LLNL-TR-849789

TEX-HEU Baseline Assemblies: Highly Enriched Uranium Plates with Polyethylene Moderator and Polyethylene Reflector

IER-297 CED-4b

Jesse Norris, Ruby Araj, David Heinrichs, and Catherine Percher

Lawrence Livermore National Laboratory

Michael Zerkle

Naval Nuclear Laboratory

External Audience (Unlimited)

June 30, 2023

Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

Acknowledgements

This work was supported by the Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy. The Criticality Experiment Design Team (CEdT) consisted of Theresa Cutler (Los Alamos National Laboratory), Michael Zerkle (Naval Nuclear Laboratory), William Marshall (Oak Ridge National Laboratory), Joetta Goda (Los Alamos National Laboratory), Catherine Percher (Lawrence Livermore National Laboratory), and Mariya Brovchenko (Institut de Radioprotection et de Sûreté Nucléaire).

These experiments were executed at the National Critical Experiments Research Center (NCERC) under the operation of Los Alamos National Laboratory's Advanced Nuclear Technology Group (NEN-2). We thank the NEN-2 experimenters directly involved in this campaign: David Hayes, Joetta Goda, Rene Sanchez, Travis Grove, Jesson Hutchinson, George McKenzie, Theresa Cutler, Jessie Walker, Nicholas Thompson, Alex McSpaden, Kenneth Valdez, and Justin Martin. We also thank Nick Wynne, with review by Chris Romero, for hardware design. Finally, we thank NCERC-FO and Mission Support and Test Services (MSTS) for their facility support. All experiment photos are courtesy of NEN-2.

This work was reviewed and accepted by the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Technical Review Group (TRG) during the December 2021 meeting. The ICSBEP is an expert group organized by the Working Party on Nuclear Criticality Safety (WPNCS) under the Nuclear Energy Agency (NEA) within the framework of the Organisation for Economic Co-operation and Development (OECD). We thank the entire TRG for their detailed review of this work and many comments. Additionally, we thank the TRG Subgroup for their final review and approval: Michael Zerkle (Naval Nuclear Laboratory), Jeffrey Favorite (Los Alamos National Laboratory), Catherine Percher (Lawrence Livermore National Laboratory), and David Heinrichs (Lawrence Livermore National Laboratory).

Table of Contents

TEX-HEU BASELINE ASSEMBLIES: HIGHLY ENRICHED URANIUM PLATES WITH POLYETHYLENE MODERATOR AND POLYETHYLENE REFLECTOR

Evaluators

Jesse Norris
Ruby Araj
Lawrence Livermore National Laboratory

Internal Reviewers

David Heinrichs
Catherine Percher
Lawrence Livermore National Laboratory

Independent Reviewer

Michael Zerkle
Naval Nuclear Laboratory

TEX-HEU BASELINE ASSEMBLIES: HIGHLY ENRICHED URANIUM PLATES WITH POLYETHYLENE MODERATOR AND POLYETHYLENE REFLECTOR

IDENTIFICATION NUMBER: HEU-MET-MIXED-021

KEY WORDS: critical experiment, highly enriched uranium, metal, high-density polyethylene, polyethylene-moderated, polyethylene-reflected, Comet, Jemima

1.0 DETAILED DESCRIPTION

1.1 Overview of Experiment

This experiment provides the baseline experimental configurations for TEX-HEU. The purpose of the TEX-HEU design is to provide multiple configurations that span the entire neutron energy spectrum and can be easily modified to incorporate diluent materials. Future experiments utilizing the TEX-HEU design are planned to incorporate hafnium, lithium, and chlorine as diluent materials. Five experimental configurations were judged to be acceptable critical benchmark experiments.

The main parameter that is varied between the experimental configurations is the thickness, or presence, of high-density polyethylene (HDPE) plates between the highly enriched uranium (HEU) plates. Varying these HDPE plates allows the fission fractions to be majority fast (Case 1), intermediate (Cases 2-4), and thermal (Case 5). These fission fractions are based on calculation and reported in Table 1.

Table 1. Comparison of the HDPE plate thicknesses and resulting fission fractions grouped by neutron energy regime (based on calculation).

Case	Nominal Moderator Thickness, in (cm)	Calculated Fission Fractions		
		Thermal (< 0.625 eV)	Intermediate (0.625 eV – 100 keV)	Fast (> 100 keV)
1	-	0.079	0.205	0.716
2	0.125 (0.3175)	0.138	0.497	0.365
3	0.250 (0.6350)	0.229	0.515	0.256
4	0.500 (1.2700)	0.389	0.437	0.174
5	1.500 (3.8100)	0.630	0.258	0.112

These experiments were funded by the U.S. Department of Energy's Nuclear Criticality Safety Program and conducted between February and June 2020 at the National Critical Experiments Research Center (NCERC) at the Nevada National Security Site in the United States of America. They were executed as a collaboration between Lawrence Livermore National Laboratory's Nuclear Criticality Safety Division and Los Alamos National Laboratory's (LANL) Advanced Nuclear Technology Group with the facility support of NCERC-FO and Mission Support and Test Services.

The HEU plates used in this experiment have a long history in many critical experiments executed by LANL. The earliest usage of similar HEU plates is in the "extension of the earlier Jemima experiments" in 1956, which used 0.118 in (0.29972 cm) thick U(93.4) plates with a 15 in (38.1 cm) outer diameter (IEU-MET-

FAST-002). Since then, these same HEU plates have been used in the Big Ten experiments in the 1970s (IEU-MET-FAST-007), the first three Zeus experiments in 1999-2002 (HEU-MET-INTER-006, HEU-MET-FAST-073, and HEU-MET-FAST-072), and the Nb-1Zr experiment in 2004 (HEU-MET-FAST-047).

1.2 Description of Experimental Configuration

1.2.1 Design of the Critical Assembly

Figure 1 shows a rendering of the TEX-HEU experiment design. The main parameter that is varied between these experiments is the thickness of the polyethylene moderator plates. Varying this thickness allows the neutron spectrum to be varied between majority thermal, intermediate, and fast. The mass of the HEU is then changed by adding or removing plates. Finally, the thickness of the upper reflector is adjusted in increments of 1/32 in (0.079375 cm) to provide fine reactivity adjustments. The polyethylene ring reflector height is adjusted to match the HEU and polyethylene plate stack to the nearest 1/32 in (0.079375 cm).

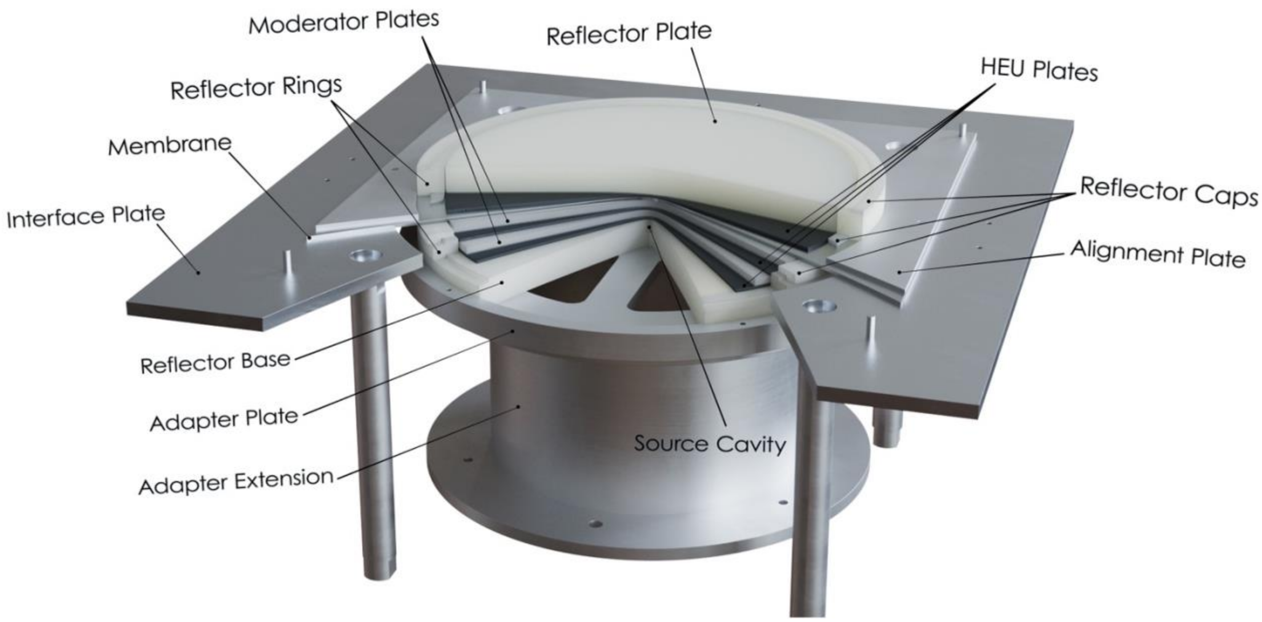


Figure 1. TEX-HEU experiment design and components.

1.2.2 Comet General Purpose Critical Assembly Machine

The Comet General Purpose Critical Assembly Machine is a vertical lift machine (VLM) used to remotely assemble a critical mass. As shown in Figure 2, Comet consists of the surrounding structure, stationary platform, and movable platen. For TEX-HEU, additional parts were affixed to Comet: an experiment platform, affixed to the stationary platform, and a lower adapter, extending the movable platen. The following sections describe these additional parts and associated design drawings are included in Appendix C.

During assembly, roughly half of the experiment is built on the upper experiment platform with the other half on the lower adapter. During operation, the movable platen is extended vertically to bring the two halves of the experiment into contact. Once fully assembled, the two halves are only separated by a thin aluminum membrane.

Figure 2. The Comet General Purpose Critical Assembly Machine.

1.2.2.1 Stationary Platform

The experiment platform holds the upper half of the experiment, shown in Figure 3. The platform consists of an interface plate and four standoffs, which connect the interface plate to the stationary platform. The membrane is placed on top of the hole in the interface plate, allowing the movable platen to lift the lower half of the experiment as it meets the upper half of the experiment through the membrane. The interface plate includes four pegs to hold the membrane and alignment plate in place while still allowing vertical movement. Schematics showing the dimensions of the interface plate, standoffs, and membrane are included in Figure 64, Figure 65, and Figure 68 of Appendix C, respectively.

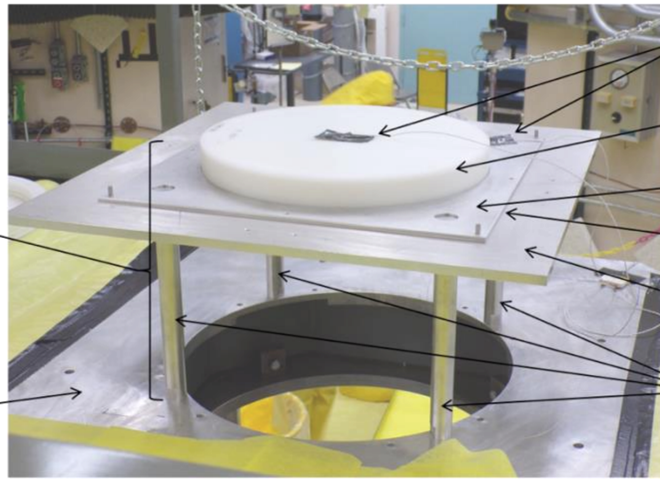


Figure 3. Upper stationary platform of the Comet machine, with the experiment platform.

The interface plate is a 28 in x 28 in x 0.5 in (71.12 cm x 71.12 cm x 1.27 cm) AL 6061-T6 plate with a 19 in (48.26 cm) diameter hole through its center. The standoffs are 12 in (30.48 cm) long AL 6061-T6 cylinders with a 1.25 in (3.175 cm) diameter. The membrane is a 21 in x 21 in (53.34 cm x 53.34 cm) AL 6061-T6 plate with a thickness of 0.125 in (0.3175 cm). The membrane features four holes, one in each corner, ensuring consistent alignment when placed onto the interface plate using the four pegs. The design allows the membrane to be lifted to 0.75 in (1.905 cm).

This membrane lift is the distance that the membrane is lifted off the interface plate as the VLM brings the two halves of the experimental configuration together. To ensure the two halves are in full contact, the membrane is lifted until a load sensor, measuring the weight on the lower movable platen, stop registering an increasing weight. Table 2 reports the membrane lift for each experimental configuration. Photos of this lift can be found in Figure 69 and Figure 70 of Appendix D.

Table 2. Estimated membrane lift for experimental configurations.

Case	Lift [in (cm)]
1	0.250 (0.635)
2[(a)]	0.125 (0.318)
3[(b)]	-
4	0.200 (0.508)
5	0.200 (0.508)

(a) Estimated based on visual observation as the instrument failed.
(b) No measurement recorded.

1.2.2.2 Movable Platen

The lower adapter holds the lower half of the experiment, shown in Figure 4. This lower adapter consists of an adapter plate and an adapter extension, which affixes the lower adapter to the movable platen. Schematics showing the dimensions of the adapter plate and adapter extension are included in Figure 66 and Figure 67 of Appendix C, respectively.

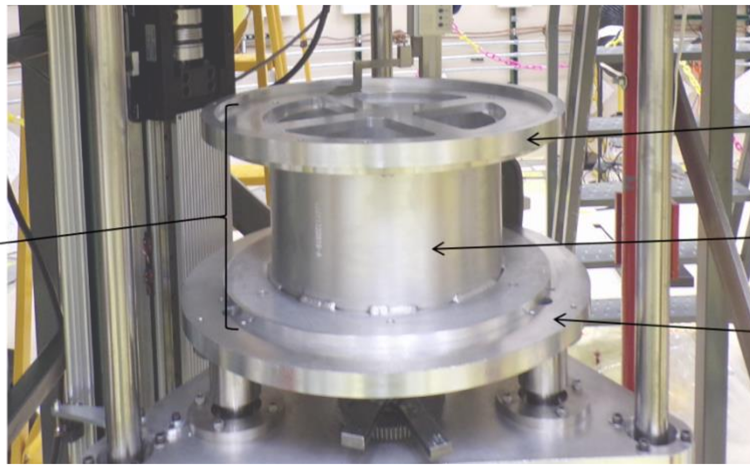


Figure 4. Lower movable platen of the Comet machine, with the lower adapter.

The adapter plate has a 0.53 in (1.3462 cm) thickness and 18.5 in (46.99 cm) outer diameter. This plate features a 17.15 in (43.561 cm) inner diameter with an additional 0.47 in (1.1938 cm) lip height, to hold the bottom polyethylene reflector plate. The adapter extension is an 8 in (20.32 cm) tall annular cylinder with a wall thickness of 0.25 in (0.635 cm) and a 12 in (30.48 cm) outer diameter. This extension includes a 2.5 in (6.35 cm) wide and 0.5 in (1.27 cm) thick top and bottom lip to affix it to the adapter plate and the platen. Both components of the lower adapter are AL 6061-T6.

The lip of the adapter plate. was measured using an electronic height gauge with a manufacturer reported resolution and indication variability of 0.01 mm and an indication accuracy of ±0.04 mm for height ranges of 0 in to 12 in (30.48 cm). These measurements are reported in Table 3. A total of seven measurements were taken from different locations around the lip of the adapter plate during various experimental configurations.

Table 3. Height measurements of the lower adapter plate lip.

Measurement (mm)
12.82
12.54
12.73
12.83
13.12
11.36
11.87

1.2.3 Highly Enriched Uranium Plates

The HEU plates are nominal 0.118 in (0.29972 cm) thick, 15 in (38.1 cm) outer diameter U(93+) plates, collectively known as the "Jemima" plates. These plates are either solid or annular cylinders with an inner annulus of 2.5 in (6.35 cm), 6 in (15.24 cm), or 10 in (25.4 cm). The annulus removes some of the HEU mass resulting in lower and higher mass plate variants. Each of these four variants is shown in Figure 5. The plates are identified in this, and previous evaluations, based on their annulus[1]: Full (HEU1), 2.5" (HEU2, Id. No. 403), 6" (HEU4, "Six Inch", Id. No. 401), and 10" (HEU5, "Ten Inch", Id. No. 402).

The HEU plates were weighed during the experiment campaign with a Mettler Toledo MS16001L under the NCERC calibration program (Cal No. 017284). The calibration for this balance was certified on June 19, 2019, and is valid through June 19, 2020. These measurements were taken on June 2, 2020. The manufacturer of the MS16001L reports a maximum capacity of 16,200 grams, precision of 0.1 grams, and linearity of 0.2 grams. The HEU plate thickness was measured with calipers. The thickness was measured at three separate locations for each plate.

Table 4 reports the mass and thickness measurements of the HEU plates, along with the inner and outer diameters. No instrument was available to measure the outer diameter or the annuli diameter of the plates. Therefore, the dimensions and uncertainties on the inner and outer diameters are based on the original design drawings of the plates. Table 5 includes the HEU plate thickness measurements that are part of MIX-MET-FAST-016, performed in 2019. These were measured using an IP67 Mitutoyo caliper (CD-24"C) with a resolution of ±0.02 in.

1.2.4 Aluminum Inserts

The aluminum inserts are 0.125 in (0.3175 cm) thick AL 6061 disks which come in three diameters: 2.4 in (6.096 cm), 5.9 in (14.986 cm), and 9.9 in (25.146 cm). Each of these three variants is shown in Figure 6. These inserts were placed within the annuli of the HEU plates to prevent any sagging of the polyethylene moderator and reflector plates due to weight. To ensure the fit, the inserts are nominally 0.1 in (0.254 cm) smaller in diameter than the corresponding HEU plate annuli.

These inserts were weighed and measured, using a coordinate-measuring machine (CMM), by LLNL's Dimensional Inspection Laboratory prior to the experiment campaign. These measurements are reported in Table 6. A description of the CMM measurements is provide in Section 1.2.5.

[1] The HEU notation is used in the Zeus benchmarks (HEU-MET-INTER-006, HEU-MET-FAST-073, and HEU-MET-FAST-072) and the Id. No. notation in used in the Big Ten benchmark (IEU-MET-FAST-007).

Table 4. HEU plate mass and dimension measurements (dimensions defined in Figure 5).

Part Type	Part ID	Mass (g)	Thickness, *c* (mm)			Inner Diameter, *b* [in (cm)]	Outer Diameter, *a* [in (cm)]
			1	2	3		
10” (HEU5)	10463	3631.7	3.18	3.27	3.21	10.005 +0.005/-0.000 (25.4127 +0.0127/-0.0000)	15 +0.000/-0.005 (38.1 +0.0000/-0.0127)
	10472	3585.7	3.04	3.18	3.12		
	10479	3564.7	3.09	3.49	3.38		
6” (HEU4)	10457	5574.1	3.20	3.45	3.30	6.005 +0.005/-0.000 (15.2527 +0.0127/-0.0000)	
	10477	5499.2	3.12	3.83	3.18		
	10493	5437.2	3.17	3.28	3.19		
	11018	5369.9	3.03	3.11	3.03		
2.5” (HEU2)	10464	6258.5	3.14	3.40	3.39	2.510 +0.005/-0.000 (6.3754 +0.0127/-0.0000)	
	10467	6335.8	3.13	3.36	3.18		
	10470	6279.0	3.04	3.30	3.20		
	10475	6230.0	3.04	3.16	3.14		
	10487	6274.9	3.16	3.41	3.20		
	10489	6343.8	3.24	3.48	3.34		
	10491	6392.4	3.14	3.46	3.45		
Full (HEU1)	11017	6501.6	3.11	3.39	3.38	-	
	11019	6470.0	3.06	3.43	3.14		
	11147	6517.3	3.14	3.37	3.34		
	11149	6383.6	3.04	3.30	3.13		
	11150	6410.3	3.11	3.29	3.23		

Table 5. HEU plate thickness measurements from MIX-MET-FAST-016 (dimensions defined in Figure 5).

Part Type	Part ID	Mass (g)	Thickness, *c* [in (mm)]		
			1	2	3
10” (HEU5)	10463	3557.8	-	-	-
	10472	3587.0	0.1245 (3.1623)	0.1215 (3.0861)	0.1200 (3.0480)
	10479	3631.7	-	-	-
6” (HEU4)	10457	5571.0	-	-	-
	10477	5497.5	0.1265 (3.2131)	0.1205 (3.0607)	0.1235 (3.1369)
	10493	5435.5	-	-	-
	11018	5368.5	0.1190 (3.0226)	0.1190 (3.0226)	0.1195 (3.0353)
2.5” (HEU2)	10464	6392.5	0.1175 (2.9845)	0.1220 (3.0988)	0.1190 (3.0226)
	10467	6335.6	0.1275 (3.2385)	0.1225 (3.1115)	0.1235 (3.1369)
	10470	6278.5	0.1250 (3.1750)	0.1190 (3.0226)	0.1240 (3.1496)
	10475	6229.9	0.1285 (3.2639)	0.1275 (3.2385)	0.1295 (3.2893)
	10487	6274.9	0.1210 (3.0734)	0.1215 (3.0861)	0.1185 (3.0099)
	10489	6344.0	0.1245 (3.1623)	0.1220 (3.0988)	0.1230 (3.1242)
	10491	6392.5	-	-	-
Full (HEU1)	11017	6505.8	0.1215 (3.0861)	0.1200 (3.0480)	0.1210 (3.0734)
	11019	6473.8	0.1195 (3.0353)	0.1190 (3.0226)	0.1185 (3.0099)
	11147	6519.8	0.1200 (3.0480)	0.1200 (3.0480)	0.1185 (3.0099)
	11149	6385.5	0.1215 (3.0861)	0.1250 (3.1750)	0.1200 (3.0480)
	11150	6419.3	0.1200 (3.0480)	0.1220 (3.0988)	0.1235 (3.1369)

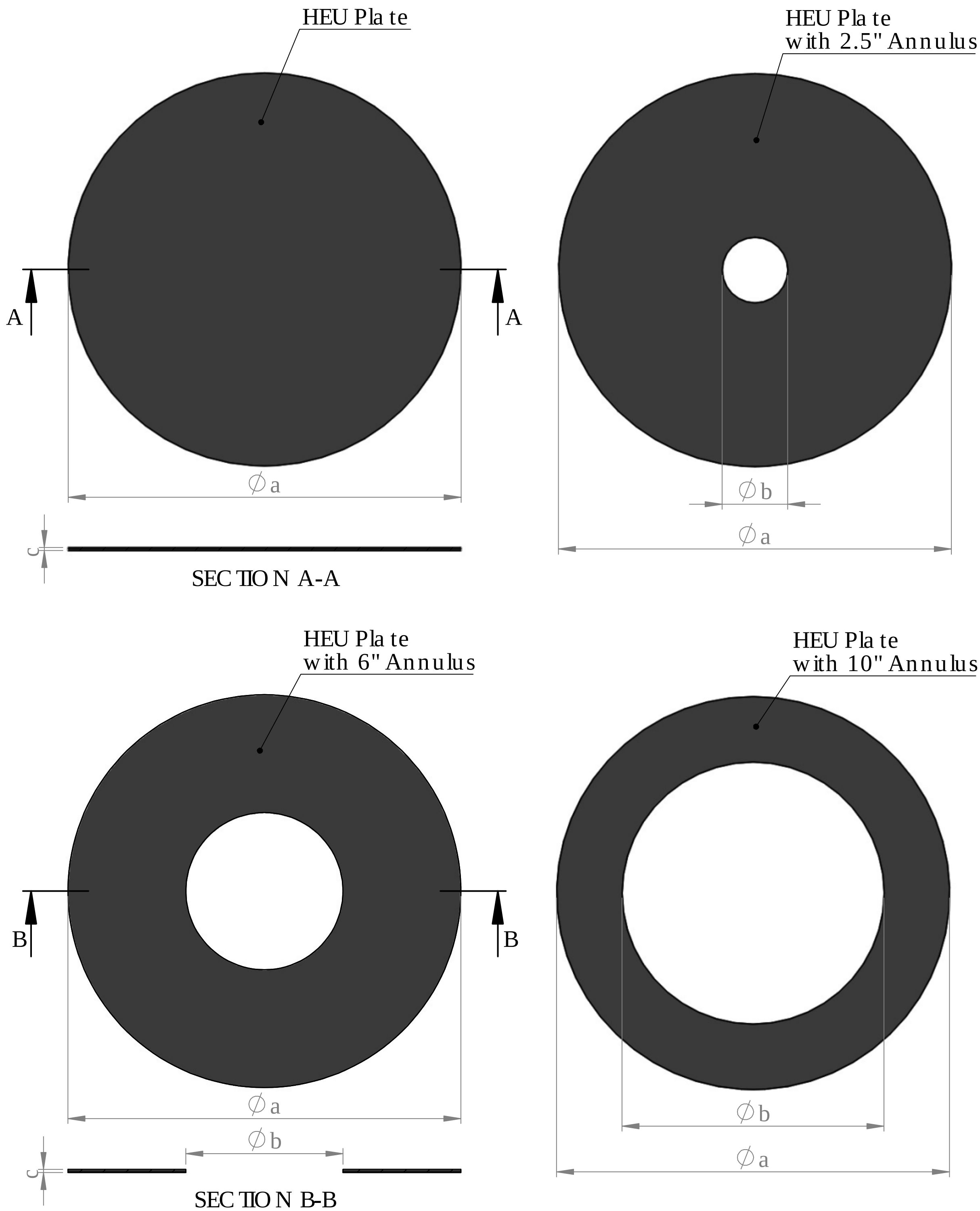


Figure 5. Schematic of the HEU plates, showing all four types.

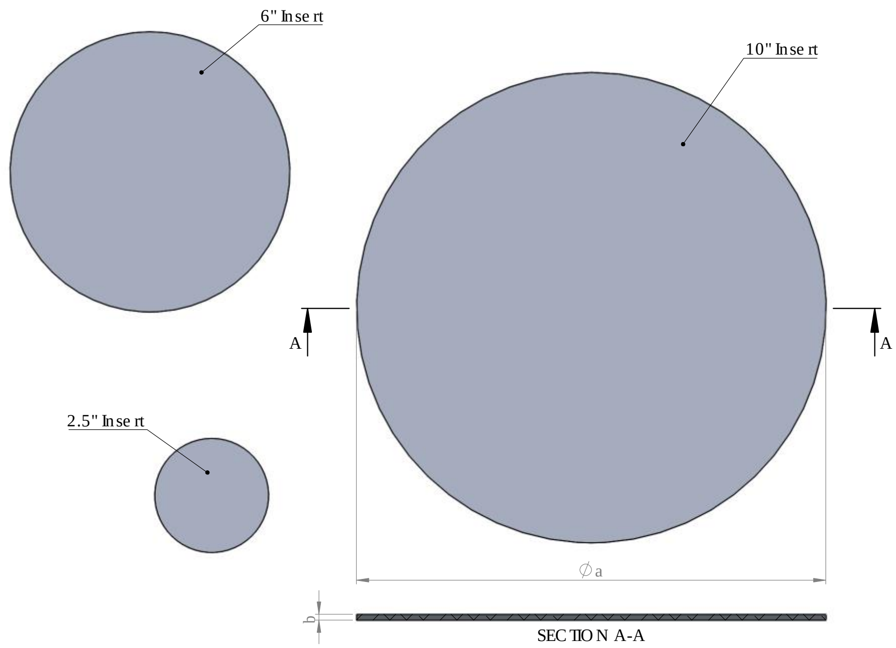


Figure 6. Schematic of the inserts, showing all three types.

Table 6. Aluminum insert mass and dimension measurements (dimensions defined in Figure 6).

Part ID	Mass (g)	Diameter, *a* [in (cm)]			Thickness, *b* [in (cm)]
		Min	Max	Average	
2.5-DISK-1	24.6	2.3945	2.3945	2.3945 (6.0820)	0.1240 (0.3150)
2.5-DISK-2	24.8	2.3955	2.3960	2.3958 (6.0852)	0.1245 (0.3162)
2.5-DISK-3	24.7	2.3960	2.3960	2.3960 (6.0858)	0.1245 (0.3162)
2.5-DISK-4	24.9	2.3960	2.3960	2.3960 (6.0858)	0.1255 (0.3188)
2.5-DISK-5	24.9	2.3950	2.3950	2.3950 (6.0833)	0.1250 (0.3175)
2.5-DISK-6	25.0	2.3940	2.3950	2.3945 (6.0820)	0.1255 (0.3188)
2.5-DISK-7	24.9	2.3950	2.3955	2.3953 (6.0839)	0.1250 (0.3175)
2.5-DISK-8	24.8	2.3945	2.3950	2.3948 (6.0827)	0.1250 (0.3175)
2.5-DISK-9	24.6	2.3945	2.3950	2.3948 (6.0827)	0.1240 (0.3150)
2.5-DISK-10	24.9	2.3955	2.3955	2.3955 (6.0846)	0.1250 (0.3175)
6-DISK-1	149.9	5.8935	5.8945	5.8940 (14.9708)	0.1240 (0.3150)
6-DISK-2	149.7	5.8915	5.8915	5.8915 (14.9644)	0.1235 (0.3137)
6-DISK-3	151.1	5.8915	5.8915	5.8920 (14.9657)	0.1250 (0.3175)
6-DISK-4	151.3	5.8930	5.8935	5.8933 (14.9689)	0.1250 (0.3175)
10-DISK-1	423.9	9.8915	9.8920	9.8918 (25.1250)	0.1240 (0.3150)
10-DISK-2	424.0	9.8920	9.8935	9.8928 (25.1276)	0.1245 (0.3162)
10-DISK-3	426.5	9.8925	9.8925	9.8925 (25.1270)	0.1250 (0.3175)

1.2.5 Polyethylene Parts

The polyethylene parts are all high-density polyethylene (HDPE). All parts were weighed and measured, using a CMM, by LLNL's Dimensional Inspection Laboratory prior to the experiment campaign.

The dimensional measurements performed by the CMM report minimum, maximum, and average values for the diameters and a single value for the thicknesses. The diameter measurements are performed by measuring many cord lengths of the diameter and computing the statistics of these many measurements. The thickness measurements are performed by creating a best-fit plane fit to many points measured at the surface. The thickness represents the distance between the base and this best-fit plane and does not provide the same statistics as the diameter measurement.

1.2.5.1 Moderator and Reflector Plates

The moderator and reflector plates are 15 in (38.1 cm) diameter plates with varying thicknesses, shown in Figure 7. The moderator plates are interspersed with the HEU plates and come in four nominal thicknesses: 0.125 in (0.3175 cm), 0.25 in (0.635 cm), 0.5 in (1.27 cm), and 1.5 in (3.81 cm). The reflector plates are used as the top reflector and come in three nominal thicknesses: 0.03125 in (0.079375 cm), 0.0625 in (1.5875 cm), and 1 in (2.54 cm). The moderator plates were also used in the top reflector to aid in the fine reactivity control for Cases 1, 3, and 4. The mass and dimensional measurements are reported in Table 7.

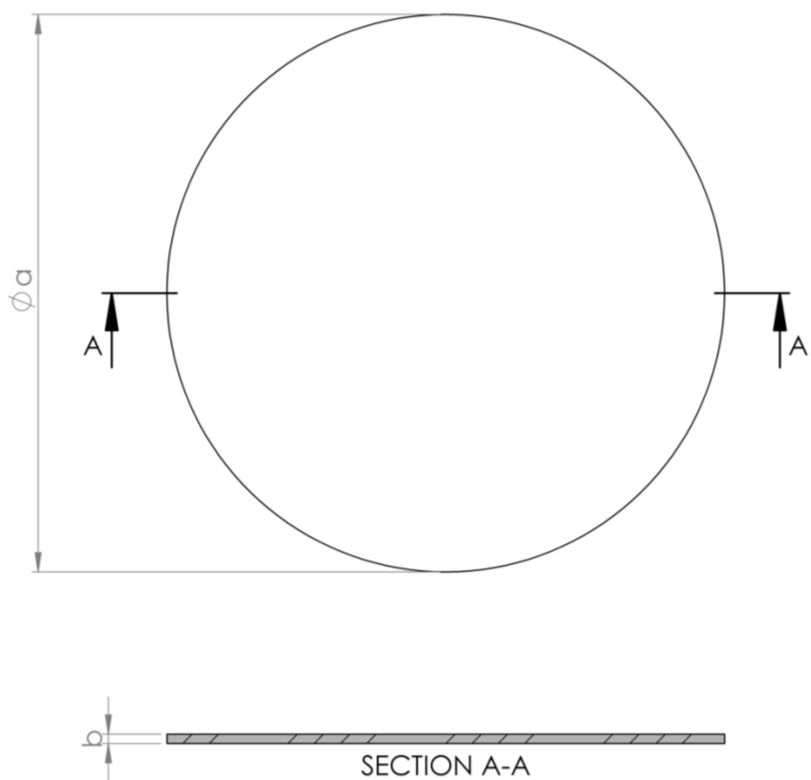


Figure 7. Schematic of the moderator and reflector plate.

Table 7. Polyethylene moderator and reflector plate mass and dimension measurements (dimensions defined in Figure 7).

Part ID	**Mass (g)**	**Diameter, *a* [in (cm)]**			**Thickness, *b* [in (cm)]**
		Min	**Max**	**Average**	
1/8-MOD-1	343.0	14.9894	14.9979	14.9948 (38.0868)	0.1249 (0.3172)
1/8-MOD-2	342.1	14.9895	14.9991	14.9947 (38.0865)	0.1259 (0.3198)
1/8-MOD-3	344.0	14.9894	14.9993	14.9950 (38.0873)	0.1253 (0.3183)
1/8-MOD-4	344.3	14.9878	14.9999	14.9944 (38.0858)	0.1251 (0.3178)
1/8-MOD-5	343.0	14.9913	14.9995	14.9955 (38.0886)	0.1246 (0.3165)
1/8-MOD-6	344.7	14.9934	15.0018	14.9965 (38.0911)	0.1255 (0.3188)
1/8-MOD-7	345.0	14.9908	15.0017	14.9959 (38.0896)	0.1248 (0.3170)
1/8-MOD-8	345.2	14.9901	15.0003	14.9956 (38.0888)	0.1251 (0.3178)
1/8-MOD-9	343.4	14.9885	14.9969	14.9940 (38.0848)	0.1248 (0.3170)
1/8-MOD-10	343.5	14.9904	15.0004	14.9962 (38.0903)	0.1266 (0.3216)
1/8-MOD-11	343.2	14.9901	14.9998	14.9954 (38.0883)	0.1249 (0.3172)
1/4-MOD-1	690.2	14.9835	14.9910	14.9879 (38.0693)	0.2512 (0.6380)
1/4-MOD-2	689.1	14.9821	14.9912	14.9866 (38.0660)	0.2532 (0.6431)
1/4-MOD-3	688.0	14.9804	14.9915	14.9853 (38.0627)	0.2497 (0.6342)
1/4-MOD-4	689.7	14.9824	14.9903	14.9868 (38.0665)	0.2558 (0.6497)
1/4-MOD-5	689.2	14.9822	14.9923	14.9869 (38.0667)	0.2555 (0.6490)
1/4-MOD-6	687.5	14.9806	14.9909	14.9862 (38.0649)	0.2539 (0.6449)
1/4-MOD-7	688.4	14.9792	14.9872	14.9843 (38.0601)	0.2531 (0.6429)
1/4-MOD-8	689.2	14.9786	14.9903	14.9855 (38.0632)	0.2524 (0.6411)
1/4-MOD-9	688.8	14.9850	14.9913	14.9883 (38.0703)	0.2540 (0.6452)
1/2-MOD-1	1377.9	14.9884	14.9953	14.9925 (38.0810)	0.5079 (1.2901)
1/2-MOD-2	1377.8	14.9866	14.9957	14.9909 (38.0769)	0.5047 (1.2819)
1/2-MOD-3	1385.0	14.9880	14.9951	14.9914 (38.0782)	0.5095 (1.2941)
1/2-MOD-4	1378.1	14.9877	14.9974	14.9926 (38.0812)	0.5044 (1.2812)
1/2-MOD-5	1380.2	14.9882	14.9950	14.9913 (38.0779)	0.5033 (1.2784)
1/2-MOD-6	1378.2	14.9870	14.9955	14.9910 (38.0771)	0.5003 (1.2708)
1/2-MOD-7	1383.7	14.9882	14.9963	14.9917 (38.0789)	0.5068 (1.2873)
1.5-MOD-1	4150.8	14.9962	15.0107	15.0035 (38.1089)	1.4998 (3.8095)
1.5-MOD-2	4132.6	14.9968	14.9977	14.9933 (38.0830)	1.5100 (3.8354)
1.5-MOD-3	4125.6	14.9846	14.9962	14.9988 (38.0970)	1.5087 (3.8321)
1.5-MOD-4	4136.2	14.9879	15.0005	14.9946 (38.0863)	1.5146 (3.8471)
1/32-REF-1	85.0	14.9832	14.9996	14.9908 (38.0766)	0.0334 (0.0848)
1/32-REF-2	85.9	14.9833	14.9983	14.9905 (38.0759)	0.0325 (0.0826)
1/16-REF-1	182.4	14.9831	14.9890	14.9858 (38.0639)	0.0728 (0.1849)
1/16-REF-2	182.9	14.9829	14.9884	14.9856 (38.0634)	0.0671 (0.1704)
1-REF-1	2766.9	14.9860	14.9934	14.9902 (38.0751)	0.9995 (2.5387)
1-REF-2	2767.2	14.9844	14.9922	14.9883 (38.0703)	1.0015 (2.5438)

1.2.5.2 Reflector Rings

The reflector rings are 17.1 in (43.434 cm) outer diameter and 15.1 in (38.354 cm) inner diameter annular cylinders which come in four nominal thicknesses: 0.25 in (0.635 cm), 0.5 in (1.27 cm), 1 in (2.54 cm), and 3 in (7.62 cm). Figure 8 shows a diagram of the reflector ring part. The rings stack around the HEU, moderator, and reflector plates to provide 1 in (2.54 cm) of reflection around the configuration. They are designed to interlock, using step joints, which keep the rings in alignment as they are stacked. On the lower half of the experiment, the bottom reflector ring interlocks with the reflector base. On the upper half of the experiment, the bottom reflector ring sits on a bottom reflector cap. The mass and dimensional measurements are reported in Table 8.

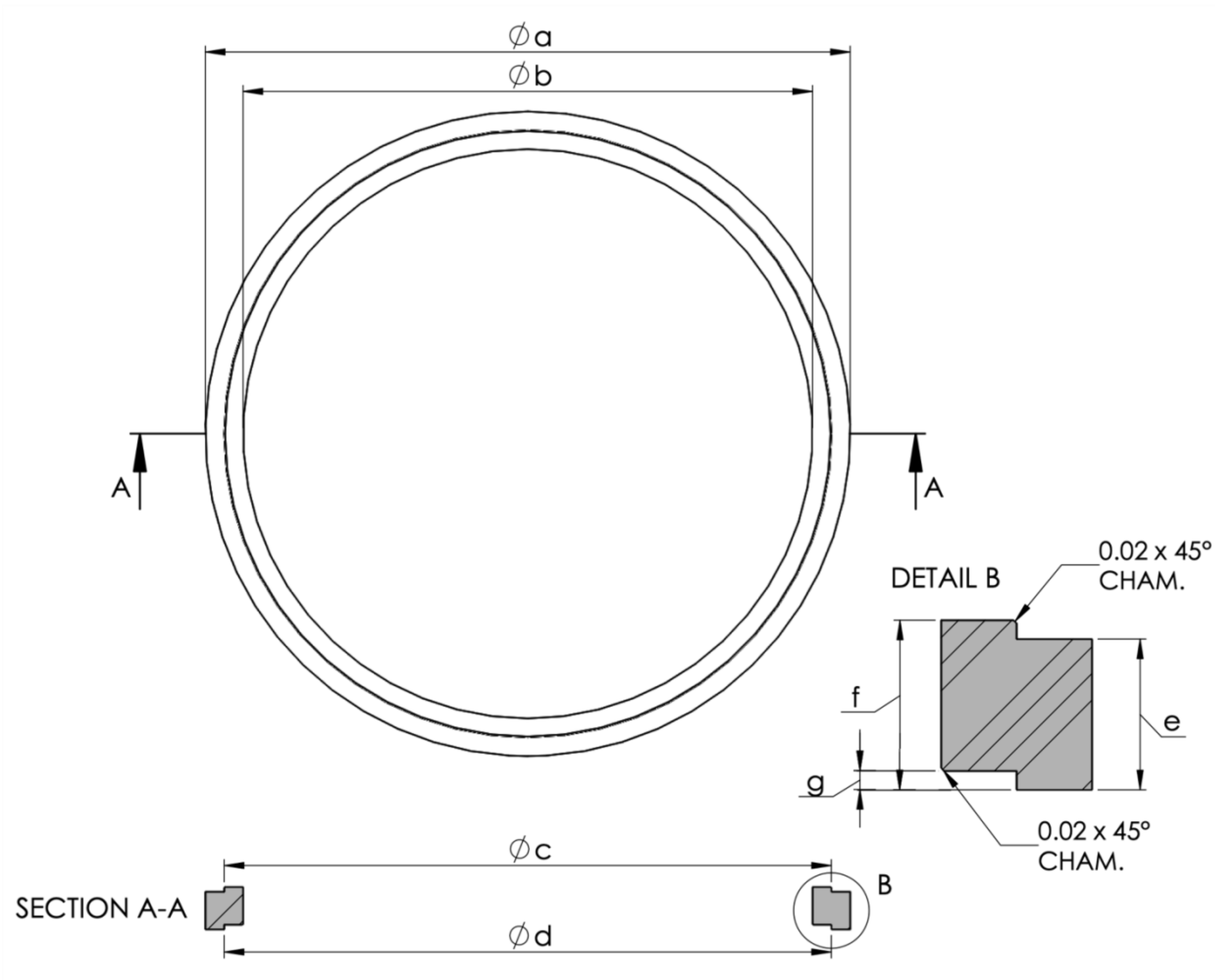


Figure 8. Schematic of the reflector ring (dimensions in inches).

Table 8. Reflector ring mass and dimension measurements (dimensions defined in Figure 8). The top side is the male, and the bottom side is the female.

Part ID	Mass (g)	Outer Diameter, *a* [in (cm)]			Inner Diameter, *b* [in (cm)]		
		Min	Max	Average	Min	Max	Average
1/4-RING-1	199.1	17.0822	17.1050	17.0933 (43.4170)	15.0657	15.0912	15.0789 (38.3004)
1/4-RING-2	198.9	17.0821	17.1019	17.0927 (43.4155)	15.0690	15.0925	15.0813 (38.3065)
1/4-RING-3	198.7	17.0816	17.1060	17.0939 (43.4185)	15.0699	15.0912	15.0811 (38.3060)
1/2-RING-1	394.1	17.0770	17.0870	17.0818 (43.3878)	15.0620	15.0728	15.0670 (38.2702)
1/2-RING-2	394.4	17.0802	17.0854	17.0830 (43.3908)	15.0660	15.0729	15.0682 (38.2732)
1/2-RING-3	392.9	17.0806	17.0855	17.0828 (43.3903)	15.0652	15.0721	15.0680 (38.2727)
1/2-RING-4	393.3	17.0793	17.0865	17.0822 (43.3888)	15.0650	15.0703	15.0676 (38.2717)
1-RING-1	805.8	17.0787	17.0852	17.0824 (43.3893)	15.0605	15.0691	15.0660 (38.2676)
1-RING-2	805.8	17.0745	17.0781	17.0767 (43.3748)	15.0572	15.0629	15.0609 (38.2547)
1-RING-3	805.8	17.0808	17.0888	17.0837 (43.3926)	15.0622	15.0700	15.0666 (38.2692)
1-RING-4	804.9	17.0696	17.0766	17.0729 (43.3652)	15.0509	15.0606	15.0560 (38.2422)
1-RING-5	804.8	17.0812	17.0868	17.0839 (43.3931)	15.0671	15.0714	15.0691 (38.2755)
3-RING-1	2384.7	17.0879	17.0916	17.0898 (43.4081)	15.0875	15.0912	15.0896 (38.3276)
3-RING-5	2384.2	17.0855	17.0915	17.0888 (43.4056)	15.0894	15.0928	15.0913 (38.3319)

Part ID	Top Step (Male) Diameter, *c* [in (cm)]			Bottom Step (Female) Diameter, *d* [in (cm)]		
	Min	Max	Average	Min	Max	Average
1/4-RING-1	16.0527	16.0778	16.0654 (40.8061)	16.0876	16.1120	16.0895 (40.8673)
1/4-RING-2	16.0532	16.0787	16.0654 (40.8061)	16.0906	16.1096	16.1003 (40.8948)
1/4-RING-3	16.0491	16.0743	16.0630 (40.8000)	16.0896	16.1120	16.1010 (40.8965)
1/2-RING-1	16.0480	16.0596	16.0537 (40.7764)	16.0836	16.0956	16.0895 (40.8673)
1/2-RING-2	16.0507	16.0575	16.0533 (40.7754)	16.0871	16.0919	16.0894 (40.8671)
1/2-RING-3	16.0471	16.0528	16.0496 (40.7660)	16.0894	16.0965	16.0922 (40.8742)
1/2-RING-4	16.0495	16.0543	16.0515 (40.7708)	16.0880	16.0938	16.0904 (40.8696)
1-RING-1	16.0564	16.0653	16.0615 (40.7962)	16.0800	16.0845	16.0824 (40.8493)
1-RING-2	16.0517	16.0575	16.0550 (40.7797)	16.0897	16.0939	16.0923 (40.8744)
1-RING-3	16.0590	16.0661	16.0628 (40.7995)	16.0799	16.0862	16.0823 (40.8490)
1-RING-4	16.0420	16.0531	16.0485 (40.7632)	16.0989	16.1075	16.1037 (40.9034)
1-RING-5	16.0624	16.0693	16.0653 (40.8059)	16.0850	16.0906	16.0880 (40.8635)
3-RING-1	16.0726	16.0780	16.0742 (40.8285)	16.0975	16.1006	16.0993 (40.8922)
3-RING-5	16.0710	16.0733	16.0720 (40.8229)	16.0994	16.1029	16.1014 (40.8976)

Table 8 (continue). Reflector ring mass and dimension measurements (dimensions defined in Figure 8). The top side is the male, and the bottom side is the female.

Part ID	Outer Edge Height, *e* [in (cm)]	Top Step Height, *f* [in (cm)]	Bottom Step Height, *g* [in (cm)]
1/4-RING-1	0.2568 (0.6523)	0.3727 (0.9467)	0.1205 (0.3061)
1/4-RING-2	0.2585 (0.6566)	0.3748 (0.9520)	0.1209 (0.3071)
1/4-RING-3	0.2575 (0.6541)	0.3721 (0.9451)	0.1205 (0.3061)
1/2-RING-1	0.5027 (1.2769)	0.6140 (1.5596)	0.1198 (0.3043)
1/2-RING-2	0.5042 (1.2807)	0.6156 (1.5636)	0.1205 (0.3061)
1/2-RING-3	0.5053 (1.2835)	0.6166 (1.5662)	0.1179 (0.2995)
1/2-RING-4	0.5050 (1.2827)	0.6156 (1.5636)	0.1184 (0.3007)
1-RING-1	1.0016 (2.5441)	1.1275 (2.8639)	0.1219 (0.3096)
1-RING-2	1.0036 (2.5491)	1.1256 (2.8590)	0.1196 (0.3038)
1-RING-3	1.0014 (2.5436)	1.1268 (2.8621)	0.1219 (0.3096)
1-RING-4	1.0052 (2.5532)	1.1232 (2.8529)	0.1161 (0.2949)
1-RING-5	0.9991 (2.5377)	1.1252 (2.8580)	0.1205 (0.3061)
3-RING-1	2.9952 (7.6078)	3.1229 (7.9322)	0.1231 (0.3127)
3-RING-5	2.9961 (7.6101)	3.1243 (7.9357)	0.1231 (0.3127)

1.2.5.3 Reflector Caps

There are two different types of reflector caps: one for fine height adjustment on the top of the reflector rings and one to provide a base for the first reflector ring on the upper half of the experiment. Figure 9 and Figure 10 show diagrams of the reflector cap part types. The reflector caps allow the ring reflector to be brought to within 0.03125 in (0.079375 cm) of the top reflector height. The bottom reflector caps provide the base for the reflector rings on the upper half of the experiment, making the reflector ring flush with the membrane. The mass and dimensional measurements are reported in Table 9.

The reflector caps are 15.1 in (38.354 cm) inner diameter, 16.1 in (40.894 cm) step diameter, and 17.1 in (43.434 cm) outer diameter rings with a 0.125 in (0.3175 cm) base thickness and additional step thickness. There are eight step thicknesses, in increments of 0.03125 in (0.079375 cm): 0 in, 0.03125 in (0.079375 cm), 0.0625 in (0.15875 cm), 0.09375 in (0.238125 cm), 0.125 in (0.3175 cm), 0.15625 in (0.396875 cm), 0.1875 in (0.47625 cm), and 0.21875 in (0.555625 cm). They are identified by the *Y-CAP-X* part identification, where *Y* is the step thickness and *X* is a unique integer. The bottom reflector cap is a 0.125 in (0.3175 cm) thick ring with a 15.1 in (38.354 cm) inner diameter and 16.1 in (40.894 cm) outer diameter. It is denoted with the *0-BOTCAP-X* part identification, where *X* is a unique integer. The bottom reflector cap and the reflector cap with 0 in step thickness are zero-height caps, meaning they sit within the step joint of the reflector ring without adding additional height.

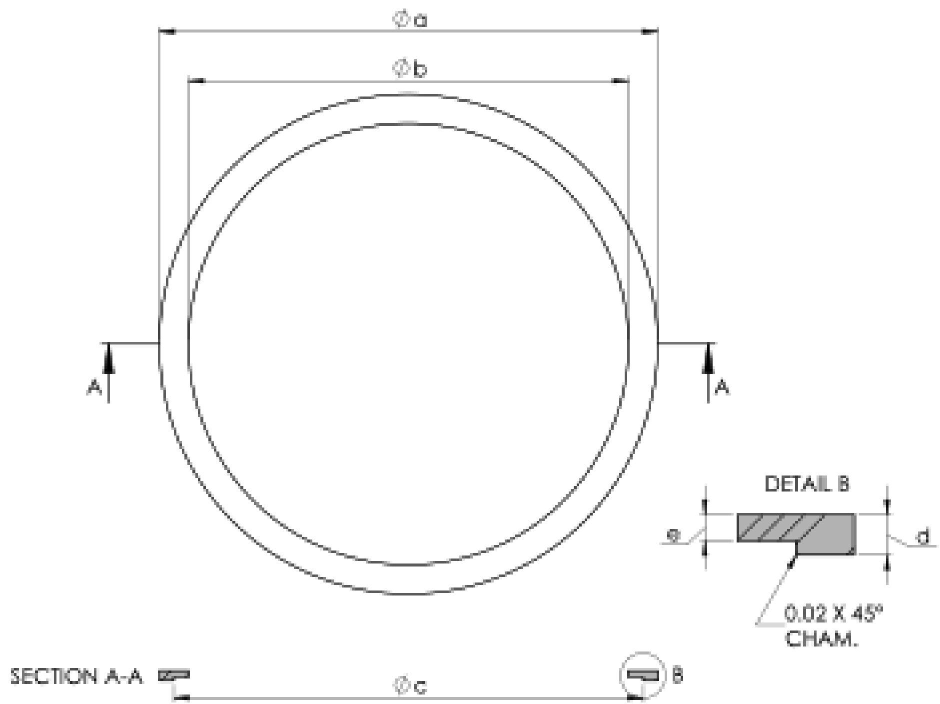


Figure 9. Schematic of the reflector cap (dimensions in inches).

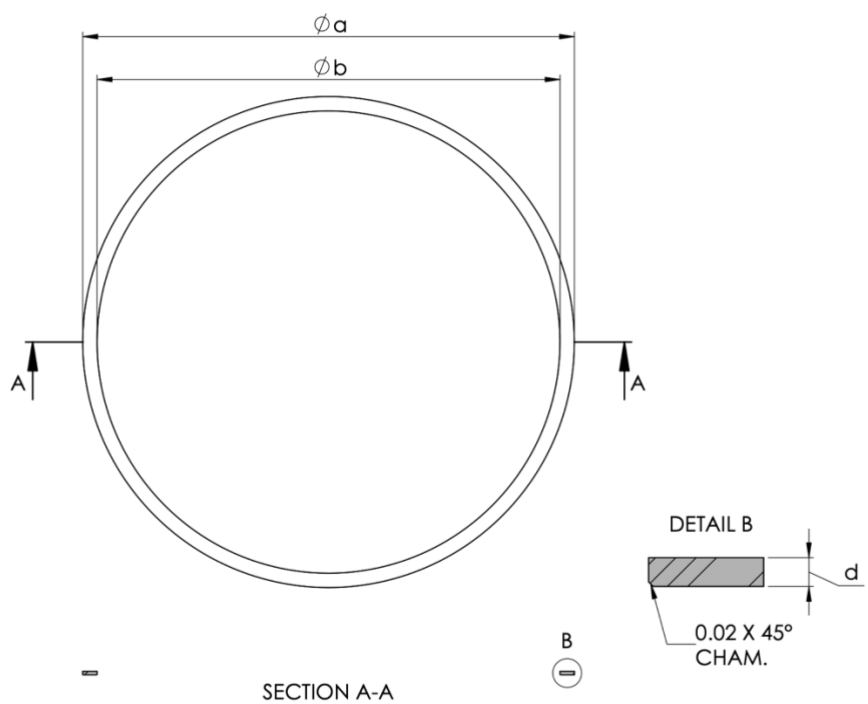


Figure 10. Schematic of the bottom reflector cap (dimensions in inches).

Table 9. Reflector cap mass and dimension measurements (dimensions defined in Figure 9 and Figure 10).

Part ID	**Mass (g)**	**Outer Diameter, *a* [in (cm)]**			**Inner Diameter, *b* [in (cm)]**		
		Min	**Max**	**Average**	**Min**	**Max**	**Average**
0-BOTCAP-1	48.2	-	-	16.0530 (40.7746)	-	-	15.0660 (38.2676)
0-BOTCAP-2	48.0	-	-	16.0530 (40.7746)	-	-	15.0650 (38.2651)
0-CAP-1	50.7	-	-	17.0470 (43.2994)	-	-	16.0790 (40.8407)
0-CAP-2	50.8	-	-	17.0460 (43.2968)	-	-	16.0770 (40.8356)
1/32-CAP-1	76.8	17.0612	17.0763	17.0689 (43.3550)	15.0604	15.0828	15.0738 (38.2875)
1/32-CAP-3	76.9	17.0651	17.0758	17.0710 (43.3603)	15.0731	15.0847	15.0773 (38.2963)
1/16-CAP-1	101.5	17.0457	17.1074	17.0791 (43.3809)	15.0554	15.1168	15.0842 (38.3139)
1/16-CAP-2	101.2	17.0690	17.0906	17.0803 (43.3840)	15.0741	15.0933	15.0850 (38.3159)
3/32-CAP-1	127.9	17.0414	17.1020	17.0725 (43.3642)	15.0511	15.1100	15.0807 (38.3050)
3/32-CAP-2	126.7	17.0687	17.0734	17.0713 (43.3611)	15.0821	15.0893	15.0850 (38.3159)
1/8-CAP-1	149.0	17.0753	17.0845	17.0788 (43.3802)	15.0748	15.0873	15.0824 (38.3093)
1/8-CAP-2	148.9	17.0692	17.0909	17.0791 (43.3809)	15.0748	15.0921	15.0817 (38.3075)
1/8-CAP-3	149.0	17.0582	17.0977	17.0781 (43.3784)	15.0652	15.1004	15.0815 (38.3070)
7/32-CAP-1	225.4	17.0781	17.0919	17.0860 (43.3984)	15.0790	15.0933	15.0861 (38.3187)
7/32-CAP-2	225.2	17.0662	17.0774	17.0706 (43.3593)	15.0692	15.0857	15.0780 (38.2981)

Part ID	**Step Diameter, *c* [in (cm)]**			**Outer Edge Height, *d* [in (cm)]**	**Step Height, *e* [in (cm)]**
	Min	**Max**	**Average**		
0-BOTCAP-1	-	-	-	0.1310 (0.3327)	-
0-BOTCAP-2	-	-	-	0.1250 (0.3175)	-
0-CAP-1	-	-	-	0.1260 (0.3200)	-
0-CAP-2	-	-	-	0.1255 (0.3188)	-
1/32-CAP-1	16.0833	16.1000	16.0930 (40.8762)	0.1647 (0.4183)	0.0344 (0.0874)
1/32-CAP-3	16.0906	16.0989	16.0943 (40.8795)	0.1664 (0.4227)	0.0350 (0.0889)
1/16-CAP-1	16.0727	16.1328	16.1012 (40.8970)	0.1953 (0.4961)	0.0681 (0.1730)
1/16-CAP-2	16.0898	16.1123	16.1025 (40.9004)	0.1912 (0.4856)	0.0673 (0.1709)
3/32-CAP-1	16.0645	16.1234	16.0946 (40.8803)	0.2431 (0.6175)	0.1006 (0.2555)
3/32-CAP-2	16.0948	16.1025	16.0978 (40.8884)	0.2443 (0.6205)	0.1000 (0.2540)
1/8-CAP-1	16.0928	16.1036	16.0993 (40.8922)	0.2531 (0.6429)	0.1292 (0.3282)
1/8-CAP-2	16.0913	16.1076	16.0981 (40.8892)	0.2540 (0.6452)	0.1290 (0.3277)
1/8-CAP-3	16.0838	16.1214	16.1011 (40.8968)	0.2535 (0.6439)	0.1281 (0.3254)
7/32-CAP-1	16.0990	16.1155	16.1073 (40.9125)	0.3444 (0.8748)	0.2290 (0.5817)
7/32-CAP-2	16.0823	16.0973	16.0904 (40.8696)	0.3517 (0.8933)	0.2242 (0.5695)

1.2.5.4 Bottom Reflector

The reflector base is a 1 in (2.54 cm) thick plate with a 17.1 in (43.434 cm) diameter and outer step joint, shown in Figure 11. It provides the foundation for the HEU plates and the ring reflectors on the lower half of the experiment. The reflector base sits in the lower adapter plate on the Comet movable platen, held in place by the lip of the plate. The center of the base has a small hole to hold the neutron source during the approach to critical. The mass and dimensional measurements are reported in Table 10.

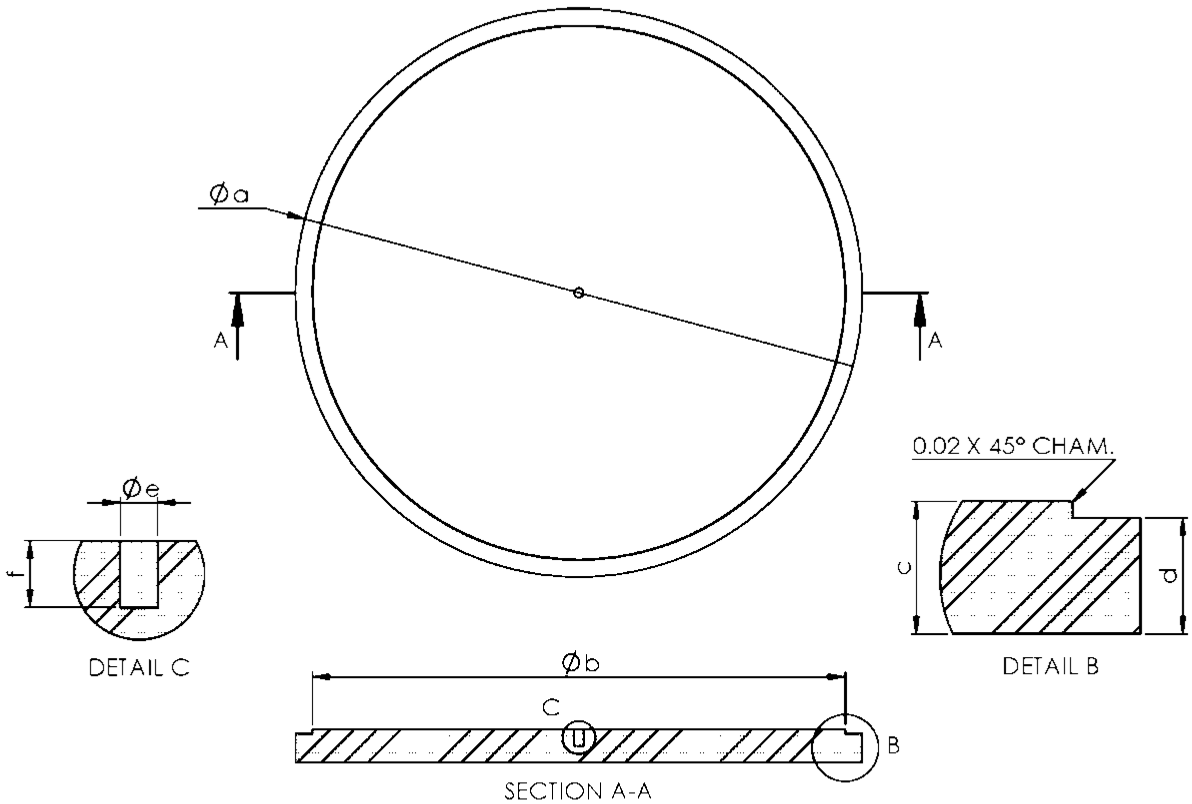


Figure 11. Schematic of the reflector base (dimensions in inches).

Table 10. Reflector base mass and dimension measurements (dimensions defined in Figure 11).

Part ID	Mass (g)	Outer Diameter, *a* [in (cm)]			Step Diameter, *b* [in (cm)]		
		Min	Max	Average	Min	Max	Average
BOTREF-1	3543.2	17.0711	17.0820	17.0761 (43.3733)	16.0507	16.0634	16.0572 (40.7853)
BOTREF-2	3544.9	17.0715	17.0814	17.0766 (43.3746)	16.0468	16.0592	16.0536 (40.7761)

Part ID	Thickness, *c* [in (cm)]	Outer Edge Height, *d* [in (cm)]	Source Diameter, *e* [in (cm)]	Source Depth, *f* [in (cm)]
BOTREF-1	1.0110 (2.5679)	0.8909 (2.2629)	0.2810 (0.7137)	0.4959 (1.2596)
BOTREF-2	1.0225 (2.5972)	0.9057 (2.3005)	0.2814 (0.7148)	0.5043 (1.2809)

1.2.6 Height Measurements

The need for accurate height measurements was determined during the design phase of this experiment. To perform such measurements a Westward Electronic Height Gauge (Model No. 2YND5) was procured. The manufacturer of the gauge reports an indication accuracy of ±0.04 mm and resolution of 0.01 mm. These height measurements were performed by the LANL experimenters during the execution of the experiment campaign.

For measurements, the height gauge was clamped to the VLM. On the stationary platform, the height gauge was placed to the interface plate and zeroed at the membrane. On the lower adapter, the height gauge was clamped to the platen and zeroed at the base of the adapter plate. Once the height gauge was clamped and zeroed, the upper half or lower half of the experiment configuration were assembled, and a height measurement was taken for each HEU plate and moderator plate in the stack.

When the experiment configuration was completely assembled, additional measurements from three new positions were taken of the overall height of the plate stack and separately of the reflector stack. For the upper half of the experiment, these measurements were again zeroed at the membrane. For the lower half of the experiment, these measurements had to be zeroed on the lip of the adapter plate since the experiment covered the base of the adapter plate. Therefore, the reported overall height measurements of the lower half of the experiments throughout Section 1.2.8 must account for the height of the lip on the adapter plate. This height is nominally 0.47 in (1.1938 cm).

1.2.7 Alignment

Comet holds the two halves of the experiment configuration and ensures the alignment between the reflector rings of the upper and lower halves of the experiment as they are brought together. The vertical alignment of the reflector rings was ensured using two T-squares.

The upper half of the experiment sits on top of the membrane and is centered directly over the lower half of the experiment using an alignment plate. This alignment plate sits on top of the membrane while setting the experiment up and is then removed prior to the final benchmark measurement. The lower half of the experiment sits in the adapter plate on the lower adapter, shown in Figure 71 of Appendix D. The lip of the adapter plate holds the reflector base in place.

To ensure the core stack was vertically aligned within the reflector rings, the plates were all pushed to one side within the reflector rings. The same was done for the aluminum inserts within the annuli of the HEU plates and the polyethylene moderator and reflector plates. This is shown in Figure 72 and Figure 73 of Appendix D.

1.2.8 Experimental Configurations

The following sections describe the five TEX-HEU experimental configurations. Each section includes a rendering of the experimental configuration, a diagram of the parts that make up the experimental configuration, and tables reporting the core stack and reflector ring height measurements, the measured reactor period, and the core stack and reflector ring parts. The rendering shows a cross section of the upper and lower halves of the experimental configuration separated by the membrane.

Table 11 summarizes the main physical characteristics of the experimental configurations, including the number of HEU plates, total HEU mass, nominal moderator plate thickness, and nominal top reflector thickness.

Table 11. Overview of experimental configurations.

Case	Number of HEU Plates	Total HEU Mass (g)	Nominal Moderator Thickness, in (cm)	Nominal Top Reflector Thickness, in (cm)
1	19	109,059.7 ± 3.8	-	0.96875 (2.460625)
2	11	69,986.9 ± 2.2	0.125 (0.3175)	1.0625 (2.69875)
3	8	51,007.8 ± 1.6	0.25 (0.635)	1.21875 (3.095625)
4	5	32,282.8 ± 1.0	0.5 (1.27)	1.65625 (4.206875)
5	5	29,529.4 ± 1.0	1.5 (3.81)	1.0125 (2.57175)

As described in Section 1.2.1, the primary change between each experimental configuration is the nominal moderator thickness. This can be seen in Table 11 where Case 1 has no moderator, producing a fast neutron spectrum critical experiment, and Case 5 has a nominal 1.5 in moderator, producing a thermal neutron spectrum critical experiment. Cases 2, 3, and 4 have moderator thickness of 0.125 in, 0.25 in, and 0.5 in, respectively, to produce neutron spectrums in between that of Case 1 and Case 5.

1.2.8.1 Case 1

The Case 1 experimental configuration includes 19 HEU plates, no polyethylene moderator, and a nominal 0.96875 in (2.460625 cm) top reflector. These 19 HEU plates consisted of five HEU1, seven HEU2, four HEU4, and three HEU5 plates, for a total HEU mass of 109.1 kg.

Figure 12 shows a rendering of the Case 1 experimental configuration. Table 12 reports the measured reactor period. Table 13 reports the height measurements of the core stack and ring reflector for the upper and lower halves of the experimental configuration. Table 14, Table 15, Table 16, and Table 17 list the parts that make up the upper and lower core stacks and ring reflectors, along with the per-layer height measurements of the core stacks. Finally, Figure 13 shows a diagram of the parts in the Case 1 experimental configuration.

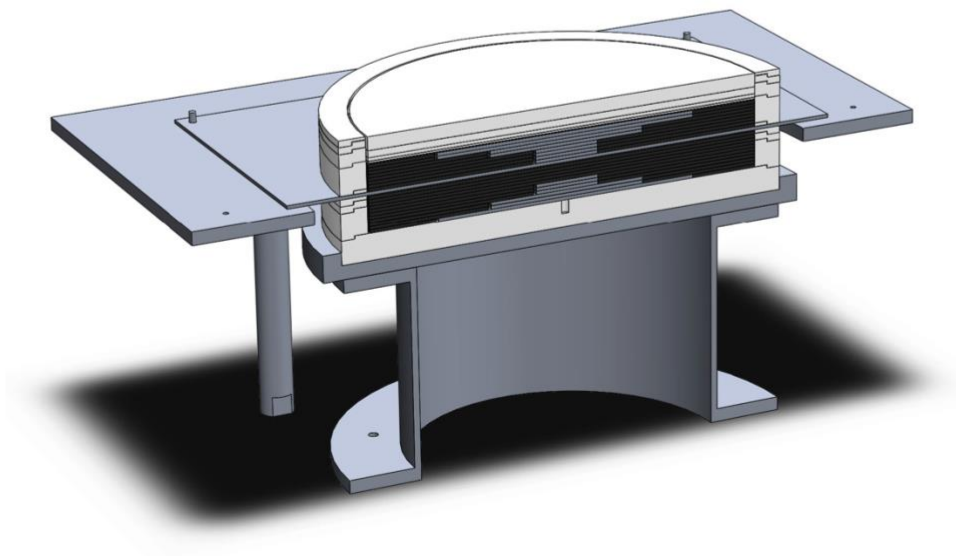


Figure 12. Rendering of the Case 1 experimental configuration.

Table 12. Case 1 period measurements.

Detector	**Period (s)**
LC_1	268.80
LC_2	265.73
LC_3	272.77
SU	287.00

Table 13. Case 1 upper and lower core stack and ring reflector height measurements.

Upper Height Measurement (mm)[a]		Lower Height Measurement (mm)[b]	
Core Stack	**Ring Reflector**	**Core Stack**	**Ring Reflector**
50.65	50.81	49.60	48.10
50.46	50.55	49.91	50.36
50.66	50.39	50.07	50.07

(a) Upper height measurements taken relative to the membrane.
(b) Lower height measurements taken relative to the lip of the adapter plate.

Table 14. Case 1 upper core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[a]	Part Description
1/2-MOD-7	50.24	Top Reflector
1/4-MOD-5	37.42	
1/8-MOD-11	30.86	
1/16-REF-1	27.77	
1/32-REF-1	26.05	
10479 (10-DISK-3)	25.23	HEU5 Plates with 10” Insert
10463 (10-DISK-2)	22.34	
10457 (6-DISK-4)	18.93	HEU4 Plates with 6” Insert
10493 (6-DISK-3)	15.44	
10467 (2.5-DISK-7)	12.34	HEU2 Plates with 2.5” Insert
10470 (2.5-DISK-6)	9.04	
10475 (2.5-DISK-5)	6.12	
10489 (2.5-DISK-4)	2.96	

(a) Height measurements taken relative to the membrane.

Table 15. Case 1 upper ring reflector parts.

Part ID (Top to Bottom)	Part Description
3/32-CAP-1	Reflector Cap
1/4-RING-1	Reflector Rings
1/2-RING-1	
1-RING-1	
0-BOTCAP-1	Reflector Base

Table 16. Case 1 lower core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[(a)]	Part Description
11017	59.77	HEU1 Plates
11150	56.81	
11019	54.14	
11147	50.85	
11149	47.43	
10464 (2.5-DISK-3)	44.18	HEU2 Plates with 2.5” Insert
10487 (2.5-DISK-2)	40.95	
10491 (2.5-DISK-1)	37.60	
11018 (6-DISK-2)	34.42	HEU4 Plates with 6” Insert
10477 (6-DISK-1)	31.03	
10472 (10-DISK-1)	27.92	HEU5 Plates with 10” Insert
BOTREF-1	25.25	Bottom Reflector

(a) Height measurements taken relative to the adapter plate.

Table 17. Case 1 lower ring reflector parts.

Part ID (Top to Bottom)	Part Description
1/8-CAP-3	Reflector Cap
1/4-RING-2	Reflector Rings
1-RING-5	
BOTREF-1	Reflector Base

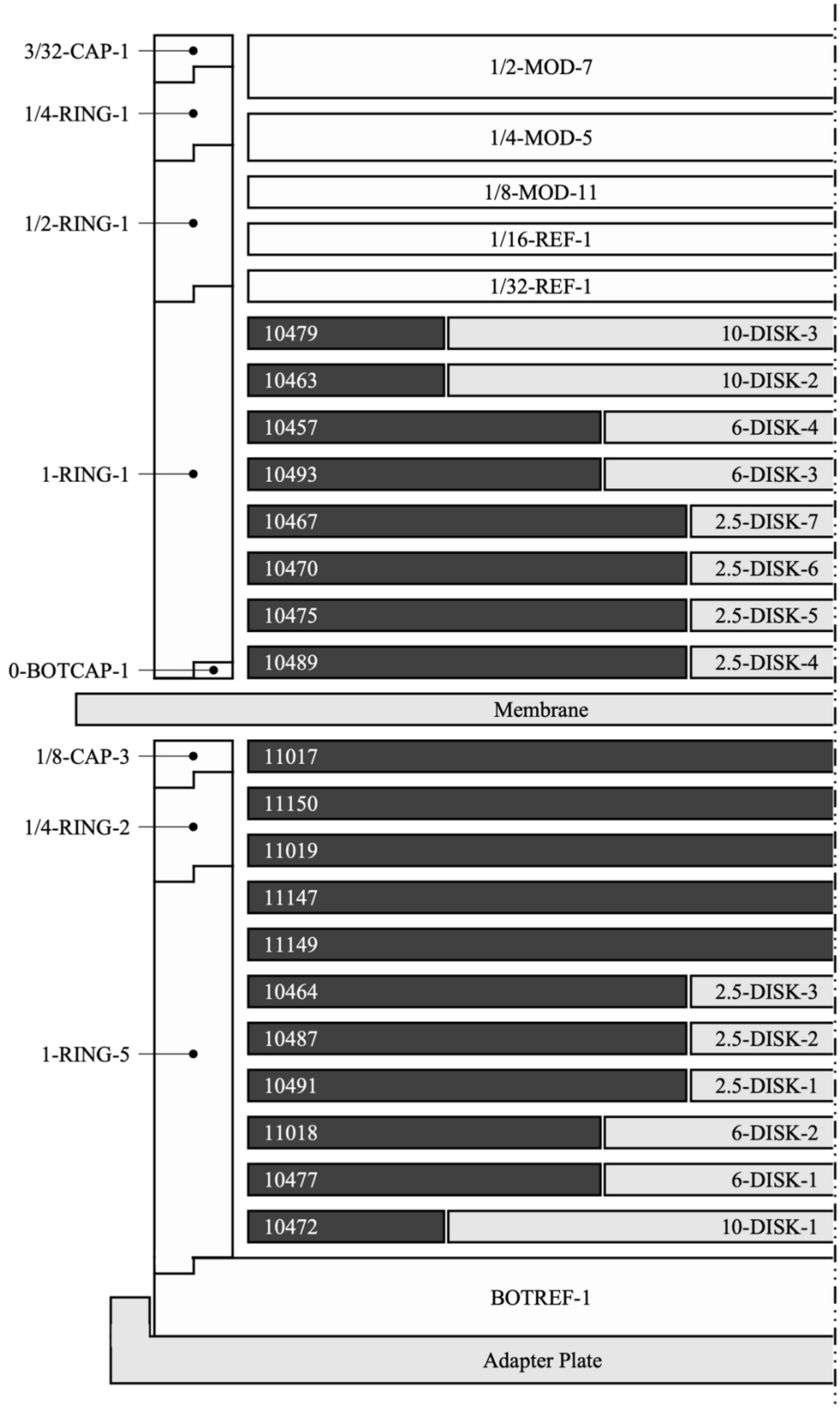


Figure 13. Axisymmetric diagram of the Case 1 experimental configuration (figure not to scale). Gaps shown between parts are not necessarily present.

1.2.8.2 Case 2

The Case 2 experimental configuration includes 11 HEU plates, 0.125 in (0.3175 cm) nominal polyethylene moderator plates between each HEU plate, and a nominal 1.03125 in (2.619375 cm) top reflector. These 11 HEU plates consisted of four HEU1 plates and seven HEU2 plates, for a total HEU mass of 70.0 kg.

Figure 14 shows a rendering of the Case 2 experimental configuration. Table 18 reports the measured reactor period. Table 19 reports the height measurements of the core stack and ring reflector for the upper and lower halves of the experimental configuration. Table 20, Table 21, Table 22, and Table 23 list the parts that make up the upper and lower core stacks and ring reflectors, along with the per-layer height measurements of the core stacks. Finally, Figure 15 shows a diagram of the parts in the Case 2 experimental configuration.

Unlike the other experimental configurations, no overall core stack height measurements were taken for Case 2. Instead, only the single per-layer height measurement of the top-most plates in upper and lower core stacks are available to represent the overall core stack heights. Furthermore, only a single ring reflector height measurement was taken, unlike the other experimental configurations which performed three.

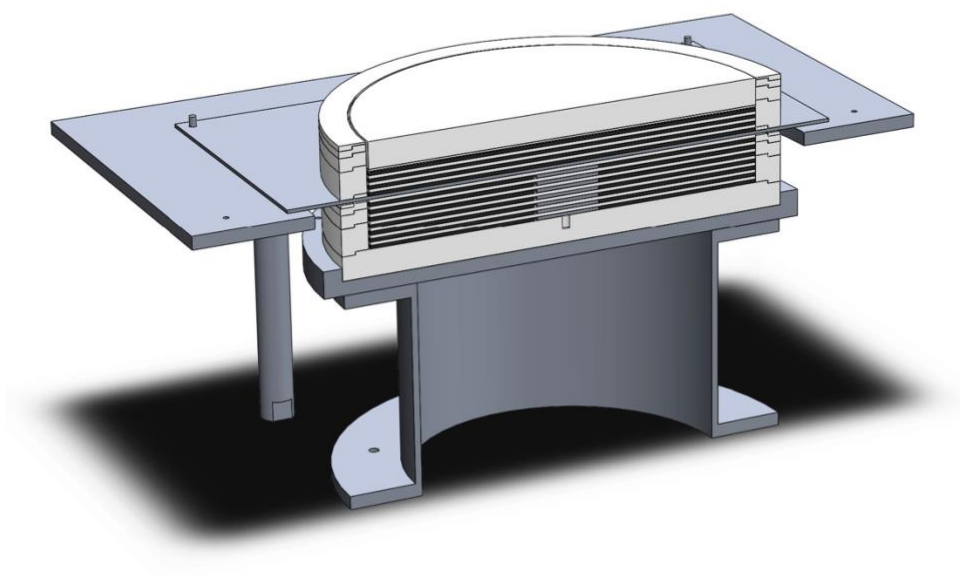


Figure 14. Rendering of the Case 2 experimental configuration.

Table 18. Case 2 period measurements.

Detector	Period (s)
LC_1	188.21
LC_2	188.64
LC_3	187.40
SU	200.67

Table 19. Case 2 upper and lower core stack and ring reflector height measurements.

Upper Height Measurements (mm)[(a)]		Lower Height Measurements (mm)[(b)]	
Core Stack	**Ring Reflector**	**Core Stack**	**Ring Reflector**
-	48.48	-	69.96

(a) Upper height measurements taken relative to the membrane.
(b) Lower height measurements taken relative to base, not the lip, of the adapter plate.

Table 20. Case 2 upper core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[(a)]	Part Description
1-REF-2	48.49	Top Reflector
1/16-REF-1	23.14	
11149	21.46	HEU1 Plate
1/8-MOD-10	18.05	1/8" Moderator Plate
11019	14.78	HEU1 Plate
1/8-MOD-9	11.89	1/8" Moderator Plate
11017	8.74	HEU1 Plate
1/8-MOD-8	6.08	1/8" Moderator Plate
11147	4.45	HEU1 Plate

(a) Height measurements taken relative to the membrane.

Table 21. Case 2 upper ring reflector parts.

Part ID (Top to Bottom)	Part Description
1/32-CAP-1	Reflector Cap
1/4-RING-2	Reflector Rings
1/2-RING-1	
1-RING-3	
0-BOTCAP-1	Reflector Base

Table 22. Case 2 lower core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[a]	Part Description
1/8-MOD-7	70.08	1/8” Moderator Plate
10464 (2.5-DISK-7)	67.19	HEU2 Plate with 2.5” Insert
1/8-MOD-6	63.47	1/8” Moderator Plate
10475 (2.5-DISK-6)	60.47	HEU2 Plate with 2.5” Insert
1/8-MOD-5	57.28	1/8” Moderator Plate
10470 (2.5-DISK-5)	54.20	HEU2 Plate with 2.5” Insert
1/8-MOD-4	50.96	1/8” Moderator Plate
10489 (2.5-DISK-4)	47.39	HEU2 Plate with 2.5” Insert
1/8-MOD-3	44.28	1/8” Moderator Plate
10491 (2.5-DISK-3)	41.47	HEU2 Plate with 2.5” Insert
1/8-MOD-2	37.70	1/8” Moderator Plate
10467 (2.5-DISK-2)	34.57	HEU2 Plate with 2.5” Insert
1/8-MOD-1	31.58	1/8” Moderator Plate
10487 (2.5-DISK-1)	28.41	HEU2 Plate with 2.5” Insert
BOTREF-1	25.18	Bottom Reflector

(a) Height measurements taken relative to the adapter plate.

Table 23. Case 2 lower ring reflector parts.

Part ID (Top to Bottom)	Part Description
0-CAP-1	Reflector Cap
1/4-RING-1	
1/2-RING-3	Reflector Rings
1-RING-5	
BOTREF-1	Reflector Base

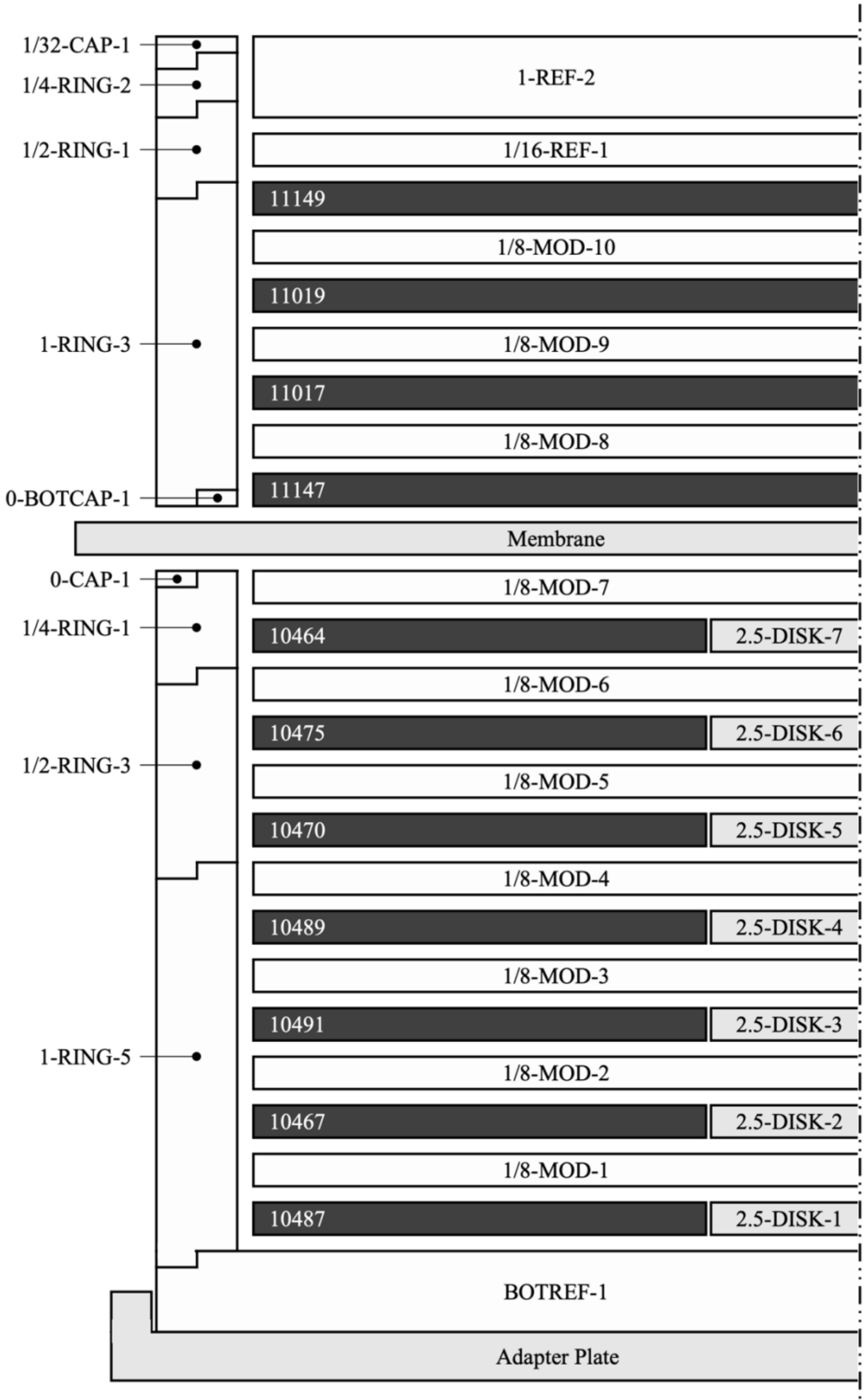


Figure 15. Axisymmetric diagram of the Case 2 experimental configuration (figure not to scale). Gaps shown between parts are not necessarily present.

1.2.8.3 Case 3

The Case 3 experimental configuration includes eight HEU plates, 0.25 in (0.635 cm) nominal polyethylene moderator plates between each HEU plate, and a nominal 1.21875 in (3.095625 cm) top reflector. These eight HEU plates consists of three HEU1 plates and five HEU2 plates, for a total HEU mass of 51.0 kg.

Figure 16 shows a rendering of the Case 3 experimental configuration. Table 24 reports the measured reactor period. Table 25 reports the height measurements of the core stack and ring reflector for the upper and lower halves of the experimental configuration. Table 26, Table 27, Table 28, and Table 29 list the parts that make up the upper and lower core stacks and ring reflectors, along with the per-layer height measurements of the core stacks. Finally, Figure 17 shows a diagram of the parts in the Case 3 experimental configuration.

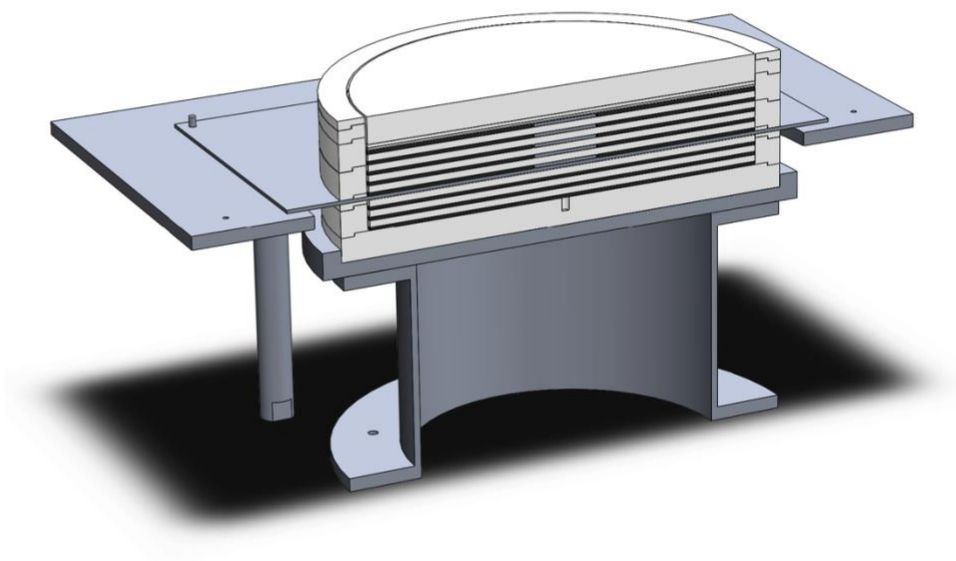


Figure 16. Rendering of the Case 3 experimental configuration.

Table 24. Case 3 period measurements.

Detector	Period (s)
LC_1	100.62
LC_2	100.45
LC_3	100.02
SU	106.49

Table 25. Case 3 upper core stack and ring reflector height measurements.

Upper Height Measurements (mm)[(a)]		Lower Height Measurements (mm)[(b)]	
Core Stack	**Ring Reflector**	**Core Stack**	**Ring Reflector**
72.27	72.59	42.00	42.28
72.50	71.84	41.46	42.17
72.55	71.77	41.72	42.66

(a) Upper height measurements taken relative to the membrane.
(b) Lower height measurements taken relative to the lip of the adapter plate.

Table 26. Case 3 upper core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[(a)]	Part Description
1-REF-2	73.09	Top Reflector
1/8-MOD-1	47.20	
1/16-REF-1	44.05	
1/32-REF-1	42.60	
10470 (2.5-DISK-5)	41.90	HEU2 Plate with 2.5” Insert
1/4-MOD-9	38.70	1/4” Moderator Plate
10489 (2.5-DISK-4)	32.60	HEU2 Plate with 2.5” Insert
1/4-MOD-8	29.20	1/4” Moderator Plate
10491 (2.5-DISK-3)	22.77	HEU2 Plate with 2.5” Insert
1/4-MOD-7	19.42	1/4” Moderator Plate
10467 (2.5-DISK-2)	13.19	HEU2 Plate with 2.5” Insert
1/4-MOD-6	10.09	1/4” Moderator Plate
10487 (2.5-DISK-1)	3.70	HEU2 Plate with 2.5” Insert

(a) Height measurements relative to the membrane.

Table 27. Case 3 upper ring reflector parts.

Part ID (Top to Bottom)	Part Description
7/32-CAP-1	Reflector Cap
1/2-RING-1	Reflector Rings
1-RING-4	
1-RING-3	
0-BOTCAP-1	Reflector Base

Table 28. Case 3 lower core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[(a)]	Part Description
1/4-MOD-3	53.87	1/4” Moderator Plate
11019	47.39	HEU1 Plate
1/4-MOD-2	44.47	1/4” Moderator Plate
11017	38.04	HEU1 Plate
1/4-MOD-1	35.14	1/4” Moderator Plate
11150	28.76	HEU1 Plate
BOTREF-1	25.35	Bottom Reflector

(a) Height measurements relative to the adapter plate.

Table 29. Case 3 lower ring reflector parts.

Part ID (Top to Bottom)	Part Description
1/8-CAP-2	Reflector Cap
1-RING-5	Reflector Ring
BOTREF-1	Reflector Base

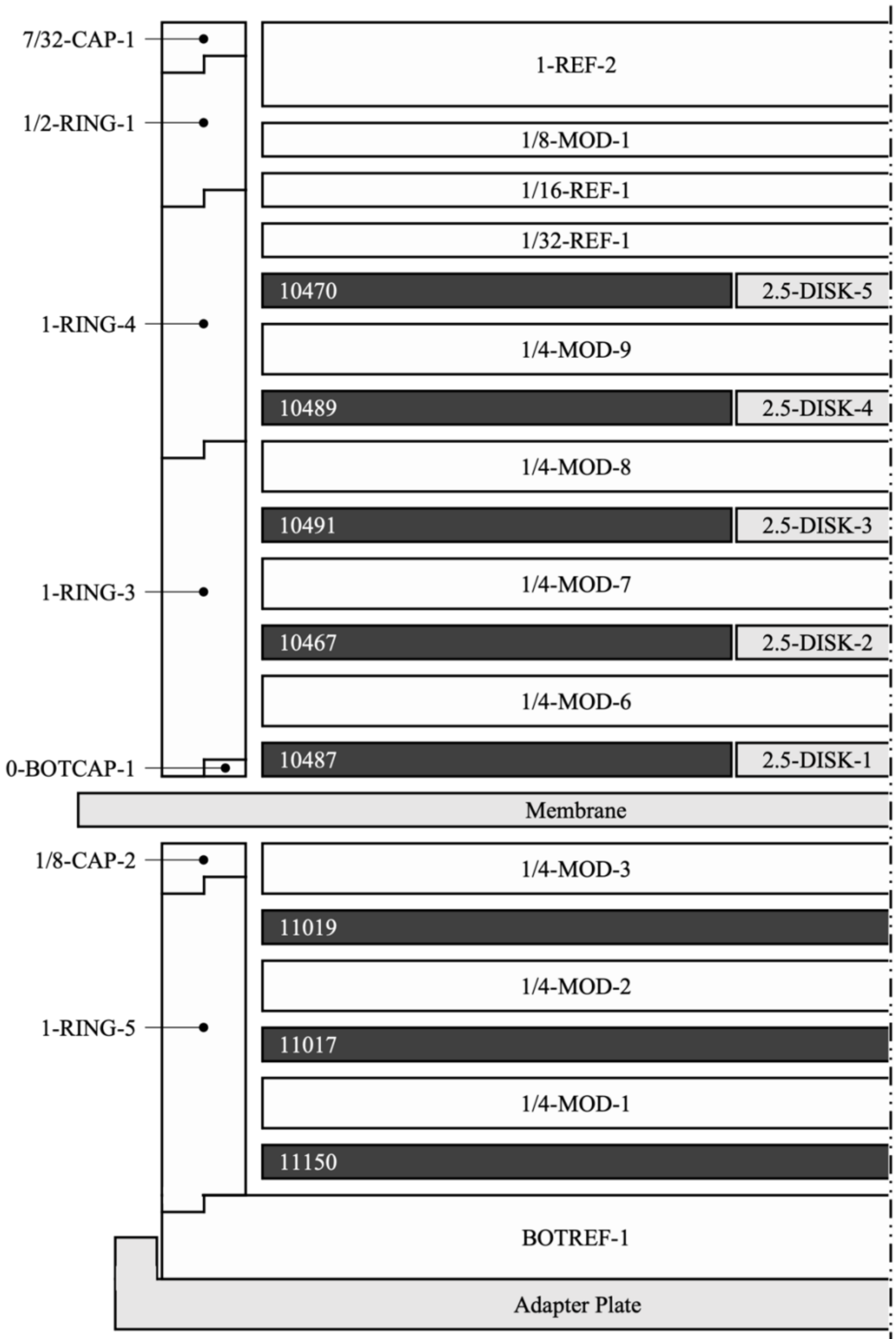


Figure 17. Axisymmetric diagram of the Case 3 experimental configuration (figure not to scale). Gaps shown between parts are not necessarily present.

1.2.8.4 Case 4

The Case 4 experimental configuration includes five HEU plates, 0.5 in (1.27 cm) nominal polyethylene moderator plates between each HEU plate, and a nominal 1.65625 in (4.206875 cm). These five HEU plates consisted of all HEU1 plates, for a total HEU mass of 32.3 kg.

Figure 18 shows a rendering of the Case 4 experimental configuration. Table 30 reports the measured reactor period. Table 31 reports the height measurements of the core stack and ring reflector for the upper and lower halves of the experimental configuration. Table 32, Table 33, Table 34, and Table 35 list the parts that make up the upper and lower core stacks and ring reflectors, along with the per-layer height measurements of the core stacks. Finally, Figure 19 shows a diagram of the parts in the Case 4 experimental configuration.

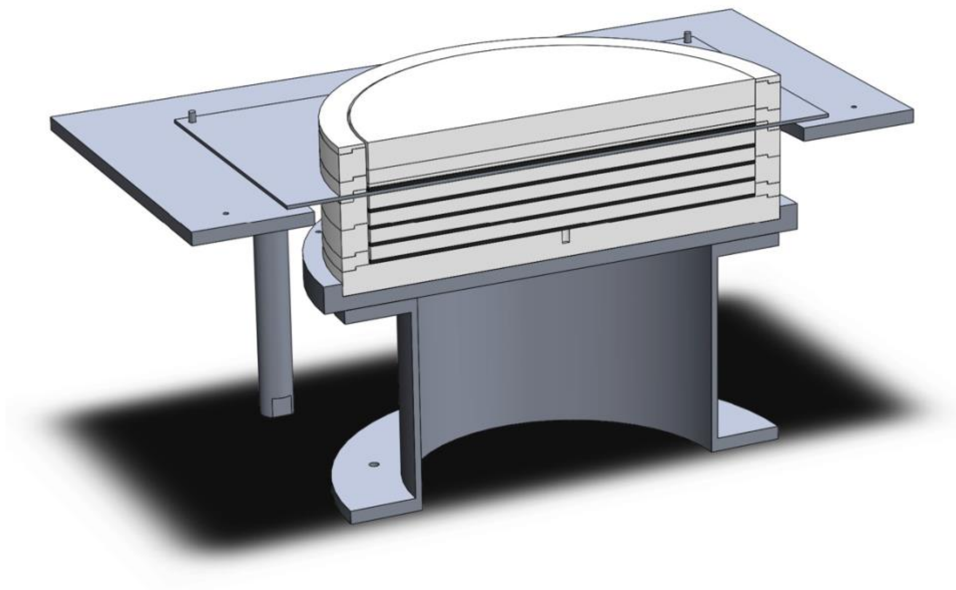


Figure 18. Rendering of the Case 4 experimental configuration.

Table 30. Case 4 period measurements.

Detector	Period (s)
LC_1	51.19
LC_2	51.77
LC_3	51.36
SU	53.96

Table 31. Case 4 upper and lower core stack and ring reflector height measurements.

Upper Height Measurements (mm)[(a)]		Lower Height Measurements (mm)[(b)]	
Core Stack	**Ring Reflector**	**Core Stack**	**Ring Reflector**
44.69	44.45	74.22	75.99
44.76	44.05	76.62	77.39
45.22	44.59	75.76	76.57

(a) Upper height measurements taken relative to the membrane.
(b) Lower height measurements taken relative to the lip of the adapter plate.

Table 32. Case 4 upper core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[(a)]	Part Description
1-REF-2	45.01	Top Reflector
1/2-MOD-6	19.19	
1/8-MOD-1	6.60	
1/32-REF-1	4.11	
11147	3.17	HEU1 Plate

(a) Height measurements relative to the membrane.

Table 33. Case 4 upper ring reflector parts.

Part ID (Top to Bottom)	Part Description
1/8-CAP-1	Reflector Cap
1-RING-3	Reflector Rings
1/2-RING-1	
0-BOTCAP-1	Reflector Base

Table 34. Case 4 lower core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[(a)]	Part Description
1/2-MOD-4	89.06	1/2” Moderator Plate
11149	76.32	HEU1 Plate
1/2-MOD-3	73.07	1/2” Moderator Plate
11019	60.91	HEU1 Plate
1/2-MOD-2	57.29	1/2” Moderator Plate
11017	44.65	HEU1 Plate
1/2-MOD-1	41.60	1/2” Moderator Plate
11150	28.92	HEU1 Plate
BOTREF-1	25.48	Bottom Reflector

(a) Height measurements relative to the adapter plate.

Table 35. Case 4 lower ring reflector parts.

Part ID (Top to Bottom)	Part Description
0-CAP-2	Reflector Cap
1-RING-1	Ring Reflectors
1-RING-5	
1/2-RING-2	
BOTREF-1	Reflector Base

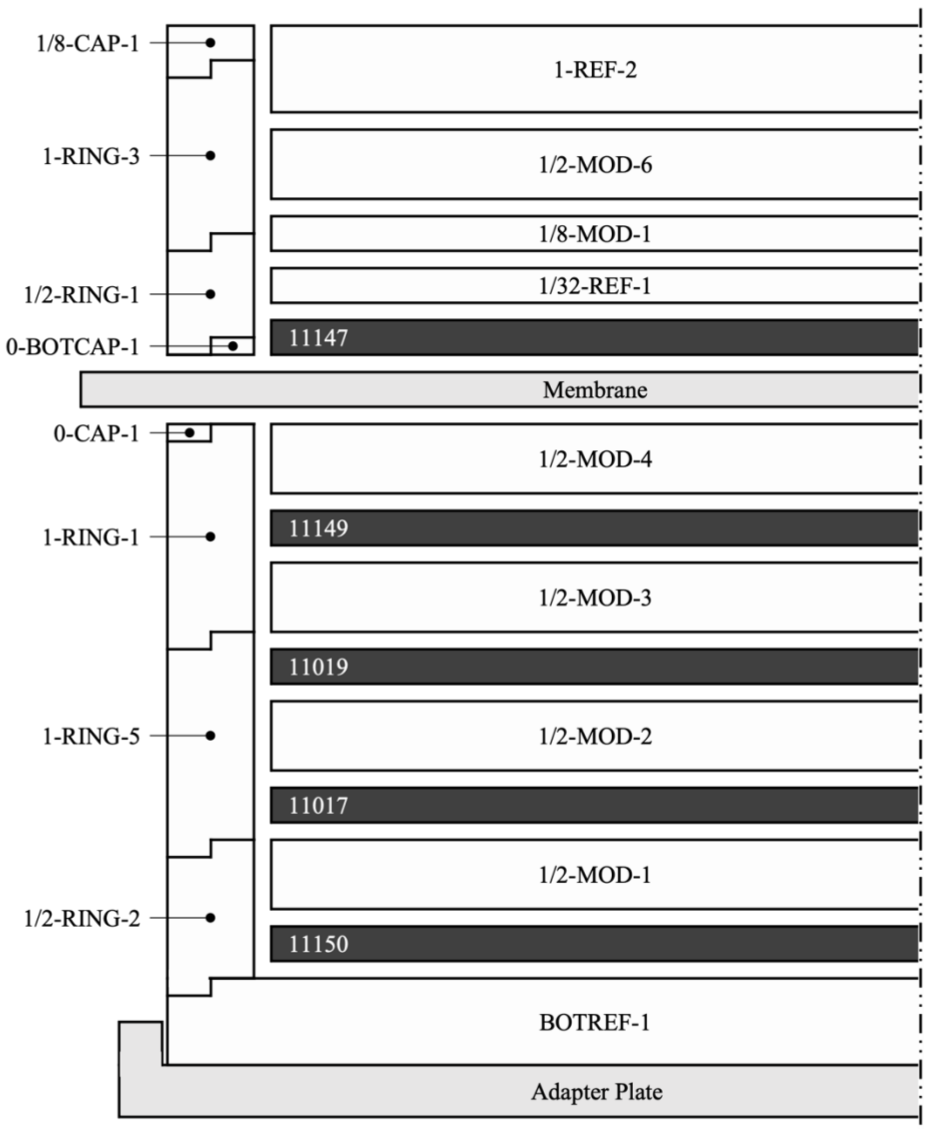


Figure 19. Axisymmetric diagram of the Case 4 experimental configuration (figure not to scale). Gaps shown between parts are not necessarily present.

1.2.8.5 Case 5

The Case 5 experimental configuration included five HEU plates, 1.5 in (3.81 cm) nominal polyethylene moderator plates between each HEU plate, and a nominal 1.125 in (2.8575 cm) top reflector. These five HEU plates consisted of two HEU1 and three HEU4 plates, for a total HEU mass of 29.5 kg.

Figure 20 shows a rendering of the Case 5 experimental configuration. Table 36 reports the measured reactor period. Table 37 reports the height measurements of the core stack and ring reflector for the upper and lower halves of the experimental configuration. Table 38, Table 39, Table 40, and Table 41 list the parts that make up the upper and lower core stacks and ring reflectors, along with the per-layer height measurements of the core stacks. Finally, Figure 21 shows a diagram of the parts in the Case 5 experimental configuration.

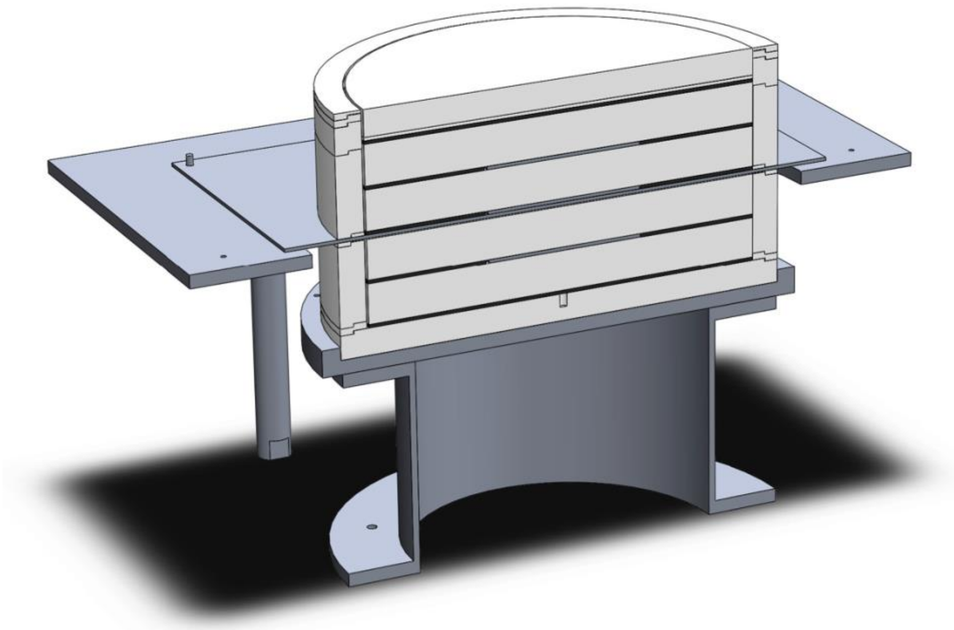


Figure 20. Rendering of the Case 5 experimental configuration.

Table 36. Case 5 period measurements.

Detector	Period (s)
LC_1	61.43
LC_2	60.45
LC_3	61.27
SU	66.41

Table 37. Case 5 upper and lower core stack and ring reflector height measurements.

Upper Height Measurements (mm)[(a)]		Lower Height Measurements (mm)[(b)]	
Core Stack	**Ring Reflector**	**Core Stack**	**Ring Reflector**
114.11	114.04	96.03	96.05
114.67	114.56	97.04	96.78
114.60	114.83	96.65	96.98

(a) Upper height measurements taken relative to the membrane.
(b) Lower height measurements taken relative to the lip of the adapter plate.

Table 38. Case 5 upper core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[(a)]	Part Description
1-REF-2	114.60	Top Reflector
1/8-MOD-1	88.69	
11017	85.45	HEU1 Plate
1.5-MOD-4	82.56	1.5” Moderator Plate
10457 (6-DISK-3)	44.07	HEU4 Plate with 6” Insert
1.5-MOD-3	41.25	1.5” Moderator Plate
10477 (6-DISK-1)	3.41	HEU4 Plate with 6” Insert

(a) Height measurements relative to the membrane.

Table 39. Case 5 upper ring reflector parts.

Part ID (Top to Bottom)	Part Description
3/32-CAP-1	Reflector Cap
1/4-RING-2	Reflector Rings
1-RING-1	
3-RING-5	
0-BOTCAP-1	Reflector Base

Table 40. Case 5 lower core stack parts and per-layer height measurements.

Part ID (Top to Bottom)	Height (mm)[(a)]	Part Description
1.5-MOD-2	108.40	1.5” Moderator Plate
10493 (6-DISK-2)	70.67	HEU4 Plate with 6” Insert
1.5-MOD-1	67.57	1.5” Moderator Plate
11147	28.78	HEU1 Plate
BOTREF-1	25.48	Bottom Reflector

(a) Height measurements relative to the adapter plate.

Table 41. Case 5 lower ring reflector parts.

Part ID (Top to Bottom)	Part Description
1/32-CAP-1	Reflector Cap
3-RING-1	Reflector Rings
1/4-RING-1	
BOTREF-1	Reflector Base

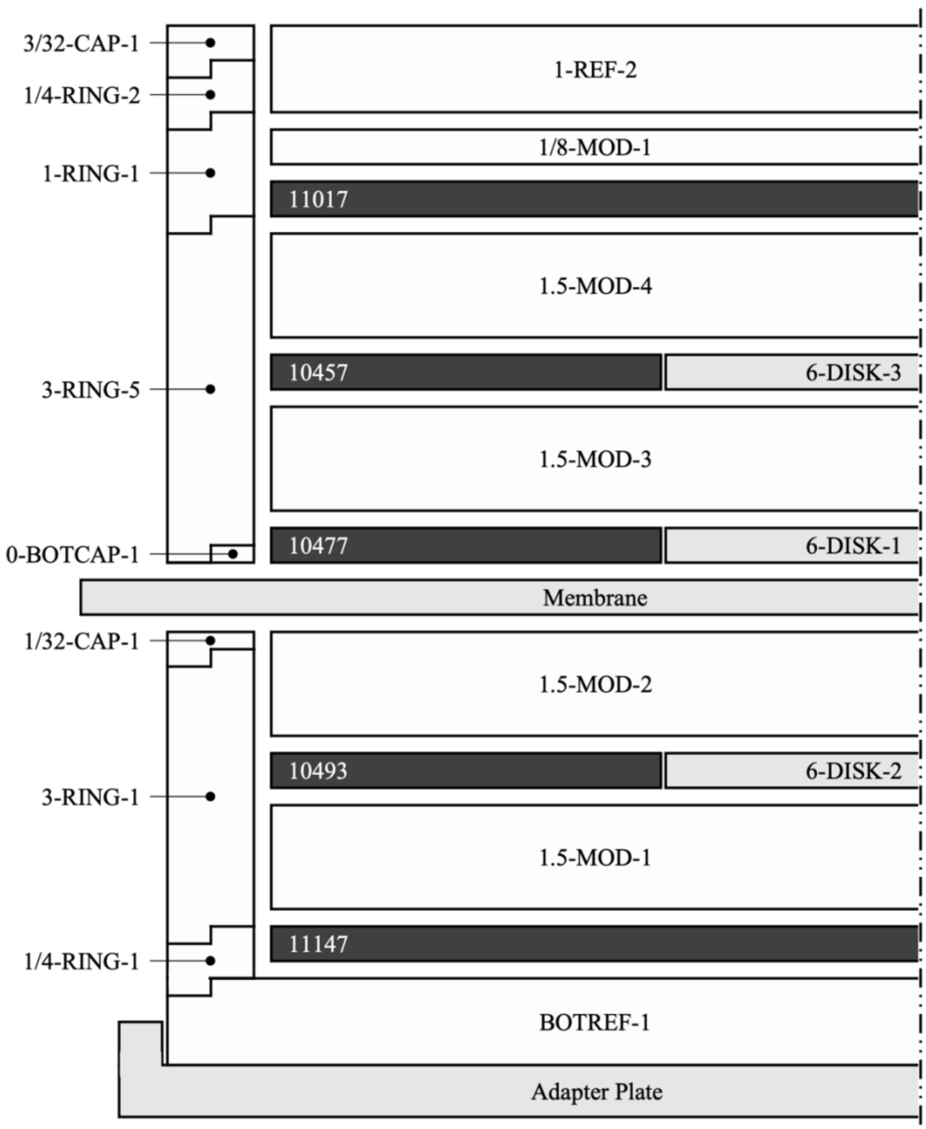


Figure 21. Axisymmetric diagram of the Case 5 experimental configuration (figure not to scale). Gaps shown between parts are not necessarily present.

1.3 Description of Material Data

1.3.1 Comet General Purpose Vertical Lift Machine

The additional parts for TEX-HEU were weighed prior to installation on Comet. The weights are reported in Table 42 and were measured during the experiment campaign with a Mettler Toledo SB16001 High-Capacity Precision Balance under the NCERC Calibration Program (Cal No. 012708). The calibration for this balance was certified on May 2, 2019, and is valid through May 2, 2020. These measurements were taken on February 24, 2020. The manufacturer of the SB16001 reports a maximum capacity of 16,100 grams, precision of 0.1 grams, and linearity of 0.3 grams.

Table 42. Additional TEX-HEU parts used on Comet.

Part ID		Mass (g)
Membrane		2396.1
Experiment Platform	Interface Plate	11242.5
	Standoffs	633.8 634.4 634.0 635.0
Lower Adapter	Adapter Plate	5014.7
	Adapter Extension	8365.3

1.3.2 Highly Enriched Uranium

The following sections summarize and reproduce relevant material information from previous ICSBEP benchmark evaluations that use the same HEU plates. These benchmark evaluations include IEU-MET-FAST-007 and HEU-MET-FAST-072. The IEU-MET-FAST-007 experiments and benchmark evaluation use the HEU2, HEU4, and HEU5 plates, identified as Id No. 403, 401, and 402, respectively. The HEU-MET-FAST-072 experiments and benchmark evaluation use the HEU1 and HEU2 plates.

1.3.2.1 ^{235}U Enrichment

Table 43 reproduces the relevant HEU plate enrichments from IEU-MET-FAST-007 and HEU-MET-FAST-072. As noted in those benchmark evaluations, the enrichment values were obtained from the LANL MASS systems for the plates used in the Big Ten assembly and a letter from Dixon Callihan (ORNL) to Hugh Paxton (LANL) dated May 20, 1960.

The IEU-MET-FAST-007 benchmark evaluation, using the HEU4 and HEU5 plates, does not report the individual plate ^{235}U enrichments. Instead it lists individual enrichment values grouped by part type. Therefore, the ^{235}U enrichments for these HEU plate types are represent as an average and standard deviation of the values from the corresponding plate type in IEU-MET-FAST-007. The HEU-MET-FAST-072 benchmark evaluation reports ^{235}U enrichment values for each individual plate. Some of the HEU plate Part IDs in HEU-MET-FAST-072 are prefaced with “B10,” which has been removed in favor of the ending 5-digit identifier.

Table 43. HEU plate ^{235}U enrichment.

Part Type	Part ID	Enrichment
10" (HEU5)	10463	93.34 ± 0.10[a]
	10472	
	10479	
6" (HEU4)	10457	93.24 ± 0.12[a]
	10477	
	10493	
	11018	
2.5" (HEU2)	10464	93.38[b]
	10467	93.41[b]
	10470	93.41[b]
	10475	93.40[b]
	10487	93.26[b]
	10489	93.39[b]
	10491	93.37[b]
Full (HEU1)	11017	93.31[b]
	11019	93.18[b]
	11147	93.17[b]
	11149	93.24[b]
	11150	93.17[b]

(a) IEU-MET-FAST-007
(b) HEU-MET-FAST-072

In addition to the ^{235}U enrichment values reported in IEU-MET-FAST-007 and HEU-MET-FAST-072, the benchmark evaluations present mass spectrometry measurements performed at LANL for HEU isotopic content of the plate, reproduced in Table 44. The measurements are reported as atomic ratios relative to ^{235}U and the uncertainties are at the 95% confidence level (2σ).

Table 44. HEU plate uranium isotopic content measurements.

Part Type	Part ID	Uranium Isotope (Atom Ratio Relative to ^{235}U)			
		^{234}U	^{235}U	^{236}U	^{238}U
10" (HEU5)	10458[a]	0.0111 ± 0.0002	1.00	$<2\times10^{-5}$	0.0577 ± 0.0012
6" (HEU4)	10493	0.0115 ± 0.0001	1.00	$(8.40 \pm 0.42)\times10^{-4}$	0.0592 ± 0.0002
	10932[a]	0.0108 ± 0.0001	1.00	$(3.50 \pm 0.04)\times10^{-3}$	0.0586 ± 0.0002
	11018[a]	0.0110 ± 0.0001	1.00	$(5.56 \pm 0.06)\times10^{-3}$	0.0555 ± 0.0002

(a) Part not used in this benchmark.

1.3.2.2 Uranium Impurity Analysis

Table 45 reproduces the HEU plate impurity measurements from IEU-MET-FAST-007 and HEU-MET-FAST-072. The reported impurities are assumed to be by weight.

Table 45. Measured HEU plate impurities.

Impurity (ppm U)	Full (HEU1)			6" (HEU4)	
	11147	11149	11150	10932[(a)]	10933[(a)]
Li	<0.1	<0.1	<0.1	<0.1	<0.1
Be	<0.1	<0.1	<0.1	<0.1	<0.1
B	0.6	0.6	0.3	0.2	<0.1
C	1100	270	320	170	170
Na	<1	<1	<1	<1	<1
Mg	<1	<1	<1	<1	1
Al	50	40	20	150	100
Si	300	400	210	80	130
Ca	<2	<2	<2	<2	<2
V	<20	<20	<20	<20	<20
Cr	5	15	5	2	3
Mn	4	7	6	7	6
Fe	100	190	90	70	30
Co	<5	<5	<5	<5	<5
Ni	20	30	20	15	15
Cu	6	5	4	4	3
Mo	50	<25	<25	-	-
Sn	<1	<1	<1	-	-
Pb	5	<1	<1	-	-

(a) Plate not used in these experiments.

1.3.3 Polyethylene

1.3.3.1 Polyethylene Density Analysis

The density of the polyethylene was analyzed at LLNL by performing high-precision volume and mass measurements of small samples taken from seven different polyethylene parts. The volume measurements were performed using a Micromeritics AccuPyc II gas displacement pycnometry system. The system used a 100 cm^3 sample chamber and was calibrated using a 51.08755 cm^3 calibration ball prior to each series of sample measurements. Each volume measurement was performed 10 times per sample. The mass measurements were performed on a balance with a precision of 10 μg. Each sample was weighed three times.

Table 46 reports the results of density measurements performed on the seven polyethylene samples. The uncertainty in the mass and volume measurements is presented as the standard deviation of the three mass measurements and 10 volume measurements. These uncertainties are then propagated in quadrature to determine the standard deviation of the calculated density.

Table 46. Polyethylene part density measurements.

Part ID	Mass (g)	Volume (cm^3)	Density (g/cm^3)[(a)]
0-CAP-3	39.92816 ± 0.00003	41.1483 ± 0.0047	0.9703 ± 0.0001
3/32-CAP-3	48.90154 ± 0.00004	50.4268 ± 0.0033	0.9698 ± 0.0001
1-RING-6	44.30622 ± 0.00001	45.6667 ± 0.0063	0.9702 ± 0.0001
1/8-MOD-38	46.37212 ± 0.00007	48.1521 ± 0.0047	0.9630 ± 0.0001
1/4-MOD-36	58.59803 ± 0.00001	61.2725 ± 0.0043	0.9564 ± 0.0001
1/2-MOD-32	57.58423 ± 0.00007	60.1526 ± 0.0022	0.9573 ± 0.0000
1.5-MOD-12	42.35975 ± 0.00002	44.2152 ± 0.0059	0.9580 ± 0.0001

(a) Derived quantity based on mass and volume measurements.

1.3.3.2 Polyethylene Impurity Analysis

Elemental analysis by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was performed on a sample of the polyethylene. This process involved adding the sample to a digestion pressure vessel with 10 mL of 6M nitric acid (HNO_3) and then digesting it in a MARS6 Microwave Digestion System (Model 910900) following the CEM “Polyethylene” procedure in the semi-quantitative, MS/MS mode.

The measured elemental impurities are reported in Table 47. The samples used for this measurement were small shavings taken from the polyethylene parts. The samples were weighed prior to digestion and had a total mass of 246.97 μg. The selection criteria required >5000 counts per second. Elements included in the analysis but not meeting this criterion are also included in Table 47.

Table 47. Polyethylene impurity analysis results (elements not meeting the selection criteria have a hyphen).

Elemental Impurity	Unit	Average	Standard Deviation
Na	μg/g	14.38	1.82
Mg	-	-	-
Al	μg/g	23.92	1.74
Si	mg/g	1.17	0.06
V	-	-	-
Cr	ng/g	921.35	7.08
Mn	-	-	-
Ni	-	-	-
Cu	-	-	-
Zn	-	-	-
Ga	-	-	-
Zr	-	-	-
Mo	-	-	-
Sn	-	-	-
La	-	-	-
Pb	-	-	-

1.3.4 Aluminum

The aluminum inserts are Aluminum Alloy 6061 (AL 6061) and all other aluminum parts, including the membrane, interface plate and standoffs, adapter plate and extension, and Comet stationary platform and movable platen are AL 6061-T6. The elemental composition of AL 6061 and AL 6061-T6 is equivalent as they are the same alloy. Therefore, all aluminum in these experiments is AL 6061. Table 48 presents handbook data for standard AL 6061.

Table 48. Elemental composition limits for standard Aluminum Alloy 6061[(a)].

Element	**Wt. %**
Al[(b)]	95.8 – 98.6
Mg	0.8 – 1.2
Si	0.4 – 0.8
Cu	0.15 – 0.4
Cr	0.04 – 0.35
Fe	Max 0.7
Zn	Max 0.25
Mn	Max 0.15
Ti	Max 0.15
Other, each	Max 0.05
Other, total	Max 0.15

(a) Aluminum alloy 6061 properties, Materials Data Repository, National Institute of Standards and Technology (NIST), U.S. Department of Commerce.
(b) Aluminum content reported is calculated as the remainder.

1.4 Temperature Data

Temperatures were measured using RTDs during experiment execution. The RTDs were placed in two locations: on the aluminum membrane, which was in direct contact with the bottom HEU plate of the upper core stack, and on the top polyethylene reflector plate. These two RTDs were removed prior to the benchmark measurement. A third RTD was in the room to measure the ambient temperature separate of the experiment. The measured temperatures are reported in Table 49.

Table 49. Measured temperature data.

Case	RTD #1[(a)] (°C)	RTD #2[(b)] (°C)	Ambient (°C)
1	11.4	8.7	11.5
2	12.3	11.1	11.4
3	12.4	11.6	11.6
4	12.2	8.2	11.7
5	11.8	8.8	11.5

(a) RTD #1 was located on the aluminum membrane.
(b) RTD #2 was located on the top polyethylene reflector plate.

1.5 Supplemental Experimental Measurements

No additional experimental measurements were performed.

2.0 EVALUATION OF EXPERIMENTAL DATA

Each configuration was evaluated using MCNP® 6.2.0 with ENDF/B-VIII.0 neutron cross section libraries. The calculations are typically run with 1,500 generations of 100,000 particles per generation, skipping the first 100 generations, resulting in a total of 140 million active histories and a typical statistical uncertainty of ±0.00003 (3 pcm) in k_{eff}. Therefore, the threshold for negligible is defined to be less than 0.00004 (4 pcm) in k_{eff}, which represents the propagated uncertainty in Δk_{eff} given a statistical uncertainty of ±0.00003. This negligibility is only reflected in the combined uncertainty tables in Section 2.5.

For a given parameter i with a mean value $x_{0,i}$ and a perturbation δx_i, the resulting effect in k_{eff} is calculated using

$$\Delta k_{\text{eff},i} = \frac{k_{\text{eff}}\left(x_{0,i}+\delta x_i\right) - k_{\text{eff}}\left(x_{0,i}-\delta x_i\right)}{2}. \qquad \text{Eq. 1}$$

The effect of the perturbation in k_{eff} for parameter i is symmetric unless otherwise stated. The standard uncertainty in k_{eff}, $u_{k,i}$, is then calculated by scaling the result of Eq. 1 with the evaluated standard uncertainty in parameter i, u_i, and the perturbation in parameter i, δx_i, using

$$u_{\text{k},i} = \frac{u_i}{\delta x_i}\left(\Delta k_{\text{eff,i}}\right). \qquad \text{Eq. 2}$$

2.1 Mass Uncertainties

All mass uncertainties are evaluated by perturbing the mass at a constant volume, requiring the part density to either increase or decrease. Where individual part measurements are performed, the evaluated uncertainty is based on the distribution of the individual part measurements within a given part type. This uncertainty is calculated using,

$$\sigma = \sqrt{\sum_{i=1}^{n} \sigma_i^2} \qquad \text{Eq. 3}$$

where σ_i is the uncertainty in the individual part mass and σ is the resulting uncertainty for the part type. This assumes the uncertainty in the individual masses in each part type are uniform and independent, which is valid given that each part is measured separately. While the same scale is typically used to measure a given set of parts, the random uncertainty component is assumed to be much less than the uncertainty in the distribution of the part masses.

2.1.1 Highly Enriched Uranium Plate Mass

Mass measurements of the HEU plates were performed during this experiment campaign in 2020, reported in Table 4, and a previous experiment campaign in 2019, reported in Table 5. Both sets of measurements were performed using a balance with a precision of 0.1 grams and linearity of ±0.2 grams.

Table 50 compares the measurement of the HEU plates performed in 2019 and 2020. The masses have an average difference of -0.4 ± 3.2 grams with the greatest difference being 9.0 grams. The discrepancy in these measurements is likely due to the difficulty in measuring these HEU plates or due to oxidization of the bare HEU metal over time. These plates had to be measured in a radiation area with the operators in full anti-contamination clothing, placing a sheet between the balance and the plate to prevent contamination. Based on this comparison, the uncertainty in HEU mass is evaluated to be the standard deviation of the difference between the measurement sets, ±3.2 grams per plate. This uncertainty is significantly larger than the measurement uncertainty of ±0.2 grams per plate.

Table 50. Comparison of HEU plate mass measurements between 2019 and 2020.

Part Type	Part ID	Mass, 2019 (g)	Mass, 2020 (g)	Difference (g)
Full (HEU1)	11150	6419.3	6410.3	-9.0
	11149	6385.5	6383.6	-1.9
	11147	6519.8	6517.3	-2.5
	11019	6473.8	6470.0	-3.8
	11017	6505.8	6501.6	-4.2
2.5” (HEU2)	10491	6392.5	6392.4	-0.1
	10489	6344.0	6343.8	-0.2
	10487	6274.9	6274.9	0.0
	10475	6229.9	6230.0	0.1
	10470	6278.5	6279.0	0.5
	10467	6335.6	6335.8	0.2
	10464	6258.6	6258.5	-0.1
6” (HEU4)	11018	5368.5	5369.9	1.4
	10493	5435.5	5437.2	1.7
	10477	5497.5	5499.2	1.7
	10457	5571.0	5574.1	3.1
10” (HEU5)	10479	3631.7	3631.7	0.0
	10472	3587.0	3585.7	-1.3
	10463	3557.8	3564.7	6.9
			Average Difference (g)	**-0.4 ± 3.2**

Table 51 summarizes the HEU mass uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is calculated using Eq. 3 with the evaluated uncertainty of ±3.2 g per HEU plate. The total HEU mass is the sum of all HEU plates in the experimental configuration. The calculations vary the HEU mass by collectively perturbing the individual plates by ±6.0 grams. Table 51 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 51. Summary of sensitivity in k_{eff} to uncertainties for HEU mass.

Case	Number of HEU Plates	Total HEU Mass (g)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	19	109059.7	±114.0	±0.00055	$\pm 3.2\sqrt{19}$	±0.00007
2	11	69986.9	±66.0	±0.00031	$\pm 3.2\sqrt{11}$	±0.00005
3	8	51007.8	±48.0	±0.00021	$\pm 3.2\sqrt{8}$	±0.00004
4	5	32282.8	±30.0	±0.00013	$\pm 3.2\sqrt{5}$	±0.00003
5	5	29529.4	±30.0	±0.00012	$\pm 3.2\sqrt{5}$	±0.00003

2.1.2 Aluminum Insert Mass

Mass measurements of the aluminum inserts are reported in Table 6. These measurements were performed using a balance with a precision of 0.1 grams.

Table 52 summarizes the aluminum insert mass measurements, reporting the average and standard deviation of the masses by part type. The uncertainties are represented as the standard deviation of the mass measurements from parts of the same type. Since the experimental configurations typically contain all types of the aluminum inserts, the evaluated uncertainty in the aluminum insert mass is chosen to be ±1.5 grams per insert for all part types representing the largest mass uncertainty. This evaluated uncertainty is significantly larger than the measurement uncertainty of ±0.1 grams per plate.

Table 52. Average aluminum insert mass by part type.

Part Type	N	Mass (g)
2.5-DISK	10	24.8 ± 0.1
6-DISK	4	150.5 ± 0.8
10-DISK	3	424.8 ± 1.5

Table 53 summarizes the aluminum insert mass uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is calculated using Eq. 3 with the evaluated uncertainty of ±1.5 g per aluminum insert. The total aluminum mass is the sum of all aluminum inserts in the experimental configuration. The calculations vary the aluminum mass by collectively perturbing the individual inserts by ±3.0 grams, representing twice the evaluated uncertainty per insert. Table 53 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 53. Summary of sensitivity in k_{eff} to uncertainties for aluminum insert mass.

Case	Number of Inserts	Total Insert Mass (g)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	14	2050.2	±42.0	±0.00017	$\pm1.5\sqrt{14}$	±0.00002
2	7	173.8	±21.0	±0.00000	$\pm1.5\sqrt{7}$	±0.00000
3	5	123.9	±15.0	±0.00000	$\pm1.5\sqrt{5}$	±0.00000
4[(a)]	No aluminum inserts.					-
5	3	450.7	±9.0	±0.00002	$\pm1.5\sqrt{3}$	±0.00000

(a) There are no aluminum inserts in the Case 4 experimental configuration.

2.1.3 Polyethylene Moderator Mass

Mass measurements of the polyethylene moderator plates are reported in Table 7. These measurements were performed using a balance with a precision of 0.1 grams.

Table 54 summarizes the polyethylene moderator plate mass measurements, reporting the average and standard deviation of the masses by part type. The uncertainties are represented as the standard deviation of the mass measurements from parts of the same type. Based on these averages, the evaluated uncertainty in polyethylene moderator plate mass is ±1.0 g, ±0.8 g, ±3.5 g, and ±10.6 g for the 1/8-MOD, 1/4-MOD, 1/2-MOD, and 1.5-MOD parts, respectively. These evaluated uncertainties are larger than the measurement uncertainty of ±0.1 grams per plate.

Table 54. Average polyethylene moderator plate mass by part type.

Part Type	N	Mass (g)
1/8-MOD	11	343.8 ± 1.0
1/4-MOD	10	689.0 ± 0.8
1/2-MOD	8	1380.9 ± 3.5
1.5-MOD	4	4136.3 ± 10.6

Table 55 summarizes the polyethylene moderator plate mass uncertainty calculation parameters and sensitivity in k_{eff}. Each experimental configuration uses a single polyethylene moderator plate type: 1/8-MOD in Case 2, 1/4-MOD in Case 3, 1/2-MOD in Case 4, and 1.5-MOD in Case 5. Except for Case 1, which does not use a polyethylene moderator.

However, the polyethylene moderator plates are also used in the top reflector, resulting in the discrepancy between the number of polyethylene moderator plates in Table 54 and Table 55. The total moderator mass is the sum of all polyethylene moderator plates in the experimental configuration, excluding any polyethylene moderator plates used in the top reflector. The calculations vary the polyethylene moderator mass by collectively perturbing the individual polyethylene moderator plates by their respective evaluated uncertainty as reported in Table 54. Table 55 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 55. Summary of sensitivity in k_{eff} to uncertainties for polyethylene moderator mass.

Case	Number of Moderator Plates	Total Moderator Mass (g)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1[(a)]	No polyethylene moderator plates.					-
2	10	3438.2	±10.0	±0.00058	$\pm 1.0\sqrt{10}$	±0.00018
3	7	4821.6	±5.6	±0.00035	$\pm 0.8\sqrt{7}$	±0.00013
4	4	5518.8	±14.0	±0.00091	$\pm 3.5\sqrt{4}$	±0.00045
5	4	16545.2	±42.4	±0.00013	$\pm 10.6\sqrt{4}$	±0.00007

(a) There are no polyethylene moderator plates in the Case 1 experimental configuration.

2.1.4 Polyethylene Reflector Mass

Mass measurements of the polyethylene reflector parts are reported in Table 7 through Table 10. These measurements were performed using a balance with a precision of 0.1 grams. The polyethylene reflector consists of individual rings, caps, and plates. Together these parts form the top reflector, upper ring reflector, lower ring reflector, and bottom reflector, as shown in Figure 22. Except for the bottom reflector, the reflectors are made up of multiple parts including the reflector rings, caps, plates, and the moderator plates as needed.

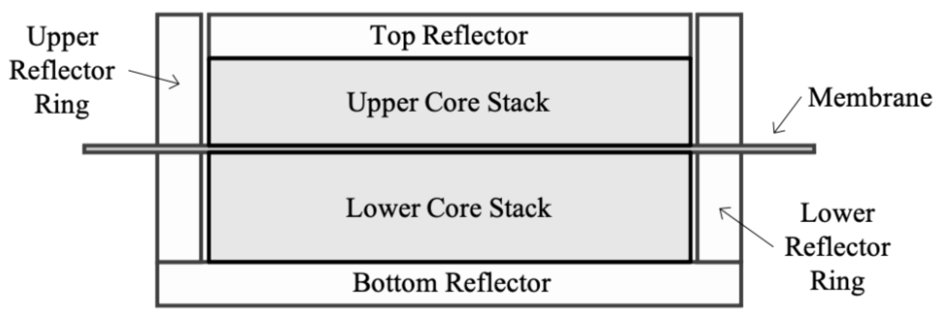


Figure 22. Diagram of an example TEX-HEU configuration showing the reflector parts: top reflector, upper reflector ring, lower reflector ring, and bottom reflector.

Table 56 summarizes the polyethylene reflector part masses, reporting the average and standard deviation of the masses by part type. The uncertainties are represented as the standard deviation of the mass measurements from parts of the same type. These standard deviations of the mass measurements are typically larger than the measurement uncertainty of ±0.1 grams per part.

Table 57 through Table 61 report the reflector parts and masses used in each experimental configuration. The part mass uncertainties are based on the distribution of mass measurements for each part type in Table 56. When the top reflector uses MOD parts, the uncertainties are based on the distribution of mass measurements for each MOD part type report in Table 54. The evaluated uncertainty for the polyethylene reflector mass is the sum in quadrature of the uncertainty for each part that makes up the reflector for each respective experimental configuration, as reported in Table 57 through Table 61.

Table 56. Average polyethylene reflector ring, cap, plate, and bottom reflector mass by part type.

Part Type	N	Mass (g)
1/32-REF	2	85.5 ± 0.6
1/16-REF	2	182.7 ± 0.4
1-REF	2	2767.1 ± 0.2
1/4-RING	3	198.9 ± 0.2
1/2-RING	4	393.7 ± 0.7
1-RING	5	805.4 ± 0.4
3-RING	2	2384.5 ± 0.4
0-CAP	2	50.8 ± 0.1
1/32-CAP	2	76.9 ± 0.1
1/16-CAP	2	101.4 ± 0.2
3/32-CAP	2	127.3 ± 0.8
1/8-CAP	2	149.0 ± 0.1
7/32-CAP	2	225.3 ± 0.1
0-BOTCAP	2	48.1 ± 0.1
BOTREF	1	3543.2 ± 0.1

Table 57. Case 1 reflector part masses.

Part Type	Part ID	Mass (g)
Top Reflector	1/2-MOD-7	1383.7 ± 3.0
	1/4-MOD-5	689.7 ± 0.9
	1/8-MOD-11	343.2 ± 1.0
	1/16-REF-1	182.4 ± 0.4
	1/32-REF-1	85.0 ± 0.6
Upper Reflector Ring	3/32-CAP-1	127.9 ± 0.8
	1/4-RING-1	199.1 ± 0.2
	1/2-RING-1	394.1 ± 0.7
	1-RING-1	805.8 ± 0.4
	0-BOTCAP-1	48.2 ± 0.1
Lower Reflector Ring	1/8-CAP-3	149.0 ± 0.1
	1/4-RING-2	198.9 ± 0.2
	1-RING-5	804.8 ± 0.4
Bottom Reflector	BOTREF-1	3543.2 ± 0.1
Total Reflector Mass (g)		**8955.0 ± 3.6**

Table 58. Case 2 reflector part masses.

Part Type	Part ID	Mass (g)
Top Reflector	1-REF-2	2767.2 ± 0.2
	1/16-REF-1	182.4 ± 0.4
Upper Ring Reflector	1/32-CAP-1	76.8 ± 0.1
	1/4-RING-2	198.9 ± 0.2
	1/2-RING-1	394.1 ± 0.7
	1-RING-3	805.8 ± 0.4
	0-BOTCAP-1	48.2 ± 0.1
Lower Ring Reflector	0-CAP-1	50.7 ± 0.1
	1/4-RING-1	199.1 ± 0.2
	1/2-RING-3	392.9 ± 0.7
	1-RING-5	804.8 ± 0.4
Bottom Reflector	BOTREF-1	3543.2 ± 0.1
Total Reflector Mass (g)		**9464.1 ± 1.3**

Table 59. Case 3 reflector part masses.

Part Type	Part ID	Mass (g)
Top Reflector	1-REF-2	2767.2 ± 0.2
	1/8-MOD-1	343.0 ± 1.0
	1/16-REF-1	182.4 ± 0.4
	1/32-REF-1	85.0 ± 0.6
Upper Ring Reflector	7/32-CAP-1	225.4 ± 0.1
	1/2-RING-1	394.1 ± 0.7
	1-RING-4	804.9 ± 0.4
	1-RING-3	805.8 ± 0.4
	0-BOTCAP-1	48.2 ± 0.1
Lower Ring Reflector	1/8-CAP-2	148.9 ± 0.1
	1-RING-5	804.8 ± 0.4
Bottom Reflector	BOTREF-1	3543.2 ± 0.1
Total Reflector Mass (g)		**10152.9 ± 1.6**

Table 60. Case 4 reflector part masses.

Part Type	Part ID	Mass (g)
Top Reflector	1-REF-2	2767.2 ± 0.2
	1/2-MOD-6	1378.2 ± 3.0
	1/8-MOD-1	343.0 ± 1.0
	1/32-REF-1	85.0 ± 0.6
Upper Ring Reflector	1/8-CAP-1	149.0 ± 0.1
	1-RING-3	805.8 ± 0.4
	1/2-RING-1	394.4 ± 0.7
	0-BOTCAP-1	48.2 ± 0.1
Lower Ring Reflector	0-CAP-2	50.8 ± 0.1
	1-RING-1	805.8 ± 0.4
	1-RING-5	804.8 ± 0.4
	1/2-RING-2	394.4 ± 0.7
Bottom Reflector	BOTREF-1	3543.2 ± 0.1
Total Reflector Mass (g)		**11569.8 ± 3.4**

Table 61. Case 5 reflector part masses.

Part Type	Part ID	Mass (g)
Top Reflector	1-REF-2	2767.2 ± 0.2
	1/8-MOD-1	343.0 ± 1.0
Upper Ring Reflector	3/32-CAP-1	127.9 ± 0.8
	1/4-RING-2	198.9 ± 0.2
	1-RING-1	805.8 ± 0.4
	3-RING-5	2384.2 ± 0.4
	0-BOTCAP-1	48.2 ± 0.1
Lower Ring Reflector	1/32-CAP-1	76.8 ± 0.1
	3-RING-1	2384.7 ± 0.4
	1/4-RING-1	199.1 ± 0.2
Bottom Reflector	BOTREF-1	3543.2 ± 0.1
Total Reflector Mass (g)		**12879.0 ± 1.5**

Table 62 summarizes the polyethylene reflector mass uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is calculated using Eq. 3 with the evaluated uncertainties reported in Table 57 through Table 61. The total reflector mass is the sum of the top reflector, upper ring reflector, lower ring reflector, and bottom reflector in each experimental configuration. The calculations vary the reflector mass by collectively perturbing the individual reflector parts by five times their respective uncertainties. This large perturbation was chosen to improve the statistics in the Δk_{eff} used in Eq. 1. Table 62 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 62. Summary of sensitivity in k_{eff} to uncertainties for polyethylene reflector mass.

Case	Total Reflector Mass (g)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	8955.0	±44.5	±0.00118	±3.6	±0.00010
2	9464.1	±18.0	±0.00025	±1.3	±0.00002
3	10152.9	±22.5	±0.00046	±1.6	±0.00003
4	11569.8	±39.0	±0.00066	±3.4	±0.00006
5	12879.0	±19.5	±0.00018	±1.5	±0.00001

2.1.5 Membrane Mass

The mass measurement of the membrane is reported in Table 42. This measurement was performed using a balance with a precision of 0.1 grams and linearity of ±0.3 grams. Therefore, the evaluated uncertainty in the membrane mass is ±0.3 grams.

Table 63 summarizes the membrane mass uncertainty calculation parameters and sensitivity in k_{eff}. The calculations vary the membrane mass by perturbing its mass by ±20.0 grams. This large perturbation was chosen to improve the statistics in the Δk_{eff} used in Eq. 1. Table 63 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 63. Summary of sensitivity in k_{eff} to uncertainties for membrane mass.

Case	Membrane Mass (g)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	2396.1	±20.0	±0.00000	±0.3	±0.00000
2			±0.00004		±0.00000
3			±0.00001		±0.00000
4			±0.00001		±0.00000
5			±0.00004		±0.00000

2.1.6 TEX-HEU Structure Mass

The mass measurements of the TEX-HEU structure components are reported in Table 42. These measurements were performed using a balance with a precision of 0.1 grams and linearity of ±0.3 grams. Therefore, the evaluated uncertainty in the TEX-HEU structure is ±0.3 grams per component.

Table 64 summarizes the TEX-HEU structure mass uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is calculated using Eq. 3 with the evaluated uncertainty of ±0.3 g per component. The total structure mass is the sum of all the TEX-HEU structural components, which are the same for all experimental configurations. The calculations vary the TEX-HEU structure mass by collectively perturbing each component by ±10%. This large perturbation was chosen to improve the statistics in the difference of Δk_{eff} used in Eq. 1. Table 64 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 64. Summary of sensitivity in k_{eff} to uncertainties for TEX-HEU structure mass.

Case	Number of Components	Total Structure Mass (g)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	7	27159.7	±10%	±0.00102	$\pm 7\sqrt{0.3}$	±0.00000
2				±0.00083		±0.00000
3				±0.00079		±0.00000
4				±0.00082		±0.00000
5				±0.00035		±0.00000

2.2 Material Uncertainties

The material uncertainties were analyzed using two methods. The first was an adjoint-based sensitivity method used to evaluate the sensitivities to the impurities[2]. The second was a direct perturbation method used to evaluate the sensitivity to the ^{235}U enrichment.

The adjoint-based sensitivity method was used to analyze the impurities by calculating a relative uncertainty in k_{eff} for each isotopic and then adding the individual contributions in quadrature to determine an overall relative uncertainty in k_{eff} for all the impurities in the material. The uncertainty from the adjoint-based sensitivity method is represented as a fractional standard deviation (FSD), defined as the calculated sensitivity divided by its associated calculational uncertainty. The control parameter adjusted renormalization method was used. For this renormalization, the majority constituent is each material was chosen as the balance. These were CH_2 in the polyethylene, U in the HEU, and Al in the aluminum. The calculations were performed using the KSEN card in MCNP® 6.2.0 with ENDF/B-VIII.0 cross sections.

[2] J. A. Favorite, Z. Perkó, B. C. Kiedrowski and C. M. Perfetti, "Adjoint-Based Sensitivity and Uncertainty Analysis for Density and Composition: A User's Guide," *Nuclear Science and Engineering,* vol. 185, pp. 384-405, 2017.

2.2.1 Highly Enriched Uranium Enrichment

Table 65 lists the combined ranges and averages of the four HEU isotopic content measurements reported in Table 44. These measurements were made relative to ^{235}U. The HEU was measured to be 93.232% ± 0.392% enriched, by weight.

Table 65. Measured HEU isotopic content relative to ^{235}U.

Isotope	Range (ppt)	Wt. %	Standard Uncertainty
^{234}U	10.8 – 11.5	1.0305E-02	2.7671E-04
^{235}U	-	9.3232E-01	3.9196E-03
^{236}U	0.02 – 5.56	2.3220E-03	2.3729E-03
^{238}U	57.7 – 59.2	5.5050E-02	7.3146E-04

In addition to the mass spectrometry measurements which can be used to infer the ^{235}U enrichment, individual plate enrichment values are available for the HEU plates used in the Big Ten experiment from LANMASS. These values are reported in previous benchmarks and are reproduced in Table 43. Based on these enrichment values, Table 66 reports the average enrichment of the HEU plates used in each experiment case. Case 1 included all the HEU plates that were used in these experiments, while Cases 2 through 5 used subsets of that population.

Table 66. Average ^{235}U enrichment based on HEU plates used in each case.

Case	^{235}U Enrichment (Wt.%)
1[(a)]	93.30 ± 0.08
2	93.32 ± 0.09
3	93.31 ± 0.10
4	93.21 ± 0.06
5	93.24 ± 0.05

(a) Represents all plates used in this experiment.

The calculated ^{235}U enrichment values based on the mass spectrometry measurements and values available from LANMASS are consistent and in good agreement. However, the uncertainty from the mass spectrometry measurements is four to eight times larger than the uncertainty from the LANMASS values. Of the four plates measured with mass spectrometry, only 11018 was used in these experiments. Therefore, the ^{235}U enrichment uncertainty will be based on the LANMASS values with an evaluated uncertainty of ±0.10% for each case. Table 67 summarizes the polyethylene composition uncertainty calculation parameters and sensitivity in k_{eff}. Table 67 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 67. Summary of sensitivity in k_{eff} to uncertainties in the HEU enrichment.

Case	Parameter Value (Wt.%)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	93.232	±0.392	±0.00339	±0.10	±0.00043
2			±0.00248		±0.00032
3			±0.00184		±0.00023
4			±0.00144		±0.00018
5			±0.00089		±0.00011

2.2.2 Highly Enriched Uranium Composition

An impurity analysis of five HEU plates is reported in Table 45. Based on these measurements, there is less than 2000 ppm U of impurities. Table 68 presents the elemental composition for the HEU, treating U as the remainder. For elements measured to be less than a given threshold, including Li, Be, Na, Mg, Ca, V, Co, and Sn, the lower bound is assumed to be 0. For these eight elements, the impurity content is assumed to be a uniform distribution centered at the midpoint within the range. For the two elements, Mo and Pb, not included with HEU plates 10932 and 10933, the average impurity content and uncertainty in the average is based only on the measurements of HEU plates 11147, 11149, and 11150. For the remaining elements, the uncertainty in the average impurity content is the standard deviation of the five measurements. Uranium is treated as the remainder.

Table 68. HEU impurity content and elemental composition.

Element	Range (ppm)	Wt. %	Standard Uncertainty
U	-	9.99893E-01	-
Li[(a)]	0 – 0.1	1.47539E-09	8.51815E-10
Be[(a)]	0 – 0.1	1.91564E-09	1.10600E-09
B	0.1 – 0.6	1.65456E-08	1.05808E-08
C	170 – 1100	2.07309E-05	2.00854E-05
Na[(a)]	0 – 1	4.88674E-08	2.82136E-08
Mg[(a)]	0 – 1	5.16630E-08	2.98276E-08
Al	20 – 150	8.25871E-06	6.03698E-06
Si	80 – 400	2.67451E-05	1.53972E-05
Ca[(a)]	0 – 2	1.70380E-07	9.83692E-08
V[(a)]	0 – 20	2.16564E-06	1.25033E-06
Cr	2 – 15	1.32628E-06	1.14859E-06
Mn	4 – 7	1.40132E-06	2.86044E-07
Fe	30 – 190	2.27921E-05	1.40057E-05
Co[(a)]	0 – 5	6.26345E-07	3.61621E-07
Ni	15 – 30	4.99009E-06	1.52790E-06
Cu	3 – 6	1.18865E-06	3.08016E-07
Mo	25 – 50	1.35954E-05	5.88699E-06
Sn[(a)]	0 – 1	2.52331E-07	7.28418E-08
Pb	1 – 5	2.05532E-06	2.03424E-06

(a) Treated as a uniform distribution within the range.

The following tables report the unconstrained isotopic density sensitivities and constrained elemental density sensitivities for the HEU composition, calculated as described in Section 2.2. The tables reporting the unconstrained isotopic density sensitivities include: Table 69 for Case 1, Table 71 for Case 2, Table 73 for Case 3, Table 75 for Case 4, and Table 77 for Case 5. The tables reporting the constrained elemental density sensitivities include: Table 70 for Case 1, Table 72 for Case 2, Table 74 for Case 3, Table 76 for Case 4, and Table 78 for Case 5.

Table 69. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 1.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
U-234	4.0307E-03	0.01460	U	5.2905E-01	0.00140
U-235	5.1793E-01	0.00140			
U-236	2.6454E-04	0.08480			
U-238	6.8247E-03	0.02200			
Li-6	-3.7202E-09	0.00110	Li	-2.5536E-08	0.00070
Li-7	-2.1816E-08	0.00080			
Be-9	-4.6709E-08	0.00040	Be	-4.6709E-08	0.00040
B-10	-5.3389E-08	1.12570	B	2.5383E-07	2.00995
B-11	3.0722E-07	1.64910			
C-12	1.8848E-05	0.47250	C	1.9648E-05	0.45530
C-13	8.0019E-07	1.05780			
Na-23	3.2632E-07	1.88740	Na	3.2632E-07	1.88740
Mg-24	-1.9017E-07	1.10840	Mg	-2.8429E-07	0.74143
Mg-25	-4.5236E-08	0.00040			
Mg-26	-4.8887E-08	0.00050			
Al-27	3.5170E-06	0.98400	Al	3.5170E-06	0.98400
Si-28	1.1700E-05	0.48260	Si	1.1288E-05	0.51089
Si-29	6.0458E-07	1.34430			
Si-30	-1.0166E-06	0.83130			
Ca-40	1.0961E-06	0.81170	Ca	1.0720E-06	0.82996
Ca-42	-5.6668E-09	0.00050			
Ca-43	-1.4248E-09	0.00110			
Ca-44	-1.5778E-08	0.00030			
Ca-46	-3.9105E-11	0.00090			
Ca-48	-1.2054E-09	0.00040			
V-50	3.0314E-07	1.07410	V	3.4416E-06	0.72507
V-51	3.1385E-06	0.78830			
Cr-50	3.2441E-07	0.88580	Cr	1.4447E-06	0.95936
Cr-52	1.3421E-06	0.96390			
Cr-53	-2.2087E-07	1.76620			
Cr-54	-9.8832E-10	113.38440			
Mn-55	1.3198E-06	1.75570	Mn	1.3198E-06	1.75570
Fe-54	-1.8099E-06	0.89870	Fe	-1.8045E-07	25.47166
Fe-56	-5.1276E-09	777.67700			
Fe-57	1.1548E-06	1.35510			
Fe-58	4.7978E-07	0.75260			

Table 69 (continued). Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 1.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
Co-59	-1.3839E-06	0.39090	Co	-1.3839E-06	0.39090
Ni-58	-1.1107E-06	1.16320	Ni	-2.3541E-06	0.71217
Ni-60	-1.6335E-07	5.80080			
Ni-61	-1.7112E-07	0.53900			
Ni-62	-7.0024E-07	0.69030			
Ni-64	-2.0866E-07	0.18170			
Cu-63	3.4996E-07	1.48730	Cu	7.0084E-07	1.07226
Cu-65	3.5088E-07	1.54480			
Mo-92	1.7371E-07	6.30600	Mo	-2.4521E-07	15.54690
Mo-94	-7.9782E-07	1.40370			
Mo-95	1.4663E-06	1.19850			
Mo-96	-1.7595E-06	0.64460			
Mo-97	2.3341E-06	0.79550			
Mo-98	-1.2753E-06	1.25390			
Mo-100	-3.8670E-07	3.37150			
Sn-112	-1.6298E-08	0.00060	Sn	6.8227E-07	1.33166
Sn-114	-1.0696E-08	0.00060			
Sn-115	-5.8767E-09	0.00040			
Sn-116	2.3204E-07	1.22810			
Sn-117	6.9054E-07	1.11790			
Sn-118	-1.6531E-07	0.64540			
Sn-119	-1.3512E-07	0.00040			
Sn-120	3.0843E-08	9.98230			
Sn-122	-6.9510E-08	0.00040			
Sn-124	1.3166E-07	1.55980			
Pb-204	-6.4337E-08	0.00060	Pb	-9.1909E-07	0.86743
Pb-206	-2.2744E-07	1.11230			
Pb-207	-2.8083E-07	1.15410			
Pb-208	-3.4648E-07	1.97140			
Total	**5.2909E-01**	**0.00140**	**Total**	**5.2909E-01**	**0.00140**

Table 70. Constrained elemental sensitivities and effect in k_{eff} for the HEU composition in Case 1.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
U	9.99893E-01	-	5.2905E-01	-	-
Li	1.47539E-09	8.51815E-10	-2.5536E-08	-2.6317E-08	1.5194E-08
Be	1.91564E-09	1.10600E-09	-4.6709E-08	-4.7723E-08	2.75526E-08
B	1.65456E-08	1.05808E-08	2.5383E-07	2.4508E-07	1.56725E-07
C	2.07309E-05	2.00854E-05	1.9648E-05	8.6793E-06	8.40905E-06
Na	4.88674E-08	2.82136E-08	3.2632E-07	3.0046E-07	1.73473E-07
Mg	5.16630E-08	2.98276E-08	-2.8429E-07	-3.1163E-07	1.79919E-07
Al	8.25871E-06	6.03698E-06	3.5170E-06	-8.5274E-07	6.23337E-07
Si	2.67451E-05	1.53972E-05	1.1288E-05	-2.8630E-06	1.64824E-06
Ca	1.70380E-07	9.83692E-08	1.0720E-06	9.8184E-07	5.66864E-07
V	2.16564E-06	1.25033E-06	3.4416E-06	2.2958E-06	1.32547E-06
Cr	1.32628E-06	1.14859E-06	1.4447E-06	7.4291E-07	6.43378E-07
Mn	1.40132E-06	2.86044E-07	1.3198E-06	5.7835E-07	1.18056E-07
Fe	2.27921E-05	1.40057E-05	-1.8045E-07	-1.2240E-05	7.52136E-06
Co	6.26345E-07	3.61621E-07	-1.3839E-06	-1.7153E-06	9.90331E-07
Ni	4.99009E-06	1.52790E-06	-2.3541E-06	-4.9944E-06	1.5292E-06
Cu	1.18865E-06	3.08016E-07	7.0084E-07	7.1917E-08	1.86359E-08
Mo	1.35954E-05	5.88699E-06	-2.4521E-07	-7.4386E-06	3.22102E-06
Sn	2.52331E-07	7.28418E-08	6.8227E-07	5.4876E-07	1.58414E-07
Pb	2.05532E-06	2.03424E-06	-9.1909E-07	-2.0066E-06	1.98599E-06

Table 71. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 2.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
U-234	2.8938E-04	0.30930	U	3.3268E-01	0.00170
U-235	3.3023E-01	0.00160			
U-236	-2.4239E-04	0.19950			
U-238	2.4037E-03	0.07120			
Li-6	-4.0522E-09	0.00080	Li	-1.7374E-08	0.00043
Li-7	-1.3322E-08	0.00050			
Be-9	-3.6279E-08	0.00040	Be	-3.6279E-08	0.00040
B-10	-2.2648E-07	0.00100	B	-3.9967E-07	0.00059
B-11	-1.7319E-07	0.00040			
C-12	1.6607E-05	0.55970	C	1.6545E-05	0.56451
C-13	-6.2364E-08	14.63800			
Na-23	-2.9349E-07	0.58850	Na	-2.9349E-07	0.58850
Mg-24	2.6898E-07	0.97390	Mg	2.0620E-07	1.27042
Mg-25	-3.1701E-08	0.00050			
Mg-26	-3.1079E-08	0.00050			
Al-27	7.1913E-06	0.49950	Al	7.1913E-06	0.49950
Si-28	-1.3096E-06	3.14990	Si	-1.8471E-06	2.36112
Si-29	-2.4367E-07	4.87310			
Si-30	-2.9383E-07	2.62250			
Ca-40	-5.5584E-08	3.81350	Ca	-7.1717E-08	2.95563
Ca-42	-3.4098E-09	0.00040			
Ca-43	-1.4850E-09	0.00160			
Ca-44	-1.0393E-08	0.00060			
Ca-46	-3.8643E-11	0.00060			
Ca-48	-8.0675E-10	0.00040			
V-50	-5.1603E-08	0.00130	V	3.5340E-06	0.66264
V-51	3.5856E-06	0.65310			
Cr-50	2.0324E-07	2.76110	Cr	-1.6911E-06	0.49997
Cr-52	-1.6281E-06	0.33570			
Cr-53	-2.7444E-07	1.11920			
Cr-54	8.1980E-09	10.12210			
Mn-55	-3.4289E-07	5.46530	Mn	-3.4289E-07	5.46530
Fe-54	1.2060E-06	1.14010	Fe	5.1501E-06	1.04012
Fe-56	3.8273E-06	1.33840			
Fe-57	3.3710E-07	2.22380			
Fe-58	-2.2033E-07	0.19620			

Table 71 (continued). Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 2.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Co-59	-1.2872E-06	0.79010	Co	-1.2872E-06	0.79010
Ni-58	3.5182E-06	0.72810	Ni	4.0465E-06	0.71307
Ni-60	1.1224E-06	1.07310			
Ni-61	-5.9766E-09	38.96880			
Ni-62	-6.9163E-07	0.62520			
Ni-64	1.0353E-07	2.59550			
Cu-63	-1.2882E-06	0.48530	Cu	-2.7925E-06	0.28463
Cu-65	-1.5043E-06	0.32630			
Mo-92	1.9269E-06	0.71780	Mo	-1.6105E-06	2.23707
Mo-94	-1.0850E-06	0.58430			
Mo-95	-2.3698E-06	0.49280			
Mo-96	2.5847E-06	0.51880			
Mo-97	-8.6119E-07	0.86470			
Mo-98	-2.0693E-06	1.15050			
Mo-100	2.6320E-07	4.29970			
Sn-112	-1.1830E-08	0.00140	Sn	2.8732E-07	1.89861
Sn-114	-7.6097E-09	0.00100			
Sn-115	-4.1121E-09	0.00040			
Sn-116	4.1232E-08	4.77840			
Sn-117	-8.6416E-08	0.00050			
Sn-118	5.8165E-08	2.99440			
Sn-119	5.8411E-08	2.48370			
Sn-120	3.4336E-07	1.32630			
Sn-122	-4.6781E-08	0.00060			
Sn-124	-5.7096E-08	0.00060			
Pb-204	-4.9921E-08	0.00030	Pb	-1.1172E-06	0.59087
Pb-206	-5.0871E-07	0.34030			
Pb-207	4.0233E-08	9.47720			
Pb-208	-5.9882E-07	0.85220			
Total	**3.3271E-01**	**0.00170**	**Total**	**3.3271E-01**	**0.00170**

Table 72. Constrained elemental sensitivities and effect in k_{eff} for the HEU composition in Case 2.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
U	9.99893E-01	-	3.3268E-01	-	-
Li	1.47539E-09	8.51815E-10	-1.7374E-08	-1.7865E-08	1.03144E-08
Be	1.91564E-09	1.10600E-09	-3.6279E-08	-3.6916E-08	2.13137E-08
B	1.65456E-08	1.05808E-08	-3.9967E-07	-4.0517E-07	2.59106E-07
C	2.07309E-05	2.00854E-05	1.6545E-05	9.6471E-06	9.34671E-06
Na	4.88674E-08	2.82136E-08	-2.9349E-07	-3.0975E-07	1.78834E-07
Mg	5.16630E-08	2.98276E-08	2.0620E-07	1.8901E-07	1.09125E-07
Al	8.25871E-06	6.03698E-06	7.1913E-06	4.4435E-06	3.24812E-06
Si	2.67451E-05	1.53972E-05	-1.8471E-06	-1.0746E-05	6.18628E-06
Ca	1.70380E-07	9.83692E-08	-7.1717E-08	-1.2841E-07	7.4135E-08
V	2.16564E-06	1.25033E-06	3.5340E-06	2.8135E-06	1.62435E-06
Cr	1.32628E-06	1.14859E-06	-1.6911E-06	-2.1324E-06	1.84669E-06
Mn	1.40132E-06	2.86044E-07	-3.4289E-07	-8.0913E-07	1.65163E-07
Fe	2.27921E-05	1.40057E-05	5.1501E-06	-2.4332E-06	1.49521E-06
Co	6.26345E-07	3.61621E-07	-1.2872E-06	-1.4956E-06	8.63482E-07
Ni	4.99009E-06	1.52790E-06	4.0465E-06	2.3862E-06	7.30634E-07
Cu	1.18865E-06	3.08016E-07	-2.7925E-06	-3.1880E-06	8.26105E-07
Mo	1.35954E-05	5.88699E-06	-1.6105E-06	-6.1339E-06	2.65606E-06
Sn	2.52331E-07	7.28418E-08	2.8732E-07	2.0337E-07	5.87074E-08
Pb	2.05532E-06	2.03424E-06	-1.1172E-06	-1.8011E-06	1.78258E-06

Table 73. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 3.

Isotope	**Sensitivity** $S_{k,i}$	**FSD** $S_{k,i}/\sigma(S_{k,i})$	**Element**	**Sensitivity** $S_{k,i}$	**FSD** $S_{k,i}/\sigma(S_{k,i})$
U-234	-9.6718E-04	0.06100	U	2.3743E-01	0.00385
U-235	2.3820E-01	0.00380			
U-236	-4.8000E-04	0.04920			
U-238	6.7567E-04	0.17690			
Li-6	-4.7754E-09	0.00090	Li	-1.4538E-08	0.00040
Li-7	-9.7628E-09	0.00040			
Be-9	-2.7969E-08	0.00020	Be	-2.7969E-08	0.00020
B-10	-2.9995E-07	0.00100	B	4.7128E-07	1.44761
B-11	7.7123E-07	0.88460			
C-12	1.3469E-05	0.56460	C	1.3271E-05	0.57530
C-13	-1.9801E-07	3.42670			
Na-23	7.9224E-07	0.64430	Na	7.9224E-07	0.64430
Mg-24	-2.5587E-08	8.56010	Mg	-7.2138E-08	3.03623
Mg-25	-2.3464E-08	0.00040			
Mg-26	-2.3087E-08	0.00030			
Al-27	-3.0852E-06	0.82340	Al	-3.0852E-06	0.82340
Si-28	1.7966E-06	3.96330	Si	1.6173E-06	4.49225
Si-29	5.9564E-07	2.05690			
Si-30	-7.7491E-07	0.98680			
Ca-40	2.2313E-07	1.49650	Ca	2.1105E-07	1.58215
Ca-42	-2.4674E-09	0.00080			
Ca-43	-1.1620E-09	0.00120			
Ca-44	-7.8047E-09	0.00050			
Ca-46	-2.9613E-11	0.00030			
Ca-48	-6.1520E-10	0.00040			
V-50	-4.4210E-08	0.00270	V	-1.6857E-06	0.83413
V-51	-1.6415E-06	0.85660			
Cr-50	-2.8876E-07	0.28030	Cr	-6.2579E-07	1.15962
Cr-52	3.3072E-07	2.10740			
Cr-53	-6.2484E-07	0.29540			
Cr-54	-4.2905E-08	0.35120			
Mn-55	1.8067E-06	0.71630	Mn	1.8067E-06	0.71630
Fe-54	-9.2401E-07	1.16520	Fe	9.9268E-06	0.33565
Fe-56	1.0042E-05	0.29890			
Fe-57	9.2971E-07	1.03510			
Fe-58	-1.2088E-07	0.68610			

Table 73 (continued). Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 3.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
Co-59	-2.2863E-06	0.42500	Co	-2.2863E-06	0.42500
Ni-58	1.6580E-06	1.10910	Ni	2.0065E-06	1.11254
Ni-60	4.2609E-07	2.27720			
Ni-61	-1.5675E-07	0.20490			
Ni-62	1.9924E-07	4.06850			
Ni-64	-1.2012E-07	0.36610			
Cu-63	1.2763E-07	4.74430	Cu	-1.2006E-06	0.54356
Cu-65	-1.3282E-06	0.18320			
Mo-92	1.9320E-06	0.59980	Mo	3.5381E-06	0.82302
Mo-94	-1.2495E-06	0.34090			
Mo-95	3.0507E-06	0.53050			
Mo-96	-5.4365E-07	1.98390			
Mo-97	4.9364E-07	1.88450			
Mo-98	-6.8415E-07	1.72900			
Mo-100	5.3901E-07	1.76750			
Sn-112	1.7556E-08	1.44490	Sn	-3.5606E-07	0.65097
Sn-114	-5.8013E-09	0.00190			
Sn-115	8.0887E-08	0.98600			
Sn-116	1.9745E-07	1.08720			
Sn-117	-6.5635E-08	0.00040			
Sn-118	-2.0047E-07	0.03460			
Sn-119	-7.0984E-08	0.00060			
Sn-120	-2.3133E-07	0.10510			
Sn-122	-3.4783E-08	0.00070			
Sn-124	-4.2953E-08	0.00070			
Pb-204	-3.8285E-08	0.00030	Pb	-1.1251E-06	0.44625
Pb-206	-3.3128E-07	0.45950			
Pb-207	-3.1432E-07	0.74290			
Pb-208	-4.4126E-07	0.94640			
Total	**2.3745E-01**	**0.00385**	**Total**	**2.3745E-01**	**0.00385**

Table 74. Constrained elemental sensitivities and effect in k_{eff} for the HEU composition in Case 3.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
U	9.99893E-01	-	2.3743E-01	-	-
Li	1.47539E-09	8.51815E-10	-1.4538E-08	-1.4889E-08	8.5959E-09
Be	1.91564E-09	1.10600E-09	-2.7969E-08	-2.8424E-08	1.64105E-08
B	1.65456E-08	1.05808E-08	4.7128E-07	4.6735E-07	2.98868E-07
C	2.07309E-05	2.00854E-05	1.3271E-05	8.3483E-06	8.08839E-06
Na	4.88674E-08	2.82136E-08	7.9224E-07	7.8064E-07	4.50701E-07
Mg	5.16630E-08	2.98276E-08	-7.2138E-08	-8.4406E-08	4.87316E-08
Al	8.25871E-06	6.03698E-06	-3.0852E-06	-5.0463E-06	3.68873E-06
Si	2.67451E-05	1.53972E-05	1.6173E-06	-4.7334E-06	2.72503E-06
Ca	1.70380E-07	9.83692E-08	2.1105E-07	1.7059E-07	9.84923E-08
V	2.16564E-06	1.25033E-06	-1.6857E-06	-2.1999E-06	1.27014E-06
Cr	1.32628E-06	1.14859E-06	-6.2579E-07	-9.4072E-07	8.14683E-07
Mn	1.40132E-06	2.86044E-07	1.8067E-06	1.4740E-06	3.00869E-07
Fe	2.27921E-05	1.40057E-05	9.9268E-06	4.5147E-06	2.77429E-06
Co	6.26345E-07	3.61621E-07	-2.2863E-06	-2.4350E-06	1.40586E-06
Ni	4.99009E-06	1.52790E-06	2.0065E-06	8.2155E-07	2.51546E-07
Cu	1.18865E-06	3.08016E-07	-1.2006E-06	-1.4828E-06	3.84244E-07
Mo	1.35954E-05	5.88699E-06	3.5381E-06	3.0977E-07	1.34134E-07
Sn	2.52331E-07	7.28418E-08	-3.5606E-07	-4.1598E-07	1.20083E-07
Pb	2.05532E-06	2.03424E-06	-1.1251E-06	-1.6132E-06	1.59664E-06

Table 75. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 4.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
U-234	-1.9879E-03	0.02150	U	1.5858E-01	0.00386
U-235	1.6177E-01	0.00360			
U-236	-6.1225E-04	0.05680			
U-238	-5.8765E-04	0.30390			
Li-6	-5.5458E-09	0.00050	Li	-1.2376E-08	0.00031
Li-7	-6.8301E-09	0.00040			
Be-9	-1.9992E-08	0.00030	Be	-1.9992E-08	0.00030
B-10	-3.7228E-07	0.00050	B	-4.1013E-07	0.13143
B-11	-3.7851E-08	1.42410			
C-12	-1.9141E-06	2.61140	C	-2.6270E-06	1.90731
C-13	-7.1285E-07	0.48450			
Na-23	4.9480E-07	0.99730	Na	4.9480E-07	0.99730
Mg-24	3.3302E-08	5.00100	Mg	4.7881E-07	1.00912
Mg-25	-1.6326E-08	0.00060			
Mg-26	4.6183E-07	0.98210			
Al-27	8.8440E-08	24.74990	Al	8.8440E-08	24.74990
Si-28	5.6262E-06	0.56940	Si	3.8505E-06	0.84819
Si-29	-1.5108E-06	0.21810			
Si-30	-2.6494E-07	2.04940			
Ca-40	-2.1896E-07	0.00030	Ca	-2.2751E-07	0.00029
Ca-42	-1.7066E-09	0.00070			
Ca-43	-8.1213E-10	0.00100			
Ca-44	-5.5700E-09	0.00040			
Ca-46	-2.0371E-11	0.00030			
Ca-48	-4.4448E-10	0.00030			
V-50	-3.2795E-08	0.00320	V	-1.7083E-06	0.57985
V-51	-1.6755E-06	0.59120			
Cr-50	-1.1196E-07	1.47110	Cr	-1.2809E-06	0.36247
Cr-52	-1.3998E-06	0.12090			
Cr-53	2.4861E-07	1.60540			
Cr-54	-1.7762E-08	1.25670			
Mn-55	5.9711E-07	3.95000	Mn	5.9711E-07	3.95000
Fe-54	-7.8139E-07	0.94240	Fe	-6.3843E-07	5.68706
Fe-56	-3.4921E-08	101.07310			
Fe-57	3.2473E-07	1.31570			
Fe-58	-1.4685E-07	0.00070			

Table 75 (continued). Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 4.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Co-59	1.1647E-06	1.25410	Co	1.1647E-06	1.25410
Ni-58	-1.8595E-06	0.56570	Ni	-2.7724E-06	0.46742
Ni-60	-9.4109E-07	0.44930			
Ni-61	5.2497E-07	0.87460			
Ni-62	-5.0560E-07	0.83330			
Ni-64	8.8236E-09	8.51050			
Cu-63	4.2653E-07	2.23990	Cu	-8.1577E-07	1.22928
Cu-65	-1.2423E-06	0.24530			
Mo-92	-5.4638E-07	1.17310	Mo	-4.4128E-06	0.42894
Mo-94	-1.1954E-06	0.29770			
Mo-95	-1.2815E-06	0.79720			
Mo-96	-7.6751E-07	0.69080			
Mo-97	4.8288E-07	1.53660			
Mo-98	-6.9392E-07	1.12160			
Mo-100	-4.1099E-07	1.82760			
Sn-112	-6.5863E-09	0.00210	Sn	3.9263E-07	1.47680
Sn-114	-4.1063E-09	0.00110			
Sn-115	-2.3638E-09	0.00030			
Sn-116	-9.0170E-08	0.00160			
Sn-117	-4.6698E-08	0.00060			
Sn-118	4.2181E-07	1.27850			
Sn-119	-4.9975E-08	0.00060			
Sn-120	1.7075E-07	1.20990			
Sn-122	3.0343E-08	1.71090			
Sn-124	-3.0378E-08	0.00050			
Pb-204	-2.7217E-08	0.00040	Pb	1.1448E-06	0.85189
Pb-206	-2.3484E-07	0.68330			
Pb-207	4.4501E-07	1.21050			
Pb-208	9.6189E-07	0.82860			
Total	**1.5858E-01**	**0.00386**	**Total**	**1.5858E-01**	**0.00386**

Table 76. Constrained elemental sensitivities and effect in k_{eff} for the HEU composition in Case 4.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
U	9.99893E-01	-	1.5858E-01	-	-
Li	1.47539E-09	8.51815E-10	-1.2376E-08	-1.2610E-08	7.28033E-09
Be	1.91564E-09	1.10600E-09	-1.9992E-08	-2.0296E-08	1.17178E-08
B	1.65456E-08	1.05808E-08	-4.1013E-07	-4.1276E-07	2.63954E-07
C	2.07309E-05	2.00854E-05	-2.6270E-06	-5.9149E-06	5.73067E-06
Na	4.88674E-08	2.82136E-08	4.9480E-07	4.8705E-07	2.81198E-07
Mg	5.16630E-08	2.98276E-08	4.7881E-07	4.7061E-07	2.71708E-07
Al	8.25871E-06	6.03698E-06	8.8440E-08	-1.2214E-06	8.92811E-07
Si	2.67451E-05	1.53972E-05	3.8505E-06	-3.9129E-07	2.25264E-07
Ca	1.70380E-07	9.83692E-08	-2.2751E-07	-2.5454E-07	1.46956E-07
V	2.16564E-06	1.25033E-06	-1.7083E-06	-2.0518E-06	1.18459E-06
Cr	1.32628E-06	1.14859E-06	-1.2809E-06	-1.4913E-06	1.29147E-06
Mn	1.40132E-06	2.86044E-07	5.9711E-07	3.7486E-07	7.65183E-08
Fe	2.27921E-05	1.40057E-05	-6.3843E-07	-4.2532E-06	2.6136E-06
Co	6.26345E-07	3.61621E-07	1.1647E-06	1.0654E-06	6.15087E-07
Ni	4.99009E-06	1.52790E-06	-2.7724E-06	-3.5638E-06	1.09119E-06
Cu	1.18865E-06	3.08016E-07	-8.1577E-07	-1.0043E-06	2.60242E-07
Mo	1.35954E-05	5.88699E-06	-4.4128E-06	-6.5690E-06	2.84448E-06
Sn	2.52331E-07	7.28418E-08	3.9263E-07	3.5261E-07	1.01789E-07
Pb	2.05532E-06	2.03424E-06	1.1448E-06	8.1887E-07	8.10472E-07

Table 77. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 5.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
U-234	-1.6376E-03	0.01590	U	1.1792E-01	0.00322
U-235	1.2011E-01	0.00310			
U-236	-3.2863E-04	0.03360			
U-238	-2.2580E-04	0.29270			
Li-6	-5.9424E-09	0.00060	Li	-9.9902E-09	0.00039
Li-7	-4.0478E-09	0.00040			
Be-9	-1.1159E-08	0.00030	Be	-1.1159E-08	0.00030
B-10	-4.1557E-07	0.00060	B	3.3951E-07	2.10104
B-11	7.5508E-07	0.94470			
C-12	2.4888E-06	1.20550	C	2.2077E-06	1.36350
C-13	-2.8106E-07	0.87260			
Na-23	-1.5364E-07	0.00150	Na	-1.5364E-07	0.00150
Mg-24	1.2302E-07	1.70930	Mg	1.0431E-07	2.01588
Mg-25	-9.2201E-09	0.00060			
Mg-26	-9.4890E-09	0.00030			
Al-27	2.1817E-06	0.62240	Al	2.1817E-06	0.62240
Si-28	-7.9401E-07	3.97470	Si	-4.0410E-07	8.01936
Si-29	4.3558E-08	7.45540			
Si-30	3.4635E-07	1.90700			
Ca-40	-3.8265E-08	2.33210	Ca	-4.3294E-08	2.06120
Ca-42	-1.0112E-09	0.00070			
Ca-43	-4.2652E-10	0.00080			
Ca-44	-3.3131E-09	0.00030			
Ca-46	-1.0478E-11	0.00060			
Ca-48	-2.6781E-10	0.00050			
V-50	-1.7308E-08	0.00340	V	8.0638E-07	1.16907
V-51	8.2369E-07	1.14450			
Cr-50	-7.2414E-08	0.91560	Cr	1.6131E-07	3.46270
Cr-52	1.3803E-07	3.32010			
Cr-53	-1.4074E-07	1.35560			
Cr-54	2.3643E-07	1.04610			
Mn-55	-1.5797E-06	0.47490	Mn	-1.5797E-06	0.47490
Fe-54	-3.1191E-07	1.93780	Fe	6.8826E-07	2.65792
Fe-56	2.4297E-08	66.88950			
Fe-57	1.0571E-06	0.55150			
Fe-58	-8.1224E-08	0.00050			

Table 77 (continued). Unconstrained isotopic and elemental density sensitivities in k_{eff} for the HEU composition in Case 5.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
Co-59	2.8485E-07	2.80410	Co	2.8485E-07	2.80410
Ni-58	7.0317E-09	180.79210	Ni	1.0444E-06	1.58929
Ni-60	9.2382E-07	1.11850			
Ni-61	2.1476E-07	0.85590			
Ni-62	-4.5805E-08	4.21780			
Ni-64	-5.5438E-08	0.00090			
Cu-63	2.0214E-07	1.75500	Cu	-4.9000E-08	14.59288
Cu-65	-2.5114E-07	2.47210			
Mo-92	1.6253E-06	0.40600	Mo	2.3301E-06	0.74770
Mo-94	-3.7226E-07	0.79200			
Mo-95	-5.3146E-07	0.96130			
Mo-96	-8.7141E-07	0.70450			
Mo-97	-2.1346E-07	2.12080			
Mo-98	1.9105E-06	0.56300			
Mo-100	7.8288E-07	0.91500			
Sn-112	-3.7187E-09	0.00280	Sn	-5.5938E-08	2.81377
Sn-114	-2.3137E-09	0.00190			
Sn-115	-1.5196E-09	0.00020			
Sn-116	-5.0911E-08	0.00120			
Sn-117	6.4383E-08	1.34150			
Sn-118	1.0410E-07	1.26400			
Sn-119	-2.8617E-08	0.00040			
Sn-120	-1.0569E-07	0.00040			
Sn-122	-1.4066E-08	0.00040			
Sn-124	-1.7585E-08	0.00100			
Pb-204	1.0430E-07	1.08700	Pb	-1.9130E-08	17.42530
Pb-206	-1.7800E-07	0.29980			
Pb-207	3.5518E-07	0.69020			
Pb-208	-3.0061E-07	0.62520			
Total	**1.1793E-01**	**0.00322**	**Total**	**1.1793E-01**	**0.00322**

Table 78. Constrained elemental sensitivities and effect in k_{eff} for the HEU composition in Case 5.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
U	9.99893E-01	-	1.1792E-01	-	-
Li	1.47539E-09	8.51815E-10	-9.9902E-09	-1.0164E-08	5.8683E-09
Be	1.91564E-09	1.10600E-09	-1.1159E-08	-1.1385E-08	6.57308E-09
B	1.65456E-08	1.05808E-08	3.3951E-07	3.3756E-07	2.15866E-07
C	2.07309E-05	2.00854E-05	2.2077E-06	-2.3707E-07	2.29689E-07
Na	4.88674E-08	2.82136E-08	-1.5364E-07	-1.5940E-07	9.20313E-08
Mg	5.16630E-08	2.98276E-08	1.0431E-07	9.8218E-08	5.67063E-08
Al	8.25871E-06	6.03698E-06	2.1817E-06	1.2077E-06	8.82842E-07
Si	2.67451E-05	1.53972E-05	-4.0410E-07	-3.5582E-06	2.04844E-06
Ca	1.70380E-07	9.83692E-08	-4.3294E-08	-6.3387E-08	3.65966E-08
V	2.16564E-06	1.25033E-06	8.0638E-07	5.5099E-07	3.18113E-07
Cr	1.32628E-06	1.14859E-06	1.6131E-07	4.8972E-09	4.24108E-09
Mn	1.40132E-06	2.86044E-07	-1.5797E-06	-1.7450E-06	3.56188E-07
Fe	2.27921E-05	1.40057E-05	6.8826E-07	-1.9996E-06	1.22876E-06
Co	6.26345E-07	3.61621E-07	2.8485E-07	2.1098E-07	1.21812E-07
Ni	4.99009E-06	1.52790E-06	1.0444E-06	4.5589E-07	1.39586E-07
Cu	1.18865E-06	3.08016E-07	-4.9000E-08	-1.8918E-07	4.90219E-08
Mo	1.35954E-05	5.88699E-06	2.3301E-06	7.2678E-07	3.14703E-07
Sn	2.52331E-07	7.28418E-08	-5.5938E-08	-8.5696E-08	2.47382E-08
Pb	2.05532E-06	2.03424E-06	-1.9130E-08	-2.6152E-07	2.58833E-07

Table 79 summarizes the effect in k_{eff} of the HEU composition for the experimental configurations. Table 80 summarizes the polyethylene composition uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is based on impurity content reported in Table 68. Table 80 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 79. Summary of effect in k_{eff} to uncertainties in the HEU composition.

Case	**u_k/k**
1	1.22738E-05
2	1.25223E-05
3	1.00793E-05
4	7.36449E-06
5	2.65128E-06

Table 80. Summary of sensitivity in k_{eff} to uncertainties in the HEU composition.

Case	**Parameter Value (Wt.%)**	**Parameter Variation in Calculation**	**Calculated Effect in k_{eff}**	**Standard Uncertainty**	**Standard Uncertainty in k_{eff}**
1	Varies (Table 68)	-	±0.00001	Varies (Table 68)	±0.00001
2			±0.00001		±0.00001
3			±0.00001		±0.00001
4			±0.00001		±0.00001
5			±0.00000		±0.00000

2.2.3 Polyethylene Composition

An impurity measurement from a 246.97 µg sample of the polyethylene is presented in Table 47. Based on these measurements, there were about 0.3 µg of impurities in the 246.97 µg sample. The other 246.67 µg is assumed to be polyethylene (CH_2). Table 81 presents the elemental composition for the polyethylene, treating CH_2 as the remainder.

Table 81. Polyethylene elemental composition.

Element	Wt. %	Standard Uncertainty
H	1.43573E+01	-
C	8.55467E+01	-
Na	1.43800E-03	±1.82000E-06
Al	2.39200E-03	±1.74000E-06
Si	1.17000E-04	±6.00000E-08
Cr	9.21350E-02	±7.08000E-06

The following tables report the unconstrained isotopic density sensitivities and constrained elemental density sensitivities for the polyethylene composition, calculated as described in Section 2.2. The tables reporting the unconstrained isotopic density sensitivities include: Table 82 for Case 1, Table 84 for Case 2, Table 86 for Case 3, Table 88 for Case 4, and Table 90 for Case 5. The tables reporting the constrained elemental density sensitivities include: Table 83 for Case 1, Table 85 for Case 2, Table 87 for Case 3, Table 89 for Case 4, and Table 91 for Case 5.

Table 82. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the polyethylene composition in Case 1.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
H-1	1.4597E-01	0.00320	H	1.4598E-01	0.00322
H-2	8.9453E-06	0.32950			
C-12	6.9457E-02	0.00290	C	7.0313E-02	0.00334
C-13	8.5591E-04	0.03880			
Na-23	3.9662E-07	1.98070	Na	3.9662E-07	1.98070
Al-27	1.4875E-06	0.62610	Al	1.4875E-06	0.62610
Si-28	3.7555E-05	0.13890	Si	4.0217E-05	0.13414
Si-29	1.3883E-06	0.75510			
Si-30	1.2739E-06	0.69910			
Cr-50	-1.3108E-08	0.00140	Cr	-1.0725E-07	0.00097
Cr-52	-5.9533E-08	0.00150			
Cr-53	-3.3174E-08	0.00150			
Cr-54	-1.4399E-09	0.00120			
Total	**2.1633E-01**	**0.00236**	**Total**	**2.1633E-01**	**0.00236**

Table 83. Constrained elemental sensitivities and effect in k_{eff} for the polyethylene composition in Case 1.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
H	1.43573E+01	-	1.4598E-01	-	-
C	8.55467E+01	-	7.0313E-02	-	-
Na	1.43800E-03	1.82000E-06	3.9662E-07	-2.71665E-06	3.43832E-09
Al	2.39200E-03	1.74000E-06	1.4875E-06	-3.69118E-06	2.68505E-09
Si	1.17000E-04	6.00000E-08	4.0217E-05	3.99639E-05	2.04943E-08
Cr	9.21350E-02	7.08000E-06	-1.0725E-07	-1.99579E-04	1.53364E-08

Table 84. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the polyethylene composition in Case 2.

Isotope	**Sensitivity** $\mathbf{S_{k,i}}$	**FSD** $\mathbf{S_{k,i}/\sigma(S_{k,i})}$	**Element**	**Sensitivity** $\mathbf{S_{k,i}}$	**FSD** $\mathbf{S_{k,i}/\sigma(S_{k,i})}$
H-1	3.1250E-01	0.00320	H	3.1251E-01	0.00320
H-2	1.2454E-05	0.30570			
C-12	8.8590E-02	0.00630	C	8.9678E-02	0.00625
C-13	1.0881E-03	0.04920			
Na-23	1.1902E-06	1.36950	Na	1.1902E-06	1.36950
Al-27	3.6378E-06	0.58800	Al	3.6378E-06	0.58800
Si-28	4.2024E-05	0.27390	Si	4.1909E-05	0.27949
Si-29	-1.3342E-06	0.88770			
Si-30	1.2188E-06	1.49090			
Cr-50	-3.6505E-08	0.00080	Cr	9.1578E-07	1.11787
Cr-52	9.8352E-07	1.03920			
Cr-53	-2.6835E-08	2.16550			
Cr-54	-4.3964E-09	0.00060			
Total	**4.0224E-01**	**0.00285**	**Total**	**4.0224E-01**	**0.00285**

Table 85. Constrained elemental sensitivities and effect in k_{eff} for the polyethylene composition in Case 2.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity** $\mathbf{S_{k,i}}$	**Constrained Sensitivity** $\mathbf{S_{k,i}^{CPA}}$	$\mathbf{u_k/k}$
H	1.43573E+01	-	3.1251E-01	-	-
C	8.55467E+01	-	8.9678E-02	-	-
Na	1.43800E-03	1.82000E-06	1.1902E-06	-1.92307E-06	2.43392E-09
Al	2.39200E-03	1.74000E-06	3.6378E-06	-1.54088E-06	1.12087E-09
Si	1.17000E-04	6.00000E-08	4.1909E-05	4.16553E-05	2.13617E-08
Cr	9.21350E-02	7.08000E-06	9.1578E-07	-1.98556E-04	1.52578E-08

Table 86. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the polyethylene composition in Case 3.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
H-1	3.9081E-01	0.00240	H	3.9082E-01	0.00240
H-2	1.1684E-05	0.64250			
C-12	9.6772E-02	0.00330	C	9.7832E-02	0.00333
C-13	1.0600E-03	0.06070			
Na-23	5.5278E-06	0.54360	Na	5.5278E-06	0.54360
Al-27	4.4681E-06	0.43750	Al	4.4681E-06	0.43750
Si-28	2.3104E-05	0.61290	Si	2.4538E-05	0.59038
Si-29	1.6495E-06	1.68090			
Si-30	-2.1552E-07	5.97910			
Cr-50	-4.9274E-08	0.00040	Cr	2.8995E-08	7.62275
Cr-52	2.0480E-07	1.07920			
Cr-53	-1.2075E-07	0.00030			
Cr-54	-5.7812E-09	0.00030			
Total	**4.8869E-01**	**0.00203**	**Total**	**4.8869E-01**	**0.00203**

Table 87. Constrained elemental sensitivities and effect in k_{eff} for the polyethylene composition in Case 3.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
H	1.43573E+01	-	3.9082E-01	-	-
C	8.55467E+01	-	9.7832E-02	-	-
Na	1.43800E-03	1.82000E-06	5.5278E-06	2.41453E-06	3.05594E-09
Al	2.39200E-03	1.74000E-06	4.4681E-06	-7.10577E-07	5.16891E-10
Si	1.17000E-04	6.00000E-08	2.4538E-05	2.42847E-05	1.24537E-08
Cr	9.21350E-02	7.08000E-06	2.8995E-08	-1.99443E-04	1.53260E-08

Table 88. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the polyethylene composition in Case 4.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
H-1	4.4461E-01	0.00160	H	4.4464E-01	0.00160
H-2	3.1640E-05	0.35270			
C-12	1.0626E-01	0.00720	C	1.0741E-01	0.00716
C-13	1.1473E-03	0.06810			
Na-23	3.5110E-07	6.85090	Na	3.5110E-07	6.85090
Al-27	2.4595E-08	100.46160	Al	2.4595E-08	100.46160
Si-28	5.7882E-05	0.20180	Si	5.6690E-05	0.21156
Si-29	-4.4482E-07	4.42460			
Si-30	-7.4693E-07	2.51540			
Cr-50	-6.4595E-08	0.00070	Cr	7.4104E-08	5.57396
Cr-52	1.8155E-08	16.89040			
Cr-53	1.2804E-07	2.16130			
Cr-54	-7.4960E-09	0.00050			
Total	**5.5211E-01**	**0.00190**	**Total**	**5.5211E-01**	**0.00190**

Table 89. Constrained elemental sensitivities and effect in k_{eff} for the polyethylene composition in Case 4.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
H	1.43573E+01	-	4.4464E-01	-	-
C	8.55467E+01	-	1.0741E-01	-	-
Na	1.43800E-03	1.82000E-06	3.5110E-07	-2.76217E-06	3.49593E-09
Al	2.39200E-03	1.74000E-06	2.4595E-08	-5.15408E-06	3.74921E-09
Si	1.17000E-04	6.00000E-08	5.6690E-05	5.64369E-05	2.89420E-08
Cr	9.21350E-02	7.08000E-06	7.4104E-08	-1.99398E-04	1.53225E-08

Table 90. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the polyethylene composition in Case 5.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
H-1	1.9695E-01	0.00650	H	1.9697E-01	0.00650
H-2	1.8660E-05	0.35910			
C-12	7.5428E-02	0.00890	C	7.6189E-02	0.00886
C-13	7.6136E-04	0.09160			
Na-23	-1.1046E-06	2.26720	Na	-1.1046E-06	2.26720
Al-27	6.2664E-07	4.53420	Al	6.2664E-07	4.53420
Si-28	8.9165E-06	1.96160	Si	2.0401E-05	0.89240
Si-29	9.9346E-06	0.36950			
Si-30	1.5497E-06	2.24030			
Cr-50	-1.1409E-07	0.00070	Cr	6.6944E-07	1.05255
Cr-52	8.4765E-07	0.77760			
Cr-53	-5.1164E-08	4.86790			
Cr-54	-1.2958E-08	0.00040			
Total	**2.7318E-01**	**0.00530**	**Total**	**2.7318E-01**	**0.00530**

Table 91. Constrained elemental sensitivities and effect in k_{eff} for the polyethylene composition in Case 5.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
H	1.43573E+01	-	1.9697E-01	-	-
C	8.55467E+01	-	7.6189E-02	-	-
Na	1.43800E-03	1.82000E-06	-1.1046E-06	-4.21787E-06	5.33833E-09
Al	2.39200E-03	1.74000E-06	6.2664E-07	-4.55204E-06	3.31126E-09
Si	1.17000E-04	6.00000E-08	2.0401E-05	2.01475E-05	1.03320E-08
Cr	9.21350E-02	7.08000E-06	6.6944E-07	-1.98803E-04	1.52767E-08

Table 92 summarizes the effect in k_{eff} of the polyethylene composition for the experimental configurations. Table 93 summarizes the polyethylene composition uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is based on the measurement uncertainty of the impurity analysis reported in Table 47. Table 93 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 92. Summary of effect in k_{eff} to uncertainties in the polyethylene composition.

Case	u_k/k
1	2.59664E-08
2	2.63876E-08
3	1.99896E-08
4	3.31466E-08
5	1.94831E-08

Table 93. Summary of sensitivity in k_{eff} to uncertainties in the polyethylene composition.

Case	Parameter Value (Wt.%)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	Varies (Table 81)	-	±0.00000	Varies (Table 81)	±0.00000
2			±0.00000		±0.00000
3			±0.00000		±0.00000
4			±0.00000		±0.00000
5			±0.00000		±0.00000

2.2.4 Aluminum Composition

The aluminum composition is based on the handbook data reported in Table 48 for AL 6061. The elemental compositions presented in Table 48 represent an upper and lower bound (Mg, Si, Cu, and Cr), a maximum upper bound with no lower bound (Fe, Zn, Mn, and Ti), or the main constituent as the remainder (Al). Table 94 presents the evaluated elemental composition for AL 6061. The uncertainty of the elemental composition is based on the range of the specification, assuming a lower bound of 0 if not given. The standard uncertainty assumes a uniform distribution within this range. Aluminum is treated as the remainder, including the other and unknown impurities.

Table 94. AL 6061 elemental composition and standard uncertainties.

Element	Wt. %	Standard Uncertainty
Al	9.73050E+01	-
Mg	1.00000E+00	±0.400/√12
Si	6.00000E-01	±0.400/√12
Cu	2.75000E-01	±0.250/√12
Cr	1.95000E-01	±0.310/√12
Fe	3.50000E-01	±0.350/√12
Zn	1.25000E-01	±0.125/√12
Mn	7.50000E-02	±0.075/√12
Ti	7.50000E-02	±0.075/√12

The following tables report the unconstrained isotopic density sensitivities and constrained elemental density sensitivities for the aluminum membrane, aluminum inserts, and aluminum structure composition, respectively. The tables reporting the unconstrained isotopic density sensitivities: Table 95, Table 96, and Table 97 for Case 1; Table 101, Table 102, and Table 103 for Case 2; Table 107, Table 108, and Table 109 for Case 3; Table 113 and Table 114 for Case 4 (experimental configuration does not include aluminum inserts); and Table 117, Table 118, and Table 119 for Case 5. The tables reporting the constrained elemental density sensitivities include: Table 98, Table 99, and Table 100 for Case 1; Table 104, Table 105, and Table 106 for Case 2; Table 110, Table 111, and Table 112 for Case 3; Table 115 and Table 116 for Case 4; and Table 120, Table 121, and Table 122 for Case 5.

Table 95. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum membrane composition in Case 1.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
Al-27	2.2773E-03	0.04730	Al	2.2773E-03	0.04730
Mg-24	1.8508E-05	0.65890	Mg	1.2881E-05	1.02033
Mg-25	-5.1275E-06	0.66400			
Mg-26	-4.9986E-07	7.04980			
Si-28	1.6907E-05	0.45180	Si	1.6497E-05	0.47772
Si-29	-2.0876E-06	0.67710			
Si-30	1.6779E-06	0.79200			
Ti-46	1.7805E-06	0.51180	Ti	1.9967E-06	1.27698
Ti-47	1.3300E-07	5.03510			
Ti-48	-1.9503E-07	10.83400			
Ti-49	-4.0668E-08	16.83890			
Ti-50	3.1888E-07	1.68500			
Cr-50	-1.2211E-06	0.66860	Cr	2.8852E-06	1.20212
Cr-52	3.8163E-06	0.79320			
Cr-53	2.3590E-07	6.00130			
Cr-54	5.4055E-08	8.16990			
Mn-55	1.0197E-06	2.70320	Mn	1.0197E-06	2.70320
Fe-54	6.4396E-07	2.17440	Fe	1.8719E-06	2.48573
Fe-56	8.3716E-07	5.21060			
Fe-57	-1.8753E-07	3.65880			
Fe-58	5.7831E-07	0.75630			
Cu-63	5.2244E-06	0.65870	Cu	5.3863E-06	0.76302
Cu-65	1.6194E-07	13.87470			
Zn-64	2.6216E-06	0.78820	Zn	2.2786E-05	0.96908
Zn-66	2.0962E-05	1.04700			
Zn-67	-1.2777E-07	3.88840			
Zn-68	-6.9254E-07	1.67500			
Zn-70	2.2268E-08	7.13230			
Total	**2.3426E-03**	**0.04752**	**Total**	**2.3426E-03**	**0.04752**

Table 96. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum insert composition in Case 1.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
Al-27	1.6264E-02	0.00890	Al	1.6264E-02	0.00890
Mg-24	1.8355E-04	0.09340	Mg	2.1889E-04	0.08495
Mg-25	1.5349E-05	0.33530			
Mg-26	1.9991E-05	0.25180			
Si-28	9.4882E-05	0.11470	Si	1.0393E-04	0.10850
Si-29	8.1231E-06	0.29860			
Si-30	9.2046E-07	1.82450			
Ti-46	-1.5830E-07	5.01800	Ti	5.7791E-06	0.75821
Ti-47	1.5841E-07	6.75720			
Ti-48	6.1830E-06	0.65600			
Ti-49	-5.5083E-07	1.29140			
Ti-50	1.4686E-07	4.64810			
Cr-50	-3.5461E-06	0.42710	Cr	-2.2944E-06	2.28683
Cr-52	8.5647E-06	0.50980			
Cr-53	-7.6630E-06	0.31010			
Cr-54	3.5002E-07	2.06890			
Mn-55	-3.0573E-05	0.17960	Mn	-3.0573E-05	0.17960
Fe-54	-7.0845E-07	2.75200	Fe	4.3731E-06	1.71607
Fe-56	4.6004E-06	1.54610			
Fe-57	5.7394E-07	2.32290			
Fe-58	-9.2795E-08	4.16610			
Cu-63	7.7185E-06	0.70900	Cu	8.8873E-06	0.75085
Cu-65	1.1688E-06	3.26710			
Zn-64	5.9388E-06	0.55750	Zn	7.1939E-06	0.64419
Zn-66	2.8593E-06	0.80140			
Zn-67	-1.8197E-06	0.45270			
Zn-68	-3.0283E-07	6.98380			
Zn-70	5.1835E-07	0.64630			
Total	**1.6580E-02**	**0.00887**	**Total**	**1.6580E-02**	**0.00887**

Table 97. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum structure composition in Case 1.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
Al-27	1.1826E-02	0.00500	Al	1.1826E-02	0.00500
Mg-24	1.8535E-04	0.03930	Mg	2.1942E-04	0.03588
Mg-25	1.7141E-05	0.12370			
Mg-26	1.6929E-05	0.12410			
Si-28	8.1827E-05	0.05510	Si	8.8576E-05	0.05312
Si-29	4.2024E-06	0.25480			
Si-30	2.5463E-06	0.32050			
Ti-46	6.5118E-07	0.60010	Ti	1.3657E-05	0.11841
Ti-47	6.4200E-07	0.54910			
Ti-48	1.1553E-05	0.12810			
Ti-49	5.6812E-07	0.52800			
Ti-50	2.4263E-07	0.99030			
Cr-50	3.3260E-06	0.25630	Cr	2.8590E-05	0.09135
Cr-52	1.7707E-05	0.12120			
Cr-53	7.2811E-06	0.16320			
Cr-54	2.7543E-07	1.00580			
Mn-55	3.6342E-05	0.07520	Mn	3.6342E-05	0.07520
Fe-54	4.3023E-06	0.23290	Fe	4.7595E-05	0.06864
Fe-56	4.2038E-05	0.07290			
Fe-57	1.0370E-06	0.41950			
Fe-58	2.1793E-07	1.34940			
Cu-63	2.0751E-05	0.11590	Cu	3.3726E-05	0.08629
Cu-65	1.2975E-05	0.12630			
Zn-64	8.7343E-06	0.16350	Zn	1.6338E-05	0.12060
Zn-66	3.4998E-06	0.27110			
Zn-67	4.0279E-07	0.93920			
Zn-68	3.6814E-06	0.24240			
Zn-70	1.9962E-08	2.99440			
Total	**1.2310E-02**	**0.00489**	**Total**	**1.2310E-02**	**0.00489**

Table 98. Constrained elemental sensitivities and effect in k_{eff} for the aluminum membrane in Case 1.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	2.2773E-03	-	-
Mg	1.00000E+00	0.400/√12	1.2881E-05	-1.05231E-05	1.21510E-06
Si	6.00000E-01	0.400/√12	1.6497E-05	2.45506E-06	4.72477E-07
Ti	7.50000E-02	0.075/√12	1.9967E-06	2.41402E-07	6.96868E-08
Cr	1.95000E-01	0.310/√12	2.8852E-06	-1.67857E-06	7.70330E-07
Mn	7.50000E-02	0.075/√12	1.0197E-06	-7.35580E-07	2.12344E-07
Fe	3.50000E-01	0.350/√12	1.8719E-06	-6.31941E-06	1.82426E-06
Cu	2.75000E-01	0.250/√12	5.3863E-06	-1.04969E-06	2.75471E-07
Zn	1.25000E-01	0.125/√12	2.2786E-05	1.98601E-05	5.73311E-06

Table 99. Constrained elemental sensitivities and effect in k_{eff} for the aluminum inserts in Case 1.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	1.6264E-02	-	-
Mg	1.00000E+00	0.400/√12	2.1889E-04	5.17455E-05	5.97505E-06
Si	6.00000E-01	0.400/√12	1.0393E-04	3.63883E-06	7.00294E-07
Ti	7.50000E-02	0.075/√12	5.7791E-06	-6.75670E-06	1.95049E-06
Cr	1.95000E-01	0.310/√12	-2.2944E-06	-3.48876E-05	1.60106E-05
Mn	7.50000E-02	0.075/√12	-3.0573E-05	-4.31088E-05	1.24445E-05
Fe	3.50000E-01	0.350/√12	4.3731E-06	-5.41275E-05	1.56253E-05
Cu	2.75000E-01	0.250/√12	8.8873E-06	-3.70775E-05	9.73031E-06
Zn	1.25000E-01	0.125/√12	7.1939E-06	-1.36991E-05	3.95460E-06

Table 100. Constrained elemental sensitivities and effect in k_{eff} for the aluminum structure in Case 1.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	1.1826E-02	-	-
Mg	1.00000E+00	0.400/√12	2.1942E-04	9.78846E-05	1.13027E-05
Si	6.00000E-01	0.400/√12	8.8576E-05	1.56545E-05	3.01270E-06
Ti	7.50000E-02	0.075/√12	1.3657E-05	4.54178E-06	1.31110E-06
Cr	1.95000E-01	0.310/√12	2.8590E-05	4.89013E-06	2.24418E-06
Mn	7.50000E-02	0.075/√12	3.6342E-05	2.72268E-05	7.85971E-06
Fe	3.50000E-01	0.350/√12	4.7595E-05	5.05785E-06	1.46007E-06
Cu	2.75000E-01	0.250/√12	3.3726E-05	3.03771E-07	7.97192E-08
Zn	1.25000E-01	0.125/√12	1.6338E-05	1.14633E-06	3.30917E-07

Table 101. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum membrane composition in Case 2.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
Al-27	2.8980E-03	0.03580	Al	2.8980E-03	0.03580
Mg-24	-2.5336E-06	4.73940	Mg	7.4791E-06	1.74891
Mg-25	1.1369E-05	0.34470			
Mg-26	-1.3563E-06	2.50580			
Si-28	6.0735E-06	1.23660	Si	7.7712E-06	1.00424
Si-29	1.5790E-06	1.05140			
Si-30	1.1874E-07	11.11300			
Ti-46	3.1226E-07	2.12620	Ti	8.4684E-07	3.87284
Ti-47	-5.3087E-08	13.85760			
Ti-48	1.1272E-06	2.70090			
Ti-49	-7.0798E-07	0.71070			
Ti-50	1.6845E-07	2.98310			
Cr-50	-6.7217E-07	1.80380	Cr	6.8603E-06	0.62292
Cr-52	2.0412E-06	1.65970			
Cr-53	5.3624E-06	0.42080			
Cr-54	1.2884E-07	3.66390			
Mn-55	3.4820E-06	1.44980	Mn	3.4820E-06	1.44980
Fe-54	-1.1078E-06	1.27100	Fe	3.0434E-07	17.37547
Fe-56	2.1803E-06	2.30650			
Fe-57	-8.9258E-07	0.85670			
Fe-58	1.2442E-07	2.62640			
Cu-63	-3.2417E-06	1.12470	Cu	-3.3482E-06	1.35429
Cu-65	-1.0652E-07	25.30980			
Zn-64	1.3863E-06	1.77410	Zn	3.6172E-06	0.96989
Zn-66	2.9974E-06	0.61300			
Zn-67	-9.0000E-08	8.34180			
Zn-68	-1.1343E-06	1.30060			
Zn-70	4.5779E-07	0.82610			
Total	**2.9250E-03**	**0.03604**	**Total**	**2.9250E-03**	**0.03604**

Table 102. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum insert composition in Case 2.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Al-27	2.3101E-04	0.26400	Al	2.3101E-04	0.26400
Mg-24	-3.4400E-06	2.06100	Mg	-2.5000E-06	3.08570
Mg-25	3.6448E-06	0.61840			
Mg-26	-2.7048E-06	0.75440			
Si-28	3.1319E-06	1.41760	Si	3.3673E-06	1.35878
Si-29	-7.3448E-07	1.08530			
Si-30	9.6990E-07	0.79030			
Ti-46	-1.6513E-07	2.07960	Ti	5.9030E-08	38.99628
Ti-47	-7.8738E-07	0.37130			
Ti-48	-4.2981E-07	4.91910			
Ti-49	1.0662E-06	0.62760			
Ti-50	3.7515E-07	1.12350			
Cr-50	-1.3779E-06	0.46930	Cr	-3.5462E-06	0.67221
Cr-52	-1.9847E-06	0.86940			
Cr-53	-8.4510E-07	1.67960			
Cr-54	6.6152E-07	0.78860			
Mn-55	-1.2422E-05	0.24090	Mn	-1.2422E-05	0.24090
Fe-54	-2.3834E-07	3.62250	Fe	-6.0638E-06	0.62365
Fe-56	-5.3728E-06	0.68180			
Fe-57	-3.5417E-07	0.99330			
Fe-58	-9.8452E-08	1.14920			
Cu-63	-6.1674E-08	44.08820	Cu	-6.2389E-07	5.25845
Cu-65	-5.6222E-07	3.26500			
Zn-64	2.2428E-07	6.07550	Zn	-7.8334E-07	2.69501
Zn-66	-1.0779E-06	0.91270			
Zn-67	4.0047E-07	1.64050			
Zn-68	-2.6902E-07	4.06860			
Zn-70	-6.1173E-08	0.83630			
Total	**2.0850E-04**	**0.29757**	**Total**	**2.0850E-04**	**0.29757**

Table 103. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum structure composition in Case 2.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Al-27	9.8198E-03	0.00510	Al	9.8198E-03	0.00510
Mg-24	1.6104E-04	0.04090	Mg	1.9924E-04	0.03643
Mg-25	1.6850E-05	0.12430			
Mg-26	2.1352E-05	0.10370			
Si-28	6.6209E-05	0.06250	Si	7.0886E-05	0.06040
Si-29	3.2955E-06	0.25930			
Si-30	1.3814E-06	0.49920			
Ti-46	1.2778E-07	1.81950	Ti	1.4085E-05	0.11731
Ti-47	4.4759E-07	0.63080			
Ti-48	1.2856E-05	0.12230			
Ti-49	3.1319E-07	0.83070			
Ti-50	3.4033E-07	0.69750			
Cr-50	1.2352E-06	0.41860	Cr	1.6035E-05	0.11932
Cr-52	9.2806E-06	0.16180			
Cr-53	4.6363E-06	0.21400			
Cr-54	8.8325E-07	0.44470			
Mn-55	3.2080E-05	0.08270	Mn	3.2080E-05	0.08270
Fe-54	3.7078E-06	0.25620	Fe	4.7649E-05	0.07020
Fe-56	4.3194E-05	0.07350			
Fe-57	4.7948E-07	0.85730			
Fe-58	2.6794E-07	0.73390			
Cu-63	2.1733E-05	0.10160	Cu	3.4614E-05	0.08122
Cu-65	1.2881E-05	0.13510			
Zn-64	6.6782E-06	0.19420	Zn	1.4155E-05	0.12490
Zn-66	2.8736E-06	0.26130			
Zn-67	7.6831E-07	0.54820			
Zn-68	3.8592E-06	0.21710			
Zn-70	-2.4567E-08	0.89270			
Total	**1.0249E-02**	**0.00499**	**Total**	**1.0249E-02**	**0.00499**

Table 104. Constrained elemental sensitivities and effect in k_{eff} for the aluminum membrane in Case 2.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	2.8980E-03	-	-
Mg	1.00000E+00	0.400/√12	7.4791E-06	-1.59246E-05	1.83882E-06
Si	6.00000E-01	0.400/√12	7.7712E-06	-6.27100E-06	1.20685E-06
Ti	7.50000E-02	0.075/√12	8.4684E-07	-9.08437E-07	2.62243E-07
Cr	1.95000E-01	0.310/√12	6.8603E-06	2.29654E-06	1.05393E-06
Mn	7.50000E-02	0.075/√12	3.4820E-06	1.72672E-06	4.98461E-07
Fe	3.50000E-01	0.350/√12	3.0434E-07	-7.88697E-06	2.27677E-06
Cu	2.75000E-01	0.250/√12	-3.3482E-06	-9.78425E-06	2.56770E-06
Zn	1.25000E-01	0.125/√12	3.6172E-06	6.91724E-07	1.99683E-07

Table 105. Constrained elemental sensitivities and effect in k_{eff} for the aluminum inserts in Case 2.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	2.3101E-04	-	-
Mg	1.00000E+00	0.400/√12	-2.5000E-06	-1.69645E-04	1.95889E-05
Si	6.00000E-01	0.400/√12	3.3673E-06	-9.69194E-05	1.86521E-05
Ti	7.50000E-02	0.075/√12	5.9030E-08	-1.24768E-05	3.60175E-06
Cr	1.95000E-01	0.310/√12	-3.5462E-06	-3.61394E-05	1.65851E-05
Mn	7.50000E-02	0.075/√12	-1.2422E-05	-2.49578E-05	7.20471E-06
Fe	3.50000E-01	0.350/√12	-6.0638E-06	-6.45644E-05	1.86381E-05
Cu	2.75000E-01	0.250/√12	-6.2389E-07	-4.65886E-05	1.22263E-05
Zn	1.25000E-01	0.125/√12	-7.8334E-07	-2.16764E-05	6.25744E-06

Table 106. Constrained elemental sensitivities and effect in k_{eff} for the aluminum structure in Case 2.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	9.8198E-03	-	-
Mg	1.00000E+00	0.400/√12	1.9924E-04	7.77066E-05	8.97279E-06
Si	6.00000E-01	0.400/√12	7.0886E-05	-2.03533E-06	3.91699E-07
Ti	7.50000E-02	0.075/√12	1.4085E-05	4.96974E-06	1.43464E-06
Cr	1.95000E-01	0.310/√12	1.6035E-05	-7.66405E-06	3.51718E-06
Mn	7.50000E-02	0.075/√12	3.2080E-05	2.29648E-05	6.62938E-06
Fe	3.50000E-01	0.350/√12	4.7649E-05	5.11184E-06	1.47566E-06
Cu	2.75000E-01	0.250/√12	3.4614E-05	1.19177E-06	3.12759E-07
Zn	1.25000E-01	0.125/√12	1.4155E-05	-1.03718E-06	2.99408E-07

Table 107. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum membrane composition in Case 3.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Al-27	3.2699E-03	0.03370	Al	3.2699E-03	0.03370
Mg-24	5.6627E-05	0.22450	Mg	6.1582E-05	0.22456
Mg-25	1.9883E-06	1.94110			
Mg-26	2.9670E-06	1.29380			
Si-28	2.4656E-05	0.31720	Si	2.7885E-05	0.29074
Si-29	1.7944E-06	0.94460			
Si-30	1.4342E-06	0.90560			
Ti-46	-1.5126E-07	4.35200	Ti	4.0703E-06	0.88565
Ti-47	5.4929E-07	1.58220			
Ti-48	4.2892E-06	0.78160			
Ti-49	3.7097E-07	1.88250			
Ti-50	-9.8788E-07	0.28620			
Cr-50	-1.3182E-07	11.38590	Cr	-2.3500E-06	1.73857
Cr-52	-2.6585E-06	1.14580			
Cr-53	-2.4966E-07	8.81420			
Cr-54	6.9002E-07	0.81730			
Mn-55	-1.0922E-05	0.48860	Mn	-1.0922E-05	0.48860
Fe-54	1.7206E-06	0.93330	Fe	5.1422E-06	1.15068
Fe-56	2.4398E-06	2.29910			
Fe-57	1.2301E-06	0.77350			
Fe-58	-2.4834E-07	0.99960			
Cu-63	-2.4183E-06	1.72600	Cu	9.9170E-07	5.19521
Cu-65	3.4100E-06	0.88570			
Zn-64	6.9942E-06	0.39310	Zn	4.0163E-06	0.91769
Zn-66	-2.9824E-06	0.51590			
Zn-67	4.3013E-07	2.14580			
Zn-68	-5.3936E-07	3.05480			
Zn-70	1.1374E-07	2.65600			
Total	**3.3603E-03**	**0.03332**	**Total**	**3.3603E-03**	**0.03332**

Table 108. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum insert composition in Case 3.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Al-27	1.0403E-04	0.47170	Al	1.0403E-04	0.47170
Mg-24	7.5108E-06	0.86810	Mg	4.6005E-06	1.53177
Mg-25	-1.4499E-06	1.31000			
Mg-26	-1.4604E-06	1.28820			
Si-28	-2.0535E-06	1.90690	Si	-2.5614E-06	1.57601
Si-29	-8.9694E-07	0.70390			
Si-30	3.8903E-07	1.92960			
Ti-46	-2.5816E-07	1.29140	Ti	-3.7557E-06	0.47246
Ti-47	-1.5465E-07	2.22990			
Ti-48	-3.8741E-06	0.41680			
Ti-49	-5.0361E-08	6.76380			
Ti-50	5.8162E-07	0.75940			
Cr-50	-9.8042E-07	0.86960	Cr	-3.3993E-06	0.68331
Cr-52	1.2071E-06	1.50290			
Cr-53	-3.2176E-06	0.36410			
Cr-54	-4.0833E-07	0.16760			
Mn-55	-7.8193E-06	0.35600	Mn	-7.8193E-06	0.35600
Fe-54	4.5402E-07	1.93380	Fe	-5.3484E-06	0.65608
Fe-56	-5.8933E-06	0.57040			
Fe-57	2.2271E-07	2.18890			
Fe-58	-1.3182E-07	0.51210			
Cu-63	-4.3772E-06	0.53250	Cu	-8.0814E-06	0.35817
Cu-65	-3.7042E-06	0.46330			
Zn-64	-5.8403E-07	2.20360	Zn	-1.5173E-06	1.28233
Zn-66	8.3417E-07	1.21210			
Zn-67	8.2774E-08	5.32140			
Zn-68	-1.7576E-06	0.54360			
Zn-70	-9.2578E-08	0.00230			
Total	**7.6148E-05**	**0.65854**	**Total**	**7.6148E-05**	**0.65854**

Table 109. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum structure composition in Case 3.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Al-27	9.3219E-03	0.00530	Al	9.3219E-03	0.00530
Mg-24	1.5239E-04	0.04160	Mg	1.8165E-04	0.03802
Mg-25	1.5383E-05	0.13230			
Mg-26	1.3880E-05	0.13230			
Si-28	6.0639E-05	0.06730	Si	6.5706E-05	0.06418
Si-29	3.3494E-06	0.27160			
Si-30	1.7176E-06	0.31830			
Ti-46	2.4042E-07	1.11730	Ti	1.0969E-05	0.14144
Ti-47	4.1052E-07	0.71940			
Ti-48	1.0177E-05	0.14550			
Ti-49	-1.5831E-07	0.55690			
Ti-50	2.9904E-07	0.72580			
Cr-50	1.0716E-06	0.48480	Cr	1.7843E-05	0.11181
Cr-52	1.0342E-05	0.15350			
Cr-53	5.9769E-06	0.17560			
Cr-54	4.5290E-07	0.65750			
Mn-55	3.3315E-05	0.08200	Mn	3.3315E-05	0.08200
Fe-54	2.7288E-06	0.29010	Fe	4.0153E-05	0.07371
Fe-56	3.6591E-05	0.07720			
Fe-57	7.4932E-07	0.51180			
Fe-58	8.3935E-08	0.96080			
Cu-63	1.8730E-05	0.11240	Cu	3.1669E-05	0.08555
Cu-65	1.2939E-05	0.13180			
Zn-64	7.2323E-06	0.17100	Zn	1.2848E-05	0.13237
Zn-66	2.1235E-06	0.38140			
Zn-67	4.5858E-07	0.64880			
Zn-68	2.9735E-06	0.26210			
Zn-70	6.0015E-08	1.73130			
Total	**9.7161E-03**	**0.00519**	**Total**	**9.7161E-03**	**0.00519**

Table 110. Constrained elemental sensitivities and effect in k_{eff} for the aluminum membrane in Case 3.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	3.2699E-03	-	-
Mg	1.00000E+00	0.400/√12	6.1582E-05	3.81786E-05	4.40848E-06
Si	6.00000E-01	0.400/√12	2.7885E-05	1.38424E-05	2.66396E-06
Ti	7.50000E-02	0.075/√12	4.0703E-06	2.31504E-06	6.68295E-07
Cr	1.95000E-01	0.310/√12	-2.3500E-06	-6.91369E-06	3.17283E-06
Mn	7.50000E-02	0.075/√12	-1.0922E-05	-1.26773E-05	3.65962E-06
Fe	3.50000E-01	0.350/√12	5.1422E-06	-3.04915E-06	8.80213E-07
Cu	2.75000E-01	0.250/√12	9.9170E-07	-5.44433E-06	1.42877E-06
Zn	1.25000E-01	0.125/√12	4.0163E-06	1.09084E-06	3.14899E-07

Table 111. Constrained elemental sensitivities and effect in k_{eff} for the aluminum inserts in Case 3.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	1.0403E-04	-	-
Mg	1.00000E+00	0.400/√12	4.6005E-06	-1.62544E-04	1.87690E-05
Si	6.00000E-01	0.400/√12	-2.5614E-06	-1.02848E-04	1.97931E-05
Ti	7.50000E-02	0.075/√12	-3.7557E-06	-1.62915E-05	4.70295E-06
Cr	1.95000E-01	0.310/√12	-3.3993E-06	-3.59924E-05	1.65176E-05
Mn	7.50000E-02	0.075/√12	-7.8193E-06	-2.03551E-05	5.87602E-06
Fe	3.50000E-01	0.350/√12	-5.3484E-06	-6.38490E-05	1.84316E-05
Cu	2.75000E-01	0.250/√12	-8.0814E-06	-5.40462E-05	1.41834E-05
Zn	1.25000E-01	0.125/√12	-1.5173E-06	-2.24103E-05	6.46931E-06

Table 112. Constrained elemental sensitivities and effect in k_{eff} for the aluminum structure in Case 3.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	9.3219E-03	-	-
Mg	1.00000E+00	0.400/√12	1.8165E-04	6.01176E-05	6.94178E-06
Si	6.00000E-01	0.400/√12	6.5706E-05	-7.21523E-06	1.38857E-06
Ti	7.50000E-02	0.075/√12	1.0969E-05	1.85352E-06	5.35064E-07
Cr	1.95000E-01	0.310/√12	1.7843E-05	-5.85600E-06	2.68743E-06
Mn	7.50000E-02	0.075/√12	3.3315E-05	2.41998E-05	6.98589E-06
Fe	3.50000E-01	0.350/√12	4.0153E-05	-2.38433E-06	6.88296E-07
Cu	2.75000E-01	0.250/√12	3.1669E-05	-1.75323E-06	4.60103E-07
Zn	1.25000E-01	0.125/√12	1.2848E-05	-2.34403E-06	6.76662E-07

Table 113. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum membrane composition in Case 4.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
Al-27	3.1585E-03	0.02920	Al	3.1585E-03	0.02920
Mg-24	5.3546E-05	0.21400	Mg	5.3321E-05	0.23120
Mg-25	3.4977E-06	0.94710			
Mg-26	-3.7226E-06	0.83640			
Si-28	1.1001E-05	0.60630	Si	1.3721E-05	0.50614
Si-29	8.2721E-07	1.80570			
Si-30	1.8931E-06	0.64960			
Ti-46	1.3041E-06	0.66530	Ti	2.2239E-06	1.44316
Ti-47	-8.6667E-07	0.64000			
Ti-48	1.7017E-06	1.74220			
Ti-49	2.9858E-07	1.83190			
Ti-50	-2.1381E-07	1.82020			
Cr-50	-1.0212E-07	12.37770	Cr	-1.2786E-06	2.77812
Cr-52	-9.4828E-07	2.84340			
Cr-53	1.8704E-07	9.92420			
Cr-54	-4.1519E-07	1.32570			
Mn-55	3.1792E-06	1.49520	Mn	3.1792E-06	1.49520
Fe-54	-1.2559E-06	1.09180	Fe	6.9804E-06	0.78977
Fe-56	8.0842E-06	0.65250			
Fe-57	3.4206E-07	2.36430			
Fe-58	-1.8999E-07	0.94920			
Cu-63	1.0108E-05	0.40300	Cu	9.9837E-06	0.48964
Cu-65	-1.2431E-07	21.73860			
Zn-64	-9.9432E-07	2.28040	Zn	-1.5282E-06	2.04020
Zn-66	6.3173E-07	2.26720			
Zn-67	1.1016E-06	0.78040			
Zn-68	-2.2056E-06	0.60460			
Zn-70	-6.1634E-08	1.71830			
Total	**3.2451E-03**	**0.02893**	**Total**	**3.2451E-03**	**0.02893**

Table 114. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum structure composition in Case 4.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Al-27	9.3481E-03	0.00520	Al	9.3481E-03	0.00520
Mg-24	1.6188E-04	0.04160	Mg	1.9210E-04	0.03777
Mg-25	1.6615E-05	0.12120			
Mg-26	1.3600E-05	0.13220			
Si-28	6.3836E-05	0.06510	Si	6.9281E-05	0.06227
Si-29	3.7586E-06	0.25670			
Si-30	1.6862E-06	0.38120			
Ti-46	1.3756E-06	0.34120	Ti	1.3820E-05	0.12328
Ti-47	5.1080E-07	0.67450			
Ti-48	1.0885E-05	0.13970			
Ti-49	2.5956E-07	0.95790			
Ti-50	7.8885E-07	0.55170			
Cr-50	1.6081E-06	0.38400	Cr	1.4925E-05	0.13156
Cr-52	9.9560E-06	0.16380			
Cr-53	3.1943E-06	0.26910			
Cr-54	1.6661E-07	1.65280			
Mn-55	3.3501E-05	0.07970	Mn	3.3501E-05	0.07970
Fe-54	2.3306E-06	0.27820	Fe	3.7911E-05	0.07641
Fe-56	3.4814E-05	0.08020			
Fe-57	8.5703E-07	0.48950			
Fe-58	-9.0598E-08	0.00650			
Cu-63	1.7955E-05	0.11700	Cu	2.7224E-05	0.09225
Cu-65	9.2694E-06	0.14850			
Zn-64	7.4927E-06	0.16310	Zn	1.4345E-05	0.11802
Zn-66	3.1735E-06	0.25290			
Zn-67	7.6159E-07	0.50720			
Zn-68	2.6185E-06	0.27490			
Zn-70	2.9845E-07	0.82850			
Total	**9.7512E-03**	**0.00509**	**Total**	**9.7512E-03**	**0.00509**

Table 115. Constrained elemental sensitivities and effect in k_{eff} for the aluminum membrane in Case 4.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
Al	9.73050E+01	-	3.1585E-03	-	-
Mg	1.00000E+00	0.400/√12	5.3321E-05	2.99174E-05	3.45456E-06
Si	6.00000E-01	0.400/√12	1.3721E-05	-3.20928E-07	6.17627E-08
Ti	7.50000E-02	0.075/√12	2.2239E-06	4.68620E-07	1.35279E-07
Cr	1.95000E-01	0.310/√12	-1.2786E-06	-5.84228E-06	2.68113E-06
Mn	7.50000E-02	0.075/√12	3.1792E-06	1.42392E-06	4.11050E-07
Fe	3.50000E-01	0.350/√12	6.9804E-06	-1.21094E-06	3.49567E-07
Cu	2.75000E-01	0.250/√12	9.9837E-06	3.54766E-06	9.31020E-07
Zn	1.25000E-01	0.125/√12	-1.5282E-06	-4.45369E-06	1.28567E-06

Table 116. Constrained elemental sensitivities and effect in k_{eff} for the aluminum structure in Case 4.

Element	**Wt.%**	**Evaluated Uncertainty (Wt.%)**	**Sensitivity $S_{k,i}$**	**Constrained Sensitivity $S_{k,i}^{CPA}$**	**u_k/k**
Al	9.73050E+01	-	9.3481E-03	-	-
Mg	1.00000E+00	0.400/√12	1.9210E-04	7.05596E-05	8.14752E-06
Si	6.00000E-01	0.400/√12	6.9281E-05	-3.64043E-06	7.00601E-07
Ti	7.50000E-02	0.075/√12	1.3820E-05	4.70466E-06	1.35812E-06
Cr	1.95000E-01	0.310/√12	1.4925E-05	-8.77439E-06	4.02674E-06
Mn	7.50000E-02	0.075/√12	3.3501E-05	2.43858E-05	7.03959E-06
Fe	3.50000E-01	0.350/√12	3.7911E-05	-4.62635E-06	1.33551E-06
Cu	2.75000E-01	0.250/√12	2.7224E-05	-6.19783E-06	1.62651E-06
Zn	1.25000E-01	0.125/√12	1.4345E-05	-8.47182E-07	2.44560E-07

Table 117. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum membrane composition in Case 5.

Isotope	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**	**Element**	**Sensitivity $S_{k,i}$**	**FSD $S_{k,i}/\sigma(S_{k,i})$**
Al-27	2.2935E-03	0.03660	Al	2.2935E-03	0.03660
Mg-24	2.5591E-05	0.44240	Mg	3.3806E-05	0.36412
Mg-25	6.9580E-06	0.51320			
Mg-26	1.2574E-06	2.58970			
Si-28	6.7393E-06	0.99680	Si	5.4864E-06	1.26866
Si-29	-2.0253E-06	0.68670			
Si-30	7.7237E-07	1.52310			
Ti-46	4.5743E-07	1.46480	Ti	-1.0382E-05	0.27470
Ti-47	-1.0693E-06	0.51350			
Ti-48	-9.5655E-06	0.27500			
Ti-49	-3.0687E-07	1.57770			
Ti-50	1.0247E-07	4.66740			
Cr-50	-4.8424E-06	0.21480	Cr	-1.5313E-05	0.23364
Cr-52	1.3276E-07	21.40370			
Cr-53	-1.0167E-05	0.18350			
Cr-54	-4.3620E-07	0.92460			
Mn-55	-2.9346E-05	0.14710	Mn	-2.9346E-05	0.14710
Fe-54	-1.5714E-06	0.79230	Fe	-2.3979E-05	0.23698
Fe-56	-2.2142E-05	0.24830			
Fe-57	-2.9381E-08	23.33910			
Fe-58	-2.3584E-07	0.87470			
Cu-63	-1.3643E-05	0.25570	Cu	-1.9610E-05	0.22734
Cu-65	-5.9670E-06	0.46520			
Zn-64	-7.2157E-09	289.18480	Zn	-2.3317E-06	1.29823
Zn-66	1.9309E-07	7.85450			
Zn-67	-2.4219E-06	0.19310			
Zn-68	7.8435E-08	19.23070			
Zn-70	-1.7409E-07	0.69950			
Total	**2.2318E-03**	**0.03841**	**Total**	**2.2318E-03**	**0.03841**

Table 118. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum insert composition in Case 5.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Al-27	-9.3796E-04	0.04750	Al	-9.3796E-04	0.04750
Mg-24	3.5663E-06	1.99910	Mg	3.4254E-07	22.55370
Mg-25	-2.7278E-06	0.76420			
Mg-26	-4.9596E-07	4.28210			
Si-28	-3.6586E-06	1.10910	Si	-2.7847E-06	1.53356
Si-29	9.5950E-07	1.13360			
Si-30	-8.5617E-08	8.96430			
Ti-46	-1.2032E-07	3.00750	Ti	-1.6076E-05	0.10826
Ti-47	-1.0205E-07	3.78510			
Ti-48	-1.5740E-05	0.10160			
Ti-49	1.7654E-10	1840.13530			
Ti-50	-1.1350E-07	2.57860			
Cr-50	-4.7006E-06	0.10450	Cr	-1.3885E-05	0.17732
Cr-52	-1.4785E-06	1.35680			
Cr-53	-8.0139E-06	0.16010			
Cr-54	3.0835E-07	1.25470			
Mn-55	-2.7596E-05	0.08990	Mn	-2.7596E-05	0.08990
Fe-54	-8.8526E-07	1.05740	Fe	-2.9390E-05	0.14728
Fe-56	-2.7249E-05	0.15480			
Fe-57	-1.1028E-06	0.20410			
Fe-58	-1.5252E-07	0.82470			
Cu-63	-2.1002E-05	0.11260	Cu	-2.7070E-05	0.11967
Cu-65	-6.0677E-06	0.36490			
Zn-64	-1.8950E-06	0.72800	Zn	-2.3671E-06	0.88060
Zn-66	-3.9663E-07	2.59850			
Zn-67	-2.8391E-07	1.66990			
Zn-68	2.0020E-07	5.33520			
Zn-70	8.1955E-09	14.49750			
Total	**-1.0568E-03**	**0.04348**	**Total**	**-1.0568E-03**	**0.04348**

Table 119. Unconstrained isotopic and elemental density sensitivities in k_{eff} for the aluminum structure composition in Case 5.

Isotope	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$	Element	Sensitivity $S_{k,i}$	FSD $S_{k,i}/\sigma(S_{k,i})$
Al-27	4.5157E-03	0.00700	Al	4.5157E-03	0.00700
Mg-24	7.7402E-05	0.05320	Mg	9.3544E-05	0.04844
Mg-25	7.2396E-06	0.17120			
Mg-26	8.9020E-06	0.16060			
Si-28	3.4584E-05	0.08220	Si	3.5890E-05	0.08093
Si-29	1.0062E-06	0.50400			
Si-30	2.9944E-07	1.04270			
Ti-46	5.6446E-07	0.58580	Ti	7.4587E-06	0.15293
Ti-47	6.2176E-07	0.47940			
Ti-48	6.3242E-06	0.16460			
Ti-49	-4.4478E-08	1.93730			
Ti-50	-7.2389E-09	15.03440			
Cr-50	8.7813E-07	0.40100	Cr	9.3403E-06	0.15019
Cr-52	5.4237E-06	0.21550			
Cr-53	3.0130E-06	0.22710			
Cr-54	2.5504E-08	3.85630			
Mn-55	1.3956E-05	0.12380	Mn	1.3956E-05	0.12380
Fe-54	1.8094E-06	0.27670	Fe	2.1422E-05	0.09052
Fe-56	1.9449E-05	0.09590			
Fe-57	9.3711E-08	1.64350			
Fe-58	6.9545E-08	1.20000			
Cu-63	8.5696E-06	0.15720	Cu	1.3986E-05	0.11936
Cu-65	5.4159E-06	0.18200			
Zn-64	5.0017E-06	0.19580	Zn	8.7102E-06	0.14880
Zn-66	2.0056E-06	0.30140			
Zn-67	2.4884E-07	0.87740			
Zn-68	1.2477E-06	0.40520			
Zn-70	2.0631E-07	1.10680			
Total	**4.7200E-03**	**0.00684**	**Total**	**4.7200E-03**	**0.00684**

Table 120. Constrained elemental sensitivities and effect in k_{eff} for the aluminum membrane in Case 5.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	2.2935E-03	-	-
Mg	1.00000E+00	0.400/√12	3.3806E-05	1.04027E-05	1.20120E-06
Si	6.00000E-01	0.400/√12	5.4864E-06	-8.55587E-06	1.64658E-06
Ti	7.50000E-02	0.075/√12	-1.0382E-05	-1.21370E-05	3.50366E-06
Cr	1.95000E-01	0.310/√12	-1.5313E-05	-1.98766E-05	9.12174E-06
Mn	7.50000E-02	0.075/√12	-2.9346E-05	-3.11013E-05	8.97817E-06
Fe	3.50000E-01	0.350/√12	-2.3979E-05	-3.21699E-05	9.28666E-06
Cu	2.75000E-01	0.250/√12	-1.9610E-05	-2.60460E-05	6.83531E-06
Zn	1.25000E-01	0.125/√12	-2.3317E-06	-5.25715E-06	1.51761E-06

Table 121. Constrained elemental sensitivities and effect in k_{eff} for the aluminum inserts in Case 5.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	2.2935E-03	-	-
Mg	1.00000E+00	0.400/√12	3.3806E-05	1.04027E-05	1.20120E-06
Si	6.00000E-01	0.400/√12	5.4864E-06	-8.55587E-06	1.64658E-06
Ti	7.50000E-02	0.075/√12	-1.0382E-05	-1.21370E-05	3.50366E-06
Cr	1.95000E-01	0.310/√12	-1.5313E-05	-1.98766E-05	9.12174E-06
Mn	7.50000E-02	0.075/√12	-2.9346E-05	-3.11013E-05	8.97817E-06
Fe	3.50000E-01	0.350/√12	-2.3979E-05	-3.21699E-05	9.28666E-06
Cu	2.75000E-01	0.250/√12	-1.9610E-05	-2.60460E-05	6.83531E-06
Zn	1.25000E-01	0.125/√12	-2.3317E-06	-5.25715E-06	1.51761E-06

Table 122. Constrained elemental sensitivities and effect in k_{eff} for the aluminum structure in Case 5.

Element	Wt.%	Evaluated Uncertainty (Wt.%)	Sensitivity $S_{k,i}$	Constrained Sensitivity $S_{k,i}^{CPA}$	u_k/k
Al	9.73050E+01	-	4.5157E-03	-	-
Mg	1.00000E+00	0.400/√12	9.3544E-05	-2.79918E-05	3.23221E-06
Si	6.00000E-01	0.400/√12	3.5890E-05	-3.70316E-05	7.12673E-06
Ti	7.50000E-02	0.075/√12	7.4587E-06	-1.65645E-06	4.78176E-07
Cr	1.95000E-01	0.310/√12	9.3403E-06	-1.43591E-05	6.58965E-06
Mn	7.50000E-02	0.075/√12	1.3956E-05	4.84085E-06	1.39743E-06
Fe	3.50000E-01	0.350/√12	2.1422E-05	-2.11157E-05	6.09559E-06
Cu	2.75000E-01	0.250/√12	1.3986E-05	-1.94367E-05	5.10082E-06
Zn	1.25000E-01	0.125/√12	8.7102E-06	-6.48177E-06	1.87113E-06

Table 123 summarizes the effect in k_{eff} of the aluminum membrane, aluminum inserts, and aluminum structure composition for the experimental configurations. Table 124 summarizes the aluminum composition uncertainty calculation parameters and sensitivity in keff. The standard uncertainty assumes a uniform distribution within this elemental composition ranges in Table 94. Table 124 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 123. Summary of effect in k_{eff} to uncertainties in the aluminum composition.

Case	Component	u_k/k
1	Membrane	6.21413E-06
	Inserts	2.83843E-05
	Structure	1.44086E-05
2	Membrane	4.25234E-06
	Inserts	4.00948E-05
	Structure	1.44086E-05
3	Membrane	7.30431E-06
	Inserts	4.06972E-05
	Structure	1.18915E-05
4	Membrane	4.68567E-06
	No aluminum inserts.	
	Structure	1.03717E-05
5	Membrane	1.77626E-05
	Inserts	4.97795E-05
	Structure	1.17888E-05

Table 124. Summary of sensitivity in k_{eff} to uncertainties in the aluminum composition.

Case	Parameter Value (Wt.%)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	Varies (Table 94)	-	±0.00003	Varies (Table 94)	±0.00003
2			±0.00004		±0.00004
3			±0.00004		±0.00004
4			±0.00001		±0.00001
5			±0.00005		±0.00005

2.3 Dimensional Uncertainties

The dimensional uncertainties are based on both measured quantities and tolerances from engineering drawings. Unless otherwise noted, any dimensional perturbations are performed conserving the part mass by increasing or decreasing the density of the part.

2.3.1 Highly Enriched Uranium Plate Dimensions

Due to the dependence of the core stack height on the thickness of the HEU plates, the uncertainty in the plate thickness is evaluated as part of the core stack height uncertainty in Section 2.3.4. This section only evaluates the uncertainty in the inner and outer diameters of the plates.

The HEU plate inner and outer diameter dimensions are reported in Table 4. No verification measurements could be performed on the inner and outer diameters of the HEU plates. These dimensions and uncertainties are based on the original design drawings of the plates. Therefore, the evaluated uncertainty of the inner and outer diameters of the plates is the tolerance on the drawings. Table 125 summarizes the inner and outer diameters of the HEU plates and reports the evaluated uncertainties.

Table 125. Summary of standard uncertainties for the HEU plate inner and outer diameters.

<table>
<tr><th>Part Type</th><th>Inner Diameter [in (cm)]</th><th>Standard Uncertainty in Inner Diameter [in (cm)]</th><th>Outer Diameter [in (cm)]</th><th>Standard Uncertainty in Outer Diameter [in (cm)]</th></tr>
<tr><td>Full (HEU1)</td><td colspan="2">No annulus.</td><td rowspan="4">14.9975 (38.09365)</td><td rowspan="4">±0.0025/√12 (±0.00635/√12)</td></tr>
<tr><td>2.5” (HEU2)</td><td>2.5125 (6.38175)</td><td rowspan="3">±0.0025/√12 (±0.00635/√12)</td></tr>
<tr><td>6” (HEU4)</td><td>6.0075 (15.25905)</td></tr>
<tr><td>10” (HEU5)</td><td>10.0075 (25.41905)</td></tr>
</table>

Table 126 summarizes the HEU plate inner and outer diameter dimension uncertainty calculation parameters and sensitivity in k_{eff}. The inner and outer diameter is based on the midpoint of the reported dimension and its tolerance. The standard uncertainty assumes a uniform distribution within the tolerance interval. Therefore, the standard uncertainty in the HEU plate inner and outer diameters is ±0.00635/√12 cm. The calculations vary both the inner and outer diameters simultaneously by ±0.00635 cm, representing the upper and lower bounds of the diameters. Table 126 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 126. Summary of sensitivity in k_{eff} to uncertainties in the HEU plate inner and outer diameters.

<table>
<tr><th>Case</th><th>Parameter Value (cm)</th><th>Parameter Variation in Calculation</th><th>Calculated Effect in k_{eff}</th><th>Standard Uncertainty</th><th>Standard Uncertainty in k_{eff}</th></tr>
<tr><td>1</td><td rowspan="5">Varies (Table 125)</td><td rowspan="5">±0.00635</td><td>±0.00018</td><td rowspan="5">±0.00635/√12</td><td>±0.00005</td></tr>
<tr><td>2</td><td>±0.00010</td><td>±0.00003</td></tr>
<tr><td>3</td><td>±0.00018</td><td>±0.00005</td></tr>
<tr><td>4</td><td>±0.00018</td><td>±0.00005</td></tr>
<tr><td>5</td><td>±0.00004</td><td>±0.00001</td></tr>
</table>

2.3.2 Aluminum Insert Dimensions

Due to the dependence of the core stack height on the thickness of the aluminum inserts, the uncertainty in the insert thickness is evaluated as part of the core stack height uncertainty in Section 2.3.4. This section only evaluates the uncertainty in the diameter of the inserts.

The aluminum insert diameters are reported in Table 6. These measurements were performed using calipers with a 0.0005 in (0.0127 mm) precision. Table 127 summarizes the aluminum insert diameter measurements, reporting the average and standard deviation of the diameters by part type. The uncertainties are represented as the standard deviation of the diameter measurements from parts of the same type. The standard deviations of the diameter measurements are significantly larger than the measurement precision of the calipers used to perform the measurements. Based on these averages, the evaluated uncertainty in the aluminum insert diameter is ±0.01 cm for all part types, which is larger than the calculated standard deviations for the party type diameters.

Table 127. Average aluminum insert diameter by part type.

Part Type	N	Diameter (cm)
2.5-DISK	10	6.084 ± 0.001
6-DISK	4	14.967 ± 0.003
10-DISK	3	25.127 ± 0.001

Table 128 summarizes the aluminum insert diameter uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is equal to the evaluated uncertainty in the outer diameters of ±0.01 cm. The calculations vary the aluminum insert diameters by collectively perturbing the individual inserts by ±0.01 cm. Table 128 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 128. Summary of sensitivity in k_{eff} to uncertainties in the aluminum insert diameters.

Case	Parameter Value (cm)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	Varies (Table 127)	±0.01	±0.00000	±0.01	±0.00000
2			±0.00002		±0.00002
3			±0.00004		±0.00004
4[(a)]			-		-
5			±0.00004		±0.00004

(a) There are no aluminum inserts in the Case 4 experimental configuration.

2.3.3 Polyethylene Moderator and Reflector Plate Dimensions

Due to the dependence of the core stack height on the thickness of the polyethylene moderator and reflector plates, the uncertainty in the plate thickness is evaluated as part of the core stack height uncertainty in Section 2.3.4. This section only evaluates the uncertainty in the diameters of the plates.

The polyethylene moderator and reflector diameter measurements are reported in Table 7. The plates were measured using a CMM by LLNL's Dimensional Inspection Laboratory prior to the experiment campaign.

The minimum, maximum, and average values reported for the diameter measurements are based on many cord length measurements. The CMM has a precision of 0.0005 in (0.00127 cm).

Table 128 summarizes the polyethylene moderator and reflector diameter measurements, reporting the average and standard deviation of the diameters by part type. The uncertainties are represented as the standard deviation of the diameter measurements from parts of the same type. The standard deviations of the diameter measurements are typically larger than the measurement precision of the machine used to perform the measurements. Based on these averages, the evaluated uncertainty in the polyethylene moderator and reflector diameter is ±0.005 cm for all part types, except for the 1.5-MOD plates which have an evaluated uncertainty of ±0.015 cm. These evaluated uncertainties were chosen such that they larger than any of the calculated standard deviations for the party type diameters. The 1.5-MOD plates have a significantly larger standard deviation than the other part types, resulting in their larger standard uncertainty.

Table 129. Average and uncertainty in thickness for polyethylene moderator and reflector plate part types.

Part Type	N	Diameter (cm)
1/8-MOD	11	38.08799 ± 0.00196
1/4-MOD	9	38.06551 ± 0.00321
1/2-MOD	7	38.07874 ± 0.00173
1.5-MOD	4	38.09378 ± 0.01171
1/32-REF	2	38.07625 ± 0.00054
1/16-REF	2	38.06368 ± 0.00036
1-REF	11	38.08799 ± 0.00196

Table 130 summarizes the polyethylene moderator and reflector plate uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is equal to the evaluated uncertainty in the outer diameters of ±0.015 cm for the 1.5-MOD plates and ±0.005 cm for all other plate types. The calculations vary the plate diameters by collectively perturbing the individual plates by ±0.02 cm. Table 130 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 130. Summary of sensitivity in k_{eff} to uncertainties in the polyethylene moderator and reflector plate diameters.

Case	Parameter Value (cm)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1[(a)]	Varies (Table 129)	±0.02	±0.00067	±0.005	±0.00017
2			±0.00023	±0.005	±0.00006
3			±0.00027	±0.005	±0.00007
4			±0.00041	±0.005	±0.00010
5			±0.00004	±0.015	±0.00003

(a) There are no polyethylene moderator plates in the Case 1 experimental configuration, but there are reflector plates.

2.3.4 Core Stack Height

The core stacks consist of the HEU plates, polyethylene moderator and reflector plates, and aluminum inserts within annuli of the HEU2, HEU4 and HEU5 plates. Three measurements were taken of the upper and lower core stack heights using an electronic height gauge for all experimental configurations, expect for Case 2 which only has a single height measurement. These height measurements are reported in the subsections of Section 1.2.8 for each of the experimental configurations. The height gauge and measurement procedure are described in Section 1.2.6. These overall core stack height measurements are in addition to the individual part thickness measurements reported in Sections 1.2.3, 1.2.4, and 1.2.5 for the HEU plates, aluminum inserts, and polyethylene parts, respectively. Therefore, the core stack height measurements can be compared to the expected core stack height based on the sum of the individual part thicknesses.

The HEU plate thickness measurements are reported in Table 4. These measurements were performed by hand while the operators were in full anti-contamination clothing. Due to the very large diameter and small thickness of the HEU plates, any offset of the caliper from a normal plane relative to the surface of the HEU plate could result in an over-prediction of the thickness. The average measured thickness of the HEU plates reported in Table 4 is 3.240 ± 0.090 mm. This is significantly larger than the expected nominal thickness and tolerance of the plates from the original engineering drawing, 0.118 ± 0.002 in (2.997 ± 0.051 mm). Due to both the difficulty in measuring the HEU plate thickness and the large discrepancy from the original drawings, the thickness measurements performed for MIX-MET-FAST-016, reported in Table 5, will be used. These measurements have an average measured thickness of 3.097 ± 0.066 mm.

The aluminum insert thickness measurements are reported in Table 6. The polyethylene moderator and reflector plates thickness measurements are reported in Table 7. Both sets of measurements were performed by LLNL's Dimensional Inspection Laboratory prior to the experiment campaign. The aluminum inserts were measured using calipers and the polyethylene plates were measured using a CMM. The calipers have a precision of 0.0005 in (0.0127 mm) The CMM has a precision of 0.0005 in (0.00127 cm). The thicknesses reported by the CMM are the distance between two best fit planes based on many surface point measurements.

The average thicknesses and associated standard deviations of the thickness measurements for the HEU plates, polyethylene moderator and reflector plates, and aluminum insert are reported in Table 131, Table 132, and Table 133, respectively. The HEU plates are based on the three individual measurements of the same plate. The polyethylene moderator and reflector plates and aluminum inserts are based on the averages of all the parts for a given part type.

Table 131. Average HEU plate thickness, based on measurements from MIX-MET-FAST-016.

Part Type	Part ID	Thickness (cm)
Full (HEU1)	11017	0.3069 ± 0.0019
	11019	0.3023 ± 0.0013
	11147	0.3035 ± 0.0022
	11149	0.3103 ± 0.0065
	11150	0.3095 ± 0.0045
2.5” (HEU2)	10464	0.3035 ± 0.0058
	10467	0.3162 ± 0.0067
	10470	0.3116 ± 0.0082
	10475	0.3264 ± 0.0025
	10487	0.3056 ± 0.0041
	10489	0.3128 ± 0.0032
	10491	0.3145 ± 0.0076
6” (HEU4)	10457	0.3027 ± 0.0007
	10477	0.3188 ± 0.0067
	10493	0.3137 ± 0.0076
	11018	0.3119 ± 0.0067
10” (HEU5)	10463	0.3002 ± 0.0048
	10472	0.3099 ± 0.0058
	10479	0.3043 ± 0.0048

Table 132. Average aluminum insert thickness by part type.

Part Type	N	Thickness (cm)
2.5-DISK	10	0.3170 ± 0.0014
6-DISK	4	0.3159 ± 0.0019
10-DISK	3	0.3162 ± 0.0013

Table 133. Average polyethylene moderator and reflector plate thickness by part type.

Part Type	N	Thickness (cm)
1/8-MOD	11	0.3181 ± 0.0015
1/4-MOD	9	0.6431 ± 0.0049
1/2-MOD	7	1.2834 ± 0.0078
1.5-MOD	4	3.8310 ± 0.0157
1/32-REF	2	0.0837 ± 0.0016
1/16-REF	2	0.1777 ± 0.0102
1-REF	2	2.5413 ± 0.0036

Table 134 through Table 138 report the expected upper and lower core stacks for the experimental configurations. The upper and lower stack heights for each experimental configuration are calculated by assigning each of these layers a thickness and uncertainty based on the parts that make up that layer. The layers consisting of polyethylene moderator, polyethylene reflector, or HEU1 plates have a thickness and uncertainty equal to that part. The layers consisting of an HEU2, HEU4, or HEU5 plate must account for the aluminum inserts placed within their annuli, some of which are greater than the measured thickness of the HEU plates. For these layers containing two parts, the layer thickness and uncertainty was chosen based on the part with the larger thickness. The presence of the aluminum inserts leads to an asymmetric uncertainty in some of the calculated core stack heights.

Table 134. Case 1 upper (left) and lower (right) core stack parts and evaluated thicknesses.

Upper Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
25	1/2-MOD-7	1.2873 ± 0.0078	1.2873 ± 0.0078
	1/4-MOD-5	0.6490 ± 0.0049	0.6490 ± 0.0049
24	1/8-MOD-11	0.3172 ± 0.0015	0.3172 ± 0.0015
23	1/16-REF-1	0.1849 ± 0.0102	0.1849 ± 0.0102
22	1/32-REF-1	0.0848 ± 0.0016	0.0848 ± 0.0016
21	10479 (10-DISK-3)	0.3043 ± 0.0048 (0.3175 ± 0.0013)	0.3175 +0.0013/-0.0013
20	10463 (10-DISK-2)	0.3002 ± 0.0048 (0.3162 ± 0.0013)	0.3162 +0.0012/-0.0013
19	10457 (6-DISK-4)	0.3188 ± 0.0067 (0.3175 ± 0.0016)	0.3188 +0.0029/-0.0067
18	10493 (6-DISK-3)	0.3119 ± 0.0067 (0.3175 ± 0.0016)	0.3175 +0.0016/-0.0016
17	10467 (2.5-DISK-7)	0.3162 ± 0.0067 (0.3175 ± 0.0014)	0.3175 +0.0014/-0.0055
16	10470 (2.5-DISK-6)	0.3116 ± 0.0082 (0.3188 ± 0.0014)	0.3188 +0.0014/-0.0013
15	10475 (2.5-DISK-5)	0.3264 ± 0.0025 (0.3175 ± 0.0014)	0.3264 +0.0025/-0.0025
14	10489 (2.5-DISK-4)	0.3128 ± 0.0032 (0.3188 ± 0.0014)	0.3188 +0.0014/-0.0013
13	1/2-MOD-7	1.2873 ± 0.0078	1.2873 ± 0.0078
		Total (cm)	**5.0747 +0.0399/-0.0477**

Lower Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
12	11017	0.3069 ± 0.0019	0.3069 ± 0.0019
11	11150	0.3095 ± 0.0045	0.3095 ± 0.0045
10	11019	0.3023 ± 0.0013	0.3023 ± 0.0013
9	11147	0.3035 ± 0.0022	0.3035 ± 0.0022
8	11149	0.3103 ± 0.0065	0.3103 ± 0.0065
7	10464 (2.5-DISK-3)	0.3035 ± 0.0058 (0.3162 ± 0.0014)	0.3162 +0.0013/-0.0014
6	10487 (2.5-DISK-2)	0.3056 ± 0.0041 (0.3162 ± 0.0014)	0.3162 +0.0013/-0.0014
5	10491 (2.5-DISK-1)	0.3145 ± 0.0076 (0.3150 ± 0.0014)	0.3150 +0.0014/-0.0070
4	11018 (6-DISK-2)	0.3027 ± 0.0007 (0.3137 ± 0.0016)	0.3137 +0.0017/-0.0016
3	10477 (6-DISK-1)	0.3137 ± 0.0076 (0.3150 ± 0.0016)	0.3150 +0.0017/-0.0063
2	10472 (10-DISK-1)	0.3099 ± 0.0058 (0.3150 ± 0.0013)	0.3150 +0.0013/-0.0012
1	BOTREF-1	2.5679 ± 0.0207	2.5679 ± 0.0207
		Total (cm)	**5.9914 +0.0457/-0.0562**

Table 135. Case 2 upper (left) and lower (right) core stack parts and evaluated thicknesses.

Upper Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
24	1-REF-2	2.5438 ± 0.0036	2.5438 ± 0.0036
23	1/16-REF-1	0.1849 ± 0.0102	0.1849 ± 0.0102
22	11149	0.3103 ± 0.0065	0.3103 ± 0.0065
21	1/8-MOD-10	0.3216 ± 0.0015	0.3216 ± 0.0015
20	11019	0.3023 ± 0.0013	0.3023 ± 0.0013
19	1/8-MOD-9	0.3170 ± 0.0015	0.3170 ± 0.0015
18	11017	0.3069 ± 0.0019	0.3069 ± 0.0019
17	1/8-MOD-8	0.3178 ± 0.0015	0.3178 ± 0.0015
16	11147	0.3035 ± 0.0022	0.3035 ± 0.0022
		Total (cm)	**4.9080 +0.0302/-0.0303**

Lower Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
15	1/8-MOD-7	0.3170 ± 0.0015	0.3170 ± 0.0015
14	10464 (2.5-DISK-7)	0.3035 ± 0.0058 (0.3175 ± 0.0014)	0.3175 +0.0014/-0.0014
13	1/8-MOD-6	0.3188 ± 0.0015	0.3188 ± 0.0015
12	10475 (2.5-DISK-6)	0.3264 ± 0.0025 (0.3188 ± 0.0014)	0.3264 +0.0025/-0.0025
11	1/8-MOD-5	0.3165 ± 0.0015	0.3165 ± 0.0015
10	10470 (2.5-DISK-5)	0.3116 ± 0.0082 (0.3175 ± 0.0014)	0.3175 +0.0014/-0.0022
9	1/8-MOD-4	0.3178 ± 0.0015	0.3178 ± 0.0015
8	10489 (2.5-DISK-4)	0.3128 ± 0.0032 (0.3188 ± 0.0014)	0.3188 +0.0014/-0.0013
7	1/8-MOD-3	0.3183 ± 0.0015	0.3183 ± 0.0015
6	10491 (2.5-DISK-3)	0.3145 ± 0.0076 (0.3162 ± 0.0014)	0.3162 +0.0013/-0.0058
5	1/8-MOD-2	0.3198 ± 0.0015	0.3198 ± 0.0015
4	10467 (2.5-DISK-2)	0.3162 ± 0.0067 (0.3162 ± 0.0014)	0.3162 +0.0013/-0.0068
3	1/8-MOD-1	0.3172 ± 0.0015	0.3172 ± 0.0015
2	10487 (2.5-DISK-1)	0.3056 ± 0.0041 (0.3150 ± 0.0014)	0.3150 +0.0014/-0.0013
1	BOTREF-1	2.5679 ± 0.0207	2.5679 ± 0.0207
		Total (cm)	**7.0208 +0.0418/-0.0525**

Table 136. Case 3 upper (left) and lower (right) core stack parts and evaluated thicknesses.

Upper Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
19	1-REF-2	2.5438 ± 0.0036	2.5438 ± 0.0036
18	1/8-MOD-1	0.3172 ± 0.0015	0.3172 ± 0.0015
17	1/16-REF-1	0.1849 ± 0.0102	0.1849 ± 0.0102
16	1/32-REF-1	0.0848 ± 0.0016	0.0848 ± 0.0016
15	10470 (2.5-DISK-5)	0.3116 ± 0.0082 (0.3175 ± 0.0014)	0.3175 +0.0014/-0.0022
14	1/4-MOD-9	0.6452 ± 0.0049	0.6452 ± 0.0049
13	10489 (2.5-DISK-4)	0.3128 ± 0.0032 (0.3188 ± 0.0014)	0.3188 +0.0014/-0.0013
12	1/4-MOD-8	0.6411 ± 0.0049	0.6411 ± 0.0049
11	10491 (2.5-DISK-3)	0.3145 ± 0.0076 (0.3162 ± 0.0014)	0.3162 +0.0013/-0.0058
10	1/4-MOD-7	0.6429 ± 0.0049	0.6429 ± 0.0049
9	10467 (2.5-DISK-2)	0.3162 ± 0.0067 (0.3162 ± 0.0014)	0.3162 +0.0013/-0.0068
8	1/4-MOD-6	0.6449 ± 0.0049	0.6449 ± 0.0049
7	10487 (2.5-DISK-1)	0.3056 ± 0.0041 (0.3150 ± 0.0014)	0.3150 +0.0014/-0.0013
		Total (cm)	**7.2885 +0.0434/-0.0542**

Lower Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
7	1/4-MOD-3	0.6342 ± 0.0049	0.6342 ± 0.0049
6	11019	0.3023 ± 0.0013	0.3023 ± 0.0013
5	1/4-MOD-2	0.6431 ± 0.0049	0.6431 ± 0.0049
4	11017	0.3069 ± 0.0013	0.3069 ± 0.0013
3	1/4-MOD-1	0.6380 ± 0.0049	0.6380 ± 0.0049
2	11150	0.3095 ± 0.0045	0.3095 ± 0.0045
1	BOTREF-1	2.5679 ± 0.0207	2.5679 ± 0.0207
		Total (cm)	**5.4020 +0.0424/-0.0424**

Table 137. Case 4 upper (left) and lower (right) core stack parts and evaluated thicknesses.

Upper Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
14	1-REF-2	2.5438 ± 0.0036	2.5438 ± 0.0036
13	1/2-MOD-6	1.2708 ± 0.0078	1.2708 ± 0.0078
12	1/8-MOD-1	0.3172 ± 0.0015	0.3172 ± 0.0015
11	1/32-REF-1	0.0848 ± 0.0016	0.0848 ± 0.0016
10	11147	0.3035 ± 0.0022	0.3035 ± 0.0022
		Total (cm)	**4.5202 +0.0167/-0.0167**

Lower Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
9	1/2-MOD-4	1.2812 ± 0.0078	1.2812 ± 0.0078
8	11149	0.3103 ± 0.0065	0.3103 ± 0.0065
7	1/2-MOD-3	1.2941 ± 0.0078	1.2941 ± 0.0078
6	11019	0.3023 ± 0.0013	0.3023 ± 0.0013
5	1/2-MOD-2	1.2819 ± 0.0078	1.2819 ± 0.0078
4	11017	0.3069 ± 0.0013	0.3069 ± 0.0013
3	1/2-MOD-1	1.2901 ± 0.0078	1.2901 ± 0.0078
2	11150	0.3095 ± 0.0045	0.3095 ± 0.0045
1	BOT-REF-1	2.5679 ± 0.0207	2.5679 ± 0.0207
		Total (cm)	**8.9442 +0.0654/-0.0654**

Table 138. Case 5 upper (left) and lower (right) core stack parts and evaluated thicknesses.

Upper Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
12	1-REF-2	2.5438 ± 0.0036	2.5438 ± 0.0036
11	1/8-MOD-1	0.3172 ± 0.0015	0.3172 ± 0.0015
10	11017	0.3069 ± 0.0013	0.3069 ± 0.0013
9	1.5-MOD-4	3.8471 ± 0.0157	3.8471 ± 0.0157
8	10457 (6-DISK-3)	0.3188 ± 0.0067 (0.3175 ± 0.0016)	0.3188 +0.0029/-0.0067
7	1.5-MOD-3	3.8321 ± 0.0157	3.8321 ± 0.0157
6	10477 (6-DISK-1)	0.3137 ± 0.0076 (0.3150 ± 0.0016)	0.3150 +0.0017/-0.0063
		Total (cm)	**11.4809 +0.0424/-0.0508**

Lower Core Stack			
Layer	**Part ID**	**Part Thickness (cm)**	**Layer Thickness (cm)**
5	1.5-MOD-2	3.8354 ± 0.0157	3.8354 ± 0.0157
4	10493 (6-DISK-2)	0.3119 ± 0.0067 (0.3137 ± 0.0016)	0.3137 +0.0017/-0.0049
3	1.5-MOD-1	3.8095 ± 0.0157	3.8095 ± 0.0157
2	11147	0.3035 ± 0.0022	0.3035 ± 0.0022
1	BOTREF-1	2.5679 ± 0.0207	2.5679 ± 0.0207
		Total (cm)	**10.8301 +0.0560/-0.0592**

Table 139 summarizes the measured and calculated core stack heights and their differences. The asymmetry in some of the calculated core stack heights is due to differing thickness of the HEU2, HEU4, and HEU5 plates and the aluminum insert present in their annuli. Since there was only a single measurement for Case 2, the uncertainty in the measurement is the indication accuracy of the electronic height gage, reported in Section 1.2.6. All the calculated core stack heights are within one standard deviation of the measured heights, except for the Case 1 and 2 upper core stack heights which are within two standard deviations. The difference between the calculated and measured core stack heights are all less than 0.06 cm. Since the measured and calculated core stack heights are within statistics of each other, nothing can be said about the presence of gaps between the layers. Therefore, there are assumed to be no axial gaps present in any of the experimental configurations.

Table 139. Comparison of measured and calculated stack heights.

Case	Upper Core Stack (cm)			Lower Core Stack (cm)		
	Measured Height	Calculated Height	Difference	Measured Height	Calculated Height	Difference
1	5.024 ± 0.011	5.075 +0.048/-0.040	0.051 +0.049/-0.041	5.977 ± 0.024	5.991 +0.056/-0.046	0.014 +0.061/-0.052
2[(a)]	4.849 ± 0.004	4.908 +0.030/-0.030	0.059 +0.030/-0.030	7.008 ± 0.004	7.021 +0.052/-0.042	0.013 +0.052/-0.042
3	7.309 ± 0.016	7.289 +0.054/-0.043	-0.020 +0.057/-0.046	5.387 ± 0.027	5.402 +0.042/-0.042	0.015 +0.050/-0.050
4	4.501 ± 0.029	4.520 +0.017/-0.017	0.019 +0.033/-0.033	8.906 ± 0.122	8.944 +0.065/-0.065	0.038 +0.138/-0.138
5	11.460 ± 0.031	11.481 +0.051/-0.042	0.021 +0.059/-0.052	10.840 ± 0.051	10.830 +0.059/-0.056	-0.010 +0.078/-0.076

(a) There was no measurement uncertainty for Case 2 as only a single height measurement was performed.

The evaluated uncertainty of the core stack heights is based on the uncertainty from the calculated core stack heights, not the uncertainty in the measured core stack heights. This is due to the measurements being statistically the same as well as the difficulty in measuring and inconsistency in the core stack height measurement uncertainties across the experimental configurations.

Table 140 summarizes the upper and lower core stack height uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is based on the evaluated uncertainties reported for the calculated core stack heights in Table 139. Additionally, to simply the standard uncertainty calculation, the asymmetric uncertainties are converted to symmetric uncertainties by assuming their midpoints. The perturbations are verified to ensure the resulting effect in k_{eff} is symmetric. The calculations vary the upper and lower core stack height separately by the evaluated uncertainty. This is done by collectively perturbing the HEU plates, polyethylene moderator and reflector plates, and aluminum insert thicknesses by their associated uncertainties reported in Table 134 through Table 138. Table 140 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 140. Summary of sensitivity in k_{eff} to uncertainties in the core stack height.

Parameter	Case	Parameter Value (cm)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
Upper Core Stack Height	1	5.075	±0.044	±0.00061	±0.044	±0.00061
	2	4.908	±0.030	±0.00053	±0.030	±0.00053
	3	7.289	±0.049	±0.00099	±0.049	±0.00099
	4	4.520	±0.017	±0.00016	±0.017	±0.00016
	5	11.481	±0.047	±0.00067	±0.047	±0.00067
Lower Core Stack Height	1	5.991	±0.051	±0.00097	±0.051	±0.00097
	2	7.021	±0.047	±0.00094	±0.047	±0.00094
	3	5.402	±0.042	±0.00059	±0.042	±0.00059
	4	8.944	±0.065	±0.00127	±0.065	±0.00127
	5	10.830	±0.058	±0.00066	±0.058	±0.00066

2.3.5 Reflector Ring Height

The ring reflector surrounds the plate stack to provide an additional 1 in (2.54 cm) of radial reflection. This reflector is modular and made of rings and caps which can be assembled to match the stack height. The parts use interlocking male (top) and female (bottom) step joints with a nominal height of 0.125 in (0.3175 cm). Each part was measured individually using a CMM; these measurements are reported in Section 1.2.5.

In addition to the individual part measurements, overall height measurements of the complete upper and lower reflectors for each case were performed using an electronic height gauge. Each ring reflector height was measured at three different locations, except for Case 2 which only had a single measurement. Table 141 summarizes these height measurements and reports their averages and uncertainties, based on the standard deviation of the three measurements. Since there was only a single measurement for Case 2, the uncertainty in the measurement is the indication accuracy of the electronic height gage, reported in Section 1.2.6.

The upper reflector measurements were taken relative to the membrane which the reflector itself sat on. The lower reflector measurements were taken relative to the lip of the adapter plate, except for Case 2 which was taken relative to the base of the adapter plate. The lip of the adapter plate was measured to be 1.247 cm ± 0.062 cm.

Table 141. Measured upper and lower reflector heights The addition of the adapter plate lip height for the lower reflector is reported in parenthesis.

Case	Upper Reflector		Lower Reflector	
	Measured Heights (cm)	Average Height (cm)	Measured Heights (cm)	Average Height (cm)
1	5.081 5.055 5.039	5.058 ± 0.021	4.810 5.036 5.007	4.951 ± 0.123 (6.198 ± 0.138)
2[(a)]	4.848	4.848 ± 0.004	6.996[(b)]	6.996 ± 0.004
3	7.259 7.184 7.177	7.207 ± 0.045	4.228 4.217 4.266	4.237 ± 0.026 (5.484 ± 0.067)
4	4.445 4.405 4.459	4.436 ± 0.028	7.599 7.739 7.657	7.665 ± 0.070 (8.912 ± 0.094)
5	11.404 11.456 11.483	11.448 ± 0.040	9.605 9.678 9.698	9.660 ± 0.049 (10.907 ± 0.079)

(a) Only a single height measurement was taken for the upper and lower reflectors in Case 2.
(b) The lower reflector height measurement was taken relative to the base of the adapter plate, not the lip.

The individual part measurements of the reflector rings, caps, and base can be used to calculate the reflector heights to be compared to the measured heights. To do so, the male and female step joints for each of the interlocking parts must be compared in case the joint has a different thickness than the other. Figure 28 shows the relationships between the measured and derived dimensions of the reflector ring and cap parts. Given the reported dimensions in Section 1.2.5, the heights of the male and female joints for each part can be calculated using these relationships.

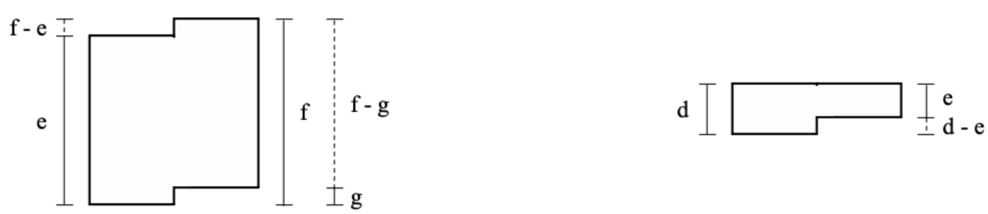


Figure 23. Diagram of the reflector ring (left) and cap (right) dimensions. The reflector ring has a male (top) and female (bottom) joint while the reflector cap only has a female (bottom) joint. The variables represent the dimensions as reported in Section 1.2.5. The solid lines represent measured quantities while the dashed lines represent derived quantities based on the measured quantities.

Table 142 reports the average top (male) and bottom (female) step heights for each reflector ring, cap, and base part type. For the reflector ring parts, the bottom (female) step heights were measured while the top (male) step heights were calculated based on the other measurements. For the reflector caps, the bottom (female) step heights were calculated based on the measurements and there is no top (male) step. For the bottom reflector, the top (male) step was calculate based on the other measurements and there is no bottom (female) step.

Table 142. Average reflector ring, cap, and base dimension uncertainties based on measured parts.

Part Type	N	Top Step Height (cm)	Bottom Step Height (cm)
1/4-RING	4	0.2929 ± 0.0018	0.3059 ± 0.0010
1/2-RING	4	0.2823 ± 0.0002	0.3026 ± 0.0031
1-RING	6	0.3130 ± 0.0017	0.3044 ± 0.0055
3-RING	6	0.3230 ± 0.0002	0.3121 ± 0.0009
BOTREF(d)	2	0.3008 ± 0.0059	-
1/32-CAP	3	-	0.3315 ± 0.0014
1/16-CAP	3	-	0.3121 ± 0.0010
3/32-CAP	3	-	0.3653 ± 0.0017
1/8-CAP	3	-	0.3169 ± 0.0003
7/32-CAP	3	-	0.3140 ± 0.0054
0-CAP	3	0.3188 ± 0.0013	-
0-BOTCAP	2	-	0.3251 ± 0.0108

(a) The top step is the male end.
(b) The bottom step is the female end.
(c) The uncertainty of the bottom reflector (BOTREF) dimension is based on the two BOTREF-1 and BOTREF-2 parts, but only BOTREF-1 was used in these experimental configurations.

The step heights typically vary between 0.28 cm and 0.32 cm, except for the 1/32-CAP and 3/32-CAP part types which have a bottom step height of 0.33 cm and 0.36 cm, respectively. This 0.04 cm range is larger than the uncertainties which vary between 0.0002 cm and 0.0060. Therefore, the interlocking step heights must be accounted to correctly calculate the reflector heights. The following figures show a diagram of the upper and lower reflector parts for each configuration, detailing the calculated step heights for each part.

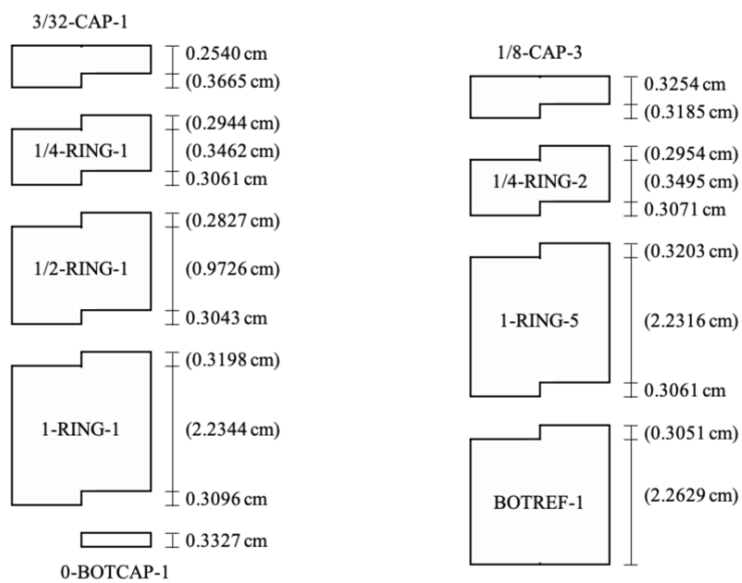


Figure 24. Case 1 ring reflector as-built height measurements; upper (left) and lower (right). Values in parenthesis are derived based on measured values reported in Section 1.2.5.

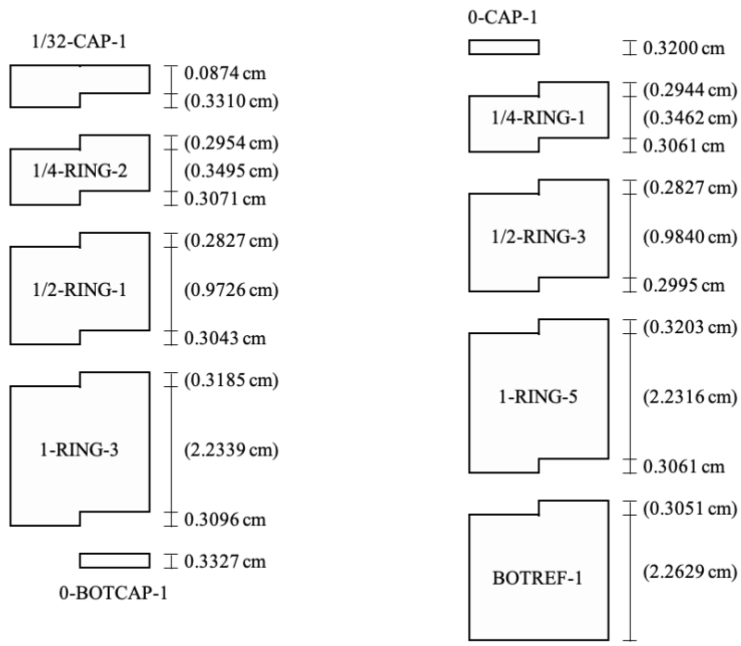


Figure 25. Case 2 ring reflector as-built height measurements; upper (left) and lower (right). Values in parenthesis are derived based on measured values reported in Section 1.2.5.

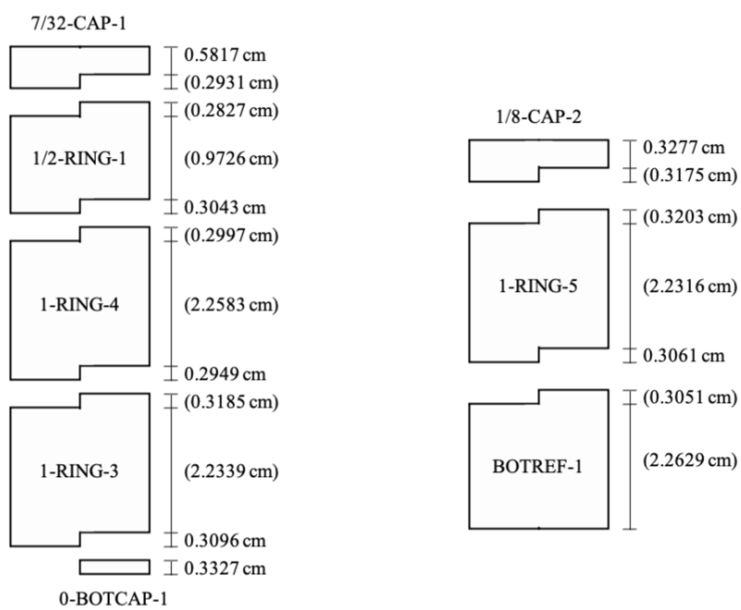


Figure 26. Case 3 ring reflector as-built height measurements; upper (left) and lower (right). Values in parenthesis are derived based on measured values reported in Section 1.2.5.

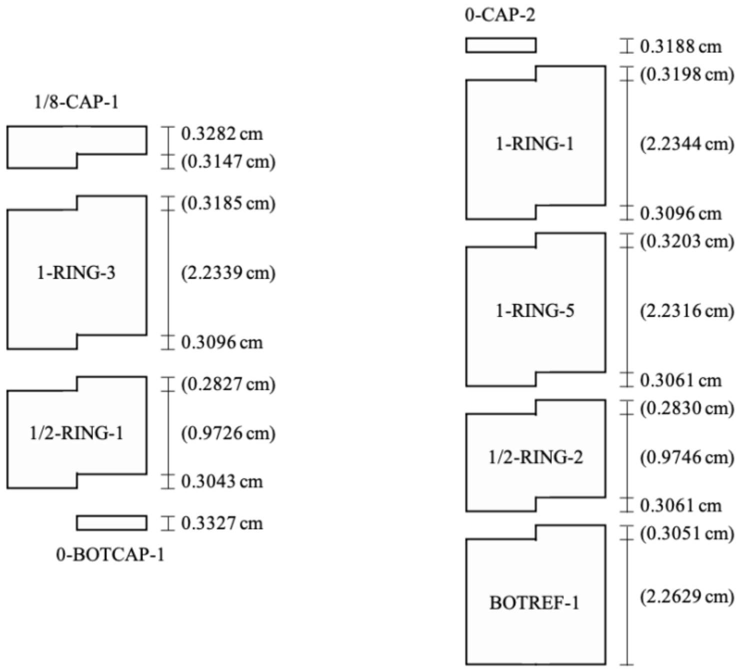


Figure 27. Case 4 ring reflector as-built height measurements; upper (left) and lower (right). Values in parenthesis are derived based on measured values reported in Section 1.2.5.

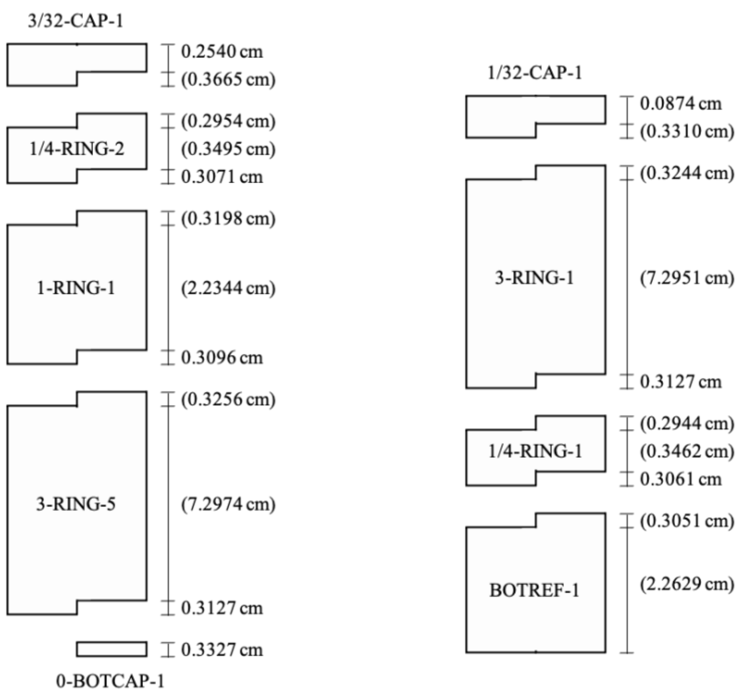


Figure 28. Case 5 ring reflector as-built height measurements; upper (left) and lower (right). Values in parenthesis are derived based on measured values reported in Section 1.2.5.

Based on these figures, Table 143 reports the calculated upper and lower reflector heights for each configuration and compares the calculated heights to the measured heights. The calculated reflector heights have an uncertainty of less than 0.04 cm, which is based on the uncertainties in each part type. The measurement uncertainties are less than 0.05 cm and 0.10 cm (except Case 1) for the upper and lower reflector heights, respectively. The lower reflector height uncertainty was larger than the upper reflector height uncertainty due to the measurements being relative to the lip of the adapter plate, described in Section 1.2.2.2. The differences between the measured and calculated upper and lower reflector heights all fall within 3σ, typically within 2σ. Therefore, there is no significant difference between the measured and calculated heights within uncertainty.

Table 143. Comparison of measured and calculated ring reflector heights.

Case	Upper Ring Reflector			Lower Ring Reflector		
	Measured Height (cm)	Calculated Height (cm)	Difference (cm)	Measured Height (cm)	Calculated Height (cm)	Difference (cm)
1	5.058 ± 0.021	5.132 ± 0.019	-0.074 ± 0.029	6.198 ± 0.138	6.114 ± 0.026	0.084 ± 0.140
2	4.848 ± 0.004	4.933 ± 0.012	-0.085 ± 0.012	6.996 ± 0.0004	7.077 ± 0.036	-0.081 ± 0.106
3	7.207 ± 0.045	7.295 ± 0.029	-0.088 ± 0.054	5.484 ± 0.067	5.449 ± 0.034	0.035 ± 0.075
4	4.436 ± 0.028	4.496 ± 0.024	-0.059 ± 0.037	8.912 ± 0.094	8.956 ± 0.038	-0.044 ± 0.101
5	11.448 ± 0.040	11.480 ± 0.026	-0.032 ± 0.048	10.907 ± 0.079	10.941 ± 0.033	-0.034 ± 0.086

The height of the lower reflector is of particular interest because the membrane will be lifted by either the lower stack or lower reflector. If the lower reflector is taller than the lower stack, there could be a gap between the top of the lower stack and the membrane. The potential for this can be seen in the photo of the lower half of Case 2 in Figure 71 of Appendix D. However, the lower reflector ring would likely compress under the weight of the membrane and upper half of the experiment if it was taller than the lower stack. Furthermore, Table 144 shows a comparison of the measured lower stack and lower reflector heights. The differences between the measured lower reflector and lower stack heights fall within 2σ, meaning there is no significant difference between the measured heights.

Table 144. Comparison of measured lower ring reflector and lower core stack heights.

Case	Reflector Height (cm)	Stack Height (cm)	Difference (cm)
1	4.951 ± 0.123	4.986 ± 0.024	0.035 ± 0.125
2	6.996 ± 0.004	7.008 ± 0.004	0.012 ± 0.006
3	4.237 ± 0.026	4.173 ± 0.027	-0.064 ± 0.037
4	7.665 ± 0.070	7.553 ± 0.070	-0.112 ± 0.099
5	9.660 ± 0.049	9.657 ± 0.051	-0.003 ± 0.071

Table 145 summarizes reflector ring height uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty is based on the standard deviation of the calculated reflector ring heights in Table 143. The calculations vary the upper and lower reflector ring heights independently by this standard deviation. Table 145 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 145. Summary of sensitivity in k_{eff} to uncertainties in the reflector ring height.

Parameter	**Case**	**Parameter Value (cm)**	**Parameter Variation in Calculation**	**Calculated Effect in k_{eff}**	**Standard Uncertainty**	**Standard Uncertainty in k_{eff}**
Upper Reflector Ring Height	1	5.075	±0.019	±0.00003	±0.019	±0.00003
	2	4.908	±0.012	±0.00003	±0.012	±0.00003
	3	7.289	±0.029	±0.00002	±0.029	±0.00002
	4	4.520	±0.024	±0.00001	±0.024	±0.00001
	5	11.481	±0.026	±0.00005	±0.026	±0.00005
Lower Reflector Ring Height	1	5.991	±0.026	±0.00036	±0.026	±0.00036
	2	7.021	±0.036	±0.00047	±0.036	±0.00047
	3	5.402	±0.034	±0.00041	±0.034	±0.00041
	4	8.944	±0.038	±0.00043	±0.038	±0.00043
	5	10.830	±0.033	±0.00024	±0.033	±0.00024

2.3.6 Core Stack Position

The core stack consists of HEU and polyethylene moderator and reflector plates with a nominal outer diameter of 15 in (38.1 cm). The stack is surrounded by polyethylene ring reflectors with a nominal inner diameter of 15.1 in (38.354 cm). Therefore, there exists a gap around the stack and reflector. During the execution of the experiment, care was taken to push the stack to one side within the reflector, described in Section 1.2.7. However, this alignment was done by hand and could have shifted during the execution of the experiment. Furthermore, any shifting of the plates in the core stacks would result in misalignment within the core stacks or between the upper and lower halves of the core stack as they were brought together on Comet.

The outer diameter of the moderator and reflector plates reported Table 7 are between 14.975 in (38.0365 cm) and 15.000 in (38.1 cm). The inner diameter measurements of the reflector rings reported in Table 8 show the actual inner diameters were between 15.050 in (38.227 cm) and 15.095 in (38.3413 cm). The outer diameter of the HEU plates were not measured so the nominal outer diameter of 15 in (38.1 cm) must be assumed. Therefore, the uncertainty in the core stack position is an offset of ±0.025 in (0.0635 cm) from the axial center of the reflector rings. This uncertainty represents the upper and lower bounds of a tolerance interval where the core stack could shift within the reflector rings.

Table 146 summarizes the core stack position uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty assumes a uniform distribution within the tolerance interval. Therefore, the standard uncertainty in the core stack position is ±0.0635/√12 cm. The calculations vary the core stack position by offsetting the core stack by ±0.0635 cm from the axial center of the reflector rings, representing the upper and lower bounds of the tolerance interval. Both the upper and lower core stacks are shifted together but in opposite directions, representing the worst-case misalignment. Table 146 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 146. Summary of sensitivity in k_{eff} to uncertainty in the core stack position.

Case	Parameter Value (cm)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	0	±0.0635	±0.00001	±0.0635/√12	±0.00000
2			±0.00006		±0.00002
3			±0.00001		±0.00000
4			±0.00004		±0.00001
5			±0.00002		±0.00001

2.3.7 Aluminum Insert Position

The aluminum inserts were placed in the annuli of the HEU2, HEU4, and HEU5 plates. These aluminum inserts have an outer diameter roughly 0.1 in (0.254 cm) smaller than the inner diameter of their respective HEU annuli. During the execution of the experiment, care was taken to push the insert to the same side within the annuli of the HEU plates as the core stack within the reflector, described in Section 1.2.7. However, this alignment was done by hand and could have shifted during the execution of the experiment.

Therefore, the uncertainty in the aluminum insert position is an offset of ±0.05 in (0.127 cm) from the axial center of the core stack. This uncertainty represents the upper and lower bounds of a tolerance interval where the aluminum inserts could shift within the annuli of the HEU plates.

Table 147 summarizes the aluminum insert position uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty assumes a uniform distribution within the tolerance interval. Therefore, the standard uncertainty in the aluminum insert position is ±0.127/√12 cm. The calculations vary the aluminum insert position by offsetting the inserts by ±0.127 cm from the axial center of the core stacks, representing the upper and lower bounds of the tolerance interval. All inserts are collectively shifted in the same direction. Table 147 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 147. Summary of sensitivity in k_{eff} to uncertainties in the aluminum insert position.

Case	Parameter Value (cm)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	0	±0.127	±0.00001	±0.127/√12	±0.00000
2			±0.00001		±0.00000
3			±0.00004		±0.00000
4[(a)]			-		-
5			±0.00001		±0.00000

(a) There are no aluminum inserts in the Case 4 experimental configuration.

2.3.8 Membrane Thickness

The membrane dimensions are reported in Section 1.2.2.1. These dimensions are based on the engineering drawing in Figure 68 of Appendix C, no verification measurements were performed. This drawing reports a thickness tolerance of ±0.010 in (±0.0254 cm). The same membrane is used for all experimental configurations.

Table 156 summarizes the membrane thickness uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty assumes a uniform distribution within the tolerance interval. Therefore, the evaluated uncertainty in the membrane thickness is ±0.010/√12 in (±0.0254/√12 cm). The calculations vary the membrane thickness by perturbing the thickness by ±0.0254 cm, representing the upper and lower bounds of the tolerance. This perturbation in the thickness has a corresponding perturbation in the length and width of the membrane to maintain a constant mass. Table 156 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 148. Summary of sensitivity in k_{eff} to uncertainty in the membrane thickness.

Case	Parameter Value (cm)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	0.3175	±0.0254	±0.00063	±0.0254/√12	±0.00018
2			±0.00043		±0.00012
3			±0.00048		±0.00014
4			±0.00033		±0.00009
5			±0.00053		±0.00015

2.3.9 Membrane Lift

The membrane lift measurements are reported in Table 2. Typically, the lift was estimated to be 0.200 in (0.508 cm). These measurements are estimated based on when the load sensor on the lower movable platen stops registering an increasing weight. Therefore, the uncertainty is assumed to be a tolerance interval between 0.100 in (0.254 cm) and 0.300 in (0.762 cm). This interval was chosen as it represents slightly greater than the upper bound and slightly less than the lower bound of the estimated lift measurements.

Table 158 summarizes the membrane lift uncertainty calculation parameters and sensitivity in k_{eff}. The standard uncertainty assumes a uniform distribution within the tolerance interval. Therefore, the standard uncertainty in the membrane lift is ±0.100/√12 in (±0.254/√12 cm). The calculations vary the membrane lift by perturbing the lift by ±0.254 cm, representing the upper and lower bounds of the tolerance. Table 158 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 149. Summary of sensitivity in k_{eff} to uncertainty in the membrane lift.

Case	Parameter Value (cm)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	0.508	±0.254	±0.00000	±0.254/√12	±0.00000
2			±0.00002		±0.00000
3			±0.00000		±0.00000
4			±0.00004		±0.00000
5			±0.00001		±0.00000

2.4 Temperature Uncertainty

The temperature of the experimental configurations and ambient temperature of the room was measured for all cases. These temperatures are reported in Table 49. All experiments were conducted at slightly below room temperature. The measured temperature of the experimental configurations ranged from 8.2°C to 12.4°C while the ambient temperature of the room was more consistent, ranging from 11.4°C to 11.7°C. Therefore, the uncertainty in the temperature is evaluated to be ±2.0°C. This is based on the expected measurement uncertainty of the instrument and bounds the variation on all three measurement instruments, summarized in Table 150.

Table 150. Evaluated temperature measurements.

Case	RTD #1 (°C)	RTD #2 (°C)	Ambient (°C)
1	11.4	8.7	11.5
2	12.3	11.1	11.4
3	12.4	11.6	11.6
4	12.2	8.2	11.7
5	11.8	8.8	11.5
Average	**12.0 ± 0.4**	**9.7 ± 1.6**	**11.5 ± 0.1**

2.4.1 Thermal Contraction

The thermal contraction is modeled using linear contraction in each dimension to capture the overall contraction of the volume. Linear contraction is defined as

$$\frac{\Delta L}{L} = \alpha_L \Delta T \qquad \text{Eq. 4}$$

where L is a particular dimension, ΔT is the change in temperature, and αL is the linear coefficient of thermal expansion. Table 151 shows the linear expansion coefficients for uranium, polyethylene, and aluminum. The midpoints of these intervals are used for this analysis.

Table 151. Typical coefficient of linear expansion.

Material	CTE, $\alpha_L \left(\frac{\mu m}{m°C}\right)$
Uranium, U; Cast	19.0
Aluminum, Al	24.0
High Density Polyethylene, Extruded	34.2 - 200

Table 152 summarizes the thermal contraction uncertainty calculation parameters and sensitivity in k_{eff}. The calculations vary the model temperature by ±10.0°C, representing five times the evaluated uncertainty. Table 152 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 152. Summary of sensitivity in k_{eff} to uncertainties for thermal contraction.

Case	Temp. (°C)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	20	±10.0	±0.00086	±2.0	±0.00017
2			±0.00111		±0.00022
3			±0.00143		±0.00026
4			±0.00142		±0.00029
5			±0.00044		±0.00009

2.4.2 Free-Gas Thermal Treatment

The effect of Doppler Broadening in the neutron cross sections is assumed to be negligible given the ±2.0°C evaluated uncertainty in temperature. Therefore, only the free-gas thermal treatment of the model is varied to estimate the uncertainty of the neutron cross sections. This is modeled using the TMP card in MCNP®, which has a default value of 2.53×10^{-8} MeV corresponding to 20°C.

Table 153 summarizes the free-gas thermal treatment uncertainty calculation parameters and sensitivity in k_{eff}. The calculations perturb the temperature by ±10.0°C, representing five times the evaluated uncertainty. This temperature perturbation results in a TMP perturbation of $\pm 8.617 \times 10^{-7}$ MeV. Table 153 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 153. Summary of sensitivity in k_{eff} to uncertainties for free-gas thermal treatment.

Case	Temp. (°C)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	20	±10.0	±0.00010	±2.0	±0.00002
2			±0.00007		±0.00001
3			±0.00001		±0.00000
4			±0.00006		±0.00001
5			±0.00018		±0.00004

2.4.3 Thermal Scattering Law

Table 154 summarizes the S(α,β) thermal scattering law for H in CH_2 uncertainty calculation parameters and sensitivity in k_{eff}. The calculation switches a 293 K thermal scattering law for a 333 K thermal scattering law. This represents a +40.0°C one-sided perturbation. Table 154 is reproduced alongside the other evaluated uncertainties in Section 2.5.

Table 154. Summary of sensitivity in k_{eff} to uncertainties to the thermal scattering law.

Case	Temp. (°C)	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty	Standard Uncertainty in k_{eff}
1	20	+40.0	±0.00061	±2.0	±0.00003
2			±0.00070		±0.00003
3			±0.00104		±0.00005
4			±0.00211		±0.00011
5			±0.01298		±0.00065

2.5 Combined Uncertainties

Table 155 presents the total combined uncertainty for each experimental configuration. These combined uncertainties are broken down into individual parameters for mass, dimension, material, and temperature uncertainties contributors in Table 156 for Case 1, Table 157 for Case 2, Table 158 for Case 3, Table 159 for Case 4, and Table 160 for Case 5. These tables summarize the uncertainty calculations described in Sections 2.1, 2.2, 2.3, and 2.4.

Table 155. Summary of calculated uncertainties for each experimental configuration.

Case	**Standard Uncertainty in Δk_{eff}**
1	±0.00132
2	±0.00126
3	±0.00129
4	±0.00148
5	±0.00119

A total of 24 parameters were included in the uncertainty analysis: 6 for mass, 11 for dimension, 4 for material, and 3 for temperature. The dominant uncertainties for each experimental configuration are the upper and lower core stack heights (20 to 130 pcm), the lower reflector ring height (20 to 50 pcm), and ^{235}U enrichment (10 to 50 pcm). All experimental configurations have similar uncertainties except for Case 4, which is driven by the lower core stack height uncertainty.

2.5.1 Case 1

Table 156. Summary of sensitivity in k_{eff} to uncertainties for Case 1.

Parameter (unit of measure)	N	Parameter Value	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty in Parameter	Standard Uncertainty in k_{eff}
Mass Uncertainties						
HEU Mass (g)	19	109059.7	±114.0	±0.00055	±3.2√19	±0.00007
Aluminum Insert Mass (g)	14	2050.2	±42.0	±0.00017	±1.5√14	Negligible
Polyethylene Moderator Mass (g)	No polyethylene moderator plates.					-
Polyethylene Reflector Mass (g)	-	8955.0	±44.5	±0.00118	±3.6	±0.00010
Membrane Mass (g)	1	2396.1	±20.0	±0.00000	±0.3	Negligible
TEX-HEU Structure Mass (g)	7	27159.7	±10%	±0.00102	±0.3√7	Negligible
Sum in Quadrature (Mass Uncertainty)						**±0.00012**
Dimensional Uncertainties						
HEU Plate Diameter (cm)	-	Varies (Table 125)	±0.00635	±0.00018	±0.00635/√12	±0.00005
Aluminum Insert Diameter (cm)	-	Varies (Table 127)	±0.01	±0.00000	±0.01	Negligible
Polyethylene Plate Diameter (cm)	-	Varies (Table 129)	±0.02	±0.00067	±0.005	±0.00017
Upper Core Stack Height (cm)	-	5.075	±0.044	±0.00061	±0.044	±0.00061
Lower Core Stack Height (cm)	-	5.991	±0.051	±0.00097	±0.051	±0.00097
Upper Ring Reflector Height (cm)	-	5.075	±0.019	±0.00003	±0.019	±0.00003
Lower Ring Reflector Height (cm)	-	5.991	±0.026	±0.00036	±0.026	±0.00036
Core Stack Position (cm)	-	0	±0.0635	±0.00001	±0.0635/√12	Negligible
Aluminum Insert Position (cm)	-	0	±0.127	±0.00001	±0.127/√12	Negligible
Membrane Thickness (cm)	-	0.3175	±0.0254	±0.00063	±0.0254/√12	±0.00018
Membrane Lift (cm)	-	0.508	±0.254	±0.00000	±0.254/√12	Negligible
Sum in Quadrature (Dimensional Uncertainty)						**±0.00123**

Parameter (unit of measure)	**N**	**Parameter Value**	**Parameter Variation in Calculation**	**Calculated Effect in k_{eff}**	**Standard Uncertainty in Parameter**	**Standard Uncertainty in k_{eff}**
Composition Uncertainties						
^{235}U Enrichment (Wt.%)	-	93.232	±0.392	±0.00339	±0.10	±0.00043
HEU Impurities (Wt.%)	-	Varies (Table 68)	-	±0.00001	Varies (Table 68)	Negligible
Polyethylene Impurities (Wt.%)	-	Varies (Table 81)	-	±0.00000	Varies (Table 81)	Negligible
Aluminum Impurities (Wt.%)	-	Varies (Table 94)	-	±0.00003	Varies (Table 94)	Negligible
					Sum in Quadrature (Composition Uncertainty)	**±0.00043**
Temperature Uncertainty						
Thermal Contraction (°C)	-	20	±10.0	±0.00086	±2.0	±0.00017
Free-Gas Thermal Treatment (°C)	-	20	±10.0	±0.00010	±2.0	Negligible
Thermal Scattering Law (°C)	-	20	+40.0	+0.00061	±2.0	±0.00003
					Sum in Quadrature (Temperature Uncertainty)	**±0.00018**
					Sum of Quadrature (Total Uncertainty)	**±0.00132**

2.5.2 Case 2

Table 157. Summary of sensitivity in k_{eff} to uncertainties for Case 2.

Parameter (unit of measure)	N	Parameter Value	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty in Parameter	Standard Uncertainty in k_{eff}
Mass Uncertainties						
HEU Mass (g)	11	69986.9	±66.0	±0.00031	±3.2√11	±0.00005
Aluminum Insert Mass (g)	7	173.8	±21.0	±0.00000	±1.5√7	Negligible
Polyethylene Moderator Mass (g)	10	3438.2	±10.0	±0.00058	±1.0√10	0.00018
Polyethylene Reflector Mass (g)	-	9464.1	±18.0	±0.00025	±1.3	Negligible
Membrane Mass (g)	1	2396.1	±20.0	±0.00004	±0.3	Negligible
TEX-HEU Structure Mass (g)	7	27159.7	±10%	±0.00083	±0.3√7	Negligible
Sum in Quadrature (Mass Uncertainty)						**±0.00019**
Dimensional Uncertainties						
HEU Plate Diameter (cm)	-	Varies (Table 125)	±0.00635	±0.00010	±0.00635/√12	±0.00003
Aluminum Insert Diameter (cm)	-	Varies (Table 127)	±0.01	±0.00002	±0.01	Negligible
Polyethylene Plate Diameter (cm)	-	Varies (Table 129)	±0.02	±0.00023	±0.005	±0.00006
Upper Core Stack Height (cm)	-	4.908	±0.030	±0.00053	±0.030	±0.00053
Lower Core Stack Height (cm)	-	7.021	±0.047	±0.00094	±0.047	±0.00094
Upper Ring Reflector Height (cm)	-	4.908	±0.012	±0.00003	±0.012	±0.00003
Lower Ring Reflector Height (cm)	-	7.021	±0.036	±0.00047	±0.036	±0.00047
Core Stack Position (cm)	-	0	±0.0635	±0.00006	±0.0635/√12	Negligible
Aluminum Insert Position (cm)	-	0	±0.127	±0.00001	±0.127/√12	Negligible
Membrane Thickness (cm)	-	0.3175	±0.0254	±0.00043	±0.0254/√12	±0.00012
Membrane Lift (cm)	-	0.508	±0.254	±0.00002	±0.254/√12	Negligible
Sum in Quadrature (Dimensional Uncertainty)						**±0.00119**

Parameter (unit of measure)	N	Parameter Value	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty in Parameter	Standard Uncertainty in k_{eff}
Composition Uncertainties						
^{235}U Enrichment (Wt.%)	-	93.232	±0.392	±0.00248	±0.10	±0.00032
HEU Impurities (Wt.%)	-	Varies (Table 68)	-	±0.00001	Varies (Table 68)	Negligible
Polyethylene Impurities (Wt.%)	-	Varies (Table 81)	-	±0.00000	Varies (Table 81)	Negligible
Aluminum Impurities (Wt.%)	-	Varies (Table 94)	-	±0.00004	Varies (Table 94)	Negligible
Sum in Quadrature (Composition Uncertainty)						**±0.00032**
Temperature Uncertainty						
Thermal Contraction (°C)	-	20	±10.0	±0.00111	±2.0	±0.00022
Free-Gas Thermal Treatment (°C)	-	20	±10.0	±0.00007	±2.0	Negligible
Thermal Scattering Law (°C)	-	20	+40.0	+0.00070	±2.0	±0.00003
Sum in Quadrature (Temperature Uncertainty)						**±0.00023**
Sum of Quadrature (Total Uncertainty)						**±0.00126**

2.5.3 Case 3

Table 158. Summary of sensitivity in k_{eff} to uncertainties for Case 3.

Parameter (unit of measure)	N	Parameter Value	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty in Parameter	Standard Uncertainty in k_{eff}
Mass Uncertainties						
HEU Mass (g)	8	51007.8	±48.0	±0.00021	±3.2√8	±0.00004
Aluminum Insert Mass (g)	5	123.9	±15.0	±0.00000	±1.5√5	Negligible
Polyethylene Moderator Mass (g)	7	4821.6	±5.6	±0.00035	±0.8√7	±0.00013
Polyethylene Reflector Mass (g)	-	10152.9	±22.5	±0.00046	±1.6	±0.00003
Membrane Mass (g)	1	2396.1	±20.0	±0.00001	±0.3	Negligible
TEX-HEU Structure Mass (g)	7	27159.7	±10%	±0.00079	±0.3√7	Negligible
					Sum in Quadrature (Mass Uncertainty)	**±0.00014**
Dimensional Uncertainties						
HEU Plate Diameter (cm)	-	Varies (Table 125)	±0.00635	±0.00018	±0.00635/√12	±0.00005
Aluminum Insert Diameter (cm)	-	Varies (Table 127)	±0.01	±0.00004	±0.01	±0.00004
Polyethylene Plate Diameter (cm)	-	Varies (Table 129)	±0.02	±0.00027	±0.005	±0.00007
Upper Core Stack Height (cm)	-	7.289	±0.049	±0.00099	±0.049	±0.00099
Lower Core Stack Height (cm)	-	5.402	±0.042	±0.00059	±0.042	±0.00059
Upper Ring Reflector Height (cm)	-	7.289	±0.029	±0.00002	±0.029	Negligible
Lower Ring Reflector Height (cm)	-	5.402	±0.034	±0.00041	±0.034	±0.00041
Core Stack Position (cm)	-	0	±0.0635	±0.00001	±0.0635/√12	Negligible
Aluminum Insert Position (cm)	-	0	±0.127	±0.00004	±0.127/√12	Negligible
Membrane Thickness (cm)	-	0.3175	±0.0254	±0.00048	±0.0254/√12	±0.00014
Membrane Lift (cm)	-	0.508	±0.254	±0.00000	±0.254/√12	Negligible
					Sum in Quadrature (Dimensional Uncertainty)	**±0.00123**

Parameter (unit of measure)	N	Parameter Value	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty in Parameter	Standard Uncertainty in k_{eff}
Composition Uncertainties						
^{235}U Enrichment (Wt.%)	-	93.232	±0.392	±0.00184	±0.10	±0.00023
HEU Impurities (Wt.%)	-	Varies (Table 68)	-	±0.00001	Varies (Table 68)	Negligible
Polyethylene Impurities (Wt.%)	-	Varies (Table 81)	-	±0.00000	Varies (Table 81)	Negligible
Aluminum Impurities (Wt.%)	-	Varies (Table 94)	-	±0.00004	Varies (Table 94)	±0.00004
Sum in Quadrature (Composition Uncertainty)						**±0.00024**
Temperature Uncertainty						
Thermal Contraction (°C)	-	20	±10.0	±0.00143	±2.0	±0.00026
Free-Gas Thermal Treatment (°C)	-	20	±10.0	±0.00001	±2.0	Negligible
Thermal Scattering Law (°C)	-	20	+40.0	+0.00104	±2.0	±0.00005
Sum in Quadrature (Temperature Uncertainty)						**±0.00026**
Sum of Quadrature (Total Uncertainty)						**±0.00129**

2.5.4 Case 4

Table 159. Summary of sensitivity in k_{eff} to uncertainties for Case 4.

Parameter (unit of measure)	N	Parameter Value	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty in Parameter	Standard Uncertainty in k_{eff}
Mass Uncertainties						
HEU Mass (g)	5	32282.8	±30.0	±0.00013	±3.2√5	±0.00003
Aluminum Insert Mass (g)	No aluminum inserts.					-
Polyethylene Moderator Mass (g)	4	5518.8	±14.0	±0.00091	±3.5√4	±0.00045
Polyethylene Reflector Mass (g)	-	11569.8	±39.0	±0.00066	±3.4	±0.00006
Membrane Mass (g)	1	2396.1	±20.0	±0.00001	±0.3	Negligible
TEX-HEU Structure Mass (g)	7	27159.7	±10%	±0.00082	±0.3√7	Negligible
					Sum in Quadrature (Mass Uncertainty)	**±0.00046**
Dimensional Uncertainties						
HEU Plate Diameter (cm)	-	Varies (Table 125)	±0.00635	±0.00018	±0.00635/√12	±0.00005
Aluminum Insert Diameter (cm)	No aluminum inserts.					-
Polyethylene Plate Diameter (cm)	-	Varies (Table 129)	±0.02	±0.00041	±0.005	±0.00010
Upper Core Stack Height (cm)	-	4.520	±0.017	±0.00016	±0.017	±0.00016
Lower Core Stack Height (cm)	-	8.944	±0.065	±0.00127	±0.065	±0.00127
Upper Ring Reflector Height (cm)	-	4.520	±0.024	±0.00001	±0.024	Negligible
Lower Ring Reflector Height (cm)	-	8.944	±0.038	±0.00043	±0.038	±0.00043
Core Stack Position (cm)	-	0	±0.0635	±0.00004	±0.0635/√12	Negligible
Aluminum Insert Position (cm)	No aluminum inserts.					-
Membrane Thickness (cm)	-	0.3175	±0.0254	±0.00033	±0.0254/√12	±0.00009
Membrane Lift (cm)	-	0.508	±0.254	±0.00004	±0.254/√12	Negligible
					Sum in Quadrature (Dimensional Uncertainty)	**±0.00136**

Parameter (unit of measure)	N	Parameter Value	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty in Parameter	Standard Uncertainty in k_{eff}
Composition Uncertainties						
^{235}U Enrichment (Wt.%)	-	93.232	±0.392	±0.00144	±0.10	±0.00018
HEU Impurities (Wt.%)	-	Varies (Table 68)	-	±0.00001	Varies (Table 68)	Negligible
Polyethylene Impurities (Wt.%)	-	Varies (Table 81)	-	±0.00000	Varies (Table 81)	Negligible
Aluminum Impurities (Wt.%)	-	Varies (Table 94)	-	±0.00001	Varies (Table 94)	Negligible
Sum in Quadrature (Composition Uncertainty)						**±0.00018**
Temperature Uncertainty						
Thermal Contraction (°C)	-	20	±10.0	±0.00144	±2.0	±0.00029
Free-Gas Thermal Treatment (°C)	-	20	±10.0	±0.00006	±2.0	Negligible
Thermal Scattering Law (°C)	-	20	+40.0	+0.00211	±2.0	±0.00011
Sum in Quadrature (Temperature Uncertainty)						**±0.00031**
Sum of Quadrature (Total Uncertainty)						**±0.00148**

2.5.5 Case 5

Table 160. Summary of sensitivity in k_{eff} to uncertainties for Case 5.

Parameter (unit of measure)	N	Parameter Value	Parameter Variation in Calculation	Calculated Effect in k_{eff}	Standard Uncertainty in Parameter	Standard Uncertainty in k_{eff}
Mass Uncertainties						
HEU Mass (g)	5	29529.4	±30.0	±0.00012	±3.2√5	±0.00003
Aluminum Insert Mass (g)	3	450.7	±9.0	±0.00002	±1.5√3	Negligible
Polyethylene Moderator Mass (g)	4	16545.2	±42.4	±0.00013	±10.6√4	±0.00007
Polyethylene Reflector Mass (g)	-	12879.0	±19.5	±0.00018	±1.5	Negligible
Membrane Mass (g)	1	2396.1	±20.0	±0.00004	±0.3	Negligible
TEX-HEU Structure Mass (g)	7	27159.7	±10%	±0.00035	±0.3√7	Negligible
					Sum in Quadrature (Mass Uncertainty)	**±0.00007**
Dimensional Uncertainties						
HEU Plate Diameter (cm)	-	Varies (Table 125)	±0.00635	±0.00014	±0.00635/√12	Negligible
Aluminum Insert Diameter (cm)	-	Varies (Table 127)	±0.01	±0.00004	±0.01	±0.00004
Polyethylene Plate Diameter (cm)	-	Varies (Table 129)	±0.02	±0.00004	±0.015	±0.00003
Upper Core Stack Height (cm)	-	11.481	±0.047	±0.00067	±0.047	±0.00067
Lower Core Stack Height (cm)	-	10.830	±0.058	±0.00066	±0.058	±0.00066
Upper Ring Reflector Height (cm)		11.481	±0.026	±0.00005	±0.026	±0.00005
Lower Ring Reflector Height (cm)		10.830	±0.033	±0.00024	±0.033	±0.00024
Core Stack Position (cm)	-	0	±0.0635	±0.00002	±0.0635/√12	Negligible
Aluminum Insert Position (cm)	-	0	±0.127	±0.00001	±0.127/√12	Negligible
Membrane Thickness (cm)	-	0.3175	±0.0254	±0.00053	±0.0254/√12	±0.00015
Membrane Lift (cm)	-	0.508	±0.254	±0.00001	±0.254/√12	Negligible
					Sum in Quadrature (Dimensional Uncertainty)	**±0.00098**

Parameter (unit of measure)	**N**	**Parameter Value**	**Parameter Variation in Calculation**	**Calculated Effect in k_{eff}**	**Standard Uncertainty in Parameter**	**Standard Uncertainty in k_{eff}**
Composition Uncertainties						
^{235}U Enrichment (Wt.%)	-	93.232	±0.392	±0.00089	±0.10	±0.00011
HEU Impurities (Wt.%)	-	Varies (Table 68)	-	±0.00000	Varies (Table 68)	Negligible
Polyethylene Impurities (Wt.%)	-	Varies (Table 81)	-	±0.00000	Varies (Table 81)	Negligible
Aluminum Impurities (Wt.%)	-	Varies (Table 94)	-	±0.00005	Varies (Table 94)	±0.00005
Sum in Quadrature (Composition Uncertainty)						**±0.00012**
Temperature Uncertainty						
Thermal Contraction (°C)	-	20	±10.0	±0.00044	±2.0	±0.00009
Free-Gas Thermal Treatment (°C)	-	20	±10.0	±0.00018	±2.0	Negligible
Thermal Scattering Law (°C)	-	20	+40.0	+0.01298	±2.0	±0.00065
Sum in Quadrature (Temperature Uncertainty)						**±0.00066**
Sum of Quadrature (Total Uncertainty)						**±0.00119**

2.6 Determination of Experimental k_{eff}

The measured reactor period was converted into reactivity using the Inhour equation.

The ENDF/B VIII.0 recommended six-group delayed neutron abundances and decay constants were used and are reproduced in Table 161[3]. The associated standard deviations included in Table 161 are based on experimental measurements[4].

Table 161. ENDF/B-VIII.0 six-group ^{235}U delayed neutron abundances and decay constants[(a)].

Group	Abundance, a_i	λ_i (s^{-1})
1	0.035 ± 0.004	0.0133 ± 0.0003
2	0.173 ± 0.024	0.1208 ± 0.0040
3	0.387 ± 0.010	0.3028 ± 0.0120
4	0.159 ± 0.012	0.8495 ± 0.1200
5	0.066 ± 0.004	2.8530 ± 0.5500

(a) The delayed neutron abundances and decay constants originate from ENDF/B-VI.

The iterated fission probability method, as implemented in the KOPTS card functionality of MCNP® 6.2.0, was employed to calculate the delayed neutron fraction, β_{eff}, and the mean generation time, Λ. The results from the calculation for each case is shown in Table 162.

Table 162. Calculated delayed neutron parameters.

Case	β_{eff}	Λ (s)
1	0.00700 ± 0.00004	(1.68427 ± 0.00460)×10^{-6}
2	0.00764 ± 0.00004	(2.22555 ± 0.00522)×10^{-6}
3	0.00789 ± 0.00004	(3.34830 ± 0.00618)×10^{-6}
4	0.00805 ± 0.00004	(6.45511 ± 0.00870)×10^{-6}
5	0.00760 ± 0.00004	(28.7323 ± 0.02117)×10^{-6}

The calculated β_{eff} for each case was multiplied by the group abundances given in Table 161 to give the six $\beta_{eff,i}$ constants required for the summation portion of the Inhour equation:

$$\rho = \frac{\Lambda}{T\beta_{\text{eff}}} + \sum_{i=1}^{6} \frac{\beta_{\text{eff},i}}{(1+\lambda_i T)\beta_{\text{eff}}}$$

[3] D. A. Brown, et. al., "ENDF/B-VIII.0: The 8th Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Sections, New Standards and Thermal Scattering Data," *Nuclear Data Sheets*, vol. 148, pp. 1-142, 2018.

[4] R. J. Tuttle, "Delayed-Neutron Data for Reactor-Physics Analysis," *Nuclear Science and Engineering,* vol. 56, pp. 37-71, 1975.

Table 163 gives the measured period in seconds from an exponential fit to the neutron population data collected from three separate detectors during the experiment. The standard deviation in the period was calculated from the three detector measurements. The calculated reactivity in dollars and the experimental k_{eff} are averaged over all detectors and include uncertainty propagation from the delayed neutron group parameters and the calculated β_{eff} and Λ. The k_{eff} is calculated through the following equation:

$$\rho = \frac{k_{\mathrm{eff}} - 1}{k_{\mathrm{eff}} \cdot \beta_{\mathrm{eff}}}$$

Table 163. Calculated reactivity and k_{eff}.

Case	**Measured Period, s**	**Reactivity, ρ ($)**	**Calculated k_{eff}**
1	268.80, 265.73, 272.77	0.037 ± 0.002	1.00026 ± 0.00001
2	188.21, 188.64, 187.40	0.050 ± 0.002	1.00038 ± 0.00002
3	100.62, 100.45, 100.02	0.085 ± 0.003	1.00067 ± 0.00003
4	51.19, 51.77, 51.36	0.139 ± 0.005	1.00112 ± 0.00004
5	61.43, 60.45, 61.27	0.123 ± 0.005	1.00094 ± 0.00004

3.0 BENCHMARK SPECIFICATIONS

3.1 Description of Model

The benchmark models include the experimental configurations and simplified models of the TEX-HEU and Comet structure. The experimental configurations consist of the upper and lower core stacks and reflector rings. The core stacks are made up of the HEU plates, aluminum inserts, polyethylene moderator and reflector plates, and a bottom reflector. The reflector rings are made up of the polyethylene reflector rings and caps. The TEX-HEU structure includes the interface plate, adapter plate, and adapter extension. The lower half of the experimental configuration, specifically the bottom reflector, sits in the adapter plate while the upper half of the experimental configuration sits on the membrane. The upper and lower halves of the experimental configuration are separated by the membrane, which is lifted slightly off the interface plate. The Comet structure includes the stationary platform and the movable platen. The adapter extension connects the adapter plate to the movable platen. The four standoffs connect the interface plate to the stationary platform, but the standoffs are not included in the models.

Two benchmark models are presented for each experimental configuration, a detailed and a simplified model. The detailed model represents each part in the core stack by its individually measured dimensions, as reported in Section 1.2. The simplified model represents each part in the core stack averaged across similar parts in the experimental configuration. This averaged part representation simplifies the geometry and allows for regular units (typically defined by an HEU plate, polyethylene moderator plate, and aluminum insert, if present) that are uniform and repeatable.

3.1.1 Model Simplifications and Bias

3.1.1.1 HEU Impurity Removal

As described in Section 2.2.2, the HEU impurities were measured to be less than 2000 ppm. This includes 19 different elemental impurities. The most prevalent of these are C, Si, Al, and Fe, making up just over 90% of the impurity content. In the benchmark models, the HEU impurities were modeled as void by reducing the HEU part densities. The bias resulting from this simplification is reported in Table 172.

3.1.1.2 Polyethylene Impurity Removal

As described in Section 2.2.3, the polyethylene impurities were measured to be roughly 0.12 wt.%. These impurities include Na, Al, Si, and Cr, none of which are significant neutron absorbers. In the benchmark models, the polyethylene impurities were modeled as void by reducing the polyethylene part densities. The bias resulting from this simplification is reported in Table 172.

3.1.1.3 Reflector Rings and Bottom Reflector

For the interlocking reflector rings, caps, and bottom reflector, the step joints have been removed and the parts are combined into a single volume. An illustration of this simplification is shown in Figure 29. The upper and lower reflectors are modeled as shown in Figure 45; the dimensions are given in each model description.

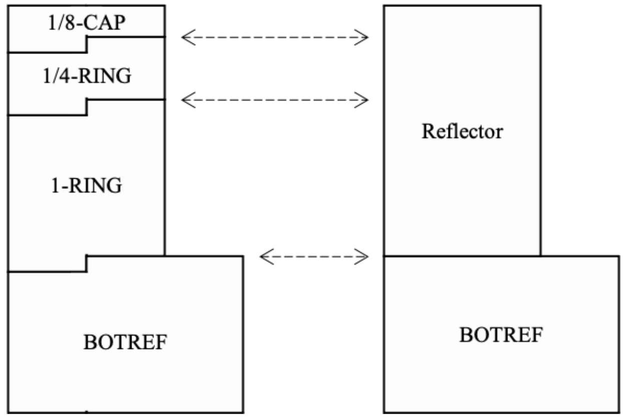
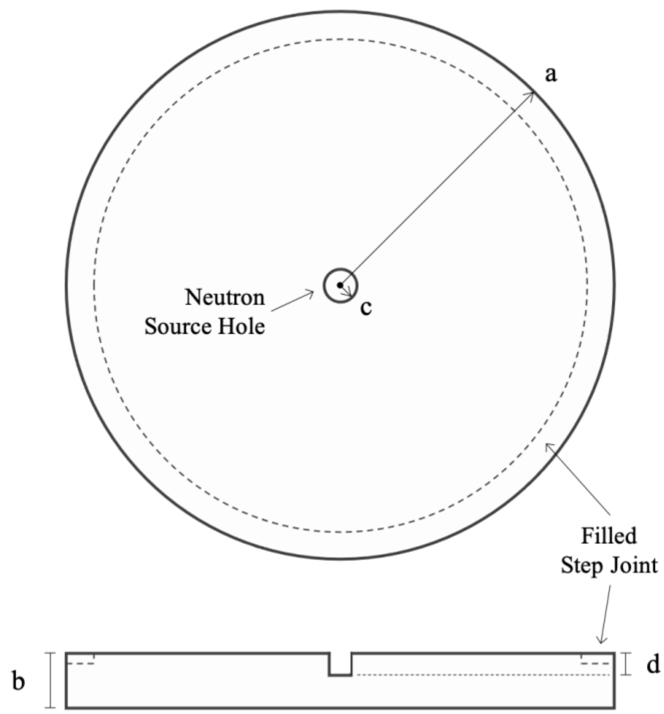


Figure 29. Example reflector simplification, showing the lower reflector rings and bottom reflector. The left shows the actual ring reflectors including the mating joints while the right shows the simplified model which removes the mating joints while maintaining the height.



Part ID	Radius, a (cm)	Thickness, b (cm)	Source Hole Radius, c (cm)	Source Hole Depth, d (cm)
BOTREF-1	21.68665	2.56794	0.35687	1.25959

Figure 30. Bottom reflector model dimensions (figure not to scale).

The model of BOTREF-1 was adjusted by filling in the outer step, which is the cylinder ring on the edge of BOTREF-1 that was machined to form the female end of a step joint for the RING or CAP parts. The dimensions of this step are reported in Table 10 and shown in Figure 11. In this figure, the outer diameter of the step is *a* (the same dimension as the overall outer diameter of BOTREF-1), the inner diameter is *b*, and the thickness is the difference between *c* and *d*.

Table 164 reports the actual and adjusted characteristics of BOTREF-1 including mass, volumes, and density. The characteristics are calculated based on Table 10 and Figure 11. The adjusted volume of BOTREF-1 is calculated by adding the step volume to the actual volume, effectively filling in the step. Doing so requires an additional 49.4 grams of mass to BOTREF-1 to conserve the density of the part. This added mass was then removed from the lower ring reflectors for each experimental configuration to conserve the overall mass and distribution of mass in the lower reflector, as described in Section 3.2.5.

Table 164. Model adjustment for mass and volume of BOTREF-1.

BOTREF-1				Adjusted BOTREF-1		
Mass (g)	**Volume (cm^3)**	**Step Volume (cm^3)**	**Density (g/cm^3)**	**Mass (g)**	**Volume (cm^3)**	**Density (g/cm^3)**
3543.2	3741.51	52.18	0.94700	3592.6	3793.69	0.94700

3.1.1.4 Comet and Room Return (Removal)

These experiments were performed on the Comet General Purpose Critical Assembly Machine at NCERC[5]. In addition to the room itself, the Comet General Purpose Critical Assembly Machine was added. Other components in the room, such as Godiva-IV and the four startup detectors, were not included as they provide negligible contributions to the calculated k_{eff}.

The room is filled with air (75.5% nitrogen, 23.2% oxygen, and 1.3% argon, by weight) modeled with a density of 0.001225 g/cm^3. The concrete walls are modeled as Portland Concrete with a density of 2.3 g/cm^3. The Comet components, separate of those already included in the experiment configuration model, are Stainless Steel 304 modeled with a density of 7.8 g/cm^3.

In the benchmark models, the Comet General Purpose Critical Assembly Machine and room are removed. The bias resulting from this simplification is reported in Table 172.

[5] S. Kim, "12-Rad Zone Analysis for CAAS Placement at the Device Assembly Facility." Lawrence Livermore National Laboratory, CSM 1532 (2008).

Table 165. Composition of Portland Concrete[6].

Element	Wt.%
H	1.0000
C	0.1000
O	52.9107
Na	1.6000
Mg	0.2000
Al	3.3872
Si	33.7021
K	1.3000
Ca	4.4000
Fe	1.4000

Table 166. Calculated bias in k_{eff} from Comet and the room, including air.

Case	Δk_{eff}	
	Comet Alone	**Comet & Room**
1	0.00129 ± 0.00006	0.00214 ± 0.00009
2	0.00158 ± 0.00007	0.00229 ± 0.00008
3	0.00153 ± 0.00006	0.00204 ± 0.00008
4	0.00143 ± 0.00007	0.00203 ± 0.00008
5	0.00104 ± 0.00006	0.00159 ± 0.00008

[6] R. McConn Jr. et al., "Compendium of Material Composition Data for Radiation Transport Modeling," Revision 1. Pacific Northwestern National Laboratory, PNNL-15870 Rev. 1 (2011).

3.1.1.5 Comet Structural Component Simplifications

The components of Comet described in Section 1.2.2 have many features required for the engineered fixturing and design. These features include counterbore holes, through-holes, screw taps, and fillets. While these features are important to the physical design of the experiment, they are of little to no importance to the neutronics modeling. Table 167 summarizes these removed features for each component.

Table 167. Features removed from Comet structural components.

Component	Removed Feature
Interface Plate	4 x 0.249” through-holes
	8 x 1/4-20 UNC through-holes
	4 x 0.500” counterbore holes
Membrane	4 x 0.284” through-holes
Adapter Plate	8 x 1/4-20 UNC taps
	3 x 7/16-14 UNC through-holes
	16 x 0.5” fillets
Adapter Extension	3 x 0.515” through-holes
	3 x 7/16-14 UNC through-holes
Stationary Platform	12 x 0.397” through-holes
	8 x 0.562” through-holes
	4 x 0.531” through-holes

3.1.1.6 Temperature Correction

As described in Section 0, the measured temperatures of the experimental configurations during operation were lower than the standard model temperature of 20°C. To simplify the model, these temperatures are corrected to 20°C. Detailed models of these configurations at the experiment temperature of 12°C are described and included in Appendix B.

Table 168 reports the calculated k_{eff} of the experimental configurations at model temperatures of 293.6 K, 300 K, 303 K, 313 K, 323 K, and 333 K. As described in Section 2.4, these models account for thermal contraction of the materials, free-gas thermal treatment for low-energy neutron transport, and thermal scattering of H in CH_2. Table 169 reports the slope of a linear least-squares fit of the values in Table 168.

Table 168. Calculated k_{eff} for the experimental configurations at various temperatures. The statistical uncertainty of the calculations is 0.00005.

Case	Model Temperature (K)					
	293.6[(a)]	300	303	313	323	333
1	0.99540	0.99491	0.99464	0.99373	0.99288	0.99205
2	0.99473	0.99392	0.99363	0.99246	0.99130	0.99018
3	0.99438	0.99365	0.99334	0.99217	0.99094	0.98965
4	0.99477	0.99427	0.99400	0.99283	0.99175	0.99068
5	0.99716	0.99906	0.99990	1.00277	1.00531	1.00779

(a) Default temperature used by MCNP® 6.2.0 with ENDF/B-VIII.0 cross sections.

Table 169. Linear least-squares fit slope and coefficient of determination.

Case	Slope (k_{eff}/°C)	R^2
1	-8.66275E-05	0.99971
2	-1.15814E-04	0.99949
3	-1.20624E-04	0.99945
4	-1.07089E-04	0.99835
5	2.71302E-04	0.99822

Table 170 reports the temperature correction bias using the linear least-squares fit reported in Table 169. The experiment temperature of the configurations is based on RTD #1, reported in Table 150.

Table 170. Calculated bias in k_{eff} from the temperature correction to 20°C.

Case	Experiment Temperature (°C)	Model Temperature (°C)	Temperature Difference (°C)	Temperature Correction Bias
1	11.4	20.0	8.6	-0.00074
2	12.3		7.7	-0.00089
3	12.4		7.6	-0.00092
4	12.2		7.8	-0.00084
5	11.8		8.2	0.00222

3.1.1.7 Average Core Stacks

Each experimental configuration consists of upper and lower core stacks of HEU plates, aluminum inserts, and polyethylene moderator and reflector plates. The thickness of each of these parts was measured individually and reported in Section 1.2. The detailed models represent each of these parts using the measured thicknesses. The simplified model represents each part as an average of the other parts of the same type in each experimental configuration.

The top reflector plates are combined to create a single top reflector plate, conserving the overall mass and thickness of the individual plates with a mass-weighted average outer diameter. The moderator plates are represented by an averaged moderator plate based on the moderator plates in each experimental configuration. The HEU plates are then set to an average thickness to conserve the total core stack height (upper core stack plus lower core stack). Since the detailed model already uses nominal outer and inner diameters for the HEU plates, no changes are made to those dimensions. Finally, the aluminum inserts are set to the same average thickness that was calculated for the HEU plates. The outer diameter is averaged based on insert of the same type across the experimental configuration. The mass of all parts is conserved by increasing or decreasing the density of the part based on the averaged dimensions.

These averaged part dimensions are reported in the simplified model sections for each experimental configuration. An average density for each part type is computed to conserve the total mass of the parts in each experimental configuration. Table 171 compares the upper and lower core stack heights for the detailed and simplified models with the measured stack heights evaluated in Section 2.3.4. The bias resulting from this simplification is reported in Table 173.

Table 171. Comparison of detailed and simplified model core stack heights versus measured heights. The Δ refers to the difference between the modeled height and the measured height.

Case		Measured (cm)	Detailed Model		Simplified Model	
			Height (cm)	Δ (cm)	Height (cm)	Δ (cm)
1	Upper	5.024 ± 0.011	5.07467	0.051	5.03899	0.015
	Lower	5.977 ± 0.024	5.99144	0.014	6.02711	0.050
2	Upper	4.849	4.90804	0.059	4.93796	0.089
	Lower	7.008	7.02081	0.013	6.99089	-0.017
3	Upper	7.309 ± 0.016	7.28853	-0.020	7.26016	-0.049
	Lower	5.387 ± 0.027	5.40199	0.015	5.43036	0.043
4	Upper	4.501 ± 0.029	4.52018	0.019	4.52315	0.022
	Lower	8.906 ± 0.122	8.94419	0.038	8.94122	0.035
5	Upper	11.460 ± 0.031	11.48088	0.021	11.45781	-0.002
	Lower	10.840 ± 0.051	10.83005	-0.010	10.85312	0.013

3.1.2 Summary of Bias Calculations

Given an unbiased model with a calculated multiplication factor of k_{eff} and a biased model due to a simplification in component i resulting in a calculated multiplication factor of $k'_{eff,i}$, the simplification bias is defined as

$$\mathrm{Bias}_i = k_{\mathrm{eff}} - k'_{\mathrm{eff},i} \; . \qquad \text{Eq. 5}$$

Therefore, the simplification bias for component i is positive when the simplification results in a reduction in k_{eff} and vice versa.

Table 172 and Table 173 present the bias calculations for the detailed and simplified models, respectively. The dominant bias is from removing the room and Comet structural components discussed in Section 3.1.1.4. The core stack simplification does not result in a large bias but greatly reduces the geometric complexity of the model.

Table 172. Summary of bias calculation results due to model simplifications for the detailed model.

Bias Component	Case 1	Case 2	Case 3	Case 4	Case 5
HEU Impurity Removal	-0.00010 ±0.00005	-0.00003 ±0.00005	+0.00003 ±0.00005	+0.00007 ±0.00005	0.00000 ±0.00005
Polyethylene Impurity Removal	-0.00003 ±0.00005	-0.00015 ±0.00005	0.00000 ±0.00005	-0.00012 ±0.00005	-0.00005 ±0.00005
Comet & Room Return (Removal)	+0.00214 ±0.00009	+0.00229 ±0.00008	+0.00204 ±0.00008	+0.00203 ±0.00008	+0.00159 ±0.00008
Temperature Correction	-0.00074 ±0.00007	-0.00089 ±0.00007	-0.00092 ±0.00007	-0.00084 ±0.00007	+0.00222 ±0.00007
Total	**+0.00127 ±0.00013**	**+0.00122 ±0.00013**	**+0.00115 ±0.00013**	**+0.00114 ±0.00013**	**+0.00376 ±0.00013**

Table 173. Summary of bias calculation results due to model simplifications for the simplified model.

Bias Component	Case 1	Case 2	Case 3	Case 4	Case 5
Detailed Model Biases	+0.00127 ±0.00013	+0.00122 ±0.00013	+0.00115 ±0.00013	+0.00114 ±0.00013	+0.00376 ±0.00013
Average Core Stacks	+0.00001 ±0.00003	-0.00020 ±0.00004	-0.00014 ±0.00004	-0.00005 ±0.00004	-0.00009 ±0.00004
Total	**+0.00128 ±0.00013**	**+0.00102 ±0.00013**	**+0.00101 ±0.00013**	**+0.00109 ±0.00013**	**+0.00367 ±0.00013**

3.2 Dimensions

3.2.1 Comet General Purpose Critical Assembly Machine

The model of the Comet General Purpose Critical Assembly Machine consists of six components. Figure 31 shows a cross section of how these components fit together. The adapter plate, adapter extension, and movable platen form a single structure referred to as the lower movable platen. The interface plate and stationary platform form another structure referred to as the upper stationary platform. The upper stationary platform is fixed in place, where the interface plate and stationary platform are separated by four 30.48 cm standoffs. The position of the lower movable platen varies along the vertical axis depending on the height of the lower half of the experiment. The membrane is fixed 0.508 cm above the interface plate for all configurations, separating the upper and lower halves of the configurations.

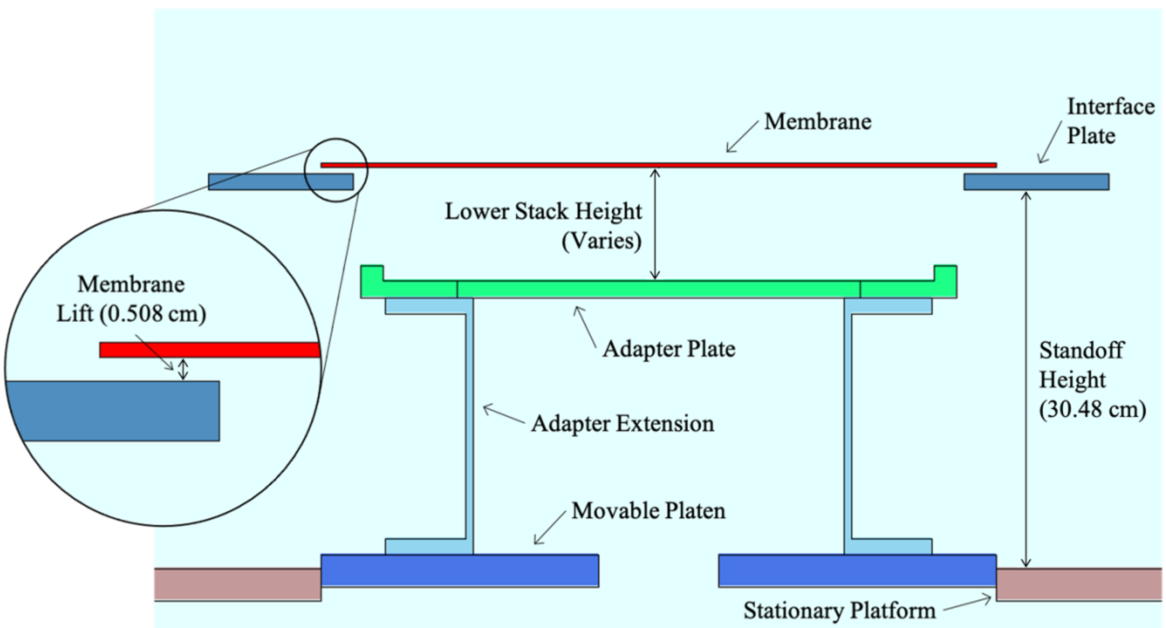


Figure 31. Comet structure components: membrane (red), interface plate (dark blue), adapter plate (teal), adapter extension (light blue), movable platen (blue), and stationary platform (brown).

Table 174 and Table 175 report the part dimensions for the upper stationary platform and lower movable platen, respectively. Since the upper stationary platform is fixed in place across all models, Table 174 also reports the upper and lower z-planes that bound the heights or thicknesses of the parts. The same is done for the lower movable platen, but the positions along the vertical axis depend on the height of the lower half of the experimental configuration, so the values are reported in the relevant model sections. In addition to these tables, each component is described in detail in the following sections.

Table 174. Model dimensions for the upper stationary platform of Comet.

<table>
<tr><th>Part</th><th>Density (g/cm^3)</th><th>Side Length (cm)</th><th>Inner Diameter (cm)</th><th>Thickness (cm)</th><th>Lower z Plane (cm)</th><th>Upper z Plane (cm)</th></tr>
<tr><td>Membrane</td><td>2.65250</td><td>53.3400</td><td>-</td><td>0.3175</td><td>0.50800</td><td>0.82550[(a)]</td></tr>
<tr><td>Interface Plate</td><td rowspan="2">2.7</td><td>71.1200</td><td>48.2600</td><td>1.2700</td><td>-1.27000</td><td>0.00000</td></tr>
<tr><td>Stationary Platform</td><td>114.3000</td><td>53.5940</td><td>2.5400</td><td>-34.29000</td><td>-31.75000</td></tr>
</table>

(a) This is the plane the upper half of the experiment sits on.

Table 175. Model dimensions for the lower movable platen of Comet.

<table>
<tr><th colspan="2">Part</th><th>Density (g/cm^3)</th><th>Outer Diameter (cm)</th><th>Inner Diameter (cm)</th><th>Thickness (cm)</th><th>Lower z Plane (cm)</th><th>Upper z Plane (cm)</th></tr>
<tr><td rowspan="2">Adapter Plate</td><td>Lip</td><td rowspan="6">2.7</td><td rowspan="2">46.9900</td><td>43.5610</td><td>1.1938</td><td colspan="2" rowspan="6">See model-specific tables in each section.</td></tr>
<tr><td>Plate</td><td>31.7500[(a)]</td><td>1.3462</td></tr>
<tr><td colspan="2" rowspan="3">Adapter Extension</td><td>43.1800</td><td rowspan="3">29.2100</td><td>1.2700</td></tr>
<tr><td>29.8450</td><td>17.780</td></tr>
<tr><td>43.1800</td><td>1.2700</td></tr>
<tr><td colspan="2">Movable Platen</td><td>53.3400</td><td>9.5250</td><td>2.5400</td></tr>
</table>

(a) See description of adapter plate inner diameter and crossbars in Section 3.2.1.3.

3.2.1.1 Membrane

The membrane was modeled as shown in Figure 32. The membrane is a square aluminum sheet with a side length of 53.34 cm and thickness of 0.3175 cm. As shown in Figure 68 of Appendix C, there are four small holes in the corners of the membrane. These holes are removed in the model as they have a negligible impact on the calculation. The membrane is the same for all experimental configurations.

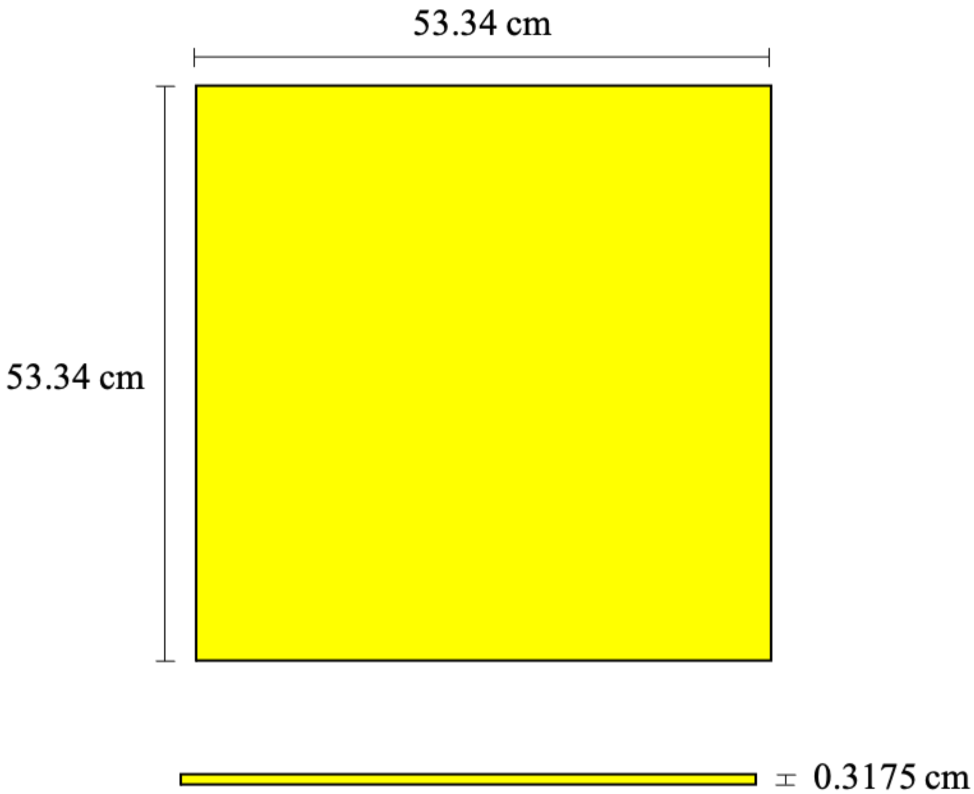


Figure 32. Membrane model dimensions (figure not to scale).

3.2.1.2 Interface Plate

The interface plate is modeled as shown in Figure 33. The interface plate is a square aluminum plate with a side length of 71.12 cm and thickness of 1.27 cm. There is a 48.26 cm diameter hole through the center of the interface plate. As shown in Figure 64 of Appendix C, there are various holes for affixing the standoffs to the interface plate and four protruding pegs to align the membrane. These components are removed in the model as they have a negligible impact on the calculation. The interface plate is the same for all experimental configurations.

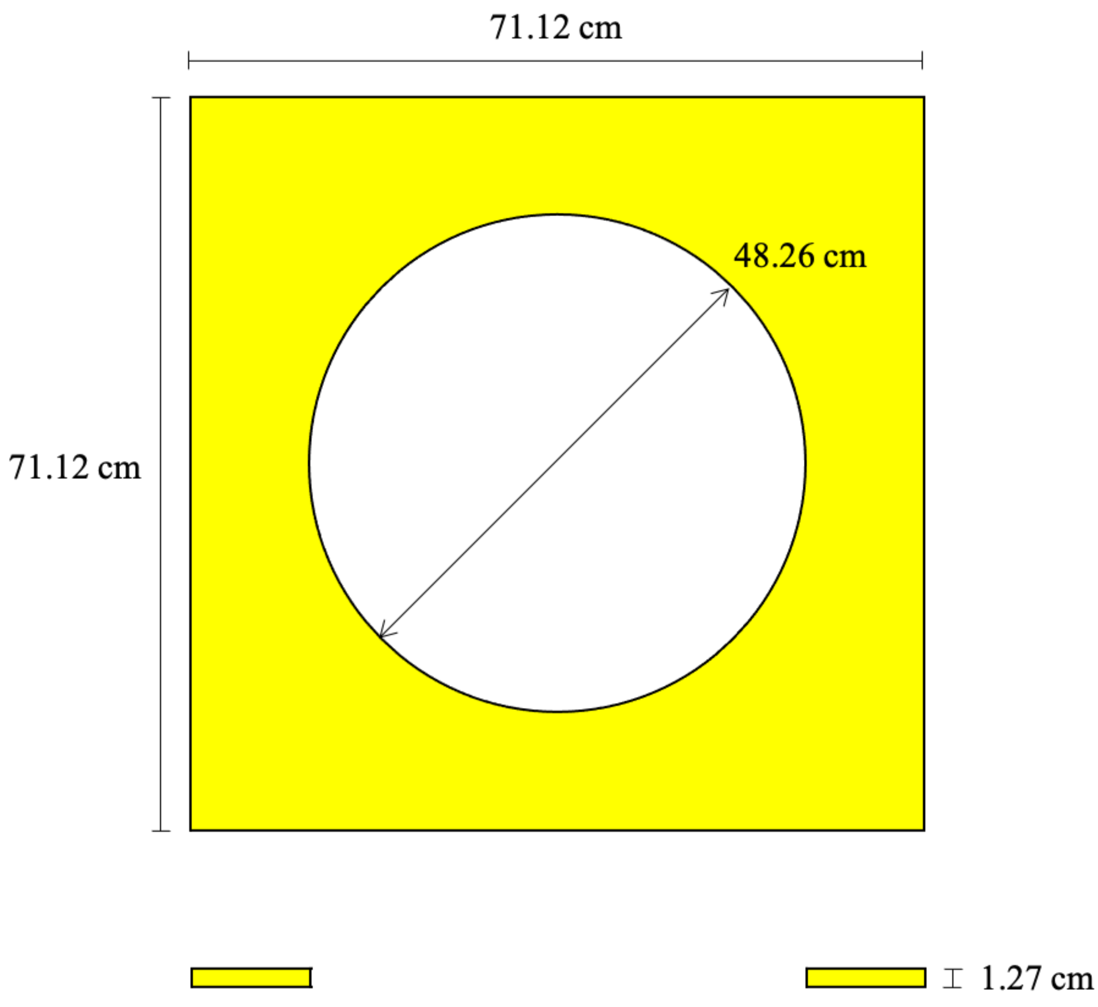


Figure 33. Interface plate model dimensions (figure not to scale).

3.2.1.3 Adapter Plate

The adapter plate is modeled as shown in Figure 34. The adapter plate is an annular cylinder with an outer lip and inner crossbars to hold the bottom reflector (BOTREF) in place. As shown in Figure 66 of Appendix C, there are various holes for affixing the adapter plate to the adapter extension. These holes are removed within the model as they have a negligible impact on the calculation. The adapter plate is the same for all experimental configurations.

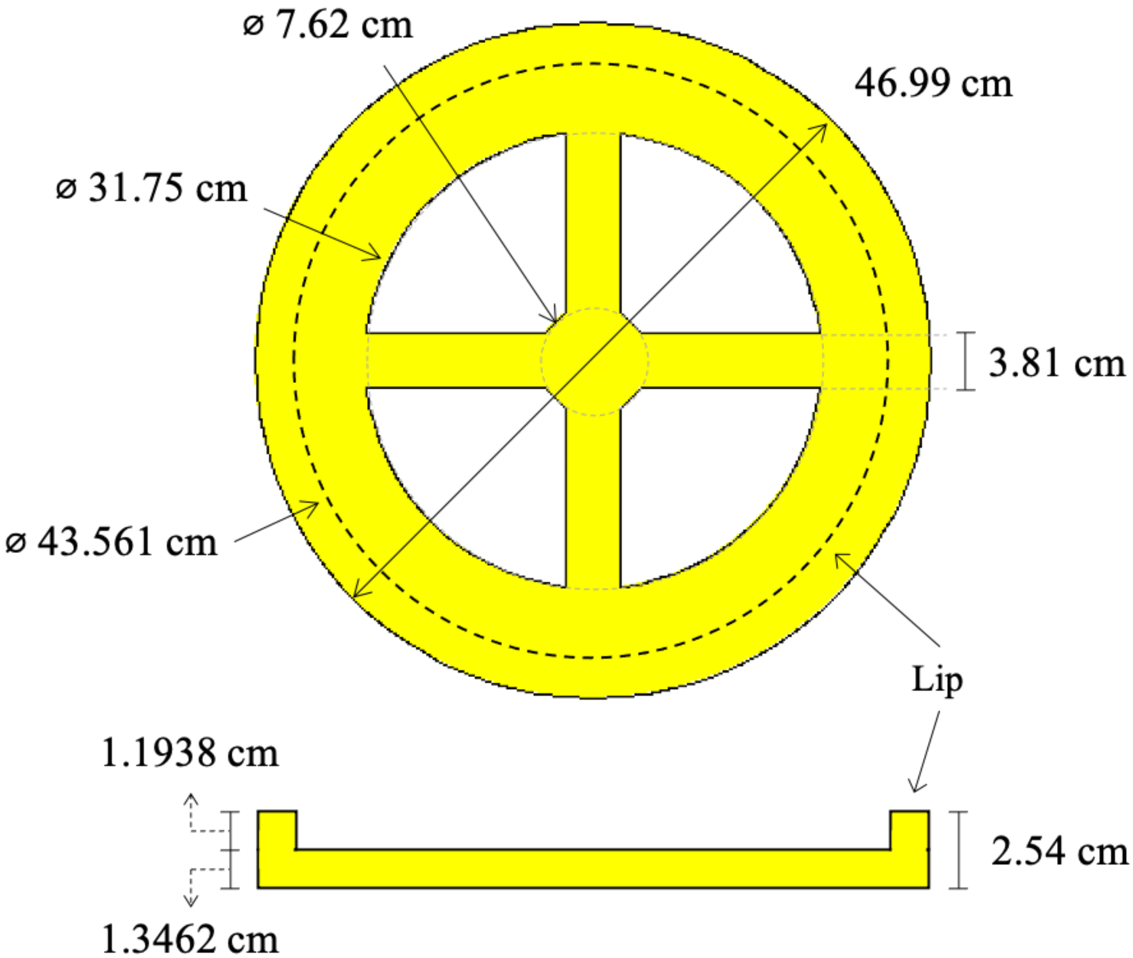


Figure 34. Adapter plate model dimensions (figure not to scale).

3.2.1.4 Adapter Extension

The adapter extension is modeled as shown in Figure 35. The adapter extension consists of a thin-walled aluminum cylinder with a top and bottom lip extending off the cylinder to affix the adapter extension to the adapter plate on top and the Comet movable platen on bottom. The annular cylinder has an inner diameter of 29.21 cm and a height of 20.32 cm with a wall thickness of 0.635 cm. The top and bottom lips have an outer diameter of 43.18 cm and thickness of 1.27 cm. As shown in Figure 67 of Appendix C, there are various holes for affixing the adapter extension to both the adapter plate and movable platen. These holes are removed within the model as they have a negligible impact on the calculation. The adapter extension is the same for all experimental configurations.

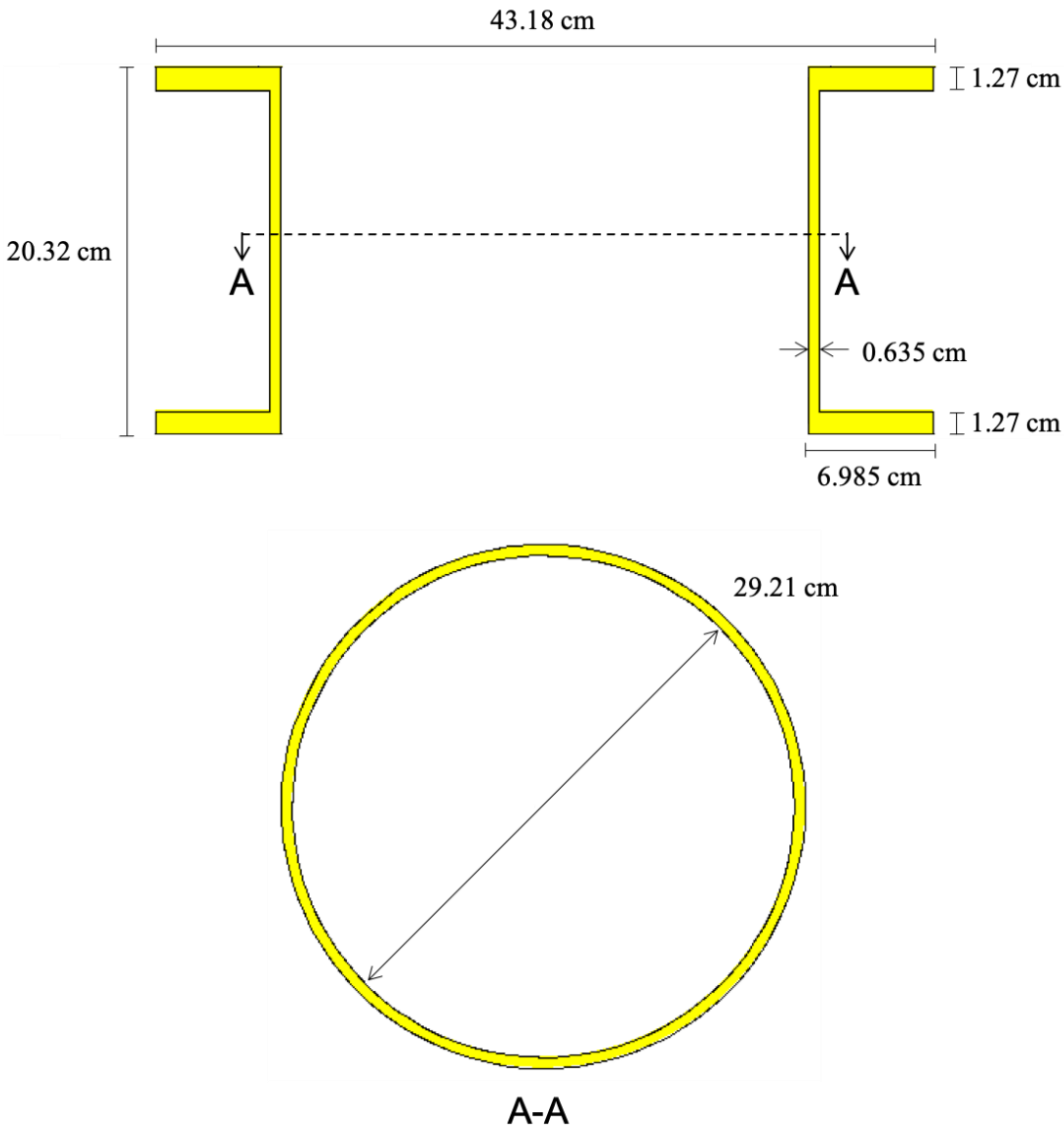


Figure 35. Adapter extension model dimensions (figures not to scale).

3.2.1.5 Comet Movable Platen

The Comet movable platen is modeled as shown in Figure 36. The platen is a circular aluminum plate with a diameter of 53.34 cm and thickness of 2.54 cm. There is a 9.525 cm diameter hole through the center of the platen. The platen is the same for all experimental configurations. As shown in Figure 63 of Appendix C, there are various holes through the movable platen for fixturing. These holes are removed within the model as they have a negligible impact on the calculation. The movable platen is the same for all experimental configurations.

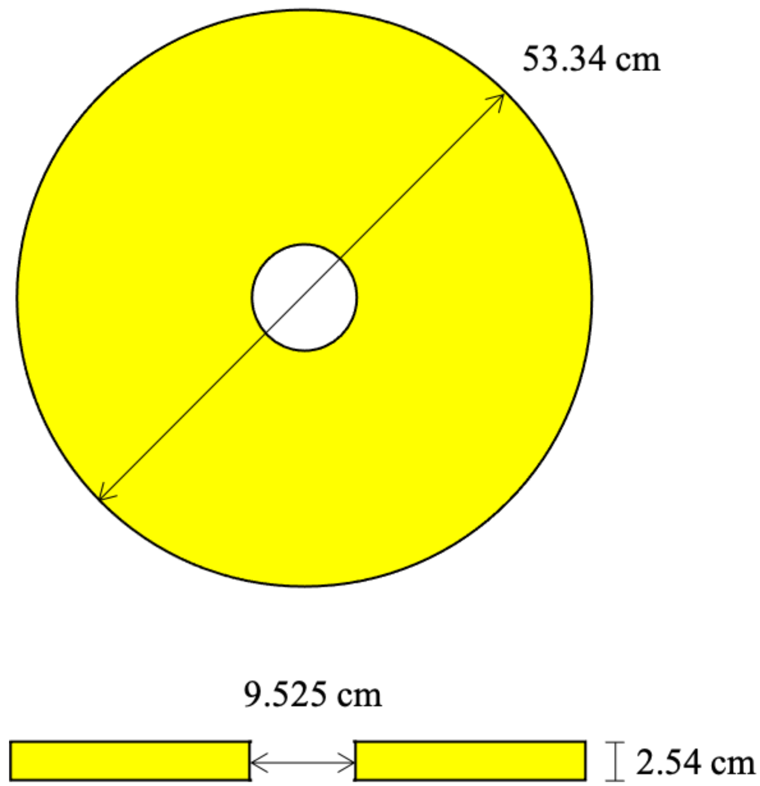


Figure 36. Comet movable platen model dimensions (figure not to scale).

3.2.1.6 Comet Stationary Platform

The Comet stationary platform is modeled as shown in Figure 37. The platform is a square aluminum plate with a side length of 114.3 cm and thickness of 2.54 cm. There is a 53.594 cm diameter hole through the center of the platform. As shown in Figure 64 of Appendix C, there are various holes through the stationary platform for fixturing and the four corners chamfered. These holes are removed, and the corners are filled within the model as they have a negligible impact on the calculation. The stationary platform is the same for all experimental configurations.

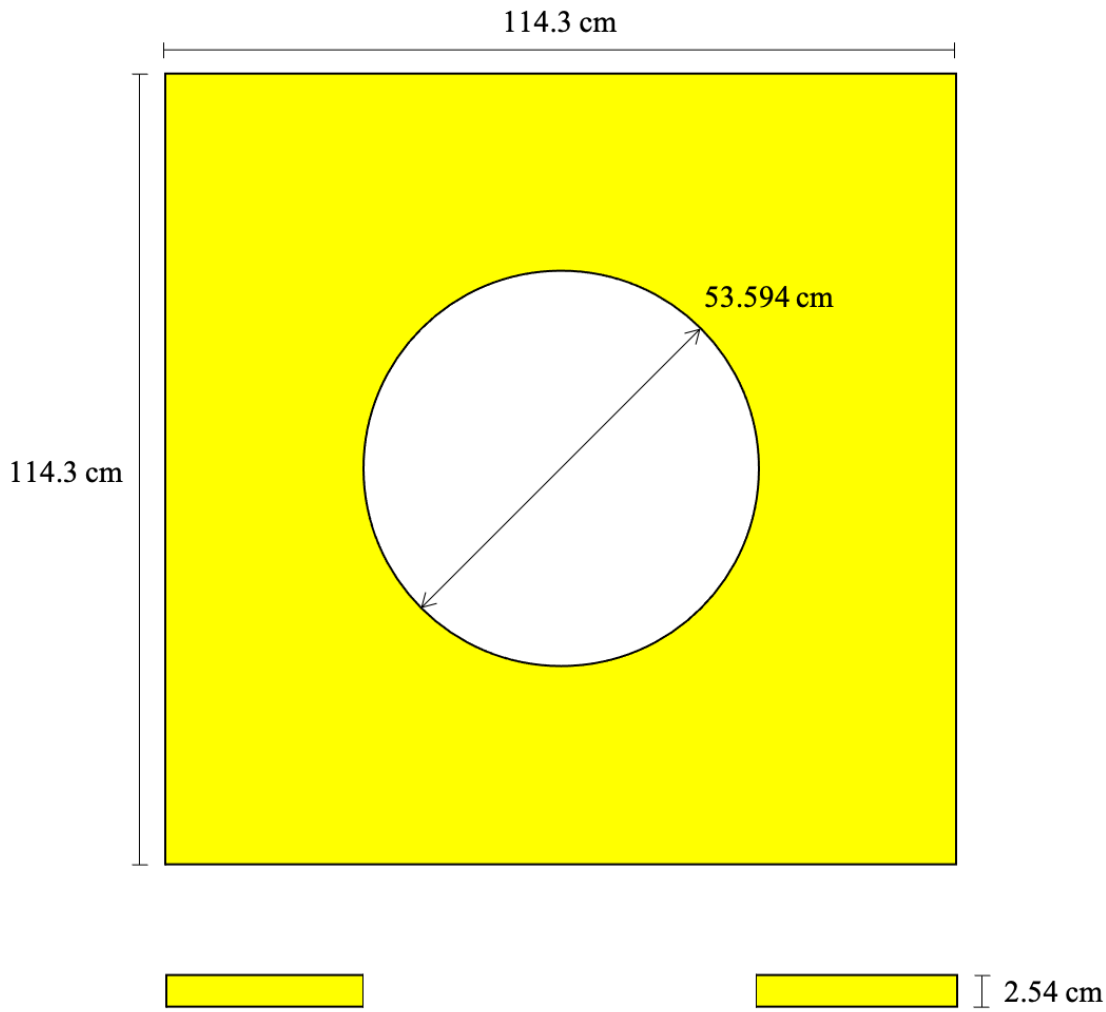
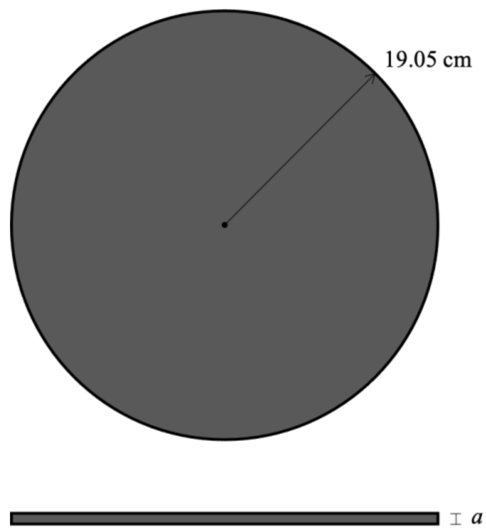


Figure 37. Comet stationary platform model dimensions (figure not to scale).

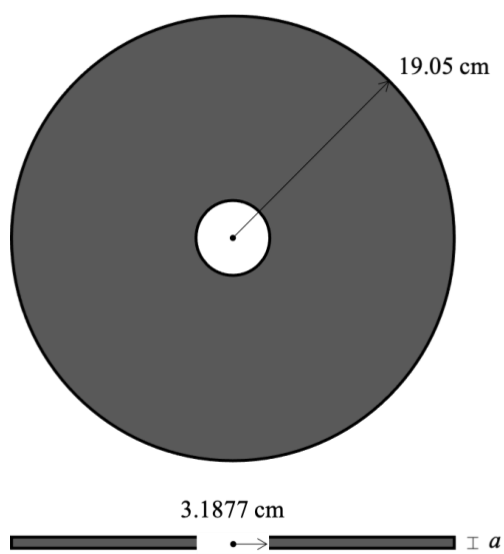
3.2.2 Highly Enriched Uranium Plates

The HEU plates are modeled as shown in Figure 38, Figure 39, Figure 40, and Figure 41. All plates are modeled with the nominal 38.1 cm outer diameter and the individually measured thicknesses. The HEU2, HEU4, and HEU5 plates are modeled with the nominal 6.3754 cm, 15.2527 cm, and 25.4127 cm nominal inner diameter, respectively. The HEU plate models are concentric with the vertical axis.



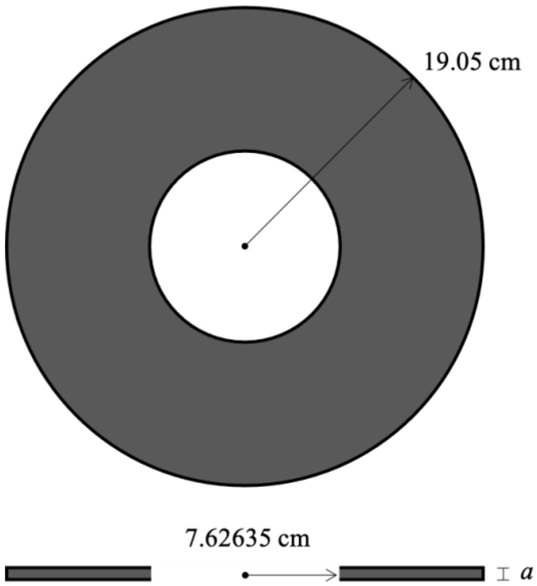
Part ID	Thickness, *a* (cm)
11017	0.30692
11019	0.30226
11147	0.30353
11149	0.31030
11150	0.30946

Figure 38. HEU1 plate model and dimensions.



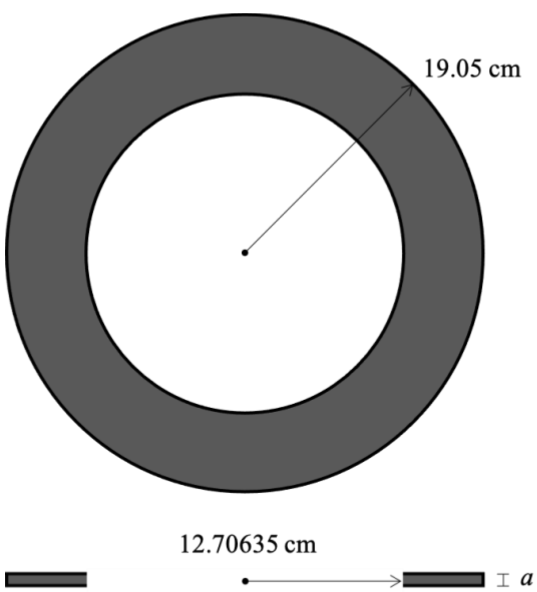
Part ID	Thickness, *a* (cm)
10464	0.30353
10467	0.31623
10470	0.31157
10475	0.32639
10487	0.30565
10489	0.31284
10491	0.31445

Figure 39. HEU2 plate model and dimensions.



Part ID	Thickness, *a* (cm)
10457	0.31877
10477	0.31369
10493	0.31191
11018	0.30268

Figure 40. HEU4 plate model and dimensions.

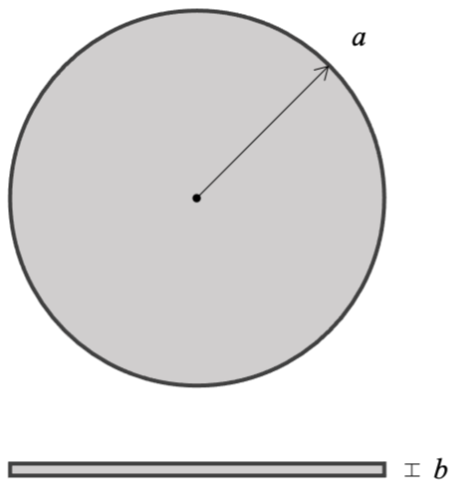


Part ID	Thickness, *a* (cm)
10463	0.30023
10472	0.30988
10479	0.30429

Figure 41. HEU5 plate model and dimensions.

3.2.3 Aluminum Inserts

The aluminum inserts are modeled as shown in Figure 42. There are three types of aluminum inserts, differentiated by their diameter, corresponding to the annuli of the HEU2, HEU4, and HEU5 plates. The aluminum insert models are concentric with the vertical axis and fit within the center of the HEU plate annuli, as shown in Figure 43.



Part ID	Radius, *a* (cm)	Thickness, *b* (cm)
2.5-DISK-1	3.04102	0.31496
2.5-DISK-2	3.04260	0.31623
2.5-DISK-3	3.04292	0.31623
2.5-DISK-4	3.04292	0.31877
2.5-DISK-5	3.04165	0.31750
2.5-DISK-6	3.04102	0.31877
2.5-DISK-7	3.04197	0.31750
2.5-DISK-8	3.04133	0.31750
2.5-DISK-9	3.04133	0.31496
2.5-DISK-10	3.04229	0.31750
6-DISK-1	7.48538	0.31496
6-DISK-2	7.48221	0.31369
6-DISK-3	7.48284	0.31750
6-DISK-4	7.48443	0.31750
10-DISK-1	12.56252	0.31496
10-DISK-2	12.56379	0.31623
10-DISK-3	12.56348	0.31750

Figure 42. Aluminum insert model and dimensions.

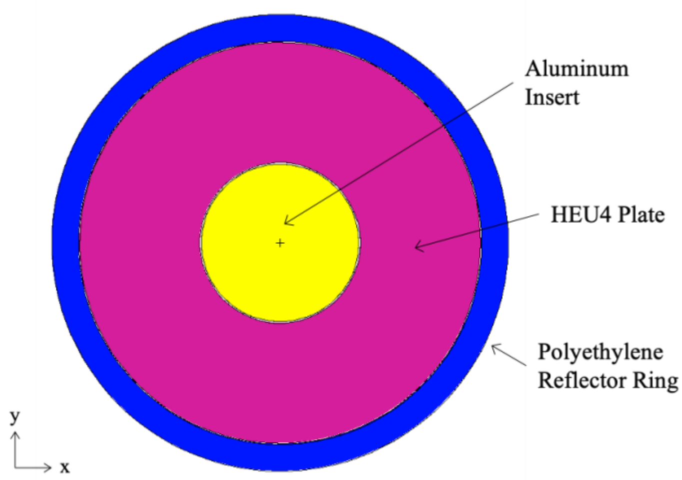
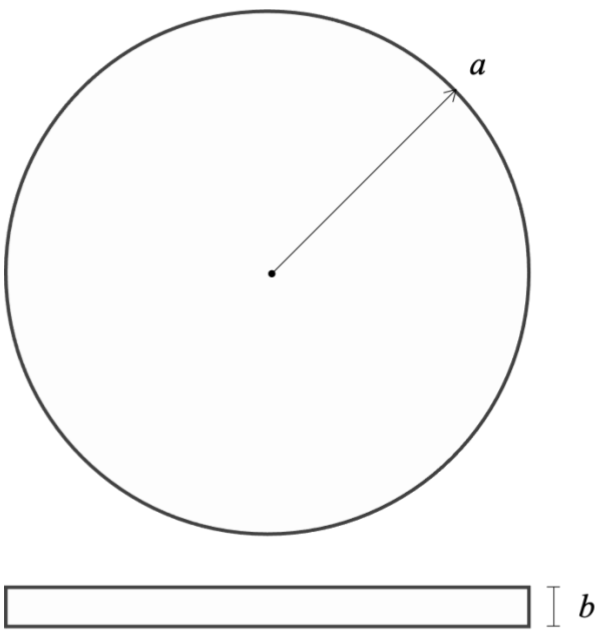


Figure 43. Cross section of an example experimental configuration showing an aluminum insert (yellow) within the annulus of HEU4 plate (pink) surrounded by a polyethylene reflector ring (blue).

3.2.4 Polyethylene Moderator and Reflector Plates

The polyethylene moderator and reflector plates are modeled as shown in Figure 44. The plates are cylinders of varying thicknesses.



Part ID	Radius, *a* (cm)	Thickness, *b* (cm)
1/8-MOD-1	19.04340	0.31725
1/8-MOD-2	19.04327	0.31979
1/8-MOD-3	19.04365	0.31826
1/8-MOD-4	19.04289	0.31775
1/8-MOD-5	19.04429	0.31648
1/8-MOD-6	19.04556	0.31877
1/8-MOD-7	19.04479	0.31699
1/8-MOD-8	19.04441	0.31775
1/8-MOD-9	19.04238	0.31699
1/8-MOD-10	19.04517	0.32156
1/8-MOD-11	19.04416	0.31725
1/4-MOD-1	19.03463	0.63805
1/4-MOD-2	19.03298	0.64313
1/4-MOD-3	19.03133	0.63424
1/4-MOD-4	19.03324	0.64973
1/4-MOD-5	19.03336	0.64897
1/4-MOD-6	19.03247	0.64491
1/4-MOD-7	19.03006	0.64287
1/4-MOD-8	19.03159	0.64110
1/4-MOD-9	19.03514	0.64516
1/2-MOD-1	19.04048	1.29007
1/2-MOD-2	19.03844	1.28194
1/2-MOD-3	19.03908	1.29413
1/2-MOD-4	19.04060	1.28118
1/2-MOD-5	19.03895	1.27838
1/2-MOD-6	19.03857	1.27076
1/2-MOD-7	19.03946	1.28727
1.5-MOD-1	19.05445	3.80949
1.5-MOD-2	19.04149	3.83540
1.5-MOD-3	19.04848	3.83210
1.5-MOD-4	19.04314	3.84708
1/32-REF-1	19.03832	0.08484
1/32-REF-2	19.03794	0.08255
1/16-REF-1	19.03197	0.18491
1/16-REF-2	19.03171	0.17043
1-REF-1	19.03755	2.53873
1-REF-2	19.03514	2.54381

Figure 44. Polyethylene moderator and reflector plate model and dimensions.

3.2.5 Polyethylene Reflector Rings and Caps

The polyethylene reflector rings surround the core stack to provide an additional 2.54 cm of radial reflection. These rings include male (top) and female (bottom) steps joints which mate with one another as the rings are stacked to provide structural support and reduce the possibility of neutron streaming paths. The stack of reflector rings is finished using a reflector cap which only have the female (bottom) step joint to provide a flat top surface to the reflector stack.

The upper and lower reflectors are modeled as shown in Figure 45, the dimension values are given in each model description. The dimensions are reported in model sections for each experimental configuration.

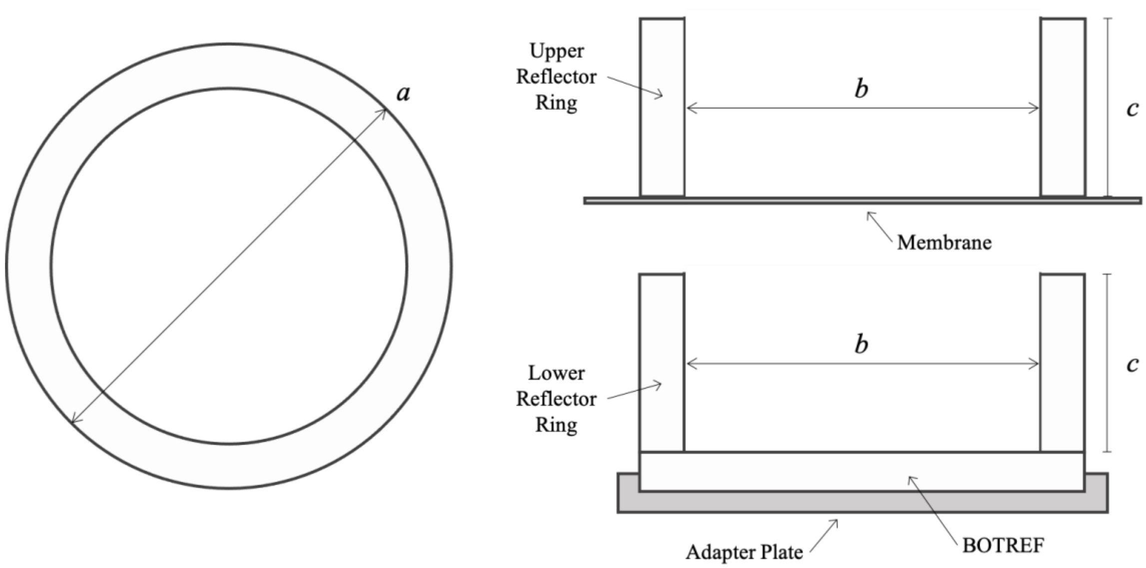
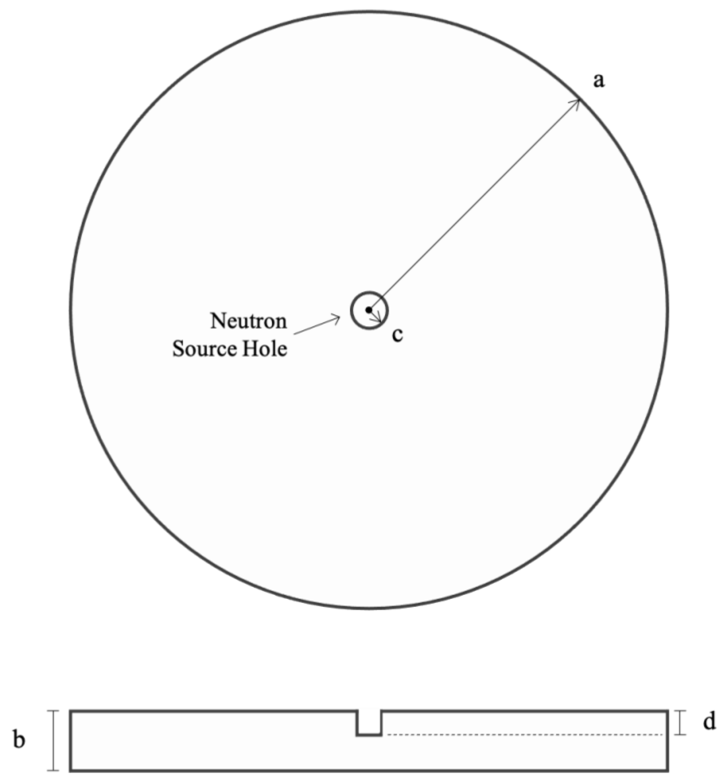


Figure 45. Polyethylene reflector ring model and dimensions. The left figure shows a cross section of the reflector which is an annular cylinder. The right figures show the upper ring reflector, which sits on top of the membrane, and the lower ring reflector, which sits on top of the bottom reflector within the adapter plate.

3.2.6 Polyethylene Bottom Reflector

The polyethylene bottom reflector is modeled as shown in Figure 46. This model includes the simplifications described in Section 3.1.1.3. The bottom reflector is a cylindrical plate with a neutron source hole on its top face. The same bottom reflector part (BOTREF-1) was used in all experimental configurations. The neutron source hole was empty during all benchmark measurements.



Part ID	Radius, *a* (cm)	Thickness, *b* (cm)	Source Hole Radius, *c* (cm)	Source Hole Depth, *d* (cm)
BOTREF-1	21.68665	2.56794	0.35687	1.25959

Figure 46. Polyethylene bottom reflector model dimensions (figure not to scale).

3.2.7 Case Models

Each experimental configuration presents a detailed and a simplified model, with accompanying tables and figures to fully describe the configuration including the parts, dimensions, masses, and axial positions. The assumed origin of the computational model is at the interface plate on the center of its top face. All axial positions reported in the following sections are relative to this origin. All parts are concentric about the vertical axis (z-axis).

3.2.7.1 Case 1

Case 1 went critical with 19 HEU plates, no polyethylene moderator, and a nominal 0.96875 in (2.460625 cm) top reflector. Figure 47 shows a cross sectional view of the detailed model. The aluminum parts (structural components, membrane, and inserts) are shown in yellow, the HEU plates in pink, and the polyethylene reflector in blue.

Figure 48 shows a diagram of the Case 1 detailed model. Table 176 provides a more detailed breakdown of the Case 1 detailed model core stack dimensions, including part densities (in g/cm^3), dimensions, and axial position. Table 177 provides similar details for the upper and lower reflector rings. Table 178 describes the axial positions of the Comet lower movable platen components specific to the Case 1 detailed model.

Figure 49, Table 188, Table 181, and Table 182 include the same information for the Case 1 simplified model. Table 179 summarizes the average part dimensions used in the Case 1 configuration. These dimensions are used to create the simplified core stack and reflector for the Case 1 simplified model.

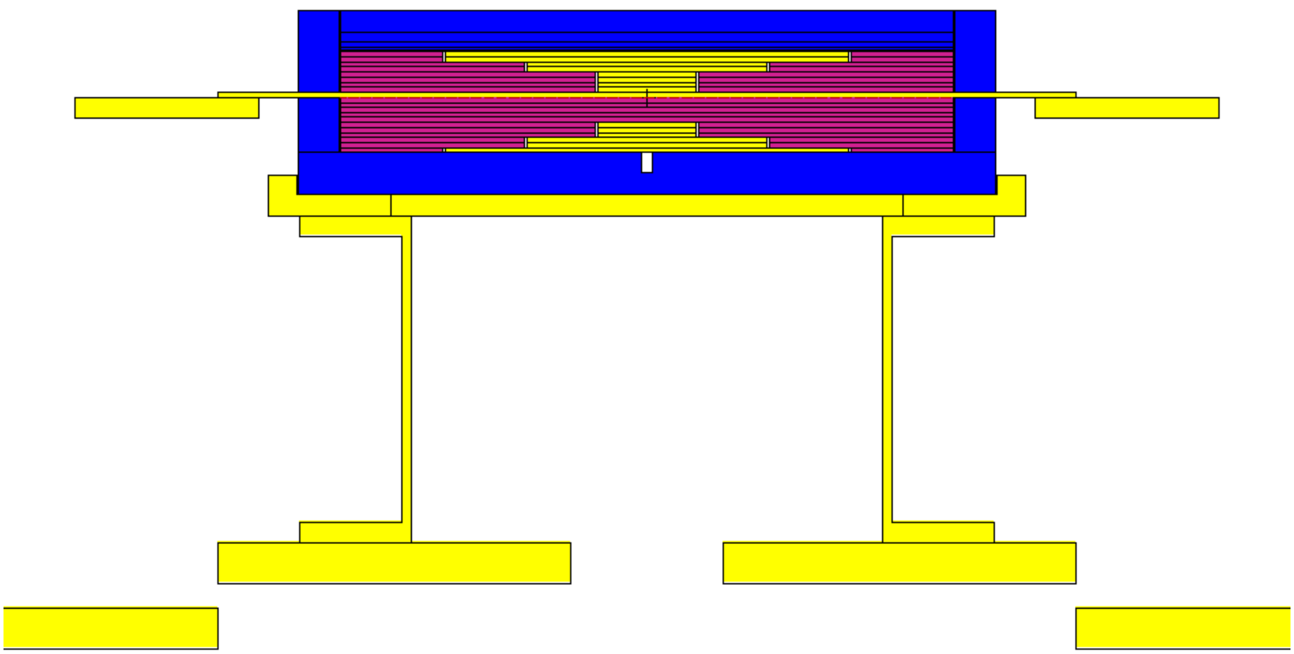


Figure 47. Case 1 detailed model.

3.2.7.1.1 Detailed Model

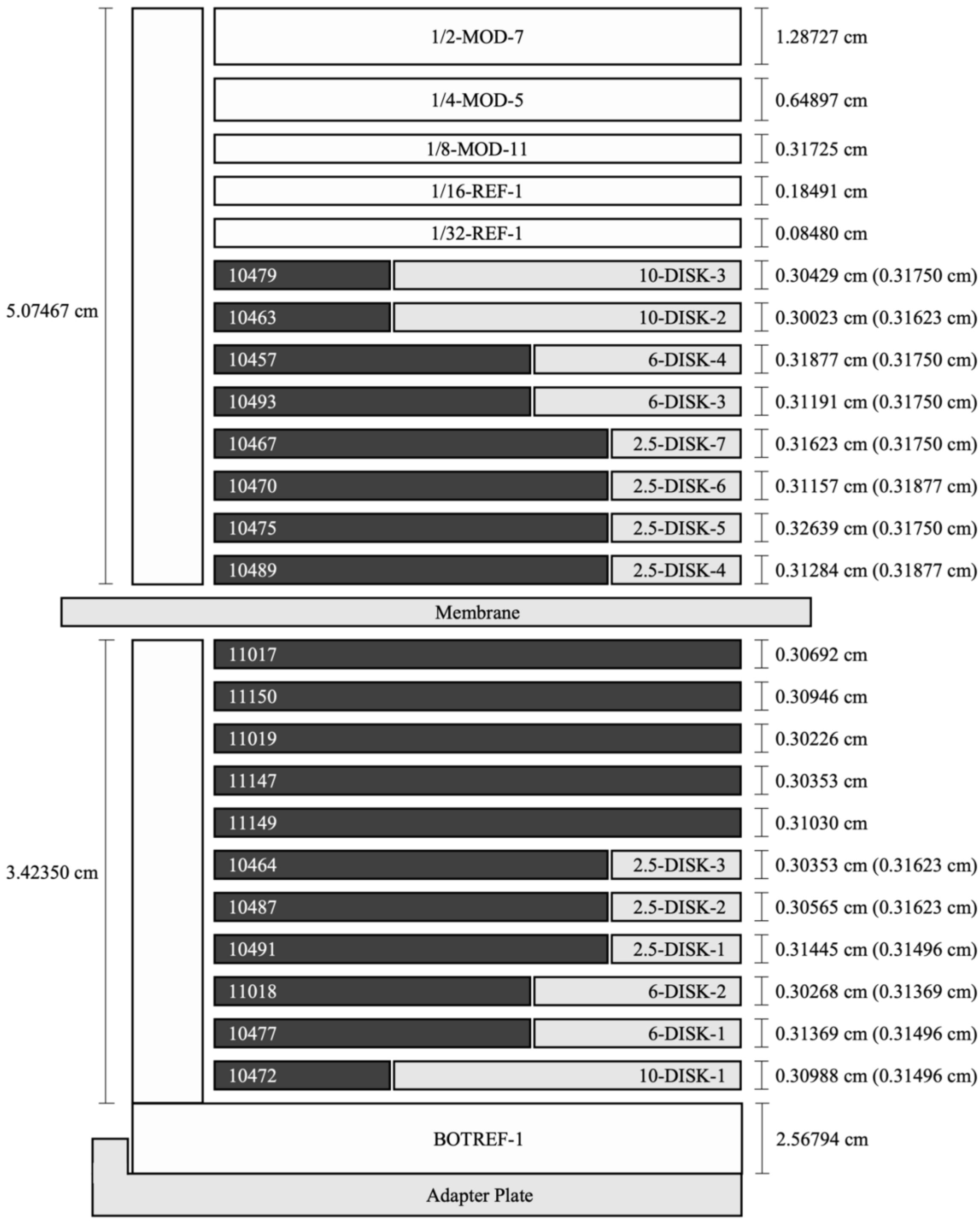


Figure 48. Diagram of the Case 1 detailed model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate thicknesses with aluminum insert thicknesses in parenthesis. Gaps shown between parts are not present.

Table 176. Case 1 detailed model core stack dimensions.

Layer	Part ID	Density (g/cm^3)	Inner Radius (cm)	Outer Radius (cm)	Thickness (cm)	Lower z Plane (cm)	Upper z Plane (cm)
26	1/2-MOD-7	0.94387	-	19.03946	1.28727	4.61289	5.90017
25	1/4-MOD-5	0.93312	-	19.03336	0.64897	3.96392	4.61289
24	1/8-MOD-11	0.94946	-	19.04416	0.31725	3.64668	3.96392
23	1/16-REF-1	0.86685	-	19.03197	0.18491	3.46177	3.64668
22	1/32-REF-1	0.87990	-	19.03832	0.08484	3.37693	3.46177
21	10479	18.51027	12.70635	19.05000	0.30429	3.05943	3.36372
	10-DISK-3	2.70898	-	12.56348	0.31750		3.37693
20	10463	19.11345	12.70635	19.05000	0.30023	2.74320	3.04343
	10-DISK-2	2.70378	-	12.56379	0.31623		3.05943
19	10457	18.26485	7.62635	19.05000	0.31877	2.42443	2.74320
	6-DISK-4	2.70787	-	7.48443	0.31750		2.74193
18	10493	18.20799	7.62635	19.05000	0.31191	2.10693	2.41884
	6-DISK-3	2.70544	-	7.48284	0.31750		2.42443
17	10467	18.07975	3.18770	19.05000	0.31623	1.78943	2.10566
	2.5-DISK-7	2.69772	-	3.04197	0.31750		2.10693
16	10470	18.18546	3.18770	19.05000	0.31157	1.47066	1.78223
	2.5-DISK-6	2.69945	-	3.04102	0.31877		1.78943
15	10475	17.22445	3.18770	19.05000	0.32639	1.14427	1.47066
	2.5-DISK-5	2.69828	-	3.04165	0.31750		1.46177
14	10489	18.29855	3.18770	19.05000	0.31284	0.82550	1.13834
	2.5-DISK-4	2.68529	-	3.04292	0.31877		1.14427
13	Membrane	2.65250	See footnote (a).		0.31750	0.50800	0.82550
12	11017	18.58061	-	19.05000	0.30692	0.20108	0.50800
11	11150	18.16932	-	19.05000	0.30946	-0.10837	0.20108
10	11019	18.77517	-	19.05000	0.30226	-0.41063	-0.10837
9	11147	18.83329	-	19.05000	0.30353	-0.71416	-0.41063
8	11149	18.04427	-	19.05000	0.31030	-1.02447	-0.71416
7	10464	18.60642	3.18770	19.05000	0.30353	-1.34070	-1.03717
	2.5-DISK-3	2.68512	-	3.04292	0.31623		-1.02447
6	10487	18.52598	3.18770	19.05000	0.30565	-1.65693	-1.35128
	2.5-DISK-2	2.69655	-	3.04260	0.31623		-1.34070
5	10491	18.34441	3.18770	19.05000	0.31445	-1.97189	-1.65743
	2.5-DISK-1	2.68839	-	3.04102	0.31496		-1.65693
4	11018	18.53090	7.62635	19.05000	0.30268	-2.28558	-1.98289
	6-DISK-2	2.71339	-	7.48221	0.31369		-1.97189
3	10477	18.31124	7.62635	19.05000	0.31369	-2.60054	-2.28685
	6-DISK-1	2.70376	-	7.48538	0.31496		-2.28558
2	10472	18.28356	12.70635	19.05000	0.30988	-2.91550	-2.60562
	10-DISK-1	2.71459	-	12.56252	0.31496		-2.60054
1	BOTREF-1	0.94700	See Section 3.2.6.		2.56794	-5.48344	-2.91550

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 177. Case 1 detailed model reflector dimensions (see Section 3.2.5).

Part	Density (g/cm^3)	Inner Radius, b (cm)	Outer Radius, a (cm)	Height, c (cm)	Lower z Plane (cm)	Upper z Plane (cm)
Upper Reflector	0.94598	19.13701	21.69482	5.07467	0.82550[(a)]	5.90017
Lower Reflector	0.98306	19.14247	21.69753	3.42350	-2.91550[(b)]	0.50800[(c)]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 178. Case 1 detailed model lower movable platen axial positions.

Part		Density (g/cm^3)	Lower z Plane (cm)	Upper z Plane (cm)
Adapter Plate	Lip	2.7	-5.48344	-4.28964
	Plate		-6.82964	-5.48344[(a)]
Adapter Extension			-8.09964	-6.82964
			-25.87964	-8.09964
			-27.14964	-25.87964
Movable Platen			-29.68964	-27.14964

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.2.7.1.2 Simplified Model

Table 179. Average part dimensions for Case 1 simplified model core stack.

Part Type	N	Thickness (cm)	Inner Diameter (cm)	Outer Diameter (cm)	Volume (cm^3)	Density (g/cm^3)
Top Reflector	5	2.52324	-	38.07583	2873.1	0.93401
HEU1	5	0.31447	-	38.10000	358.5	18.00870
HEU2	7		6.37540	38.10000	348.5	18.08412
HEU4	4		15.25270	38.10000	301.1	18.16917
HEU5	3		25.41270	38.10000	199.0	18.05857
2.5-DISK	7		-	6.08403	9.1	2.71582
6-DISK	4		-	14.96743	55.3	2.72003
10-DISK	3		-	25.12653	155.9	2.72427
BOTREF	1	2.56794	-	43.37329	3793.7	0.94700

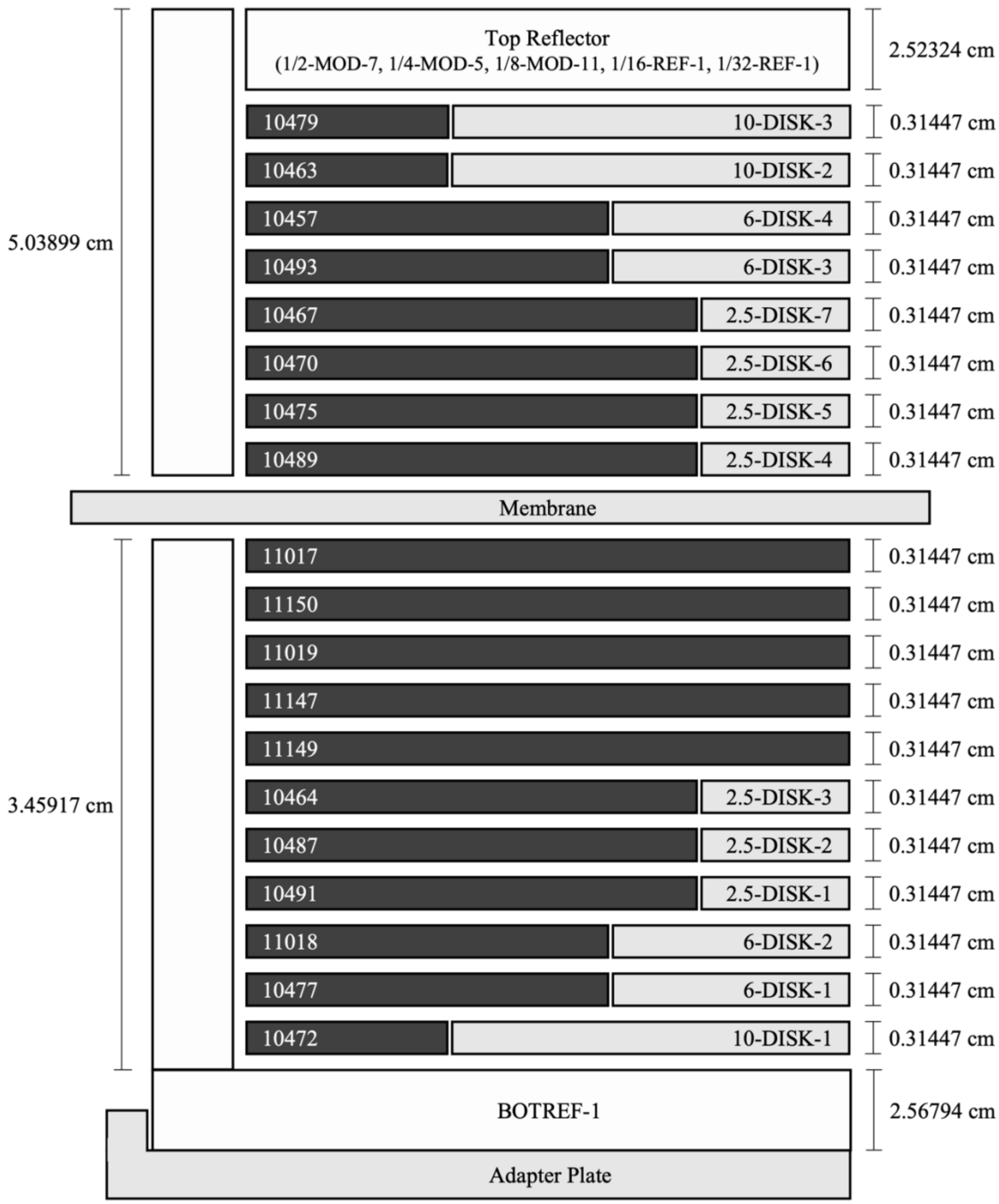


Figure 49. Diagram of the Case 1 simplified model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate and aluminum insert thicknesses. Gaps shown between parts are not necessarily present.

Table 180. Case 1 simplified model core stack dimensions.

Layer	Part ID	Density (g/cm^3)	Inner Radius (cm)	Outer Radius (cm)	Thickness (cm)	Lower z Plane (cm)	Upper z Plane (cm)
22	Top Reflector	0.93401	-	38.07590	2.52324	3.34126	5.86449
21	10479	18.05857	12.70635	19.05000	0.31447	3.02679	3.34126
	10-DISK-3	2.72427	-	12.56326	0.31447		
20	10463	18.05857	12.70635	19.05000	0.31447	2.71232	3.02679
	10-DISK-2	2.72427	-	12.56326	0.31447		
19	10457	18.16917	7.62635	19.05000	0.31447	2.39785	2.71232
	6-DISK-4	2.72003	-	7.48371	0.31447		
18	10493	18.16917	7.62635	19.05000	0.31447	2.08338	2.39785
	6-DISK-3	2.72003	-	7.48371	0.31447		
17	10467	18.08412	3.18770	19.05000	0.31447	1.76891	2.08338
	2.5-DISK-7	2.71582	-	3.04201	0.31447		
16	10470	18.08412	3.18770	19.05000	0.31447	1.45444	1.76891
	2.5-DISK-6	2.71582	-	3.04201	0.31447		
15	10475	18.08412	3.18770	19.05000	0.31447	1.13997	1.45444
	2.5-DISK-5	2.71582	-	3.04201	0.31447		
14	10489	18.08412	3.18770	19.05000	0.31447	0.82550	1.13997
	2.5-DISK-4	2.71582	-	3.04201	0.31447		
13	Membrane	2.65250	See footnote (a).		0.31750	0.50800	0.82550
12	11017	18.00870	-	19.05000	0.31447	0.19353	0.50800
11	11150	18.00870	-	19.05000	0.31447	-0.12094	0.19353
10	11019	18.00870	-	19.05000	0.31447	-0.43541	-0.12094
9	11147	18.00870	-	19.05000	0.31447	-0.74988	-0.43541
8	11149	18.00870	-	19.05000	0.31447	-1.06435	-0.74988
7	10464	18.08412	3.18770	19.05000	0.31447	-1.37882	-1.06435
	2.5-DISK-3	2.71582	-	3.04201	0.31447		
6	10487	18.08412	3.18770	19.05000	0.31447	-1.69329	-1.37882
	2.5-DISK-2	2.71582	-	3.04201	0.31447		
5	10491	18.08412	3.18770	19.05000	0.31447	-2.00776	-1.69329
	2.5-DISK-1	2.71582	-	3.04201	0.31447		
4	11018	18.16917	7.62635	19.05000	0.31447	-2.32223	-2.00776
	6-DISK-2	2.72003	-	7.48371	0.31447		
3	10477	18.16917	7.62635	19.05000	0.31447	-2.63670	-2.32223
	6-DISK-1	2.72003	-	7.48371	0.31447		
2	10472	18.05857	12.70635	19.05000	0.31447	-2.95117	-2.63670
	10-DISK-1	2.72427	-	12.56326	0.31447		
1	BOTREF-1	0.94700	See Section 3.2.6.		2.56794	-5.51911	-2.95117

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 181. Case 1 simplified model reflector dimensions (see Section 3.2.5).

Part	**Density (g/cm^3)**	**Inner Radius, b (cm)**	**Outer Radius, a (cm)**	**Height, c (cm)**	**Lower z Plane (cm)**	**Upper z Plane (cm)**
Upper Reflector	0.95268	19.13701	21.69482	5.03899	0.82550[a]	5.86449
Lower Reflector	0.97292	19.14247	21.69753	3.45917	-2.95117[b]	0.50800[c]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 182. Case 1 simplified model lower movable platen axial positions.

Part		**Density (g/cm^3)**	**Lower z Plane (cm)**	**Upper z Plane (cm)**
Adapter Plate	Lip	2.7	-5.51911	-4.32531
	Plate		-6.86531	-5.51911[a]
Adapter Extension			-8.13531	-6.86531
			-25.91531	-8.13531
			-27.18531	-25.91531
Movable Platen			-29.72531	-27.18531

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.2.7.2 Case 2

Case 2 went critical with 11 HEU plates, 0.125 in (0.3175 cm) nominal polyethylene moderator plates between each HEU plate, and a nominal 1.03125 in (2.619375 cm) top reflector. Figure 50 shows a cross sectional view of the detailed model. The aluminum parts (structural components, membrane, and inserts) are shown in yellow, the HEU plates in pink, and the polyethylene moderator plates and reflector in blue.

Figure 48 shows a diagram of the Case 2 detailed model. Table 183 provides a more detailed breakdown of the Case 2 detailed model core stack dimensions, including part densities (in g/cm^3), dimensions, and axial position. Table 184 provides similar details for the upper and lower reflector rings. Table 185 describes the axial positions of the Comet lower movable platen components specific to the Case 2 detailed model.

Figure 52, Table 187, Table 188, and Table 189 include the same information for the Case 2 simplified model. Table 186 summarizes the average part dimensions used in the Case 2 configuration. These dimensions are used to create the simplified core stack and reflector for the Case 2 simplified model.

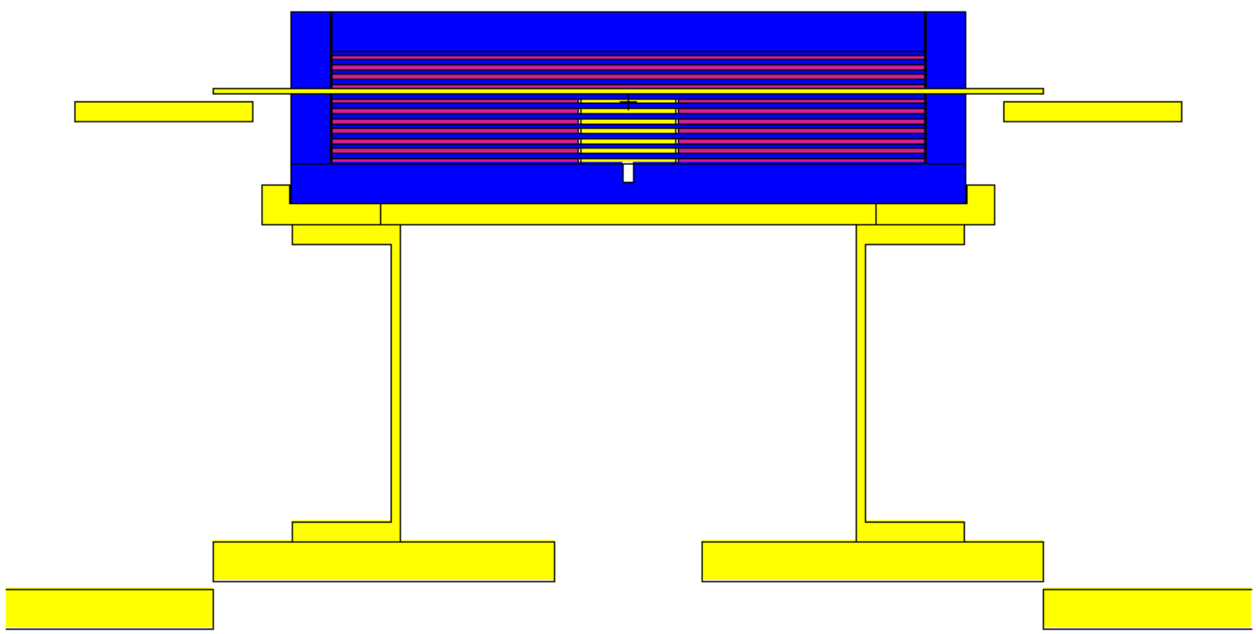


Figure 50. Case 2 detailed model.

3.2.7.2.1 Detailed Model

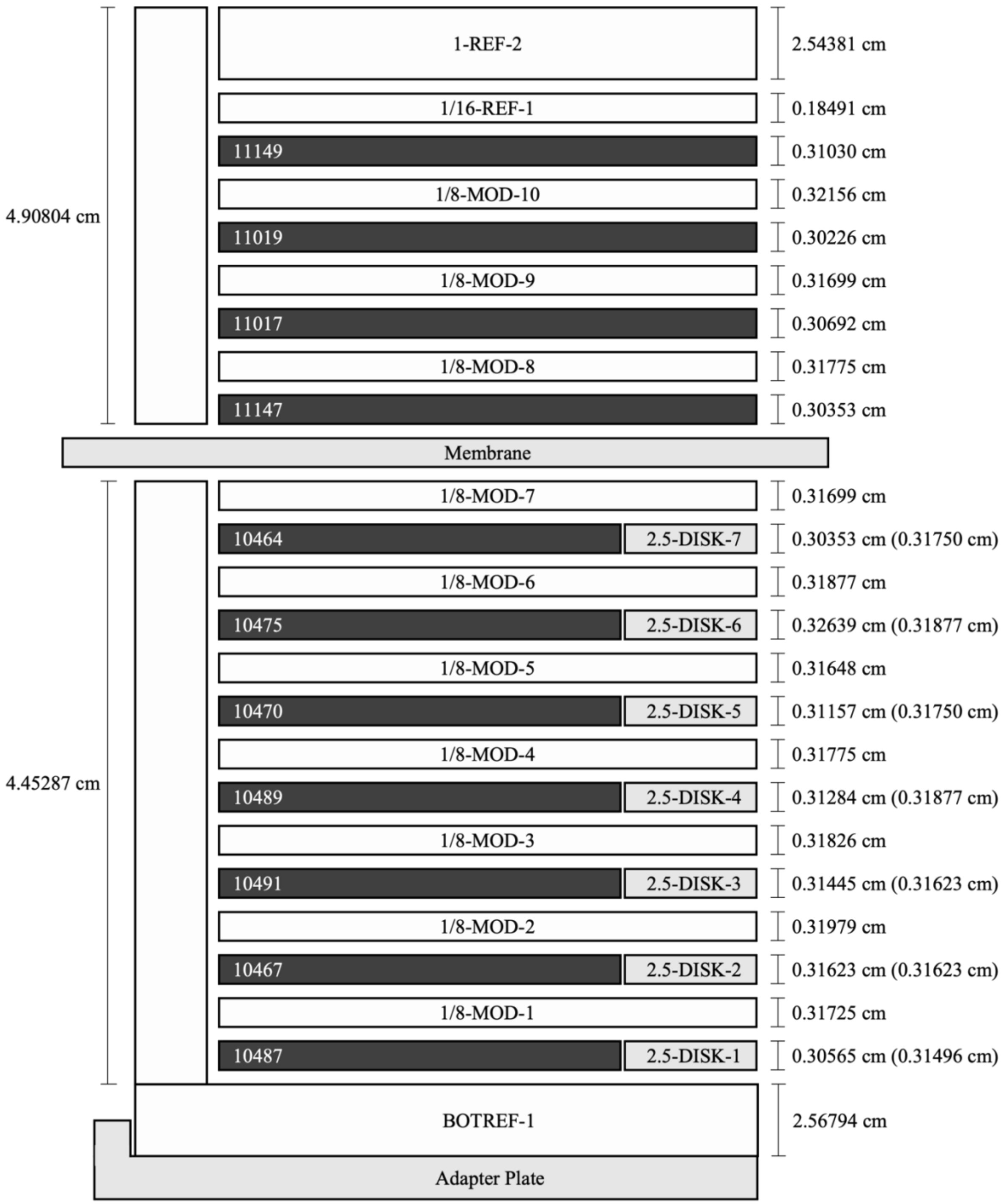


Figure 51. Diagram of the Case 2 detailed model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate thicknesses with aluminum insert thicknesses in parenthesis. Gaps shown between parts are not necessarily present.

Table 183. Case 2 detailed model core stack dimensions.

Layer	Part ID	Density (g/cm^3)	Inner Radius (cm)	Outer Radius (cm)	Thickness (cm)	Lower z Plane (cm)	Upper z Plane (cm)
25	1-REF-2	0.95564	-	19.03514	2.54381	3.18973	5.73354
24	1/16-REF-1	0.86685	-	19.03197	0.18491	3.00482	3.18973
23	11149	18.04427	-	19.05000	0.31030	2.69452	3.00482
22	1/8-MOD-10	0.93743	-	19.04517	0.32156	2.37295	2.69452
21	11019	18.77517	-	19.05000	0.30226	2.07069	2.37295
20	1/8-MOD-9	0.95095	-	19.04238	0.31699	1.75370	2.07069
19	11017	18.58061	-	19.05000	0.30692	1.44678	1.75370
18	1/8-MOD-8	0.95344	-	19.04441	0.31775	1.12903	1.44678
17	11147	18.83329	-	19.05000	0.30353	0.82550	1.12903
16	Membrane	2.65250	See footnote (a).		0.31750	0.50800	0.82550
15	1/8-MOD-7	0.95514	-	19.04479	0.31699	0.19101	0.50800
14	10464	18.60642	3.18770	19.05000	0.30353	-0.12649	0.17704
	2.5-DISK-7	2.69772	-	3.04197	0.31750		0.19101
13	1/8-MOD-6	0.94891	-	19.04556	0.31877	-0.44526	-0.12649
12	10475	17.22445	3.18770	19.05000	0.32639	-0.77165	-0.44526
	2.5-DISK-6	2.69945	-	3.04102	0.31877		-0.45288
11	1/8-MOD-5	0.95118	-	19.04429	0.31648	-1.08814	-0.77165
10	10470	18.18546	3.18770	19.05000	0.31157	-1.40564	-1.09406
	2.5-DISK-5	2.69828	-	3.04165	0.31750		-1.08814
9	1/8-MOD-4	0.95111	-	19.04289	0.31775	-1.72339	-1.40564
8	10489	18.29855	3.18770	19.05000	0.31284	-2.04216	-1.72932
	2.5-DISK-4	2.68529	-	3.04292	0.31877		-1.72339
7	1/8-MOD-3	0.94869	-	19.04365	0.31826	-2.36042	-2.04216
6	10491	18.34441	3.18770	19.05000	0.31445	-2.67665	-2.36220
	2.5-DISK-3	2.68512	-	3.04292	0.31623		-2.36042
5	1/8-MOD-2	0.93899	-	19.04327	0.31979	-2.99644	-2.67665
4	10467	18.07975	3.18770	19.05000	0.31623	-3.31267	-2.99644
	2.5-DISK-2	2.69655	-	3.04260	0.31623		-2.99644
3	1/8-MOD-1	0.94898	-	19.04340	0.31725	-3.62991	-3.31267
2	10487	18.52598	3.18770	19.05000	0.30565	-3.94487	-3.63923
	2.5-DISK-1	2.68839	-	3.04102	0.31496		-3.62991
1	BOTREF-1	0.94700	See Section 3.2.6.		2.56794	-6.51281	-3.94487

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 184. Case 2 detailed model reflector dimensions (see Section 3.2.5).

Part	Density (g/cm^3)	Inner Radius, b (cm)	Outer Radius, a (cm)	Height, c (cm)	Lower z Plane (cm)	Upper z Plane (cm)
Upper Reflector	0.94589	19.13759	21.69622	4.90804	0.82550[a]	5.73354
Lower Reflector	0.95713	19.13914	21.69617	4.45287	-3.94487[b]	0.50800[c]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 185. Case 2 detailed model lower movable platen axial positions.

Part		Density (g/cm^3)	Lower z Plane (cm)	Upper z Plane (cm)
Adapter Plate	Lip	2.7	-6.51281	-5.31901
	Plate		-7.85901	-6.51281[a]
Adapter Extension			-9.12901	-7.85901
			-26.90901	-9.12901
			-28.17901	-26.90901
Movable Platen			-30.71901	-28.17901

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.2.7.2.2 Simplified Model

Table 186. Average part dimensions for Case 2 simplified model core stack.

Part Type	N	Thickness (cm)	Inner Diameter (cm)	Outer Diameter (cm)	Volume (cm^3)	Density (g/cm^3)
Top Reflector	2	2.72872	-	38.06989	3106.1	0.94962
HEU1	4	0.31369	-	38.10000	357.6	18.08581
HEU2	7		6.37540	38.10000	347.6	18.12908
2.5-DISK	7		-	6.08403	9.1	2.72257
1/8-MOD	10	0.31816	-	38.08796	362.5	0.94846
BOTREF	1	2.56794	-	43.37329	3793.7	0.94700

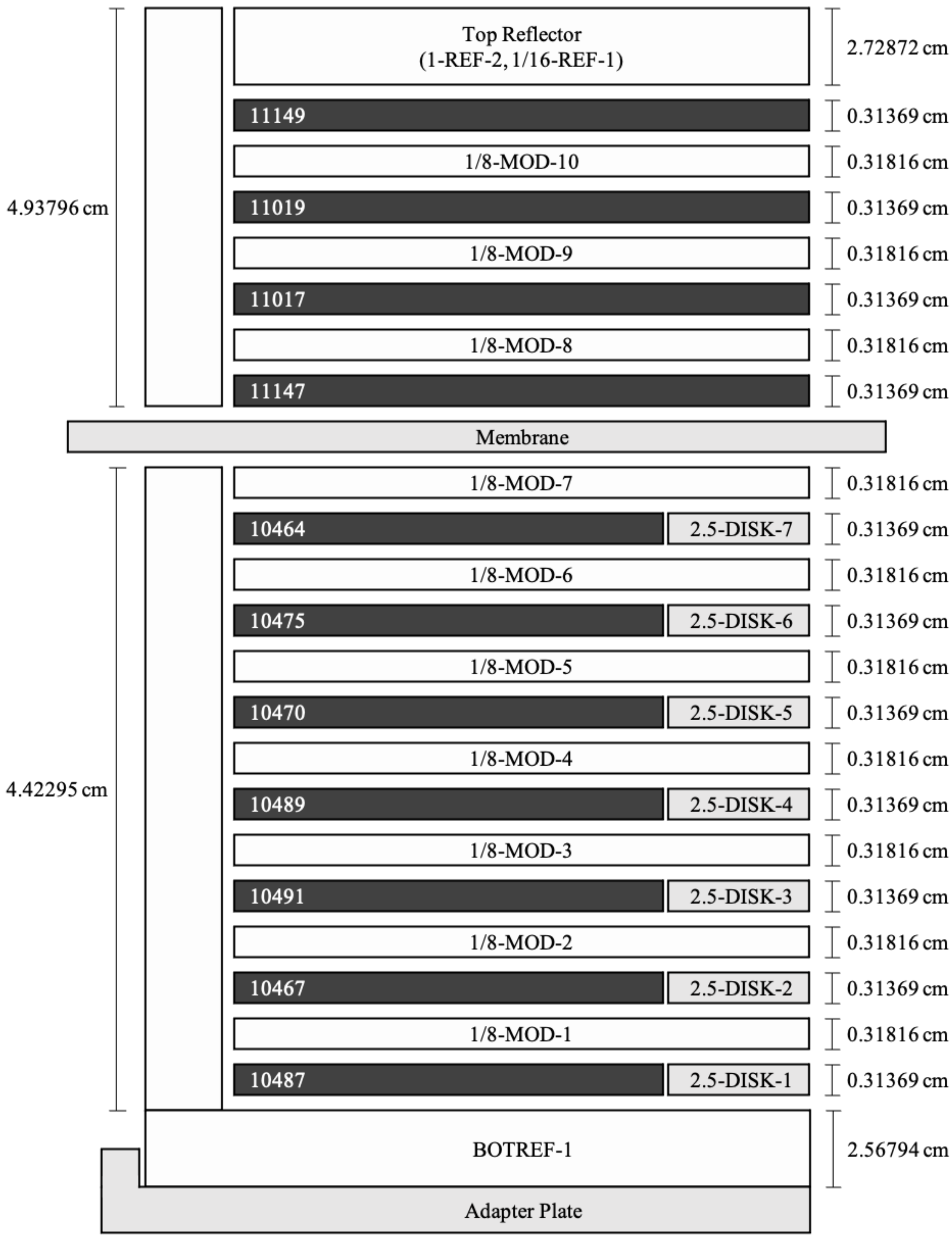


Figure 52. Diagram of the Case 2 simplified model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate and aluminum insert thicknesses. Gaps shown between parts are not necessarily present.

Table 187. Case 2 simplified model core stack dimensions.

<table>
<tr><th>Layer</th><th>Part ID</th><th>Density (g/cm^3)</th><th>Inner Radius (cm)</th><th>Outer Radius (cm)</th><th>Thickness (cm)</th><th>Lower z Plane (cm)</th><th>Upper z Plane (cm)</th></tr>
<tr><td>24</td><td>Top Reflector</td><td>0.94962</td><td>-</td><td>38.06989</td><td>2.72872</td><td>3.03474</td><td>5.76346</td></tr>
<tr><td>23</td><td>11149</td><td>18.08581</td><td>-</td><td>19.05000</td><td>0.31369</td><td>2.72105</td><td>3.03474</td></tr>
<tr><td>22</td><td>1/8-MOD-10</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>2.40289</td><td>2.72105</td></tr>
<tr><td>21</td><td>11019</td><td>18.08581</td><td>-</td><td>19.05000</td><td>0.31369</td><td>2.08920</td><td>2.40289</td></tr>
<tr><td>20</td><td>1/8-MOD-9</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>1.77104</td><td>2.08920</td></tr>
<tr><td>19</td><td>11017</td><td>18.08581</td><td>-</td><td>19.05000</td><td>0.31369</td><td>1.45735</td><td>1.77104</td></tr>
<tr><td>18</td><td>1/8-MOD-8</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>1.13919</td><td>1.45735</td></tr>
<tr><td>17</td><td>11147</td><td>18.08581</td><td>-</td><td>19.05000</td><td>0.31369</td><td>0.82550</td><td>1.13919</td></tr>
<tr><td>16</td><td>Membrane</td><td>2.65250</td><td colspan="2">See footnote (a).</td><td>0.31750</td><td>0.50800</td><td>0.82550</td></tr>
<tr><td>15</td><td>1/8-MOD-7</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>0.18984</td><td>0.50800</td></tr>
<tr><td rowspan="2">14</td><td>10464</td><td>18.12908</td><td>3.18770</td><td>19.05000</td><td>0.31369</td><td rowspan="2">-0.12385</td><td rowspan="2">0.18984</td></tr>
<tr><td>2.5-DISK-7</td><td>2.72257</td><td>-</td><td>3.04201</td><td>0.31369</td></tr>
<tr><td>13</td><td>1/8-MOD-6</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>-0.44201</td><td>-0.12385</td></tr>
<tr><td rowspan="2">12</td><td>10475</td><td>18.12908</td><td>3.18770</td><td>19.05000</td><td>0.31369</td><td rowspan="2">-0.75570</td><td rowspan="2">-0.44201</td></tr>
<tr><td>2.5-DISK-6</td><td>2.72257</td><td>-</td><td>3.04201</td><td>0.31369</td></tr>
<tr><td>11</td><td>1/8-MOD-5</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>-1.07386</td><td>-0.75570</td></tr>
<tr><td rowspan="2">10</td><td>10470</td><td>18.12908</td><td>3.18770</td><td>19.05000</td><td>0.31369</td><td rowspan="2">-1.38755</td><td rowspan="2">-1.07386</td></tr>
<tr><td>2.5-DISK-5</td><td>2.72257</td><td>-</td><td>3.04201</td><td>0.31369</td></tr>
<tr><td>9</td><td>1/8-MOD-4</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>-1.70571</td><td>-1.38755</td></tr>
<tr><td rowspan="2">8</td><td>10489</td><td>18.12908</td><td>3.18770</td><td>19.05000</td><td>0.31369</td><td rowspan="2">-2.01940</td><td rowspan="2">-1.70571</td></tr>
<tr><td>2.5-DISK-4</td><td>2.72257</td><td>-</td><td>3.04201</td><td>0.31369</td></tr>
<tr><td>7</td><td>1/8-MOD-3</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>-2.33756</td><td>-2.01940</td></tr>
<tr><td rowspan="2">6</td><td>10491</td><td>18.12908</td><td>3.18770</td><td>19.05000</td><td>0.31369</td><td rowspan="2">-2.65125</td><td rowspan="2">-2.33756</td></tr>
<tr><td>2.5-DISK-3</td><td>2.72257</td><td>-</td><td>3.04201</td><td>0.31369</td></tr>
<tr><td>5</td><td>1/8-MOD-2</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>-2.96941</td><td>-2.65125</td></tr>
<tr><td rowspan="2">4</td><td>10467</td><td>18.12908</td><td>3.18770</td><td>19.05000</td><td>0.31369</td><td rowspan="2">-3.28310</td><td rowspan="2">-2.96941</td></tr>
<tr><td>2.5-DISK-2</td><td>2.72257</td><td>-</td><td>3.04201</td><td>0.31369</td></tr>
<tr><td>3</td><td>1/8-MOD-1</td><td>0.94846</td><td>-</td><td>19.04398</td><td>0.31816</td><td>-3.60126</td><td>-3.28310</td></tr>
<tr><td rowspan="2">2</td><td>10487</td><td>18.12908</td><td>3.18770</td><td>19.05000</td><td>0.31369</td><td rowspan="2">-3.91495</td><td rowspan="2">-3.60126</td></tr>
<tr><td>2.5-DISK-1</td><td>2.72257</td><td>-</td><td>3.04201</td><td>0.31369</td></tr>
<tr><td>1</td><td>BOTREF-1</td><td>0.94700</td><td colspan="2">See Section 3.2.6.</td><td>2.56794</td><td>-6.48289</td><td>-3.91495</td></tr>
</table>

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 188. Case 2 simplified model reflector dimensions (see Section 3.2.5).

Part	Density (g/cm^3)	Inner Radius, b (cm)	Outer Radius, a (cm)	Height, c (cm)	Lower z Plane (cm)	Upper z Plane (cm)
Upper Reflector	0.94016	19.13759	21.69622	4.93796	0.82550[a]	5.76346
Lower Reflector	0.96360	19.13914	21.69617	4.42295	-3.91495[b]	0.50800[c]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 189. Case 2 simplified model lower movable platen axial positions.

Part		Density (g/cm^3)	Lower z Plane (cm)	Upper z Plane (cm)
Adapter Plate	Lip	2.7	-6.48289	-5.28909
	Plate		-7.82909	-6.48289[a]
Adapter Extension			-9.09909	-7.82909
			-26.87909	-9.09909
			-28.14909	-26.87909
Movable Platen			-30.68909	-28.14909

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.2.7.3 Case 3

Case 3 went critical with 8 HEU plates, 0.25 in (0.635 cm) nominal polyethylene moderator plates between each HEU plate, and a nominal 1.21875 in (3.095625 cm) top reflector. Figure 53 shows a cross sectional view of the detailed model. The aluminum parts (structural components, membrane, and inserts) are shown in yellow, the HEU plates in pink, and the polyethylene moderator plates and reflector in blue.

Figure 54 shows a diagram of the Case 3 detailed model. Table 190 provides a more detailed breakdown of the Case 3 detailed model core stack dimensions, including part densities (in g/cm^3), dimensions, and axial position. Table 191 provides similar details for the upper and lower reflector rings. Table 192 describes the axial positions of the Comet lower movable platen components specific to the Case 3 detailed model.

Figure 55, Table 194, Table 195, and Table 196 include the same information for the Case 3 simplified model. Table 193 summarizes the average part dimensions used in the Case 3 configuration. These dimensions are used to create the simplified core stack and reflector for the Case 3 simplified model.

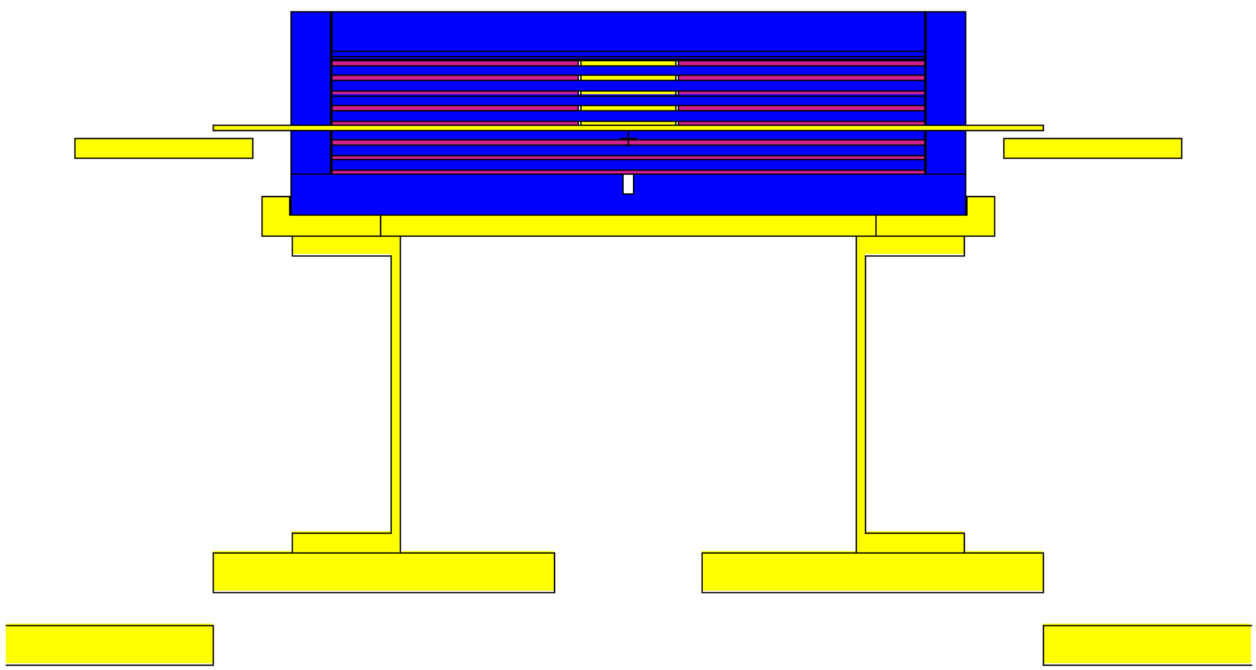


Figure 53. Case 3 detailed model.

3.2.7.3.1 Detailed Model

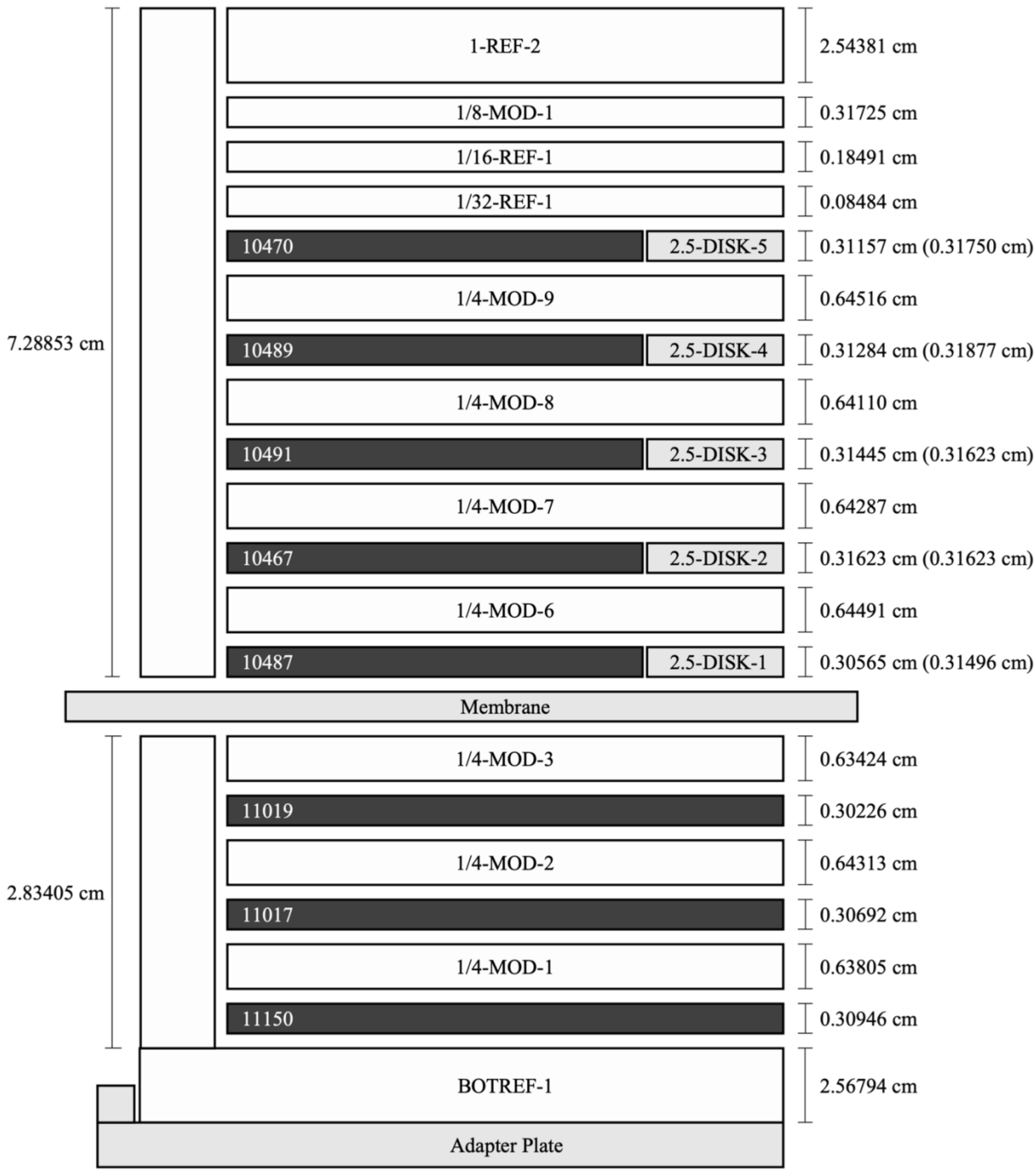


Figure 54. Diagram of the Case 3 detailed model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate thicknesses with aluminum insert thicknesses in parenthesis. Gaps shown between parts are not necessarily present.

Table 190. Case 3 detailed model core stack dimensions.

Layer	Part ID	Density (g/cm^3)	Inner Radius (cm)	Outer Radius (cm)	Thickness (cm)	Lower z Plane (cm)	Upper z Plane (cm)
21	1-REF-2	0.95564	-	19.03514	2.54381	5.57022	8.11403
20	1/8-MOD-1	0.94898	-	19.04340	0.31725	5.25297	5.57022
19	1/16-REF-1	0.86685	-	19.03197	0.18491	5.06806	5.25297
18	1/32-REF-1	0.87990	-	19.03832	0.08484	4.98323	5.06806
17	10470	18.18546	3.18770	19.05000	0.31157	4.66573	4.97730
	2.5-DISK-5	2.69828	-	3.04165	0.31750		4.98323
16	1/4-MOD-9	0.93792	-	19.03514	0.64516	4.02057	4.66573
15	10489	18.29855	3.18770	19.05000	0.31284	3.70180	4.01464
	2.5-DISK-4	2.68529	-	3.04292	0.31877		4.02057
14	1/4-MOD-8	0.94476	-	19.03159	0.64110	3.06070	3.70180
13	10491	18.34441	3.18770	19.05000	0.31445	2.74447	3.05892
	2.5-DISK-3	2.68512	-	3.04292	0.31623		3.06070
12	1/4-MOD-7	0.94121	-	19.03006	0.64287	2.10160	2.74447
11	10467	18.07975	3.18770	19.05000	0.31623	1.78537	2.10160
	2.5-DISK-2	2.69655	-	3.04260	0.31623		2.10160
10	1/4-MOD-6	0.93678	-	19.03247	0.64491	1.14046	1.78537
9	10487	18.52598	3.18770	19.05000	0.30565	0.82550	1.13115
	2.5-DISK-1	2.68839	-	3.04102	0.31496		1.14046
8	Membrane	2.65250	See footnote (a).		0.31750	0.50800	0.82550
7	1/4-MOD-3	0.95334	-	19.03133	0.63424	-0.12624	0.50800
6	11019	18.77517	-	19.05000	0.30226	-0.42850	-0.12624
5	1/4-MOD-2	0.94150	-	19.03298	0.64313	-1.07163	-0.42850
4	11017	18.58061	-	19.05000	0.30692	-1.37854	-1.07163
3	1/4-MOD-1	0.95035	-	19.03463	0.63805	-2.01659	-1.37854
2	11150	18.16932	-	19.05000	0.30946	-2.32605	-2.01659
1	BOTREF-1	0.94700	See Section 3.2.6.		2.56794	-4.89399	-2.32605

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 191. Case 3 detailed model reflector dimensions (see Section 3.2.5).

Part	Density (g/cm^3)	Inner Radius, b (cm)	Outer Radius, a (cm)	Height, c (cm)	Lower z Plane (cm)	Upper z Plane (cm)
Upper Reflector	0.95254	19.13235	21.69122	7.28853	0.82550[(a)]	8.11403
Lower Reflector	0.97332	19.14026	21.69560	2.83405	-2.32605[(b)]	0.50800[(c)]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 192. Case 3 detailed model lower movable platen axial positions.

<table>
<tr><th colspan="2">Part</th><th>Density (g/cm^3)</th><th>Lower z Plane (cm)</th><th>Upper z Plane (cm)</th></tr>
<tr><td rowspan="2">Adapter Plate</td><td>Lip</td><td rowspan="6">2.7</td><td>-4.89399</td><td>-3.70019</td></tr>
<tr><td>Plate</td><td>-6.24019</td><td>-4.89399[(a)]</td></tr>
<tr><td colspan="2" rowspan="3">Adapter Extension</td><td>-7.51019</td><td>-6.24019</td></tr>
<tr><td>-25.29019</td><td>-7.51019</td></tr>
<tr><td>-26.56019</td><td>-25.29019</td></tr>
<tr><td colspan="2">Movable Platen</td><td>-29.10019</td><td>-26.56019</td></tr>
</table>

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.2.7.3.2 Simplified Model

Table 193. Average part dimensions for Case 3 simplified model core stack.

Part Type	N	Thickness (cm)	Inner Diameter (cm)	Outer Diameter (cm)	Volume (cm^3)	Density (g/cm^3)
Top Reflector	4	3.13080	-	38.07178	3564.1	0.94767
HEU1	3	0.31279	-	38.10000	356.6	18.11681
HEU2	5		6.37540	38.10000	346.6	18.24793
2.5-DISK	5		-	6.08444	9.1	2.72469
1/4-MOD	7	0.64189	-	38.06469	730.5	0.94366
BOTREF	1	2.56794	-	43.37329	3793.7	0.94700

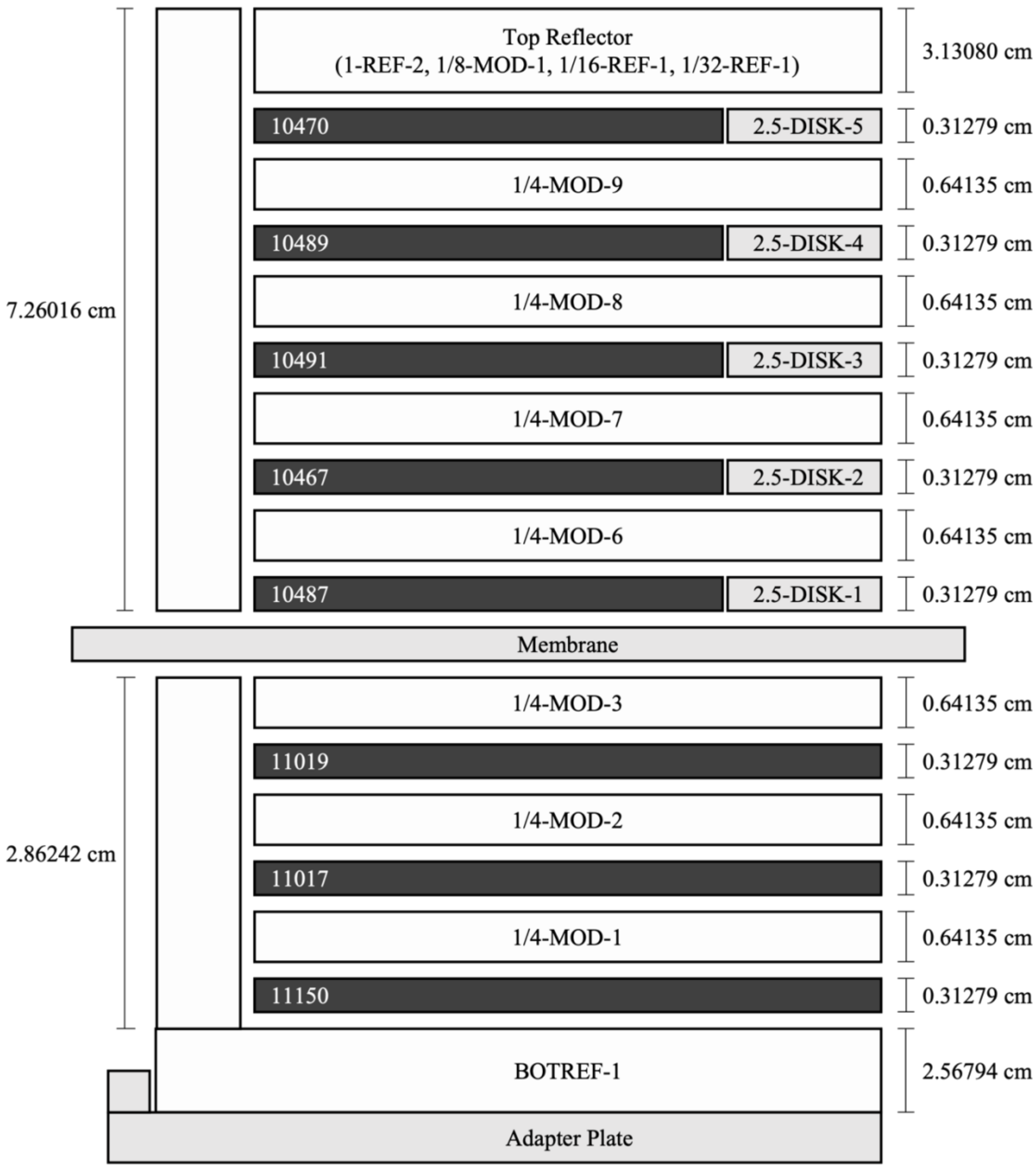


Figure 55. Diagram of the Case 3 simplified model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate and aluminum insert thicknesses. Gaps shown between parts are not necessarily present.

Table 194. Case 3 simplified model core stack dimensions.

Layer	Part ID	Density (g/cm^3)	Inner Radius (cm)	Outer Radius (cm)	Thickness (cm)	Lower z Plane (cm)	Upper z Plane (cm)
18	Top Reflector	0.94767	-	38.07178	3.13080	4.95485	8.08566
17	10470	18.11470	3.18770	19.05000	0.31279	4.64206	4.95485
	2.5-DISK-5	2.73788	-	3.04222	0.31279		
16	1/4-MOD-9	0.94374	-	19.03260	0.64135	4.00071	4.64206
15	10489	18.30165	3.18770	19.05000	0.31279	3.68792	4.00071
	2.5-DISK-4	2.73788	-	3.04222	0.31279		
14	1/4-MOD-8	0.94429	-	19.03260	0.64135	3.04657	3.68792
13	10491	18.44186	3.18770	19.05000	0.31279	2.73378	3.04657
	2.5-DISK-3	2.71589	-	3.04222	0.31279		
12	1/4-MOD-7	0.94319	-	19.03260	0.64135	2.09243	2.73378
11	10467	18.27857	3.18770	19.05000	0.31279	1.77964	2.09243
	2.5-DISK-2	2.72688	-	3.04222	0.31279		
10	1/4-MOD-6	0.94196	-	19.03260	0.64135	1.13829	1.77964
9	10487	18.10287	3.18770	19.05000	0.31279	0.82550	1.13829
	2.5-DISK-1	2.70489	-	3.04222	0.31279		
8	Membrane	2.65250	See footnote (a).		0.31750	0.50800	0.82550
7	1/4-MOD-3	0.94264	-	19.03260	0.64135	-0.13335	0.50800
6	11019	18.14308	-	19.05000	0.31279	-0.44614	-0.13335
5	1/4-MOD-2	0.94415	-	19.03260	0.64135	-1.08749	-0.44614
4	11017	18.23169	-	19.05000	0.31279	-1.40028	-1.08749
3	1/4-MOD-1	0.94566	-	19.03260	0.64135	-2.04163	-1.40028
2	11150	17.97567	-	19.05000	0.31279	-2.35442	-2.04163
1	BOTREF-1	0.94700	See Section 3.2.6.		2.56794	-4.92236	-2.35442

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 195. Case 3 simplified model reflector dimensions (see Section 3.2.5).

Part	Density (g/cm^3)	Inner Radius, b (cm)	Outer Radius, a (cm)	Height, c (cm)	Lower z Plane (cm)	Upper z Plane (cm)
Upper Reflector	0.95626	19.13235	21.69122	7.26016	0.82550[a]	8.08566
Lower Reflector	0.96367	19.14026	21.69560	2.86405	-2.35442[b]	0.50800[c]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 196. Case 3 simplified model lower movable platen axial positions.

Part		Density (g/cm^3)	Lower z Plane (cm)	Upper z Plane (cm)
Adapter Plate	Lip	2.7	-4.92236	-3.72856
	Plate		-6.26856	-4.92236[a]
Adapter Extension			-7.53856	-6.26856
			-25.31856	-7.53856
			-26.58856	-25.31856
Movable Platen			-29.12856	-26.58856

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.2.7.4 Case 4

Case 4 went critical with 5 HEU plates, 0.5 in (1.27 cm) nominal polyethylene moderator plates between each HEU plate, and a nominal 1.65625 in (4.206875 cm). Figure 56shows a cross sectional view of the detailed model. The aluminum parts (structural components, membrane, and inserts) are shown in yellow, the HEU plates in pink, and the polyethylene moderator plates and reflector in blue.

Figure 57 shows a diagram of the Case 4 detailed model. Table 197 provides a more detailed breakdown of the Case 4 detailed model core stack dimensions, including part densities (in g/cm^3), dimensions, and axial position. Table 198 provides similar details for the upper and lower reflector rings. Table 199 describes the axial positions of the Comet lower movable platen components specific to the Case 4 detailed model.

Figure 58, Table 201, Table 202, and Table 203 include the same information for the Case 4 simplified model. Table 200 summarizes the average part dimensions used in the Case 4 configuration. These dimensions are used to create the simplified core stack and reflector for the Case 4 simplified model.

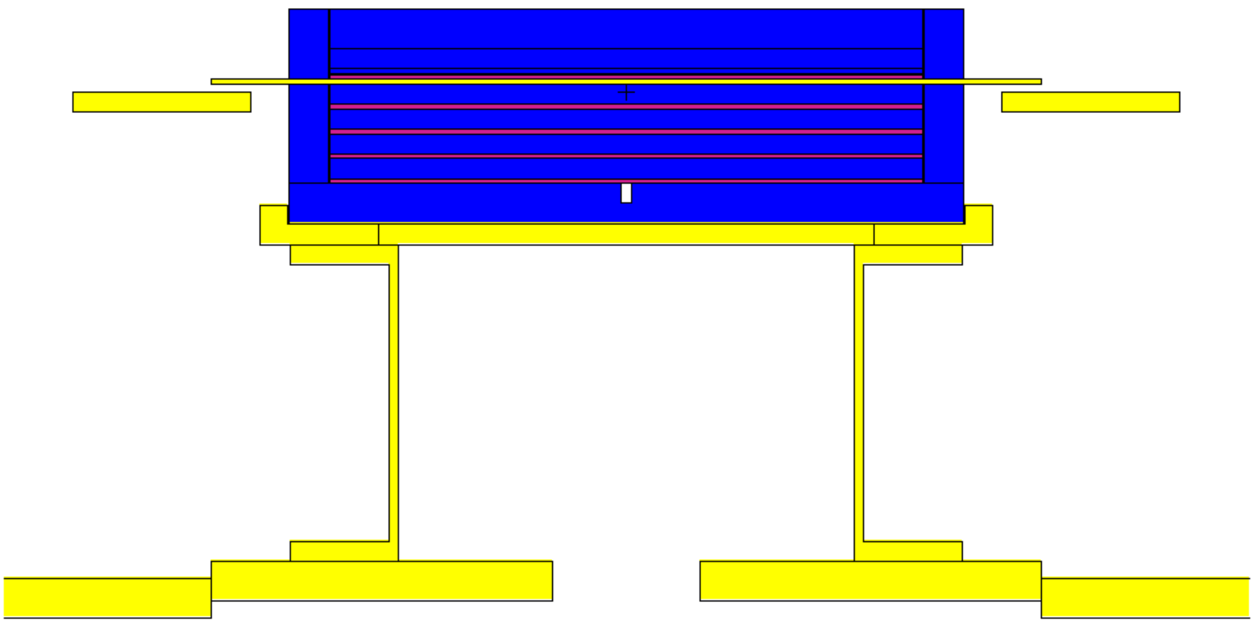


Figure 56. Case 4 detailed model.

3.2.7.4.1 Detailed Model

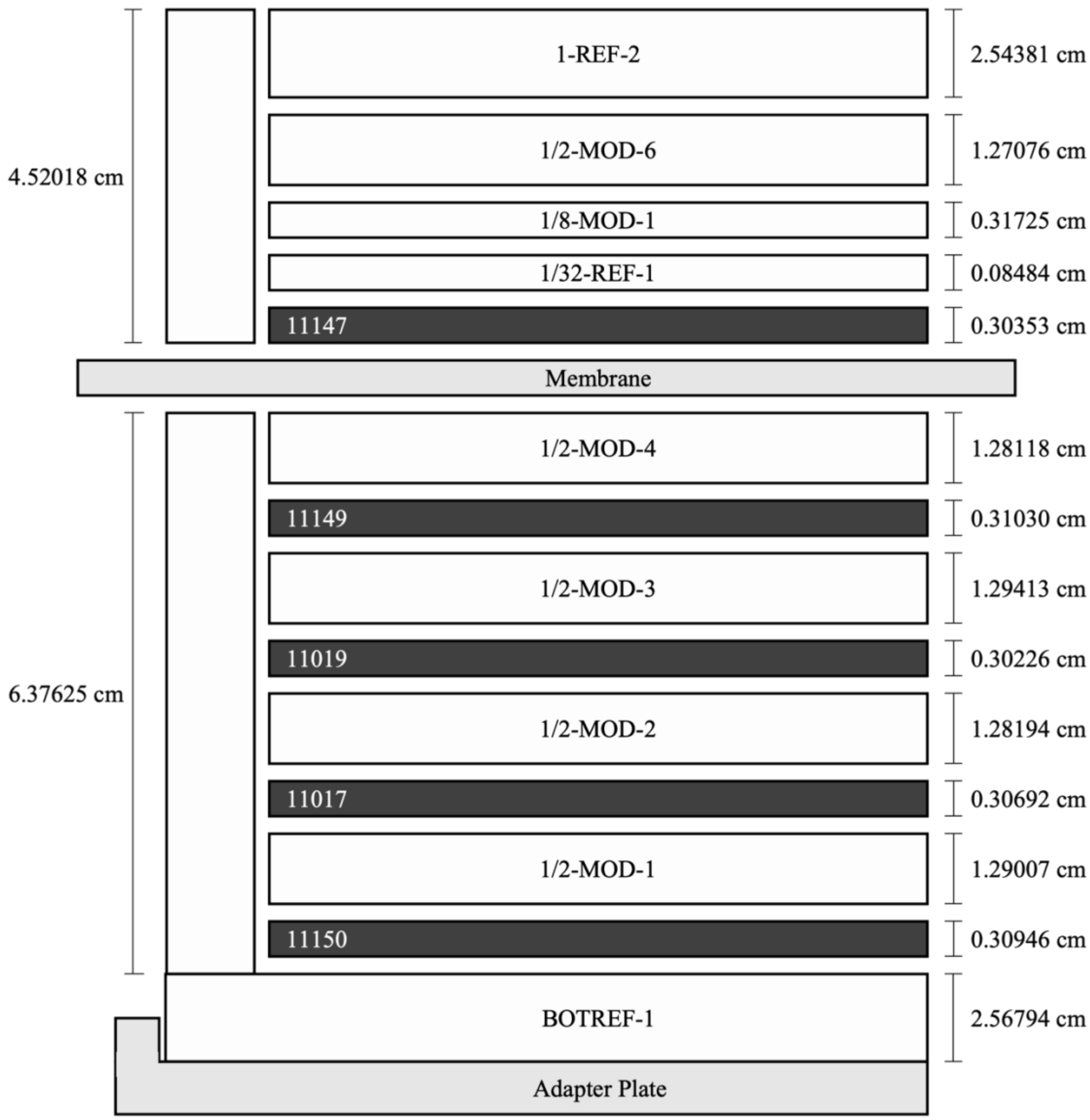


Figure 57. Diagram of the Case 4 detailed model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate thicknesses with aluminum insert thicknesses in parenthesis. Gaps shown between parts are not necessarily present.

Table 197. Case 4 detailed model core stack dimensions.

Layer	Part ID	Density (g/cm^3)	Inner Radius (cm)	Outer Radius (cm)	Thickness (cm)	Lower z Plane (cm)	Upper z Plane (cm)
15	1-REF-2	0.95564	-	19.03514	2.54381	2.80187	5.34568
14	1/2-MOD-6	0.95242	-	19.03857	1.27076	1.53111	2.80187
13	1/8-MOD-1	0.94898	-	19.04340	0.31725	1.21387	1.53111
12	1/32-REF-1	0.87990	-	19.03832	0.08484	1.12903	1.21387
11	11147	18.83329	-	19.05000	0.30353	0.82550	1.12903
10	Membrane	2.65250	See footnote (a).		0.31750	0.50800	0.82550
9	1/2-MOD-4	0.94441	-	19.04060	1.28118	-0.77318	0.50800
8	11149	18.04427	-	19.05000	0.31030	-1.08348	-0.77318
7	1/2-MOD-3	0.93979	-	19.03908	1.29413	-2.37761	-1.08348
6	11019	18.77517	-	19.05000	0.30226	-2.67987	-2.37761
5	1/2-MOD-2	0.94386	-	19.03844	1.28194	-3.96181	-2.67987
4	11017	18.58061	-	19.05000	0.30692	-4.26872	-3.96181
3	1/2-MOD-1	0.93778	-	19.04048	1.29007	-5.55879	-4.26872
2	11150	18.16932	-	19.05000	0.30946	-5.86825	-5.55879
1	BOTREF-1	0.94700	See Section 3.2.6.		2.56794	-8.43619	-5.86825

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 198. Case 4 detailed model reflector dimensions (see Section 3.2.5).

Part	Density (g/cm^3)	Inner Radius, b (cm)	Outer Radius, a (cm)	Height, c (cm)	Lower z Plane (cm)	Upper z Plane (cm)
Upper Reflector	0.94191	19.13684	21.69491	4.52018	0.82550[a]	5.34568
Lower Reflector	0.95882	19.13595	21.69440	6.37625	-5.86825[b]	0.50800[c]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 199. Case 4 detailed model lower movable platen axial positions.

Part		Density (g/cm^3)	Lower z Plane (cm)	Upper z Plane (cm)
Adapter Plate	Lip	2.7	-8.43619	-7.24239
	Plate		-9.78239	-8.43619[a]
Adapter Extension			-11.05239	-9.78239
			-28.83239	-11.05239
			-30.10239	-28.83239
Movable Platen			-32.64239	-30.10239

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.2.7.4.2 Simplified Model

Table 200. Average part dimensions for Case 4 simplified model core stack.

Part Type	N	Thickness (cm)	Inner Diameter (cm)	Outer Diameter (cm)	Volume (cm^3)	Density (g/cm^3)
Top Reflector	4	4.21665	-	38.07370	4800.7	0.95264
HEU1	5	0.30649	-	38.10000	349.4	18.47738
1/2-MOD	4	1.28683	-	38.07930	1465.5	0.94145
BOTREF	1	2.56794	-	43.37329	3793.7	0.94700

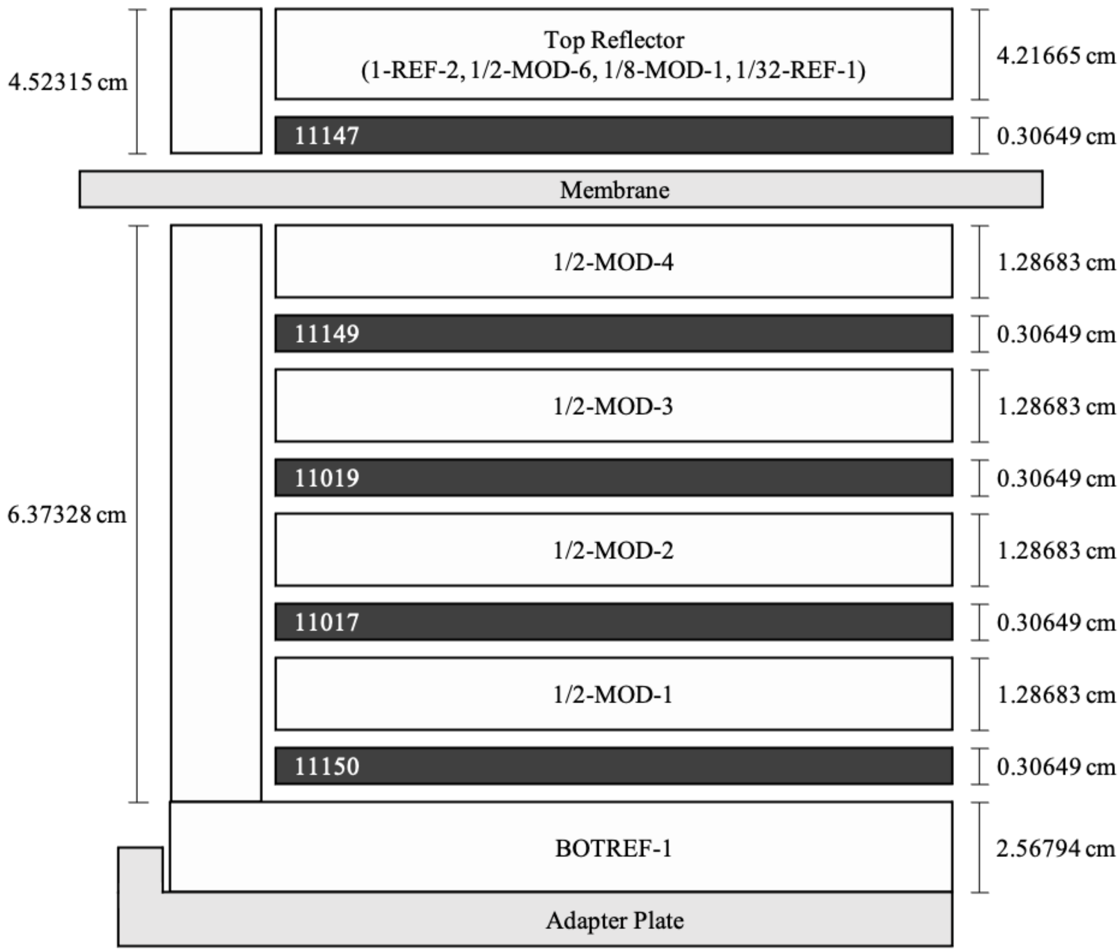


Figure 58. Diagram of the Case 4 simplified model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate and aluminum insert thicknesses. Gaps shown between parts are not necessarily present.

Table 201. Case 4 simplified model core stack dimensions.

Layer	Part ID	Density (g/cm^3)	Inner Radius (cm)	Outer Radius (cm)	Thickness (cm)	Lower z Plane (cm)	Upper z Plane (cm)
12	Top Reflector	0.95264	-	19.03685	4.21665	1.13199	5.34865
11	11147	18.47738	-	19.05000	0.30649	0.82550	1.13199
10	Membrane	2.65250	See footnote (a).		0.31750	0.50800	0.82550
9	1/2-MOD-4	0.94145	-	19.03965	1.28683	-0.77883	0.50800
8	11149	18.47738	-	19.05000	0.30649	-1.08532	-0.77883
7	1/2-MOD-3	0.94145	-	19.03965	1.28683	-2.37215	-1.08532
6	11019	18.47738	-	19.05000	0.30649	-2.67864	-2.37215
5	1/2-MOD-2	0.94145	-	19.03965	1.28683	-3.96547	-2.67864
4	11017	18.47738	-	19.05000	0.30649	-4.27196	-3.96547
3	1/2-MOD-1	0.94145	-	19.03965	1.28683	-5.55879	-4.27196
2	11150	18.47738	-	19.05000	0.30649	-5.86528	-5.55879
1	BOTREF-1	0.94700	See Section 3.2.6.		2.56794	-8.43322	-5.86528

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 202. Case 4 simplified model reflector dimensions (see Section 3.2.5).

Part	Density (g/cm^3)	Inner Radius, b (cm)	Outer Radius, a (cm)	Height, c (cm)	Lower z Plane (cm)	Upper z Plane (cm)
Upper Reflector	0.94130	19.13684	21.69491	4.52315	0.82550[(a)]	5.34865
Lower Reflector	0.95927	19.13595	21.69440	6.37328	-5.86528[(b)]	0.50800[(c)]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 203. Case 4 simplified model lower movable platen axial positions.

<table>
<tr><th colspan="2">Part</th><th>Density (g/cm^3)</th><th>Lower z Plane (cm)</th><th>Upper z Plane (cm)</th></tr>
<tr><td rowspan="2">Adapter Plate</td><td>Lip</td><td rowspan="6">2.7</td><td>-8.43322</td><td>-7.23942</td></tr>
<tr><td>Plate</td><td>-9.77942</td><td>-8.43322[(a)]</td></tr>
<tr><td colspan="2" rowspan="3">Adapter Extension</td><td>-11.04942</td><td>-9.77942</td></tr>
<tr><td>-28.82942</td><td>-11.04942</td></tr>
<tr><td>-30.09942</td><td>-28.82942</td></tr>
<tr><td colspan="2">Movable Platen</td><td>-32.63942</td><td>-30.09942</td></tr>
</table>

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.2.7.5 Case 5

Case 5 went critical with 5 HEU plates, 1.5 in (3.81 cm) nominal polyethylene moderator plates between each HEU plate, and a nominal 1.125 in (2.8575 cm) top reflector. Figure 59 shows a cross sectional view of the detailed model. The aluminum parts (structural components, membrane, and inserts) are shown in yellow, the HEU plates in pink, and the polyethylene moderator plates and reflector in blue.

Figure 60 shows a diagram of the Case 4 detailed model. Table 204 provides a more detailed breakdown of the Case 4 detailed model core stack dimensions, including part densities (in g/cm^3), dimensions, and axial position. Table 205 provides similar details for the upper and lower reflector rings. Table 206 describes the axial positions of the Comet lower movable platen components specific to the Case 4 detailed model.

Figure 58, Table 208, Table 209, and Table 210 include the same information for the Case 4 simplified model. Table 207summarizes the average part dimensions used in the Case 4 configuration. These dimensions are used to create the simplified core stack and reflector for the Case 4 simplified model.

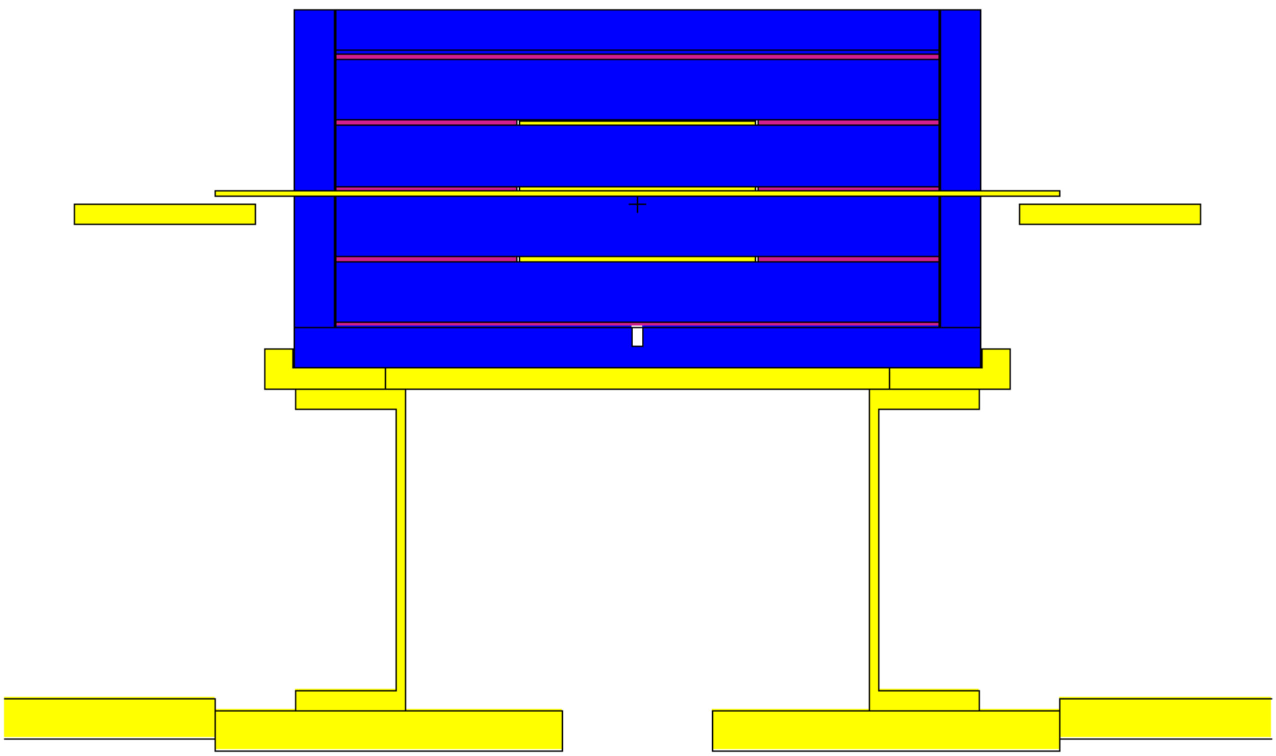


Figure 59. Case 5 detailed model.

3.2.7.5.1 Detailed Model

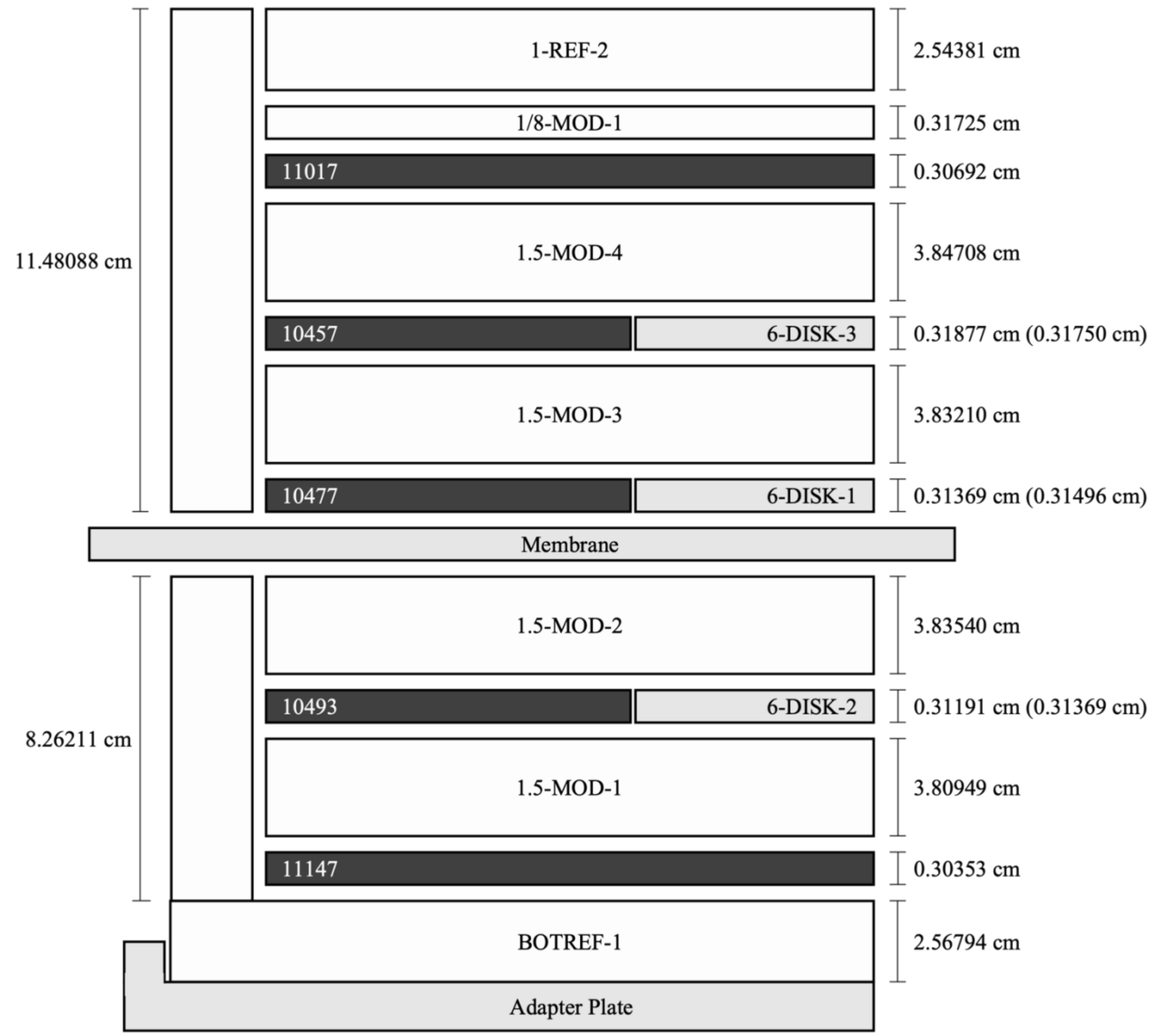


Figure 60. Diagram of the Case 5 detailed model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate thicknesses with aluminum insert thicknesses in parenthesis. Gaps shown between parts are not necessarily present.

Table 204. Case 5 detailed model core stack dimensions.

Layer	Part ID	Density (g/cm^3)	Inner Radius (cm)	Outer Radius (cm)	Thickness (cm)	Lower z Plane (cm)	Upper z Plane (cm)
13	1-REF-2	0.95564	-	19.03514	2.54381	9.76257	12.30638
12	1/8-MOD-1	0.94898	-	19.04340	0.31725	9.44533	9.76257
11	11017	18.58061	-	19.05000	0.30692	9.13841	9.44533
10	1.5-MOD-4	0.94372	-	19.04314	3.84708	5.29133	9.13841
9	10457	18.26485	7.62635	19.05000	0.31877	4.97256	5.29133
	6-DISK-3	2.70544	-	7.48284	0.31750		5.29006
8	1.5-MOD-3	0.94445	-	19.04848	3.83210	1.14046	4.97256
7	10477	18.31124	7.62635	19.05000	0.31369	0.82550	1.13919
	6-DISK-1	2.70376	-	7.48538	0.31496		1.14046
6	Membrane	2.65250	See footnote (a).		0.31750	0.50800	0.82550
5	1.5-MOD-2	0.94593	-	19.04149	3.83540	-3.32740	0.50800
4	10493	18.20799	7.62635	19.05000	0.31191	-3.64109	-3.32918
	6-DISK-2	2.71339	-	7.48221	0.31369		-3.32740
3	1.5-MOD-1	0.95526	-	19.05445	3.80949	-7.45058	-3.64109
2	11147	18.83329	-	19.05000	0.30353	-7.75411	-7.45058
1	BOTREF-1	0.94700	See Section 3.2.6.		2.56794	-10.32205	-7.75411

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 205. Case 5 detailed model reflector dimensions (see Section 3.2.5).

Part	Density (g/cm^3)	Inner Radius, b (cm)	Outer Radius, a (cm)	Height, c (cm)	Lower z Plane (cm)	Upper z Plane (cm)
Upper Reflector	0.95116	19.15706	21.70044	11.48088	0.82550[(a)]	12.30638
Lower Reflector	0.96864	19.16220	21.70361	8.26211	-7.75411[(b)]	0.50800[(c)]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 206. Case 5 detailed model lower movable platen axial positions.

Part		Density (g/cm^3)	Lower z Plane (cm)	Upper z Plane (cm)
Adapter Plate	Lip	2.7	-10.32205	-9.12825
	Plate		-11.66825	-10.32205[(a)]
Adapter Extension			-12.93825	-11.66825
			-30.71825	-12.93825
			-31.98825	-30.71825
Movable Platen			-34.52825	-31.98825

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.2.7.5.2 Simplified Model

Table 207. Average part dimensions for Case 5 simplified model core stack.

Part Type	N	Thickness (cm)	Inner Diameter (cm)	Outer Diameter (cm)	Volume (cm^3)	Density (g/cm^3)
Top Reflector	2	2.86106	-	38.07210	3257.1	0.95490
HEU1	2	0.31157	-	38.10000	355.2	18.32501
HEU4	3		15.25270	38.10000	298.3	18.45005
6-DISK	3		-	14.96695	54.8	2.74062
1.5-MOD	4	3.83102	-	38.09378	4366.3	0.94733
BOTREF	1	2.56794	-	43.37329	3793.7	0.94700

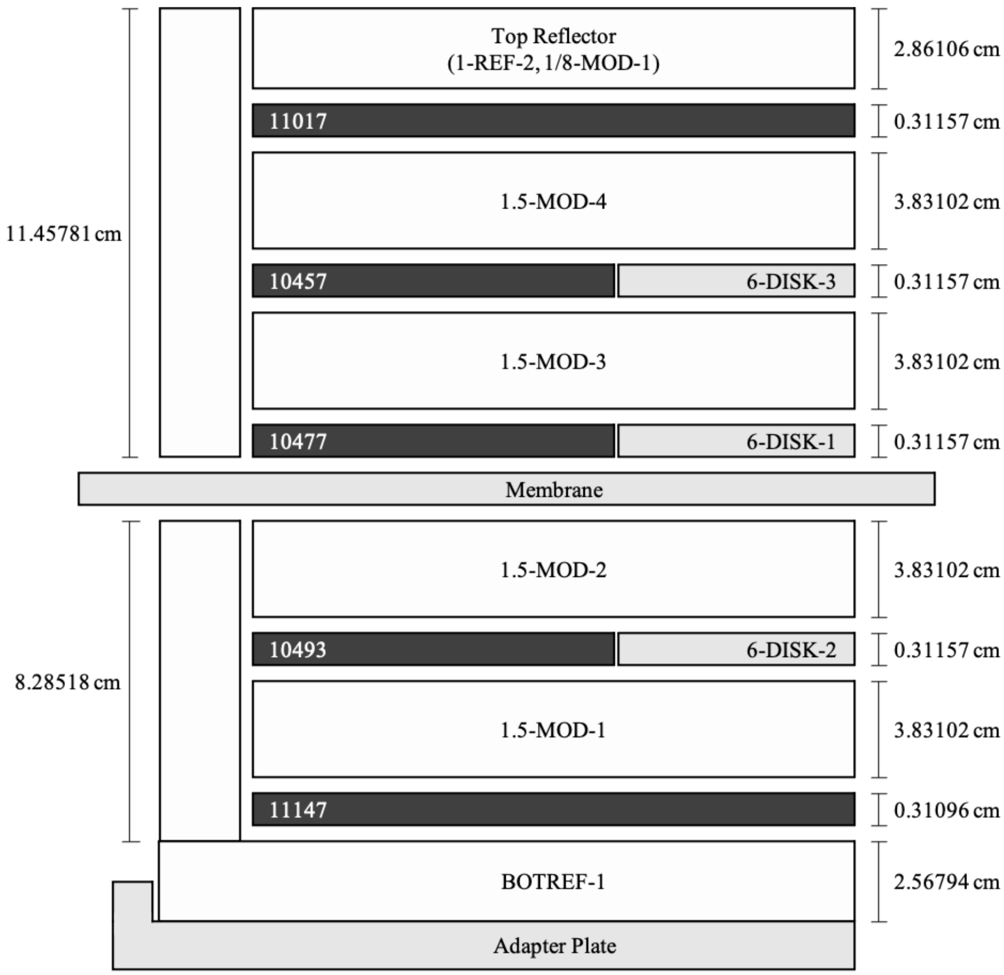


Figure 61. Diagram of the Case 5 simplified model configuration (figure not to scale). The left-hand measurements are the reflector heights, and the right-hand measurements are the plate and aluminum insert thicknesses. Gaps shown between parts are not necessarily present.

Table 208. Case 5 simplified model core stack dimensions.

Layer	Part ID	Density (g/cm^3)	Inner Radius (cm)	Outer Radius (cm)	Thickness (cm)	Lower z Plane (cm)	Upper z Plane (cm)
12	Top Reflector	0.95490	-	19.03605	2.86106	9.42226	12.28331
11	11017	18.32501	-	19.05000	0.31157	9.11068	9.42226
10	1.5-MOD-4	0.94733	-	19.04689	3.83102	5.27967	9.11068
9	10457	18.45005	7.62635	19.05000	0.31157	4.96809	5.27967
	6-DISK-3	2.74062	-	7.48348	0.31157		
8	1.5-MOD-3	0.94733	-	19.04689	3.83102	1.13707	4.96809
7	10477	18.45005	7.62635	19.05000	0.31157	0.82550	1.13707
	6-DISK-1	2.74062	-	7.48348	0.31157		
6	Membrane	2.65250	See footnote (a).		0.31750	0.50800	0.82550
5	1.5-MOD-2	0.94733	-	19.04689	3.83102	-3.32302	0.50800
4	10493	18.45005	7.62635	19.05000	0.31157	-3.63459	-3.32302
	6-DISK-2	2.74062	-	7.48348	0.31157		
3	1.5-MOD-1	0.94733	-	19.04689	3.83102	-7.46561	-3.63459
2	11147	18.32501	-	19.05000	0.31157	-7.77718	-7.46561
1	BOTREF-1	0.94700	See Section 3.2.6.		2.56794	-10.34512	-7.77718

(a) The membrane is a 53.34 cm by 53.34 cm square sheet.

Table 209. Case 5 simplified model reflector dimensions (see Section 3.2.5).

Part	Density (g/cm^3)	Inner Radius, b (cm)	Outer Radius, a (cm)	Height, c (cm)	Lower z Plane (cm)	Upper z Plane (cm)
Upper Reflector	0.95307	19.15706	21.70044	11.45781	0.82550[a]	12.28331
Lower Reflector	0.96594	19.16220	21.70361	8.28518	-7.77718[b]	0.50800[c]

(a) This plane is the top of the membrane.
(b) This plane is the top of the bottom reflector (BOTREF-1).
(c) This plane is the bottom of the membrane.

Table 210. Case 5 simplified model lower movable platen axial positions.

Part		Density (g/cm^3)	Lower z Plane (cm)	Upper z Plane (cm)
Adapter Plate	Lip	2.7	-10.34512	-9.15132
	Plate		-11.69132	-10.34512[a]
Adapter Extension			-12.96132	-11.69132
			-30.74132	-12.96132
			-32.01132	-30.74132
Movable Platen			-34.55132	-32.01132

(a) This is the plane the lower half of the experiment sits on (the base of BOTREF-1).

3.3 Material Data

3.3.1 Highly Enriched Uranium

The HEU plates are modeled with a ^{235}U enrichment of 93.232%, by weight. The impurities were removed from the HEU as the uncertainty analysis in Section 2.2.2 determined their contribution to k_{eff} was negligible. Table 211 reports the elemental and isotopic composition of the HEU material used across all models. Table 212 reports the atom densities for the HEU plates used in the detailed models. Table 213 reports the atom densities for the HEU plates used in the simplified models, averaged across each part type as described in Section 3.1.1.7.

Table 211. HEU elemental and isotopic composition used in all models.

Element	Wt.%	Isotope	Wt.%	At.%
U	1.0000E+02	^{234}U	1.0305E+00	1.0356E+00
		^{235}U	9.3232E+01	9.3294E+01
		^{236}U	2.3220E-01	2.3137E-01
		^{238}U	5.5050E+00	5.4390E+00

Table 212. HEU plate atom densities by part used in detailed models.

Part ID	Atom Density (atoms-b/cm)				
	^{234}U	^{235}U	^{236}U	^{238}U	Total
10463	5.06790E-04	4.56567E-02	1.13229E-04	2.66179E-03	4.89385E-02
10472	4.84785E-04	4.36743E-02	1.08312E-04	2.54621E-03	4.68137E-02
10479	4.90796E-04	4.42159E-02	1.09655E-04	2.57779E-03	4.73941E-02
10457	4.84289E-04	4.36297E-02	1.08202E-04	2.54361E-03	4.67658E-02
10477	4.85519E-04	4.37405E-02	1.08476E-04	2.55007E-03	4.68845E-02
10493	4.82782E-04	4.34938E-02	1.07865E-04	2.53569E-03	4.66202E-02
11018	4.91343E-04	4.42652E-02	1.09778E-04	2.58066E-03	4.74470E-02
10464	4.93346E-04	4.44456E-02	1.10225E-04	2.59118E-03	4.76403E-02
10467	4.79381E-04	4.31875E-02	1.07105E-04	2.51783E-03	4.62918E-02
10470	4.82184E-04	4.34400E-02	1.07731E-04	2.53255E-03	4.65625E-02
10475	4.56703E-04	4.11444E-02	1.02038E-04	2.39872E-03	4.41019E-02
10487	4.91213E-04	4.42534E-02	1.09748E-04	2.57997E-03	4.74344E-02
10489	4.85183E-04	4.37102E-02	1.08401E-04	2.54830E-03	4.68520E-02
10491	4.86399E-04	4.38197E-02	1.08673E-04	2.55469E-03	4.69695E-02
11017	4.92661E-04	4.43839E-02	1.10072E-04	2.58758E-03	4.75742E-02
11019	4.97820E-04	4.48487E-02	1.11225E-04	2.61468E-03	4.80724E-02
11147	4.99361E-04	4.49875E-02	1.11569E-04	2.62277E-03	4.82212E-02
11149	4.78441E-04	4.31028E-02	1.06895E-04	2.51289E-03	4.62010E-02
11150	4.81756E-04	4.34015E-02	1.07636E-04	2.53030E-03	4.65212E-02

Table 213. HEU plate atom densities by part type used in simplified models.

Part Type		**Atom Density (atoms-b/cm)**				
		^{234}U	^{235}U	^{236}U	^{238}U	**Total**
Full (HEU1)	Case 1	4.77497E-04	4.30178E-02	1.06684E-04	2.50794E-03	4.61099E-02
	Case 2	4.79542E-04	4.32020E-02	1.07141E-04	2.51867E-03	4.63073E-02
	Case 3	4.80364E-04	4.32760E-02	1.07325E-04	2.52299E-03	4.63867E-02
	Case 4	4.89924E-04	4.41373E-02	1.09461E-04	2.57321E-03	4.73099E-02
	Case 5	4.85884E-04	4.37734E-02	1.08558E-04	2.55199E-03	4.69198E-02
2.5” (HEU2)	Case 1	4.79497E-04	4.31979E-02	1.07131E-04	2.51844E-03	4.63030E-02
	Case 2	4.80689E-04	4.33053E-02	1.07397E-04	2.52470E-03	4.64181E-02
	Case 3	4.83840E-04	4.35892E-02	1.08101E-04	2.54125E-03	4.67224E-02
6” (HEU4)	Case 1	4.81752E-04	4.34011E-02	1.07635E-04	2.53028E-03	4.65208E-02
	Case 5	4.89200E-04	4.40720E-02	1.09299E-04	2.56940E-03	4.72399E-02
10” (HEU5)	Case 1	4.78820E-04	4.31369E-02	1.06980E-04	2.51488E-03	4.62376E-02

3.3.2 Polyethylene

The polyethylene parts are modeled as CH_2. The impurities were removed from the polyethylene as the uncertainty analysis in Section 2.2.3 determined their contribution to k_{eff} was negligible. Table 214 reports the elemental and isotopic composition of the polyethylene material used across all models. Table 216 reports the atom densities for the polyethylene parts used in the detailed models. Table 214 reports the atom densities for the polyethylene parts used in the simplified models, averaged across each part type as described in Section 3.1.1.7. Table 217 and Table 218 report the polyethylene reflector components, including the top and bottom reflector plates and upper and lower reflector rings, used in the detailed and simplified models, respectively.

Table 214. Polyethylene elemental and isotopic composition used in all models.

Element	Wt.%	Isotope	Wt.%	At.%
H	1.4371E+01	^{1}H	1.4369E+01	6.6661E+01
		^{2}H	2.1557E-03	5.0040E-03
C	8.5629E+01	^{12}C	8.4687E+01	3.2996E+01
		^{13}C	9.4192E-01	3.3867E-01

Table 215. Polyethylene moderator plate atom densities by part type used in simplified models.

Part Type		Atom Density (atoms-b/cm)		
		H	C	Total
1/8-MOD	Case 2	8.14402E-02	4.07201E-02	1.22160E-01
1/4-MOD	Case 3	8.10280E-02	4.05140E-02	1.21542E-01
1/2-MOD	Case 4	8.08381E-02	4.04190E-02	1.21257E-01
1.5-MOD	Case 5	8.13428E-02	4.06714E-02	1.22014E-01

Table 216. Polyethylene moderator and reflector plate atom densities by part used in detailed models.

Part ID	Atom Density (atoms-b/cm)		
	H	C	Total
1/8-MOD-1	8.14841E-02	4.07421E-02	1.22226E-01
1/8-MOD-2	8.06259E-02	4.03130E-02	1.20939E-01
1/8-MOD-3	8.14602E-02	4.07301E-02	1.22190E-01
1/8-MOD-4	8.16686E-02	4.08343E-02	1.22503E-01
1/8-MOD-5	8.16747E-02	4.08374E-02	1.22512E-01
1/8-MOD-6	8.14790E-02	4.07395E-02	1.22219E-01
1/8-MOD-7	8.20145E-02	4.10072E-02	1.23022E-01
1/8-MOD-8	8.18690E-02	4.09345E-02	1.22804E-01
1/8-MOD-9	8.16548E-02	4.08274E-02	1.22482E-01
1/8-MOD-10	8.04942E-02	4.02471E-02	1.20741E-01
1/8-MOD-11	8.15251E-02	4.07626E-02	1.22288E-01
1/4-MOD-1	8.16020E-02	4.08010E-02	1.22403E-01
1/4-MOD-2	8.08424E-02	4.04212E-02	1.21264E-01
1/4-MOD-3	8.18589E-02	4.09295E-02	1.22788E-01
1/4-MOD-4	8.00887E-02	4.00444E-02	1.20133E-01
1/4-MOD-5	8.01234E-02	4.00617E-02	1.20185E-01
1/4-MOD-6	8.04364E-02	4.02182E-02	1.20655E-01
1/4-MOD-7	8.08178E-02	4.04089E-02	1.21227E-01
1/4-MOD-8	8.11220E-02	4.05610E-02	1.21683E-01
1/4-MOD-9	8.05347E-02	4.02673E-02	1.20802E-01
1/2-MOD-1	8.05227E-02	4.02613E-02	1.20784E-01
1/2-MOD-2	8.10448E-02	4.05224E-02	1.21567E-01
1/2-MOD-3	8.06955E-02	4.03478E-02	1.21043E-01
1/2-MOD-4	8.10921E-02	4.05461E-02	1.21638E-01
1/2-MOD-5	8.14077E-02	4.07039E-02	1.22112E-01
1/2-MOD-6	8.17805E-02	4.08902E-02	1.22671E-01
1/2-MOD-7	8.10462E-02	4.05231E-02	1.21569E-01
1.5-MOD-1	8.20241E-02	4.10121E-02	1.23036E-01
1.5-MOD-2	8.12232E-02	4.06116E-02	1.21835E-01
1.5-MOD-3	8.10959E-02	4.05480E-02	1.21644E-01
1.5-MOD-4	8.10331E-02	4.05166E-02	1.21550E-01
1/32-REF-1	7.55493E-02	3.77747E-02	1.13324E-01
1/32-REF-2	7.84704E-02	3.92352E-02	1.17706E-01
1/16-REF-1	7.44332E-02	3.72166E-02	1.11650E-01
1/16-REF-2	8.09807E-02	4.04903E-02	1.21471E-01
1-REF-1	8.21910E-02	4.10955E-02	1.23287E-01
1-REF-2	8.20565E-02	4.10283E-02	1.23085E-01

Table 217. Polyethylene reflector component atom densities used in detailed models.

Part Type		Atom Density (atoms-b/cm)		
		H	C	Total
Upper Reflector Ring	Case 1	8.12275E-02	4.06138E-02	1.21841E-01
	Case 2	8.12198E-02	4.06099E-02	1.21830E-01
	Case 3	8.17900E-02	4.08950E-02	1.22685E-01
	Case 4	8.08781E-02	4.04390E-02	1.21317E-01
	Case 5	8.16716E-02	4.08358E-02	1.22507E-01
Lower Reflector Ring	Case 1	8.44109E-02	4.22055E-02	1.26616E-01
	Case 2	8.21844E-02	4.10922E-02	1.23277E-01
	Case 3	8.35748E-02	4.17874E-02	1.25362E-01
	Case 4	8.23301E-02	4.11650E-02	1.23495E-01
	Case 5	8.16716E-02	4.08358E-02	1.22507E-01
Top Reflector	All	See individual parts in Table 216.		
Bottom Reflector	All	8.13142E-02	4.06571E-02	1.21971E-01

Table 218. Polyethylene reflector component atom densities used in simplified models.

Part Type		Atom Density (atoms-b/cm)		
		H	C	Total
Upper Reflector Ring	Case 1	8.18027E-02	4.09013E-02	1.22704E-01
	Case 2	8.07276E-02	4.03638E-02	1.21091E-01
	Case 3	8.21096E-02	4.10548E-02	1.23164E-01
	Case 4	8.08251E-02	4.04126E-02	1.21238E-01
	Case 5	8.18360E-02	4.09180E-02	1.22754E-01
Lower Reflector Ring	Case 1	8.35405E-02	4.17703E-02	1.25311E-01
	Case 2	8.27403E-02	4.13702E-02	1.24110E-01
	Case 3	8.27464E-02	4.13732E-02	1.24120E-01
	Case 4	8.23684E-02	4.11842E-02	1.23553E-01
	Case 5	8.29409E-02	4.14704E-02	1.24411E-01
Top Reflector	Case 1	8.01997E-02	4.00999E-02	1.20300E-01
	Case 2	8.15399E-02	4.07699E-02	1.22310E-01
	Case 3	8.13721E-02	4.06861E-02	1.22058E-01
	Case 4	8.17995E-02	4.08997E-02	1.22699E-01
	Case 5	8.19932E-02	4.09966E-02	1.22990E-01
Bottom Reflector	All	8.13142E-02	4.06571E-02	1.21971E-01

3.3.3 Aluminum

The aluminum parts are modeled as AL 6061, as described in Section 1.3.4. Table 219 reports the elemental and isotopic composition of the aluminum material used across all models. Table 220 reports the atom densities for the aluminum inserts used in the detailed models. Table 221 reports the atom densities for the aluminum inserts used in the simplified models, averaged across each part type as described in Section 3.1.1.7. Table 222 report the atom densities for the aluminum structural components, including membrane, interface plate, lower adapter plate, lower adapter extension, Comet stationary platform, and Comet movable platen, used across all models.

Table 219. Aluminum elemental and isotopic composition used in all models.

Element	Wt.%	Isotope	Wt.%	At.%
Al	9.7305E+01	^{27}Al	9.7305E+01	9.7784E+01
Mg	1.0000E+00	^{24}Mg	7.8990E-01	8.9296E-01
		^{25}Mg	1.0000E-01	1.0852E-01
		^{26}Mg	1.1010E-01	1.1490E-01
Si	6.0000E-01	^{28}Si	5.5338E-01	5.3632E-01
		^{29}Si	2.8020E-02	2.6219E-02
		^{30}Si	1.8600E-02	1.6826E-02
Cu	2.7500E-01	^{63}Cu	1.9022E-01	8.1959E-02
		^{65}Cu	8.4783E-02	3.5406E-02
Cr	1.9500E-01	^{50}Cr	8.4728E-03	4.1811E-03
		^{52}Cr	1.6339E-01	8.5294E-02
		^{53}Cr	1.8525E-02	9.4879E-03
		^{54}Cr	4.6118E-03	2.3183E-03
Fe	3.5000E-01	^{54}Fe	2.0650E-02	1.0380E-02
		^{56}Fe	3.2102E-01	1.5561E-01
		^{57}Fe	7.3500E-03	3.5003E-03
		^{58}Fe	9.8000E-04	4.5867E-04
Zn	1.2500E-01	^{64}Zn	6.0750E-02	2.5766E-02
		^{66}Zn	3.4875E-02	1.4344E-02
		^{67}Zn	5.1250E-03	2.0763E-03
		^{68}Zn	2.3500E-02	9.3808E-03
		^{70}Zn	7.5000E-04	2.9082E-04
Mn	7.5000E-02	^{55}Mn	7.5000E-02	3.7016E-02
Ti	7.5000E-02	^{46}Ti	6.0000E-03	3.5403E-03
		^{47}Ti	5.4750E-03	3.1618E-03
		^{48}Ti	5.5350E-02	3.1300E-02
		^{49}Ti	4.1250E-03	2.2850E-03
		^{50}Ti	4.0500E-03	2.1987E-03

Table 220. Aluminum insert atom densities by part used in detailed models.

Part ID	Atom Density (atoms-b/cm)				
	Al	Mg	Si	Cu	Cr
2.5-DISK-1	5.83859E-02	6.66106E-04	3.45866E-04	7.00622E-05	6.07161E-05
2.5-DISK-2	5.85634E-02	6.68131E-04	3.46917E-04	7.02751E-05	6.09006E-05
2.5-DISK-3	5.83150E-02	6.65297E-04	3.45446E-04	6.99770E-05	6.06423E-05
2.5-DISK-4	5.83187E-02	6.65339E-04	3.45468E-04	6.99815E-05	6.06462E-05
2.5-DISK-5	5.86009E-02	6.68559E-04	3.47140E-04	7.03201E-05	6.09396E-05
2.5-DISK-6	5.86261E-02	6.68847E-04	3.47289E-04	7.03504E-05	6.09659E-05
2.5-DISK-7	5.85886E-02	6.68418E-04	3.47067E-04	7.03053E-05	6.09268E-05
2.5-DISK-8	5.83778E-02	6.66014E-04	3.45818E-04	7.00525E-05	6.07077E-05
2.5-DISK-9	5.83740E-02	6.65971E-04	3.45796E-04	7.00479E-05	6.07037E-05
2.5-DISK-10	5.85762E-02	6.68278E-04	3.46994E-04	7.02906E-05	6.09140E-05
6-DISK-1	5.87200E-02	6.69917E-04	3.47845E-04	7.04630E-05	6.10634E-05
6-DISK-2	5.89289E-02	6.72301E-04	3.49083E-04	7.07138E-05	6.12808E-05
6-DISK-3	5.87564E-02	6.70333E-04	3.48061E-04	7.05067E-05	6.11013E-05
6-DISK-4	5.88091E-02	6.70935E-04	3.48373E-04	7.05700E-05	6.11562E-05
10-DISK-1	5.89551E-02	6.72600E-04	3.49238E-04	7.07452E-05	6.13080E-05
10-DISK-2	5.87203E-02	6.69922E-04	3.47847E-04	7.04635E-05	6.10639E-05
10-DISK-3	5.88332E-02	6.71209E-04	3.48516E-04	7.05989E-05	6.11812E-05

Table 220 (continued). Aluminum insert atom densities by part used in detailed models.

Part ID	Atom Density (atoms-b/cm)				
	Fe	Zn	Mn	Ti	Total
2.5-DISK-1	1.01463E-04	3.09484E-05	2.21018E-05	2.53598E-05	5.97086E-02
2.5-DISK-2	1.01771E-04	3.10424E-05	2.21690E-05	2.54369E-05	5.98900E-02
2.5-DISK-3	1.01340E-04	3.09108E-05	2.20749E-05	2.53290E-05	5.96360E-02
2.5-DISK-4	1.01346E-04	3.09127E-05	2.20764E-05	2.53306E-05	5.96398E-02
2.5-DISK-5	1.01836E-04	3.10623E-05	2.21832E-05	2.54532E-05	5.99284E-02
2.5-DISK-6	1.01880E-04	3.10757E-05	2.21927E-05	2.54642E-05	5.99542E-02
2.5-DISK-7	1.01815E-04	3.10558E-05	2.21785E-05	2.54478E-05	5.99158E-02
2.5-DISK-8	1.01449E-04	3.09441E-05	2.20987E-05	2.53563E-05	5.97003E-02
2.5-DISK-9	1.01442E-04	3.09421E-05	2.20973E-05	2.53547E-05	5.96964E-02
2.5-DISK-10	1.01794E-04	3.10493E-05	2.21738E-05	2.54425E-05	5.99032E-02
6-DISK-1	1.02043E-04	3.11254E-05	2.22282E-05	2.55049E-05	6.00501E-02
6-DISK-2	1.02407E-04	3.12362E-05	2.23073E-05	2.55957E-05	6.02638E-02
6-DISK-3	1.02107E-04	3.11447E-05	2.22420E-05	2.55207E-05	6.00874E-02
6-DISK-4	1.02198E-04	3.11727E-05	2.22620E-05	2.55436E-05	6.01414E-02
10-DISK-1	1.02452E-04	3.12501E-05	2.23173E-05	2.56071E-05	6.02907E-02
10-DISK-2	1.02044E-04	3.11256E-05	2.22284E-05	2.55051E-05	6.00505E-02
10-DISK-3	1.02240E-04	3.11855E-05	2.22711E-05	2.55541E-05	6.01660E-02

Table 221. Aluminum insert atom densities by part type used in simplified models.

Part Type		Atom Density (atoms-b/cm)				
		Al	**Mg**	**Si**	**Cu**	**Cr**
2.5-DISK	Case 1	5.89818E-02	6.72904E-04	3.49396E-04	7.07772E-05	6.13357E-05
	Case 2	5.91284E-02	6.74577E-04	3.50265E-04	7.09531E-05	6.14882E-05
	Case 3	5.91743E-02	6.75101E-04	3.50537E-04	7.10082E-05	6.15360E-05
6-DISK	Case 1	5.90732E-02	6.73947E-04	3.49937E-04	7.08869E-05	6.14308E-05
	Case 5	5.95205E-02	6.79050E-04	3.52587E-04	7.14236E-05	6.18959E-05
10-DISK	Case 1	5.91654E-02	6.74999E-04	3.50484E-04	7.09975E-05	6.15267E-05

Table 221 (continued). Aluminum insert atom densities by part type used in simplified models.

Part Type		Atom Density (atoms-b/cm)				
		Fe	**Zn**	**Mn**	**Ti**	**Total**
2.5-DISK	Case 1	1.02498E-04	3.12642E-05	2.23273E-05	2.56186E-05	6.03179E-02
	Case 2	1.02753E-04	3.13419E-05	2.23829E-05	2.56823E-05	6.04678E-02
	Case 3	1.02833E-04	3.13663E-05	2.24002E-05	2.57023E-05	6.05148E-02
6-DISK	Case 1	1.02657E-04	3.13127E-05	2.23620E-05	2.56583E-05	6.04114E-02
	Case 5	1.03435E-04	3.15498E-05	2.25313E-05	2.58526E-05	6.08688E-02
10-DISK	Case 1	1.02817E-04	3.13615E-05	2.23969E-05	2.56984E-05	6.05057E-02

Table 222. Aluminum structural component atom densities by part used in all models.

Element	Membrane	Other Structural Components[(a)]
Al	5.76066E-02	5.86382E-02
Mg	6.57215E-04	6.68985E-04
Si	3.41250E-04	3.47361E-04
Cu	2.50213E-05	2.54694E-05
Cr	5.99057E-05	6.09785E-05
Fe	2.18068E-05	2.21973E-05
Zn	1.00109E-04	1.01901E-04
Mn	6.91270E-05	7.03649E-05
Ti	3.05353E-05	3.10821E-05
Total	5.89116E-02	5.99666E-02

(a) These other structural components include the interface plate, lower adapter plate, lower adapter extension, Comet stationary platform, and Comet movable platen.

3.4 Temperature Data

All benchmark cases use a temperature of 293.6 K (20.45°C), the default temperature used by MCNP® 6.2.0 using ENDF/B-VIII.0 cross sections.

3.5 Experimental and Benchmark-Model k_{eff}

As discussed in Section 2.6, the k_{eff} of the experimental configurations was calculated based on the measured reactor period. The experimental k_{eff} uncertainty was calculated by summing the combined modeling uncertainty (Section 2.5) and the experiment measurement uncertainty (Section 2.6) in quadrature. A calculation bias was determined based on the model simplification described in Section 3.1.1. There is an additional bias for the simplified model due to the averaging of the part dimensions in the core stack. The expected benchmark k_{eff} is determined by subtracting the bias from the experimental k_{eff}, summarized in Table 172 for the detailed models and in Table 173 for the simplified models. The benchmark model uncertainty was calculated by summing the experimental k_{eff} uncertainty and the bias uncertainty in quadrature.

Table 223. Expected benchmark model k_{eff} for detailed models.

Case	Experimental k_{eff} ± 1σ	Bias in k_{eff} ± 1σ	Benchmark Model k_{eff}
1	1.00026 ± 0.00132	0.00127 ± 0.00013	0.99899 ± 0.00133
2	1.00038 ± 0.00126	0.00122 ± 0.00013	0.99916 ± 0.00127
3	1.00067 ± 0.00129	0.00115 ± 0.00013	0.99952 ± 0.00130
4	1.00112 ± 0.00148	0.00114 ± 0.00013	0.99998 ± 0.00149
5	1.00094 ± 0.00119	0.00376 ± 0.00013	0.99718 ± 0.00120

Table 224. Expected benchmark model k_{eff} for simplified models.

Case	Experimental k_{eff} ± 1σ	Bias in k_{eff} ± 1σ	Benchmark Model k_{eff}
1	1.00026 ± 0.00132	0.00128 ± 0.00013	0.99898 ± 0.00133
2	1.00038 ± 0.00126	0.00102 ± 0.00013	0.99936 ± 0.00127
3	1.00067 ± 0.00129	0.00101 ± 0.00013	0.99966 ± 0.00130
4	1.00112 ± 0.00148	0.00109 ± 0.00013	1.00003 ± 0.00149
5	1.00094 ± 0.00119	0.00367 ± 0.00013	0.99727 ± 0.00120

4.0 RESULTS OF SAMPLE CALCULATIONS

Results from MCNP® 6.2.0 using ENDF/B-VIII.0 cross sections for the detailed and simplified models are presented in Table 225. Calculated fission fractions using MCNP® 6.2.0 with ENDF/B-VIII.0 cross sections are presented in Table 226.

Table 225. Sample calculation results using MCNP® 6.2.0 with ENDF/B-VIII.0 (United States).

Case	MCNP® 6.2.0 (Continuous Energy ENDF/B-VIII.0)	
	Detailed	Simplified
1	0.99578 ± 0.00002	0.99577 ± 0.00002
2	0.99487 ± 0.00003	0.99507 ± 0.00003
3	0.99473 ± 0.00003	0.99487 ± 0.00003
4	0.99511 ± 0.00003	0.99516 ± 0.00003
5	0.99913 ± 0.00003	0.99922 ± 0.00003

Table 226. Fission fractions for each case, calculated using MCNP® 6.2.0 with ENDF/B-VIII.0.

Case	Thermal Fission Fractions (< 0.625 eV)	Intermediate Fission Fractions (0.625 eV – 100 keV)	Fast Fission Fractions (> 100 keV)
1	0.079	0.205	0.716
2	0.138	0.497	0.365
3	0.229	0.515	0.256
4	0.389	0.437	0.174
5	0.630	0.258	0.112

Results from KENO V.a in SCALE 6.3.0 using ENDF/B-VII.1 and ENDF/B-VIII.0 cross sections for the detailed and simplified models are presented in Table 227. These results were provided by William Marshall of Oak Ridge National Laboratory.

Table 227. Sample calculation results using KENO V.a in SCALE 6.3.0 with ENDF/B-VII.1 and ENDF/B-VIII.0 (United States).

Case	KENO V.a / SCALE 6.3.0 (Continuous Energy ENDF/B-VII.1)		KENO V.a / SCALE 6.3.0 (Continuous Energy ENDF/B-VIII.0)	
	Detailed	Simplified	Detailed	Simplified
1	0.99674 ± 0.00010	0.99658 ± 0.00010	0.99548 ± 0.00010	0.99537 ± 0.00010
2	0.99350 ± 0.00010	0.99381 ± 0.00010	0.99444 ± 0.00010	0.99463 ± 0.00010
3	0.99506 ± 0.00010	0.99474 ± 0.00010	0.99480 ± 0.00010	0.99445 ± 0.00010
4	0.99608 ± 0.00010	0.99647 ± 0.00010	0.99452 ± 0.00010	0.99479 ± 0.00010
5	1.00192 ± 0.00010	1.00196 ± 0.00010	0.99817 ± 0.00010	0.99834 ± 0.00010

Results from MC21 10.2 using ENDF/B-VIII.0 cross sections for the detailed and simplified models are presented in Table 228. These results were provided by Daniel Kelly of Naval Nuclear Laboratory.

Table 228. Sample calculation results using MC21 10.2 with ENDF/B-VIII.0 (United States).

Case	**MC21 10.2 (Continuous Energy ENDF/B-VIII.0)**	
	Detailed	**Simplified**
1	0.99569 ± 0.00004	0.99562 ± 0.00004
2	0.99463 ± 0.00004	0.99490 ± 0.00004
3	0.99471 ± 0.00004	0.99485 ± 0.00004
4	0.99506 ± 0.00004	0.99516 ± 0.00004
5	0.99938 ± 0.00004	0.99981 ± 0.00004

Table 229 presents the calculated-over-experiment (C/E) values using MCNP® 6.2.0 with ENDF/B-VIII.0 cross sections. These MCNP® 6.2.0 with ENDF/B-VIII.0 calculations consistently underpredict the experimental values, except for the Case 5 detailed model which agrees with the benchmark k_{eff}.

Table 229. C/E results for sample calculations using MCNP® 6.2.0 with ENDF/B-VIII.0 (United States) with combined experimental and calculational uncertainties.

Case	**MCNP® 6.2.0 (Continuous Energy ENDF/B-VIII.0)**	
	Detailed	**Simplified**
1	0.99678 ± 0.00133	0.99678 ± 0.00133
2	0.99570 ± 0.00127	0.99571 ± 0.00127
3	0.99521 ± 0.00130	0.99521 ± 0.00130
4	0.99513 ± 0.00149	0.99513 ± 0.00149
5	1.00196 ± 0.00120	1.00196 ± 0.00120

Table 230 presents the C/E values using KENO V.a in SCALE 6.3.0 with ENDF/B-VII.1 and ENDF/B-VIII.0 cross sections. These results were provided by William Marshall of Oak Ridge National Laboratory.

Table 230. C/E results for sample calculations using KENO V.a in SCALE 6.3.0 with ENDF/B-VII.1 and ENDF/B-VIII.0 (United States) with combined experimental and calculational uncertainties.

Case	**KENO V.a / SCALE 6.3.0 (Continuous Energy ENDF/B-VII.1)**		**KENO V.a / SCALE 6.3.0 (Continuous Energy ENDF/B-VIII.0)**	
	Detailed	**Simplified**	**Detailed**	**Simplified**
1	0.99774 ± 0.00133	0.99760 ± 0.00133	0.99649 ± 0.00133	0.99638 ± 0.00133
2	0.99433 ± 0.00127	0.99445 ± 0.00127	0.99527 ± 0.00127	0.99527 ± 0.00127
3	0.99554 ± 0.00130	0.99508 ± 0.00130	0.99528 ± 0.00130	0.99480 ± 0.00130
4	0.99611 ± 0.00149	0.99645 ± 0.00149	0.99454 ± 0.00149	0.99477 ± 0.00149
5	1.00475 ± 0.00120	1.00471 ± 0.00120	1.00099 ± 0.00120	1.00107 ± 0.00120

Table 231 presents the C/E values using MC21 10.2 with ENDF/B-VIII.0 cross sections. These results were provided by Daniel Kelly of Naval Nuclear Laboratory. These MC21 10.2 with ENDF/B-VIII.0 calculations consistently underpredict the experimental values, except for Case 5 where the detailed model which agrees with the benchmark k_{eff} and the simplified model slightly exceeds the benchmark model 2σ uncertainty.

Table 231. C/E results for sample calculations using MC21 10.2 with ENDF/B-VIII.0 (United States) with combined experimental and calculational uncertainties.

Case	MC21 10.2 (Continuous Energy ENDF/B-VIII.0)	
	Detailed	**Simplified**
1	0.99669 ± 0.00133	0.99663 ± 0.00133
2	0.99546 ± 0.00127	0.99554 ± 0.00127
3	0.99519 ± 0.00130	0.99519 ± 0.00130
4	0.99508 ± 0.00149	0.99513 ± 0.00149
5	1.00221 ± 0.00120	1.00255 ± 0.00120

5.0 REFERENCES

No references.

APPENDIX A: TYPICAL INPUT LISTINGS

A.1 MCNP® 6.2.0 INPUT LISTINGS

All cases listed use ENDF/B-VIII.0 nuclear data. Calculations are typically executed with 4,000 generations of 100,000 particles per generation, skipping the first 100 generations, resulting in a total of 390 million active histories.

DETAILED CASE 1

Input: MCNP6.2 Detailed Case 1

DETAILED CASE 2

Input: MCNP6.2 Detailed Case 2

DETAILED CASE 3

Input: MCNP6.2 Detailed Case 3

DETAILED CASE 4

Input: MCNP6.2 Detailed Case 4

DETAILED CASE 5

Input: MCNP6.2 Detailed Case 5

SIMPLIFIED CASE 1

Input: MCNP6.2 Simplified Case 1

SIMPLIFIED CASE 2

Input: MCNP6.2 Simplified Case 2

SIMPLIFIED CASE 3

Input: MCNP6.2 Simplified Case 3

SIMPLIFIED CASE 4

Input: MCNP6.2 Simplified Case 4

SIMPLIFIED CASE 5

Input: MCNP6.2 Simplified Case 5

APPENDIX B: TYPICAL INPUT LISTINGS AT 12°C

As a simplification bias in Section 3.1.1.6, the model is corrected from the experiment temperature reported in Section 0 to room temperature at 20°C. This is done to ease the burden on the user, allowing the standard temperature nuclear data libraries distributed with the codes to be used without modification. However, this results in a significant bias in the most thermal configuration, Case 5. Due to the magnitude of this bias, this Appendix includes detailed models at the experiment temperature of 12°C to provide the user an example set of inputs if they would like to produce the required nuclear data.

To accurately model below room temperature, all the considerations described in Section 2.4 are accounted for. This includes the thermal contraction of the materials in the core stack, the modeled free-gas thermal temperature, and Doppler broadening in the nuclear data including a 12°C thermal scattering law.

B.1 MCNP® 6.2.0 INPUT LISTINGS

To accommodate the changes to the nuclear data with MCNP® 6.2.0, a custom cross section directory (xsdir) file was generated using a 12x library identifier (e.g., the H in CH_2 TSL is h-poly.12x and the U-235 continuous energy neutron cross section is 92235.12x). This new identifier was chosen to avoid any collision with existing identifiers.

DETAILED CASE 1

Input: MCNP6.2 Detailed Case 1 (12C)

DETAILED CASE 2

Input: MCNP6.2 Detailed Case 2 (12C)

DETAILED CASE 3

Input: MCNP6.2 Detailed Case 3 (12C)

DETAILED CASE 4

Input: MCNP6.2 Detailed Case 4 (12C)

DETAILED CASE 5

Input: MCNP6.2 Detailed Case 5 (12C)

APPENDIX C: DESIGN DRAWINGS FOR TEX-HEU PARTS

C.1 COMET STATIONARY PLATFORM

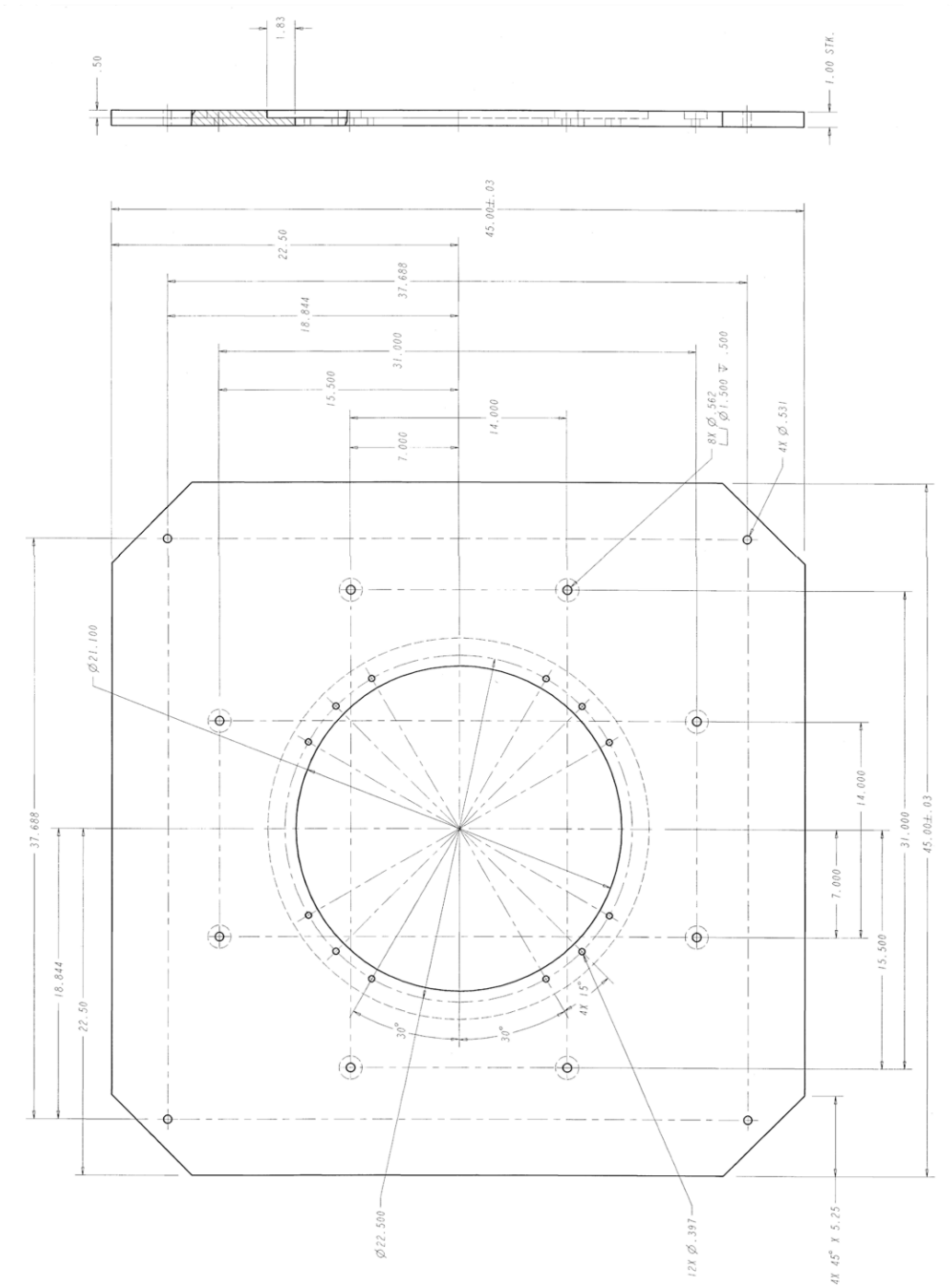


Figure 62. Schematic of the Comet stationary platform[7].

[7] Drawing No. 128Y-270955, Rev. E, "Zeus Experiment Details LACEF." Los Alamos National Laboratory, December 2000.

C.2 COMET MOVABLE PLATEN

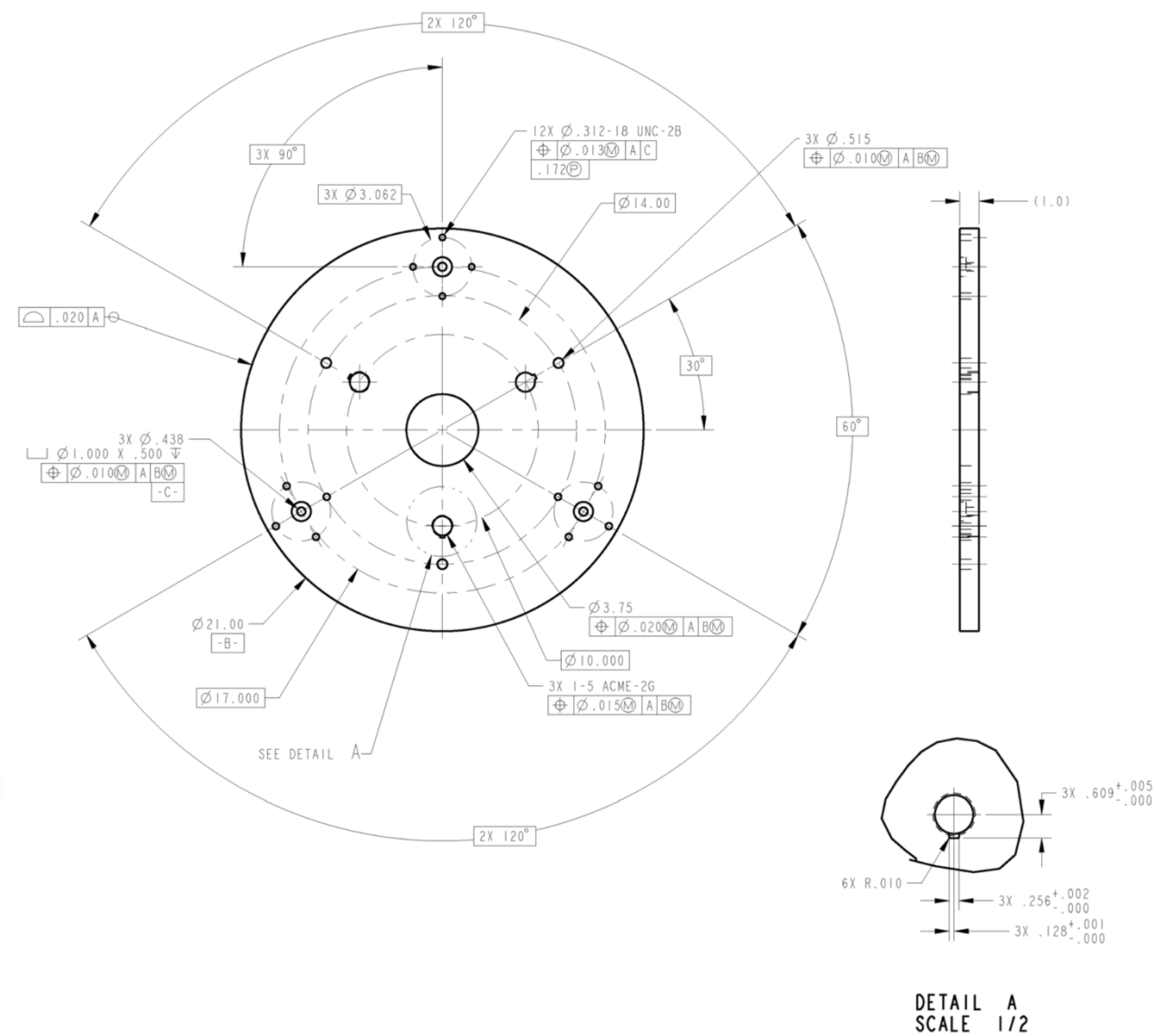


Figure 63. Schematic of the Comet movable platen[8].

[8] Drawing No. 128Y-270958, Rev. D, "Driver Motor Details Comet." Los Alamos National Laboratory, February 2019.

C.3 INTERFACE PLATE

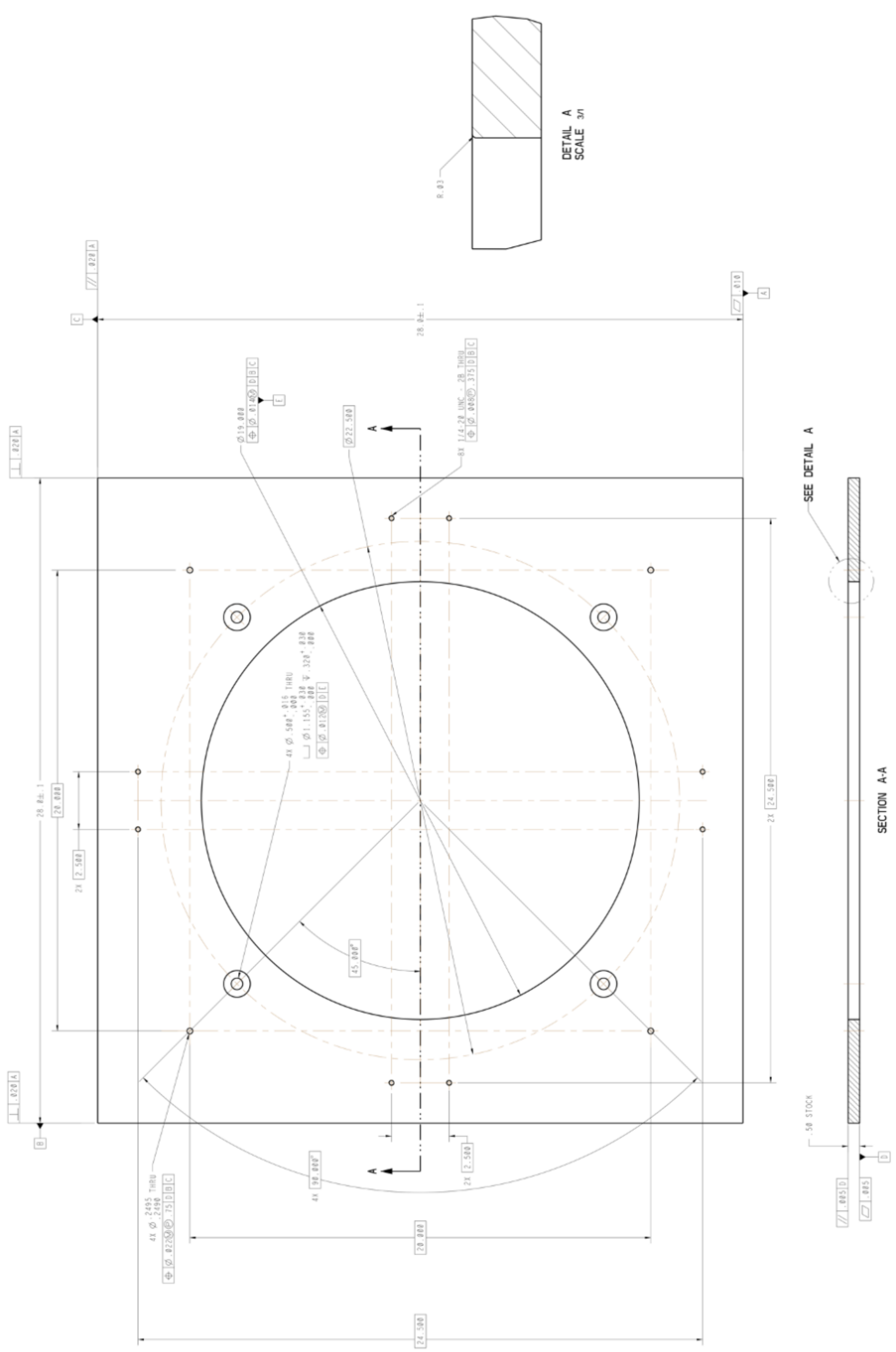


Figure 64. Schematic of the interface plate (dimensions in inches).

C.4 STANDOFFS

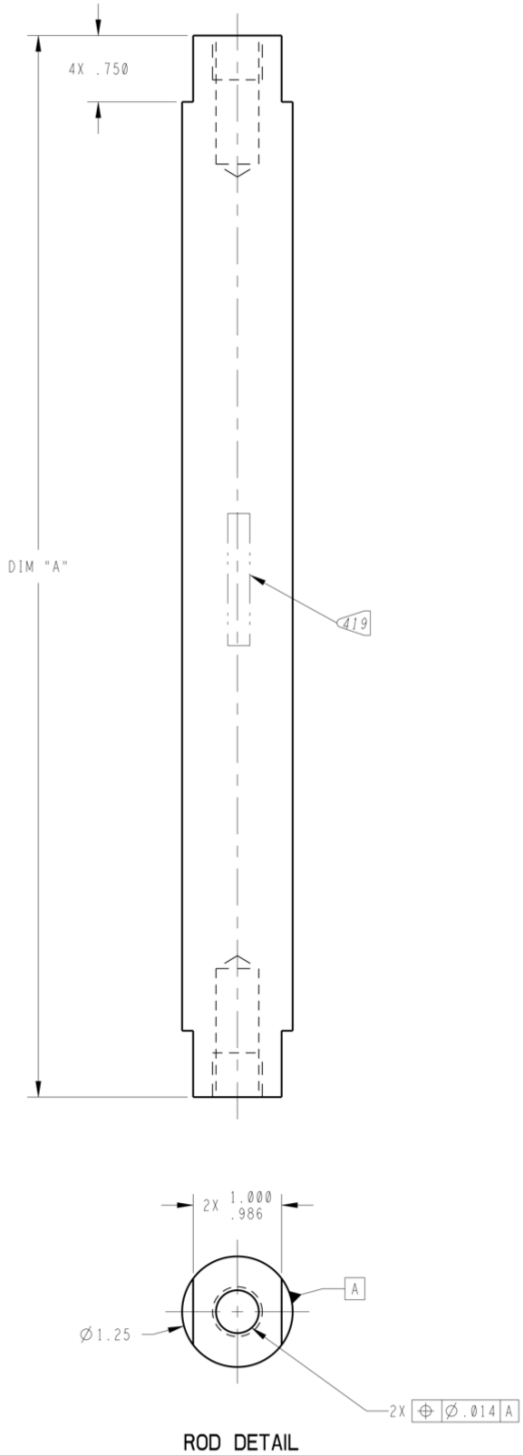


Figure 65. Schematic of the standoffs, DIM “A” is 12.000 (dimensions in inches).

C.5 ADAPTER PLATE

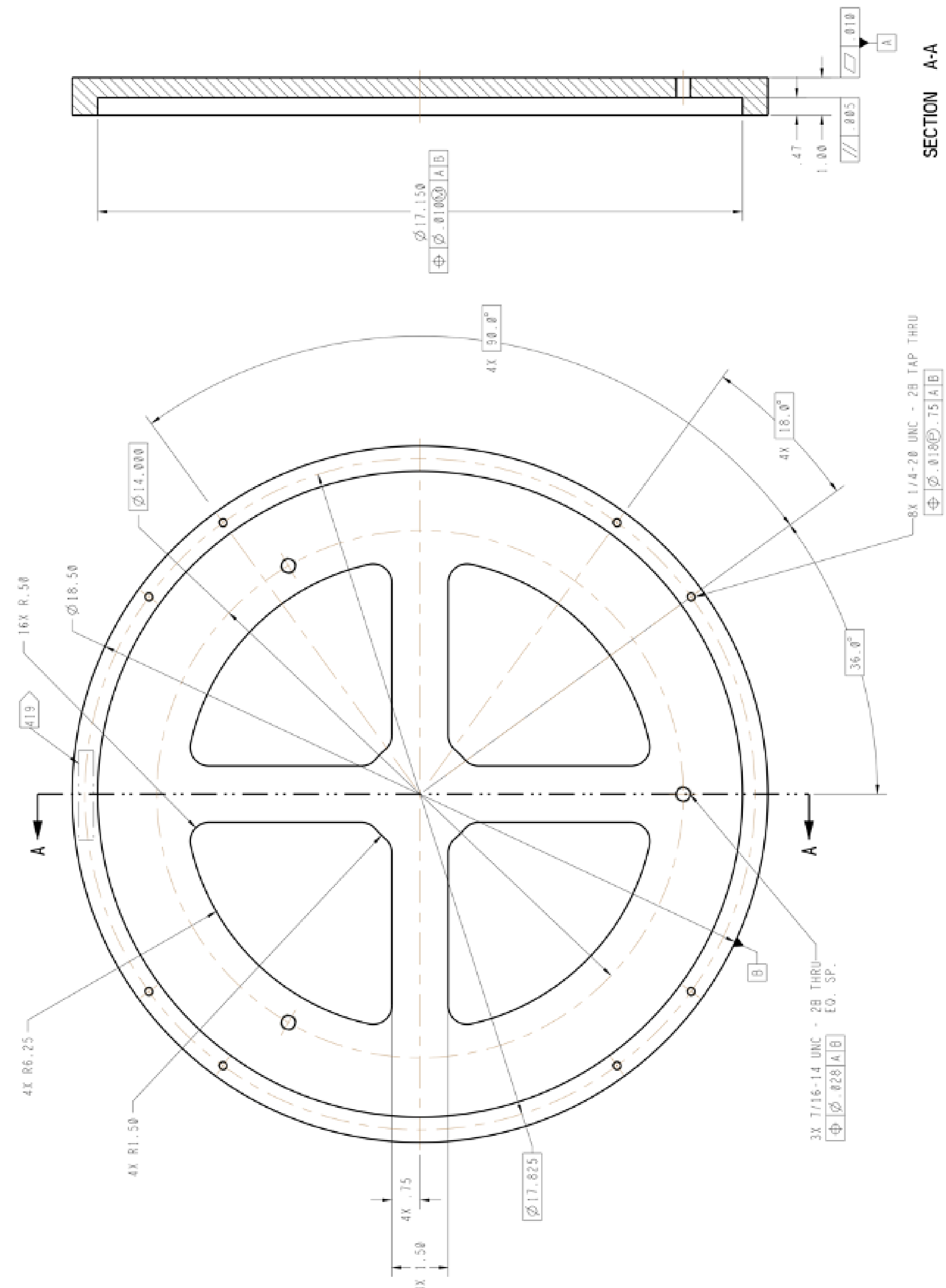
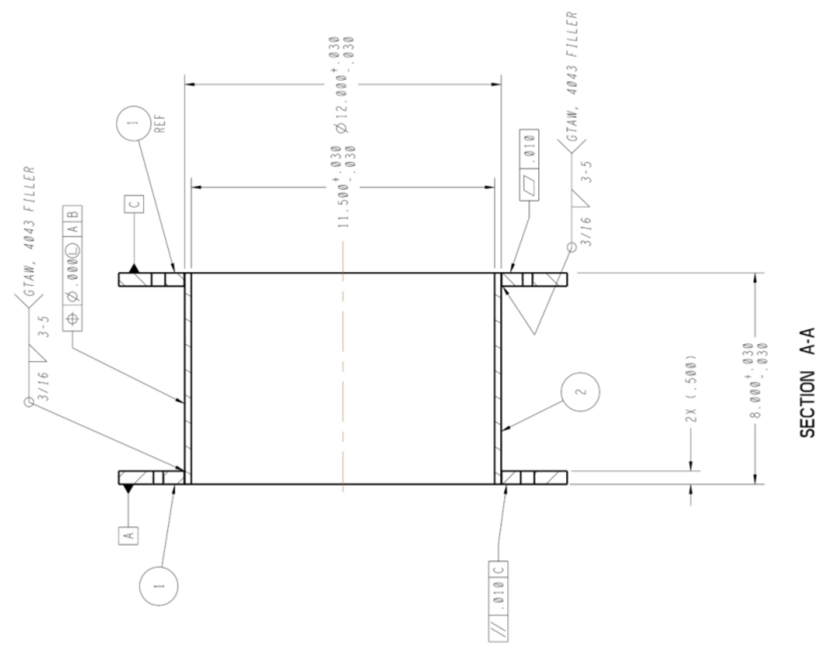


Figure 66. Schematic of the adapter plate, part of the lower adapter (dimensions in inches).

C.6 ADAPTER EXTENSION



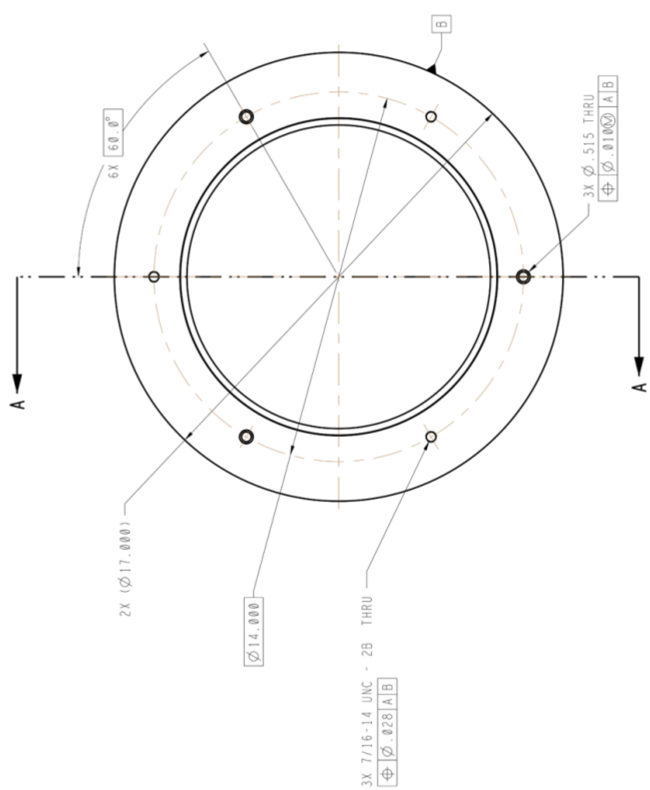


Figure 67. Schematic of the adapter extension, part of the lower adapter (dimensions in inches).

C.7 MEMBRANE

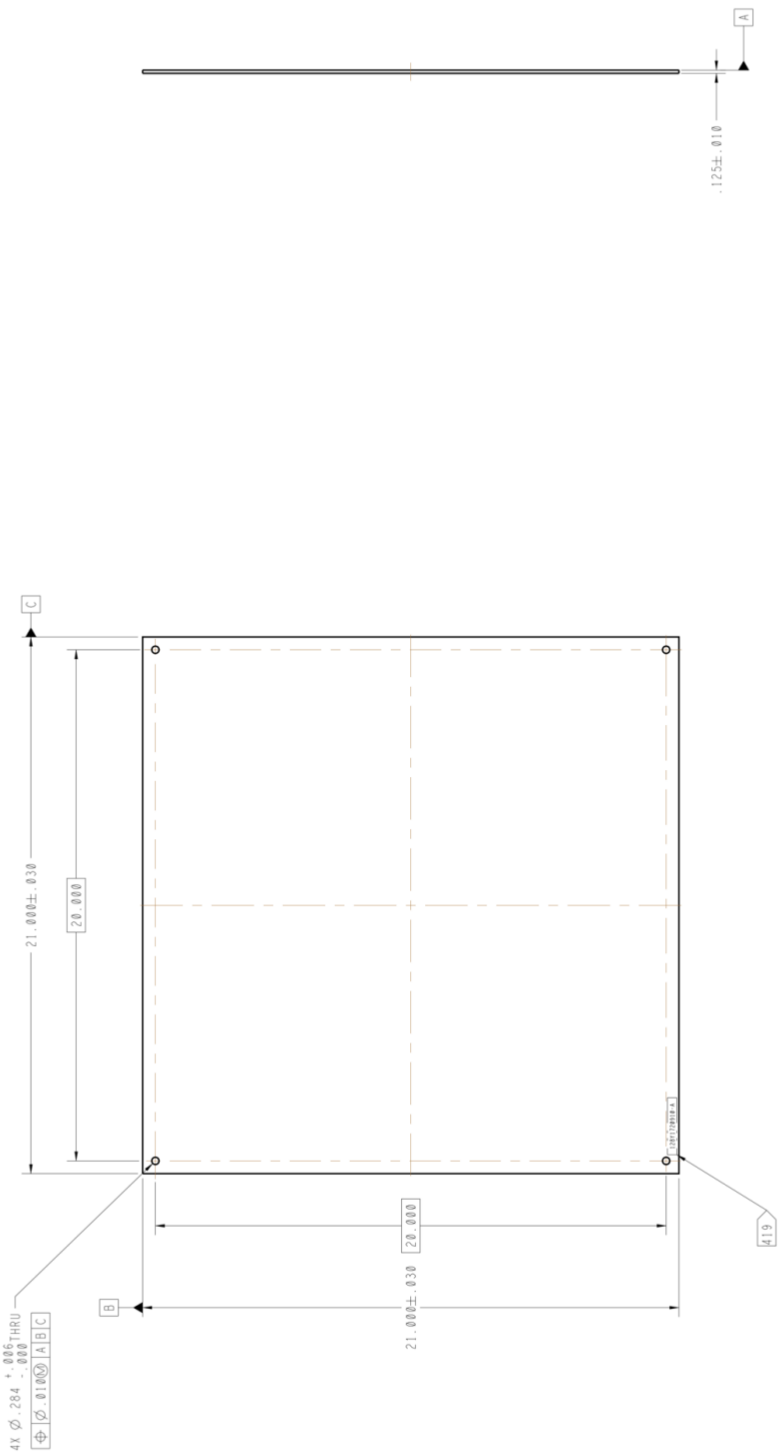


Figure 68. Schematic of the membrane (dimensions in inches).

APPENDIX D: PHOTOGRAPHS OF THE TEX-HEU EXPERIMENT

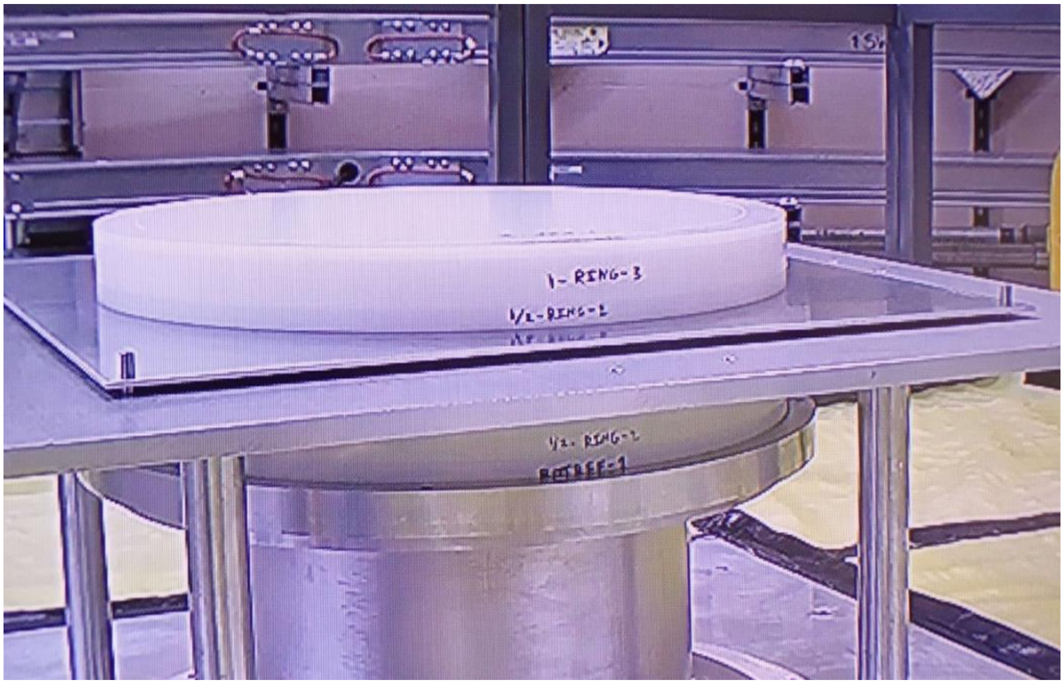


Figure 69. Fully assembled Case 3 experiment during operation (i.e., a photo of a critical nuclear reactor).

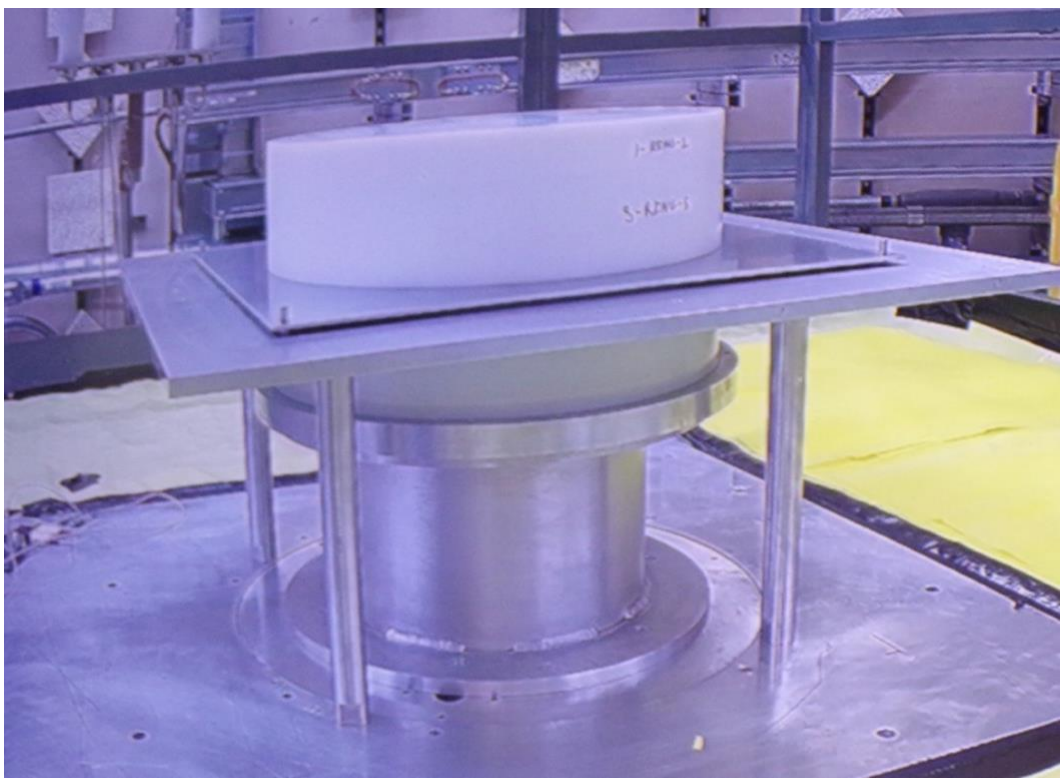


Figure 70. Fully assembled Case 5 experiment during operation.

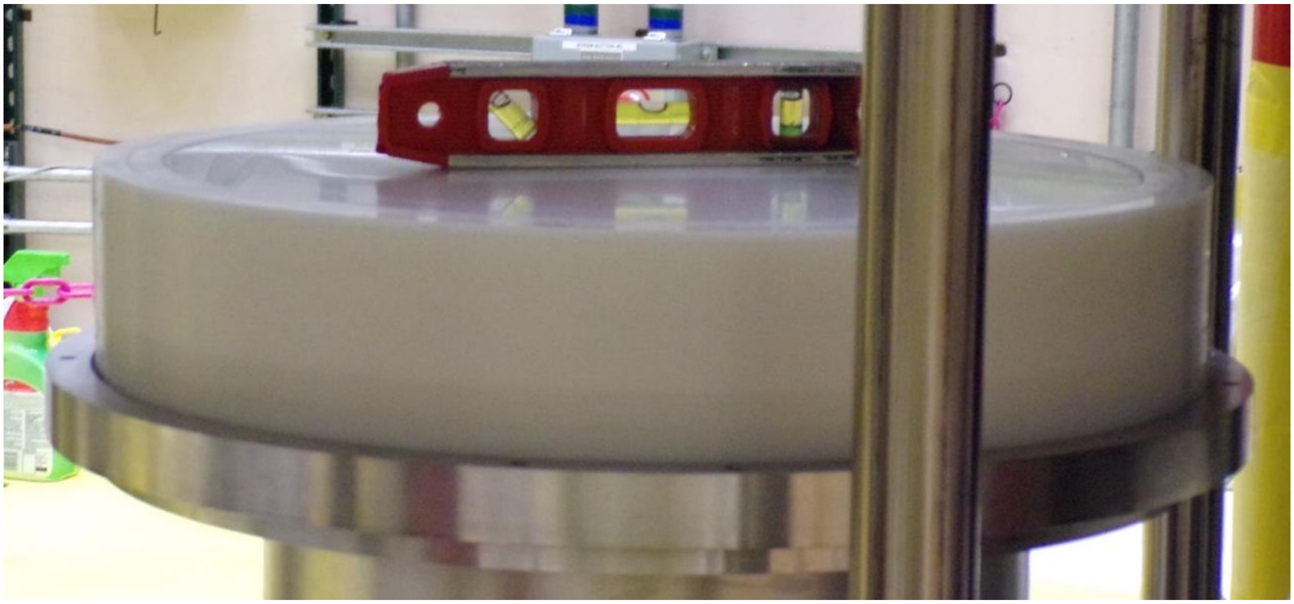


Figure 71. Lower stack of Case 4.

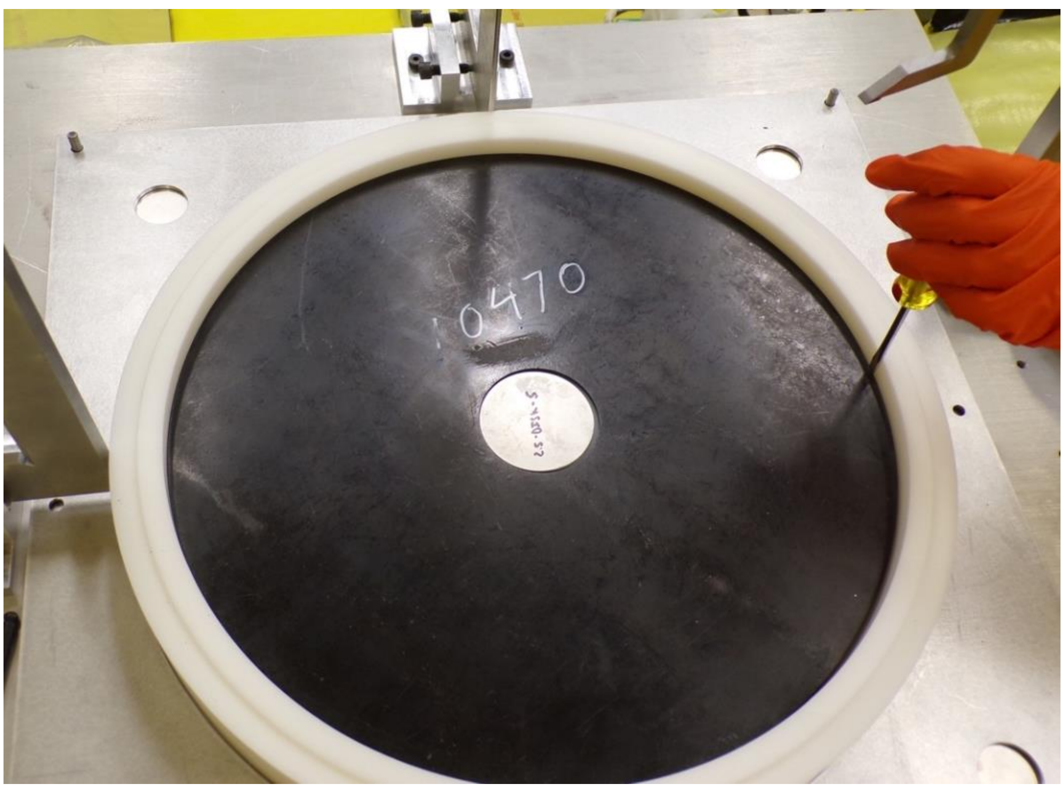


Figure 72. Experimenter positioning an HEU2 plate within the polyethylene reflector ring. Notice the 2.5" aluminum insert has also been pushed in the same direction.

Figure 73. Upper half of the Case 3 configuration. Notice the crescent shaped gap on the right side of the 1-REF-2 part. This gap is from pushing the entire core stack to one side within the reflector ring.