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ZPR-3 ASSEMBLY 11: A CYLINDRICAL ASSEMBLY OF HIGHLY ENRICHED URANIUM AND DEPLETED URANIUM WITH AN AVERAGE ^{235}U ENRICHMENT OF 12 ATOM % AND A DEPLETED URANIUM REFLECTOR

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1.0 DETAILED DESCRIPTION

1.1 Overview of Experiments

Over a period of 30 years, more than a hundred Zero Power Reactor (ZPR) critical assemblies were constructed at Argonne National Laboratory. The ZPR facilities, ZPR-3, ZPR-6, ZPR-9 and ZPPR, were all fast critical assembly facilities. The ZPR critical assemblies were constructed to support fast reactor development, but data from some of these assemblies are also well suited for nuclear data validation and to form the basis for criticality safety benchmarks. A number of the Argonne ZPR/ZPPR critical assemblies have been evaluated as ICSBEP and IRPhEP benchmarks.

Of the three classes of ZPR assemblies, engineering mockups, engineering benchmarks and physics benchmarks, the last group tends to be most useful for criticality safety. Because physics benchmarks were designed to test fast reactor physics data and methods, they were as simple as possible in geometry and composition. The principal fissile species was ^{235}U or ^{239}Pu. Fuel enrichments ranged from 9% to 95%. Often there were only one or two main core diluent materials, such as aluminum, graphite, iron, sodium or stainless steel. The cores were reflected (and insulated from room return effects) by one or two layers of materials such as depleted uranium, lead or stainless steel. Despite their more complex nature, a small number of assemblies from the other two classes would make useful criticality safety benchmarks because they have features related to criticality safety issues, such as reflection by soil-like material.

ZPR-3 Assembly 11 (ZPR-3/11) was designed as a fast reactor physics benchmark experiment with an average core ^{235}U enrichment of approximately 12 at.% and a depleted uranium reflector. Approximately 79.7% of the total fissions in this assembly occur above 100 keV, approximately 20.3% occur below 100 keV, and essentially none below 0.625 eV – thus the classification as a “fast” assembly. This assembly is Fast Reactor Benchmark No. 8 in the Cross Section Evaluation Working Group (CSEWG) Benchmark Specifications[a] and has historically been used as a data validation benchmark assembly.

Loading of ZPR-3 Assembly 11 began in early January 1958, and the Assembly 11 program ended in late January 1958. The core consisted of highly enriched uranium (HEU) plates and depleted uranium plates loaded into stainless steel drawers, which were inserted into the central square stainless steel tubes of a 31 x 31 matrix on a split table machine. The core unit cell consisted of two columns of 0.125 in.-wide (3.175 mm) HEU plates, six columns of 0.125 in.-wide (3.175 mm) depleted uranium plates and one column of 1.0 in.-wide (25.4 mm) depleted uranium plates. The length of each column was 10 in. (254.0 mm) in each half of the core. The axial blanket consisted of 12 in. (304.8 mm) of depleted uranium behind the core. The

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[a] Cross Section Evaluation Working Group Benchmark Specifications, BNL-19302, Vol. II, (ENDF 202) (September 1986).

thickness of the depleted uranium radial blanket was approximately 14 in. (355.6 mm), and the length of the radial blanket in each half of the matrix was 22 in. (558.8 mm). The assembly geometry approximated a right circular cylinder as closely as the square matrix tubes allowed.

According to the logbook[a] and loading records for ZPR-3/11, the reference critical configuration was loading 10 which was critical on January 21, 1958. Subsequent loadings were very similar but less clean for criticality because there were modifications made to accommodate reactor physics measurements other than criticality. Accordingly, ZPR-3/11 loading 10 was selected as the only configuration for this benchmark. As documented below, it was determined to be acceptable as a criticality safety benchmark experiment.

A very accurate transformation to a simplified model is needed to make any ZPR assembly a practical criticality-safety benchmark. There is simply too much geometric detail in an exact (as-built) model of a ZPR assembly, even a clean core such as ZPR-3/11 loading 10. The transformation must reduce the detail to a practical level without masking any of the important features of the critical experiment. And it must do this without increasing the total uncertainty far beyond that of the original experiment. Such a transformation is described in Section 3. It was obtained using a pair of continuous-energy Monte Carlo calculations. First, the critical configuration was modeled in full detail – every plate, drawer, matrix tube, and air gap was modeled explicitly. Then the regionwise compositions and volumes from the detailed as-built model were used to construct a homogeneous, two-dimensional (RZ) model of ZPR-3/11 that conserved the mass of each nuclide and volume of each region. The simple cylindrical model is the criticality-safety benchmark model. The difference in the calculated k_{eff} values between the as-built three-dimensional model and the homogeneous two-dimensional benchmark model was used to adjust the measured excess reactivity of ZPR-3/11 loading 10 to obtain the k_{eff} for the benchmark model. Uncertainties associated with this simplification, which go beyond Monte Carlo statistical uncertainties, were included in the k_{eff} uncertainty of the benchmark model. The net difference in k_{eff} and each of the effects that contribute to it are small.

1.2 Description of Experimental Configuration

A lot of details must be presented to describe precisely the as-built assembly. Also, it is useful to define some jargon (to be shown in italics) to facilitate the presentation. For those unfamiliar with ZPR assemblies, the task of absorbing this may be tedious if not a bit overwhelming. In fact, the task of modeling the exact plate-by-plate loading would be unreasonable to do by hand. In practice, the information contained in this section was accumulated in an electronic database and processed into models using computer programs. Readers interested only in using the benchmark model need not be concerned with any of these details, since Section 3 contains a complete specification of the criticality-safety benchmark model.

1.2.1 The ZPR-3 Facility - The ZPR-3 fast critical facility was a horizontal split-table type machine consisting of a large, cast-steel bed supporting two tables or carriages, one stationary and the other movable. Details of the ZPR-3 facility are given in the hazard evaluation report for the facility.[b] A pictorial view of the ZPR-3 facility is shown in Figure 1. Each table was 100 in. (2.54 m)[c] wide and 67 in. (1.70 m) long. Stainless steel square tubes, nominally 2 in. (51 mm) on a side (inside dimension), 0.040 inches (1 mm) thick, and 33.5 in. (851 mm) long, were stacked horizontally on each table to form a 31-row and 31-column square "honeycomb" matrix. Each 31 x 31 array of matrix tubes was pressed tightly together and clamped in place on its table by steel structural members.

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[a] Applied Physics Division Experiment Logbook Number 698E, Argonne National Laboratory, 1958.

[b] R. O. Brittan *et al*, "Hazard Evaluation Report on the Fast Reactor Zero Power Experiment ZPR-III," Argonne National Laboratory Report ANL-6408, October 1961.

[c] Almost all of the references give dimensions in English units and some also give metric equivalents. We display the metric equivalent in parentheses when practical, as a courtesy to international readers.

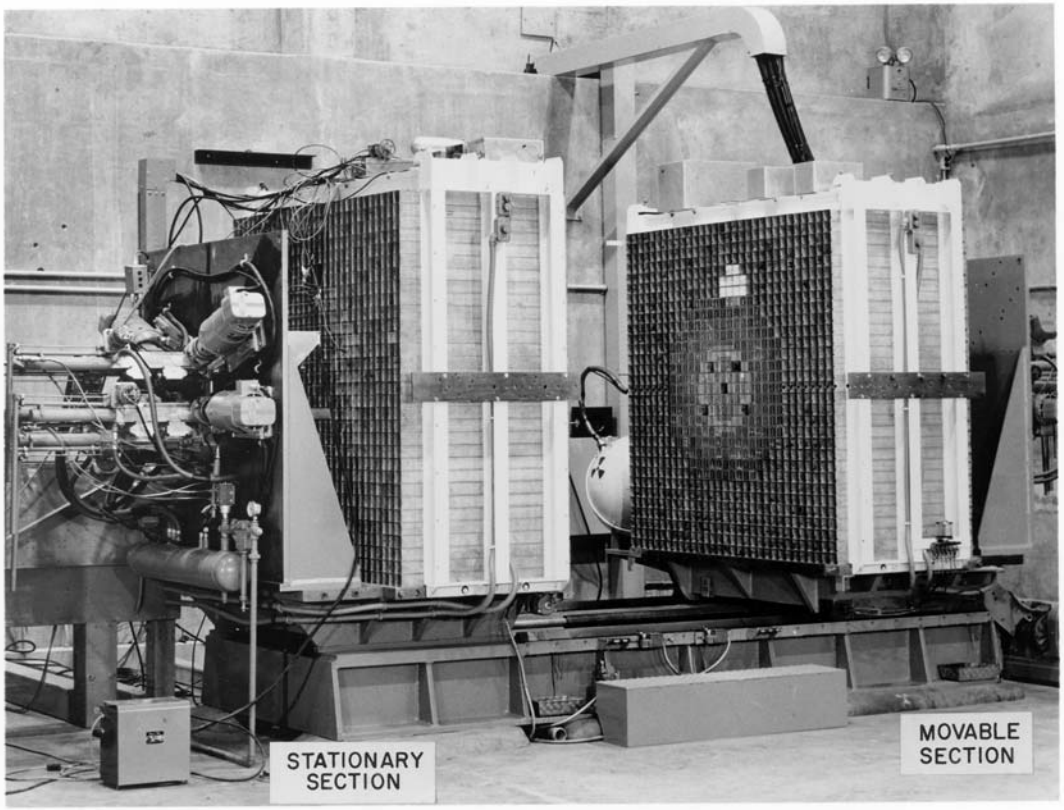

Figure 1. View of the ZPR-3 Facility.

The matrix pitch was measured in November 1959. The reported pitch values were 2.1835 in. (55.461 mm) in the horizontal direction and 2.1755 in. (55.258 mm) in the vertical direction.[a]

Except during reactor operation, the tables were separated by 5 feet (1.5 m). For reactor operation, the movable table was driven against the stationary table with a nut and lead screw mechanism, forming a cubical 31 x 31 matrix array, 67 inches (1.7 m) on a side.[b]

A *matrix position* is specified by three parameters: matrix half (S or M), row letter (A-Z and AA-EE starting from the top), and column number (1-31 starting from the left looking from the movable half towards the stationary half). For example, the central position in the movable half is M-P/16. Because the column numbers for both halves start from the same side of the machine, the row and column numbers in the stationary and movable tables of the machine align when the tables are brought together. For example, the matrix positions designated as row N, column 15 in the stationary and movable halves (S-N/15 and M-N/15) are directly aligned when the movable table touches the stationary table.

The stationary and movable matrix halves are sometimes designated as half 1 and half 2, respectively, in ZPR documents. That convention is retained here.

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[a] L. H. Berkes, ZPR-3 Hot Constants Memo, March 31, 1960.

[b] Slight misalignment of the matrix bundles was unavoidable, resulting in a small (approximately 1 mm) gap at the interface when the tables were driven to the closed position.

During startup, a neutron source had to be present in each half of any ZPR-3 loading that did not contain an inherent source in the core (e.g., ^{240}Pu). Figure 1 provides a partial view of the movable half's spherical source pig (shielded container) and the source transport tube connecting the pig to matrix row P. The source pig is the light sphere at the lower center of Figure 1. It is between the movable half and the wall and is partially hidden by the movable half. There was a corresponding pig and tube for the stationary half. The safety documents, which were based on uranium fuel, required the presence of drawers in ZPR-3/11 that could accommodate a source tube.[a] In ZPR-3/11, the source was located in S-P/24 and M-P/24. BF_3 proportional counters were located in S-M/10 and M-M/10.

A steel back plate, roughly 30 inches (76 cm) behind the matrix tubes on each table, supported control rod drives. The drives were mounted on the outboard side of the plate and were connected to control rods by steel shafts that projected through holes in the plate.

ZPR-3 had no system to cool the matrix loading when Assembly 11 was in the ZPR-3 matrix. It was not until the mid 1960s, when plutonium fuel containing a substantial fraction of heat-emitting ^{240}Pu came into use, that a rudimentary forced-air cooling system was devised.

A small number of thermocouples were in the ZPR-3 matrix to monitor the core temperature. Before plutonium fuel was used at ZPR-3, there was only one thermocouple per half. Five more thermocouples per half were added when plutonium fuel came into use. Each thermocouple, and its electrical lead, was installed in the small, axial interstitial gap that existed where the rounded corners of four matrix tubes met.[b] No record of the axial and radial locations of these thermocouples has been found. The logbook entries for critical configurations include measured temperatures. The logbook entries for critical ZPR-3/11 configurations consistently list only one matrix temperature.

The matrix machine was near (approximately 2 m from) a corner of a large cell (room), approximately 45 feet by 42 feet and 30 feet tall (14 × 13 × 9 m).

The desired average composition was achieved by loading the matrix with drawers containing rectangular plates of different materials such as highly enriched uranium, depleted uranium, graphite, etc. A specific plate-loading pattern in a drawer is called a *drawer master*. The plates were bare material or had a cladding or, in the case of uranium, may have had a protective coating. Figure 2 shows a matrix tube, drawer and related hardware. Figure 3 shows a typical loaded ZPR drawer although the drawer shown in Figure 3 was not used in ZPR-3/11.

There were usually many plate sizes available for a given material and a limited number of plates of any one size. Consequently, there were often several drawer masters that had essentially the same composition, differing only in the plate sizes used. The number of similar drawer masters was increased by the fact that drawers for the stationary and movable halves had different (opposite, mirror image) drawer masters.

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[a] J. M. Gasidlo, Private Communication, April 2, 2009.
[b] J. M. Gasidlo, Private Communication, April 10, 2009.

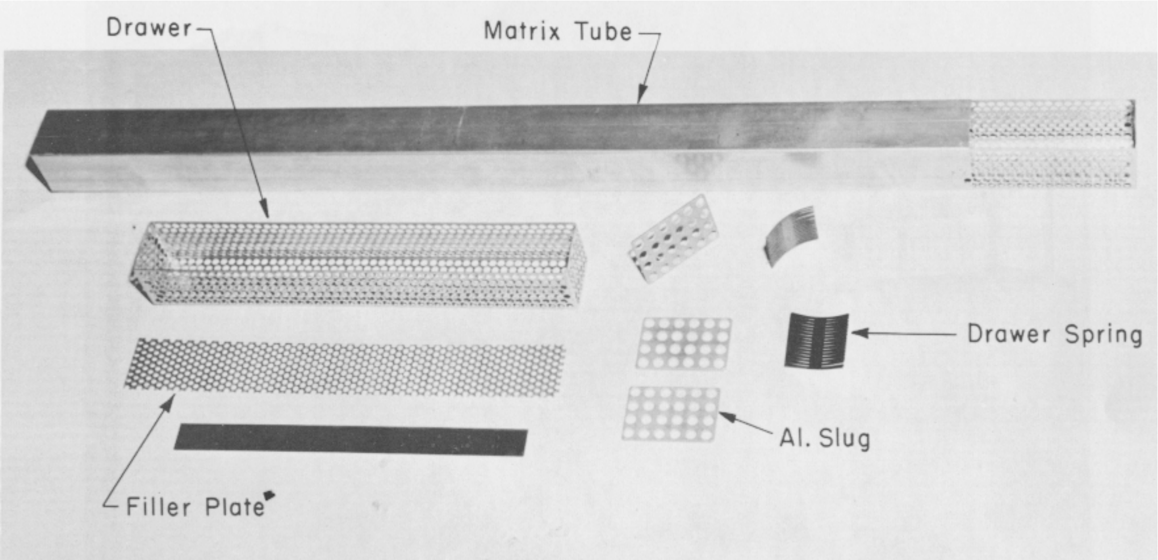

Figure 2. Typical ZPR-3 Drawer.

Figure 3. Typical Loaded ZPR Drawer.[a]

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[a] The plates are elevated above the bottom of the drawer in this photograph.

The specification of which drawer master was in each matrix position is known as a *matrix loading map*. In ZPR-3/11, as in most ZPR-3 assemblies, a given matrix position had two drawers, a *front drawer* and a *back drawer* (the front drawers in the stationary and movable halves were adjacent to the interface between halves). Correspondingly, there are two matrix loading maps for each half, a front map and a back map.

The ZPR-3 drawers themselves can be categorized as either normal drawers or control drawers. Each normal drawer had 2 inch-tall (51 mm) front, back, and side walls, and a 2 inch-wide bottom wall. Most normal drawers had approximately 0.03-inch-thick (0.8-mm), highly perforated Type 304 stainless steel wall material. The rest of the normal drawers had approximately 0.04-inch-thick non-perforated aluminum walls. Each normal front drawer had a tab at the front edge of each side wall. There were corresponding notches in the side walls of the matrix tubes. The tabs fit in the notches to provide positive seating of the drawer in the tube, with the front of the drawer flush with the front of the matrix tube. Each normal back drawer had a handle extending from its back wall, which allowed the drawer to be extracted from the back of the matrix tube. In ZPR-3/11, all front and back drawers were stainless steel drawers. The control drawer is described below.

The only type of operational control rod used in ZPR-3 was the *dual-purpose* (DP) control rod, so-called because it was a drawer that contained a core unit cell that could be driven in and out along a matrix tube to adjust reactivity. For ZPR-3/11, there were five DP rods in each half. Four DP rods per half were designated as safety rods, and the remaining DP rod per half was used as a control rod.

The control drawer itself was basically like a normal drawer but had some special features. Because the DP control drawer had to be strong enough to undergo rapid acceleration and deceleration, it was made of non-perforated Type 304 stainless steel with twice the wall thickness (0.063 in. = 1.6 mm) of normal-drawer walls. To minimize the possibility of a DP drawer binding in the matrix tube through which it moved, the DP drawer width was made 0.063 in. (1.6 mm) less than that of a normal drawer. A consequence of these two design features was that the width of the plate loading had to be 1/8 inch (3.2 mm) less than the normal 2-inch wide (51 mm) plate loading. To act as a single rigid body, the DP drawer not only had to be thick walled, it had to be at least as long as the combination of a normal front drawer and back drawer. The DP drawer's nominal length was 32 inches (813 mm) which is nearly as long as that of a matrix tube. Finally, the design included a wall at 15 ¼ in. dividing the drawer into front and back compartments. This helped stiffen the drawer, but more importantly, it allowed the drawer's plate loading to be locked in place more effectively, with springs inserted at the back of each compartment.[a]

The full details of a ZPR-3 loading are not contained in published reports because of their complexity. Instead, it was usual to give details of a representative drawer master for each region, the matrix loading map in terms of representative drawer masters, and the average composition for each material region. However, the detailed description of ZPR-3/11 was archived in loading records.

1.2.2 The Matrix and Drawer Loading Data - Figures 4 and 5 are general matrix loading diagrams for the stationary half and movable half, respectively, of the reference ZPR-3/11 core. Note that matrix column 1 is on the left side of Figure 4 but on the right side of Figure 5. This implies that the views are looking from the matrix interface towards the half being shown. These are the views fuel handlers had when installing front drawers into the matrix. The nearly cylindrical boundaries of the core and radial blanket regions are shown. In the locations designated as partial core, the drawers contained both core material and radial blanket material in the patterns shown in Figures 4 and 5 to provide a better approximation of a cylindrical core boundary.

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[a] J. M. Gasidlo, Private Communication, April 7, 2009.

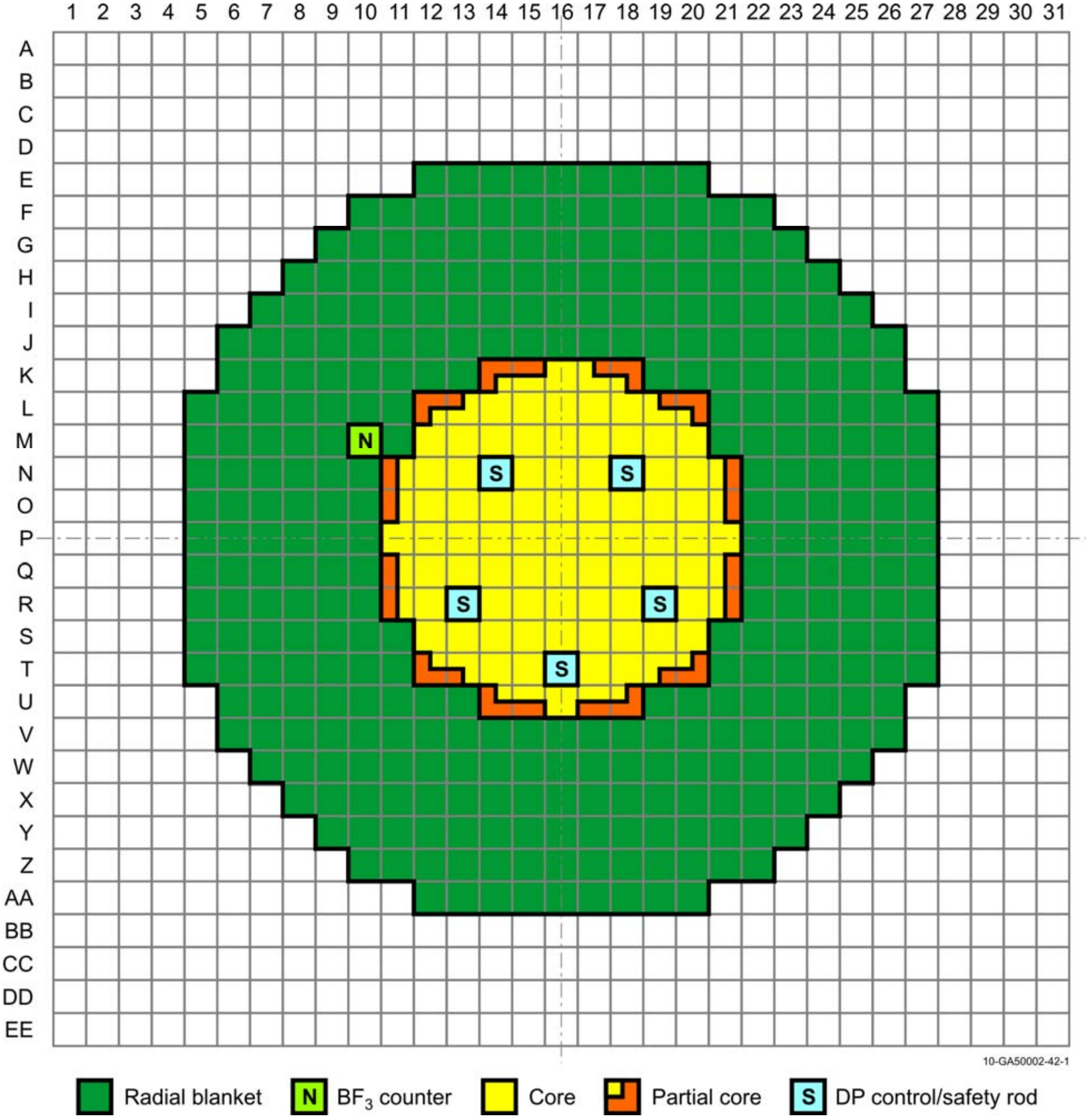

Figure 4. ZPR-3/11 Loading 10 Core Layout – Half 1 (Stationary Half).

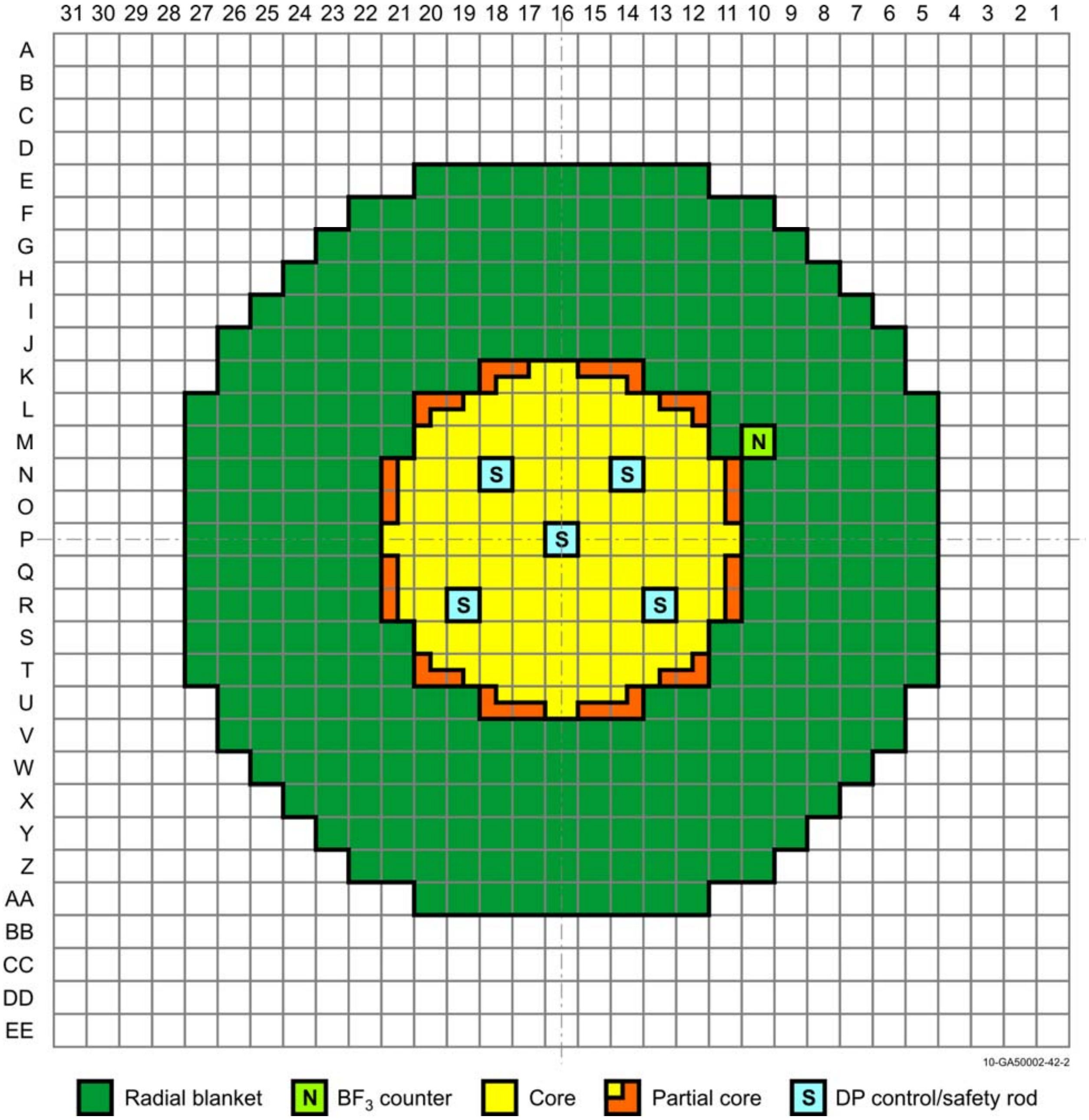

Figure 5. ZPR-3/11 Loading 10 Core Layout – Half 2 (Movable Half).

The position designated N in Figures 4 and 5 contained a BF_3 proportional counter which replaced the equivalent volume of depleted uranium plates at that position. Some of the matrix locations in row P contained a small penetration in the side walls through which a source tube could pass. In cases where the source tube was required, as in ZPR-3/11, the plate loadings in the source tube locations were adjusted to make space for the source tube. Safety documents required the presence of the source tube drawers even if an external neutron source was not needed. The sources were located in S-P/24 and M-P/24 for ZPR-3/11.

Figure 6 shows a normal core drawer master (11-1), and Figure 7 shows a DP control rod drawer master (11C1) in ZPR-3/11. Figure 7 shows only fifteen columns (1.875 in.) of plates because drawer master 11C1 was the DP control drawer in ZPR-3/11. Because of the thicker walls and slightly smaller drawer width in DP drawers, a DP drawer was not wide enough to hold sixteen columns of 0.125 in.-wide plates. Also, Figure 7 shows only the 15 in. of core and axial blanket plates between the drawer front and the divider wall at 15 ¼ in. in the DP drawers. To complete the axial blanket in the DP drawer, 1/8 x 2 x 3 in. depleted uranium plates and 1/8x2x2 in. depleted uranium plates occupied the seven inches immediately behind the divider wall in the DP drawers. For normal drawers, the last seven inches of the depleted uranium axial blanket was placed in a back drawer positioned behind the front drawer.

Figure 8 shows one of the fourteen different partial core drawer masters that were used at the core boundary of ZPR-3/11 loading 10 to produce a better approximation of a cylindrical core boundary. If the front view of a partial drawer master is divided into quadrants, each partial drawer master consisted of one quadrant, two quadrants or three quadrants containing core material. The remaining quadrants contained the depleted uranium radial blanket. The specific quadrants containing core material in a partial drawer varied according to the position of the partial drawer in the matrix relative to the normal core drawers (right, left, above or below), but the core quadrants were always adjacent to the normal core drawers.

Figures 6 – 8 show the drawer masters as they are loaded for the stationary half. When a drawer master is used in the stationary half, the plate loading in the drawer corresponds to Figures 6 – 8. When the same drawer master is used in the movable half, the plate loading order in the X-direction is reversed so the drawer master in the movable half is the mirror image of the corresponding drawer master in the stationary half. This is necessary to ensure that like columns of plates align when the halves of the matrix are brought together. Also, this reversal is necessary for partial drawers in the movable half to ensure that core sections of the partial drawers are adjacent to the normal core drawers in the movable half.

The numbers shown in Figures 6, 7 and 8 indicate the dimensions in inches.

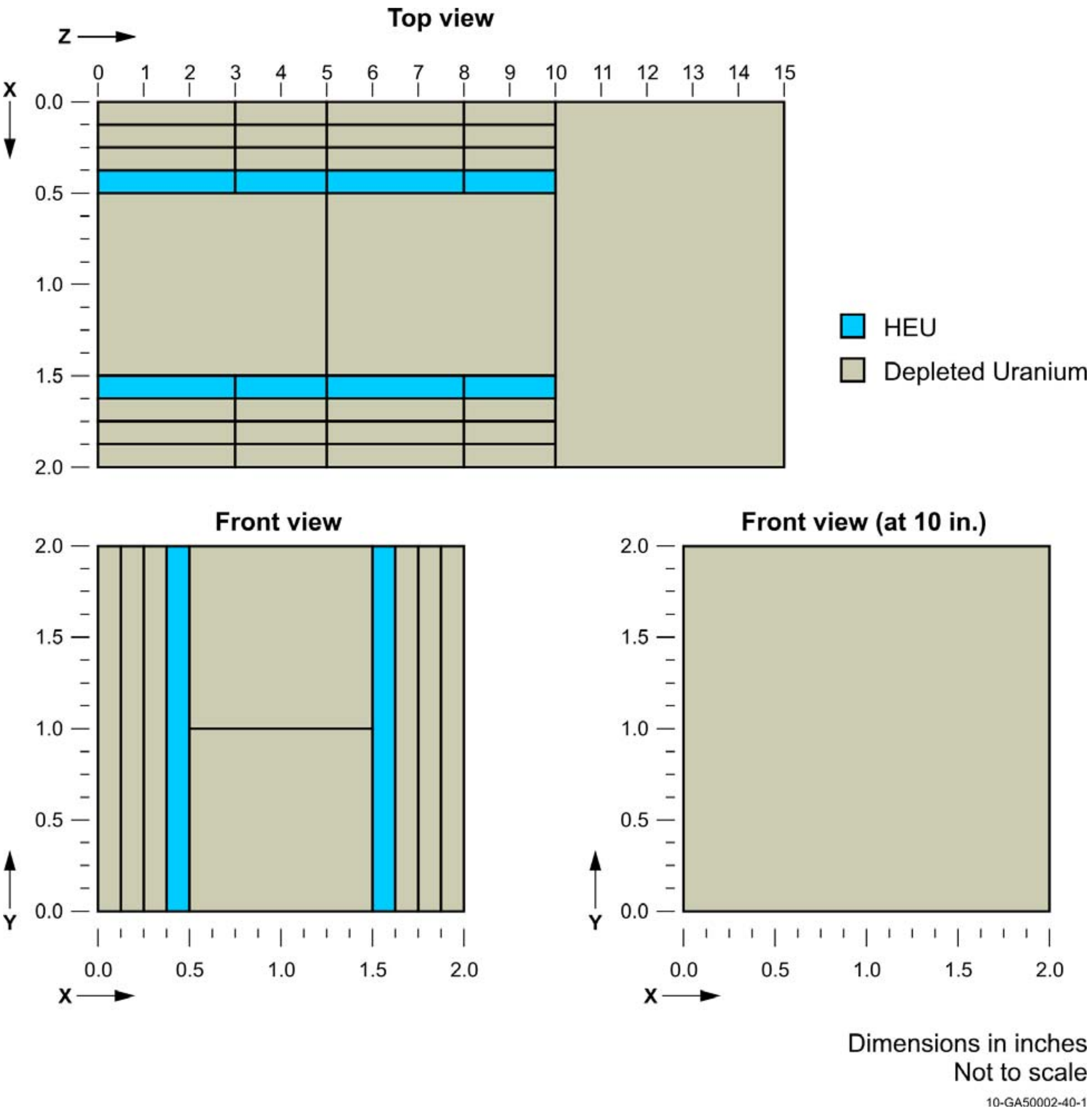

Figure 6. Loading Pattern for ZPR-3/11 Normal Core Drawer Master 11-1.

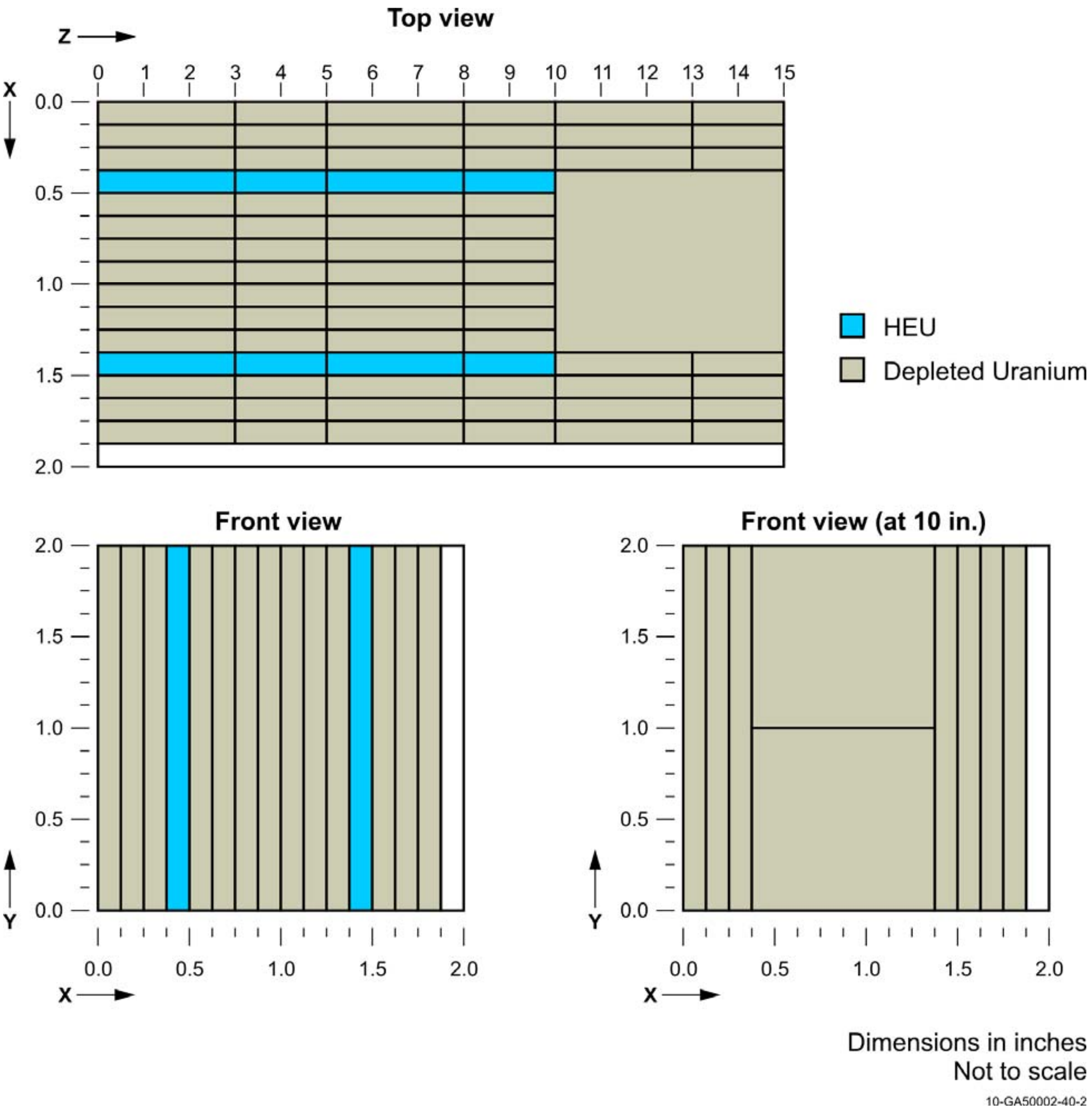

Figure 7. Loading Pattern for ZPR-3/11 DP Control Rod Drawer Master 11C1[a].

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[a] A DP control rod drawer is narrower than a standard drawer. Only fifteen 0.125-in. plate columns can be loaded into a DP control rod drawer.

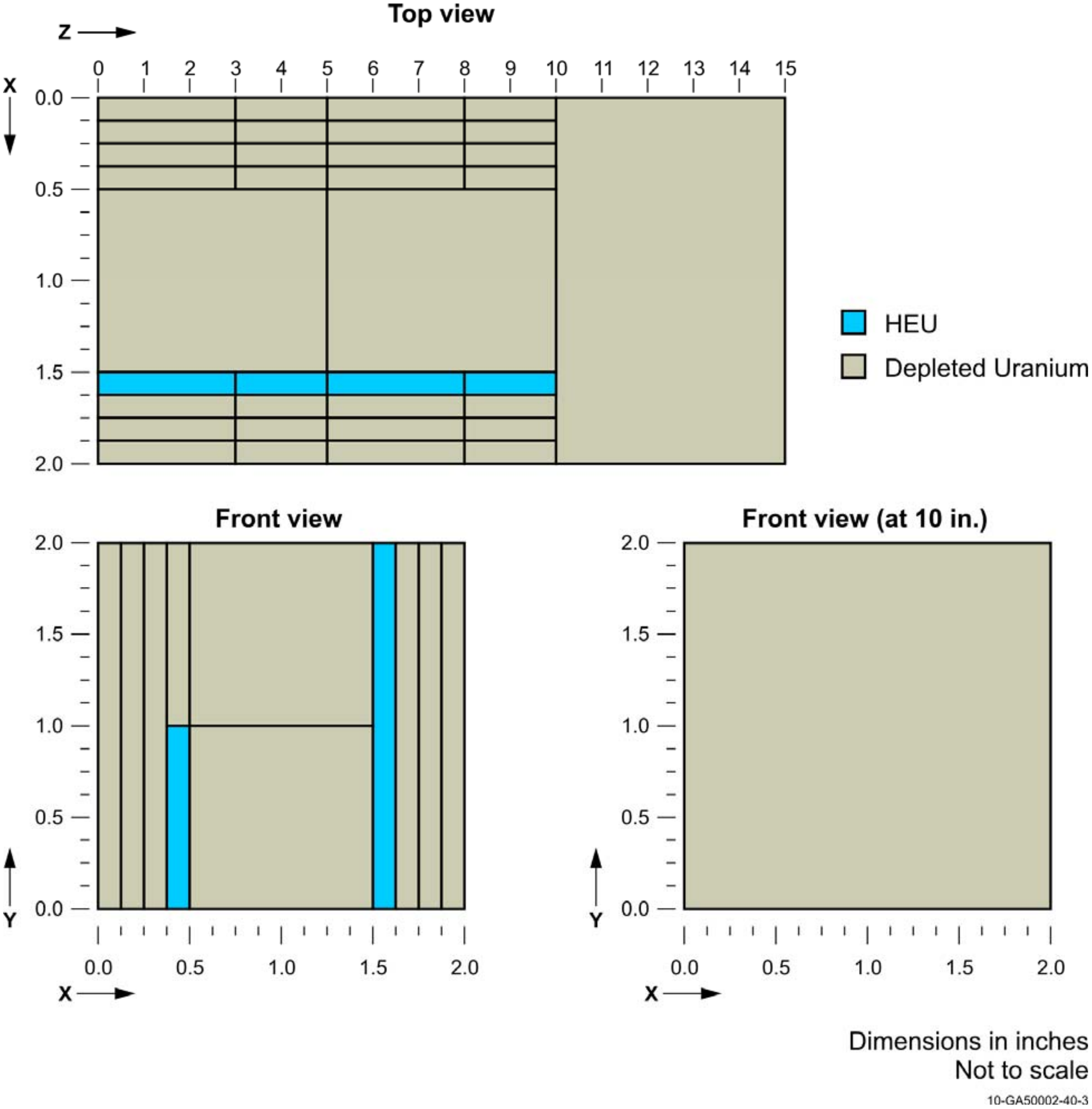

Figure 8. Loading Pattern for ZPR-3/11 Partial Core Drawer Master 11-2.

Detailed matrix loading maps for the stationary and movable halves of ZPR-3/11 loading 10 are shown in Tables 1 - 4. More precisely, Tables 1 and 2 show the front- and back-drawer matrix loadings, respectively, for half 1, the stationary half. Tables 3 and 4 show the front- and back-drawer matrix loadings, respectively, for half 2, the movable half. Note that, unlike the general matrix loading map set, Figures 4 and 5, matrix column 1 is on the left side of all of these tables. This implies that the view in all of these tables is looking from the movable half (half 2) towards the stationary half (half 1).

Since the DP control rod drawer was long enough to accommodate both the core and the axial blanket, there were no actual back drawers behind the DP drawers. The symbol "x" shown in the back-drawer maps for the DP rod positions represent the drive shafts attached to the backs of the DP drawers.

The depleted uranium blocks in the radial blanket were loaded directly into the matrix tubes without drawers. The front drawer maps (Tables 1 and 3) show the drawer masters for the radial blanket, which encompass the full axial height of the radial blanket. The back drawer maps in Tables 2 and 4 show only the actual back drawers behind the 15.25 in. front drawers and the drive shafts of the DP drawers.

A unique one-character symbol is used to represent each drawer master in Tables 1 – 4. A broad look at these tables reveals large portions dominated by a single symbol, i.e., by one drawer master. In the core, the dominant drawer master is 11-1 (identification symbol A), the only full normal core drawer master. In the radial reflector, almost all of the matrix tubes had the same loading of depleted uranium blocks (identification symbol X). Empty spaces in Tables 1 and 3 represent empty matrix tubes.

Table 5 and Table B.1 are used to define completely the drawer master represented by each of the symbols. Table 5 gives the correspondence between the one-character symbols in Tables 1 – 4 and the multi-character drawer master identifiers that appear on the archived drawer master diagrams. Table 5 also gives the length and type of each drawer, and how many of each drawer master type were in ZPR-3/11 loading 10. Drawers of length 15.25 in. are front drawers, while drawers of length 11.25 in. are back drawers. The "partial" designation in Table 5 indicates that this drawer master contained both core material and radial blanket material in the first ten inches. Partial drawers were used to provide a closer approximation of a cylindrical boundary at the core periphery.

Table 1. ZPR-3/11 Loading 10 - Stationary Half Front Drawer Matrix Map.

→ X
↓
Y

COLUMN

ROW	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A																															
B																															
C																															
D																															
E												X	X	X	X	X	X	X	X	X											
F										X	X	X	X	X	X	X	X	X	X	X	X	X									
G									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X								
H								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							
I							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
J						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
K						X	X	X	X	X	X	X	X	U	I	A	L	T	X	X	X	X	X	X	X	X					
L					X	X	X	X	X	X	X	U	B	A	A	A	A	A	E	T	X	X	X	X	X	X	X				
M					X	X	X	X	X	Y	X	A	A	A	A	A	A	A	A	A	X	X	X	X	X	X	X				
N					X	X	X	X	X	X	F	A	A	Z	A	A	A	Z	A	A	G	X	X	X	X	X	X				
O					X	X	X	X	X	X	F	A	A	A	A	A	A	A	A	A	G	X	X	X	X	X	X				
P					X	X	X	X	X	X	A	A	A	A	A	A	A	A	A	A	A	X	X	X	X	X	X				
Q					X	X	X	X	X	X	F	A	A	A	A	A	A	A	A	A	G	X	X	X	X	X	X				
R					X	X	X	X	X	X	F	A	Z	A	A	A	A	A	Z	A	G	X	X	X	X	X	X				
S					X	X	X	X	X	X	X	A	A	A	A	A	A	A	A	A	X	X	X	X	X	X	X				
T					X	X	X	X	X	X	X	R	C	A	A	Z	A	A	D	S	X	X	X	X	X	X	X				
U						X	X	X	X	X	X	X	X	R	H	A	H	S	X	X	X	X	X	X	X	X					
V						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
W							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							
Y									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X								
Z										X	X	X	X	X	X	X	X	X	X	X	X	X									
AA												X	X	X	X	X	X	X	X	X											
BB																															
CC																															
DD																															
EE																															

Table 2. ZPR-3/11 Loading 10 - Stationary Half Back Drawer Matrix Map.

→ X

↓

Y

COLUMN

ROW	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A																															
B																															
C																															
D																															
E																															
F																															
G																															
H																															
I																															
J																															
K														a	a	a	a	a													
L												a	a	a	a	a	a	a	a	a											
M												a	a	a	a	a	a	a	a	a											
N											a	a	a	x	a	a	a	x	a	a	a										
O											a	a	a	a	a	a	a	a	a	a	a										
P											a	a	a	a	a	a	a	a	a	a	a										
Q											a	a	a	a	a	a	a	a	a	a	a										
R											a	a	x	a	a	a	a	a	x	a	a										
S												a	a	a	a	a	a	a	a	a											
T												a	a	a	a	x	a	a	a	a											
U														a	a	a	a	a													
V																															
W																															
X																															
Y																															
Z																															
AA																															
BB																															
CC																															
DD																															
EE																															

Table 3. ZPR-3/11 Loading 10 - Movable Half Front Drawer Matrix Map.

→ X
↓
Y

COLUMN

ROW	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A																															
B																															
C																															
D																															
E												X	X	X	X	X	X	X	X	X											
F										X	X	X	X	X	X	X	X	X	X	X	X	X									
G									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X								
H								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							
I							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
J						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
K						X	X	X	X	X	X	X	X	T	I	A	M	U	X	X	X	X	X	X	X	X					
L					X	X	X	X	X	X	X	T	E	A	A	A	A	A	B	U	X	X	X	X	X	X	X				
M					X	X	X	X	X	Y	X	A	A	A	A	A	A	A	A	A	X	X	X	X	X	X	X				
N					X	X	X	X	X	X	G	A	A	Z	A	A	A	Z	A	A	F	X	X	X	X	X	X				
O					X	X	X	X	X	X	G	A	A	A	A	A	A	A	A	A	F	X	X	X	X	X	X				
P					X	X	X	X	X	X	A	A	A	A	A	Z	A	A	A	A	A	X	X	X	X	X	X				
Q					X	X	X	X	X	X	G	A	A	A	A	A	A	A	A	A	F	X	X	X	X	X	X				
R					X	X	X	X	X	X	G	A	Z	A	A	A	A	A	Z	A	F	X	X	X	X	X	X				
S					X	X	X	X	X	X	X	A	A	A	A	A	A	A	A	A	X	X	X	X	X	X	X				
T					X	X	X	X	X	X	X	S	D	A	A	A	A	A	C	R	X	X	X	X	X	X	X				
U						X	X	X	X	X	X	X	X	S	H	A	H	R	X	X	X	X	X	X	X	X					
V						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
W							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							
Y									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X								
Z										X	X	X	X	X	X	X	X	X	X	X	X	X									
AA												X	X	X	X	X	X	X	X	X											
BB																															
CC																															
DD																															
EE																															

Table 4. ZPR-3/11 Loading 10 - Movable Half Back Drawer Matrix Map.

→ X
↓
Y

COLUMN

ROW	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A																															
B																															
C																															
D																															
E																															
F																															
G																															
H																															
I																															
J																															
K														a	a	a	a	a													
L												a	a	a	a	a	a	a	a	a											
M												a	a	a	a	a	a	a	a	a											
N											a	a	a	x	a	a	a	x	a	a	a										
O											a	a	a	a	a	a	a	a	a	a	a										
P											a	a	a	a	a	x	a	a	a	a	a										
Q											a	a	a	a	a	a	a	a	a	a	a										
R											a	a	x	a	a	a	a	a	x	a	a										
S												a	a	a	a	a	a	a	a	a											
T												a	a	a	a	a	a	a	a	a											
U														a	a	a	a	a													
V																															
W																															
X																															
Y																															
Z																															
AA																															
BB																															
CC																															
DD																															
EE																															

Table 5. Drawer Identification and Type Data.

Identification Symbol	Drawer Master Identifier	Role of Drawer	Length (inches)	Number in ZPR-3/11 Loading 10
Core Drawer Masters				
A	11-1	Normal Core	15.25	144
B	11-2	Normal Core/Partial	15.25	2
C	11-3	Normal Core/Partial	15.25	2
D	11-4	Normal Core/Partial	15.25	2
E	11-5	Normal Core/Partial	15.25	2
F	11-6	Normal Core/Partial	15.25	8
G	11-7	Normal Core/Partial	15.25	8
H	11-8	Normal Core/Partial	15.25	4
I	11-9	Normal Core/Partial	15.25	2
L	11-12	Normal Core/Partial	15.25	1
M	11-13	Normal Core/Partial	15.25	1
R	11-18	Normal Core/Partial	15.25	4
S	11-19	Normal Core/Partial	15.25	4
T	11-20	Normal Core/Partial	15.25	4
U	11-21	Normal Core/Partial	15.25	4
Control Rod Drawer Masters				
Z	11C1	DP Safety/Control Rod	32.50	10
x	Drive shaft	DP Drive Shaft	-----	10
Reflector Drawer Masters				
X	238	Radial Blanket	22.00	670
a	11-00	Axial Blanket	11.25	192
Y	bf3	BF_3 Detector Radial Blanket	22.00	2

Table 6 provides the drawer plate loading description for drawer master 11-1. Table B.1 in Appendix B provides the drawer plate loading description for each drawer master used in ZPR-3/11 loading 10. The information in Table 6 is provided to accompany the explanation of the drawer plate loading descriptions in Table B.1. All dimensions and locations in Table 6 and Table B.1 are in inch units.

There is a header row starting the description of each drawer master. The header gives the one-character identification symbol and the multi-character identifier of the drawer master. Each remaining row for the drawer master describes a contiguous block of identical plates. The row gives a) the plate name and nominal dimensions, b) the starting position of the block, c) the number of plates in the block in each direction, and d) a rotation code (spatial orientation) for the block of plates. Table 6 and Table B.1 do not include the small spring placed in the back of each normal drawer to push the plates toward the front of the drawer.

Most plates were loaded with the standard orientation, designated by rotation code 1. Consider, for example, the 1/8x2x3 in. depleted uranium plate in Table 6. The standard orientation is that the first plate dimension (1/8 in.) is in the X-direction, the second plate dimension (2 in.) is in the Y-direction and the third plate dimension (3 in.) is in the Z-direction. A rotation code of 4 corresponds to rotating the plate 90 degrees about the X-axis. A rotation code of 5 corresponds to rotating the plate 90 degrees about the Z-axis. A rotation code of 6 means the plate is rotated 90 degrees about the Y-axis.

It should be noted that the number of decimal places in the starting locations in Table 6 and Table B.1 does not mean that those locations were known that accurately. Rather, it reflects the fact that some ZPR plate types had thicknesses of 0.0625 in., so the code that produces these tables must accommodate more than three decimal places for some assemblies. Thus, despite the displayed precision, the locations shown in Table 6 and Table B.1 are just nominal locations.

Unless otherwise noted for a specific case, the first dimension for any plate, drawer or other rectangular object is the X-dimension, the second dimension is the Y-dimension and the third dimension is the Z-dimension. For example, for a plate with listed dimensions of 1/8 x 2 x3 in., 1/8 in. is the X-dimension, 2 in. is the Y-dimension and 3 in. is the Z-dimension. This convention applies throughout this document.

If the drawer master appears in both a stationary-half and a movable-half matrix map (Tables 1 - 4), then the starting X location of the block must be transformed when the master is used in the movable half. The header row of all such drawer masters includes a warning to that effect. The starting X location can be used directly in all other cases. The transformation is specified where the table is interpreted below.

Table 6. Drawer Plate Loading Description for ZPR-3/11 Drawer Master 11-1[(a)].

Plate ID (dimensions in inches)	**Starting X Location**	**Starting Y Location**	**Starting Z Location**	**X #**	**Y #**	**Z #**	**Rotation**
Identification Symbol A, Drawer Master 11-1, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	3	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	8.0000	1	1	1	1
Depleted Uranium (1x1x5) - APW	0.5000	0.0000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	0.5000	1.0000	0.0000	1	1	2	1
U(93) (1/8x2x3)	1.5000	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	1.5000	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	8.0000	1	1	1	1
Depleted Uranium (1/8x2x3) – APW	1.6250	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) – APW	1.6250	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) – APW	1.6250	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) – APW	1.6250	0.0000	8.0000	3	1	1	1
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1

(a) All dimensions and locations are in inch units.

The interpretation of the information given in Table 6 will be illustrated by explaining the first drawer master (11-1) described therein with the aid of the loading pattern diagram in Figure 9 below. Note that Figure 9 is a duplicate of Figure 6 above and is reproduced here for the convenience of the reader. Figure 9 presents an X-Z view, i.e., looking down at the top of this drawer master, and shows the columns of plates. (The drawer itself is not shown – only its contents.) The origin of the drawer master coordinate system is at the front lower left corner of the space inside the drawer, which is near the upper left corner of the figure. The X-axis is along the drawer width and is divided in eighth-inch units from zero to two inches (16 eighths). The Z-axis

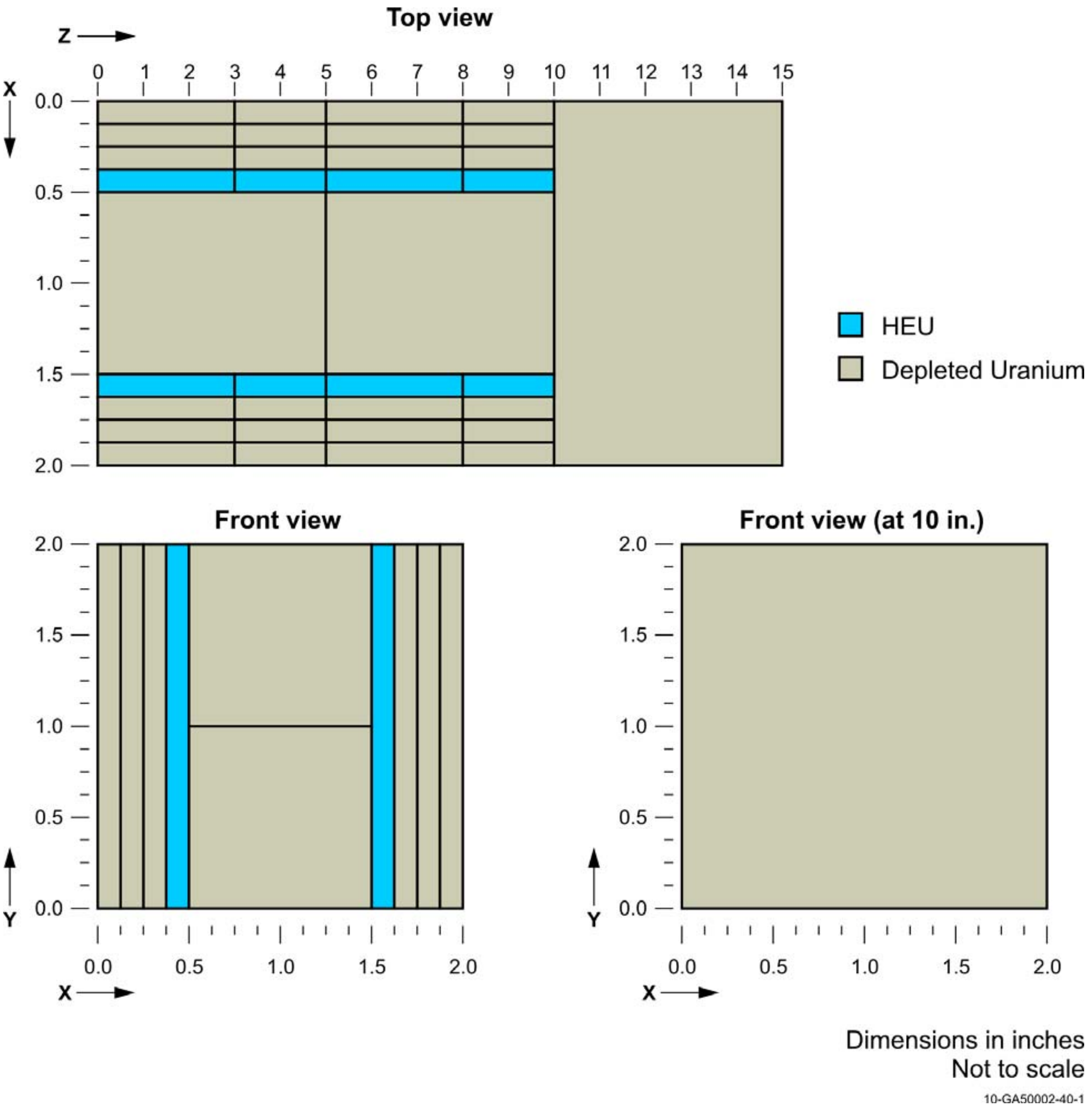

Figure 9. Loading Pattern for ZPR-3/11 Drawer Master 11-1.

is along the drawer length and goes from zero to 15 inches in inch units.[a] The Y-axis is transverse to the page, pointing towards the viewer, and the range encompassing the plate loading is from zero to two inches. The plates displayed in Figure 9 are 2 inches tall.

For each row the plate ID gives an approximate indication of the plate material. A full composition description is given in Section 1.3. The remaining columns of Table 6 give the starting position of the plate within the drawer, the number of contiguous plates in each direction and the rotation parameter.

The drawer master in Table 6 is 11-1, identification symbol A. This is a normal core drawer. In the core region, which extends from 0 to 10 in., columns 1, 2, 3, 7, 8 and 9 each consist of one 1/8x2x3 in. depleted uranium (DU) plate, one 1/8x2x2 in. DU plate, one 1/8x2x3 in. DU plate and one 1/8x2x2 in. DU plate. Columns 4 and 6 each consist of one 1/8x2x3 in. HEU plate, one 1/8x2x2 in. HEU plate, one 1/8x2x3 in. HEU plate and one 1/8x2x2 in. HEU plate. Column 5 consists of two 1x1x5 in. DU plates at Y=0 in. and two 1x1x5 in. DU plates at Y=1.0 in. The last five inches of the drawer, which extends from 10 in. to 15 in., is occupied by one 2x2x5 in. DU block. This block forms the first 5 in. of the axial blanket. Table 6, Table B.1 and Figure 9 do not show the small retainer spring at the back of the drawer. This spring pushed the plates forward to eliminate any gap between the front of the plates and the front plate of the drawer.

In using these loading data, one must keep in mind the difference between the convention for identifying matrix positions in the two halves and the convention for viewing drawer masters in the two halves. It was noted in Section 1.2.1 that, for both halves, the matrix column number (essentially the X-coordinate) is counted from the left when looking from the movable half towards the stationary half. In contrast, the origin of the drawer master coordinates is at the left edge of the plates when looking from the matrix interface (Z=0) towards the matrix half that contains the drawer. The perspective is the same in both conventions for the stationary half but opposite for the movable half.

ZPR-3/11 was built early enough in the history of the ZPR-3 facility operations that the supervisors and technicians who loaded the drawers were responsible for interpreting drawer masters differently depending on where drawers were to be loaded. At that time, it was allowed to define a single drawer master for use in loading positions in both halves of the matrix, even when the master was asymmetric about the X midplane. In working from such a drawer master, the person loading a drawer destined for the stationary half would follow the drawer master exactly as presented. But, if the drawer based on that master was destined for the movable half, the person would have to load plate columns in opposite order in the X direction to what appeared in the drawer master. A further complication was that this need to reverse the drawer master order of plate columns only applied to drawer masters that were used for both matrix halves; if the drawer master was used only for drawers in the movable half, it was defined to be read as is. Later on in the history of ZPR-3—as well as during the entire history of ZPR-6, ZPR-9 and ZPPR—it was required that different drawer masters be defined for each half (with the possible exception of symmetric drawer masters), presumably because the early system presented an unnecessary risk of a loading error.

A consequence of the effort to be faithful to what the loading records actually show is that the reader here gets to share in the potential confusion created by this early system. As noted in the paragraph immediately preceding Table 6, drawer masters subject to this X-direction-reversal requirement are identified as such in their header row. When using one of these drawer masters to represent a drawer in the movable half, the printed Starting X Location number is transformed as follows: take the tabulated value, add to it the nominal plate width (from the first column) and subtract that sum from 2.0000. For example, in the second drawer master in Table B.1, 11-2, the starting X location of the 1/8x2x1 HEU plates becomes 2.0000 – (0.3750 + 0.1250) = 1.5000 in the movable half. Consider Figure 8, the drawing of this same drawer master. For insertion into the stationary half, the drawer would be loaded exactly as shown in Figure 8. For a drawer to

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[a] Note that the coordinate convention for ZPR assemblies is unusual in that the Z direction is horizontal, not vertical.

be loaded into the movable half, the order of the plate columns would be reversed; for instance the 1/8x2x1 HEU plates would be loaded to the right of center rather than to the left of center. Reversing the loading order in the drawer for the movable half ensures that like columns of plates align when the two halves of the matrix are brought together.

Although the loading data in this subsection and in Table B.1 are complete and well suited for processing with a computer, they obviously are cumbersome to interpret by hand. An interpretation of the geometric region implications of the data is offered in the next subsection.

1.2.3 Characteristics of the Assembly Regions - When the early ZPR-3 assemblies were built, analytical capabilities and calculational tools were extremely limited. At that time simple spherical, cylindrical and slab models were the only practical options for analyzing many of the critical assemblies. The partial drawers listed in Tables 5 and B.1 were used to smooth the core boundary, reduce edge effects and improve the cylindrical approximation.

The core was loaded into the first 10 in. of the 15.25 in. front drawer shown in Figure 6 and the first 10 in. of the DP control drawer shown in Figure 7 above. The first 5 in. of the axial blanket was loaded behind the core in the front drawers. The remaining 7 in. of the axial blanket was loaded into back drawers which were loaded behind the front drawers containing the core. The only exceptions to the front drawer-back drawer pairing were the DP drawers which were long enough to contain the 10 in. core and 12 in. axial blanket. The radial blanket consisted of 22 in. of depleted uranium blocks per half. These blocks were loaded directly into the matrix tubes. The thickness of the radial blanket was approximately 14 in.

ZPR-3/11 had relatively few complications for a ZPR assembly. There were few drawer masters. There were no perturbations to the core and axial reflector except for the small composition deviation in the DP rod locations. There were a small number of minor perturbations in the radial reflector—source tube drawer master and detector drawer master— but all of these were outside the core. The geometry was about as close to cylindrical as possible. The thick depleted uranium radial and axial blankets made room return insignificant.

1.2.4 Measurement Technique and Excess Reactivity - Excess reactivity is the system reactivity when all control elements are in their most reactive positions. Excess reactivities in ZPR-3/11 were measured with a calibrated control rod. No information concerning the method used to calibrate the control rods is available.

The reference critical configuration had DP control drawer #10, which was in S-T/16, withdrawn 5.885 in. when the reactor was at the reference power level. The other nine DP drawers were fully inserted. The matrix temperature listed in the logbook was 20.9 °C. No measured temperature coefficient for ZPR-3/11 has been found.

No reported excess reactivity has been found for ZPR-3/11 loading 10. Determination of the excess reactivity from the position of DP control drawer #10 is discussed in Section 2.

1.3 Description of Material Data

Composition data presented here were taken from several sources. Some of the composition data were taken from the electronic plate material library (ADEN library). These data are essentially the same as those in the most recent issue of a ZPR/ZPPR working document referred to informally as the “hot constants memo.” That issue was first released in 1983, after all of the other ZPR facilities were shut down, and was updated periodically until the shutdown of ZPPR.

Earlier versions of the hot constants memo—from ZPR-3, from the early period of ZPR-6&9, and the final (1978) version from ZPR-6&9—were consulted to resolve ambiguities about material description details, to infer which "lot" of material could have been used in ZPR-3/11 and to supply data missing from the ADEN library. Specifically, it was necessary to consult earlier documents because the depleted uranium plates used in ZPR-3/11 were replaced in 1962. Consequently, the depleted uranium plates used in ZPR-3/11 are not listed in the last ZPPR hot constants memo or the ADEN library. Data for the depleted uranium plates were taken from the earliest available ZPR-3 hot constants memo. Appendix A of the published ZPR-3/48 document ANL-7759 also has relevant composition and geometry details. In the case of ambiguities, preference was given to the data source closest in time to the date of the experiment.

The original documentation on most of the inventory used in ZPR-3/11 has been lost. The hot constants memos (and the ADEN library) give average compositions by batch or lot, which are what are given in the tables below. The memos do not give uncertainties, and the issue of estimating composition uncertainties is addressed in Section 2.

This section also contains material dimensions, some details of which were not presented in Section 1.2. Available data on wall thicknesses of plate cladding and drawers were collected in the 1980s and put into an electronic cladding library. That is the source of such data presented here. Plate outer dimensions given below are the nominal values from the hot constants memos, which are all that are available, except in rare instances. **In all tables in this section, dimensions are provided in units of inches.**

Most masses and weight percents in the inventory are time invariant, with the only significant exceptions being those for ^{241}Pu and ^{241}Am. Since these time-dependent nuclides were not present in ZPR-3/11, there is no decay issue here.

Table 7 shows the mass and composition information for the three types of HEU plates present in the ZPR-3/11 loading 10 core. The number of plates shown in this and similar tables is the number used in loading 10. The HEU plates were coated with Kel-F, a paint-like protective coating applied to minimize corrosion and material loss during handling. The average mass of Kel-F per plate was 0.083 g for 1/8x2x3 in. plates, 0.057 g for 1/8x2x2 in. plates and 0.030 g for 1/8x2x1 in. plates. Table 8 shows the composition of Kel-F. The mass values for H, C, F and Cl in Table 7 are the average masses of Kel-F per plate listed in the preceding sentence multiplied by the weight percents listed in Table 8. The actual thickness of the Kel-F coating on the plates is not known.

Table 7. Mass and Composition of the HEU Plates.

Plate ID	HEU (1/8x2x3)	HEU (1/8x2x2)	HEU (1/8x2x1)
Nominal Size (in.)	0.125x2.0x3.0	0.125x2.0x2.0	0.125x2.0x1.0
Number of Plates	680	680	130
Element	Mass (g)	Mass (g)	Mass (g)
^{234}U	2.0058	1.3031	0.6583
^{235}U	206.1900	134.2100	67.2200
^{236}U	0.9698	0.6301	0.3183
^{238}U	11.9244	7.7468	3.9134
H	0.00042	0.00029	0.00015
C	0.01710	0.01174	0.00618
F	0.04017	0.02759	0.01452
Cl	0.02532	0.01739	0.00915

Table 8. Kel-F Composition.

Element	Weight Percent
Hydrogen	0.5
Carbon	20.6
Chlorine	30.5
Fluorine	48.4

Table 9 shows the mass and composition information for the four types of depleted uranium plates used in the core and the two types of depleted uranium plates in the axial and radial blankets. The hot constants memos and ADEN library only list a combined mass of ^{234}U and ^{238}U for the depleted uranium plates. No additional information regarding the ^{234}U is available.

The depleted uranium plates were coated with Kel-F. The average mass of Kel-F per plate was 0.083 g for 1/8x2x3 in. plates, 0.057 g for 1/8x2x2 in. plates and 0.030 g for 1/8x2x1 in. plates in Table 9. The average mass of Kel-F per plate was 0.14 g for 1x1x5 in. plates, 0.15 g for 2x2x2 in. plates and 0.30 g for 2x2x5 in. plates in Table 9. The mass values for H, C, F and Cl in Table 9 are the average masses of Kel-F per plate listed in the preceding sentences multiplied by the weight percents listed in Table 8.

Table 9. Mass and Composition of the Depleted Uranium Plates.

Plate ID	Depleted U (1/8x2x1)	Depleted U (1/8x2x2)	Depleted U (1/8x2x3)	Depleted U (1x1x5)	Depleted U (2x2x2)	Depleted U (2x2x5)
Nominal Size (in.)	0.125x2.0x1.0	0.125x2.0x2.0	0.125x2.0x3.0	1.0x1.0x5.0	2.0x2.0x2.0	2.0x2.0x5.0
Number of Plates	130	3010	2860	788	864	3072
Element	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)
^{235}U	0.15	0.30	0.45	3.07	4.92	12.36
^{238}U	72.60	147.94	221.46	1528.93	2453.08	6167.64
H	0.00015	0.00029	0.00042	0.00070	0.00075	0.00150
C	0.00618	0.01174	0.01710	0.02884	0.03090	0.06180
F	0.01452	0.02759	0.04017	0.06776	0.07260	0.14520
Cl	0.00915	0.01739	0.02532	0.04270	0.04575	0.09150

Slightly different compositions for the Type 304 stainless steel drawers and matrix tubes are given in different documents. These are shown in Table 10. Only the first composition totals to 100 wt.%. The stainless steel compositions listed in Table 10 differ from current (2010) standard specifications for Type 304 stainless steel and may differ from the standard specifications for this steel in the early 1950s when the drawers and matrix tubes were fabricated. The compositions listed in Table 10 are the values reported by the experimenters and are the values used by ZPR-3 personnel for planning and analysis of experiments.

Table 10. Element Wt% Data for Type 304 Stainless Steel Drawers and Matrix Tubes

Source	Component	Fe	Cr	Ni	Mn	Si	Total
ANL-7759, Appendix A[(a)]	plate-drawer-tube average	73.4	17.0	8.4	0.75	0.45	100.0
ZPR-3 Hot Constants[(b)]	plate-drawer-tube average	71.4	17.0	8.4	0.74	0.44	98.0
ZPR-3 Hot Constants[(b)]	matrix tubes	72.0	16.9	7.8	0.7	0.50	97.9
ZPR-3 Hot Constants[(b)]	drawers	70.0	17.4	9.6	1.5	0.36	98.9

(a) A. M. Broomfield *et al*, “ZPR-3 Assemblies 48, 48A, and 48B: The Study of a Dilute Plutonium-fueled Assembly and Its Variants,” Argonne National Laboratory Report ANL-7759, December 1970.
(b) W. P Murphy and R. Rowberry, ZPR-3 Hot Constants Memo, July 14, 1966.

The masses and dimensions of the stainless steel drawer components and of the matrix tubes that are given explicitly in Appendix A of ANL-7759 are shown in Table 11. The ZPR-3 hot constants memos give no drawer component dimensions but give the same masses. Explicit data are not given in either reference for drawer back plates or the DP compartment divider, but values can be inferred. The mass is per inch of length in the Z-direction for the matrix tube and for drawer bottom + sides. The normal drawer components had smaller masses than the DP drawer components because the DP drawer walls were twice as thick and were non-perforated, while the normal drawers were perforated. The first dimension in Table 11 is the X-dimension (width), the second dimension in Table 11 is the Y-dimension (height), and the third dimension in Table 11 is the Z-dimension (thickness or length).

Table 11. Mass and Dimensions of Stainless Steel Drawer and Matrix Components.

Plate ID	DP Front Plate	DP Bottom + Sides[(a)]	Normal Front Plate	Normal Bottom + Sides[(a)]	Matrix Tube[(a)]
Outside Dimensions (in.)	2.001x2.063x0.063	2.001x2.063x1 (0.063 wall)	2.064x2.035x0.032	2.064x2.035x1 (0.032 wall)	2.1835x2.1755x1 (0.040 wall)
Mass (g)	31.00	48.44	9.85	10.36	44.64

(a) Mass per inch of length for bottoms+sides of drawers and for the matrix tube.

The normal drawer front plate, back plate and sides were 0.032 in. (0.8128 mm) thick.[a]

The retainer springs were made of mild steel. The mass by element for a spring is: 9.862 g Fe, 0.097 g C. One retainer spring was used at the back of each normal front or back drawer. To prevent any plate shifting under acceleration or deceleration of the DP control rod drawers, as many retainer springs as possible (up to four) were pressed into the gap at the back of each of the two compartments of each DP drawer.[b]

Each DP drawer is divided into two compartments by a small plate at Z = 15.25 in., and each DP drawer is connected to a control rod drive by a shaft attached to the back of the drawer. No further information has been discovered regarding the dimensions or compositions of these components. The divider plate was

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[a] W. R. Robinson and K. E. Freese, ZPR-6&9 Hot Constants Memo, p. 36, 1978.
[b] J. M. Gasidlo, Private Communication, April 9, 2009.

represented in the as-built ZPR-3/11 model by a 1.75 x 2.0 x 0.0625 in. steel plate containing 0.006 g C, 0.071 g Si, 5.620 g Cr, 0.440 g Mn, 21.246 g Fe, 3.356 g Ni, 0.012 g Cu and 0.003 g Mo. The DP control rod drive shaft was represented in the as-built ZPR-3/11 model by a column of 0.25 x 2 x 1 in. steel plates containing 0.030 g C, 0.170 g Si, 11.677 g Cr, 0.954 g Mn, 44.258 g Fe, 5.437 g Ni, 0.130 g Cu and 0.260 g Mo per plate.

1.4 Supplemental Experimental Measurements

A list of experiments performed in ZPR-3/11 is given below.

- Criticality.
- Fission rate ratios.
- Rossi alpha.
- Small sample worths.
- Track plate irradiations.

This list was compiled from the loading records and logbook. The only available data for measurements other than criticality are summarized in the Cross Section Evaluation Working Group Benchmark Specifications[a]. Available information is not sufficient to evaluate any measurements other than criticality.

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[a] Cross Section Evaluation Working Group Benchmark Specifications, BNL-19302, Vol. II, (ENDF 202) (September 1986).

2.0 EVALUATION OF EXPERIMENTAL DATA

The reactivity effects of many of the uncertainties discussed below were quantified using TWODANT[a] (two-dimensional S_N code) RZ models of the benchmark. The radial boundaries preserved the area of each region in the X-Y plane of the X-Y-Z geometry as-built model. Axial boundaries preserved the volumes of the core, radial blanket, lower axial blanket (the portion inside the front drawer), upper axial blanket (inside the back drawer) and the small volume between the lower and upper axial blanket regions which consists of the retainer spring and back plate of the front drawer plus the front plate of the back drawer. The calculations used cross sections derived from ENDF/B-V.2 data using the Argonne cross section processing codes ETOE-2/MC^2-2/SDX.[b] The eigenvalue convergence criterion was 10^{-7}, which allowed any non-negligible effect ($> 10^{-4}\Delta k$) to be computed explicitly with a pair of TWODANT calculations. The uncertainties are displayed in units of $\%\Delta k$ (100 times the change in k_{eff}). For consistency in accounting, they are displayed to four decimal places, even though that level of precision is not always justified on physical grounds.

The uncertainties affecting criticality have been divided into three broad categories. They are uncertainties associated with 1) measurement technique, 2) geometry, and 3) compositions. Each category is considered in turn and then the combined experimental uncertainty is presented. Two adjustments to the measured excess reactivity are also identified. Each uncertainty estimate is one standard deviation.

2.1 Measurement Technique Uncertainties

Excess reactivities in ZPR-3/11 were measured with calibrated control rods. Details regarding the calibration technique are not available. The reference critical configuration had DP control drawer #10 withdrawn 5.885 inches when the reactor was at the reference power level. All other DP drawers were fully inserted. The matrix temperature listed in the logbook for the reference reactor startup is 20.9 °C.

No reported excess reactivity has been found for ZPR-3/11, so the excess reactivity was computed by continuous energy Monte Carlo as the difference between k_{eff} for the as-built model with all DP rods fully inserted and k_{eff} for the as-built model with DP control rod #10 withdrawn 5.885 inches. The computed excess reactivity for ZPR-3/11 loading 10 is 0.1289 ± 0.0038 %Δk based on one billion histories for each configuration. For each configuration, ten independent calculations with different seed random numbers were performed. Each calculation consisted of 500 generations with 200,000 particles per generation after skipping the initial 100 generations to converge the source.

The ± 0.0038 %Δk uncertainty in the preceding paragraph is just the Monte Carlo statistical uncertainty. Uncertainties in cross section data make an additional contribution. The DP rod withdrawal worth is similar to the central worth of the core composition, which typically can be computed quite accurately by k-difference. The 1σ uncertainty on this quantity is estimated to be no more than 3% of the worth or ± 0.0039 %Δk. The combined uncertainty, then, is ± 0.0054 %Δk.

There also are a few uncertainty contributions associated with the core temperature. It was acknowledged, in an internal report,[c] that the thermocouple average was not the true core average, although it was a reliable parameter to measure changes in true core-average temperature. During the early programs at ZPR-3, there was only one thermocouple in each half of the matrix.

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[a] R. E. Alcouffe, F. W. Brinkley, D. R. Marr, and R. D. O'Dell, "User's Guide for TWODANT: A Code package for Two-Dimensional, Diffusion-Accelerated, Neutral-Particle Transport," LA-10049-M, Revised February 1, 1990.

[b] B. J. Toppel, H. Henryson II, and C. G. Stenberg, "ETOE-II/MC^2-2/SDX Multigroup Cross Section Processing," RSIC Seminar Workshop on Multigroup Cross Sections, ORNL, (March 14, 1978).

[c] W. G. Davey and R. L. McVean, Private Communication, March 1969.

The logbook lists a single matrix temperature of 20.9 °C for the reference reactor startup. Based on the temperature ranges for the reference critical configurations for ZPR-3/6F (see IEU-MET-FAST-015, Section 2.1) and ZPR3/12 (see IEU-COMP-FAST-004, Section 2.1), a value of 1 °C is taken to represent ±1σ of the true core temperature. No measured temperature coefficient has been found for ZPR-3/11, so the Argonne cross section processing codes discussed above were used with the TWODANT model to compute a temperature coefficient for ZPR-3/11. The computed temperature coefficient for ZPR-3/11 was -8.027×10^{-4} %Δk/°C. Using this temperature coefficient with the 1 °C temperature uncertainty yields a reactivity uncertainty of ±0.0008 %Δk.

The uncertainty in the calibration of the TCs, which is a systematic uncertainty, is estimated to be 0.5 °C. This converts to a ±0.0004 %Δk uncertainty in excess reactivity. When added in quadrature with the ±0.0008 %Δk averaging uncertainty from above, the combined uncertainty is ±0.0009 %Δk. This value is negligible compared to other uncertainties discussed below, so further effort with respect to refining temperature uncertainties is not warranted.

The final core temperature issue is that the temperature distribution in the core changed when the matrix halves closed. It took significant time to establish the new asymptotic distribution and, "in those days," sufficient time was not always allowed.[a] According to the logbook, the startup occurred at 8:30 AM, and shutdown occurred at 9:25 AM on January 21, 1958. This was the first startup of the day. The decay heat source in ZPR-3/11 was very small because of the very long half-lives of the uranium isotopes that made up the radioactive components of the core composition. Given the short operating time and the low decay heat source, it does not seem likely that core heating over the duration of the measurement would be a significant issue. For this startup, the asymptotic temperature uncertainty effect is assumed to be less than 0.001 %Δk.

Estimates of the configuration reproducibility uncertainty are not available. In ZPR-3/56B (see MIX-COMP-FAST-004, Section 2.1), ±2.5 Ih[b] or ±0.0059 %Δk was adopted as a reasonable 1σ estimate of the reproducibility uncertainty based on repeated measurements. The decay heat source in ZPR-3/11 is much smaller than the decay heat source in ZPR-3/56B. It is likely that the ZPR-3/56B results would bound the ZPR-3/11 case. Dividing this bounding value by $\sqrt{3}$ yields the 1σ uncertainty ± 0.0034 %Δk as the estimated reproducibility uncertainty for ZPR-3/11. This uncertainty is small relative to uncertainties related to geometry and composition, so further refinement of the worth of the reproducibility uncertainty is not warranted.

The conversion from the natural measurement units, inhours (Ih), to units of k_{eff} requires knowledge of the delayed neutron kinetics parameters, particularly β_{eff}. The estimated uncertainty in the reactivity conversion factor was 5% in previous ICSBEP benchmarks for ZPR assemblies. That value will be used here for consistency. This uncertainty is normally applied to the measured excess reactivity which usually was reported in units of inhours for ZPR assemblies.

In the present case no reported excess reactivity was found, so the excess reactivity was computed as the difference in reactivity between the as-built model with all rods fully inserted and the as-built model with DP control rod #10 withdrawn 5.885 in., the reported critical rod position. A reported excess reactivity corresponds to the difference between these two configurations. Likewise, no measured temperature coefficient was found, so a temperature coefficient was computed for ZPR-3/11. The calculated excess reactivity and the reactivity uncertainties associated with the temperature uncertainties are in units of k_{eff}, so there is no need to apply the uncertainty in the reactivity conversion factor to the computed excess reactivity or to the temperature uncertainties.

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[a] J. M. Gasidlo, Private Communication, April 9, 2009.

[b] An inhour (Ih) is a unit of reactivity and is defined as the amount of positive reactivity corresponding to an asymptotic power rise with a time constant or period of one hour. Reactivity is rarely (if ever) reported in inhours today, but the inhour was a common unit for measuring and reporting reactivity during the period when ZPR-3 operated.

If, for simplicity, the 5% uncertainty in the conversion factor is applied to the uncertainty related to reproducibility, the contribution of the uncertainty in the reactivity conversion is approximately 0.0002 %Δk. This value is negligible compared to geometry and composition uncertainties, so further refinement of the reactivity conversion uncertainty is not worthwhile.

2.2 Geometry Uncertainties

Because the matrix halves were not perfectly aligned, there was a small gap between the two halves, even at the nominal full closure position. There could also be a small gap because of uncertainty in the actual position of the movable half at full closure relative to the position indicated by the instruments. Typically, the actual physical gap varied from 0 to 30 mils (0.0 – 0.8 mm). As-built and benchmark models do not include an interface gap because of its small, non-uniform and imprecisely known size. Consequently, a gap correction is derived here in conjunction with the gap uncertainty analysis, and the correction is applied to the calculated k_{eff} in Section 3.5.

No measured gap coefficient of reactivity has been located, so the worth of the gap was computed by continuous energy Monte Carlo as the difference between k_{eff} for the as-built model with no gap and k_{eff} for the as-built model with a small gap between the halves. The computed gap worth for ZPR-3/11 loading 10 with an average gap of 0.4 mm is -0.0382 ± 0.0045 %Δk based on one billion histories for each configuration. The estimated 1σ uncertainty in the gap width is 0.1 mm, making the total uncertainty in both the gap worth and the gap closure correction ± 0.0106 %Δk.

Besides the interface gap, there are three issues regarding the exact location of materials. One is the possibility that the drawer fronts might not have been flush with the front edge of the matrix tubes. Care was taken to make the drawers flush with the matrix, and the drawer-tab — matrix-tube-notch design feature made that easy for fuel handlers. Another issue is the possibility that the plate columns might not have been all the way forward against the drawer front. This problem was minimized by taking care to do this when loading the plates in drawers, by using springs to hold the plates there, and by inserting the drawer tabs into the matrix tube notches slowly. These two issues are assumed to be covered by the interface gap uncertainty.

The third issue to consider is deviations from nominal dimensions for plates, drawers, and matrix tubes. Deviations in the dimensions that affect the precise X- and Y-positions of materials within the unit cell are too small to impact k_{eff} significantly. The dimensions that determine the volumes over which the material masses are distributed can have an effect. The plate lengths, drawer front thickness, and the length of front drawers affect the axial positions of materials, similar to the interface gap effect. It is estimated that the uncertainties in these dimensions collectively have no larger effect than 50% of the interface gap effect; accordingly, an uncertainty of ±0.0191 %Δk was assigned.

A deviation from the nominal average spacing between matrix tubes also would affect the region volumes. At the ZPR-3 facility, measurements were made of the average spacing with the matrix filled. The average pitch was measured in 1959 to be 2.1835 inches wide and 2.1755 inches high. These were reported as typical values, and it was noted that the values may change with assembly loading.[a] It is estimated that the error in these measurements is ±1 mil, i.e., ±0.001 in. (see ICSBEP benchmark IEU-MET-FAST-012, Section 2.2). The implied change in reactivity was estimated by computing the resulting change in k_{eff} using TWODANT calculations of the benchmark model with the nominal matrix pitch and with the matrix pitch increased and decreased by 1 mil (0.0254 mm). Compositions were adjusted to preserve mass when the matrix pitch was changed. The estimated reactivity effect is ±0.0254 %Δk.

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[a] L. H. Berkes, ZPR-3 Hot Constants Memo, March 31, 1960.

One final consideration with regard to axial positioning uncertainties relates to the actual positions of the DP rods, which were fully inserted for the benchmark configuration. This uncertainty, negligibly small compared to the uncertainty components discussed above, is included in the measurement uncertainties provided in Section 2.1.

An adjustment and an uncertainty are needed for room return of neutrons to the assembly. The assembly description above encompasses only the matrix tubes and their contents. An upper bound for the room return effect was computed by adding 5 cm of steel axially and 15 cm of steel radially to the TWODANT RZ model. The result, 0.0018 %Δk, is negligibly small and is treated as a negative adjustment to the benchmark k_{eff} (relative to the experimental k_{eff}). The associated uncertainty, assumed to be 50% of the computed value, i.e., ± 0.0009 %Δk, will be included in the adjustments discussed in Section 3.5.

2.3 Composition Uncertainties

A bit of history about the materials inventory records is needed to appreciate the extent and limitations of the information available on the compositions used in ZPR-3/11. The material inventory for Argonne's ZPR facilities was accumulated over a period of more than three decades, starting in the mid-1950s. The procurement acceptance process required thorough documentation on dimensions, masses, composition, etc. of the various core components. Information needed for day-to-day operations was extracted and compiled in working documents known informally as "hot constants memos." These memos give batch or lot average values of dimensions, masses, and weight percents of constituents but no uncertainties. The original documentation on most of the inventory used in ZPR-3/11 has been lost, but the hot constants documents are available. Consequently, indirect evidence and estimates were used to quantify many of the composition uncertainties. Compositions given in these hot constants documents are used directly. That is, weight fractions are not adjusted or renormalized to sum to 100%.

The composition uncertainty for a component is treated in two parts, the uncertainty in total mass and the uncertainty in the weight percents of the constituents. Since these two sources of uncertainty are independent, they are added in quadrature. The reactivity effect of the composition uncertainty was determined by computing the change in k_{eff} using the TWODANT model of the benchmark. In some cases sensitivity coefficients computed with this model were used and in other cases the specific perturbation was calculated explicitly.

The details of the mass measurements are unknown. For the plates and most of the drawers it is assumed that measurements of masses were within 0.01 g of actual value for plates of up to tens of grams and within 1 g for larger plates weighing kilograms, i.e., the uncertainty in weighing was 0.1%. The working standard used to calibrate the scale is taken to have an uncertainty of 0.05%, which is a systematic uncertainty. The uncertainty in weighing could be statistical, but since no details of the process are available, we assume this to also be a systematic uncertainty, making a total uncertainty in mass of 0.15%. Mass uncertainty assumptions made for other items are specified as needed.

ZPR-3/11 was built using a very limited number of materials. The only materials which could contribute in a significant way to the composition uncertainties are the HEU plates, depleted uranium plates, Kel-F coating on the HEU and depleted uranium plates, stainless steel drawers, and the stainless steel matrix. Masses and compositions for all of these materials are known reasonably well.

There are three sources of evidence currently available regarding the uncertainties in the isotopic weight percents for the enriched uranium. One is a 1982 internal memorandum on the uncertainty in a measurement that used 1/16 x 2 x 3 in. plates. These values are shown (rounded to 2 decimal places) in the third column of Table 12 (following the typical wt.%, which are shown in the second column). It quotes an enrichment of

93.17 ± 0.02 wt.% observed in selected Special Materials records. This quoted uncertainty appears reasonable. In fact, it is believed the enrichment for any single fuel fabrication batch may have been known even better. However, because of the large inventory of 93% enriched uranium fuel, it was derived from many fuel batches. The enrichment uncertainty values quoted in these Special Materials records are consistent with the second source, which is a series of recent (1996) mass-spectroscopy measurements on 1/16-inch plates. The quoted uncertainties in measurement of the uranium weight fractions for a single sample were 1%, 0.25%, 2.5%, and 0.5% for ^{234}U, ^{235}U, ^{236}U, and ^{238}U, respectively. The observed consistency among 20 samples is much better than the quoted measurement uncertainties. The fourth column of Table 12 shows estimated uncertainties based on the standard deviation of the distribution of these measured values. Review of a limited number of mass-spectroscopy measurements on 1/8-inch plates indicates a similar consistency of the measured values with the mean enrichment values. Finally, an estimate of the uncertainties in the weight fractions for this enriched uranium can be inferred from the distribution of the enrichment values given in the ZPPR hot constants memo. The ^{235}U weight percent values range from 93.05 – 93.30. These values appear to have a normal distribution with approximately 70% of the values within ±0.05% of their mean value. Estimated uncertainty values based on the distribution of these quoted enrichments, shown in the final column of Table 12, are consistent with the previous values and would appear to cover possible systematic uncertainties without adding unnecessary conservatism. Because the sum of the uranium isotopic fractions should be 100.0%, the uncertainty in the ^{238}U weight fractions is also assumed to be ±0.05 wt.%.

The reactivity effect due to the uncertainty in the enriched uranium isotopic fractions was calculated directly using a TWODANT model of the benchmark. The ^{235}U mass was increased by 0.05 wt.% of the uranium mass and the ^{238}U mass was reduced correspondingly. This produced an uncertainty of 0.0241%Δk. Although the 0.05 wt.% uncertainty estimate is itself uncertain, its computed reactivity effect is so small that a reasonable revision of the wt.% estimate clearly would also yield an unimportant reactivity effect. The component uncertainties of ^{234}U and ^{236}U (also based on corresponding changes in ^{238}U mass) were 0.0013%Δk and less than 0.0001%Δk, respectively.

Table 12. Enriched-Uranium Uncertainty Data.

Isotope	(Nominal Value) wt.%	Uncertainty,[(a)] wt.%	Uncertainty,[(b)] wt.%	Uncertainty,[(c)] wt.%
^{234}U	(0.91)	± 0.01	± 0.01	± 0.01
^{235}U	(93.17)	± 0.02	± 0.02	± 0.05
^{236}U	(0.44)	± 0.01	± 0.01	± 0.01
^{238}U	(5.48)	± 0.03	± 0.02	± 0.05

(a) Uncertainty values quoted in SPM records.
(b) Uncertainty values estimated from distribution of recent (1996) mass spectroscopy measurements.
(c) Uncertainty values estimated from distribution of enrichments listed in hot constants memo.

The impurity levels in the enriched uranium were estimated from recent chemical analyses of the plate material. Information on the analyses associated with the procurement of the uranium plates is no longer available and the hot constants memos do not list any impurities. However, chemical analysis results are available from a recent process to recover the enriched uranium from fuel plates damaged by corrosion. Analysis reports were obtained for 20 samples, each of which was analyzed for 18 impurities. The 18 analytes do not include the corrosion impurities, oxygen and hydrogen. The analysis reports indicate that, “Less-than values are limits of quantification, which are ten times the minimum detection limit.” From an examination of the 20 reports, it was judged that large variations in the quantification limit and a sparsity of values beyond the quantification limit preclude the determination of a reliable weight ppm value for nine of the impurities. An example is cadmium, for which the quantification limit ranges from 10 to 70 ppm over the 20 samples and there is no value beyond the quantification limit. For each of the other nine measured impurities, there are at least six ppm values beyond the quantification limit and the other quantification limits are consistent. An example is nickel, for which there are 16 values, ranging from 120 to 220 ppm, that are beyond the quantification limit, and there are four reports giving only "less-than values" (quantification limits), which range from 180 to 290 ppm. By averaging the values beyond the quantification limit, the following nine weight ppm estimates were obtained: C 340, Ni 174, Fe 125, Cu 65, Na 63, Ca 40, Si 35, Al 30, Mn 13.

This collection of nine impurity values, which total to 885 weight ppm, was taken to be a reasonable approximation to the initial impurity level in the enriched uranium. On the one hand, it tends to be an underestimate because it does not include any contribution from the nine other analytes or from elements that were not analyzed. On the other hand, it tends to be an overestimate because some of the measured carbon came from the recovery processes, which occurred after the plates were used in the assembly. Apparently, little carbon was introduced by the recovery processes, since the carbon value is typical for enriched uranium. It is assumed that these opposing effects approximately balance and it is estimated that a one-sigma uncertainty of 50% applies to this impurity model.

The reported impurity levels for the Godiva critical assembly provide some evidence that at least the estimated total impurity level in the enriched uranium plates is reasonable.[a] Godiva was composed of "virgin material", whose estimated total impurity level is ≈400 weight ppm, comprised primarily of C at 160 ppm, Si at 110 ppm and Fe at 70 ppm. It is further stated in LA-4208 that "recycled material" has impurity levels that are about twice as large. The ZPR enriched uranium apparently was made from recycled material, given the presence of ^{236}U, and the adopted 885 ppm impurity estimate is consistent with the ≈800 ppm estimate in LA-4208.

The effect of the estimated enriched uranium impurities was calculated directly with TWODANT. Since the presence of the impurities was neglected in the reference model, the perturbation consisted of adding the nine impurities and reducing the enriched uranium to preserve mass. The computed effect of including the impurities is -0.0392 %Δk, implying that increasing the benchmark k_{eff} (relative to the experimental k_{eff}) by this amount would compensate for the omission of the impurities from the model. The 50% uncertainty in the impurity level corresponds to ±0.0196 %Δk, which must be added in quadrature with the other k_{eff} uncertainty components.

The effect of increasing the mass of the enriched uranium by the assumed 0.15% uncertainty was calculated directly with TWODANT. The result is 0.0660 %Δk.

The uncertainty for the Kel-F coating on the HEU plates is dominated by the possibility that some flaked off in handling the plates. It is assumed, pessimistically, that 10% of the coating could have been lost. The computed worth of removing 10% of the Kel-F from the HEU plates is 0.0002% Δk. For convenience this is not treated as a one-sided uncertainty.

Adding in quadrature the uranium mass, enrichment, impurity and Kel-F mass uncertainty effects yields a k_{eff} uncertainty contribution associated with the HEU plates of ±0.0730 %Δk. The net adjustment for the benchmark k_{eff} for impurities in the HEU is 0.0392 %Δk.

Each unit cell in the core contained six columns of 0.3175 cm depleted uranium plates and one column of 2.54 cm depleted uranium plates. The radial blanket consisted of approximately 35.56 cm of depleted uranium plates, and the axial blanket consisted of approximately 30.5 cm of depleted uranium plates. The

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[a] G. E. Hansen and H. C. Paxton, "Reevaluated Critical Specifications of Some Los Alamos Fast-Neutron Systems," LA-4208, Los Alamos Scientific Laboratory (1969).

assumed 0.15% uncertainty in the mass of the depleted uranium plates in the core and blankets was calculated to have a 0.0046 %Δk effect.

The uncertainty in the ^{235}U wt.% in the depleted uranium plates is taken to be 0.02% (about 10% of the ^{235}U wt.%) from information given in the hot constants memos. The ^{235}U concentration was increased by this amount, and the ^{238}U concentration was decreased to preserve total uranium mass. The resulting uncertainty in k_{eff} is 0.0879 %Δk.

There is no information concerning impurities in the depleted uranium plates, so a 0.042 wt.% contamination of iron was assumed based on an impurity level of 0.042 wt.% listed in the hot constants memos for depleted U_3O_8. The computed uncertainty in k_{eff} equivalent to the assumed iron impurity is 0.0022 %Δk. The uncertainty for the depleted uranium plates is completely dominated by the uncertainty in the ^{235}U content, so further refinement of the depleted uranium impurity level does not seem to be warranted.

The earliest ZPR-3 hot constants memo is not clear regarding Kel-F coating on depleted uranium plates. Subsequent releases of the ZPR-3 hot constants memo clearly show the presence of Kel-F coating on depleted uranium plates. On the other hand, these memos clearly show a titanium oxide coating on graphite plates, an unspecified coating on boron carbide plates and Kel-F coating on iron plates. If it was deemed necessary to coat common materials such as graphite and iron to prevent oxidation and material loss, it seems likely that the depleted uranium plates would have been coated. It could also be the case that some portion of the depleted uranium inventory was coated.

There does not seem to be a way to determine whether all, some or none of the depleted uranium plates were coated at this late date, so a 100% uncertainty was assumed for the Kel-F coating on the depleted uranium plates. The computed worth of removing 100% of the assumed Kel-F from the depleted uranium plates is 0.0096 %Δk. This is a small value compared to the effect of the uncertainty in the ^{235}U content of the depleted uranium plates. The Kel-F uncertainty makes a very small contribution to the total uncertainty for the depleted uranium plates and a negligible contribution to the total uncertainty in Section 2.5. Further effort to refine the Kel-F uncertainty is not warranted.

The quadrature sum of all uncertainties for the depleted uranium plates, i.e., uranium mass, ^{235}U wt.%, impurities and Kel-F mass, is 0.0886 %Δk.

The stainless steel components in this assembly are the front drawers, back drawers and matrix tubes. These components are made of Type 304 stainless steel. Rigorously, the uncertainties for all the components are uncorrelated and therefore should be evaluated separately. The uncertainty effect was computed for each separable assembly component (matrix tubes, front drawers and back drawers) and then those results were added in quadrature. The front 15.25 in. of the DP control rod drawers was included with the normal front drawers. The remainder of the DP control rod drawers was included with the back drawers.

It is estimated that the mass of the matrix tubes is uncertain by 2% and the masses of the other stainless steel components are uncertain by 0.15%. The calculated effect of changing the matrix tube mass by 2% yielded an uncertainty in k_{eff} of 0.0011 %Δk. The effects of 0.15% mass changes in the front drawers and back drawers are <0.0001 %Δk for the front drawers and <0.0001 %Δk for the back drawers.

Table 10 in Section 1.3 shows multiple sets of weight percent data for the stainless steel drawers and matrix tubes. From reading ZPR-3 reports written for later ZPR-3 assemblies, it is clear that stainless steel weight percent differences of the magnitudes shown in Table 10 were not considered significant. It appears that the average composition shown in the first data row of Table 10 was used for all Type 304 stainless steel components in calculations at that time. In contrast, the hot constants compositions for drawers and matrix tubes were used in the benchmark models presented in Section 3 because these component-specific compositions are believed to be more accurate.

It can be seen that all the other compositions in the table have weight percents that do not account for one to two percent of the composition. Comparing the first two compositions, it can be seen that the only significant difference is a 2 percentage point higher Fe wt.% in the first composition, which is why only the first composition does not have a deficit in total wt.%. It is not known whether the Fe weight percent was adjusted arbitrarily or for well founded reasons. Consequently, the Fe wt.% uncertainties for matrix tubes and drawers are being treated here as Type B, where the range is the difference between the Fe wt.% in the first average composition and the Fe wt.% in the matrix or drawer composition. The standard uncertainty is this range divided by √12, or approximately 1.0%. With the Fe wt.% adjustment issue covered by this uncertainty, it seems most consistent to compute the Fe contributions to the matrix and drawer composition biases for the as-built model using the hot constants average composition (second row of Table 10), which is consistent with the matrix and drawer compositions in having unadjusted Fe.

Table 13 gives the estimated wt.% uncertainty for each element in the Type 304 stainless steel compositions. To put these values in perspective, representative weight percents, specifically the average composition from ANL-7759, are shown in parentheses. The uncertainty for each of the major elements was taken to be 0.2 wt.%, and the uncertainty for Mn in the stainless steel was taken to be 0.075 wt.% (or 10% of the nominal value) for consistency with previous ZPR evaluations. The uncertainty for silicon was assumed to be one half of the last significant figure provided in ANL-7759, due to round-off error.

Table 13. Type 304 Stainless Steel
Weight Percent Uncertainty Data.

Element	Wt.% Uncertainty (ANL-7759 wt.%)
Fe	matrix 0.4, drawers 1.0, all else 0.2 (73.4)
Cr	0.2 (17.0)
Ni	0.2 (8.4)
Mn	0.075 (0.75)
Si	0.005 (0.45)

The k_{eff} uncertainty contributions due to the weight percent uncertainty for the elements comprising the stainless steel were computed by perturbing the reference TWODANT model using the data in Table 13. The results by element and component category are given in Table 14. In all of the perturbations, the reference steel mass in the core was preserved by reducing the atom density of the Fe element in proportion to the modification made to the other element.

Table 14. Contribution from the Stainless Steel wt.% Uncertainty
to the k_{eff} Uncertainty (%Δk).

Element	Matrix	Front Drawers	Back Drawers
Fe	0.0001	<0.0001	<0.0001
Cr	0.0002	<0.0001	<0.0001
Ni	0.0003	0.0001	<0.0001
Mn	<0.0001	<0.0001	<0.0001
Si	<0.0001	<0.0001	<0.0001
Quadrature Sum	0.0004	<0.0002	<0.0002

The quadrature sum of the steel mass and composition uncertainties for the matrix is 0.0012 %Δk. The quadrature sums for the front drawers and back drawers are 0.0002 %Δk and <0.0002 %Δk, respectively. The quadrature sum of all the steel wt.% uncertainties is 0.0013 %Δk, which is dominated by the uncertainty in the mass of the matrix tubes.

The quadrature sum of all composition uncertainties, i.e., composition uncertainties for HEU plates, depleted uranium plates and the steel in front drawers, back drawers and the matrix tubes, for ZPR-3/11 is 0.1144 %Δk.

2.4 Humidity

A very small adjustment and uncertainty due to the presence of humidity in the air was derived for an earlier ZPR assembly. This was done by comparing calculations with the assembly gaps filled by dry air and by saturated air. The calculated effect, 0.0001% Δk, is assumed to apply to this assembly and will be included simply as an (obviously negligible) uncertainty.

2.5 Combined Uncertainties and Final k_{eff}

All of the uncertainties discussed in the previous sections are collected in Table 15. The uncertainties in the measurement technique are not important. The uncertainties in the composition category are an order of magnitude larger than those in the measurement technique category. The main sources of uncertainty were found to be the matrix interface gap, nominal plate and drawer dimensions, matrix tube pitch, HEU plate mass and ^{235}U enrichment in HEU and depleted uranium plates. These uncertainties are not correlated.

After including the total uncertainty from Table 15, the excess reactivity was 0.1289 ± 0.1198 %Δk, so the experimental k_{eff} is 1.001289 ± 0.001198. Note that the estimated uncertainty is comparable to the excess reactivity, yet there is no doubt that the assembly was slightly supercritical. The uncertainty estimates are believed to be reasonable. Treating the uncertainties as if they were 1σ of a normal distribution should be acceptable for the purposes of the benchmark models.

Table 15. Summary of Uncertainties in the Experimental k_{eff} for ZPR-3/11 Loading 10.

Source of Uncertainty	**Uncertainty in Excess Reactivity, %Δk**
Measurement Technique	
Excess Reactivity	0.0054
Inhour to Δk Conversion	0.0002
Temperature Uncertainty	0.0009
Temperature Distribution	0.0010
Reproducibility	0.0034
Subtotal	**0.0065**
Geometry	
Matrix Interface Gap	0.0106
Nominal Plate, Drawer Dimensions	0.0191
Matrix Tube Pitch	0.0254
Subtotal	**0.0335**
Composition	
HEU Plates	0.0730
Depleted Uranium Plates	0.0886
Steel in Matrix Tubes	0.0012
Steel in Drawers	0.0003
Humidity	0.0001
Subtotal	**0.1148**
Total	**0.1198**

ZPR-3/11 loading 10 has been determined to be an acceptable criticality-safety benchmark experiment.

3.0 BENCHMARK SPECIFICATIONS

3.1 Description of Model

Even the most casual perusal of Section 1 makes it clear that the as-built model of ZPR-3/11 is much too complicated to be a practical criticality-safety benchmark model without a great amount of simplification. Fortunately, it is possible to eliminate virtually all of the complexity, yielding a simple benchmark model, without losing any of the essential physics. Furthermore, this can be done without compromising the high accuracy of the experiment.

This was accomplished by computing the transformation from the detailed as-built experiment model to the simple benchmark model using the VIM continuous-energy Monte Carlo code.[a] Note that the term "transformation" will be used repeatedly throughout Section 3 and will, in all cases, refer to both the simplification of the model from the as-built platewise heterogeneous experiment model to the homogeneous benchmark model, and also the correction of k_{eff} to account for these simplifications. VIM eigenvalue calculations were made for the as-built model and for the benchmark model. The k_{eff} correction is simply the difference in k_{eff} between the benchmark and as-built models.

The modeling of all the experimental detail was made tractable by the development of the BLDVIM computer code[b] to generate the VIM input files for the as-built model. BLDVIM reads an electronic database containing a description of the ZPR plate and drawer inventory, the assembly drawer masters, and the matrix loading map. The code and database were rewritten for UNIX-based workstations, at which time the values of Avogadro's number and the atomic masses were made to conform to the values recommended by the ICSBEP. The VIM input for the as-built model of ZPR-3/11 loading 10 is provided in Appendix B.

Development of a practical benchmark model of any ZPR assembly starts from an as-built model. Ideally, every geometric and compositional detail of the experimental configuration would be included as faithfully as possible in the as-built model. In reality, details that are both difficult/cumbersome to model and obviously insignificant to k_{eff} are simplified. One example is that perforated drawer walls are replaced with solid walls having the equivalent average density. Another example is that the cladding is smeared into the small clearance gaps between the cladding and the "meat" of a fuel plate for clad plutonium plates.

In addition, the scope of the as-built model is limited to the matrix and its contents, and minor but non-negligible details within the as-built model scope were omitted. The matrix interface gap and impurities in the HEU were discussed in Section 2. The worths derived in Section 2 for the interface gap and HEU impurities are included in Section 3.5 as adjustments to the benchmark k_{eff}.

It needs to be kept in mind that, compared to what the as-built model does include, these deficiencies are few and unimportant. The deficiencies were identified here for completeness and should be kept in perspective. The as-built model is extremely detailed; it represents explicitly every plate, every drawer wall and matrix tube wall, etc.

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[a] R. N. Blomquist, R. M. Lell and E. M. Gelbard, "VIM – A Continuous Energy Monte Carlo Code at ANL," A Review of the Theory and Application of Monte Carlo Methods, Proceedings of a Seminar-Workshop, Oak Ridge, TN, April 21-23, 1980, ORNL/RSIC-44, p. 31, August 1980.

[b] R. W. Schaefer, R. D. McKnight and P. J. Collins, "Lessons Learned from Applying VIM to Fast Reactor Critical Experiments," *Proceedings of the Nuclear Criticality Technology Safety Workshop*, San Diego, CA, pp. 129-136, LA-13439-C (1995).

A benchmark model of ZPR-3/11 loading 10 was generated in exactly the same way as was used for previous ZPR benchmarks. The key features retained in the benchmark model are the region-averaged compositions and region volumes. The geometric model is an RZ model that preserves the areas of the X-Y boundaries of the core, radial blanket and empty matrix tubes in the as-built model. Axial dimensions of each region conserve the region volumes. Note that since axial regions in the as-built model core have been defined at fuel plate boundaries (which may vary between different matrix positions due to differences in thicknesses of drawer fronts of normal and DP drawers), the axial extent which conserves the region volume may be "non-physical", i.e., it may not correspond exactly to any actual fuel-plate boundary. Masses of the constituents within these regions are then homogenized to produce the region-averaged compositions, thereby conserving material masses within each region. The VIM output edits for the as-built model included the region-average compositions, which were extracted to construct the benchmark model.

The simplification (afforded by the benchmark model) that yielded by far the greatest elimination of detail was the smearing of plates, drawers, and matrix tubes into homogeneous mixtures. The plate heterogeneity effects, which require much effort to capture accurately in effective homogenized cross sections in a deterministic modeling approach, are included in the Monte Carlo-calculated Δk of the transformation.

This transformation process has been used previously with success. Loadings from the ZPPR-21 assembly were transformed into simple benchmarks for the criticality-safety assessment of Pu-U-Zr fuel treatment at Argonne's Fuel Conditioning Facility (FCF). Using sensitivity calculations and generalized-least-squares fitting, it was shown[a] that the results from this plate critical assembly are consistent with those from the homogeneous assemblies Jezebel and Godiva.

The homogeneous RZ benchmark model resulting from the transformation of the as-built platewise heterogeneous ZPR-3/11 loading 10 model is defined in the remainder of this section.

3.2 Dimensions

Figure 10 shows the benchmark RZ model for ZPR-3/11 loading 10. The boundary conditions are reflecting along the bottom (Z = 0.0 cm) and left side (R = 0.0 cm) and vacuum along the top (Z = 85.09 cm) and right side (R = 96.82257 cm). Table 16 provides the same dimension information. It should be noted that the number of decimal places shown in Figure 10 and Table 16 does not mean that those dimensions were known that accurately. Rather, the values in the figure and table reflect the conversion from units of inches to units of centimeters.

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[a] D. N. Olsen, P. J. Collins and S. G. Carpenter, "Experiments of IFR Fuel Criticality in ZPPR-21," *ICNC '91 International Conference on Criticality Safety*, Oxford, UK, September 9-13, 1991.

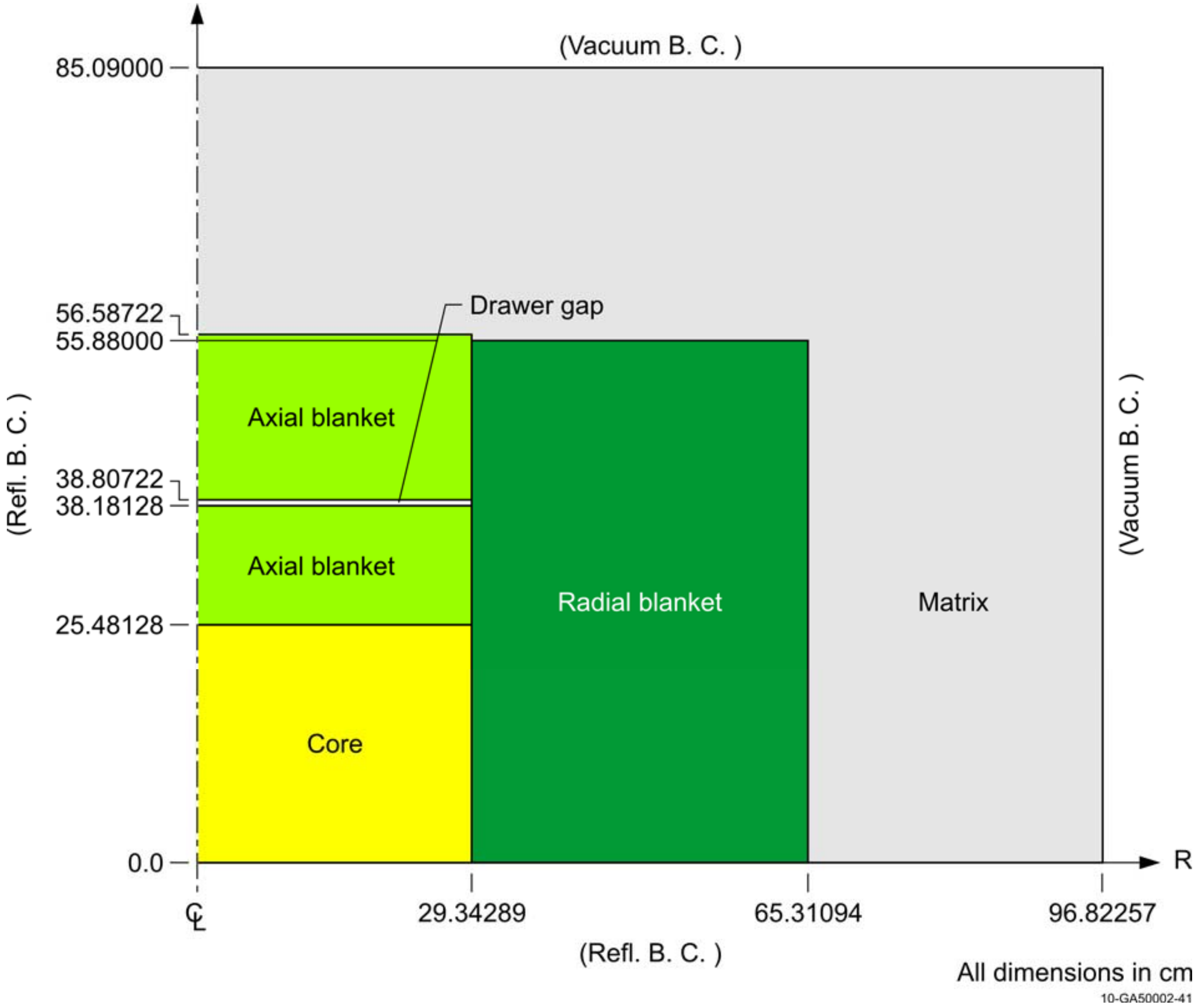

Figure 10. ZPR-3/11 Loading 10 Benchmark Model.

Table 16. Benchmark Model Region Dimensions.

Region	Inner Radius (cm)	Outer Radius (cm)	Lower Height (cm)	Upper Height (cm)
Core	0.0	29.34289	0.0	25.48128
Axial Blanket - 1	0.0	29.34289	25.48128	38.18128
Drawer Gap	0.0	29.34289	38.18128	38.80722
Axial Blanket - 2	0.0	29.34289	38.80722	56.58722
Radial Blanket	29.34289	65.31094	0.0	55.88000
Matrix[(a)]	0.0	96.82257	0.0	85.09000

(a) The matrix fills the remaining space that is not occupied by the core, axial blanket, drawer gap and radial blanket.

3.3 Material Data

Table 17 contains the region-dependent composition data for the benchmark model of ZPR-3/11 Loading 10.

Table 17. Compositions of the Benchmark Model Regions
of ZPR-3/11 Loading 10 (atoms/barn-cm).

Nuclide	**Core**	**Axial Blanket**	**Radial Blanket**	**Drawer Gap**	**Matrix**
^{235}U	4.53407E-03	8.09067E-05	8.12459E-05	0.00000E+00	0.00000E+00
^{238}U	3.42487E-02	3.98361E-02	4.00215E-02	0.00000E+00	0.00000E+00
^{234}U	4.35964E-05	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
^{236}U	2.09005E-05	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
Cr	1.43070E-03	1.44626E-03	1.11410E-03	3.51152E-03	1.10960E-03
Ni	6.12862E-04	6.17031E-04	4.56291E-04	1.63391E-03	4.53554E-04
Fe	5.74369E-03	5.81474E-03	4.54724E-03	1.94781E-02	4.52968E-03
C	3.80965E-05	1.04630E-05	8.72693E-06	2.68742E-04	0.00000E+00
Mo	0.00000E+00	0.00000E+00	0.00000E+00	5.56095E-08	0.00000E+00
^{55}Mn	7.09685E-05	7.04151E-05	4.41475E-05	2.37482E-04	4.34957E-05
Cu	0.00000E+00	0.00000E+00	0.00000E+00	3.35551E-07	0.00000E+00
^{1}H	1.11171E-05	3.03708E-06	2.49611E-06	0.00000E+00	0.00000E+00
Si	7.25666E-05	7.38710E-05	6.08317E-05	1.50111E-04	6.07700E-05
Cl	1.91113E-05	5.24861E-06	4.32545E-06	0.00000E+00	0.00000E+00
^{19}F	5.65882E-05	1.55418E-05	1.28088E-05	0.00000E+00	0.00000E+00

The small amounts of molybdenum and copper shown in Table 17 come from impurities in the materials used to model the divider plates in the DP drawers and control rod drive shafts for the DP drawers.

For the convenience of readers whose computer codes require total atom densities, the total atom densities for the benchmark compositions in Table 17 are:

1) Core -	4.690295E-02 at/b-cm,
2) Axial Blanket -	4.797361E-02 at/b-cm,
3) Radial Blanket -	4.635372E-02 at/b-cm,
4) Drawer Gap -	2.528024E-02 at/b-cm,
5) Matrix -	6.197097E-03 at/b-cm.

3.4 Temperature Data

The matrix temperature of ZPR-3/11 loading 10 during the criticality measurement was 20.9 °C. The temperature coefficient of -8.027×10^{-4} %Δk/°C was used to normalize the benchmark k_{eff} to 300 K (27 °C). This is a temperature commonly assumed when processing cross sections. The benchmark (relative to the experimental) excess reactivity must be decreased by 0.0048 %Δk for this. The benchmark temperature is 300 K (27 °C).

3.5 Experimental and Benchmark-Model k_{eff}

Recall from Section 2.1 that the measurement for which we actually have records was establishment of a critical state for the described assembly with DP Rod #10 withdrawn 5.885 inches and all the other DP (fueled) controls fully inserted. Full insertion of Rod #10 resulted in a small excess reactivity but no records of the excess reactivity or of the Rod #10 calibration were found. Consequently, calculations described in Section 2.1 were used to determine that the excess reactivity was 0.1289 ± 0.0054 %Δk, where this uncertainty reflects the total uncertainty for this pair of calculations. This is the first in a series of six adjustments obtained using high fidelity calculations to get from the experimental criticality records we have to an adjusted "experimental k_{eff}" that can be used with the benchmark model. The total of all uncertainties in this excess reactivity value, which are summarized in Table 15, is 0.1198 %Δk. Thus, the experimental k_{eff} = 1.0013 ± 0.0012.

As described in earlier sections, four small "modeling" adjustments need to be applied to this experimental k_{eff} to make the conditions consistent with the as-built model of ZPR-3/12 loading 10. These adjustments consist of: the neglect of structure beyond the matrix tubes and all their contents (i.e., room return, see Section 2.2); the neglect of the matrix interface gap (see Section 2.2); the neglect of the HEU plate impurities (see Section 2.3); and the adjustment of the temperature to 300 K (see Section 3.4). These adjustments acknowledge that the model we call "as-built" actually models some slightly idealized conditions. The Δk for each model idealization and the net Δk are summarized in Table 18. The net adjustment is only 0.07 %Δk and involves little cancellation of effects. Application of this net adjustment to the experimental k_{eff} yields a value of 1.0020 ± 0.0012, and is referred to as the as-built model k_{eff}. This is basically an experimental result with small calculational adjustments. It is the k_{eff} we aspire to reproduce with calculations of the as-built model.

Table 18. Model Biases to Experimental k_{eff}.[(a,b)]

Model Bias	%Δk
Room return neglected	-0.0018 ± 0.0009
No interface gap	+0.0382 ± 0.0106[(c)]
HEU impurities omitted	+0.0392 ± 0.0196[(c)]
20.9 °C to 27 °C	-0.0048 ± 0.0024[(d)]
Net Bias	0.0708 ± 0.0026

(a) Resulting from experimental features either altered or neglected in the as-built model.
(b) Biases for room return, HEU impurities and temperature were computed with ENDF/B-V.2 data. The bias for the interface gap was computed with ENDF/B-VII.0 data.
(c) These uncertainties have been included in the experiment uncertainty (see Table 17). To avoid double counting, they are omitted from the uncertainty in the net bias.
(d) Uncertainty assumed to be 50% of reactivity worth.

The sixth and last adjustment to the measured result is the transformation from the as-built model conditions to the benchmark model conditions. The transformation Δk (bias) from the as-built configuration to the benchmark model that was described in Section 3.1 was calculated using the VIM continuous-energy Monte Carlo code. The individual k_{eff} values and the transformation Δk for ZPR-3/11 loading 10 are shown in Table 19. The uncertainties shown are just the statistical standard deviations from VIM using the combined track-length and analog estimators. There are two sets of results – one based on ENDF/B-V.2 and the other based on ENDF/B-VII.0 cross section data.

Table 19. Eigenvalues for Transformation from As-Built Model
to RZ Benchmark Model for ZPR-3/11 Loading 10.

	As-Built-Model k_{eff}	RZ Benchmark-Model k_{eff}	Transformation Δk (Bias)
VIM (ENDF/B-V.2)	1.0102 ± 0.0001	1.0053 ± 0.0001	-0.0049 ± 0.0001
VIM (ENDF/B-VII.0)	1.0019 ± 0.0001	0.9973 ± 0.0002	-0.0046 ± 0.0002

An estimate of the total uncertainty in the transformation Δk from the as-built platewise heterogeneous critical-assembly model to the homogeneous spherical model is needed. Since there are no significant geometric approximations in the as-built model and there are no cross section processing approximations associated with either model, the only sources of uncertainty added to the original experimental uncertainty come from Monte Carlo statistical precision and the sensitivity of the calculated Δk values to uncertainties in basic cross section data. The major uncertainties in the assembly arise from fission production and absorption in uranium. Uncertainties in the k_{eff} of fast reactor assemblies due to calculations with ENDF/B-V data have been quantified to be in the range of 2% Δk.[a]

Because there is a strong correlation between the heterogeneous-assembly and homogeneous-assembly calculations, the difference in the two calculations can have a much smaller uncertainty than does either individual calculation. That is, the calculations for the transformation Δk value are based on a set of evaluated cross sections applied to two models having identical region-averaged compositions (and therefore having similar neutron energy spectra and similar sensitivities of k_{eff} to the cross sections), and are thus highly correlated. The ensuing uncertainty in the transformation Δk is therefore assumed smaller by more than an order of magnitude, or about ±0.1% Δk. Adding in quadrature the estimated 0.1 %Δk uncertainty due to use of ENDF/B-VII.0 cross sections and the 0.04% uncertainty due to the Monte Carlo statistics yields a total uncertainty in the transformation Δk of ±0.1% Δk.

This uncertainty estimate is believed to be realistic but still sufficiently small for criticality-safety benchmark purposes, i.e., it does not significantly increase the uncertainty in the benchmark representation relative to the actual experiment. For a clean physics benchmark assembly such as ZPR-3/11, the actual correlations between the calculations of the as-built and simplified models are likely higher than the values assumed in deriving the estimated uncertainty in the transformation. The agreement within the small statistical uncertainty between the calculations using two different cross section files lends support for this expectation.

The experimental and benchmark model k_{eff} values are summarized in Table 20. The data in Table 20 are in units of k_{eff}. The experimental k_{eff}, shown in the first row, is the value arrived at earlier in this subsection. The adjusted experimental k_{eff}, shown in the second row, was obtained by adding the experimental k_{eff} from the first row and the net bias from Table 18, using the uncertainties for room return and temperature adjustment in Table 18 to avoid double counting two uncertainty components. The third row contains the transformation Δk from Table 19 produced using the most modern cross sections available (ENDF/B-VII.0). The transformation Δk is the difference between the final benchmark model k_{eff} and the as-built model k_{eff}. The transformation Δk includes all of the differences between the benchmark model and the as-built experiment except for those listed in Table 18. Adding the transformation Δk to the adjusted experimental k_{eff} yields the benchmark model k_{eff} shown in the last row of the table. It is the k_{eff} against which k_{eff} results calculated using the benchmark model should be compared. The uncertainty in this k_{eff} includes contributions from all sources.

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[a] Table IV in: D. N. Olsen, P. J. Collins and S. G. Carpenter, "Experiments of IFR Fuel Criticality in ZPPR-21," *ICNC '91 International Conference on Criticality Safety*, Oxford, UK, September 9-13, 1991.

Table 20. Experimental and Benchmark-Model Eigenvalues.[(a)]

	ZPR-3/11
Experimental k_{eff}	1.0013 ± 0.0012
As-Built Experimental k_{eff}	1.0020 ± 0.0012
Monte Carlo Transformation of Model	-0.0046 ± 0.0010
Benchmark-Model k_{eff}	0.9974 ± 0.0016

(a) Each uncertainty estimate is one standard deviation.

4.0 RESULTS OF SAMPLE CALCULATIONS

Results of sample calculations of the benchmark models are given in Table 21 for ZPR-3/11 loading 10. These results are based on accumulating 500 generations with 20,000 neutrons per generation for a total of 10,000,000 histories after skipping 100 initial generations to converge the source. More details of the calculations, including input listings, are given in Appendix A.

Table 21. Sample Calculation Results for ZPR-3/11 Loading 10.

Code (Cross Section Set) → Case ↓	VIM (Continuous Energy ENDF/B-V.2)	VIM (Continuous Energy ENDF/B-VII.0)	MCNP5 (Continuous Energy ENDF/B-VII.0)
ZPR-3/11 Benchmark	1.0053 ± 0.0001	0.9973 ± 0.0002	0.9966 ± 0.0002

Agreement between the benchmark k_{eff} value (0.9974 ± 0.0016) and the calculated results is excellent with ENDF/B-VII.0 data. The difference between the benchmark k_{eff} and the k_{eff} computed with ENDF/B-V.2 data and the improvement with ENDF/B-VII.0 data are consistent with results for previous ZPR benchmarks whose core fissionable material consisted of uranium with intermediate enrichment such as ZPR-9/1 (IEU-MET-FAST-013) and ZPR-9/2 (IEU-MET-FAST-014).

5.0 REFERENCES

There are no published references available for this evaluation.

APPENDIX A: TYPICAL INPUT LISTINGS

A.1 KENO Input Listings

Calculations for the ZPR-3/11 benchmark have not been performed using SCALE/KENO.

A.2 MCNP Input Listings

The MCNP5 code was used with the ENDF/B-VII.0 continuous energy cross sections for all nuclides. The calculation used 10 million histories, with 20,000 neutron histories per generation and 500 active generations after skipping 100 generations.

MCNP5 ENDF/B-VII.0 Input Listing, Table 21.

```
IEU-MET-FAST-016 - ZPR-3/11 L010 - Benchmark Model - V7 XS
1     1  4.690295e-2  -1   4  -5  imp:n=1 $ core
2     2  4.797361e-2  -1  -4   6  imp:n=1 $ inner ax blkt-bottom
3     2  4.797361e-2  -1   5  -7  imp:n=1 $ inner ax blkt-top
4     4  2.528024e-2  -1  -6   8  imp:n=1 $ drawer gap-bottom
5     4  2.528024e-2  -1   7  -9  imp:n=1 $ drawer gap-top
6     2  4.797361e-2  -1  -8  10  imp:n=1 $ outer ax blkt-bottom
7     2  4.797361e-2  -1   9 -11  imp:n=1 $ outer ax blkt-top
8     3  4.635372e-2   1  -2  12 -13  imp:n=1 $ radial bklt
9     5  6.197097e-3   1  -2  10 -12  imp:n=1 $ matrix-rb lower
10    5  6.197097e-3   1  -2 -11  13  imp:n=1 $ matrix-rb upper
11    5  6.197097e-3  -3 -10  14  imp:n=1 $ matrix-bottom
12    5  6.197097e-3   2  -3  10 -11  imp:n=1 $ matrix-radial
13    5  6.197097e-3  -3  11 -15  imp:n=1 $ matrix-top
14    0               (3:-14:15)  imp:n=0 $ external void

1     cz     29.34289
2     cz     65.31094
3     cz     96.82257
4     pz    -25.48128
5     pz     25.48128
6     pz    -38.18128
7     pz     38.18128
8     pz    -38.80722
9     pz     38.80722
10    pz    -56.58722
11    pz     56.58722
12    pz    -55.88000
13    pz     55.88000
14    pz    -85.09000
15    pz     85.09000

mode  n
kcode  20000  1.0  100  600
sdef   erg=d1 rad=d2 ext=d3 pos 0 0 0.0 axs 0 0 1
sp1    -2
si2    0.0  29.30
si3    -25.4  25.4
m001      92235.70c   4.53407E-03     92238.70c   3.42487E-02
          92234.70c   4.35964E-05     92236.70c   2.09005E-05
          24050.70c   6.21639E-05     24052.70c   1.19878E-03
          24053.70c   1.35916E-04     24054.70c   3.38361E-05
          28058.70c   4.18401E-04     28060.70c   1.59957E-04
          28061.70c   6.92534E-06     28062.70c   2.20017E-05
          28064.70c   5.57704E-06     26054.70c   3.33134E-04
          26056.70c   5.26811E-03     26057.70c   1.26361E-04
          26058.70c   1.60823E-05      6000.70c   3.80965E-05
          25055.70c   7.09685E-05
           1001.70c   1.11171E-05     14028.70c   6.69282E-05
          14029.70c   3.39829E-06     14030.70c   2.24013E-06
          17035.70c   1.44806E-05     17037.70c   4.63067E-06
           9019.70c   5.65882E-05
m002      92235.70c   8.09067E-05     92238.70c   3.98361E-02
          24050.70c   6.28400E-05     24052.70c   1.21182E-03
          24053.70c   1.37395E-04     24054.70c   3.42040E-05
          28058.70c   4.21247E-04     28060.70c   1.61045E-04
          28061.70c   6.97245E-06     28062.70c   2.21514E-05
          28064.70c   5.61498E-06     26054.70c   3.37255E-04
          26056.70c   5.33328E-03     26057.70c   1.27924E-04
```

MCNP5 ENDF/B-VII.0 Input Listing, 21 (Cont'd).

```
         26058.70c   1.62813E-05      6000.70c   1.04630E-05
         25055.70c   7.04151E-05
          1001.70c   3.03708E-06     14028.70c   6.81312E-05
         14029.70c   3.45938E-06     14030.70c   2.28040E-06
         17035.70c   3.97687E-06     17037.70c   1.27174E-06
          9019.70c   1.55418E-05
m003     92235.70c   8.12459E-05     92238.70c   4.00215E-02
         24050.70c   4.84076E-05     24052.70c   9.33504E-04
         24053.70c   1.05839E-04     24054.70c   2.63485E-05
         28058.70c   3.11510E-04     28060.70c   1.19092E-04
         28061.70c   5.15609E-06     28062.70c   1.63808E-05
         28064.70c   4.15225E-06     26054.70c   2.63740E-04
         26056.70c   4.17073E-03     26057.70c   1.00039E-04
         26058.70c   1.27323E-05      6000.70c   8.72693E-06
         25055.70c   4.41475E-05
          1001.70c   2.49611E-06     14028.70c   5.61051E-05
         14029.70c   2.84875E-06     14030.70c   1.87787E-06
         17035.70c   3.27739E-06     17037.70c   1.04806E-06
          9019.70c   1.28088E-05
m004     24050.70c   1.52576E-04     24052.70c   2.94230E-03
         24053.70c   3.33594E-04     24054.70c   8.30475E-05
         28058.70c   1.11547E-03     28060.70c   4.26451E-04
         28061.70c   1.84632E-05     28062.70c   5.86574E-05
         28064.70c   1.48686E-05     26054.70c   1.12973E-03
         26056.70c   1.78653E-02     26057.70c   4.28518E-04
         26058.70c   5.45387E-05      6000.70c   2.68742E-04
         42100.70c   5.35519E-09     42092.70c   8.25245E-09
         42094.70c   5.14388E-09     42095.70c   8.85303E-09
         42096.70c   9.27567E-09     42097.70c   5.31071E-09
         42098.70c   1.34186E-08     25055.70c   2.37482E-04
         29063.70c   2.32101E-07     29065.70c   1.03450E-07
         14028.70c   1.38447E-04
         14029.70c   7.02970E-06     14030.70c   4.63393E-06
m005     24050.70c   4.82121E-05     24052.70c   9.29734E-04
         24053.70c   1.05412E-04     24054.70c   2.62420E-05
         28058.70c   3.09641E-04     28060.70c   1.18378E-04
         28061.70c   5.12516E-06     28062.70c   1.62826E-05
         28064.70c   4.12734E-06     26054.70c   2.62721E-04
         26056.70c   4.15462E-03     26057.70c   9.96530E-05
         26058.70c   1.26831E-05
         25055.70c   4.34957E-05
         14028.70c   5.60482E-05
         14029.70c   2.84586E-06     14030.70c   1.87597E-06
totnu
ctme     9000.0
```

A.3 TWODANT Input Listings

Sample input listings for TWODANT are not provided here because none of the TWODANT calculations utilized standard cross section libraries. However, most of the sensitivity results presented in Section 2 are based on TWODANT calculations which use the ANL code sequence MC^2-2/SDX to generate 20 broad group cross sections appropriate for the regions of the model. More importantly, only an RZ representation of the ZPR-3 Assembly 11 critical assembly was used for the TWODANT sensitivity calculations.

A.4 MONK8B Input Listings

Calculations for the ZPR-3 Assembly 11 benchmark have not been performed using the MONK code.

A.5 VIM Input Listings

This input for the benchmark model was run with Version 5.1 of the VIM code with an ENDF/B-VII.0 continuous-energy cross section library. All the cross sections correspond to 300 K. The VIM calculation used 10 million histories, with 20,000 neutron histories per generation and 500 active generations after skipping 100 generations.

```
VIM ENDF/B-VII.0 Input Listing, Table 21.


   111111111IEU-MET-FAST-016 - ZPR-3/11 L010 - Benchmark Model - V7 XS
   500     3     0   100     0     0
 20000 50000    10     0     0     0
     1     1     0     0    50     0
    35     5     6     1     8 50000
 999999999.0 1.00000E-05 2.75000E+02 1.00000E+00 1.00000E-05 1.99900E+07
 9.50000E-01 0.00000E+00 1.00000E+03 0.00000E+00
     1     0     0     0     3     0     0     0     0     0     1     0
 30300 40300 60300 8030021030121030221030321030422030122030322030422030      08
22030623030123030223030323030427030028030128030228030428030528030628030 7      08
28030829030034030134030235030038030538030638030754030154030257030 0            08


     0     0     1
  CYL    1   0.00000   0.00000 -25.48128  50.96256  29.34289
  CYL    2   0.00000   0.00000 -38.18128  76.36256  29.34289
  CYL    3   0.00000   0.00000 -38.80722  77.61444  29.34289
  CYL    4   0.00000   0.00000 -56.58722 113.17444  29.34289
  CYL    5   0.00000   0.00000 -55.88000 111.76000  65.31094
  CYL    6   0.00000   0.00000 -56.58722 113.17444  65.31094
  CYL    7   0.00000   0.00000 -85.09000 170.18000  96.82257
  CYL    8   0.00000   0.00000    -400.0     800.0     300.0
  END
  COR    8     +1
  ABL    8     +2     -1
  GAP    8     +3     -2
  ABU    8     +4     -3
  RBL    8     +5     -4
  VD1    8     +6     -5     -4
  MAT    8     +7     -6
  LEK    8     +8     -7
  END
     1         1.0     2         1.0     3         1.0     4         1.0
     5         1.0     6         1.0     7         1.0
     1   101   1             2   200   2             3   300   4
     4   400   2             5   500   3             6   600   5
     7   600   5             8         -1
 30300 40300 60300 8030021030121030221030321030422030122030322030422030 5   1   1
220306230301230302230303230304270300280301280302280304280305280306280307
2803082903003403013403023503003803053803063803075403015403025703 00
 30300 40300 60300 803002103012103022103032103042203012203032203042 20305   2   2
220306230301230302230303230304270300280301280302280304280305280306280307
280308290300340301340302350300380305380306380307540301540302570300
 30300 40300 60300 803002103012103022103032103042203012203032203042 20305   3   3
220306230301230302230303230304270300280301280302280304280305280306280307
280308290300340301340302350300380305380306380307540301540302570300
 30300 40300 60300 803002103012103022103032103042203012203032203042 20305   4   4
220306230301230302230303230304270300280301280302280304280305280306280307
280308290300340301340302350300380305380306380307540301540302570300
 30300 40300 60300 803002103012103022103032103042203012203032203042 20305   5   5
220306230301230302230303230304270300280301280302280304280305280306280307
280308290300340301340302350300380305380306380307540301540302570300
 4.53407E-03 3.42487E-02 4.35964E-05 2.09005E-05 6.21639E-05 1.19878E-03   1   1
 1.35916E-04 3.38361E-05 4.18401E-04 1.59957E-04 6.92534E-06 2.20017E-05
 5.57704E-06 3.33134E-04 5.26811E-03 1.26361E-04 1.60823E-05 3.80965E-05
 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20
 1.00000E-20 7.09685E-05 1.00000E-20 1.00000E-20 1.11171E-05 6.69282E-05
 3.39829E-06 2.24013E-06 1.44806E-05 4.63067E-06 5.65882E-05
 8.09067E-05 3.98361E-02 1.00000E-20 1.00000E-20 6.28400E-05 1.21182E-03   2   2
 1.37395E-04 3.42040E-05 4.21247E-04 1.61045E-04 6.97245E-06 2.21514E-05
```

VIM ENDF/B-VII.0 Input Listing, Table 21 (Cont'd).

```
 5.61498E-06 3.37255E-04 5.33328E-03 1.27924E-04 1.62813E-05 1.04630E-05
 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20
 1.00000E-20 7.04151E-05 1.00000E-20 1.00000E-20 3.03708E-06 6.81312E-05
 3.45938E-06 2.28040E-06 3.97687E-06 1.27174E-06 1.55418E-05
 8.12459E-05 4.00215E-02 1.00000E-20 1.00000E-20 4.84076E-05 9.33504E-04   3   3
 1.05839E-04 2.63485E-05 3.11510E-04 1.19092E-04 5.15609E-06 1.63808E-05
 4.15225E-06 2.63740E-04 4.17073E-03 1.00039E-04 1.27323E-05 8.72693E-06
 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20
 1.00000E-20 4.41475E-05 1.00000E-20 1.00000E-20 2.49611E-06 5.61051E-05
 2.84875E-06 1.87787E-06 3.27739E-06 1.04806E-06 1.28088E-05
 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 1.52576E-04 2.94230E-03   4   4
 3.33594E-04 8.30475E-05 1.11547E-03 4.26451E-04 1.84632E-05 5.86574E-05
 1.48686E-05 1.12973E-03 1.78653E-02 4.28518E-04 5.45387E-05 2.68742E-04
 5.35519E-09 8.25245E-09 5.14388E-09 8.85303E-09 9.27567E-09 5.31071E-09
 1.34186E-08 2.37482E-04 2.32101E-07 1.03450E-07 1.00000E-20 1.38447E-04
 7.02970E-06 4.63393E-06 1.00000E-20 1.00000E-20 1.00000E-20
 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 4.82121E-05 9.29734E-04   5   5
 1.05412E-04 2.62420E-05 3.09641E-04 1.18378E-04 5.12516E-06 1.62826E-05
 4.12734E-06 2.62721E-04 4.15462E-03 9.96530E-05 1.26831E-05 1.00000E-20
 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20 1.00000E-20
 1.00000E-20 4.34957E-05 1.00000E-20 1.00000E-20 1.00000E-20 5.60482E-05
 2.84586E-06 1.87597E-06 1.00000E-20 1.00000E-20 1.00000E-20
 1.00000e-05
```

APPENDIX B: Drawer Plate Loading Description for ZPR-3/11 Loading 10

Table B.1. Drawer Plate Loading Description for ZPR-3/11 Loading 10[(a)].

Plate ID (dimensions in inches)	Starting X Location	Starting Y Location	Starting Z Location	X #	Y #	Z #	Rotation
Identification Symbol A, Drawer Master 11-1, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	3	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	8.0000	1	1	1	1
Depleted Uranium (1x1x5) - APW	0.5000	0.0000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	0.5000	1.0000	0.0000	1	1	2	1
U(93) (1/8x2x3)	1.5000	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	1.5000	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	8.0000	1	1	1	1
Depleted Uranium (1/8x2x3) – APW	1.6250	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) – APW	1.6250	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) – APW	1.6250	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) – APW	1.6250	0.0000	8.0000	3	1	1	1
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1
Identification Symbol B, Drawer Master 11-2, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	3	1	1	1
U(93) (1/8x2x1)	0.3750	0.0000	0.0000	1	1	5	4
Depleted Uranium (1/8x2x1) - APW	0.3750	1.0000	0.0000	1	1	5	4
Depleted Uranium (1x1x5) - APW	0.5000	0.0000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	0.5000	1.0000	0.0000	1	1	2	1
U(93) (1/8x2x3)	1.5000	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	1.5000	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	8.0000	1	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	8.0000	3	1	1	1
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1

Table B.1. Drawer Plate Loading Description for ZPR-3/11 Loading 10[(a)] (Cont'd).

Plate ID (dimensions in inches)	Starting X Location	Starting Y Location	Starting Z Location	X #	Y #	Z #	Rotation
Identification Symbol C, Drawer Master 11-3, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	3	1	1	1
Depleted Uranium (1/8x2x1) - APW	0.3750	0.0000	0.0000	1	1	5	4
U(93) (1/8x2x1)	0.3750	1.0000	0.0000	1	1	5	4
Depleted Uranium (1x1x5) - APW	0.5000	0.0000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	0.5000	1.0000	0.0000	1	1	2	1
U(93) (1/8x2x3)	1.5000	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	1.5000	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	8.0000	1	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	8.0000	3	1	1	1
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1
Identification Symbol D, Drawer Master 11-4, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	3	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	8.0000	1	1	1	1
Depleted Uranium (1x1x5) - APW	0.5000	0.0000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	0.5000	1.0000	0.0000	1	1	2	1
Depleted Uranium (1/8x2x1) - APW	1.5000	0.0000	0.0000	1	1	5	4
U(93) (1/8x2x1)	1.5000	1.0000	0.0000	1	1	5	4
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	8.0000	3	1	1	1
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1

Table B.1. Drawer Plate Loading Description for ZPR-3/11 Loading 10[(a)] (Cont'd).

Plate ID (dimensions in inches)	Starting X Location	Starting Y Location	Starting Z Location	X #	Y #	Z #	Rotation
Identification Symbol E, Drawer Master 11-5, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	3	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	8.0000	1	1	1	1
Depleted Uranium (1x1x5) - APW	0.5000	0.0000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	0.5000	1.0000	0.0000	1	1	2	1
U(93) (1/8x2x1)	1.5000	0.0000	0.0000	1	1	5	4
Depleted Uranium (1/8x2x1) - APW	1.5000	1.0000	0.0000	1	1	5	4
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	8.0000	3	1	1	1
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1
Identification Symbol F, Drawer Master 11-6, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	4	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	4	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	4	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	4	1	1	1
Depleted Uranium (1x1x5) - APW	0.5000	0.0000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	0.5000	1.0000	0.0000	1	1	2	1
U(93) (1/8x2x3)	1.5000	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	1.5000	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	1.5000	0.0000	8.0000	1	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.6250	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.6250	0.0000	8.0000	3	1	1	1
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1

Table B.1. Drawer Plate Loading Description for ZPR-3/11 Loading 10(a) (Cont'd).

Plate ID (dimensions in inches)	Starting X Location	Starting Y Location	Starting Z Location	X #	Y #	Z #	Rotation
Identification Symbol G, Drawer Master 11-7, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	3	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	8.0000	1	1	1	1
Depleted Uranium (1x1x5) - APW	0.5000	0.0000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	0.5000	1.0000	0.0000	1	1	2	1
Depleted Uranium (1/8x2x3) - APW	1.5000	0.0000	0.0000	4	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.5000	0.0000	3.0000	4	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.5000	0.0000	5.0000	4	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.5000	0.0000	8.0000	4	1	1	1
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1
Identification Symbol H, Drawer Master 11-8, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	1	4	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	1	4	1	5
Depleted Uranium (1x1x5) - APW	0.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	1.0000	0.5000	0.0000	1	1	2	1
U(93) (1/8x2x3)	0.0000	1.5000	0.0000	1	1	1	5
U(93) (1/8x2x2)	0.0000	1.5000	3.0000	1	1	1	5
U(93) (1/8x2x3)	0.0000	1.5000	5.0000	1	1	1	5
U(93) (1/8x2x2)	0.0000	1.5000	8.0000	1	1	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	8.0000	1	3	1	5
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1

Table B.1. Drawer Plate Loading Description for ZPR-3/11 Loading 10[(a)] (Cont'd).

Plate ID (dimensions in inches)	**Starting X Location**	**Starting Y Location**	**Starting Z Location**	**X #**	**Y #**	**Z #**	**Rotation**
Identification Symbol I, Drawer Master 11-9, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	1	3	1	5
U(93) (1/8x2x3)	0.0000	0.3750	0.0000	1	1	1	5
U(93) (1/8x2x2)	0.0000	0.3750	3.0000	1	1	1	5
U(93) (1/8x2x3)	0.0000	0.3750	5.0000	1	1	1	5
U(93) (1/8x2x2)	0.0000	0.3750	8.0000	1	1	1	5
Depleted Uranium (1x1x5) - APW	0.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	1.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1/8x2x3) - APW	0.0000	1.5000	0.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.5000	3.0000	1	4	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	1.5000	5.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.5000	8.0000	1	4	1	5
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1
Identification Symbol L, Drawer Master 11-12 (only in Half 1)							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	1	3	1	5
U(93) (1/8x2x3)	0.0000	0.3750	0.0000	1	1	1	5
U(93) (1/8x2x2)	0.0000	0.3750	3.0000	1	1	1	5
U(93) (1/8x2x3)	0.0000	0.3750	5.0000	1	1	1	5
U(93) (1/8x2x2)	0.0000	0.3750	8.0000	1	1	1	5
Depleted Uranium (1x1x5) - APW	0.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	1.0000	0.5000	0.0000	1	1	2	1
U(93) (1/8x2x1)	0.0000	1.5000	0.0000	1	1	5	2
Depleted Uranium (1/8x2x1) - APW	1.0000	1.5000	0.0000	1	1	5	2
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	8.0000	1	3	1	5
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1

Table B.1. Drawer Plate Loading Description for ZPR-3/11 Loading 10[(a)] (Cont'd).

Plate ID (dimensions in inches)	**Starting X Location**	**Starting Y Location**	**Starting Z Location**	**X #**	**Y #**	**Z #**	**Rotation**
Identification Symbol M, Drawer Master 11-13 (only in Half 2)							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	1	3	1	5
U(93) (1/8x2x3)	0.0000	0.3750	0.0000	1	1	1	5
U(93) (1/8x2x2)	0.0000	0.3750	3.0000	1	1	1	5
U(93) (1/8x2x3)	0.0000	0.3750	5.0000	1	1	1	5
U(93) (1/8x2x2)	0.0000	0.3750	8.0000	1	1	1	5
Depleted Uranium (1x1x5) - APW	0.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	1.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1/8x2x1) - APW	0.0000	1.5000	0.0000	1	1	5	2
U(93) (1/8x2x1)	1.0000	1.5000	0.0000	1	1	5	2
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	8.0000	1	3	1	5
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1
Identification Symbol R, Drawer Master 11-18, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	1	4	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	1	4	1	5
Depleted Uranium (1x1x5) - APW	0.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	1.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1/8x2x1) - APW	0.0000	1.5000	0.0000	1	1	5	2
U(93) (1/8x2x1)	1.0000	1.5000	0.0000	1	1	5	2
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	8.0000	1	3	1	5
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1

Table B.1. Drawer Plate Loading Description for ZPR-3/11 Loading 10[(a)] (Cont'd).

Plate ID (dimensions in inches)	Starting X Location	Starting Y Location	Starting Z Location	X #	Y #	Z #	Rotation
Identification Symbol S, Drawer Master 11-19, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	1	4	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	1	4	1	5
Depleted Uranium (1x1x5) - APW	0.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	1.0000	0.5000	0.0000	1	1	2	1
U(93) (1/8x2x1)	0.0000	1.5000	0.0000	1	1	5	2
Depleted Uranium (1/8x2x1) - APW	1.0000	1.5000	0.0000	1	1	5	2
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	1.6250	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.6250	8.0000	1	3	1	5
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1
Identification Symbol T, Drawer Master 11-20, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	1	3	1	5
U(93) (1/8x2x1)	0.0000	0.3750	0.0000	1	1	5	2
Depleted Uranium (1/8x2x1) - APW	1.0000	0.3750	0.0000	1	1	5	2
Depleted Uranium (1x1x5) - APW	0.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	1.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1/8x2x3) - APW	0.0000	1.5000	0.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.5000	3.0000	1	4	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	1.5000	5.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.5000	8.0000	1	4	1	5
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1
Identification Symbol U, Drawer Master 11-21, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	1	3	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	1	3	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	1	3	1	5
Depleted Uranium (1/8x2x1) - APW	0.0000	0.3750	0.0000	1	1	5	2
U(93) (1/8x2x1)	1.0000	0.3750	0.0000	1	1	5	2
Depleted Uranium (1x1x5) - APW	0.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1x1x5) - APW	1.0000	0.5000	0.0000	1	1	2	1
Depleted Uranium (1/8x2x3) - APW	0.0000	1.5000	0.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.5000	3.0000	1	4	1	5
Depleted Uranium (1/8x2x3) - APW	0.0000	1.5000	5.0000	1	4	1	5
Depleted Uranium (1/8x2x2) - APW	0.0000	1.5000	8.0000	1	4	1	5
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	10.0000	1	1	1	1

Table B.1. Drawer Plate Loading Description for ZPR-3/11 Loading 10[(a)] (Cont'd).

Plate ID (dimensions in inches)	Starting X Location	Starting Y Location	Starting Z Location	X #	Y #	Z #	Rotation
Identification Symbol Z, Drawer Master 11C1, Transform Starting X Location for Movable Half							
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	8.0000	3	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	0.3750	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	0.3750	0.0000	8.0000	1	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.5000	0.0000	0.0000	7	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.5000	0.0000	3.0000	7	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.5000	0.0000	5.0000	7	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.5000	0.0000	8.0000	7	1	1	1
U(93) (1/8x2x3)	1.3750	0.0000	0.0000	1	1	1	1
U(93) (1/8x2x2)	1.3750	0.0000	3.0000	1	1	1	1
U(93) (1/8x2x3)	1.3750	0.0000	5.0000	1	1	1	1
U(93) (1/8x2x2)	1.3750	0.0000	8.0000	1	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.5000	0.0000	0.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.5000	0.0000	3.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.5000	0.0000	5.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.5000	0.0000	8.0000	3	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	10.0000	3	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	13.0000	3	1	1	1
Depleted Uranium (1x1x5) - APW	0.3750	0.0000	10.0000	1	2	1	1
Depleted Uranium (1/8x2x3) - APW	1.3750	0.0000	10.0000	4	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.3750	0.0000	13.0000	4	1	1	1
DP Retainer Spring (1.75x2x1/16)	0.0000	0.0000	15.0000	1	1	1	1
DP Retainer Spring (1.75x2x1/16)	0.0000	0.0000	15.0625	1	1	1	1
DP Drawer Divider Plate (1. 75x2x1/16)	0.0000	0.0000	15.1250	1	1	1	1
Depleted Uranium (1/8x2x3) - APW	0.0000	0.0000	15.1875	8	1	1	1
Depleted Uranium (1/8x2x3) - APW	1.0000	0.0000	15.1875	7	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	18.1875	8	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.0000	0.0000	18.1875	7	1	1	1
Depleted Uranium (1/8x2x2) - APW	0.0000	0.0000	20.1875	8	1	1	1
Depleted Uranium (1/8x2x2) - APW	1.0000	0.0000	20.1875	7	1	1	1

Table B.1. Drawer Plate Loading Description for ZPR-3/11 Loading 10[(a)] (Cont'd).

Plate ID (dimensions in inches)	**Starting X Location**	**Starting Y Location**	**Starting Z Location**	**X #**	**Y #**	**Z #**	**Rotation**
Identification Symbol a, Drawer Master 11-00 (Axial Blanket)							
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	0.0000	1	1	1	1
Depleted Uranium (2x2x2) - APW	0.0000	0.0000	5.0000	1	1	1	1
Identification Symbol x, DP CR shaft							
Stainless Steel (1/4x2x1)	0.9225	0.0000	0.0000	1	1	7	1
Identification Symbol X, Drawer Master 238 (Radial Blanket)							
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	0.0000	1	1	4	1
Depleted Uranium (2x2x2) - APW	0.0000	0.0000	20.0000	1	1	1	1
Identification Symbol Y, Drawer Master bf3 (BF_3 Detector Radial Blanket)							
Depleted Uranium (2x2x5) - APW	0.0000	0.0000	2.0000	1	1	4	1
Depleted Uranium (2x2x2) - APW	0.0000	0.0000	22.0000	1	1	1	1

(a) all dimensions and locations are in inch units.

APPENDIX C: VIM MODEL OF “AS-BUILT” ZPR-3/11 LOADING 10

This input for the as-built ZPR-3 Assembly 11 critical assembly was run with Version 5.1 of the VIM code with an ENDF/B-VII.0 continuous energy cross section library. All the cross sections correspond to 300 K. The VIM calculation used 10 million histories, with 20,000 neutron histories per generation and 500 active generations after skipping 100 generations.

Note that the “experimental k_{eff} adjusted to correspond to the as-built model” is 1.0020 ± 0.0012.

VIM ENDF/B-VII.0 “As-Built” Model Input Listing

```
   388474211ZPR-3/11  LOADING 10  01/21/58 - REFERENCE - V7 XS - 01        01
   500     3     0   100     0     0                                       02
 20000 50000    10     0     0     0                                       03
     0     1     0     0    50     0                                       04
    35    23     1     1  1886 50000                                       05
 1.00000E+09 1.00000E-05 2.75000E+02 1.00000E+00 1.00000E-05 1.99900E+07   06AN
 9.50000E-01 0.00000E+00 1.00000E+00 0.00000E+00                           06BN
     1     0     0     0     3     0     0     0     0     0     1     0     0   07N
 30300 40300 60300 80300210301210302210303210304220301220303220304220305   08
220306230301230302230303230304270300280301280302280304280305280306280307   08
280308290300340301340302350300380305380306380307540301540302570300         08
                                                                           09
                                                                           10
    36    31    31     2    65    60     1                                 13
     0     0     0   200                                                   14
     5.54609      5.52577    85.09000                                      15
           0           2           0           2     0.00000     1.00000   16
  RPP    1   0.00000   5.54609   0.00000   0.10160   0.00000   2.54000     17
  RPP    2   0.00000   5.54609   5.42417   5.52577   0.00000   2.54000     17
  RPP    3   0.00000   0.10160   0.10160   5.42417   0.00000   2.54000     17
  RPP    4   5.44449   5.54609   0.10160   5.42417   0.00000   2.54000     17
  RPP    5   0.00000   5.54609   0.00000   0.10160   2.54000  38.73500     17
  RPP    6   0.00000   5.54609   5.42417   5.52577   2.54000  38.73500     17
  RPP    7   0.00000   0.10160   0.10160   5.42417   2.54000  38.73500     17
  RPP    8   5.44449   5.54609   0.10160   5.42417   2.54000  38.73500     17
  RPP    9   0.14922   5.39687   0.10160   5.34924   0.00000   0.08128     17
  RPP   10   0.14922   5.39687   0.10160   5.34924  38.65372  38.73500     17
  RPP   11   0.14922   0.23050   0.18288   5.34924   0.08128  38.65372     17
  RPP   12   5.31559   5.39687   0.18288   5.34924   0.08128  38.65372     17
  RPP   13   0.14922   5.39687   0.10160   0.18288   0.08128  38.65372     17
  RPP   14   0.23050   5.31051   0.18288   5.26288  25.48128  38.18128     17
  RPP   15   0.23050   1.18301   0.18288   5.26288   0.08128   7.70128     17
  RPP   16   0.23050   1.18301   0.18288   5.26288   7.70128  12.78128     17
  RPP   17   0.23050   1.18301   0.18288   5.26288  12.78128  20.40128     17
  RPP   18   0.23050   1.18301   0.18288   5.26288  20.40128  25.48128     17
  RPP   19   1.18301   1.50050   0.18288   5.26288   0.08128   7.70128     17
  RPP   20   1.18301   1.50050   0.18288   5.26288   7.70128  12.78128     17
  RPP   21   1.18301   1.50050   0.18288   5.26288  12.78128  20.40128     17
  RPP   22   1.18301   1.50050   0.18288   5.26288  20.40128  25.48128     17
  RPP   23   1.50050   4.04051   0.18288   2.72288   0.08128  25.48128     17
  RPP   24   1.50050   4.04051   2.72288   5.26288   0.08128  25.48128     17
  RPP   25   4.04051   4.35801   0.18288   5.26288   0.08128   7.70128     17
  RPP   26   4.04051   4.35801   0.18288   5.26288   7.70128  12.78128     17
  RPP   27   4.04051   4.35801   0.18288   5.26288  12.78128  20.40128     17
  RPP   28   4.04051   4.35801   0.18288   5.26288  20.40128  25.48128     17
  RPP   29   4.35801   5.31051   0.18288   5.26288   0.08128   7.70128     17
  RPP   30   4.35801   5.31051   0.18288   5.26288   7.70128  12.78128     17
  RPP   31   4.35801   5.31051   0.18288   5.26288  12.78128  20.40128     17
  RPP   32   4.35801   5.31051   0.18288   5.26288  20.40128  25.48128     17
  RPP   33   0.23050   5.31051   0.18288   5.26288  38.18128  38.34003     17
  RPP   34   0.10160   0.14922   0.10160   5.34924   2.54000  38.73500     17
  RPP   35   5.39687   5.44449   0.10160   5.34924   2.54000  38.73500     17
  RPP   36   0.10160   5.44449   5.34924   5.42417   0.00000  38.73500     17
  RPP   37   0.23050   5.31559   5.26288   5.34924   0.08128  38.34003     17
  RPP   38   5.31051   5.31559   0.18288   5.26288  20.40128  38.34003     17
  RPP   39   5.31051   5.31559   0.18288   5.26288   0.08128   2.54000     17
  RPP   40   5.39687   5.44449   0.10160   5.34924   0.00000   2.54000     17
  RPP   41   5.31051   5.31559   0.18288   5.26288  12.78128  20.40128     17
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RPP    42   0.10160   0.14922   0.10160   5.34924   0.00000   2.54000      17
RPP    43   5.31051   5.31559   0.18288   5.26288   7.70128  12.78128      17
RPP    44   0.23050   5.31559   0.18288   5.34924  38.34003  38.65372      17
RPP    45   5.31051   5.31559   0.18288   5.26288   2.54000   7.70128      17
RPP    46   0.00000   5.54609   0.00000   0.10160  38.73500  85.09000      17
RPP    47   0.00000   5.54609   5.42417   5.52577  38.73500  85.09000      17
RPP    48   0.00000   0.10160   0.10160   5.42417  38.73500  85.09000      17
RPP    49   5.44449   5.54609   0.10160   5.42417  38.73500  85.09000      17
RPP    50   0.14922   5.39687   0.10160   5.34924  38.73500  38.81628      17
RPP    51   0.14922   5.39687   0.10160   5.34924  67.22872  67.31000      17
RPP    52   0.14922   0.23050   0.18288   5.34924  38.81628  67.22872      17
RPP    53   5.31559   5.39687   0.18288   5.34924  38.81628  67.22872      17
RPP    54   0.14922   5.39687   0.10160   0.18288  38.81628  67.22872      17
RPP    55   0.23050   5.31051   0.18288   5.26288  38.81628  51.51628      17
RPP    56   0.23050   5.31051   0.18288   5.26288  51.51628  56.59628      17
RPP    57   0.23050   5.31051   0.18288   5.26288  56.59628  56.75503      17
RPP    58   0.10160   0.14922   0.10160   5.34924  38.73500  67.31000      17
RPP    59   5.39687   5.44449   0.10160   5.34924  38.73500  67.31000      17
RPP    60   0.10160   5.44449   5.34924   5.42417  38.73500  67.31000      17
RPP    61   0.23050   5.31559   0.18288   5.34924  56.75503  67.22872      17
RPP    62   0.23050   5.31559   5.26288   5.34924  38.81628  56.75503      17
RPP    63   5.31051   5.31559   0.18288   5.26288  38.81628  56.75503      17
RPP    64   0.10160   5.44449   0.10160   5.42417  67.31000  85.09000      17
RPP    65   0.23558   5.31559   0.18288   5.26288  25.48128  38.18128      17
RPP    66   4.36309   5.31559   0.18288   5.26288   0.08128   7.70128      17
RPP    67   4.36309   5.31559   0.18288   5.26288   7.70128  12.78128      17
RPP    68   4.36309   5.31559   0.18288   5.26288  12.78128  20.40128      17
RPP    69   4.36309   5.31559   0.18288   5.26288  20.40128  25.48128      17
RPP    70   4.04558   4.36309   0.18288   5.26288   0.08128   7.70128      17
RPP    71   4.04558   4.36309   0.18288   5.26288   7.70128  12.78128      17
RPP    72   4.04558   4.36309   0.18288   5.26288  12.78128  20.40128      17
RPP    73   4.04558   4.36309   0.18288   5.26288  20.40128  25.48128      17
RPP    74   1.50558   4.04558   0.18288   2.72288   0.08128  25.48128      17
RPP    75   1.50558   4.04558   2.72288   5.26288   0.08128  25.48128      17
RPP    76   1.18809   1.50558   0.18288   5.26288   0.08128   7.70128      17
RPP    77   1.18809   1.50558   0.18288   5.26288   7.70128  12.78128      17
RPP    78   1.18809   1.50558   0.18288   5.26288  12.78128  20.40128      17
RPP    79   1.18809   1.50558   0.18288   5.26288  20.40128  25.48128      17
RPP    80   0.23558   1.18809   0.18288   5.26288   0.08128   7.70128      17
RPP    81   0.23558   1.18809   0.18288   5.26288   7.70128  12.78128      17
RPP    82   0.23558   1.18809   0.18288   5.26288  12.78128  20.40128      17
RPP    83   0.23558   1.18809   0.18288   5.26288  20.40128  25.48128      17
RPP    84   0.23558   5.31559   0.18288   5.26288  38.18128  38.34003      17
RPP    85   0.23050   0.23558   0.18288   5.26288  20.40128  38.34003      17
RPP    86   0.23050   0.23558   0.18288   5.26288   0.08128   2.54000      17
RPP    87   0.23050   0.23558   0.18288   5.26288  12.78128  20.40128      17
RPP    88   0.23050   0.23558   0.18288   5.26288   7.70128  12.78128      17
RPP    89   0.23050   0.23558   0.18288   5.26288   2.54000   7.70128      17
RPP    90   0.23558   5.31559   0.18288   5.26288  38.81628  51.51628      17
RPP    91   0.23558   5.31559   0.18288   5.26288  51.51628  56.59628      17
RPP    92   0.23558   5.31559   0.18288   5.26288  56.59628  56.75503      17
RPP    93   0.23050   0.23558   0.18288   5.26288  38.81628  56.75503      17
RPP    94   0.00000   5.54609   0.00000   0.10160   2.54000  82.55000      17
RPP    95   0.00000   5.54609   5.42417   5.52577   2.54000  82.55000      17
RPP    96   0.00000   0.10160   0.10160   5.42417   2.54000  82.55000      17
RPP    97   5.44449   5.54609   0.10160   5.42417   2.54000  82.55000      17
RPP    98   0.15177   5.39432   0.10160   5.32130   0.00000   0.12573      17
RPP    99   0.15177   5.39432   0.10160   5.32130  82.42427  82.55000      17
RPP   100   0.15177   0.27750   0.22733   5.32130   0.12573  82.42427      17
RPP   101   5.26860   5.39432   0.22733   5.32130   0.12573  82.42427      17
RPP   102   0.15177   5.39432   0.10160   0.22733   0.12573  82.42427      17
RPP   103   1.22999   3.77000   0.22733   5.30733  25.52573  38.22573      17
RPP   104   0.27750   4.72250   0.22733   5.30733  38.54323  38.70198      17
RPP   105   0.27750   1.22999   0.22733   5.30733   0.12573   7.74573      17
RPP   106   0.27750   1.22999   0.22733   5.30733   7.74573  12.82573      17
RPP   107   0.27750   1.22999   0.22733   5.30733  12.82573  20.44573      17
RPP   108   0.27750   1.22999   0.22733   5.30733  20.44573  25.52573      17
RPP   109   1.22999   1.54749   0.22733   5.30733   0.12573   7.74573      17
RPP   110   1.22999   1.54749   0.22733   5.30733   7.74573  12.82573      17
RPP   111   1.22999   1.54749   0.22733   5.30733  12.82573  20.44573      17
RPP   112   1.22999   1.54749   0.22733   5.30733  20.44573  25.52573      17
RPP   113   1.54749   3.77000   0.22733   5.30733   0.12573   7.74573      17
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RPP  114   1.54749   3.77000   0.22733   5.30733   7.74573  12.82573      17
RPP  115   1.54749   3.77000   0.22733   5.30733  12.82573  20.44573      17
RPP  116   1.54749   3.77000   0.22733   5.30733  20.44573  25.52573      17
RPP  117   3.77000   4.08750   0.22733   5.30733   0.12573   7.74573      17
RPP  118   3.77000   4.08750   0.22733   5.30733   7.74573  12.82573      17
RPP  119   3.77000   4.08750   0.22733   5.30733  12.82573  20.44573      17
RPP  120   3.77000   4.08750   0.22733   5.30733  20.44573  25.52573      17
RPP  121   4.08750   5.04000   0.22733   5.30733   0.12573   7.74573      17
RPP  122   4.08750   5.04000   0.22733   5.30733   7.74573  12.82573      17
RPP  123   4.08750   5.04000   0.22733   5.30733  12.82573  20.44573      17
RPP  124   4.08750   5.04000   0.22733   5.30733  20.44573  25.52573      17
RPP  125   0.27750   1.22999   0.22733   5.30733  25.52573  33.14573      17
RPP  126   0.27750   1.22999   0.22733   5.30733  33.14573  38.22573      17
RPP  127   3.77000   5.04000   0.22733   5.30733  25.52573  33.14573      17
RPP  128   3.77000   5.04000   0.22733   5.30733  33.14573  38.22573      17
RPP  129   0.27750   4.72250   0.22733   5.30733  38.22573  38.38448      17
RPP  130   0.27750   4.72250   0.22733   5.30733  38.38448  38.54323      17
RPP  131   0.27750   2.81750   0.22733   5.30733  38.70198  46.32198      17
RPP  132   2.81750   5.04000   0.22733   5.30733  38.70198  46.32198      17
RPP  133   0.27750   2.81750   0.22733   5.30733  46.32198  51.40198      17
RPP  134   2.81750   5.04000   0.22733   5.30733  46.32198  51.40198      17
RPP  135   0.27750   2.81750   0.22733   5.30733  51.40198  56.48198      17
RPP  136   2.81750   5.04000   0.22733   5.30733  51.40198  56.48198      17
RPP  137   0.10160   0.15177   0.10160   5.32130   2.54000  82.55000      17
RPP  138   5.39432   5.44449   0.10160   5.32130   2.54000  82.55000      17
RPP  139   0.10160   5.44449   5.32130   5.42417   0.00000  82.55000      17
RPP  140   0.27750   5.26860   5.30733   5.32130   0.12573  56.48198      17
RPP  141   5.04000   5.26860   0.22733   5.30733   0.12573  38.22573      17
RPP  142   5.39432   5.44449   0.10160   5.32130   0.00000   2.54000      17
RPP  143   0.10160   0.15177   0.10160   5.32130   0.00000   2.54000      17
RPP  144   5.04000   5.26860   0.22733   5.30733  38.70198  56.48198      17
RPP  145   0.27750   5.26860   0.22733   5.32130  56.48198  82.42427      17
RPP  146   4.72250   5.26860   0.22733   5.30733  38.22573  38.70198      17
RPP  147   0.00000   5.54609   0.00000   0.10160  82.55000  85.09000      17
RPP  148   0.00000   5.54609   5.42417   5.52577  82.55000  85.09000      17
RPP  149   0.00000   0.10160   0.10160   5.42417  82.55000  85.09000      17
RPP  150   5.44449   5.54609   0.10160   5.42417  82.55000  85.09000      17
RPP  151   2.44475   3.07975   0.10160   5.18160  82.55000  85.09000      17
RPP  152   0.10160   5.44449   5.18160   5.42417  82.55000  85.09000      17
RPP  153   0.10160   2.44475   0.10160   5.18160  82.55000  85.09000      17
RPP  154   3.07975   5.44449   0.10160   5.18160  82.55000  85.09000      17
RPP  155   1.77610   4.31609   0.22733   5.30733  25.52573  38.22573      17
RPP  156   0.82359   5.26860   0.22733   5.30733  38.54323  38.70198      17
RPP  157   4.31609   5.26860   0.22733   5.30733   0.12573   7.74573      17
RPP  158   4.31609   5.26860   0.22733   5.30733   7.74573  12.82573      17
RPP  159   4.31609   5.26860   0.22733   5.30733  12.82573  20.44573      17
RPP  160   4.31609   5.26860   0.22733   5.30733  20.44573  25.52573      17
RPP  161   3.99859   4.31609   0.22733   5.30733   0.12573   7.74573      17
RPP  162   3.99859   4.31609   0.22733   5.30733   7.74573  12.82573      17
RPP  163   3.99859   4.31609   0.22733   5.30733  12.82573  20.44573      17
RPP  164   3.99859   4.31609   0.22733   5.30733  20.44573  25.52573      17
RPP  165   1.77610   3.99859   0.22733   5.30733   0.12573   7.74573      17
RPP  166   1.77610   3.99859   0.22733   5.30733   7.74573  12.82573      17
RPP  167   1.77610   3.99859   0.22733   5.30733  12.82573  20.44573      17
RPP  168   1.77610   3.99859   0.22733   5.30733  20.44573  25.52573      17
RPP  169   1.45860   1.77610   0.22733   5.30733   0.12573   7.74573      17
RPP  170   1.45860   1.77610   0.22733   5.30733   7.74573  12.82573      17
RPP  171   1.45860   1.77610   0.22733   5.30733  12.82573  20.44573      17
RPP  172   1.45860   1.77610   0.22733   5.30733  20.44573  25.52573      17
RPP  173   0.50610   1.45860   0.22733   5.30733   0.12573   7.74573      17
RPP  174   0.50610   1.45860   0.22733   5.30733   7.74573  12.82573      17
RPP  175   0.50610   1.45860   0.22733   5.30733  12.82573  20.44573      17
RPP  176   0.50610   1.45860   0.22733   5.30733  20.44573  25.52573      17
RPP  177   4.31609   5.26860   0.22733   5.30733  25.52573  33.14573      17
RPP  178   4.31609   5.26860   0.22733   5.30733  33.14573  38.22573      17
RPP  179   0.50610   1.77610   0.22733   5.30733  25.52573  33.14573      17
RPP  180   0.50610   1.77610   0.22733   5.30733  33.14573  38.22573      17
RPP  181   0.82359   5.26860   0.22733   5.30733  38.22573  38.38448      17
RPP  182   0.82359   5.26860   0.22733   5.30733  38.38448  38.54323      17
RPP  183   2.72859   5.26860   0.22733   5.30733  38.70198  46.32198      17
RPP  184   0.50610   2.72859   0.22733   5.30733  38.70198  46.32198      17
RPP  185   2.72859   5.26860   0.22733   5.30733  46.32198  51.40198      17
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RPP  186   0.50610   2.72859   0.22733   5.30733  46.32198  51.40198      17
RPP  187   2.72859   5.26860   0.22733   5.30733  51.40198  56.48198      17
RPP  188   0.50610   2.72859   0.22733   5.30733  51.40198  56.48198      17
RPP  189   0.27750   0.50610   0.22733   5.30733   0.12573  38.22573      17
RPP  190   0.27750   0.50610   0.22733   5.30733  38.70198  56.48198      17
RPP  191   0.27750   0.82359   0.22733   5.30733  38.22573  38.70198      17
RPP  192   2.46634   3.10134   0.10160   5.18160  82.55000  85.09000      17
RPP  193   0.10160   2.46634   0.10160   5.18160  82.55000  85.09000      17
RPP  194   3.10134   5.44449   0.10160   5.18160  82.55000  85.09000      17
RPP  195   1.18301   1.50050   0.18288   2.72288   0.08128  25.48128      17
RPP  196   1.18301   1.50050   2.72288   5.26288   0.08128  25.48128      17
RPP  197   5.31051   5.31559   0.18288   5.26288  25.48128  38.34003      17
RPP  198   5.31051   5.31559   2.72288   5.26288   0.08128  25.48128      17
RPP  199   5.31051   5.31559   0.18288   2.72288   0.08128  25.48128      17
RPP  200   4.04051   4.35801   0.18288   2.72288   0.08128  25.48128      17
RPP  201   4.04051   4.35801   2.72288   5.26288   0.08128  25.48128      17
RPP  202   0.23050   1.50050   0.18288   5.26288   0.08128   7.70128      17
RPP  203   0.23050   1.50050   0.18288   5.26288   7.70128  12.78128      17
RPP  204   0.23050   1.50050   0.18288   5.26288  12.78128  20.40128      17
RPP  205   0.23050   1.50050   0.18288   5.26288  20.40128  25.48128      17
RPP  206   4.04051   5.31051   0.18288   5.26288   0.08128   7.70128      17
RPP  207   4.04051   5.31051   0.18288   5.26288   7.70128  12.78128      17
RPP  208   4.04051   5.31051   0.18288   5.26288  12.78128  20.40128      17
RPP  209   4.04051   5.31051   0.18288   5.26288  20.40128  25.48128      17
RPP  210   0.23050   5.31051   0.18288   1.45288   0.08128   7.70128      17
RPP  211   0.23050   5.31051   0.18288   1.45288   7.70128  12.78128      17
RPP  212   0.23050   5.31051   0.18288   1.45288  12.78128  20.40128      17
RPP  213   0.23050   5.31051   0.18288   1.45288  20.40128  25.48128      17
RPP  214   0.23050   2.77051   1.45288   3.99288   0.08128  25.48128      17
RPP  215   2.77051   5.31051   1.45288   3.99288   0.08128  25.48128      17
RPP  216   0.23050   5.31051   3.99288   4.31038   0.08128   7.70128      17
RPP  217   0.23050   5.31051   3.99288   4.31038   7.70128  12.78128      17
RPP  218   0.23050   5.31051   3.99288   4.31038  12.78128  20.40128      17
RPP  219   0.23050   5.31051   3.99288   4.31038  20.40128  25.48128      17
RPP  220   0.23050   5.31051   4.31038   5.26288   0.08128   7.70128      17
RPP  221   0.23050   5.31051   4.31038   5.26288   7.70128  12.78128      17
RPP  222   0.23050   5.31051   4.31038   5.26288  12.78128  20.40128      17
RPP  223   0.23050   5.31051   4.31038   5.26288  20.40128  25.48128      17
RPP  224   0.23050   5.31051   0.18288   1.13538   0.08128   7.70128      17
RPP  225   0.23050   5.31051   0.18288   1.13538   7.70128  12.78128      17
RPP  226   0.23050   5.31051   0.18288   1.13538  12.78128  20.40128      17
RPP  227   0.23050   5.31051   0.18288   1.13538  20.40128  25.48128      17
RPP  228   0.23050   5.31051   1.13538   1.45288   0.08128   7.70128      17
RPP  229   0.23050   5.31051   1.13538   1.45288   7.70128  12.78128      17
RPP  230   0.23050   5.31051   1.13538   1.45288  12.78128  20.40128      17
RPP  231   0.23050   5.31051   1.13538   1.45288  20.40128  25.48128      17
RPP  232   0.23050   5.31051   3.99288   5.26288   0.08128   7.70128      17
RPP  233   0.23050   5.31051   3.99288   5.26288   7.70128  12.78128      17
RPP  234   0.23050   5.31051   3.99288   5.26288  12.78128  20.40128      17
RPP  235   0.23050   5.31051   3.99288   5.26288  20.40128  25.48128      17
RPP  236   0.23050   2.77051   3.99288   4.31038   0.08128  25.48128      17
RPP  237   2.77051   5.31051   3.99288   4.31038   0.08128  25.48128      17
RPP  238   5.31051   5.31559   0.18288   3.99288  20.40128  25.48128      17
RPP  239   5.31051   5.31559   0.18288   3.99288  12.78128  20.40128      17
RPP  240   5.31051   5.31559   3.99288   5.26288   2.54000  25.48128      17
RPP  241   5.31051   5.31559   0.18288   3.99288   2.54000   7.70128      17
RPP  242   5.31051   5.31559   0.18288   3.99288   7.70128  12.78128      17
RPP  243   0.23050   2.77051   1.13538   1.45288   0.08128  25.48128      17
RPP  244   2.77051   5.31051   1.13538   1.45288   0.08128  25.48128      17
RPP  245   5.31051   5.31559   0.18288   3.99288   0.08128   2.54000      17
RPP  246   5.31051   5.31559   0.18288   3.99288   2.54000  25.48128      17
RPP  247   5.31051   5.31559   3.99288   5.26288   0.08128  25.48128      17
RPP  248   4.04558   4.36309   0.18288   2.72288   0.08128  25.48128      17
RPP  249   4.04558   4.36309   2.72288   5.26288   0.08128  25.48128      17
RPP  250   0.23050   0.23558   0.18288   5.26288  25.48128  38.34003      17
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RPP  252   0.23050   0.23558   0.18288   2.72288   0.08128  25.48128      17
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RPP  254   1.18809   1.50558   2.72288   5.26288   0.08128  25.48128      17
RPP  255   4.04558   5.31559   0.18288   5.26288   0.08128   7.70128      17
RPP  256   4.04558   5.31559   0.18288   5.26288   7.70128  12.78128      17
RPP  257   4.04558   5.31559   0.18288   5.26288  12.78128  20.40128      17
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  RPP  261   0.23558   1.50558   0.18288   5.26288  12.78128  20.40128      17
  RPP  262   0.23558   1.50558   0.18288   5.26288  20.40128  25.48128      17
  RPP  263   0.23558   5.31559   0.18288   1.45288   0.08128   7.70128      17
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310   101  16   56005   311   100  13   57005   312   100   0   58005   19
313   100   0   59005   314   100   0   60005   315   100   0   61005   19
316   100   0   62005   317   100   0   63005   318   100   0   64005   19
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373   100   0   59006   374   100   0   60006   375   100   0   61006   19
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535   100   0   41009    536   100   0   42009    537   100   0   43009    19
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544   100  14   50009    545   100  14   51009    546   100  15   52009    19
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