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Critical Configuration and Physics Measurements for Beryllium Reflected Assemblies of $U(93.15)O_2$ Fuel Rods (1.506-cm Pitch and 7-Tube Clusters)

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CRITICAL CONFIGURATION AND PHYSICS MEASUREMENTS FOR BERYLLIUM REFLECTED ASSEMBLIES OF U(93.15)O_2 FUEL RODS (1.506-CM PITCH AND 7-TUBE CLUSTERS)

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Space Reactor - SPACE

SCCA-SPACE-EXP-003
CRIT-SPEC-*REAC*-RRATE

Status of Compilation/Evaluation/Peer Review

Section 1	Compiled	Independent Review	Working Group Review	Approved
1.0 DETAILED DESCRIPTION				
1.1 Description of the Critical and/or Subcritical Configuration	YES	YES	YES	YES
1.2 Description of Buckling and Extrapolation-Length Measurements	NA	NA	NA	NA
1.3 Description of Spectral-Characteristics Measurements	YES	YES	YES	YES
1.4 Description of Reactivity-Effects Measurements	YES	NO	NO	NO
1.5 Description of Reactivity-Coefficient Measurements	NA	NA	NA	NA
1.6 Description of Kinetics Measurements	NA	NA	NA	NA
1.7 Description of Reaction-Rate Distribution Measurements	YES	YES	YES	YES
1.8 Description of Power-Distribution Measurements	NA	NA	NA	NA
1.9 Description of Isotopic Measurements	NA	NA	NA	NA
1.10 Description of Other Miscellaneous Types of Measurements	NA	NA	NA	NA
Section 2	**Evaluated**	**Independent Review**	**Working Group Review**	**Approved**
2.0 EVALUATION OF EXPERIMENTAL DATA				
2.1 Evaluation of Critical and/or Subcritical Configuration Data	YES	YES	YES	YES
2.2 Evaluation of Buckling and Extrapolation Length Data	NA	NA	NA	NA
2.3 Evaluation of Spectral-Characteristics Data	YES	YES	YES	YES
2.4 Evaluation of Reactivity-Effects Data	NO	NO	NO	NO
2.5 Evaluation of Reactivity-Coefficient Data	NA	NA	NA	NA
2.6 Evaluation of Kinetics-Measurements Data	NA	NA	NA	NA
2.7 Evaluation of Reaction-Rate Distributions	YES	YES	YES	YES
2.8 Evaluation of Power-Distribution Data	NA	NA	NA	NA
2.9 Evaluation of Isotopic Measurements	NA	NA	NA	NA
2.10 Evaluation of Other Miscellaneous Types of Measurements	NA	NA	NA	NA

Section 3	Compiled	Independent Review	Working Group Review	Approved
3.0 BENCHMARK SPECIFICATIONS				
3.1 Benchmark-Model Specifications for Critical and/or Subcritical Measurements	YES	YES	YES	YES
3.2 Benchmark-Model Specifications for Buckling and Extrapolation-length Measurements	NA	NA	NA	NA
3.3 Benchmark-Model Specifications for Spectral-Characteristics Measurements	YES	YES	YES	YES
3.4 Benchmark-Model Specifications for Reactivity-Effects Measurements	NO	NO	NO	NO
3.5 Benchmark-Model Specifications for Reactivity-Coefficient Measurements	NA	NA	NA	NA
3.6 Benchmark-Model Specifications for Kinetics Measurements	NA	NA	NA	NA
3.7 Benchmark-Model Specifications for Reaction-Rate Distribution Measurements	YES	YES	YES	YES
3.8 Benchmark-Model Specifications for Power-Distribution Measurements	NA	NA	NA	NA
3.9 Benchmark-Model Specifications for Isotopic Measurements	NA	NA	NA	NA
3.10 Benchmark-Model Specifications of Other Miscellaneous Types of Measurements	NA	NA	NA	NA
Section 4	**Compiled**	**Independent Review**	**Working Group Review**	**Approved**
4.0 RESULTS OF SAMPLE CALCULATIONS				
4.1 Results of Calculations of the Critical or Subcritical Configurations	YES	YES	YES	YES
4.2 Results of Buckling and Extrapolation Length Calculations	NA	NA	NA	NA
4.3 Results of Spectral-Characteristics Calculations	YES	YES	YES	YES
4.4 Results of Reactivity-Effect Calculations	NO	NO	NO	NO
4.5 Results of Reactivity-Coefficient Calculations	NA	NA	NA	NA
4.6 Results of Kinetics-Parameter Calculations	NA	NA	NA	NA
4.7 Results of Reaction-Rate Distribution	YES	YES	YES	YES
4.8 Results of Power-Distribution Calculations	NA	NA	NA	NA
4.9 Results of Isotopic Calculations	NA	NA	NA	NA
4.10 Results of Calculations of Other Miscellaneous Types of Measurements	NA	NA	NA	NA
Section 5	**Compiled**	**Independent Review**	**Working Group Review**	**Approved**
5.0 REFERENCES	YES	YES	YES	YES
Appendix A: Computer Codes, Cross Sections, and Typical Input Listings	YES	YES	YES	YES

CRITICAL CONFIGURATION AND PHYSICS MEASUREMENTS FOR BERYLLIUM REFLECTED ASSEMBLIES OF U(93.15)O_2 FUEL RODS (1.506-CM PITCH AND 7-TUBE CLUSTERS)

IDENTIFICATION NUMBER: SCCA-SPACE-EXP-003
CRIT-SPEC-*REAC*-RRATE

KEY WORDS: 1.506-cm pitch, 7-tube clusters, acceptable, assembly, beryllium-reflected, cadmium ratios, critical experiments, dioxide, fuel rods, highly enriched, medium power reactor experiment, reactivity worth measurements, small modular reactor, space reactor, un-moderated, uranium

SUMMARY INFORMATION

1.0 DETAILED DESCRIPTION

A series of small, compact critical assembly (SCCA) experiments were completed from 1962–1965 at Oak Ridge National Laboratory's (ORNL's) Critical Experiments Facility (CEF) in support of the Medium-Power Reactor Experiments (MPRE) program. In the late 1950s, efforts were made to study "power plants for the production of electrical power in space vehicles."[(a)] The MPRE program was a part of those efforts and studied the feasibility of a stainless-steel system, boiling potassium 1 MW(t), or about 140 kW(e), reactor. The program was carried out in [fiscal years] 1964, 1965, and 1966. A summary of the program's effort was compiled in 1967.[a] The delayed critical experiments were a mockup of a small, potassium-cooled space power reactor for validation of reactor calculations and reactor physics methods.

Initial experiments, performed in November and December of 1962, consisted of a core of un-moderated stainless-steel tubes, each containing 26 UO_2 fuel pellets, surrounded by a graphite reflector. Measurements were performed to determine critical reflector arrangements, fission-rate distributions, and cadmium ratio distributions. Subsequent experiments used beryllium reflectors and also measured the reactivity for various materials placed in the core. "The [assemblies were built] on [a] vertical assembly machine so that the movable part was the core and bottom reflector" (see Reference 1). The experiment studied in this evaluation was the third of the series and had the fuel in a 1.506-cm-triangular and 7-tube clusters leading to two critical configurations (see References 4 and 5). Once the critical configurations had been achieved, various measurements of reactivity, relative axial and radial activation rates of ^{235}U, and cadmium ratios were performed. The cadmium ratio, reactivity, and activation rate measurements were performed on the 1.506-cm-array critical configuration and are described in Sections 1.3, 1.4, and 1.7, respectively.

Information for this evaluation was compiled from References 1 through 5, from the experimental logbook,[b] and from communication with the experimenter, John T. Mihalczo.

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[a] A. P. Fraas, "Summary of the MPRE Design and Development Program," ORNL-4048, Oak Ridge National Laboratory (1967).

[b] Radiation Safety Information Computation Center (RSICC), The ORNL Critical Experiments Logbooks, Book 75r, http://rsicc.ornl.gov/RelatedLinks.aspx?t=criticallist, logbook page 81-114.

1.1 Description of the Critical and/or Subcritical Configuration

(The criticality portion of this evaluation has been reviewed and approved by the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and has been published under the following identifier: HEU-COMP-FAST-004.[a])

1.2 Description of Buckling and Extrapolation Length Measurements

Buckling and extrapolation-length measurements were not performed.

1.3 Description of Spectral Characteristics Measurements

1.3.1 Overview of the Experiment

Cadmium ratios were measured with enriched uranium metal foils at various locations in the assembly with the fuel tube at the 1.506-cm spacing. They are described in the following subsections.

1.3.2 Geometry of the Experiment Configuration and Measurement Procedure

The experiment configuration was the same as the first critical configuration described in HEU-COMP-FAST-004 (Case 1). The experimenter placed 0.75-cm-diameter × 0.010-cm-thick 93.15%-^{235}U-enriched uranium metal foils[b] with and without 0.051-cm-thick cadmium covers at various locations in the core and top reflector. One part of the cadmium cover was cup shaped and contained the uranium foil. The other part was a lid that fit over the exposed side of the foil when it was in the cup shaped section of the cover.[c] As can be seen in the logbook (pages 103 and 105), two runs were required to obtain all the measurements necessary for the cadmium ratios. The bare foil measurements within the top reflector were performed first as part of the axial foil activation measurements. The results of these measurements are used for both the axial activation results and the cadmium ratios. Cadmium covered foils were then placed at the same locations through the top reflector in a different run. Three pairs of bare and cadmium covered foils were also placed through the core tank. One pair was placed at the midplane of the core 11.35 cm from the center of the core. Two pairs of foils were placed on top of fuel tubes 3.02 and 12.06 cm from the center of the core.[d]

Uranium foils were selected from hundreds of identical foils "according to their activity when exposed to the same neutron flux." Corresponding bare and covered foils had the same activity to less than 1% after activation in the same neutron flux for the same time."[e] The activation of the uranium metal foils was measured after removal from the assembly using two lead-shielded NaI scintillation detectors as follows.

The NaI scintillators were carefully matched and had detection efficiencies for counting delayed-fission-product gamma rays with energies above 250 KeV within 5%. In all foil activation measurements, one foil at a specific location was used as a normalizing foil to remove the effects of the decay of fission products during the counting measurements with the NaI detectors. The normalization foil was placed on one NaI scintillator and the other foil on the other NaI detector and the activities measured

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[a] International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2012).

[b] Reference 4 reports the foil enrichment as 93.2 wt.%, but according to the experimenter, it was 93.15 wt.% (September 19, 2011).

[c] Personal communication with J.T. Mihalczo, August 14, 2012.

[d] Radiation Safety Information Computation Center (RSICC), The ORNL Critical Experiments Logbooks, Book 75r, http://rsicc.ornl.gov/RelatedLinks.aspx?t=criticallist, logbook page 103 and 105.

[e] Personal communication with J.T. Mihalczo, November 9, 2012.

simultaneously. The activation of a particular foil was compared to that of the normalization foil by dividing the count rate for each foil by that of the normalization foil. "Use of a normalization foil corrects for the time decay after irradiation since it is decaying at the same rate as the foil of interest. So the relative distribution is measured with respect to the normalization foil position."[a] To correct for the differing efficiencies of the two NaI detectors, the normalization foil was counted in Detector 1 simultaneously with the foil at position *x* in Detector 2, and then the normalization foil was counted simultaneously in Detector 2 with the foil from position *x* in Counter 1. The activity of the foil from position *x* was divided by the activity of the normalization foil counted simultaneously. This resulted in two values of the ratio that were then averaged. This procedure essentially removed the effect of the differing efficiencies of the two NaI detectors. Differing efficiencies of 10% resulted in errors in the ratios measured to less than 1%. The background counting rates obtained with the foils used for the measurements on the NaI detectors before their irradiation measurement were subtracted from all count rates. [b] The results of the cadmium ratio measurements are given in Table 1.3-1 and some results are shown in Figure 1.3-1. "No correction has been made for self shielding in the foils" (Reference 4).

Table 1.3-1. Cadmium Ratio (see Reference 4).

Distribution through Top Reflector(a)	
Distance from Center of Fuel Tube (cm)(b)	Cadmium Ratio(c)
15.91	1.37
17.18	1.56
18.45	1.70
19.72	1.76
20.99	1.97
22.26	2.06
Measurement at Axial Core Midplane	
Distance from Core Center (cm)	Cadmium Ratio(c)
11.35(d)	1.24
Measurement at 15.44 cm Above Core Midplane(e)	
Distance from Core Center (cm)	Cadmium Ratio(c)
3.02	1.39
12.06	1.87

(a) These ratios coincide with the position of the relative activation of ^{235}U fission foils in the top reflector measurements in Table 1.7-1.
(b) Foils were placed horizontally between sections of reflector at ½ inch spacing.
(c) The cadmium ratio is defined as the ratio of the bare-to-cadmium-covered foil activity.
(d) This is foil location 9 on Figure 1.4-2.
(e) Foils were placed on top of the fuel tubes.

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[a] Personal email communication with J.T. Mihalczo, December 3, 2013.

[b] Personal email communication with J. T. Mihalczo, September 27, 2011, and November 23, 2011. The experimenter believes a 250-KeV threshold was used "so as to not count the natural activity of the uranium foils" (November 14, 2011).

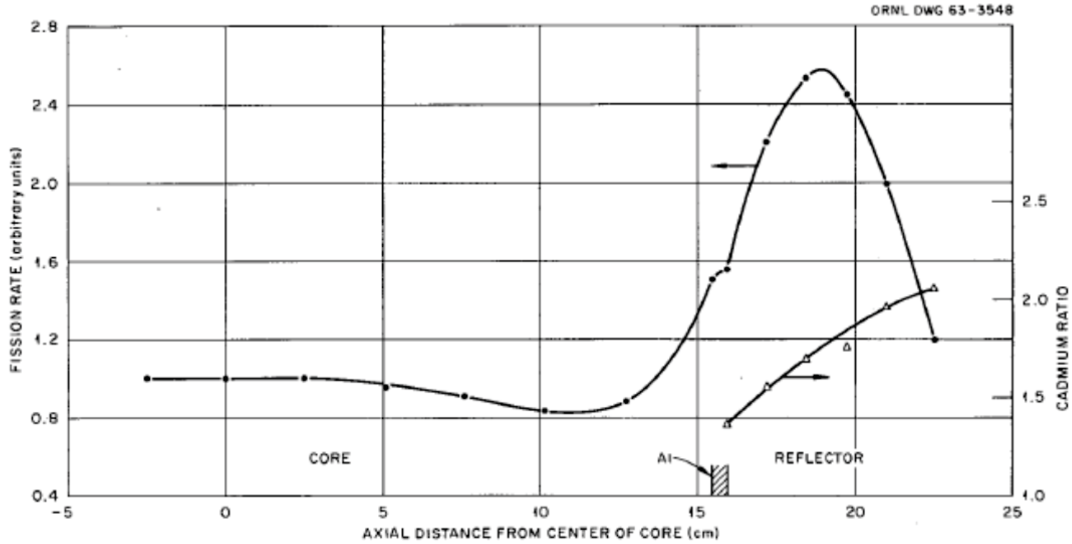

Figure 1.3-1. Plot of Relative Activation of ^{235}U Fission Foils (see Section 1.7) and Cadmium Ratios in the Top Reflector (see Reference 4).

1.3.3 Material Data

The uranium foils were 93.15 wt.% enriched. No impurity data were given for the uranium foils but according to the experimenter, the impurity content of the uranium foil was similar to that for the uranium metal described in HEU-MET-FAST-051.[a] The composition of the cadmium covers was not specified. Material data for the core and reflector parts are the same as those given in Section 1.3 of HEU-COMP-FAST-004.

1.3.4 Temperature Data

The temperature is the same as for the critical configuration, 72°F (22°C).[b]

1.3.5 Additional Information Relevant to Spectral Characteristics Measurements

Additional information was not identified.

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[a] International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2012).

[b] Personal email communication with J. T. Mihalczo, May 23, 2011.

1.4 Description of Reactivity Effects Measurements

1.4.1 Overview of the Experiment

Various reactivity measurements were performed. The reactivity of fuel tubes at various locations in the core and the effect of fuel tube movement at the periphery of the core were measured. The worth of various neutron absorbing and moderating materials inserted into the core and the worth of adding thickness to the top reflector were also measured. Finally the worth of adding potassium to the core was measured, which also led to some other worth measurements as the core was reconfigured to accommodate the potassium. These reactivity effect measurements are described and summarized below.

1.4.2 Geometry of the Experiment Configuration and Measurement Procedure

1.4.2.1 Fuel Effect Reactivity Measurements

The worth of fuel tubes at various radial locations in the core was measured by "observing the change in the stable reactor period when the fuel tube was removed" (Reference 4). Fuel tube reactivities were measured relative to the center fuel tube reactivity.[a] The worth of fuel tubes versus radial position is given in Table 1.4-1 and Figure 1.4-1. The locations of the fuel tubes are shown in Figure 1.4-2.

Table 1.4-1. Fuel Tube Reactivity Worth
Versus Radial Position (see Reference 4).

Fuel Tube Position[(a)]	Distance From Core Center	Reactivity (¢)
1	0	32.0
2	2.59	32.0
3	5.23	30.8
4	7.75	27.2
5	10.48	25.5
6	10.56	25.6
7	11.78	22.6

(a) Positions given in Figure 1.4-2

[a] It is not clear what it means to be measured relative to the center fuel tube. The reported results are not relative to the center fuel tube.

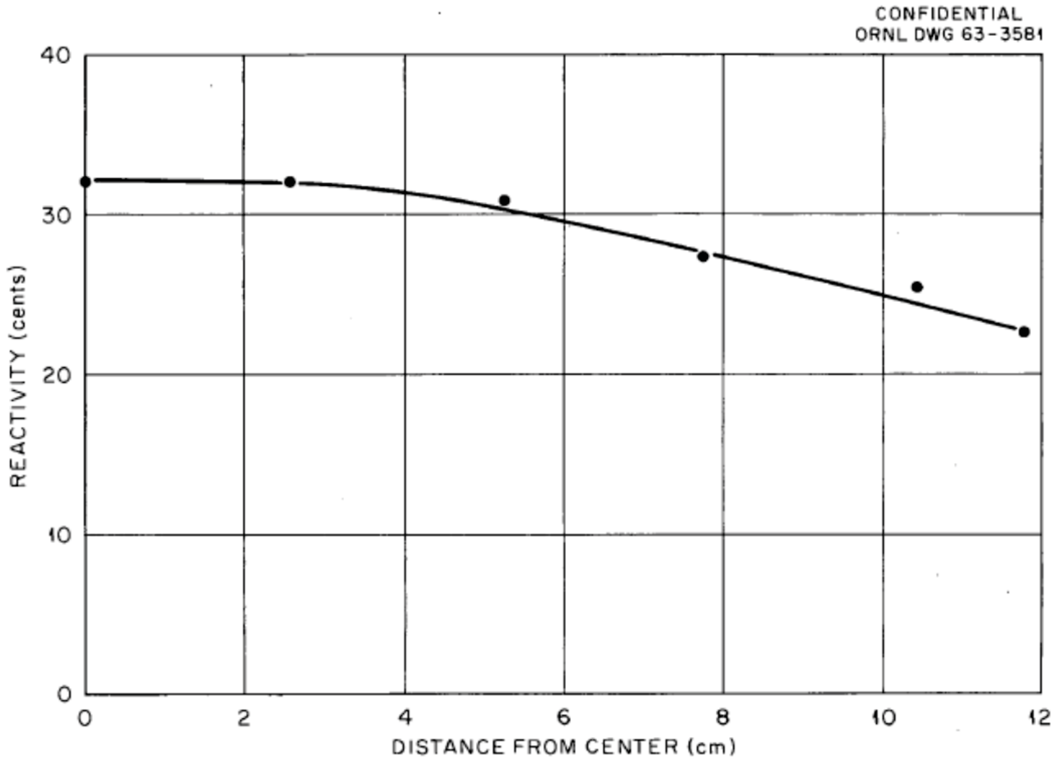

Figure 1.4-1. Reactivity Worth of Fuel Tube Versus Radius (see Reference 4).

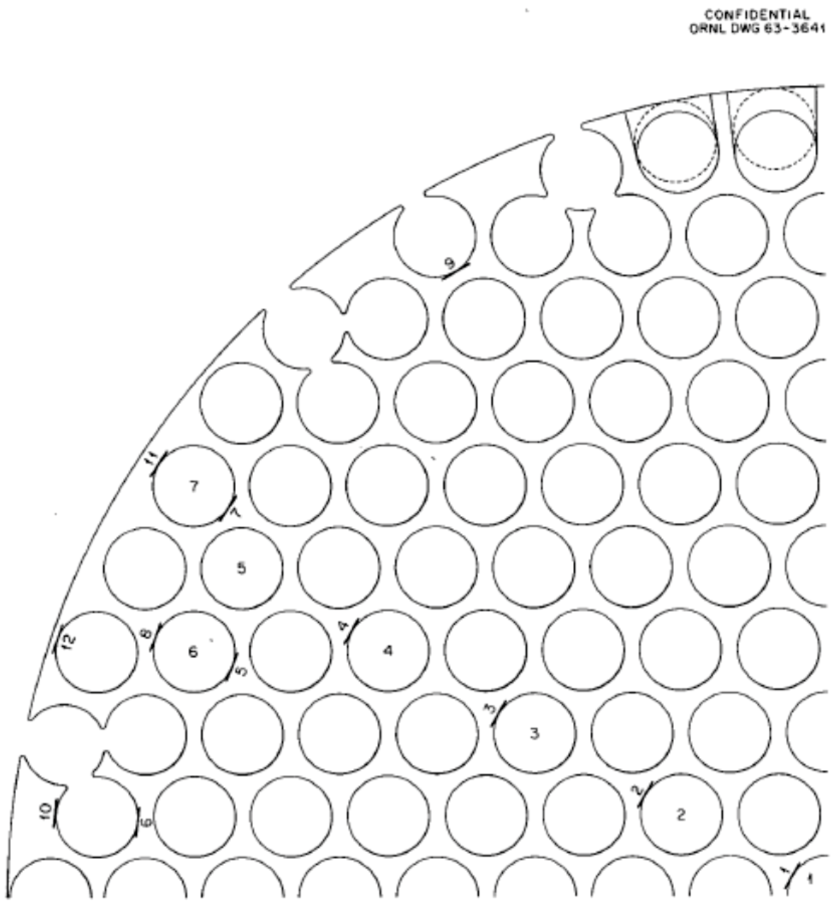

Figure 1.4-2. Foil Locations for Radial Fission Rate Distribution and Fuel Tube Locations for Fuel Reactivity Measurements (see Reference 4).

A credible accident condition where twenty fuel tubes at the periphery of the core were moved from their normal location in the lattice out to the edge of the core was simulated. An example of this movement is shown for two fuel tubes in Figure 1.4-2. The measured reactivity effect was -8.2 ¢ for displacement of twenty fuel tubes.

An additional reactivity worth was measured for changing the fuel tubes from a regular lattice assembly to a 7-tube cluster assembly. The grid plate for this assembly is shown in Figure 1.4-3. This change was evaluated as an additional critical configuration and is described in HEU-COMP-FAST-004.

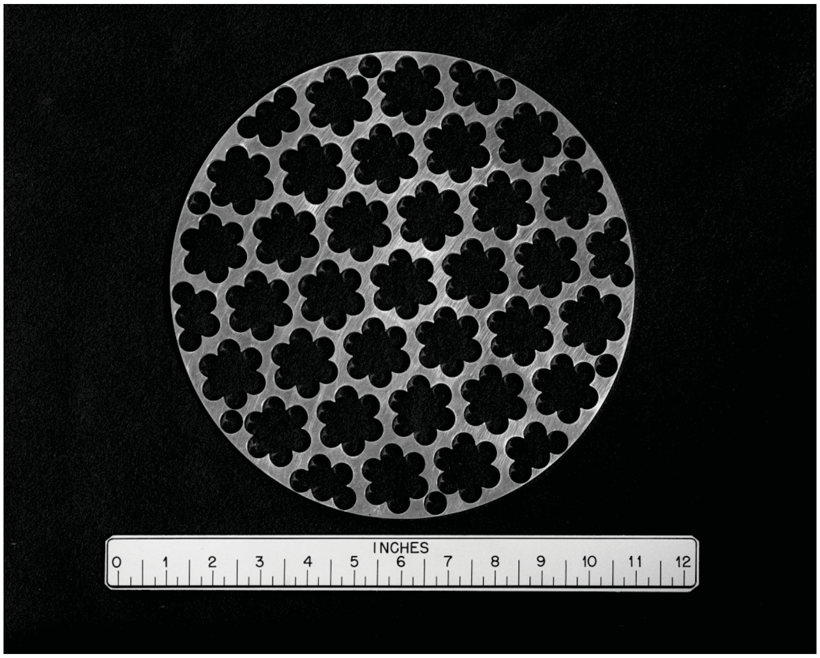

Figure 1.4-3. Grid Plate for 7-Tube-Cluster Assembly (see Reference 4).

1.4.2.2 Neutron Absorbing and Moderating Material Reactivity Measurements

The effect of adding various neutron absorbing and moderating materials was also measured. Materials were added to the core as rods, filled stainless steel tubes, and discs or lids that fit between the top of the fuel tubes and the top of the core tank.[a] The results of the reactivity measurements, reported in cents per kilogram material, from Reference 4 as well as the total reactivity, found in the logbook, are summarized in Table 1.4-2. Any discrepancies between the logbook and Reference 4 data are footnoted in Table 1.4-2. Rod locations are shown in Figure 1.4-4.

[a] Personal communication with J.T. Mihalczo, September 27, 2012.

Table 1.4-2. Reactivity Effects of Absorbing and Moderating Material in the Core
(See Reference 4 and the logbook).

Material	Form	Number	Location	Total Weight (g)	Total Reactivity [(a)] (cents)	Reactivity Coefficient (cents/kg)	Logbook Reference Pages
Type 347 Stainless Steel	0.317 cm dia rods 30.5 cm long	90	All positions filled	1704	14.8	8.7	94
	0.317 cm dia rods 30.5 cm long	46	Every other position	871	7.92	9.1	84, 86
W	0.317 cm dia rods 30.5 cm long	46	Every other position	2110	-4.27	-2.0	86, 87
Nb[(b)]	0.317 cm dia rods 30.5 cm long	90[(c)]	All positions	1050	4.9	4.7	86, 107
CH_2	0.317 cm dia rods 30.5 cm long	8	Odd number holes between 43-57	18.42[(d)]	24.43	1320	86, 88
C	0.305 cm dia rods 30.5 cm long	23	Every 4th position	82	7.5	91	86, 94
B_4C	Filled with B_4C[(e)]	1	Center fuel tube position	30.5	-6.65	-220	91, 92
Stainless Steel	Disc 0.317 cm thick for top of core tank	1	Top of core	1290	7.97[(f)]	6.2[(g)]	85, 86
Al	Lid for top of core tank, 0.317 cm thick	1	Top of core	464	16.62[(h)]	36	85, 86
Al	Lid for top of core tank, 0.159 cm thick	1	Top of core	226	8.14[(i)]	36[(j)]	85, 86
Cd	Lid for top of core, 0.066 cm thick	1	Top of core	286.5[(k)]	-45.7	-160[(l)]	91, 92

(a) These values are reported in the logbook.
(b) Reference 4 and the logbook use the element name columbium, Cb, which is now known is niobium, Nb.
(c) Reference 4 gives this value as 46 but the logbook gives it as 90. The reported mass corresponds to 90 rods.
(d) In Reference 4 this mass was rounded to18.4 g.
(e) An empty fuel tube was filled with B_4C and placed in the center fuel tube position. The reactivity was compared to the reactivity of an empty fuel tube in the center fuel tube position to find the reactivity of just the B_4C.
(f) This value was calculated by the evaluator by taking the difference of the reactivity of the system with the stainless steel lid in place, 12.23 cents, and the reactivity of the system without the lid, 4.26 cents.
(g) The reactivity coefficient given in Reference 4 and the reactivity reported in the logbook do not agree. Reference 4 gives a reactivity of 18 cents per kg but using values from the logbook a reactivity of 6.2 cents per kg is calculated. The correct value is 6.2 cents per kg as calculated from the logbook and as confirmed by the experimenter. (Personal communication with J.T. Mihalczo, September 27, 2012.)
(h) This value was calculated by the evaluator by taking the difference of the reactivity of the system with the stainless steel lid in place, 20.88 cents, and the reactivity of the system without the lid, 4.26 cents.
(i) This value was calculated by the evaluator by taking the difference of the reactivity of the system with the stainless steel lid in place, 12.4 cents, and the reactivity of the system without the lid, 4.26 cents.
(j) Reference 4 incorrectly reports this value as 35 cents per kg. (Personal communication with J.T. Mihalczo, September 27, 2012.)
(k) In Reference 4 this was rounded to 287 g.
(l) In Reference 4 this value is reported as a value but it should be a negative worth.

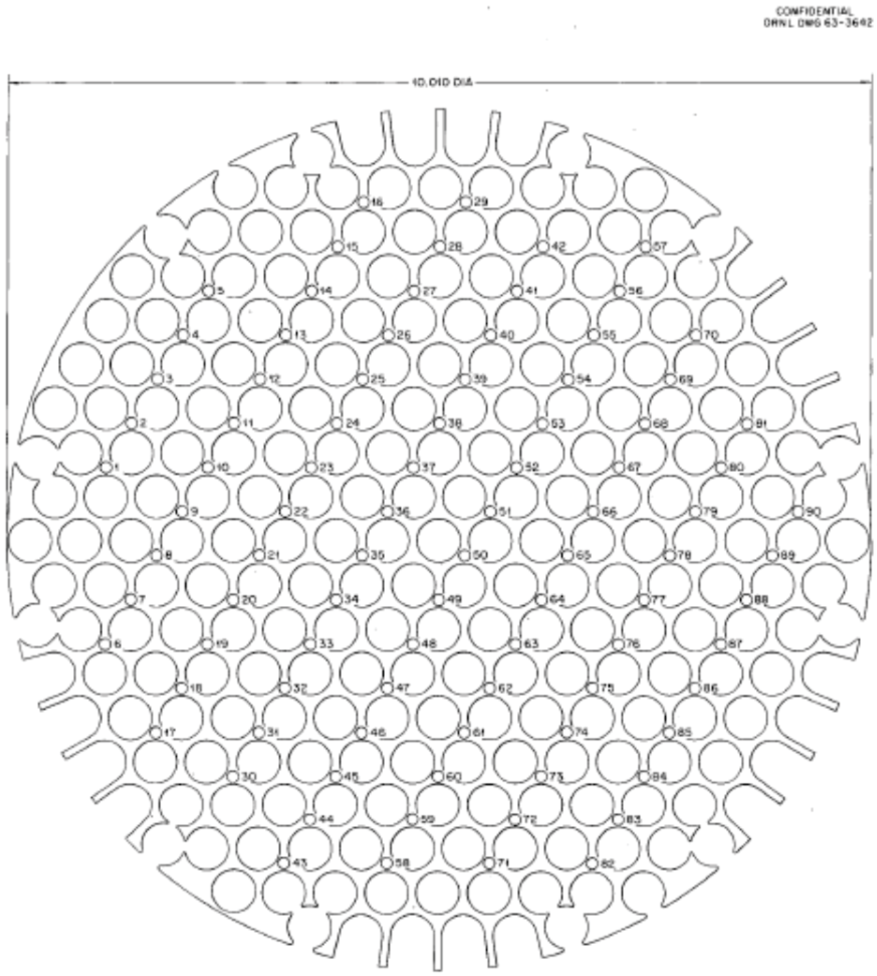

Figure 1.4-4. Locations of Samples in Reactivity Coefficient Measurements (see Reference 4).

1.4.2.3 Potassium Reactivity Measurements

The reactivity effect of adding potassium to the core was also studied. The critical configuration was changed by first switching the aluminum core tank for a calandria type vessel made of Type 304 and 307 Stainless Steel. This core tank is shown in Figure 1.4-5. The fuel and reflector arrangement was not changed. The change of the core tank resulted in a reactivity change of +28 ¢. The thickness of the top beryllium reflector was then decreased to 6.35 cm to compensate for the increased reactivity. The system then had a reactivity of +13.4 ¢. When 3,403 g of potassium was added to the core the reactivity was +32 ¢, i.e. an increase of 18.6 ¢. The resulting potassium reactivity coefficient was reported as +5.4 ¢/kg in Reference 4. The calandria type vessel was sent to Y-12 for filling. The experimenter believes that the potassium was pumped into the tank through a tube at the bottom, until the potassium filled the tank and overflowed through a tube, at the top of the tank, which was then sealed, all the while keeping the potassium liquid. The tank was probably X-rayed to check that there was no air at the top of the tank.[a] In the logbook two mass measurements were reported. The first reported the empty core mass as 13,372 g and the filled with potassium core mass as 16,765 grams. This difference gives a potassium mass of

[a] Personal email communication with J.T. Mihalczo, January 3, 2012.

3,393 g. The potassium mass of 3,403 g used in Reference 4 was reported “as per X-10 [Hofman]” in the logbook.[a]

Figure 1.4-5. Potassium Filled Calandria (see Reference 4).[b]

[a] Radiation Safety Information Computation Center (RSICC), The ORNL Critical Experiments Logbooks, Book 75r, http://rsicc.ornl.gov/RelatedLinks.aspx?t=criticallist, logbook page 111. It is not known exactly what “as per X-10 [Hofman]” means, but Hofman was probably responsible for the measurement.

[b] ORNL Photo 39928.

1.4.3 Material Data

All core and reflector materials were the same as those used in the critical configuration as given in HEU-COMP-FAST-004 unless stated otherwise.

1.4.3.1 Fuel Effect Reactivity Measurements

No additional material was used for the fuel effect reactivity measurements.

1.4.3.2 Neutron Absorbing and Moderating Material Reactivity Measurements

Various additional materials were added to the core region to test the reactivity worth of those materials. The materials investigated include Type 347 Stainless Steel, tungsten (W), niobium (Nb),[a] polyethylene (CH_2), graphite, boron carbide (B_4C), aluminum (Al), and cadmium (Cd). Impurity data for these materials were not given.

As can be seen in Table 1.4-2 the worth of a stainless steel disc was measured. The type of stainless steel used for this disc was not given.

1.4.3.3 Potassium Reactivity Measurements

The core tank was switched from a Type 1100 Aluminum core tank to a Type 304 and 307 Stainless Steel calandria type core tank for the potassium reactivity measurements. Tubes of the tank were Type 347 Stainless Steel and the end plates and tank were Type 304 Stainless Steel. Potassium was added to the core tank. The form and purity of the potassium was not given.

1.4.4 Temperature Data

The temperature is the same as for the critical configuration, 72°F (22°C).[b]

1.4.5 Additional Information Relevant to Reactivity Effects Measurements

Additional information was not identified.

1.5 Description of Reactivity Coefficient Measurements

The worths per gram of various materials placed in the core were given in Reference 4. These reactivity coefficients are based on the absolute measured worth of a sample and the sample mass. The measured absolute worth values were evaluated and not the calculated reactivity coefficients. For reference the reactivity coefficients calculated using the sample mass and measured reactivity are provided in Section 1.4.

1.6 Description of Kinetics Measurements

Kinetics measurements were not performed.

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[a] The logbook and Reference 4 use the historical name of columbium (Cb) for niobium.

[b] Personal email communication with J. T. Mihalczo, May 23, 2011.

1.7 Description of Reaction-Rate Distribution Measurements

1.7.1 Overview of the Experiment

Activation measurements were taken through the core and top reflector.

1.7.2 Geometry of the Experiment Configuration and Measurement Procedure

The activation measurements were performed for the critical assembly (as described in Section 1 of HEU-COMP-FAST-004). Measurements were performed using 93.15 wt.% enriched uranium metal foils that were 0.75-cm in diameter and 0.010-cm-thick.[a] These foils were taped tangent to the fuel tubes within the core, placed on top of fuel tubes, and placed between sections of reflector. The foils were stiff and did not curve around the fuel tube when taped tangentially to the side of the fuel tube. A small piece of Teflon tape was placed in the vertical direction, along the length of the fuel tube, to hold the foils in place.[b] For the foils in the core, the activation is a spatial average over the diameter of the foil. For the foils in the reflector they represent a point axially and are averaged over the foil dimensions in the radial direction. No correction for self-shielding in the foils was made when obtaining the results in Tables 1.7-1, 1.7-2 and 1.7-3. Results are plotted in Figures 1.7-1 and 1.7-2. From Figure 1.7-2 it can be seen that the "radial fission rate distribution at the core midplane is flat to within 2.54 cm of the side reflector, where it increases to a maximum, at the core boundary, about 3.7 greater than at the center" (Reference 4). Foil locations within the core are given in Figure 1.4-2.

[a] Reference 4 reports the foil enrichment as 93.2 wt.%, but according to the experimenter, it was 93.15 wt.% September 19, 2011).

[b] Personal email communication with J.T. Mihalczo, December 4, 2013.

Table 1.7-1. Axial Activation Fission Rate Distribution (see Reference 4).

Axial Fission Rate Distribution[(a)]	
Distance from Center of Fuel Tube (cm)[(b)]	Relative Fission Rate (Arbitrary Units)
-2.54	1.02
0	1.00
2.54	1.00
5.08	0.95
7.62	0.91
10.16	0.83
12.7	0.88
15.44	1.51
15.91	1.56
17.18	2.21
18.45	2.53
19.72	2.45
20.99	2.00
22.26	1.20

(a) Activation foils were 0.010-cm-thick by 0.75-cm-dia HEU metal foil.

(b) Foils in the core were taped tangent to the center fuel tube. Foils in the top reflector were placed between beryllium blocks at ½ inch spacing.

Table 1.7-2. Radial Activation Fission Rate Distribution (see Reference 4).

Radial Fission Rate Distribution at Core Midplane[(a)]		
Location[(b)]	Distance from Core Center (cm)	Relative Fission Rate (Arbitrary Units)
1	0.635	1.0
2	3.25	0.98
3	5.87	0.99
4	8.53	1.04
5	9.93	1.06
6	10.74	1.12
7	11.12	1.21
8	11.2	1.55
9	11.35	1.45
10	12.06	3.04
11	12.47	3.68
12	12.62	3.56

(a) Activation foils were 0.010-cm-thick by 0.75-cm-dia HEU metal foil taped tangent to the fuel tubes.
(b) Foil locations within the core are given in Figure 1.4-2.

Table 1.7-3. Radial Activation Fission Rate Distribution (see Reference 4).

Radial Fission Rate Distribution at 15.44 cm Above Core Midplane[(a)]		
Location[(b)]	Distance from Core Center (cm)	Relative Fission Rate (Arbitrary Units)
13	0	1.51
14	3.02	1.63
15	12.06	2.50

(a) Activation foils were 0.010-cm-thick by 0.75-cm-dia HEU metal foil.
(b) Foils were laid on top of fuel tubes. These locations are not shown in Figure 1.4-2.

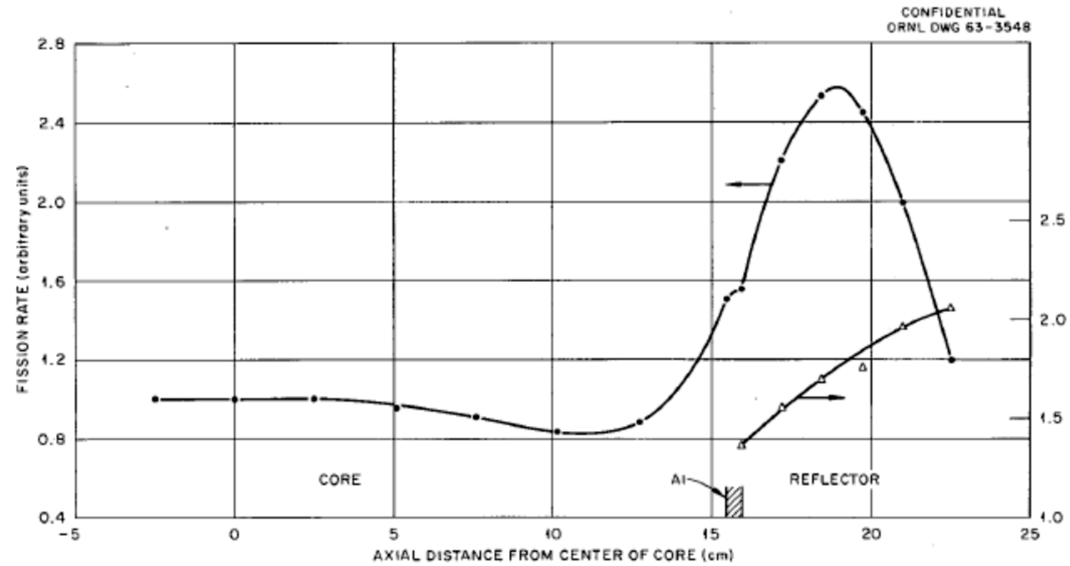

Figure 1.7-1. Plot of Axial Relative Activation of ^{235}U Fission Foils and Cadmium Ratios (see Section 1.3) (see Reference 4).

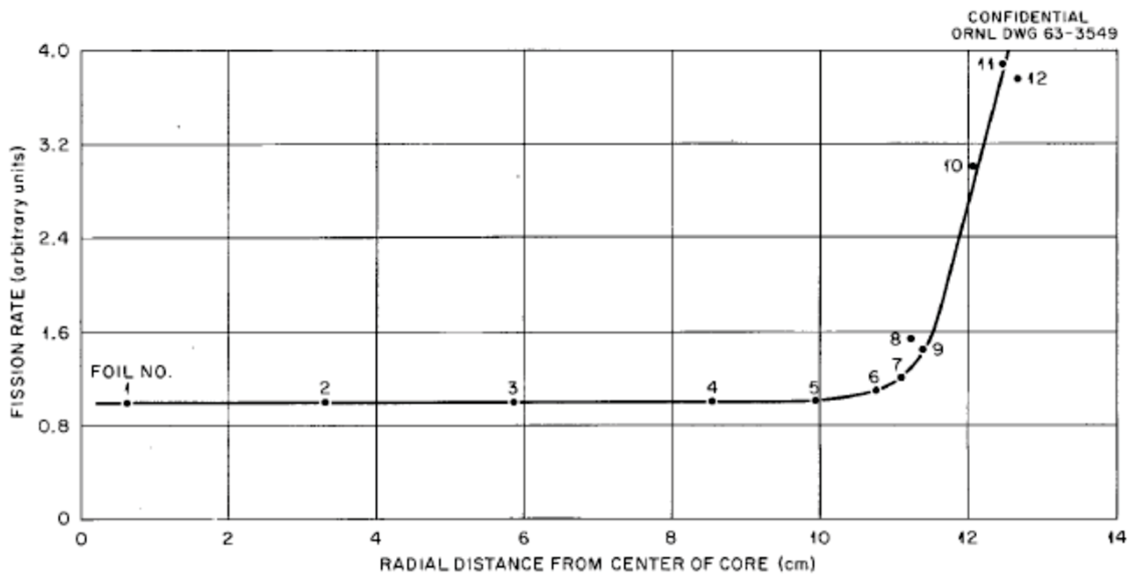

Figure 1.7-2. Plot of Radial Relative Activation of ^{235}U Fission Foils at the Core Midplane (see Reference 4).

1.7.3 Material Data

Material data for the core and reflector parts are the same as those given for the critical configuration (see Section 1.3 of HEU-COMP-FAST-004). The uranium metal foils were the same foils used for the cadmium ratio measurements (see Section 1.3.3).

1.7.4 Temperature Data

The temperature is the same as for the critical configuration, 72°F (22°C).[a]

1.7.5 Additional Information Relevant to Reaction-Rate Distribution Measurements

Additional information is not available.

1.8 Description of Power Distribution Measurements

The axial and radial relative power distribution is the same as the relative fission rate that was measured in the core region of Assembly 1 (see Section 1.7).

1.9 Description of Isotopic Measurements

Isotopic measurements were not performed.

1.10 Description of Other Miscellaneous Types of Measurements

Other miscellaneous types of measurements were not performed.

[a] Personal email communication with J. T. Mihalczo, May 23, 2011.

2.0 EVALUATION OF EXPERIMENTAL DATA

2.1 Evaluation of Critical and/or Subcritical Configuration Data

(The criticality portion of this evaluation has been reviewed and approved by the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and has been published under the following identifier: HEU-COMP-FAST-004.[a])

2.2 Evaluation of Buckling and Extrapolation Length Data

Buckling and extrapolation-length measurements were not performed.

2.3 Evaluation of Spectral Characteristics Data

The cadmium ratio measurements were a ratio of the activation of bare 93.15 wt% ^{235}U metal foils to the activation of 93.15 wt% ^{235}U metal foils with cadmium covers. The uncertainty in the uranium foils and cadmium covers dimensions, materials, and placements are the same as for the cadmium ratios in SCCA-SPACE-EXP-002. The effects of these uncertainties have been reevaluated using the detailed benchmark model described in Section 3.3. In order to obtain statistically significant results for perturbation calculations a scaling factor was used. The uncertainty values were scaled by 1, 5, 10, 50, and/or 100. An uncertainty is considered negligible if the effect was less than 0.0057, the rounding uncertainty ($0.01/\sqrt{3}$).

According to the experimenter, the measurement uncertainty in the cadmium ratio would have been 0.5 %. It is believed that this uncertainty is based on the number of counts taken for each foil, 100,000. (i.e., the square root of the number of counts is divided by the number of counts). This yields the measurement uncertainty in a single foil. Because a ratio of activations is taken, this uncertainty is then added to itself in quadrature giving a total measurement uncertainty of about 0.447%. It is believed that this value is arbitrarily rounded up to 0.5%.This value was taken as the total measurement uncertainty. There is also an additional uncertainty in the measurements of $\pm 0.01/\sqrt{3}$ for rounding; however, this uncertainty is negligible in relation to the other evaluated uncertainties.

In the benchmark models, the uranium foils and cadmium covers were modeled without impurities. The effect of adding impurities is treated as an uncertainty. According to the experimenter, the effect of foil composition would have been negligible because the cadmium ratio is a ratio.[b] However, to calculate the effect of impurities in the uranium foils the uranium composition from HEU-MET-FAST-051[c] was used. A scaling factor was used to determine the effect of the uranium foil impurities. It was found that the effect was negligible. The uranium foils were modeled at the nominal density of 18.75 g/cm^3 given in HEU-MET-FAST-051. Using the mass and dimensions of the various uranium parts used in that evaluation, it is found that the density of the parts had a standard deviation of ±0.04 g/cm^3; this value was taken to be the 1σ uncertainty in the uranium foil density. The calculated effect of the uncertainty in uranium density is negligible.

Since the composition of the cadmium covers was not specified, pure cadmium was assumed. The effect of possible impurities in the cadmium covers was determined by replacing the pure cadmium with a 5N

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[a] International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2012).

[b] Personal communication with J.T. Mihalczo, August 14, 2012.

[c] *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2012).

cadmium composition.[a] Using a scaling factor, it was determined that the effect of impurities in the cadmium was negligible. The cadmium was modeled with a nominal density of 8.65g/cm^3. The uncertainty in the density was taken to be ±0.01 g/cm^3.[b] The calculated effect of the uncertainty in cadmium density is negligible.

The uncertainty in the thickness for the 0.051-cm-thick cadmium covers is ± 0.001 cm. The uncertainty in the thickness of the 0.01 cm thick uranium foil is ±0.001 cm. The uncertainty in the cadmium diameter is ±0.001 cm. The uncertainty in the uranium foil diameter is ±0.01 cm. Using scaling factors for the perturbation calculations, it was determined that the uncertainty in the cadmium and uranium thicknesses and diameters all had a negligible effect.

The experimental, material, and dimension uncertainties are summarized in Table 2.3-1.

Table 2.3-1. Uncertainty Effect in Cadmium Ratio due to Uranium and Cadmium Material Properties.

Uncertainty		Effect
Measurement	±	0.5%
Uranium Composition	±	NEG
Uranium Density	±	NEG
Cadmium Composition		NEG
Cadmium Density	±	NEG
Uranium Foil Thickness	±	NEG
Uranium Foil Diameter	±	NEG
Total	±	0.5%
Rounding	±	$0.01/\sqrt{3}$

The foil positions were reported to two decimal places; however, it is believed that, in many cases. position was calculated based on dimensions of the assembly rather than measured locations. When necessary, the location of the foils was adjusted from the given value to ensure correct location in the benchmark model. For example, two cadmium ratios were measured for foils laid on top of the fuel tubes, the heights of which are given as 15.44 cm above the core midplane. No definition of the core midplane is given and it is assumed that it is the axial center of the fuel tubes (15.24 cm above the bottom of the fuel tubes). If this is true, the foils located at a height of 15.44 cm above the midplane of the core would be floating 0.2 cm above the top of the 30.48-cm-long fuel tubes. The height of these foils was adjusted so they sat on top of the fuel tubes. The positions of the foils in the upper reflector were shifted up so that the bottom most foil was sitting on the inside bottom surface of the upper reflector tank and not in the middle of the bottom plate of the reflector tank. All other foils in the upper reflector were also shifted to maintain a 1.27 cm spacing. The uncertainty in the foil position is taken to be ±0.1 cm.

The position uncertainty for the cadmium ratios in the upper beryllium reflector were evaluated separately from the cadmium ratios in the core tank region. To determine the uncertainty in the cadmium ratios in the upper reflector, the distribution of cadmium ratios in the upper reflector was calculated. The cadmium ratio distribution was obtained using the detailed benchmark model. The bare and cadmium covered foils in the upper reflector were shifted axially by 0.05 cm; all foils were shifted to maintain the

[a] "High Purity Cadmium," ESPI Metals, http://www.espimetals.com/index.php/online-catalog/346-cadmium-cd accessed June 28, 2012.

[b] PROTEUS-GCR-EXP-001.

1.27 cm spacing between foils. This created multiple models. Each model was calculated using MCNP seven times with seven different random numbers. The results of these seven runs were averaged with a variance weighting. A polynomial was fit to the cadmium ratio distribution. This equation was used to determine the uncertainty in the cadmium ratio within the upper reflector as a function of position. The trendline and the resulting uncertainty equation are given as Equation 2.3-1 where y is the cadmium ratio, σ_y is the uncertainty in the cadmium ratio, x is the axial position in the upper reflector and σ_x is the uncertainty in the axial position. The x value must be as measured from the bottom of the fuel tubes and be between the values of 31.15 and 38.105 cm. The uncertainty in the position is 0.1 cm. The calculated distribution is shown in Figure 2.3-1. This method was used rather than a direct perturbation analysis due to the high variability and noise seen in the distribution of the Monte Carlo results for a single calculation where the reported statistical uncertainty was considered negligible.

$$y = -0.01083274x^2 + 0.82570802x - 13.83639373$$
$$\sigma_y = (-2 \cdot 0.01083274x + 0.82570802) \cdot \sigma_x$$

Equation 2.3-1

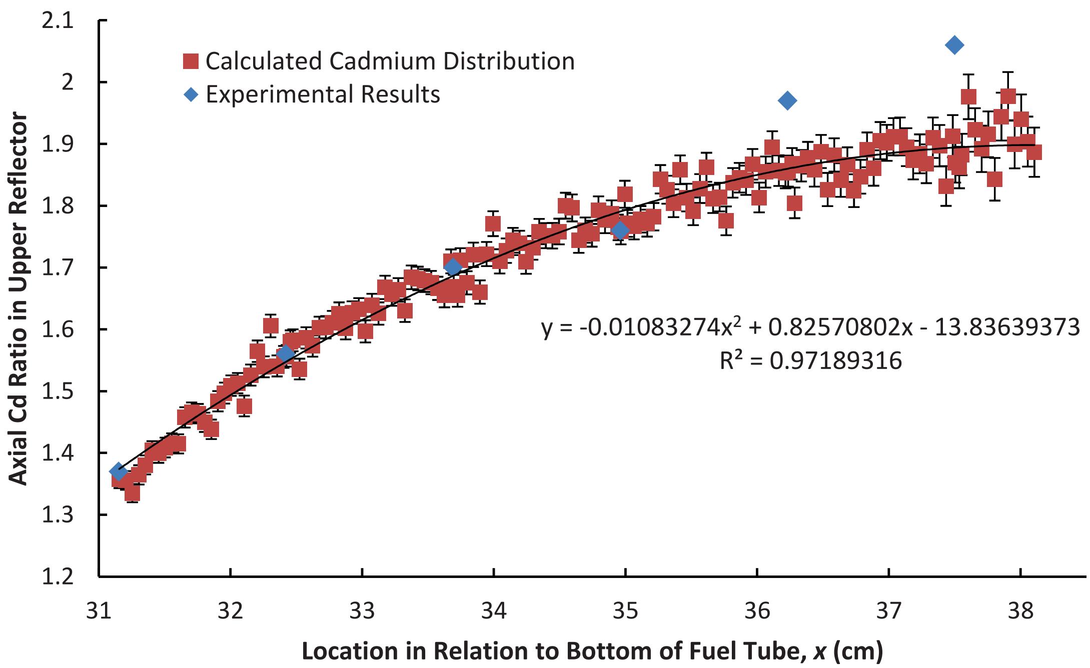

Figure 2.3-1. Calculated Distribution of Cadmium Ratio in Upper Beryllium Reflector.

The uncertainty in the axial position was calculated using Equation 2.3-1. The effect of the uncertainty in the radial position of the cadmium ratios was also evaluated and found to be negligible.

For the single cadmium ratio measurement at the midplane of the fuel, near the edge of the core, the position was evaluated by moving the foil from the inner surface of the fuel tube, to which it was tangentially taped, to the outer surface of the fuel tube one position closer to the center of the core. The effect of doing this was 0.14 ± 0.015 ΔCd Ratio. This was taken to be a bounding uncertainty with a uniform distribution, thus the 1σ uncertainty in the position for the cadmium ratio measurement at the midplane of the core was 0.081 or 6.8%.

The uncertainty in the two cadmium ratios at the top of the fuel tubes was evaluated by shifting the positions of the foils radially. When the change in cadmium ratio was scaled to the 1σ position uncertainty of 0.1 cm, it was found that the position uncertainty in the cadmium ratio was negligible for the cadmium ratio near the radial center of the core (R=3.02 cm) and approximately 1% for the cadmium ratio near the edge of the core (R=12.06 cm).

The effects of the positional uncertainties are given in Table 2.3-2 for each cadmium ratio. Both the given and adjusted foil locations are given in Table 2.3-2.

Table 2.3-2. Uncertainty in Cadmium Ratio Position.

Cadmium Ratio				Effect	
Cd Ratio		Given Location (cm)[(a)]	Modified Location (cm)[(b)]	Position	
Distribution in Top Beryllium Reflector					
1	H	15.91	15.915	0.015	1.10%
2	H	17.18	17.185	0.012	0.76%
3	H	18.45	18.455	0.010	0.56%
4	H	19.72	19.725	0.007	0.39%
5	H	20.99	20.995	NEG	
6	H	22.26	22.265	NEG	
Cadmium Ratio at Core Midplane					
7	R	11.35	11.413	0.081	6.5%
Distribution at 15.24 cm Above Core Midplane[(c)]					
8	R	3.02	3.02	NEG	
9	R	12.06	12.06	0.021	1.0%

(a) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).
(b) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material. To obtain the position in the top reflector in relation to the bottom of the fuel tube, 15.24 cm must be added to the modified location.
(c) This height was given as 15.44 cm but was modified so foils lay on top of the fuel tubes and not 0.2 cm above.

The total experimental uncertainties are given in Table 2.3-3.[a]

[a] As discussed in Section 1.3 the foils were selected such that the foils were the same "to less than 1% for activation in the same neutron flux". This would lead to an uncertainty in the ratio or normalized measurements of less than 1% in foil properties due to foil correlation. For the benchmark experimental uncertainty each property was perturbed individually thus the actual uncertainty is probably somewhere between the 1% suggested by the experimenter and the benchmark experimental uncertainty.

Table 2.3-3. Total Uncertainty in Cadmium Ratio.

Cadmium Ratio				Effect			
Cd Ratio		Given Location (cm)[(a)]	Modified Location (cm)[(b)]	Cadmium Ratio			
Distribution in Top Beryllium Reflector							
1	H	15.91	15.915	1.37	±	0.017	(1.28%)
2	H	17.18	17.185	1.56	±	0.015	(0.99%)
3	H	18.45	18.455	1.70	±	0.014	(0.84%)
4	H	19.72	19.725	1.76	±	0.013	(0.72%)
5	H	20.99	20.995	1.97	±	0.011	(0.58%)
6	H	22.26	22.265	2.06	±	0.012	(0.57%)
Cadmium Ratio at Core Midplane							
7	R	11.35	11.413	1.24	±	0.081	(6.57%)
Distribution at 15.24 cm Above Core Midplane[(c)]							
8	R	3.02	3.02	1.39		0.009	(0.65%)
9	R	12.06	12.06	1.87		0.024	(1.27%)

(a) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).
(b) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(c) This height was given as 15.44 cm but was modified so foils lay on top of the fuel tubes and not 0.2 cm above them.

2.4 Evaluation of Reactivity Effects Data

Reactivity effects measurements were not evaluated.

2.5 Evaluation of Reactivity Coefficient Data

The worths per gram of various materials placed in the core were given in Reference 4. These reactivity coefficients are based on the absolute measured worth of a sample and the sample mass. The measured absolute worth values were not evaluated. For reference, the reactivity coefficients calculated using the sample mass and measured reactivity are provided in Section 1.4.

2.6 Evaluation of Kinetics Measurements Data

Kinetics measurements were not performed

2.7 Evaluation of Reaction-Rate Distributions

The uncertainty in the uranium foils dimensions, materials, and placement used for the activation measurements are the same as for the radial measurements of the activation of ^{235}U fission foils in SCCA-SPACE-EXP-002. The effects of these uncertainties have been reevaluated using the simple benchmark model described in Section 3.7.

According to the experimenter the measurement uncertainty in the radial foil measurements in SCCA-SPACE-EXP-002 would have been 0.5 %. This is applied as the experimental uncertainty for this evaluation as well.

In the benchmark model, the uranium foils were modeled without impurities. To calculate the effect of impurities in the uranium foils the uranium composition from HEU-MET-FAST-051[a] was used. It was found that the maximum 1σ uncertainty effect for the uranium foil composition is 1.86 %. The density of the foils was 18.75 g/cm^3; the nominal density in HEU-MET-FAST-051. Using the mass and dimensions of the various uranium parts used in that evaluation it is found that the density of the parts had a standard deviation of ±0.04 g/cm^3; this value was taken to be the 1σ uncertainty in the uranium foil density. The effect of this uncertainty was ±0.83 %. The effect of foil enrichment was evaluated by comparing calculated neutron flux for 100 wt.% ^{235}U foils to 93.15 wt.% ^{235}U foils. It was found that this 6.8 wt.% change in enrichment yields a maximum change in the calculated normalized neutron flux results of only 2 %. Based on these results, it is assumed that the effect of uncertainty in the foil enrichment would be negligible.

The uncertainty in the uranium foil thickness is ±0.001 cm. The maximum 1σ effect of the uncertainty in the uranium foil thickness is ±0.90 %. The uncertainty in the uranium foil diameter is ±0.01 cm, which has a maximum 1σ effect of ±0.27 %.

Because the measurements were normalized to a foil in the top reflector, the uncertainty in all points is multiplied by $\sqrt{2}$. Since the same value is applied to all measurement points for the majority of the uncertainties, and the remaining position uncertainty is negligible for the normalization point, this simplified approach is justified. There is also an additional uncertainty in the measurements of ±0.01, bounding with a uniform distribution, due to the rounding of the measured values.

The foil dimension, material, and rounding uncertainties are summarized in Table 2.7-1.

Table 2.7-1. Summary of Experimental Uncertainty in Activation of ^{235}U Fission Foils.

Uncertainty		Effect
Measurement	±	0.5%
Uranium Composition	±	1.28%
Uranium Density	±	0.83%
Uranium Foil Enrichment	±	NEG
Uranium Foil Thickness	±	0.90%
Uranium Foil Diameter	±	0.27%
Total	±	1.86%√2[(a)]
Rounding	±	0.01/√3

(a) The √2 accounts for the added uncertainty from the normalization.

The foil position uncertainty is the same as for the cadmium ratio measurement, ±0.10 cm. The positions of the foils in the core tank were adjusted so that foils were touching the side of a fuel tube and not floating between fuel tubes or sitting on the top of the fuel tube. The positions of the foils in the upper reflector were shifted up so that the bottom most foil was sitting on the inside bottom surface of the upper reflector tank. All other foils in the upper reflector were also shifted to maintain a 1.27 cm spacing (see Section 2.3). The effect of the foil position varied widely between foils and the calculated effect of axial

[a] *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2012).

and radial foil position was preserved for each foil. Table 2.7-2 gives the axial and radial foil position uncertainties. The given and adjusted foil locations are given in Table 2.7-2.

Table 2.7-2. Calculated Effect of Uncertainty in Position of ^{235}U Fission Foils.

Foil[a]	Given Location (cm)[b]		Modified Location (cm)[c]	Axial Position	Radial Position	Total Position Uncertainty
Axial Foil Activation Distribution						
1	H	-2.54	-2.54	NEG	1.01%	1.01%
2	H	0	0.00	NEG	NEG	NEG
3	H	2.54	2.54	0.21%	0.71%	0.74%
4	H	5.08	5.08	NEG	0.47%	0.47%
5	H	7.62	7.62	0.27%	NEG	0.27%
6	H	10.16	10.16	NEG	0.91%	0.91%
7	H	12.7	12.70	0.45%	NEG	0.45%
8	H	15.44	15.24	0.42%	NEG	0.42%
9	H	15.91	15.915	5.57%	0.86%	5.63%
10	H	17.18	17.185	2.72%	1.88%	3.30%
11	H	18.45	18.455	0.17%	2.96%	2.97%
12	H	19.72	19.725	NEG	1.21%	1.21%
13	H	20.99	20.995	1.70%	0.36%	1.74%
14	H	22.26	22.265	7.21%	1.29%	7.32%
Radial Foil Activation Distribution at Core Midplane						
15[d]	R	0.635	0.635	-[d]	-[d]	-[d]
16	R	3.25	3.243	0.18%	0.64%	0.66%
17	R	5.87	5.852	0.35%	1.06%	1.11%
18	R	8.53	8.460	0.14%	1.00%	1.01%
19	R	9.93	9.907	0.45%	2.05%	2.10%
20	R	10.74	10.735	0.17%	1.45%	1.46%
21	R	11.12	11.127	0.26%	2.41%	2.42%
22	R	11.2	11.177	0.46%	2.12%	2.17%
23	R	11.35	11.413	0.53%	11.10%	11.11%
24	R	12.06	12.005	0.44%	6.45%	6.46%
25	R	12.47	12.397	1.07%	3.35%	3.52%
26	R	12.62	12.589	0.40%	NEG	0.40%
Foil Activation Distribution at 15.24 cm Above Core Midplane[e]						
27[f]	R	0	0	-[f]	-[f]	-[f]
28	R	3.02	3.02	0.89%	0.39%	0.97%
29	R	12.06	12.06	2.92%	3.57%	4.62%

(a) These foil numbers were assigned by the evaluator.
(b) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).
(c) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(d) This foil is a duplicate of foil 2.
(e) This height was given as 15.44 cm but was modified so foils lay on top of the fuel tubes and not 0.2 cm above them.
(f) This foil is a duplicate of foil 8.

The effect of material, dimensional, normalization and rounding uncertainties in Table 2.7-1 and the effect of the positional uncertainties from Table 2.7-2 are added in quadrature to obtain the total experimental uncertainty. The experimental results and the total experimental uncertainty, given as an absolute change in foil activation and a percentage, are summarized in Table 2.7-3. The given and adjusted foil locations are given in Table 2.7-3.

Table 2.7-3. Experimental Results of Relative Activation of ^{235}U Fission Foils Distribution and Total Experimental Uncertainty Effect.

Foil[a]	Given Location (cm)[b]		Modified Location (cm)[c]	Relative Foil Activation with Experimental Uncertainty[d]			
Axial Foil Activation Distribution							
1	H	-2.54	-2.54	1.02	±	0.034	(2.82%)
2	H	0	0.00	1.00	±	0.025	(1.86%)
3	H	2.54	2.54	1.00	±	0.032	(2.73%)
4	H	5.08	5.08	0.95	±	0.031	(2.67%)
5	H	7.62	7.62	0.91	±	0.030	(2.64%)
6	H	10.16	10.16	0.83	±	0.029	(2.78%)
7	H	12.7	12.70	0.88	±	0.029	(2.67%)
8	H	15.44	15.24	1.51	±	0.044	(2.66%)
9	H	15.91	15.915	1.56	±	0.099	(6.22%)
10	H	17.18	17.185	2.21	±	0.095	(4.22%)
11	H	18.45	18.455	2.53	±	0.102	(3.97%)
12	H	19.72	19.725	2.45	±	0.073	(2.90%)
13	H	20.99	20.995	2.00	±	0.065	(3.15%)
14	H	22.26	22.265	1.20	±	0.095	(7.78%)
Radial Foil Activation Distribution at Core Midplane							
15[d]	R	0.635	0.635	1.00	±	-[e]	-[e]
16	R	3.25	3.243	0.98	±	0.032	(2.71%)
17	R	5.87	5.852	0.99	±	0.033	(2.86%)
18	R	8.53	8.460	1.04	±	0.034	(2.82%)
19	R	9.93	9.907	1.06	±	0.040	(3.36%)
20	R	10.74	10.735	1.12	±	0.038	(3.01%)
21	R	11.12	11.127	1.21	±	0.047	(3.57%)
22	R	11.2	11.177	1.55	±	0.056	(3.41%)
23	R	11.35	11.413	1.45	±	0.166	(11.42%)
24	R	12.06	12.005	3.04	±	0.213	(6.98%)
25	R	12.47	12.397	3.68	±	0.163	(4.39%)
26	R	12.62	12.589	3.56	±	0.096	(2.66%)
Foil Activation Distribution at 15.24 cm Above Core Midplane[f]							
27[f]	R	0	0	1.51	±	-[g]	-[g]
28	R	3.02	3.02	1.63	±	0.049	(2.80%)
29	R	12.06	12.06	2.50	±	0.134	(5.31%)

(a) These foil numbers were assigned by the evaluator.
(b) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).
(c) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(d) The total experimental uncertainty is the sum of the effects of the composition and dimensional uncertainties (1.86%) and rounding and normalization foils from Table 2.7-1 and the effect of the positional uncertainty (Table 2.7-2). The normalization uncertainty was not applied to the normalization foil, foil 2.
(e) This foil is a duplicate of foil 2 and will be omitted from tables from this point forward.
(f) This height was given as 15.44 cm but was modified so foils lay on top of the fuel tubes and not 0.2 cm above them.
(g) This foil is a duplicate of foil 8 and will be omitted from tables from this point forward.

2.8 Evaluation of Power Distribution Data

The relative power distribution in the core is the same as the relative fission rate as was measured in the core region of Assembly 1.

2.9 Evaluation of Isotopic Measurements

Isotopic measurements were not performed.

2.10 Evaluation of Other Miscellaneous Types of Measurements

Other miscellaneous types of measurements were not performed.

3.0 BENCHMARK SPECIFICATIONS

3.1 Benchmark-Model Specifications for Critical and/or Subcritical Measurements

(The criticality portion of this evaluation has been reviewed and approved by the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and has been published under the following identifier: HEU-COMP-FAST-004[a].)

3.2 Benchmark-Model Specifications for Buckling and Extrapolation-Length Measurements

Buckling and extrapolation-length measurements were not performed.

3.3 Benchmark-Model Specifications for Spectral Characteristics Measurements

3.3.1 Description of the Benchmark-Model Simplifications

The simple and detailed benchmark models were the same as the Case 1 simple detailed benchmark models for the critical configuration described in HEU-COMP-FAST-004. The total simplification biases for the detailed and simple benchmark models were calculated and are given in Table 3.3-1.[b] Biases arising from individual simplifications were not calculated. A bias in the cadmium ratio measurements is considered negligible if it is less than the statistical uncertainty of the Monte Carlo calculation. For biases that are negligible, the bias uncertainty is preserved; as can be seen in Table 3.3-1. The given and modified locations are given in Table 3.3-1 (see Section 2.3 for discussion).

Cadmium ratio measurements were evaluated using explicit modeling of the foils and covers. Neutron flux calculations were made over the foil and a multiplier for the ^{235}U fission cross section was used.

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[a] International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2012).

[b] These biases and simplifications are described in HEU-COMP-FAST-004 and include the: room return and air effects; temperature bias; use of nominal diameters for top and bottom reflectors; removal of shims; removal of grid plates and grid plate spacer tubes; grid plate and end cap simplification effect; simplification of the fuel tube; homogenization of the fuel; removal of fuel impurities; and removal of side, top, and bottom reflector impurities.

Table 3.3-1. Simplification Bias of Cadmium Ratios.

Cadmium Ratio			Effect	
Cd Ratio	Given Location (cm)[(a)]	Modified Location (cm)[(b)]	Detailed Benchmark Model Simplification Bias (ΔCd Ratio)	Simple Benchmark Model Simplification Bias (ΔCd Ratio)
Distribution in Top Beryllium Reflector				
1	H 15.91	15.915	NEG ± 0.026	NEG ± 0.029
2	H 17.18	17.185	NEG ± 0.030	0.054 ± 0.035
3	H 18.45	18.455	NEG ± 0.035	0.040 ± 0.036
4	H 19.72	19.725	0.076 ± 0.039	0.060 ± 0.041
5	H 20.99	20.995	0.106 ± 0.047	NEG ± 0.046
6	H 22.26	22.265	0.109 ± 0.046	0.066 ± 0.063
Cadmium Ratio at Core Midplane				
7	R 11.35	11.413	NEG ± 0.019	NEG ± 0.019
Distribution at 15.24 cm Above Core Midplane[(c)]				
8	R 3.02	3.02	0.035 ± 0.032	0.099 ± 0.031
9	R 12.06	12.06	NEG ± 0.033	0.053 ± 0.047

(a) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).

(b) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.

(c) This height was given as 15.44 cm but was modified so foils lay on top of the fuel tubes and not 0.2 cm above them.

3.3.2 Dimensions

The simple and detailed benchmark models for the cadmium ratio measurements are the same as the Case 1 benchmark models for the critical configurations given in HEU-COMP-FAST-004 (see Section 3.2.1 for dimensions). Figure 3-3.1 shows the locations for the cadmium ratio measurements. These locations have been adjusted, as described in Section 2.3, from the given locations. The uranium foil and cadmium cover locations are the same for the simple and detailed benchmark models. (Figure 3-3.1 shows the detailed benchmark model.) When bare foils are being measured, the location shown in Figure 3-3.1 is the bottom center of the foils for horizontally positioned foils and the center of the foil surface which is touching the fuel tube for the vertical foil. When the cadmium cover was added the bottom center of the foil shifted up 0.051 cm, the thickness of the cadmium cover, for the horizontal foils and in 0.051 cm radially for the one vertical foil. The locations in Figure 3-3.1 are then the bottom center of the cadmium cover for the horizontally positioned foils and the center of the cadmium cover surface which is touching the fuel tube for the vertical foil.

For both the detailed and simple benchmark models, the uranium foils are 0.75-cm in diameter and 0.01-cm thick. The cadmium covers are 0.051-cm thick on either side of the uranium foil and have a diameter of 0.85 cm. The uranium foil and cadmium cover are shown in Figure 3-3.2.

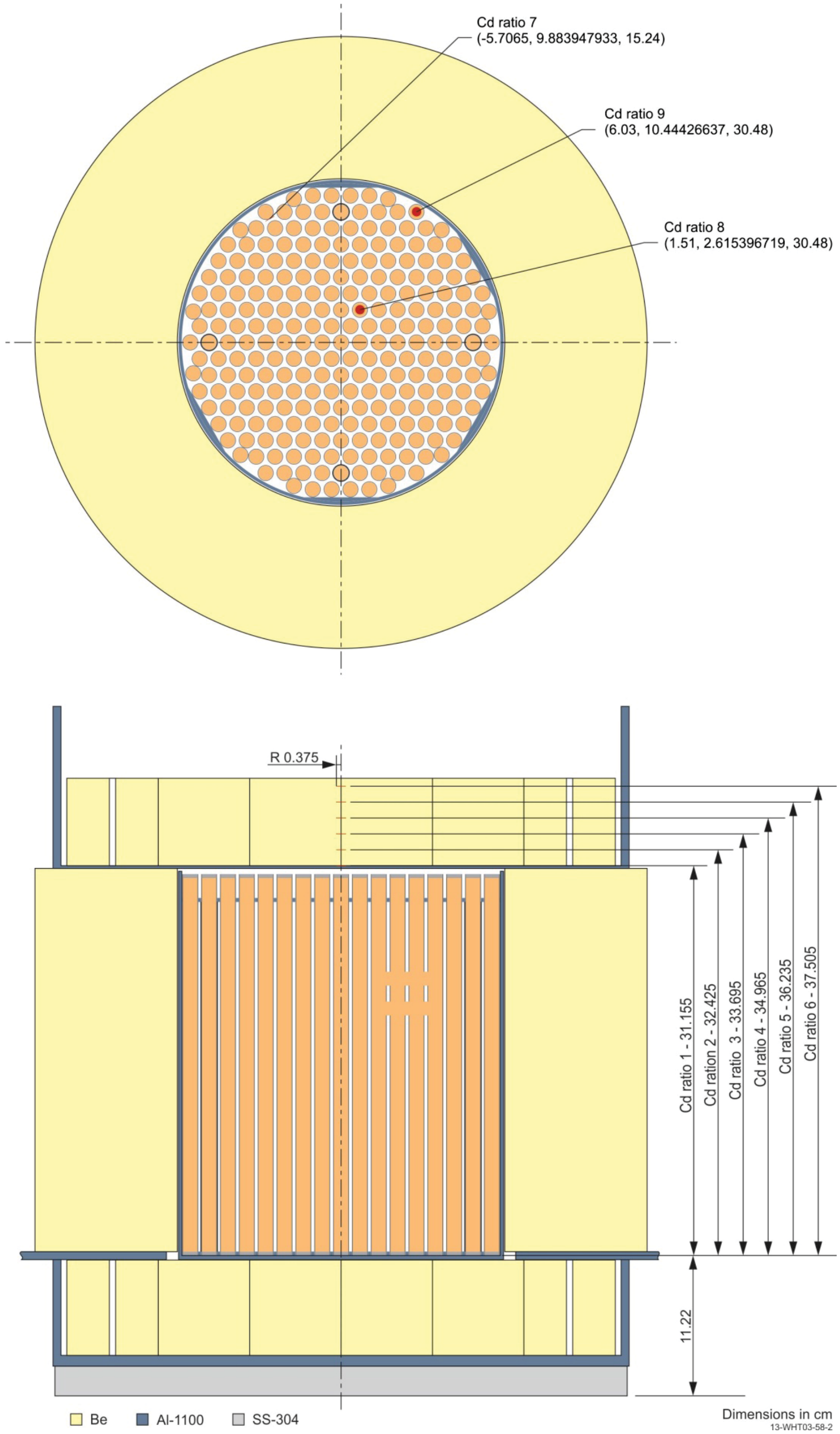

Figure 3.3-1. Uranium Foil and Cadmium Cover Locations.[a]

[a] The foils in the upper reflector are oriented horizontally. The foils at a height of 30.48 cm are horizontally positioned on the top of the fuel tubes. One vertical foil is placed at the midplane of the core (height of 15.24). With sufficient magnification, it can be seen that all foils are explicitly modeled in Figure 3.3-1.

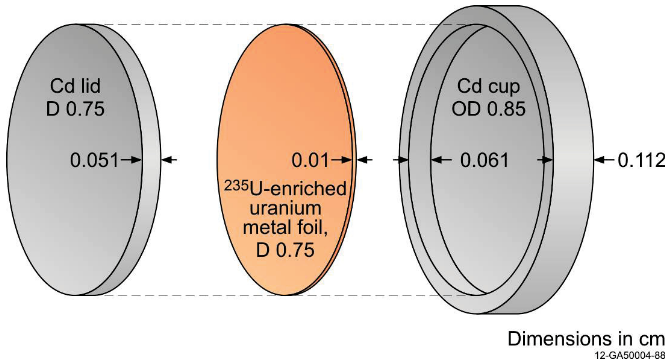

Figure 3.3-2. Uranium Foils and Cadmium Covers.

3.3.3 Material Data

The material data for the simple and detailed benchmark model for the cadmium ratios are the same as the material data for the Case 1 benchmark models for the critical configuration (see HEU-COMP-FAST-004, Section 3.3.1).

For the simple and detailed benchmark models, the uranium foils have a density of 18.75 g/cm^3 (see Section 2.3). The composition is given in Table 3.3-2.

Table 3.3-2. Uranium Metal Foil Composition.

Element	wt.%	Isotopic enrichment	Atoms/barn-cm
U Total	99.95 wt%$^{(a)}$	-	4.7983E-02
^{234}U	-	0.97 wt%	4.6775E-04
^{235}U	-	93.14 wt%	4.4722E-02
^{236}U	-	0.24 wt%	1.1475E-04
^{238}U	-	5.65 wt%	2.6786E-03

(a) The total weight percent is reduced because impurities were replaced with void.

The cadmium covers have a density of 8.65 g/cm^3. The composition is given in Table 3.3-3.

Table 3.3-3. Cadmium Cover Composition.

Element	wt.%	Atoms/barn-cm
Cd Total	99.99911 wt%$^{(a)}$	4.6340E-02

(a) The total weight percent is reduced because impurities were replaced with void.

3.3.4 Temperature Data

The temperature is the same as for the critical configuration, 72°F (22°C).[a]

3.3.5 Experimental and Benchmark-Model Spectral Characteristics Measurements

The benchmark values for the cadmium ratios are found by applying the biases in Table 3.3-1 to the experimental results. The uncertainty in the benchmark model is found by adding in quadrature the uncertainty in the experimental results, discussed in Section 2.3, and the bias uncertainty given in Table 3.3-1. The benchmark results are given in Table 3.3-4.

Table 3.3-4. Benchmark Cadmium Ratios.

Cd Ratio	Given Location (cm)[(a)]		Modified Location (cm)[(b)]	Detailed Benchmark Model Value			Simple Benchmark Model Value		
Distribution in Top Beryllium Reflector									
1	H	15.91	15.915	1.370	±	0.031	1.370	±	0.034
2	H	17.18	17.185	1.560	±	0.034	1.614	±	0.038
3	H	18.45	18.455	1.700	±	0.037	1.740	±	0.039
4	H	19.72	19.725	1.836	±	0.041	1.820	±	0.043
5	H	20.99	20.995	2.076	±	0.049	1.970	±	0.048
6	H	22.26	22.265	2.169	±	0.048	2.126	±	0.065
Cadmium Ratio at Core Midplane									
7	R	11.35	11.413	1.240	±	0.084	1.240	±	0.084
Distribution at 15.24 cm Above Core Midplane[(c)]									
8	R	3.02	3.02	1.425	±	0.033	1.489	±	0.032
9	R	12.06	12.06	1.870	±	0.040	1.923	±	0.052

(a) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).
(b) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(c) This height was given as 15.44 cm but was modified so foils lay on top of the fuel tubes and not 0.2 cm above them.

3.4 Benchmark-Model Specifications for Reactivity Effects Measurements

The reactivity effect measurements were not evaluated

3.5 Benchmark-Model Specifications for Reactivity Coefficient Measurements

Reactivity coefficient measurements were not evaluated.

3.6 Benchmark-Model Specifications for Kinetics Measurements

Kinetics measurements were not performed.

[a] Personal email communication with J. T. Mihalczo, May 23, 2011.

3.7 Benchmark-Model Specifications for Reaction-Rate Distribution Measurements

3.7.1 Description of the Benchmark-Model Simplifications

The simple and detailed benchmark models are the same as the Case 1 simple and detailed benchmark models for the critical configuration described in HEU-COMP-FAST-004. The total simplification biases for the detailed and simple benchmark models were calculated and are given in Table 3.3-1.[a] Biases arising from individual simplifications were not calculated. A bias in the foil activation measurements is considered negligible if it is less than the statistical uncertainty of the Monte Carlo calculation. For biases that are negligible, the bias uncertainty is preserved; as can be seen in Table 3.7-1.

Foil activation measurements were evaluated using explicit modeling of the foils and calculated neutron fluxes over the foil volume and a multiplier for the ^{235}U fission cross section.

[a] These biases and simplifications are described in HEU-COMP-FAST-004 and include: room return and air effects; temperature bias; use of nominal diameters for top and bottom reflectors; removal of shims; removal of grid plates and grid plate spacer tubes; grid plate and end cap simplification effect; simplification of the fuel tube; homogenization of the fuel; removal of fuel impurities; and removal of side, top, and bottom reflector impurities.

Table 3.7-1. Simplification Bias of Foil Activation.

Foil[a]	Given Location (cm)[b]		Modified Location (cm)[c]	Detailed Benchmark Model Simplification Bias (ΔCd Ratio)			Simple Benchmark Model Simplification Bias (ΔCd Ratio)		
Axial Foil Activation Distribution									
1	H	-2.54	-2.54	0.012	±	0.003	NEG	±	0.003
2	H	0	0.00	NEG	±	0.003	NEG	±	0.003
3	H	2.54	2.54	0.005	±	0.003	NEG	±	0.003
4	H	5.08	5.08	NEG	±	0.003	NEG	±	0.003
5	H	7.62	7.62	-0.003	±	0.003	NEG	±	0.003
6	H	10.16	10.16	0.004	±	0.003	NEG	±	0.003
7	H	12.7	12.70	0.010	±	0.003	NEG	±	0.003
8	H	15.44	15.24	-0.041	±	0.005	0.070	±	0.005
9	H	15.91	15.915	-0.023	±	0.005	0.056	±	0.005
10	H	17.18	17.185	0.034	±	0.007	0.081	±	0.007
11	H	18.45	18.455	NEG	±	0.008	0.018	±	0.008
12	H	19.72	19.725	-0.076	±	0.008	NEG	±	0.008
13	H	20.99	20.995	-0.064	±	0.006	NEG	±	0.007
14	H	22.26	22.265	-0.079	±	0.004	-0.031	±	0.004
Radial Foil Activation Distribution at Core Midplane									
16	R	3.25	3.243	0.034	±	0.003	0.008	±	0.003
17	R	5.87	5.852	0.007	±	0.003	-0.004	±	0.003
18	R	8.53	8.460	NEG	±	0.003	NEG	±	0.003
19	R	9.93	9.907	0.004	±	0.003	NEG	±	0.003
20	R	10.74	10.735	NEG	±	0.004	NEG	±	0.004
21	R	11.12	11.127	-0.014	±	0.004	-0.006	±	0.004
22	R	11.2	11.177	NEG	±	0.005	0.015	±	0.005
23	R	11.35	11.413	NEG	±	0.005	-0.014	±	0.005
24	R	12.06	12.005	-0.017	±	0.011	0.045	±	0.011
25	R	12.47	12.397	-0.083	±	0.013	-0.059	±	0.013
26	R	12.62	12.589	-0.018	±	0.013	0.020	±	0.013
Foil Activation Distribution at 15.24 cm Above Core Midplane[d]									
28	R	3.02	3.02	0.035	±	0.005	0.136	±	0.005
29	R	12.06	12.06	-0.064	±	0.009	0.175	±	0.010

(a) These foil numbers were assigned by the evaluator. Foil number 27 and 15 are skipped because these foils were duplicates of Foil 2 and 8, respectively.
(b) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).
(c) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(d) This height was given as 15.44 cm but was modified so foils lay on top of the fuel tubes and not 0.2 cm above them.

3.7.2 Dimensions

The simple and detailed benchmark models for the foil activation measurements are the same as the Case 1 benchmark models for the critical configurations given in HEU-COMP-FAST-004 (see Section 3.2.1 for dimensions). Figure 3-7.1 shows the locations for the foils. These locations have been adjusted, as described in Section 2.3 and 2.7, from the given locations. The uranium foil locations are the same for the simple and detailed benchmark models. (Figure 3-7.1 shows the detailed benchmark model.) The location shown in Figure 3-7.1 is the bottom center of the foils for horizontal foils and the center of the foil touching the fuel tube for vertical foils.

For both the detailed and simple benchmark models, the uranium foils are 0.75-cm in diameter and 0.01-cm thick.

3.7.3 Material Data

The material data for the simple and detailed benchmark model for the foil activation measurements are the same as the material data for the Case 1 benchmark models for the critical configuration (see HEU-COMP-FAST-004, Section 3.3.1).

For the simple and detailed benchmark models, the uranium foils have a density of 18.75 g/cm^3 (see Section 2.3). The composition is given in Table 3.7-2.

Table 3.7-2. Uranium Metal Foil Composition.

Element	wt.%	Isotopic enrichment	Atoms/barn-cm
U Total	99.95 wt%[(a)]	-	4.7983E-02
^{234}U	-	0.97 wt%	4.6775E-04
^{235}U	-	93.14 wt%	4.4722E-02
^{236}U	-	0.24 wt%	1.1475E-04
^{238}U	-	5.65 wt%	2.6786E-03

(a) The total weight percent is reduced because impurities were replaced with void.

3.7.4 Temperature Data

The temperature is the same as for the critical configuration, 72°F (22°C).[a]

3.7.5 Experimental and Benchmark-Model Spectral Characteristics Measurements

The benchmark values for the foil activations are found by applying the biases in Table 3.7-1 to the experimental results. The uncertainty in the benchmark model is found by adding, in quadrature, the uncertainty in the experimental results, discussed in Section 2.7, and the bias uncertainty given in Table 3.7-1. The benchmark results are given in Table 3.7-3.

[a] Personal email communication with J. T. Mihalczo, May 23, 2011.

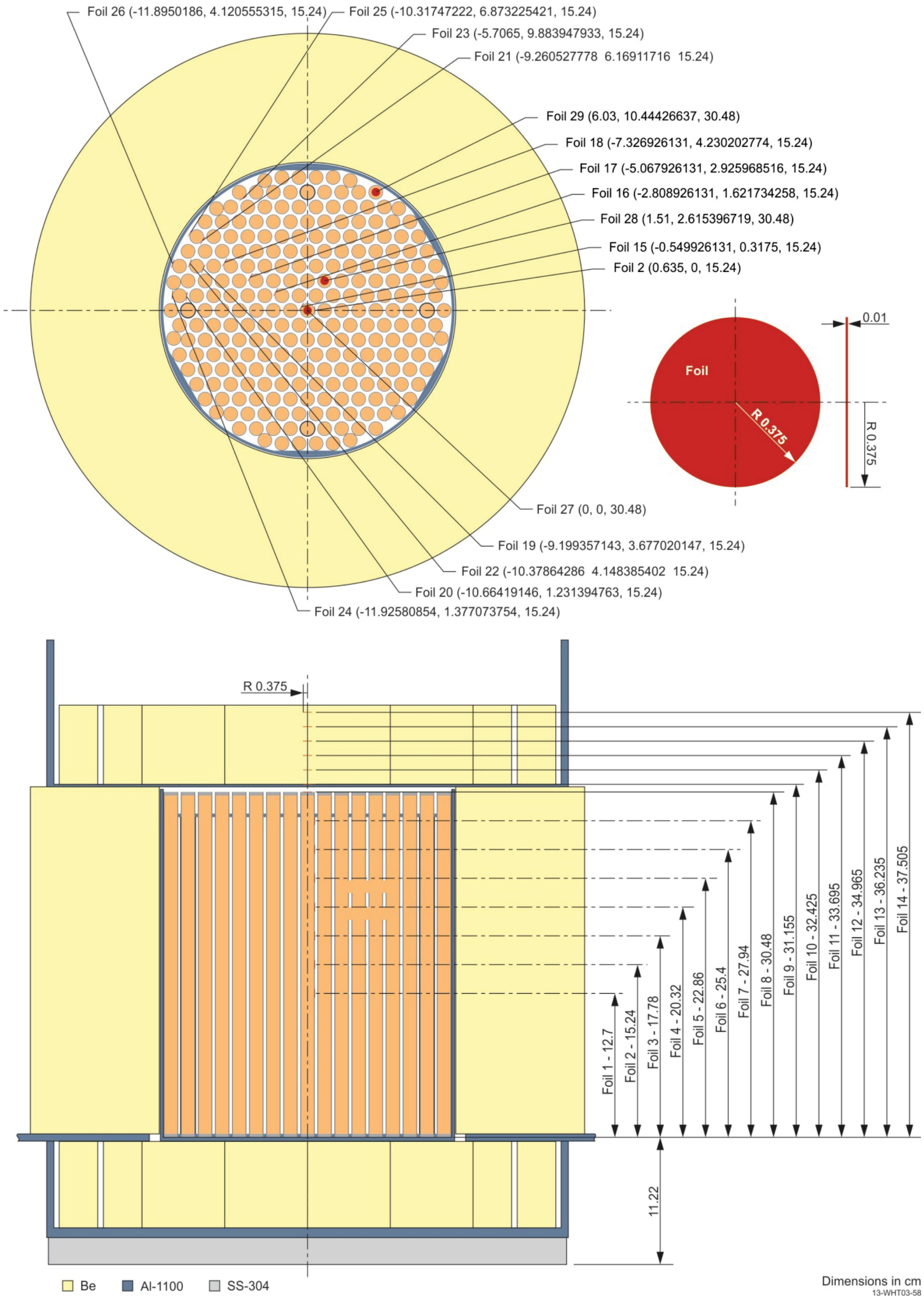

Figure 3.7-1. Uranium Foil Cover Locations. [a]

[a] The foils in the upper reflector are oriented horizontally. The foils at a height of 30.48 cm are horizontally position foils on the top of the fuel tubes. The foils at a height of 15.24) are vertically positions tangent to the side of the fuel tubes. The axial fuel tubes on the center fuel tube are oriented vertically. With sufficient magnification, it can be seen that all foils are explicitly modeled in Figure 3.7-1.

Table 3.7-3. Benchmark Relative Foil Activation.

Foil[a]		Given Location (cm)[b]	Modified Location (cm)[c]	Detailed Benchmark Model Value			Simple Benchmark Model Value		
Axial Foil Activation Distribution									
1	H	-2.54	-2.54	1.032	±	0.029	1.020	±	0.029
2	H	0	0.00	1.000	±	0.019	1.000	±	0.019
3	H	2.54	2.54	1.005	±	0.028	1.000	±	0.028
4	H	5.08	5.08	0.950	±	0.026	0.950	±	0.026
5	H	7.62	7.62	0.907	±	0.024	0.910	±	0.024
6	H	10.16	10.16	0.834	±	0.023	0.830	±	0.023
7	H	12.7	12.70	0.890	±	0.024	0.880	±	0.024
8	H	15.44	15.24	1.469	±	0.041	1.580	±	0.041
9	H	15.91	15.915	1.537	±	0.097	1.616	±	0.097
10	H	17.18	17.185	2.244	±	0.094	2.291	±	0.094
11	H	18.45	18.455	2.530	±	0.101	2.548	±	0.101
12	H	19.72	19.725	2.374	±	0.071	2.450	±	0.071
13	H	20.99	20.995	1.936	±	0.063	2.000	±	0.063
14	H	22.26	22.265	1.121	±	0.093	1.169	±	0.093
Radial Foil Activation Distribution at Core Midplane									
16	R	3.25	3.243	1.014	±	0.027	0.988	±	0.027
17	R	5.87	5.852	0.997	±	0.028	0.986	±	0.028
18	R	8.53	8.460	1.040	±	0.029	1.040	±	0.029
19	R	9.93	9.907	1.064	±	0.036	1.060	±	0.036
20	R	10.74	10.735	1.120	±	0.034	1.120	±	0.034
21	R	11.12	11.127	1.196	±	0.043	1.204	±	0.043
22	R	11.2	11.177	1.550	±	0.053	1.565	±	0.053
23	R	11.35	11.413	1.450	±	0.166	1.436	±	0.166
24	R	12.06	12.005	3.023	±	0.212	3.085	±	0.212
25	R	12.47	12.397	3.597	±	0.162	3.621	±	0.162
26	R	12.62	12.589	3.542	±	0.096	3.580	±	0.096
Foil Activation Distribution at 15.24 cm Above Core Midplane[d]									
28	R	3.02	3.02	1.665	±	0.046	1.766	±	0.046
29	R	12.06	12.06	2.436	±	0.133	2.675	±	0.133

(a) These foil numbers were assigned by the evaluator. Foil number 27 and 15 are skipped because these foils were duplicates of Foil 2 and 8, respectively.
(b) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).
(c) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(d) This height was given as 15.44 cm but was modified so foils lay on top of fuel tube and not 0.2 cm above them.

3.8 Benchmark-Model Specifications for Power Distribution Measurements

The relative power distribution is related to the relative fission rate that was measured in the core region of Assembly 1.

3.9 Benchmark-Model Specifications for Isotopic Measurements

Isotopic measurements were not performed.

3.10 Benchmark-Model Specifications for Other Miscellaneous Types of Measurements

Other miscellaneous types of measurements were not performed.

4.0 RESULTS OF SAMPLE CALCULATIONS

4.1 Results of Calculations of the Critical or Subcritical Configurations

(The criticality portion of this evaluation has been reviewed and approved by the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and has been published under the following identifier: HEU-COMP-FAST-004[a].)

4.2 Results of Buckling and Extrapolation Length Calculations

Buckling and extrapolation-length measurements were not performed.

4.3 Results of Spectral-Characteristics Calculations

The cadmium ratios were calculated using a model as described in Section 3.3 with MCNP5-1.60 and ENDF/B-VII.0 neutron cross section libraries. Foils and covers were explicitly modeled and tallies were taken in the foil cells. Tally multipliers were also used. A total of 2,000 cycles were run, skipping the first 150 cycles, with 1,000,000 histories per cycle. Seven different random numbers were used for each calculation. The variance-weighted average of the seven tally results was taken for the calculated distributions. The tally for the bare and covered foils was divided to find the cadmium ratio. Sample calculation results are given in Table 4.3-1 and 4.3.2. The calculated results agree well with the benchmark results and are all within 3σ. The cadmium ratios in the upper reflector are plotted in Figures 4.3-1 and 4.3-2.

[a] International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2012).

Table 4.3-1. Sample Results for Cadmium Ratio Detailed Benchmark Model.

Cadmium Ratio												
Cd Ratio	Given Location (cm)[a]		Modified Location (cm)[b]	Detailed Benchmark Model Value			Detailed Calculated Value			(C-E)/E [c]	C/E Ratio[c]
Distribution in Top Beryllium Reflector											
1	H	15.91	15.915	1.370	±	0.031	1.358	±	0.015	-0.89%	0.99
2	H	17.18	17.185	1.560	±	0.034	1.557	±	0.018	-0.18%	1.00
3	H	18.45	18.455	1.700	±	0.037	1.669	±	0.019	-1.83%	0.98
4	H	19.72	19.725	1.836	±	0.041	1.758	±	0.021	-4.24%	0.96
5	H	20.99	20.995	2.076	±	0.049	1.856	±	0.025	-10.60%	0.89
6	H	22.26	22.265	2.169	±	0.048	1.870	±	0.032	-13.80%	0.86
Cadmium Ratio at Core Midplane											
7	R	11.35	11.413	1.240	±	0.084	1.185	±	0.010	-4.42%	0.96
Distribution at 15.24 cm Above Core Midplane[d]											
8	R	3.02	3.02	1.425	±	0.033	1.363	±	0.014	-4.34%	0.96
9	R	12.06	12.06	1.870	±	0.040	2.063	±	0.024	10.33%	1.10

(a) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).
(b) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(c) "E" is the expected or benchmark value. "C" is the calculated value.
(d) This height was given as 15.44 cm but was modified so foils lay on top of the fuel tubes and not 0.2 cm above them.

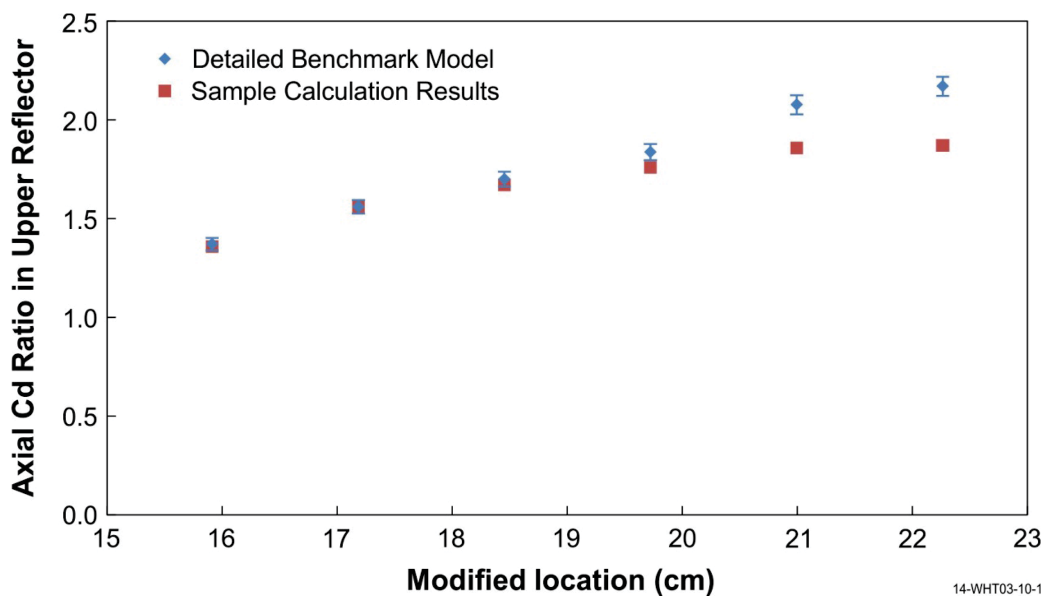

Figure 4.3-1. Benchmark and Calculated Results for Cadmium Ratio in Upper Reflector for Detailed Benchmark Model.

Table 4.3-2. Sample Results for Cadmium Ratio Simple Benchmark Model.

Cadmium Ratio			Effect							
Cd Ratio	Given Location (cm)(a)		Modified Location (cm)(b)	Simple Benchmark Model Value			Simple Calculated Value			(C-E)/E (c)	C/E Ratio(c)
Distribution in Top Beryllium Reflector											
1	H	15.91	15.915	1.370	±	0.034	1.368	±	0.025	-0.11%	1.00
2	H	17.18	17.185	1.614	±	0.038	1.611	±	0.030	-0.17%	1.00
3	H	18.45	18.455	1.740	±	0.039	1.709	±	0.031	-1.79%	0.98
4	H	19.72	19.725	1.820	±	0.043	1.818	±	0.035	-0.08%	1.00
5	H	20.99	20.995	1.970	±	0.048	1.824	±	0.039	-7.40%	0.93
6	H	22.26	22.265	2.126	±	0.065	1.936	±	0.055	-8.94%	0.91
Cadmium Ratio at Core Midplane											
7	R	11.35	11.413	1.240	±	0.084	1.179	±	0.016	-4.92%	0.95
Distribution at 15.24 cm Above Core Midplane(d)											
8	R	3.02	3.02	1.489	±	0.032	1.462	±	0.028	-1.83%	0.98
9	R	12.06	12.06	1.923	±	0.052	2.116	±	0.040	10.05%	1.10

(a) Locations were given as axial distance from the center of the fuel tube, or height (H), radial distance from the core center, radius (R).
(b) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(c) "E" is the expected or benchmark value. "C" is the calculated value.
(d) This height was given as 15.44 cm but was modified so foils lay on top of the fuel tubes and not 0.2 cm above them.

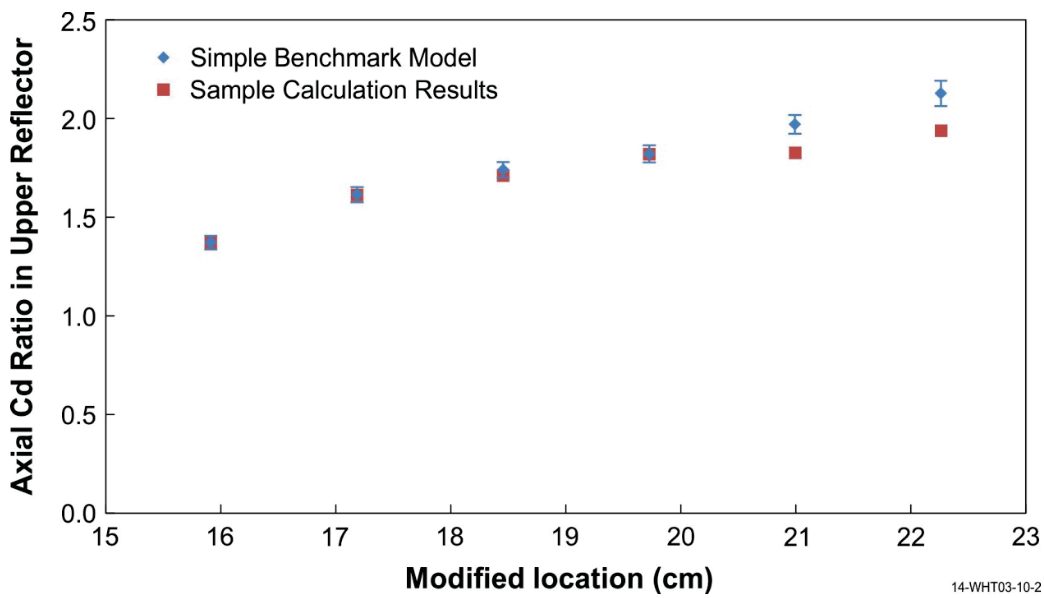

Figure 4.3-2. Benchmark and Calculated Results for Cadmium Ratio in Upper Reflector for Simple Benchmark Model

4.4 Results of Reactivity-Effects Calculations

The reactivity effect measurements were not evaluated

4.5 Results of Reactivity Coefficient Calculations

Reactivity coefficient measurements were not evaluated.

4.6 Results of Kinetics Parameter Calculations

Kinetics measurements were not performed.

4.7 Results of Reaction-Rate Distribution Calculations

The relative foil activations were calculated using a model as described in Section 3.7 with MCNP5-1.60 and ENDF/B-VII.0 neutron cross section libraries. Foils were explicitly modeled and tallies were taken in the foil cells. Tally multipliers were also used. A total of 2,000 cycles were run, skipping the first 150 cycles, with 1,000,000 histories per cycle. Seven different random numbers were used for each calculation. The variance weighted average of the seven tally results was taken for the calculated distributions. The tallies for the foils were normalized. Sample calculation results are given in Table 4.7-1 and 4.7.2 and shown in Figures 4.7-1 through 4.7-4. All sample calculation results are within 3σ of the benchmark value except Foil 26 at the edge of the core midplane, which is 5.6σ high. It is interesting to note that the calculated results for the foil that does not match the curve in Figure 1.7-2 (labeled as Foil 8 in Figure 1.7-2) are nearly identical for the simple and detailed benchmark models (see Figure 4.7-2 and 4.7-4). This leads one to believe that the data point is not an outlier, but that foil activity depends on more than just radial position but also factors such as foil position in relation to surrounding fuel tubes (see Figure 1.4-2, foil location 7 vs. 8 vs. 9).

Table 4.7-1. Sample Results for Detailed Benchmark Model Foil Activation Measurements.

Foil[a]		Given Location (cm)[b]	Modified Location (cm)[c]	Detailed Benchmark Model Value			Sample Calculation Results			(C-E)/E [d]	C/E Ratio[d]
Axial Foil Activation Distribution											
1	H	-2.54	-2.54	1.032	±	0.029	1.008	±	0.003	-2.30%	0.98
2	H	0	0.00	1.000	±	0.019	1.000	±	0.002	0.00%	1.00
3	H	2.54	2.54	1.005	±	0.028	0.986	±	0.002	-1.90%	0.98
4	H	5.08	5.08	0.950	±	0.026	0.954	±	0.002	0.43%	1.00
5	H	7.62	7.62	0.907	±	0.024	0.912	±	0.002	0.52%	1.01
6	H	10.16	10.16	0.834	±	0.023	0.874	±	0.002	4.85%	1.05
7	H	12.7	12.70	0.890	±	0.024	0.880	±	0.002	-1.15%	0.99
8	H	15.44	15.24	1.469	±	0.041	1.538	±	0.004	4.75%	1.05
9	H	15.91	15.915	1.537	±	0.097	1.548	±	0.004	0.70%	1.01
10	H	17.18	17.185	2.244	±	0.094	2.249	±	0.006	0.22%	1.00
11	H	18.45	18.455	2.530	±	0.101	2.572	±	0.006	1.67%	1.02
12	H	19.72	19.725	2.374	±	0.071	2.434	±	0.006	2.51%	1.03
13	H	20.99	20.995	1.936	±	0.063	1.941	±	0.005	0.22%	1.00
14	H	22.26	22.265	1.121	±	0.093	1.170	±	0.003	4.35%	1.04
Radial Foil Activation Distribution at Core Midplane											
16	R	3.25	3.243	1.014	±	0.027	1.010	±	0.003	-0.42%	1.00
17	R	5.87	5.852	0.997	±	0.028	0.990	±	0.002	-0.75%	0.99
18	R	8.53	8.460	1.040	±	0.029	1.001	±	0.002	-3.75%	0.96
19	R	9.93	9.907	1.064	±	0.036	1.046	±	0.003	-1.72%	0.98
20	R	10.74	10.735	1.120	±	0.034	1.099	±	0.003	-1.90%	0.98
21	R	11.12	11.127	1.196	±	0.043	1.142	±	0.003	-4.50%	0.95
22	R	11.2	11.177	1.550	±	0.053	1.547	±	0.004	-0.21%	1.00
23	R	11.35	11.413	1.450	±	0.166	1.438	±	0.004	-0.85%	0.99
24	R	12.06	12.005	3.023	±	0.212	3.392	±	0.008	12.20%	1.12
25	R	12.47	12.397	3.597	±	0.162	3.977	±	0.010	10.57%	1.11
26	R	12.62	12.589	3.542	±	0.096	4.075	±	0.010	15.05%	1.15
Foil Activation Distribution at 15.24 cm Above Core Midplane[e]											
28	R	3.02	3.02	1.665	±	0.046	1.609	±	0.004	-3.41%	0.97
29	R	12.06	12.06	2.436	±	0.133	2.760	±	0.007	13.32%	1.13

(a) These foil numbers were assigned by the evaluator. Foil number 27 and 15 are skipped because these foils were duplicates of foil 2 and 8, respectively.
(b) Locations were given as axial distance from the center of the fuel tube, height (H), or radial distance from the core center, radius (R).
(c) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(d) "E" is the expected or benchmark value. "C" is the calculated value.
(e) This height was given as 15.44 cm but was modified so foils lay on top of fuel tube and not 0.2 cm above them.

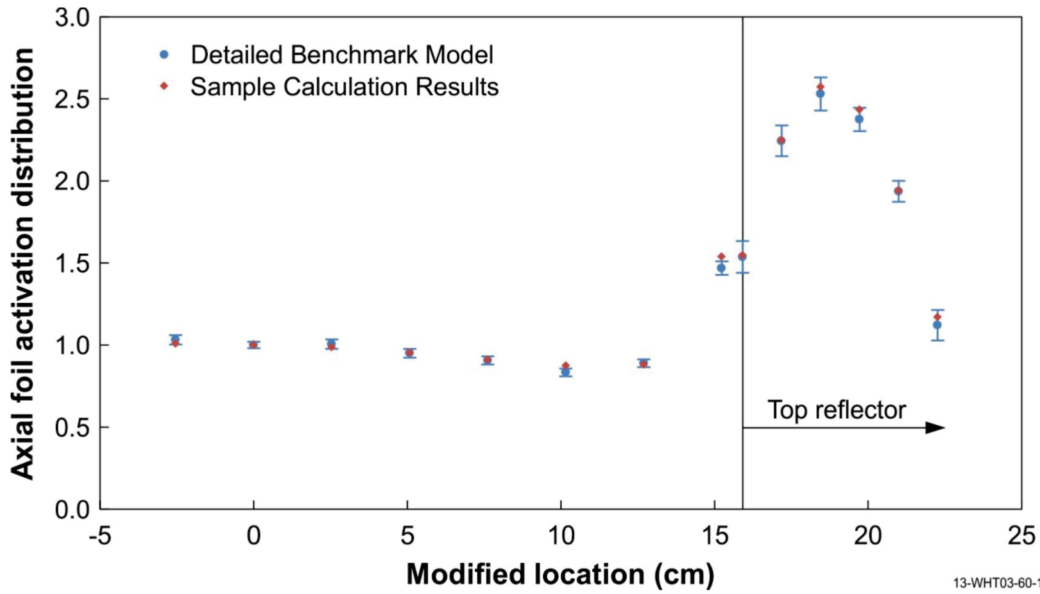

Figure 4.7-1. Benchmark and Calculated Results for Axial Foil Distribution for Detailed Benchmark Model.

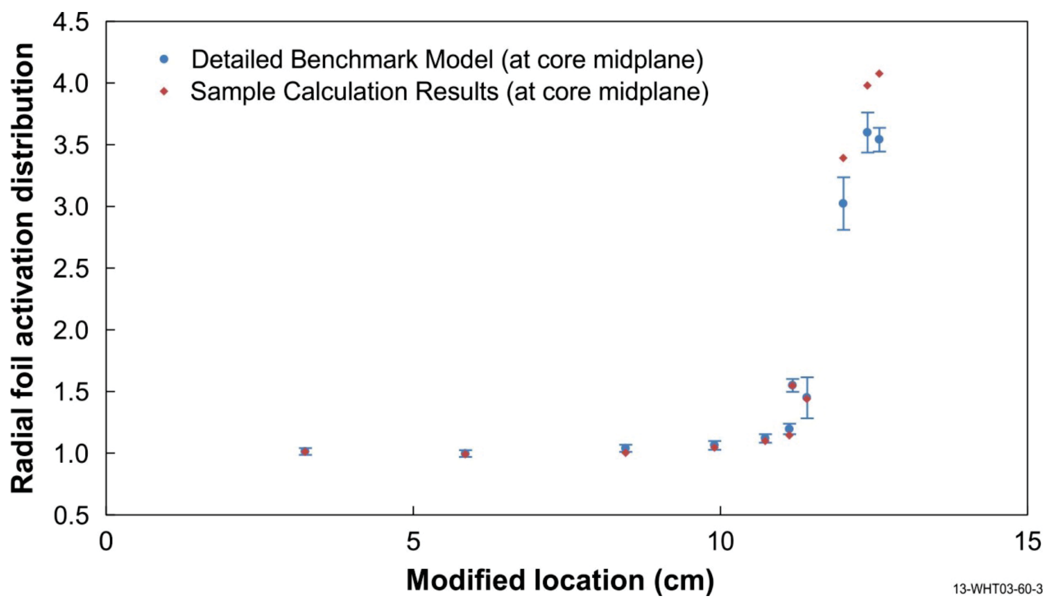

Figure 4.7-2. Benchmark and Calculated Results for Radial Foil Distribution for Detailed Model.

Table 4.7-2. Sample Results for Simple Benchmark Model Foil Activation Measurements.

Foil[(a)]		Given Location (cm)[(b)]	Modified Location (cm)[(c)]	Simple Benchmark Model Value			Sample Calculation Results			(C-E)/E [(d)]	C/E Ratio[(d)]
Axial Foil Activation Distribution											
1	H	-2.54	-2.54	1.020	±	0.029	0.995	±	0.002	-2.47%	0.98
2	H	0	0.00	1.000	±	0.019	1.000	±	0.002	0.00%	1.00
3	H	2.54	2.54	1.000	±	0.028	0.980	±	0.002	-2.05%	0.98
4	H	5.08	5.08	0.950	±	0.026	0.953	±	0.002	0.35%	1.00
5	H	7.62	7.62	0.910	±	0.024	0.916	±	0.002	0.63%	1.01
6	H	10.16	10.16	0.830	±	0.023	0.873	±	0.002	5.14%	1.05
7	H	12.7	12.70	0.880	±	0.024	0.872	±	0.002	-0.88%	0.99
8	H	15.44	15.24	1.580	±	0.041	1.650	±	0.004	4.41%	1.04
9	H	15.91	15.915	1.616	±	0.097	1.626	±	0.004	0.66%	1.01
10	H	17.18	17.185	2.291	±	0.094	2.296	±	0.006	0.22%	1.00
11	H	18.45	18.455	2.548	±	0.101	2.594	±	0.006	1.81%	1.02
12	H	19.72	19.725	2.450	±	0.071	2.506	±	0.006	2.29%	1.02
13	H	20.99	20.995	2.000	±	0.063	2.006	±	0.005	0.28%	1.00
14	H	22.26	22.265	1.169	±	0.093	1.218	±	0.003	4.17%	1.04
Radial Foil Activation Distribution at Core Midplane											
16	R	3.25	3.243	0.988	±	0.027	0.983	±	0.002	-0.43%	1.00
17	R	5.87	5.852	0.986	±	0.028	0.978	±	0.002	-0.76%	0.99
18	R	8.53	8.460	1.040	±	0.029	1.001	±	0.002	-3.76%	0.96
19	R	9.93	9.907	1.060	±	0.036	1.040	±	0.003	-1.91%	0.98
20	R	10.74	10.735	1.120	±	0.034	1.100	±	0.003	-1.77%	0.98
21	R	11.12	11.127	1.204	±	0.043	1.150	±	0.003	-4.48%	0.96
22	R	11.2	11.177	1.565	±	0.053	1.559	±	0.004	-0.36%	1.00
23	R	11.35	11.413	1.436	±	0.166	1.424	±	0.004	-0.83%	0.99
24	R	12.06	12.005	3.085	±	0.212	3.454	±	0.009	11.96%	1.12
25	R	12.47	12.397	3.621	±	0.162	4.001	±	0.010	10.50%	1.11
26	R	12.62	12.589	3.580	±	0.096	4.113	±	0.010	14.89%	1.15
Foil Activation Distribution at 15.24 cm Above Core Midplane[(e)]											
28	R	3.02	3.02	1.766	±	0.046	1.709	±	0.004	-3.22%	0.97
29	R	12.06	12.06	2.675	±	0.133	3.000	±	0.007	12.13%	1.12

(a) These foil numbers were assigned by the evaluator. Foil number 27 and 15 are skipped because these foils were duplicates of foil 2 and 8, respectively.
(b) Locations were given as axial distance from the center of the fuel tube, height (H), radial distance from the core center, or radius (R).
(c) Many of the foil locations were modified so that the foil was in a feasible location, i.e. not floating in air or in the middle of a solid mass of material.
(d) "E" is the expected or benchmark value. "C" is the calculated value.
(e) This height was given as 15.44 cm but was modified so foils lay on top of fuel tube and not 0.2 cm above them.

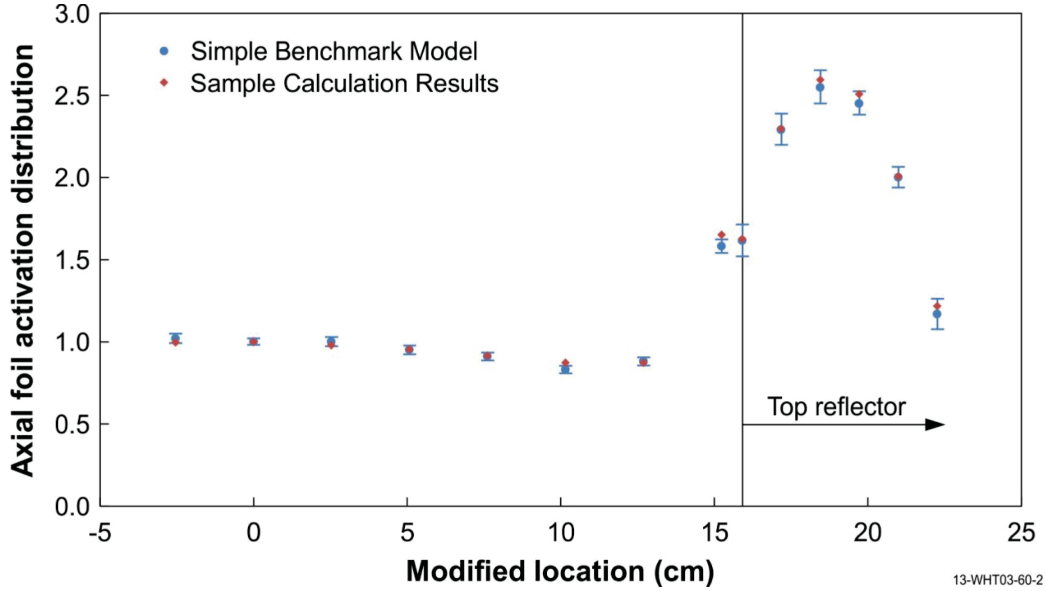

Figure 4.7-3. Benchmark and Calculated Results for Axial Foil Distribution for Simple Benchmark Model.

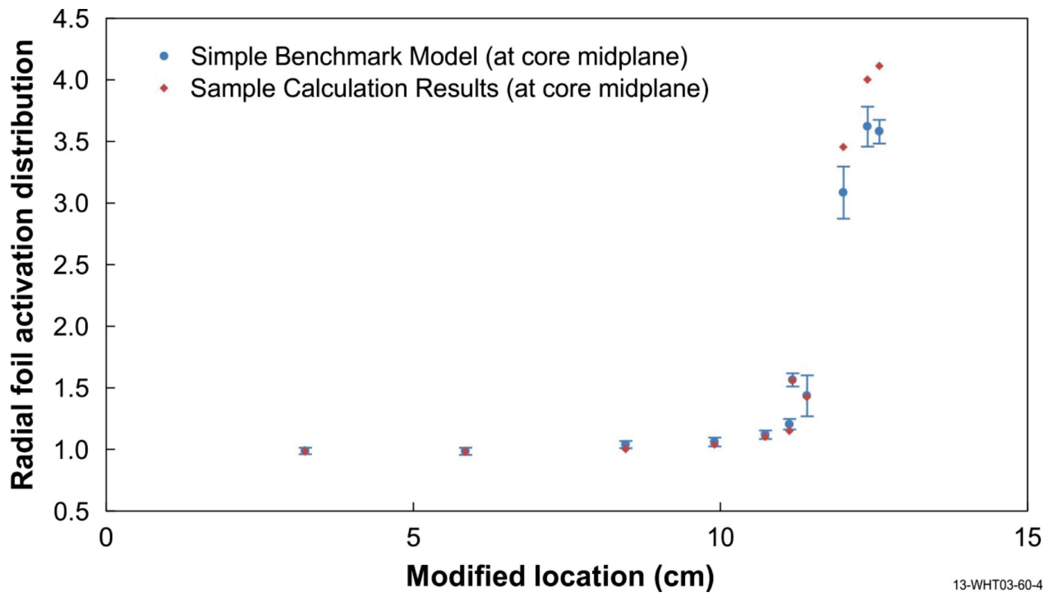

Figure 4.7-4. Benchmark and Calculated Results for Radial Foil Distribution for Simple Benchmark Model

4.8 Results of Power Distribution Calculations

The relative power distribution is the same as the relative fission rate as was measured in the core region of Assembly 1.

4.9 Results of Isotopic Calculations

Isotopic measurements were not performed.

4.10 Results of Calculations for Other Miscellaneous Types of Measurements

Other miscellaneous types of measurements were not performed.

5.0 REFERENCES

1. J.T. Mihalczo, “A Small Graphite-Reflected UO_2 Critical Assembly,” ORNL-TM-450, Oak Ridge National Laboratory (1962).

2. J.T. Mihalczo, “A Small Graphite-Reflected UO_2 Assembly,” *Proc. 5th Int. Conf. Nucl. Crit. Safety*, Albuquerque, NM, September 17-21 (1995).

3. J.T. Mihalczo, “A Small Graphite-Reflected UO2 Critical Assembly, Part II,” ORNL-TM-561, Oak Ridge National Laboratory (1963).

4. J.T. Mihalczo, “A Small Beryllium-Reflected UO2 Assembly,” ORNL-TM-655, Oak Ridge National Laboratory (1963).

5. J.T. Mihalczo, “A Small, Beryllium-Reflected UO_2 Critical Assembly,” *Trans. Am. Nucl. Soc.,* **72**, 196-198 (1995).

APPENDIX A: COMPUTER CODES, CROSS SECTIONS, AND TYPICAL INPUT LISTINGS

A.1 Critical/Subcritical Configurations

(The criticality portion of this evaluation has been reviewed and approved by the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and has been published under the following identifier: HEU-COMP-FAST-004[a].)

A.2 Buckling and Extrapolation Length Configurations

Buckling and extrapolation-length measurements were not performed.

A.3 Spectral-Characteristics Configurations

Models were creating using Monte Carlo n-Particle (MCNP), Version 5-1.60, and ENDF/B-VII.0 neutron cross section libraries. Isotopic abundances for all elements except uranium (see Section 3.3.3 for uranium isotopic abundances) were taken from "Nuclides and Isotopes: Chart of the Nuclides," Sixteenth Edition, KAPL, 2002.

A.3.1 Name(s) of Code System(s) Used

1. Monte Carlo n-Particle, Version 5.1.60 (MCNP5).

A.3.2 Bibliographic References for the Codes Used

1. F. B. Brown, R. F. Barrett, T. E. Booth, J. S. Bull, L. J. Cox, R. A. Forster, T. J. Goorley, R. D. Mosteller, S. E. Post, R. E. Prael, E. C. Selcow, A. Sood, and J. Sweezy, "MCNP Version 5," LA-UR-02-3935, Los Alamos National Laboratory (2002).

A.3.3 Origin of Cross-section Data

The evaluated neutron data file library ENDF/B-VII.0[b] was utilized in the benchmark-model analysis.

A.3.4 Spectral Calculations and Data Reduction Methods Used

Not applicable.

A.3.5 Number of Energy Groups or If Continuous-energy Cross Sections are Used in the Different Phases of Calculation

1. Continuous-energy cross sections.

2. Continuous-energy cross sections.

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[a] International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2012).

[b] M. B. Chadwick, et al., "ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology," *Nucl. Data Sheets*, **107**: 2931-3060 (2006).

A.3.6 Component Calculations

- Type of cell calculation – reactor core and reflectors
- Geometry – fuel pin and assembly lattice
- Theory used – Not applicable
- Method used – Monte Carlo
- Calculation characteristics
  - MCNP5 – histories/cycles/cycles skipped = 1,000,000/2,000/150
    continuous-energy cross sections

A.3.7 Other Assumptions and Characteristics

Not applicable.

A.3.8 Typical Input Listings for Each Code System Type

The input deck for only the simple benchmark model was provided. The input lines for the uranium foils and cadmium covers are identical in the detailed benchmark model. An input deck for the detailed benchmark model of the system is available in HEU-COMP-FAST-004.

MCNP5 Input Deck for Cadmium Ratio Benchmark Models:
<u>*Bare Foils*</u>

```
SCCA-FUND-EXP-002-001 and HEU-COMP-FAST-002
C
C
C   Cell Cards
1   1  6.54398E-02  (-25 22 -24) u=11 imp:n=1         $fuel pellet
2   0       -22:(25 22 -24 ):24 u=11 imp:n=1  $void around pellet
4   0     -21 22 -23  fill=11 u=12 imp:n=1
C
C  BASIC FUEL TUBE W/ GRID PLATE
15   15 7.50555E-02 (1 -24 -20 21) u=12 imp:n=1  $Fuel tube
16   15 7.50555E-02 (1 -22 -21):(23 -24 -21) u=12 imp:n=1  $end caps
21   0    -1:20:24 u=12 imp:n=1
C     BASIC FUEL TUBES FOR TUBES WHICH ARE MOVED IN
22  0     -21 22 -23  fill=11 u=13 imp:n=1
23   15 7.50555E-02 (21) u=13 imp:n=1  $Fuel tube
24   15 7.50555E-02 (-22 -21):(23 -21) u=13 imp:n=1  $end caps
C   BASIC FUEL TUBES
40  0   -12 fill=12 u=1 imp:n=1
C   FUEL TUBES WHICH ARE MOVED IN
41  0   -13 fill=13 (-3.766 -11.458 0) imp:n=1
42  0   -14 fill=13 (3.766 -11.458 0) imp:n=1
43  0   -15 fill=13 (3.766 11.458 0) imp:n=1
44  0   -16 fill=13 (-3.766 11.458 0) imp:n=1
45  0   -17 fill=13 (-8.039 -8.989 0) imp:n=1
46  0   -18 fill=13 (8.039 -8.989 0) imp:n=1
47  0   -19 fill=13 (-8.039 8.989 0) imp:n=1
48  0   -30 fill=13 (8.039 8.989 0) imp:n=1
49  0   -31 fill=13 (-11.805 -2.467 0) imp:n=1
50  0   -32 fill=13 (11.805 -2.467 0) imp:n=1
51  0   -33 fill=13 (-11.805 2.467 0) imp:n=1
52  0   -34 fill=13 (11.805 2.467 0) imp:n=1
C
C  VOID
```

```
62  0  -999  u=9 imp:n=1
C   Core Assembly
68  0   -11  lat=2  u=2 imp:n=1 fill= -10:10 -10:10 0:0
     9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9  $ROW 1
       9 9 9 9 9 9 9 9 9 9 9 9 9 1 1 1 1 9 9 9 9  $ROW 2
        9 9 9 9 9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 9 9  $ROW 3
         9 9 9 9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 4
          9 9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 5
           9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 6
            9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 7
             9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 8
              9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 9
               9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 10
                9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 11
                 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9  $ROW 12
                  9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9  $ROW 13
                   9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9  $ROW 14
                    9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9  $ROW 15
                     9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9  $ROW 16
                      9 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9 9  $ROW 17
                       9 9 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9 9 9 9  $ROW 18
                        9 9 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9 9 9 9 9  $ROW 19
                         9 9 9 9 1 1 1 1 9 9 9 9 9 9 9 9 9 9 9 9 9  $ROW 20
                          9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9  $ROW 21
C   Core Tank
70  0 -51 1 -53 13 14 15 16 17 18 19 30 31 32 33 34 706 707 708 fill=2 imp:n=1
74  2 5.88014E-02 (-53 1 -50 51):(-1 52 -50) imp:n=1 $Core Tank
C
C  Reflectors
C  Void Universe
99   0  -999  u=19 imp:n=1
C  Top Reflector
100  8  1.20554E-01 301 -57 -302 700 701 702 703 704 705 imp:n=1
102  0  302 -57 -303  imp:n=1
103  13 7.07826E-02 (301 -303 57 -58):(300 -301 -58) imp:n=1
196  0 -999 300 (58):(-999 303) imp:n=1
C  Bottom Reflector
300  10 1.20636E-01 -57 -304 305  imp:n=1
301  14 6.72481E-02 (57 -58 -304 305):(-305 306 -58) imp:n=1
307  0   58 -304 306 -999 imp:n=1
C   Side Reflector
320  9 1.21199E-01  320 -321 322 -323 imp:n=1
321   0  -300 53 -320 imp:n=1
322   0  -53 50 -320 322 imp:n=1
323   0  -322 50 -326 304 imp:n=1
324   0 -300 52 321 325 -999 imp:n=1
325   0 -306 327 -999 imp:n=1
C  Support Structure/Additional Reflectors
350  30 6.08580E-02 -325 326 imp:n=1 $Support Plate for Be
351  31 8.75101E-02 -327 imp:n=1 $SS304 Plate
C
700 50 4.79835E-02 -700 imp:n=1
701 50 4.79835E-02 -701 imp:n=1
702 50 4.79835E-02 -702 imp:n=1
703 50 4.79835E-02 -703 imp:n=1
704 50 4.79835E-02 -704 imp:n=1
705 50 4.79835E-02 -705 imp:n=1
C
706 50 4.79835E-02 -706 imp:n=1
707 50 4.79835E-02 -707 imp:n=1
708 50 4.79835E-02 -708 imp:n=1
C
999  0  999 imp:n=0

C   Surface Cards
1    pz   0.      $bottom of fuel
11   rhp  0 0 -10  0 0 50   0.753 0 0
12   rhp  0 0 -11  0 0 52   1 0 0
13   rcc  -3.766 -11.458 0  0 0 30.48  0.635
14   rcc  3.766 -11.458 0  0 0 30.48  0.635
15   rcc  3.766 11.458 0  0 0 30.48  0.635
16   rcc  -3.766 11.458 0  0 0 30.48  0.635
17   rcc  -8.039 -8.989 0  0 0 30.48  0.635
18   rcc  8.039 -8.989 0  0 0 30.48  0.635
19   rcc  -8.039 8.989 0  0 0 30.48  0.635
20   cz   0.635   $OR Clad
```

```
21   cz   0.584   $IR Clad
22   pz   0.3     $top of bottom cap
23   pz  30.18    $bottom of top cap
24   pz  30.48    $Top of fuel tube
25   cz   0.5705  $OR of Pellet
30   rcc  8.039 8.989 0  0 0 30.48  0.635
31   rcc  -11.805 -2.467 0  0 0 30.48  0.635
32   rcc  11.805 -2.467 0  0 0 30.48  0.635
33   rcc  -11.805 2.467 0  0 0 30.48  0.635
34   rcc  11.805 2.467 0  0 0 30.48  0.635
C  Core Tank
50  cz  12.98  $OR Core Tank
51  cz  12.726 $IR Core Tank
52  pz  -0.33   $Bottom of Core Tank
53  pz  30.71  $Top of Core Tank
C  simple model to preflector
57   cz 20.65   $Ir upper and lower tank
58   cz 21.285 $OR upper and lower tank
C
300    pz  30.935
301    pz  31.155
302    pz 38.14
303    pz  43.885
C
304    pz -0.33
305    pz -7.95
306    pz -8.84
C   Side Reflector
320    cz  13.08
321    cz  24.45
322    pz 0.305
323    pz 30.935
C
C    Be Support Plate
325  rpp -37.5 37.5  -37.5 37.5  -0.33 0.305
326  cz  13.95
C    SS304 Plate
327  rcc 0. 0. -11.22  0. 0. 2.38  22.86
C
700  rcc  0  0  31.155  0  0  0.01  0.375
701  rcc  0  0  32.425  0  0  0.01  0.375
702  rcc  0  0  33.695  0  0  0.01  0.375
703  rcc  0  0  34.965  0  0  0.01  0.375
704  rcc  0  0  36.235  0  0  0.01  0.375
705  rcc  0  0  37.505  0  0  0.01  0.375
C
706 rcc -5.7065 9.883947933 15.24  0.005 -0.008660254 0  0.375
C
707 rcc 1.51  2.615396719  30.48  0  0  0.01  0.375
708 rcc 6.03  10.44426637  30.48  0  0  0.01  0.375
C
999   rpp  -500 500   -500 500  -500 500

C   Data Cards
m1   92234.70c   2.21403E-04
      92235.70c   2.03324E-02
      92236.70c   1.02154E-04
      92238.70c   1.15733E-03
      8016.70c   4.35205E-02
      8017.70c   1.06012E-04   $ Tot   6.54398E-02
C   Fuel Clad
m15   26054.70c   2.97938E-03
      26056.70c   4.67699E-02
      26057.70c   1.08012E-03
      26058.70c   1.43744E-04
      6000.70c   1.37950E-04
      25055.70c   7.53997E-04
      14028.70c   6.80144E-04
      14029.70c   3.45361E-05
      14030.70c   2.27664E-05
      24050.70c   6.23067E-04
      24052.70c   1.20152E-02
      24053.70c   1.36243E-03
      24054.70c   3.39138E-04
      28058.70c   5.28531E-03
      28060.70c   2.03589E-03
```

```
      28061.70c   8.84989E-05
      28062.70c   2.82173E-04
      28064.70c   7.18612E-05
      15031.70c   3.00906E-05
      16032.70c   1.83924E-05
      16033.70c   1.47248E-07
      16034.70c   8.31174E-07
      16036.70c   3.87494E-09
      41093.70c   2.86989E-04
      73181.70c   1.28933E-05   $tot   7.50555E-02
C   Core Tank
m2   13027.70c   5.85485E-02
      29063.70c   2.16403E-05
      29065.70c   9.64537E-06
      14028.70c   1.24044E-04
      14029.70c   6.29865E-06
      14030.70c   4.15212E-06
      26054.70c   3.95341E-06
      26056.70c   6.20601E-05
      26057.70c   1.43324E-06
      26058.70c   1.90738E-07
      25055.70c   7.23754E-06
      30000.70c   1.21614E-05   $ Tot   5.88014E-02
C   Reflectors
C  ************************************
C  Top Reflector
m8   4009.70c   1.20554E-01
C   Side Reflector
m9   4009.70c   1.21199E-01
C   Bottom Reflector
m10   4009.70c   1.20636E-01
C    *************************************
C  Upper reflector tank
m13   13027.70c   7.04918E-02
      29063.70c   2.60429E-05
      29065.70c   1.16077E-05
      14028.70c   1.49280E-04
      14029.70c   7.58007E-06
      14030.70c   4.99684E-06
      26054.70c   4.75770E-06
      26056.70c   7.46858E-05
      26057.70c   1.72482E-06
      25055.70c   8.70996E-06
      30000.70c   1.46355E-06   $ Tot   7.07826E-02
C  lower reflector tank
m14   13027.70c   6.69718E-02
      29063.70c   2.47424E-05
      29065.70c   1.10280E-05
      14028.70c   1.41826E-04
      14029.70c   7.20156E-06
      14030.70c   4.74732E-06
      26054.70c   4.52013E-06
      26056.70c   7.09564E-05
      26057.70c   1.63869E-06
      25055.70c   8.27504E-06
      30000.70c   1.39047E-06   $ Tot   6.72481E-02
C   ***************************************
C  Additional Bottom Reflectors
C   Be Support Plate (Al1100)
m30   13027.70c   6.06080E-02
      29063.70c   2.23913E-05
      29065.70c   9.98012E-06
      14028.70c   1.28349E-04
      14029.70c   6.51725E-06
      14030.70c   4.29622E-06
      26054.70c   4.09062E-06
      26056.70c   6.42139E-05
      26057.70c   1.48298E-06
      25055.70c   7.48872E-06
      30000.70c   1.25834E-06   $ Tot   6.08580E-02
C   SS304 Support Plate
m31   26054.70c   3.51905E-03
      26056.70c   5.52415E-02
      26057.70c   1.27577E-03
      26058.70c   1.69781E-04
      6000.70c   1.60142E-04
```

```
      25055.70c   8.75287E-04
      14028.70c   7.89554E-04
      14029.70c   4.00916E-05
      14030.70c   2.64287E-05
      24050.70c   7.63478E-04
      24052.70c   1.47229E-02
      24053.70c   1.66946E-03
      24054.70c   4.15564E-04
      28058.70c   5.29886E-03
      28060.70c   2.04111E-03
      28061.70c   8.87257E-05
      28062.70c   2.82896E-04
      28064.70c   7.20454E-05
      15031.70c   3.49310E-05
      16032.70c   2.13510E-05
      16033.70c   1.70934E-07
      16034.70c   9.64879E-07
      16034.70c   4.49827E-09   $ tot   8.75101E-02
C    U Foils
m50   92234.70c   4.67753E-04
      92235.70c   4.47223E-02
      92236.70c   1.14750E-04
      92238.70c   2.67865E-03   $ total   4.79835E-02
C    Cd Covers
m55   48106.70c   5.79249E-04
      48108.70c   4.12425E-04
      48110.70c   5.78786E-03
      48111.70c   5.93151E-03
      48112.70c   1.11818E-02
      48113.70c   5.66274E-03
      48114.70c   1.33135E-02
      48116.70c   3.47086E-03   $ total   4.63399E-02
C   Scattering Cards
mt1   o2/u.10t  u/o2.10t
mt2    al27.12t
mt8   be.10t
mt9   be.10t
mt10  be.10t
mt13   al27.12t
mt14   al27.12t
mt20   al27.12t
mt22   al27.12t
C m23    al27.12t
mt30   al27.12t
C
kcode  100000 1 150 2150
ksrc   0.0692  4.5245 0.77787  0  8.8072 0.7787
       0.0692 -4.3864 0.77787  0 -8.7382 0.7787
       3.8736 0 0.7787   7.6780 0 0.7787
      -3.7353 0 0.7787  -7.8510 0 0.7787
f4:n  700
fm4   1 50 -6
C
f14:n   701
fm14   1 50 -6
C
f24:n   702
fm24   1 50 -6
C
f34:n   703
fm34   1 50 -6
C
f44:n   704
fm44   1 50 -6
C
f54:n  705
fm54   1 50 -6
C
f64:n   706
fm64   1 50 -6
c
f74:n   707
fm74   1 50 -6
C
f84:n   708
fm84   1 50 -6
```

```
C  rand  seed=7065399757867  $ r2
C  rand  seed=5724484131590  $ r3
C  rand  seed=417647895433   $ r4
C  rand  seed=8132049697893  $ r5
C  rand  seed=8663498807872  $ r6
C  rand  seed=7447087897166  $ r7
```

Cadmium Covered Foils

```
SCCA-FUND-EXP-002-001 and HEU-COMP-FAST-002
C
C
C   Cell Cards
1   1  6.54398E-02  (-25 22 -24) u=11 imp:n=1         $fuel pellet
2   0       -22:(25 22 -24 ):24 u=11 imp:n=1  $void around pellet
4   0    -21 22 -23  fill=11 u=12 imp:n=1
C
C  BASIC FUEL TUBE W/ GRID PLATE
15   15 7.50555E-02 (1 -24 -20 21) u=12 imp:n=1  $Fuel tube
16   15 7.50555E-02 (1 -22 -21):(23 -24 -21) u=12 imp:n=1  $end caps
21   0    -1:20:24 u=12 imp:n=1
C     BASIC FUEL TUBES FOR TUBES WHICH ARE MOVED IN
22  0    -21 22 -23  fill=11 u=13 imp:n=1
23   15 7.50555E-02 (21) u=13 imp:n=1  $Fuel tube
24   15 7.50555E-02 (-22 -21):(23 -21) u=13 imp:n=1  $end caps
C   BASIC FUEL TUBES
40  0   -12 fill=12 u=1 imp:n=1
C   FUEL TUBES WHICH ARE MOVED IN
41  0   -13 fill=13 (-3.766 -11.458 0) imp:n=1
42  0   -14 fill=13 (3.766 -11.458 0) imp:n=1
43  0   -15 fill=13 (3.766 11.458 0) imp:n=1
44  0   -16 fill=13 (-3.766 11.458 0) imp:n=1
45  0   -17 fill=13 (-8.039 -8.989 0) imp:n=1
46  0   -18 fill=13 (8.039 -8.989 0) imp:n=1
47  0   -19 fill=13 (-8.039 8.989 0) imp:n=1
48  0   -30 fill=13 (8.039 8.989 0) imp:n=1
49  0   -31 fill=13 (-11.805 -2.467 0) imp:n=1
50  0   -32 fill=13 (11.805 -2.467 0) imp:n=1
51  0   -33 fill=13 (-11.805 2.467 0) imp:n=1
52  0   -34 fill=13 (11.805 2.467 0) imp:n=1
C
C  VOID
62  0  -999  u=9 imp:n=1
C   Core Assembly
68  0   -11  lat=2  u=2 imp:n=1 fill= -10:10 -10:10 0:0
     9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9  $ROW 1
       9 9 9 9 9 9 9 9 9 9 9 9 9 1 1 1 1 9 9 9 9  $ROW 2
        9 9 9 9 9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 9 9  $ROW 3
         9 9 9 9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 4
          9 9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 5
           9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 6
            9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 7
             9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 8
              9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 9
               9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 10
                9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 11
                 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9  $ROW 12
                  9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9  $ROW 13
                   9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9  $ROW 14
                    9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9  $ROW 15
                     9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9  $ROW 16
                      9 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9 9  $ROW 17
                       9 9 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9 9 9 9  $ROW 18
                        9 9 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9 9 9 9 9  $ROW 19
                         9 9 9 9 1 1 1 1 9 9 9 9 9 9 9 9 9 9 9 9 9  $ROW 20
                          9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9  $ROW 21
C   Core Tank
70  0  -51 1 -53 13 14 15 16 17 18 19 30 31 32 33 34 706 707 708 fill=2 imp:n=1
74  2 5.88014E-02 (-53 1 -50 51):(-1 52 -50) imp:n=1 $Core Tank
C
C  Reflectors
C  Void Universe
99   0  -999  u=19 imp:n=1
C  Top Reflector
100  8  1.20554E-01 301 -57 -302 700 701 702 703 704 705 imp:n=1
102  0  302 -57 -303  imp:n=1
103  13 7.07826E-02 (301 -303 57 -58):(300 -301 -58) imp:n=1
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```
196  0 -999 300 (58):(-999 303) imp:n=1
C  Bottom Reflector
300  10 1.20636E-01 -57 -304 305  imp:n=1
301  14 6.72481E-02 (57 -58 -304 305):(-305 306 -58) imp:n=1
307  0   58 -304 306 -999 imp:n=1
C   Side Reflector
320  9 1.21199E-01  320 -321 322 -323 imp:n=1
321   0  -300 53 -320 imp:n=1
322   0  -53 50 -320 322 imp:n=1
323   0  -322 50 -326 304 imp:n=1
324   0 -300 52 321 325 -999 imp:n=1
325   0 -306 327 -999 imp:n=1
C  Support Structure/Additional Reflectors
350  30 6.08580E-02 -325 326 imp:n=1 $Support Plate for Be
351  31 8.75101E-02 -327 imp:n=1 $SS304 Plate
C
700 55 4.63399E-02 -700 710 imp:n=1
701 55 4.63399E-02 -701 711 imp:n=1
702 55 4.63399E-02 -702 712 imp:n=1
703 55 4.63399E-02 -703 713 imp:n=1
704 55 4.63399E-02 -704 714 imp:n=1
705 55 4.63399E-02 -705 715 imp:n=1
C
706 55 4.63399E-02 -706 716 imp:n=1
707 55 4.63399E-02 -707 717 imp:n=1
708 55 4.63399E-02 -708 718 imp:n=1
C
710 50 4.79835E-02 -710 imp:n=1
711 50 4.79835E-02 -711 imp:n=1
712 50 4.79835E-02 -712 imp:n=1
713 50 4.79835E-02 -713 imp:n=1
714 50 4.79835E-02 -714 imp:n=1
715 50 4.79835E-02 -715 imp:n=1
716 50 4.79835E-02 -716 imp:n=1
717 50 4.79835E-02 -717 imp:n=1
718 50 4.79835E-02 -718 imp:n=1
C
999  0  999 imp:n=0

C   Surface Cards
1    pz   0.      $bottom of fuel
11   rhp  0 0 -10  0 0 50   0.753 0 0
12   rhp  0 0 -11  0 0 52   1 0 0
13   rcc  -3.766 -11.458 0  0 0 30.48  0.635
14   rcc  3.766 -11.458 0  0 0 30.48  0.635
15   rcc  3.766 11.458 0  0 0 30.48  0.635
16   rcc  -3.766 11.458 0  0 0 30.48  0.635
17   rcc  -8.039 -8.989 0  0 0 30.48  0.635
18   rcc  8.039 -8.989 0  0 0 30.48  0.635
19   rcc  -8.039 8.989 0  0 0 30.48  0.635
20   cz   0.635   $OR Clad
21   cz   0.584   $IR Clad
22   pz   0.3     $top of bottom cap
23   pz  30.18    $bottom of top cap
24   pz  30.48    $Top of fuel tube
25   cz   0.5705  $OR of Pellet
30   rcc  8.039 8.989 0  0 0 30.48  0.635
31   rcc  -11.805 -2.467 0  0 0 30.48  0.635
32   rcc  11.805 -2.467 0  0 0 30.48  0.635
33   rcc  -11.805 2.467 0  0 0 30.48  0.635
34   rcc  11.805 2.467 0  0 0 30.48  0.635
C  Core Tank
50  cz  12.98  $OR Core Tank
51  cz  12.726 $IR Core Tank
52  pz  -0.33   $Bottom of Core Tank
53  pz  30.71  $Top of Core Tank
C  simple model to preflector
57   cz 20.65   $Ir upper and lower tank
58   cz 21.285 $OR upper and lower tank
C
300    pz  30.935
301    pz  31.155
302    pz 38.14
303    pz  43.885
C
304    pz -0.33
```

```
305    pz -7.95
306    pz -8.84
C   Side Reflector
320    cz  13.08
321    cz  24.45
322    pz 0.305
323    pz 30.935
C
C    Be Support Plate
325  rpp -37.5 37.5  -37.5 37.5  -0.33 0.305
326  cz  13.95
C    SS304 Plate
327  rcc 0. 0. -11.22  0. 0. 2.38  22.86
C
700  rcc  0  0  31.155  0  0  0.112  0.425
701  rcc  0  0  32.425  0  0  0.112  0.425
702  rcc  0  0  33.695  0  0  0.112  0.425
703  rcc  0  0  34.965  0  0  0.112  0.425
704  rcc  0  0  36.235  0  0  0.112  0.425
705  rcc  0  0  37.505  0  0  0.112  0.425
C
706  rcc  -5.7065  9.883947933  15.24  0.056  -0.096994845  0  0.425
C
707  rcc  1.51  2.615396719  30.48  0  0  0.112  0.425
708  rcc  6.03  10.44426637  30.48  0  0  0.112  0.425
C
710  rcc  0  0  31.206  0  0  0.01  0.375
711  rcc  0  0  32.476  0  0  0.01  0.375
712  rcc  0  0  33.746  0  0  0.01  0.375
713  rcc  0  0  35.016  0  0  0.01  0.375
714  rcc  0  0  36.286  0  0  0.01  0.375
715  rcc  0  0  37.556  0  0  0.01  0.375
C
716  rcc  -5.681  9.839780638  15.24  0.005  -0.008660254  0  0.375
C
717  rcc  1.51  2.615396719  30.531  0  0  0.01  0.375
718  rcc  6.03  10.44426637  30.531  0  0  0.01  0.375
C
999   rpp  -500 500   -500 500  -500 500

C   Data Cards
m1   92234.70c   2.21403E-04
      92235.70c   2.03324E-02
      92236.70c   1.02154E-04
      92238.70c   1.15733E-03
      8016.70c   4.35205E-02
      8017.70c   1.06012E-04   $ Tot   6.54398E-02
C   Fuel Clad
m15   26054.70c   2.97938E-03
      26056.70c   4.67699E-02
      26057.70c   1.08012E-03
      26058.70c   1.43744E-04
      6000.70c   1.37950E-04
      25055.70c   7.53997E-04
      14028.70c   6.80144E-04
      14029.70c   3.45361E-05
      14030.70c   2.27664E-05
      24050.70c   6.23067E-04
      24052.70c   1.20152E-02
      24053.70c   1.36243E-03
      24054.70c   3.39138E-04
      28058.70c   5.28531E-03
      28060.70c   2.03589E-03
      28061.70c   8.84989E-05
      28062.70c   2.82173E-04
      28064.70c   7.18612E-05
      15031.70c   3.00906E-05
      16032.70c   1.83924E-05
      16033.70c   1.47248E-07
      16034.70c   8.31174E-07
      16036.70c   3.87494E-09
      41093.70c   2.86989E-04
      73181.70c   1.28933E-05   $tot   7.50555E-02
C   Core Tank
m2   13027.70c   5.85485E-02
      29063.70c   2.16403E-05
```

```
      29065.70c   9.64537E-06
      14028.70c   1.24044E-04
      14029.70c   6.29865E-06
      14030.70c   4.15212E-06
      26054.70c   3.95341E-06
      26056.70c   6.20601E-05
      26057.70c   1.43324E-06
      26058.70c   1.90738E-07
      25055.70c   7.23754E-06
      30000.70c   1.21614E-05   $ Tot   5.88014E-02
C   Reflectors
C  ************************************
C  Top Reflector
m8   4009.70c   1.20554E-01
C   Side Reflector
m9   4009.70c   1.21199E-01
C   Bottom Reflector
m10   4009.70c   1.20636E-01
C    *************************************
C  Upper reflector tank
m13   13027.70c   7.04918E-02
      29063.70c   2.60429E-05
      29065.70c   1.16077E-05
      14028.70c   1.49280E-04
      14029.70c   7.58007E-06
      14030.70c   4.99684E-06
      26054.70c   4.75770E-06
      26056.70c   7.46858E-05
      26057.70c   1.72482E-06
      25055.70c   8.70996E-06
      30000.70c   1.46355E-06   $ Tot   7.07826E-02
C  lower reflector tank
m14   13027.70c   6.69718E-02
      29063.70c   2.47424E-05
      29065.70c   1.10280E-05
      14028.70c   1.41826E-04
      14029.70c   7.20156E-06
      14030.70c   4.74732E-06
      26054.70c   4.52013E-06
      26056.70c   7.09564E-05
      26057.70c   1.63869E-06
      25055.70c   8.27504E-06
      30000.70c   1.39047E-06   $ Tot   6.72481E-02
C   **************************************
C  Additional Bottom Reflectors
C   Be Support Plate (Al1100)
m30   13027.70c   6.06080E-02
      29063.70c   2.23913E-05
      29065.70c   9.98012E-06
      14028.70c   1.28349E-04
      14029.70c   6.51725E-06
      14030.70c   4.29622E-06
      26054.70c   4.09062E-06
      26056.70c   6.42139E-05
      26057.70c   1.48298E-06
      25055.70c   7.48872E-06
      30000.70c   1.25834E-06   $ Tot   6.08580E-02
C   SS304 Support Plate
m31   26054.70c   3.51905E-03
      26056.70c   5.52415E-02
      26057.70c   1.27577E-03
      26058.70c   1.69781E-04
      6000.70c   1.60142E-04
      25055.70c   8.75287E-04
      14028.70c   7.89554E-04
      14029.70c   4.00916E-05
      14030.70c   2.64287E-05
      24050.70c   7.63478E-04
      24052.70c   1.47229E-02
      24053.70c   1.66946E-03
      24054.70c   4.15564E-04
      28058.70c   5.29886E-03
      28060.70c   2.04111E-03
      28061.70c   8.87257E-05
      28062.70c   2.82896E-04
      28064.70c   7.20454E-05
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      15031.70c   3.49310E-05
      16032.70c   2.13510E-05
      16033.70c   1.70934E-07
      16034.70c   9.64879E-07
      16034.70c   4.49827E-09   $ tot   8.75101E-02
C    U Foils
m50   92234.70c   4.67753E-04
      92235.70c   4.47223E-02
      92236.70c   1.14750E-04
      92238.70c   2.67865E-03   $ total   4.79835E-02
C    Cd Covers
m55   48106.70c   5.79249E-04
      48108.70c   4.12425E-04
      48110.70c   5.78786E-03
      48111.70c   5.93151E-03
      48112.70c   1.11818E-02
      48113.70c   5.66274E-03
      48114.70c   1.33135E-02
      48116.70c   3.47086E-03   $ total   4.63399E-02
C   Scattering Cards
mt1   o2/u.10t  u/o2.10t
mt2    al27.12t
mt8   be.10t
mt9   be.10t
mt10  be.10t
mt13   al27.12t
mt14   al27.12t
mt20   al27.12t
mt22   al27.12t
mt30   al27.12t
C
kcode  100000 1 150 2150
ksrc   0.0692  4.5245 0.77787  0  8.8072 0.7787
       0.0692 -4.3864 0.77787  0 -8.7382 0.7787
       3.8736 0 0.7787   7.6780 0 0.7787
      -3.7353 0 0.7787  -7.8510 0 0.7787
f4:n  710
fm4   1 50 -6
C
f14:n   711
fm14   1 50 -6
C
f24:n   712
fm24   1 50 -6
C
f34:n   713
fm34   1 50 -6
C
f44:n   714
fm44   1 50 -6
C
f54:n  715
fm54   1 50 -6
C
f64:n   716
fm64   1 50 -6
c
f74:n   707
fm74   1 50 -6
C
f84:n   708
fm84   1 50 -6
c
C  rand  seed=7065399757867  $ r2
C  rand  seed=5724484131590  $ r3
C  rand  seed=417647895433   $ r4
C  rand  seed=8132049697893  $ r5
C  rand  seed=8663498807872  $ r6
C  rand  seed=7447087897166  $ r7
```

A.4 Reactivity-Effects Configurations

The reactivity-effect measurements were not evaluated.

A.5 Reactivity Coefficient Configurations

Reactivity coefficient measurements were not evaluated.

A.6 Kinetics Parameter Configurations

Kinetics measurements were not performed.

A.7 Reaction-Rate Configurations

Models were creating using Monte Carlo n-Particle (MCNP), Version 5-1.60, and ENDF/B-VII.0 neutron cross section libraries. Isotopic abundances for all elements except uranium (see Section 3.3.3 for uranium isotopic abundances) were taken from "Nuclides and Isotopes: Chart of the Nuclides," Sixteenth Edition, KAPL, 2002.

A.7.1 Name(s) of Code System(s) Used

1. Monte Carlo n-Particle, Version 5.1.60 (MCNP5).

A.7.2 Bibliographic References for the Codes Used

1. F. B. Brown, R. F. Barrett, T. E. Booth, J. S. Bull, L. J. Cox, R. A. Forster, T. J. Goorley, R. D. Mosteller, S. E. Post, R. E. Prael, E. C. Selcow, A. Sood, and J. Sweezy, "MCNP Version 5," LA-UR-02-3935, Los Alamos National Laboratory (2002).

A.7.3 Origin of Cross-section Data

The evaluated neutron data file library ENDF/B-VII.0[a] was utilized in the benchmark-model analysis.

A.7.4 Spectral Calculations and Data Reduction Methods Used

Not applicable.

A.7.5 Number of Energy Groups or If Continuous-energy Cross Sections are Used in the Different Phases of Calculation

1. Continuous-energy cross sections.

2. Continuous-energy cross sections.

[a] M. B. Chadwick, et al., "ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology," *Nucl. Data Sheets*, **107**: 2931-3060 (2006).

A.7.6 Component Calculations

- Type of cell calculation – reactor core and reflectors
- Geometry – fuel pin and assembly lattice
- Theory used – Not applicable
- Method used – Monte Carlo
- Calculation characteristics
  - MCNP5 – histories/cycles/cycles skipped = 1,000,000/2,000/150
    continuous-energy cross sections

A.7.7 Other Assumptions and Characteristics

Not applicable.

A.7.8 Typical Input Listings for Each Code System Type

The input deck for only the simple benchmark model is provided. The input lines for the uranium foils are identical in the detailed benchmark model. An input deck for the detailed benchmark model of the system is available in HEU-COMP-FAST-004.

MCNP5 Input Deck for Cadmium Ratio Benchmark Models:
Bare Foils

```
SCCA-FUND-EXP-002-001 and HEU-COMP-FAST-002
C
C
C   Cell Cards
1   1  6.54398E-02  (-25 22 -24) u=11 imp:n=1         $fuel pellet
2   0      -22:(25 22 -24 ):24 u=11 imp:n=1  $void around pellet
4   0    -21 22 -23  fill=11 u=12 imp:n=1
C
C  BASIC FUEL TUBE W/ GRID PLATE
15   15 7.50555E-02 (1 -24 -20 21) u=12 imp:n=1  $Fuel tube
16   15 7.50555E-02 (1 -22 -21):(23 -24 -21) u=12 imp:n=1  $end caps
21   0    -1:20:24 u=12 imp:n=1
C     BASIC FUEL TUBES FOR TUBES WHICH ARE MOVED IN
22  0    -21 22 -23  fill=11 u=13 imp:n=1
23   15 7.50555E-02 (21) u=13 imp:n=1  $Fuel tube
24   15 7.50555E-02 (-22 -21):(23 -21) u=13 imp:n=1  $end caps
C   BASIC FUEL TUBES
40  0   -12 fill=12 u=1 imp:n=1
C   FUEL TUBES WHICH ARE MOVED IN
41  0   -13 fill=13 (-3.766 -11.458 0) imp:n=1
42  0   -14 fill=13 (3.766 -11.458 0) imp:n=1
43  0   -15 fill=13 (3.766 11.458 0) imp:n=1
44  0   -16 fill=13 (-3.766 11.458 0) imp:n=1
45  0   -17 fill=13 (-8.039 -8.989 0) imp:n=1
46  0   -18 fill=13 (8.039 -8.989 0) imp:n=1
47  0   -19 fill=13 (-8.039 8.989 0) imp:n=1
48  0   -30 fill=13 (8.039 8.989 0) imp:n=1
49  0   -31 fill=13 (-11.805 -2.467 0) imp:n=1
50  0   -32 fill=13 (11.805 -2.467 0) imp:n=1
51  0   -33 fill=13 (-11.805 2.467 0) imp:n=1
52  0   -34 fill=13 (11.805 2.467 0) imp:n=1
C
C  VOID
```

```
62  0  -999  u=9 imp:n=1
C   Core Assembly
68  0   -11  lat=2  u=2 imp:n=1 fill= -10:10 -10:10 0:0
     9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9  $ROW 1
       9 9 9 9 9 9 9 9 9 9 9 9 9 1 1 1 1 9 9 9 9  $ROW 2
        9 9 9 9 9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 9 9  $ROW 3
         9 9 9 9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 4
          9 9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 5
           9 9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 6
            9 9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 7
             9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9  $ROW 8
              9 9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 9
               9 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 10
                9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9  $ROW 11
                 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9  $ROW 12
                  9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9  $ROW 13
                   9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9  $ROW 14
                    9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9  $ROW 15
                     9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9  $ROW 16
                      9 1 1 1 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9 9  $ROW 17
                       9 9 1 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9 9 9 9  $ROW 18
                        9 9 1 1 1 1 1 1 1 1 1 9 9 9 9 9 9 9 9 9 9  $ROW 19
                         9 9 9 9 1 1 1 1 9 9 9 9 9 9 9 9 9 9 9 9 9  $ROW 20
                          9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9  $ROW 21
C   Core Tank
70  0   -51 1 -53 13 14 15 16 17 18 19 30 31 32 33 34
     700 701 702 703 704 705 706 707 720 721 722 723 724 725 726 727 728 729
        730 731  741 742 fill=2 imp:n=1
74  2 5.88014E-02 (-53 1 -50 51):(-1 52 -50) imp:n=1 $Core Tank
C
C  Reflectors
C  Void Universe
99   0  -999  u=19 imp:n=1
C  Top Reflector
100  8  1.20554E-01 301 -57 -302 707 708 709 710 711 712 713 imp:n=1
102  0  302 -57 -303  imp:n=1
103  13 7.07826E-02 (301 -303 57 -58):(300 -301 -58) imp:n=1
196  0 -999 300 (58):(-999 303) imp:n=1
C  Bottom Reflector
300  10 1.20636E-01 -57 -304 305  imp:n=1
301  14 6.72481E-02 (57 -58 -304 305):(-305 306 -58) imp:n=1
307  0   58 -304 306 -999 imp:n=1
C   Side Reflector
320  9 1.21199E-01  320 -321 322 -323 imp:n=1
321   0  -300 53 -320 imp:n=1
322   0  -53 50 -320 322 imp:n=1
323   0  -322 50 -326 304 imp:n=1
324   0 -300 52 321 325 -999 imp:n=1
325   0 -306 327 -999 imp:n=1
C  Support Structure/Additional Reflectors
350  30 6.08580E-02 -325 326 imp:n=1 $Support Plate for Be
351  31 8.75101E-02 -327 imp:n=1 $SS304 Plate
C
700  50 4.79835E-02 -700 imp:n=1
701  50 4.79835E-02 -701 imp:n=1
702  50 4.79835E-02 -702 imp:n=1
703  50 4.79835E-02 -703 imp:n=1
704  50 4.79835E-02 -704 imp:n=1
705  50 4.79835E-02 -705 imp:n=1
706  50 4.79835E-02 -706 imp:n=1
707  50 4.79835E-02 -707 imp:n=1
708  50 4.79835E-02 -708 imp:n=1
709  50 4.79835E-02 -709 imp:n=1
710  50 4.79835E-02 -710 imp:n=1
711  50 4.79835E-02 -711 imp:n=1
712  50 4.79835E-02 -712 imp:n=1
713  50 4.79835E-02 -713 imp:n=1
720  50 4.79835E-02 -720 imp:n=1
721  50 4.79835E-02 -721 imp:n=1
722  50 4.79835E-02 -722 imp:n=1
723  50 4.79835E-02 -723 imp:n=1
724  50 4.79835E-02 -724 imp:n=1
725  50 4.79835E-02 -725 imp:n=1
726  50 4.79835E-02 -726 imp:n=1
727  50 4.79835E-02 -727 imp:n=1
728  50 4.79835E-02 -728 imp:n=1
```

```
729  50 4.79835E-02 -729 imp:n=1
730  50 4.79835E-02 -730 imp:n=1
731  50 4.79835E-02 -731 imp:n=1
741  50 4.79835E-02 -741 imp:n=1
742  50 4.79835E-02 -742 imp:n=1
C
999  0  999 imp:n=0

C   Surface Cards
1    pz   0.      $bottom of fuel
11   rhp  0 0 -10  0 0 50   0.753 0 0
12   rhp  0 0 -11  0 0 52   1 0 0
13   rcc  -3.766 -11.458 0  0 0 30.48  0.635
14   rcc  3.766 -11.458 0  0 0 30.48  0.635
15   rcc  3.766 11.458 0  0 0 30.48  0.635
16   rcc  -3.766 11.458 0  0 0 30.48  0.635
17   rcc  -8.039 -8.989 0  0 0 30.48  0.635
18   rcc  8.039 -8.989 0  0 0 30.48  0.635
19   rcc  -8.039 8.989 0  0 0 30.48  0.635
20   cz   0.635   $OR Clad
21   cz   0.584   $IR Clad
22   pz   0.3     $top of bottom cap
23   pz  30.18    $bottom of top cap
24   pz  30.48    $Top of fuel tube
25   cz   0.5705  $OR of Pellet
30   rcc  8.039 8.989 0  0 0 30.48  0.635
31   rcc  -11.805 -2.467 0  0 0 30.48  0.635
32   rcc  11.805 -2.467 0  0 0 30.48  0.635
33   rcc  -11.805 2.467 0  0 0 30.48  0.635
34   rcc  11.805 2.467 0  0 0 30.48  0.635
C  Core Tank
50  cz  12.98  $OR Core Tank
51  cz  12.726 $IR Core Tank
52  pz  -0.33   $Bottom of Core Tank
53  pz  30.71  $Top of Core Tank
C  simple model to preflector
57   cz 20.65   $Ir upper and lower tank
58   cz 21.285 $OR upper and lower tank
C
300    pz  30.935
301    pz  31.155
302    pz 38.14
303    pz  43.885
C
304    pz -0.33
305    pz -7.95
306    pz -8.84
C   Side Reflector
320    cz  13.08
321    cz  24.45
322    pz 0.305
323    pz 30.935
C
C    Be Support Plate
325  rpp -37.5 37.5  -37.5 37.5  -0.33 0.305
326  cz  13.95
C    SS304 Plate
327  rcc 0. 0. -11.22  0. 0. 2.38  22.86
C
700  rcc  0.635  0  12.7  0.01  0  0  0.375
701  rcc  0.635  0  15.24  0.01  0  0  0.375
702  rcc  0.635  0  17.78  0.01  0  0  0.375
703  rcc  0.635  0  20.32  0.01  0  0  0.375
704  rcc  0.635  0  22.86  0.01  0  0  0.375
705  rcc  0.635  0  25.4  0.01  0  0  0.375
706  rcc  0.635  0  27.94  0.01  0  0  0.375
C
707  rcc  0  0  30.48  0  0  0.01  0.375
708  rcc  0  0  31.155  0  0  0.01  0.375
709  rcc  0  0  32.425  0  0  0.01  0.375
710  rcc  0  0  33.695  0  0  0.01  0.375
711  rcc  0  0  34.965  0  0  0.01  0.375
712  rcc  0  0  36.235  0  0  0.01  0.375
713  rcc  0  0  37.505  0  0  0.01  0.375
C
720  rcc  -0.549926131  0.3175  15.24  -0.008660254  0.005  0  0.375
```

```
721  rcc  -2.808926131  1.621734258  15.24  -0.008660254  0.005  0  0.375
722  rcc  -5.067926131  2.925968516  15.24  -0.008660254  0.005  0  0.375
723  rcc  -7.326926131  4.230202774  15.24  -0.008660254  0.005  0  0.375
724  rcc  -9.199357143  3.677020147  15.24  0.009285714  -0.003711537  0  0.375
725  rcc  -10.66419146  1.231394763  15.24  0.009933993  -0.001147079  0  0.375
726  rcc  -9.260527778  6.16911716  15.24  0.008322397  -0.00554416  0  0.375
727  rcc  -10.37864286  4.148385402  15.24  -0.009285714  0.003711537  0  0.375
728  rcc  -5.7065  9.883947933  15.24  0.005  -0.008660254  0  0.375
729  rcc  -11.92580854  1.377073754  15.24  -0.009933993  0.001147079  0  0.375
730  rcc  -10.31747222  6.873225421  15.24  -0.008322397  0.00554416  0  0.375
731  rcc  -11.8950186  4.120555315  15.24  -0.009449112  0.003273268  0  0.375
C
741  rcc  1.51  2.615396719  30.48  0  0  0.01  0.375
742  rcc  6.03  10.44426637  30.48  0  0  0.01  0.375
C
999   rpp  -500 500   -500 500  -500 500

C   Data Cards
m1   92234.70c   2.21403E-04
      92235.70c   2.03324E-02
      92236.70c   1.02154E-04
      92238.70c   1.15733E-03
      8016.70c   4.35205E-02
      8017.70c   1.06012E-04   $ Tot   6.54398E-02
C   Fuel Clad
m15   26054.70c   2.97938E-03
      26056.70c   4.67699E-02
      26057.70c   1.08012E-03
      26058.70c   1.43744E-04
      6000.70c   1.37950E-04
      25055.70c   7.53997E-04
      14028.70c   6.80144E-04
      14029.70c   3.45361E-05
      14030.70c   2.27664E-05
      24050.70c   6.23067E-04
      24052.70c   1.20152E-02
      24053.70c   1.36243E-03
      24054.70c   3.39138E-04
      28058.70c   5.28531E-03
      28060.70c   2.03589E-03
      28061.70c   8.84989E-05
      28062.70c   2.82173E-04
      28064.70c   7.18612E-05
      15031.70c   3.00906E-05
      16032.70c   1.83924E-05
      16033.70c   1.47248E-07
      16034.70c   8.31174E-07
      16036.70c   3.87494E-09
      41093.70c   2.86989E-04
      73181.70c   1.28933E-05   $tot   7.50555E-02
C   Core Tank
m2   13027.70c   5.85485E-02
      29063.70c   2.16403E-05
      29065.70c   9.64537E-06
      14028.70c   1.24044E-04
      14029.70c   6.29865E-06
      14030.70c   4.15212E-06
      26054.70c   3.95341E-06
      26056.70c   6.20601E-05
      26057.70c   1.43324E-06
      26058.70c   1.90738E-07
      25055.70c   7.23754E-06
      30000.70c   1.21614E-05   $ Tot   5.88014E-02
C   Reflectors
C  ************************************
C  Top Reflector
m8   4009.70c   1.20554E-01
C   Side Reflector
m9   4009.70c   1.21199E-01
C   Bottom Reflector
m10   4009.70c   1.20636E-01
C    ************************************
C  Upper reflector tank
m13   13027.70c   7.04918E-02
      29063.70c   2.60429E-05
      29065.70c   1.16077E-05
```

```
      14028.70c   1.49280E-04
      14029.70c   7.58007E-06
      14030.70c   4.99684E-06
      26054.70c   4.75770E-06
      26056.70c   7.46858E-05
      26057.70c   1.72482E-06
      25055.70c   8.70996E-06
      30000.70c   1.46355E-06   $ Tot   7.07826E-02
C  lower reflector tank
m14   13027.70c   6.69718E-02
      29063.70c   2.47424E-05
      29065.70c   1.10280E-05
      14028.70c   1.41826E-04
      14029.70c   7.20156E-06
      14030.70c   4.74732E-06
      26054.70c   4.52013E-06
      26056.70c   7.09564E-05
      26057.70c   1.63869E-06
      25055.70c   8.27504E-06
      30000.70c   1.39047E-06   $ Tot   6.72481E-02
C   ***************************************
C  Additional Bottom Reflectors
C   Be Support Plate (Al1100)
m30   13027.70c   6.06080E-02
      29063.70c   2.23913E-05
      29065.70c   9.98012E-06
      14028.70c   1.28349E-04
      14029.70c   6.51725E-06
      14030.70c   4.29622E-06
      26054.70c   4.09062E-06
      26056.70c   6.42139E-05
      26057.70c   1.48298E-06
      25055.70c   7.48872E-06
      30000.70c   1.25834E-06   $ Tot   6.08580E-02
C   SS304 Support Plate
m31   26054.70c   3.51905E-03
      26056.70c   5.52415E-02
      26057.70c   1.27577E-03
      26058.70c   1.69781E-04
      6000.70c   1.60142E-04
      25055.70c   8.75287E-04
      14028.70c   7.89554E-04
      14029.70c   4.00916E-05
      14030.70c   2.64287E-05
      24050.70c   7.63478E-04
      24052.70c   1.47229E-02
      24053.70c   1.66946E-03
      24054.70c   4.15564E-04
      28058.70c   5.29886E-03
      28060.70c   2.04111E-03
      28061.70c   8.87257E-05
      28062.70c   2.82896E-04
      28064.70c   7.20454E-05
      15031.70c   3.49310E-05
      16032.70c   2.13510E-05
      16033.70c   1.70934E-07
      16034.70c   9.64879E-07
      16034.70c   4.49827E-09   $ tot   8.75101E-02
C    U Foils
m50   92234.70c   4.67753E-04
      92235.70c   4.47223E-02
      92236.70c   1.14750E-04
      92238.70c   2.67865E-03   $ total   4.79835E-02
C    Cd Covers
m55   48106.70c   5.79249E-04
      48108.70c   4.12425E-04
      48110.70c   5.78786E-03
      48111.70c   5.93151E-03
      48112.70c   1.11818E-02
      48113.70c   5.66274E-03
      48114.70c   1.33135E-02
      48116.70c   3.47086E-03   $ total   4.63399E-02
C   Scattering Cards
mt1   o2/u.10t  u/o2.10t
mt2    al27.12t
mt8   be.10t
```

```
mt9   be.10t
mt10  be.10t
mt13   al27.12t
mt14   al27.12t
C mt20   al27.12t
C mt22   al27.12t
C m23    al27.12t
mt30   al27.12t
C
kcode  100000 1 150 2150
ksrc   0.0692  4.5245 0.77787  0  8.8072 0.7787
       0.0692 -4.3864 0.77787  0 -8.7382 0.7787
       3.8736 0 0.7787   7.6780 0 0.7787
      -3.7353 0 0.7787  -7.8510 0 0.7787
f4:n  700
fm4   1 50 -6
C
f14:n   701
fm14   1 50 -6
C
f24:n   702
fm24   1 50 -6
C
f34:n   703
fm34   1 50 -6
C
f44:n   704
fm44   1 50 -6
C
f54:n  705
fm54   1 50 -6
C
f64:n   706
fm64   1 50 -6
C
f74:n   707
fm74   1 50 -6
C
f84:n   708
fm84   1 50 -6
C
f94:n   709
fm94   1 50 -6
C
f104:n   710
fm104   1 50 -6
C
f114:n   711
fm114   1 50 -6
C
f124:n   712
fm124   1 50 -6
C
f134:n   713
fm134   1 50 -6
C
f144:n   720
fm144   1 50 -6
C
f154:n   721
fm154   1 50 -6
C
f164:n   722
fm164   1 50 -6
C
f174:n   723
fm174   1 50 -6
C
f184:n   724
fm184   1 50 -6
C
f194:n   725
fm194   1 50 -6
C
f204:n   726
fm204   1 50 -6
```

```
C
f214:n   727
fm214   1 50 -6
C
f224:n   728
fm224   1 50 -6
C
f234:n   729
fm234   1 50 -6
C
f244:n   730
fm244   1 50 -6
C
f254:n   731
fm254   1 50 -6
C
f264:n   741
fm264   1 50 -6
C
f274:n   742
fm274   1 50 -6
C  rand  seed=7065399757867  $ r2
C  rand  seed=5724484131590  $ r3
C  rand  seed=417647895433   $ r4
C  rand  seed=8132049697893  $ r5
C  rand  seed=8663498807872  $ r6
C  rand  seed=7447087897166  $ r7
```

A.8 Power Distribution Configurations

The axial relative power distribution is the same as the relative fission rate as was measured in the core region of Assembly 1 (see Section A.7).

A.9 Isotopic Configurations

Isotopic measurements were not performed.

A.10 Configurations of Other Miscellaneous Types of Measurements

Other miscellaneous types of measurements were not performed.