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

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March 2013

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Space Reactor-SPACE

SCCA-SPACE-EXP-002
CRIT-SPEC-REAC-RRATE

CRITICAL CONFIGURATION AND PHYSICS MEASUREMENTS FOR ASSEMBLIES OF U(93.15)O_2 FUEL RODS (1.506-CM PITCH)

Evaluator

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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	YES	YES	YES
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	YES	YES	YES	YES
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	YES	YES	YES	YES
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	YES	YES	YES	YES
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 Calculations	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 ASSEMBLIES OF U(93.15)O_2 FUEL RODS (1.506-CM PITCH)

IDENTIFICATION NUMBER: SCCA-SPACE-EXP-002
CRIT-SPEC-REAC-RRATE

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

SUMMARY INFORMATION

1.0 DETAILED DESCRIPTION

A series of small, compact critical assemblies (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] 1962 through 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 unmoderated stainless-steel tubes, each containing 26 UO_2 fuel pellets, surrounded by a graphite reflector. Measurements were performed to determine critical reflector arrangements, relative 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 second of the series and had the fuel rods in a 1.506-cm-triangular pitch. One critical configuration was found (see Reference 3). Once the critical configuration had been achieved, various measurements of reactivity, relative axial and radial activation rates of ^{235}U,[bc] and cadmium ratios were performed. The cadmium ratio, reactivity, and activation rate measurements performed on the critical configuration 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,[d] 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] What was referred to as the fission rates in References 1, 2 and 3 are induced fissions in a uranium fission counter for the axial measurements and relative activation of ^{235}U fission foils for the radial measurements (see Section 1.7.1). (Personal communication with J.T. Mihalczo, September 19, 2011).

[c] Axial measurements in the core were made to determine the axial power density distribution.

[d] Radiation Safety Information Computation Center (RSICC), The ORNL Critical Experiments Logbooks, Book 75r, http://rsicc.ornl.gov/RelatedLinks.aspx?t=criticallist, logbook page 63-77.

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-002.[a])

1.2 Description of Buckling and Extrapolation Length Measurements

Buckling and extrapolation-length measurements were not made.

1.3 Description of Spectral Characteristics Measurements

1.3.1 Overview of Experiment

Cadmium ratios were measured with enriched uranium metal foils through the lower section of the radial reflector and are described in the following subsections. The cadmium ratio measurements have been judged to be acceptable as benchmark experiments.

1.3.2 Geometry of the Experiment Configuration and Measurement Procedure

The experiment configuration was the same as the critical configuration described in HEU-COMP-FAST-002. The 1.27-cm-diameter radial holes in the lower side reflector, located 7.63 cm below the midplane of the core, were used for the cadmium ratio measurements. The experimenter inserted 0.75-cm-diameter × 0.010-cm-thick 93.15 wt.%-^{235}U-enriched uranium metal foils,[b] some with 0.051-cm-thick cadmium covers and some without, into the radial holes in the side reflector by placing them between sections of graphite plugs. One part of the cadmium cover was cup-shaped and the uranium foil fit tightly into the cup. 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. The outside diameter of the cadmium cover was 0.85 cm. A drawing of a HEU metal foil and the cadmium cover is given in Figure 1.3-1.[c] According to the logbook five bare foils were distributed through two radial holes to maximize distance between the foils and five covered foils were distributed through two different radial holes, again to maximize distance between the foils.

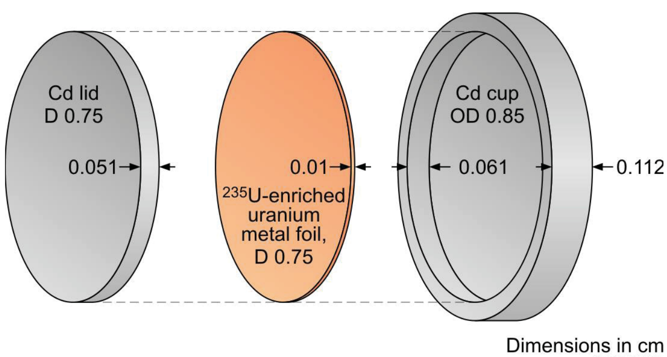

Figure 1.3-1. HEU Metal Foil and Cadmium Cover.

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

[b] References 1 and 2 report 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 and November 9, 2012.

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 were “the same foil to less than 1% for activation in the same neutron flux for the same time.” [a] 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 %. All foils were counted for at least 100,000 counts. The measurement uncertainty would have been 0.5 %.[b] 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 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. 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. [c] The results of the cadmium ratio measurements are given in Table 1.3-1 and Figure 1.3-2. “No correction has been made for self shielding in the foils” (Reference 3).

Table 1.3-1. Radial Cadmium Ratio (see Reference 3).

Distance from Core(a) (cm)	Cadmium Ratio(b)
0.5	2.97
6.0	4.91
12.0	6.01
18.0	6.60
24.0	7.67

(a) Reported as measured from the core-reflector interface; no additional information was given.
(b) The cadmium ratio is defined as the ratio of the bare-to-cadmium-covered foil activity.

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

[b] Personal communication with J.T. Mihalczo, August 15, 2012.

[c] 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).

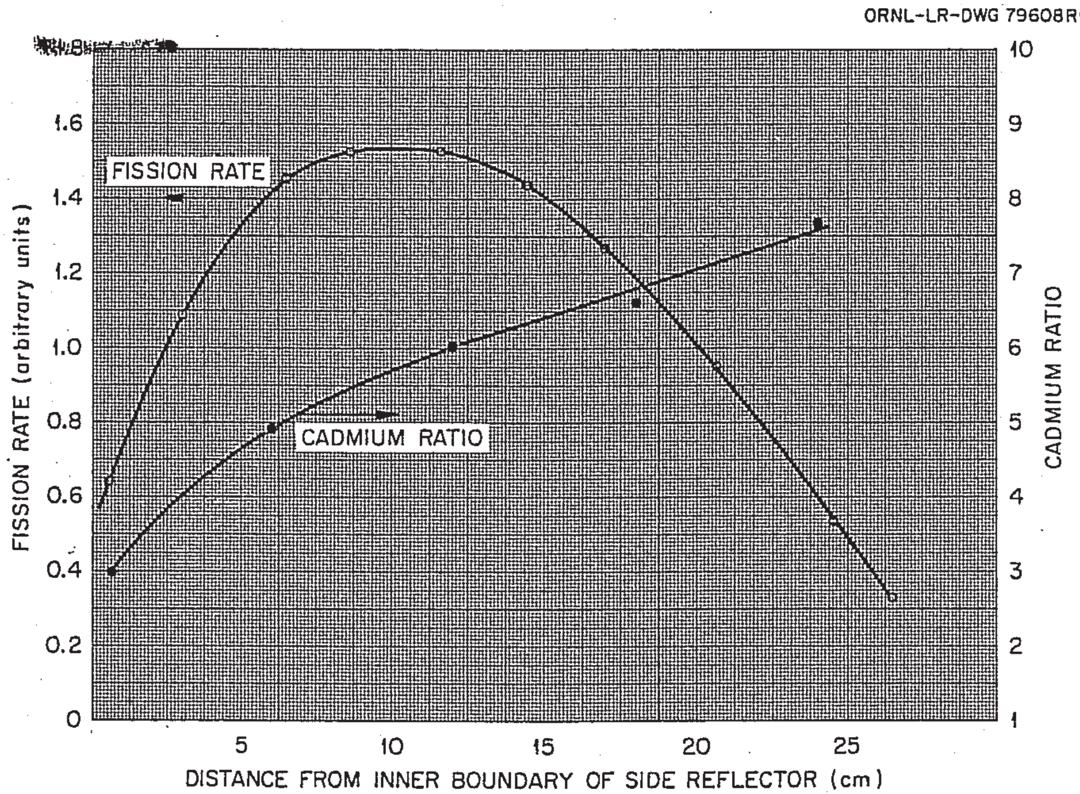

Figure 1.3-2. Plot of Relative Radial Activation of ^{235}U Fission Foils (see Section 1.7) and Cadmium Ratios in the Radial Reflector (see Reference 3).

1.3.3 Material Data

Material data for the core and reflector parts are the same as those given for the critical configuration (see HEU-COMP-FAST-002).

The uranium foils were 93.15 wt.% ^{235}U enriched. No impurity data were given for the uranium in the published reports or the logbooks 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] No material data for the cadmium foils were given.

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 Experiment

The critical configurations included five of six graphite plugs inserted into 1.27-cm-diameter radial holes in the graphite side reflector. The worth of one of these graphite plugs was measured and reported in References 3. The graphite plugs were inserted into the holes in the radial reflector for fine adjustments of the reactivity (see Reference 2).

1.4.2 Geometry of the Experiment Configuration and Measurement Procedure

The reactivities were measured using the reactor period method.

The logbook gives the diameter of the graphite plugs in the radial holes in the graphite reflector as 0.437 inches or 1.110 cm. An erroneous diameter of 0.95-cm was given in Reference 3.[a] The worth of one of these plugs was about 2 ¢ per plug. Although no uncertainty was given in the published reports or logbooks, the experimenter has suggested an uncertainty in the worth measurements of 10%.[b]

1.4.3 Material Data

The material data are the same as those given for the critical configuration (see Section 1.3 of HEU-COMP-FAST-002).

1.4.4 Temperature Data

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

1.4.5 Additional Information Relevant to Reactivity Effects Measurements

Additional information was not identified.

1.5 Description of Reactivity Coefficient Measurements

Reactivity coefficient measurements were not performed.

1.6 Description of Kinetics Measurements

Kinetics measurements were not performed.

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[a] RSICC Lobgook 75r, p. 40, Personal communication with J.T. Mihalczo, September 5, 2012.

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

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

1.7 Description of Reaction-Rate Distribution Measurements

1.7.1 Overview of Experiment

The relative axial distribution of induced fission in a uranium fission counter was measured. Within the core region of the assembly, this distribution is directly proportional to the relative fission-rate distribution.

Radial and axial distributions of the relative activation of ^{235}U fission foils in the reflector were also measured. These measurements were also labeled as fission rates in Reference 3; however, according to the experimenter, it should be called the relative activation of ^{235}U fission foils in the radial and top axial reflectors or the radial and axial distributions of the relative activation of ^{235}U fission foils.[a]

Henceforth, the measurements labeled *fission rate* in Reference 3 will be called *axial distribution of the induced fission in a uranium fission counter* or *axial activation of ^{235}U fission foils* for the axial measurements and *radial activation of ^{235}U fission foils* for the radial measurements. *Relative activation* and *activation measurements* are used as a general term to refer to all of these measurements.

The axial distribution of the induced fission in a uranium fission counter was judged unacceptable as a benchmark experiment. The axial and radial activations of ^{235}U fission foils were judged to be acceptable as a benchmark experiment.

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-002).

1.7.2.1 Axial Measurements

A 2.5-cm-long × 0.64-cm-diameter ^{235}U fission counter was used for the axial scans. The counter was inserted through a hole in the top reflector and into the space in the core from which the center fuel rod had been removed. The count locations were based on the midpoint of the 2.5-cm-long detector chamber and were measured using a selsyn meter; the selsyn meter measured the height in centimeters to two significant figures.[b] Counts were recorded on a digital readout scaler.[c] During the axial fission-rate scans, the reactor power was monitored with an external BF_3 counter sitting on the floor meters away from the assembly.[d] About 100,000 counts were collected on the BF_3 monitor at each point and an average of about 10,000 counts on the fission counter. Counter results were normalized to an arbitrary location in the assembly and are summarized in Table 1.7-1, and the results are plotted in Figure 1.7-1. According to the experimenter, because the induced fission rates were normalized, the effect of composition of the fission counter would have a negligible effect.[e]

Three uranium foils identical to those used in the cadmium ratio measurements and the radial foil activation measurements were placed in the top reflector. The results of these foil activations are given in Table 1.7-1.

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[a] Personal communication with J. T. Mihalczo, September 19, 2011 and November 14, 2011.

[b] RSICC Lobgook 75r, p. 48, Personal email communication with J.T. Mihalczo, November 7, 2012.

[c] Personal email communication with J. T. Mihalczo, November, 14, 2011.

[d] Personal email communication with J. T. Mihalczo, September 29, 2011.

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

Table 1.7-1. Relative Axial Induced Fission in a Uranium Fission Counter (see Reference 3).

Distance from Bottom of Core[(a)] (cm)	Relative Fission Rate[(b)]	
	Counter [(b)]	Foils[(c)]
5.0	0.12	
7.5	0.09	
10.0	0.12	
12.6	0.10	
15.1	0.11	
17.7	0.11	
20.2	0.10	
22.8	0.10	
25.3	0.13	
27.8	0.40	
30.4	0.67	
32.9	0.88	
35.4	0.99	
39.7	0.94	1.0
40.5	1.01	
42.8	1.02	0.97
45.8	0.87	0.86
48.1	0.69	
50.7	0.44	
53.2	0.23	

(a) Measured from the bottom of the stainless-steel fuel tubes if reference to the center of the counter.
(b) The detector was a ^{235}U fission counter 2.5 cm long × 0.64 cm diameter.
(c) The foils are the same as those used in the radial activation and cadmium ratio measurements.

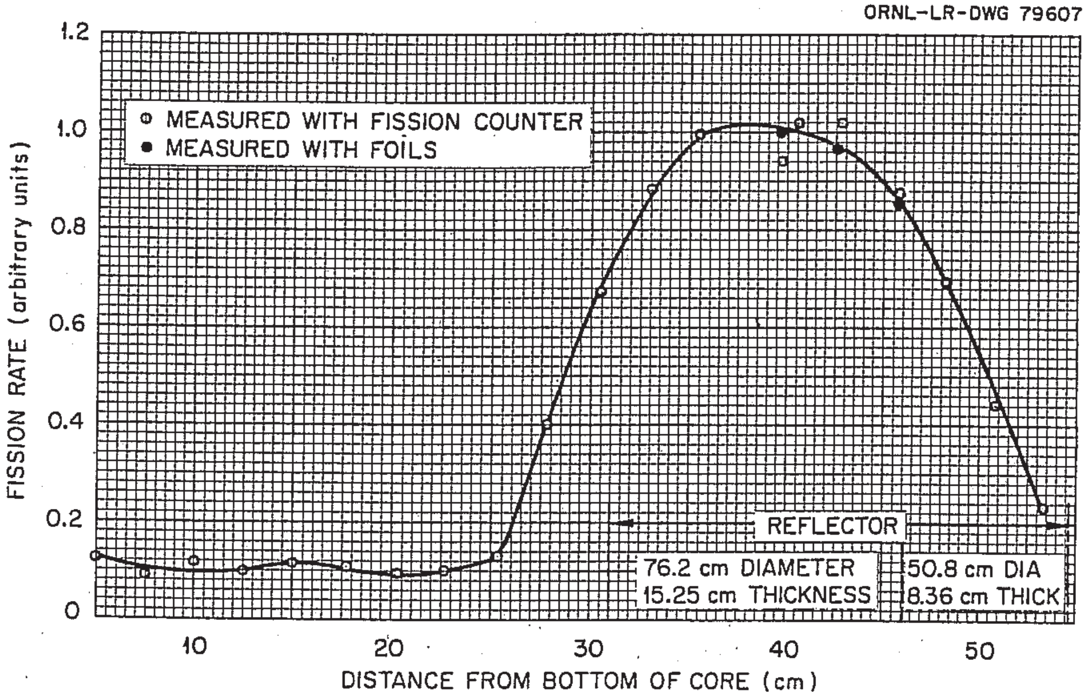

Figure 1.7-1. Normalized Relative Axial Fission Distribution in a Uranium Fission Counter (see Reference 3).

1.7.2.2 Radial Measurements

The relative activation of ^{235}U fission foils was measured in the lower radial reflector, from the core tank out through the side reflector 7.63 cm below the core midplane, using the radial holes in the reflector. Foils were placed between sections of radial graphite plugs and placed at predetermined locations in the side reflector.[a] Additionally, three foils were placed in the top reflector at 39.7, 42.8, and 45.8 cm above the bottom of the core. The 39.7 cm foil was used for normalization of both the axial and radial activation measurements. After activation, foils were placed in NaI detectors and the activity of the foils was measured, as described in Section 1.3.[b] The relative radial distribution activation of ^{235}U fission foils is given in Table 1.7-2 and Figure 1.7-2. A test irradiation, noted in the log book, showed counts of up to 40,000 per minute, depending on the discriminator setting. For each count in a particular NaI detector 100,000 counts were accumulated.[c] The data from the axial and radial measurements of the first assembly were expressed in the same arbitrary units, via the normalization foil in the top reflector.

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[a] Personal email communication with J. T. Mihalczo, September 13, 2011.

[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).

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

Table 1.7-2. Relative Radial Activation of ^{235}U Fission Foils in Radial Reflector (see Reference 3).

Distance from Core (cm)[b]	Relative Radial Distribution[c]
0.5	0.65
3.0	1.08
6.5	1.45
8.5	1.53
11.7	1.52
14.5	1.44
17.0	1.27
20.7	0.95
24.5	0.54
26.5	0.33

(a) Measured from the core-reflector interface. This was the inside surface of the side reflector. (Personal communication with the experimenter, January 12, 2013.)

(b) Measured in the lower side reflector 7.63 cm below core midplane.

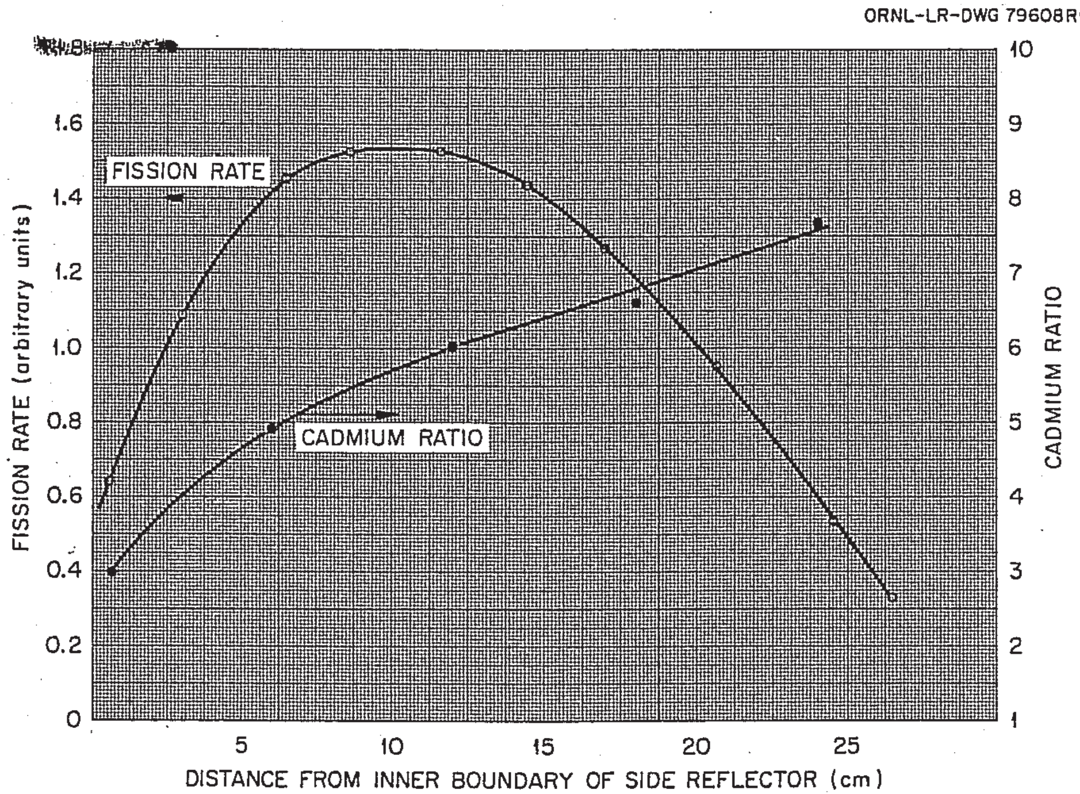

Figure 1.7-2. Relative Radial Activation of ^{235}U Fission Foils in the Lower Radial Reflector (Relative to foil in the top reflector[a]) and Cadmium Ratios in the Lower Radial Reflector (see Reference 3).

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-002).

1.7.3.1 Axial Measurements

The active material in the fission counter was ^{235}U, but the material of the counter housing was brass.[b] According to the experimenter, the enrichment and isotopics of the uranium in the counter was the same as for the uranium metal described in HEU-MET-FAST-052.[c,d]

1.7.3.2 Radial Measurements

The irradiated foils were 93.15 wt.% ^{235}U.[e] The purity of the foils was not given. According to the experimenter, the enrichment and isotopics of the uranium metal foils was the same as the uranium metal described in HEU-MET-FAST-052.[b,c]

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[a] Personal communication with J.T. Mihaclzo, August 29, 2012.

[b] Personal communication with J. T. Mihalczo, September 19, 2011.

[c] Personal communication with J. T. Mihalczo, November 23, 2011.

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

[e] References 1 and 2 report the foil enrichment as 93.2 wt.%, but according to the experimenter, it was 93.15 wt.% (September 19, 2011).

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 relative power distribution is the same as the relative fission rate that was measured in the core region of the assembly (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

The measurements were evaluated using Monte Carlo N-Particle (MCNP) Version 5-1.60[a] and ENDF/B-VII.0[b] neutron cross section libraries. All models were calculated such that the statistical uncertainty in k_{eff}, σ_{MC}, is less than or equal to ±0.00006.

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-002.[c])

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. 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. 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 was taken as the total measurement uncertainty. 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.

Uncertainties for the uranium metal and cadmium covers composition and geometry were evaluated using the simple benchmark model. 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.[d] However, to calculate the effect of impurities in the uranium foils the uranium composition from HEU-MET-FAST-051[e] was used. It was found that a maximum 1σ uncertainty effect for the uranium foil composition is 0.44%. This is used for the uranium foil uncertainty. 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 effect of this uncertainty was ±0.25%. To determine the effect of impurities in the

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[a] 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).

[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).

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

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

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

cadmium covers a 5N cadmium composition[a] is assumed. The average effect on the cadmium ratio is ±0.83%. 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 uncertainty in the cadmium density had a negligible effect.

The uncertainty in the cadmium thickness would have been ± 0.001 cm. The maximum 1σ effect of the uncertainty in the cadmium thickness is ±0.24%. The uncertainty in the uranium foil thickness would have also been ±0.001 cm. The maximum 1σ effect of the uncertainty in the uranium foil thickness is ±1.68%. The uncertainty in the cadmium diameter would have been ±0.001 cm and had a negligible effect. The uncertainty in the uranium foil diameter would have been ±0.01 cm and had a maximum 1σ effect of ±0.26%. The foil position was measured to one decimal place thus the uncertainty in the foil position would have been ±0.1 cm. The effect of the positional uncertainty was negligible. These uncertainties are summarized in Table 2.3-1.

The total experimental uncertainty is 2.04% plus the rounding uncertainty and is summarized in Table 2.3-1.[c] The uncertainty in the cadmium ratio is given in Table 2.3-2 and is shown in Figure 2.3-1.

Table 2.3-1. Summary of Experimental Uncertainty in Cadmium Ratio.

Uncertainty	Effect	
Measurement	±	0.5%
Uranium Composition	±	0.44%
Uranium Density	±	0.26%
Cadmium Composition	±	0.83%
Cadmium Density	±	NEG
Cadmium Thickness	±	0.24%
Uranium Foil Thickness	±	1.68%
Cadmium Diameter	±	NEG
Uranium Foil Diameter	±	0.26%
Foil Position	±	NEG
Total	±	2.04%
Rounding	±	0.01/√3

[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

[c] 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 2.3-2. Uncertainty in Cadmium Ratio.

Distance from Core (cm)[(a)]	Cadmium Ratio[(b)]		
0.5	2.97	±	0.036
6.0	4.91	±	0.046
12.0	6.01	±	0.050
18.0	6.60	±	0.053
24.0	7.67	±	0.057

(a) Measured from the core-reflector interface. This was the inside surface of the side reflector.
(b) Measured through lower side reflector: 7.63 cm below the midplane of the core.

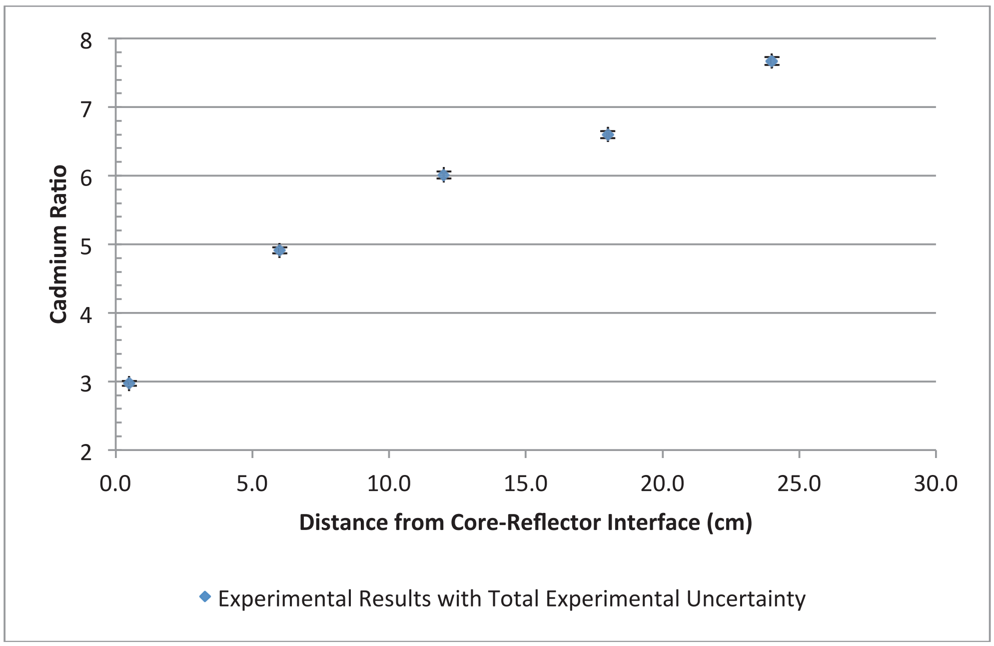

Figure 2.3-1. Experimental Cadmium Ratio with Total Experimental Uncertainty.

2.4 Evaluation of Reactivity Effects Data

No uncertainty in the worth measurements was reported. A 10% 1σ total uncertainty was assumed for the worth measurements.[a] An additional rounding uncertainty of ±0.5 ¢ (1σ) was also included in the worth measurement.[b] The worth of one radial plug was about 2 ± 0.54 ¢.

2.5 Evaluation of Reactivity Coefficient Data

Reactivity coefficient measurements were not performed.

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[a] A 10% uncertainty was recommended by the experimenter, November 23, 2011.

[b] The experimenter believes that the ±0.5 ¢ (1σ) rounding uncertainty is not justified but it is retained in the total experimental based in the judgement of the evaluator, the other reviewers, and the technical review group.

2.6 Evaluation of Kinetics Measurements Data

Kinetics measurements were not performed

2.7 Evaluation of Reaction-Rate Distributions

2.7.1 Axial Measurements

Upon evaluating and reviewing the axial induced fission in a uranium fission counter data it was found that the data are unacceptable as benchmark experiments. The calculation bias for the axial measurements was very high for the top of the core and bottom of the top reflector region. The same measurement in the first experiment, SCCA-SPACE-EXP-001, did not have a large calculational bias thus it was judged that the axial uranium fission counter measurement was unacceptable. The calculational bias for the simple model can be seen in Figure 2.7-1. It is apparent from this figure that there may have been a shift in the data that could have simply been due to a clerical error but this cannot be verified and the data must be rejected, in the absence of clarifying information. The evaluation of the axial uranium fission counter data has been preserved in Appendix B.

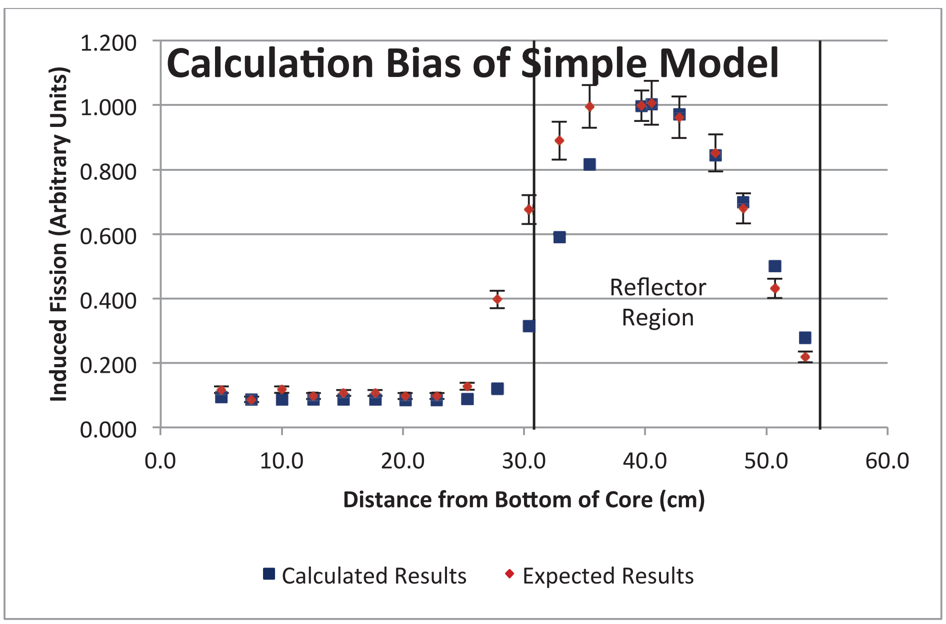

Figure 2.7-1. Calculation bias in Simple Model of Axial Measurement.

Three axial fission rate measurements were performed using uranium foils placed axially in the top reflector. The foils were identical to the uranium foils used in the radial foil activation measurements. The uncertainty in these measurements was judged to be the same as the uncertainty in the radial foil activation for SCCA-SPACE-EXP-001 and for this experiment: ±2.26% for the normalization point (39.7 cm) and ±2.26%√2 for the other two points (see Table 2.7-2 for a summary of the total uncertainty).[a] The axial activation of uranium foils results with associated experimental uncertainty is given in Table 2.7-1.

[a] The experimenter believes that the ±0.5 ¢ (1σ) rounding uncertainty is not justified but it is retained in the total experimental based in the judgement of the evaluator, the other reviewers, and the technical review group.

Table 2.7-1. Uncertainty in Relative Axial Activation of ^{235}U Fission Foils Distribution.

Distance from Bottom of Core (cm)	Axial Distribution ($\pm2.26\%\sqrt{2}$)[(a)]		
39.7	1.0	±	0.023
42.8	0.97	±	0.032
45.8	0.86	±	0.028

(a) The √2 accounts for the added uncertainty for the normalization and is not needed for the 39.7 cm measurement since it is the normalization foil.

2.7.2 Radial Measurements

No uncertainty in the radial measurement of the activation of ^{235}U fission foils was reported by the experimenter. According to the experimenter the measurement uncertainty would have been 0.5 %.

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 0.79 %. 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 ±0.08 %. The effect of foil enrichment and purity was evaluated by comparing tallies 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 normalized tally results of only 0.6 %. 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 would have been ±0.001 cm. The maximum 1σ effect of the uncertainty in the uranium foil thickness is ±2.05 %. The uncertainty in the uranium foil diameter would have been ±0.01 cm and had a maximum 1σ effect of ±0.08 %. 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 uncertainty is applied to all measurement points 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. These uncertainties, added in quadrature, are summarized in Table 2.7-2, given in Table 2.7-3 and shown in Figure 2.7-2.[b]

The relative radial activation of the ^{235}U fission foils was measured from the core-reflector interface; however, there was a 0.1-cm gap between the outside of the core and the inside of the side reflector. The zero point for these measurements was assumed to be at the inside surface of the side reflector. Radial plugs were in place when the activation of ^{235}U fission foils measurements were made.[c]

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

[b] The experimenter believes that the ±0.5 ¢ (1σ) rounding uncertainty is not justified but it is retained in the total experimental based in the judgement of the evaluator, the other reviewers, and the technical review group.

[c] Personal email communication with J. T. Mihalczo, September 13, 2011.

Table 2.7-2. Summary of Experimental Uncertainty in Radial Activation of ^{235}U Fission Foils.

Uncertainty		Effect
Measurement	±	0.5%
Uranium Composition	±	0.79%
Uranium Density	±	0.08%
Uranium Foil Enrichment	±	NEG
Uranium Foil Thickness	±	2.05%
Uranium Foil Diameter	±	0.08%
Foil Position	±	NEG
Total	±	2.26%√2[(a)]
Rounding	±	0.01/√3

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

Table 2.7-3. Uncertainty in Relative Radial Activation of ^{235}U Fission Foils Distribution.

Distance from Core (cm)[(a)]	Radial Distribution[(b)(c)]		
0.5	0.65	±	0.022
3.0	1.08	±	0.035
6.5	1.45	±	0.047
8.5	1.53	±	0.049
11.7	1.52	±	0.049
14.5	1.44	±	0.046
17.0	1.27	±	0.041
20.7	0.95	±	0.031
24.5	0.54	±	0.018
26.5	0.33	±	0.012

(a) Measured from the core-reflector interface. This was the inside surface of the side reflector.
(b) Normalized to axial foil in top reflector.
(c) Measured through lower side reflector, 7.63 cm below the core midplane.

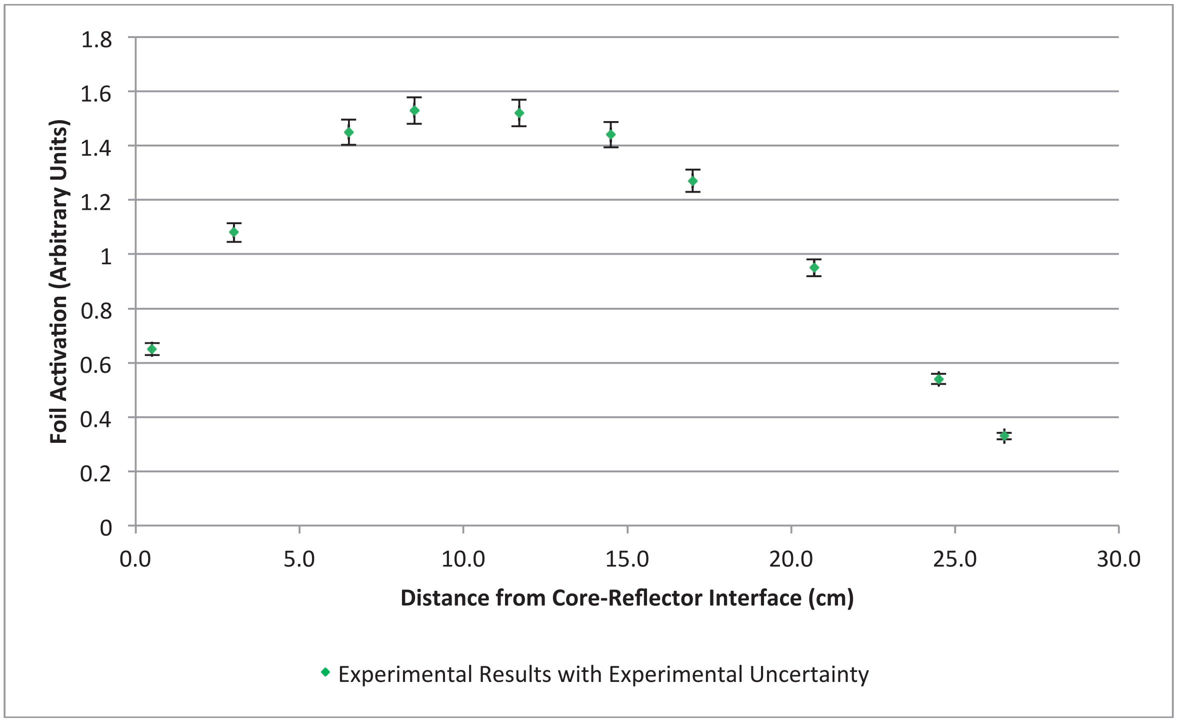

Figure 2.7-2. Uncertainty in Relative Radial Distribution of Activation of ^{235}U Fission Foils.

2.8 Evaluation of Power Distribution Data

The axial relative power distribution in the core is the same as the relative fission rate as was measured in the core region (see Section 2.7).

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

Models of the experiment were created using MCNP5 with ENDF.B-VII.0 neutron cross section libraries. Two benchmark models were created, a detailed and a simple benchmark model. The biases for the two benchmark models were determined by comparing against an as built model. All models were calculated with MCNP5 such that the statistical uncertainty (1σ) of k_{eff} was not more than 0.00006.

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-002.[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 detailed benchmark model was the same as the detailed benchmark model for the critical configuration described in HEU-COMP-FAST-002. The simple benchmark model for the cadmium ratio measurements had one less simplification than the critical simple benchmark model; the holes and plugs in the lower side and in both top reflectors were not homogenized into the reflector mass. All other simplifications given in Table 3-2 in HEU-COMP-FAST-002 were performed. The total simplification bias for the detailed and simple benchmark models was calculated and is given in Table 3.3-1. 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.

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

Table 3.3-1. Simplification Bias of Cadmium Ratios.

Distance from Core (cm)[(a)]	Detailed Benchmark Model Simplification Bias			Simple Benchmark Model Simplification Bias		
0.5	-	±	0.015	0.091	±	0.015
6.0	-	±	0.019	0.103	±	0.020
12.0	-	±	0.024	0.117	±	0.025
18.0	-	±	0.032	0.145	±	0.033
24.0	-0.095	±	0.050	0.064	±	0.051

(a) Measured from the core-reflector interface (i.e., the inside surface of the side reflector). Measured through lower side reflector 7.63 cm below the midplane of the core.

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

3.3.2 Dimensions

The detailed benchmark model for the cadmium ratio measurements was the same as the detailed benchmark model for the critical configurations given in HEU-COMP-FAST-002 (see Section 3.2.1 for dimensions). The detailed benchmark model is shown in Figure 3.3-1 for reference but HEU-COMP-FAST-002 should be used for a full description of the model.

The simple benchmark model for the cadmium ratio measurements was similar to the simple benchmark for the critical configuration given in HEU-COMP-FAST-002 but the plugs and plug holes in the lower side and top reflectors were modeled explicitly. There were six 1.27-cm-diameter radial foil holes 7.63 cm below the midplane of the core. Five of the six holes were filled with 1.11-cm graphite plugs. Similarly, a 1.27-cm-diameter hole ran axially through the center of the lower and upper top reflectors and was filled with a 1.11-cm graphite plug. The dimensions and locations of these foil holes and plugs can be seen in Figure 3.3-2. All other dimensions were the same as those given in HEU-COMP-FAST-002 for the simple benchmark model (see Section 3.2.2).

For both the detailed and simple benchmark models, the uranium foils were 0.75-cm in diameter and 0.01-cm thick. The five bare foils were placed in two of the plugged holes and the five covered foils were placed in two other plugged holes. Foils were distributed to maximize distance between them. The cadmium covers completely enclosed the uranium metal foils, were 0.051-cm thick and extended just beyond the diameter of the uranium foils as shown in Figure 3.3-3.

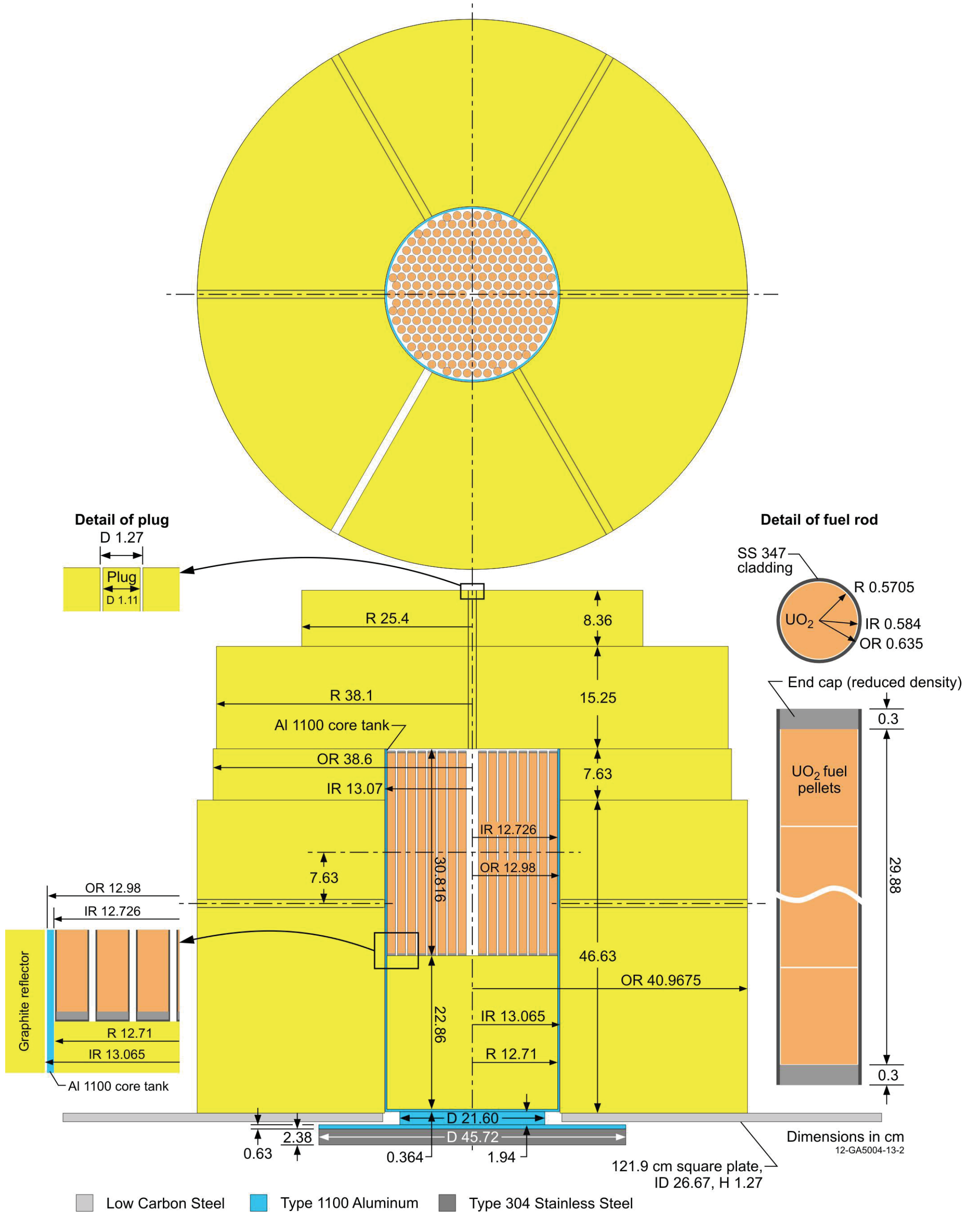

Figure 3.3-1. Detailed Benchmark Model.[a]

[a] Simplification and biases applied to the detailed benchmark model from the as-built model include: room return bias, replacing air with void, grid plate simplification, fuel tube end cap simplification, and temperature bias.

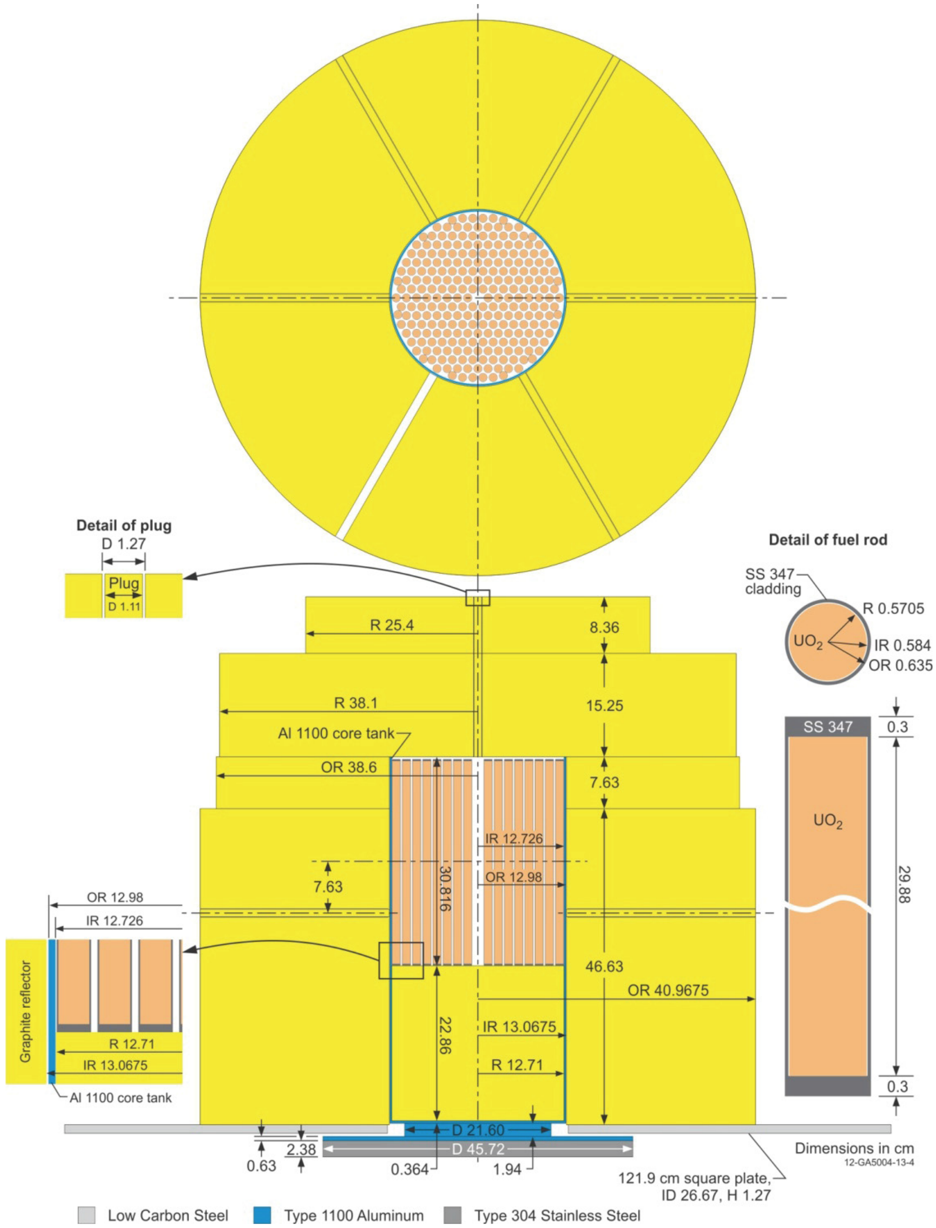

Figure 3.3-2. Simple Benchmark Model.[a]

[a] Additional simplifications for the simple benchmark model applied to the detailed benchmark model include: side reflector inside diameter averaging, removing of shims, removing of grid plate spacer tubes, removing of grid plates, simplification of the fuel tube, and the removal of fuel and graphite impurities.

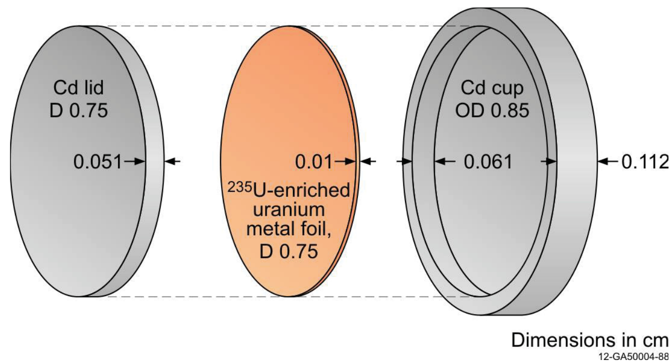

Figure 3.3-3. Uranium Foils and Cadmium Covers.

3.3.3 Material Data

The material data for the detailed benchmark model for the cadmium ratios was the same as the material data for the detailed benchmark model for the critical configuration (see HEU-COMP-FAST-002, Section 3.3.1).

The material data for the simple benchmark model for the cadmium ratios was the same for all materials except the lower side, lower top, and upper top reflectors. The material data for all sections of reflector is given in Table 3.3-2. All other material data can be found in HEU-COMP-FAST-002, Section 3.3.2.

Table 3.3-2. Simple Benchmark Model, Reflector Composition.

Element	wt.%	Lower Side Reflector Atom/barn-cm	Upper Side Reflector Atom/barn-cm	Lower Top Reflector Atom/barn-cm	Upper Top Reflector Atom/barn-cm	Bottom Reflector Atom/barn-cm
C[(a)]	99.45355%	8.7771E-02	8.6742E-02	8.8986E-02	8.3883E-02	8.2566E-02

(a) Impurities in the graphite were replaced with void.

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

Table 3.3-3. 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 had a density of 8.65 g/cm^3. The composition is given in Table 3.3-4.

Table 3.3-4. 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 Parameters

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 3.3-5 and Figure 3.3-3.

Table 3.3-5. Benchmark Cadmium Ratios.

Distance from Core (cm)[(a)]	Detailed Benchmark Cadmium Ratios			Simple Benchmark Cadmium Ratios		
0.5	2.97	±	0.04	3.06	±	0.04
6.0	4.91	±	0.05	5.01	±	0.05
12.0	6.01	±	0.06	6.13	±	0.06
18.0	6.60	±	0.06	6.74	±	0.06
24.0	7.58	±	0.08	7.73	±	0.08

(a) Measured from the core-reflector interface (i.e., the inside surface of the side reflector). Measured through lower side reflector 7.63 cm below the midplane of the core.

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

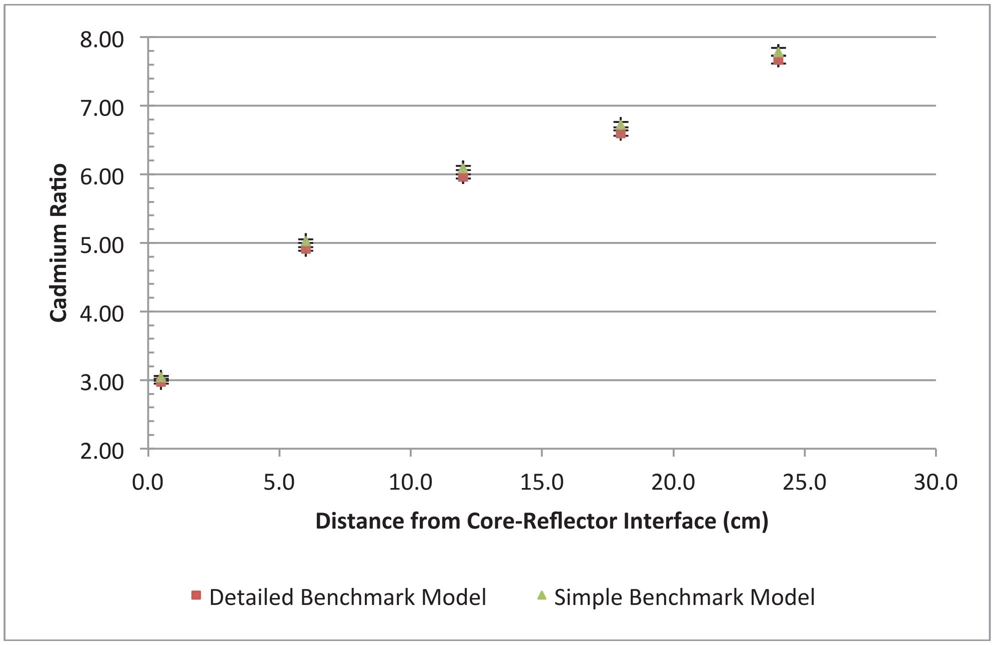

Figure 3.3-3. Benchmark Cadmium Ratios.[a]

3.4 Benchmark-Model Specifications for Reactivity Effects Measurements

3.4.1 Description of the Benchmark Model Simplifications

The models used to determine the radial graphite plug worth were the same as the detailed and simple benchmark models used for the cadmium ratio measurements but without the uranium foils and cadmium covers and were run using MCNP5 and ENDF/B-VII.0 neutron cross section libraries. They were run until the statistical uncertainty of k_{eff} was 0.00002. Thus, the statistical uncertainty in the reactivity calculation was 0.00003, or approximately 0.39 ¢ for the plug worth measurements (1σ) and 0.56 ¢ for the bias calculation. Biases were considered negligible if they were less than 0.00006 $\Delta\rho$ (in units of Δk_{eff}).

The simplifications in the geometry from the as built model to the detailed and simple benchmark models had a negligible bias for the calculation of the graphite plug worth. The associated bias uncertainty was 0.56 ¢. The benchmark worth of one radial graphite plug is given in Table 3.4-1.

Table 3.4-1. Benchmark Experiment Worth Value.

	Reactivity
Worth of One Radial Graphite Plugs	2 ± 0.78 ¢[(a)]

(a) Total uncertainty was found by adding in quadrature the measurement uncertainty, ±0.54 ¢, in Section 2.4 and the bias uncertainty of ±0.56 ¢.

[a] The zero point is the inside surface of the side reflector.

3.4.2 Dimensions

The detailed and simple benchmark models were identical to those used for the evaluation of the cadmium ratio (see Section 3.3.2). To model the worth of a radial graphite plug one plug was removed from the benchmark model and the resulting change to k_{eff} was used to determine the worth of a plug.

3.4.3 Material Data

The detailed and simple benchmark model materials were identical to those used for the evaluation of the cadmium ratio (see Section 3.3.3)

3.4.4 Temperature Data

The temperature was the same as the benchmark model (see Section 3.1.4).

3.4.5 Experimental and Benchmark-Model Reactivity Effect Parameters

The worth of one radial plug was 2 ± 0.78 ¢.

3.5 Benchmark-Model Specifications for Reactivity Coefficient Measurements

Reactivity coefficient measurements were not performed.

3.6 Benchmark-Model Specifications for Kinetics Measurements

Kinetics measurements were not performed.

3.7 Benchmark-Model Specifications for Reaction-Rate Distribution Measurements

3.7.1 Description of the Benchmark Model Simplifications

The model for the evaluation of the reaction-rate distribution was the same as the model used for the evaluation of the cadmium ratios (see Section 3.3.1).

A bias in the reaction-rate distribution measurements in 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.

3.7.1.1 Axial Measurement

The axial distribution of induced fission in a uranium fission counter measurements were found to be unacceptable as a benchmark experiment. Evaluated data have been preserved in Appendix B.

The model used for axial foil activation measurements used a mesh of cells superimposed over the geometry that had a radius of 0.32 cm and extended from the bottom of the core tank to the top of the top reflector. Each cell had a height of 0.01 cm. Cell-averaged flux tallies were used. A tally multiplier for the ^{235}U fission cross section was also used. It is believed that this method for modeling the reaction-rate distribution would have a negligible bias. The simplification biases for the detailed and simple benchmark model for the three axial activation foils were negligible. The bias uncertainty was ±0.007 for all three foils for both benchmark models.

3.7.1.2 Radial Measurement

A superimposed mesh was used to model the radial reaction-rate distributions. The cells had a radius of 0.375 cm and extended from the core tank out through the side reflector. Each cell had a height of 0.01 cm. An identically sized mesh tally was also used to model the activation of the foil that was placed in the top reflector (39.7 cm above to bottom of the core) for normalization of the radial measurements to axial measurements. A tally multiplier for the uranium fission cross section (93.2 wt.% ^{235}U, 6.8 wt.% ^{238}U) was used. It is believed that this method for modeling the reaction-rate distribution would have a negligible bias. The simplification bias on the measurement due to geometry simplifications is given in Table 3.7-1. Statistically insignificant biases were not included in Table 3.7-1 but the associated bias uncertainty was preserved.

Table 3.7-1. Simplification Bias of Distribution of Relative Radial Activation of ^{235}U Fission Foils.

Distance from Core (cm)[a]	Simplification Bias[b]					
	Detailed Benchmark Model			Simple Benchmark Model		
0.5	-	±	0.004	-	±	0.004
3.0	0.007	±	0.006	-0.008	±	0.006
6.5	0.009	±	0.007	-0.013	±	0.007
8.5	-	±	0.008	-0.014	±	0.008
11.7	0.009	±	0.008	-0.017	±	0.008
14.5	-	±	0.008	-0.013	±	0.008
17.0	-	±	0.007	-0.016	±	0.007
20.7	-	±	0.006	-0.011	±	0.006
24.5	-	±	0.004	-0.009	±	0.004
26.5	-0.010	±	0.003	-0.014	±	0.003

(a) Measured from the core-reflector interface.
(b) Calculated by comparing as-built model results to detailed and simple benchmark-model results.

3.7.2 Dimensions

The dimensions for the detailed and simple benchmark models for the axial and radial foil activation measurements were the same as those used for the evaluation of the cadmium ratio (see Sections 3.3.2) but without the cadmium covers.

3.7.3 Material Data

The material data for the detailed and simple benchmark models of the axial and radial foil activation measurements were the same as those used for the evaluation of the cadmium ratio (see Sections 3.3.3).

3.7.4 Temperature Data

The temperature was the same as the cadmium ratio benchmark model (see Section 3.1.4).

3.7.5 Experimental and Benchmark-Model Reaction-Rate Distribution Parameters

3.7.5.1 Axial Measurement

The benchmark values of the axial ^{235}U fission foil activation measurements are given in Table 3.7-2. 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 of ±0.007. The benchmark values for the detailed and simple benchmark models are identical.

Table 3.7-2. Benchmark Relative Axial Distribution of Activation of ^{235}U Fission Foils.

Distance from Bottom of Core (cm)	Detailed Benchmark Model			Simple Benchmark Model		
39.7	1.0	±	0.02	1.0	±	0.02
42.8	0.97	±	0.03	0.97	±	0.03
45.8	0.86	±	0.03	0.86	±	0.03

3.7.5.2 Radial Measurement

The radial distribution of the activation of ^{235}U fission foils and the associated uncertainties, as discussed in Section 2.7, are given in Table 3.7-3 and Figure 3.7-1.

Table 3.7-3. Benchmark Distribution of Relative Radial Activation of ^{235}U Fission Foils.

Distance from Core (cm)[a]	Foil Activation[b][c][d]					
	Detailed Benchmark Model			Simple Benchmark Model		
0.5	0.65	±	0.02	0.65	±	0.02
3.0	1.09	±	0.04	1.07	±	0.04
6.5	1.46	±	0.05	1.44	±	0.05
8.5	1.53	±	0.05	1.52	±	0.05
11.7	1.53	±	0.05	1.50	±	0.05
14.5	1.44	±	0.05	1.43	±	0.05
17.0	1.27	±	0.04	1.25	±	0.04
20.7	0.95	±	0.03	0.94	±	0.03
24.5	0.54	±	0.02	0.53	±	0.02
26.5	0.32	±	0.01	0.32	±	0.01

(a) Measured from the core-reflector interface.
(b) Normalized to axial foil in the top reflector at 39.7 cm from the bottom of the core.
(c) Measured through lower side reflector 7.63 cm below the midplane of the core.
(d) The total uncertainty includes the experimental and bias uncertainties added in quadrature.

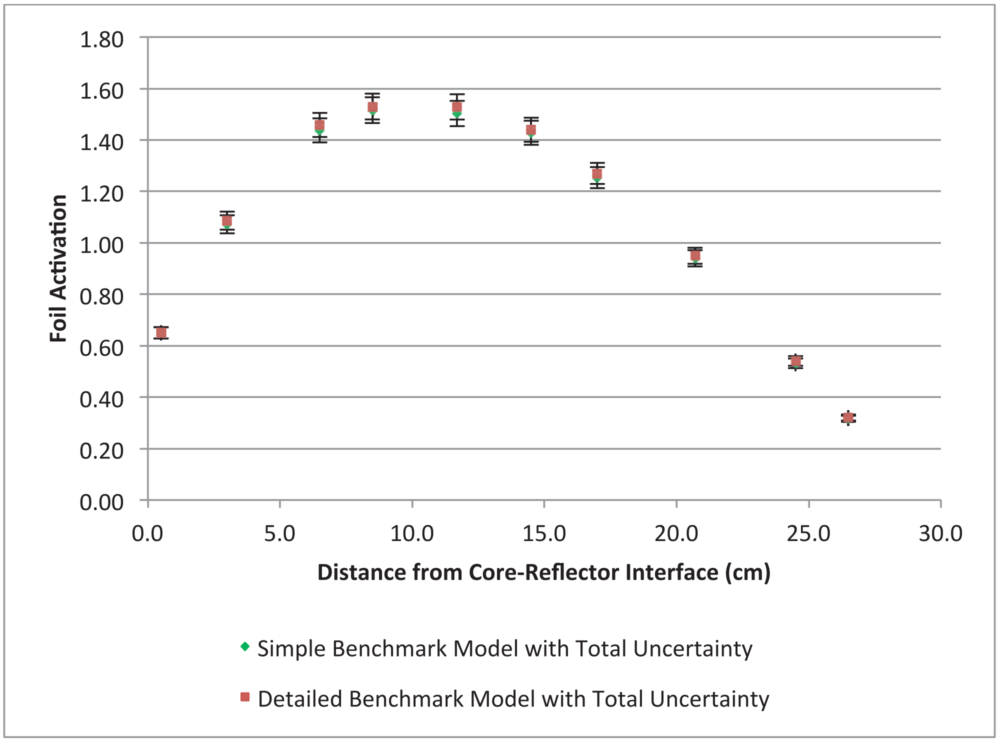

Figure 3.7-1. Benchmark Relative Radial Distribution of Activation of ^{235}U Fission Foils.[a]

3.8 Benchmark-Model Specifications for Power Distribution Measurements

The axial relative power distribution is the same as the relative fission rate as was measured in the core region (see Appendix B.3).

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.

[a] The zero point was assumed to be at the inside surface of the side reflector.

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-002.[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 evaluated 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 and shown in Figure 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. Radial Activation of ^{235}U Fission Foils, Detailed Model.

Distance from Core (cm)[(a)]	Cadmium Ratio						(C-E)/E[(b)]	C/E[(b)] Ratio		
	Detailed Benchmark Value			Detailed Calculated Value						
0.5	2.97	±	0.04	3.22	±	0.01	8.30%	1.08	±	0.01
6.0	4.91	±	0.05	4.91	±	0.01	-0.04%	1.00	±	0.01
12.0	6.01	±	0.06	5.85	±	0.02	-2.65%	0.97	±	0.01
18.0	6.60	±	0.06	6.56	±	0.02	-0.54%	0.99	±	0.01
24.0	7.58	±	0.08	6.92	±	0.04	-8.65%	0.91	±	0.01

(a) Zero point is the inside surface of side reflector.
(b) "E" is the expected or benchmark value. "C" is the calculated value.

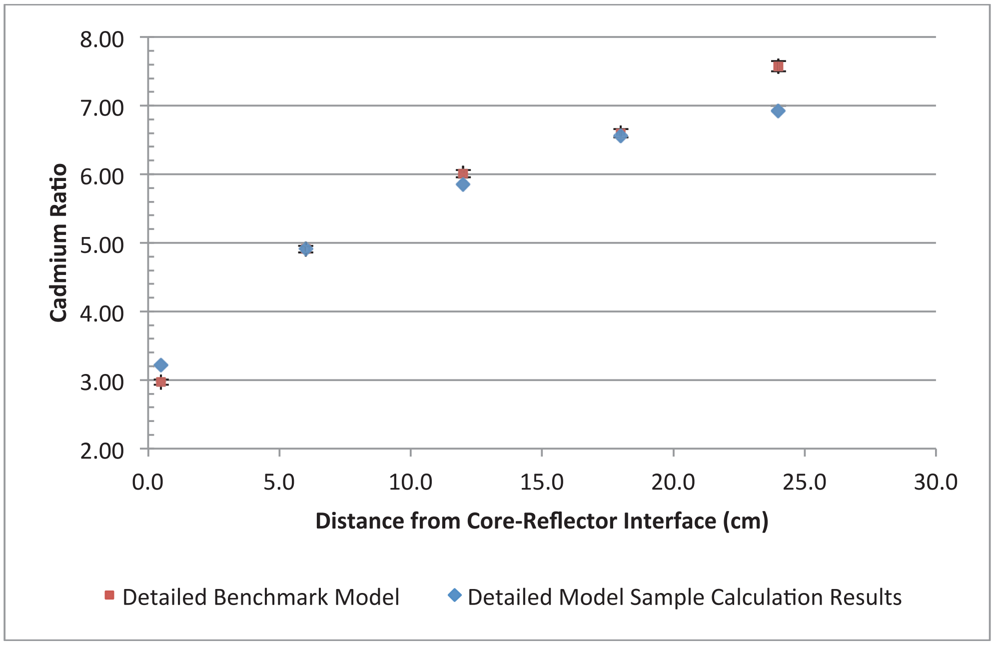

Figure 4.3-1. Cadmium Ratios, Detailed Model.

Table 4.3-2. Radial Activation of ^{235}U Fission Foils, Simple Model.

Distance from Core (cm)[(a)]	Cadmium Ratio						(C-E)/E[(b)]	C/E[(b)] Ratio		
	Simple Benchmark Value			Simple Calculated Value						
0.5	3.06	±	0.04	3.31	±	0.01	8.08%	1.08	±	0.01
6.0	5.01	±	0.05	5.01	±	0.01	-0.15%	1.00	±	0.01
12.0	6.13	±	0.06	5.98	±	0.02	-2.34%	0.98	±	0.01
18.0	6.74	±	0.06	6.70	±	0.02	-0.64%	0.99	±	0.01
24.0	7.73	±	0.08	7.08	±	0.04	-8.47%	0.92	±	0.01

(a) Zero point is the inside surface of side reflector.
(b) "E" is the expected or benchmark value. "C" is the calculated value.

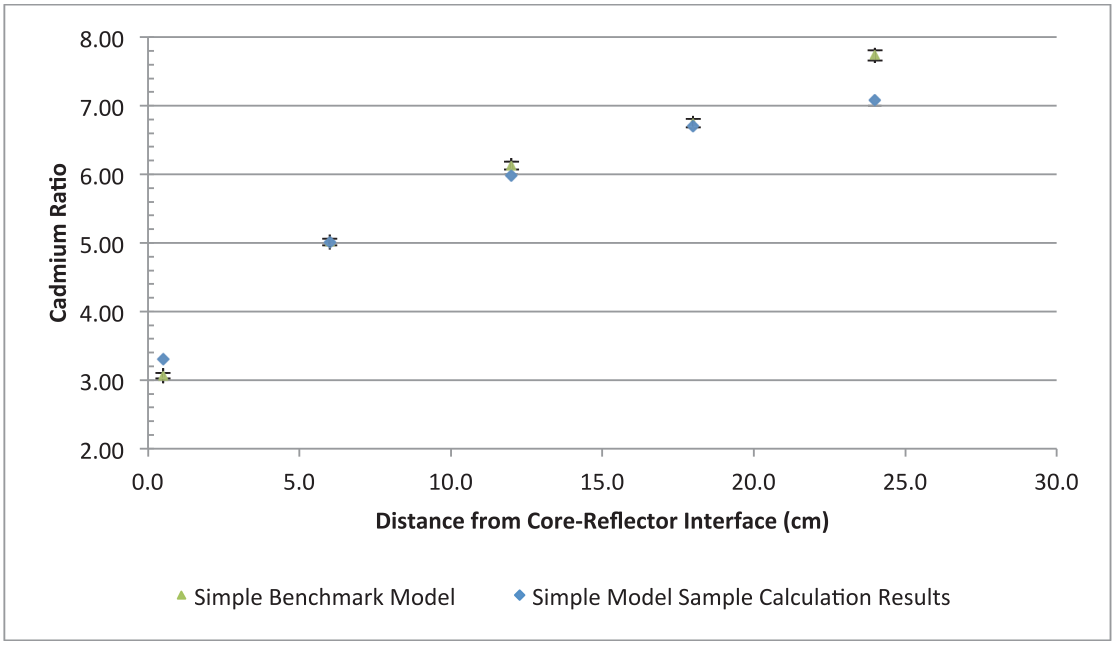

Figure 4.3-2. Cadmium Ratios, Simple Model.

4.4 Results of Reactivity-Effects Calculations

Worth measurements were evaluated by removing a graphite plug from the model described in Section 3.4. The models were run using MCNP5-1.60 and ENDF/B-VII.0 neutron cross section libraries. The models were run until the Monte Carlo statistical uncertainty was 0.00002; this required 1,000,000 histories per cycle for 2,000 cycles, skipping the first 150 cycles. The benchmark values and sample calculation results are given in Table 4.4-1. The detailed model calculated within 1σ of the detailed benchmark model. The simple model calculates within 1.5σ of the simple benchmark model.

Table 4.4-1. Worth Measurement Sample Calculation Results.[a]

Worth of One Radial Graphite Plug					
		Benchmark Results	MCNP5 ENDF/B-VII.0	$\frac{C-E}{E}$[c]	C/E[c] Ratio
Detailed Model	(Δk_{eff})	-	0.00009 ± 0.00003	-	-
	(¢)	2 ± 0.78 ¢[b]	1.25 ± 0.40 ¢	-37.60%	0.62 ± 0.31
Simple Model	(Δk_{eff})	-	0.00006 ± 0.00003	-	-
	(¢)	2 ± 0.78 ¢[b	0.83 ± 0.39 ¢	-58.38%	0.42 ± 0.26

(a) Both the detailed and simple models calculate within 2σ of the detailed and simple benchmark models.
(b) Total uncertainty was found by adding in quadrature the measurement uncertainty in Section 2.4 and the bias uncertainty in Section 3.4.
(d) "E" is the expected or benchmark value. "C" is the calculated value.

4.5 Results of Reactivity Coefficient Calculations

Reactivity coefficient measurements were not performed.

4.6 Results of Kinetics Parameter Calculations

Kinetics measurements were not performed.

4.7 Results of Reaction-Rate Distribution Calculations

The relative and radial activations of ^{235}U fission foils distribution were evaluated using models as described in Section 3.7 in MCNP5-1.60 and ENDF/B-VII.0 neutron cross section libraries. An fmesh cell flux tally and a fission cross section tally multiplier were used to simulate the measurements. An fmesh is a mesh of cells superimposed over a geometry for the purpose of performing tallies. 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.

4.7.1 Axial Measurements

The axial distribution of induced fission in a uranium fission counter measurements were found to be unacceptable as a benchmark experiment. Evaluated data have been preserved in Appendix B.

For the axial activation measurements, the fmesh extended from the bottom of the core to the top of the top reflector for the axial measurements and had a radius of 0.32 cm. The tally multiplier was for ^{235}U. Results are given in Table 4.7-1.

Table 4.7-1. Relative Axial Distribution of ^{235}U Fission Foil Activation.

	Distance from Core (cm)	Foil Activation		(C-E)/E[(a)]	C/E[(a)] Ratio
		Benchmark Value	Calculated Value		
Detailed Model	39.7	1.00 ± 0.02	1.000 ± 0.005	0.0%	1.00 ± 0.02
	42.8	0.97 ± 0.03	0.976 ± 0.005	0.6%	1.01 ± 0.03
	45.8	0.86 ± 0.03	0.860 ± 0.004	0.0%	1.00 ± 0.03
Simple Model	39.7	1.00 ± 0.02	1.000 ± 0.005	0.0%	1.00 ± 0.02
	42.8	0.97 ± 0.03	0.979 ± 0.005	0.9%	1.01 ± 0.03
	45.8	0.86 ± 0.03	0.852 ± 0.005	-0.9%	1.00 ± 0.03

(a) "E" is the expected or benchmark value. "C" is the calculated value.

4.7.2 Radial Measurements

For the radial measurements, the fmesh extended from a radius of 11.485 cm (halfway between the core tank wall and the inside surface of the side reflector) through a plugged radial hole to the outside of the side reflector and had a radius of 0.375 cm. The normalization value was modeled using an identically sized fmesh spanning the height of the top reflector. The foil 39.7 cm above the bottom of the core was used for the normalization. The tally multiplier was for 93.2 wt.% ^{235}U (6.8 wt.% ^{238}U) fission cross sections. Results are given in Table 4.7-2 and 4.7.3 and plotted in Figure 4.7-1 and 4.7-.2.

Table 4.7-2. Radial Activation of ^{235}U Fission Foils, Detailed Model.

Distance from Core (cm)[a]	Foil Activation[b]						(C-E)/E[c]	C/E[c] Ratio		
	Benchmark Value			Calculated Value						
0.5	0.65	±	0.02	0.608	±	0.003	-6.43%	0.94	±	0.03
3.0	1.09	±	0.04	1.051	±	0.004	-3.31%	0.97	±	0.03
6.5	1.46	±	0.05	1.412	±	0.005	-3.19%	0.97	±	0.03
8.5	1.53	±	0.05	1.502	±	0.005	-1.85%	0.98	±	0.03
11.7	1.53	±	0.05	1.532	±	0.005	0.20%	1.00	±	0.03
14.5	1.44	±	0.05	1.431	±	0.005	-0.65%	0.99	±	0.03
17.0	1.27	±	0.04	1.271	±	0.005	0.10%	1.00	±	0.03
20.7	0.95	±	0.03	0.951	±	0.004	0.10%	1.00	±	0.03
24.5	0.54	±	0.02	0.555	±	0.003	2.72%	1.03	±	0.04
26.5	0.32	±	0.01	0.330	±	0.002	3.08%	1.03	±	0.04

(a) Zero point is the inside surface of side reflector.
(b) Normalized to the midpoint of the top reflector of Case 1.
(c) "E" is the expected or benchmark value. "C" is the calculated value.

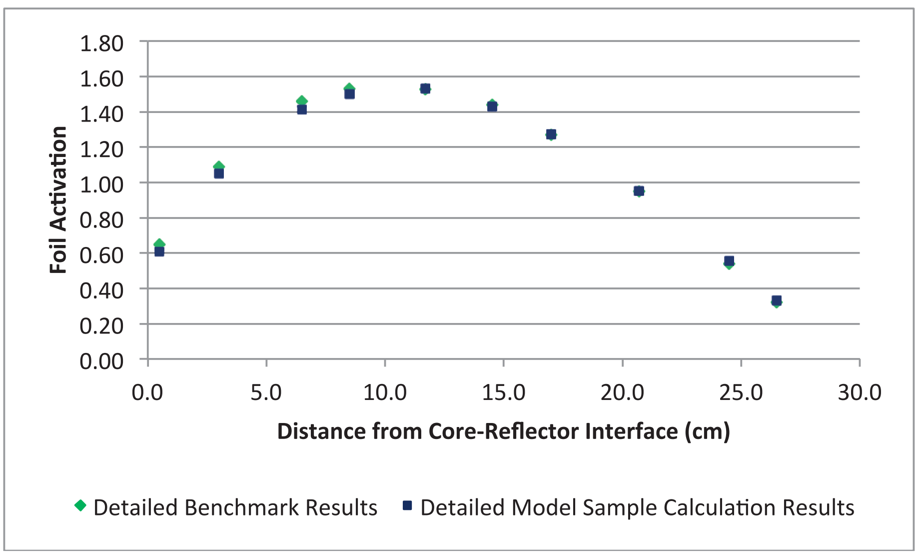

Figure 4.7-1. Relative Radial Activation of ^{235}U Fission Foils in the Radial Reflector of Detailed Model.

Table 4.7-3. Radial Activation of ^{235}U Fission Foils, Simple Model.

Distance from Core (cm)[a]	Foil Activation[b] Benchmark Value			Foil Activation[b] Calculated Value			(C-E)/E[c]	C/E[c] Ratio		
0.5	0.65	±	0.02	0.604	±	<0.001	-7.04%	0.93	±	0.03
3.0	1.07	±	0.04	1.036	±	<0.001	-3.36%	0.97	±	0.03
6.5	1.44	±	0.05	1.391	±	<0.001	-3.23%	0.97	±	0.03
8.5	1.52	±	0.05	1.486	±	0.001	-1.96%	0.98	±	0.03
11.7	1.50	±	0.05	1.506	±	0.002	0.20%	1.00	±	0.03
14.5	1.43	±	0.05	1.416	±	0.003	-0.77%	0.99	±	0.03
17.0	1.25	±	0.04	1.255	±	0.004	0.14%	1.00	±	0.03
20.7	0.94	±	0.03	0.945	±	0.004	0.57%	1.01	±	0.03
24.5	0.53	±	0.02	0.549	±	0.005	3.45%	1.03	±	0.04
26.5	0.32	±	0.01	0.326	±	0.005	3.12%	1.03	±	0.04

(a) Zero point is the inside surface of side reflector.
(b) Normalized to the midpoint of the top reflector of Case 1.
(c) "E" is the expected or benchmark value. "C" is the calculated value.

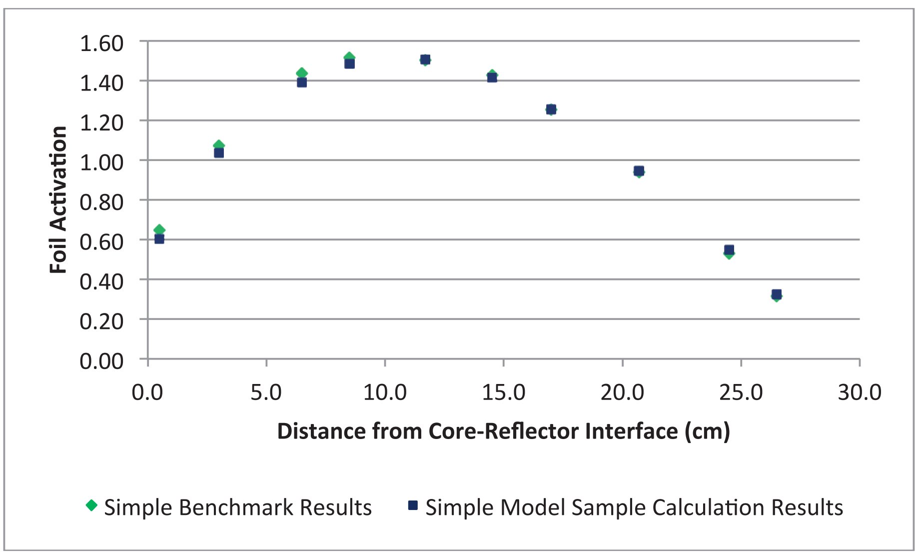

Figure 4.7-2. Relative Radial Activation of ^{235}U Fission Foils in the Radial Reflector of Simple Model.

4.8 Results of Power Distribution Calculations

Power density distribution measurements were not performed in the radial direction, but axial relative power density distribution measurements were performed in the central fuel pin location. Power density is proportional to the fission rate in a fission counter traversed axially through the core (see Appendix B.4).

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

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 were taken from "Nuclides and Isotopes: Chart of the Nuclides," Sixteenth Edition, KAPL, 2002.

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-002.[a])

A.2 Buckling and Extrapolation Length Configurations

Buckling and extrapolation-length measurements were not performed.

A.3 Spectral-Characteristics Configurations

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

1. Monte Carlo n-Particle, Versions 5.1.51 and 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.

[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

MCNP5 Input Deck for Cadmium Ratio Benchmark Models:
Detailed Model

```
SCCA-FUND-EXP-002-001 and HEU-COMP-FAST-002
C
C
C   Cell Cards
1   1  6.57372E-02  (-25 22 -26) u=10 imp:n=1         $fuel pellet
2   0      -22:(25 22 -26 ):26 u=10 imp:n=1  $void around pellet
3   0      -28  lat=1 u=11 imp:n=1 fill= 0:0  0:0 -1:26
         11 10 10 10 10 10 10 10 10 10 10 10 10 10
          10 10 10 10 10 10 10 10 10 10 10 10 10 11
C        Normal Fuel Tube
4   0    -21 22 -23  fill=11 u=12 imp:n=1
15   15 8.19858E-02 (1 -24 -20 21) u=12 imp:n=1  $Fuel tube
16   16 2.17619E-02 (1 -22 -21):(23 -24 -21) u=12 imp:n=1  $end caps
17   20 7.01794E-02 -160 166  u=12 imp:n=1 $Grid Plate
18   20 7.01794E-02 -161 166  u=12 imp:n=1 $Grid Plate
600  0  -160 -166 20 u=12 imp:n=1
601  0  -161 -166 20 u=12 imp:n=1
19   0    -1:(1  160 161 20 -24):24 u=12 imp:n=1
C     Fuel tubes that have been moved in
20  0    -21 22 -23  fill=11 u=13 imp:n=1
21   15 8.19858E-02 (21) u=13 imp:n=1  $Fuel tube
22   16 2.17619E-02 (-22 -21):(23 -21) u=13 imp:n=1  $end caps
C     Fuel tubes with grid plates
29  0    -21 22 -23  fill=11 u=14 imp:n=1
30   15 8.19858E-02 (1 -24 -20 21) u=14 imp:n=1  $Fuel tube
31   16 2.17619E-02 (1 -22 -21):(23 -24 -21) u=14 imp:n=1  $end caps
32   20 7.01794E-02 -160 166  u=14 imp:n=1 $Grid Plate
33   20 7.01794E-02 -161 166  u=14 imp:n=1 $Grid Plate
602  0  -160 -166 20 u=14 imp:n=1
603  0  -161 -166 20 u=14 imp:n=1
34   0     20 -163 164 -165 u=14 imp:n=1
35   21 8.16965E-02 -162 163 u=14 imp:n=1 $Spacer Tube
36   0    -1:(164 162 -165):(165 161 20 -24):24 u=14 imp:n=1
C     Normal Fuel Tube
110  0   -12 fill=12 u=1 imp:n=1
C     Fuel Tubes that have been moved in
111  0   -13 fill=13 (-3.766 -11.458 0) imp:n=1
112  0   -14 fill=13 (3.766 -11.458 0) imp:n=1
113  0   -15 fill=13 (3.766 11.458 0) imp:n=1
114  0   -16 fill=13 (-3.766 11.458 0) imp:n=1
```

```
115  0   -17 fill=13 (-8.039 -8.989 0) imp:n=1
116  0   -18 fill=13 (8.039 -8.989 0) imp:n=1
117  0   -19 fill=13 (-8.039 8.989 0) imp:n=1
118  0   -30 fill=13 (8.039 8.989 0) imp:n=1
119  0   -31 fill=13 (-11.805 -2.467 0) imp:n=1
120  0   -32 fill=13 (11.805 -2.467 0) imp:n=1
121  0   -33 fill=13 (-11.805 2.467 0) imp:n=1
122  0   -34 fill=13 (11.805 2.467 0) imp:n=1
C
C    Void Universe w/ Grid plate
127  20 7.01794E-02 -160 u=9 imp:n=1
128  20 7.01794E-02 -161 u=9 imp:n=1
129  0  -999 161 160 u=9 imp:n=1
C    Center Location w/ hole in grid plate
123  20 7.01794E-02 -160 166 u=8 imp:n=1
124  20 7.01794E-02 -161 166 u=8 imp:n=1
606  0  -160 -166 u=8 imp:n=1
607  0  -161 -166 u=8 imp:n=1
126  0  -999 161 160 u=8 imp:n=1
C   Core Assembly
130  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 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 14 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 14 1 1 1 1 1 1 1 8 1 1 1 1 1 1 1 14 1 9 9  $ROW 11
                 9 9 1 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 1 9 9 9 9  $ROW 13
                   9 1 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 1 9 9 9 9 9  $ROW 15
                     9 1 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 1 9 9 9 9 9 9 9  $ROW 17
                       9 9 1 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 14 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
131  0   -151 1 -153 13 14 15 16 17 18 19 30 31 32 33 34
          -101  -103  -105  -107  -109      fill=2 imp:n=1
132  22 6.01138E-02 -151 113 -114 #131 imp:n=1  $Al Shims
133  0   -151 1 -113 #131 13 14 15 16 17 18 19 30 31 32 33 34 imp:n=1
134  0   -151 114 -153 #131 13 14 15 16 17 18 19 30 31 32 33 34 imp:n=1
135  0  -210 -211 150  imp:n=1
136  0  -152 -150 220 213 250  imp:n=1
137  0  -310 -212 150  imp:n=1
140  2 5.82903E-02 (-153 154 -150 151):(-154 152 -150) imp:n=1 $Core Tank
C
C  Reflectors
50  10 8.91041E-02 -200 237  imp:n=1   $Lower Top reflector
77  10 8.91041E-02 -238 -200 imp:n=1
78  0   -237 238 -200 imp:n=1
51  11 8.39948E-02 200 -201  237 imp:n=1 $Upper Top Refleltor
79  11 8.39948E-02 -238 -201 imp:n=1
80  0  -237 238 -201 imp:n=1
52  8  8.78956E-02 310 -212 225 227 229 231 233 235 imp:n=1 $Lower Side Reflector
65  8  8.78956E-02 -212 310 -226 711 713 imp:n=1
66  8  8.78956E-02 -212 310 -228 710 712 714 imp:n=1
67  8  8.78956E-02 -212 310 -230 701 703 imp:n=1
68  8  8.78956E-02 -212 310 -232 700 702 704 imp:n=1
69  8  8.78956E-02 -212 310 -234 imp:n=1
71  0   -212 310 -235 imp:n=1
72  0   -212 310 -233 234 imp:n=1
73  0   -212 310 -231 232 imp:n=1
74  0   -212 310 -229 230 imp:n=1
75  0   -212 310 -227 228 imp:n=1
76  0   -212 310 -225 226 imp:n=1
700  200 4.79835E-02 -700 imp:n=1
701  200 4.79835E-02 -701 imp:n=1
702  200 4.79835E-02 -702 imp:n=1
703  200 4.79835E-02 -703 imp:n=1
704  200 4.79835E-02 -704 imp:n=1
```

```
705  200 4.79835E-02 -705 imp:n=1
706  200 4.79835E-02 -706 imp:n=1
707  200 4.79835E-02 -707 imp:n=1
708  200 4.79835E-02 -708 imp:n=1
709  200 4.79835E-02 -709 imp:n=1
710  201 4.63399E-02 705 -710 imp:n=1
711  201 4.63399E-02 706 -711 imp:n=1
712  201 4.63399E-02 707 -712 imp:n=1
713  201 4.63399E-02 708 -713 imp:n=1
714  201 4.63399E-02 709 -714 imp:n=1
81  0   -1 -151 154 220 imp:n=1
53  9  8.68493E-02 210 -211 imp:n=1 $Upper Side Reflector
54  12 8.26756E-02 -220   imp:n=1   $bottom Reflector
C  Support Structure/Additional Reflectors
60  30 6.01329E-02 -250 imp:n=1 $Uppwer Al Plate
61  31 5.99935E-02 -251 imp:n=1 $Lower Al Plate
62  32 8.75101E-02 -252 imp:n=1 $SS304 Plate
63  33 8.31237E-02 -253 254 imp:n=1 $Iron Table
64  0  -999 #60 #61 #62 #63 212 211 200 201  imp:n=1
999  0  999 imp:n=0

C   Surface Cards
1    pz   0.      $bottom of fuel
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
26   pz   1.445   $Top of bottom fuel pellet
28   rpp  -0.9 0.9  -0.9 0.9  0.2978 1.4472  $pellet lattice box
11   rhp  0 0 -10  0 0 50   0.753 0 0
12   rhp  0 0 -11  0 0 52   1 0 0
C  13   rcc  0 0 0  0 0 30.48  0.635
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
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
150  cz  12.98  $OR Core Tank
151  cz  12.726 $IR Core Tank
152  pz  -23.224   $Bottom of Core Tank
154  pz  -22.86   $top of bottom of core tank
153  pz  30.816  $Top of Core Tank
C  Grid Plate
160   rcc 0 0 0  0 0 0.317  12.8 $bottom grid plate
161   rcc 0 0 28.257  0 0 0.317  12.8 $top grip plate
166   cz 0.642
C  Grid Plate Spacer Tubes
162   rcc 0 0 0.317  0 0 27.94  0.685
163   cz  0.642
164   pz 0.317
165   pz 28.257
C    Al Shims
101   p -2.9708 12.3744 15  0.0000 12.3744 30  2.9708 12.3744 15
103   p 9.2311 8.7600 15  10.7165 6.1872 30  12.2019 3.6144 15
105   p 12.2019 -3.6144 15  10.7165 -6.1872 30  9.2311 -8.7600 15
107   p 2.9708 -12.3744 15  0.0000 -12.3744 30  -2.9708 -12.3744 15
109   p -9.2311 -8.7600 15  -10.7165 -6.1872 30  -12.2019 -3.6144 15
113   pz 14.4
114   pz 16.31
C   Al Fuel Tube Clips
115  rcc 0 0 14.99  0 0 0.5  12.8
C  Reflectors
C   Top Reflectors
200  rcc 0 0 30.816   0 0 15.25   38.1 $Lower Top Reflector
201  rcc 0 0 46.066   0 0 8.36    25.4 $Upper Top Reflector
C  Side Reflectors
210  cz  13.07  $IR Upper Side Reflector
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211  rcc 0 0 23.186   0 0 7.63   38.6  $Upper Side Reflector
310  cz  13.065  $IR Lower Side Reflector
212  rcc 0 0 -23.444  0 0 46.63  40.9675 $Lower Side Reflector
213  pz -23.444 $surface for creating void regions
C  Bottom Reflector
220  rcc 0 0 -22.86  0 0 22.86  12.71 $bottom reflector
C  Foil Holes in lower side and top reflector
225  rcc 0 0 7.61 -50 0 0 0.635 $west hole
226  rcc 0 0 7.61 -50 0 0 0.555 $west plug
227  rcc 0 0 7.61 -40 69.3 0 0.635 $nnw hole
228  rcc 0 0 7.61 -40 69.3 0 0.555 $nnw plug
229  rcc 0 0 7.61 40 69.3 0 0.635 $nne hole
230  rcc 0 0 7.61 40 69.3 0 0.555 $nne plug
231  rcc 0 0 7.61 50 0 0 0.635 $west hole
232  rcc 0 0 7.61 50 0 0 0.555 $west plug
233  rcc 0 0 7.61 40 -69.3 0 0.635 $sse hole
234  rcc 0 0 7.61 40 -69.3 0 0.555 $sse plug
235  rcc 0 0 7.61 -40 -69.3 0 0.635 $ssw hole
236  rcc 0 0 7.61 -40 -69.3 0 0.555 $ssw plug
237  cz  0.635
238  cz  0.555
239  pz  45.96
240  pz 54.32
C  Additional Bottom Reflectors
250  rcc 0 0 -25.164  0 0 1.94  10.8  $Al Upper Plate
251  rcc 0 0 -25.794  0 0 0.63  22.86 $Al Lower Plate
252  rcc 0 0 -28.174  0 0 2.38  22.86 $SS304 Plate
253  rpp -60.95 60.95  -60.95 60.95  -24.82 -23.55 $Iron Table
254  cz 13.335
C    Bare Foils
700   rcc 13.56   0   7.61   0.01   0   0   0.375
701   rcc 9.53   16.5064442   7.61   0.005   0.008660254   0   0.375
702   rcc 25.06   0   7.61   0.01   0   0   0.375
703   rcc 15.53   26.89874904   7.61   0.005   0.008660254   0   0.375
704   rcc 37.06   0   7.61   0.01   0   0   0.375
C    Covered Foils
705   rcc -6.78   11.74330448   7.61   -0.005   0.008660254   0   0.375
706   rcc -19.06   2.33513E-15   7.61   -0.01   1.22515E-18   0   0.375
707   rcc -12.53   21.70259662   7.61   -0.005   0.008660254   0   0.375
708   rcc -31.06   3.80531E-15   7.61   -0.01   1.22515E-18   0   0.375
709   rcc -18.53   32.09490146   7.61   -0.005   0.008660254   0   0.375
C    Covers
710   rcc -6.7545   11.69913718   7.61   -0.056   0.096994845   0   0.38
711  rcc  -19.009   2.32888E-15   7.61   -0.112   1.37217E-17   0   0.38
712   rcc -12.5045   21.65842932   7.61   -0.056   0.096994845   0   0.38
713   rcc -31.009   3.79906E-15   7.61   -0.112   1.37217E-17   0   0.38
714   rcc -18.5045   32.05073417   7.61   -0.056   0.096994845   0   0.38
C
999   rpp  -500 500   -500 500  -500 500

C   Data Cards
m1    92234.70c   2.22221E-04
      92235.70c   2.04075E-02
      92236.70c   1.02532E-04
      92238.70c   1.16161E-03
      8016.70c   4.36813E-02
      8017.70c   1.06404E-04
      47107.70c   5.62272E-07
      47109.70c   5.22379E-07
      4009.70c   9.73675E-08
      24050.70c   1.12435E-07
      24052.70c   2.16820E-06
      24053.70c   2.45856E-07
      24054.70c   6.11987E-08
      3006.70c   4.74083E-08
      3007.70c   5.84702E-07
      28058.70c   8.33992E-07
      28060.70c   3.21252E-07
      28061.70c   1.39646E-08
      28062.70c   4.45253E-08
      28064.70c   1.13393E-08
      50112.70c   7.17017E-09
      50114.70c   4.87867E-09
      50115.70c   2.51325E-09
      50116.70c   1.07479E-07
      50117.70c   5.67700E-08
      50118.70c   1.79032E-07
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      50119.70c   6.34966E-08
      50120.70c   2.40829E-07
      50122.70c   3.42246E-08
      50124.70c   4.27992E-08
      13027.70c   3.57743E-06
      20040.70c   7.07498E-06
      20042.70c   4.72195E-08
      20043.70c   9.85261E-09
      20044.70c   1.52241E-07
      20046.70c   2.91929E-10
      20048.70c   1.36477E-08
      29063.70c   1.20986E-06
      29065.70c   5.39253E-07
      12024.70c   1.14073E-06
      12025.70c   1.44414E-07
      12026.70c   1.59000E-07
      15031.70c   9.44341E-06
      5010.70c   5.38407E-08
      5011.70c   2.16716E-07
      26054.70c   7.95942E-07
      26056.70c   1.24946E-05
      26057.70c   2.88555E-07
      26058.70c   3.84013E-08
      25055.70c   4.25932E-07
      56130.70c   2.25774E-10
      56132.70c   2.15124E-10
      56134.70c   5.14807E-09
      56135.70c   1.40406E-08
      56136.70c   1.67286E-08
      56137.70c   2.39235E-08
      56138.70c   1.52713E-07
      19039.70c   3.48837E-06
      19040.70c   4.37645E-10
      19041.70c   2.51747E-07
      11023.70c   1.27230E-06
      14028.70c   5.76320E-06
      14029.70c   2.92641E-07
      14030.70c   1.92911E-07   $ TOT   6.57372E-02
C   Fuel Clad
m15   26054.70c   3.25448E-03
      26056.70c   5.10884E-02
      26057.70c   1.17985E-03
      26058.70c   1.57017E-04
      6000.70c   1.50688E-04
      25055.70c   8.23618E-04
      14028.70c   7.42946E-04
      14029.70c   3.77250E-05
      14030.70c   2.48686E-05
      24050.70c   6.80598E-04
      24052.70c   1.31247E-02
      24053.70c   1.48823E-03
      24054.70c   3.70452E-04
      28058.70c   5.77334E-03
      28060.70c   2.22388E-03
      28061.70c   9.66705E-05
      28062.70c   3.08228E-04
      28064.70c   7.84965E-05
      15031.70c   3.28690E-05
      16032.70c   2.00907E-05
      16033.70c   1.60844E-07
      16034.70c   9.07921E-07
      16036.70c   4.23273E-09
      41093.70c   3.13488E-04
      73181.70c   1.40839E-05   $ tot   8.19858E-02
C   End Caps
m16   26054.70c   8.63854E-04
      26056.70c   1.35607E-02
      26057.70c   3.13175E-04
      26058.70c   4.16778E-05
      6000.70c   3.99979E-05
      25055.70c   2.18617E-04
      14028.70c   1.97204E-04
      14029.70c   1.00135E-05
      14030.70c   6.60099E-06
      24050.70c   1.80655E-04
      24052.70c   3.48374E-03
      24053.70c   3.95029E-04
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      24054.70c   9.83310E-05
      28058.70c   1.53245E-03
      28060.70c   5.90295E-04
      28061.70c   2.56597E-05
      28062.70c   8.18144E-05
      28064.70c   2.08357E-05
      15031.70c   8.72458E-06
      16032.70c   5.33276E-06
      16033.70c   4.26936E-08
      16034.70c   2.40994E-07
      16034.70c   1.12352E-09
      41093.70c   8.32108E-05
      73181.70c   3.73835E-06   $ tot   2.17619E-02
C   Core Tank
m2   13027.70c   5.80397E-02
      29063.70c   2.14522E-05
      29065.70c   9.56154E-06
      14028.70c   1.22966E-04
      14029.70c   6.24391E-06
      14030.70c   4.11603E-06
      26054.70c   3.91905E-06
      26056.70c   6.15207E-05
      26057.70c   1.42078E-06
      26058.70c   1.89080E-07
      25055.70c   7.17463E-06
      30000.70c   1.20557E-05   $ Tot   5.82903E-02
C   Grid Plate
m20   13027.70c   0.069877686
      29063.70c   2.58277E-05
      29065.70c   1.15117E-05
      14028.70c   1.48047E-04
      14029.70c   7.51744E-06
      14030.70c   4.95555E-06
      26054.70c   4.71840E-06
      26056.70c   7.40687E-05
      26057.70c   1.71057E-06
      26058.70c   2.27645E-07
      25055.70c   8.63800E-06
      30000.70c   1.45146E-05   $ Tot   7.01794E-02
C   Grid Plate Spacer Tube
m21   26054.70c   3.24300E-03
      26056.70c   5.09082E-02
      26057.70c   1.17569E-03
      26058.70c   1.56463E-04
      6000.70c   1.50157E-04
      25055.70c   8.20712E-04
      14028.70c   7.40325E-04
      14029.70c   3.75919E-05
      14030.70c   2.47808E-05
      24050.70c   6.78197E-04
      24052.70c   1.30784E-02
      24053.70c   1.48298E-03
      24054.70c   3.69145E-04
      28058.70c   5.75297E-03
      28060.70c   2.21603E-03
      28061.70c   9.63294E-05
      28062.70c   3.07140E-04
      28064.70c   7.82196E-05
      15031.70c   3.27530E-05
      16032.70c   2.00198E-05
      16033.70c   1.60276E-07
      16034.70c   9.04718E-07
      16036.70c   4.21780E-09
      41093.70c   3.12383E-04
      73181.70c   1.40342E-05   $ tot   8.16965E-02
C   Al Shim
m22    13027.70c   5.98555E-02
      29063.70c   2.21234E-05
      29065.70c   9.86068E-06
      14028.70c   1.26813E-04
      14029.70c   6.43926E-06
      14030.70c   4.24481E-06
      26054.70c   4.04166E-06
      26056.70c   6.34455E-05
      26057.70c   1.46523E-06
      25055.70c   7.39910E-06
      30000.70c   1.24328E-05   $ Tot   6.01138E-02
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C   Reflectors
C  **********************************
C  Lower Side Reflector
m8      13027.70c   1.06083E-05
      56130.70c   1.80020E-10
      56132.70c   1.71528E-10
      56134.70c   4.10479E-09
      56135.70c   1.11952E-08
      56136.70c   1.33385E-08
      56137.70c   1.90753E-08
      56138.70c   1.21765E-07
      5010.70c   9.75675E-09
      5011.70c   3.92721E-08
      20040.70c   2.10263E-05
      20042.70c   1.40333E-07
      20043.70c   2.92812E-08
      20044.70c   4.52449E-07
      20046.70c   8.67592E-10
      20048.70c   4.05599E-08
      27059.70c   5.39646E-08
      24050.70c   1.41738E-08
      24052.70c   2.73329E-07
      24053.70c   3.09933E-08
      24054.70c   7.71488E-09
      29063.70c   1.15392E-08
      29065.70c   5.14320E-09
      26054.70c   4.37148E-06
      26056.70c   6.86229E-05
      26057.70c   1.58480E-06
      26058.70c   2.10908E-07
      19039.70c   1.26429E-07
      19040.70c   1.58616E-11
      19041.70c   9.12406E-09
      3006.70c   2.29096E-08
      3007.70c   2.82552E-07
      71175.70c   5.90195E-09
      71176.70c   1.56925E-10
      12024.70c   3.44528E-08
      12025.70c   4.36167E-09
      12026.70c   4.80219E-09
      25055.70c   1.92963E-08
      42092.70c   8.19883E-09
      42094.70c   5.11046E-09
      42095.70c   8.79552E-09
      42096.70c   9.21540E-09
      42097.70c   5.27620E-09
      42098.70c   1.33314E-08
      42100.70c   5.32040E-09
      11023.70c   1.38336E-07
      28058.70c   3.32007E-07
      28060.70c   1.27889E-07
      28061.70c   5.55923E-09
      28062.70c   1.77252E-08
      28064.70c   4.51410E-09
      14028.70c   1.87988E-06
      14029.70c   9.54558E-08
      14030.70c   6.29252E-08
      38084.70c   3.38768E-10
      38086.70c   5.96474E-09
      38087.70c   4.23460E-09
      38088.70c   4.99562E-08
      22046.70c   9.86374E-08
      22047.70c   8.89530E-08
      22048.70c   8.81400E-07
      22049.70c   6.46822E-08
      22050.70c   6.19323E-08
      23000.70c   4.57824E-06
      39089.70c   1.31163E-07
      6000.70c   8.77787E-02   $ tot   8.78956E-02
C
C  Upper Side Reflector
m9      13027.70c   1.04820E-05
      56130.70c   1.77877E-10
      56132.70c   1.69486E-10
      56134.70c   4.05593E-09
      56135.70c   1.10619E-08
      56136.70c   1.31797E-08
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      56137.70c   1.88482E-08
      56138.70c   1.20315E-07
      5010.70c   9.64060E-09
      5011.70c   3.88046E-08
      20040.70c   2.07760E-05
      20042.70c   1.38663E-07
      20043.70c   2.89327E-08
      20044.70c   4.47063E-07
      20046.70c   8.57264E-10
      20048.70c   4.00771E-08
      27059.70c   5.33222E-08
      24050.70c   1.40051E-08
      24052.70c   2.70075E-07
      24053.70c   3.06243E-08
      24054.70c   7.62304E-09
      29063.70c   1.14019E-08
      29065.70c   5.08197E-09
      26054.70c   4.31944E-06
      26056.70c   6.78060E-05
      26057.70c   1.56594E-06
      26058.70c   2.08397E-07
      19039.70c   1.24924E-07
      19040.70c   1.56727E-11
      19041.70c   9.01544E-09
      3006.70c   2.26369E-08
      3007.70c   2.79188E-07
      71175.70c   5.83169E-09
      71176.70c   1.55057E-10
      12024.70c   3.40427E-08
      12025.70c   4.30974E-09
      12026.70c   4.74503E-09
      25055.70c   1.90666E-08
      42092.70c   8.10123E-09
      42094.70c   5.04962E-09
      42095.70c   8.69081E-09
      42096.70c   9.10570E-09
      42097.70c   5.21339E-09
      42098.70c   1.31727E-08
      42100.70c   5.25707E-09
      11023.70c   1.36689E-07
      28058.70c   3.28055E-07
      28060.70c   1.26366E-07
      28061.70c   5.49305E-09
      28062.70c   1.75142E-08
      28064.70c   4.46036E-09
      14028.70c   1.85750E-06
      14029.70c   9.43195E-08
      14030.70c   6.21761E-08
      38084.70c   3.34735E-10
      38086.70c   5.89374E-09
      38087.70c   4.18419E-09
      38088.70c   4.93615E-08
      22046.70c   9.74632E-08
      22047.70c   8.78941E-08
      22048.70c   8.70907E-07
      22049.70c   6.39122E-08
      22050.70c   6.11951E-08
      23000.70c   4.52374E-06
      39089.70c   1.29601E-07
      6000.70c   8.67337E-02   $ tot   8.68493E-02
C
C  Lower Top Reflector
m10   13027.70c   1.07542E-05
      56130.70c   1.82495E-10
      56132.70c   1.73887E-10
      56134.70c   4.16123E-09
      56135.70c   1.13491E-08
      56136.70c   1.35219E-08
      56137.70c   1.93376E-08
      56138.70c   1.23439E-07
      5010.70c   9.89090E-09
      5011.70c   3.98121E-08
      20040.70c   2.13154E-05
      20042.70c   1.42263E-07
      20043.70c   2.96838E-08
      20044.70c   4.58670E-07
      20046.70c   8.79521E-10
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      20048.70c   4.11176E-08
      27059.70c   5.47066E-08
      24050.70c   1.43687E-08
      24052.70c   2.77087E-07
      24053.70c   3.14194E-08
      24054.70c   7.82095E-09
      29063.70c   1.16979E-08
      29065.70c   5.21391E-09
      26054.70c   4.43159E-06
      26056.70c   6.95665E-05
      26057.70c   1.60659E-06
      26058.70c   2.13808E-07
      19039.70c   1.28167E-07
      19040.70c   1.60796E-11
      19041.70c   9.24951E-09
      3006.70c   2.32246E-08
      3007.70c   2.86436E-07
      71175.70c   5.98310E-09
      71176.70c   1.59082E-10
      12024.70c   3.49265E-08
      12025.70c   4.42164E-09
      12026.70c   4.86822E-09
      25055.70c   1.95617E-08
      42092.70c   8.31156E-09
      42094.70c   5.18073E-09
      42095.70c   8.91645E-09
      42096.70c   9.34211E-09
      42097.70c   5.34875E-09
      42098.70c   1.35147E-08
      42100.70c   5.39356E-09
      11023.70c   1.40238E-07
      28058.70c   3.36572E-07
      28060.70c   1.29647E-07
      28061.70c   5.63566E-09
      28062.70c   1.79690E-08
      28064.70c   4.57616E-09
      14028.70c   1.90573E-06
      14029.70c   9.67682E-08
      14030.70c   6.37903E-08
      38084.70c   3.43426E-10
      38086.70c   6.04675E-09
      38087.70c   4.29283E-09
      38088.70c   5.06431E-08
      22046.70c   9.99936E-08
      22047.70c   9.01760E-08
      22048.70c   8.93518E-07
      22049.70c   6.55715E-08
      22050.70c   6.27838E-08
      23000.70c   4.64119E-06
      39089.70c   1.32966E-07
      6000.70c   8.89856E-02   $ tot   8.91041E-02
C
C  Upper Top Reflector
m11   13027.70c   1.01375E-05
      56130.70c   1.72031E-10
      56132.70c   1.63916E-10
      56134.70c   3.92262E-09
      56135.70c   1.06984E-08
      56136.70c   1.27465E-08
      56137.70c   1.82288E-08
      56138.70c   1.16361E-07
      5010.70c   9.32375E-09
      5011.70c   3.75293E-08
      20040.70c   2.00932E-05
      20042.70c   1.34105E-07
      20043.70c   2.79818E-08
      20044.70c   4.32370E-07
      20046.70c   8.29089E-10
      20048.70c   3.87599E-08
      27059.70c   5.15697E-08
      24050.70c   1.35448E-08
      24052.70c   2.61198E-07
      24053.70c   2.96178E-08
      24054.70c   7.37250E-09
      29063.70c   1.10271E-08
      29065.70c   4.91494E-09
      26054.70c   4.17748E-06
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      26056.70c   6.55775E-05
      26057.70c   1.51447E-06
      26058.70c   2.01548E-07
      19039.70c   1.20818E-07
      19040.70c   1.51576E-11
      19041.70c   8.71914E-09
      3006.70c   2.18929E-08
      3007.70c   2.70012E-07
      71175.70c   5.64002E-09
      71176.70c   1.49961E-10
      12024.70c   3.29238E-08
      12025.70c   4.16810E-09
      12026.70c   4.58907E-09
      25055.70c   1.84400E-08
      42092.70c   7.83497E-09
      42094.70c   4.88366E-09
      42095.70c   8.40517E-09
      42096.70c   8.80643E-09
      42097.70c   5.04205E-09
      42098.70c   1.27398E-08
      42100.70c   5.08429E-09
      11023.70c   1.32196E-07
      28058.70c   3.17273E-07
      28060.70c   1.22213E-07
      28061.70c   5.31251E-09
      28062.70c   1.69386E-08
      28064.70c   4.31376E-09
      14028.70c   1.79645E-06
      14029.70c   9.12195E-08
      14030.70c   6.01326E-08
      38084.70c   3.23734E-10
      38086.70c   5.70003E-09
      38087.70c   4.04667E-09
      38088.70c   4.77392E-08
      22046.70c   9.42599E-08
      22047.70c   8.50053E-08
      22048.70c   8.42283E-07
      22049.70c   6.18116E-08
      22050.70c   5.91838E-08
      23000.70c   4.37506E-06
      39089.70c   1.25342E-07
      6000.70c   8.38831E-02   $ tot   8.39948E-02
C
C  Bottom Reflector
m12   13027.70c   9.97828E-06
      56130.70c   1.69329E-10
      56132.70c   1.61342E-10
      56134.70c   3.86102E-09
      56135.70c   1.05303E-08
      56136.70c   1.25463E-08
      56137.70c   1.79425E-08
      56138.70c   1.14533E-07
      5010.70c   9.17731E-09
      5011.70c   3.69398E-08
      20040.70c   1.97776E-05
      20042.70c   1.31999E-07
      20043.70c   2.75423E-08
      20044.70c   4.25579E-07
      20046.70c   8.16067E-10
      20048.70c   3.81511E-08
      27059.70c   5.07597E-08
      24050.70c   1.33321E-08
      24052.70c   2.57096E-07
      24053.70c   2.91526E-08
      24054.70c   7.25670E-09
      29063.70c   1.08539E-08
      29065.70c   4.83775E-09
      26054.70c   4.11187E-06
      26056.70c   6.45475E-05
      26057.70c   1.49068E-06
      26058.70c   1.98383E-07
      19039.70c   1.18921E-07
      19040.70c   1.49196E-11
      19041.70c   8.58219E-09
      3006.70c   2.15490E-08
      3007.70c   2.65771E-07
      71175.70c   5.55144E-09
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      71176.70c   1.47605E-10
      12024.70c   3.24067E-08
      12025.70c   4.10263E-09
      12026.70c   4.51700E-09
      25055.70c   1.81504E-08
      42092.70c   7.71192E-09
      42094.70c   4.80696E-09
      42095.70c   8.27316E-09
      42096.70c   8.66811E-09
      42097.70c   4.96286E-09
      42098.70c   1.25397E-08
      42100.70c   5.00443E-09
      11023.70c   1.30120E-07
      28058.70c   3.12290E-07
      28060.70c   1.20293E-07
      28061.70c   5.22907E-09
      28062.70c   1.66726E-08
      28064.70c   4.24601E-09
      14028.70c   1.76824E-06
      14029.70c   8.97868E-08
      14030.70c   5.91881E-08
      38084.70c   3.18649E-10
      38086.70c   5.61050E-09
      38087.70c   3.98312E-09
      38088.70c   4.69894E-08
      22046.70c   9.27794E-08
      22047.70c   8.36702E-08
      22048.70c   8.29054E-07
      22049.70c   6.08408E-08
      22050.70c   5.82542E-08
      23000.70c   4.30635E-06
      39089.70c   1.23373E-07
      6000.70c   8.25656E-02   $ tot   8.26756E-02
C     *************************************
C  Additional Bottom Reflectors
C   Al Upper Reflector
m30   13027.70c   5.98746E-02
      29063.70c   2.21304E-05
      29065.70c   9.86383E-06
      14028.70c   1.26853E-04
      14029.70c   6.44131E-06
      14030.70c   4.24616E-06
      26054.70c   4.04295E-06
      26056.70c   6.34657E-05
      26057.70c   1.46570E-06
      25055.70c   7.40146E-06
      30000.70c   1.24368E-05   $ Tot   6.01329E-02
C   Al Lower Reflector
m31   13027.70c   5.97358E-02
      29063.70c   2.20791E-05
      29065.70c   9.84096E-06
      14028.70c   1.26559E-04
      14029.70c   6.42638E-06
      14030.70c   4.23632E-06
      26054.70c   4.03358E-06
      26056.70c   6.33185E-05
      26057.70c   1.46230E-06
      25055.70c   7.38430E-06
      30000.70c   1.24080E-05   $ Tot   5.99935E-02
C   SS304 Reflector
m32   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
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      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   Iron Table
m33   26054.70c   4.66345E-03
      26056.70c   7.32063E-02
      26057.70c   1.69065E-03
      26058.70c   2.24995E-04
      6000.70c   9.43427E-04
      12024.70c   1.47307E-03
      12025.70c   1.86488E-04
      12026.70c   2.05324E-04
      15031.70c   2.92673E-05
      16032.70c   3.35422E-05
      16033.70c   2.68536E-07
      16034.70c   1.51581E-06
      16036.70c   7.06673E-09
      14028.70c   2.97691E-04
      14029.70c   1.51160E-05
      14030.70c   9.96460E-06
      29063.70c   9.86750E-05
      29065.70c   4.39808E-05   $ tot   8.31237E-02
m200   92234.70c   4.67753E-04
      92235.70c   4.47223E-02
      92236.70c   1.14750E-04
      92238.70c   2.67865E-03   $ total   4.79835E-02
m201   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   grph.10t
mt9   grph.10t
mt10  grph.10t
mt11  grph.10t
mt12  grph.10t
mt20   al27.12t
mt22   al27.12t
mt30  al27.12t
mt31  al27.12t
C
kcode  1000000 1 150 2150
ksrc   0 5.25 5  0 10.5 10  0 -5.25 5  0 -10.5 10
       6.0 0 5   10.5 0 10  -6.0 0 5   -10.5 0 10
       6.5 5.25 5  -6.5 5.25 10  -6.5 -5.25 5  6.5 -5.25 10
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
f4:n  700
fm4   1 200 -6
f14:n   701
fm14   1 200 -6
f24:n   702
fm24   1 200 -6
f34:n   703
fm34   1 200 -6
f44:n   704
fm44   1 200 -6
f54:n  705
fm54   1 200 -6
f64:n   706
fm64   1 200 -6
f74:n   707
fm74   1 200 -6
f84:n   708
```

```
fm84   1 200 -6
f94:n   709
fm94   1 200 -6
```

Simple Model

```
SCCA-FUND-EXP-002-001 and HEU-COMP-FAST-002
C
C
C   Cell Cards
1   1  6.54398E-02  (22 -23 -25) u=10 imp:n=1         $fuel pellet
2   0       -22:(25 22 -23 ):23 u=10 imp:n=1  $void around pellet
4   0    -21 22 -23  fill=10 u=12 imp:n=1
C
C
5   15 7.61160E-02 (1 -24 -20 21):(1 -22 -21):(23 -24 -21) u=12 imp:n=1  $Fuel tube and end caps
6   0    -1:(1 20 -24):24 u=12 imp:n=1
C
C
7   0    -21 22 -23  fill=10 u=13 imp:n=1
C
C
8   15 7.61160E-02 21:-22:23 u=13 imp:n=1  $Fuel tube and end caps for u=13
C
10  0   -12 fill=12 u=1 imp:n=1
11  0   -13 fill=13 (-3.766 -11.458 0) imp:n=1
12  0   -14 fill=13 (3.766 -11.458 0) imp:n=1
13  0   -15 fill=13 (3.766 11.458 0) imp:n=1
14  0   -16 fill=13 (-3.766 11.458 0) imp:n=1
15  0   -17 fill=13 (-8.039 -8.989 0) imp:n=1
16  0   -18 fill=13 (8.039 -8.989 0) imp:n=1
17  0   -19 fill=13 (-8.039 8.989 0) imp:n=1
18  0   -30 fill=13 (8.039 8.989 0) imp:n=1
19  0   -31 fill=13 (-11.805 -2.467 0) imp:n=1
20  0   -32 fill=13 (11.805 -2.467 0) imp:n=1
21  0   -33 fill=13 (-11.805 2.467 0) imp:n=1
22  0   -34 fill=13 (11.805 2.467 0) imp:n=1
C
C
C   Core Assembly
30  0   -11  lat=2  u=2 imp:n=1 fill= -10:10 -10:10 0:0
     2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  $ROW 1
       2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 2 2 2 2  $ROW 2
        2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 2 2  $ROW 3
         2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 2 2  $ROW 4
          2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 2  $ROW 5
           2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 2  $ROW 6
            2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2  $ROW 7
             2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2  $ROW 8
              2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2  $ROW 9
               2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2  $ROW 10
                2 2 1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 2 2  $ROW 11
                 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2  $ROW 12
                  2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2  $ROW 13
                   2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2  $ROW 14
                    2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2  $ROW 15
                     2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2  $ROW 16
                      2 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2  $ROW 17
                       2 2 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2  $ROW 18
                        2 2 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2  $ROW 19
                         2 2 2 2 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2  $ROW 20
                          2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  $ROW 21
C
C   Core Tank
31  0   -151 1 -153 13 14 15 16 17 18 19 30 31 32 33 34 fill=2 imp:n=1
140  2 5.82903E-02 (-153 154 -150 151):(-154 152 -150) imp:n=1 $Core Tank
33  0  150 -210 -153 213  imp:n=1
34  0  -152 -150 220 213 250  imp:n=1
81  0   -1 -151 154 220 imp:n=1
C
C  Reflectors
50  10 8.89856E-02 -200 237  imp:n=1   $Lower Top reflector
77  10 8.89856E-02 -238 -200 imp:n=1
78  0   -237 238 -200 imp:n=1
51  11 8.38831E-02 200 -201  237 imp:n=1 $Upper Top Refleltor
79  11 8.38831E-02 -238 -201 imp:n=1
80  0  -237 238 -201 imp:n=1
52  8  8.77706E-02 210 -212
          225 227 229 231 233 235 imp:n=1 $Lower Side Reflector
65  8  8.77706E-02 -212 210 -226 711 713 imp:n=1 $ 4
66  8  8.77706E-02 -212 210 -228 710 712 714 imp:n=1 $ 3
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67  8  8.77706E-02 -212 210 -230 701 703 imp:n=1 $ 2
68  8  8.77706E-02 -212 210 -232 700 702 704 imp:n=1 $ 1
69  8  8.77706E-02 -212 210 -234 imp:n=1
71  0   -212 210 -235 imp:n=1
72  0   -212 210 -233 234 imp:n=1
73  0   -212 210 -231 232 imp:n=1
74  0   -212 210 -229 230 imp:n=1
75  0   -212 210 -227 228 imp:n=1
76  0   -212 210 -225 226 imp:n=1
700  200 4.79835E-02 -700 imp:n=1
701  200 4.79835E-02 -701 imp:n=1
702  200 4.79835E-02 -702 imp:n=1
703  200 4.79835E-02 -703 imp:n=1
704  200 4.79835E-02 -704 imp:n=1
705  200 4.79835E-02 -705 imp:n=1
706  200 4.79835E-02 -706 imp:n=1
707  200 4.79835E-02 -707 imp:n=1
708  200 4.79835E-02 -708 imp:n=1
709  200 4.79835E-02 -709 imp:n=1
710  201 4.63399E-02 705 -710 imp:n=1
711  201 4.63399E-02 706 -711 imp:n=1
712  201 4.63399E-02 707 -712 imp:n=1
713  201 4.63399E-02 708 -713 imp:n=1
714  201 4.63399E-02 709 -714 imp:n=1
53  9  8.77706E-02 210 -211 imp:n=1 $Upper Side Reflector
54  12 8.25656E-02 -220   imp:n=1   $bottom Reflector
C  Support Structure/Additional Reflectors
60  30 6.01489E-02 -250 imp:n=1 $Uppwer Al Plate
61  31 6.00094E-02 -251 imp:n=1 $Lower Al Plate
62  32 8.75101E-02 -252 imp:n=1 $SS304 Plate
63  33 8.31237E-02 -253 254 imp:n=1 $Iron Table
64  0  -999 #60 #61 #62 #63 212 211 200 201  imp:n=1
C
999 0  999 imp:n=0

C   Surface Cards
1    pz   0.      $bottom of core tank
20   cz   0.635   $OR Clad
21   cz   0.584   $IR Clad
22   pz   0.3     $top of bottom cap/Bottom of Fuel
23   pz  30.18    $bottom of top cap/Top of Fuel
24   pz  30.48    $Top of fuel tube
25   cz   0.5705  $OR of Pellet
28   rpp  -0.9 0.9  -0.9 0.9  0.2978 1.4472  $pellet lattice box
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
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
C  Core Tank
150  cz  12.98  $OR Core Tank
151  cz  12.726 $IR Core Tank
152  pz  -23.224   $Bottom of Core Tank
154  pz  -22.86   $top of bottom of core tank
153  pz  30.816  $Top of Core Tank
C
C  Reflectors
C   Top Reflectors
200  rcc 0 0 30.816   0 0 15.25   38.1 $Lower Top Reflector
201  rcc 0 0 46.066   0 0 8.36    25.4 $Upper Top Reflector
C  Side Reflectors
210  cz  13.0675  $IR
211  rcc 0 0 23.186   0 0 7.63   38.6  $Upper Side Reflector
212  rcc 0 0 -23.444  0 0 46.63  40.9675 $Lower Side Reflector
213  pz -23.444 $surface for creating void regions
C  Bottom Reflector
220  rcc 0 0 -22.86  0 0 22.86  12.71 $bottom reflector
```

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C  Foil Holes in lower side and top reflector
225  rcc 0 0 7.61 -50 0 0 0.635 $west hole
226  rcc 0 0 7.61 -50 0 0 0.555 $west plug
227  rcc 0 0 7.61 -40 69.3 0 0.635 $nnw hole
228  rcc 0 0 7.61 -40 69.3 0 0.555 $nnw plug
229  rcc 0 0 7.61 40 69.3 0 0.635 $nne hole
230  rcc 0 0 7.61 40 69.3 0 0.555 $nne plug
231  rcc 0 0 7.61 50 0 0 0.635 $west hole
232  rcc 0 0 7.61 50 0 0 0.555 $west plug
233  rcc 0 0 7.61 40 -69.3 0 0.635 $sse hole
234  rcc 0 0 7.61 40 -69.3 0 0.555 $sse plug
235  rcc 0 0 7.61 -40 -69.3 0 0.635 $ssw hole
236  rcc 0 0 7.61 -40 -69.3 0 0.555 $ssw plug
237  cz  0.635
238  cz  0.555
239  pz  45.96
240  pz 54.32
C  Additional Bottom Reflectors
250  rcc 0 0 -25.164  0 0 1.94  10.8  $Al Upper Plate
251  rcc 0 0 -25.794  0 0 0.63  22.86 $Al Lower Plate
252  rcc 0 0 -28.174  0 0 2.38  22.86 $SS304 Plate
253  rpp -60.95 60.95  -60.95 60.95  -24.82 -23.55 $Iron Table
254  cz 13.335
C  Bare Foils
700   rcc 13.5625   0   7.61   0.01   0   0   0.375
701   rcc 9.53125   16.50860926   7.61   0.005   0.008660254   0   0.375
702   rcc 25.0625   0   7.61   0.01   0   0   0.375
703   rcc 15.53125   26.90091411   7.61   0.005   0.008660254   0   0.375
704   rcc 37.0625   0   7.61   0.01   0   0   0.375
C  Covered Foils
705   rcc -6.78125   11.74546954   7.61   -0.005   0.008660254   0   0.375
706   rcc -19.0625   2.33544E-15   7.61   -0.01   1.22515E-18   0   0.375
707   rcc -12.53125   21.70476168   7.61   -0.005   0.008660254   0   0.375
708   rcc -31.0625   3.80562E-15   7.61   -0.01   1.22515E-18   0   0.375
709   rcc -18.53125   32.09706653   7.61   -0.005   0.008660254   0   0.375
C  Cd Covers
710   rcc -6.75575   11.70130224   7.61   -0.056   0.096994845   0   0.38
711   rcc -19.0115   2.32919E-15   7.61   -0.112   1.37217E-17   0   0.38
712   rcc -12.50575   21.66059439   7.61   -0.056   0.096994845   0   0.38
713   rcc -31.0115   3.79937E-15   7.61   -0.112   1.37217E-17   0   0.38
714   rcc -18.50575   32.05289923   7.61   -0.056   0.096994845   0   0.38
C
999   rpp  -500 500   -500 500  -500 500

C   Data Cards
C  Fuel
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   3.02148E-03
      26056.70c   4.74308E-02
      26057.70c   1.09538E-03
      26058.70c   1.45775E-04
      6000.70c   1.39900E-04
      25055.70c   7.64651E-04
      14028.70c   6.89755E-04
      14029.70c   3.50241E-05
      14030.70c   2.30881E-05
      24050.70c   6.31871E-04
      24052.70c   1.21850E-02
      24053.70c   1.38168E-03
      24054.70c   3.43930E-04
      28058.70c   5.35999E-03
      28060.70c   2.06466E-03
      28061.70c   8.97493E-05
      28062.70c   2.86160E-04
      28064.70c   7.28766E-05
      15031.70c   3.05157E-05
      16032.70c   1.86523E-05
      16033.70c   1.49328E-07
      16034.70c   8.42918E-07
      16036.70c   3.92969E-09
      41093.70c   2.91044E-04
```

```
      73181.70c   1.30755E-05   $tot   7.61160E-02
C   Core Tank
m2   13027.70c   5.80397E-02
      29063.70c   2.14522E-05
      29065.70c   9.56154E-06
      14028.70c   1.22966E-04
      14029.70c   6.24391E-06
      14030.70c   4.11603E-06
      26054.70c   3.91905E-06
      26056.70c   6.15207E-05
      26057.70c   1.42078E-06
      26058.70c   1.89080E-07
      25055.70c   7.17463E-06
      30000.70c   1.20557E-05   $ Tot   5.82903E-02
C   Reflectors
C  ************************************
C  Lower Side Reflector
m8   6000.70c   8.77706E-02   $ tot   8.77706E-02
C
C  Upper Side Reflector
m9   6000.70c   8.67421E-02   $ tot   8.67421E-02
C
C  Lower Top Reflector
m10   6000.70c   8.89856E-02   $ tot   8.89856E-02
C
C  Upper Top Reflector
m11   6000.70c   8.38831E-02   $ tot   8.38831E-02
C
C  Bottom Reflector
m12   6000.70c   8.25656E-02   $ tot   8.25656E-02
C    ************************************
C  Additional Bottom Reflectors
C   Al Upper Reflector
m30   13027.70c   5.98746E-02
      29063.70c   2.21304E-05
      29065.70c   9.86383E-06
      14028.70c   1.26853E-04
      14029.70c   6.44131E-06
      14030.70c   4.24616E-06
      26054.70c   4.04295E-06
      26056.70c   6.34657E-05
      26057.70c   1.46570E-06
      25055.70c   7.40146E-06
      30000.70c   1.24368E-05   $ Tot   6.01329E-02
C   Al Lower Reflector
m31   13027.70c   5.97358E-02
      29063.70c   2.20791E-05
      29065.70c   9.84096E-06
      14028.70c   1.26559E-04
      14029.70c   6.42638E-06
      14030.70c   4.23632E-06
      26054.70c   4.03358E-06
      26056.70c   6.33185E-05
      26057.70c   1.46230E-06
      25055.70c   7.38430E-06
      30000.70c   1.24080E-05   $ Tot   5.99935E-02
C   SS304 Reflector
m32   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   Iron Table
m33   26054.70c   4.66345E-03
      26056.70c   7.32063E-02
      26057.70c   1.69065E-03
      26058.70c   2.24995E-04
      6000.70c   9.43427E-04
      12024.70c   1.47307E-03
      12025.70c   1.86488E-04
      12026.70c   2.05324E-04
      15031.70c   2.92673E-05
      16032.70c   3.35422E-05
      16033.70c   2.68536E-07
      16034.70c   1.51581E-06
      16036.70c   7.06673E-09
      14028.70c   2.97691E-04
      14029.70c   1.51160E-05
      14030.70c   9.96460E-06
      29063.70c   9.86750E-05
      29065.70c   4.39808E-05   $ tot   8.31237E-02
m200   92234.70c   4.67753E-04
      92235.70c   4.47223E-02
      92236.70c   1.14750E-04
      92238.70c   2.67865E-03   $ total   4.79835E-02
m201   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   grph.10t
mt9   grph.10t
mt10  grph.10t
mt11  grph.10t
mt12  grph.10t
mt30  al27.12t
mt31  al27.12t
C
kcode  1000000 1 150 2000
C  kcode  100 1 10 150
ksrc   0 5.25 5  0 10.5 10  0 -5.25 5  0 -10.5 10
       6.0 0 5   10.5 0 10  -6.0 0 5   -10.5 0 10
       6.5 5.25 5  -6.5 5.25 10  -6.5 -5.25 5  6.5 -5.25 10
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
f4:n  700
fm4   1 200 -6
f14:n   701
fm14   1 200 -6
f24:n   702
fm24   1 200 -6
f34:n   703
fm34   1 200 -6
f44:n   704
fm44   1 200 -6
f54:n  705
fm54   1 200 -6
f64:n   706
fm64   1 200 -6
f74:n   707
fm74   1 200 -6
f84:n   708
fm84   1 200 -6
f94:n   709
fm94   1 200 -6
```

A.4 Reactivity-Effects Configurations

The input decks for analysis of the graphite plug worth are the same as those used for the cadmium ratios as described in Section 3.3 but without the foils and with the adjustments discussed in Section 3.4.

A.5 Reactivity Coefficient Configurations

Reactivity coefficient measurements were not performed

A.6 Kinetics Parameter Configurations

Kinetics measurements were not performed.

A.7 Reaction-Rate Configurations

MCNP5 Input Decks for Evaluating ^{235}U Fission Reaction-Rate Measurements:

The input decks for analysis of the radial and axial ^{235}U fission reaction-rate measurements is that of the cadmium ratio measurements described in Section 3.3 but without the foils and with the following tally-card specifications appended to the end of the input deck:

Axial Activation of ^{235}U Fission Foils Tally-Card [a]

```
m1000 92235.70 -.932
   92238.70 -.068
fmesh4:n geom cyl origin 0 0 0.005
     imesh 0.32 iints 1
     jmesh 55 jints 5500
     kmesh 1 kints 1
fm4 1 1000 -6
```

Radial Activation of ^{235}U Fission Foils Tally-Card

```
m1000 92235.70 -.932
   92238.70 -.068
fmesh4:n geom cyl origin 0 0 7.61
     axs 1 0 0 vec 0 0 1
     imesh 0.375 iints 1
     jmesh 41 jints 4100
     kmesh 1 kints 1
fm4 1 1000 -6
```

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 (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.

[a] An identical tally card was used when evaluating the axial distribution of the induced fission in a uranium fission counter but the tally results were then averaged over the 2.5 cm detecctor length.

APPENDIX B: EVALUATED DATA FROM AXIAL DISTRIBUTION OF INDUCED FISSIONS IN A URANIUM FISSION COUNTER

B.1 DETAILED DESCRIPTION

A description of the measurements can be found in Section 1.7.

B.2 EVALUATION OF EXPERIMENTAL DATA

For the measurement of the axial induced fission in a uranium fission counter, as discussed in Section 1.7.2, an average of about 10,000 counts were collected on the fission counter. The measurement uncertainty in a single measurement can be approximated by taking the square root of the number of counts then dividing by the number of counts ($\sqrt{10{,}000}/10{,}000$). This yields an approximate measurement uncertainty of ±1.0%. The axial detector location was evaluated by calculating the gradient of the measured data. This yielded a maximum 1σ uncertainty of 4.62% between Case 1 and 2. The detector could have moved radial during measurement buy a maximum of 0.716 cm. A 1σ uncertainty of ±0.413 cm in the radial detector position was evaluated and was found to have a negligible effect. This was taken as the 1σ uncertainty in the detector location. A ±0.1 cm uncertainty in the 2.5 cm detector length yields a maximum 1σ uncertainty of approximately 0.05%.

The effect of the fission counter enrichment was evaluated by comparing tallies for a 100 wt.% ^{235}U counter to a 93.15 wt.% ^{235}U counter. It was found that this 6.8 wt.% change in enrichment yields a maximum change in the normalized tally results of 5.0% for Case 1 and 10.4% for Case 2. When scaled to an enrichment uncertainty of 0.0177% (see Section 2.1.5.1), the effect of this uncertainty would be negligible. According to the experimenter, because the induced fission rates were normalized, the effect of composition of the fission counter would have a negligible effect.[a]

Because the measurements were normalized, the uncertainty in all points except the normalization point (33.02 cm for Case 1 and 16.51 cm for Case 2) is multiplied by $\sqrt{2}$. Since the same uncertainty is applied to all measurement point this simplified approach is justified. The normalization uncertainty does not apply to the normalization point.[b] 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. These uncertainties, added in quadrature, are summarized in Table B.2-1, given in Table B.2-2 and shown in Figure B.2-1. Measurements made in the reflector region are highlighted.

---

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

[b] The uncertainty in the normalization point was preserved, as can be seen in Table 2.7-1. It should be noted that if data were being used strictly for trending purposes the uncertainty on the normalization point would be zero, since this point has been forced to a value of 1.

Table B.2-1. Summary of Experimental Uncertainty in Axial Distribution of Induced Fission in a Uranium Fission Counter.

Uncertainty	Effect	
Measurement	±	1.0%
Axial Detector Position	±	4.62%
Radial Detector Position	±	NEG
Detector Length	±	0.05%
Detector Enrichment	±	NEG
Detector Composition	±	NEG
Total	±	4.73%√2[(a)]
Total-Normalization Point		4.73%
Rounding	±	0.01/√3

(a) The √2 accounts for the added uncertainty from the normalization. This does not apply to the normalization point (33.02 cm for Case 1 and 16.51 cm for Case 2).

Table B.2-2. Uncertainty in Axial Distribution of the Induced Fission in a Uranium Fission Counter.

Distance from Bottom of Core[(a)] (cm)	Induced Fission[(b)] (Arbitrary Units)		
	Case 1[(c)]		
5.0	0.12	±	0.010
7.5	0.09	±	0.008
10.0	0.12	±	0.010
12.6	0.1	±	0.009
15.1	0.11	±	0.009
17.7	0.11	±	0.009
20.2	0.1		0.009
22.8	0.1	±	0.009
25.3	0.13		0.010
27.8	0.4	±	0.027
30.4	0.67		0.045
32.9	0.88	±	0.059
35.4	0.99	±	0.066
39.7	0.94	±	0.048
40.5	1.01	±	0.068
42.8	1.02	±	0.065
45.8	0.87	±	0.058
48.1	0.69	±	0.047
50.7	0.44	±	0.030
53.2	0.23	±	0.016

(a) Measured from the bottom of the stainless-steel fuel tubes.
(b) The detector was ^{235}U fission counter 2.5 cm long × 0.64 cm diameter unless noted otherwise.
(c) Uncertainty is summarized in Table B-1.

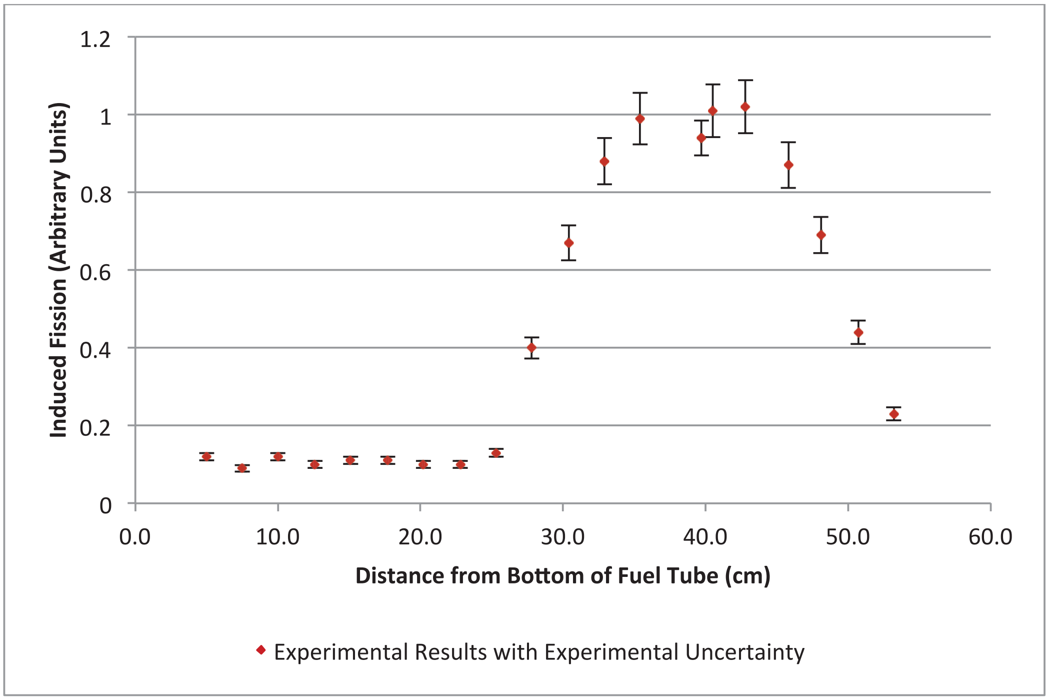

Figure B.2-1. Uncertainty in Axial Distribution of the Induced Fission in a Uranium Fission Counter.

B.3 MODEL SPECIFICATIONS

B.3.1 Description of the Model Simplifications

The model used for axial fission counter measurements was the same as that used for the radial uranium foil activation measurements but the tallies were modeled using a mesh of cells superimposed over the geometry that had a radius of 0.32 cm and extended from the bottom of the core tank to the top of the top reflector. Each cell had a height of 0.01 cm. Cell-averaged flux tallies were used. A tally multiplier for the ^{235}U fission cross section was also used. Tally results were then averaged over the 2.5 cm active length of the uranium fission counter. It is believed that this method for modeling the reaction-rate distribution would have a negligible bias. The simplification bias on the measurement due to geometry simplifications for the detailed and simple models is given in Table B.3-1. Statistically insignificant biases were not included in Table B.3-1 but the associated bias uncertainty was preserved.

Table B.3-1. Simplification Bias of Relative Axial Distribution of the Induced Fission in a Uranium Fission Counter.

Distance from Bottom of Core (cm)	Simplification Bias[(a)]					
	Detailed Model			Simple Model		
5.0	-	±	<0.001	-0.003	±	<0.001
7.5	0.001	±	<0.001	-0.003	±	<0.001
10.0	0.001	±	<0.001	-0.003	±	<0.001
12.6	0.001	±	<0.001	-0.003	±	<0.001
15.1	0.001	±	<0.001	-0.003	±	<0.001
17.7	0.001	±	<0.001	-0.003	±	<0.001
20.2	0.001	±	<0.001	-0.003	±	<0.001
22.8	0.001	±	<0.001	-0.003	±	<0.001
25.3	0.001	±	<0.001	-0.003	±	<0.001
27.8	0.001	±	<0.001	-0.003	±	<0.001
30.4	0.001	±	<0.001	0.005	±	<0.001
32.9	0.001	±	<0.001	0.010	±	<0.001
35.4	-	±	<0.001	0.006	±	<0.001
39.7	-0.001	±	<0.001	-0.002	±	<0.001
40.5	-0.001	±	<0.001	-0.003	±	<0.001
42.8	-0.002	±	<0.001	-0.008	±	<0.001
45.8	-0.003	±	<0.001	-0.008	±	<0.001
48.1	-0.004	±	<0.001	-0.011	±	<0.001
50.7	-0.006	±	<0.001	-0.009	±	<0.001
53.2	-0.009	±	<0.001	-0.012	±	<0.001

(a) Calculated by comparing as-built model results to detailed and simple model results.

B.3.2 Dimensions

The dimensions for the detailed and simple models were the same as those for the radial foil activation measurements (see Section 3.7.2). For the axial activation measurements the plugs in the top reflectors were removed.

B.3.3 Material Data

The material data for the detailed and simple models were the same as those used for the evaluation of the radial foil activation measurements (see Sections 3.7.3).

B.3.4 Temperature Data

The temperature was the same as the radial foil activation measurements (see Section 3.7.4).

B.3.5 Experimental and Model Reaction-Rate Distribution Values

The expected values of the induced fission in uranium-fission-counter measurements are found by applying the biases in Table B.3-1 to the experimental results. The uncertainty in the model is found by adding in quadrature the uncertainty in the experimental results, discussed in Section B.2, and the bias uncertainty given in Table B.3-1. The expected results are given in Table B.3-2 and Figure B.3-1.

Measurements in the core region are fission rates. Measurements above the top of the core region are highlighted.

Table B.3-2. Expected Relative Axial Distribution of the Induced Fission in a Uranium Fission Counter.(a)

Distance from Bottom of Core(b) (cm)	Induced Fission in Fission Counter(c) (Arbitrary Units)					
	Detailed Model(d)			Simple Model(d)		
5.0	0.12	±	0.01	0.12	±	0.01
7.5	0.09	±	0.01	0.09	±	0.01
10.0	0.12	±	0.01	0.12	±	0.01
12.6	0.10	±	0.01	0.10	±	0.01
15.1	0.11	±	0.01	0.11	±	0.01
17.7	0.11	±	0.01	0.11	±	0.01
20.2	0.10	±	0.01	0.10	±	0.01
22.8	0.10	±	0.01	0.10	±	0.01
25.3	0.13	±	0.01	0.13	±	0.01
27.8	0.40	±	0.03	0.40	±	0.03
30.4	0.67	±	0.05	0.68	±	0.05
32.9	0.88	±	0.06	0.89	±	0.06
35.4	0.99	±	0.07	1.00	±	0.07
39.7	0.94	±	0.05	0.94	±	0.05
40.5	1.01	±	0.07	1.01	±	0.07
42.8	1.02	±	0.07	1.01	±	0.07
45.8	0.87	±	0.06	0.86	±	0.06
48.1	0.69	±	0.05	0.68	±	0.05
50.7	0.43	±	0.03	0.43	±	0.03
53.2	0.22	±	0.02	0.22	±	0.02

(a) These are relative fission rates in the core and relative radial activation of ^{235}U in the reflector.
(b) Measured from the bottom of the stainless-steel fuel tubes.
(c) The detector was a ^{235}U fission counter 2.5 cm long × 0.64 cm in diameter.
(d) The total uncertainty includes the experimental and bias uncertainties added in quadrature.

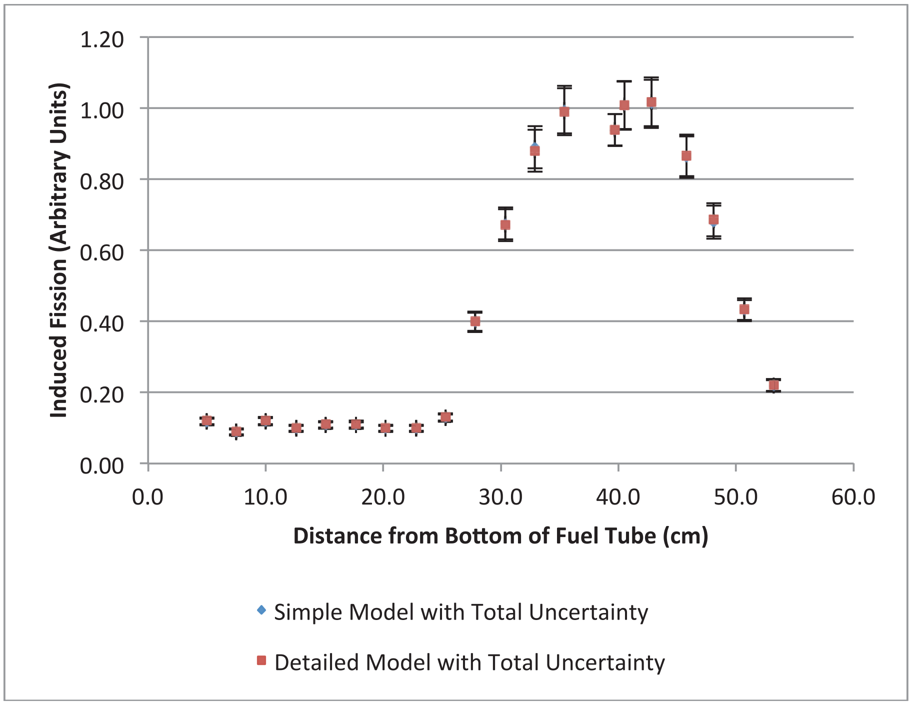

Figure B.3-1. Relative Axial Distribution of the Induced Fission in a Uranium Fission Counter.

B.4 RESULTS OF SAMPLE CALCULATIONS

The relative axial induced fission in the uranium fission counter distributions was evaluated using models as described in Section B.3 in MCNP5-1.60 and ENDF/B-VII.0 neutron cross section libraries. An fmesh cell flux tally and a fission cross section tally multiplier were used to simulate the measurements. An fmesh is a mesh of cells superimposed over a geometry for the purpose of performing tallies. 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 fmesh extended from the bottom of the core to the top of the top reflector for the axial measurements and had a radius of 0.32 cm. The tally multiplier was for ^{235}U. It can be seen in Tables B.4-1 and B.4-2 and in Figures B.4-1 and B.4-2 that the calculated values deviated greatly from the expected values between 25 and 35 cm above the bottom of the core. The cause of this large calculational bias is unknown and is not seen in SCCA-FUND-EXP-001 which is highly correlated to this experiment. The tally multiplier was for a ^{235}U fission cross section.

Table B.4-1. Relative Axial Distribution of the Induced Fission in a Uranium Fission Counter, Detailed Model.

Distance from Bottom of Core[(a)]	Induced Fission[(a)] (Arbitrary Units)						(C-E)/E[(b)]	C/E Ratio[(b)]		
	Expected Values			Calculated Values						
5.0	0.12	±	0.01	0.097	±	0.000	-19.2%	0.81	±	0.07
7.5	0.09	±	0.01	0.090	±	0.000	-0.5%	0.99	±	0.09
10.0	0.12	±	0.01	0.089	±	0.000	-26.0%	0.74	±	0.06
12.6	0.10	±	0.01	0.090	±	0.000	-11.0%	0.89	±	0.08
15.1	0.11	±	0.01	0.090	±	0.000	-19.1%	0.81	±	0.07
17.7	0.11	±	0.01	0.089	±	0.000	-19.6%	0.80	±	0.07
20.2	0.10	±	0.01	0.088	±	0.000	-12.5%	0.87	±	0.08
22.8	0.10	±	0.01	0.088	±	0.000	-12.8%	0.87	±	0.08
25.3	0.13	±	0.01	0.092	±	0.000	-29.6%	0.70	±	0.06
27.8	0.40	±	0.03	0.122	±	0.000	-69.5%	0.31	±	0.02
30.4	0.67	±	0.05	0.310	±	0.000	-53.8%	0.46	±	0.03
32.9	0.88	±	0.06	0.580	±	0.000	-34.1%	0.66	±	0.04
35.4	0.99	±	0.07	0.809	±	0.000	-18.3%	0.82	±	0.05
39.7	0.94	±	0.05	0.999	±	0.000	6.3%	1.06	±	0.05
40.5	1.01	±	0.07	1.005	±	0.000	-0.4%	1.00	±	0.07
42.8	1.02	±	0.07	0.977	±	0.000	-4.0%	0.96	±	0.07
45.8	0.87	±	0.06	0.850	±	0.000	-2.0%	0.98	±	0.07
48.1	0.69	±	0.05	0.705	±	0.000	2.8%	1.03	±	0.07
50.7	0.43	±	0.03	0.504	±	0.000	16.0%	1.16	±	0.08
53.2	0.22	±	0.02	0.282	±	0.000	27.4%	1.27	±	0.09

(a) Measured from bottom of fuel tube. Measurements above the top of the core region are highlighted.
(b) “E” is the expected value. “C” is the calculated value.

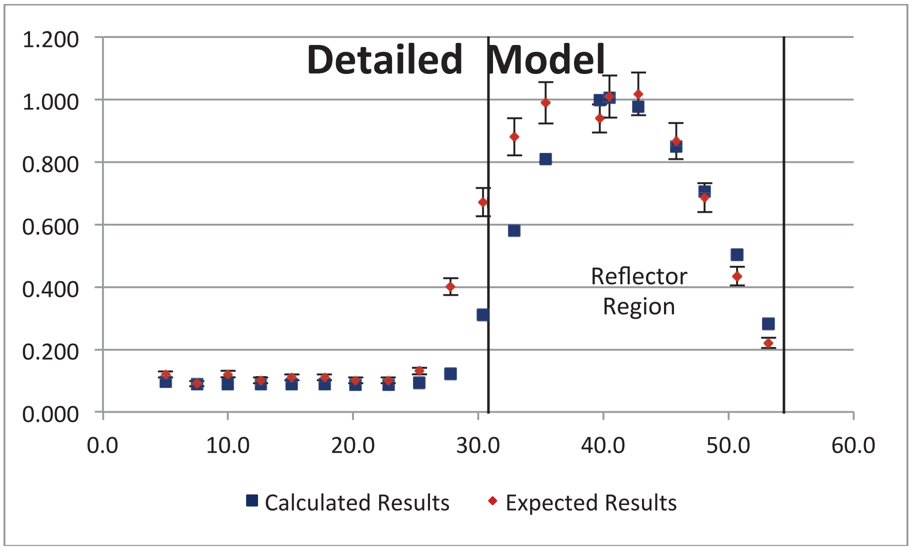

Figure B.4-1. Relative Axial Uranium Fission Counter Count Rate Distribution, Detailed Model.

Table B.4-2. Relative Axial Distribution of the Induced Fission in a Uranium Fission Counter, Simple Model.

Distance from Bottom of Core[(a)]	Induced Fission[(a)] (Arbitrary Units) Expected Values			Calculated Values			(C-E)/E[(b)]	C/E Ratio[(b)]		
5.0	0.12	±	0.01	0.094	±	0.000	-19.8%	0.83	±	0.07
7.5	0.09	±	0.01	0.087	±	0.000	-0.6%	1.04	±	0.10
10.0	0.12	±	0.01	0.086	±	0.000	-26.9%	0.76	±	0.06
12.6	0.10	±	0.01	0.086	±	0.000	-11.5%	0.92	±	0.08
15.1	0.11	±	0.01	0.086	±	0.000	-19.8%	0.84	±	0.07
17.7	0.11	±	0.01	0.085	±	0.000	-20.3%	0.83	±	0.07
20.2	0.10	±	0.01	0.084	±	0.000	-13.0%	0.91	±	0.08
22.8	0.10	±	0.01	0.084	±	0.000	-13.3%	0.90	±	0.08
25.3	0.13	±	0.01	0.089	±	0.000	-30.4%	0.72	±	0.06
27.8	0.40	±	0.03	0.119	±	0.000	-70.1%	0.31	±	0.02
30.4	0.68	±	0.05	0.314	±	0.000	-53.5%	0.46	±	0.03
32.9	0.89	±	0.06	0.590	±	0.000	-33.8%	0.65	±	0.04
35.4	1.00	±	0.07	0.815	±	0.000	-18.1%	0.81	±	0.05
39.7	0.94	±	0.05	0.998	±	0.000	6.3%	1.06	±	0.05
40.5	1.01	±	0.07	1.003	±	0.000	-0.4%	1.00	±	0.07
42.8	1.01	±	0.07	0.971	±	0.000	-4.1%	0.96	±	0.07
45.8	0.86	±	0.06	0.845	±	0.000	-2.0%	0.99	±	0.07
48.1	0.68	±	0.05	0.698	±	0.000	2.8%	1.04	±	0.07
50.7	0.43	±	0.03	0.500	±	0.000	16.1%	1.17	±	0.08
53.2	0.22	±	0.02	0.279	±	0.000	27.8%	1.29	±	0.10

(a) Measured from bottom of fuel tube. Measurements above the top of the core region are highlighted.
(b) "E" is the expected value. "C" is the calculated value.

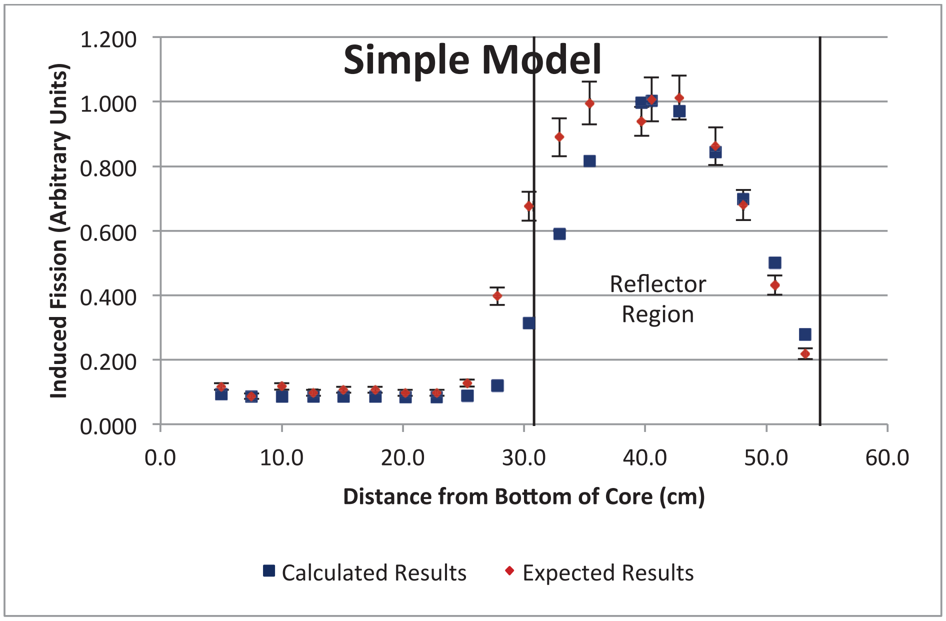

Figure B.4-2. Relative Axial Uranium Fission Counter Count Rate Distribution, Simple Model.