.07
159	49	0.1775	0.95	0.75	0.50	1.60	2.07
159	49	0.1689	0.96	0.75	0.50	1.60	2.07
159	49	0.1534	0.93	0.75	0.50	1.60	2.06
159	49	0.1346	0.97	0.75	0.50	1.60	2.07
159	49	0.1214	0.96	0.75	0.50	1.60	2.07
159	49	0.1049	0.95	0.75	0.50	1.60	2.07
159	49	0.0879	0.95	0.65	0.50	1.60	2.04
159	49	0.0734	1.00	0.65	0.50	1.60	2.06
159	49	0.0503	1.06	0.65	0.50	1.60	2.09
159	49	0.0336	1.08	0.65	0.50	1.60	2.10
159	60	0.1505	0.96	0.75	0.50	1.60	2.07
159	60	0.1458	0.97	0.75	0.50	1.60	2.08
159	60	0.1391	0.94	0.75	0.50	1.60	2.06
159	60	0.1261	0.97	0.75	0.50	1.60	2.08
159	60	0.1103	0.96	0.75	0.50	1.60	2.07
159	60	0.0989	1.00	0.75	0.50	1.60	2.09
159	60	0.0839	0.99	0.75	0.50	1.60	2.09
159	60	0.0703	1.03	0.65	0.50	1.60	2.07
159	60	0.0585	1.01	0.65	0.50	1.60	2.06
159	60	0.0399	1.04	0.65	0.50	1.60	2.07
159	60	0.0263	1.01	0.65	0.50	1.60	2.06
159	64	0.0985	0.99	0.75	0.50	1.60	2.09
159	64	0.0958	0.95	0.75	0.50	1.60	2.07
159	64	0.0911	0.96	0.75	0.50	1.60	2.07
159	64	0.0823	0.99	0.75	0.50	1.60	2.09
159	64	0.0714	0.97	0.75	0.50	1.60	2.07
159	64	0.0641	1.00	0.75	0.50	1.60	2.09
159	64	0.0551	1.05	0.75	0.50	1.60	2.12
159	64	0.0452	1.00	0.65	0.50	1.60	2.06
159	64	0.0383	1.06	0.65	0.50	1.60	2.09
159	64	0.0254	1.06	0.65	0.50	1.60	2.09
159	64	0.0176	1.22	0.65	0.50	1.60	2.17

5.2 Cell-Averaged Reaction Rate Distributions in ZPPR-15

Tables 5.21 – 5.31 show the cell-averaged reaction rates with the total uncertainties listed. Note that the uncertainties in Tables 5.21 – 5.31 are relative uncertainties, i.e., the total uncertainty divided by the measured value, expressed in percent. The letters in the “Region” column (column 3) of Tables 5.21 – 5.27 for ZPPR-15B designate:

IC – inner core,
 OC – outer core,
 RB – radial blanket,
 RR – radial reflector,
 SP – sodium pool,
 SH -shield,
 SSNA – stainless steel-sodium shield zone, and
 BCNA – boron carbide-sodium shield zone.

The letters in the “Region” column (column 3) of Tables 5.28 – 5.31 for ZPPR-15D L203 designate:

IC – inner core with one 1/16 inch HEU fuel column,
 IC D – inner core with two 1/16 inch HEU fuel columns,
 IC SD – inner core with one 1/8 inch HEU fuel column,
 OC – outer core with one 1/16 inch HEU fuel column,
 OC D – outer core with two 1/16 inch HEU fuel columns,
 OC SD – outer core with one 1/8 inch HEU fuel column,
 RB – radial blanket, and
 AB – axial blanket.

Columns 4 – 7 in Tables 5.21 to 5.31 list the X- and Y-boundaries of the cell relative to the coordinate system described in Section 2. The Z coordinate in column 8 of these tables is the Z-coordinate of the foils in half 1. The Z-coordinates in these tables do not include the 0.030 in (0.762 mm) front plate of the drawer. All dimensions in these tables are in centimeters.

Table 5.21 ZPPR-15B L123 – $^{235}\text{U}(\text{n},\text{f})$ Cell-Averaged Reaction Rate

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	Z	$^{235}\text{U}(\text{n},\text{f})$	σ_{total} , %
159	17	SP	33.1470	38.6715	154.6860	160.2105	6.3100	0.0274	2.25
159	18	SP	38.6715	44.1960	154.6860	160.2105	6.3100	0.0443	2.08
159	19	SP	44.1960	49.7205	154.6860	160.2105	6.3100	0.0619	2.07
159	20	SP	49.7205	55.2450	154.6860	160.2105	6.3100	0.0798	2.06
159	21	SH-SSNA	55.2450	60.7695	154.6860	160.2105	6.3100	0.1400	2.03
159	22	SH-SSNA	60.7695	66.2940	154.6860	160.2105	6.3100	0.1760	2.03
159	23	SH-SSNA	66.2940	71.8185	154.6860	160.2105	6.3100	0.2470	2.02
159	24	SH-SSNA	71.8185	77.3430	154.6860	160.2105	6.3100	0.3290	2.01
159	25	SH-SSNA	77.3430	82.8675	154.6860	160.2105	6.3100	0.4150	2.01
159	26	RR-SSNA	82.8675	88.3920	154.6860	160.2105	6.3100	0.4910	2.01
159	27	RR-SSNA	88.3920	93.9165	154.6860	160.2105	6.3100	0.5370	2.00
159	28	RR-SSNA	93.9165	99.4410	154.6860	160.2105	6.3100	0.5070	2.01

159	29	RB	99.4410	104.9655	154.6860	160.2105	6.3100	0.4140	2.03
159	30	RB	104.9655	110.4900	154.6860	160.2105	6.3100	0.4760	2.02
159	31	RB	110.4900	116.0145	154.6860	160.2105	6.3100	0.6070	2.03
159	32	OC	116.0145	121.5390	154.6860	160.2105	6.3100	0.7640	1.81
159	33	OC	121.5390	127.0635	154.6860	160.2105	6.3100	0.9260	1.85
159	34	OC	127.0635	132.5880	154.6860	160.2105	6.3100	1.0540	1.81
159	35	OC	132.5880	138.1125	154.6860	160.2105	6.3100	1.2020	1.82
159	36	OC	138.1125	143.6370	154.6860	160.2105	6.3100	1.2880	1.80
159	37	IC	143.6370	149.1615	154.6860	160.2105	6.3100	1.3720	1.80
159	38	IC	149.1615	154.6860	154.6860	160.2105	6.3100	1.4290	1.81
159	40	IC	160.2105	165.7350	154.6860	160.2105	6.3100	1.5330	1.80
159	42	IC	171.2595	176.7840	154.6860	160.2105	6.3100	1.5910	1.80
159	44	IC	182.3085	187.8330	154.6860	160.2105	6.3100	1.6160	1.80
159	46	IC	193.3575	198.8820	154.6860	160.2105	6.3100	1.6280	1.81
159	48	IC	204.4065	209.9310	154.6860	160.2105	6.3100	1.6430	1.80
159	49	IC	209.9310	215.4555	154.6860	160.2105	6.3100	1.6480	1.80
159	51	IC	220.9800	226.5045	154.6860	160.2105	6.3100	1.6400	1.81
159	53	IC	232.0290	237.5535	154.6860	160.2105	6.3100	1.6060	1.80
159	55	IC	243.0780	248.6025	154.6860	160.2105	6.3100	1.5940	1.81
159	57	IC	254.1270	259.6515	154.6860	160.2105	6.3100	1.5400	1.80
159	59	IC	265.1760	270.7005	154.6860	160.2105	6.3100	1.4500	1.81
159	60	IC	270.7005	276.2250	154.6860	160.2105	6.3100	1.3830	1.81
159	61	OC	276.2250	281.7495	154.6860	160.2105	6.3100	1.2950	1.80
159	62	OC	281.7495	287.2740	154.6860	160.2105	6.3100	1.1880	1.81
159	63	OC	287.2740	292.7985	154.6860	160.2105	6.3100	1.0660	1.81
159	64	OC	292.7985	298.3230	154.6860	160.2105	6.3100	0.9320	1.81
159	65	OC	298.3230	303.8475	154.6860	160.2105	6.3100	0.7730	1.81
159	66	RB	303.8475	309.3720	154.6860	160.2105	6.3100	0.6130	2.01
159	67	RB	309.3720	314.8965	154.6860	160.2105	6.3100	0.4840	2.03
159	68	RB	314.8965	320.4210	154.6860	160.2105	6.3100	0.4150	2.03
159	69	RR	320.4210	325.9455	154.6860	160.2105	6.3100	0.5080	2.02
159	70	RR	325.9455	331.4700	154.6860	160.2105	6.3100	0.5360	2.01
159	71	RR	331.4700	336.9945	154.6860	160.2105	6.3100	0.4910	2.02
159	72	RR	336.9945	342.5190	154.6860	160.2105	6.3100	0.4030	2.01
159	73	RR	342.5190	348.0435	154.6860	160.2105	6.3100	0.3150	2.02
159	74	RR	348.0435	353.5680	154.6860	160.2105	6.3100	0.2260	2.04
159	75	RR	353.5680	359.0925	154.6860	160.2105	6.3100	0.1480	2.04
159	76	RR	359.0925	364.6170	154.6860	160.2105	6.3100	0.0830	2.06

Table 5.22 ZPPR-15B L123 – $^{238}\text{U}(\text{n},\text{f})$ Cell-Averaged Reaction Rate

Row	Column	Region	$X_{\min}$	$X_{\max}$	$Y_{\min}$	$Y_{\max}$	Z	$^{238}\text{U}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
159	30	RB	104.9655	110.4900	154.6860	160.2105	7.7000	0.00402	3.63
159	32	OC	116.0145	121.5390	154.6860	160.2105	7.7000	0.02123	2.87
159	33	OC	121.5390	127.0635	154.6860	160.2105	7.7000	0.02526	2.86
159	34	OC	127.0635	132.5880	154.6860	160.2105	7.7000	0.03262	2.86
159	35	OC	132.5880	138.1125	154.6860	160.2105	7.7000	0.03314	2.86
159	36	OC	138.1125	143.6370	154.6860	160.2105	7.7000	0.03895	2.85
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	0.03383	2.85
159	63	OC	287.2740	292.7985	154.6860	160.2105	7.7000	0.03275	2.86
159	64	OC	292.7985	298.3230	154.6860	160.2105	7.7000	0.02523	2.86
159	65	OC	298.3230	303.8475	154.6860	160.2105	7.7000	0.02109	2.87
159	66	RB	303.8475	309.3720	154.6860	160.2105	7.7000	0.00941	3.40
159	67	RB	309.3720	314.8965	154.6860	160.2105	7.7000	0.00399	3.63
159	68	RB	314.8965	320.4210	154.6860	160.2105	7.7000	0.00195	4.21

Table 5.23 ZPPR-15B L123 – $^{238}\text{U}(\text{n},\gamma)$ Cell-Averaged Reaction Rate

Row	Column	Region	$X_{\min}$	$X_{\max}$	$Y_{\min}$	$Y_{\max}$	Z	$^{238}\text{U}(\text{n},\gamma)$	$\sigma_{\text{total}}, \%$
159	30	RB	104.9655	110.4900	154.6860	160.2105	7.7000	0.0591	2.00
159	32	OC	116.0145	121.5390	154.6860	160.2105	7.7000	0.0955	2.16
159	33	OC	121.5390	127.0635	154.6860	160.2105	7.7000	0.1140	2.16
159	34	OC	127.0635	132.5880	154.6860	160.2105	7.7000	0.1304	2.16
159	35	OC	132.5880	138.1125	154.6860	160.2105	7.7000	0.1466	2.16
159	36	OC	138.1125	143.6370	154.6860	160.2105	7.7000	0.1593	2.16
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	0.2114	2.16
159	63	OC	287.2740	292.7985	154.6860	160.2105	7.7000	0.1304	2.16
159	64	OC	292.7985	298.3230	154.6860	160.2105	7.7000	0.1147	2.16
159	65	OC	298.3230	303.8475	154.6860	160.2105	7.7000	0.0961	2.17
159	66	RB	303.8475	309.3720	154.6860	160.2105	7.7000	0.0762	2.00
159	67	RB	309.3720	314.8965	154.6860	160.2105	7.7000	0.0600	2.00
159	68	RB	314.8965	320.4210	154.6860	160.2105	7.7000	0.0493	2.00

Table 5.24 ZPPR-15B L134 – $^{239}\text{Pu}(\text{n},\text{f})$ Cell-Averaged Reaction Rate.

Row	Column	Region	$X_{\min}$	$X_{\max}$	$Y_{\min}$	$Y_{\max}$	Z	$^{239}\text{Pu}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
159	51	IC	220.9800	226.5045	154.6860	160.2105	9.0800	1.620	1.89
159	53	IC	232.0290	237.5535	154.6860	160.2105	9.0800	1.594	1.89
159	55	IC	243.0780	248.6025	154.6860	160.2105	9.0800	1.568	1.89
159	57	IC	254.1270	259.6515	154.6860	160.2105	9.0800	1.531	1.89
159	59	IC	265.1760	270.7005	154.6860	160.2105	9.0800	1.458	1.89
159	60	IC	270.7005	276.2250	154.6860	160.2105	9.0800	1.414	1.89
159	61	OC	276.2250	281.7495	154.6860	160.2105	9.0800	1.340	1.89
159	62	OC	281.7495	287.2740	154.6860	160.2105	9.0800	1.239	1.89
159	63	OC	287.2740	292.7985	154.6860	160.2105	9.0800	1.108	1.90
159	64	OC	292.7985	298.3230	154.6860	160.2105	9.0800	0.966	1.90
159	65	OC	298.3230	303.8475	154.6860	160.2105	9.0800	0.792	1.90

Table 5.25 ZPPR-15B L134 – $^{235}\text{U}(\text{n},\text{f})$ Cell-Averaged Reaction Rate.

Row	Column	Region	$X_{\min}$	$X_{\max}$	$Y_{\min}$	$Y_{\max}$	Z	$^{235}\text{U}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
159	17	SP	33.1470	38.6715	154.6860	160.2105	6.3100	0.00126	3.65
159	18	SP	38.6715	44.1960	154.6860	160.2105	6.3100	0.00178	2.97
159	19	SP	44.1960	49.7205	154.6860	160.2105	6.3100	0.00207	2.74
159	20	SP	49.7205	55.2450	154.6860	160.2105	6.3100	0.00225	2.62
159	21	SH-BCNA	55.2450	60.7695	154.6860	160.2105	6.3100	0.00226	2.62
159	22	SH-BCNA	60.7695	66.2940	154.6860	160.2105	6.3100	0.00436	3.00
159	23	SH-BCNA	66.2940	71.8185	154.6860	160.2105	6.3100	0.00953	2.23
159	24	SH-BCNA	71.8185	77.3430	154.6860	160.2105	6.3100	0.0210	2.02
159	25	SH-BCNA	77.3430	82.8675	154.6860	160.2105	6.3100	0.0496	2.01
159	26	RR-SSNA	82.8675	88.3920	154.6860	160.2105	6.3100	0.196	2.00
159	27	RR-SSNA	88.3920	93.9165	154.6860	160.2105	6.3100	0.344	2.01
159	28	RR-SSNA	93.9165	99.4410	154.6860	160.2105	6.3100	0.398	2.01
159	29	RB	99.4410	104.9655	154.6860	160.2105	6.3100	0.379	2.02
159	30	RB	104.9655	110.4900	154.6860	160.2105	6.3100	0.459	2.00
159	31	RB	110.4900	116.0145	154.6860	160.2105	6.3100	0.594	2.00
159	32	OC	116.0145	121.5390	154.6860	160.2105	6.3100	0.758	1.80
159	33	OC	121.5390	127.0635	154.6860	160.2105	6.3100	0.926	1.81
159	34	OC	127.0635	132.5880	154.6860	160.2105	6.3100	1.061	1.82
159	35	OC	132.5880	138.1125	154.6860	160.2105	6.3100	1.187	1.80
159	36	OC	138.1125	143.6370	154.6860	160.2105	6.3100	1.279	1.80
159	37	IC	143.6370	149.1615	154.6860	160.2105	6.3100	1.370	1.80
159	38	IC	149.1615	154.6860	154.6860	160.2105	6.3100	1.433	1.80
159	40	IC	160.2105	165.7350	154.6860	160.2105	6.3100	1.532	1.80
159	42	IC	171.2595	176.7840	154.6860	160.2105	6.3100	1.584	1.80

159	44	IC	182.3085	187.8330	154.6860	160.2105	6.3100	1.601	1.81
159	46	IC	193.3575	198.8820	154.6860	160.2105	6.3100	1.633	1.80
159	48	IC	204.4065	209.9310	154.6860	160.2105	6.3100	1.635	1.80
159	49	IC	209.9310	215.4555	154.6860	160.2105	6.3100	1.639	1.80
159	51	IC	220.9800	226.5045	154.6860	160.2105	6.3100	1.629	1.81
159	53	IC	232.0290	237.5535	154.6860	160.2105	6.3100	1.614	1.80
159	55	IC	243.0780	248.6025	154.6860	160.2105	6.3100	1.593	1.80
159	57	IC	254.1270	259.6515	154.6860	160.2105	6.3100	1.535	1.80
159	59	IC	265.1760	270.7005	154.6860	160.2105	6.3100	1.446	1.80
159	60	IC	270.7005	276.2250	154.6860	160.2105	6.3100	1.375	1.80
159	61	OC	276.2250	281.7495	154.6860	160.2105	6.3100	1.293	1.80
159	62	OC	281.7495	287.2740	154.6860	160.2105	6.3100	1.191	1.80
159	63	OC	287.2740	292.7985	154.6860	160.2105	6.3100	1.062	1.80
159	64	OC	292.7985	298.3230	154.6860	160.2105	6.3100	0.928	1.81
159	65	OC	298.3230	303.8475	154.6860	160.2105	6.3100	0.771	1.80
159	66	RB	303.8475	309.3720	154.6860	160.2105	6.3100	0.610	2.01
159	67	RB	309.3720	314.8965	154.6860	160.2105	6.3100	0.483	2.01
159	68	RB	314.8965	320.4210	154.6860	160.2105	6.3100	0.413	2.02

Table 5.26 ZPPR-15B L134 – $^{238}\text{U}(\text{n},\text{f})$ Cell-Averaged Reaction Rate

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	Z	$^{238}\text{U}(\text{n},\text{f})$	σ_{total} , %
159	19	SP	44.1960	49.7205	154.6860	160.2105	7.7000	0.00000225	6.93
159	21	SH-BCNA	55.2450	60.7695	154.6860	160.2105	7.7000	0.00000551	6.15
159	22	SH-BCNA	60.7695	66.2940	154.6860	160.2105	7.7000	0.00001078	5.86
159	23	SH-BCNA	66.2940	71.8185	154.6860	160.2105	7.7000	0.00002137	5.85
159	24	SH-BCNA	71.8185	77.3430	154.6860	160.2105	7.7000	0.00004159	5.84
159	25	SH-BCNA	77.3430	82.8675	154.6860	160.2105	7.7000	0.0000838	5.83
159	26	RR-SSNA	82.8675	88.3920	154.6860	160.2105	7.7000	0.0001935	5.86
159	27	RR-SSNA	88.3920	93.9165	154.6860	160.2105	7.7000	0.0003899	5.54
159	29	RB	99.4410	104.9655	154.6860	160.2105	7.7000	0.001887	4.49
159	30	RB	104.9655	110.4900	154.6860	160.2105	7.7000	0.003951	4.04
159	31	RB	110.4900	116.0145	154.6860	160.2105	7.7000	0.009349	3.43
159	32	OC	116.0145	121.5390	154.6860	160.2105	7.7000	0.02116	2.88
159	33	OC	121.5390	127.0635	154.6860	160.2105	7.7000	0.02526	2.87
159	34	OC	127.0635	132.5880	154.6860	160.2105	7.7000	0.03250	2.87
159	35	OC	132.5880	138.1125	154.6860	160.2105	7.7000	0.03311	2.86
159	36	OC	138.1125	143.6370	154.6860	160.2105	7.7000	0.03876	2.86
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	0.03345	2.86
159	63	OC	287.2740	292.7985	154.6860	160.2105	7.7000	0.03228	2.87
159	64	OC	292.7985	298.3230	154.6860	160.2105	7.7000	0.02520	2.87
159	65	OC	298.3230	303.8475	154.6860	160.2105	7.7000	0.02115	2.87
159	66	RB	303.8475	309.3720	154.6860	160.2105	7.7000	0.009345	3.40
159	67	RB	309.3720	314.8965	154.6860	160.2105	7.7000	0.004090	3.62
159	68	RB	314.8965	320.4210	154.6860	160.2105	7.7000	0.001922	4.27
159	70	RR	325.9455	331.4700	154.6860	160.2105	7.7000	0.0004047	5.60
159	72	RR	336.9945	342.5190	154.6860	160.2105	7.7000	0.0000886	5.87
159	74	RR	348.0435	353.5680	154.6860	160.2105	7.7000	0.00002301	5.83
159	76	RR	359.0925	364.6170	154.6860	160.2105	7.7000	0.00000639	7.49

Table 5.27 ZPPR-15B L134 – $^{238}\text{U}(\text{n},\gamma)$ Cell-Averaged Reaction Rate

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	Z	$^{238}\text{U}(\text{n},\gamma)$	$\sigma_{\text{total}}, \%$
159	29	RB	99.4410	104.9655	154.6860	160.2105	7.7000	0.04604	2.00
159	30	RB	104.9655	110.4900	154.6860	160.2105	7.7000	0.05795	2.01
159	31	RB	110.4900	116.0145	154.6860	160.2105	7.7000	0.07449	1.99
159	32	OC	116.0145	121.5390	154.6860	160.2105	7.7000	0.09532	2.17
159	33	OC	121.5390	127.0635	154.6860	160.2105	7.7000	0.1139	2.18
159	34	OC	127.0635	132.5880	154.6860	160.2105	7.7000	0.1302	2.17
159	35	OC	132.5880	138.1125	154.6860	160.2105	7.7000	0.1470	2.17
159	36	OC	138.1125	143.6370	154.6860	160.2105	7.7000	0.1586	2.17
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	0.2117	2.17
159	63	OC	287.2740	292.7985	154.6860	160.2105	7.7000	0.1315	2.17
159	64	OC	292.7985	298.3230	154.6860	160.2105	7.7000	0.1154	2.17
159	65	OC	298.3230	303.8475	154.6860	160.2105	7.7000	0.09642	2.17
159	66	RB	303.8475	309.3720	154.6860	160.2105	7.7000	0.07685	1.99
159	67	RB	309.3720	314.8965	154.6860	160.2105	7.7000	0.05992	1.99
159	68	RB	314.8965	320.4210	154.6860	160.2105	7.7000	0.04951	1.99

Table 5.28 ZPPR-15D L203 – $^{239}\text{Pu}(\text{n},\text{f})$ Cell-Averaged Reaction Rate

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	Z	$^{239}\text{Pu}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
159	49	IC	209.9310	215.4555	154.6860	160.2105	9.0800	1.501	2.14
159	50	IC	215.4555	220.9800	154.6860	160.2105	9.0800	1.459	2.17
159	51	IC	220.9800	226.5045	154.6860	160.2105	9.0800	1.482	2.15
159	52	IC	226.5045	232.0290	154.6860	160.2105	9.0800	1.495	2.14
159	53	IC	232.0290	237.5535	154.6860	160.2105	9.0800	1.498	2.14
159	54	IC	237.5535	243.0780	154.6860	160.2105	9.0800	1.503	2.16
159	55	IC	243.0780	248.6025	154.6860	160.2105	9.0800	1.468	2.15
159	56	IC SD	248.6025	254.1270	154.6860	160.2105	9.0800	1.517	2.16
159	57	IC SD	254.1270	259.6515	154.6860	160.2105	9.0800	1.501	2.14
159	58	IC	259.6515	265.1760	154.6860	160.2105	9.0800	1.419	2.18
159	59	IC	265.1760	270.7005	154.6860	160.2105	9.0800	1.390	2.16
159	60	IC	270.7005	276.2250	154.6860	160.2105	9.0800	1.337	2.15
159	61	OC D	276.2250	281.7495	154.6860	160.2105	9.0800	1.250	2.16
159	62	OC SD	281.7495	287.2740	154.6860	160.2105	9.0800	1.167	2.18
159	63	OC D	287.2740	292.7985	154.6860	160.2105	9.0800	1.046	2.18
159	64	OC SD	292.7985	298.3230	154.6860	160.2105	9.0800	0.913	2.18
159	65	OC D	298.3230	303.8475	154.6860	160.2105	9.0800	0.745	2.30
159	66	RB	303.8475	309.3720	154.6860	160.2105	9.0800	0.574	2.21
159	67	RB	309.3720	314.8965	154.6860	160.2105	9.0800	0.440	2.25
159	68	RB	314.8965	320.4210	154.6860	160.2105	9.0800	0.384	2.34

152	49	IC	209.9310	215.4555	193.3575	198.8820	9.0800	1.482	2.15
153	49	IC	209.9310	215.4555	187.8330	193.3575	9.0800	1.489	2.15
154	49	IC	209.9310	215.4555	182.3085	187.8330	9.0800	1.482	2.15
155	49	IC	209.9310	215.4555	176.7840	182.3085	9.0800	1.475	2.15
156	49	IC	209.9310	215.4555	171.2595	176.7840	9.0800	1.500	2.14
157	49	IC	209.9310	215.4555	165.7350	171.2595	9.0800	1.455	2.20
158	49	IC	209.9310	215.4555	160.2105	165.7350	9.0800	1.480	2.17
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	1.501	2.14
159	49	IC	209.9310	215.4555	154.6860	160.2105	12.7800	1.451	2.15
159	49	IC	209.9310	215.4555	154.6860	160.2105	17.8600	1.371	2.14
159	49	IC	209.9310	215.4555	154.6860	160.2105	25.4800	1.246	2.16
159	49	IC	209.9310	215.4555	154.6860	160.2105	33.1000	1.090	2.20
159	49	IC	209.9310	215.4555	154.6860	160.2105	38.1800	0.954	2.20
159	49	IC	209.9310	215.4555	154.6860	160.2105	43.2600	0.826	2.21
159	60	IC	270.7005	276.2250	154.6860	160.2105	7.7000	1.337	2.15
159	60	IC	270.7005	276.2250	154.6860	160.2105	12.7800	1.277	2.13
159	60	IC	270.7005	276.2250	154.6860	160.2105	17.8600	1.234	2.19
159	60	IC	270.7005	276.2250	154.6860	160.2105	25.4800	1.113	2.16
159	60	IC	270.7005	276.2250	154.6860	160.2105	33.1000	0.952	2.20
159	60	IC	270.7005	276.2250	154.6860	160.2105	38.1800	0.841	2.20
159	60	IC	270.7005	276.2250	154.6860	160.2105	43.2600	0.700	2.21
159	64	IC	292.7985	298.3230	154.6860	160.2105	7.7000	0.913	2.18
159	64	IC	292.7985	298.3230	154.6860	160.2105	12.7800	0.879	2.19
159	64	IC	292.7985	298.3230	154.6860	160.2105	17.8600	0.845	2.25
159	64	IC	292.7985	298.3230	154.6860	160.2105	25.4800	0.745	2.24
159	64	IC	292.7985	298.3230	154.6860	160.2105	33.1000	0.648	2.24
159	64	IC	292.7985	298.3230	154.6860	160.2105	38.1800	0.565	2.30
159	64	IC	292.7985	298.3230	154.6860	160.2105	43.2600	0.477	2.29

Table 5.29 ZPPR-15D L203 – $^{235}\text{U}(\text{n},\text{f})$ Cell-Averaged Reaction Rate

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	Z	$^{235}\text{U}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
159	29	RB	99.4410	104.9655	154.6860	160.2105	6.3100	-----	-----
159	30	RB	104.9655	110.4900	154.6860	160.2105	6.3100	0.450	1.93
159	31	RB	110.4900	116.0145	154.6860	160.2105	6.3100	0.558	1.95
159	32	OC D	116.0145	121.5390	154.6860	160.2105	6.3100	0.695	1.85
159	33	OC SD	121.5390	127.0635	154.6860	160.2105	6.3100	0.811	1.81
159	34	OC D	127.0635	132.5880	154.6860	160.2105	6.3100	0.958	1.78
159	35	OC SD	132.5880	138.1125	154.6860	160.2105	6.3100	1.054	1.77
159	36	OC D	138.1125	143.6370	154.6860	160.2105	6.3100	1.156	1.81
159	37	IC	143.6370	149.1615	154.6860	160.2105	6.3100	1.221	1.77

159	38	IC	149.1615	154.6860	154.6860	160.2105	6.3100	1.293	1.79
159	39	IC	154.6860	160.2105	154.6860	160.2105	6.3100	1.354	1.78
159	40	IC SD	160.2105	165.7350	154.6860	160.2105	6.3100	1.397	1.78
159	41	IC SD	165.7350	171.2595	154.6860	160.2105	6.3100	1.421	1.77
159	42	IC	171.2595	176.7840	154.6860	160.2105	6.3100	1.435	1.77
159	43	IC	176.7840	182.3085	154.6860	160.2105	6.3100	1.442	1.77
159	44	IC	182.3085	187.8330	154.6860	160.2105	6.3100	1.447	1.77
159	45	IC	187.8330	193.3575	154.6860	160.2105	6.3100	1.446	1.77
159	46	IC	193.3575	198.8820	154.6860	160.2105	6.3100	1.448	1.77
159	47	IC	198.8820	204.4065	154.6860	160.2105	6.3100	1.453	1.77
159	48	IC	204.4065	209.9310	154.6860	160.2105	6.3100	1.431	1.77
159	49	IC	209.9310	215.4555	154.6860	160.2105	6.3100	1.433	1.75
159	50	IC	215.4555	220.9800	154.6860	160.2105	6.3100	1.445	1.75
159	51	IC	220.9800	226.5045	154.6860	160.2105	6.3100	1.435	1.75
159	52	IC	226.5045	232.0290	154.6860	160.2105	6.3100	1.438	1.77
159	53	IC	232.0290	237.5535	154.6860	160.2105	6.3100	1.456	1.77
159	54	IC	237.5535	243.0780	154.6860	160.2105	6.3100	1.441	1.79
159	55	IC	243.0780	248.6025	154.6860	160.2105	6.3100	1.429	1.75
159	56	IC SD	248.6025	254.1270	154.6860	160.2105	6.3100	1.424	1.75
159	57	IC SD	254.1270	259.6515	154.6860	160.2105	6.3100	1.400	1.76
159	58	IC	259.6515	265.1760	154.6860	160.2105	6.3100	1.354	1.76
159	59	IC	265.1760	270.7005	154.6860	160.2105	6.3100	1.292	1.77
159	60	IC	270.7005	276.2250	154.6860	160.2105	6.3100	1.217	1.75
159	61	OC D	276.2250	281.7495	154.6860	160.2105	6.3100	1.155	1.76
159	62	OC SD	281.7495	287.2740	154.6860	160.2105	6.3100	1.047	1.77
159	63	OC D	287.2740	292.7985	154.6860	160.2105	6.3100	0.955	1.78
159	64	OC SD	292.7985	298.3230	154.6860	160.2105	6.3100	0.816	1.77
159	65	OC D	298.3230	303.8475	154.6860	160.2105	6.3100	0.694	1.80
159	66	RB	303.8475	309.3720	154.6860	160.2105	6.3100	0.559	1.89
159	67	RB	309.3720	314.8965	154.6860	160.2105	6.3100	0.449	1.93
159	68	RB	314.8965	320.4210	154.6860	160.2105	6.3100	0.393	1.97
139	49	RB	209.9310	215.4555	265.1760	270.7005	6.3100	0.400	1.96
140	49	RB	209.9310	215.4555	259.6515	265.1760	6.3100	0.452	1.93
141	49	RB	209.9310	215.4555	254.1270	259.6515	6.3100	0.554	1.95
142	49	OC D	209.9310	215.4555	248.6025	254.1270	6.3100	0.689	1.80
143	49	OC SD	209.9310	215.4555	243.0780	248.6025	6.3100	0.816	1.77
144	49	OC D	209.9310	215.4555	237.5535	243.0780	6.3100	0.935	1.78
145	49	OC SD	209.9310	215.4555	232.0290	237.5535	6.3100	1.047	1.77
146	49	OC D	209.9310	215.4555	226.5045	232.0290	6.3100	1.148	1.78
147	49	IC	209.9310	215.4555	220.9800	226.5045	6.3100	1.233	1.80
148	49	IC	209.9310	215.4555	215.4555	220.9800	6.3100	1.293	1.79

149	49	IC	209.9310	215.4555	209.9310	215.4555	6.3100	1.347	1.78
150	49	IC SD	209.9310	215.4555	204.4065	209.9310	6.3100	1.390	1.78
151	49	IC SD	209.9310	215.4555	198.8820	204.4065	6.3100	1.406	1.77
152	49	IC	209.9310	215.4555	193.3575	198.8820	6.3100	1.428	1.77
153	49	IC	209.9310	215.4555	187.8330	193.3575	6.3100	1.437	1.77
154	49	IC	209.9310	215.4555	182.3085	187.8330	6.3100	1.425	1.77
155	49	IC	209.9310	215.4555	176.7840	182.3085	6.3100	1.445	1.77
156	49	IC	209.9310	215.4555	171.2595	176.7840	6.3100	1.439	1.77
157	49	IC	209.9310	215.4555	165.7350	171.2595	6.3100	1.449	1.77
158	49	IC	209.9310	215.4555	160.2105	165.7350	6.3100	1.433	1.77
159	49	IC	209.9310	215.4555	154.6860	160.2105	6.3100	1.433	1.75
160	49	IC	209.9310	215.4555	149.1615	154.6860	6.3100	1.442	1.77
161	49	IC	209.9310	215.4555	143.6370	149.1615	6.3100	1.443	1.79
162	49	IC	209.9310	215.4555	138.1125	143.6370	6.3100	1.389	1.76
163	49	IC	209.9310	215.4555	132.5880	138.1125	6.3100	1.444	1.79
164	49	IC	209.9310	215.4555	127.0635	132.5880	6.3100	1.435	1.79
165	49	IC	209.9310	215.4555	121.5390	127.0635	6.3100	1.426	1.77
166	49	IC SD	209.9310	215.4555	116.0145	121.5390	6.3100	1.401	1.77
167	49	IC SD	209.9310	215.4555	110.4900	116.0145	6.3100	1.372	1.80
168	49	IC	209.9310	215.4555	104.9655	110.4900	6.3100	1.354	1.78
169	49	IC	209.9310	215.4555	99.4410	104.9655	6.3100	1.288	1.77
170	49	IC	209.9310	215.4555	93.9165	99.4410	6.3100	1.215	1.77
171	49	OC D	209.9310	215.4555	88.3920	93.9165	6.3100	1.143	1.78
172	49	OC SD	209.9310	215.4555	82.8675	88.3920	6.3100	1.045	1.77
173	49	OC D	209.9310	215.4555	77.3430	82.8675	6.3100	0.930	1.79
174	49	OC SD	209.9310	215.4555	71.8185	77.3430	6.3100	0.813	1.81
175	49	OC D	209.9310	215.4555	66.2940	71.8185	6.3100	0.685	1.80
176	49	RB	209.9310	215.4555	60.7695	66.2940	6.3100	0.553	1.89
177	49	RB	209.9310	215.4555	55.2450	60.7695	6.3100	0.452	1.93
178	49	RB	209.9310	215.4555	49.7205	55.2450	6.3100	0.401	1.96
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	1.433	1.75
159	49	IC	209.9310	215.4555	154.6860	160.2105	12.7800	1.388	1.76
159	49	IC	209.9310	215.4555	154.6860	160.2105	17.8600	1.339	1.76
159	49	IC	209.9310	215.4555	154.6860	160.2105	25.4800	1.197	1.78
159	49	IC	209.9310	215.4555	154.6860	160.2105	33.1000	1.056	1.77
159	49	IC	209.9310	215.4555	154.6860	160.2105	38.1800	0.928	1.79
159	49	IC	209.9310	215.4555	154.6860	160.2105	43.2600	0.809	1.77
159	49	AB	209.9310	215.4555	154.6860	160.2105	48.3400	0.699	1.99
159	49	AB	209.9310	215.4555	154.6860	160.2105	53.4200	0.582	1.98
159	49	AB	209.9310	215.4555	154.6860	160.2105	63.5800	0.387	2.06
159	49	AB	209.9310	215.4555	154.6860	160.2105	73.7400	0.283	2.04

159	60	IC	270.7005	276.2250	154.6860	160.2105	7.7000	1.217	1.75
159	60	IC	270.7005	276.2250	154.6860	160.2105	12.7800	1.174	1.78
159	60	IC	270.7005	276.2250	154.6860	160.2105	17.8600	1.122	1.76
159	60	IC	270.7005	276.2250	154.6860	160.2105	25.4800	1.021	1.77
159	60	IC	270.7005	276.2250	154.6860	160.2105	33.1000	0.881	1.76
159	60	IC	270.7005	276.2250	154.6860	160.2105	38.1800	0.784	1.78
159	60	IC	270.7005	276.2250	154.6860	160.2105	43.2600	0.665	1.81
159	60	AB	270.7005	276.2250	154.6860	160.2105	48.3400	0.573	1.98
159	60	AB	270.7005	276.2250	154.6860	160.2105	53.4200	0.477	2.01
159	60	AB	270.7005	276.2250	154.6860	160.2105	63.5800	0.314	2.01
159	60	AB	270.7005	276.2250	154.6860	160.2105	73.7400	0.221	2.11
159	64	IC	292.7985	298.3230	154.6860	160.2105	7.7000	0.816	1.77
159	64	IC	292.7985	298.3230	154.6860	160.2105	12.7800	0.782	1.78
159	64	IC	292.7985	298.3230	154.6860	160.2105	17.8600	0.752	1.78
159	64	IC	292.7985	298.3230	154.6860	160.2105	25.4800	0.673	1.76
159	64	IC	292.7985	298.3230	154.6860	160.2105	33.1000	0.581	1.78
159	64	IC	292.7985	298.3230	154.6860	160.2105	38.1800	0.515	1.80
159	64	IC	292.7985	298.3230	154.6860	160.2105	43.2600	0.440	1.83
159	64	AB	292.7985	298.3230	154.6860	160.2105	48.3400	0.372	1.99
159	64	AB	292.7985	298.3230	154.6860	160.2105	53.4200	0.308	2.14
159	64	AB	292.7985	298.3230	154.6860	160.2105	63.5800	0.203	2.15
159	64	AB	292.7985	298.3230	154.6860	160.2105	73.7400	0.147	2.03

Table 5.30 ZPPR-15D L203 – $^{238}\text{U}(\text{n},\text{f})$ Cell-Averaged Reaction Rate

Row	Column	Region	$X_{\min}$	$X_{\max}$	$Y_{\min}$	$Y_{\max}$	Z	$^{238}\text{U}(\text{n},\text{f})$	$\sigma_{\text{total}}, \%$
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	0.02775	3.01
159	50	IC	215.4555	220.9800	154.6860	160.2105	7.7000	0.02805	3.01
159	51	IC	220.9800	226.5045	154.6860	160.2105	7.7000	0.02782	3.13
159	52	IC	226.5045	232.0290	154.6860	160.2105	7.7000	0.02843	3.00
159	53	IC	232.0290	237.5535	154.6860	160.2105	7.7000	0.02863	3.00
159	54	IC	237.5535	243.0780	154.6860	160.2105	7.7000	0.02915	3.10
159	55	IC	243.0780	248.6025	154.6860	160.2105	7.7000	0.03033	3.08
159	56	IC SD	248.6025	254.1270	154.6860	160.2105	7.7000	0.03602	2.98
159	57	IC SD	254.1270	259.6515	154.6860	160.2105	7.7000	0.03555	2.98
159	58	IC	259.6515	265.1760	154.6860	160.2105	7.7000	0.03417	3.07
159	59	IC	265.1760	270.7005	154.6860	160.2105	7.7000	0.03261	2.99
159	60	IC	270.7005	276.2250	154.6860	160.2105	7.7000	0.03226	2.99
159	61	OC D	276.2250	281.7495	154.6860	160.2105	7.7000	0.03275	2.99
159	62	OC SD	281.7495	287.2740	154.6860	160.2105	7.7000	0.03223	3.04
159	63	OC D	287.2740	292.7985	154.6860	160.2105	7.7000	0.02937	3.03
159	64	OC SD	292.7985	298.3230	154.6860	160.2105	7.7000	0.02462	3.06
159	65	OC D	298.3230	303.8475	154.6860	160.2105	7.7000	0.01952	3.10
159	66	RB	303.8475	309.3720	154.6860	160.2105	7.7000	0.00899	4.02
159	67	RB	309.3720	314.8965	154.6860	160.2105	7.7000	0.00417	5.97
159	68	RB	314.8965	320.4210	154.6860	160.2105	7.7000	0.00225	9.66
139	49	RB	209.9310	215.4555	265.1760	270.7005	7.7000	0.00207	5.97
140	49	RB	209.9310	215.4555	259.6515	265.1760	7.7000	0.00395	6.19
141	49	RB	209.9310	215.4555	254.1270	259.6515	7.7000	0.00852	4.06
142	49	OC D	209.9310	215.4555	248.6025	254.1270	7.7000	0.01810	3.38
143	49	OC SD	209.9310	215.4555	243.0780	248.6025	7.7000	0.02418	3.06
144	49	OC D	209.9310	215.4555	237.5535	243.0780	7.7000	0.02916	3.03
145	49	OC SD	209.9310	215.4555	232.0290	237.5535	7.7000	0.03182	2.95
146	49	OC D	209.9310	215.4555	226.5045	232.0290	7.7000	0.03416	3.06
147	49	IC	209.9310	215.4555	220.9800	226.5045	7.7000	0.03185	3.11
148	49	IC	209.9310	215.4555	215.4555	220.9800	7.7000	0.03226	2.99
149	49	IC	209.9310	215.4555	209.9310	215.4555	7.7000	0.03308	2.98
150	49	IC SD	209.9310	215.4555	204.4065	209.9310	7.7000	0.03543	2.98
151	49	IC SD	209.9310	215.4555	198.8820	204.4065	7.7000	0.03559	2.98
152	49	IC	209.9310	215.4555	193.3575	198.8820	7.7000	0.03018	2.98
153	49	IC	209.9310	215.4555	187.8330	193.3575	7.7000	0.02859	3.00
154	49	IC	209.9310	215.4555	182.3085	187.8330	7.7000	0.02825	3.00
155	49	IC	209.9310	215.4555	176.7840	182.3085	7.7000	0.02852	3.00
156	49	IC	209.9310	215.4555	171.2595	176.7840	7.7000	0.02808	3.01

157	49	IC	209.9310	215.4555	165.7350	171.2595	7.7000	0.02811	3.01
158	49	IC	209.9310	215.4555	160.2105	165.7350	7.7000	0.02803	3.01
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	0.02775	3.01
159	49	IC	209.9310	215.4555	154.6860	160.2105	12.7800	0.02692	3.02
159	49	IC	209.9310	215.4555	154.6860	160.2105	17.8600	0.02594	3.04
159	49	IC	209.9310	215.4555	154.6860	160.2105	25.4800	0.02318	3.10
159	49	IC	209.9310	215.4555	154.6860	160.2105	33.1000	0.02001	3.03
159	49	IC	209.9310	215.4555	154.6860	160.2105	38.1800	0.01756	3.10
159	49	IC	209.9310	215.4555	154.6860	160.2105	43.2600	0.01291	3.29
159	49	AB	209.9310	215.4555	154.6860	160.2105	48.3400	0.00684	6.10
159	49	AB	209.9310	215.4555	154.6860	160.2105	53.4200	0.00363	7.59
159	49	AB	209.9310	215.4555	154.6860	160.2105	63.5800	0.00129	9.44
159	49	AB	209.9310	215.4555	154.6860	160.2105	73.7400	0.00066	17.54
159	60	IC	270.7005	276.2250	154.6860	160.2105	7.7000	0.03226	2.99
159	60	IC	270.7005	276.2250	154.6860	160.2105	12.7800	0.03130	3.01
159	60	IC	270.7005	276.2250	154.6860	160.2105	17.8600	0.02950	3.03
159	60	IC	270.7005	276.2250	154.6860	160.2105	25.4800	0.02712	3.07
159	60	IC	270.7005	276.2250	154.6860	160.2105	33.1000	0.02257	3.02
159	60	IC	270.7005	276.2250	154.6860	160.2105	38.1800	0.01887	3.12
159	60	IC	270.7005	276.2250	154.6860	160.2105	43.2600	0.01462	3.28
159	60	AB	270.7005	276.2250	154.6860	160.2105	48.3400	0.00741	6.01
159	60	AB	270.7005	276.2250	154.6860	160.2105	53.4200	0.00384	7.41
159	60	AB	270.7005	276.2250	154.6860	160.2105	63.5800	0.00121	17.54
159	60	AB	270.7005	276.2250	154.6860	160.2105	73.7400	0.00081	13.64
159	64	IC	292.7985	298.3230	154.6860	160.2105	7.7000	0.02462	3.06
159	64	IC	292.7985	298.3230	154.6860	160.2105	12.7800	0.02395	3.08
159	64	IC	292.7985	298.3230	154.6860	160.2105	17.8600	0.02235	3.12
159	64	IC	292.7985	298.3230	154.6860	160.2105	25.4800	0.02030	3.02
159	64	IC	292.7985	298.3230	154.6860	160.2105	33.1000	0.01707	3.10
159	64	IC	292.7985	298.3230	154.6860	160.2105	38.1800	0.01475	3.21
159	64	IC	292.7985	298.3230	154.6860	160.2105	43.2600	0.01089	3.09
159	64	AB	292.7985	298.3230	154.6860	160.2105	48.3400	0.00527	6.50
159	64	AB	292.7985	298.3230	154.6860	160.2105	53.4200	0.00271	6.46
159	64	AB	292.7985	298.3230	154.6860	160.2105	63.5800	0.00097	11.40
159	64	AB	292.7985	298.3230	154.6860	160.2105	73.7400	0.00082	25.59

Table 5.31 ZPPR-15D L203 – $^{238}\text{U}(\text{n},\gamma)$ Cell-Averaged Reaction Rate

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	Z	$^{238}\text{U}(\text{n},\gamma)$	$\sigma_{\text{total}}, \%$
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	0.1818	2.07
159	50	IC	215.4555	220.9800	154.6860	160.2105	7.7000	0.1825	2.06
159	51	IC	220.9800	226.5045	154.6860	160.2105	7.7000	0.1827	2.06
159	52	IC	226.5045	232.0290	154.6860	160.2105	7.7000	0.1826	2.06
159	53	IC	232.0290	237.5535	154.6860	160.2105	7.7000	0.1815	2.07
159	54	IC	237.5535	243.0780	154.6860	160.2105	7.7000	0.1816	2.08
159	55	IC	243.0780	248.6025	154.6860	160.2105	7.7000	0.1769	2.07
159	56	IC SD	248.6025	254.1270	154.6860	160.2105	7.7000	0.1763	2.06
159	57	IC SD	254.1270	259.6515	154.6860	160.2105	7.7000	0.1711	2.08
159	58	IC	259.6515	265.1760	154.6860	160.2105	7.7000	0.1692	2.07
159	59	IC	265.1760	270.7005	154.6860	160.2105	7.7000	0.1617	2.06
159	60	IC	270.7005	276.2250	154.6860	160.2105	7.7000	0.1505	2.07
159	61	OC D	276.2250	281.7495	154.6860	160.2105	7.7000	0.1410	2.08
159	62	OC SD	281.7495	287.2740	154.6860	160.2105	7.7000	0.1278	2.07
159	63	OC D	287.2740	292.7985	154.6860	160.2105	7.7000	0.1143	2.09
159	64	OC SD	292.7985	298.3230	154.6860	160.2105	7.7000	0.0985	2.09
159	65	OC D	298.3230	303.8475	154.6860	160.2105	7.7000	0.0860	2.08
159	66	RB	303.8475	309.3720	154.6860	160.2105	7.7000	0.0691	2.04
159	67	RB	309.3720	314.8965	154.6860	160.2105	7.7000	0.0561	2.08
159	68	RB	314.8965	320.4210	154.6860	160.2105	7.7000	0.0464	2.06
139	49	RB	209.9310	215.4555	265.1760	270.7005	7.7000	0.0469	2.06
140	49	RB	209.9310	215.4555	259.6515	265.1760	7.7000	0.0562	2.08
141	49	RB	209.9310	215.4555	254.1270	259.6515	7.7000	0.0693	2.04
142	49	OC D	209.9310	215.4555	248.6025	254.1270	7.7000	0.0848	2.08
143	49	OC SD	209.9310	215.4555	243.0780	248.6025	7.7000	0.0991	2.09
144	49	OC D	209.9310	215.4555	237.5535	243.0780	7.7000	0.1137	2.07
145	49	OC SD	209.9310	215.4555	232.0290	237.5535	7.7000	0.1272	2.07
146	49	OC D	209.9310	215.4555	226.5045	232.0290	7.7000	0.1384	2.08
147	49	IC	209.9310	215.4555	220.9800	226.5045	7.7000	0.1504	2.07
148	49	IC	209.9310	215.4555	215.4555	220.9800	7.7000	0.1600	2.06
149	49	IC	209.9310	215.4555	209.9310	215.4555	7.7000	0.1668	2.07
150	49	IC SD	209.9310	215.4555	204.4065	209.9310	7.7000	0.1695	2.07
151	49	IC SD	209.9310	215.4555	198.8820	204.4065	7.7000	0.1744	2.08
152	49	IC	209.9310	215.4555	193.3575	198.8820	7.7000	0.1755	2.07
153	49	IC	209.9310	215.4555	187.8330	193.3575	7.7000	0.1791	2.07
154	49	IC	209.9310	215.4555	182.3085	187.8330	7.7000	0.1805	2.07
155	49	IC	209.9310	215.4555	176.7840	182.3085	7.7000	0.1812	2.07
156	49	IC	209.9310	215.4555	171.2595	176.7840	7.7000	0.1819	2.08
157	49	IC	209.9310	215.4555	165.7350	171.2595	7.7000	0.1818	2.07

158	49	IC	209.9310	215.4555	160.2105	165.7350	7.7000	0.1834	2.06
159	49	IC	209.9310	215.4555	154.6860	160.2105	7.7000	0.1818	2.07
159	49	IC	209.9310	215.4555	154.6860	160.2105	12.7800	0.1775	2.07
159	49	IC	209.9310	215.4555	154.6860	160.2105	17.8600	0.1689	2.07
159	49	IC	209.9310	215.4555	154.6860	160.2105	25.4800	0.1534	2.06
159	49	IC	209.9310	215.4555	154.6860	160.2105	33.1000	0.1346	2.07
159	49	IC	209.9310	215.4555	154.6860	160.2105	38.1800	0.1214	2.07
159	49	IC	209.9310	215.4555	154.6860	160.2105	43.2600	0.1049	2.07
159	49	AB	209.9310	215.4555	154.6860	160.2105	48.3400	0.0879	2.04
159	49	AB	209.9310	215.4555	154.6860	160.2105	53.4200	0.0734	2.06
159	49	AB	209.9310	215.4555	154.6860	160.2105	63.5800	0.0503	2.09
159	49	AB	209.9310	215.4555	154.6860	160.2105	73.7400	0.0336	2.10
159	60	IC	270.7005	276.2250	154.6860	160.2105	7.7000	0.1505	2.07
159	60	IC	270.7005	276.2250	154.6860	160.2105	12.7800	0.1458	2.08
159	60	IC	270.7005	276.2250	154.6860	160.2105	17.8600	0.1391	2.06
159	60	IC	270.7005	276.2250	154.6860	160.2105	25.4800	0.1261	2.08
159	60	IC	270.7005	276.2250	154.6860	160.2105	33.1000	0.1103	2.07
159	60	IC	270.7005	276.2250	154.6860	160.2105	38.1800	0.0989	2.09
159	60	IC	270.7005	276.2250	154.6860	160.2105	43.2600	0.0839	2.09
159	60	AB	270.7005	276.2250	154.6860	160.2105	48.3400	0.0703	2.07
159	60	AB	270.7005	276.2250	154.6860	160.2105	53.4200	0.0585	2.06
159	60	AB	270.7005	276.2250	154.6860	160.2105	63.5800	0.0399	2.07
159	60	AB	270.7005	276.2250	154.6860	160.2105	73.7400	0.0263	2.06
159	64	IC	292.7985	298.3230	154.6860	160.2105	7.7000	0.0985	2.09
159	64	IC	292.7985	298.3230	154.6860	160.2105	12.7800	0.0958	2.07
159	64	IC	292.7985	298.3230	154.6860	160.2105	17.8600	0.0911	2.07
159	64	IC	292.7985	298.3230	154.6860	160.2105	25.4800	0.0823	2.09
159	64	IC	292.7985	298.3230	154.6860	160.2105	33.1000	0.0714	2.07
159	64	IC	292.7985	298.3230	154.6860	160.2105	38.1800	0.0641	2.09
159	64	IC	292.7985	298.3230	154.6860	160.2105	43.2600	0.0551	2.12
159	64	AB	292.7985	298.3230	154.6860	160.2105	48.3400	0.0452	2.06
159	64	AB	292.7985	298.3230	154.6860	160.2105	53.4200	0.0383	2.09
159	64	AB	292.7985	298.3230	154.6860	160.2105	63.5800	0.0254	2.09
159	64	AB	292.7985	298.3230	154.6860	160.2105	73.7400	0.0176	2.17

6 Spectral Index/Reaction Rate Ratios in ZPPR-15

In addition to the reaction rate distributions based on mapping foil data, the absolute reaction rate distributions and the cell-averaged reaction rate distributions, it was common practice at ZPPR to determine and report reaction rate ratios. A reaction rate ratio, also known as a spectral index, was determined by dividing one cell-averaged reaction rate by another cell-averaged reaction rate at the same location. The denominator was typically either the $^{239}\text{Pu}(n,f)$ reaction

rate or the $^{235}\text{U}(\text{n},\text{f})$ reaction rate. The reaction rates were commonly abbreviated as F9 for $^{239}\text{Pu}(\text{n},\text{f})$, F5 for $^{235}\text{U}(\text{n},\text{f})$, F8 for $^{238}\text{U}(\text{n},\text{f})$ and C8 for $^{238}\text{U}(\text{n},\gamma)$.

6.1 Spectral Index/Reaction Rate Ratio Uncertainties

The following is a summary of the uncertainty discussion for spectral indices in Refs. 4 and 5. Some uncertainty components are common to all absolute reaction rate calibrations, so these common components do not contribute to the total uncertainties for the spectral indices. The total uncertainty for a reaction rate ratio or spectral index combines a) the uncertainty for the mapping foil in the numerator, b) the uncertainty for the mapping foil in the denominator, c) the uncertainty for the cell factor for the numerator reaction, d) the uncertainty in the cell factor for the denominator reaction, e) the systematic uncertainties in determination of in-plate reaction rates and f) the uncertainty in the calibration factor for the reaction rate ratio.

Tables 6.1 – 6.4 give the uncertainties for the spectral indices determined in ZPPR-15B L134 and ZPPR-15D L203. Columns 1 and 2 in these tables give the row and column, respectively, in which the foils were located. Columns 3 and 4 give the uncertainties for the numerator and denominator mapping foils, respectively. These are the mapping foil uncertainties derived in Section 3.1 and shown in the tables in Section 3.2.

Columns 5 and 6 show the uncertainties in the cell factors for the numerator and denominator, respectively, from Section 5.1. For the core regions, the cell factor uncertainties are slightly conservative bounding values for the various types of core unit cells and cell factors.

Columns 7 and 8 show the systematic uncertainties in determining the in-plate reaction rates for the numerator and denominator, respectively, from Table 5.1. Column 9 is the uncertainty in the reaction rate ratio calibration. The uncertainty components in columns 3 through 9 are added in quadrature to produce the total uncertainties shown in column 10. All uncertainties in Tables 6.1 – 6.4 are relative uncertainties expressed in percent.

Ref. 4 provides a detailed description of procedures for determining absolute reaction rate calibrations and calibration factors.

The 1.5% uncertainty in the calibration factor for the F8/F5 ratio in column 9 of Table 6.1 combines 1) a 1% uncertainty for the fission count rate for ^{238}U , 2) a 0.4% uncertainty for the fission count rate for ^{235}U , 3) a 0.7% uncertainty in ^{238}U counts for the natural uranium deposit irradiated at ZPPR as part of the calibration, 4) a 0.3% uncertainty in the fission chamber counts from the natural uranium deposit irradiated in the Argonne Fast Source Reactor and 5) a 0.8% uncertainty in the mass fraction ratio for the natural uranium deposit.

Table 6.1 Uncertainties for the F8/F5 Ratio in ZPPR-15B L134^a

Row	Column	$\sigma_{\text{map, F8, \%}}$	$\sigma_{\text{map, F5, \%}}$	$\sigma_{\text{CF, F8, \%}}$	$\sigma_{\text{CF, F5, \%}}$	$\sigma_{\text{in-plate, F8, \%}}$	$\sigma_{\text{in-plate, F5, \%}}$	$\sigma_{\text{calib, F8/F5, \%}}$	$\sigma_{\text{total, \%}}$
159	19	6.15	2.07	2.43	1.00	0.50	0.50	1.50	7.20
159	21	5.26	1.92	2.43	1.00	0.50	0.50	1.50	6.40
159	22	4.92	2.41	2.43	1.00	0.50	0.50	1.50	6.30
159	23	4.91	1.33	2.43	1.00	0.50	0.50	1.50	5.96
159	24	4.89	0.94	2.43	1.00	0.50	0.50	1.50	5.87
159	25	4.89	0.90	2.43	1.00	0.50	0.50	1.50	5.86
159	26	4.92	0.88	2.43	1.00	0.50	0.50	1.50	5.88
159	27	4.54	0.92	2.43	1.00	0.50	0.50	1.50	5.57
159	29	3.16	0.92	2.43	1.00	0.50	0.50	1.50	4.53
159	30	2.48	0.90	2.43	1.00	0.50	0.50	1.50	4.07
159	31	1.28	0.89	2.43	1.00	0.50	0.50	1.50	3.48
159	32	1.03	0.89	1.00	0.50	1.50	0.50	1.50	2.80
159	33	1.00	0.90	1.00	0.50	1.50	0.50	1.50	2.79
159	34	1.00	0.92	1.00	0.50	1.50	0.50	1.50	2.80
159	35	0.97	0.89	1.00	0.50	1.50	0.50	1.50	2.78
159	36	0.96	0.89	1.00	0.50	1.50	0.50	1.50	2.78
159	49	0.95	0.88	1.00	0.50	1.50	0.50	1.50	2.77

a. F8/F5 is the $^{238}\text{U}(\text{n},\text{f})/^{235}\text{U}(\text{n},\text{f})$ reaction rate ratio.

The 0.9% uncertainty in the calibration factor for the F5/F9 ratio in column 9 of Table 6.2 consists of 1) a 0.42% uncertainty in the ^{239}Pu thermal cross section used in the calibration, 2) a 0.28% uncertainty in the ^{239}Pu g-factor used in the calibration, 3) a 0.31% uncertainty in the ^{235}U thermal cross section used in the calibration, 4) a 0.16% uncertainty in the ^{235}U g-factor used in the calibration, 5) a 0.4% uncertainty in the ^{235}U fission count rate and 6) a 0.5% uncertainty in the ^{239}Pu fission count rate.

Table 6.2 Uncertainties for the F5/F9 Ratio in ZPPR-15D L203^a

Row	Column	$\sigma_{\text{map, F5, \%}}$	$\sigma_{\text{map, F9, \%}}$	$\sigma_{\text{CF, F5, \%}}$	$\sigma_{\text{CF, F9, \%}}$	$\sigma_{\text{in-plate, F5, \%}}$	$\sigma_{\text{in-plate, F9, \%}}$	$\sigma_{\text{calib, F5/F9, \%}}$	$\sigma_{\text{total, \%}}$
159	49	0.91	1.05	0.50	1.00	0.50	0.50	0.90	2.12
159	50	0.91	1.10	0.50	1.00	0.50	0.50	0.90	2.14
159	51	0.91	1.05	0.50	1.00	0.50	0.50	0.90	2.12
159	52	0.94	1.05	0.50	1.00	0.50	0.50	0.90	2.13
159	53	0.94	1.05	0.50	1.00	0.50	0.50	0.90	2.13
159	54	0.98	1.09	0.50	1.00	0.50	0.50	0.90	2.17
159	55	0.91	1.06	0.50	1.00	0.50	0.50	0.90	2.12
159	56	0.91	1.08	0.50	1.00	0.50	0.50	0.90	2.14
159	57	0.91	1.05	0.50	1.00	0.50	0.50	0.90	2.12
159	58	0.92	1.12	0.50	1.00	0.50	0.50	0.90	2.16
159	59	0.93	1.08	0.50	1.00	0.50	0.50	0.90	2.14
159	60	0.90	1.05	0.50	1.00	0.50	0.50	0.90	2.12
159	61	0.92	1.08	0.50	1.00	0.50	0.50	0.90	2.14
159	62	0.94	1.12	0.50	1.00	0.50	0.50	0.90	2.16
159	63	0.96	1.11	0.50	1.00	0.50	0.50	0.90	2.17
159	64	0.94	1.11	0.50	1.00	0.50	0.50	0.90	2.17
159	65	0.99	1.34	0.50	1.00	0.50	0.50	0.90	2.31
159	66	0.97	1.32	0.50	1.00	0.50	0.50	0.90	2.29
159	67	1.05	1.39	0.50	1.00	0.50	0.50	0.90	2.37
159	68	1.11	1.53	0.50	1.00	0.50	0.50	0.90	2.48
158	49	0.94	1.10	0.50	1.00	0.50	0.50	0.90	2.16
157	49	0.94	1.15	0.50	1.00	0.50	0.50	0.90	2.18
156	49	0.94	1.05	0.50	1.00	0.50	0.50	0.90	2.13
155	49	0.94	1.05	0.50	1.00	0.50	0.50	0.90	2.13
154	49	0.94	1.05	0.50	1.00	0.50	0.50	0.90	2.13
153	49	0.94	1.05	0.50	1.00	0.50	0.50	0.90	2.13
152	49	0.94	1.05	0.50	1.00	0.50	0.50	0.90	2.13
158	49	0.91	1.05	0.50	1.00	0.50	0.50	0.90	2.12
158	49	0.91	1.06	0.50	1.00	0.50	0.50	0.90	2.13
158	49	0.92	1.04	0.50	1.00	0.50	0.50	0.90	2.12
158	49	0.95	1.08	0.50	1.00	0.50	0.50	0.90	2.15
158	49	0.93	1.15	0.50	1.00	0.50	0.50	0.90	2.18
158	49	0.97	1.16	0.50	1.00	0.50	0.50	0.90	2.20
158	49	0.95	1.17	0.50	1.00	0.50	0.50	0.90	2.20
159	60	0.90	1.05	0.50	1.00	0.50	0.50	0.90	2.12
159	60	0.95	1.02	0.50	1.00	0.50	0.50	0.90	2.12
159	60	0.92	1.14	0.50	1.00	0.50	0.50	0.90	2.17
159	60	0.94	1.08	0.50	1.00	0.50	0.50	0.90	2.15
159	60	0.93	1.16	0.50	1.00	0.50	0.50	0.90	2.18
159	60	0.95	1.16	0.50	1.00	0.50	0.50	0.90	2.19
159	60	1.01	1.18	0.50	1.00	0.50	0.50	0.90	2.23
159	64	0.94	1.11	0.50	1.00	0.50	0.50	0.90	2.17
159	64	0.95	1.13	0.50	1.00	0.50	0.50	0.90	2.18
159	64	0.97	1.24	0.50	1.00	0.50	0.50	0.90	2.24
159	64	0.92	1.24	0.50	1.00	0.50	0.50	0.90	2.22
159	64	0.96	1.23	0.50	1.00	0.50	0.50	0.90	2.23
159	64	0.99	1.33	0.50	1.00	0.50	0.50	0.90	2.31
159	64	1.05	1.32	0.50	1.00	0.50	0.50	0.90	2.33

a. F5/F9 is the $^{235}\text{U}(\text{n},\text{f})/^{239}\text{Pu}(\text{n},\text{f})$ reaction rate ratio.

The 1.2% uncertainty in the calibration factor for the C8/F9 ratio in column 9 of Table 6.3 consists of 1) a 0.6% uncertainty in the ^{238}U thermal cross section used in the calibration, 2) a 0.2% uncertainty in the ^{238}U g-factor used in the calibration, 3) a 0.42% uncertainty in the ^{239}Pu thermal cross section used in the calibration, 4) a 0.28% uncertainty in the ^{239}Pu g-factor used in the calibration, 5) a 0.5% uncertainty in counting statistics and a 0.3% positioning uncertainty for the ^{238}U measurement and 6) a 0.5% uncertainty in counting statistics and a 0.3% positioning uncertainty for the ^{239}Pu measurement.

Table 6.3 Uncertainties for the C8/F9 Ratio in ZPPR-15D L203^a

Row	Column	$\sigma_{\text{map, C8, \%}}$	$\sigma_{\text{map, F9, \%}}$	$\sigma_{\text{CF, C8, \%}}$	$\sigma_{\text{CF, F9, \%}}$	$\sigma_{\text{in-plate, C8, \%}}$	$\sigma_{\text{in-plate, F9, \%}}$	$\sigma_{\text{calib, C8/F9, \%}}$	$\sigma_{\text{total, \%}}$
159	49	0.94	1.05	0.60	1.00	0.50	0.50	1.20	2.30
159	50	0.94	1.10	0.60	1.00	0.50	0.50	1.20	2.33
159	51	0.94	1.05	0.60	1.00	0.50	0.50	1.20	2.30
159	52	0.94	1.05	0.60	1.00	0.50	0.50	1.20	2.30
159	53	0.95	1.05	0.60	1.00	0.50	0.50	1.20	2.30
159	54	0.97	1.09	0.60	1.00	0.50	0.50	1.20	2.33
159	55	0.95	1.06	0.60	1.00	0.50	0.50	1.20	2.31
159	56	0.94	1.08	0.60	1.00	0.50	0.50	1.20	2.31
159	57	0.97	1.05	0.60	1.00	0.50	0.50	1.20	2.31
159	58	0.96	1.12	0.60	1.00	0.50	0.50	1.20	2.34
159	59	0.94	1.08	0.60	1.00	0.50	0.50	1.20	2.31
159	60	0.96	1.05	0.60	1.00	0.50	0.50	1.20	2.31
159	61	0.97	1.08	0.60	1.00	0.50	0.50	1.20	2.33
159	62	0.96	1.12	0.60	1.00	0.50	0.50	1.20	2.34
159	63	0.99	1.11	0.60	1.00	0.50	0.50	1.20	2.35
159	64	0.99	1.11	0.60	1.00	0.50	0.50	1.20	2.35
159	65	0.98	1.34	0.60	1.00	0.50	0.50	1.20	2.46
159	66	1.00	1.32	0.60	1.00	0.50	0.50	1.20	2.46
159	67	1.08	1.39	0.60	1.00	0.50	0.50	1.20	2.53
159	68	1.05	1.53	0.60	1.00	0.50	0.50	1.20	2.60
158	49	0.94	1.10	0.60	1.00	0.50	0.50	1.20	2.32
157	49	0.94	1.15	0.60	1.00	0.50	0.50	1.20	2.35
156	49	0.97	1.05	0.60	1.00	0.50	0.50	1.20	2.31
155	49	0.95	1.05	0.60	1.00	0.50	0.50	1.20	2.30
154	49	0.95	1.05	0.60	1.00	0.50	0.50	1.20	2.30
153	49	0.95	1.05	0.60	1.00	0.50	0.50	1.20	2.30
152	49	0.95	1.05	0.60	1.00	0.50	0.50	1.20	2.31
158	49	0.94	1.05	0.60	1.00	0.50	0.50	1.20	2.30
158	49	0.95	1.06	0.60	1.00	0.50	0.50	1.20	2.31
158	49	0.96	1.04	0.60	1.00	0.50	0.50	1.20	2.30
158	49	0.93	1.08	0.60	1.00	0.50	0.50	1.20	2.31
158	49	0.97	1.15	0.60	1.00	0.50	0.50	1.20	2.36
158	49	0.96	1.16	0.60	1.00	0.50	0.50	1.20	2.36
158	49	0.95	1.17	0.60	1.00	0.50	0.50	1.20	2.36
159	60	0.96	1.05	0.60	1.00	0.50	0.50	1.20	2.31
159	60	0.97	1.02	0.60	1.00	0.50	0.50	1.20	2.30
159	60	0.94	1.14	0.60	1.00	0.50	0.50	1.20	2.34
159	60	0.97	1.08	0.60	1.00	0.50	0.50	1.20	2.33
159	60	0.96	1.16	0.60	1.00	0.50	0.50	1.20	2.36
159	60	1.00	1.16	0.60	1.00	0.50	0.50	1.20	2.38
159	60	0.99	1.18	0.60	1.00	0.50	0.50	1.20	2.38
159	64	0.99	1.11	0.60	1.00	0.50	0.50	1.20	2.35
159	64	0.95	1.13	0.60	1.00	0.50	0.50	1.20	2.34
159	64	0.96	1.24	0.60	1.00	0.50	0.50	1.20	2.40
159	64	0.99	1.24	0.60	1.00	0.50	0.50	1.20	2.41
159	64	0.97	1.23	0.60	1.00	0.50	0.50	1.20	2.40
159	64	1.00	1.33	0.60	1.00	0.50	0.50	1.20	2.47
159	64	1.05	1.32	0.60	1.00	0.50	0.50	1.20	2.48

a. C8/F9 is the $^{238}\text{U}(\text{n},\gamma)/^{239}\text{Pu}(\text{n},\text{f})$ reaction rate ratio.

The 1.7% uncertainty in the calibration factor for the F8/F9 ratio in column 9 of Table 6.4 combines 1) a 1% uncertainty for the fission count rate for ^{238}U , 2) a 0.5% uncertainty for the fission count rate for ^{239}Pu , 3) a 0.7% uncertainty in ^{238}U counts for the natural uranium deposit irradiated at ZPPR as part of the calibration, 4) a 0.3% uncertainty in the fission chamber counts from the natural uranium deposit irradiated in the Argonne Fast Source Reactor, 5) a 0.8% uncertainty in the mass fraction ratio of the natural uranium deposit and 6) a 0.6% uncertainty from the ^{235}U and ^{239}Pu thermal cross sections and g-factors used in the calibration.

Table 6.4 Uncertainties for the F8/F9 Ratio in ZPPR-15D L203^a

Row	Column	σ_{map} , F8, %	σ_{map} , F9, %	σ_{CF} , F8, %	σ_{CF} , F9, %	$\sigma_{\text{in-plate}}$, F8, %	$\sigma_{\text{in-plate}}$, F9, %	σ_{calib} , F8/F9, %	σ_{total} , %
159	49	1.39	1.05	1.70	1.00	0.50	0.50	1.70	3.21
159	50	1.38	1.10	1.70	1.00	0.50	0.50	1.70	3.22
159	51	1.62	1.05	1.70	1.00	0.50	0.50	1.70	3.32
159	52	1.37	1.05	1.70	1.00	0.50	0.50	1.70	3.20
159	53	1.36	1.05	1.70	1.00	0.50	0.50	1.70	3.20
159	54	1.57	1.09	1.70	1.00	0.50	0.50	1.70	3.31
159	55	1.52	1.06	1.70	1.00	0.50	0.50	1.70	3.27
159	56	1.31	1.08	1.70	1.00	0.50	0.50	1.70	3.19
159	57	1.32	1.05	1.70	1.00	0.50	0.50	1.70	3.18
159	58	1.51	1.12	1.70	1.00	0.50	0.50	1.70	3.29
159	59	1.34	1.08	1.70	1.00	0.50	0.50	1.70	3.20
159	60	1.35	1.05	1.70	1.00	0.50	0.50	1.70	3.19
159	61	1.33	1.08	1.70	1.00	0.50	0.50	1.70	3.20
159	62	1.45	1.12	1.70	1.00	0.50	0.50	1.70	3.26
159	63	1.43	1.11	1.70	1.00	0.50	0.50	1.70	3.25
159	64	1.49	1.11	1.70	1.00	0.50	0.50	1.70	3.28
159	65	1.56	1.34	1.70	1.00	0.50	0.50	1.70	3.40
159	66	2.49	1.32	1.70	1.00	0.50	0.50	1.70	3.90
159	67	5.06	1.39	1.70	1.00	0.50	0.50	1.70	5.91
159	68	9.13	1.53	1.70	1.00	0.50	0.50	1.70	9.64
158	49	1.38	1.10	1.70	1.00	0.50	0.50	1.70	3.22
157	49	1.38	1.15	1.70	1.00	0.50	0.50	1.70	3.24
156	49	1.38	1.05	1.70	1.00	0.50	0.50	1.70	3.21
155	49	1.37	1.05	1.70	1.00	0.50	0.50	1.70	3.20
154	49	1.37	1.05	1.70	1.00	0.50	0.50	1.70	3.20
153	49	1.36	1.05	1.70	1.00	0.50	0.50	1.70	3.20
152	49	1.32	1.05	1.70	1.00	0.50	0.50	1.70	3.18
158	49	1.39	1.05	1.70	1.00	0.50	0.50	1.70	3.21
158	49	1.42	1.06	1.70	1.00	0.50	0.50	1.70	3.23
158	49	1.45	1.04	1.70	1.00	0.50	0.50	1.70	3.24

158	49	1.58	1.08	1.70	1.00	0.50	0.50	1.70	3.31
158	49	1.43	1.15	1.70	1.00	0.50	0.50	1.70	3.26
158	49	1.56	1.16	1.70	1.00	0.50	0.50	1.70	3.33
158	49	1.92	1.17	1.70	1.00	0.50	0.50	1.70	3.51
159	60	1.35	1.05	1.70	1.00	0.50	0.50	1.70	3.19
159	60	1.38	1.02	1.70	1.00	0.50	0.50	1.70	3.20
159	60	1.43	1.14	1.70	1.00	0.50	0.50	1.70	3.26
159	60	1.52	1.08	1.70	1.00	0.50	0.50	1.70	3.28
159	60	1.41	1.16	1.70	1.00	0.50	0.50	1.70	3.26
159	60	1.61	1.16	1.70	1.00	0.50	0.50	1.70	3.35
159	60	1.89	1.18	1.70	1.00	0.50	0.50	1.70	3.50
159	64	1.49	1.11	1.70	1.00	0.50	0.50	1.70	3.28
159	64	1.53	1.13	1.70	1.00	0.50	0.50	1.70	3.30
159	64	1.60	1.24	1.70	1.00	0.50	0.50	1.70	3.38
159	64	1.40	1.24	1.70	1.00	0.50	0.50	1.70	3.28
159	64	1.58	1.23	1.70	1.00	0.50	0.50	1.70	3.36
159	64	1.77	1.33	1.70	1.00	0.50	0.50	1.70	3.49
159	64	1.56	1.32	1.70	1.00	0.50	0.50	1.70	3.38

a. F8/F9 is the $^{238}\text{U}(\text{n},\text{f})/^{239}\text{Pu}(\text{n},\text{f})$ reaction rate ratio.

6.2 Spectral Indices/Reaction Rate Ratios

Tables 6.5 – 6.8 give the reaction rate ratios and the associated total uncertainties. The total uncertainty listed for each entry in Tables 6.5 – 6.8 is the relative uncertainty, i.e., the total uncertainty divided by the measured value, expressed in percent.

The letters in the “Region” column (column 3) of Table 6.5 for ZPPR-15B L134 designate:

- IC – inner core,
- OC – outer core,
- RB – radial blanket,
- RR – radial reflector,
- SP – sodium pool,
- SH -shield,
- SSNA – stainless steel-sodium shield zone, and
- BCNA – boron carbide-sodium shield zone.

The letters in the “Region” column (column 3) of Tables 6.6 – 6.8 for ZPPR-15D L203 designate:

- IC – inner core with one 1/16 inch HEU fuel column,
- IC D – inner core with two 1/16 inch HEU fuel columns,
- IC SD – inner core with one 1/8 inch HEU fuel column,

OC – outer core with one 1/16 inch HEU fuel column,
 OC D – outer core with two 1/16 inch HEU fuel columns,
 OC SD – outer core with one 1/8 inch HEU fuel column,
 RB – radial blanket, and
 AB – axial blanket.

Columns 4 – 7 of Tables 6.5 – 6.8 list the X- and Y-boundaries of the cell relative to the coordinate system described in Section 2. All dimensions in Tables 6.5 – 6.8 are in centimeters.

Table 6.5 F8/F5 Ratio for ZPPR-15B L134^a

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	F8/F5 ^b	σ _{total} , %
159	19	SP	44.1960	49.7205	154.6860	160.2105	0.001232	7.20
159	21	SH-BCNA	55.2450	60.7695	154.6860	160.2105	0.002438	6.40
159	22	SH-BCNA	60.7695	66.2940	154.6860	160.2105	0.002472	6.30
159	23	SH-BCNA	66.2940	71.8185	154.6860	160.2105	0.002242	5.96
159	24	SH-BCNA	71.8185	77.3430	154.6860	160.2105	0.00198	5.87
159	25	SH-BCNA	77.3430	82.8675	154.6860	160.2105	0.00169	5.86
159	26	RR-BCNA	82.8675	88.3920	154.6860	160.2105	0.000987	5.88
159	27	RR-SSNA	88.3920	93.9165	154.6860	160.2105	0.001133	5.57
159	29	RB	99.4410	104.9655	154.6860	160.2105	0.004979	4.53
159	30	RB	104.9655	110.4900	154.6860	160.2105	0.008608	4.07
159	31	RB	110.4900	116.0145	154.6860	160.2105	0.01574	3.48
159	32	OC	116.0145	121.5390	154.6860	160.2105	0.02792	2.80
159	33	OC	121.5390	127.0635	154.6860	160.2105	0.02728	2.79
159	34	OC	127.0635	132.5880	154.6860	160.2105	0.03063	2.80
159	35	OC	132.5880	138.1125	154.6860	160.2105	0.02789	2.78
159	36	OC	138.1125	143.6370	154.6860	160.2105	0.0303	2.78
159	49	IC	209.9310	215.4555	154.6860	160.2105	0.02041	2.77

- F8/F5 is the $^{238}\text{U}(\text{n},\text{f})/^{235}\text{U}(\text{n},\text{f})$ reaction rate ratio.
- The Z-coordinate of the ^{235}U foil is 6.31 cm, the Z-coordinate of the ^{238}U foil is 7.70 cm, and the Z-coordinate of the ^{239}Pu foil is 9.08 cm.

Table 6.6 F5/F9 Ratio for ZPPR-15D L203^a

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	F5/F9 ^b	σ _{total} , %
159	49	IC	209.9310	215.4555	154.6860	160.2105	0.955	2.12
159	50	IC	215.4555	220.9800	154.6860	160.2105	0.990	2.14
159	51	IC	220.9800	226.5045	154.6860	160.2105	0.968	2.12
159	52	IC	226.5045	232.0290	154.6860	160.2105	0.962	2.13
159	53	IC	232.0290	237.5535	154.6860	160.2105	0.972	2.13
159	54	IC	237.5535	243.0780	154.6860	160.2105	0.959	2.17
159	55	IC	243.0780	248.6025	154.6860	160.2105	0.973	2.12
159	56	IC SD	248.6025	254.1270	154.6860	160.2105	0.939	2.14
159	57	IC SD	254.1270	259.6515	154.6860	160.2105	0.933	2.12
159	58	IC	259.6515	265.1760	154.6860	160.2105	0.954	2.16
159	59	IC	265.1760	270.7005	154.6860	160.2105	0.929	2.14
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.910	2.12
159	61	OC D	276.2250	281.7495	154.6860	160.2105	0.924	2.14
159	62	OC SD	281.7495	287.2740	154.6860	160.2105	0.897	2.16
159	63	OC D	287.2740	292.7985	154.6860	160.2105	0.913	2.17
159	64	OC SD	292.7985	298.3230	154.6860	160.2105	0.893	2.17
159	65	OC D	298.3230	303.8475	154.6860	160.2105	0.932	2.31
159	66	RB	303.8475	309.3720	154.6860	160.2105	0.975	2.29
159	67	RB	309.3720	314.8965	154.6860	160.2105	1.020	2.37
159	68	RB	314.8965	320.4210	154.6860	160.2105	1.022	2.48
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.968	2.16
157	49	IC	209.9310	215.4555	165.7350	171.2595	0.996	2.18
156	49	IC	209.9310	215.4555	171.2595	176.7840	0.959	2.13
155	49	IC	209.9310	215.4555	176.7840	182.3085	0.980	2.13
154	49	IC	209.9310	215.4555	182.3085	187.8330	0.962	2.13
153	49	IC	209.9310	215.4555	187.8330	193.3575	0.965	2.13
152	49	IC	209.9310	215.4555	193.3575	198.8820	0.964	2.13
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.955	2.12
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.957	2.13
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.977	2.12
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.961	2.15
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.969	2.18
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.972	2.20
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.980	2.20
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.910	2.12
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.919	2.12
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.909	2.17
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.917	2.15

159	60	IC	270.7005	276.2250	154.6860	160.2105	0.925	2.18
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.932	2.19
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.950	2.23
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.893	2.17
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.890	2.18
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.890	2.24
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.903	2.22
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.896	2.23
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.911	2.31
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.922	2.33

- a. F5/F9 is the $^{235}\text{U}(\text{n},\text{f})/^{239}\text{Pu}(\text{n},\text{f})$ reaction rate ratio.
b. The Z-coordinate of the ^{235}U foil is 6.31 cm, the Z-coordinate of the ^{238}U foil is 7.70 cm, and the Z-coordinate of the ^{239}Pu foil is 9.08 cm.

Table 6.7 C8/F9 Ratio for ZPPR-15D L203^a

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	C8/F9 ^b	σ _{total} , %
159	49	IC	209.9310	215.4555	154.6860	160.2105	0.1211	2.30
159	50	IC	215.4555	220.9800	154.6860	160.2105	0.1251	2.33
159	51	IC	220.9800	226.5045	154.6860	160.2105	0.1233	2.30
159	52	IC	226.5045	232.0290	154.6860	160.2105	0.1221	2.30
159	53	IC	232.0290	237.5535	154.6860	160.2105	0.1212	2.30
159	54	IC	237.5535	243.0780	154.6860	160.2105	0.1208	2.33
159	55	IC	243.0780	248.6025	154.6860	160.2105	0.1205	2.31
159	56	IC SD	248.6025	254.1270	154.6860	160.2105	0.1162	2.31
159	57	IC SD	254.1270	259.6515	154.6860	160.2105	0.1140	2.31
159	58	IC	259.6515	265.1760	154.6860	160.2105	0.1192	2.34
159	59	IC	265.1760	270.7005	154.6860	160.2105	0.1163	2.31
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.1126	2.31
159	61	OC D	276.2250	281.7495	154.6860	160.2105	0.1128	2.33
159	62	OC SD	281.7495	287.2740	154.6860	160.2105	0.1095	2.34
159	63	OC D	287.2740	292.7985	154.6860	160.2105	0.1093	2.35
159	64	OC SD	292.7985	298.3230	154.6860	160.2105	0.1078	2.35
159	65	OC D	298.3230	303.8475	154.6860	160.2105	0.1155	2.46
159	66	RB	303.8475	309.3720	154.6860	160.2105	0.1206	2.46
159	67	RB	309.3720	314.8965	154.6860	160.2105	0.1275	2.53
159	68	RB	314.8965	320.4210	154.6860	160.2105	0.1208	2.60
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.1239	2.32
157	49	IC	209.9310	215.4555	165.7350	171.2595	0.1249	2.35
156	49	IC	209.9310	215.4555	171.2595	176.7840	0.1213	2.31
155	49	IC	209.9310	215.4555	176.7840	182.3085	0.1228	2.30
154	49	IC	209.9310	215.4555	182.3085	187.8330	0.1218	2.30

153	49	IC	209.9310	215.4555	187.8330	193.3575	0.1203	2.30
152	49	IC	209.9310	215.4555	193.3575	198.8820	0.1184	2.31
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.1211	2.30
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.1223	2.31
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.1232	2.30
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.1231	2.31
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.1235	2.36
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.1271	2.36
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.1270	2.36
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.1126	2.31
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.1142	2.30
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.1127	2.34
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.1133	2.33
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.1159	2.36
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.1175	2.38
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.1200	2.38
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.1078	2.35
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.1090	2.34
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.1078	2.40
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.1104	2.41
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.1102	2.40
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.1136	2.47
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.1156	2.48

- a. C8/F9 is the $^{238}\text{U}(n,\gamma)/^{239}\text{Pu}(n,f)$ reaction rate ratio.
b. The Z-coordinate of the ^{235}U foil is 6.31 cm, the Z-coordinate of the ^{238}U foil is 7.70 cm, and the Z-coordinate of the ^{239}Pu foil is 9.08 cm.

Table 6.8 F8/F9 Ratio for ZPPR-15D L203^a

Row	Column	Region	X _{min}	X _{max}	Y _{min}	Y _{max}	F8/F9 ^b	σ _{total} , %
159	49	IC	209.9310	215.4555	154.6860	160.2105	0.01849	3.21
159	50	IC	215.4555	220.9800	154.6860	160.2105	0.01923	3.22
159	51	IC	220.9800	226.5045	154.6860	160.2105	0.01877	3.32
159	52	IC	226.5045	232.0290	154.6860	160.2105	0.01902	3.20
159	53	IC	232.0290	237.5535	154.6860	160.2105	0.01911	3.20
159	54	IC	237.5535	243.0780	154.6860	160.2105	0.01939	3.31
159	55	IC	243.0780	248.6025	154.6860	160.2105	0.02066	3.27
159	56	IC SD	248.6025	254.1270	154.6860	160.2105	0.02374	3.19
159	57	IC SD	254.1270	259.6515	154.6860	160.2105	0.02368	3.18
159	58	IC	259.6515	265.1760	154.6860	160.2105	0.02408	3.29
159	59	IC	265.1760	270.7005	154.6860	160.2105	0.02346	3.20
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.02413	3.19

159	61	OC D	276.2250	281.7495	154.6860	160.2105	0.02620	3.20
159	62	OC SD	281.7495	287.2740	154.6860	160.2105	0.02762	3.26
159	63	OC D	287.2740	292.7985	154.6860	160.2105	0.02808	3.25
159	64	OC SD	292.7985	298.3230	154.6860	160.2105	0.02696	3.28
159	65	OC D	298.3230	303.8475	154.6860	160.2105	0.02632	3.40
159	66	RB	303.8475	309.3720	154.6860	160.2105	0.01527	3.90
159	67	RB	309.3720	314.8965	154.6860	160.2105	0.00948	5.91
159	68	RB	314.8965	320.4210	154.6860	160.2105	0.00584	9.64
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.01894	3.22
157	49	IC	209.9310	215.4555	165.7350	171.2595	0.01932	3.24
156	49	IC	209.9310	215.4555	171.2595	176.7840	0.01872	3.21
155	49	IC	209.9310	215.4555	176.7840	182.3085	0.01934	3.20
154	49	IC	209.9310	215.4555	182.3085	187.8330	0.01906	3.20
153	49	IC	209.9310	215.4555	187.8330	193.3575	0.01920	3.20
152	49	IC	209.9310	215.4555	193.3575	198.8820	0.02036	3.18
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.01849	3.21
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.01855	3.23
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.01892	3.24
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.01860	3.31
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.01836	3.26
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.01840	3.33
158	49	IC	209.9310	215.4555	160.2105	165.7350	0.01563	3.51
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.02413	3.19
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.02451	3.20
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.02391	3.26
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.02437	3.28
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.02371	3.26
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.02243	3.35
159	60	IC	270.7005	276.2250	154.6860	160.2105	0.02089	3.50
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.02696	3.28
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.02724	3.30
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.02646	3.38
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.02724	3.28
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.02633	3.36
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.02612	3.49
159	64	OC	292.7985	298.3230	154.6860	160.2105	0.02283	3.38

- F8/F9 is the $^{238}\text{U}(n,f)/^{239}\text{Pu}(n,f)$ reaction rate ratio.
- The Z-coordinate of the ^{235}U foil is 6.31 cm, the Z-coordinate of the ^{238}U foil is 7.70 cm, and the Z-coordinate of the ^{239}Pu foil is 9.08 cm.

7 As-Built Models and Calculations

As-built MCNP models have been created for the foil irradiation measurements in ZPPR-15B and ZPPR-15D. In principle, the foil reaction rates measured in ZPPR-15 could be computed by Monte Carlo. In practice, very large computer resources would be required to calculate the foil reaction rates measured in these experiments by direct Monte Carlo. An individual foil has a diameter of ~ 12 mm and a thickness of ~ 0.12 mm. Consequently, a single foil occupies a negligible fraction of the assembly volume. Very few neutrons will enter any given foil, so the statistical uncertainty of the calculated reaction rate for that foil will be very large. It might be possible to use weight windows, splitting/Russian roulette and other forms of biasing to force more tracks through a given foil to lower the variance for that foil. However, there were foils distributed at 50 – 100 matrix locations in the core, radial blanket, axial blanket and reflector to measure reaction rate distributions, so any technique that lowers the variance for one foil or group of foils near the same location will make the variance worse for foils at other locations.

Another problem with any direct Monte Carlo calculation of the foil measurements is that the flux falls by several orders of magnitude between the core and the reflector, which exacerbates the problem of obtaining meaningful statistics for the foil measurements, particularly in regions outside of the core.

The combination of the negligible volumes of individual foils, the large number of foils in the core, blanket and reflector, and the large reduction in flux between the core center and the reflector makes any direct Monte Carlo calculation of fluxes or reaction rates in the foils in ZPPR-15 impractical for any realistic amount of computational effort.

Monte Carlo calculations with point detectors and other next event estimators are also impractical for ZPPR-15 as-built models. A point detector or similar next event estimator would create a score in each foil at each neutron collision, but the complexity of the ZPPR-15 as-built geometry makes this approach infeasible. Next event estimators can work well in models with large, homogeneous regions because it is relatively straightforward to compute the contribution to a next event estimator under those circumstances. However, as-built models of ZPPR-15 do not contain any large, homogeneous regions. Instead, each individual matrix tube in an as-built model contains many distinct cells with thicknesses ranging from ~ 0.1 mm to ~ 10 mm.

Consider a neutron scattering event at point (x_1, y_1, z_1) and a point detector at point (x_2, y_2, z_2) . The point detector estimator assumes that after the collision at (x_1, y_1, z_1) the neutron travels directly to the point detector and scores the contribution to the point detector estimator. This means that it is necessary to compute the distance through every cell between (x_1, y_1, z_1) and (x_2, y_2, z_2) , to compute the appropriate cross section in each of those cells and then to compute the optical path length through each of those cells. This process is repeated for every point detector at every collision. For a few detectors in a model with large, homogeneous regions, next event estimators can work very well. For an as-built ZPPR-15 model with many thousands of very small cells and many locations of interest, i.e., foil positions, next event estimators such as point detectors do not seem to be computationally practical. This has been confirmed in previous calculations of as-built ZPPR models.

Consequently, it is necessary to convert the as-built MCNP models of foil measurement loadings to deterministic models in order to perform meaningful calculations of the foil reaction rate measurements.

8 Fission Chamber Measurements for ^{237}Np and ^{242}Pu

Back-to-back (BTB) fission chambers were used to measure threshold fission rates in ^{237}Np and ^{242}Pu in the BCNA shield configuration in ZPPR-15B L141. The BTB flowing gas ionization chambers used in the measurement are described in Ref. 4. Two chambers were irradiated simultaneously. Each chamber contained a deposit of ^{237}Np and a deposit of ^{242}Pu . One chamber was located in the sodium pool outside of the BCNA shield region, and one chamber was located in the radial blanket on the opposite side of the core from the shield. In order to make space for the fission chamber, it was necessary to remove most of the material from the first 6 in (15.24 cm) at the front of the drawer and to leave a 0.5 inch channel through the materials in the drawer for cables and gas tubes.

The measured ^{237}Np and ^{242}Pu fission rates were corrected for counts contributed by the small amount of fissionable impurities in the deposits. Mass spectrometry and alpha counting were used to determine the deposit compositions. The corrections for fissions in impurities were determined by calculations.

Uncertainties for the measured threshold fission rates were estimated based on counting statistics and the ability to distinguish counts due to fission from counts resulting from alpha decay in the deposits. The ZPPR staff estimated that the uncertainties for ^{237}Np fissions were 2% for the chamber in the radial blanket and 3.6% for the chamber in the sodium pool outside the BCNA shield configuration. For ^{242}Pu fissions, the experimenters estimated a 1.5% uncertainty for the chamber in the radial blanket and a 5% uncertainty for the chamber in the sodium pool outside of the BCNA shield. There is no additional information to refine these uncertainty estimates.

Table 8.1 shows the measured ^{237}Np fission rates in the BTB counters, and Table 8.2 shows the measured ^{242}Pu fission rates in the BTB counters. The coordinates listed in Tables 8.1 and 8.2 are the boundaries of the matrix tube in which the measurement was performed. The coordinate system is that described in Section 3.2. The BTB chamber and related hardware occupied the front 15.24 cm of the drawer. The BTB chamber was not described in any detail. Based on the BTB chambers used for foil calibration, the ^{237}Np and ^{242}Pu were deposited on small, thin stainless steel substrates in approximately the center of the BTB chamber. The deposits were very thin and were approximately centered in the drawer in the X- and Y-directions. The exact axial coordinates of the deposits are not listed in the published reports. The BTB chamber was probably forward of the center of the 15.24 cm volume at the front of the drawer. Based on Figure 1 of Ref. 4, the deposits were centered approximately 2.7 cm from the front of the chamber, so the lowest possible Z-coordinate is 2.7 cm. It is not clear whether there was any framework in the front of the drawer to support the BTB chamber. A reasonable Z-coordinate range for the axial position of the deposits for modeling calculations is 2.7 – 5.08 cm. The control rods were far from the BTB chamber, and there was nothing near the axial center of the core to cause sharp axial gradients in the flux profile.

Uncertainties in Tables 8.1 and 8.2 are relative total uncertainties, i.e., the total uncertainty divided by the measured value, expressed in percent.

Table 8.1 ^{237}Np Fission Rates in the ZPPR-15B BCNA Shield Configuration

Row	Column	$X_{\min}$	$X_{\max}$	$Y_{\min}$	$Y_{\max}$	$^{237}\text{Np}(n,f)^a$	$\sigma_{\text{total}}, \%$
158	67 ^b	309.3720	314.8965	160.2105	165.7350	0.1070	2.0
158	19 ^c	44.1960	49.7205	160.2105	165.7350	0.0002045	3.6

- Measured reaction rates are in units of 10^{-17} reactions/atom-second at a reactor power of approximately 1 watt.
- Location 158-67 is in the radial blanket.
- Location 158-19 is in the sodium pool outside the BCNA shield.

Table 8.2 ^{242}Pu Fission Rates in the ZPPR-15B BCNA Shield Configuration

Row	Column	$X_{\min}$	$X_{\max}$	$Y_{\min}$	$Y_{\max}$	$^{242}\text{Pu}(n,f)^a$	$\sigma_{\text{total}}, \%$
158	67 ^b	309.3720	314.8965	160.2105	165.7350	0.07967	1.5
158	19 ^c	44.1960	49.7205	160.2105	165.7350	0.0001498	5.0

- Measured reaction rates are in units of 10^{-17} reactions/atom-second at a reactor power of approximately 1 watt.
- Location 158-67 is in the radial blanket.
- Location 158-19 is in the sodium pool outside the BCNA shield.

9 Summary

The foil irradiation measurements of reaction rates performed in ZPPR-15B L123, ZPPR-15B L134 and ZPPR-15D L203 were described and analyzed. In ZPPR-15, foils were irradiated to measure distributions for $^{239}\text{Pu}(n,f)$, $^{235}\text{U}(n,f)$, $^{238}\text{U}(n,f)$, $^{238}\text{U}(n,\gamma)$, $^{115}\text{In}(n,n')$ and $^{115}\text{In}(n,\gamma)$ reaction rates. The measured foil data are presented in several forms. The basic mapping foil data provide relative or normalized distributions of reaction rates and can be renormalized to any desired basis such as the highest measured reaction rate for the foil type. Absolute reaction rate data provide distributions relative to a specific reactor power. Cell-averaged reaction rates are average reaction rates at a specific axial location for a unit cell consisting of a drawer, the plates in the drawer and the surrounding matrix tube. Reaction rate ratios or spectral indices are ratios of cell-averaged reaction rates for two different reactions at a specific axial location.

Uncertainty analyses were performed for the mapping foil data, absolute reaction rates, cell-averaged reaction rates and spectral indices obtained in ZPPR-15B and ZPPR-15D. The reaction rate data and the associated total uncertainties were tabulated as a function of position for each category of reaction rate data.

Reaction rates in ^{237}Np and ^{242}Pu deposits were measured in a back-to-back fission chamber in ZPPR-15B loading 141. The ^{237}Np and ^{242}Pu fission rate measurements were described and the uncertainties stated.

As-built MCNP models were created for the reaction rate measurements in ZPPR-15 loadings 123, 134, 141 and 203. Because a) each foil occupies a negligible volume in a ZPPR-15 assembly and b) there were many foils in the assembly, it is unlikely that reaction rates in the foils can be computed by Monte Carlo for any realistic computational effort. It is likely necessary to convert the MCNP models to deterministic models in order to compute meaningful reaction rates for comparison with the measured values.

10 References

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