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IDENTIFICATION NUMBER: HEU-MET-THERM-033 SPECTRA

KEY WORDS: acceptable, array, critical experiment, foil, HEU, Planet, polyethylene-moderated, polyethylene-reflected, rhenium, uranium metal

1.0 DETAILED DESCRIPTION

1.1 Overview of Experiment

The 2 × 2 array HEU-Re experiment was performed on the Planet universal critical assembly machine on November 4th, 2003 at the Los Alamos Critical Experiments Facility (LACEF) at Los Alamos National Laboratory (LANL). For this experiment, there were 10 ½ units, each full unit containing four HEU foils and two rhenium foils. The top unit contained only two HEU foils. A total of 42 HEU foils were used for this experiment. Rhenium is a desirable cladding material for space nuclear power applications.

This experiment consisted of HEU foils interleaved with rhenium foils and is moderated and reflected by polyethylene plates. A unit consisted of a polyethylene plate, which has a recess for rhenium foils, and four HEU foils in a single layer in the top recess of each polyethylene plate.

The Planet universal criticality assembly machine has been previously used in experiments containing HEU foils interspersed with SiO_2 (HEU-MET-THERM-001), Al (HEU-MET-THERM-008), MgO (HEU-MET-THERM-009), Gd foils (HEU-MET-THERM-010), 2 × 2 × 26 Al (HEU-MET-THERM-012), Fe (HEU-MET-THERM-013 and HEU-MET-THERM-015), 2 × 2 × 23 SiO_2 (HEU-MET-THERM-014), 2 × 2 × 11 hastelloy plates (HEU-MET-THERM-016), and concrete (HEU-MET-THERM-018). This report describes the 2 × 2 array HEU-Re experiment.

The 2 × 2 array of HEU-Re is considered acceptable for use as a benchmark critical experiment.

1.2 Description of Experimental Configuration

The information included in this evaluation was obtained from logbooks, conversations with the experimenters, engineering drawings, analysis reports, and the Safety Analysis Report for LACEF. An example experimental setup is shown in Figure 1.

Figure 1. Typical Array HEU-Polyethylene Experiment on the Planet Critical Assembly Machine.

1.2.1 Assembly

The system is divided into two sections as shown in Figure 1. The movable bottom section of the system rests on a 31 × 31 × 1.25 inch (78.74 × 78.74 × 3.175 cm) aluminum support plate called the movable platen. A 26.6 × 26.6 × 0.25 inch (67.564 × 6.564 × 0.635 cm) thick mounting plate rests on top of the platen and is shown in Figure 2. The length and width have a tolerance of ± 0.1 inch (0.254 cm) and the thickness has a tolerance of ± 0.01 inch (0.0254 cm). The platen and mounting plate are made of 6061-T6 aluminum. Both of these plates ride on a hydraulic lift. This hydraulic lift is a hollow cylinder constructed of carbon steel.

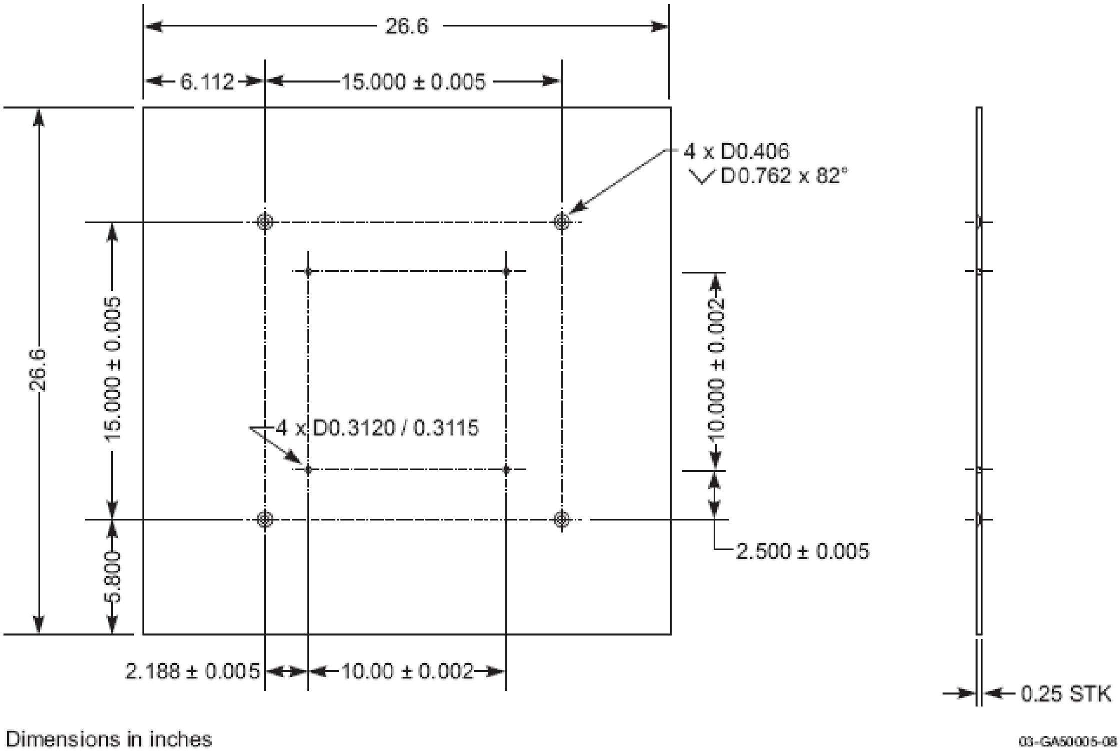

Figure 2. Schematic of the Aluminum Mounting Plate that Supports the Lower Stack.

The top half of the system rests on a stationary platform (see Figure 1). This top platform is composed of 6061-T6 aluminum and has dimensions of 45 × 45 × 1 inch (114.30 × 114.30 × 2.54 cm) as shown in Figure 3, with the length, width, and thickness all having a tolerance of ± 0.1 inch (0.254 cm). A 6061-T6 aluminum dowel-pin plate rests on the top platform with dimensions 34 × 34 × 0.5 inches (86.36 × 86.36 × 1.27 cm) as shown in Figure 4, with the length and width having a tolerance of ± 0.1 inch (0.254 cm) and the thickness having a tolerance of ± 0.01 inch (0.0254 cm). This plate attaches the top part of the assembly to the top platform. Both the top platform and dowel-pin plate have large central holes inside them so that the bottom part of the assembly can pass through them and contact the upper part of the assembly (see Figures 3 and 4). A polyethylene plate with dimensions 29.6 × 29.6 inches (75.184 × 75.184 cm) with a tolerance of ± 0.1 inch (0.254 cm) rests on the dowel-pin plate and is the first polyethylene plate for the upper part of the assembly. This first plate had a thickness of 0.415 ± 0.001 inch (10.541 ± 0.0254 mm). This polyethylene plate is shown in Figure 5. As the bottom half of the assembly is raised, the reactivity of the system increases and the system approaches a critical state when the bottom section begins to lift the upper section of the assembly. To disassemble the system, the bottom stack is lowered to its initial position. There are no control or safety rods inside the assembly.

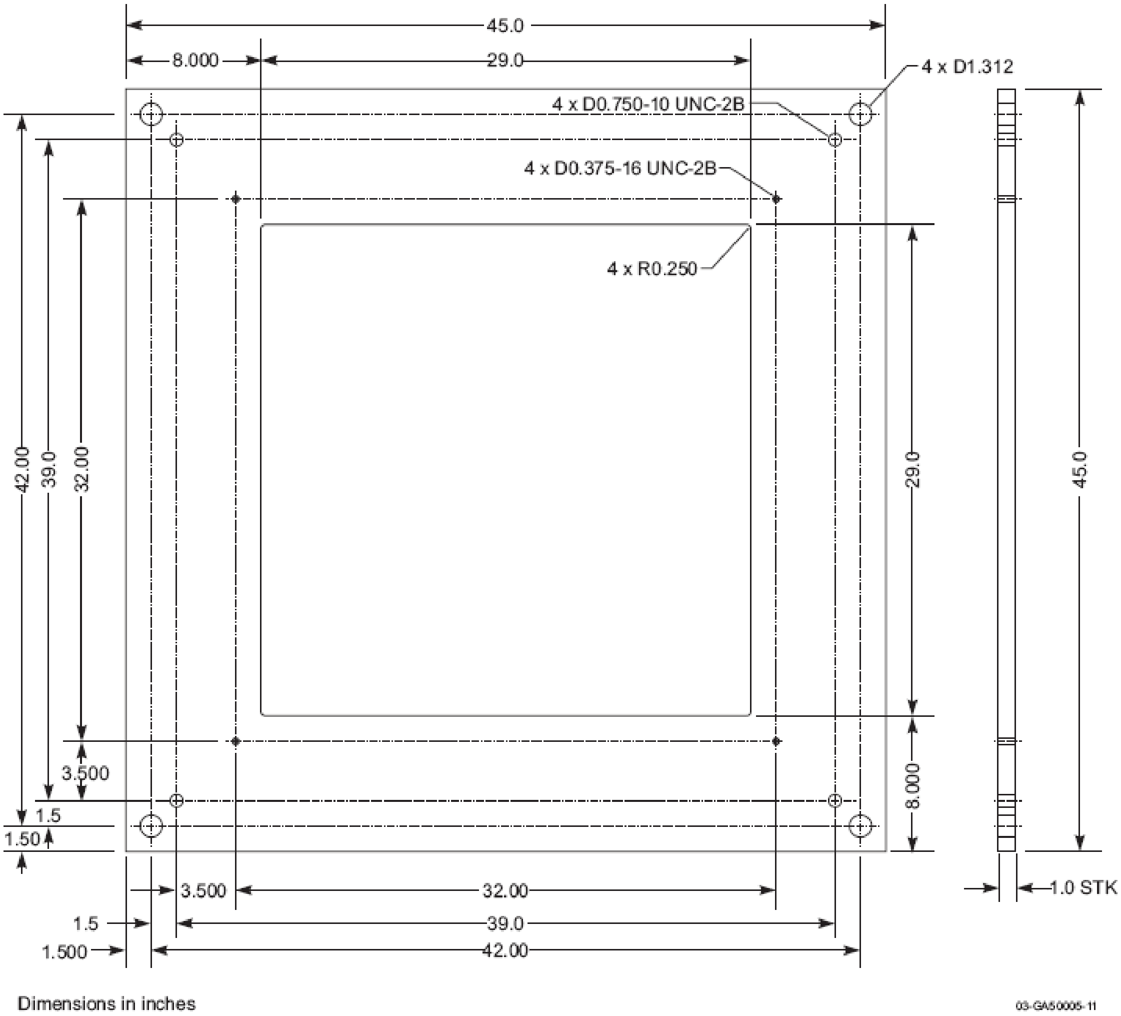

Figure 3. Schematic of the Aluminum Top Support Platform.

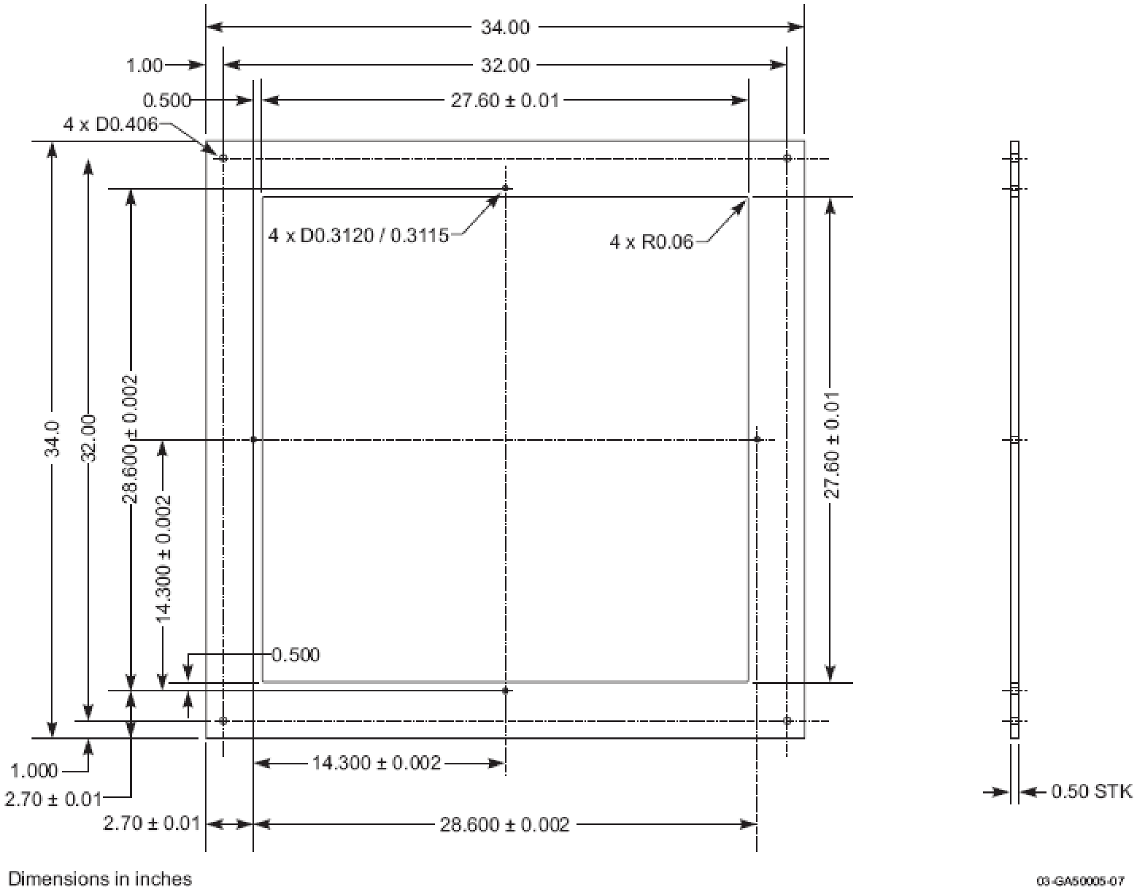

Figure 4. Schematic of the Aluminum Dowel-Pin Plate.

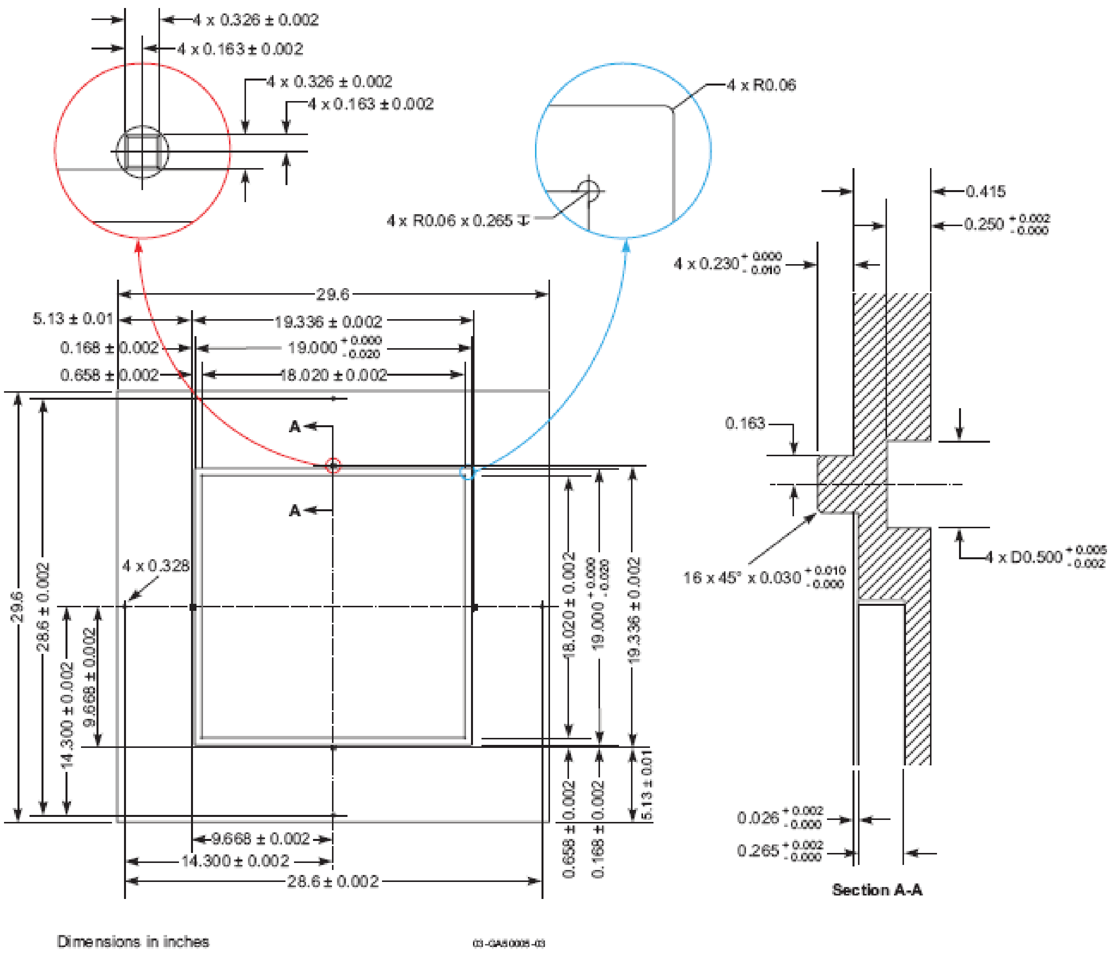

Figure 5. Schematic of the Lowest Polyethylene Plate in the Upper Stack.

The safety features for this assembly include three radiation monitors located at various distances from the system. If the radiation exceeds a certain level, the monitors send a signal that terminates the pressure feeding the hydraulic pump which results in the bottom of the stack returning to its initial lowered position.

This experiment consists of HEU foils laminated with polyethylene, rhenium foils, polyethylene inserts, and polyethylene plates. The polyethylene moderator plates have recesses to allow placement of the polyethylene inserts and HEU foils. The first recess in the polyethylene plates is for the polyethylene inserts and has a depth of 0.265 inch (+0.002, -0.000) [6.731 mm (+0.0508, -0.000)]. The second recess has a depth of 0.026 inch (+0.002, -0.000) [0.6604 mm (+0.0508, -0.000)] and holds the HEU foils. Two different sized polyethylene moderating plates were used for this experiment. The first set is on the bottom section of the stack which rests on the movable platform. The second set rests on the top stationary platform and have a larger length and width. There are also polyethylene reflector plates at the bottom and top of the system.

Figures 6 and 7 show the bottom polyethylene reflector plates. Figures 8 and 9 show the moderating plates that are located in the bottom and top parts of the assembly, respectively. Figure 10 shows the moderating plate 16 S in which the neutron source is placed. The hole that the source is placed in has a volume of 1.4 cm³ (± 0.0074). Figure 11 shows the moderator plate that contains the thermocouple used to measure the temperature of the assembly. The hole that the thermocouple is placed in has a volume of 0.1248 mm³. The location of the thermocouple plate is unknown. The thermocouple used was a K type with a 1/16 inch (1.5875 mm) wire probe. Figures 12 and 13 show the top polyethylene reflector plates.

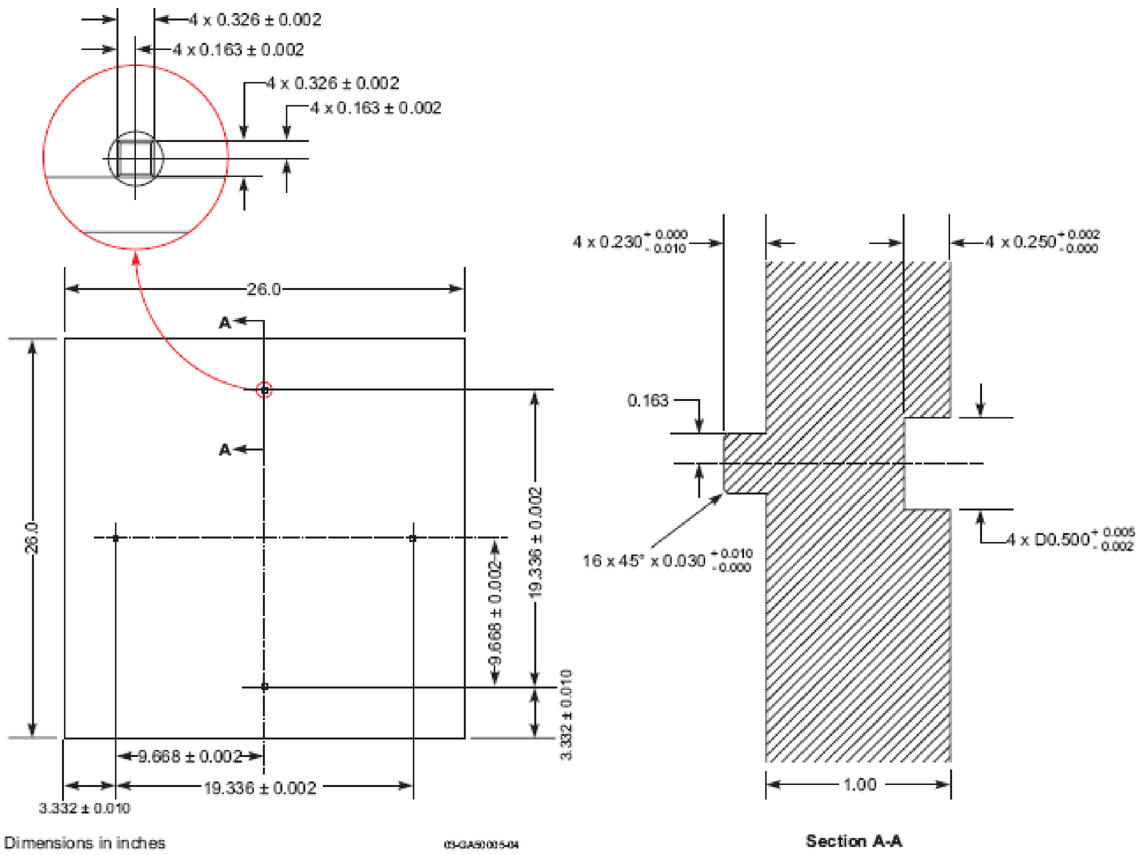

Figure 6. Schematic of the Bottom Reflector Plates.

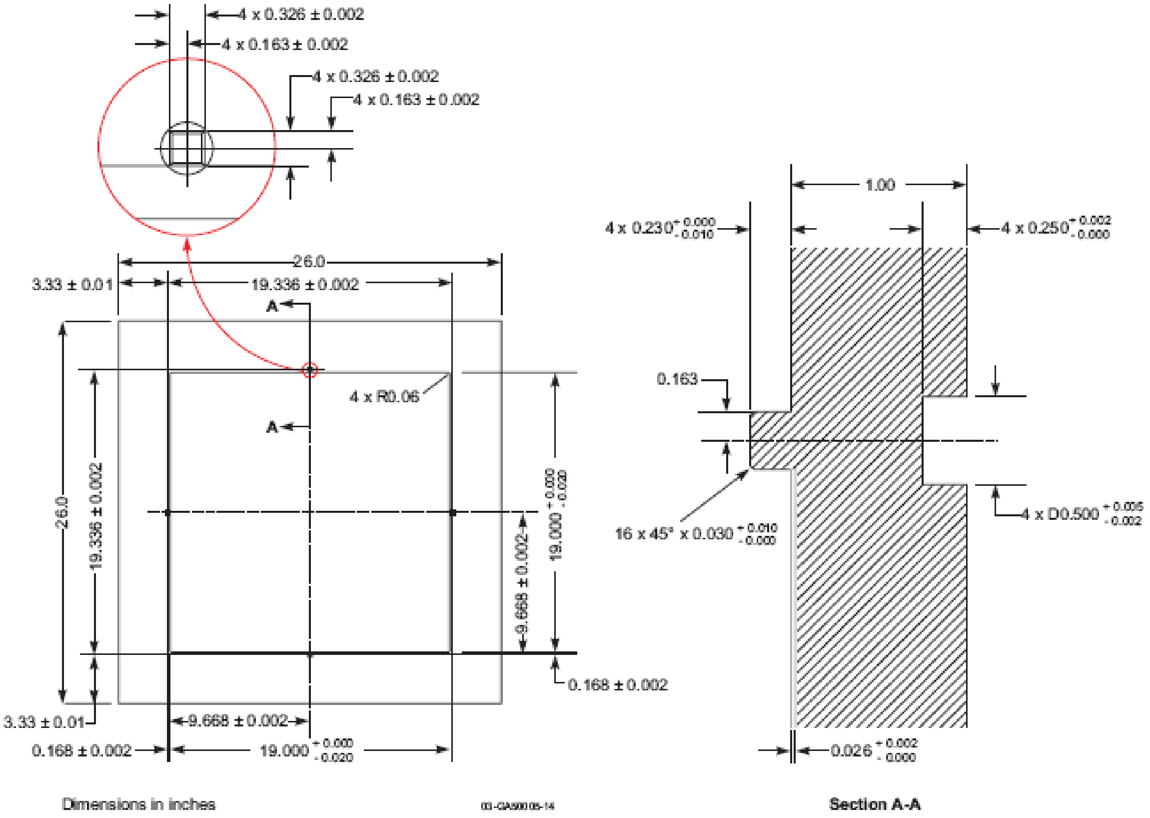

Figure 7. Schematic of the Bottom Reflector Plate with Foil Recess.

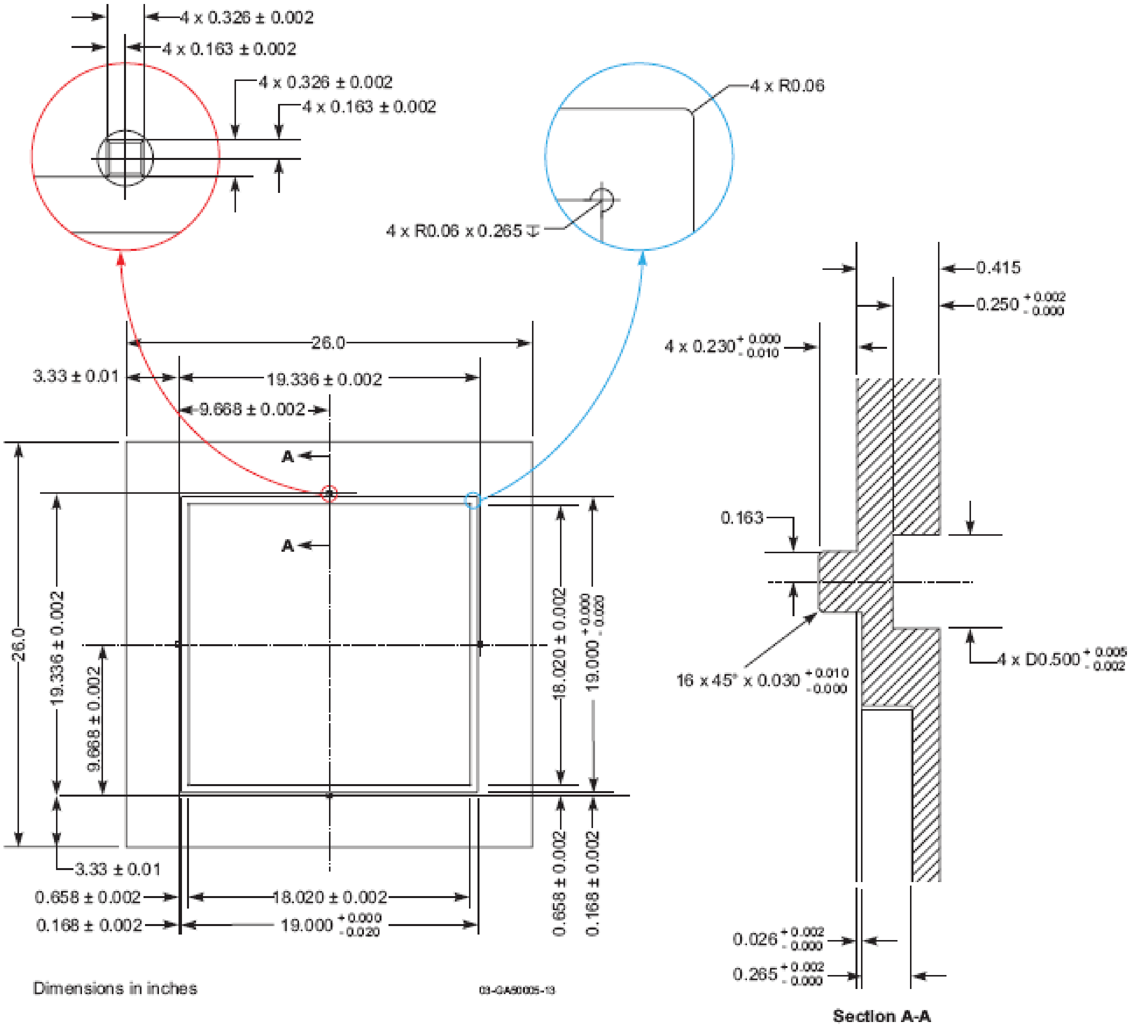

Figure 8. Schematic of the Lower Polyethylene Moderating Plates.

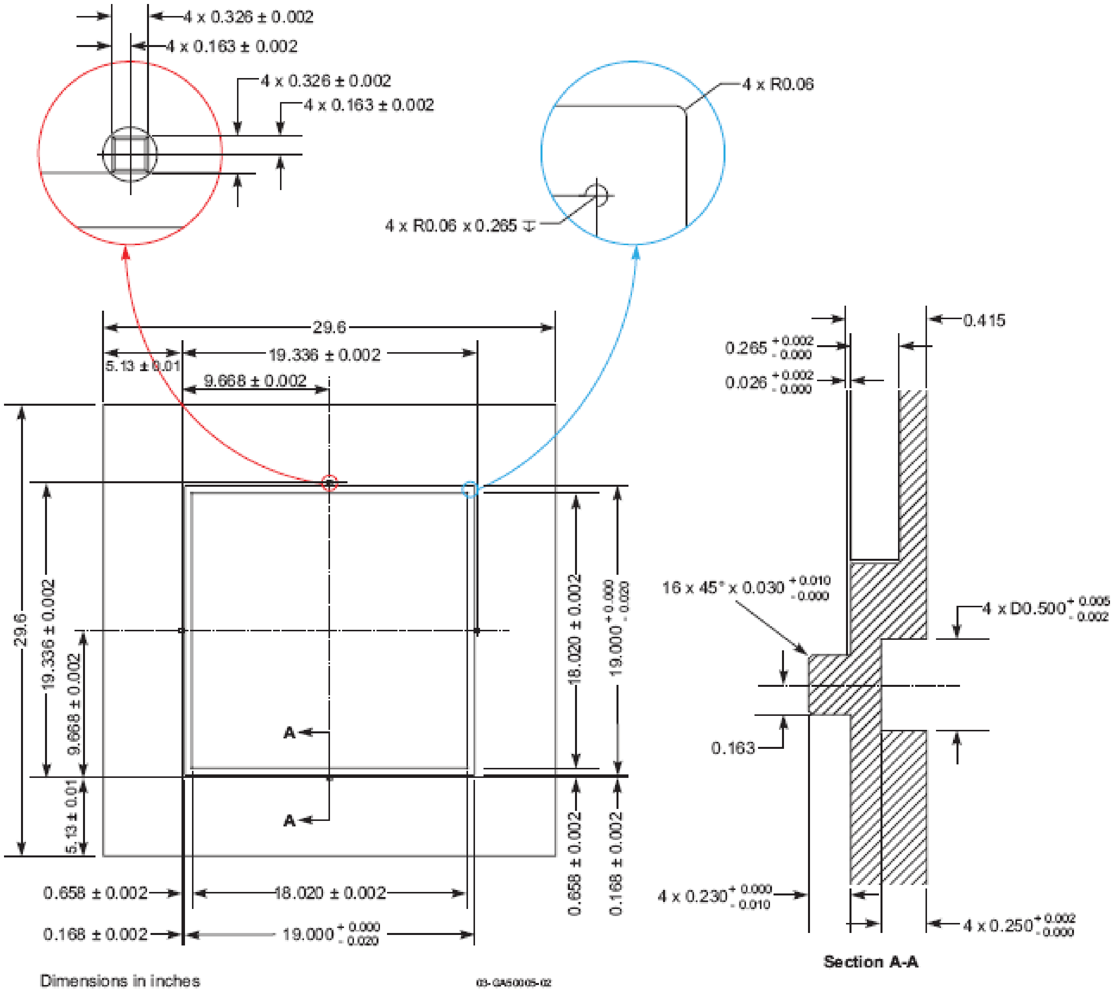

Figure 9. Schematic of the Upper Polyethylene Moderating Plates.

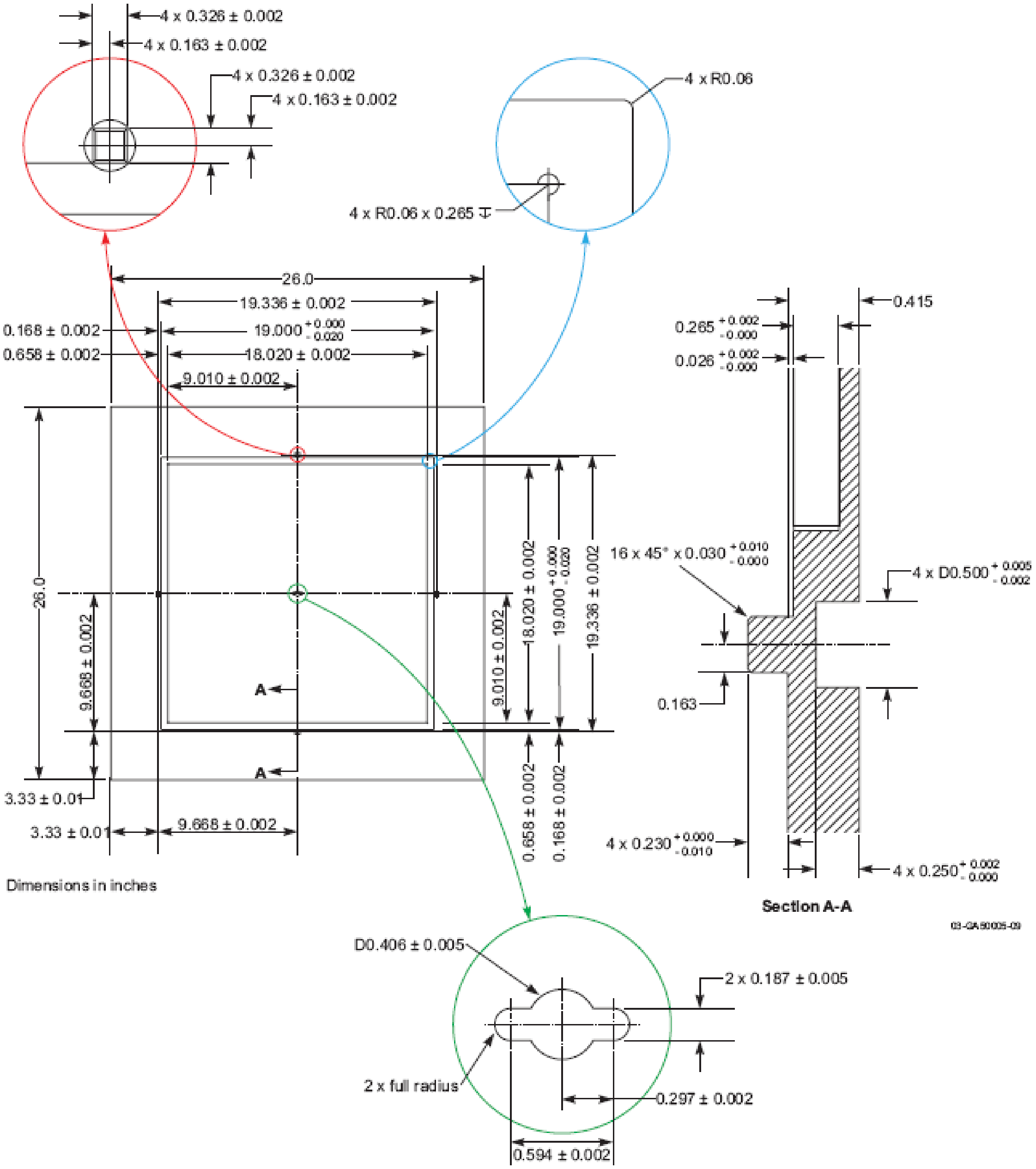

Figure 10. Schematic of Polyethylene Plate 16 S with Neutron Source.

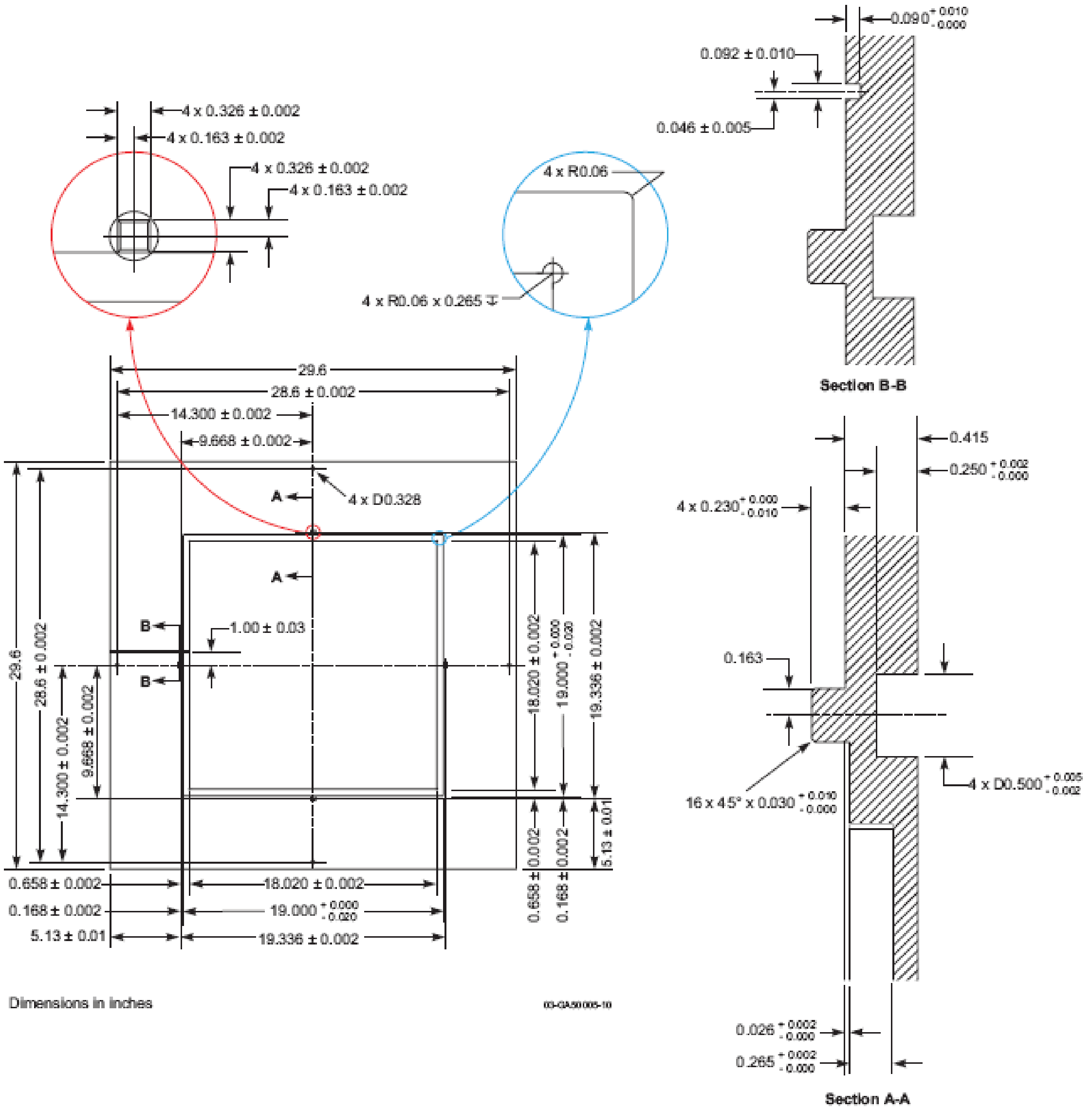

Figure 11. Schematic of the Polyethylene Plate that Houses the Thermocouple.

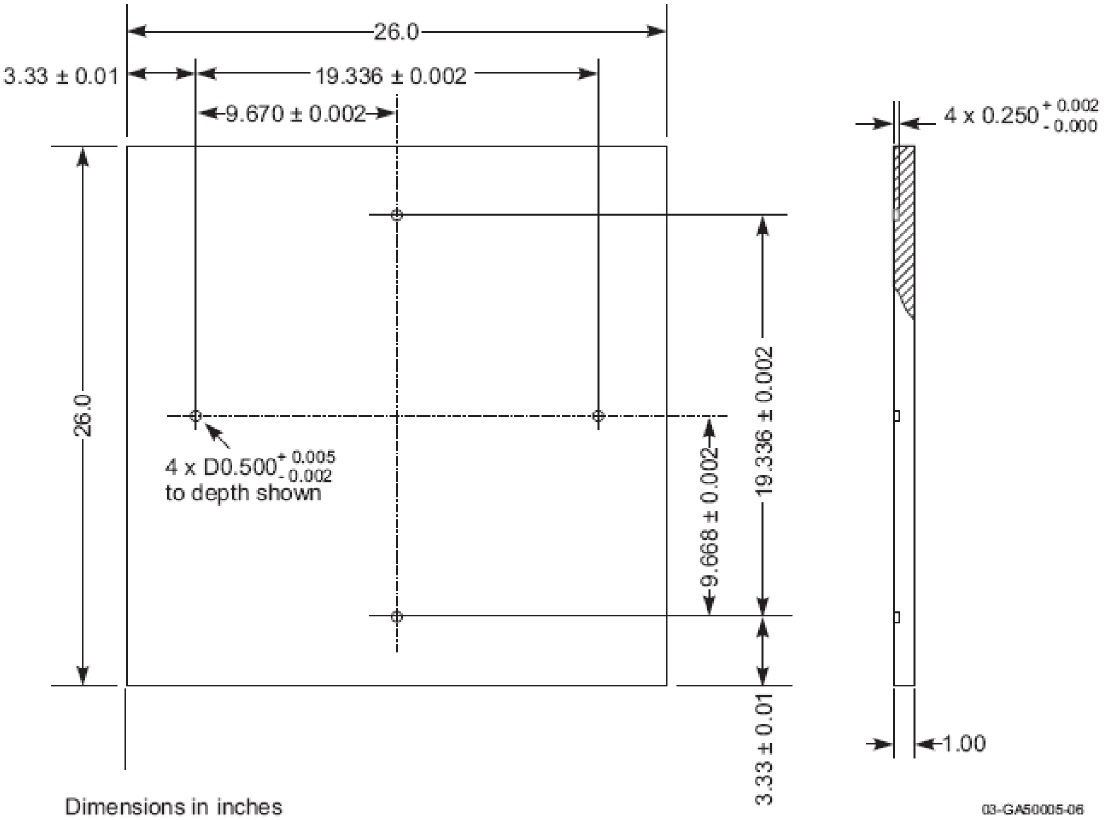

Figure 12. Schematic of the Top Reflector Plate (ID #30).

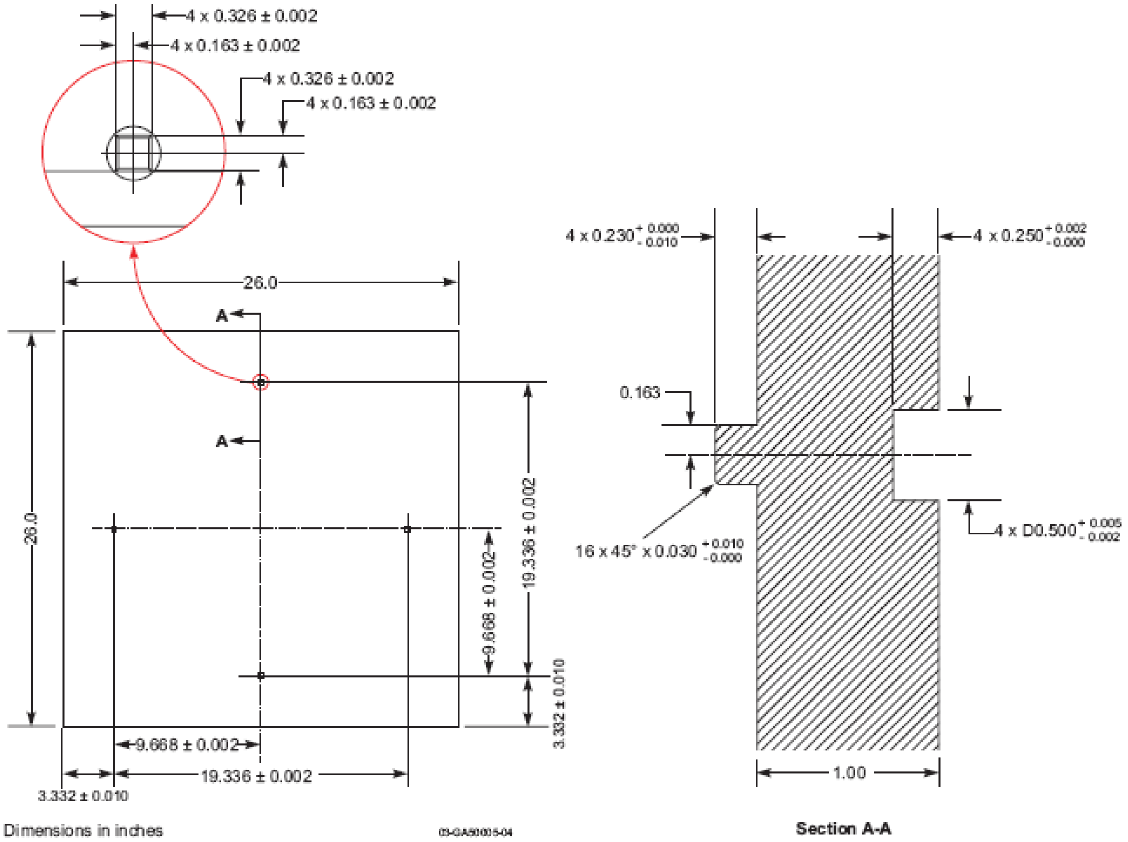

Figure 13. Schematic of the Remaining Top Reflector Plates.

The construction for this experimental configuration began by placing the bottom part of the assembly on the aluminum mounting plate (see Figure 2). A polyethylene reflector plate, ID #1, was fixed to the mounting plate using four 5/16 inch (7.9375 mm) OD, 5/8 inch (15.875 mm) long stainless steel dowel-pins. The next three plates were polyethylene reflectors #2, 3, and 4. The last reflector (#4) of the bottom stack contains a recess for placement of four HEU foils. The recess for the HEU foils was 19.000 × 19.000 inches (48.260 × 48.260 cm) with a tolerance of (+0.000, -0.020) [+0.000, -0.0508]. The depth of the recess was 0.026 (+0.002, -0.000) inch [0.6604 (+0.0508, -0.000) mm]. The polyethylene moderator plates that rest above the reflector plates have a recess for both rhenium foils and HEU foils. The bottom recess is filled by four polyethylene inserts. Two rhenium foils then rest on the inserts as shown in Figure 14. The top recess of the polyethylene plate then contained four HEU foils. For the full configuration with each component ID number, see Figure 15, which shows a vertical slice through of the final critical configuration.

The polyethylene inserts and HEU foils are listed in the order that the experimenters placed them in the stack. The first polyethylene insert was placed in the NE corner, the second insert was placed in the NW corner, the third insert was placed in the SW corner, and the last insert was placed in the SE corner. Polyethylene inserts on the left-hand-side of Figure 15 correspond to plates in the NE and NW corners. Inserts on the right hand side correspond to SW and SE corners.

The placement of the HEU foils followed the same procedure as the polyethylene inserts, with the exception of the top layer. For all the layers except the top layer, the first foil was placed in the NE corner, the second foil in the NW corner, the third in the SW, and the last foil in the SE corner. For the final layer of HEU foils, the first foil was placed in the NE corner and the second foil was placed in the SW corner, so that the foils would be diagonal to one another.

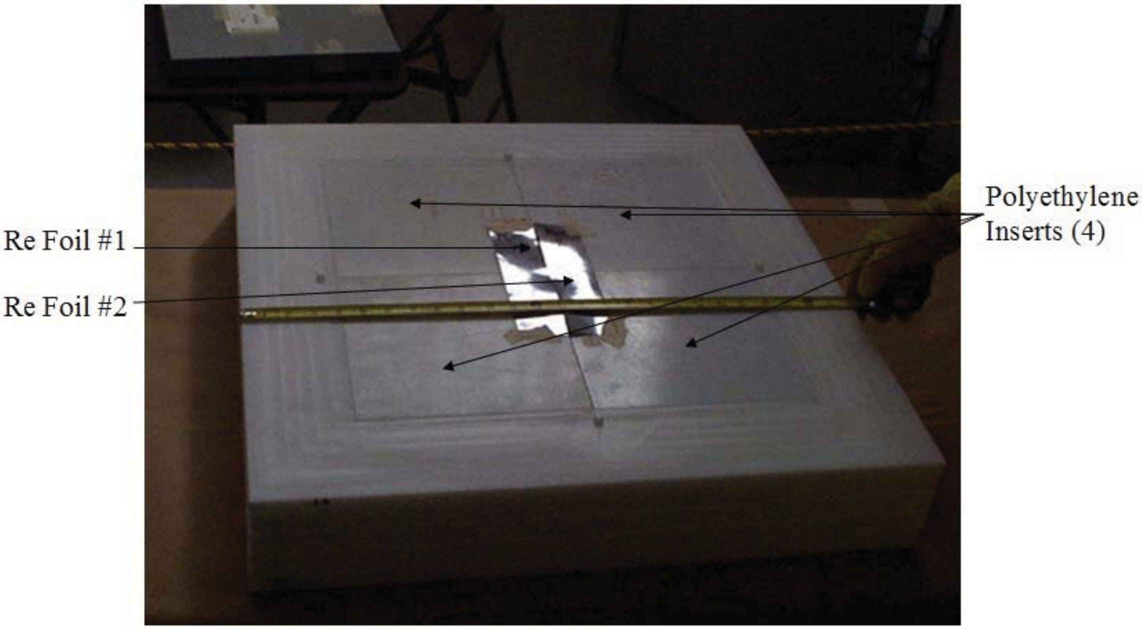

Figure 14. View of the Rhenium Foil Placement.

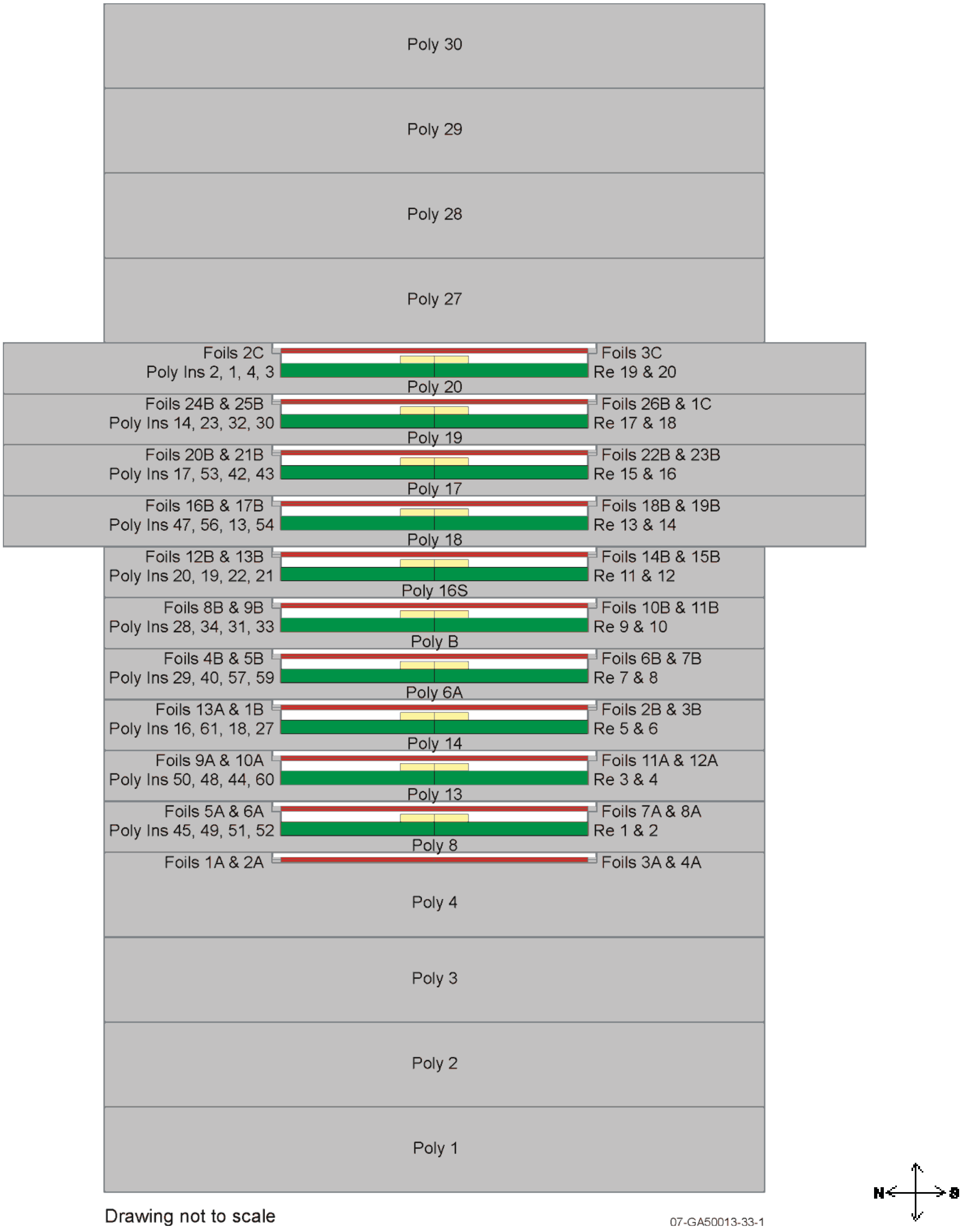

Figure 15. Schematic of the HEU-Re Experiment.

The horizontal dimensions of the HEU foil recesses in the polyethylene plates are 19.000 × 19.000 inches (+0.000, -0.020) [48.260 × 48.260 cm (+0.000, -0.0508)]. The horizontal dimension of the lamination of the HEU foils is 10.0 × 10.0 inches (25.4 × 25.4 cm). This leads to an overlap of foils in the middle of the recess. The foils were placed in such a way that the laminated sides overlapped each other in the center. Figure 16 shows a top view of the HEU foil placement for a full unit. Figure 17 shows a top view of the HEU foil placement for the top fuel layer of the experiment.

No measurement of the critical stack height was performed.

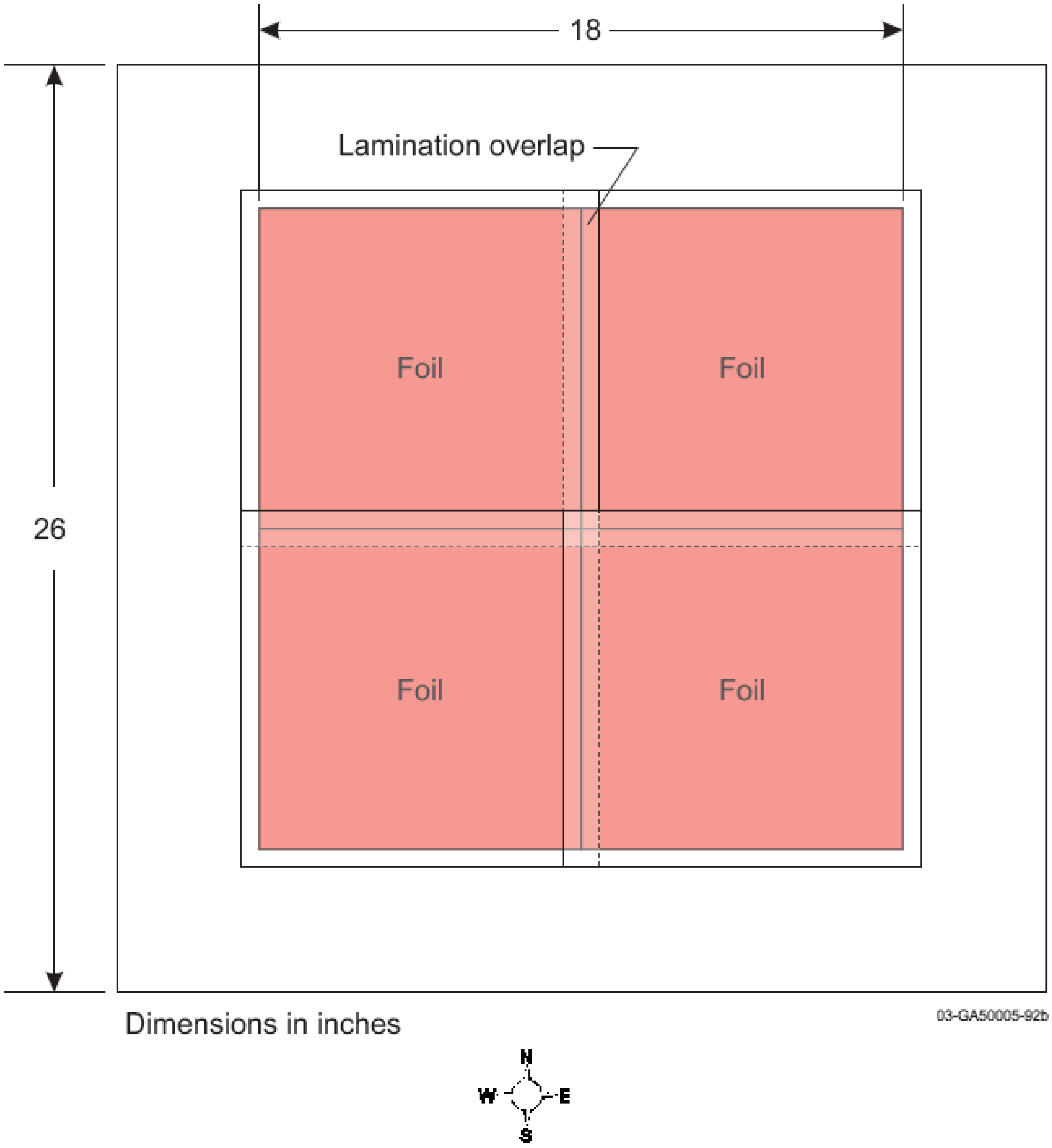

Figure 16. Profile View of the HEU Foil Arrangement for a Small Polyethylene Plate Unit.

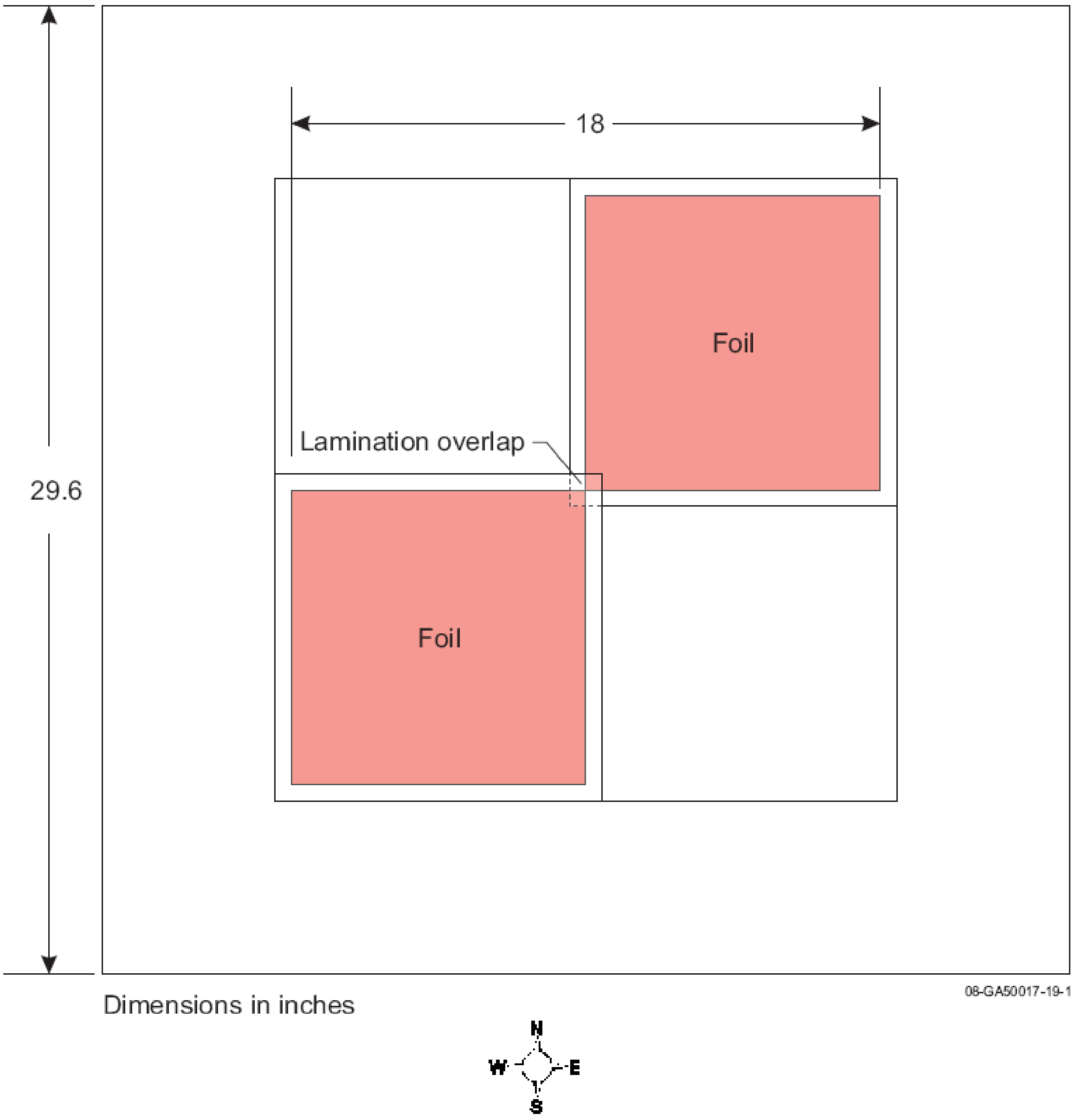

Figure 17. Profile View of the HEU Foil Arrangement for the Top Fuel Layer.

1.2.2 Rhenium Foils

In total, 20 rhenium foils were used in this experiment. These rhenium foils are nominally 8 × 2 inches (20.32 × 5.08 cm) in length and width with a thickness of 0.006 inch (0.1524 mm). All three dimensions were machined by laser; however, no specified tolerances are reported for these foils. The foils were placed adjacent to each other as shown in Figure 14 secured to the polyethylene inserts with masking tape from 3M™. No details on the taping of the foils were reported in the logbooks and the experimenters had no further information about the taping beyond the information reported here. The foils were centered with a measuring tape and touched each other without overlapping. This leads to a nominal length and width of 8 × 4 inches (20.32 × 10.16 cm) in each unit. The individual masses of the rhenium foils are listed in Table 1. Foils numbered 1-20 were used for this experiment. Foils numbered 1-9 were permanently shipped for chemical analysis and the masses of these foils are unknown. Table 1 shows the masses of foils 10-25 using a balance with a 1σ accuracy of ± 1 g. No other data is reported on the rhenium foils.

Table 1. Rhenium Foil Measured Masses.

Part Number	**Mass in Grams**
10	28.7
11	27.8
12	27.1
13	27.5
14	25.5
15	28.4
16	26.9
17	28.8
18	25.9
19	29.0
20	27.2
21	29.4
22	28.1
23	28.3
24	28.3
25	28.4

1.2.3 Polyethylene Moderator and Reflector Plates

The moderator in this experiment was polyethylene. There were 6 small polyethylene plates in the lower part of the assembly and 4 large polyethylene plates in the upper part of the stack. These moderating plates had recesses for the HEU foils and rhenium foils. The nominal dimensions for the small bottom moderating plates were 26.0 × 26.0 inches (66.04 × 66.04 cm) in length and width with a tolerance of ± 0.1 inch (0.254 cm). The large moderating plates had dimensions 29.6 × 29.6 inches (75.184 × 75.184 cm) with a tolerance of ± 0.1 inch (0.254 cm). All of the moderating plates have a thickness of 0.415 ± 0.001 inch (10.541 ± 0.0254 mm).

The recess for the inserts has a nominal length and width of 18.020 × 18.020 inches (45.7708 × 45.7708 cm) with a tolerance of ± 0.002 inch. The recess had a nominal depth of 0.265 (+0.002, -0.000) inch [6.731 (+0.0508, -0.000) mm]. The recess for the HEU foils was 19.000 × 19.000 inches (48.260 × 48.260 cm) with a tolerance of (+ 0.000, -0.020) [+ 0.000, -0.0508)]. The depth of the recess for HEU foils was 0.026 (+ 0.002, -0.000) inch [0.6604 (+ 0.00508, -0.000) mm].

The bottom and top reflectors each contain four polyethylene reflector plates. The reflectors have nominal dimensions of 26.0 × 26.0 × 1.0 inch (66.04 × 66.04 × 2.54 cm) with a tolerance of ± 0.1 inch (0.254 cm). The bottom reflector plate #4 has a foil recess with the same dimensions as the polyethylene moderator HEU foil recesses. The description and masses of the polyethylene plates are shown in Table 2 (their specific location in the assembly can be seen in Figure 15). The 1σ accuracy of the balance used to measure the polyethylene plates was ± 0.05 g.

Table 2. Masses for Polyethylene Moderator and Reflector Plates.

Part Number	Description	Mass in Grams
Poly 1	Reflector	10755.0
Poly 2	Reflector	10759.6
Poly 3	Reflector	10762.2
Poly 4	Reflector (with recess for foils)	10568.7
Poly 8	Moderator	2898.6
Poly 13	Moderator	2896.8
Poly 14	Moderator	2894.1
Poly 6 A	Moderator	2895.1
Poly B	Moderator	2895.1
Poly 16 S	Moderator (source holder)	2909.5
Poly 18	Moderator	4210.6
Poly 17	Moderator	4221.0
Poly 19	Moderator	4230.6
Poly 20	Moderator	4229.6
Poly 27	Reflector	10668.8
Poly 28	Reflector	10707.8
Poly 29	Reflector	10662.4
Poly 30	Reflector	10671.8

1.2.4 HEU Foils

A total of 42 HEU foils were used for this experiment. The top layer of fuel contained only two HEU foils. The HEU foils were nominally 9 × 9 × 0.003 inches (22.86 × 22.86 × 0.00762 cm) before lamination. The lamination material was polyethylene. The final laminated foils had nominal dimensions of 10.0 × 10.0 inches (25.40 × 25.40 cm) with a thickness of 0.009 inch [0.2286 mm] (0.003 inch [0.0762 mm] for the bottom lamination sheet, 0.003 inch [0.0762 mm] for the HEU foil, and 0.003 inch [0.0762 mm] for the top lamination sheet). The length and width of the lamination were cut by a laser with the thickness of the foils determined by a rolling process. The foils were weighed before and after lamination. The measured masses of the HEU foils are shown in Table 3 (their specific location in the assembly can be seen in Figure 15). The accuracy of the balance used to measure foils 1A – 13A was ± 0.2 g. The accuracy of the balance used to measure foils 1B – 26B and 1C – 3C was ± 0.5 g.

Table 3. HEU Foil Masses Before and After Lamination.[a]

Foil Reference Number	Mass Before Lamination (g)	Mass After Lamination (g)	Foil Reference Number	Mass Before Lamination (g)	Mass After Lamination (g)
1A	69.0	79.1	9B	66	76
2A	71.3	81.4	10B	67	77
3A	71.4	81.6	11B	71	81
4A	69.4	79.3	12B	70	81
5A	70.8	81.1	13B	65	76
6A	70.2	80.5	14B	67	77
7A	70.6	80.2	15B	66	76
8A	71.1	81.4	16B	69	79
9A	71.3	81.5	17B	66	77
10A	71.8	82.1	18B	65	75
11A	72.4	82.3	19B	68	78
12A	71.3	81.4	20B	67	78
13A	70.4	80.4	21B	69	79
1B	69	78	22B	69	79
2B	68	79	23B	69	80
3B	66	76	24B	67	78
4B	64	74	25B	67	77
5B	67	77	26B	64	74
6B	67	78	1C	71	81
7B	65	75	2C	71	81
8B	69	78	3C	71	82

(a) The weights for these foils may be different in previous evaluations. The weights that are reported in Table 3 are from 1995 when the first lamination of the foils was done. The lamination on some of the foils ruptured therefore that foils were re-laminated in 2002. The old lamination was removed, and the bare foil was weighted (*August 2002*), then the foil was re-laminated and re-weighed (*August 2002*). It is important to note that during the re-lamination process between 2-3 grams of HEU per foil were lost.

1.2.5 Polyethylene Inserts

Polyethylene inserts were used to fill in the recess in the polyethylene moderating plates. The large and small moderating plates have a recess that has a nominal length and width of 18.020 × 18.020 inches (45.7708 × 45.7708 cm) with a tolerance of ± 0.002 inch (0.0508 mm). The recess had a nominal depth of 0.265 (+ 0.002, -0.000) inch [6.731 (+ 0.0508, -0.000) mm]. Four polyethylene inserts were used to fill this recess, each with dimensions of 9.000 × 9.000 × 0.250 inches (22.86 × 22.86 × 0.635 cm). The polyethylene inserts length and width each had a tolerance of ± 0.005 inch (0.127 mm). The thickness of the polyethylene inserts had a tolerance of ± 0.01 inch (0.0254 cm). The rhenium foils were centered on top of the four polyethylene inserts as shown in Figure 14. The measured masses of the polyethylene inserts are shown in Table 4 (their specific location in the assembly can be seen in Figure 15). Inserts 1-26 were weighed on a different scale from inserts 27-62. The accuracy of both scales used to weigh inserts was ± 0.2 g.

Table 4. Masses of Polyethylene Inserts.

Part Number	Mass in Grams	Part Number	Mass in Grams
1	314.04	33	320.3
2	314.64	34	321.2
3	314.35	40	320.2
4	316.92	42	320.0
13	314.64	43	320.2
14	315.45	44	319.6
16	321.04	45	319.6
17	316.06	47	321.6
18	315.58	48	320.7
19	318.68	49	320.6
20	315.69	50	320.8
21	313.37	51	320.8
22	317.64	52	322.0
23	314.04	53	318.9
27	322.5	54	320.0
28	322.0	56	317.5
29	319.5	57	318.3
30	319.8	59	318.1
31	322.3	60	320.9
32	317.6	61	321.0

1.2.6 Experimental Procedure

The bottom part of the core was placed on the movable platen of the Planet assembly machine. The top part of the core was placed on the top platform. To measure the temperature of the experiment, a thermocouple was placed near the center of the assembly by height. The measured temperature of the experiment was 18.0 ºC ± 0.5°C.

The lower portion of the assembly, which contained a PuBe source with an emission rate of approximately 10^5 neutrons/s, was raised remotely by a hydraulic lift and stepping motor until it contacted the top portion of the assembly and began to lift the top portion of the assembly. The neutron leakage from the assembly was measured with four BF_3 detectors, and 1/M as a function of number of units was plotted. (A unit is defined as four HEU foils in a single layer). Figure 15 presents the stacking sequence of the foils, polyethylene plates, and polyethylene inserts for the final configuration. The aluminum support plates, e.g., dowel-pin plate and mounting plates, are shown in previous figures.

The HEU-Re-polyethylene experiment was first performed with 43 HEU foils or 10 ¾ units (4 foils per layer with the exception of only 3 foils in the top layer). This resulted in a delayed criticality with a period of 27.60 seconds. However, the stack was not fully closed (the lower and upper halves were not in contact) and there was a small, immeasurable separation. As a result, the experimenters decided to remove one HEU foil from the top fuel layer in order to fully close the gap in the experiment and measure the system reactivity (resulting stack of 10 ½ units).

After removing one HEU foil from the top layer of the stack, the stack was fully closed; however, delayed critical was not achieved with 10 ½ units and the stack fully closed. Table 5 is a replication of the data provided in the logbook of the approach to critical with 10 ½ units in the assembly. Figure 18 is the graph plotting the approach to critical with 2 to 8 units by the experimenters.

Table 5. Data in Logbook from 2 × 2 Rhenium Foil Experiment with 10 ½ Units.

Separation (inches)	Count rate	1/M	Unit Prediction
0.46	1807	1.0	--
0.40	1936	0.933	-0.44
0.301	2811	0.643	+0.08
0.219	3647	0.495	-0.06
0.1	5147	0.351	-0.19

The logbook (See Appendix B) reported that at zero separation with 10 ½ units (42 foils), the Count Rate was 51966 with a multiplication of 150. As a result, using the 1/M curve for the approach to critical for this experiment as layers of foils were added to the stack until reaching 10 ½ units and the data written in the logbook of the approach to critical (and reproduced in Table 5), the experimenters estimated that delayed critical would occur at approximately 10.72 units with a fully closed stack (based on extrapolation of the 1/M curve).

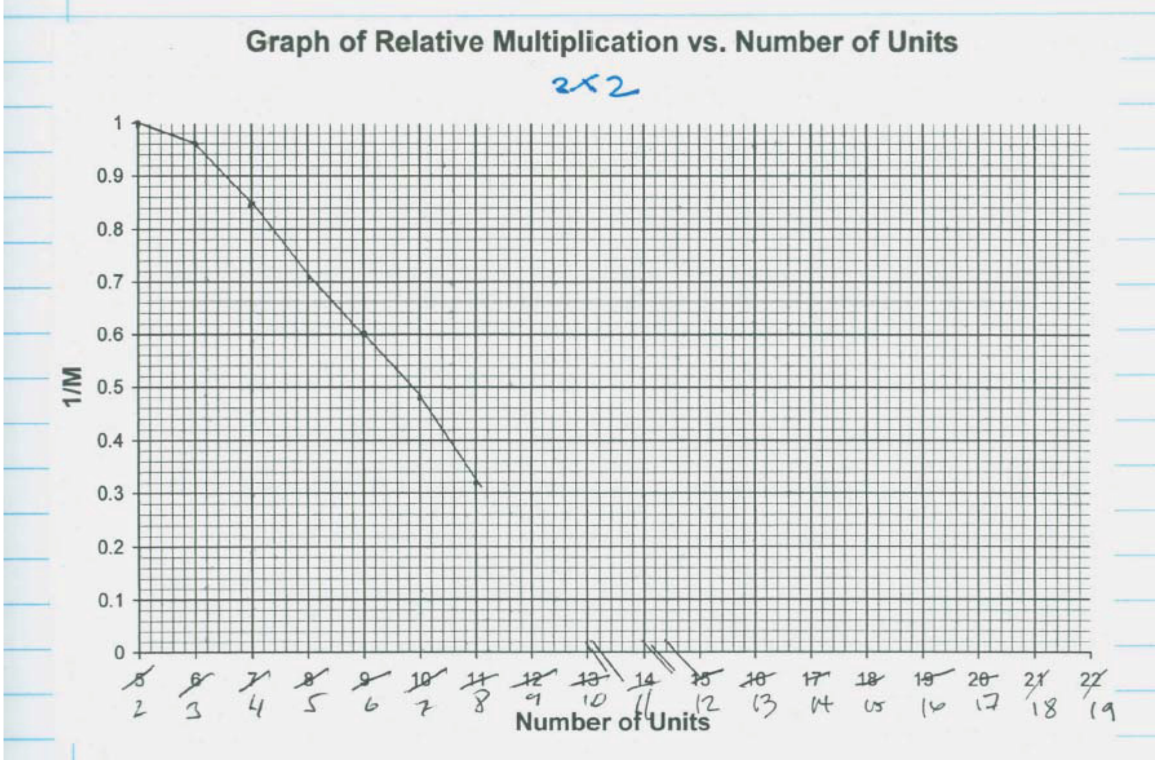

Figure 18. 1/M Curve for HEU-Re 2 × 2 Experiment in Logbook.

Based on the HEU-Re 2 × 2 experiment with 10 ½ units or 42 foils and the estimated delayed critical ($k_{eff} = 1.0000$) of 10.72 units for the experiment, experimenters used the equation $k_{eff} = (10.5/10.72)^{\wedge}(1/3)$[a] to estimate a k_{eff} of 0.9931 for this system. The experimentalist reported[b] that the observed uncertainty in k_{eff} was ± 0.03\$. In the logbook the value of 0.0068 is used for β_{eff}. Therefore the uncertainty in experimental k_{eff} is 0.0002. Therefore, the experimental k_{eff} for this configuration was 0.9931 ± 0.0002.

1.3 Description of Material Data

1.3.1 HEU Foils

The masses of the HEU foils in this evaluation come from the most recent measurements with these foils prior to the re-lamination performed in 1998. The accuracy of the balance used for the mass measurements was ± 0.2 g for foils 1A – 13A. The accuracy of the balance used to measure foils 1B – 26B and 1C – 3C was ± 0.5 g. The measured masses of the foils before lamination and calculated densities are shown in Table 6. The nominal dimensions of the HEU foils before lamination were 9 × 9 × 0.003 inch (22.86 × 22.86 × 0.00762 cm) which results in a volume of 0.243 cubic inch (3.98206 cubic centimeters). The uranium foils were most likely cut by the original experimenters when the foils were first used; and no specified tolerances exist. For this experiment, the average HEU foil density calculated

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[a] Rene Sanchez, David Loaiza, Glenn Brunson, and Robert Kimpland, "Critical Experiments with Highly Enriched Uranium and Matrix Elements (Si, Mg, Al, Gd, and Fe)," Nuclear Science and Engineering: Vol. 147, No. 3, 307-318, 2004.

[b] Personal communication with Rene Sanchez from Los Alamos National Laboratory.

from the total mass and total volume of the foils was 17.226 g/cm³. The experimental standard deviation in the densities listed in Table 6 is ± 0.586 g/cm³. It is interesting to point out that the calculated density for the foils is a bit lower than the theoretical density. The actual volume of the foils was not measured but is expected to be less than the nominal volume.

Table 6. Measured Masses and Calculated Densities for HEU Foils.

Foil Reference Number	Mass Before Lamination (g)	Calculated Foil Density (g/cm³) [(a)]	Foil Reference Number	Mass Before Lamination (g)	Calculated Foil Density (g/cm³) [(a)]
1A	69.0	17.328	9B	66	16.574
2A	71.3	17.905	10B	67	16.825
3A	71.4	17.930	11B	71	17.830
4A	69.4	17.428	12B	70	17.579
5A	70.8	17.780	13B	65	16.323
6A	70.2	17.629	14B	67	16.825
7A	70.6	17.730	15B	66	16.574
8A	71.1	17.855	16B	69	17.328
9A	71.3	17.905	17B	66	16.574
10A	71.8	18.031	18B	65	16.323
11A	72.4	18.182	19B	68	17.077
12A	71.3	17.905	20B	67	16.825
13A	70.4	17.679	21B	69	17.328
1B	69	17.328	22B	69	17.328
2B	68	17.077	23B	69	17.328
3B	66	16.574	24B	67	16.825
4B	64	16.072	25B	67	16.825
5B	67	16.825	26B	64	16.072
6B	67	16.825	1C	71	17.830
7B	65	16.323	2C	71	17.830
8B	69	17.328	3C	71	17.830

(a) Derived from mass divided by nominal volume.

The isotopic composition of the foils is shown in Table 7. The atom percent values were directly measured and used to calculate the weight percents. This information was obtained from a chemical analysis report prepared by NMT-1 (LANL Sample Management Group). The uncertainty reported in this analysis was ± 0.02 atom percent ^{235}U. The uncertainty represents a 95% confidence interval. No impurity analysis was performed on the HEU foils.

Table 7. Composition of the HEU Foils.

Isotope	Weight Percent (a)	Atom Percent
^{233}U	0.0000	0.0000
^{234}U	1.1339	1.1395
^{235}U	93.2321	93.2919
^{236}U	0.2581	0.2572
^{238}U	5.3759	5.3114

(a) Weight percents were calculated from atom percents.

1.3.2 Polyethylene Material Data

The moderator and reflector for this experiment were comprised of high-density polyethylene with a formula of C_2H_4. The weights of the polyethylene moderator and reflector plates are presented in Table 8. The average density of the polyethylene plates calculated from the total mass and total volume of the plates was 0.962 g/cm^3. The experimental 1σ standard deviation of the densities listed in Table 8 was 0.007 g/cm^3. In addition, an average density was calculated for the reflector, upper moderating, and lower moderating plates. The average density for the reflector plates was 0.967 g/cm^3 with a standard deviation from the densities of the reflector plates listed in Table 8 of 0.004 g/cm^3. The average density for the upper moderating plates was 0.961 g/cm^3 with a standard deviation from the densities of upper moderating plates listed in Table 8 of 0.002 g/cm^3. Finally, the average density for the lower moderating plates was 0.956 g/cm^3 with a standard deviation from the densities of the lower moderating plates listed in Table 8 of 0.002 g/cm^3.

Table 8. Polyethylene Plate Masses and Calculated Densities.

Part Number	Description	Mass in Grams	Calculated Density (g/cm³)[(a)]
Poly 1	Reflector	10755.0	0.971
Poly 2	Reflector	10759.6	0.971
Poly 3	Reflector	10762.2	0.972
Poly 4	Reflector	10568.7	0.967
Poly 8	Moderator	2898.6	0.956
Poly 13	Moderator	2896.8	0.955
Poly 14	Moderator	2894.1	0.954
Poly 6 A	Moderator	2895.1	0.954
Poly B	Moderator	2895.1	0.954
Poly 16 S	Moderator	2909.5	0.960 [(b)]
Poly 18	Moderator	4210.6	0.958
Poly 17	Moderator	4221.0	0.961
Poly 19	Moderator	4230.6	0.963
Poly 20	Moderator	4229.6	0.962
Poly 27	Reflector	10668.8	0.963
Poly 28	Reflector	10707.8	0.967
Poly 29	Reflector	10662.4	0.963
Poly 30	Reflector	10671.8	0.963

(a) Calculated by dividing the masses by the nominal volumes.
(b) Calculated by dividing the masses by the nominal volumes and subtracting the volume of the hole for the neutron source.

The foil lamination is also made of high-density polyethylene with a formula of C_2H_4. The lamination mass was determined from the HEU foil masses before and after lamination (see Table 3). Table 9 shows the foil lamination masses and calculated densities. The average lamination density calculated from the total mass and total volume of the lamination was 1.037 g/cm³ with a 1σ standard deviation from the densities listed in Table 9 of 0.050 g/cm³.

Table 9. Lamination Masses and Calculated Densities.

Foil Reference Number	Lamination Mass (g)	Calculated Lamination Density (g/cm³) [(a)]	Foil Reference Number	Lamination Mass (g)	Calculated Lamination Density (g/cm³) [(a)]
1A	10.1	1.027	9B	10.0	1.017
2A	10.1	1.027	10B	10.0	1.017
3A	10.2	1.037	11B	10.0	1.017
4A	9.9	1.007	12B	11.0	1.119
5A	10.3	1.048	13B	11.0	1.119
6A	10.3	1.048	14B	10.0	1.017
7A	9.6	0.976	15B	10.0	1.017
8A	10.3	1.048	16B	10.0	1.017
9A	10.2	1.037	17B	11.0	1.119
10A	10.3	1.048	18B	10.0	1.017
11A	9.9	1.007	19B	10.0	1.017
12A	10.1	1.027	20B	11.0	1.119
13A	10.0	1.017	21B	10.0	1.017
1B	9.0	0.915	22B	10.0	1.017
2B	11.0	1.119	23B	11.0	1.119
3B	10.0	1.017	24B	11.0	1.119
4B	10.0	1.017	25B	10.0	1.017
5B	10.0	1.017	26B	10.0	1.017
6B	11.0	1.119	1C	10.0	1.017
7B	10.0	1.017	2C	10.0	1.017
8B	9.0	0.915	3C	11.0	1.119

(a) Calculated from mass divided by nominal volume.

The measurements for the impurities in the lamination, the moderator plates, and the inserts were performed using x-ray fluorescence. The results for the impurities in the polyethylene are shown in Table 10. These results have an uncertainty of ± 10% within a 67% confidence level. In the last column of Table 10, the results for measurement of 900-ppm standards are given. This result is the basis for the ± 10% uncertainty. The uncertainties close to the detection limit are unquantifiable and probably larger than what is indicated by the calibration using 900-ppm standards. All elements between masses of 14 (Si) and 92 (U) were sought. For elements listed as less than a value (e.g., <11), the specific elements were present but are below the minimum detectable level. Only the elements found were reported.

Table 10. Polyethylene Impurities, 1st Evaluation.

Impurity	Plates/Inserts (ppm)	Lamination (ppm)	900 ppm Standards
Ca	58	< 25	901
Ti	< 11	< 11	914
V	< 8	< 8	908
Cr	< 6	< 6	906
Mn	< 5	< 5	906
Fe	< 23	< 23	906
Co	< 15	< 15	906
Ni	< 11	< 11	---
Cu	< 9	< 9	910
Zn	< 7	< 7	914
Br	< 1	< 1	913
Ag	< 3	< 3	---
Cd	< 2	< 2	920
Sn	3	< 3	922
Sb	< 3	40	---
Ba	< 12	< 12	922
Pb	< 6	< 6	923

Later, on the reviewer request, an additional chemical analysis was performed to determine the boron content in the polyethylene plates. This was the 2nd evaluation, which focused only on boron content. There is no table data for the 2nd evaluation. The analysis was performed using the inductive coupled plasma mass spectroscopy technique. In this technique, a small sample of polyethylene is dissolved into solution. A portion of the aqueous sample is aspirated into a high-temperature plasma that ionizes the sample. A quadrupole system filters the elements by individual mass and then it is measured electronically. Calibration standards are used to calculate the concentration of the elements in question for final quantification. The results of this chemical analysis showed that the boron content in the polyethylene plates was present but below the minimum detectable level of 10 ppm.

Since the uncertainty of the multiplication factor due to B (< 10 ppm) and Cd (< 2 ppm) detection limits was too large, an additional analysis was performed to further determine the boron content of the plates. Two representative polyethylene plates, an insert and a moderator plate, were analyzed by Evans Analytical Group LLC - Shiva Technologies.[a] The results of the analysis are presented in Tables 11 and 12. Specifically, the detection limits of B and Cd were reduced to < 0.5 ppm.

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[a] ICP-MS Analytical Report, Job # S09Z7172, Shiva ID S090906076 and S090906077, Dated September 4, 2009, Evans Analytical Group - Shiva Technologies, 6707 Brooklawn Parkway, Syracuse, New York 13211 (www.eaglabs.com).

Table 11. Polyethylene Insert Sample Impurities, 3rd Evaluation.

Element	**Concentration [ppm wt]**	**Element**	**Concentration [ppm wt]**	**Element**	**Concentration [ppm wt]**
Li	< 0.5	Ga	< 0.5	Nd	< 0.5
Be	< 0.5	Ge	< 0.5	Sm	< 0.5
B	< 0.5	As	< 0.5	Eu	< 0.5
C	-	Se	< 0.5	Gd	< 0.5
N	-	Br	-	Tb	< 0.5
O	-	Rb	< 0.5	Dy	< 0.5
F	-	Sr	< 0.5	Ho	< 0.5
Na	25	Y	< 0.5	Er	< 0.5
Mg	10	Zr	< 0.5	Tm	< 0.5
Al	39	Nb	< 0.5	Yb	< 0.5
Si	< 500	Mo	< 0.5	Lu	< 0.5
P	< 500	Ru	< 0.5	Hf	< 0.5
S	-	Rb	< 0.5	Ta	< 0.5
Cl	-	Pd	< 0.5	W	< 0.5
K	< 5	Ag	< 0.5	Re	< 0.5
Ca	42	Cd	< 0.5	Os	< 0.5
Sc	< 0.5	In	-	Ir	< 0.5
Ti	3.3	Sn	< 0.5	Pt	< 0.5
V	< 0.5	Sb	< 0.5	Au	< 0.5
Cr	< 0.5	Te	< 0.5	Hg	< 0.5
Mn	< 0.5	I	-	Tl	< 0.5
Fe	7.7	Cs	< 0.5	Pb	< 0.5
Co	< 0.5	Ba	< 0.5	Bi	< 0.5
Ni	< 0.5	La	< 0.5	Th	< 0.5
Cu	0.6	Ce	< 0.5	U	< 0.5
Zn	< 0.5	Pr	< 0.5		

Table 12. Polyethylene Moderator Plate Impurities, 3rd Evaluation.

Element	Concentration [ppm wt]	Element	Concentration [ppm wt]
Li	< 0.5	Pd	< 0.5
Be	< 0.5	Ag	< 0.5
B	< 0.5	Cd	< 0.5
C	-	In	-
N	-	Sn	< 0.5
O	-	Sb	< 0.5
F	-	Te	< 0.5
Na	14	I	-
Mg	3.0	Cs	< 0.5
Al	4.9	Ba	< 0.5
Si	< 500	La	< 0.5
P	< 500	Ce	< 0.5
S	-	Pr	< 0.5
Cl	-	Nd	< 0.5
K	< 5	Sm	< 0.5
Ca	15	Eu	< 0.5
Sc	< 0.5	Gd	< 0.5
Ti	1.2	Tb	< 0.5
V	< 0.5	Dy	< 0.5
Cr	4.4	Ho	< 0.5
Mn	< 0.5	Er	< 0.5
Fe	7.5	Tm	< 0.5
Co	< 0.5	Yb	< 0.5
Ni	< 0.5	Lu	< 0.5
Cu	0.2	Hf	< 0.5
Zn	< 0.5	Ta	< 0.5
Ga	< 0.5	W	< 0.5
Ge	< 0.5	Re	< 0.5
As	< 0.5	Os	< 0.5
Se	< 0.5	Ir	< 0.5
Br	-	Pt	< 0.5
Rb	< 0.5	Au	< 0.5
Sr	< 0.5	Hg	< 0.5
Y	< 0.5	Tl	< 0.5
Zr	< 0.5	Pb	< 0.5
Nb	< 0.5	Bi	< 0.5
Mo	< 0.5	Th	< 0.5
Ru	< 0.5	U	< 0.5
Rb	< 0.5		

1.3.3 Rhenium Foils

The masses and densities of the rhenium foils are shown in Table 13. Foils number 1-20 were used for this experiment. Foils 1-9 were shipped to chemical analysis and the masses of these foils remains unknown. Table 13 shows the masses and calculated densities of foils 10-25. The 1σ accuracy of the balance used to measure the rhenium foils was ± 1 g. The average density for rhenium foils 10-25 calculated from the total mass and total volume of these foils is 17.691 g/cm³ with a 1σ standard deviation from the densities listed in Table 13 of 0.670 g/cm³. The impurities measured by NSL Analytical Services Inc. are presented in Table 14. Only the elements that were detected are listed in Table 14.

Table 13. Rhenium Mass and Density.

Part Number	**Mass in Grams**	**Density (g/cm³)** [(a)]
10	28.7	18.244
11	27.8	17.671
12	27.1	17.226
13	27.5	17.481
14	25.5	16.209
15	28.4	18.053
16	26.9	17.099
17	28.8	18.307
18	25.9	16.464
19	29.0	18.434
20	27.2	17.290
21	29.4	18.689
22	28.1	17.862
23	28.3	17.989
24	28.3	17.989
25	28.4	18.053

(a) Calculated from masses divided by nominal volume.

Table 14. Composition of the Rhenium Foils.

Element	Concentration (wt.%)
Re	99.9
Al	< 0.1
Ca	< 0.01
Fe	< 0.1
K	< 0.01
Mo	< 0.1
Ni	< 0.01
Ti	< 0.01
W	< 0.01

1.3.4 Polyethylene Insert Material Data

The polyethylene inserts for this experiment were made of high-density polyethylene with a formula of C_2H_4. The measured masses for the polyethylene inserts are presented in Table 15. The 1σ accuracy of the balance used to measure the polyethylene inserts was ± 0.2 g. The average density for the inserts calculated from the total mass and total volume of the inserts was 0.960 g/cm^3 with a 1σ standard deviation from the densities listed in Table 15 of 0.008 g/cm^3.

Table 15. Polyethylene Insert Mass and Calculated Density.

Part Number	Mass in Grams	Calculated Density (g/cm³) [(a)]	Part Number	Mass in Grams	Calculated Density (g/cm³) [(a)]
1	314.04	0.946	33	320.3	0.965
2	314.64	0.948	34	321.2	0.968
3	314.35	0.947	40	320.2	0.965
4	316.92	0.955	42	320.0	0.964
13	314.64	0.948	43	320.2	0.965
14	315.45	0.951	44	319.6	0.963
16	321.04	0.967	45	319.6	0.963
17	316.06	0.952	47	321.6	0.969
18	315.58	0.951	48	320.7	0.966
19	318.68	0.960	49	320.6	0.966
20	315.69	0.951	50	320.8	0.967
21	313.37	0.944	51	320.8	0.967
22	317.64	0.957	52	322.0	0.970
23	314.04	0.946	53	318.9	0.961
27	322.5	0.972	54	320.0	0.964
28	322.0	0.970	56	317.5	0.957
29	319.5	0.963	57	318.3	0.959
30	319.8	0.964	59	318.1	0.959
31	322.3	0.971	60	320.9	0.967
32	317.6	0.957	61	321.0	0.967

(a) Calculated from masses divided by nominal volumes.

1.3.5 Supporting Structures

The supporting structures around the experiment consisted of the aluminum Dowel-Pin plate (Figure 4) and the aluminum mounting plate described in Figure 2. The density used for these plates was obtained from the reference used to obtain the values provided in Table 16 and it was 2.7 g/cm^3. The chemical composition for aluminum 6061-T6 is given in Table 16.

Table 16. 6061-T6 Aluminum Composition.[(a)]

Chemical Composition in Percent								
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4-0.8	0.7 max	0.15-0.40	0.15 max	0.8-1.2	0.04-0.35	0.25 max	0.15 max	98

(a) from Matweb.

1.4 Supplemental Experimental Measurements

No supplemental experiments were performed in the 2 × 2 HEU-Re-Polyethylene Experiment.

2.0 EVALUATION OF EXPERIMENTAL DATA

The information included in this report was obtained from logbooks, conversations with the experimenter, engineering drawings, analysis reports, and the Safety Analysis Report for LACEF.

The reactivity effects of many of the uncertainties discussed below were quantified using an MCNP model. The MCNP analysis was performed by employing a detailed three-dimensional model with continuous-energy cross-sections from ENDF/B-VI.6 neutron data. The MCNP calculations had 6,000,000 active histories. A total of 5,000 histories per generation were used and 1,250 generations of neutrons. The first 50 generations were skipped to obtain a well-distributed neutron source. The MCNP calculations had a statistical uncertainty in *keff* of 0.0002 to 0.0003. The representation of the experiment in MCNP is described in Section 3.0. The input decks for the simplified and detailed models are provided in Appendix A.

Uncertainty values are taken from differences between the Monte Carlo calculations where one parameter is perturbed at once and the reference (basic) benchmark model. When the uncertainty is small, in order to reduce the relative statistical uncertainty it is verified by additional calculation where the varied parameter is significantly over-perturbed and the corresponding uncertainty scaled back.

The effect of the random variation of a component (plate, insert, foil, gap) dimension among other components of an assembly was estimated by dividing by $\sqrt{(CN)}$, where N is the number of components in the assembly and C is a correction factor introduced to take into account the unequal importance of components. According to the ICSBEP uncertainty guide the magnitude of C lies between 0.5 and 1. We assumed the C value to be 0.5. However it is important to note that this is only a rough estimate. We assumed that there is no systematic error in component dimensions.

The uncertainties affecting the experiment have been divided into broad categories. They are 1) material mass measurements, 2) material dimensions, 3) and impurities. Each category is considered in turn and then the combined experimental uncertainty is presented. Each final uncertainty estimate is one standard deviation.

The first category includes the material mass uncertainty, calculated by changes in atom density. The uncertainties in the mass of the fuel (uranium foils), in the mass of the rhenium foils, in the mass of the polyethylene reflector and moderator plates, in the mass of the lamination on the uranium foils, and in the mass of the polyethylene inserts were considered. The uncertainties in the ^{235}U enrichment, ^{234}U content, and ^{236}U content were also investigated under this category.

The second category includes the material dimensional uncertainties of the different components. The dimensional uncertainties examined include the change in volume of the fuel (uranium foils), the rhenium foils, the large and small moderating and reflector plates, the polyethylene inserts, and the uranium foil lamination. In addition, under this category, the effect of varying the axial gaps in the experiment, the central location of the rhenium foils, the potential overlap of the rhenium foils, and the potential partial shift of the assembly were also examined.

The third category includes uncertainties associated with the impurities in the materials used in the experiment, including the fuel, the rhenium foils, and the polyethylene. Also, the tape used to secure the rhenium foils was considered.

Finally, the uncertainties due to the surroundings were also considered.

2.1 Material Mass

The uncertainty of k_{eff} due to uncertainty in the fuel mass was determined by calculating the sensitivity to small variations in the HEU mass. This same method was also used to determine the uncertainty in the masses of the Rhenium foils and polyethylene. All MCNP calculations in this evaluation had a statistical uncertainty in k_{eff} of 0.0002 to 0.0003.

The mass parameters were varied in small amounts to provide a Δk_{eff}. The change in k_{eff} was defined as

$$\Delta k_{eff} = \frac{\left|k_{eff}(p) - k_{eff}(p + T.U.)\right| + \left|k_{eff}(p - T.U.) - k_{eff}(p)\right|}{2} \qquad (1)$$

where $k_{eff}(p)$ is the base case and T.U. is the total uncertainty of the mass of the component being investigated. From the uncertainty guide, the mass uncertainty (standard deviation) for the total mass of N masses is given by:

$$\sigma_T = \sqrt{N\sigma_r^2 + N^2\sigma_s^2 + \frac{N\sigma_c^2}{12}} \qquad (2)$$

where σ_T is the uncertainty in the total mass, σ_r is the random uncertainty of the measuring device, σ_s is the systematic measurement uncertainty, σ_c is the round-off resolution, and N is the total number of pieces of a given material type in the assembly. The first term, random measurement uncertainty σ_r, is accounted for by setting it equal to 0.5 g for the HEU foils, lamination, rhenium foils, and polyethylene inserts because every time these materials were weighed, the balance recorded the same weight within the resolution of the balance,[a] which is 0.5 g. For the polyethylene plates, the random measurement was set to ± 2.0 grams. The second term, systematic measurement uncertainty σ_s, is set equal to the entire range of ± 0.1 gram, which is the best estimate based on calibration certificates. The third term, round-off resolution σ_c, is set equal to the entire range of the accuracy of the balance, which is ± 0.2 gram for the 10 foils whose masses are given to one decimal place. For the other 32 foils whose masses are rounded to the nearest gram, the round-off resolution is set equal to the entire range of ± 0.5 gram. N is equal to 42 for the HEU foils, 25 for the Rhenium foils, 18 for the polyethylene plates, 40 for the polyethylene inserts, and 42 for the lamination. The total uncertainty is the square root of the sum of the three terms described.

In order to estimate the Δk_{eff} of the total mass uncertainty, the density of the material can be increased or decreased by the factor $(M + \sigma_T)/M$, where σ_T is the total mass uncertainty and M is the total material mass.

The first change applied to the HEU mass was due to the total mass uncertainty. The variation in the mass was manifested through a change in the atom density of the fuel while keeping the dimensions constant. The mass uncertainty in the fuel comes from the weighing of the fuel and the physical variation of the foil masses. To characterize this uncertainty the total mass uncertainty was obtained from the random, systematic, and round-off uncertainties. For the HEU-Re-polyethylene experiment, the relative

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[a] HEU-MET-THERM-012 - 2 x 2 x 26 Array of highly enriched uranium with aluminum, moderated and reflected by polyethylene, Section 2.1.

uncertainty for the total nominal mass of the HEU of 0. 156 % has an effect on Δk_{eff} of ± 0.00067. The standard uncertainty is ± 0.00067.

The uncertainty in the fuel enrichment was also analyzed. The reported 2σ uncertainty in the enrichment (the uncertainty in the enrichment is only known with a confidence level of 95%) was ± 0.02 atom percent. Since the enrichment analysis was performed for only one foil, it is assumed that all the foils used have the same uncertainty in the enrichment. Decreasing or increasing the weight fraction in ^{238}U compensated for the change in the weight fraction in ^{235}U. The other uranium isotopes remained unchanged. For this experiment, the resulting uncertainty in k_{eff} due to the 2σ uncertainty in the enrichment has an effect on Δk_{eff} of ± 0.00021. Consequently the standard uncertainty is ± 0.00011.

The uncertainties in the ^{234}U content (1.1339 atom percent) and ^{236}U content (0.2581 atom percent) were analyzed. The reported 2σ uncertainty in the enrichment (the uncertainty in the enrichment is only known with a confidence level of 95%) was ± 0.02 atom percent. There was no uncertainty provided for the ^{234}U or ^{236}U content; therefore, an uncertainty of ± 0.02 atom percent is assumed. Decreasing or increasing the atom percent in ^{238}U compensated for the change in the atom percent in both the ^{234}U and ^{236}U. Each calculation was performed individually. The other uranium isotopes remained unchanged. For this experiment, the resulting uncertainty in k_{eff} due to the 2σ uncertainty in the ^{234}U has an effect on Δk_{eff} of ± 0.00001 and the resulting uncertainty due to the 2σ uncertainty in the ^{236}U is also ± 0.00001. Consequently the standard uncertainty in Δk_{eff} is negligible for both isotopes.

The effect of mass uncertainty in the Rhenium foils was calculated by adjusting the atom density and maintaining the dimensions of the Rhenium foils. Foils number 1-20 were used in this experiment; however, 1-9 were sent for chemical analyses prior to being weighed. Weights are provided for foils numbered 10-25. As a result, the uncertainty comes from the weights of foils 10-25 which is applied to the Rhenium foils used in this experiment and the physical variation of the foil masses used in the experiment. To characterize this uncertainty the total mass uncertainty was obtained from the random, systematic, and round-off uncertainties for the 16 measured and available foils and extrapolated to the foils used in this experiment. For the HEU-Re-polyethylene experiment, the relative uncertainty for the total nominal mass of the Rhenium foils of 0.274% has an effect on Δk_{eff} of ± 0.00005. The standard uncertainty is also ± 0.00005.

The effect of mass uncertainty in the polyethylene was also calculated. Adjusting the atom density and maintaining the dimensions of the polyethylene plates, lamination, and inserts represent the uncertainty in the mass of the polyethylene material. The relative uncertainty for the total mass of the polyethylene plates of 0.015 wt.% has an effect on Δk_{eff} of ± 0.00006. The standard uncertainty is ± 0.00006. The effect on k_{eff} due to the relative uncertainty for the total mass of the polyethylene laminations (1.052 wt.%) is ± 0.00016. Therefore, the standard uncertainty is ± 0.00016 for the lamination. The uncertainty in the mass of the polyethylene inserts, based on the relative uncertainty for the total mass (0.032 wt.%), has an effect on Δk_{eff} is ± 0.00022. The standard uncertainty is ± 0.00022.

The effect of uncertainty in hydrogen (H) to carbon (C) ratio in polyethylene on k_{eff} was also investigated. Polyethylene molecule is a long chain of carbon atoms, with two hydrogen atoms attached to each carbon atom. It is a common practice to write the chemical formula for polyethylene as $(C_2H_4)_N$, where N stands for the number of ethylene molecules in the chain. In calculations of number densities of atoms in polyethylene it is usually assumed that hydrogen to carbon atom ratio is 2. However in reality there are additional hydrogen atoms, one at each end of the molecule. Moreover, sometimes some of the carbons, instead of having hydrogens attached to them, will have long chains of polyethylene attached to them. The difference between "theoretical" H to C ratio, which is 2, and the "real" one (>2) strongly depends on the length of the chain and is approximately inversely proportional to the chain length. The perturbation method was used to quantify the uncertainty. It was assumed that there is no branching of the polyethylene molecules, meaning that all chains are linear and that H to C ratio is $2(N+1)/N$. When $N \geq 1000$, the relative difference between "theoretical" and "real" H to C atomic ratio is ≤ 0.1 %, which has an effect in $\Delta k_{eff} \leq \pm 0.00005$. In this experiment the so called high density polyethylene was used, which has very long chains ($N >> 10^5$), meaning that the relative difference between "theoretical" and "real" is much less than 1×10^{-5}. The effect of uncertainty in the H to C ratio on k_{eff} is therefore considered to be negligible, that is much less than 1×10^{-5}.

2.2 Material Dimensions

This uncertainty includes tolerances in the engineering drawings and their effect in the as-built component. The material dimensions were obtained from the original engineering drawings, from conversations with the experimenter, and from assumptions in cases where no data existed. The computations for uncertainty in the dimensions varied the dimensions while adjusting the material density to keep the material mass constant. In addition, only one dimension (e.g., x-direction) was varied at a time, and then the results from each varied dimension were combined quadratically. For each material, the dimensional uncertainty was affected most by varying the z-dimension (material thickness).

The uranium foils were cut by the experimenter and no specified tolerances exist. The horizontal dimensions of the foils were measured to be 9 inches after being cut. This dimension is a representative measurement of the foil rather than a maximum or minimum measurement.

The foils were cut by a laser. For this analysis, based on a discussion with the machinists who cut the foil, a bounding uncertainty of ± 0.05 % was assumed for the horizontal dimensions of the foil. The horizontal dimensions were increased and then decreased by this amount. The thickness of the foils was probably obtained by rolling of the foils. It was assumed that the bounding uncertainty in foil thickness is 3 %. This assumption is supported by the fact that variations of HEU foil masses from the average are of similar range. The analysis of uncertainty in the foil was performed with MCNP. Varying the dimensions and maintaining the masses of the HEU foils and lamination constant modeled this uncertainty. The effect of changing the dimension of all HEU foils by the tolerance (3 dimensions combined quadratically) is much smaller than 5 pcm and therefore considered negligible.

The Rhenium foils were nominally 8 × 2 inches in length and width with a thickness of 0.006 inch; however, no specified tolerances are reported for these foils. The Rhenium foils were cut by a laser. For this analysis, based on a discussion with the machinists who cut the HEU foils, a bounding uncertainty of ± 0.05 % was assumed for the horizontal dimensions of the Rhenium foil. The horizontal dimensions were increased and then decreased by this amount. The thickness of the foils was probably obtained by rolling of the foils. It was assumed that the bounding uncertainty in foil thickness is 3 %. This assumption is supported by the fact that variations of Rhenium foil masses from the average are of similar range. The analysis of uncertainty in the foil was performed with MCNP. Varying the dimensions and maintaining the masses of the HEU foils and lamination constant modeled this uncertainty. The effect of changing the dimension of all Rhenium foils by the tolerance (3 dimensions combined quadratically) leads to a $\Delta k_{\text{eff}} = \pm 0.0006$. The resulting standard uncertainty (divided by $\sqrt{3}$) is ± 0.0004.

The uncertainties in the Rhenium foil location and possible overlap were also analyzed. Figure 14 shows the Rhenium foils approximately centered on the polyethylene inserts using a tape measure and the intersections of the inserts as guides. Therefore, an uncertainty of ± 0.25 inch was assumed for the central location of the foils to demonstrate that Re foil overlap is negligible. Also, an uncertainty of a maximum overlap of 0.25 inch and 0.25-inch gap between foils was assumed to demonstrate that Re foil location is negligible. The effect of the location of the foils (2 dimensions combined quadratically) leads to a Δk_{eff} <0.0001; therefore, the resulting uncertainty due to the location of the Rhenium foils is negligible. For the possible overlap condition, the resulting uncertainty in Δk_{eff} is <0.0001. Therefore, the resulting uncertainty due to the possible overlap of Rhenium foils is negligible.

Adjusting the dimensions by the tolerance provided in the original engineering drawings assessed effects of the uncertainty of the polyethylene plate dimensions. The engineering drawings show that the tolerance for the width and length of the plates was ± 0.1 inch while the thickness had a tolerance of ± 0.01 inch. Varying the nominal dimensions by the tolerance and maintaining constant the masses of the plates modeled this uncertainty. The variation was performed one dimension at a time. In effect, these changes in the dimensions of the plates change the neutron leakage. The effects of the dimensional tolerance in each of the 3 directions were calculated (keeping mass constant) and combined quadratically to get an effect Δk_{eff} of ± 0.0003. Therefore, the standard uncertainty (tolerance divided by √3) is ± 0.0002.

The critical assembly consists of two sections. The top half of the system rests on a stationary platform and the bottom section rides on a hydraulic lift. Both the bottom plate for the bottom part of the assembly and the bottom plate for the top part of the assembly rest on aluminum plates that contain 4 dowels in order to assure proper alignment of the assembly in the vertical direction. Additionally, in order to achieve zero separation for a critical configuration, the bottom section is raised until it lifts the top half of the system slightly from its stationary platform. However, it is possible that there is a slight misalignment of plates in the middle portion of the assembly. Because a noticeable misalignment of the assembly would cause the experimenters to stop the experiment and realign the sections, it is judged sufficient to calculate the effect of a shift of the middle section of the assembly of 1 cm (5 moderating polyethylene plates in the bottom part of the assembly are shifted at a time). This shift was performed in 2 directions and combined quadratically to get an effect Δk_{eff} of <0.0001. Therefore, the resulting uncertainty due to the possible shifting of polyethylene plates is negligible.

The final laminated foils had nominal dimensions of 10.0 × 10.0 inches with a thickness of 0.009 inch. No tolerances were specified for these dimensions. Bounding dimensional uncertainties for the width and length of the foils were assumed as ± 0.1 inch while the thickness was assumed as ± 0.001 inch. These assumptions are consistent with the dimensional uncertainties used for the polyethylene plates and are considered sufficiently bounding. The mass was kept constant while the dimensions were varied. The effects of the dimensional uncertainty in each of the 3 directions were calculated individually and combined quadratically to get an effect Δk_{eff} of ± 0.0004. Therefore, standard uncertainty (divided by √3) is ± 0.0002.

Four polyethylene inserts were used to fill the polyethylene moderator plates. Each insert had the dimensions of 9.000 × 9.000 × 0.250 inch. The polyethylene inserts length and width each had a tolerance of ± 0.005 inch. The thickness of the polyethylene inserts had a tolerance of ± 0.01 inch. Adjusting the dimensions provided in the engineering drawings assessed the effect of the uncertainty of the polyethylene inserts. The mass was kept constant when the dimensions were varied. The effects of the dimensional tolerance in each of the 3 directions were calculated individually (keeping mass constant) and combined quadratically to get an effect Δk_{eff} of ± 0.0002. Therefore, standard uncertainty (tolerance divided by √3) is ± 0.0001.

2.3 Axial Gaps

From the drawings of the experiment (Figure 15), assuming that the HEU foils are laying straight across the foil recess region, it is evident that there exist air gaps in two locations: 1) above the HEU foils, 2) between the polyethylene inserts where the Rhenium foils are secured and the HEU foils except on the first unit made up of four HEU foils where the air gap is only above the fissile material. However, because the thin, laminated HEU foils are not load-bearing elements and the point of overlapping of the four foils in the center likely rests on the Rhenium foils below, a complex gap profile exists.

The air gaps that exist above and below the foils are the result of the material recesses. The gap above the HEU foils is due to the foil recess. The foils recess is 0.026 inch deep (+0.002, -0.000) and the thickness of a laminated HEU foil is 0.009 inch, which yields a total air gap of approximately 0.017 inch. Although a smaller gap exists above HEU foils due to the overlapping foils, it is small enough to disregard it in the axial gap analysis. The second gap is due to the polyethylene insert recess in the moderating polyethylene plate. As mentioned before, the polyethylene insert thickness is 0.25 inch and the recess in the moderating plate where the polyethylene inserts are placed is 0.265 inch deep, which yields a total air gap below the HEU foils of 0.015 inch, excluding the location of the Rhenium foils which are only 0.006 inch thick yielding a total air gap between the Rhenium foils and HEU foils of approximately 0.009 inch.

For this experiment, the HEU foils are modeled in a horizontal plane across the foil recess. The effect of reducing the air gap below and above the HEU foils by 0.002 inch and increasing this air gap by the same amount below and above the HEU foils sufficiently bounds the gap profile uncertainty. Both effects were calculated separately, with polyethylene plate and insert masses kept constant by adjusting the polyethylene density. The effect in Δk_{eff} of the change in these air gaps is ± 0.0010 and the standard uncertainty (divided by $\sqrt{3}$) is ± 0.0006.

2.4 Surroundings

The experimenters did not make corrections for measurements of the effects of room return and the assembly machine in the HEU-Re-polyethylene experiment. Calculations were performed to determine the effect that these two parameters have on the criticality of the system. As Figure 1 illustrates, the Planet assembly machine is quite a distance away from any walls. The closest wall to the assembly is 8 feet away. The floor and ceiling are approximately 10 and >20 feet from the assembly, respectively.

As stated above, room reflection was modeled. The model had the following conditions: A 12-in-thick concrete wall in the form of a sphere surrounded the entire experiment. In other words, the experiment was in the center of a thick shell of concrete. The concrete-wall shell had an inner radius of 10 ft and an outer radius of 11 ft. This Model is bounds the one that assumes the exact locations of the floor, ceiling, and other walls. The effect in Δk_{eff} due to room return is + 0.0003. Thus, the effect of ± 0.0003 is estimated as the standard uncertainty in Δk_{eff} from room return. Because the effect of adding the surroundings is + 0.0003, a bias of - 0.0003 is applied and the structures are omitted from the benchmark model. The resulting standard uncertainty of the surrounding bias is ± 0.0003.

The assembly aluminum plates, shown in previous figures, were made of Al-6061-T6. Al-6061-T6 has a density of 2.7 g/cm^3, composition is given in Table 16. The effect of including the aluminum support plates present in the model was determined to be + 0.0006. Because the effect of adding the support structure components is + 0.0006, a bias of – 0.0006 is applied. Additionally, ± 0.0006 is estimated as the standard uncertainty from the support plates.

2.5 Impurities

No chemical impurity analyses were conducted for the HEU foils. Typical HEU impurities are found in HEU-MET-THERM-001 for similar uranium foils used in other polyethylene experiments and are listed in Table 17.

Table 17. Typical HEU Impurities in HEU-MET-THERM-001.

Impurity	Concentration (ppm)
Carbon	200
Silicon	100
Iron	100
Total trace impurities (Th, Al, Mn, Mg, Ni, Cu, and Ca)	<50

The impurities listed in Table 17 are assumed as an average value of impurities for the HEU foils. Therefore, using the impurity level above as a midpoint value for the impurity level of the HEU foils, it is assumed that 2 times the values is a reasonable bounding impurity level (2σ) which yields a Δk_{eff} = - 0.0006. Because the HEU impurity level is assumed as an average over the range of possible impurity levels, $\Delta k_{eff}/2$ or - 0.0003 is the estimated impurity effect and also is assumed as the 1σ uncertainty for the impurities of the HEU foils. Because the effect of adding the impurities is - 0.0003, a bias of + 0.0003 is applied and the HEU impurities are omitted from the benchmark model. The resulting standard uncertainty of the impurities bias is ± 0.0003.

The Rhenium foils composition including impurities detected as present but below detection limits is summarized in Table 14. The concentration of Rhenium was 99.9 wt.%. The sum of the detection limits of all impurities totals 0.35 wt.%; however, because the impurity values are given as less than the detection limits and the Rhenium concentration is 99.9 wt.% with no uncertainty assigned to the Rhenium concentration value, a bounding value (2σ) of the detection limit for the impurities (0.35 wt.%) was calculated. The Rhenium concentration 99.65 wt.% with the balance as the ratio of impurities listed in Table 14 yields a Δk_{eff} = + 0.0008. Because the probability of the impurity level is equiprobable over the range of possible impurity levels, $\Delta k_{eff}/2\sqrt{3}$ or ± 0.0002 is the 1σ uncertainty for the impurities of the Rhenium foils. Because the impurity values are given as detection limits rather than measurement values, they are omitted in the benchmark model. Additionally, because the range of impurities is between 0.0 – 0.35 wt.% and the midrange value of impurities of 0.175 wt.% yields a Δk_{eff} of + 0.0004, a - 0.0004 bias is applied for the omission of Rhenium impurities. The resulting standard uncertainty of the impurities bias is ± 0.0002.

Figure 14 shows that the foils were placed adjacent to each other and secured to the polyethylene inserts with tape. No details on the taping of the foils were reported; however, the experimenter stated generic 3M masking tape was used. Material Safety Data Sheets for a variety of 3M Masking Tapes provide a simple, generic composition of 55-75 wt.% saturated crepe paper ($C_6H_{10}O_5$) with a density range of 0.2 – 0.4 g/cm^3 and a natural rubber adhesive (C_5H_8) with an approximate density of 6 pounds/cubic foot. The foils were centered with a measuring tape and touched each other while trying to prevent overlapping. Figure 14 shows two Rhenium foils secured with tape pieces measuring approximately ½ to 1½ inches length by ½ to 1½ inches width of tape at the top and bottom of each foil (four pieces of tape per unit). This results in approximately 40 pieces of tape used in the experiment to secure Rhenium foils

1 – 20 or a range of approximately 10 to 90 square inches of tape used in the experiment (using ½ × ½ pieces as the minimum tape size and 1½ × 1½ pieces as the maximum tape size). The Material Safety Data Sheets for a variety of 3M Masking Tapes provide a range of thickness of 4 – 8 mils.[a] As a result, an average of 40 square inches of 6 mils masking tape with an average of 65 wt.% saturated crepe paper and 35 wt.% adhesive was assumed for the tape. The effect of the tape was determined by adding a strip of 1 inch x 4 inch tape to each layer of inserts in the experiment adjacent to the Rhenium foils. The effect of tape leads to a Δk_{eff} = + 0.0002. The resulting standard uncertainty of the tape bias is ± 0.0001. Because the addition of the tape is negligible, it is omitted in the benchmark model.

The reported impurities in polyethylene were given in Section 1.3. In order to determine the effect of the impurities in the polyethylene plates, the highest reported level of each elemental impurity listed in Table 10, 11 and 12 was included in the model or, if a detection limit was provided, then the impurities were added at half of the detection limit. The effect in Δk_{eff} of including the impurities in the polyethylene plates and inserts was -0.0013. For the polyethylene, the impurities listed in Table 10 were used due to a lack of further impurity sampling, and the effect in Δk_{eff} of including the impurities in the polyethylene lamination was -0.0006. The effects of the impurities are included in the standard uncertainties in Δk_{eff} (the resulting standard uncertainty is ± 0.0008 and ± 0.0004, respectively) and are given in the summary table. Because the impurity values are mostly given as detection limits rather than measurement values, impurities for the polyethylene plates, inserts, and lamination are omitted in the benchmark model and a bias of + 0.0019 is applied.

2.6 Reactivity

The logbook reported that at zero separation with 10 ½ units (42 foils), the Count Rate was 51966 with a multiplication of 150. As a result, using the 1/M curve for 10 ½ units and the data in the logbook of the approach to critical, the experimenters estimated that delayed critical would occur at approximately 10.72 units with a fully closed stack. Using Figure 18, an uncertainty range of 10.70 to 10.75 was estimated as a reasonable range for determining delayed critical. Experimenters used the equation $k_{eff} = (10.5/10.72)\text{\^{}}(1/3)$[b] to estimate a k_{eff} of 0.99311 for this system.

Using this equation and the range of 10.70 to 10.75 to estimate a k_{eff} range of uncertainty for reactivity for this experiment gives Δk_{eff} of 0.99373 to 0.99219, respectively. Therefore, standard uncertainty (range divided by 2) is ± 0.00077.

The experimentalist reported[c] that the observed uncertainty in k_{eff} was ± 0.03 $. In the logbook the value of 0.0068 is used for β_{eff}. Therefore the uncertainty in experimental k_{eff} is 0.0002. This uncertainty value is bound by the uncertainty range established by Figure 18.

In order to determine the reactivity worth of the Rhenium in this experiment, the Rhenium foils were replaced by void. This experimental model Δk_{eff} = 1.05651.

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[a] mil = one thousandth (10^{-3}) of an inch (0.0254 millimeter).

[b] Rene Sanchez, David Loaiza, Glenn Brunson, and Robert Kimpland, "Critical Experiments with Highly Enriched Uranium and Matrix Elements (Si, Mg, Al, Gd, and Fe)," Nuclear Science and Engineering: Vol. 147, No. 3, 307-318, 2004.

[c] Personal communication with Rene Sanchez from Los Alamos National Laboratory.

2.7 Temperature

The measured temperature of the experiment was 18.0 ºC ± 0.5°C. The effect of uncertainty in temperature on k_{eff} is less than 0.0001 and is therefore considered negligible.

The temperature in this experiment was reported to be 18.0 ± 0.5 ºC. The 1 σ uncertainty in temperature of the experiment is therefore ± 0.5 °C. The effect of temperature on k_{eff} was investigated by changing the cross section data and the dimensions of the assembly, respectively.

Adjusting the thermal scattering data for H in polyethylene for a 57 K change (from 293 K to 350 K)[a] leads to Δk_{eff}=0.0142. Adjusting the cross section data (except thermal scattering data) for a 107 K change (from 293 K to 400 K) leads to Δk_{eff}=0.0005.

Thermal expansion coefficient of polyethylene is approximately 2×10^{-4}/K. Increasing the temperature by 57 K, leads to 1.14 % change in the assembly dimensions. The corresponding change in k_{eff} is -0.0092 (results taken from Section 2.2).

When both temperature effects (change in cross section and change in dimensions) are combined we obtain that changing the temperature by 57 K leads to Δk_{eff} = ±0.0020. Considering that the temperature effect is symmetric in the interval ±57 K around 18.0 °C, the resulting uncertainty on k_{eff} due to the uncertainty in temperature (± 0.5 ºC) was calculated to be ± 0.00001.

2.8 Combining Uncertainties

A summary of the uncertainties discussed in the previous sections is collected in Table 18. All sensitivity calculations were performed using MCNP with the ENDF/B-VI library. The uncertainties which are below 10 pcm and are impossible to quantify, are denoted as negligible. Of the uncertainties due to variations in mass: polyethylene plate mass uncertainty, lamination mass uncertainty and the enrichment are important. Of the uncertainties due to variations in geometry: the axial air gaps and HEU foils are most significant. Of the composition uncertainties: the composition uncertainty of polyethylene impurities (plates, inserts, and lamination) is most significant. The total experimental uncertainty was derived from the effects given and combined using the sum of the squares.

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[a] This temperature interval was chosen, because the cross section data, that we used, were evaluated at these temperatures.

Table 18. Summary of Uncertainties for the Experiment.

Source of Uncertainty	Parameter Variation in Calculation	Calculated Effect (Δk_{eff}) of Variation	Standard Uncertainty of Parameter	Standard Uncertainty in Δk_{eff}
HEU Mass	0.156%	± 0.00067	0.156	± 0.00067
Enrichment in ^{235}U (at.%)	0.020%	± 0.00021	0.020 / 2	± 0.00011
^{234}U Content	0.020%	± 0.00001	0.020 / 2	Negligible
^{236}U Content	0.020%	± 0.00001	0.020 / 2	Negligible
Re foils Mass	0.274%	± 0.00005	0.274	± 0.00005
Poly Plates Mass	0.015%	± 0.00006	0.015	± 0.00006
Poly Lamination Mass	1.052%	± 0.00016	1.052	± 0.00016
Poly Insert Mass	0.032%	± 0.00017	0.032	± 0.00017
HEU foil length	0.05%	Negligible	0.05 / √3	Negligible
HEU foil width	0.05%		0.05 / √3	
HEU foil thickness	3%		3 / √3	
Re foils length	0.05%	± 0.0006	0.05 / √3	± 0.0004
Re foils width	0.05%		0.05 / √3	
Re foils thickness	3%		0.05 / √3	
Re foil location	0.25 inch	0	0.25 / √3	Negligible
Re foil overlap	0.25 inch	0	0.25 / √3	Negligible
Poly Plates length	0.100 inch	± 0.0003	0.100 / √3	± 0.0002
Poly Plates width	0.100 inch		0.100 / √3	
Poly Plates thickness	0.01 inch		0.001 / √3	
Partial Assembly shift	1.0 cm	0	1/ √3	Negligible
Poly Lamination length	0.100 inch	± 0.0004	0.100 / √3	± 0.0002
Poly Lamination width	0.100 inch		0.100 / √3	
Poly Lamination thickness	0.001 inch		0.001 / √3	
Poly Insert length	0.005 inch	± 0.0002	0.005 / √3	± 0.0001
Poly Insert width	0.005 inch		0.005 / √3	
Poly Insert thickness	0.01 inch		0.01 / √3	
Axial Air Gaps	0.002 inch	± 0.0010	0.002 / √3	± 0.0006
Room Return	Included	+0.0003	--	± 0.0003
Structures(a)	Included	+0.0006	--	± 0.0006
Temperature	0.5°C	0	0.5°C	Negligible
Reactivity	See §2.6	± 0.00154	See §2.6	± 0.00077
Impurity in HEU Foils(a)	Included	+0.0006	0.0006/ 2	± 0.0003
Impurity in Re Foils(a)	Included	+0.0004	0.0004 / √3	± 0.0002
Tape	Included	-0.0002	0.0002 / √3	± 0.0001
Impurity in Poly Plates/Inserts(a)	Included	-0.0013	0.0013 / √3	± 0.0008
Impurity in Lamination(a)	Included	-0.0006	0.0006/ √3	± 0.0004
Total Uncertainty	Quadratically Combined Total: ± 0.0018			

(a) Bias applied.

2.9 Summary

Uncertainties in the k_{eff} value of the benchmark experiment arise from neutron return from surroundings, uncertainties in material measurements (primarily density, masses, and compositions of HEU foils and polyethylene plates and inserts), and machining tolerances of components. Individually, the effects are small, and taken together they may be compensating. The experiment is acceptable as a benchmark experiment.

3.0 BENCHMARK SPECIFICATIONS

3.1 Description of Model

The 2 × 2 array HEU-Re-polyethylene experiment is similar to the typical HEU-polyethylene array represented in Figure 1. For the most part, this arrangement is a practical criticality safety benchmark with some simplification needed. Two benchmark models were derived for the experiment. The two benchmark models are practically identical with respect to the benchmark-model k_{eff}. A simple model can be transformed from the as-built experiment without compromising the accuracy of the experiment.

Both models ignore the effects of room-returned neutrons and structures because the fissile material is surrounded by a reflector that is effectively infinite. As a result, void is also used versus modeling air. The photo in Figure 1 shows that the Planet assembly machine is quite some distance from the walls, floor, and ceiling. Only the north wall is within 8 feet of the Planet assembly. Since it has been shown that the Planet structure and a bounding model of concrete walls have very small or no effect on calculated k_{eff}, the room return was deemed to be insignificant. The uncertainty in this approximation has been included in the total uncertainty (Table 18). Additionally the cutout volume of the neutron source and thermocouple were not included as they are deemed negligible due to the small volumes (1.4 cm^3 and 0.1248 mm^3, respectively).

3.1.1 Simplified Model

Five major regions exist: the HEU foils, the Rhenium foils, the polyethylene plates, the polyethylene inserts, and the lamination used for the foils. The density of the HEU foils is derived from the foils that were used in the final configuration (Figure 14). As mentioned earlier and as in previous evaluations that used these polyethylene plates, the sides of the lamination of the HEU foils overlapped each other. The effect of including and not including the lamination overlap had no effect on k_{eff} (<0.0001). This small effect might be due to the fact that the overlapping laminated foils in the detailed model do not fit in the recess. Therefore, a small gap had to be introduced between polyethylene plates. In addition, another small gap was introduced between the laminated foils and the polyethylene inserts. As a consequence, the lamination of the foils was treated as a uniform sheet of lamination on the top and bottom of the HEU foils, with lamination mass conserved. It was also decided to leave a small gap of 0.1 inch on either side of the lamination for the expansion analysis. In addition, the tolerance on the foil recess is (+0.000, -0.020). Therefore, it was speculated that the foil recess in some of the polyethylene plates might be smaller than specified.

The dimensions for the polyethylene plates, HEU foils, Rhenium foils, polyethylene inserts, and laminating sheets that were applied to the HEU foils are the same as the nominal linear dimensions. Mass and/or average density is conserved. This approach does not change the magnitude of k_{eff} in the system. The aluminum supporting plates are not included in the benchmark model. The effect of omitting the aluminum support plates is small (+ 0.0006). Additionally, the neutron source and thermocouple wells were omitted (replaced by polyethylene) and the effect of omission is negligible (< 0.0001).

The density of the HEU foils of 17.226 g/cm^3 is the average density of the foils listed in Table 6 and was derived from the masses in Table 6 and the linear dimensions.

The density of the Rhenium foils of 17.691 g/cm^3 is the average density of the foils listed in Table 13 and was derived from the masses in Table 13 and the linear dimensions.

The average density for the polyethylene plates was 0.962 g/cm^3. In addition, an average density was calculated for the reflector, upper moderating, and lower moderating plates. The average density for the reflector plates was 0.967 g/cm^3. The average density for the upper moderating plates was 0.961 g/cm^3.

Finally, the average density for the lower moderating plates was 0.956 g/cm^3. The average density for the polyethylene lamination was 1.037 g/cm^3. The average density for the polyethylene inserts was 0.960 g/cm^3.

Note that the densities are only presented to 3 significant figures, but all atom number densities were calculated from measured masses and nominal volumes with 6 significant figures on the density.

Since the impurities for the HEU foils are not well known, they are not included. Also, the impurity elements for the Rhenium foils, tape securing the Rhenium foils, polyethylene inserts, laminating sheets for the HEU foils, and polyethylene plates are not included in the simplified model. Calculations described in Section 2.5 show that estimated impurities in the lamination material, the polyethylene plates and inserts all have a small effect in the k_{eff} of the system (~-0.25% in k_{eff}). This effect is included as a bias in the benchmark model k_{eff} of the simplified model.

3.1.2 Detailed Model

The detailed model is similar to the simple model except that all the components (polyethylene plates, HEU foils, Rhenium foils, laminating sheets for the HEU foils, and polyethylene inserts) are modeled individually. The dimensions of the fuel, Rhenium foils, laminating sheets, polyethylene plates, and polyethylene inserts for the detailed model were derived from the original drawings and are the same as the simplified model. The masses and linear dimensions of each part were given in Section 1. Special attention was placed on the modeling of the polyethylene plate and its corresponding recesses. The individual densities for each HEU foil, Rhenium foil, polyethylene plate, lamination, and polyethylene insert were used rather than an average density. Impurities in the lamination and polyethylene plates and inserts were not included in the detailed model because most of the impurities are below the detectable level as seen in Table 18 and their effect in the k_{eff} of the system is small. Thus, this effect is also included as a bias in the benchmark k_{eff} of the detailed model.

3.2 Dimensions

3.2.1 Simplified Model

The simplified benchmark model consists of repeating layers of a polyethylene plate, polyethylene inserts, laminated HEU foils, and Rhenium foils. The average density for each material is used. The entire experimental arrangement is made up of 10 repeating layers of the materials and 10 ½ units of HEU foils. All the moderating plates and the upper reflector plate at the bottom of the assembly have four HEU foils per unit with the exception of the top moderating plate which only contains 2 HEU foils placed diagonally from one another. A schematic of a laminated HEU foil for a HEU unit (4 foils per layer) is shown in Figure 19. This uniform sheet of lamination was 47.752 cm in length and width. A schematic of the laminated HEU foils for the top HEU layer (2 foils placed diagonally) is shown in Figure 20. A schematic of a Rhenium foil is shown in Figure 21. This uniform sheet of foil was 20.32 × 10.16 cm in length and width, respectively. Reflector plate ID# 4 was modeled with a small recess as illustrated in Figure 22. The small recess in this plate was used to accommodate the first layer of HEU foils. The remaining reflector plates had the same outer dimensions as Reflector plate ID# 4 without the recess. A schematic of a polyethylene moderator plate (small) is shown in Figure 23. The wider polyethylene moderator plate used for the top part of the assembly is shown in Figure 24. Schematics of a polyethylene insert are shown in Figure 25. A schematic of the simplified benchmark is shown in Figure 26. The dimensions in Figure 26 correspond to the location of the top of each moderating plate from the bottom of the assembly. An enlarged schematic of a single unit cell (cross-sectional view) is shown in Figure 27.

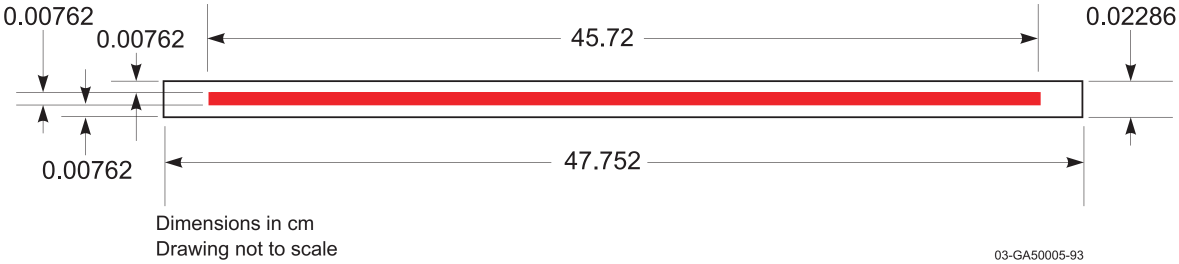
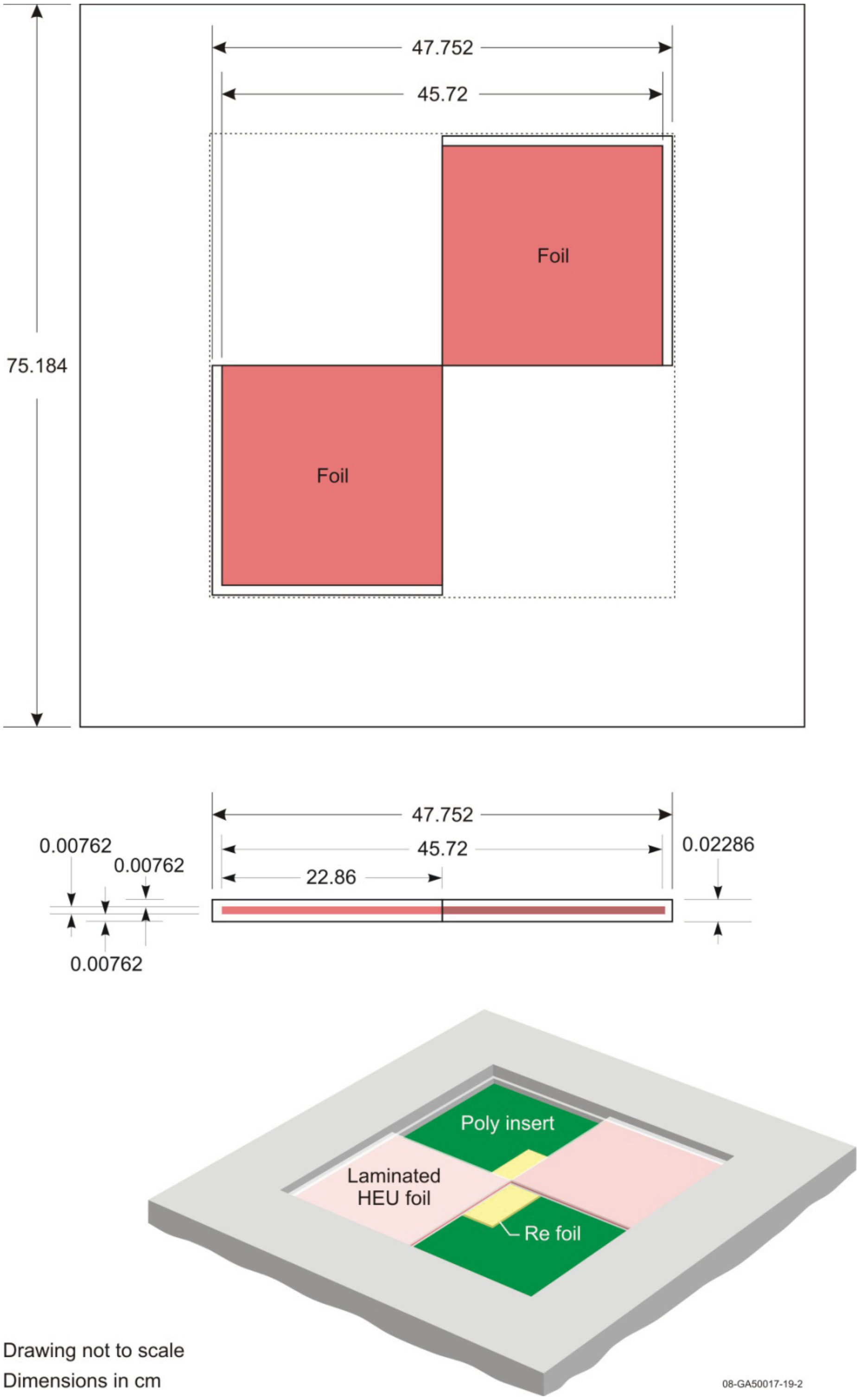


Figure 19. Schematic of Model Representing 4 Laminated HEU Foils for Simple Model.



Drawing not to scale
Dimensions in cm

Figure 20. Schematic of Model Representing 2 Laminated HEU Foils for Top Fuel Layer of Simple Model.

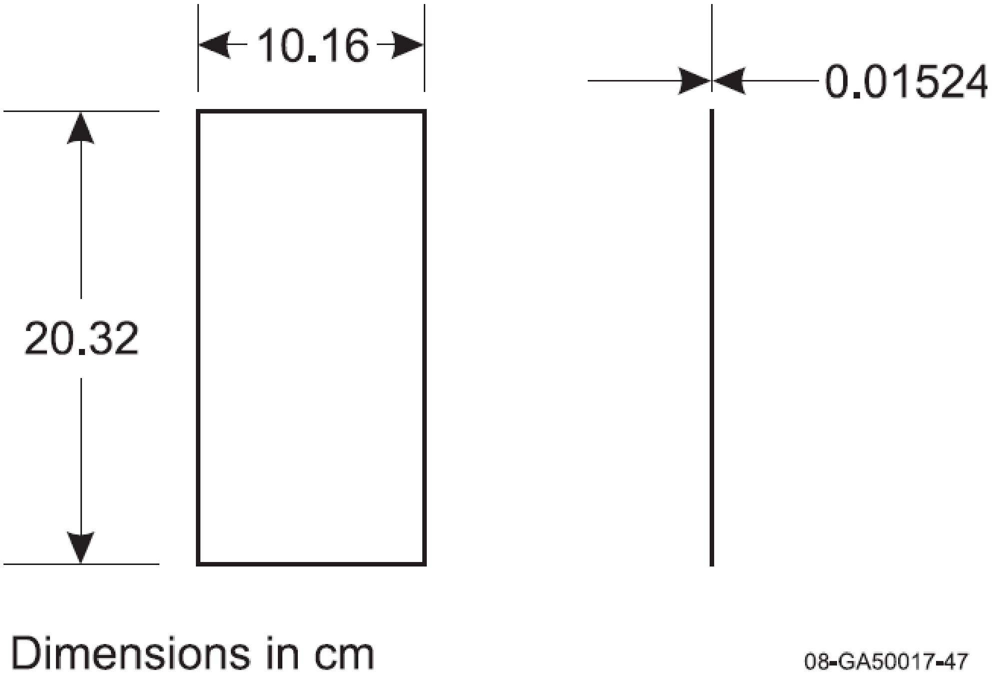


Figure 21. Schematic of Model Representing Rhenium Foils for Simple Model.

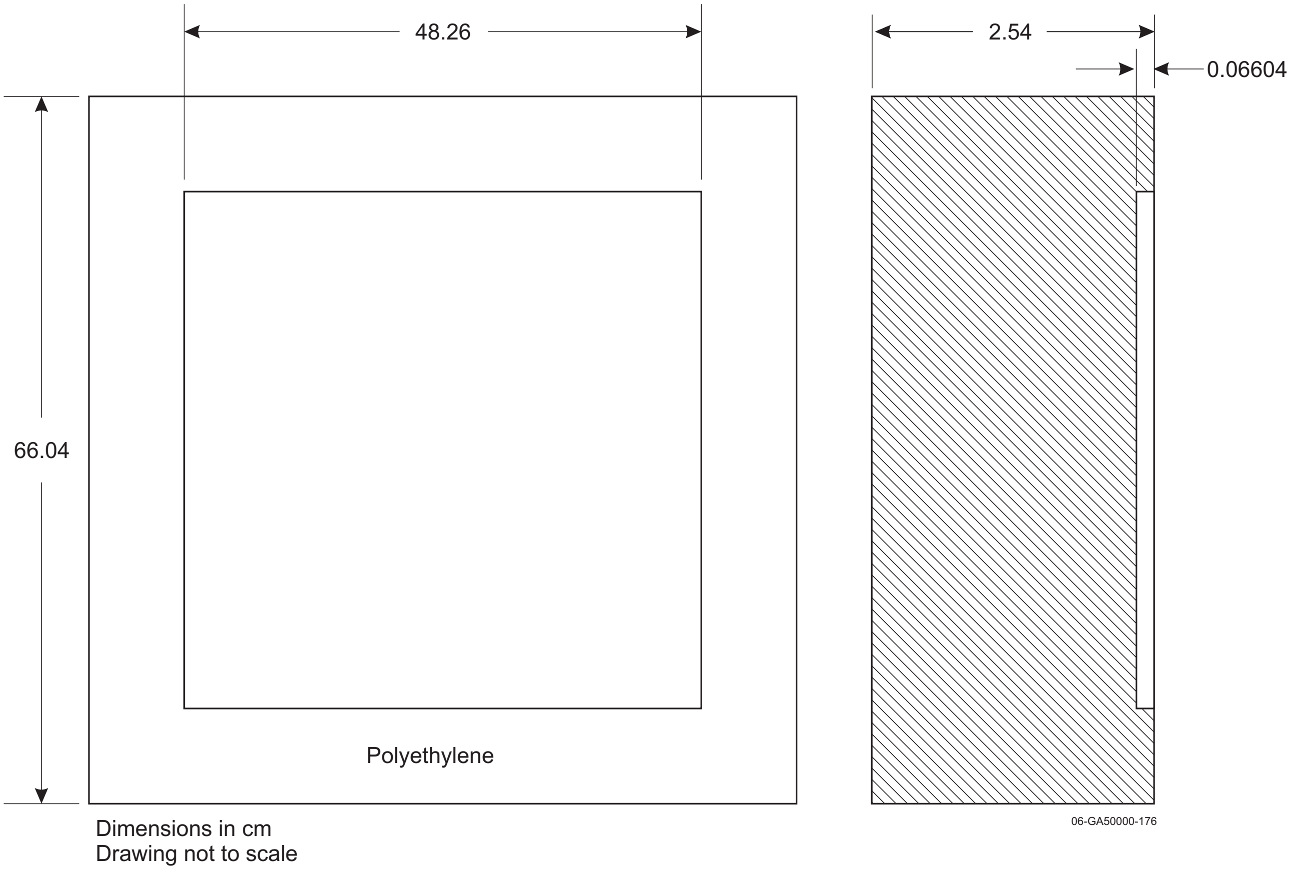


Figure 22. Schematic of Reflector Plate Poly 4.

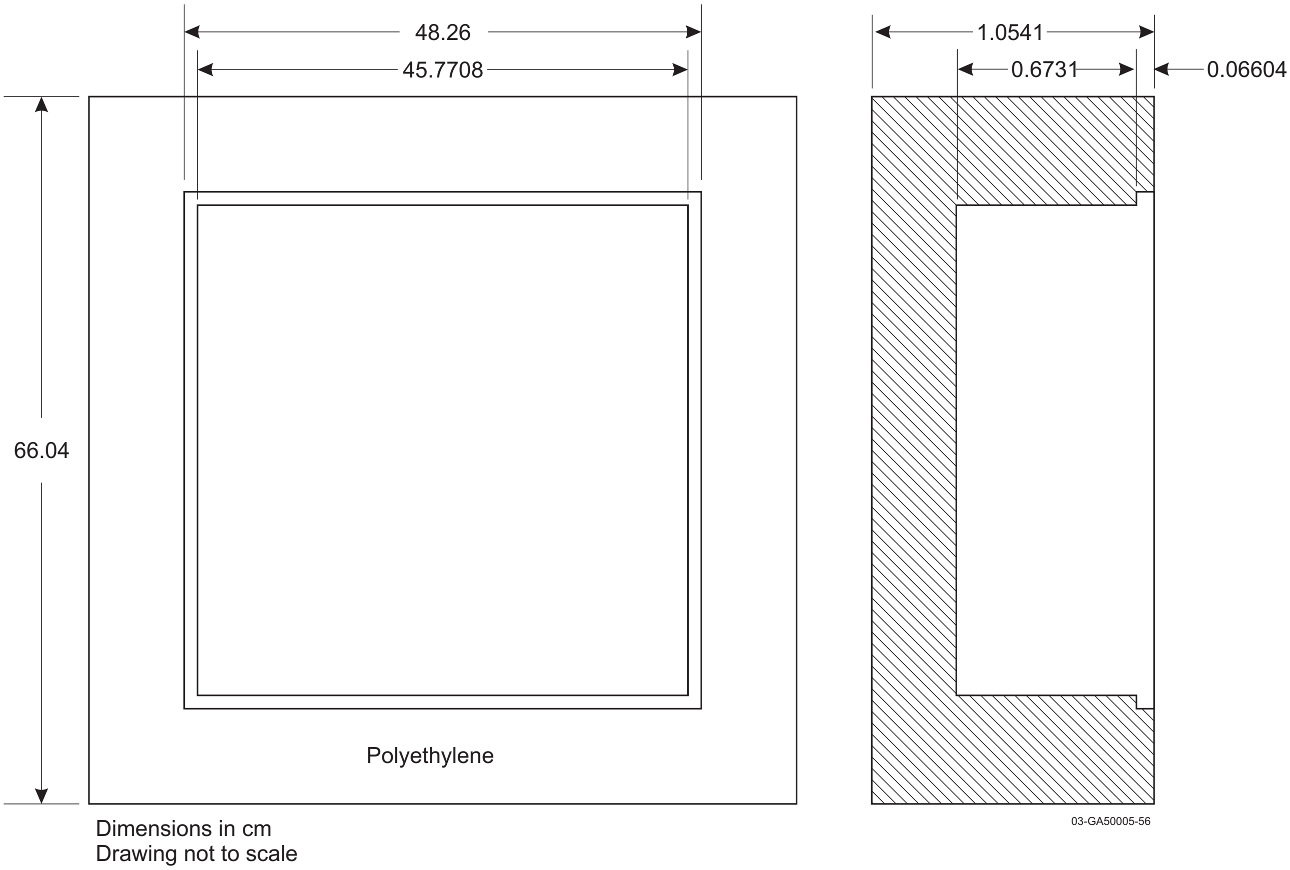


Figure 23. Schematic of the Small Moderating Plate.

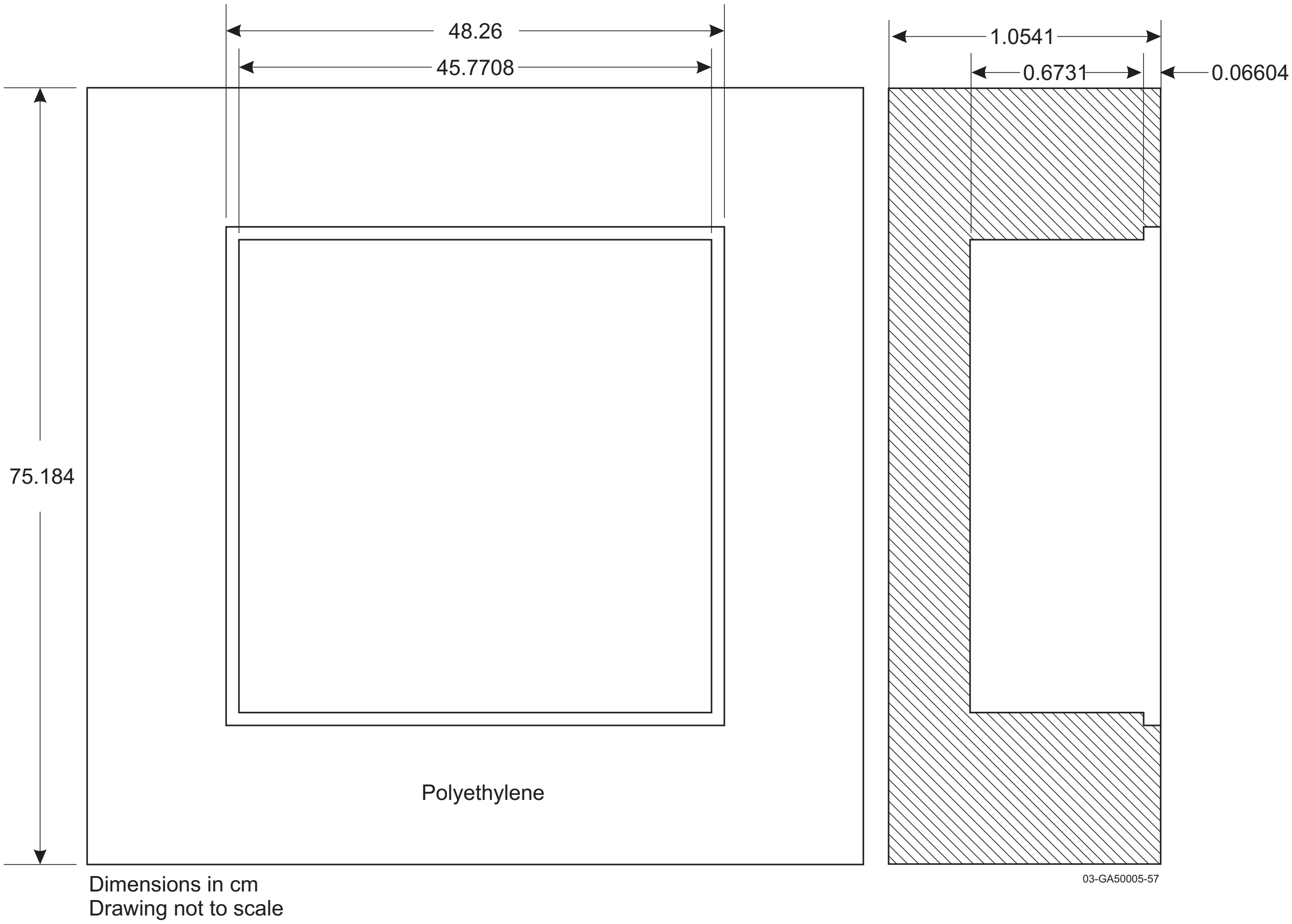


Figure 24. Schematic of the Wider Moderating Plate.

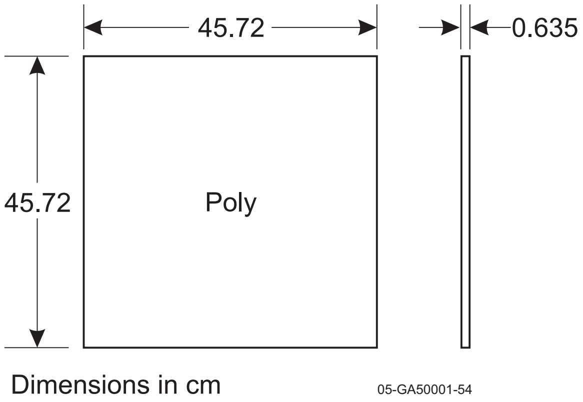


Figure 25. Schematic of the Polyethylene Insert.

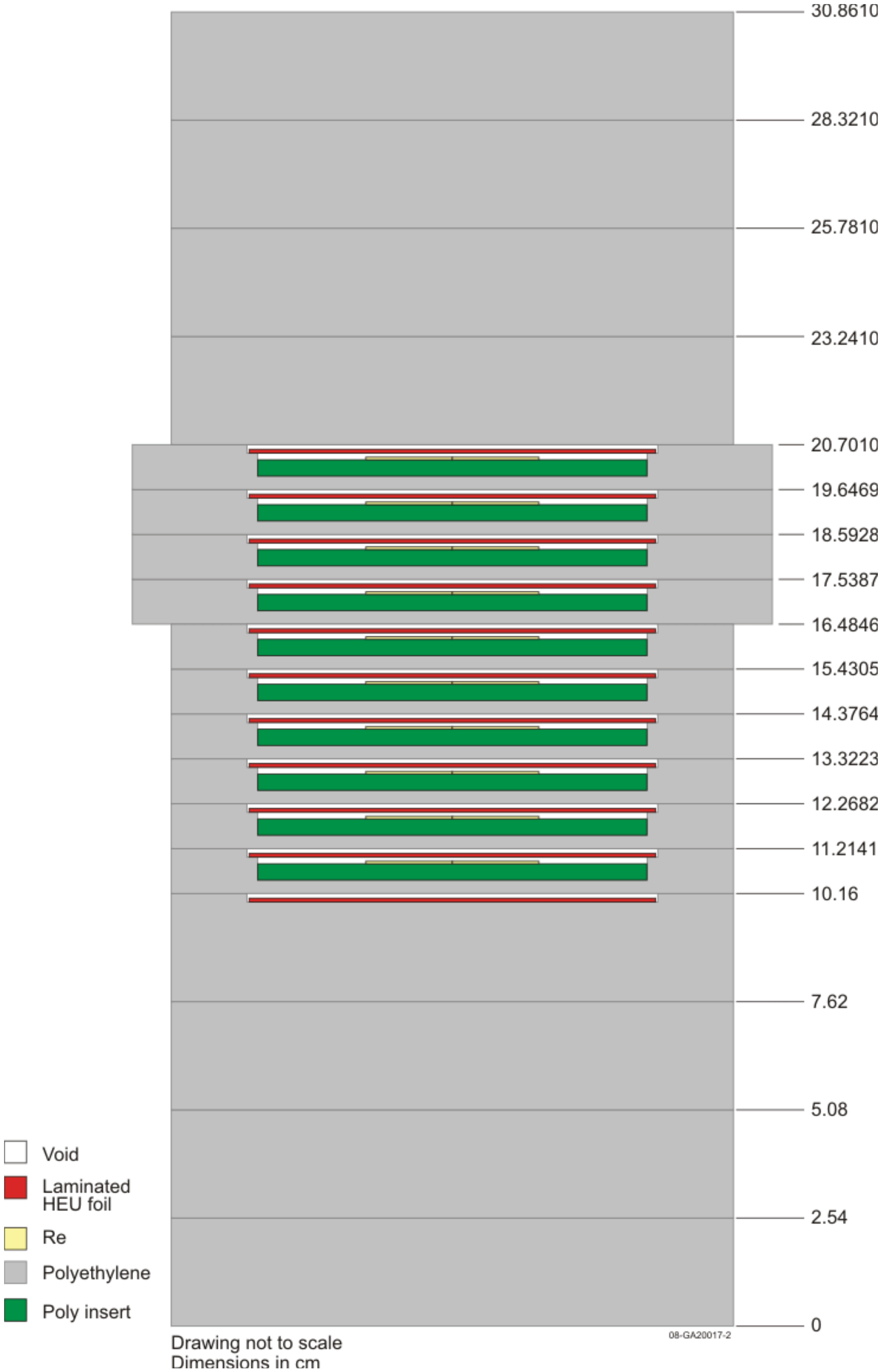


Figure 26. Schematic of the Simple Benchmark Model.

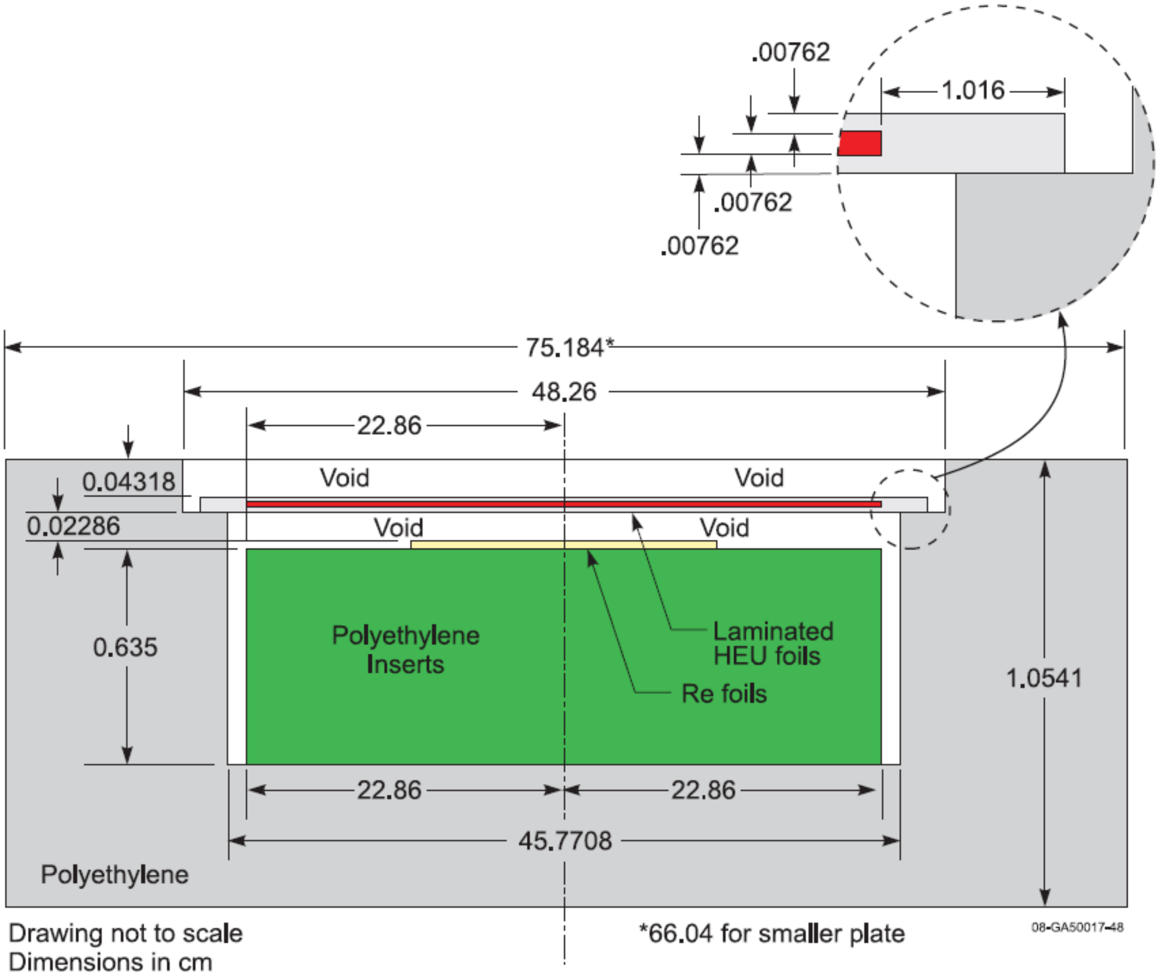


Figure 27. Schematic of a Single Unit for the Configuration with the Polyethylene Inserts, Rhenium foils, and HEU Laminated Foils for Both Simple and Detailed Models (cross-sectional view).

3.2.2 Detailed Model

Each moderating plate has two recesses as shown in Figure 27. The first recess is for the polyethylene inserts and Rhenium foils and has a depth of 0.6731 cm. The second recess is for the laminated foils (see Figure 26) and has a depth of 0.06604 cm. The thickness of a laminated foil is 0.02286 cm, thus leaving a small gap between the top of the laminated foil and the bottom of the polyethylene plate of 0.04318 cm. The width of each HEU foil is 22.86 cm, and the width of each laminated foil is 23.876 cm. A cross-section of a set of HEU foils laminated with polyethylene for the detailed model is shown in Figure 28.

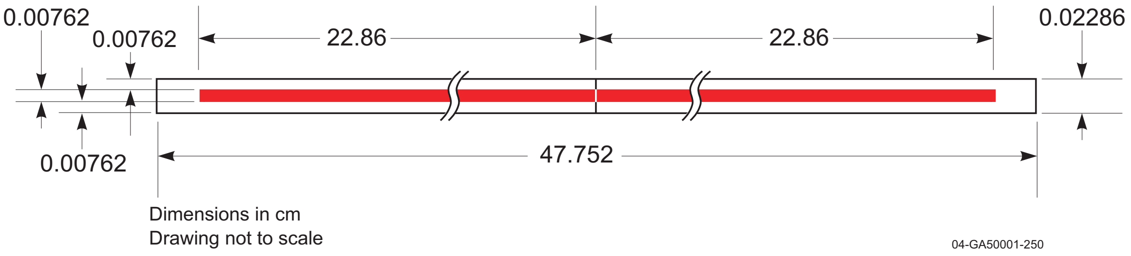


Figure 28. Schematic of HEU Foils and Lamination for the Detailed Model.

The individual density for each polyethylene plate, HEU foil, Rhenium foil, polyethylene insert, and laminating sheet is used. A schematic of the detailed model is shown in Figure 29. Figure 29.a shows a vertical slice through the stack, which consists mostly of the lower portion of the stack. Figure 29.b shows a vertical slice through the stack, which consists mostly of the upper portion of the stack. Polyethylene inserts and HEU foils in each layer are listed in circular order, always beginning with the same corner.

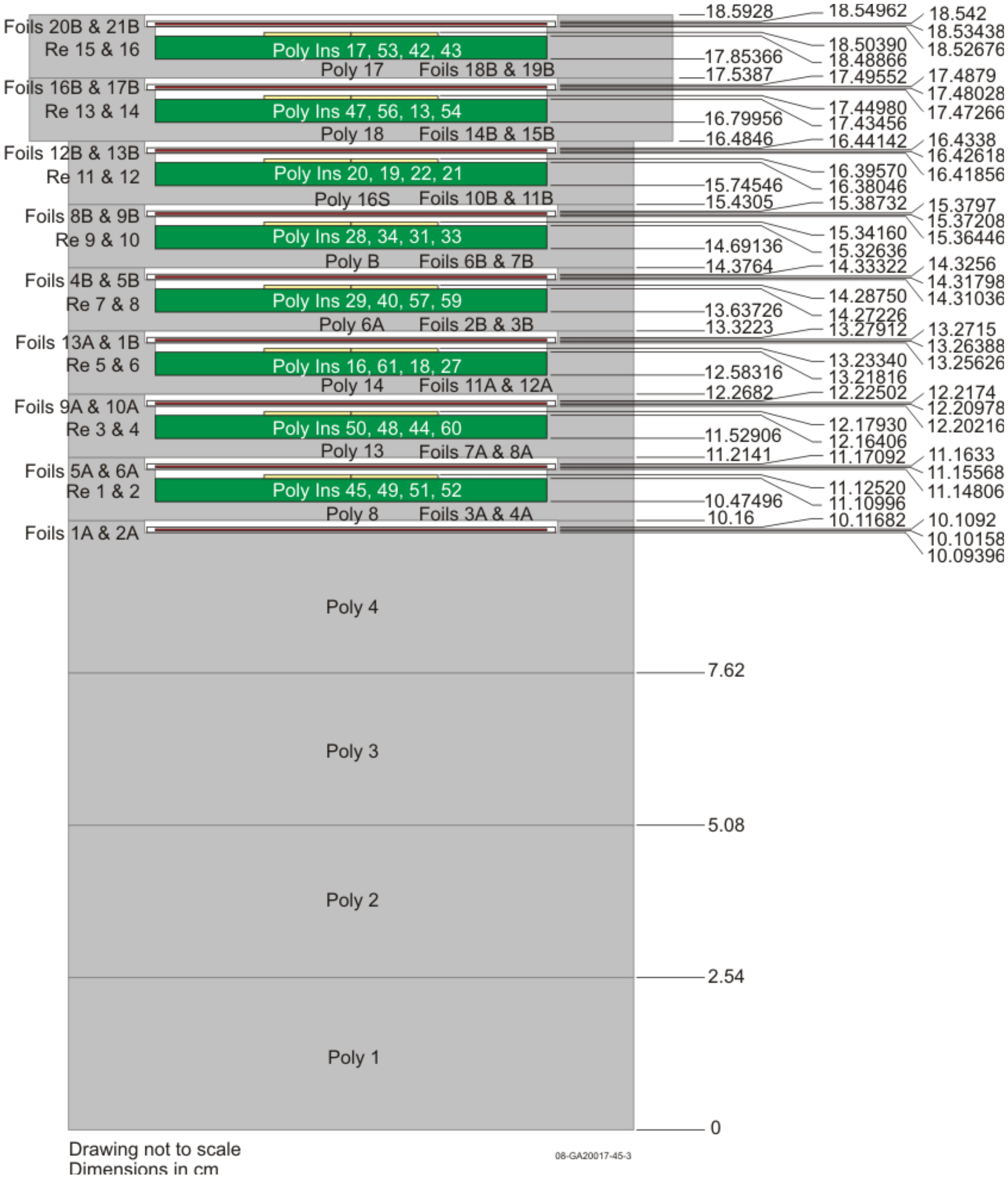


Figure 29.a. Cross-sectional View of Detailed Model (mostly lower portion of assembly).

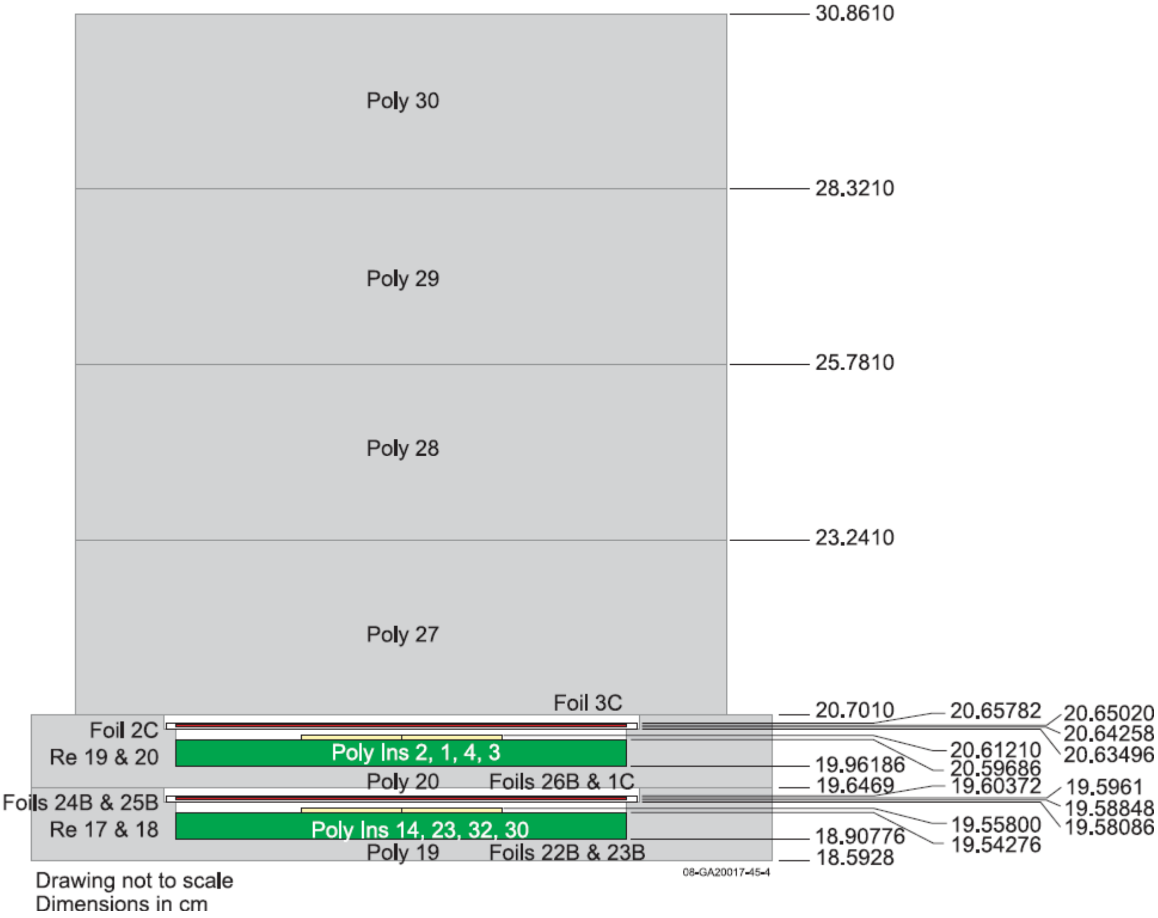


Figure 29.b. Cross-sectional View of Detailed Model (mostly upper portion of assembly).

3.3 Material Data

3.3.1 Simplified Model

The atomic densities for the individual uranium isotopes were calculated by

$$N_i = \frac{w_{fi}\rho_{av}N_A}{A_{wi}} \text{ (i corresponds to } ^{234}U, ^{235}U, ^{236}U, \text{and } ^{238}U) \qquad (3)$$

where N_i is the atom density of isotope i, w_{fi} is the weight fraction of isotope I,[a] ρ_{av} is the average uranium metal density, A_{wi} is the atomic mass of the isotope, and N_A is Avogadro's number. The atom densities for the HEU fuel are given in Table 19 with an enrichment of 93.2321 wt.% in ^{235}U and an average density of 17.226 g/cm^3.

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[a] 16th Edition, Nuclides and Isotopes: Chart of the Nuclides.

Table 19. Isotopic Composition for HEU Foils (simplified model).

Isotope	**Atomic Density [atom/barn-cm]**
^{234}U	5.0259E-04
^{235}U	4.1148E-02
^{236}U	1.1343E-04
^{238}U	2.3427E-03
^{Total}U	4.4107E-02

The average density for the Rhenium foils is 17.691 g/cm^3. The corresponding atom densities for the Rhenium foils at 99.9 wt.% is Re-185 at 2.1287 × 10^{-2} atoms/barn-cm and Re-187 at 3.5248 × 10^{-2} atoms/barn-cm for a total of 5.6535 × 10^{-2} atoms/barn-cm.

The average density for the polyethylene plates is 0.962 g/cm^3. In addition, an average density was calculated for the reflector, upper moderating, and lower moderating plates. The average density for the reflector plates was 0.967 g/cm^3. The average density for the upper moderating plates was 0.961 g/cm^3. Finally, the average density for the lower moderating plates was 0.956 g/cm^3. The densities were obtained by dividing the total mass of all components by the total volume of all components. The corresponding atom densities for the polyethylene plates are presented in Table 20. Table 20 also shows the number densities for the polyethylene lamination and inserts. The densities for the lamination and inserts in Table 20 are 1.037 g/cm^3 and 0.960 g/cm^3, respectively.

Note that the densities are only presented to 3 significant figures, but all atom number densities were calculated from measured masses and nominal volumes with 6 significant figures on the density.

Table 20. Number Densities for Simplified Model.

Element	Atomic Density [atom/barn-cm]
Rhenium Foils[(a)]	
Re-185	2.1522×10^{-2} (b)
Re-187	3.5637×10^{-2} (b)
Polyethylene Small Moderating Plates	
C	4.1022×10^{-2} (b)
H	8.2045×10^{-2} (b)
Polyethylene Large Moderating Plates	
C	4.1258×10^{-2} (b)
H	8.2517×10^{-2} (b)
Polyethylene Reflector Plates	
C	4.1521×10^{-2} (b)
H	8.3043×10^{-2} (b)
Polyethylene Lamination	
C	4.4521×10^{-2} (b)
H	8.9043×10^{-2} (b)
Polyethylene Inserts	
C	4.1216×10^{-2} (b)
H	8.2431×10^{-2} (b)

(a) 16th Edition, Chart of the Nuclides.
(b) atom number densities were calculated from measured masses and nominal volumes with 6 significant figures on the density.

3.3.2 Detailed Model

In the detailed model, individual densities were used for each component, with the exception of Rhenium foils 1-9. Rhenium foils numbered 1-20 were used in the experiment; however, foils 1-9 were permanently shipped for chemical analysis and the masses of these foils are unknown. Therefore, for Rhenium foils 1-9, the average foil density of 17.691 g/cm^3 is used with the remaining foils 10-25 using the individual densities listed in Table 13. The polyethylene impurity content for the plates, inserts, and lamination were not included in the detailed model.

The number densities for each of the HEU foils and lamination are presented in Table 21. The atomic densities for each of the Rhenium foils are presented in Table 22. The atomic densities for the polyethylene plates are shown in Table 23, and the atomic densities for the polyethylene inserts are shown in Table 24.

Table 21. HEU Foil Atomic Densities [atom/barn-cm] (Detailed model).

	Lamination[(a)]		**HEU Foils**[(a)]			
ID	**C**	**H**	**^{234}U**	**^{235}U**	**^{236}U**	**^{238}U**
1A	4.4092E-02	8.8184E-02	5.0557E-04	4.1392E-02	1.1410E-04	2.3566E-03
2A	4.4092E-02	8.8184E-02	5.2240E-04	4.2770E-02	1.1790E-04	2.4350E-03
3A	4.4521E-02	8.9043E-02	5.2313E-04	4.2830E-02	1.1806E-04	2.4384E-03
4A	4.3233E-02	8.6467E-02	5.0849E-04	4.1631E-02	1.1476E-04	2.3702E-03
5A	4.4994E-02	8.9987E-02	5.1876E-04	4.2471E-02	1.1708E-04	2.4180E-03
6A	4.4994E-02	8.9987E-02	5.1435E-04	4.2111E-02	1.1608E-04	2.3975E-03
7A	4.1902E-02	8.3805E-02	5.1730E-04	4.2352E-02	1.1675E-04	2.4112E-03
8A	4.4994E-02	8.9987E-02	5.2094E-04	4.2651E-02	1.1757E-04	2.4282E-03
9A	4.4521E-02	8.9043E-02	5.2240E-04	4.2770E-02	1.1790E-04	2.4350E-03
10A	4.4994E-02	8.9987E-02	5.2608E-04	4.3071E-02	1.1873E-04	2.4522E-03
11A	4.3233E-02	8.6467E-02	5.3048E-04	4.3432E-02	1.1972E-04	2.4727E-03
12A	4.4092E-02	8.8184E-02	5.2240E-04	4.2770E-02	1.1790E-04	2.4350E-03
13A	4.3663E-02	8.7325E-02	5.1581E-04	4.2230E-02	1.1641E-04	2.4043E-03
1B	3.9284E-02	7.8567E-02	5.0557E-04	4.1392E-02	1.1410E-04	2.3566E-03
2B	4.8042E-02	9.6084E-02	4.9824E-04	4.0792E-02	1.1245E-04	2.3224E-03
3B	4.3663E-02	8.7325E-02	4.8357E-04	3.9591E-02	1.0914E-04	2.2540E-03
4B	4.3663E-02	8.7325E-02	4.6892E-04	3.8391E-02	1.0583E-04	2.1857E-03
5B	4.3663E-02	8.7325E-02	4.9089E-04	4.0190E-02	1.1079E-04	2.2882E-03
6B	4.8042E-02	9.6084E-02	4.9089E-04	4.0190E-02	1.1079E-04	2.2882E-03
7B	4.3663E-02	8.7325E-02	4.7625E-04	3.8991E-02	1.0748E-04	2.2199E-03
8B	3.9284E-02	7.8567E-02	5.0557E-04	4.1392E-02	1.1410E-04	2.3566E-03
9B	4.3663E-02	8.7325E-02	4.8357E-04	3.9591E-02	1.0914E-04	2.2540E-03
10B	4.3663E-02	8.7325E-02	4.9089E-04	4.0190E-02	1.1079E-04	2.2882E-03
11B	4.3663E-02	8.7325E-02	5.2021E-04	4.2591E-02	1.1741E-04	2.4248E-03
12B	4.8042E-02	9.6084E-02	5.1289E-04	4.1991E-02	1.1575E-04	2.3907E-03
13B	4.8042E-02	9.6084E-02	4.7625E-04	3.8991E-02	1.0748E-04	2.2199E-03
14B	4.3663E-02	8.7325E-02	4.9089E-04	4.0190E-02	1.1079E-04	2.2882E-03
15B	4.3663E-02	8.7325E-02	4.8357E-04	3.9591E-02	1.0914E-04	2.2540E-03
16B	4.3663E-02	8.7325E-02	5.0557E-04	4.1392E-02	1.1410E-04	2.3566E-03
17B	4.8042E-02	9.6084E-02	4.8357E-04	3.9591E-02	1.0914E-04	2.2540E-03
18B	4.3663E-02	8.7325E-02	4.7625E-04	3.8991E-02	1.0748E-04	2.2199E-03
19B	4.3663E-02	8.7325E-02	4.9824E-04	4.0792E-02	1.1245E-04	2.3224E-03
20B	4.8042E-02	9.6084E-02	4.9089E-04	4.0190E-02	1.1079E-04	2.2882E-03
21B	4.3663E-02	8.7325E-02	5.0557E-04	4.1392E-02	1.1410E-04	2.3566E-03
22B	4.3663E-02	8.7325E-02	5.0557E-04	4.1392E-02	1.1410E-04	2.3566E-03
23B	4.8042E-02	9.6084E-02	5.0557E-04	4.1392E-02	1.1410E-04	2.3566E-03
24B	4.8042E-02	9.6084E-02	4.9089E-04	4.0190E-02	1.1079E-04	2.2882E-03
25B	4.3663E-02	8.7325E-02	4.9089E-04	4.0190E-02	1.1079E-04	2.2882E-03
26B	4.3663E-02	8.7325E-02	4.6892E-04	3.8391E-02	1.0583E-04	2.1857E-03
1C	4.3663E-02	8.7325E-02	5.2021E-04	4.2591E-02	1.1741E-04	2.4248E-03
2C	4.3663E-02	8.7325E-02	5.2021E-04	4.2591E-02	1.1741E-04	2.4248E-03
3C	4.8042E-02	9.6084E-02	5.2021E-04	4.2591E-02	1.1741E-04	2.4248E-03

(a) These number densities are calculated from each foil mass/volume.

Table 22. Rhenium Foils Atomic Densities [atom/barn-cm] (Detailed model).

ID	Re
Re 1	5.7159E-02(a)
Re 2	5.7159E-02(a)
Re 3	5.7159E-02(a)
Re 4	5.7159E-02(a)
Re 5	5.7159E-02(a)
Re 6	5.7159E-02(a)
Re 7	5.7159E-02(a)
Re 8	5.7159E-02(a)
Re 9	5.7159E-02(a)
Re 10	5.8945E-02
Re 11	5.7094E-02
Re 12	5.5656E-02
Re 13	5.6480E-02
Re 14	5.2370E-02
Re 15	5.8328E-02
Re 16	5.5246E-02
Re 17	5.9149E-02
Re 18	5.3194E-02
Re 19	5.9559E-02
Re 20	5.5863E-02

(a) Average foil density of 17.691 g/cm3 was used.

Table 23. Polyethylene Plate Atomic Densities [atom/barn-cm]
(Detailed model - in order of stacking in model).

ID	C	H
Poly 1	4.1688E-02	8.3376E-02
Poly 2	4.1688E-02	8.3376E-02
Poly 3	4.1731E-02	8.3461E-02
Poly 4	4.1516E-02	8.3032E-02
Poly 8	4.1044E-02	8.2088E-02
Poly 13	4.1001E-02	8.2002E-02
Poly 14	4.0958E-02	8.1916E-02
Poly 6A	4.0958E-02	8.1916E-02
Poly B	4.0958E-02	8.1916E-02
Poly 16S	4.1216E-02	8.2431E-02
Poly 18	4.1130E-02	8.2259E-02
Poly 17	4.1258E-02	8.2517E-02
Poly 19	4.1344E-02	8.2689E-02
Poly 20	4.1301E-02	8.2603E-02
Poly 27	4.1344E-02	8.2689E-02
Poly 28	4.1516E-02	8.3032E-02
Poly 29	4.1344E-02	8.2689E-02
Poly 30	4.1344E-02	8.2689E-02

Table 24. Polyethylene Inserts Atomic Densities [atom/barn-cm] (Detailed model).

ID	C	H
Poly 45	4.1344E-02	8.2689E-02
Poly 49	4.1473E-02	8.2946E-02
Poly 51	4.1516E-02	8.3032E-02
Poly 52	4.1645E-02	8.3290E-02
Poly 50	4.1516E-02	8.3032E-02
Poly 48	4.1473E-02	8.2946E-02
Poly 44	4.1344E-02	8.2689E-02
Poly 60	4.1516E-02	8.3032E-02
Poly 16	4.1516E-02	8.3032E-02
Poly 61	4.1516E-02	8.3032E-02
Poly 18	4.0829E-02	8.1658E-02
Poly 27	4.1731E-02	8.3461E-02
Poly 29	4.1344E-02	8.2689E-02
Poly 40	4.1430E-02	8.2860E-02
Poly 57	4.1173E-02	8.2345E-02
Poly 59	4.1173E-02	8.2345E-02
Poly 28	4.1645E-02	8.3290E-02
Poly 34	4.1559E-02	8.3118E-02
Poly 31	4.1688E-02	8.3376E-02
Poly 33	4.1430E-02	8.2860E-02
Poly 20	4.0829E-02	8.1658E-02
Poly 19	4.1216E-02	8.2431E-02
Poly 22	4.1087E-02	8.2173E-02
Poly 21	4.0529E-02	8.1057E-02
Poly 47	4.1602E-02	8.3204E-02
Poly 56	4.1087E-02	8.2173E-02
Poly 13	4.0700E-02	8.1401E-02
Poly 54	4.1387E-02	8.2774E-02
Poly 17	4.0872E-02	8.1744E-02
Poly 53	4.1258E-02	8.2517E-02
Poly 42	4.1387E-02	8.2774E-02
Poly 43	4.1430E-02	8.2860E-02
Poly 14	4.0829E-02	8.1658E-02
Poly 23	4.0614E-02	8.1229E-02
Poly 32	4.1087E-02	8.2173E-02
Poly 30	4.1387E-02	8.2774E-02
Poly 2	4.0700E-02	8.1401E-02
Poly 1	4.0614E-02	8.1229E-02
Poly 4	4.1001E-02	8.2002E-02
Poly 3	4.0657E-02	8.1315E-02

3.4 Temperature Data

The temperature in this experiment was reported to be 18.0 °C.

3.5 Experimental and Benchmark-Model k_{eff}

For this experiment, delayed critical was not achieved (M=150). The 1/M curve showed that delayed critical would occur at approximately 10.72 units when the stack was fully closed. Using the equation $k_{eff} = (10.5/10.72)^\wedge(1/3)$ gives a k_{eff} of 0.99311 for this system. Therefore, the experimental k_{eff} for this configuration was 0.9931.

The uncertainty in the benchmark-model k_{eff} for the assembly is ± 0.0018. This uncertainty was derived from calculations found in Section 2. The effect of room-return neutrons was negligible.

The bias associated with this experiment is due to the omission of the impurity elements from polyethylene plates/inserts, lamination used for the HEU foils, the Rhenium foils, and the omission of the tape securing the Rhenium foils (+0.0017) and the omission of the aluminum support plates and walls (-0.0009) in the simplified and detailed models.

The k_{eff} for the simple benchmark model for this experiment is 0.9939 ± 0.0018 (1σ). For the detailed benchmark model, k_{eff} is also 0.9939 ± 0.0018 (1σ).

It is important to note that there is large difference between the calculated and the benchmark k_{eff}. The reason for this discrepancy remains unknown. A computational analysis showed that the thermal scattering data for H in Polyethylene is very important in this experiment.

4.0 RESULTS OF SAMPLE CALCULATIONS

Table 25 summarizes the k_{eff} computed with different combinations of cross sections. The MCNP calculations used the ENDF/B-V and ENDF/B-VI cross-section libraries. In the code utilizing the ENDF/B-VI library, the elements H used release 6, C used release 6, ^{235}U and ^{238}U used release 5, and ^{234}U and ^{236}U used release 0. In Appendix A, a more detailed discussion of the calculations, including input listings, is presented.

Table 25. Sample Calculation Results (United States).

Cross Section Library → Model ↓	**MCNP ENDF/B-V**	**MCNP ENDF/B-VI.5[(a)]**	**MCNP ENDF/B-VII.0[(b)]**	**MCNP JEFF-3.1**	**MCNP JENDL-3.3[(c)]**
Simplified	1.0035±0.0003	1.0036±0.0003	1.0032±0.0003	1.0048±0.0003	1.0030±0.0003
Detailed	1.0041±0.0003	1.0047±0.0003	1.0041±0.0003	1.0049±0.0003	1.0041±0.0003

(a) According to the MCNP5 manual, Appendix G, the cross section data .66c for 235U and 238U was evaluated from B-VI.5.
(b) ENDF/B-VII.0, JEFF-3.1, and JENDL-3.3 results provided by John D. Bess at the Idaho National Laboratory.
(c) ENDF/B-VII.0 thermal scattering treatment used for polyethylene.

It is important to note that there is large difference between the calculated and the benchmark k_{eff}. The reason for this discrepancy remains unknown. A computational analysis showed that the thermal scattering data for H in Polyethylene is very important in this experiment.

5.0 REFERENCES

There are no published references.

APPENDIX A: TYPICAL INPUT LISTINGS

A.1 MCNP Input Listing

Version 5 of the MCNP code with the continuous energy .66c cross-sections (i.e., ENDF/B-VI.5) was used to create the HEU-Re-polyethylene models. The thermal scattering law data (poly.60t) was used for the hydrogen in the polyethylene.

The MCNP calculations had 6,000,000 active histories. A total of 5,000 histories per generation were used and 1,250 generations of neutrons. The first 50 generations were skipped to obtain a well-distributed neutron source. The input files for the simplified and detailed models are listed below.

```
MCNP ENDF/B-VI.5 INPUT LISTING, SIMPLE MODEL, TABLE 25.

HEU/Re moderated/reflected by polyethylene - simple model
C hmt33001 - base case
C Cell Cards
1   1 0.124564 1 -2 3 -4 100 -101 $Reflector 1
2   1 0.124564 1 -2 3 -4 101 -102 $Reflector 2
3   1 0.124564 1 -2 3 -4 102 -103 $Reflector 3
4   1 0.124564 (1 -2 3 -4 103 -104):(1 -26 3 -4 104 -108):&
               (27 -2 3 -4 104 -108):(3 -28 1 -2 104 -108):&
               (29 -4 1 -2 104 -108) $Reflector 4
5   5 0.044107 10 12 -30 -31 105 -106 $Foil 1A
6   4 0.133586 22 24 -30 -31 104 -107 #5 $Lamination 1A
7   5 0.044107 10 -13 -30 31 105 -106 $Foil 2A
8   4 0.133586 22 -25 -30 31 104 -107 #7 $Lamination 2A
9   5 0.044107 -11 -13 30 31 105 -106 $Foil 3A
10  4 0.133586 -23 -25 30 31 104 -107 #9 $Lamination 3A
11  5 0.044107 -11 12 30 -31 105 -106 $Foil 4A
12  4 0.133586 -23 24 30 -31 104 -107 #11 $Lamination 4A
13  0          (26 -27 28 -29 107 -108):(26 -22 28 -29 104 -108):&
               (23 -27 28 -29 104 -108):(28 -24 26 -27 104 -108):&
               (25 -29 26 -27 104 -108) $Void
14  6 0.123067 (1 -2 3 -4 108 -109):(1 -18 3 -4 109 -112):&
               (19 -2 3 -4 109 -112):(3 -20 1 -2 109 -112):&
               (21 -4 1 -2 109 -112):(1 -26 3 -4 112 -116):&
               (27 -2 3 -4 112 -116):(3 -28 1 -2 112 -116):&
               (29 -4 1 -2 112 -116) $Poly 8
15  2 0.123685 10 12 -30 -31 109 -110 $Insert 45
16  2 0.123685 10 -13 -30 31 109 -110 $Insert 49
17  2 0.123685 -11 -13 30 31 109 -110 $Insert 51
18  2 0.123685 -11 12 30 -31 109 -110 $Insert 52
19  3 0.057159 14 -15 16 -31 110 -111 $Re 1
20  3 0.057159 14 -15 31 -17 110 -111 $Re 2
21  0          (18 -10 20 -21 109 -110):(11 -19 20 -21 109 -110):&
               (20 -12 18 -19 109 -110):(13 -21 18 -19 109 -111):&
               (18 -19 20 -21 110 -112 #19 #20) $Void 1
22  5 0.044107 10 12 -30 -31 113 -114 $Foil 5A
23  4 0.133586 22 24 -30 -31 112 -115 #22 $Lamination 5A
24  5 0.044107 10 -13 -30 31 113 -114 $Foil 6A
25  4 0.133586 22 -25 -30 31 112 -115 #24 $Lamination 6A
26  5 0.044107 -11 -13 30 31 113 -114 $Foil 7A
27  4 0.133586 -23 -25 30 31 112 -115 #26 $Lamination 7A
28  5 0.044107 -11 12 30 -31 113 -114 $Foil 8A
29  4 0.133586 -23 24 30 -31 112 -115 #28 $Lamination 8A
30  0          (26 -27 28 -29 115 -116):(26 -22 28 -29 112 -116):&
               (23 -27 28 -29 112 -116):(28 -24 26 -27 112 -116):&
               (25 -29 26 -27 112 -116) $Void 2
31  6 0.123067 (1 -2 3 -4 116 -117):(1 -18 3 -4 117 -120):&
               (19 -2 3 -4 117 -120):(3 -20 1 -2 117 -120):&
               (21 -4 1 -2 117 -120):(1 -26 3 -4 120 -124):&
               (27 -2 3 -4 120 -124):(3 -28 1 -2 120 -124):&
               (29 -4 1 -2 120 -124) $Poly 13
32  2 0.123685 10 12 -30 -31 117 -118 $Insert 50
```

```
33  2 0.123685 10 -13 -30 31 117 -118 $Insert 48
34  2 0.123685 -11 -13 30 31 117 -118 $Insert 44
35  2 0.123685 -11 12 30 -31 117 -118 $Insert 60
36  3 0.057159 14 -15 16 -31 118 -119 $Re 3
37  3 0.057159 14 -15 31 -17 118 -119 $Re 4
38  0          (18 -10 20 -21 117 -118):(11 -19 20 -21 117 -118):&
               (20 -12 18 -19 117 -118):(13 -21 18 -19 117 -118):&
               (18 -19 20 -21 118 -120 #36 #37) $Void 1
39  5 0.044107 10 12 -30 -31 121 -122 $Foil 9A
40  4 0.133586 22 24 -30 -31 120 -123 #39 $Lamination 9A
41  5 0.044107 10 -13 -30 31 121 -122 $Foil 10A
42  4 0.133586 22 -25 -30 31 120 -123 #41 $Lamination 10A
43  5 0.044107 -11 -13 30 31 121 -122 $Foil 11A
44  4 0.133586 -23 -25 30 31 120 -123 #43 $Lamination 11A
45  5 0.044107 -11 12 30 -31 121 -122 $Foil 12A
46  4 0.133586 -23 24 30 -31 120 -123 #45 $Lamination 12A
47  0          (26 -27 28 -29 123 -124):(26 -22 28 -29 120 -124):&
               (23 -27 28 -29 120 -124):(28 -24 26 -27 120 -124):&
               (25 -29 26 -27 120 -124) $Void 2
48  6 0.123067 (1 -2 3 -4 124 -125):(1 -18 3 -4 125 -128):&
               (19 -2 3 -4 125 -128):(3 -20 1 -2 125 -128):&
               (21 -4 1 -2 125 -128):(1 -26 3 -4 128 -132):&
               (27 -2 3 -4 128 -132):(3 -28 1 -2 128 -132):&
               (29 -4 1 -2 128 -132) $Poly 14
49  2 0.123685 10 12 -30 -31 125 -126 $Insert 16
50  2 0.123685 10 -13 -30 31 125 -126 $Insert 61
51  2 0.123685 -11 -13 30 31 125 -126 $Insert 18
52  2 0.123685 -11 12 30 -31 125 -126 $Insert 27
53  3 0.057159 14 -15 16 -31 126 -127 $Re 5
54  3 0.057159 14 -15 31 -17 126 -127 $Re 6
55  0          (18 -10 20 -21 125 -126):(11 -19 20 -21 125 -126):&
               (20 -12 18 -19 125 -126):(13 -21 18 -19 125 -126):&
               (18 -19 20 -21 126 -128 #53 #54) $Void 1
56  5 0.044107 10 12 -30 -31 129 -130 $Foil 13A
57  4 0.133586 22 24 -30 -31 128 -131 #56 $Lamination 13A
58  5 0.044107 10 -13 -30 31 129 -130 $Foil 1B
59  4 0.133586 22 -25 -30 31 128 -131 #58 $Lamination 1B
60  5 0.044107 -11 -13 30 31 129 -130 $Foil 2B
61  4 0.133586 -23 -25 30 31 128 -131 #60 $Lamination 2B
62  5 0.044107 -11 12 30 -31 129 -130 $Foil 3B
63  4 0.133586 -23 24 30 -31 128 -131 #62 $Lamination 3B
64  0          (26 -27 28 -29 131 -132):(26 -22 28 -29 128 -132):&
               (23 -27 28 -29 128 -132):(28 -24 26 -27 128 -132):&
               (25 -29 26 -27 128 -132) $Void 2
65  6 0.123067 (1 -2 3 -4 132 -133):(1 -18 3 -4 133 -136):&
               (19 -2 3 -4 133 -136):(3 -20 1 -2 133 -136):&
               (21 -4 1 -2 133 -136):(1 -26 3 -4 136 -140):&
               (27 -2 3 -4 136 -140):(3 -28 1 -2 136 -140):&
               (29 -4 1 -2 136 -140) $Poly 6A
66  2 0.123685 10 12 -30 -31 133 -134 $Insert 29
67  2 0.123685 10 -13 -30 31 133 -134 $Insert 40
68  2 0.123685 -11 -13 30 31 133 -134 $Insert 57
69  2 0.123685 -11 12 30 -31 133 -134 $Insert 59
70  3 0.057159 14 -15 16 -31 134 -135 $Re 7
71  3 0.057159 14 -15 31 -17 134 -135 $Re 8
72  0          (18 -10 20 -21 133 -134):(11 -19 20 -21 133 -134):&
               (20 -12 18 -19 133 -134):(13 -21 22 -23 133 -134):&
               (18 -19 20 -21 134 -136 #70 #71) $Void 1
73  5 0.044107 10 12 -30 -31 137 -138 $Foil 4B
74  4 0.133586 22 24 -30 -31 136 -139 #73 $Lamination 4B
75  5 0.044107 10 -13 -30 31 137 -138 $Foil 5B
76  4 0.133586 22 -25 -30 31 136 -139 #75 $Lamination 5B
77  5 0.044107 -11 -13 30 31 137 -138 $Foil 6B
78  4 0.133586 -23 -25 30 31 136 -139 #77 $Lamination 6B
79  5 0.044107 -11 12 30 -31 137 -138 $Foil 7B
80  4 0.133586 -23 24 30 -31 136 -139 #79 $Lamination 7B
81  0          (26 -27 28 -29 139 -140):(26 -22 28 -29 136 -140):&
               (23 -27 28 -29 136 -140):(28 -24 26 -27 136 -140):&
               (25 -29 26 -27 136 -140) $Void 2
82  6 0.123067 (1 -2 3 -4 140 -141):(1 -18 3 -4 141 -144):&
               (19 -2 3 -4 141 -144):(3 -20 1 -2 141 -144):&
               (21 -4 1 -2 141 -144):(1 -26 3 -4 144 -148):&
```

```
               (27 -2 3 -4 144 -148):(3 -28 1 -2 144 -148):&
               (29 -4 1 -2 144 -148) $Poly B
83  2 0.123685 10 12 -30 -31 141 -142 $Insert 28
84  2 0.123685 10 -13 -30 31 141 -142 $Insert 34
85  2 0.123685 -11 -13 30 31 141 -142 $Insert 31
86  2 0.123685 -11 12 30 -31 141 -142 $Insert 33
87  3 0.057159 14 -15 16 -31 142 -143 $Re 9
88  3 0.057159 14 -15 31 -17 142 -143 $Re 10
89  0          (18 -10 20 -21 141 -142):(11 -19 20 -21 141 -142):&
               (20 -12 18 -19 141 -142):(13 -21 18 -19 141 -142):&
               (18 -19 20 -21 142 -144 #87  #88) $Void 1
90  5 0.044107 10 12 -30 -31 145 -146 $Foil 8B
91  4 0.133586 22 24 -30 -31 144 -147 #90 $Lamination 8B
92  5 0.044107 10 -13 -30 31 145 -146 $Foil 9B
93  4 0.133586 22 -25 -30 31 144 -147 #92 $Lamination 9B
94  5 0.044107 -11 -13 30 31 145 -146 $Foil 10B
95  4 0.133586 -23 -25 30 31 144 -147 #94 $Lamination 10B
96  5 0.044107 -11 12 30 -31 145 -146 $Foil 11B
97  4 0.133586 -23 24 30 -31 144 -147 #96 $Lamination 11B
98  0          (26 -27 28 -29 147 -148):(26 -22 28 -29 144 -148):&
               (23 -27 28 -29 144 -148):(28 -24 26 -27 144 -148):&
               (25 -29 26 -27 144 -148) $Void 2
99  6 0.123067 (1 -2 3 -4 148 -149):(1 -18 3 -4 149 -152):&
               (19 -2 3 -4 149 -152):(3 -20 1 -2 149 -152):&
               (21 -4 1 -2 149 -152):(1 -26 3 -4 152 -156):&
               (27 -2 3 -4 152 -156):(3 -28 1 -2 152 -156):&
               (29 -4 1 -2 152 -156) $Poly 16S
100 2 0.123685 10 12 -30 -31 149 -150 $Insert 20
101 2 0.123685 10 -13 -30 31 149 -150 $Insert 19
102 2 0.123685 -11 -13 30 31 149 -150 $Insert 22
103 2 0.123685 -11 12 30 -31 149 -150 $Insert 21
104 3 0.057159 (14 -15 16 -31 150 -151) $Re 11
105 3 0.057159 (14 -15 31 -17 150 -151) $Re 12
106 0          (18 -10 20 -21 149 -150):(11 -19 20 -21 149 -150):&
               (20 -12 18 -19 149 -150):(13 -21 18 -19 149 -150):&
               (18 -19 20 -21 150 -152 #104 #105) $Void 1
107 5 0.044107 10 12 -30 -31 153 -154 $Foil 12B
108 4 0.133586 22 24 -30 -31 152 -155 #107 $Lamination 12B
109 5 0.044107 10 -13 -30 31 153 -154 $Foil 13B
110 4 0.133586 22 -25 -30 31 152 -155 #109 $Lamination 13B
111 5 0.044107 -11 -13 30 31 153 -154 $Foil 14B
112 4 0.133586 -23 -25 30 31 152 -155 #111 $Lamination 14B
113 5 0.044107 -11 12 30 -31 153 -154 $Foil 15B
114 4 0.133586 -23 24 30 -31 152 -155 #113 $Lamination 15B
115 0          (26 -27 28 -29 155 -156):(26 -22 28 -29 152 -156):&
               (23 -27 28 -29 152 -156):(28 -24 26 -27 152 -156):&
               (25 -29 26 -27 152 -156) $Void 2
116 7 0.123775 (5 -6 7 -8 156 -157):(5 -18 7 -8 157 -160):&
               (19 -6 7 -8 157 -160):(7 -20 5 -6 157 -160):&
               (21 -8 5 -6 157 -160):(5 -26 7 -8 160 -164):&
               (27 -6 7 -8 160 -164):(7 -28 5 -6 160 -164):&
               (29 -8 5 -6 160 -164) $Poly 18
117 2 0.123685 10 12 -30 -31 157 -158 $Insert 47
118 2 0.123685 10 -13 -30 31 157 -158 $Insert 56
119 2 0.123685 -11 -13 30 31 157 -158 $Insert 13
120 2 0.123685 -11 12 30 -31 157 -158 $Insert 54
121 3 0.057159 14 -15 16 -31 158 -159 $Re 13
122 3 0.057159 14 -15 31 -17 158 -159 $Re 14
123 0          (18 -10 20 -21 157 -158):(11 -19 20 -21 157 -158):&
               (20 -12 18 -19 157 -158):(13 -21 18 -19 157 -158):&
               (18 -19 20 -21 158 -160 #121 #122) $Void 1
124 5 0.044107 10 12 -30 -31 161 -162 $Foil 16B
125 4 0.133586 22 24 -30 -31 160 -163 #124 $Lamination 16B
126 5 0.044107 10 -13 -30 31 161 -162 $Foil 17B
127 4 0.133586 22 -25 -30 31 160 -163 #126 $Lamination 17B
128 5 0.044107 -11 -13 30 31 161 -162 $Foil 18B
129 4 0.133586 -23 -25 30 31 160 -163 #128 $Lamination 18B
130 5 0.044107 -11 12 30 -31 161 -162 $Foil 19B
131 4 0.133586 -23 24 30 -31 160 -163 #130 $Lamination 19B
132 0          (26 -27 28 -29 163 -164):(26 -22 28 -29 160 -164):&
               (23 -27 28 -29 160 -164):(28 -24 26 -27 160 -164):&
               (25 -29 26 -27 160 -164) $Void 2
```

```
133 7 0.123775 (5 -6 7 -8 164 -165):(5 -18 7 -8 165 -168):&
               (19 -6 7 -8 165 -168):(7 -20 5 -6 165 -168):&
               (21 -8 5 -6 165 -168):(5 -26 7 -8 168 -172):&
               (27 -6 7 -8 168 -172):(7 -28 5 -6 168 -172):&
               (29 -8 5 -6 168 -172) $Poly 17
134 2 0.123685 10 12 -30 -31 165 -166 $Insert 17
135 2 0.123685 10 -13 -30 31 165 -166 $Insert 53
136 2 0.123685 -11 -13 30 31 165 -166 $Insert 42
137 2 0.123685 -11 12 30 -31 165 -166 $Insert 43
138 3 0.057159 14 -15 16 -31 166 -167 $Re 15
139 3 0.057159 14 -15 31 -17 166 -167 $Re 16
140 0          (18 -10 20 -21 165 -166):(11 -19 20 -21 165 -166):&
               (20 -12 18 -19 165 -166):(13 -21 18 -19 165 -166):&
               (18 -19 20 -21 166 -168 #138 #139) $Void 1
141 5 0.044107 10 12 -30 -31 169 -170 $Foil 20B
142 4 0.133586 22 24 -30 -31 168 -171 #141 $Lamination 20B
143 5 0.044107 10 -13 -30 31 169 -170 $Foil 21B
144 4 0.133586 22 -25 -30 31 168 -171 #143 $Lamination 21B
145 5 0.044107 -11 -13 30 31 169 -170 $Foil 22B
146 4 0.133586 -23 -25 30 31 168 -171 #145 $Lamination 22B
147 5 0.044107 -11 12 30 -31 169 -170 $Foil 23B
148 4 0.133586 -23 24 30 -31 168 -171 #147 $Lamination 23B
149 0          (26 -27 28 -29 171 -172):(26 -22 28 -29 168 -172):&
               (23 -27 28 -29 168 -172):(28 -24 26 -27 168 -172):&
               (25 -29 26 -27 168 -172) $Void 2
150 7 0.123775 (5 -6 7 -8 172 -173):(5 -18 7 -8 173 -176):&
               (19 -6 7 -8 173 -176):(7 -20 5 -6 173 -176):&
               (21 -8 5 -6 173 -176):(5 -26 7 -8 176 -180):&
               (27 -6 7 -8 176 -180):(7 -28 5 -6 176 -180):&
               (29 -8 5 -6 176 -180) $Poly 19
151 2 0.123685 10 12 -30 -31 173 -174 $Insert 14
152 2 0.123685 10 -13 -30 31 173 -174 $Insert 23
153 2 0.123685 -11 -13 30 31 173 -174 $Insert 32
154 2 0.123685 -11 12 30 -31 173 -174 $Insert 30
155 3 0.057159 14 -15 16 -31 174 -175 $Re 17
156 3 0.057159 14 -15 31 -17 174 -175 $Re 18
157 0          (18 -10 20 -21 173 -174):(11 -19 20 -21 173 -174):&
               (20 -12 18 -19 173 -174):(13 -21 18 -19 173 -174):&
               (18 -19 20 -21 174 -176 #155 #156) $Void 1
158 5 0.044107 10 12 -30 -31 177 -178 $Foil 24B
159 4 0.133586 22 24 -30 -31 176 -179 #158 $Lamination 24B
160 5 0.044107 10 -13 -30 31 177 -178 $Foil 25B
161 4 0.133586 22 -25 -30 31 176 -179 #160 $Lamination 25B
162 5 0.044107 -11 -13 30 31 177 -178 $Foil 26B
163 4 0.133586 -23 -25 30 31 176 -179 #162 $Lamination 26B
164 5 0.044107 -11 12 30 -31 177 -178 $Foil 1C
165 4 0.133586 -23 24 30 -31 176 -179 #164 $Lamination 1C
166 0          (26 -27 28 -29 179 -180):(26 -22 28 -29 176 -180):&
               (23 -27 28 -29 176 -180):(28 -24 26 -27 176 -180):&
               (25 -29 26 -27 176 -180) $Void 2
167 7 0.123775 (5 -6 7 -8 180 -181):(5 -18 7 -8 181 -184):&
               (19 -6 7 -8 181 -184):(7 -20 5 -6 181 -184):&
               (21 -8 5 -6 181 -184):(5 -26 7 -8 184 -188):&
               (27 -6 7 -8 184 -188):(7 -28 5 -6 184 -188):&
               (29 -8 5 -6 184 -188) $Poly 20
168 2 0.123685 10 12 -30 -31 181 -182 $Insert 2
169 2 0.123685 10 -13 -30 31 181 -182 $Insert 1
170 2 0.123685 -11 -13 30 31 181 -182 $Insert 4
171 2 0.123685 -11 12 30 -31 181 -182 $Insert 3
172 3 0.057159 14 -15 16 -31 182 -183 $Re 19
173 3 0.057159 14 -15 31 -17 182 -183 $Re 20
174 0          (18 -10 20 -21 181 -182):(11 -19 20 -21 181 -182):&
               (20 -12 18 -19 181 -182):(13 -21 18 -19 181 -182):&
               (18 -19 20 -21 182 -184 #172 #173) $Void 1
175 5 0.044107 10 12 -30 -31 185 -186 $Foil 2C
176 4 0.133586 22 24 -30 -31 184 -187 #175 $Lamination 2C
177 0          22 -25 -30 31 184 -187 $Void
178 5 0.044107 -11 -13 30 31 185 -186 $Foil 3C
179 4 0.133586 -23 -25 30 31 184 -187 #178 $Lamination 3C
180 0          -23 24 30 -31 184 -187 $Void
181 0          (26 -27 28 -29 187 -188):(26 -22 28 -29 184 -188):&
               (23 -27 28 -29 184 -188):(28 -24 26 -27 184 -188):&
```

```
               (25 -29 26 -27 184 -188) $Void 2
182 1 0.124564 1 -2 3 -4 188 -189 $Reflector 27
183 1 0.124564 1 -2 3 -4 189 -190 $Reflector 28
184 1 0.124564 1 -2 3 -4 190 -191 $Reflector 29
185 1 0.124564 1 -2 3 -4 191 -192 $Reflector 30
186 0          (-1:2:-3:4:-100:192) &
               (-5:6:-7:8:-156:188) -300 $Outside Assembly
999 0 300 $Outer World

C Surface Cards
1   px -33.02   $Back of Reflector/Small Moderator Plates
2   px 33.02    $Front of Reflector/Small Moderator Plates
3   py -33.02   $Left of Reflector/Small Moderator Plates
4   py 33.02    $Right of Reflector/Small Moderator Plates
5   px -37.592  $Back of Large Moderator Plates
6   px 37.592   $Front of Large Moderator Plates
7   py -37.592  $Left of Large Moderator Plates
8   py 37.592   $Right of Large Moderator Plates
10  px -22.86   $Back of Poly inserts/HEU foils
11  px 22.86    $Front of Poly inserts/HEU foils
12  py -22.86   $Left of Poly inserts/HEU foils
13  py 22.86    $Right of Poly inserts/HEU foils
14  px -10.16   $Back of Re foils
15  px 10.16    $Front of Re foils
16  py -5.08    $Left of Re foils
17  py 5.08     $Right of Re foils
18  px -22.8854 $Back of inner recess
19  px 22.8854  $Front of inner recess
20  py -22.8854 $Left of inner recess
21  py 22.8854  $Right of inner recess
22  px -23.876  $Back of Poly lamination
23  px 23.876   $Front of Poly lamination
24  py -23.876  $Left of Poly lamination
25  py 23.876   $Right of Poly lamination
26  px -24.13   $Back of outer recess
27  px 24.13    $Front of outer recess
28  py -24.13   $Left of outer recess
29  py 24.13    $Right of outer recess
30  px 0        $Midplane (x-dir)
31  py 0        $Midplane (y-dir)
100 pz 0        $Poly 1
101 pz 2.54     $Poly 2
102 pz 5.08     $Poly 3
103 pz 7.62     $Poly 4
104 pz 10.09396 $Lamination
105 pz 10.10158 $Foils 1A, 2A, 3A, 4A
106 pz 10.1092  $Lamination
107 pz 10.11682 $Void
108 pz 10.16    $Poly 8
109 pz 10.47496 $Poly inserts 45, 49, 51, 52
110 pz 11.10996 $Re 1, 2
111 pz 11.12520 $Void
112 pz 11.14806 $Lamination
113 pz 11.15568 $Foils 5A, 6A, 7A, 8A
114 pz 11.1633  $Lamination
115 pz 11.17092 $Void
116 pz 11.2141  $Poly 13
117 pz 11.52906 $Poly inserts 50, 48, 44, 60
118 pz 12.16406 $Re 3, 4
119 pz 12.17930 $Void
120 pz 12.20216 $Lamination
121 pz 12.20978 $Foils 9A, 10A, 11A, 12A
122 pz 12.2174  $Lamination
123 pz 12.22502 $Void
124 pz 12.2682  $Poly 14
125 pz 12.58316 $Poly inserts 16, 61, 18, 27
126 pz 13.21816 $Re 5, 6
127 pz 13.23340 $Void
128 pz 13.25626 $Lamination
129 pz 13.26388 $Foils 13A, 1B, 2B, 3B
130 pz 13.2715  $Lamination
131 pz 13.27912 $Void
```

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132 pz 13.3223  $Poly 6A
133 pz 13.63726 $Poly inserts 29, 40, 57, 59
134 pz 14.27226 $Re 7, 8
135 pz 14.28750 $Void
136 pz 14.31036 $Lamination
137 pz 14.31798 $Foils 4B, 4B, 6B, 7B
138 pz 14.3256  $Lamination
139 pz 14.33322 $Void
140 pz 14.3764  $Poly B
141 pz 14.69136 $Poly inserts 28, 34, 31, 33
142 pz 15.32636 $Re 9, 10
143 pz 15.34160 $Void
144 pz 15.36446 $Lamination
145 pz 15.37208 $Foils 8B, 9B, 10B, 11B
146 pz 15.3797  $Lamination
147 pz 15.38732 $Void
148 pz 15.4305  $Poly 16S
149 pz 15.74546 $Poly inserts 20, 19, 22, 21
150 pz 16.38046 $Re 11, 12
151 pz 16.39570 $Void
152 pz 16.41856 $Lamination
153 pz 16.42618 $Foils 12B, 13B, 14B, 15B
154 pz 16.4338  $Lamination
155 pz 16.44142 $Void
156 pz 16.4846  $Poly 18
157 pz 16.79956 $Poly inserts 47, 56, 13, 54
158 pz 17.43456 $Re 13, 14
159 pz 17.44980 $Void
160 pz 17.47266 $Lamination
161 pz 17.48028 $Foils 16B, 17B, 18B, 19B
162 pz 17.4879  $Lamination
163 pz 17.49552 $Void
164 pz 17.5387  $Poly 17
165 pz 17.85366 $Poly inserts 17, 53, 42, 43
166 pz 18.48866 $Re 15, 16
167 pz 18.50390 $Void
168 pz 18.52676 $Lamination
169 pz 18.53438 $Foils 20B, 21B, 22B, 23B
170 pz 18.542   $Lamination
171 pz 18.54962 $Void
172 pz 18.5928  $Poly 19
173 pz 18.90776 $Poly inserts 14, 23, 32, 30
174 pz 19.54276 $Re 17, 18
175 pz 19.55800 $Void
176 pz 19.58086 $Lamination
177 pz 19.58848 $Foils 24B, 25B, 26B, 1C
178 pz 19.5961  $Lamination
179 pz 19.60372 $Void
180 pz 19.6469  $Poly 20
181 pz 19.96186 $Poly inserts 2, 1, 4, 3
182 pz 20.59686 $Re 19, 20
183 pz 20.61210 $Void
184 pz 20.63496 $Lamination
185 pz 20.64258 $Foils 2C, 3C
186 pz 20.65020 $Lamination
187 pz 20.65782 $Void
188 pz 20.7010  $Poly 27
189 pz 23.2410  $Poly 28
190 pz 25.7810  $Poly 29
191 pz 28.3210  $Poly 30
192 pz 30.8610  $Top of Assembly
300 so 200      $Outer World

C Data Cards
m1    1001.66c  8.3043e-2 $Poly Reflector
      6000.66c  4.1521e-2
mt1   poly.60t
m2    1001.66c  8.2457e-2 $Poly Insert
      6000.66c  4.1228e-2
mt2   poly.60t
m3    75185.66c 2.1522e-2 $Rhenium
      75187.66c 3.5637e-2
```

```
m4    1001.66c  8.9057e-2 $Poly Lamination
      6000.66c  4.4529e-2
mt4   poly.60t
m5    92234.66c 5.0259e-4 $HEU
      92235.66c 4.1148e-2
      92236.66c 1.1343e-4
      92238.66c 2.3427e-3
m6    1001.66c  8.2045e-2 $Poly small plate
      6000.66c  4.1022e-2
mt6   poly.60t
m7    1001.66c  8.2517e-2 $Poly large plate
      6000.66c  4.1258e-2
mt7   poly.60t
totnu
MODE N
IMP:N 1 185r 0
kcode 5000 1.0 50 1250
ksrc  0.1 0.1 10.104
      0.1 0.1 11.159
      0.1 0.1 12.213
      0.1 0.1 13.267
      0.1 0.1 14.321
      0.1 0.1 15.376
      0.1 0.1 16.429
      0.1 0.1 17.484
      0.1 0.1 18.538
      0.1 0.1 19.592
      0.1 0.1 20.646
```

MCNP ENDF/B-VI.5 INPUT LISTING, DETAILED MODEL, TABLE 25.

```
HEU/Re moderated/reflected by polyethylene - detailed model
C hmt33002 - base case
C Cell Cards
1   1   0.125063 1 -2 3 -4 100 -101 $Reflector 1
2   2   0.125063 1 -2 3 -4 101 -102 $Reflector 2
3   3   0.125192 1 -2 3 -4 102 -103 $Reflector 3
4   4   0.124543 (1 -2 3 -4 103 -104):(1 -26 3 -4 104 -108):&
                 (27 -2 3 -4 104 -108):(3 -28 1 -2 104 -108):&
                 (29 -4 1 -2 104 -108) $Reflector 4
5   5   0.044368 10 12 -30 -31 105 -106 $Foil 1A
6   47  0.132276 22 24 -30 -31 104 -107 #5 $Lamination 1A
7   6   0.045845 10 -13 -30 31 105 -106 $Foil 2A
8   48  0.132276 22 -25 -30 31 104 -107 #7 $Lamination 2A
9   7   0.04909 -11 -13 30 31 105 -106 $Foil 3A
10  49  0.133564 -23 -25 30 31 104 -107 #9 $Lamination 3A
11  8   0.044624 -11 12 30 -31 105 -106 $Foil 4A
12  50  0.129700 -23 24 30 -31 104 -107 #11 $Lamination 4A
13  0            (26 -27 28 -29 107 -108):(26 -22 28 -29 104 -108):&
                 (23 -27 28 -29 104 -108):(28 -24 26 -27 104 -108):&
                 (25 -29 26 -27 104 -108) $Void
14  90  0.123131 (1 -2 3 -4 108 -109):(1 -18 3 -4 109 -112):&
                 (19 -2 3 -4 109 -112):(3 -20 1 -2 109 -112):&
                 (21 -4 1 -2 109 -112):(1 -26 3 -4 112 -116):&
                 (27 -2 3 -4 112 -116):(3 -28 1 -2 112 -116):&
                 (29 -4 1 -2 112 -116) $Poly 8
15  100 0.124033 10 12 -30 -31 109 -110 $Insert 45
16  101 0.124419 10 -13 -30 31 109 -110 $Insert 49
17  102 0.124548 -11 -13 30 31 109 -110 $Insert 51
18  103 0.124934 -11 12 30 -31 109 -110 $Insert 52
19  144 0.057159 14 -15 16 -31 110 -111 $Re 1
20  144 0.057159 14 -15 31 -17 110 -111 $Re 2
21  0            (18 -10 20 -21 109 -110):(11 -19 20 -21 109 -110):&
                 (20 -12 18 -19 109 -110):(13 -21 18 -19 109 -111):&
                 (18 -19 20 -21 110 -112 #19 #20) $Void 1
22  9   0.045525 10 12 -30 -31 113 -114 $Foil 5A
23  51  0.134891 22 24 -30 -31 112 -115 #22 $Lamination 5A
24  10  0.045139 10 -13 -30 31 113 -114 $Foil 6A
25  52  0.134981 22 -25 -30 31 112 -115 #24 $Lamination 6A
26  11  0.045397 -11 -13 30 31 113 -114 $Foil 7A
27  53  0.125707 -23 -25 30 31 112 -115 #26 $Lamination 7A
28  12  0.045717 -11 12 30 -31 113 -114 $Foil 8A
29  54  0.134981 -23 24 30 -31 112 -115 #28 $Lamination 8A
30  0            (26 -27 28 -29 115 -116):(26 -22 28 -29 112 -116):&
                 (23 -27 28 -29 112 -116):(28 -24 26 -27 112 -116):&
                 (25 -29 26 -27 112 -116) $Void 2
31  91  0.123003 (1 -2 3 -4 116 -117):(1 -18 3 -4 117 -120):&
                 (19 -2 3 -4 117 -120):(3 -20 1 -2 117 -120):&
                 (21 -4 1 -2 117 -120):(1 -26 3 -4 120 -124):&
                 (27 -2 3 -4 120 -124):(3 -28 1 -2 120 -124):&
                 (29 -4 1 -2 120 -124) $Poly 13
32  104 0.124548 10 12 -30 -31 117 -118 $Insert 50
33  105 0.124419 10 -13 -30 31 117 -118 $Insert 48
34  106 0.124038 -11 -13 30 31 117 -118 $Insert 44
35  107 0.124548 -11 12 30 -31 117 -118 $Insert 60
36  144 0.057159 14 -15 16 -31 118 -119 $Re 3
37  144 0.057159 14 -15 31 -17 118 -119 $Re 4
38  0            (18 -10 20 -21 117 -118):(11 -19 20 -21 117 -118):&
                 (20 -12 18 -19 117 -118):(13 -21 18 -19 117 -118):&
                 (18 -19 20 -21 118 -120 #36 #37) $Void 1
39  13  0.045845 10 12 -30 -31 121 -122 $Foil 9A
40  55  0.133564 22 24 -30 -31 120 -123 #39 $Lamination 9A
41  14  0.046168 10 -13 -30 31 121 -122 $Foil 10A
42  56  0.134981 22 -25 -30 31 120 -123 #41 $Lamination 10A
43  15  0.046555 -11 -13 30 31 121 -122 $Foil 11A
44  57  0.129700 -23 -25 30 31 120 -123 #43 $Lamination 11A
45  16  0.045845 -11 12 30 -31 121 -122 $Foil 12A
46  58  0.132276 -23 24 30 -31 120 -123 #45 $Lamination 12A
47  0            (26 -27 28 -29 123 -124):(26 -22 28 -29 120 -124):&
                 (23 -27 28 -29 120 -124):(28 -24 26 -27 120 -124):&
                 (25 -29 26 -27 120 -124) $Void 2
```

```
48  92  0.122874 (1 -2 3 -4 124 -125):(1 -18 3 -4 125 -128):&
                 (19 -2 3 -4 125 -128):(3 -20 1 -2 125 -128):&
                 (21 -4 1 -2 125 -128):(1 -26 3 -4 128 -132):&
                 (27 -2 3 -4 128 -132):(3 -28 1 -2 128 -132):&
                 (29 -4 1 -2 128 -132) $Poly 14
49  108 0.124548 10 12 -30 -31 125 -126 $Insert 16
50  109 0.124548 10 -13 -30 31 125 -126 $Insert 61
51  110 0.122487 -11 -13 30 31 125 -126 $Insert 18
52  111 0.125192 -11 12 30 -31 125 -126 $Insert 27
53  144 0.057159 14 -15 16 -31 126 -127 $Re 5
54  144 0.057159 14 -15 31 -17 126 -127 $Re 6
55  0            (18 -10 20 -21 125 -126):(11 -19 20 -21 125 -126):&
                 (20 -12 18 -19 125 -126):(13 -21 18 -19 125 -126):&
                 (18 -19 20 -21 126 -128 #53 #54) $Void 1
56  17  0.045267 10 12 -30 -31 129 -130 $Foil 13A
57  59  0.130988 22 24 -30 -31 128 -131 #56 $Lamination 13A
58  18  0.044368 10 -13 -30 31 129 -130 $Foil 1B
59  60  0.117851 22 -25 -30 31 128 -131 #58 $Lamination 1B
60  19  0.043725 -11 -13 30 31 129 -130 $Foil 2B
61  61  0.144125 -23 -25 30 31 128 -131 #60 $Lamination 2B
62  20  0.042437 -11 12 30 -31 129 -130 $Foil 3B
63  62  0.130988 -23 24 30 -31 128 -131 #62 $Lamination 3B
64  0            (26 -27 28 -29 131 -132):(26 -22 28 -29 128 -132):&
                 (23 -27 28 -29 128 -132):(28 -24 26 -27 128 -132):&
                 (25 -29 26 -27 128 -132) $Void 2
65  93  0.122874 (1 -2 3 -4 132 -133):(1 -18 3 -4 133 -136):&
                 (19 -2 3 -4 133 -136):(3 -20 1 -2 133 -136):&
                 (21 -4 1 -2 133 -136):(1 -26 3 -4 136 -140):&
                 (27 -2 3 -4 136 -140):(3 -28 1 -2 136 -140):&
                 (29 -4 1 -2 136 -140) $Poly 6A
66  112 0.124033 10 12 -30 -31 133 -134 $Insert 29
67  113 0.124290 10 -13 -30 31 133 -134 $Insert 40
68  114 0.123518 -11 -13 30 31 133 -134 $Insert 57
69  115 0.123518 -11 12 30 -31 133 -134 $Insert 59
70  144 0.057159 14 -15 16 -31 134 -135 $Re 7
71  144 0.057159 14 -15 31 -17 134 -135 $Re 8
72  0            (18 -10 20 -21 133 -134):(11 -19 20 -21 133 -134):&
                 (20 -12 18 -19 133 -134):(13 -21 22 -23 133 -134):&
                 (18 -19 20 -21 134 -136 #70 #71) $Void 1
73  21  0.041152 10 12 -30 -31 137 -138 $Foil 4B
74  63  0.130988 22 24 -30 -31 136 -139 #73 $Lamination 4B
75  22  0.043080 10 -13 -30 31 137 -138 $Foil 5B
76  64  0.130988 22 -25 -30 31 136 -139 #75 $Lamination 5B
77  23  0.043080 -11 -13 30 31 137 -138 $Foil 6B
78  65  0.144125 -23 -25 30 31 136 -139 #77 $Lamination 6B
79  24  0.041795 -11 12 30 -31 137 -138 $Foil 7B
80  66  0.130988 -23 24 30 -31 136 -139 #79 $Lamination 7B
81  0            (26 -27 28 -29 139 -140):(26 -22 28 -29 136 -140):&
                 (23 -27 28 -29 136 -140):(28 -24 26 -27 136 -140):&
                 (25 -29 26 -27 136 -140) $Void 2
82  94  0.122874 (1 -2 3 -4 140 -141):(1 -18 3 -4 141 -144):&
                 (19 -2 3 -4 141 -144):(3 -20 1 -2 141 -144):&
                 (21 -4 1 -2 141 -144):(1 -26 3 -4 144 -148):&
                 (27 -2 3 -4 144 -148):(3 -28 1 -2 144 -148):&
                 (29 -4 1 -2 144 -148) $Poly B
83  116 0.124934 10 12 -30 -31 141 -142 $Insert 28
84  117 0.124677 10 -13 -30 31 141 -142 $Insert 34
85  118 0.125063 -11 -13 30 31 141 -142 $Insert 31
86  119 0.124290 -11 12 30 -31 141 -142 $Insert 33
87  144 0.057159 14 -15 16 -31 142 -143 $Re 9
88  145 0.058945 14 -15 31 -17 142 -143 $Re 10
89  0            (18 -10 20 -21 141 -142):(11 -19 20 -21 141 -142):&
                 (20 -12 18 -19 141 -142):(13 -21 18 -19 141 -142):&
                 (18 -19 20 -21 142 -144 #87  #88) $Void 1
90  25  0.044368 10 12 -30 -31 145 -146 $Foil 8B
91  67  0.117851 22 24 -30 -31 144 -147 #90 $Lamination 8B
92  26  0.042437 10 -13 -30 31 145 -146 $Foil 9B
93  68  0.130988 22 -25 -30 31 144 -147 #92 $Lamination 9B
94  27  0.043080 -11 -13 30 31 145 -146 $Foil 10B
95  69  0.130988 -23 -25 30 31 144 -147 #94 $Lamination 10B
96  28  0.045653 -11 12 30 -31 145 -146 $Foil 11B
97  70  0.130988 -23 24 30 -31 144 -147 #96 $Lamination 11B
```

```
98  0            (26 -27 28 -29 147 -148):(26 -22 28 -29 144 -148):&
                 (23 -27 28 -29 144 -148):(28 -24 26 -27 144 -148):&
                 (25 -29 26 -27 144 -148) $Void 2
99  95  0.123647 (1 -2 3 -4 148 -149):(1 -18 3 -4 149 -152):&
                 (19 -2 3 -4 149 -152):(3 -20 1 -2 149 -152):&
                 (21 -4 1 -2 149 -152):(1 -26 3 -4 152 -156):&
                 (27 -2 3 -4 152 -156):(3 -28 1 -2 152 -156):&
                 (29 -4 1 -2 152 -156) $Poly 16S
100 120 0.122487 10 12 -30 -31 149 -150 $Insert 20
101 121 0.123647 10 -13 -30 31 149 -150 $Insert 19
102 122 0.123260 -11 -13 30 31 149 -150 $Insert 22
103 123 0.121586 -11 12 30 -31 149 -150 $Insert 21
104 146 0.057094 (14 -15 16 -31 150 -151) $Re 11
105 147 0.055656 (14 -15 31 -17 150 -151) $Re 12
106 0            (18 -10 20 -21 149 -150):(11 -19 20 -21 149 -150):&
                 (20 -12 18 -19 149 -150):(13 -21 18 -19 149 -150):&
                 (18 -19 20 -21 150 -152 #104 #105) $Void 1
107 29  0.045011 10 12 -30 -31 153 -154 $Foil 12B
108 71  0.144125 22 24 -30 -31 152 -155 #107 $Lamination 12B
109 30  0.041795 10 -13 -30 31 153 -154 $Foil 13B
110 72  0.144125 22 -25 -30 31 152 -155 #109 $Lamination 13B
111 31  0.043080 -11 -13 30 31 153 -154 $Foil 14B
112 73  0.130988 -23 -25 30 31 152 -155 #111 $Lamination 14B
113 32  0.042437 -11 12 30 -31 153 -154 $Foil 15B
114 74  0.130988 -23 24 30 -31 152 -155 #113 $Lamination 15B
115 0            (26 -27 28 -29 155 -156):(26 -22 28 -29 152 -156):&
                 (23 -27 28 -29 152 -156):(28 -24 26 -27 152 -156):&
                 (25 -29 26 -27 152 -156) $Void 2
116 96  0.123389 (5 -6 7 -8 156 -157):(5 -18 7 -8 157 -160):&
                 (19 -6 7 -8 157 -160):(7 -20 5 -6 157 -160):&
                 (21 -8 5 -6 157 -160):(5 -26 7 -8 160 -164):&
                 (27 -6 7 -8 160 -164):(7 -28 5 -6 160 -164):&
                 (29 -8 5 -6 160 -164) $Poly 18
117 124 0.124806 10 12 -30 -31 157 -158 $Insert 47
118 125 0.123260 10 -13 -30 31 157 -158 $Insert 56
119 126 0.122101 -11 -13 30 31 157 -158 $Insert 13
120 127 0.124162 -11 12 30 -31 157 -158 $Insert 54
121 148 0.056480 14 -15 16 -31 158 -159 $Re 13
122 149 0.052370 14 -15 31 -17 158 -159 $Re 14
123 0            (18 -10 20 -21 157 -158):(11 -19 20 -21 157 -158):&
                 (20 -12 18 -19 157 -158):(13 -21 18 -19 157 -158):&
                 (18 -19 20 -21 158 -160 #121 #122) $Void 1
124 33  0.044368 10 12 -30 -31 161 -162 $Foil 16B
125 75  0.130988 22 24 -30 -31 160 -163 #124 $Lamination 16B
126 34  0.042437 10 -13 -30 31 161 -162 $Foil 17B
127 76  0.144125 22 -25 -30 31 160 -163 #126 $Lamination 17B
128 35  0.041795 -11 -13 30 31 161 -162 $Foil 18B
129 77  0.130988 -23 -25 30 31 160 -163 #128 $Lamination 18B
130 36  0.043725 -11 12 30 -31 161 -162 $Foil 19B
131 78  0.130988 -23 24 30 -31 160 -163 #130 $Lamination 19B
132 0            (26 -27 28 -29 163 -164):(26 -22 28 -29 160 -164):&
                 (23 -27 28 -29 160 -164):(28 -24 26 -27 160 -164):&
                 (25 -29 26 -27 160 -164) $Void 2
133 97  0.123775 (5 -6 7 -8 164 -165):(5 -18 7 -8 165 -168):&
                 (19 -6 7 -8 165 -168):(7 -20 5 -6 165 -168):&
                 (21 -8 5 -6 165 -168):(5 -26 7 -8 168 -172):&
                 (27 -6 7 -8 168 -172):(7 -28 5 -6 168 -172):&
                 (29 -8 5 -6 168 -172) $Poly 17
134 128 0.122616 10 12 -30 -31 165 -166 $Insert 17
135 129 0.123775 10 -13 -30 31 165 -166 $Insert 53
136 130 0.124162 -11 -13 30 31 165 -166 $Insert 42
137 131 0.124290 -11 12 30 -31 165 -166 $Insert 43
138 150 0.058328 14 -15 16 -31 166 -167 $Re 15
139 151 0.055246 14 -15 31 -17 166 -167 $Re 16
140 0            (18 -10 20 -21 165 -166):(11 -19 20 -21 165 -166):&
                 (20 -12 18 -19 165 -166):(13 -21 18 -19 165 -166):&
                 (18 -19 20 -21 166 -168 #138 #139) $Void 1
141 37  0.043080 10 12 -30 -31 169 -170 $Foil 20B
142 79  0.144125 22 24 -30 -31 168 -171 #141 $Lamination 20B
143 38  0.044367 10 -13 -30 31 169 -170 $Foil 21B
144 80  0.130988 22 -25 -30 31 168 -171 #143 $Lamination 21B
145 39  0.044367 -11 -13 30 31 169 -170 $Foil 22B
```

```
146 81  0.130988 -23 -25 30 31 168 -171 #145 $Lamination 22B
147 40  0.044367 -11 12 30 -31 169 -170 $Foil 23B
148 82  0.144125 -23 24 30 -31 168 -171 #147 $Lamination 23B
149 0            (26 -27 28 -29 171 -172):(26 -22 28 -29 168 -172):&
                 (23 -27 28 -29 168 -172):(28 -24 26 -27 168 -172):&
                 (25 -29 26 -27 168 -172) $Void 2
150 98  0.124033 (5 -6 7 -8 172 -173):(5 -18 7 -8 173 -176):&
                 (19 -6 7 -8 173 -176):(7 -20 5 -6 173 -176):&
                 (21 -8 5 -6 173 -176):(5 -26 7 -8 176 -180):&
                 (27 -6 7 -8 176 -180):(7 -28 5 -6 176 -180):&
                 (29 -8 5 -6 176 -180) $Poly 19
151 132 0.122487 10 12 -30 -31 173 -174 $Insert 14
152 133 0.121843 10 -13 -30 31 173 -174 $Insert 23
153 134 0.123260 -11 -13 30 31 173 -174 $Insert 32
154 135 0.124162 -11 12 30 -31 173 -174 $Insert 30
155 152 0.059149 14 -15 16 -31 174 -175 $Re 17
156 153 0.053194 14 -15 31 -17 174 -175 $Re 18
157 0            (18 -10 20 -21 173 -174):(11 -19 20 -21 173 -174):&
                 (20 -12 18 -19 173 -174):(13 -21 18 -19 173 -174):&
                 (18 -19 20 -21 174 -176 #155 #156) $Void 1
158 41  0.043080 10 12 -30 -31 177 -178 $Foil 24B
159 83  0.144125 22 24 -30 -31 176 -179 #158 $Lamination 24B
160 42  0.043080 10 -13 -30 31 177 -178 $Foil 25B
161 84  0.130988 22 -25 -30 31 176 -179 #160 $Lamination 25B
162 43  0.041152 -11 -13 30 31 177 -178 $Foil 26B
163 85  0.130988 -23 -25 30 31 176 -179 #162 $Lamination 26B
164 44  0.045653 -11 12 30 -31 177 -178 $Foil 1C
165 86  0.130988 -23 24 30 -31 176 -179 #164 $Lamination 1C
166 0            (26 -27 28 -29 179 -180):(26 -22 28 -29 176 -180):&
                 (23 -27 28 -29 176 -180):(28 -24 26 -27 176 -180):&
                 (25 -29 26 -27 176 -180) $Void 2
167 99  0.123904 (5 -6 7 -8 180 -181):(5 -18 7 -8 181 -184):&
                 (19 -6 7 -8 181 -184):(7 -20 5 -6 181 -184):&
                 (21 -8 5 -6 181 -184):(5 -26 7 -8 184 -188):&
                 (27 -6 7 -8 184 -188):(7 -28 5 -6 184 -188):&
                 (29 -8 5 -6 184 -188) $Poly 20
168 136 0.122101 10 12 -30 -31 181 -182 $Insert 2
169 137 0.121843 10 -13 -30 31 181 -182 $Insert 1
170 138 0.123003 -11 -13 30 31 181 -182 $Insert 4
171 139 0.121972 -11 12 30 -31 181 -182 $Insert 3
172 154 0.059559 14 -15 16 -31 182 -183 $Re 19
173 155 0.055863 14 -15 31 -17 182 -183 $Re 20
174 0            (18 -10 20 -21 181 -182):(11 -19 20 -21 181 -182):&
                 (20 -12 18 -19 181 -182):(13 -21 18 -19 181 -182):&
                 (18 -19 20 -21 182 -184 #172 #173) $Void 1
175 45  0.045653 10 12 -30 -31 185 -186 $Foil 2C
176 87  0.130988 22 24 -30 -31 184 -187 #175 $Lamination 2C
177 0            22 -25 -30 31 184 -187 $Void
178 46  0.045653 -11 -13 30 31 185 -186 $Foil 3C
179 88  0.144125 -23 -25 30 31 184 -187 #178 $Lamination 3C
180 0            -23 24 30 -31 184 -187 $Void
181 0            (26 -27 28 -29 187 -188):(26 -22 28 -29 184 -188):&
                 (23 -27 28 -29 184 -188):(28 -24 26 -27 184 -188):&
                 (25 -29 26 -27 184 -188) $Void 2
182 140 0.124033 1 -2 3 -4 188 -189 $Reflector 27
183 141 0.124548 1 -2 3 -4 189 -190 $Reflector 28
184 142 0.124033 1 -2 3 -4 190 -191 $Reflector 29
185 143 0.124033 1 -2 3 -4 191 -192 $Reflector 30
186 0            (-1:2:-3:4:-100:192) &
                 (-5:6:-7:8:-156:188) -300 $Outside Assembly
999 0            300 $Outer World

C Surface Cards
1   px -33.02   $Back of Reflector/Small Moderator Plates
2   px 33.02    $Front of Reflector/Small Moderator Plates
3   py -33.02   $Left of Reflector/Small Moderator Plates
4   py 33.02    $Right of Reflector/Small Moderator Plates
5   px -37.592  $Back of Large Moderator Plates
6   px 37.592   $Front of Large Moderator Plates
7   py -37.592  $Left of Large Moderator Plates
8   py 37.592   $Right of Large Moderator Plates
10  px -22.86   $Back of Poly inserts/HEU foils
```

```
11  px 22.86    $Front of Poly inserts/HEU foils
12  py -22.86   $Left of Poly inserts/HEU foils
13  py 22.86    $Right of Poly inserts/HEU foils
14  px -10.16   $Back of Re foils
15  px 10.16    $Front of Re foils
16  py -5.08    $Left of Re foils
17  py 5.08     $Right of Re foils
18  px -22.8854 $Back of inner recess
19  px 22.8854  $Front of inner recess
20  py -22.8854 $Left of inner recess
21  py 22.8854  $Right of inner recess
22  px -23.876  $Back of Poly lamination
23  px 23.876   $Front of Poly lamination
24  py -23.876  $Left of Poly lamination
25  py 23.876   $Right of Poly lamination
26  px -24.13   $Back of outer recess
27  px 24.13    $Front of outer recess
28  py -24.13   $Left of outer recess
29  py 24.13    $Right of outer recess
30  px 0        $Midplane (x-dir)
31  py 0        $Midplane (y-dir)
100 pz 0        $Poly 1
101 pz 2.54     $Poly 2
102 pz 5.08     $Poly 3
103 pz 7.62     $Poly 4
104 pz 10.09396 $Lamination
105 pz 10.10158 $Foils 1A, 2A, 3A, 4A
106 pz 10.1092  $Lamination
107 pz 10.11682 $Void
108 pz 10.16    $Poly 8
109 pz 10.47496 $Poly inserts 45, 49, 51, 52
110 pz 11.10996 $Re 1, 2
111 pz 11.12520 $Void
112 pz 11.14806 $Lamination
113 pz 11.15568 $Foils 5A, 6A, 7A, 8A
114 pz 11.1633  $Lamination
115 pz 11.17092 $Void
116 pz 11.2141  $Poly 13
117 pz 11.52906 $Poly inserts 50, 48, 44, 60
118 pz 12.16406 $Re 3, 4
119 pz 12.17930 $Void
120 pz 12.20216 $Lamination
121 pz 12.20978 $Foils 9A, 10A, 11A, 12A
122 pz 12.2174  $Lamination
123 pz 12.22502 $Void
124 pz 12.2682  $Poly 14
125 pz 12.58316 $Poly inserts 16, 61, 18, 27
126 pz 13.21816 $Re 5, 6
127 pz 13.23340 $Void
128 pz 13.25626 $Lamination
129 pz 13.26388 $Foils 13A, 1B, 2B, 3B
130 pz 13.2715  $Lamination
131 pz 13.27912 $Void
132 pz 13.3223  $Poly 6A
133 pz 13.63726 $Poly inserts 29, 40, 57, 59
134 pz 14.27226 $Re 7, 8
135 pz 14.28750 $Void
136 pz 14.31036 $Lamination
137 pz 14.31798 $Foils 4B, 4B, 6B, 7B
138 pz 14.3256  $Lamination
139 pz 14.33322 $Void
140 pz 14.3764  $Poly B
141 pz 14.69136 $Poly inserts 28, 34, 31, 33
142 pz 15.32636 $Re 9, 10
143 pz 15.34160 $Void
144 pz 15.36446 $Lamination
145 pz 15.37208 $Foils 8B, 9B, 10B, 11B
146 pz 15.3797  $Lamination
147 pz 15.38732 $Void
148 pz 15.4305  $Poly 16S
149 pz 15.74546 $Poly inserts 20, 19, 22, 21
150 pz 16.38046 $Re 11, 12
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151 pz 16.39570 $Void
152 pz 16.41856 $Lamination
153 pz 16.42618 $Foils 12B, 13B, 14B, 15B
154 pz 16.4338  $Lamination
155 pz 16.44142 $Void
156 pz 16.4846  $Poly 18
157 pz 16.79956 $Poly inserts 47, 56, 13, 54
158 pz 17.43456 $Re 13, 14
159 pz 17.44980 $Void
160 pz 17.47266 $Lamination
161 pz 17.48028 $Foils 16B, 17B, 18B, 19B
162 pz 17.4879  $Lamination
163 pz 17.49552 $Void
164 pz 17.5387  $Poly 17
165 pz 17.85366 $Poly inserts 17, 53, 42, 43
166 pz 18.48866 $Re 15, 16
167 pz 18.50390 $Void
168 pz 18.52676 $Lamination
169 pz 18.53438 $Foils 20B, 21B, 22B, 23B
170 pz 18.542   $Lamination
171 pz 18.54962 $Void
172 pz 18.5928  $Poly 19
173 pz 18.90776 $Poly inserts 14, 23, 32, 30
174 pz 19.54276 $Re 17, 18
175 pz 19.55800 $Void
176 pz 19.58086 $Lamination
177 pz 19.58848 $Foils 24B, 25B, 26B, 1C
178 pz 19.5961  $Lamination
179 pz 19.60372 $Void
180 pz 19.6469  $Poly 20
181 pz 19.96186 $Poly inserts 2, 1, 4, 3
182 pz 20.59686 $Re 19, 20
183 pz 20.61210 $Void
184 pz 20.63496 $Lamination
185 pz 20.64258 $Foils 2C, 3C
186 pz 20.65020 $Lamination
187 pz 20.65782 $Void
188 pz 20.7010  $Poly 27
189 pz 23.2410  $Poly 28
190 pz 25.7810  $Poly 29
191 pz 28.3210  $Poly 30
192 pz 30.8610  $Top of Assembly
300 so 200      $Outer World

C Data Cards
m1    1001.66c    8.3376e-2    $Poly Reflector 1
      6000.66c    4.1688e-2
mt1   poly.60t
m2    1001.66c    8.3376e-2    $Poly Reflector 2
      6000.66c    4.1688e-2
mt2   poly.60t
m3    1001.66c    8.3461e-2    $Poly Reflector 3
      6000.66c    4.1731e-2
mt3   poly.60t
m4    1001.66c    8.3032e-2    $Poly Reflector 4
      6000.66c    4.1516e-2
mt4   poly.60t
m5    92234.66c   5.0557e-4     $HEU 1A
      92235.66c   4.1392e-2
      92236.66c   1.1410e-4
      92238.66c   2.3566e-3
m6    92234.66c   5.2240e-4     $HEU 2A
      92235.66c   4.2770e-2
      92236.66c   1.1790e-4
      92238.66c   2.4350e-3
m7    92234.66c   5.2313e-4     $HEU 3A
      92235.66c   4.2830e-2
      92236.66c   1.1806e-4
      92238.66c   2.4384e-3
m8    92234.66c   5.0849e-4     $HEU 4A
      92235.66c   4.1631e-2
      92236.66c   1.1476e-4
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      92238.66c   2.3702e-3
m9    92234.66c   5.1876e-4     $HEU 5A
      92235.66c   4.2471e-2
      92236.66c   1.1708e-4
      92238.66c   2.4180e-3
m10   92234.66c   5.1435e-4     $HEU 6A
      92235.66c   4.2111e-2
      92236.66c   1.1608e-4
      92238.66c   2.3975e-3
m11   92234.66c   5.1730e-4     $HEU 7A
      92235.66c   4.2352e-2
      92236.66c   1.1675e-4
      92238.66c   2.4112e-3
m12   92234.66c   5.2094e-4     $HEU 8A
      92235.66c   4.2651e-2
      92236.66c   1.1757e-4
      92238.66c   2.4282e-3
m13   92234.66c   5.2240e-4     $HEU 9A
      92235.66c   4.2270e-2
      92236.66c   1.1790e-4
      92238.66c   2.4350e-3
m14   92234.66c   5.2608e-4     $HEU 10A
      92235.66c   4.3071e-2
      92236.66c   1.1873e-4
      92238.66c   2.4522e-3
m15   92234.66c   5.3048e-4     $HEU 11A
      92235.66c   4.3432e-2
      92236.66c   1.1972e-4
      92238.66c   2.4727e-3
m16   92234.66c   5.2240e-4     $HEU 12A
      92235.66c   4.2770e-2
      92236.66c   1.1790e-4
      92238.66c   2.4350e-3
m17   92234.66c   5.1581e-4     $HEU 13A
      92235.66c   4.2230e-2
      92236.66c   1.1641e-4
      92238.66c   2.4043e-3
m18   92234.66c   5.0557e-4     $HEU 1B
      92235.66c   4.1392e-2
      92236.66c   1.1410e-4
      92238.66c   2.3566e-3
m19   92234.66c   4.9824e-4     $HEU 2B
      92235.66c   4.0792e-2
      92236.66c   1.1245e-4
      92238.66c   2.3224e-3
m20   92234.66c   4.8357e-4     $HEU 3B
      92235.66c   3.9591e-2
      92236.66c   1.0914e-4
      92238.66c   2.2540e-3
m21   92234.66c   4.6892e-4     $HEU 4B
      92235.66c   3.8391e-2
      92236.66c   1.0583e-4
      92238.66c   2.1857e-3
m22   92234.66c   4.9089e-4     $HEU 5B
      92235.66c   4.0190e-2
      92236.66c   1.1079e-4
      92238.66c   2.2882e-3
m23   92234.66c   4.9089e-4     $HEU 6B
      92235.66c   4.0190e-2
      92236.66c   1.1079e-4
      92238.66c   2.2882e-3
m24   92234.66c   4.7625e-4     $HEU 7B
      92235.66c   3.8991e-2
      92236.66c   1.0748e-4
      92238.66c   2.2199e-3
m25   92234.66c   5.0557e-4     $HEU 8B
      92235.66c   4.1392e-2
      92236.66c   1.1410e-4
      92238.66c   2.3566e-3
m26   92234.66c   4.8357e-4     $HEU 9B
      92235.66c   3.9591e-2
      92236.66c   1.0914e-4
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      92238.66c   2.2540e-3
m27   92234.66c   4.9089e-4      $HEU 10B
      92235.66c   4.0190e-2
      92236.66c   1.1079e-4
      92238.66c   2.2882e-3
m28   92234.66c   5.2021e-4      $HEU 11B
      92235.66c   4.2591e-2
      92236.66c   1.1741e-4
      92238.66c   2.4248e-3
m29   92234.66c   5.1289e-4      $HEU 12B
      92235.66c   4.1991e-2
      92236.66c   1.1575e-4
      92238.66c   2.3907e-3
m30   92234.66c   4.7625e-4      $HEU 13B
      92235.66c   3.8991e-2
      92236.66c   1.0748e-4
      92238.66c   2.2199e-3
m31   92234.66c   4.9089e-4      $HEU 14B
      92235.66c   4.0190e-2
      92236.66c   1.1079e-4
      92238.66c   2.2882e-3
m32   92234.66c   4.8357e-4      $HEU 15B
      92235.66c   3.9591e-2
      92236.66c   1.0914e-4
      92238.66c   2.2540e-3
m33   92234.66c   5.0557e-4      $HEU 16B
      92235.66c   4.1392e-2
      92236.66c   1.1410e-4
      92238.66c   2.3566e-3
m34   92234.66c   4.8357e-4      $HEU 17B
      92235.66c   3.9591e-2
      92236.66c   1.0914e-4
      92238.66c   2.2540e-3
m35   92234.66c   4.7625e-4      $HEU 18B
      92235.66c   3.8991e-2
      92236.66c   1.0748e-4
      92238.66c   2.2199e-3
m36   92234.66c   4.9824e-4      $HEU 19B
      92235.66c   4.0792e-2
      92236.66c   1.1245e-4
      92238.66c   2.3224e-3
m37   92234.66c   4.9089e-4      $HEU 20B
      92235.66c   4.0190e-2
      92236.66c   1.1079e-4
      92238.66c   2.2882e-3
m38   92234.66c   5.0557e-4      $HEU 21B
      92235.66c   4.1392e-2
      92236.66c   1.1410e-4
      92238.66c   2.3566e-3
m39   92234.66c   5.0557e-4      $HEU 22B
      92235.66c   4.1392e-2
      92236.66c   1.1410e-4
      92238.66c   2.3566e-3
m40   92234.66c   5.0557e-4      $HEU 23B
      92235.66c   4.1392e-2
      92236.66c   1.1410e-4
      92238.66c   2.3566e-3
m41   92234.66c   4.9089e-4      $HEU 24B
      92235.66c   4.0190e-2
      92236.66c   1.1079e-4
      92238.66c   2.2882e-3
m42   92234.66c   4.9089e-4      $HEU 25B
      92235.66c   4.0190e-2
      92236.66c   1.1079e-4
      92238.66c   2.2882e-3
m43   92234.66c   4.6892e-4      $HEU 26B
      92235.66c   3.8391e-2
      92236.66c   1.0583e-4
      92238.66c   2.1857e-3
m44   92234.66c   5.2021e-4      $HEU 1C
      92235.66c   4.2591e-2
      92236.66c   1.1741e-4
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      92238.66c   2.4248e-3
m45   92234.66c   5.2021e-4     $HEU 2C
      92235.66c   4.2591e-2
      92236.66c   1.1741e-4
      92238.66c   2.4248e-3
m46   92234.66c   5.2021e-4     $HEU 3C
      92235.66c   4.2591e-2
      92236.66c   1.1741e-4
      92238.66c   2.4248e-3
m47   1001.66c    8.8184e-2     $Poly Lamination 1A
      6000.66c    4.4092e-2
mt47  poly.60t
m48   1001.66c    8.8184e-2     $Poly Lamination 2A
      6000.66c    4.4092e-2
mt48  poly.60t
m49   1001.66c    8.9043e-2     $Poly Lamination 3A
      6000.66c    4.4521e-2
mt49  poly.60t
m50   1001.66c    8.6467e-2     $Poly Lamination 4A
      6000.66c    4.3233e-2
mt50  poly.60t
m51   1001.66c    8.9987e-2     $Poly Lamination 5A
      6000.66c    4.4994e-2
mt51  poly.60t
m52   1001.66c    8.9987e-2     $Poly Lamination 6A
      6000.66c    4.4994e-2
mt52  poly.60t
m53   1001.66c    8.3805e-2     $Poly Lamination 7A
      6000.66c    4.1902e-2
mt53  poly.60t
m54   1001.66c    8.9987e-2     $Poly Lamination 8A
      6000.66c    4.4994e-2
mt54  poly.60t
m55   1001.66c    8.9043e-2     $Poly Lamination 9A
      6000.66c    4.4521e-2
mt55  poly.60t
m56   1001.66c    8.9987e-2     $Poly Lamination 10A
      6000.66c    4.4994e-2
mt56  poly.60t
m57   1001.66c    8.6467e-2     $Poly Lamination 11A
      6000.66c    4.3233e-2
mt57  poly.60t
m58   1001.66c    8.8184e-2     $Poly Lamination 12A
      6000.66c    4.4092e-2
mt58  poly.60t
m59   1001.66c    8.7325e-2     $Poly Lamination 13A
      6000.66c    4.3663e-2
mt59  poly.60t
m60   1001.66c    7.8567e-2     $Poly Lamination 1B
      6000.66c    3.9284e-2
mt60  poly.60t
m61   1001.66c    9.6084e-2     $Poly Lamination 2B
      6000.66c    4.8042e-2
mt61  poly.60t
m62   1001.66c    8.7325e-2     $Poly Lamination 3B
      6000.66c    4.3663e-2
mt62  poly.60t
m63   1001.66c    8.7325e-2     $Poly Lamination 4B
      6000.66c    4.3663e-2
mt63  poly.60t
m64   1001.66c    8.7325e-2     $Poly Lamination 5B
      6000.66c    4.3663e-2
mt64  poly.60t
m65   1001.66c    9.6084e-2     $Poly Lamination 6B
      6000.66c    4.8042e-2
mt65  poly.60t
m66   1001.66c    8.7325e-2     $Poly Lamination 7B
      6000.66c    4.3663e-2
mt66  poly.60t
m67   1001.66c    7.8567e-2     $Poly Lamination 8B
      6000.66c    3.9284e-2
mt67  poly.60t
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m68   1001.66c    8.7325e-2     $Poly Lamination 9B
      6000.66c    4.3663e-2
mt68  poly.60t
m69   1001.66c    8.7325e-2     $Poly Lamination 10B
      6000.66c    4.3663e-2
mt69  poly.60t
m70   1001.66c    8.7325e-2     $Poly Lamination 11B
      6000.66c    4.3663e-2
mt70  poly.60t
m71   1001.66c    9.6084e-2     $Poly Lamination 12B
      6000.66c    4.8042e-2
mt71  poly.60t
m72   1001.66c    9.6084e-2     $Poly Lamination 13B
      6000.66c    4.8042e-2
mt72  poly.60t
m73   1001.66c    8.7325e-2     $Poly Lamination 14B
      6000.66c    4.3663e-2
mt73  poly.60t
m74   1001.66c    8.7325e-2     $Poly Lamination 15B
      6000.66c    4.3663e-2
mt74  poly.60t
m75   1001.66c    8.7325e-2     $Poly Lamination 16B
      6000.66c    4.3663e-2
mt75  poly.60t
m76   1001.66c    9.6084e-2     $Poly Lamination 17B
      6000.66c    4.8042e-2
mt76  poly.60t
m77   1001.66c    8.7325e-2     $Poly Lamination 18B
      6000.66c    4.3663e-2
mt77  poly.60t
m78   1001.66c    8.7325e-2     $Poly Lamination 19B
      6000.66c    4.3663e-2
mt78  poly.60t
m79   1001.66c    9.6084e-2     $Poly Lamination 20B
      6000.66c    4.8042e-2
mt79  poly.60t
m80   1001.66c    8.7325e-2     $Poly Lamination 21B
      6000.66c    4.3663e-2
mt80  poly.60t
m81   1001.66c    8.7325e-2     $Poly Lamination 22B
      6000.66c    4.3663e-2
mt81  poly.60t
m82   1001.66c    9.6084e-2     $Poly Lamination 23B
      6000.66c    4.8042e-2
mt82  poly.60t
m83   1001.66c    9.6084e-2     $Poly Lamination 24B
      6000.66c    4.8042e-2
mt83  poly.60t
m84   1001.66c    8.7325e-2     $Poly Lamination 25B
      6000.66c    4.3663e-2
mt84  poly.60t
m85   1001.66c    8.7325e-2     $Poly Lamination 26B
      6000.66c    4.3663e-2
mt85  poly.60t
m86   1001.66c    8.7325e-2     $Poly Lamination 1C
      6000.66c    4.3663e-2
mt86  poly.60t
m87   1001.66c    8.7325e-2     $Poly Lamination 2C
      6000.66c    4.3663e-2
mt87  poly.60t
m88   1001.66c    9.6084e-2     $Poly Lamination 3C
      6000.66c    4.8042e-2
mt88  poly.60t
m90   1001.66c    8.2088e-2    $Poly Moderator 8
      6000.66c    4.1044e-2
mt90  poly.60t
m91   1001.66c    8.2002e-2    $Poly Moderator 13
      6000.66c    4.1001e-2
mt91  poly.60t
m92   1001.66c    8.1916e-2    $Poly Moderator 14
      6000.66c    4.0958e-2
mt92  poly.60t
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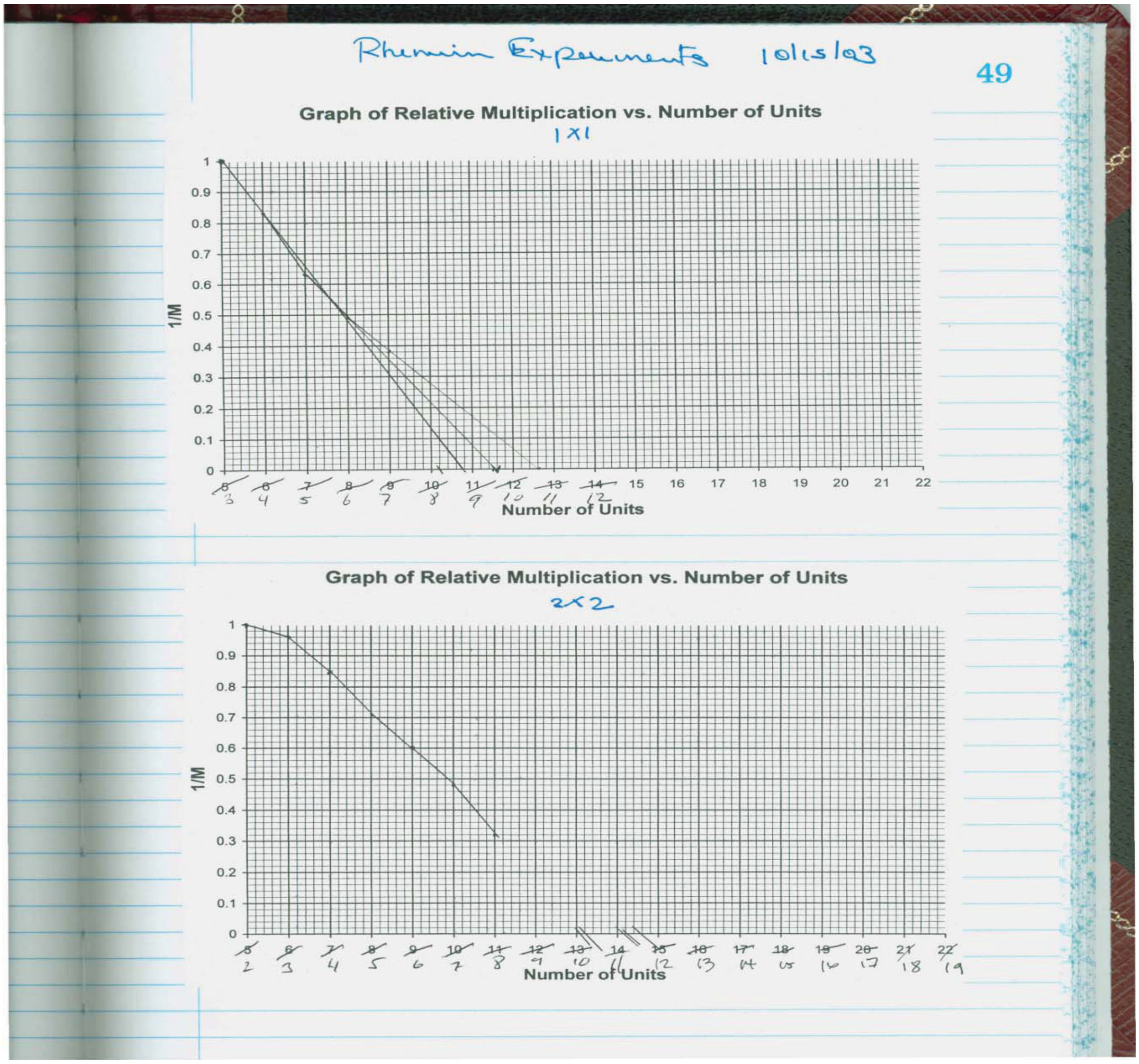
m93   1001.66c    8.1916e-2    $Poly Moderator 6A
      6000.66c    4.0958e-2
mt93  poly.60t
m94   1001.66c    8.1916e-2    $Poly Moderator B
      6000.66c    4.0958e-2
mt94  poly.60t
m95   1001.66c    8.2431e-2    $Poly Moderator 16S
      6000.66c    4.1216e-2
mt95  poly.60t
m96   1001.66c    8.2259e-2    $Poly Moderator 18
      6000.66c    4.1130e-2
mt96  poly.60t
m97   1001.66c    8.2517e-2    $Poly Moderator 17
      6000.66c    4.1258e-2
mt97  poly.60t
m98   1001.66c    8.2689e-2    $Poly Moderator 19
      6000.66c    4.1344e-2
mt98  poly.60t
m99   1001.66c    8.2603e-2    $Poly Moderator 20
      6000.66c    4.1301e-2
mt99  poly.60t
m100  1001.66c    8.2689e-2    $Poly Insert 45
      6000.66c    4.1344e-2
mt100 poly.60t
m101  1001.66c    8.2946e-2    $Poly Insert 49
      6000.66c    4.1473e-2
mt101 poly.60t
m102  1001.66c    8.3032e-2    $Poly Insert 51
      6000.66c    4.1516e-2
mt102 poly.60t
m103  1001.66c    8.3290e-2    $Poly Insert 52
      6000.66c    4.1645e-2
mt103 poly.60t
m104  1001.66c    8.3032e-2    $Poly Insert 50
      6000.66c    4.1516e-2
mt104 poly.60t
m105  1001.66c    8.2946e-2    $Poly Insert 48
      6000.66c    4.1473e-2
mt105 poly.60t
m106  1001.66c    8.2689e-2    $Poly Insert 44
      6000.66c    4.1344e-2
mt106 poly.60t
m107  1001.66c    8.3032e-2    $Poly Insert 60
      6000.66c    4.1516e-2
mt107 poly.60t
m108  1001.66c    8.3048e-2    $Poly Insert 16
      6000.66c    4.1516e-2
mt108 poly.60t
m109  1001.66c    8.3048e-2    $Poly Insert 61
      6000.66c    4.1516e-2
mt109 poly.60t
m110  1001.66c    8.1658e-2    $Poly Insert 18
      6000.66c    4.0829e-2
mt110 poly.60t
m111  1001.66c    8.3461e-2    $Poly Insert 27
      6000.66c    4.1731e-2
mt111 poly.60t
m112  1001.66c    8.2689e-2    $Poly Insert 29
      6000.66c    4.1344e-2
mt112 poly.60t
m113  1001.66c    8.2860e-2    $Poly Insert 40
      6000.66c    4.1430e-2
mt113 poly.60t
m114  1001.66c    8.2345e-2    $Poly Insert 57
      6000.66c    4.1173e-2
mt114 poly.60t
m115  1001.66c    8.2345e-2    $Poly Insert 59
      6000.66c    4.1173e-2
mt115 poly.60t
m116  1001.66c    8.3290e-2    $Poly Insert 28
      6000.66c    4.1645e-2
mt116 poly.60t
```

```
m117  1001.66c    8.3118e-2    $Poly Insert 34
      6000.66c    4.1559e-2
mt117 poly.60t
m118  1001.66c    8.3376e-2    $Poly Insert 31
      6000.66c    4.1688e-2
mt118 poly.60t
m119  1001.66c    8.2860e-2    $Poly Insert 33
      6000.66c    4.1430e-2
mt119 poly.60t
m120  1001.66c    8.1658e-2    $Poly Insert 20
      6000.66c    4.0829e-2
mt120 poly.60t
m121  1001.66c    8.2431e-2    $Poly Insert 19
      6000.66c    4.1216e-2
mt121 poly.60t
m122  1001.66c    8.2173e-2    $Poly Insert 22
      6000.66c    4.1087e-2
mt122 poly.60t
m123  1001.66c    8.1057e-2    $Poly Insert 21
      6000.66c    4.0529e-2
mt123 poly.60t
m124  1001.66c    8.3204e-2    $Poly Insert 47
      6000.66c    4.1602e-2
mt124 poly.60t
m125  1001.66c    8.2173e-2    $Poly Insert 56
      6000.66c    4.1087e-2
mt125 poly.60t
m126  1001.66c    8.1401e-2    $Poly Insert 13
      6000.66c    4.0700e-2
mt126 poly.60t
m127  1001.66c    8.2774e-2    $Poly Insert 54
      6000.66c    4.1387e-2
mt127 poly.60t
m128  1001.66c    8.1744e-2    $Poly Insert 17
      6000.66c    4.0872e-2
mt128 poly.60t
m129  1001.66c    8.2517e-2    $Poly Insert 53
      6000.66c    4.1258e-2
mt129 poly.60t
m130  1001.66c    8.2774e-2    $Poly Insert 42
      6000.66c    4.1387e-2
mt130 poly.60t
m131  1001.66c    8.2860e-2    $Poly Insert 43
      6000.66c    4.1430e-2
mt131 poly.60t
m132  1001.66c    8.1658e-2    $Poly Insert 14
      6000.66c    4.0829e-2
mt132 poly.60t
m133  1001.66c    8.1229e-2    $Poly Insert 23
      6000.66c    4.0614e-2
mt133 poly.60t
m134  1001.66c    8.2173e-2    $Poly Insert 32
      6000.66c    4.1087e-2
mt134 poly.60t
m135  1001.66c    8.2774e-2    $Poly Insert 30
      6000.66c    4.1387e-2
mt135 poly.60t
m136  1001.66c    8.1401e-2    $Poly Insert 2
      6000.66c    4.0700e-2
mt136 poly.60t
m137  1001.66c    8.1229e-2    $Poly Insert 1
      6000.66c    4.0614e-2
mt137 poly.60t
m138  1001.66c    8.2002e-2    $Poly Insert 4
      6000.66c    4.1001e-2
mt138 poly.60t
m139  1001.66c    8.1315e-2    $Poly Insert 3
      6000.66c    4.0657e-2
mt139 poly.60t
m140  1001.66c    8.2689e-2    $Poly Reflector 27
      6000.66c    4.1344e-2
mt140 poly.60t
```

```
m141  1001.66c    8.3032e-2    $Poly reflector 28
      6000.66c    4.1516e-2
mt141 poly.60t
m142  1001.66c    8.2689e-2    $Poly Reflector 29
      6000.66c    4.1344e-2
mt142 poly.60t
m143  1001.66c    8.2689e-2    $Poly Reflector 30
      6000.66c    4.1344e-2
mt143 poly.60t
m144  75185.66c 2.1522e-2 $Rhenium 1-9
      75187.66c 3.5637e-2
m145  75185.66c 2.2194e-2 $Rhenium 10
      75187.66c 3.6751e-2
m146  75185.66c 2.1497e-2 $Rhenium 11
      75187.66c 3.5597e-2
m147  75185.66c 2.0956e-2 $Rhenium 12
      75187.66c 3.4700e-2
m148  75185.66c 2.1266e-2 $Rhenium 13
      75187.66c 3.5214e-2
m149  75185.66c 1.9719e-2 $Rhenium 14
      75187.66c 3.2652e-2
m150  75185.66c 2.1962e-2 $Rhenium 15
      75187.66c 3.6366e-2
m151  75185.66c 2.0801e-2 $Rhenium 16
      75187.66c 3.4444e-2
m152  75185.66c 2.2271e-2 $Rhenium 17
      75187.66c 3.6878e-2
m153  75185.66c 2.0029e-2 $Rhenium 18
      75187.66c 3.3165e-2
m154  75185.66c 2.2426e-2 $Rhenium 19
      75187.66c 3.7134e-2
m155  75185.66c 2.1034e-2 $Rhenium 20
      75187.66c 3.4826e-2
totnu
MODE N
IMP:N 1 185r 0
kcode 5000 1.0 50 1250
ksrc  0.1 0.1 10.104
      0.1 0.1 11.159
      0.1 0.1 12.213
      0.1 0.1 13.267
      0.1 0.1 14.321
      0.1 0.1 15.376
      0.1 0.1 16.429
      0.1 0.1 17.484
      0.1 0.1 18.538
      0.1 0.1 19.592
      0.1 0.1 20.646
```

APPENDIX B: LOGBOOK INFORMATION



Rhenium Experiments 10/15/03

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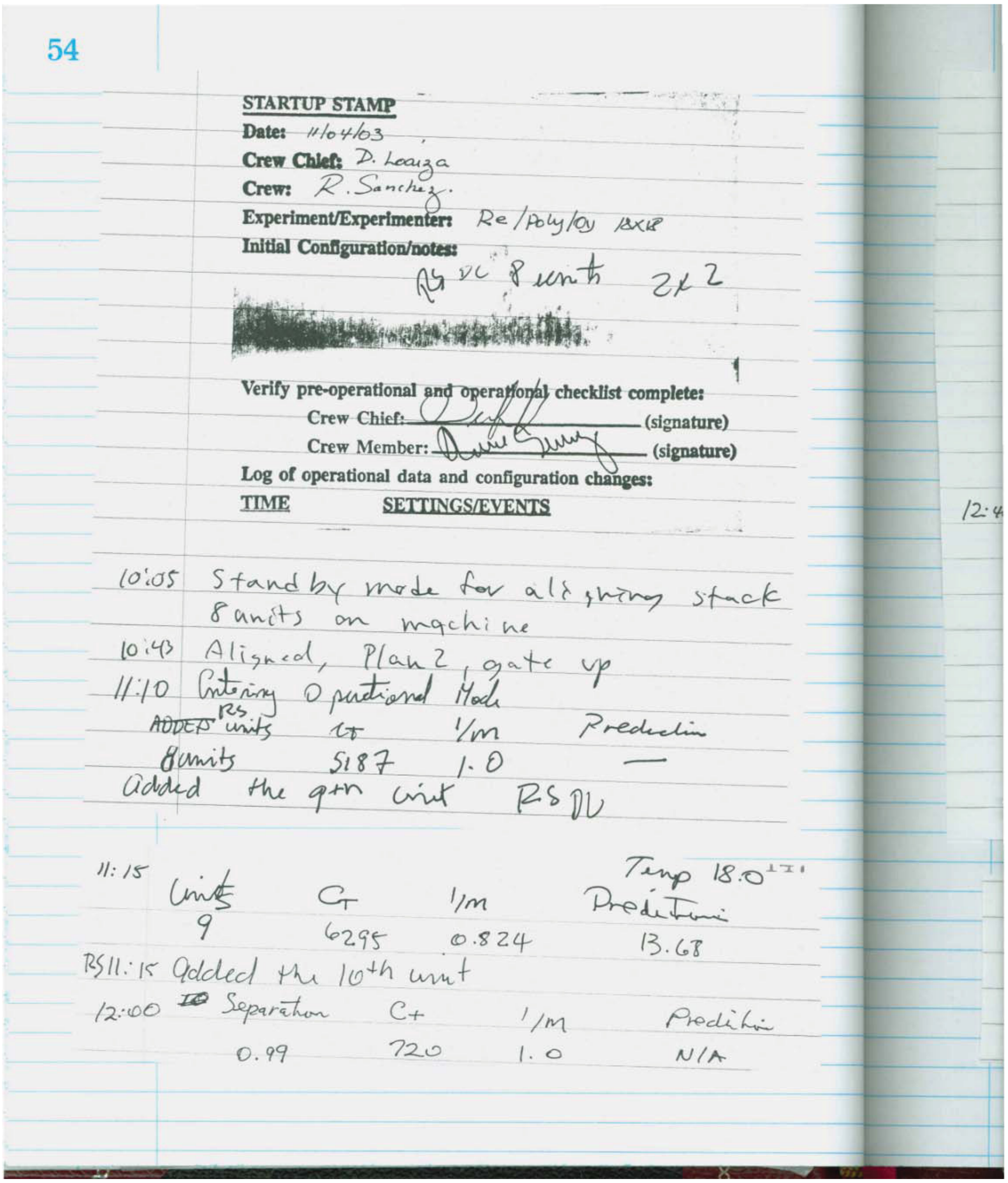
Graph of Relative Multiplication vs. Number of Units

1x1

Graph of Relative Multiplication vs. Number of Units

2x2



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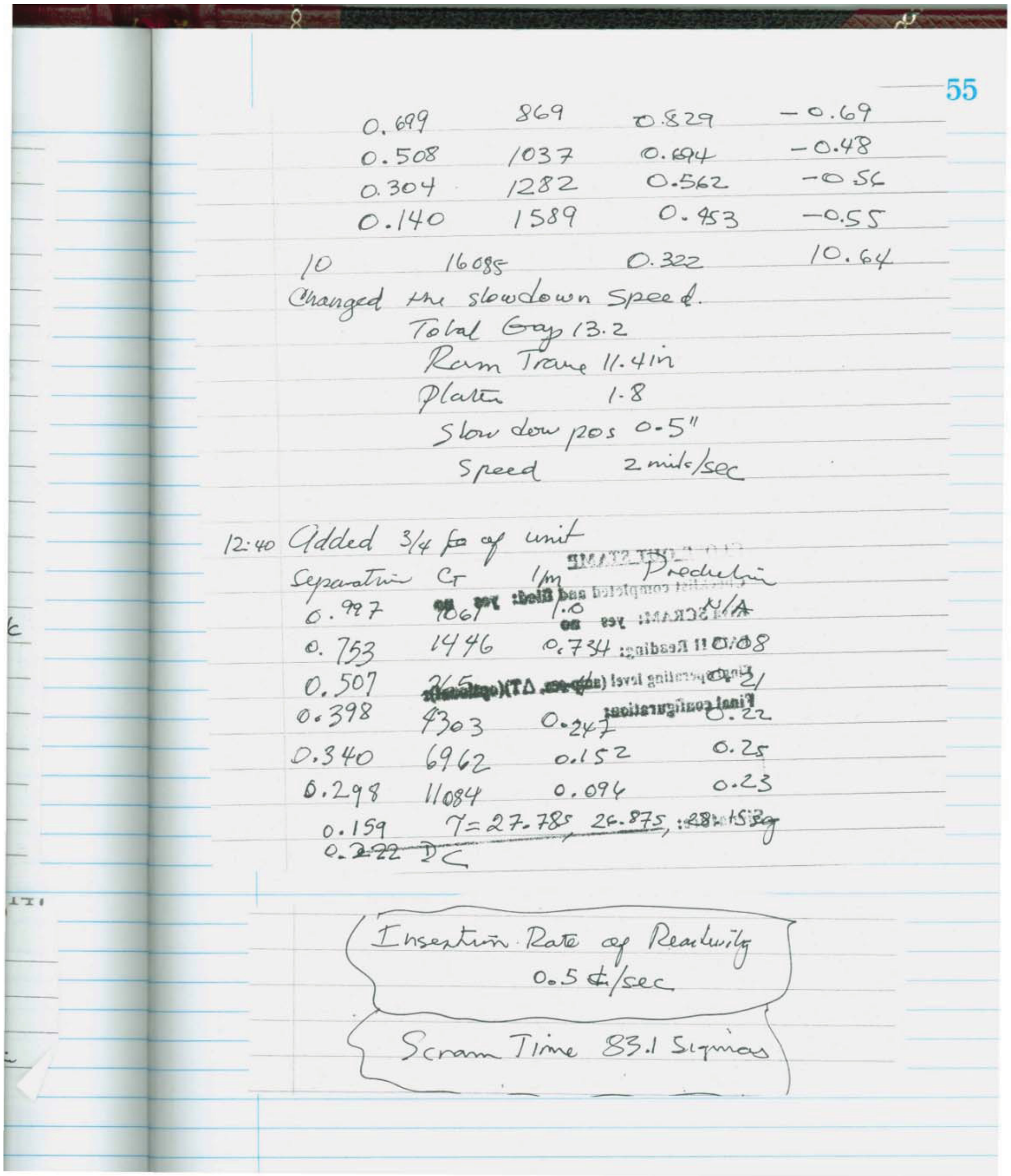
STARTUP STAMP
Date: 11/04/03
Crew Chief: D. Loaiza
Crew: R. Sanchez.
Experiment/Experimenter: Re/Poly/Cu 18x18
Initial Configuration/notes:
RS DC 8 units 2x2
[redacted]

Verify pre-operational and operational checklist complete:
Crew Chief: ______ (signature)
Crew Member: ______ (signature)
Log of operational data and configuration changes:
TIME **SETTINGS/EVENTS**

12:4

10:05 Standby mode for aligning stack
8 units on machine
10:43 Aligned, Plan 2, gate up
11:10 Entering Operational Mode
~~ADDED~~ RS units Ct 1/m Prediction
8 units 5187 1.0 —
Added the 9th unit RS DL

11:15 Temp 18.0 ℃
Units Ct 1/m Prediction
9 6295 0.824 13.68
RS 11:15 Added the 10th unit
12:00 ~~IO~~ Separation Ct 1/m Prediction
0.99 720 1.0 N/A



55

0.699	869	0.829	−0.69
0.508	1037	0.694	−0.48
0.304	1282	0.562	−0.56
0.140	1589	0.453	−0.55
10	16085	0.322	10.64

Changed the slowdown speed.

Total Gap 13.2
Ram Trave 11.4in
Platen 1.8
Slow dow pos 0.5"
Speed 2 mils/sec

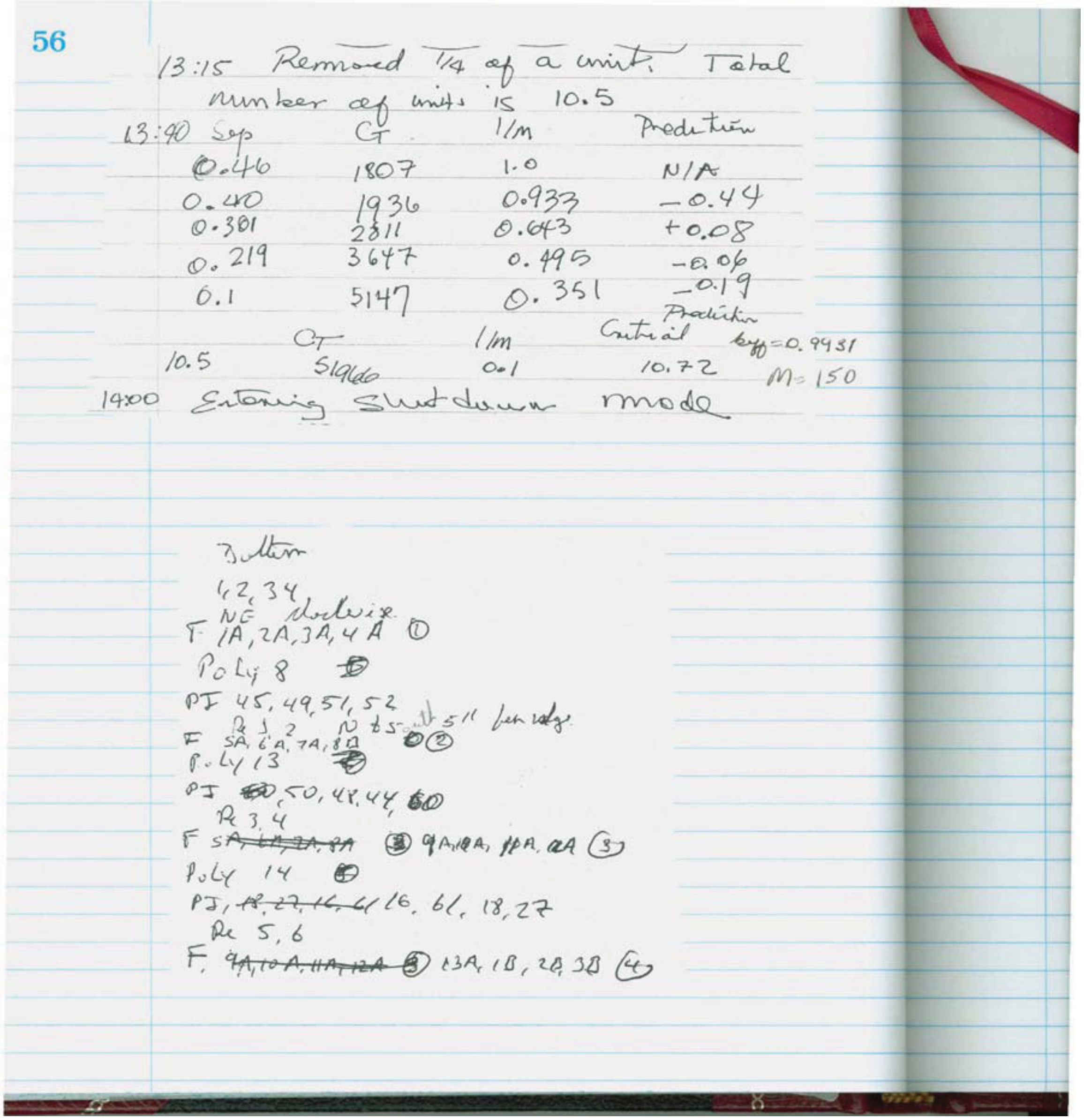
12:40 Added 3/4 fo of unit

Separation	C_T	1/m	Prediction
0.997	1061	1.0	N/A
0.753	1446	0.734	0.08
0.507	265		0.21
0.398	4303	0.247	0.22
0.340	6962	0.152	0.25
0.298	11084	0.094	0.23

0.159 τ = 27.785, 26.875, 28.15
0.222 DC

Insertion Rate of Reactivity
0.5 ¢/sec

Scram Time 83.1 Sigmas



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13:15 Removed 1/4 of a unit. Total number of units is 10.5

13:40 Sep	CT	1/m	Prediction
0.46	1807	1.0	N/A
0.40	1936	0.933	−0.44
0.381	2811	0.643	+0.08
0.219	3647	0.495	−0.06
0.1	5147	0.351	−0.19

	CT	1/m	Prediction Critical
10.5	51966	0.1	10.72

keff = 0.9931
M = 150

1400 Entering shutdown mode

Bottom

1, 2, 3 4,
NE clockwise
F 1A, 2A, 3A, 4A ①
Poly 8 [illegible]
PJ 45, 49, 51, 52
Re 1, 2 N to south 5" from edge
F 5A, 6A, 7A, 8A [illegible] ②
Poly 13 [illegible]
PJ [illegible], 50, 48, 44, [illegible]
Re 3, 4
F 5~~A, 6A, 7A, 8A~~ [illegible] 9A, 10A, 11A, 12A ③
Poly 14 [illegible]
PJ, ~~48, 27, 16, 61~~ 16, 61, 18, 27
Re 5, 6
F, ~~9A, 10A, 11A, 12A~~ [illegible] 13A, 1B, 2B, 3B ④