ORNL/TM-2019/1409

Two Delayed Critical 15-Inch-Diameter Interacting Enriched (93.14) Uranium Metal Cylinders without Moderator and Reflector

John T. Mihalczo

September 2020

Approved for public release. Distribution is unlimited.

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/TM-2019/1409

Isotope and Fuel Cycle Technology Division

TWO DELAYED CRITICAL 15-INCH-DIAMETER INTERACTING ENRICHED (93.14) URANIUM METAL CYLINDERS WITHOUT MODERATOR AND REFLECTOR

John T. Mihalczo

September 2020

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This report very accurately documents the configuration and the materials for experiments with two unmoderated, unreflected, interacting, coaxial, highly enriched, 15 in. diameter uranium metal cylinders performed at the Oak Ridge Critical Experiments Facility (ORCEF) from May to August 1963. These experiments are described in logbooks E-19 and E-20 associated with experiments in the east cell of ORCEF. Measurements were also performed in April and May of 1965 and are described in logbooks E-22 and E-23 The information is sufficiently accurate that it can be used as the basis for preparation of benchmarks for International Criticality Safety Benchmark Program (ICSBEP) at Idaho National Laboratory. The thickness of the cylinders was varied, and the spacing between them was adjusted to achieve a delayed critical configuration. The average enrichment of the uranium metal was 94.14 wt.% ^{235}U. The heights of the 15 in. diameter, equal-height cylinders varied from 1 5/8 to 3.0 in. All interacting cylinders were assembled coaxially with their flat faces parallel, and their combined masses varied between 182 and 325 kg of highly enriched uranium (HEU) metal. The data from the 12 experiments described are acceptable for use as criticality safety benchmark experiments for the ICSBEP and EURATOM's Nuclear Energy Agency nuclear criticality safety benchmark program once the uncertainty analysis is completed. Based on previous ICSBEP benchmarks with this enriched uranium metal at ORCEF, the uncertainties in k_{eff} are expected to be as low as ±0.0002.

1. DESCRIPTION OF MEASUREMENTS

1.1 OVERVIEW OF EXPERIMENT

A variety of critical experiments were constructed with unreflected and unmoderated highly enriched uranium metal during the 1960s and 1970s at the Oak Ridge Critical Experiments Facility (ORCEF) in support of criticality safety of the Y-12 Plant [1]–[7]. Of these hundreds of delayed critical assemblies, twelve assemblies of two 15 in. diameter interacting coaxial uranium metal cylinders were assembled to delayed criticality without a moderator or reflector. In some cases, the assemblies were repeated with different uranium metal parts and in one case with the same parts. The height of the two 15 in. diameter interacting cylinders varied from 1.625 to 3.00 in., with varying separation distance between cylinders up to 52 in. All coaxial interacting cylinders were assembled with their flat faces parallel and their combined masses varied between 182 and 325 kg of HEU metal. The spacing between cylinders was the variable that was adjusted to achieve delayed criticality. The experiments were performed between April 1963 and August 1965. Interaction experiments with 11 in. diameter HEU metal cylinders have been reported and analyzed in HEU-MET-FAST-051. Other HEU metal experiments at ORCEF already in the Nuclear Energy Agency benchmark database are HEU-MET-FAST-059, -061, -071, and -100.

The data from these six experiments described should be acceptable for use as criticality safety benchmark experiments in the international criticality safety benchmark program (ICSBEP) when the uncertainty analysis is performed. Based on previous ICSBEP benchmarks with this enriched uranium metal at ORCEF, it is expected that the uncertainties in k_{eff} could be as low as ± 0.0002.

1.2 DESCRIPTION OF EXPERIMENTAL CONFIGURATION

These experiments were performed in the 35 × 35 × 30 ft high east cell of ORCEF. The assemblies of uranium metal were located approximately 11.7 ft from the 5 ft. thick concrete west wall, 12.7 ft. from the 2 ft. thick concrete north wall, and 9.2 ft. above the concrete floor. The purpose of these experiments included the evaluation of storage and handling limits for the Y-12 Plant and providing data for verification of calculation methods and cross sections for nuclear criticality safety applications. These included single cylinders of various diameters, two interacting cylinders of various diameters, three interacting cylinders, and complex geometry assemblies. All interacting cylinders were assembled coaxially with their flat faces parallel, and the combined masses of the interacting cylinders masses varied between 62 and 325 kg of HEU metal. The experiments described here include two interacting cylinders with nominal diameters of 15 in. with the nominal height of upper and lower sections varied from 1.625 to 3.00 in... The cylinders are unmoderated and unreflected with various separation distances between them. Note, all dimensions were measured and recorded in inches. When dimensions are rounded to the nearest inch or one-eighth inch, they are nominal dimensions, otherwise they are measured. The 12 experiments and their repeated configurations are summarized in Table 1. For all configurations, the experimental k_{eff} was 1.0000. These configurations have the lowest uncertainties and include all the support structure and the air in, walls of, and floor of the experimental cell and would be best for checking the accuracy of the ability of calculational methods to predict experimental results. This is because corrections for these effects have uncertainties.

Table 1. Summary of masses, measured separation, and experimental k_{eff} for delayed critical experiments with two interacting cylinders of 15 in. diameter.

Experiment	Nominal Cylinder Thickness (in.)(1)	Mass of (2) Upper Section (g)	Mass of(2) Lower Section (g)	Mass of (2) Assembly (g)	Measured Separation (in.)
1	1.625 E-19 page 275	87,900	87,760	175,660	0.5270
2	1.750 E-19 page 280	94,682	94,603	189,285	1.3811
3	1.875 E-19 page 284	101,525	101,313	202,838	1.5971
3a(3)	1.875 E-20 page 91	101,329	101,313	202,642	1.5736
4	2.000 E-19 page 288	108,299	108,095	216,394	2.2463, 2.2441
4a	2.000 E-20 page 97	108,159	108,163	216,322	2.2162, 2.2063
5	2.125 E-19 page 292	114,983	114,886	229,869	2.9713
5a	2.125 E-20 page 100	115,035	114,829	229,864	2.9578
6	2.250 E-19 page 295	121,804	121,688	243,492	3.8334
6a	2.250 E-20 page101	121,855	121,611	243,496	3.8427
7	2.375 E-19 page 299	128,586	128,420	257,006	4.9095
7a	2.375 E-20 page102	128,460	128,454	256,914	4.8854
8	2.500 E-20 page 13	135,345	135,236	270,671	6.2938
8a	2.500 E-20 page 106	135,388	135,212	270,600	6.3183
9	2.625 E-20 page 114	142,195	141,940	284,135	8.2266
10	2.750 E-20 page 120	148,977	148,783	297,760	11.241
10a	2.750 E-22 page 257	148,975	149,254	298,229	11.366
11	2.875 E-22 page 261	155,978	155,988	311,966	17.447
11a(4)	2.875 E-22 page 289	155,978	155,988	311,966	17.307
12(5)	3.000 E-23 page 18	164,345	160,990	325,355	52.500
12a	3.000 (5) E-23 page 12	163,078	162,991	325,989	51.471

(1) Nominal dimensions except for spacing. Logbooks have several designations depending on where they are stored Logbook E-19 is designated *Book12r* in the ICSBEP database and *H00170* in the ORNL logbook files; designations for E-20 are *book12r* in the ICSBEP database and *H00162* in the ORNL files; logbook E-22 is designated as *book13r* in ICSBEP and *H00163* in the ORNL files; logbook E 23 is designated as *book14r* in the ICSBEP database and *H00164* in the ORNL files.

(2) Mass calculated by summing individual component masses

(3) Letter "a" indicated a repeated configuration with the same nominal dimensions but with different uranium metal parts.

(4) Exact repeat of 11 but with the assembly more centered in the cell with the vertical assembly machine on top of the horizontal assembly machine.

(5) The bottom cylinder was missing a 15 in. outer diameter (OD), 13 in. inner diameter (ID), 1/8 in. thick annular ring, which was placed on top of the top cylinder

1.3 EXPERIMENT METHODOLOGY

The cylinders comprised layers of discs with dimensions machined to precise tolerances. The experiments were performed in a deliberate and step-by-step manner, with observed data recorded.[1]

1.3.1 General Assembly Procedure

The assemblies were constructed on a vertical assembly machine [8] that primarily consisted of a hydraulic lift (22 in. vertical motion) to support the lower section (see Figure 1) and a stationary upper half consisting of four vertical posts spaced 4 ft. apart, which held a low-mass support consisting of a 30 in. ID clamping ring supported by vertical poles by aluminum tubing (see Figure 2). The aluminum clamping ring held a 0.010 in. thick stainless steel (304L) diaphragm on which the uranium metal of the upper section was supported. The bottom uranium metal part of the upper section was a 15 in. diameter cylindrical disc so that the central 7 in. diameter discs and annular ring sections of the upper assembly would not sag with the diaphragm. This ensured that the bottom of the upper section was the same distance above the lower section. The aluminum clamping ring was supported by a lightweight aluminum structure mounted on the four vertical poles of the assembly machine (see Figure 2). The clamping ring contained thirty-four 3/8 in. diam., 1.5 in. long stainless-steel bolts. The lower section was supported on a low-mass aluminum support tower mounted on the vertical lift, also shown in Figure 2. The lower support stand supported the uranium metal with 0.125 in. thick aluminum edges, oriented vertically and 120° apart. Thin aluminum foil thicknesses were used to adjust the height of the parts on the lower support stand so that the top surface of the lower cylinder was flat. This assured the same distance between the lower and upper cylinders at all radii. Lateral motion of the lower section was restrained by small aluminum pieces bolted to the 120° vertical members. These pieces are visible in Figure 2. The low-mass support stand was bolted to the vertical lift as shown in Figure 2. The arrangement of Figure 2 was used for most of the two interacting cylinders—the only difference was the distance between the upper and lower sections. These low-mass support structures were used to minimize the reactivity effects of the support structure. Support structure details are described in Appendix A.

[1] All Rossi-α data for these measurements are stored in Records Management Services Department at ORNL and at the ICSBEP at Idaho National Laboratory. In the title line for each measurement, the first entry is the date of each measurement, which can be correlated with the dates in the east cell of ORCEF logbooks.

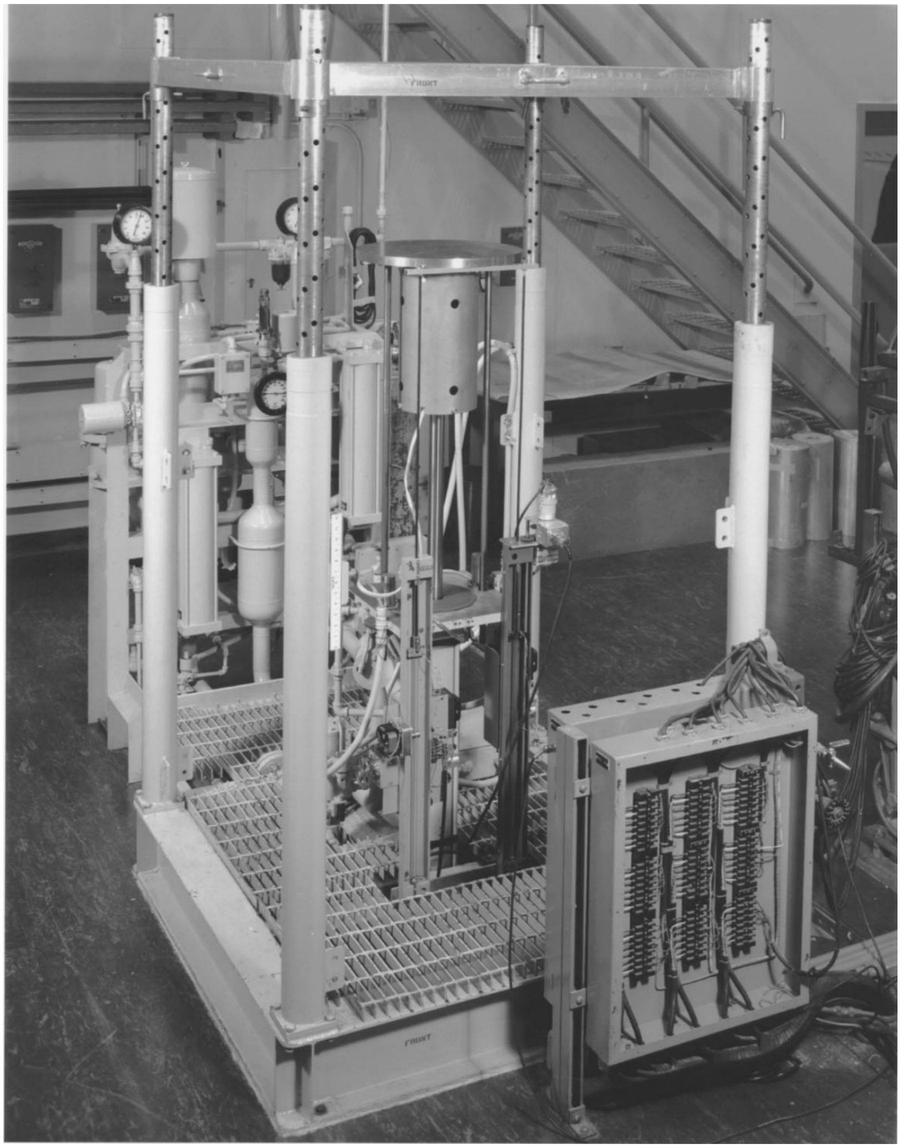

Figure 1. Photograph of the vertical assembly machine with the movable table up. (Upper support structure on the four vertical poles were not used in these measurements. No lower support structures are in this photograph).[2]

[2] Safety Review of the Oak Ridge Critical Experiments Facility, Oak Ridge National Laboratory, Oak Ridge, TN (1962).

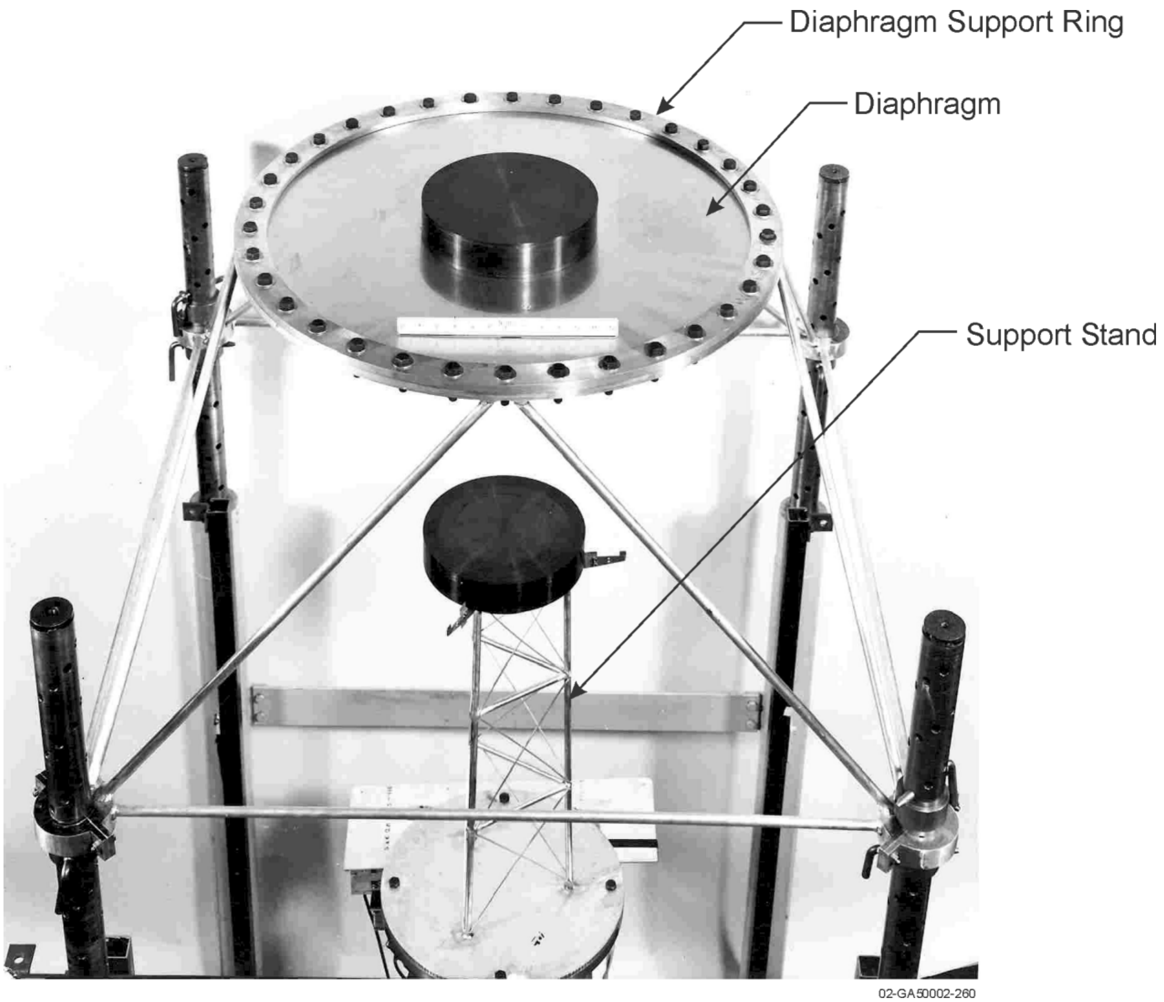

Figure 2. A typical uranium metal assembly for two interacting 11 in. diameter uranium (93.14 wt. % ^{235}U) metal cylinders. Two interacting 15 in. diam uranium metal cylinders were assembled in the same manner on this exact same apparatus.

For these interacting-cylinder experiments, the lower section was raised beyond delayed criticality to increase the fission rate to a measurable level. Then the spacing was adjusted until near exactly delayed criticality was achieved (reactor period >5,000 s). Separation of the upper and lower assemblies was monitored remotely by selsyn readout, which was available in the control room. The selsyn readouts were accurate to 0.0005 in. The separation of the two halves of the assemblies was measured as follows. At several points of the compass (N, NE, E, SE, S, SW, W, NW), the distance between the top (outer diameter [OD]) of the lower uranium cylinder and the bottom of the upper diaphragm at the radial location of the outer diameter of the upper cylinder was measured with a micrometer accurate to 0.001 in. The motion of the table was followed with a selsyn motor that indicated the height of the lower support table above the down position to 0.001 in. This selsyn readout was verified against physical measurements of the height of the lower support table above the down position. There were two selsyn readouts, 180° apart, which in most cases were both used to obtain the separation. The difference between the selsyn readout with the lower support table at the critical position and the selsyn readout with the table down was equal to the distance the vertical support table was raised. The separation between the top of the lower uranium with the vertical table down and the bottom of the stainless-steel diaphragm supporting the upper section was measured. The total separation minus the amount the table was raised is the separation of the two cylinders minus the stainless-steel diaphragm supporting the upper section. The upper diaphragm thickness (0.010 in. thick) was added to this difference to obtain the total vertical distance between the upper and lower cylinders. The upper uranium cylinder parts were usually assembled on a 15 in. diam. uranium disc that was adjacent to the stainless-steel diaphragm to support the upper uranium at the same height across the whole lower surface, so the measured separations were unambiguous. In some of the early experiments the 15 in. diam. plate was not available, and this resulted in the bottom not being at the same height because of sagging of the diaphragm. This resulted in an uneven measurement for the top of the upper cylinder. For these cases and all others, the separation of the two cylinders was measured at the outer diameter.

For the larger thickness 15 in. diameter cylinders that could not be safely assembled by hand, the apparatus was modified to safely assemble these systems. The modification is shown in Figure 3 for the previously benchmarked 11 in. diameter interacting cylinders. The same type of configuration was used for the two interacting 15 in. diameter cylinders. Part of the upper section was attached to a cable that lowered the top of the upper section. The cable was attached to a 15 in. diameter cylindrical plate at four locations. Part of the lower section was mounted on a stainless-steel diaphragm. The assembly was completed by lowering the top of the upper cylinder and raising the part of the lower cylinder mounted on the support stand until it was in contact with the part of the lower cylinder mounted on the diaphragm. The spacing between cylinders was adjusted by repositioning the diaphragm. For experiments 10, 10a, 11, 11a, 12, and 12a, some of the uranium of the lower section was mounted on the second stainless-steel diaphragm and the top part of the upper cylinder was lowered remotely as shown in Figure 3. The separation of the upper portion of the lower cylinder on the lower diaphragm from the upper cylinder was measured with an inside micrometer to 0.001 in. For assembly of the lower section, the lower (major) section of the lower cylinder was raised until it contacted the upper portion of the lower section without lifting it appreciably (<0.001 in.). Then, the separation of the top of the lower section and the bottom of the upper cylinder was the inside micrometer reading plus the diaphragm thickness.

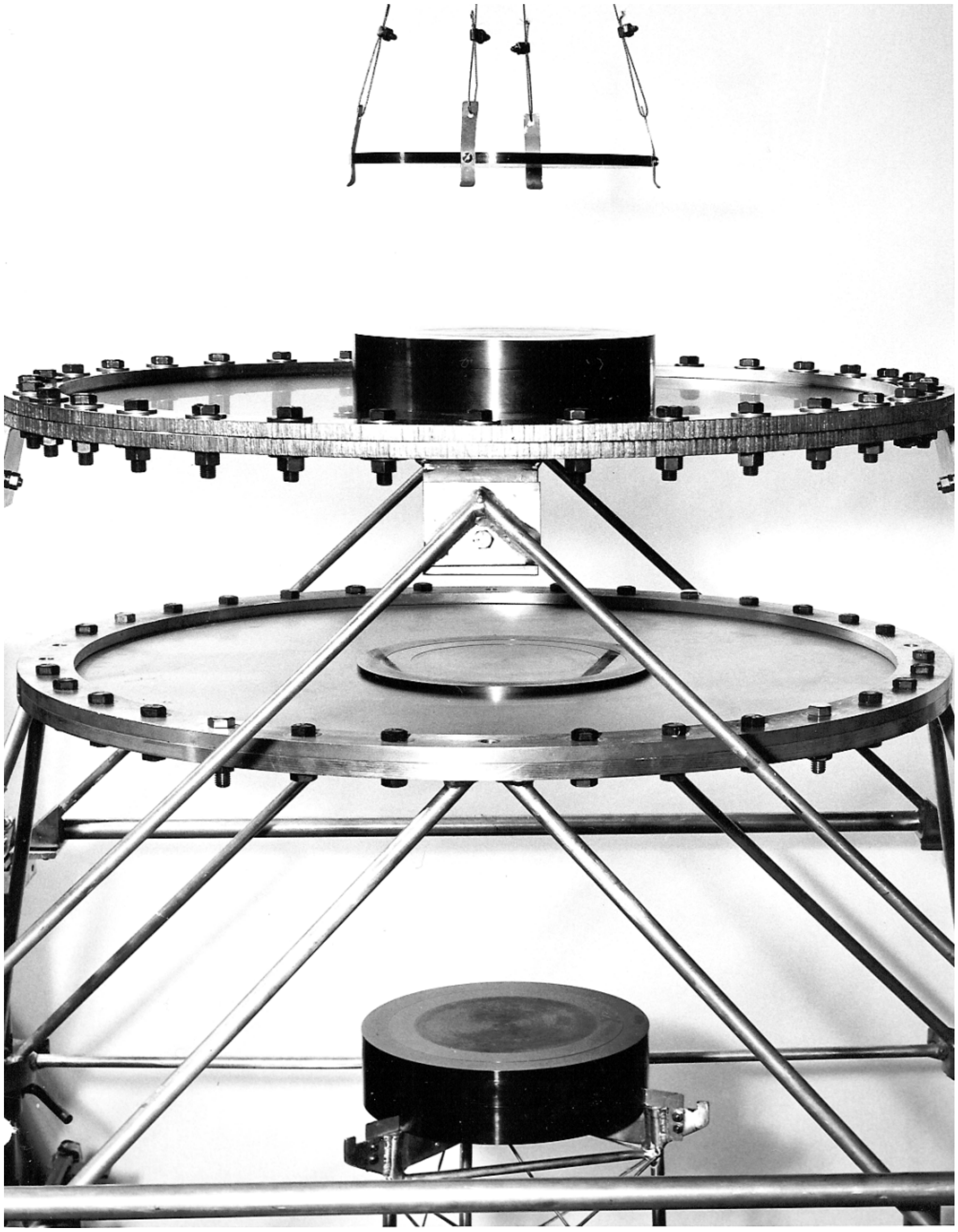

Figure 3. A typical two-diaphragm assembly for uranium (93.14 wt.% ^{235}U) metal interacting 11 in. diameter cylinders. In this example, the upper and lower sections could not be manually assembled with a very high margin of safety. This arrangement was used for experiments 10, 10a, 11, 11b, 12, and 12a.[3]

The assembly heights of the central discs and the surrounding ring sections were measured to ±0.0005 in. as follows. As it was safe to do so, appropriate parts were stacked by hand on a flat surface that was used to measure the height of various radial sections of the assemblies. For the nominal 15 in. diameter cylinders, each half of these assemblies consisted of 7 in. OD cylinders, 7 in. ID/9 in. OD annuli, 9 in. ID/11 in. OD annuli, 11 in. ID/13 in. OD annuli, and 13 in. ID/15 in. OD annuli. In all experiments the upper and middle cylinders contained a 15 in. diameter cylindrical disc on the bottom of each cylinders. For example, for the lower sections, the 7 in. diameter cylinders were stacked on a precision flat surface, and the distance between the upper surface and the precision flat surface was measured. In stacking all

[3]Photo 40000, Oak Ridge National Laboratory.

parts in the assemblies, the azimuth orientation of the parts was positioned so that the location of the part numbers on the upper surface was always oriented toward the north wall of the experimental cell. This ensured reproducibility when restacking assemblies or parts of assemblies for height measurements. The parts were always positioned with the surface with the scribed part number facing up. Thus, for the height measurements on the precision flat surface, the orientation of the 7 in. diameter cylinders was consistent with the assembly. The height of the upper and lower sections of the 7 in. diameter cylinders was normally measured at azimuth locations N, E, S, W, SW, and NE, and the values were averaged. To obtain the average void in this stack of parts, the sum of the actual measured heights of all the parts was subtracted from the measured stack height. This process was repeated for all applicable annuli, and each annulus stack was measured separately. This process was performed separately for the lower section and the upper section. For the upper sections that were stacked on a 15 in. diameter disc, the bottom cylindrical plate was on the flat surface, and the appropriate radial sections of the assembly were stacked on the uranium plate for the height measurements for each radial section. This procedure allowed safe measurements of the stacked height of each concentric annulus and the central cylinder. The measured heights for the cylinder and annular sets and the average for each assembly are provided in the description of the experiments. The thickness of the outer ring of the lower section was measured on the support stand as the experiments progressed. Some recently discovered details from inspection reports for the uranium metal parts are provided in Appendix B.

1.3.2 Assembly Alignment

The upper and lower sections were aligned using the processes described below. Uncertainty in radial alignment of parts on each half is ±0.002 in.

1.3.2.1 Upper Section

For assembly of the upper section, uranium metal was added to the top diaphragm. Uranium was positioned with a ruler the appropriate distance from the inside of the aluminum ring, which holds the stainless diaphragm. Usually a plate of uranium metal (15 in. OD) was placed on the diaphragm, and additional material was stacked on the plate. Layers of uranium metal for 15 in. diameter cylinders typically consisted of a 7 in. diameter cylinder, 7 in. ID/9 in. OD annulus, 9 in. ID/11 in. OD annulus, 11 in. ID/13 in. OD annulus, and a 13 in. ID/15 in. OD annulus. The rest of the material was then added to the top cylinder. The location of the material was continuously adjusted with a precise high-quality level with the level in one direction and then rotated 90° on the parts. If the assembly was not exactly centered in the diaphragm, it would not be precisely level because of the sag in the diaphragm as it was loaded. The locations of various layers of material were adjusted so that the outside radii were the same. Two precisely machined steel blocks (±0.0001 in.) were used to squeeze the material at the outer radial surface until it was aligned radially. An edge of the machined block was held at one outside radial location, and material was adjusted until no light was visible between the machined block and the uranium metal. This process was repeated 90° from the position of the original adjustment, rechecked again at the original position, and small adjustments were made if necessary. This process continued until the outside radii of the parts were precisely aligned and the upper section assembly was complete. The alignment of outer radii of the upper or lower section was less than ±0.001 in. Of course, if two positions 90° apart are adjusted, the positions at 180° and 270° can be off only by the difference in the diameters of the outside parts.

For experiments that used the remote addition of the top plate as shown in Figure 3 (10, 10a, 11, 11a, 12, and 12a), the alignment of the top plate with the rest of the upper section was accomplished using the four alignment clips shown in Figure 3.

1.3.2.2 Lower Section

For the lower section, the same procedure was used except that the parts were leveled by shimming on the underside with aluminum foil. Various thicknesses of aluminum foil were used for the 7 in. diameter disc and annular rings. The foil was placed between the three 120° upper edges of the support stand and the lowest parts so that the upper surface of the lower cylinder was flat. For experiments that used the additional diaphragm shown in Figure 3 (10, 10a, 11, 11a, 12, and 12a), the lower cylinder was aligned using the method described for the lateral alignment of upper section with the lower section.

1.3.3 Lateral Alignment of the Upper Section with the Lower Section for Two Interacting Cylinders

There were two identical fixtures (see Figure 4) used for lateral alignment between the upper section and the lower section. They were U-shaped and were machined out of 0.375 in. thick aluminum. The end pieces were carefully machined at the Y-12 shops to be perpendicular to the long direction of the fixture and coplanar with each other. When leveled properly, the front face of the 4 × 4 × ½ in. end pieces were vertical and in the same plane to within ±0.001 in. This fixture was carefully machined and handled delicately when not in use so as not to damage it. In use, the lower side of the upper leg rested on the top surface of the clamping ring for the diaphragm. The fixture was perpendicular to the outer radial surface of the cylinder. The fixture was moved inward until it touched the uranium of the top section. The leveling screws were adjusted until the fixture was level.

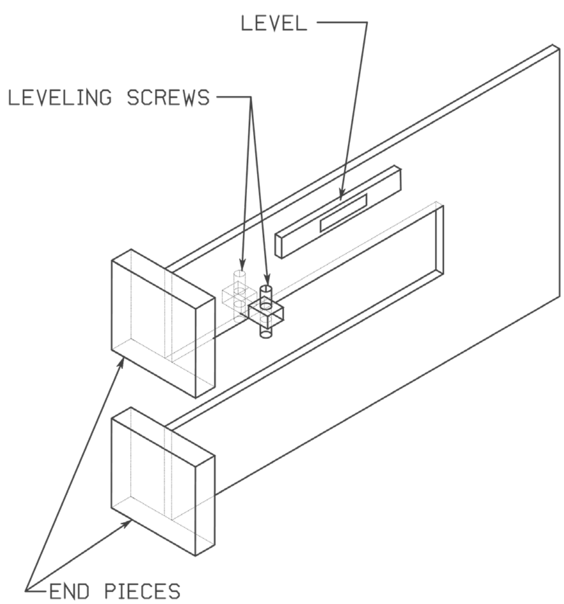

Figure 4. Sketch of the fixture for lateral alignment of uranium metal cylinders.

The second fixture was placed 90° apart from the first in a similar manner. Both fixtures were moved back slightly, and the lower section was raised until part of the lower cylinder was as high as the lower end piece of the fixture. In some cases, material was removed to ensure subcriticality. Normally, the 7 in. diameter inside cylinders were removed with a tool using a suction cup. Then both fixtures were nearly adjusted properly. Removal or additions of material from the top section sometimes required small leveling adjustments. The fixtures were moved in until they touched uranium (either on the top or the lower section). When lack of contact was observed at either of the front faces of the fixture, the lower section was lowered to the full-out position, and the position of the uranium on the lower support stand was adjusted. The lower lift table was raised, and the alignment was checked.

The process was repeated several times as necessary. The final 0.005 in. adjustments were usually made by moving the top section. This was a long and tedious procedure that took 12 hours or more; however, it was always performed. This resulted in the top and bottom sections being aligned within ±0.005 in. For close spacing between cylinders, alignment was done with partial loading with these fixtures. For larger separations, the fixture was used with partial loading and closer spacing than that for delayed criticality. For spacing larger than 6 in., the alignment was ±0.025 in because of the uncertainty in the lateral position of the lift.

For configurations assembled as shown in Figure 3, the lateral alignment fixtures were used to align the upper cylinder with the portion of the lower cylinder on the additional diaphragm to hold part of the lower cylinder. The alignment fixtures were then used to align the upper portion of the lower cylinder with the part of the lower cylinder mounted on the vertical lift.

Lateral Alignment Accuracy Summary for Two Interacting Cylinders

For assemblies configured as shown in Figure 2, the following uncertainties apply:

- For the upper and lower assembly separation less than 6 in., the alignment uncertainty is ±0.005 in.
- For the upper and lower assembly separation greater than 6 in., the alignment uncertainty is ±0.025 in.

For assemblies configured as shown in Figure 3, the following uncertainties apply:

- For the upper plate of upper cylinder and the upper cylinder, the alignment uncertainty is ±0.001 in.
- For the lower portion of the upper cylinder and the upper portion of the lower cylinder mounted on the lower diaphragm, the alignment uncertainty is ±0.005 in.
- For the upper and lower portion of the lower cylinder, the alignment uncertainty is ±0.025 in.

1.3.4 Upward Motion Limitation

To prevent the vertical table supporting the lower uranium cylinder from getting too close to the upper cylinder, there were two adjustable flanges on 1 in. diameter threaded rods attached to the bottom of the 1 in. thick plate of the vertical table. These threaded steel rods were 180° apart and penetrated through the thick plate that the movable table rested on when down. As the vertical table moved upward, its motion was limited when the flanges came in contact with the bottom of the fixed steel plate. The location of the flanges with respect to the bottom of the fixed table was measured by vertical distance transmitters that measured the last 0.050 in. to 0.001 in. These were used to measure small displacements of the lower uranium cylinder from the upper. These had to be adjusted in steps appropriately to achieve the position of the lower movable table for criticality. Once adjusted they were used to measure small displacements of the lower table from the critical position. In some experiments they were not adjusted properly and did not provide position data for the last 0.05 in.

1.3.5 Position Measurement

The upward location of the vertical table was measured by two mechanical selsyns that read out to 0.001 in. When the vertical table was in the down position, they were usually adjusted to read 00.000. In many cases, they read slightly off zero in the down position. In these cases, the difference had to be added or subtracted from the distance from upper surface of the lower uranium to the under surface of the diaphragm supporting the upper uranium cylinder which was measured at several locations to 0.001 in. with an inside micrometer. These measurements were performed at many angular locations corresponding to the outer lower surface of the uranium cylinders where the uranium was in close contact with the diaphragm. The thickness of the diaphragm was added to the micrometer reading to get the total distance between the uranium cylinders with the vertical table in the down position. This distance with the distance the table was moved upward was used to get the separation of the upper and lower uranium cylinders. The measurements with selsyn 2 were more reliable than selsyn 1 and tracked the upward motion of the table more reliably. If the results of selsyn 1 did not agree with those of selsyn 2, they were discarded. Selsyn readout measuring differences were more accurate than individual values.

1.3.6 Reactivity Effects of the Support Structure

The support structure reactivity worth consisted primarily of the reactivity effects of the diaphragm(s), the aluminum diaphragm support ring(s), and the aluminum support stand for the lower section. The removal of the support structure resulted in experimental k_{eff} values lower than unity. The diaphragm support ring and support stand for the lower section were reflectors rather than separators except for systems assembled as shown in Figure 3. The combined reactivity effect of all other supports, like the four vertical poles and tubing for the diaphragm support ring, was less than 1 cent and was not evaluated. The reactivity of the support structure was evaluated by assembling the system to delayed critical or a known measured reactivity, adding additional support structure, and obtaining the reactivity of the support structure from the difference in measured reactor period from the assembly without the additional support structure. To evaluate this effect, an inverted support stand like that for the lower section was added to the top of the uranium of the upper section. It was suspended in such a way that it did not press down on the upper cylinder. The thickness of the diaphragm and clamping ring were doubled. These reactivity effects were measured separately for some experiments and collectively for others. When measured separately, the results were assumed to be additive. For some of the experiments, the reactivity was not measured but only the change in the separation associated with the support structure was determined. The change in spacing of the support structure was the most reliable way to determine the effects of the support structure because it did not involve any other measurements or their associated uncertainties. For some of the repeated measurements these support structure affects were not measured but were assumed to be the same as the initial configurations.

The results of these measurements of the effects of the support structure are given in the description of each experiment. The effect of room return should be estimated for each of the 12 experiments from Monte Carlo simulations and be included in the correction of the experiments for removal of supports and surroundings.

2. DESCRIPTION OF EXPERIMENTS

2.1 EXPERIMENT 1

On May 20, 1963, a symmetric assembly of two 15 in. diameter, interacting, coaxial cylinders with nominal heights of 1.625 in. was measured at delayed criticality (k_{eff} = 1.00000) with a separation of 0.5270 in. The separation includes the thickness of the diaphragm (0.01 in.), so it is the distance from the top of the uranium of the lower section and the lower surface of the uranium metal of the upper cylinder. The makeup of the assembly is depicted in Figure 5 and includes the assembled configuration with the support structure. This configuration would be the best for comparing calculated k_{eff} with measurements because there are no corrections to the system with their associated uncertainties. This comparison calculation should include the support structure, the air in the room, and the walls, floor, and ceiling of the experimental cell. The lower section of the assembly consisted of three 7 in. diameter cylinders, one 15 in. diameter cylinder, and 12 annuli. The upper section of the assembly consisted of two 7 in. diameter cylinders and six annuli. The bottom layer of the upper cylinder was a 15 in. diameter disc (part 2821) on which the other parts were assembled. This disk was used in most assemblies so that the location of the bottom of the upper cylindrical assembly could be precisely located. Without it, the individual annuli and 7 in. diameter parts would not be the same distance from the lower section because of the sag of the diaphragm. The upper section of the assembly had a mass of 87,900 g, and the lower section had a mass of 87,760 g. The total mass of the uranium assembly was 175,660 g. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated by measuring the change in spacing by doubling the support structure. Without these supports, the separation of the cylinder would have been 0.0317 in. closer (i.e., 0.4895 in.). The measured reactivity change associated with a change in separation of the upper and lower cylinder was measured to be 1.075 cents per thousandth of an inch (cents/mil). Without the air in the cell and the cell structure, the separation would have been lower. Table 2 includes the measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference of the average air gap between parts that composed the central 7 in. diameter section and the various annuli. These gaps should be included in the detailed model when comparing calculations with measurements.

Table 2. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 1 with two interacting 15 in. OD cylinders 1.625 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	**7ID-9OD**	**9ID-11OD**	**11ID-13OD**	**13ID-15OD**
Upper	Measured thickness (in.)[a]	1.6273	1.6234	1.6235	1.6255	1.6230
	Thickness of parts (in.)[b]	1.62165	1.62003	1.6200	1.62515	1.6164
	Number of gaps	1	1	1	2	2
	Average gap thickness (mils)[c]	5.61	3.38	3.50	1.75	3.3
Lower	Measured thickness (in.)	1.6236	1.6207	1.623	1.6217	1.6227
	Thickness of parts (in.)	1.62295	1.6211	1.6201	1.6217	1.6145
	Number of gaps	3	3	3	3	3
	Average gap thickness (mils)	0	0	0.96	0	2.73

[a] Measured height is an average of several measurements with 0.001 in. accuracy. Part thickness from the inspection reports (with accuracy on 0.0001 in.) were summed. The average gap thickness between parts of a radial annuli or central 7 in. diameter disc was the difference between the measured height and the sum of the part thicknesses divided by the number of gaps. This of course assumed the gaps between all parts in a section are the same.
[b] Sum of part thicknesses.
[c] One mil is one thousandth of an inch.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary, the configurations for experiment 1 and the k_{eff} values are given in Table 3.

Table 3. Summary of configurations and neutron multiplication factors for experiment 1.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	0.5270	1.00000
Without support structure, no correction for room return	0.4895	1.00000

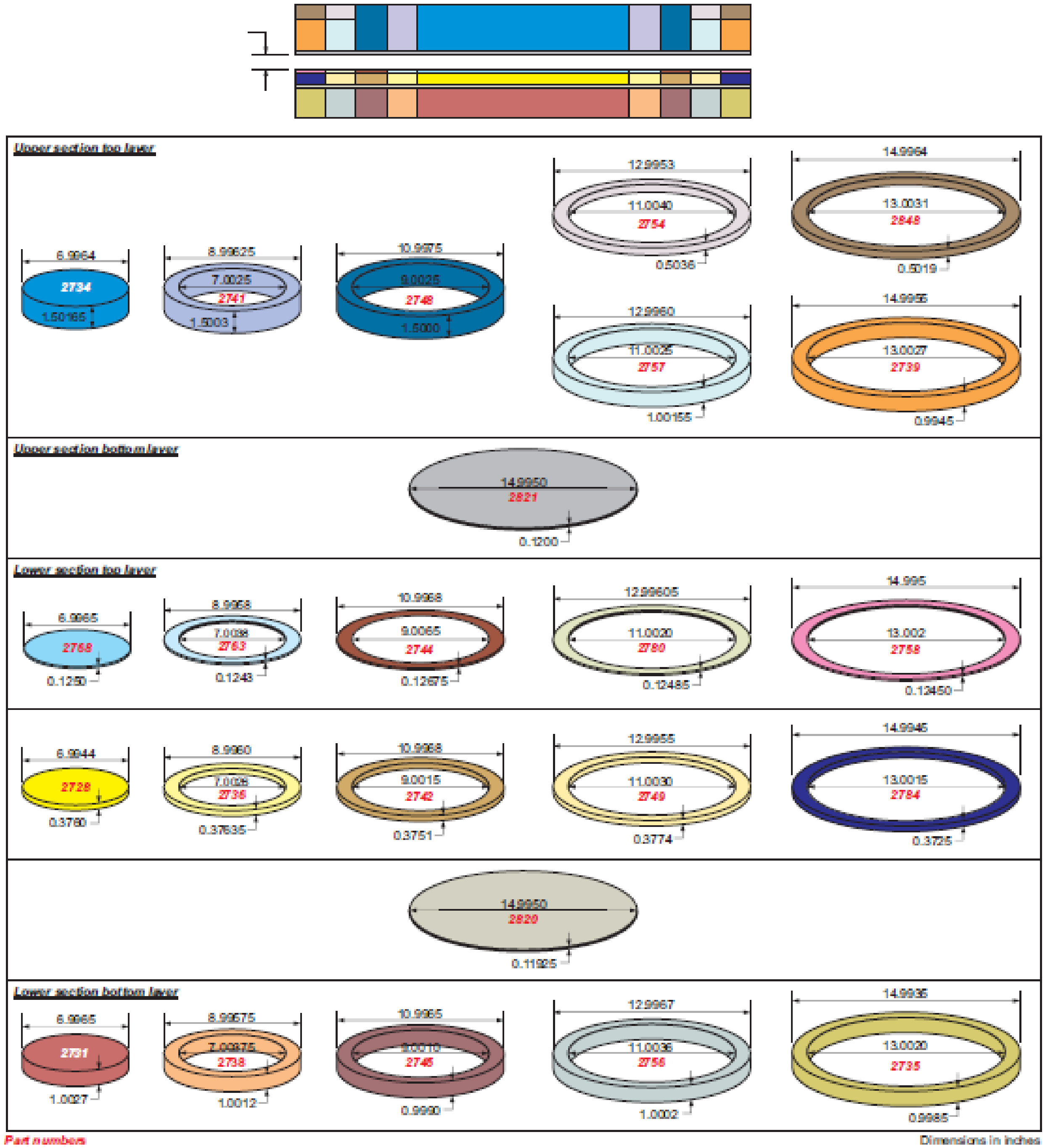

Figure 5. Experiment 1—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 1.625 in., spaced 0.5270 in. apart.

In addition, the prompt neutron decay constant at delayed criticality (May 21, 1963) was measured but is not reported here.

2.2 EXPERIMENT 2

On May 21, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 1.750 in. was measured at delayed criticality with a separation of 1.3811 in. The makeup of the assembly is depicted in Figure 6. This assembly is a slight modification of the previous assembly. A 1/8 in. thick layer of uranium parts was added to the top cylinder of the experiment 1, and the 1/8 in. thick top layer of uranium in the lower section was replaced by a ¼ in. thick layer of uranium parts. The experimental k_{eff} of the configuration as assembled was 1.00000. The upper section of the assembly had a mass of 94,682 g, and the lower section had a mass of 94,603 g. The total mass of the uranium assembly was 189,285 g. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated by measuring the reactivity associated with these supports. Without these supports, the separation of the cylinder would have been 0.033 in. closer (i.e., 1.3471 in.). The reactivity effect of the diaphragm and clamping ring were 13.5, 13.3, and 12.95 cents with an average value of 13.25 ± 0.28 cents. The reactivity associated with the lower support stand was 27.2 and 22.4 cents for an average value of 24.8 ± 3.4 cents. Consequently, the total reactivity associated with the support structure is 38.05 ± 3.41 cents or $\Delta k_{eff} = 0.00251 \pm 0.00023$. Without the air in the cell and the cell structure, the separation would have been lower. The measured reactivity change associated with a change in separation of the upper and lower cylinder is 1.05 cents per thousandths of an inch (mil). Table 4 includes the measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts along with the difference of the average air gap between parts that composed the central 7 in. diameter section, and the various annuli are given in Table 4.

Table 4. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 2 with two interacting 15 in. OD cylinders 1.750 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	1.75492	1.74933	1.7530	1.7515	1.74933
	Thickness of parts (in.)[a]	1.74765	1.7446	1.74675	1.7500	1.7509
	Number of gaps	2	2	2	3	3
	Average gap thickness(mils)[b]	3.9	2.4	3.1	0.5	0
Lower	Measured thickness (in.)	1.75042	1.7485	1.7474	1.7537	1.7509
	Thickness of parts (in.)	1.7482	1.7468	1.7478	1.7486	1.7439
	Number of gaps	3	3	3	3	3
	Average gap thickness (mils)	0.5	0.56	0	2.0	2.3

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary, the configurations for experiment 2 and the k_{eff} values are given in Table 5.

In addition, the prompt neutron decay constant at delayed criticality (May 22, 1963) was measured but is not reported here.

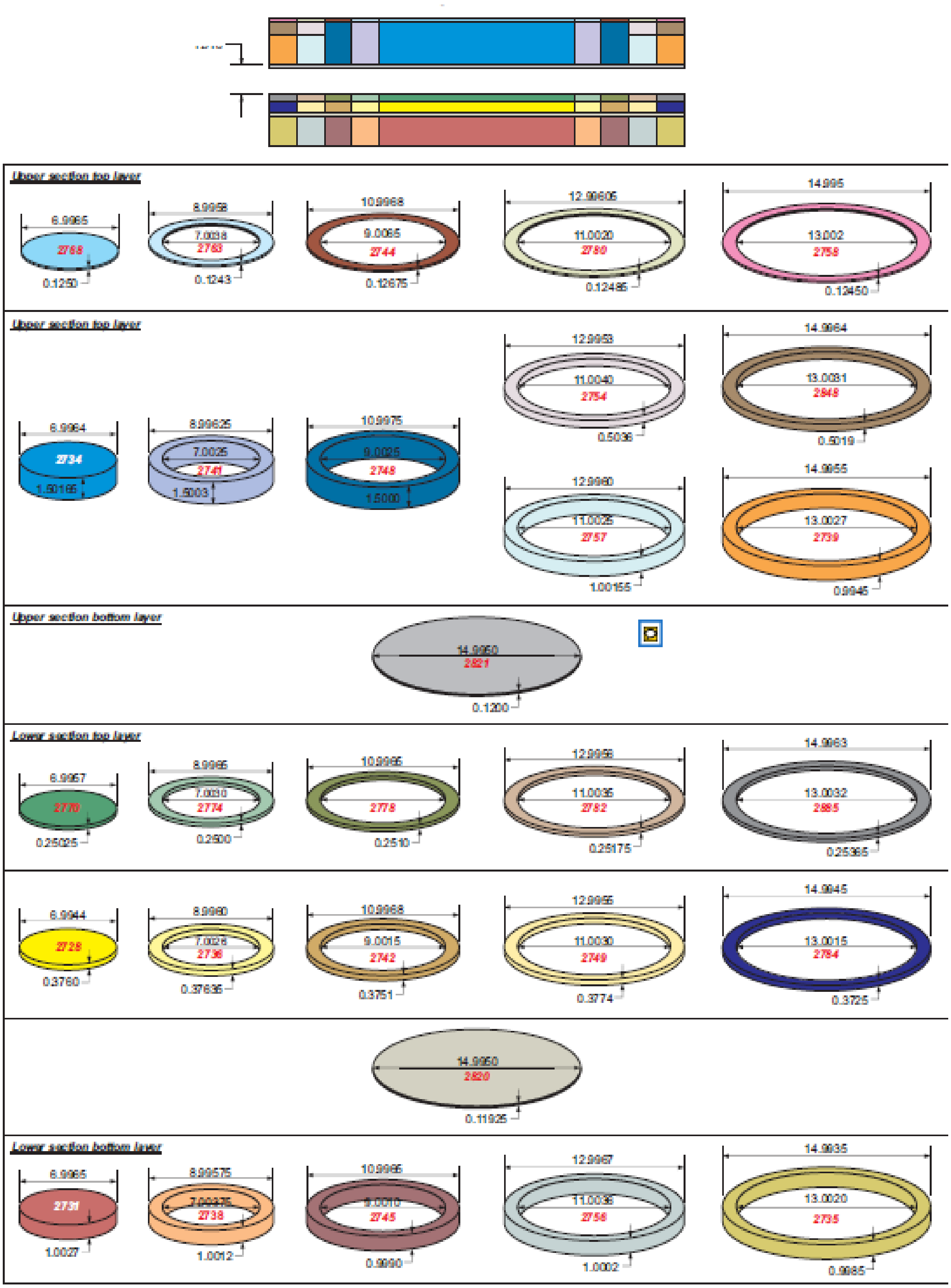

Figure 6. Experiment 2—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt. % ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 1.750 in., spaced 1.3811 in. apart.

Table 5. Summary of configurations and neutron multiplication factors for experiment 2.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	1.3811	1.00000
Without support structure, no correction for room return	1.3811	0.99749 ± 0.00023
Without support structure, no correction for room return	1.3471	1.00000

2.3 EXPERIMENT 3

On May 22, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 1 7/8 in. was measured at delayed criticality with a separation of 1.5971 in. The makeup of the assembly is depicted in Figure 7. This assembly is a slight modification of the previous assembly. An 1/4 in. thick layer of parts replaced the 1/8 in. thick layer on top of the upper cylinder of experiment 2, and a 3/8 in. layer of uranium metal parts replace the ¼ in. thick layer on top of the lower cylinder of experiment 2. The upper and lower cylinders of the assembly had a mass of 101,525 g and 101,313 g, respectively. The total mass of the assembly was 202,838 g. The experimental k_{eff} of the configuration as assembled with the support structure was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated. The measured reactivity worths of the diaphragm and diaphragm support rings were 13.6, 13.6, and 12.3 for an average value of 13.17 ± 0.75 cents and that of the support stand for the lower section were 26.6, 26.5, and 22.4 cents for an average value of 25.16 ± 2.40 cents. Thus, the total reactivity of the support structure was 38.33 ± 2.51 cents. Without these supports, the separation of the cylinder would have been 0.0409 in. closer (i.e., 1.5505 in.). Without the air in the cell and the cell structure, the separation would have been lower. The measured reactivity change associated with a change in separation of the upper and lower cylinder is 1.01 cents per thousandth of an inch (mil). Table 6 includes the measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts along with the difference of the average air gap between parts that composed the central 7 in. diameter section, and the various annuli.

Table 6. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 3 with two interacting 15 in. OD cylinders 1.875 in. high (continued).

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	1.8760	1.8768	1.8773	1.8778	1.8783
	Thickness of parts (in.)[a]	1.86909	1.86489	1.87324	1.86244	1.86824
	Number of gaps	2	2	2	3	3
	Average gap thickness(mils)[b]	3.5	6.0	2.0	3.2	3.4
Lower	Measured thickness (in.)	1.8758	1.8739	1.8729	1.8757	1.8721
	Thickness of parts (in.)	1.87265	1.87305	1.86895	1.87230	1.86494
	Number of gaps	3	3	3	3	3
	Average gap thickness (mils)	1.0	0.28	1.3	1.1	2.4

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.

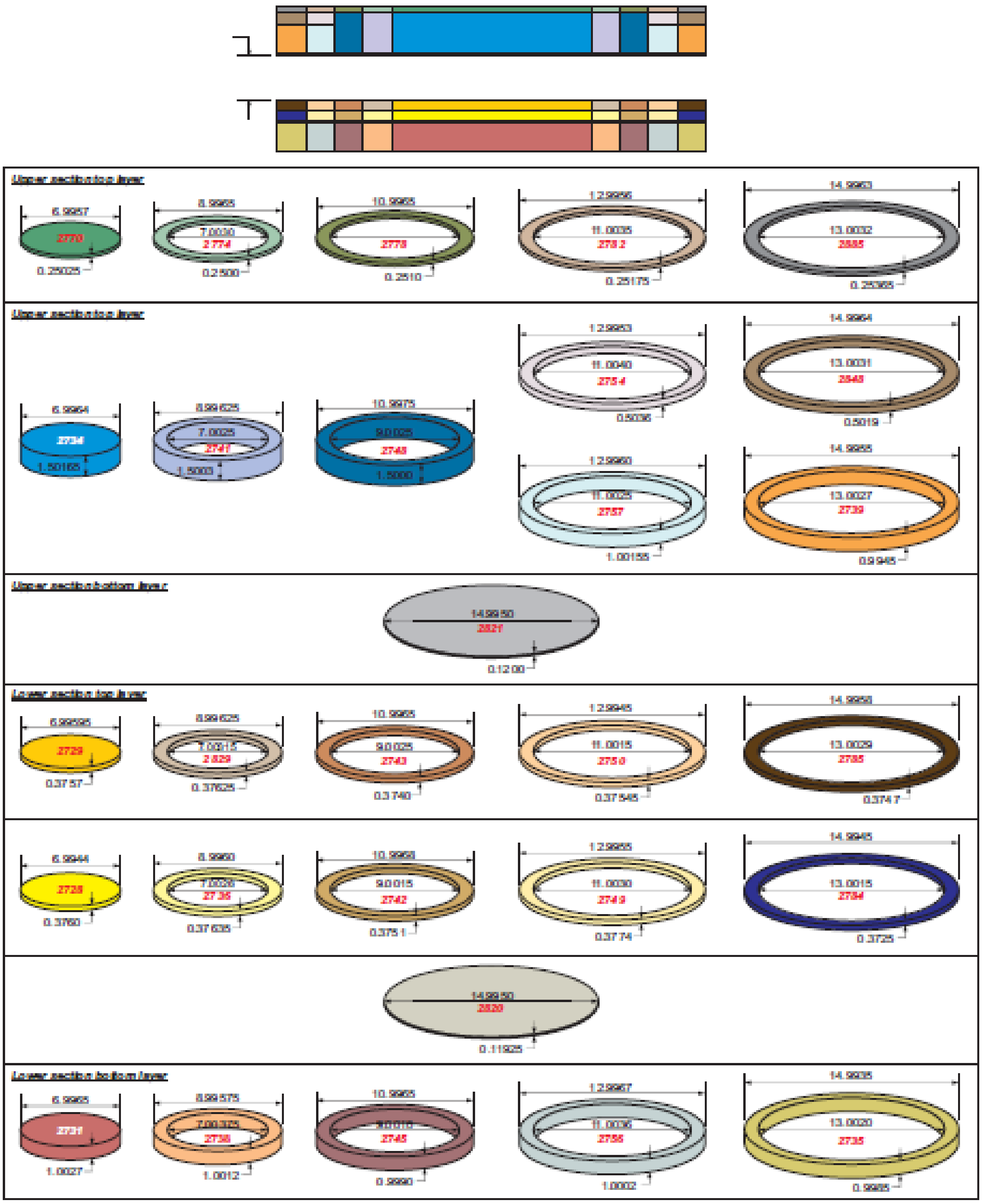

Figure 7. Experiment 3—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 1.875 in., spaced 1.5971 in. apart.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary, the configurations for experiment 3 and the k_{eff} values are given in Table 7.

Table 7. Summary of configurations and neutron multiplication factors for experiment 3.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	1.5971	1.00000
Without support structure, no correction for room return	1.5971	0.99747 ± 0.00016
Without support structure, no correction for room return	1.5505	1.00000

In addition, the prompt neutron decay constant at delayed criticality (May 23, 1963) was measured but is not reported here.

2.4 EXPERIMENT 3A

On July 31, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 1 7/8 in. was measured at delayed criticality with a separation of 1.5736 in. This assembly is a repeat of experiment 3 but had the same lower section as experiment 3. The upper section uranium metal parts were different, and the makeup of the assembly is depicted in Figure 8. The upper and lower cylinders of the assembly had a mass of 101,329 g and 101313 g, respectively. The total mass of the assembly was 202,642 g. The experimental k_{eff} of the configuration as assembled with the support structure was 1.00000. Without these supports, the separation of the cylinder would have been 0.0379 in. closer (i.e., 1.5357 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The measured reactivity change associated with a change in separation of the upper and lower cylinder is 1.07 cents per thousandth of an inch (mil). The measured height of the various sections of the upper and lower cylinder and the sum of the measured heights of the individual parts along with the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 8.

Table 8. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 3a with two interacting 15 in. OD cylinders 1.875 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	1.8831	1.8831	1.8831	1.8830	1.88876
	Thickness of parts (in.)[a]	1.8690	1.86489	1.87324	1.87244	1.86824
	Number of gaps	5	5	5	5	5
	Average gap thickness(mils)[b]	2.8	3.6	2.0	2.1	4.1
Lower	Measured thickness (in.)	1.8758	1.8739	1.8729	1.8757	1.8721
	Thickness of parts (in.)	1.87265	1.87305	1.86895	1.87230	1.86494
	Number of gaps	3	3	3	3	3
	Average gap thickness(mils)	1.0	0.28	1.3	1.1	2.4

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.

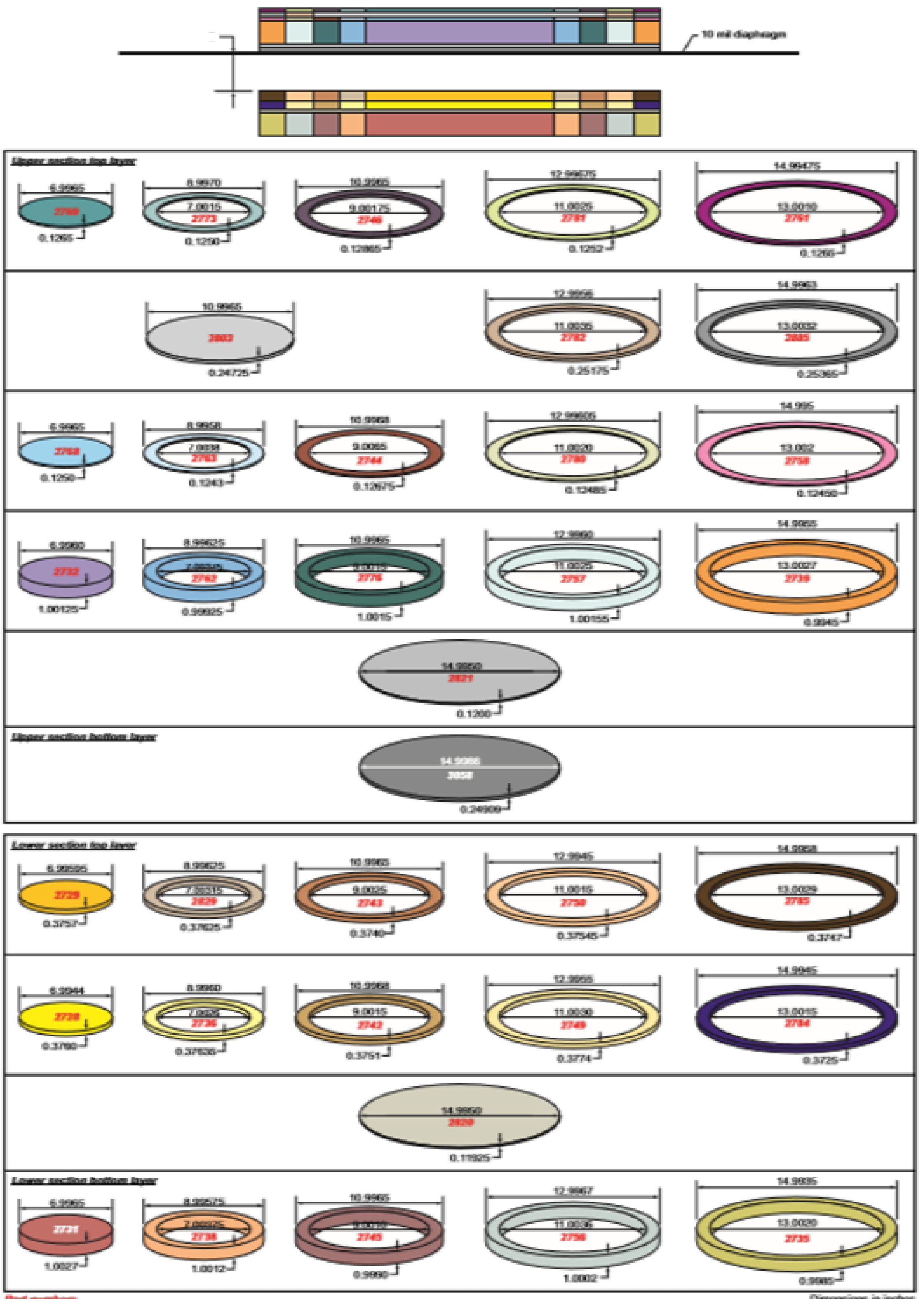

Figure 8. Experiment 3a—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with height of 1.875 in., spaced 1.5736 in. apart.

It is not necessary to calculate the effects of room return using Monte Carlo simulations. Instead, the value from experiment 3 can be used. In summary, the configurations for experiment 3a and the k_{eff} values are given in Table 9.

Table 9. Summary of configurations and neutron multiplication factors for experiment 3a.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	1.5736	1.00000
Without support structure, no correction for room return	1.5357	1.00000

In addition, the prompt neutron decay constant at delayed criticality (August 1, 1963) was measured but is not reported here.

2.5 EXPERIMENT 4

On May 23, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2.0 in. was measured at delayed criticality with a separation of 2.2463 in., which includes the thickness of the diaphragm. This configuration was completely reassembled with the same uranium parts on August 2, 1963 (Book E-20, p. 98), and the measured separation was 2.2441 in. This demonstrates the reproducibility of the restacking, assembly, and the measured separation. The makeup of the assembly is depicted in Figure 9. The upper and lower cylinders of the assembly had a mass of 108,299 g and 108,695 g, respectively. The total mass of the assembly was 216,394 g. The experimental k_{eff} of the configuration as assembled with the support structure was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated by determining the change in spacing when the support structure was doubled. Without these supports, the separation of the cylinder would have been 0.04415 in. closer (i.e., 2.2022 in.). The measured reactivity change associated with a change in separation of the upper and lower cylinder was measured to be 0.93 cents per thousandth of an inch (cents/mil). Without the air in the cell and the cell structure, the separation would have been lower yet. The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts along with the difference from which the average air gap between parts that composed the central 7 in. diameter section, and the various annuli are given in Table 10. These gaps should be included in the detailed model when comparing calculations with measurements.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary the configurations for experiment 4 and the k_{eff} values are given in Table11.

Table 10. Measured height of each radial increment, sum of inspection report heights, and average gap between parts of each radial section for experiment 4 with two interacting 15 in. OD cylinders 2.000 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.001	1.99842	2.0015	2.0032	2.0053
	Thickness of parts (in.)[a]	1.9954	1.99255	1.9959	2.0021	1.99655
	Number of gaps	3	3	3	4	4
	Average gap thickness (mils)[b]	1.9	2.0	1.9	2.7	2.2
Lower	Measured thickness (in.)	2.0001	2.0003	2.00233	2.00117	1.9978
	Thickness of parts (in.)	1.9965	1.99735	1.9941	1.99715	1.98945
	Number of gaps	4	4	4	4	4
	Average gap thickness (mils)	0.9	1.6	2.1	1.0	2.1

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.

Table 11. Summary of configurations and neutron multiplication factors for experiment 4.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	2.2463	1.00000
Without support structure, no correction for room return	2.2022	1.00000

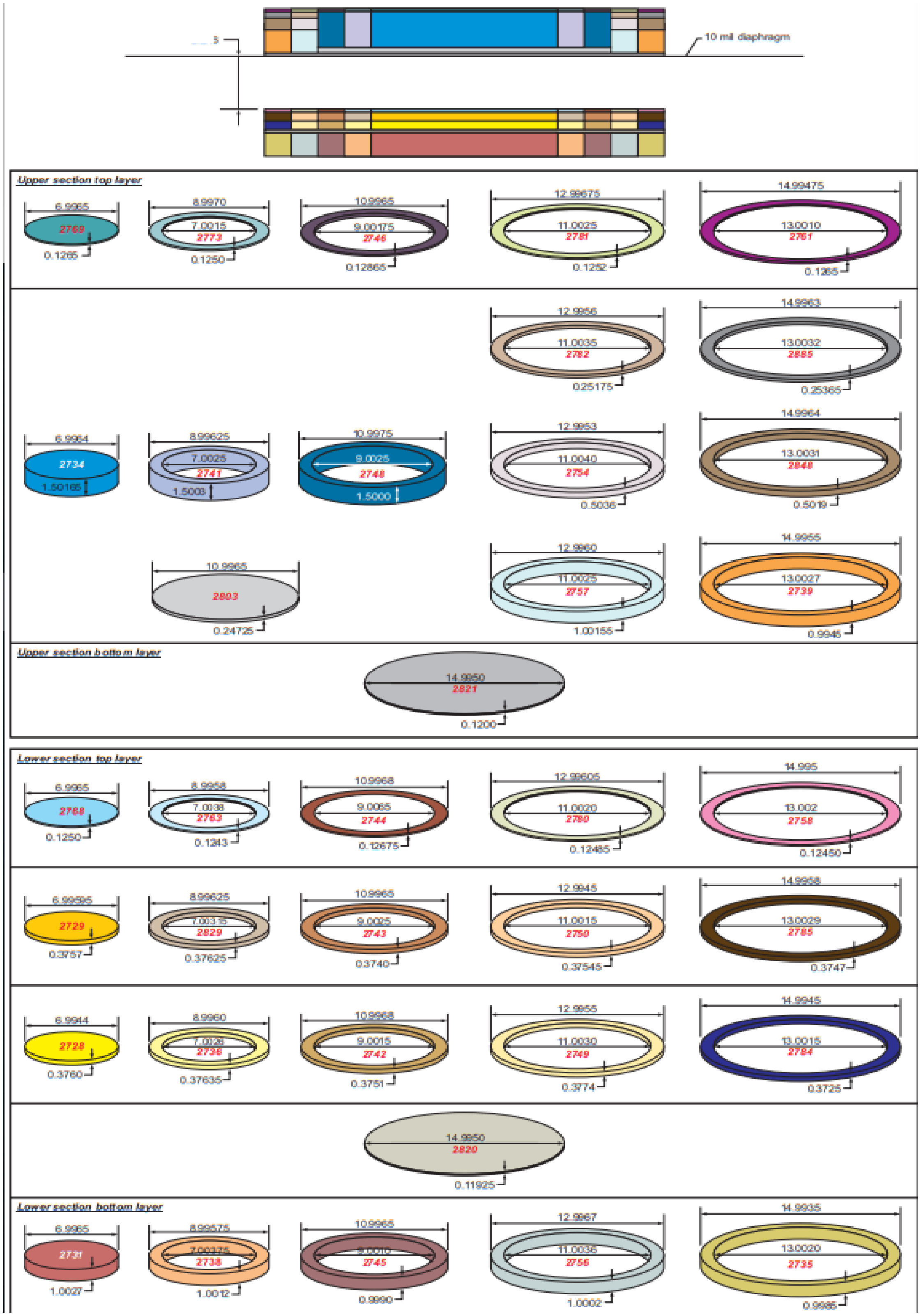

Figure 9. Experiment 4a—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.000 in., spaced 2.2463 in. apart.

2.6 EXPERIMENT 4A

On August 2, 1963, a symmetric assembly of two 15 in. -diameter, interacting cylinders with nominal heights of 2.00 in. was measured at delayed criticality with a separation of 2.2162 in. This assembly is a repeat of experiment 4 but had the same lower section as experiment 3 but with a 1/8 layer added to the bottom section and the upper section had ¼ in. thick layer replacing the 1/8 in. thick upper layer of experiment 3a. The upper section uranium metal parts were different, and the makeup of the assembly is depicted in Figure 10. This assembly was restacked with the same uranium metal parts, reassembled on August 5, 1963 (Logbook E 20, page 99) and the remeasured separation was 2.2087 inches. The upper and lower cylinders of the assembly had a mass of 108,159 g and 108,163 g, respectively. The total mass of the assembly was 216,322 g. The experimental k_{eff} of the configuration as assembled with the support structure was 1.00000. Without these supports, the separation of the cylinder would have been closer. Neither the effects of the support structure were not measured for experiment 4a nor was the reactivity change per unit of separation. A good assumption is that these are the same as for experiment 4. Thus the change in separation due to the support structure was 0.04415, and the spacing without the support structure was 2.17205. The in reactivity per change in height was 0.93 cents per thousandths. Without the air in the cell and the cell structure, the separation would have been lower yet. The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter and the various annuli are given in Table 12. The thicknesses of the lower cylinder were not measured so those of experiment 3a were used.

Table 12. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 4a with two interacting 15 in. OD cylinders 2.000 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.0060	2.0060	2.0060	2.00625	2.0076
	Thickness of parts (in.)[a]	1.99283	1.99989	1.99589	1.99789	1.99319
	Number of gaps	5	5	5	5	5
	Average gap thickness (mils)[b]	2.6	1.2	2.0	1.7	2.0
Lower	Measured thickness (in.)	NM[c]	NM	NM	NM	NM
	Thickness of parts (in.)	2.00015	1.99805	1.9960	1.9885	1.99745
	Number of gaps	4	4	4	4	4
	Average gap thickness (mils)	1.0	0.28	1.3	1.7	2.4

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.
[c] NM means not measured and values from experiment 4 are used.

The effects of room return need not be calculated using Monte Carlo simulations. The calculated change in k_{eff} from room return for experiment 4 can be used. In summary the configurations for experiment 4a and the k_{eff} values are given in Table 13. This assembly was restacked twice with the same uranium metal parts and both values are given. It was assumed that the change in separation due to the support structure was the same as experiment 4.

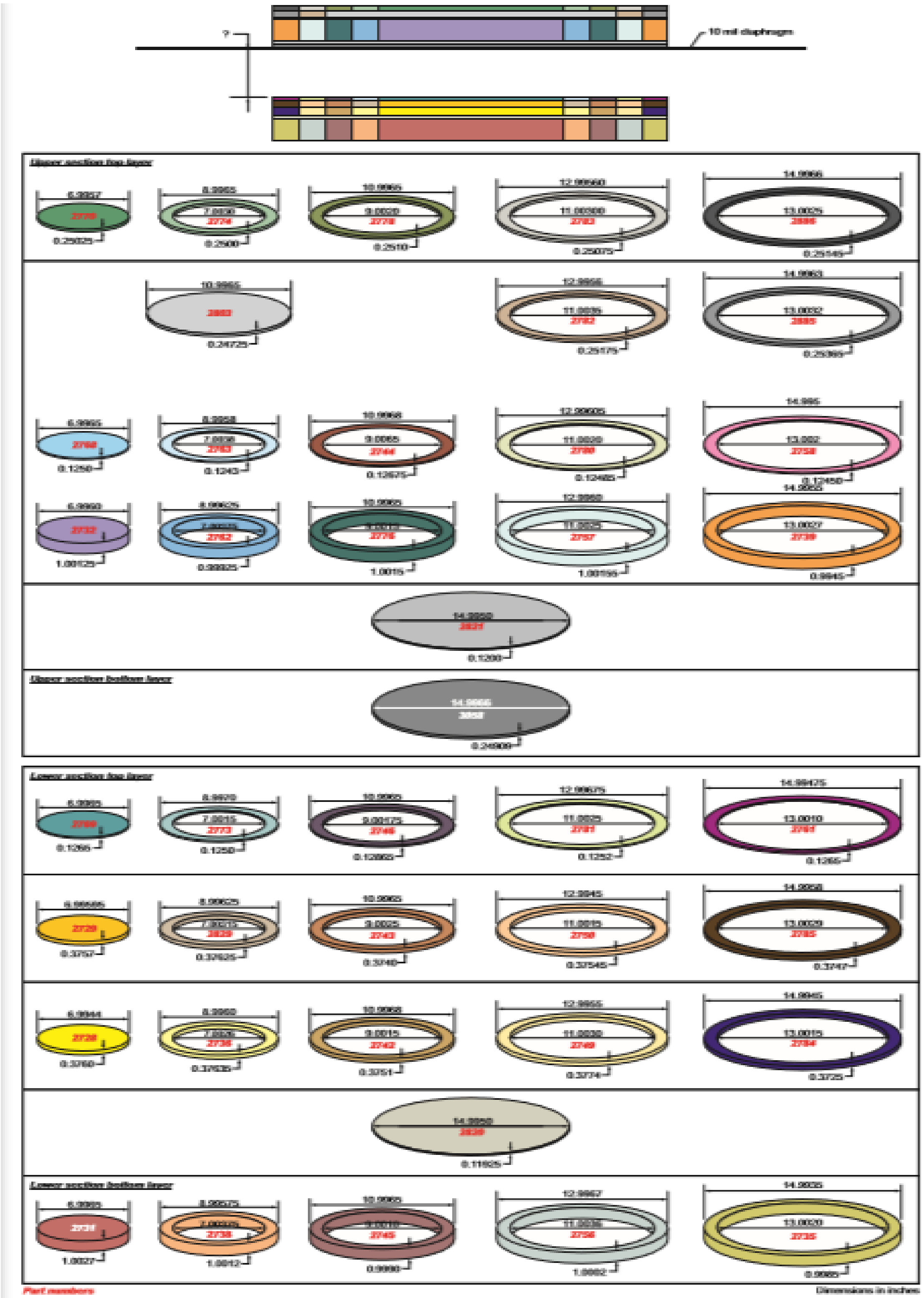

Figure 10. Experiment 4a—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.000 in., spaced 2.2162 in. apart.

Table 13. Summary of configurations and neutron multiplication factors for experiment 4a.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	2.2162, 2.2063	1.00000
Without support structure, no correction for room return	2.1722, 2.1622	1.00000

In addition, the prompt neutron decay constant at delayed criticality (May 23, 1963) was measured but is not reported here.

2.7 EXPERIMENT 5

On May 24, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2-1/8 in. was measured at delayed criticality with a separation of 2.9713 in. The makeup of the assembly is depicted in Figure 11. This assembly is a modification of experiment 4. The 1/8 in. thick layer of parts on the top cylinder of experiment 4 was replaced with a ¼ in. thick layer of parts. The upper 7/8 in. thick section of experiments 4 was replaced by a 1 in. thick section composed of ½ and 1 in. thick uranium metal parts. The upper and lower cylinders of the assembly had a mass of 114,983 g and 114,886 g, respectively. The total mass of the assembly was 229,869 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated by measuring the change in spacing with the extra support structure present. Without these supports, the separation of the cylinder would have been 0.05225 in. closer (i.e., 2.91905 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The measured reactivity change associated with a change in separation of the upper and lower cylinder is 0.78 cents per thousandths of an inch (mil). The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 14.

Table 14. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 5 with two interacting 15 in. OD cylinders 2.125 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.1203	2.1224	2.1255	2.1285	2.1305
	Thickness of parts (in.)[a]	2.11695	2.11605	2.1185	2.12765	2.1215
	Number of gaps	3	3	3	4	4
	Average gap thickness (mils)[b]	1.1	2.1	1.3	0.21	2.25
Lower	Measured thickness (in.)	2.1230	2.1223	2.1237	2.1293	2.1260
	Thickness of parts (in.)	2.1232	2.1197	2.11975	2.12625	2.1124
	Number of gaps	2	2	2	3	3
	Average gap thickness (mils)	0.0	1.3	2.0	1.0	4.5

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary, the configurations for experiment 5 and the keff values are given in Table 15.

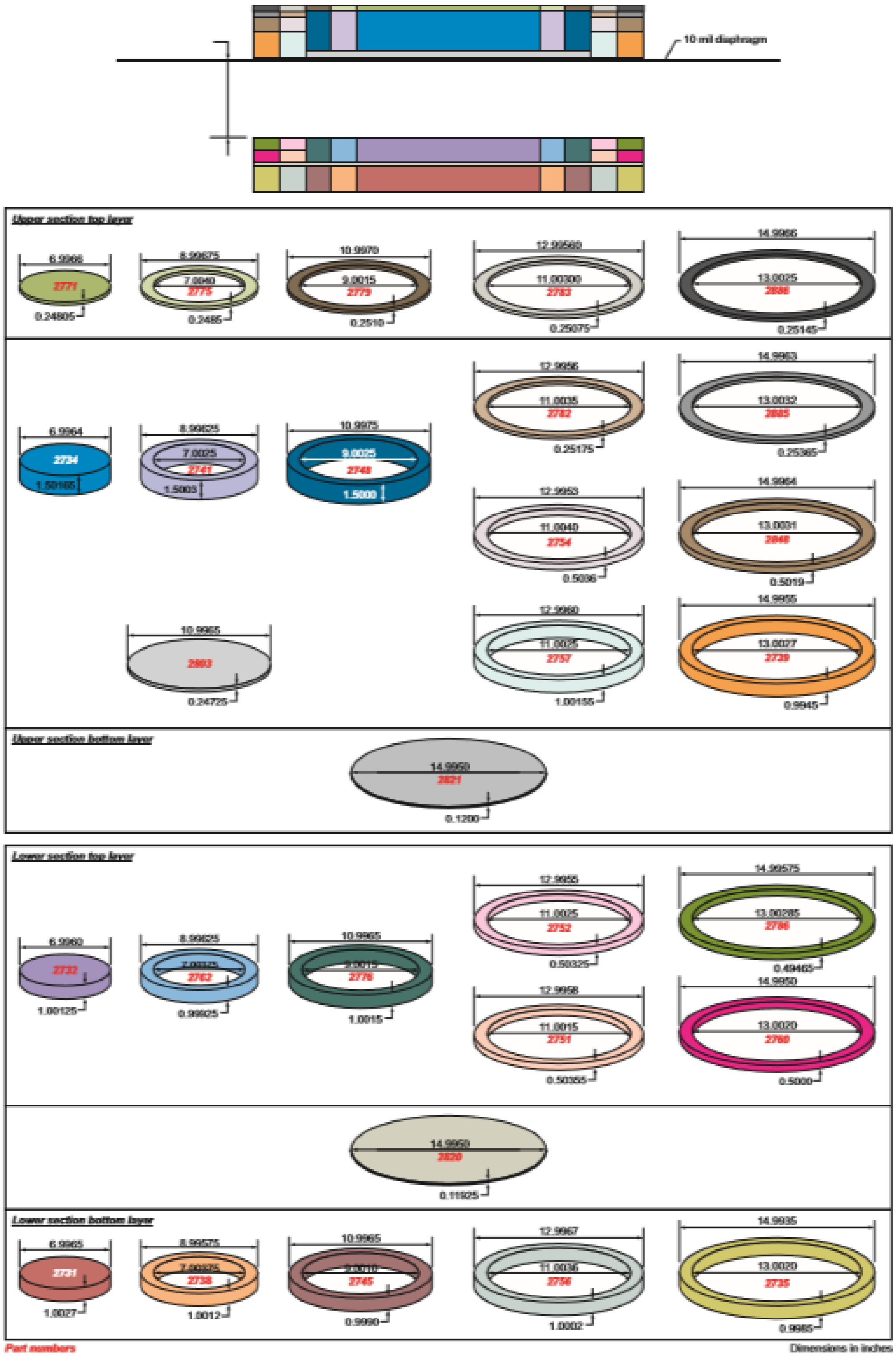

Figure 10. Experiment 5—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.125 in., spaced 2.9713 in. apart.

Table 15. Summary of configurations and neutron multiplication factors for experiment 5.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	2.9713	1.00000
Without support structure, no correction for room return	2.91905	1.00000

In addition, the prompt neutron decay constant at delayed criticality (May 23, 1963) was measured but is not reported here.

2.8 EXPERIMENT 5A

On May 31, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2 1/8 in. was measured at delayed criticality with a separation of 2.9578 in. The makeup of the assembly is depicted in Figure 12. The upper and lower cylinders of the assembly had a mass of 115,035 g and 114,829 g, respectively. The total mass of the assembly was 229,864 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was not evaluated. It was assumed that the change in spacing or this experiment as the same as experiment 5. Thus, without these supports, the separation of the cylinder would have been 0.05225 in. closer (i.e., 2.90555 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder is 0.78 cents per thousandth of an inch (mil). There is no record of the measured height of the outer two annuli of the lower cylinder. The values for the lower section were assumed to be the same as experiment 5, and all are given in Table 16.

Table 16. Measured height of each radial increment, sum of inspection report heights, and average gap between parts of each radial section for experiment 5a with two interacting 15 in. OD cylinders 2.125 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.1287	2.1287	2.1287	2.1369	2.1384
	Thickness of parts (in.)[a]	2.11719	2.11695	2.12894	2.12904	2.12198
	Number of gaps	3	3	3	5	5
	Average gap thickness(mils)[b]	3.8	3.9	0	1.6	3.3
Lower	Measured thickness (in.)	2.123	2.1223	2.1327	NM[c]	NM
	Thickness of parts (in.)	2.1232	2.1197	2.11975	2.121	2.11235
	Number of gaps	2	2	2	2	2
	Average gap thickness(mils)	0.0	1.3	6.5	1.0	4.5

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.
[c] NM means not measured and values from experiment 5 are used.

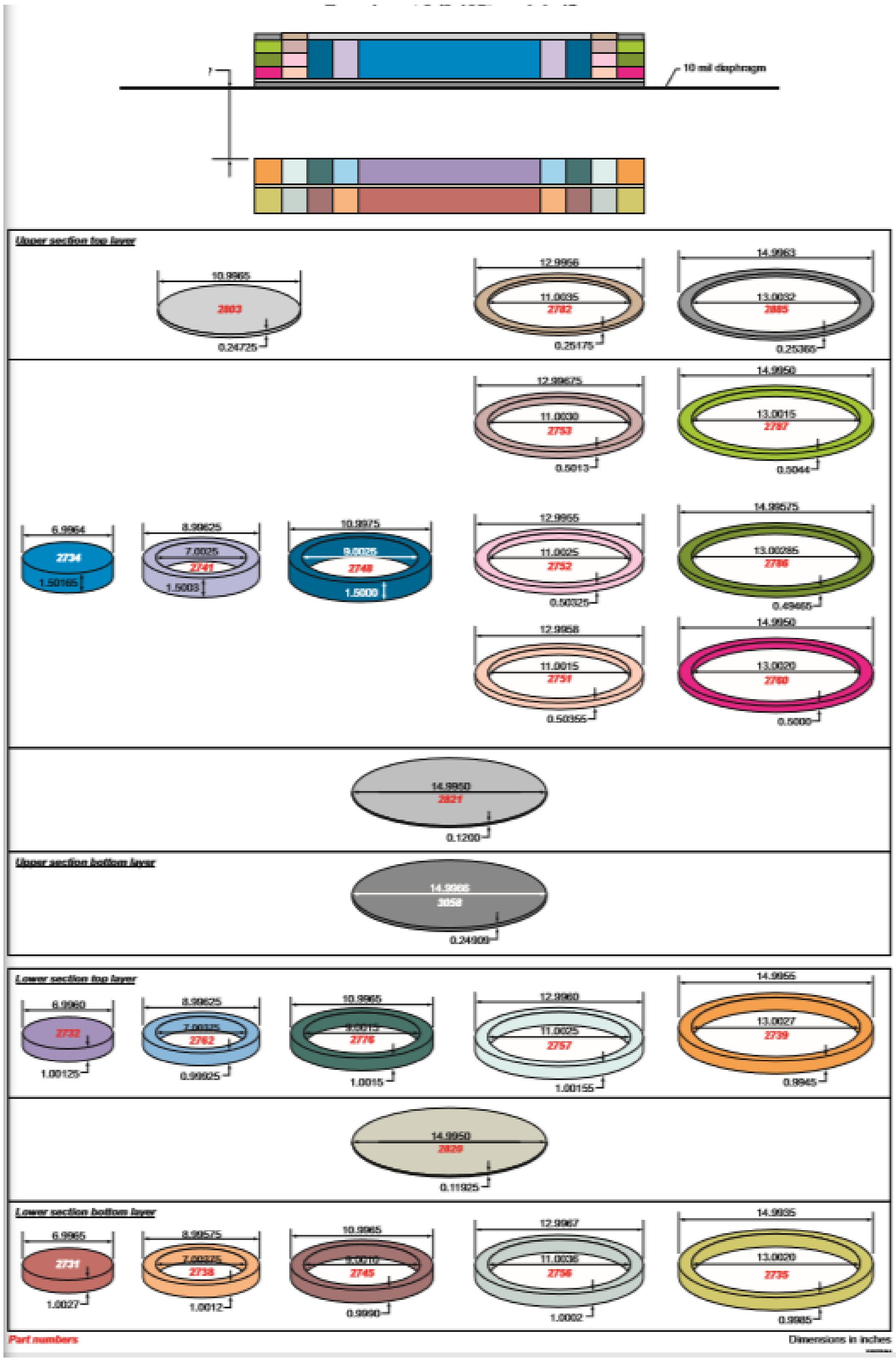

Figure 12. Experiment 5a—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.125 in., spaced 2.9578 in. apart.

The effects of room return need not calculated using Monte Carlo simulations, but the value from experiment 5 can be used. In summary the configurations for experiment 5a and the k_{eff} values are given in Table 17.

Table 17. Summary of configurations and neutron multiplication factors for experiment 5a.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	2.9578	1.00000
Without support structure, no correction for room return	2.90555	1.00000

In addition, the prompt neutron decay constant at delayed criticality (May 23, 1963) was measured but is not reported here.

2.9 EXPERIMENT 6

On May 28, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2 1/4 in. was measured at delayed criticality with a separation of 3.8334 in. The makeup of the assembly is depicted in Figure 13. The upper and lower cylinders of the assembly had a mass of 121,804 g and 121,668 g, respectively. The total mass of the assembly was 243,472 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand evaluated. Without these supports, the separation of the cylinder would have been 0.0805 in. closer (i.e., 3.7529. in.). Without the air in the cell and the cell structure, the separation would have been lower yet.

The reactivity change associated with a change in separation of the upper and lower cylinder is 0.54 cents per thousandth of an inch (mil). The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 18.

Table 18. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 6 with two interacting 15 in. OD cylinders 2.250 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.2505	2.2460	2.2463	2.2548	2.2527
	Thickness of parts (in.)[a]	2.2446	2.2438	2.24125	2.24543	2.24255
	Number of gaps	3	3	3	4	4
	Average gap thickness (mils)[b]	1.97	0.73	1.7	2.34	2.54
Lower	Measured thickness (in.)	2.250	2.2478	2.2518	2.2540	2.2418
	Thickness of parts (in.)	2.2482	2.2440	2.2465	2.2511	2.2369
	Number of gaps	3	3	3	4	4
	Average gap thickness (mils)	0.6	1.27	1.77	0.73	1.22

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.

In addition, the prompt neutron decay constant at delayed criticality (May 28, 1963) and the coupling reactivity were measured but both are not reported here.

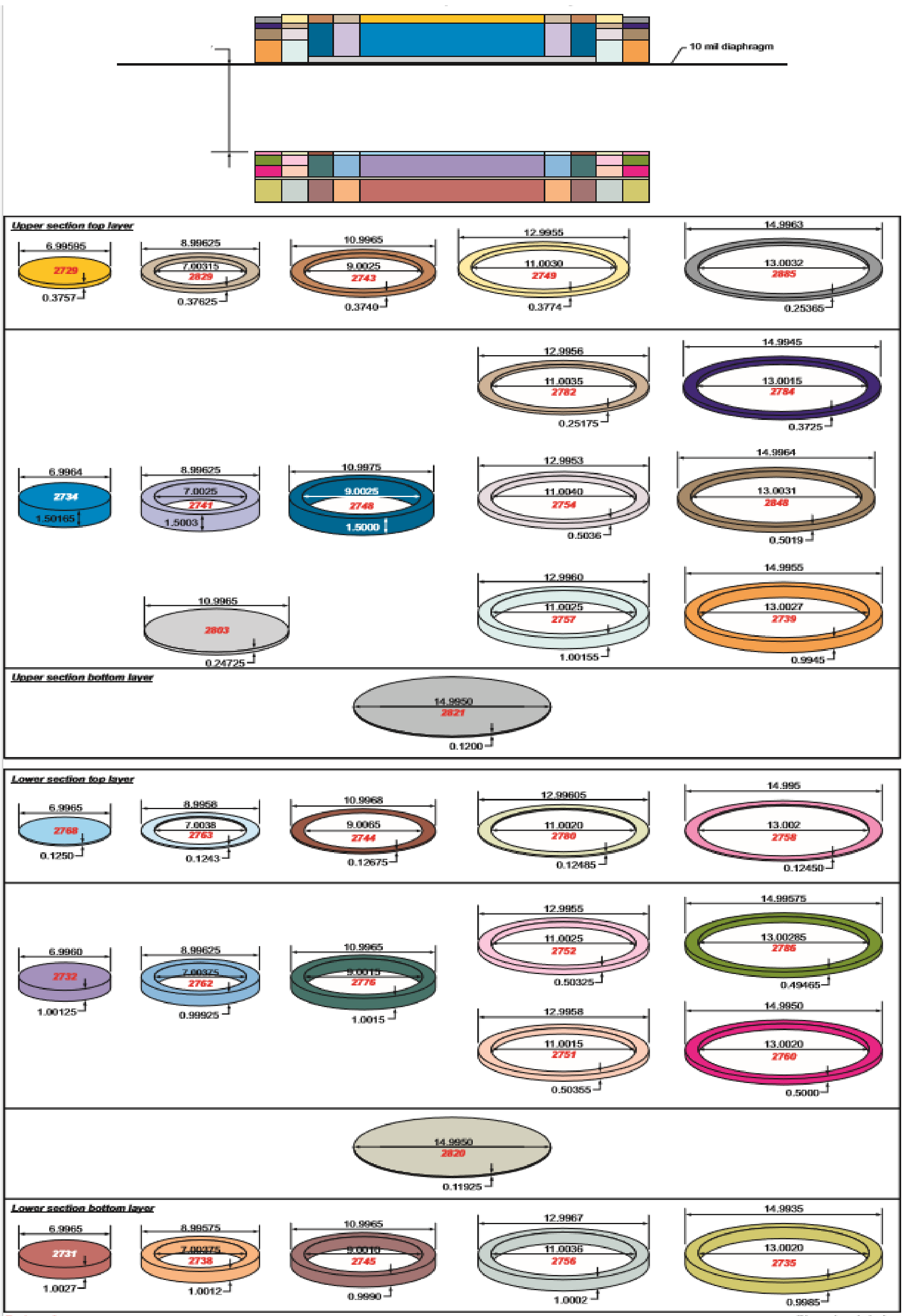

Figure 13. Experiment 6—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.250 in., spaced 3.8334 in. apart.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary the configurations for experiment 6 and the k_{eff} values are given in Table 19.

Table 19. Summary of configurations and neutron multiplication factors for experiment 6.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	3.8334	1.00000
Without support structure, no correction for room return	3.7529	1.00000
Without support structure but corrected for room return	3.7529	0.9999??

2.10 EXPERIMENT 6A

On August 5, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2 1/4 in. was measured at delayed criticality with a separation of 3.8427 in. The makeup of the assembly is depicted in Figure 14. The upper and lower cylinders of the assembly had a mass of 121,855 g and 121,611 g, respectively. The total mass of the assembly was 243,496 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated. Without these supports, the separation of the cylinder would have been 0.068 in. closer (i.e., 3.7747 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder is 0.517 cents per thousandth of an inch (mil). The measured height of the various sections of the upper (measured) and lower (not measured and assumed the same as experiment 6) cylinder and the sum of the measured heights of the individual parts along with the difference annuli are given in Table 20.

Table 20. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 6a with two interacting 15 in. OD cylinders 2.250 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.2548	2.2548	2.2548	2.2638	2.2630
	Thickness of parts (in.)[a]	2.24449	2.24164	2.24499	2.25414	2.24829
	Number of gaps	4	4	4	6	6
	Average gap thickness (mils)[b]	2.6	3.3	2.5	0.73	2.4
Lower	Measured thickness (in.)	NM	NM	NM	NM	Nm
	Thickness of parts (in.)	2.2482	2.244	2.2465	2.24585	2.23675
	Number of gaps	3	3	3	3	3
	Average gap thickness (mils)	0.6	1.27	1.77	0.73	1.22

[a] Sum of part thicknesses
[b] One mil is one thousandth of an inch.

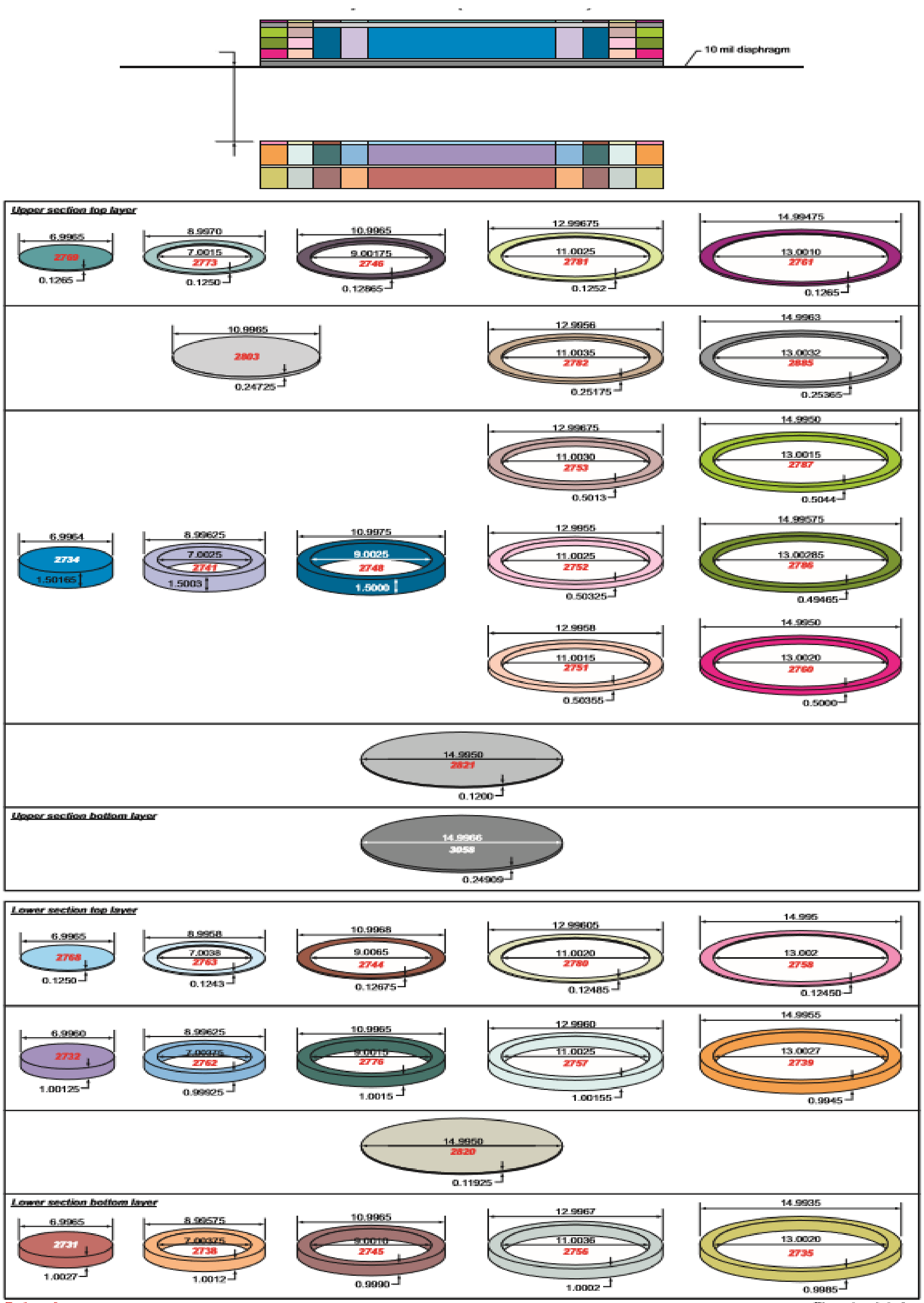

Figure 14. Experiment 6a—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.250 in., spaced 3.8427 in. apart.

The effects of room return need not be calculated using Monte Carlo simulations but that for experiment 6 can be used. In summary the configurations for experiment 6a and the k_{eff} values are given in Table 21.

Table 21. Summary of configurations and neutron multiplication factors for experiment 6a.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	3.8427	1.00000
Without support structure, no correction for room return	3.7747	1.00000

In addition, the prompt neutron decay constant at delayed criticality (May 28, 1963) and the coupling reactivity were measured, but neither are reported here.

2.11 EXPERIMENT 7

On May 28, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2 3/8 in. was measured at delayed criticality with a separation of 4.9095 in. The makeup of the assembly is depicted in Figure 15. The upper and lower cylinders of the assembly had a mass of 128,586 g and 128,420 g, respectively. The total mass of the assembly was 257,006 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated. Without these supports, the separation of the cylinder would have been 0.0895 in. closer (i.e., 4.820 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder is 0.409 cents per thousandths of an inch (mil). The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 22.

Table 22. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 7 with two interacting 15 in. OD cylinders 2.375 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.3758	2.3717	2.3748	2.3783	2.3798
	Thickness of parts (in.)[a]	2.3695	2.3681	2.368	2.37915	2.3675
	Number of gaps	4	4	4	5	5
	Average gap thickness (mils)[b]	1.6	0.9	1.7	0.0	2.5
Lower	Measured thickness (in.)	2.3721	2.3726	2.37463	2.3783	2.3778
	Thickness of parts (in.)	2.37125	2.368	2.37075	2.377	2.36335
	Number of gaps	3	3	3	4	4
	Average gap thickness (mils)	0.28	1.4	1.3	0.32	3.6

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.

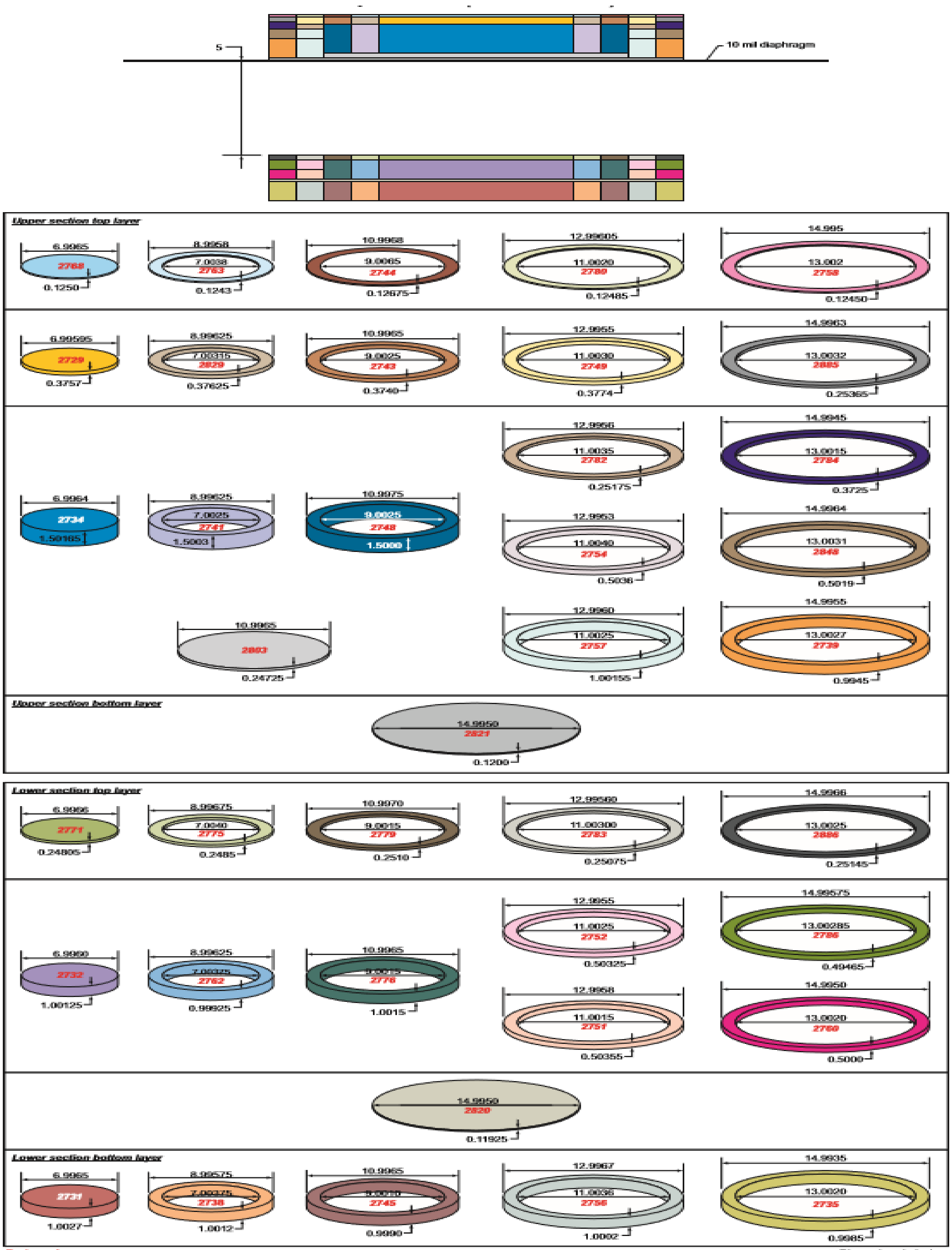

Figure 15. Experiment 7—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.375 in., spaced 4.9095 in. apart.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary the configurations for experiment 7 and the k_{eff} values are given in Table 23.

Table 23. Summary of configurations and neutron multiplication factors for experiment 7.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	4.9095	1.00000
Without support structure, no correction for room return	4.8200	1.00000

In addition, the prompt neutron decay constant at delayed criticality (May28, 1963) and the coupling reactivity were measured but both are not reported here.

2.12 EXPERIMENT 7A

On August 5, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2 3/8 in. was measured at delayed criticality with a separation of 4.8854 in. The makeup of the assembly is depicted in Figure 16. The upper and lower cylinders of the assembly had a mass of 128,460 g and 128454 g, respectively. The total mass of the assembly was 2 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was not evaluated and was assumed to be the same as experiment 7. Without these supports, the separation of the cylinder would have been 0.0895 in. closer (i.e., 4.7959 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder was not measured and is assumed to be the same as experiment 7 and is 0.409 cents per thousandth of an inch (mil). The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 24.

Table 24. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 7a with two interacting 15 in. OD cylinders 2.375 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.3699	2.3699	2.3699	2.3774	2.37880
	Thickness of parts (in.)[a]	2.36604	2.36514	2.36734	2.37789	2.36734
	Number of gaps	4	4	4	6	6
	Average gap thickness (mils)[b]	0.96	1.2	0.64	0.0	1.9
Lower	Measured thickness (in.)	NM[c]	NM	NM	NM	NM
	Thickness of parts (in.)	2.37345	2.3697	2.37075	2.37275	2.3659
	Number of gaps	4	4	4	4	4
	Average gap thickness (mils)	0.28	1.4	1.3	0.32	3.6

[a] Sum of part thicknesses
[b] One mil is one thousandth of an inch.
[c]NM means not measured and values used were from experiment 7.

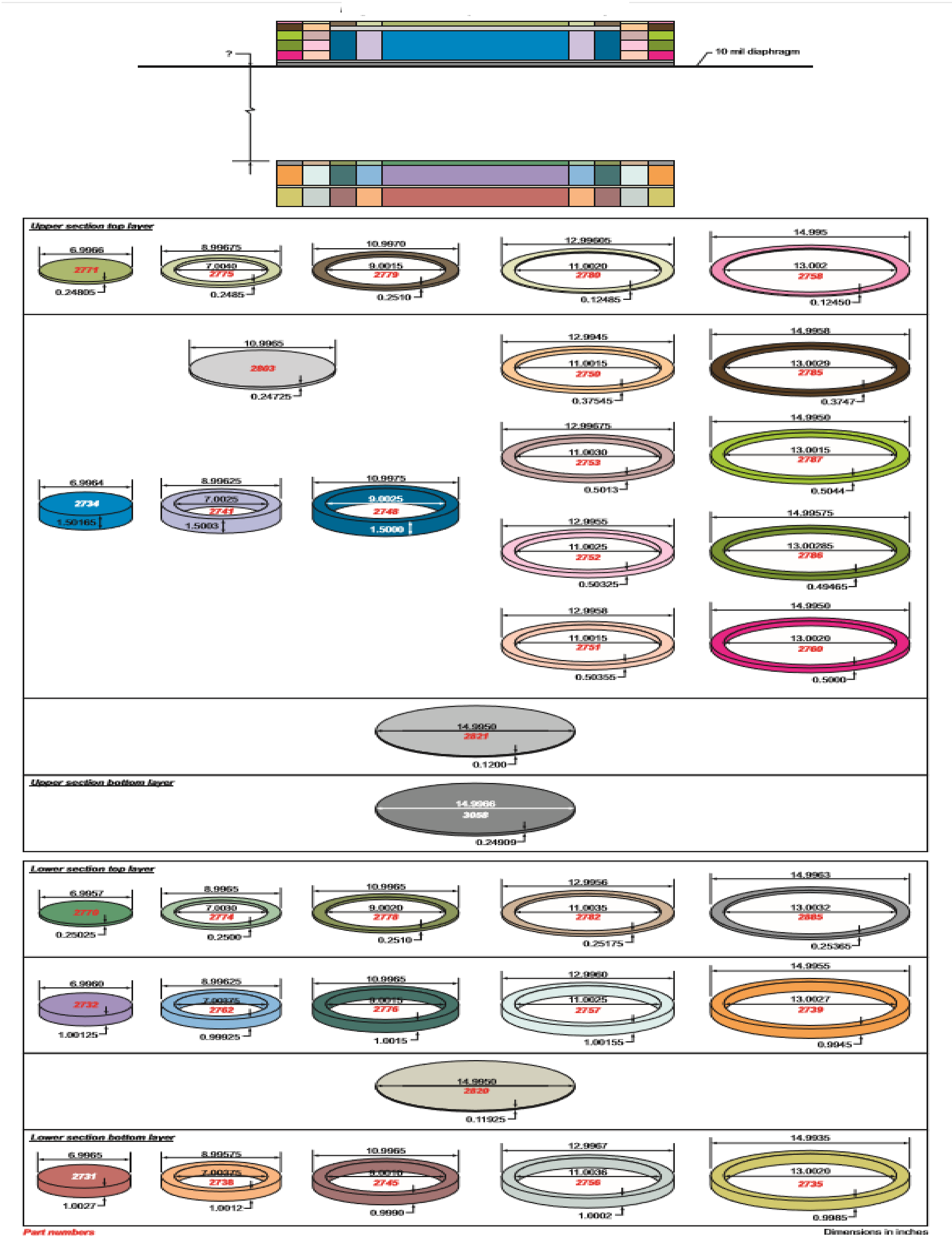

Figure 16. Experiment 7a—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.375 in., spaced 4.8854 in. apart.

The effects of room return need not calculated using Monte Carlo simulations, but instead the value from experiment 7 can be used. In summary the configurations for experiment 7a and the k_{eff} values are given in Table 25.

Table 25. Summary of configurations and neutron multiplication factors for experiment 7a.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	4.8854	1.00000
Without support structure, no correction for room return	4.7959	1.00000

In addition, the prompt neutron decay constant at delayed criticality (May 28, 1963) and the coupling reactivity were measured, but neither are reported here.

2.13 EXPERIMENT 8

On May 31, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2.5 in. was measured at delayed criticality with a separation of 6.2938 in. The makeup of the assembly is depicted in Figure 17. The upper and lower cylinders of the assembly had a mass of 135,345 g and 135,236 g, respectively. The total mass of the assembly was 270,581 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated. Without these supports, the separation of the cylinder would have been 0.1220 in. closer (i.e., 6.1718 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder is 0.295 cents per thousandth of an inch (mil). The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 26.

Table 26. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 8 with two interacting 15 in. OD cylinders 2.500 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.5015	2.5015	2.5015	2.5018	2.5018
	Thickness of parts (in.)[a]	2.49265	2.4923	2.49225	2.50505	2.494
	Number of gaps	4	4	4	5	5
	Average gap thickness (mils)[b]	2.2	2.3	2.3	0.0	1.56
Lower	Measured thickness (in.)	2.5032	2.5032	2.5032	2.5029	2.5027
	Thickness of parts (in.)	2.4992	2.49605	2.49485	2.5018	2.4871
	Number of gaps	4	4	4	5	5
	Average gap thickness (mils)	1.0	1.8	2.1	0.22	3.1

[a] Sum of part thicknesses.
[b] One mil is one thousandth of an inch.

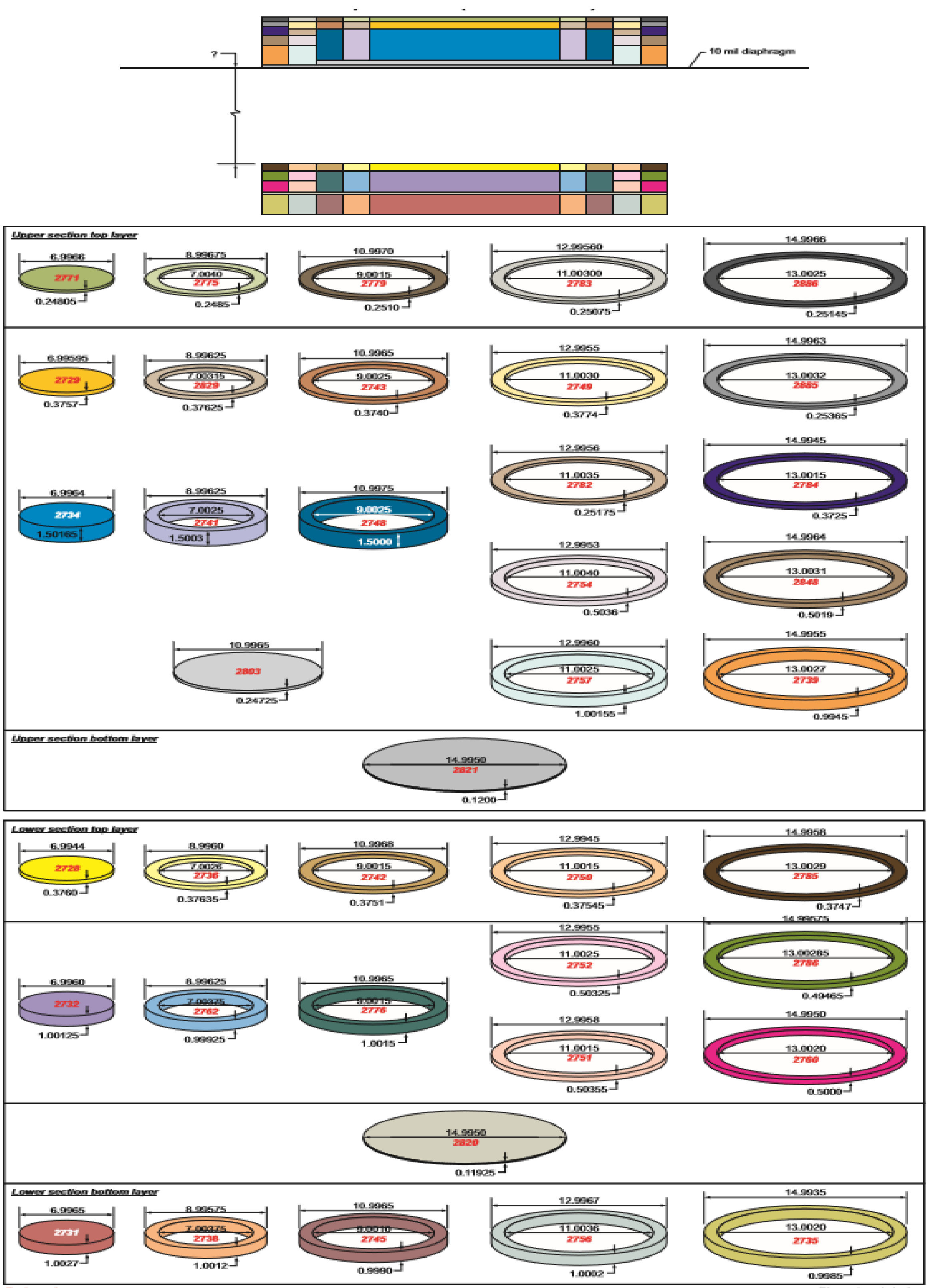

Figure 17. Experiment 8—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.500 in., spaced 6.2938 in. apart.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary the configurations for experiment 7a and the k_{eff} values are given in Table 27.

Table 27. Summary of configurations and neutron multiplication factors for experiment 8.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	6.2938	1.00000
Without support structure, no correction for room return	6.1718	1.00000

In addition, the prompt neutron decay constant at delayed criticality (June 3, 1963) was measured but is not reported here.

2.14 EXPERIMENT 8A

On August 6, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2-1/2 in. was measured at delayed criticality with a separation of 6.3183 in. This assembly used the configuration shown in Figure 3 and is composed of uranium parts from experiment 8. The makeup of the assembly is depicted in Figure 18. The upper and lower cylinders of the assembly had a mass of 135,388 g and 135,212 g, respectively. The total mass of the assembly was 270,600 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower stand was evaluated. Without these supports, the separation of the cylinder would have been 0.1666 in. closer (i.e., 6.1573 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder is 0.291 cents per thousandth of an inch (mil). The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 28.

Table 28. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 8a with two interacting 15 in. OD cylinders 2.500 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.5015	2.5015	2.5015	2.5118	2.5118
	Thickness of parts (in.)[a]	2.49399	2.49259	2.49144	2.50539	2.49399
	Number of gaps	4	4	4	6	6
	Average gap thickness (mils)[b]	1.9	2.2	2.5	1.06	3.0
Lower	Measured thickness (in.)	2.5032	2.5032	2.5032	2.5029	2.5029
	Thickness of parts (in.)	2.49872	2.494	2.4975	2.4976	2.4904
	Number of gaps	4	4	4	4	4
	Average gap thickness (mils)	1.1	2.3	1.4	1.3	3.1

[a] Sum of part thicknesses
[b] One mil is one thousandth of an inch.

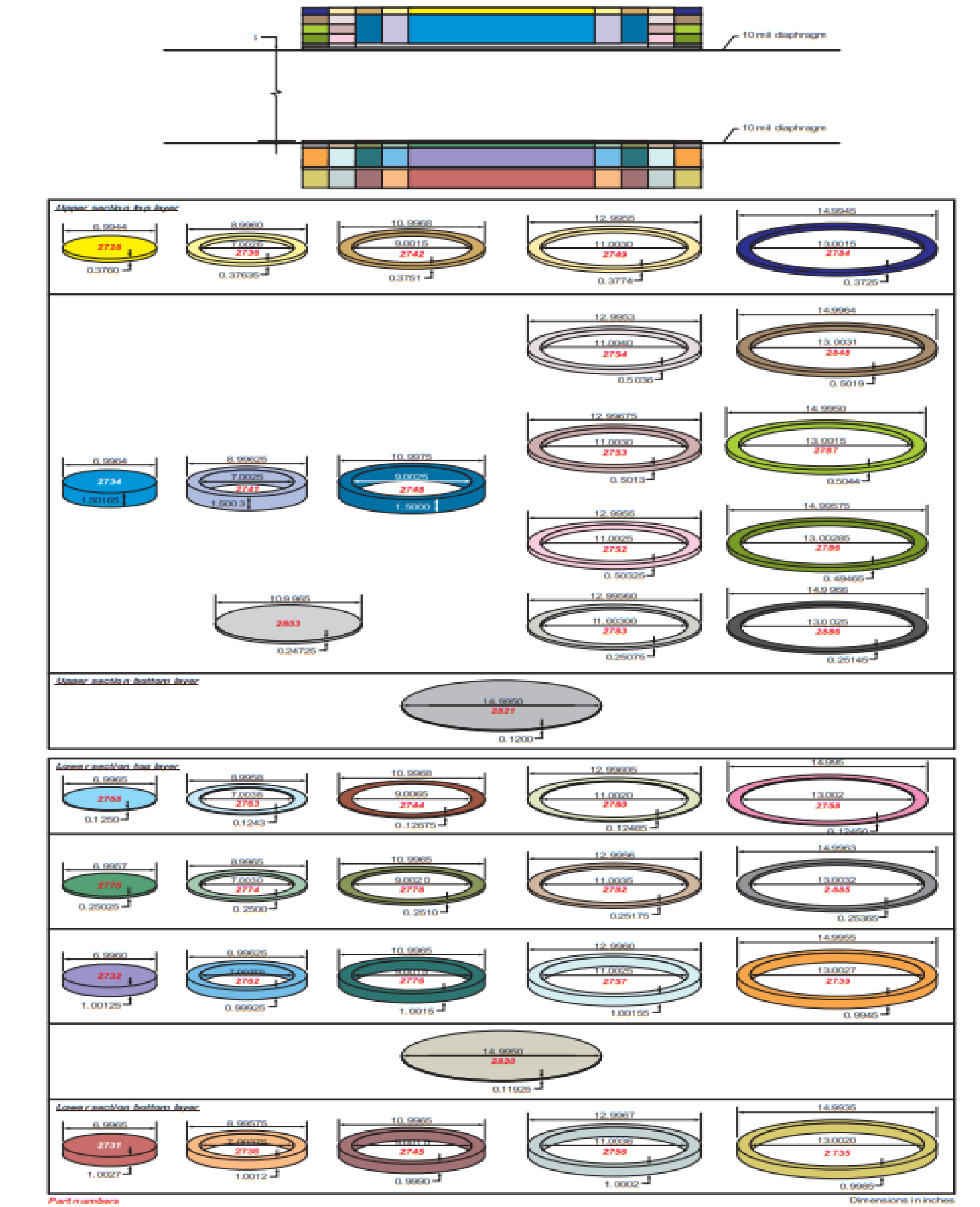

Figure 18. Experiment 8a—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.500 in., spaced 6.3183 in. apart.

The effects of room return need not be calculated using Monte Carlo simulations, and the value was assumed to be that of experiment 12. In summary the configurations for experiment 8a and the k_{eff} values are given in Table 29.

Table 29. Summary of configurations and neutron multiplication factors for experiment 8a.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	6.3183	1.00000
Without support structure, no correction for room return	6.1573	1.00000

In addition, the prompt neutron decay constant at delayed criticality (August 7, 1963) was measured but is not reported here.

2.15 EXPERIMENT 9

On August 8, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2 5/8 in. was measured at delayed criticality with a separation of 8.2266 in. The makeup of the assembly is depicted in Figure 19. The upper and lower cylinders of the assembly had a mass of 142,195 g and 141,940 g, respectively. The total mass of the assembly was 284,135 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated. Without these supports, the separation of the cylinder would have been 0.249 in. closer (i.e., 7.9776 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder is 0.2067 cents per thousandth of an inch (mil). The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 30.

Table 30. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 9 with two interacting 15 in. OD cylinders 2.625 in. high.

Cylinder		For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.6305	2.6305	2.6305	2.6430	2.6430
	Thickness of parts (in.)[a]	2.62049	2.61799	2.62009	2.63059	2.63049
	Number of gaps	3	3	3	5	5
	Average gap thickness (mils)[b]	3.3	4.2	3.5	1.24	2.5
Lower	Measured thickness (in.)	2.6299	2.6299	2.6299	2.6249	2.6249
	Thickness of parts (in.)	2.6239	2.62025	2.6205	2.6213	2.61245
	Number of gaps	4	4	4	4	4
	Average gap thickness (mils)	1.25	2.4	2.4	0.9	3.1

[a] Sum of part thicknesses
[b] One mil is one thousandth of an inch.

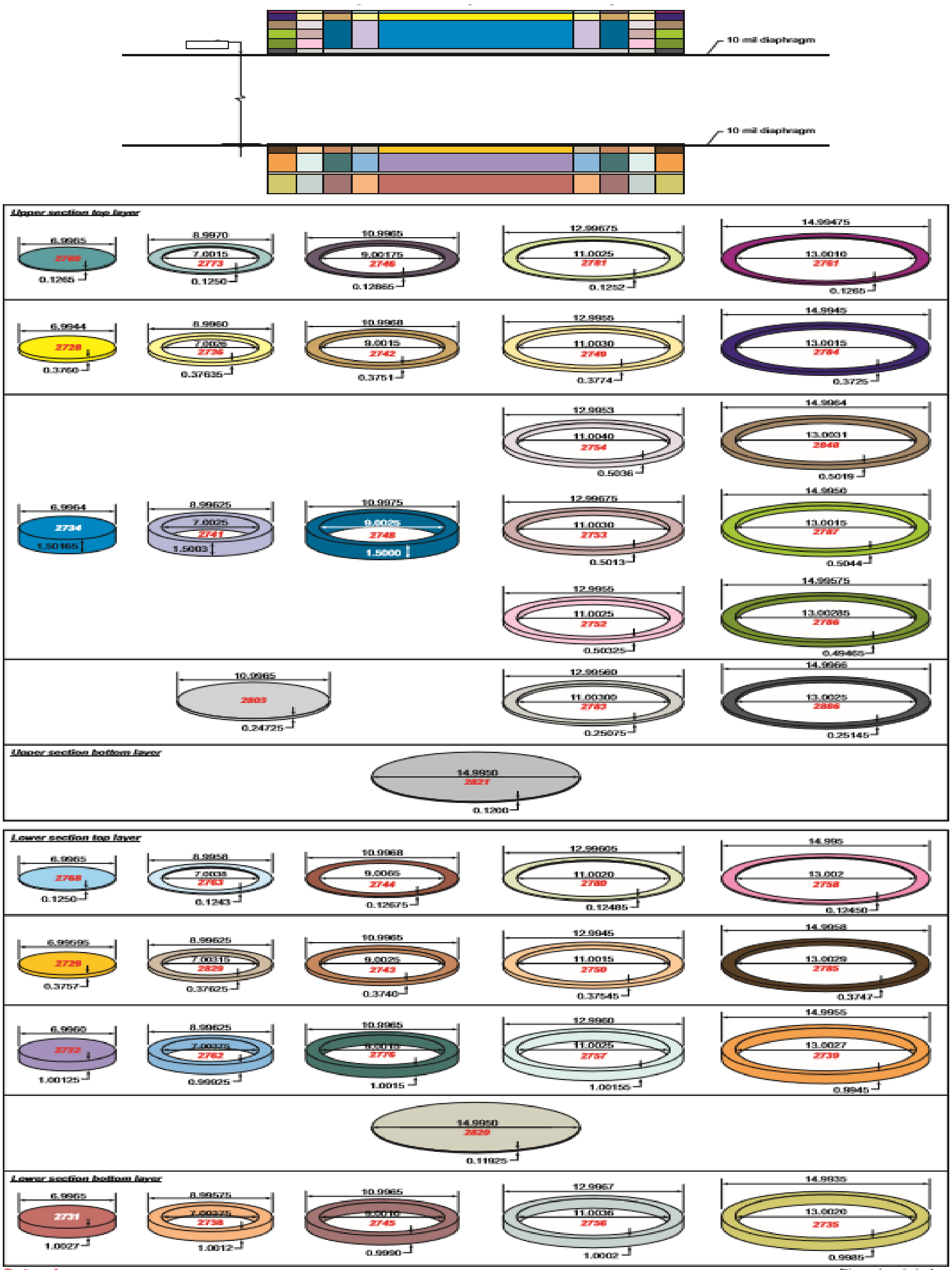

Figure 19. Experiment 9—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.625 in., spaced 8.2266 in. apart.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary the configurations for experiment 9 and the k_{eff} values are given in Table 31.

Table 31. Summary of configurations and neutron multiplication factors for experiment 9.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	8.2266	1.00000
Without support structure, no correction for room return	7.9776	1.00000
Without support structure but corrected for room return	7.9776	0.9999??

In addition, the prompt neutron decay constant at delayed criticality (August 9, 1963) was measured but is not reported here.

2.16 EXPERIMENT 10

On August 12, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2 3/4 in. was measured at delayed criticality with a separation of 11.241 in. The makeup of the assembly is depicted in Figure 20. The upper and lower cylinders of the assembly had a mass of 148,977 g and 149754 g, respectively. The total mass of the assembly was 297,760 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated. Without these supports, the separation of the cylinder would have been 0.379 in. closer (i.e., 10.861 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder is 0.1184 cents per thousandth of an inch (mil). The measured height of the various sections of the upper and lower cylinder and the sum of the measured heights of the individual parts along with the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 32.

Table 32. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 10 with two interacting 15-in-OD cylinders 2.750 -in.-high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.7566	2.7566	2.7566	2.7661	2.7661
	Thickness of parts (in.)[a]	2.76034	2.74229	2.75544	2.75909	2.74494
	Number of gaps	6	6	6	8	8
	Average gap thickness (mils)[b]	0.0	2.4	1.2	0.9	2.1
Lower	Measured thickness (in.)	2.7548	2.7548	2.7548	2.7521	2.7521
	Thickness of parts (in.)	2.74915	2.74595	2.74475	2.7477	2.7406
	Number of gaps	4	4	4	4	4
	Average gap thickness (mils)	1.4	2.2	2.5	1.1	2.9

[a] Sum of part thicknesses
[b] One mil is one thousandth of an inch.

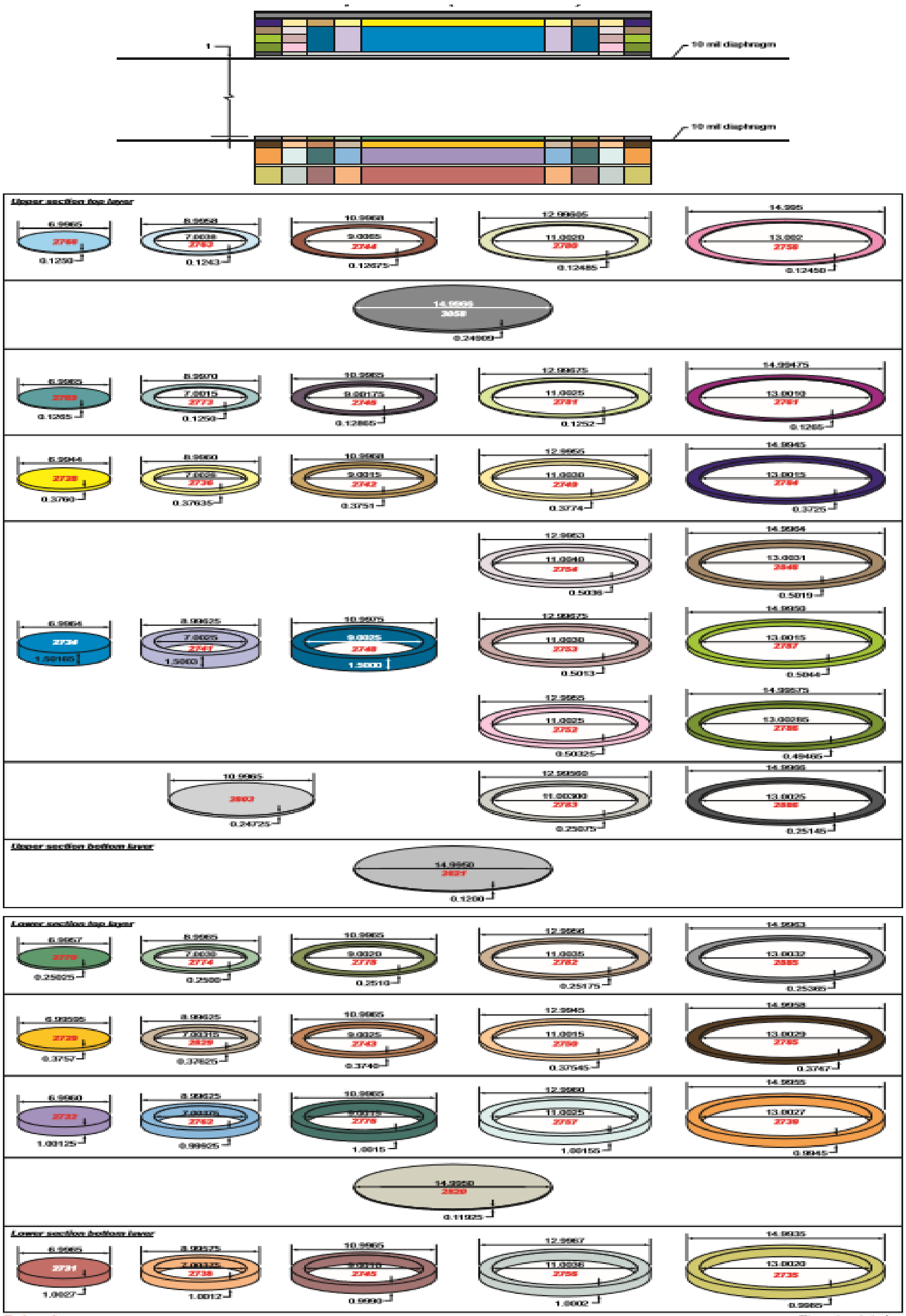

Figure 20. Experiment 10—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.750 in., spaced 11.241 in. apart.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary the configurations for experiment 10 and the k_{eff} values are given in Table 33.

Table 33. Summary of configurations and neutron multiplication factors for experiment 10.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	11.241	1.00000
Without support structure, no correction for room return	10.869	1.00000

In addition, the prompt neutron decay constant at delayed criticality (August 13, 1963) and the coupling reactivity were measured, but neither are reported here.

2.17 EXPERIMENT 10A

On April 13, 1963, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2 3/4 in. was measured at delayed criticality with a separation of 11.366 in. The makeup of the assembly is depicted in Figure 21. The upper and lower cylinders of the assembly had a mass of 148,975 g and 149,254 g, respectively. The total mass of the assembly was 298,229 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was not evaluated. It is a good assumption to use the values for experiment 10. Thus, without these supports, the separation of the cylinder would have been 0.379 in. closer (i.e., 10.987 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder is 0.1184 cents per thousandth of an inch (mil). The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 34.

Table 34. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 10a with two interacting 15 in. OD cylinders 2.750 in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.7566	2.7566	2.7566	2.7661	2.7661
	Thickness of parts (in.)[a]	2.74884	2.74524	2.75084	2.75644	2.74624
	Number of gaps	7	7	7	5	5
	Average gap thickness (mils)[b]	1.1	1.6	0.64	1.9	4.0
Lower	Measured thickness (in.)	2.7548	2.7548	2.7548	2.7521	2.7521
	Thickness of parts (in.)	2.75555	2.74925	2.7524	2.76196	2.7531
	Number of gaps	2	2	2	4	4
	Average gap thickness (mils)	0.0	2.8	1.2	0.0	0.0

[a] Sum of part thicknesses
[b] One mil is one thousandth of an inch.

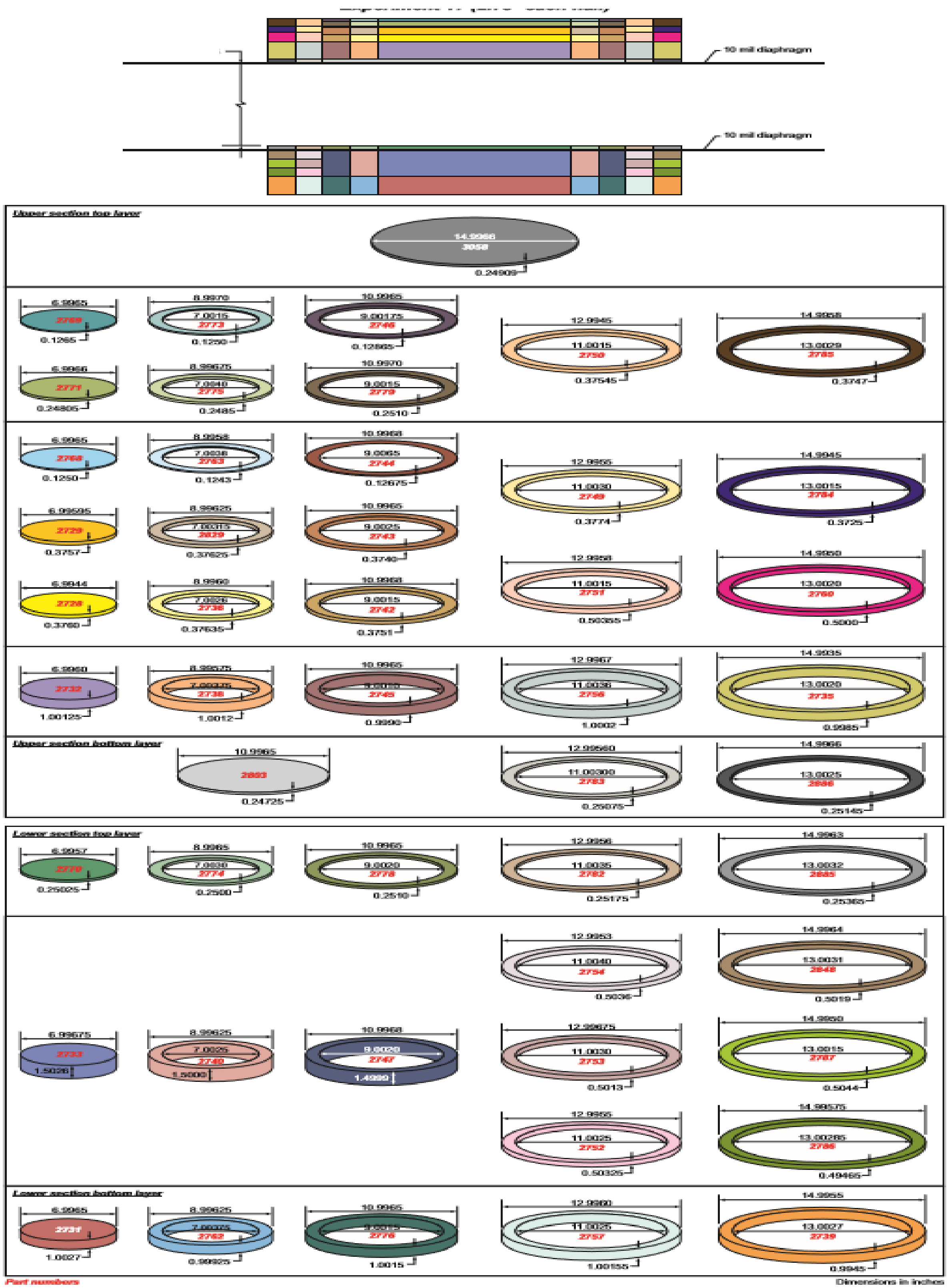

Figure 21. Experiment 10a—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.750 in., spaced 11.366 in. apart.

The effects of room return need not be calculated using Monte Carlo simulations, and the value was assumed to be that of experiment 12. In summary the configurations for experiment 12a and the k_{eff} values are given in Table 35.

Table 35. Summary of configurations and neutron multiplication factors for experiment 10a.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	11.366	1.00000
Without support structure, no correction for room return	10.987	1.00000

In addition, a Rossi-α measurement (April 13, 1965) was performed to obtain the prompt neutron decay constant as well as fission density distributions in the cylinders and ^{235}U foil activation in the space between the upper and lower cylinders, but neither are reported here.

2.18 EXPERIMENT 11

On April 15, 1965, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 2 7/8 in. was measured at delayed criticality with a separation of 17.457 in. The makeup of the assembly is depicted in Figure 22. The upper and lower cylinders of the assembly had a mass of 155,978 g and 155,988 g, respectively. The total mass of the assembly was 311,966 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was evaluated. Without these supports, the separation of the cylinder would have been 0.751 in. closer (i.e., 16.706 in.). Without the air in the cell and the cell structure, the separation would have been lower yet. The reactivity change associated with a change in separation of the upper and lower cylinder is 0.0452 cents per thousandth of an inch (mil). The measured height of the various sections of the upper and lower cylinder, the sum of the measured heights of the individual parts, and the difference from which the average air gap between parts that composed the central 7 in. diameter section and the various annuli are given in Table 36.

Table 36. Measured height of each radial increment, sum of inspection report heights and average gap between parts of each radial section for experiment 11 with two interacting 15 in. OD cylinders 2.875. in. high.

Cylinder	Quantity	For radial thicknesses in inches of				
		7OD	7ID-9OD	9ID-11OD	11ID-13OD	13ID-15OD
Upper	Measured thickness (in.)	2.8824	2.8824	2.8824	2.8824	2.8824
	Thickness of parts (in.)[a]	2.87614	2.87219	2.87674	2.88084	2.87839
	Number of gaps	6	6	6	7	7
	Average gap thickness (mils)[b]	1.04	1.7	0.94	0.22	0.57
Lower	Measured thickness (in.)	2.8768	2.8768	2.8768	2.8768	2.8768
	Thickness of parts (in.)	2.8853	2.8756	2.8765	2.8871	2.86795
	Number of gaps	2	2	2	4	4
	Average gap thickness (mils)	0.0	0.6	0.15	0.0	2.2

[a] Sum of part thicknesses
[b] One mil is one thousandth of an inch.

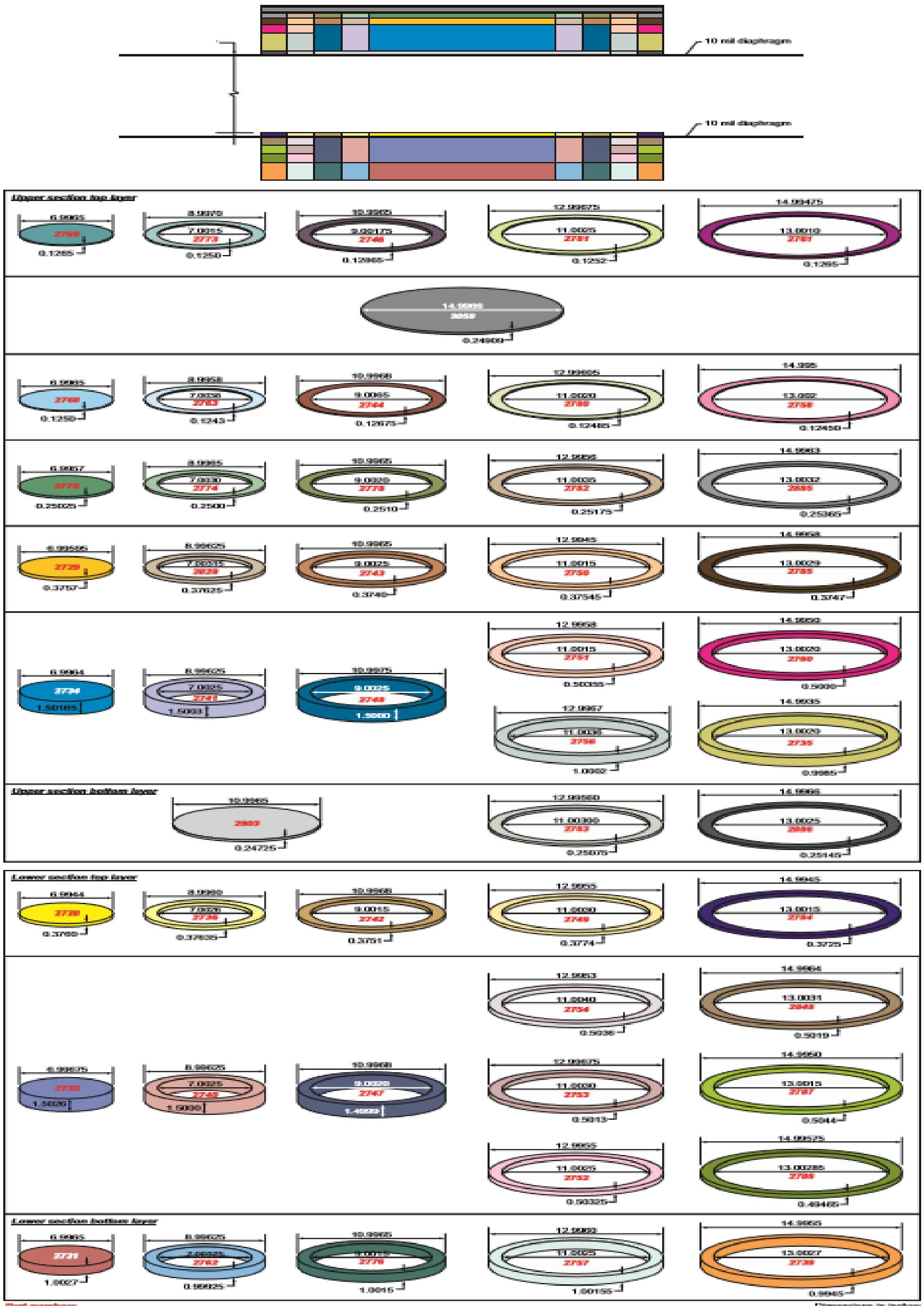

Figure 22. Experiment 11—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 2.875 in., spaced 17.447 in. apart.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary the configurations for experiment 7a and the k_{eff} values are given in Table 37.

This configuration of the two 15 in. diameter interacting 2 7/8 in.-thick cylinders was reassembled on May 6, 1965, as follows. The configuration was removed from the vertical assembly machine. The vertical assembly machine was moved to the center of the cell and located on top of the horizontal assembly with both halves together. The system was exactly reassembled, and delayed criticality achieved. This resulted in the vertical assembly machine resting on a 1 in. thick, square steel plate with the top of the plate 24 in. above the floor. Now the assembly is 17.5 ft. from all walls of the east cell but now 11.2 ft. above the floor. The critical spacing was reduced by 0.140 in. This difference is due to the reduction in reactivity from moving farther from the walls and floor. Monte Carlo simulation can be used to separate these effects by calculating the changes in reflection associated with location in the room. The reactivity effects of the support structure and the change in reactivity per change in separation were assumed to the same as the other location in the room.

Table 37. Summary of configurations and neutron multiplication factors for experiment 11.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	17.447, 17.307	1.00000
Without support structure, no correction for room return	16.686, 16.556	1.00000

In addition, a Rossi-α measurement (April 19, 1965) was performed to obtain the prompt neutron decay constant as well as fission density distributions in the cylinders and ^{235}U foil activation in the space between the upper and lower cylinders, but neither are reported here. These measurements were not with the vertical assembly machine more centered in the east cell.

2.19 EXPERIMENT 12

On May 19, 1965, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 3 in. was measured at delayed criticality with a separation of 52.5 in. The makeup of the assembly is depicted in Figure 23. The upper and lower cylinders of the assembly had a mass of 163,078 g and 162,991 g, respectively. The total mass of the assembly was 325,989 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand were not evaluated. Without these supports, the separation of the cylinder would have been closer. Without the air in the cell and the cell structure, the separation would have been lower yet. The height of the various sections of the upper and lower cylinder were not measured. Since most of the uranium metal parts were the same as experiment 11, the average gaps between parts were assumed to be the same as experiment 11, For the upper section, the gaps were assumed to be 1.04, 1.7, 0.94, 0.22, and 0.57 thousandths from the inside out, and for the lower section, the gaps were assumed to be 0.0, 0.6, 0.15, 0.0, and 2.2 thousandths.

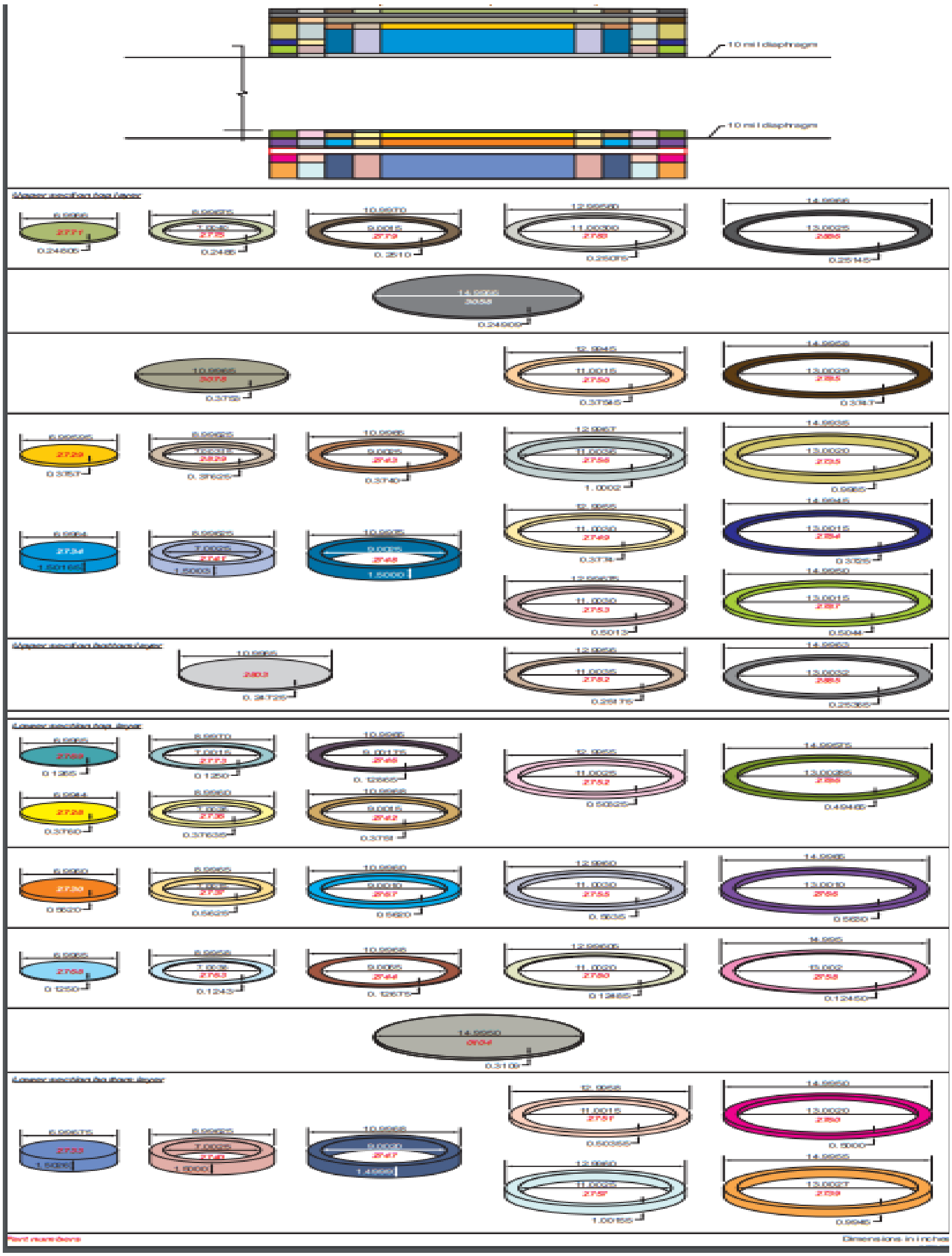

Figure 23. Experiment 12—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 3.000 in., spaced 52.50 in. apart.

The effects of room return should be calculated using Monte Carlo simulations assuming the wall and floor were 2 ft. thick and the concrete was Oak Ridge concrete, which used crushed limestone instead of sand in the aggregate. In summary the configurations for experiment 12 and the k_{eff} values are given in Table 38.

Table 38. Summary of configurations and neutron multiplication factors for Experiment 12.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	52.5	1.00000

In addition, a Rossi-α measurement (May 24, 1965) was performed to obtain the prompt neutron decay constant as well as fission density distributions in the cylinders and ^{235}U foil activation in the space between the upper and lower cylinders, but neither are reported here.

2.20 EXPERIMENT 12A

On August 18, 1965, a symmetric assembly of two 15 in. diameter, interacting cylinders with nominal heights of 3.00 in. was adjusted to delayed critical with a separation of 51.472 in. The upper and lower cylinders of the assembly had a mass of 164345 g and 16090 g, respectively and the configuration is shown in Figure 24. The total mass of the assembly was 325,355 g. The experimental k_{eff} of the configuration as assembled was 1.00000. The presence of the support structure consisting of the diaphragm, diaphragm support rings, and the lower support stand was not evaluated. Without these supports, the separation of the cylinder would have been closer. Without the air in the cell and the cell structure, the separation would have been lower yet. The heights of the various sections of the upper and lower cylinder were not measured. Since most of the uranium metal parts were the same as experiment 11, the average gaps between parts were assumed to be the same as experiment 11. For the upper section, the gaps were assumed to be 1.04, 1.7, 0.94, 0.22, and 0.57 thousandths from the inside out, and for the lower section, the gaps were assumed to be 0.0, 0.6, 0.15, 0.0 and 2.2 thousandths.

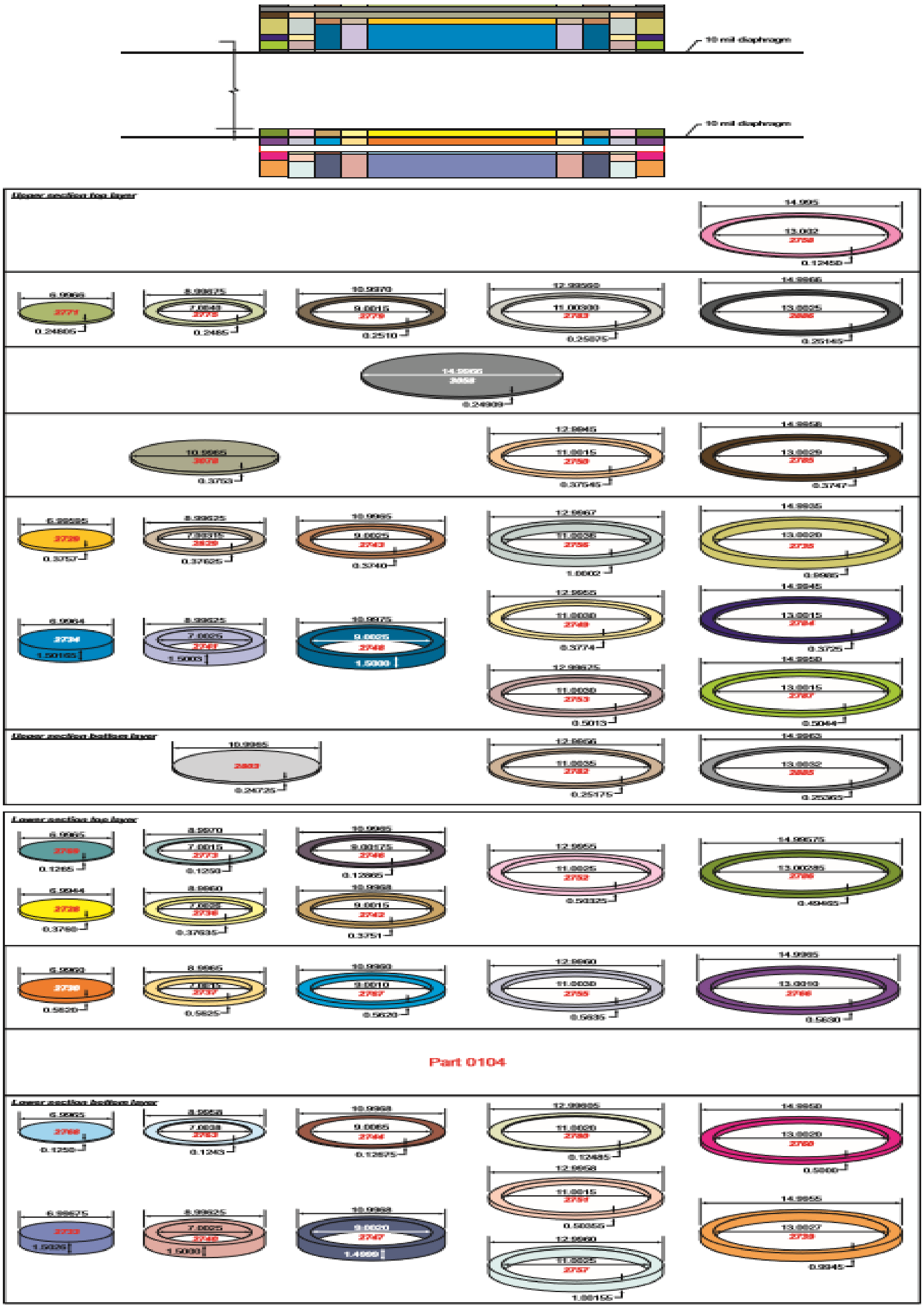

Figure 24. Experiment 12a—Configuration of delayed critical unreflected, unmoderated uranium (93.14 wt.% ^{235}U) metal 15 in. diameter interacting cylinders with nominal height of 3.000 in., spaced 51.472 in. apart.

The effects of room return need not be calculated using Monte Carlo simulations, and the value assumed for experiment 12 can be used. In summary the configurations for experiment 12a and the k_{eff} values are given in Table 40.

Table 40. Summary of configurations and neutron multiplication factors for experiment 12a.

Configuration	Spacing (in.)	Neutron multiplication factor
With support structure, no correction for room return	51.471	1.0000

In addition, a Rossi-α measurement (August 19, 1965) was performed to obtain the prompt neutron decay constant as well as fission density distributions in the cylinders and ^{235}U foil activation in the space between the upper and lower cylinders, but neither are reported here.

3. DESCRIPTION OF MATERIAL DATA

The set of cylinders and annuli were machined from HEU metal with a nominal density of 18.75 g/cm^3 and impurity content of 489 ppm. The solid cylinders had a nominal diameter of 7 in. and were fabricated with varying heights up to 1.5 in. The masses were measured at the Y-12 Plant to within 1 g with an uncertainty of ±0.5 g. The dimensions were measured to tenths of thousandths of inches with an uncertainty of ±0.00005 in. The uranium isotopics were measured by spectrographic analysis, and the uncertainty on the ^{234}U, ^{235}U, and ^{236}U isotopic content was ±0.005 wt.%. The ^{238}U content was obtained by the difference from unity. These uncertainties are described in an ORNL report [9]

The average isotopic content of the parts from mass spectrographic analysis are 93.141 wt.% ^{235}U, 0.966 wt.% ^{234}U, and 0.244 wt.% ^{236}U. The impurity content was measured by spectrographic analysis with an average impurity content of 489 ppm wt.%. This value is very close to the quoted typical value for cast uranium metal (93.20 wt.% ^{235}U enriched) at the Oak Ridge Y-12 Plant: 99.95 g of uranium per 100 g of material with an average impurity content of 500 ppm wt.% [8].

The masses, dimensions, impurity content, and isotopic content are given in Tables 41, 42, and 43. The average density in parenthesis from Table 41 weighted by the mass of each part is 18.747 g/cm^3. The isotopic analysis of one 7 in. diameter disc was not available. Each uranium metal part has a part number scribed on one flat surface of the annuli or cylinder for identification that was also used for orientation of parts in an assembly. The surface of the part with the scribed number was the upper surface for all parts in all assemblies. The numbers given in the tables for the part numbers are the last four digits of the part numbers. The first six digits were the same for all part numbers and were used to identify uranium metal parts for ORCEF.

The data in Table 43 is the measured impurity content for the uranium metal used in the all experiments with uranium metal discs and annuli. Eleven randomly sampled cylinder/annuli parts were analyzed. Only average and range information exists [4]. The values assumed at that time for oxygen and nitrogen were 20 ppm for both. It was assumed that these were the values for the 7 in. diameter discs. The values for carbon at this time (early 1960s) were much lower than present day values, which have added carbon from many recasting of the material.

Some recently discovered data from Y-12 National Security Complex inspection reports for 37 HEU metal parts showed that the mass for each part was measured three times; the dimensions were measured at three different locations for each part; and the uranium isotopics usually were measured by dividing a metal chip from the machining process into thirds and performing isotopic analysis on each third. These data are not available for all parts. The masses measured were rounded to grams, and in no case for these 37 parts did the three mass measurements differ by more than 1 g. The heights in the table were all measured to one-tenth of a thousandth. The height measured at three different locations on the parts to ±0.0001 in. was the same at all locations for 98% of the parts. Consequently, the heights are known to half of a ten thousandth of an inch. The outside diameters for the three measurements for each individual part were identical for more than 80% of the parts, which only differed by 0.00005 in.

The isotopic enrichments are measured to 0.01 wt.% and thus are known to ±0.005 wt.%. The weight percent of ^{235}U for the three measurements for each individual part was identical for more than 95 % of the parts, which only differed by 0.02 wt. %. The weight percent of ^{234}U for the three measurements for each individual part was identical for all 37 parts measured. The weight percent of ^{234}U for the three measurements for each individual part was identical except for three of the 37 parts, which only differed by 0.02 wt.% for two parts and 0.05 wt.% for the other. Although these data are not available for all the parts used in these measurements, the accuracies are expected to be similar.

Table 41. Average dimensions of uranium (93.14 wt.% ^{235}U) metal cylinders and annuli for delayed critical experiments with two 15 in. diameter interacting cylinders.

Part Number	Measured Mass (g)	Measured Height (in.)	Measured Inner Diameter (in.)	Measured Outer Diameter (in.)
2728	4,435	0.3760	—	6.9944
2729	4,440	0.3757	—	6.99595
2730	6,646	0.5620	—	6.9960
2731	11,841	1.0027	—	6.9965
2732	11,814	1.00125	—	6.9960
2733	1,7742	1.5026	—	6.99675
2734	17,742	1.50165	—	6.9964
2735[a]	13,409	0.9985	13.0020	14.9935
2736[a]	2,895	0.37635	7.0026	8.9960
2737[a]	4,336	0.5625	7.0015	8.9965
2738[a]	7,710	1.0012	7.00375	8.99575
2739[a]	13,461	0.9945	13.0027(13.00265)	14.9955
2740[a]	11,568	1.5000	7.0025	8.99625
2741	11,568	1.5003	7.0025	8.9965
2742[a]	3,617	0.3751	9.0015	10.9968(10.99675)
2743[a]	3,621	0.3740	9.0025	10.9965
2744[a]	1,223	0.12675	9.0065	10.9968(10.99675)
2745[a]	9,634	0.9990	9.0010	10.9965
2746[a]	1,238	0.12865	9.00175	10.9965
2747[a]	14,436	1.4999	9.0020	10.9968(10.99675)
2748[a]	14,462	1.5000	9.0025	10.9975
2749[a]	4,360	0.3774	11.0030	12.9955
2750[a]	4,336	0.37545	11.0015	12.9945
2751[a]	5,822	0.50355	11.0015	12.9957(12.99575
2752[a]	5,811	0.50325	11.0025	12.9955

2753 [a]	5,872	0.50130	11.0030	12.99675
2754 [a]	5,826	0.5036	11.0040	12.9953
2755 [a]	6,514	0.5635	11.0030	12.9960(12.99595)
2756 [a]	11,567	1.0002	11.0036	12.9967
2757 [a]	11,575	1.00155	11.0025	12.9960
2758	1,685	0.1245	12.9965	14.99665
2760	6,743	05000	13.0020	14.9950
2761	1,706a	0/1265	13.0010	14.99475
2762	7,703a	0.99925	7.00375	8.99625
2763	953a	0.1243	7.0038	8.9958
2766	7,605a	0.5630	13.0010	14.9965
2767	5,410	0.5620	9.0010	10.99595

Table 41. Average dimensions of uranium (93.14 wt.% ^{235}U) metal cylinders and annuli for delayed critical experiments with two 15 in. diameter interacting cylinders (continued).

Part Number	Measured Mass (g)	Measured Height (in.)	Measured Inner Diameter (in.)	Measured Outer Diameter (in.)
2768	1,481	0.1250	—	6.9965
2769	1,495	0.1265(.1259?)	—	6.9965
2770	2,955	0.25025	—	6.9957
2771	2,916	0.24805	—	6.9966
2773 [a]	962	0.1250(0.125,0.126,0.126)	7.0015	8.9970
2774 [a]	1,930	0.2500	7.0030	8.9965
2775 [a]	1,917	0.2485	7.0040	8.99675
2776 [a]	9,644	1.0015	9.0015	10.9965
2778 [a]	2,411	0.2510	9.0020	10.9965
2779 [a]	2,417	0.2510	9.0015	10.9970
2780[a]	1,440	0.12485	11.0020	12..99605
2781	1,449	0.1252	11.0025	12.99675
2782	2,914	0.25175	11.0035	12.9956
2783	2,900	0.28075	11.0030	12.9956
2784 [a]	5,039	0.3725	13.0015	14.9945
2785 [a]	5,043	0.3747	13.0029(13.00285)	14.9958(14.99575)
2786	6,717	0.49965	13.0015	14.9950
2787	6,788	0.5055	13.0015	14.9950
2803	7,220	0.44725	—	10.9965
2820	6,471	0.11925	—	14.9950
2821	6,518	0.1200	—	14.9950
2829 [a]	2,895	0.37625	7.00315	8.99625
2848 [a]	6,748	0.5019	13.0031	14.9964
2885	3,415	0.25365	13.0032	14.9963
2886	3,384	0.25145	13.0025	14.9966
3058	13,533	0.24909	—	14.9966
3078	10,959	0.3753	—	10.9965
0104	16,865	0.3109	—	14.99505

Table 42. Summary of average uranium isotopics of metal cylinders and annuli, for delayed critical experiments with two 15 in. diameter interacting cylinders.[(a)]

Part Number	Measured ^{235}U (wt.%)	Measured ^{234}U (wt.%)	Measured ^{236}U (wt.%)	^{238}U [(b)] (wt.%)
2728	93.17	0.97	0.24	5.62
2729	93.15	0.99	0.26	5.60
2730	93.14	0.97	0.25	5.64
2731	93.13	0.97	0.22	5.68
2732	93.17	0.95	0.21	5.67
2733	93.15	0.96	0.26	5.63
2734	93.18	0.95	0.24	5.63
2735	93.12	0.98	0.25	5.65
2736	93.17	1.01	0.21	5.61
2737	93.08	0.99	0.29	5.64
2738	93.15	0.98	0.24	5.63
2739	93.16	0.96	0.25	5.63
2740	93.17	0.97	0.24	5.62
2741	93.18	0.96	0.25	5.61
2742	93.14	0.98	0.23	5.65
2743	93.14	0.98	0.23	5.65
2744	93.14	0.98	0.23	5.65
2745	93.20	0.96	0.22	5.62
2746	93.09	1.00	0.22	5.69
2747	93.16	0.98	0.19	5.67
2748	93.09	1.00	0.22	5.69
2749	93.19	0.98	0.25	5.58
2750	93.12	0.95	0.25	5.68
2751	93.13	0.98	0.24	5.65
2752	93.13	0.98	0.24	5.65
2753	93.12	0.95	0.25	5.68
2754	93.10	0.96	0.28	5.66
2755	93.10	0.96	0.28	5.66
2756	93.18	0.93	0.25	5.64
2757	93.20	0.96	0.23	5.61
2758	93.16	0.98	0.27	5.59
2760	93.13	0.99	0.24	5.64
2761	93.12	0.96	0.27	5.65
2762	93.13	0.97	0.27	5.63
2763	93.18	0.96	0.25	5.61
2766	93.16	0.98	0.27	5.59
2767	93.14	0.96	0.26	5.64
2768	93.14	0.92	0.26	5.68

Table 42. Summary of average uranium isotopics of metal cylinders and annuli, for delayed critical experiments with two 15 in. diameter interacting cylinders[(a)] (continued).

Part Number	Measured ^{235}U (wt.%)	Measured ^{234}U (wt.%)	Measured ^{236}U (wt.%)	^{238}U [(b)] (wt.%)
2769	93.15	0.97	0.25	5.63
2770	93.13	0.99	0.26	5.62
2771	Not available	Not available	Not available	Not available
2773	93.17	0.97	0.24	5.62
2774	93.08	0.99	0.29	5.64
2775	93.15	0.98	0.24	5.61
2776	93.16	0.96	0.23	5.65
2778	93.16	0.96	0.23	5.65
2779	93.16	0/96	0.23	5.65
2780	93.13	0.98	0.25	5.58
2781	93.19	0.98	0.25	5.58
2782	93.20	0.96	0.23	5.61
2783	93.18	0.93	0.25	5.64
2784	93.13(93.11,93.13,93.11)	0.99	0.24(0.26,0.24,0.26)	5.64
2785	93.11(93.14,93.11,93.14)	0.99(0.98,0.99,0.98)	0.26(0.24,0.26,0.24)	5.64
2786	93.14	0.98	0.24	5.64
2787	93.14	0.98	0.24	5.64
2803	93.14	1.00	0.23	5.63
2820	93.18	—	—	—
2821	93.31	—	—	—
2829	93.10	0.99	0.24	5.67
2848	93.18	0.99	0.24	5.59
2885	93.11	0.99	0.26	5.64
2886	93.11	0.99	0.26	5.64
3058	Not available[(c)]	Not available	Not available	Not available
3078	Not available	Not available	Not available	Not available
0104	Not available	Not available	Not available	Not available

[(a)] Mass spectrographic analysis.
[(b)] By difference from 100%.
[(c)] Where analysis was not available, the mass weighted average of all other parts should be used.

Table 43. Measured impurity content of uranium metal cylinders and annuli for delayed critical experiments with two 15 in. diameter interacting cylinders.[a]

Element	Parts Per Million by Weight (ppm)	Range (ppm)
Ag	8	3–25
Bi	164	81–311
C	5	0–9
Co	5	2–15
Cr	7	4–12
Cu	25	10–40
Mg	3	2–3
Mn	56	25–89
N	30	—
Na	27	15–50
Ni	100	—
O	20	—
Sb	38	10–80
Ti	1	—

[a] Mass spectrographic analysis, except nitrogen and oxygen, which are assumed to be 20 ppm.

4. SUPPLEMENTAL EXPERIMENTAL MEASUREMENTS

Supplemental experimental Rossi-α measurements were performed and are not reported here. These data can be acquired from Record Management Services Department at ORNL or John Bess at Idaho National Laboratory. These Rossi-α measurements are unique because the flight time across the largest gaps between cylinders is a large part of the neutron lifetime and depends strongly on the energy spectrum of neutrons going between interacting cylinders. In addition, foil activation measurements were performed in the uranium metal cylinders and in the gaps between them for some of the larger spacings.

5. CONCLUSIONS

These accurate descriptions of the configuration and materials allow these experiments to be incorporated into to the ICSBEP. Uncertainty analysis needs to be performed to determine the accuracy of the neutron multiplication actors, k_{eff}. This analysis should mimic that performed for other ICSBEP nuclear criticality safety benchmarks already documented with these materials in the ICSBEP and Nuclear Energy Agency programs such as HEU-MET-FAST-051 and others. Because of the accurate descriptions of the configuration and material the uncertainties in the k_{eff} values should be as low as ±0.0002.

REFERENCES

1. J. T. Mihalczo, Brief Summary of Unreflected and Unmoderated Cylindrical Critical Experiments with Oralloy at Oak Ridge, ORNL/TM-1999/302, Oak Ridge National Laboratory, Oak Ridge, TN (November 1999).

2. J. T. Mihalczo, "Prompt-Neutron Decay in a Two-Component Enriched Uranium Metal Critical Assembly," *Trans. Am. Nucl. Soc.* **6**, 60 (1963).
3. J. T. Mihalczo, "Prompt Neutron Decay in a Two-Component Enriched Uranium Metal Critical Assembly," ORNL/TM-470, Oak Ridge National Laboratory, Oak Ridge, TN (1963).
4. J. T. Mihalczo, "Graphite and Polyethylene Reflected Uranium-Metal Cylinders and Annuli," Y-DR-81, Oak Ridge Y-12 Plant, Oak Ridge, TN (1972).
5. J. T. Mihalczo, "Prompt Neutron Lifetime in Critical Enriched-Uranium Metal Cylinders and Annuli," *Nucl. Sci. Eng*. **20**, 60–65 (1964).
6. J. T. Mihalczo, "Monte Carlo Calculations of Two Core Delayed Critical Assemblies," *Trans. Am. Nucl. Soc.* **11**, 603 (1968).
7. J. T. Mihalczo, "Prompt Neutron Time Behavior in Delayed Critical Coupled Uranium Metal Cylinders," *Proceedings of the International Conference on Fast Critical Experiments and Their Analysis*, ANL-7320, 237–41 (October 1966).
8. J. T. Mihalczo, J. J. Lynn, and J. R. Taylor, Delayed Critical ORNL Unreflected Uranium (93.20) Metal Sphere and the Pure Unreflected Uranium (93.80) Sphere Critical Mass, Ann. of Nucl. Energy **29**, 525 (2002).
9. John T. Mihalczo, Uncertainties in Masses, Dimensions, Impurities, and Isotopics of HEU Metal Used in Critical Experiments at ORCEF, ORNL/TM-2012/32, Oak Ridge National Laboratory, Oak Ridge, TN (September 2012). [OSTI #1052246]

APPENDIX A. SUPPORT STRUCTURE

The support structure is described in this appendix. Figure A.1 represents the diaphragm and rings with its support structure. Figure A.2 represents the low-mass support structure. Both structures can be seen in Figure 2. These support structures were used in many other critical experiments with enriched uranium metal at ORCEF.

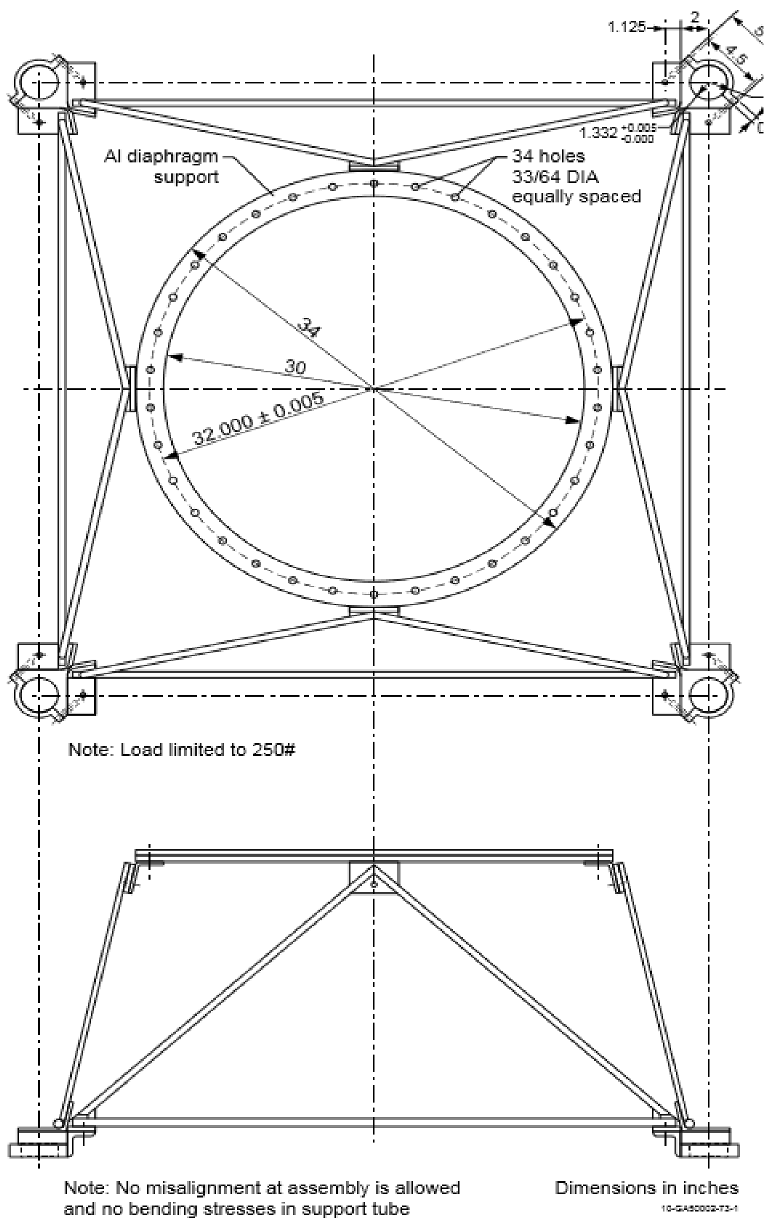

Figure A.1. Diaphragm support structure.

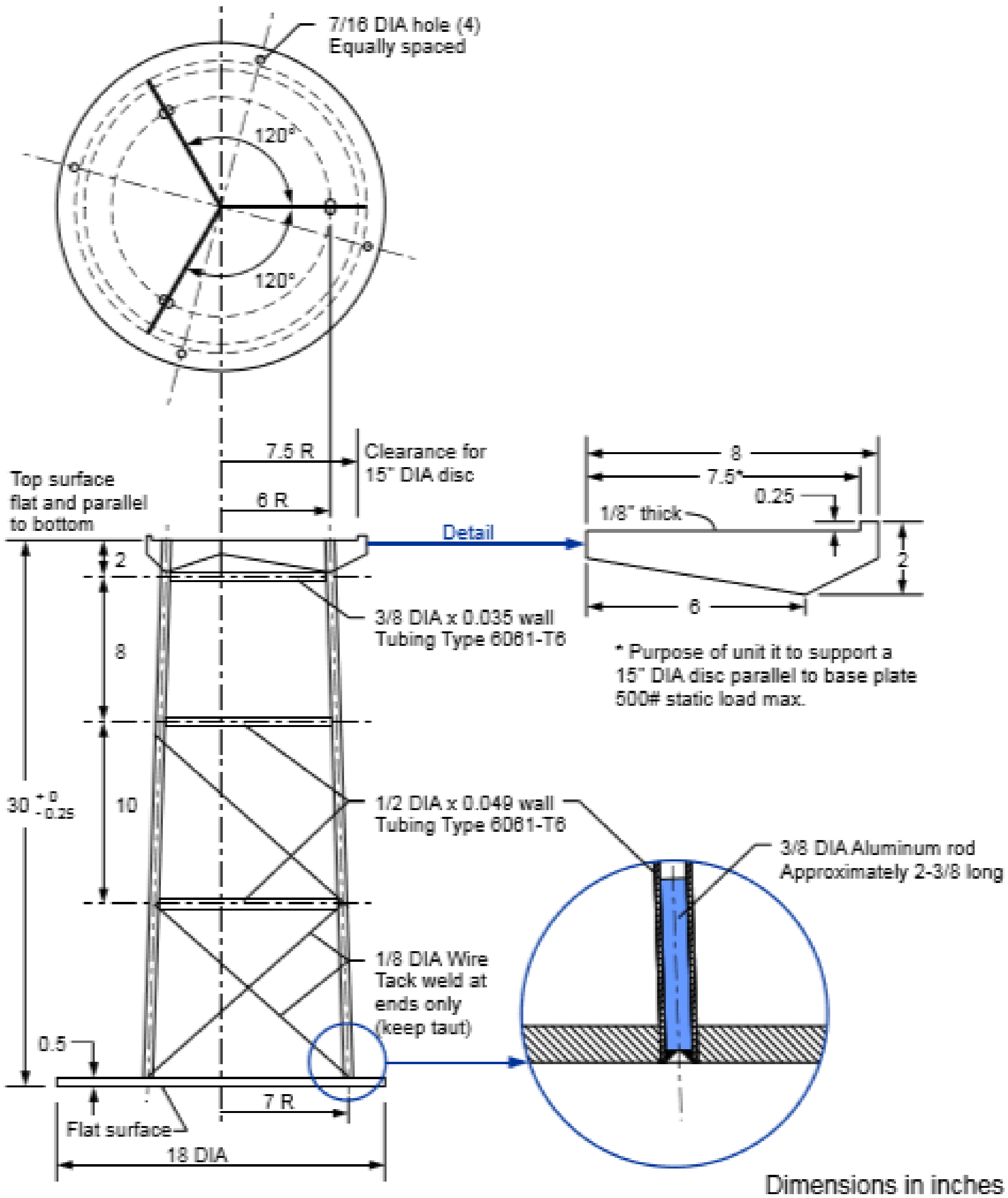

Figure A.2. Details of the lower support structure

APPENDIX B. UNCERTAINTIES IN MATERIALS PROVIDED BY THE Y-12 NATIONAL SECURITY COMPLEX

The uncertainties in the masses, dimension, and uranium isotopics measured at the Y-12 National Security Complex are discussed in the following reference.

John T. Mihalczo, Uncertainties in Masses, Dimensions, Impurities, and Isotopics of HEU Metal Used in Critical Experiments at ORCEF,, ORNL/TM-2012/32, Oak Ridge National Laboratory, Oak Ridge, TN (September 2012). [OSTI #1052246]

Some recently discovered data from Y-12 National Security Complex inspection reports for highly enriched metal parts are given in Table B.1 For some parts, only two results were available. The data in this appendix are the results of individual measurements of these quantities. The mass for each part was measured three times; the dimensions were measured at three different locations for each part; the uranium isotopics usually were measured by dividing a metal chip from the machining process into thirds and performing isotopic analysis on each third. These data are not available for all parts, and for some parts, only two results are presented. The masses measured were rounded to grams, and in no case for these 37 parts did the mass differ for the three individual measurements. The heights in the table were all measured to one-tenth of a thousandth, but zeros after the decimal are not listed. For example, where the entry of the table is given as 1.5, the measured value was 1.5000 in. The height measured at three different locations on the parts to ±0.0001 in. was the same at all locations for all but 1 of 37 parts. Thus, the heights are known to half of a ten thousandth of an inch.

The inside diameters for the three measurements for each individual part were identical except for 3 of the 37 parts. In two cases, they differed by 0.00005 in. and in the other case by 0.0001 in. The outside diameters for the three measurements for each individual part were identical except for 6 of the 37 parts, which differed by 0.00005 in.

The isotopic enrichments are measured to 0.01 wt.% and thus are known to ±0.005 wt.%. The weight percent of ^{235}U for the three measurements for each individual part was identical except for 1 of the 37 parts, which differed by 0.02 wt.%. The weight percent of ^{234}U for the three measurements for each individual part was identical for all 37 parts. The weight percent of ^{234}U for the three measurements for each individual part was identical except for 3 of the 37 parts, which differed by 0.02 wt.% for two parts and 0.05 wt.% for the other.

Measured mass (g), dimension (in.), and uranium isotopics (wt.%) from inspection reports

Table B.1. Results of inspection reports for HEU metal parts.

Test	Part	Mass (g)	Height (in.)	ID (in.)	OD (in.)	U-235	U-234	U-236	U-238
HMF051	2735	13409	0.9985	13.002	14.9935	93.12	0.98	0.25	5.65
HMF071	—	13409	0.9985	13.002	14.9935	93.12	0.98	0.25	5.65
HMF076	—	13409	0.9985	13.002	14.9935	93.12	0.98	0.25	5.65
HMF051	2736	2895	0.37635	7.0026	8.996	93.17	1.01	0.21	5.61
HMF071	—	2895	0.37635	7.0026	8.996	93.17	1.01	0.21	5.61
HMF076	—	2895	0.37635	7.0026	8.996	93.17	1.01	0.21	5.61
HMF051	2737	4336	0.5625	7.0015	8.9965	93.08	0.99	0.29	5.64
HMF071	—	4336	0.5625	7.0015	8.9965	93.08	0.99	0.29	5.64

Table B.1. Results of inspection reports for HEU metal parts (continued).

Test	Part	Mass (g)	Height (in.)	ID (in.)	OD (in.)	U-235	U-234	U-236	U-238
HMF076	—	4336	0.5625	7.0015	8.9965	93.08	0.99	0.29	5.64
HMF051	2738	7710	1.0012	7.00375	8.99575	93.15	0.98	0.24	5.63
HMF071	—	7710	1.0012	7.00375	8.99575	93.15	0.98	0.24	5.63
HMF076	—	7710	1.0012	7.00375	8.99575	93.15	0.98	0.24	5.63
HMF051	2739	13461	0.9945	13.0027	14.9955	93.16	0.96	0.25	5.63
HMF071	—	13461	0.9945	13.00265	14.9955	93.16	0.96	0.25	5.63
HMF076	—	13461	0.9945	13.0027	14.9955	93.16	0.96	0.25	5.63
HMF051	2740	11568	1.5	7.0025	8.99625	93.17	0.97	0.24	5.62
HMF071	—	11568	1.5	7.0025	8.99625	93.17	0.97	0.24	5.62
HMF076	—	11568	1.5	7.0025	8.99625	93.17	0.97	0.24	5.62
HMF051	2742	3617	0.3751	9.0015	10.9968	93.14	0.98	0.23	5.65
HMF071	—	3617	0.3751	9.0015	10.99675	93.14	0.98	0.23	5.65
HMF076	—	3617	0.3751	9.0015	10.9968	93.14	0.98	0.23	5.65
HMF051	2743	3621	0.374	9.0025	10.9965	93.14	0.98	0.23	5.65
HMF071	—	3621	0.374	9.0025	10.9965	93.14	0.98	0.23	5.65
HMF076	—	3621	0.374	9.0025	10.9965	93.14	0.98	0.23	5.65
HMF051	2744	1223	0.12675	9.0065	10.9968	93.14	0.98	0.23	5.65
HMF071	—	1223	0.12675	9.0065	10.99675	93.14	0.98	0.23	5.65
HMF076	—	1223	0.12675	9.0065	10.9968	93.14	0.98	0.23	5.65
HMF051	2745	9634	0.999	9.001	10.9965	93.2	0.96	0.22	5.62
HMF071	—	9634	0.999	9.001	10.9965	93.2	0.96	0.22	5.62
HMF076	—	9634	0.999	9.001	10.9965	93.2	0.96	0.22	5.62
HMF051	2746	1238	0.12865	9.00175	10.9965	93.09	1	0.22	5.69
HMF071	—	1238	0.12865	9.00175	10.9965	93.09	1	0.22	5.69
HMF076	—	1238	0.12865	9.00175	10.9965	93.09	1	0.22	5.69
HMF051	2747	14436	1.4999	9.002	10.9968	93.16	0.98	0.19	5.67
HMF071	—	14436	1.4999	9.002	10.99675	93.16	0.98	0.19	5.67
HMF076	—	14436	1.4999	9.002	10.9968	93.16	0.98	0.19	5.67
HMF051	2748	14462	1.5	9.0025	10.9975	93.09	1	0.22	5.69
HMF071	—	14462	1.5	9.0025	10.9975	93.09	1	0.22	5.69
HMF076	—	14462	1.5	9.0025	10.9975	93.09	1	0.22	5.69
HMF051	2749	4360	0.3774	11.003	12.9955	93.19	0.98	0.25	5.58
HMF071	—	4360	0.3774	11.003	12.9955	93.19	0.98	0.25	5.58
HMF076	—	4360	0.3774	11.003	12.9955	93.19	0.98	0.25	5.58
HMF051	2750	4336	0.37545	11.0015	12.9945	93.12	0.95	0.25	5.68
HMF071	—	4336	0.37545	11.0015	12.9945	93.12	0.95	0.25	5.68
HMF076	—	4336	0.37545	11.0015	12.9945	93.12	0.95	0.25	5.68
HMF051	2751	5822	0.50355	11.0015	12.9958	93.13	0.98	0.24	5.65
HMF071	—	5822	0.50355	11.0015	12.99575	93.13	0.98	0.24	5.65
HMF076	—	5822	0.50355	11.0015	12.9958	93.13	0.98	0.24	5.65

Table B.1. Results of inspection reports for HEU metal parts (continued).

Test	Part	Mass (g)	Height (in.)	ID (in.)	OD (in.)	U-235	U-234	U-236	U-238
HMF051	2752	—	—	—	—	—	—	—	—
HMF071	—	5811	0.50325	11.0025	12.9955	93.13	0.98	0.24	5.65
HMF076	—	5811	0.50325	11.0025	12.9955	93.13	0.98	0.24	5.65
HMF051	2753	—	—	—	—	—	—	—	—
HMF071	—	5782	0.5013	11.003	12.99675	93.12	0.95	0.25	5.69
HMF076	—	5782	0.5013	11.003	12.99675	93.12	0.95	0.28	5.66
HMF051	2754	5826	0.5036	11.004	12.9953	93.1	0.96	0.28	5.66
HMF071	—	5826	0.5036	11.004	12.9953	93.1	0.96	0.28	5.66
HMF076	—	5826	0.5036	11.004	12.9953	93.1	0.96	0.28	5.66
HMF051	2755	6514	0.5635	11.003	12.996	93.1	0.96	0.28	5.66
HMF071	—	6514	0.5635	11.003	12.99595	93.1	0.96	0.28	5.66
HMF076	—	6514	0.5635	11.003	12.996	93.1	0.96	0.28	5.66
HMF051	2756	11567	1.0002	11.0036	12.9967	93.18	0.93	0.25	5.64
HMF071	—	11567	1.0002	11.0036	12.9967	93.18	0.93	0.25	5.64
HMF076	—	11567	1.0002	11.0036	12.9967	93.18	0.93	0.25	5.64
HMF051	2757	11575	1.00155	11.0025	12.996	93.2	0.96	0.23	5.61
HMF071	—	11575	1.00155	11.0025	12.996	93.2	0.96	0.23	5.61
HMF076	—	11575	1.00155	11.0025	12.996	93.2	0.96	0.23	5.61
HMF051	2761	—	—	—	—	—	—	—	—
HMF071	—	1706	0.1265	13.001	14.99475	93.12	0.96	0.27	5.65
HMF076	—	1706	0.1265	13.001	14.99475	93.12	0.96	0.27	5.65
HMF051	2762	7703	0.99925	7.00375	8.99625	93.13	0.97	0.27	5.63
HMF071	—	7703	0.99925	7.0037	8.99625	93.13	0.97	0.27	5.63
HMF076	—	7703	0.99925	7.00375	8.99625	93.13	0.97	0.27	5.63
HMF051	2763	953	0.1243	7.0038	8.9958	93.18	0.96	0.25	5.66
HMF071	—	953	0.1243	7.0038	8.9958	93.18	0.96	0.25	5.61
HMF076	—	953	0.1243	7.0038	8.9958	93.18	0.96	0.25	5.61
HMF051	2766	7605	0.563	13.001	14.9965	93.16	0.98	0.27	5.59
HMF071	—	7605	0.563	13.001	14.9965	93.16	0.98	0.27	5.59
HMF076	—	7605	0.563	13.001	14.9965	93.16	0.98	0.27	5.59
HMF051	2773	962	0.125	7.0015	8.997	93.17	0.97	0.24	5.62
HMF071	—	962	0.126	7.0015	8.997	93.17	0.97	0.24	5.62
HMF076	—	962	0.126	7.0015	8.997	93.17	0.97	0.24	5.62
HMF051	2774	1930	0.25	7.003	8.9965	93.08	0.99	0.24	5.69
HMF071	—	1930	0.25	7.003	8.9965	93.08	0.99	0.29	5.64
HMF076	—	1930	0.25	7.003	8.9965	93.08	0.99	0.29	5.64
HMF051	2775	1917	0.2485	7.004	8.99675	93.15	0.98	0.24	5.63
HMF071	—	1917	0.2485	7.004	8.99675	93.15	0.98	0.24	5.63
HMF076	—	1917	0.2485	7.004	8.99675	93.15	0.98	0.24	5.63
HMF051	2776	9644	1.0015	9.0015	10.9965	93.16	0.96	0.23	5.65

Table B.1. Results of inspection reports for HEU metal parts (continued).

Test	Part	Mass (g)	Height (in.)	ID (in.)	OD (in.)	U-235	U-234	U-236	U-238
HMF071	—	9644	1.0015	9.0015	10.9965	93.16	0.96	0.23	5.65
HMF076	—	9644	1.0015	9.0015	10.9965	93.16	0.96	0.23	5.65
HMF051	2778	2411	0.251	9.002	10.9965	93.16	0.96	0.23	5.65
HMF071	—	2411	0.251	9.002	10.9965	93.16	0.96	0.23	5.65
HMF076	—	2411	0.251	9.002	10.9965	93.16	0.96	0.23	5.65
HMF051	2779	2417	0.251	9.0015	10.997	93.16	0.96	0.23	5.65
HMF071	—	2417	0.251	9.0015	10.997	93.16	0.96	0.23	5.65
HMF076	—	2417	0.251	9.0015	10.997	93.16	0.96	0.23	5.65
HMF051	2780	—	—	—	—	—	—	—	—
HMF071	—	1440	0.12485	11.002	12.99605	93.13	0.98	0.25	5.64
HMF076	—	1440	0.12485	11.002	12.99605	93.13	0.98	0.25	5.64
HMF071	2784	5039	0.3725	13.0015	14.9945	93.13	0.99	0.24	5.64
HMF076	—	5039	0.3725	13.0015	14.9945	93.11	0.99	0.26	5.64
HMF051	2785	5043	0.3747	13.0029	14.9958	93.14	0.98	0.24	5.64
HMF071	—	5043	0.3747	13.00285	14.99575	93.11	0.99	0.26	5.64
HMF076	—	5043	0.3747	13.0029	14.9958	93.14	0.98	0.24	5.64
HMF051	2829	2895	0.37625	7.00315	8.99625	93.1	0.99	0.24	5.67
HMF071	—	2895	0.37625	7.00315	8.99625	93.1	0.99	0.24	5.67
HMF076	—	2895	0.37625	7.00315	8.99625	93.1	0.99	0.24	5.67
HMF051	2848	6748	0.5019	13.0031	14.9964	93.18	0.99	0.24	5.66
HMF071	—	6748	0.5019	13.0031	14.9964	93.18	0.99	0.24	5.59
HMF076	—	6748	0.5019	13.0031	14.9964	93.18	0.99	0.24	5.59