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

Margaret Marshall
John D. Bess
J. Blair Briggs
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March 2013

Idaho National Laboratory

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Margaret A. Marshall[3]
John D. Bess
J. Blair Briggs
Michael F. Murphy[1]
John T. Mihalczo[2]

[1]Under Subcontract to the OECD NEA
[2]Oak Ridge National Laboratory
[3]Idaho National Laboratory/University of Idaho

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Space Reactor - SPACE

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

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

Evaluator

Margaret A. Marshall
Idaho National Laboratory/University of Idaho

Internal Reviewers

John D. Bess
J. Blair Briggs
Idaho National Laboratory

Independent Reviewers

Michael F. Murphy
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John T. Mihalczo
Oak Ridge National Laboratory

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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	NO	NO	NO
1.4 Description of Reactivity Effects Measurements	YES	NO	NO	NO
1.5 Description of Reactivity Coefficient Measurements	NA	NA	NA	NA
1.6 Description of Kinetics Measurements	NA	NA	NA	NA
1.7 Description of Reaction-Rate Distribution Measurements	YES	NO	NO	NO
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	NO	NO	NO	NO
2.4 Evaluation of Reactivity Effects Data	NO	NO	NO	NO
2.5 Evaluation of Reactivity Coefficient Data	NA	NA	NA	NA
2.6 Evaluation of Kinetics Measurements Data	NA	NA	NA	NA
2.7 Evaluation of Reaction-Rate Distributions	NO	NO	NO	NO
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	NO	NO	NO	NO
3.4 Benchmark-Model Specifications for Reactivity Effects Measurements	NO	NO	NO	NO
3.5 Benchmark-Model Specifications for Reactivity Coefficient Measurements	NA	NA	NA	NA
3.6 Benchmark-Model Specifications for Kinetics Measurements	NA	NA	NA	NA
3.7 Benchmark-Model Specifications for Reaction-Rate Distribution Measurements	NO	NO	NO	NO
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	NO	NO	NO	NO
4.4 Results of Reactivity Effect Calculations	NO	NO	NO	NO
4.5 Results of Reactivity Coefficient Calculations	NA	NA	NA	NA
4.6 Results of Kinetics Parameter Calculations	NA	NA	NA	NA
4.7 Results of Reaction-Rate Distribution Calculations	NO	NO	NO	NO
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	NO	NO	NO	NO

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

IDENTIFICATION NUMBER: SCCA-SPACE-EXP-003
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 assembly (SCCA) experiments were completed from 1962–1965 at Oak Ridge National Laboratory's (ORNL's) Critical Experiments Facility (CEF) in support of the Medium-Power Reactor Experiments (MPRE) program. In the late 1950s, efforts were made to study "power plants for the production of electrical power in space vehicles."[(a)] The MPRE program was a part of those efforts and studied the feasibility of a stainless-steel system, boiling potassium 1 MW(t), or about 140 kW(e), reactor. The program was carried out in [fiscal years] 1964, 1965, and 1966. A summary of the program's effort was compiled in 1967.[a] The delayed critical experiments were a mockup of a small, potassium-cooled space power reactor for validation of reactor calculations and reactor physics methods.

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

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

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

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

1.1 Description of the Critical and/or Subcritical Configuration

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

1.2 Description of Buckling and Extrapolation Length Measurements

Buckling and extrapolation-length measurements were not made.

1.3 Description of Spectral Characteristics Measurements

1.3.1 Overview of Experiment

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

1.3.2 Geometry of the Experiment Configuration and Measurement Procedure

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

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

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

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

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

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

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.[a] The results of the cadmium ratio measurements are given in Table 1.3-1 and some results are shown in Figure 1.3-1. "No correction has been made for self shielding in the foils" (Reference 4).

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

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

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

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

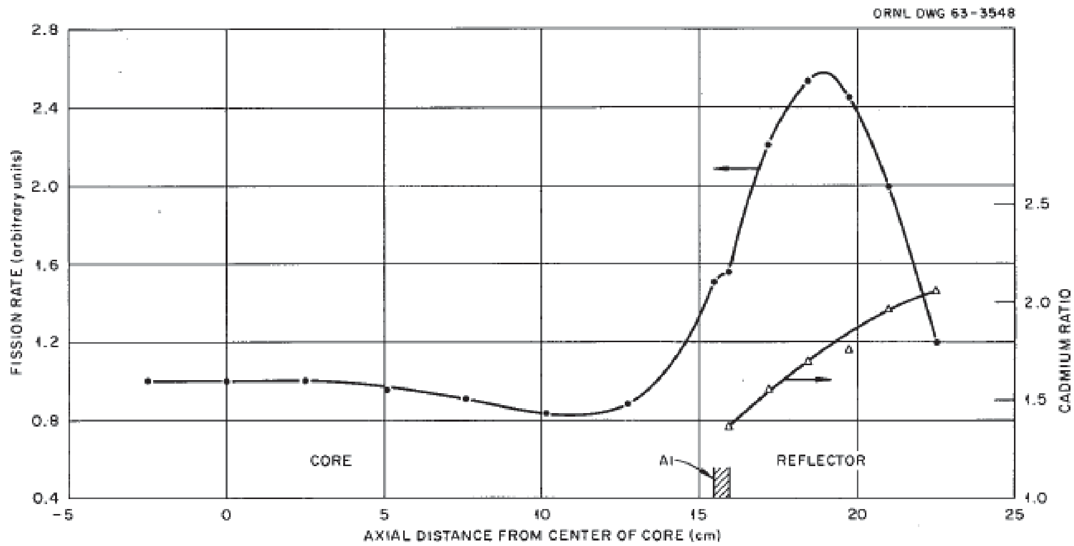

Figure 1.3-1. Plot of Relative Activation of ^{235}U Fission Foils (see Section 1.7) and Cadmium Ratios in the Top Reflector (see Reference 4).

1.3.3 Material Data

The uranium foils were 93.15 wt.% enriched. No impurity data were given for the uranium foils but according to the experimenter, the impurity content of the uranium foil was similar to that for the uranium metal described in HEU-MET-FAST-051.[a] No impurity data was given for the cadmium foils. Material data for the core and reflector parts are the same as those given in Section 1.3 of HEU-COMP-FAST-004.

1.3.4 Temperature Data

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

1.3.5 Additional Information Relevant to Spectral Characteristics Measurements

Additional information was not identified.

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

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

1.4 Description of Reactivity Effects Measurements

1.4.1 Overview of Experiment

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

1.4.2 Geometry of the Experiment Configuration and Measurement Procedure

1.4.2.1 Fuel Effect Reactivity Measurements

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

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

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

(a) Positions given in Figure 1.4-2

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

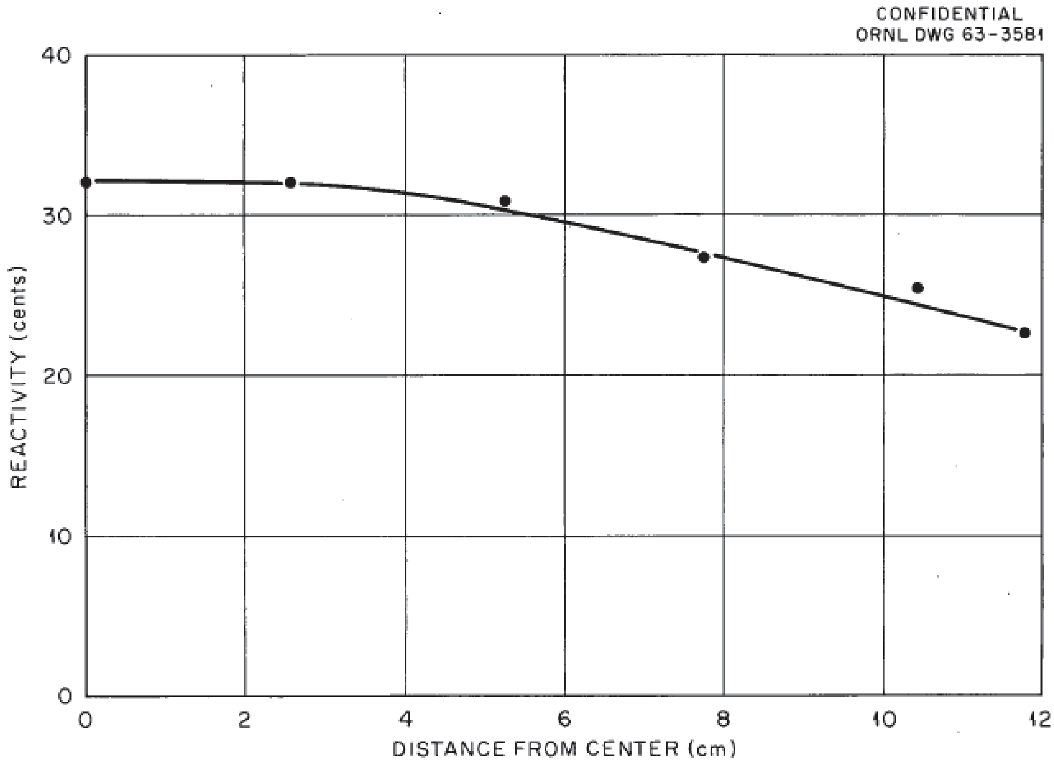

Figure 1.4-1. Reactivity Worth of Fuel Tube Versus Radius (see Reference 4).

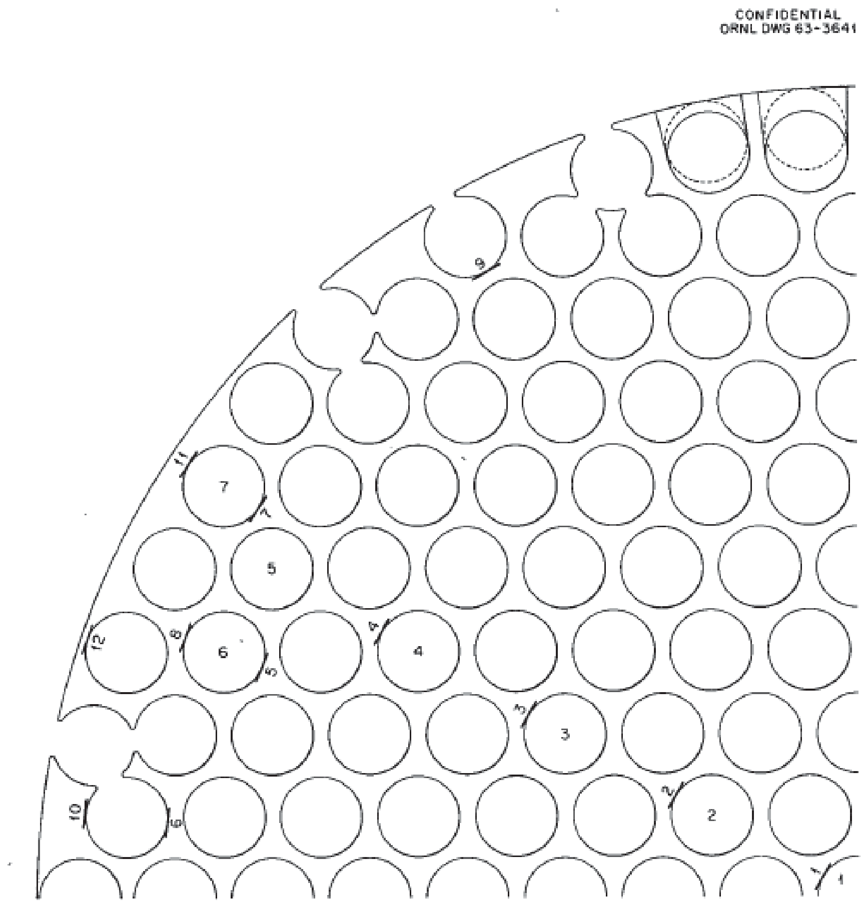

Figure 1.4-2. Foil Locations for Radial Fission Rate Distribution and Fuel Tube Locations for Fuel Reactivity Measurements (see Reference 4).

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

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

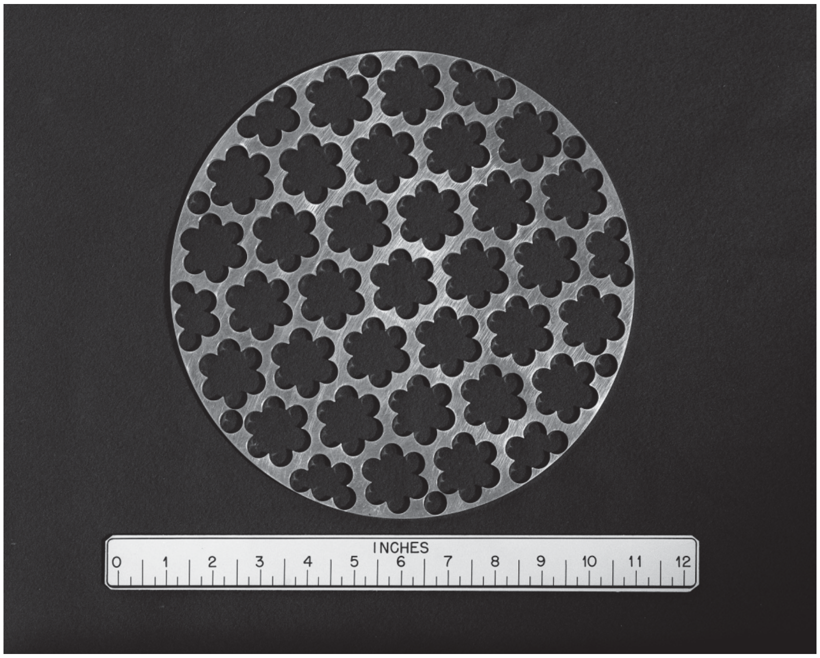

Figure 1.4-3. Grid Plate for 7-Tube-Cluster Assembly (see Reference 4).

1.4.2.2 Neutron Absorbing and Moderating Material Reactivity Measurements

The effect of adding various neutron absorbing and moderating materials was also measured. Materials were added to the core as rods, filled stainless steel tubes, and discs or lids that fit between the top of the fuel tubes and the top of the core tank.[a] Table 1.4-2 summarizes the results of the reactivity measurements reported in cents per kilogram material from Reference 4 as well as the total reactivity as found in the logbook. Any discrepancies between the logbook and Reference 4 data are footnoted in Table 1.4-2. Rod locations are shown in Figure 1.4-3.

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

Table 1.4-1. Reactivity Effects of Absorbing and Moderating Material in the Core
(See Reference 4 and the logbook).

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

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

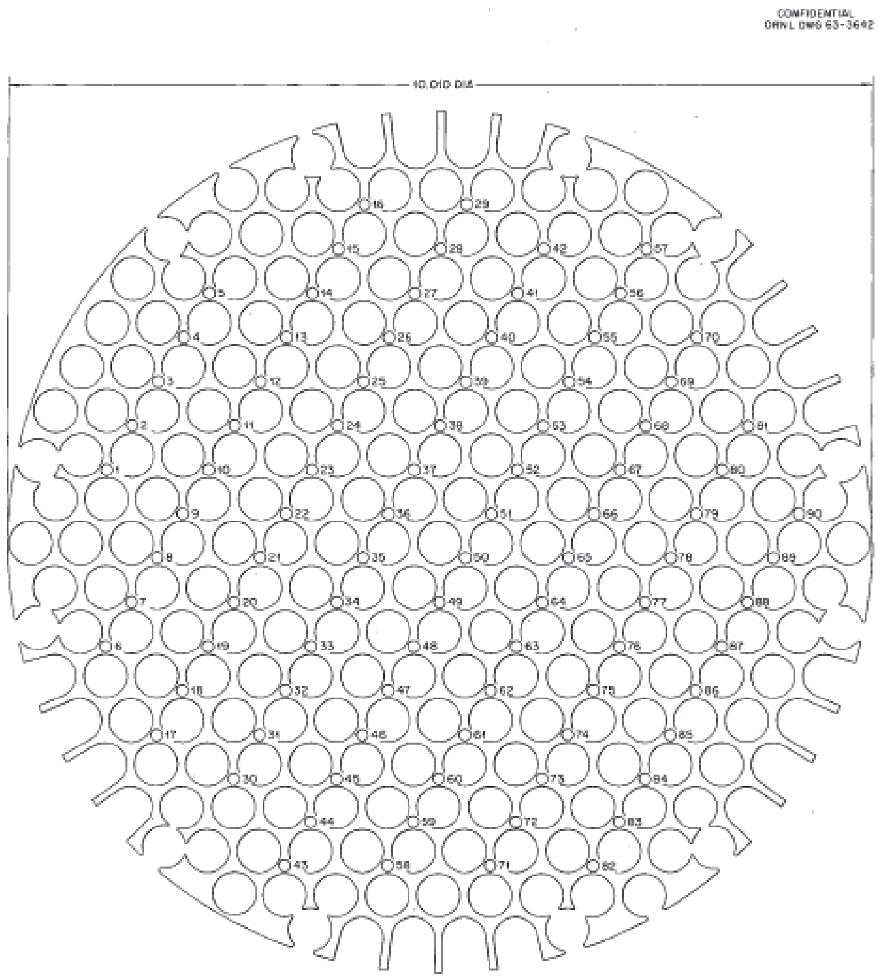

Figure 1.4-3. Locations of Samples in Reactivity Coefficient Measurements (see Reference 4).

1.4.2.3 Potassium Reactivity Measurements

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

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

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

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

[a] Radiation Safety Information Computation Center (RSICC), The ORNL Critical Experiments Logbooks, Book 75r, http://rsicc.ornl.gov/RelatedLinks.aspx?t=criticallist, logbook page 111. It is not know what "as per X-10 [Hofman]" means.

[b] ORNL Photo 39928.

1.4.3 Material Data

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

1.4.3.1 Fuel Effect Reactivity Measurements

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

1.4.3.2 Neutron Absorbing and Moderating Material Reactivity Measurements

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

As can be seen in Table 1.4-1 the worth of a stainless steel disc was measured. The type of stainless steel used for this disc was not given.

1.4.3.3 Potassium Reactivity Measurements

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

1.4.4 Temperature Data

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

1.4.5 Additional Information Relevant to Reactivity Effects Measurements

Additional information was not identified.

1.5 Description of Reactivity Coefficient Measurements

Reactivity coefficient for various materials placed in the core were measured and are reported in Section 1.4.

1.6 Description of Kinetics Measurements

Kinetics measurements were not performed.

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

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

1.7 Description of Reaction-Rate Distribution Measurements

1.7.1 Overview of Experiment

Activation measurements were taken through the core and top reflector.

1.7.2 Geometry of the Experiment Configuration and Measurement Procedure

The activation measurements were performed for the critical assembly (as described in Section 1 of HEU-COMP-FAST-004). Measurements were performed using 93.15 wt. % enriched uranium metal foils that were 0.75-cm in diameter and 0.010-cm-thick.[a] These foils were taped tangent to the fuel tubes within the core, placed on top of fuel tubes, and placed between sections of reflector. For the foils in the core, the activation is a spatial average over the diameter of the foil. For the foils in the reflector they represent a point axially and are averaged over the foil dimensions in the radial direction. No correction for self-shielding in the foils was made when obtaining the results in Tables 1.7-1, 1.7-2 and 1.7-3. Results are plotted in Figures 1.7-1 and 1.7-2. From Figure 1.7-2 it can be seen that the "radial fission rate distribution at the core midplane is flat to within 2.54 cm of the side reflector, where it increases to a maximum, at the core boundary, about 3.7 greater than at the center" (Reference 4). Foil locations within the core are given in Figure 1.4-2.

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

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

(a) Activation foils were 0.010-cm-thick by 0.75-cm-dia HEU metal foil.
(b) Foils in the core were taped tangent to the center fuel tube. Foils in the top reflector were placed between beryllium blocks at ½ inch spacing.

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

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

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

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

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

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

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

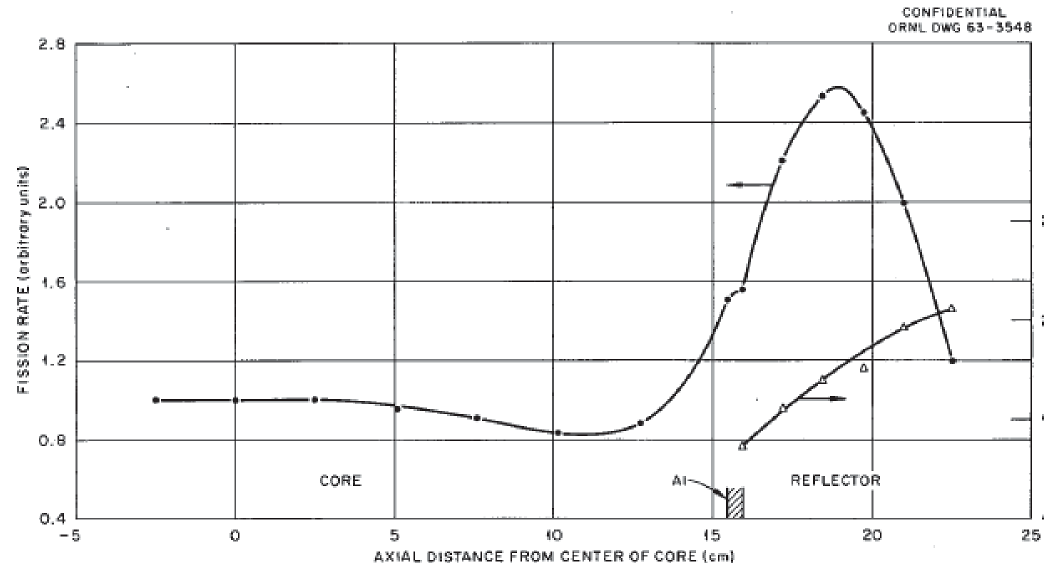

Figure 1.7-1. Plot of Axial Relative Activation of ^{235}U Fission Foils and Cadmium Ratios (see Section 1.3) (see Reference 4).

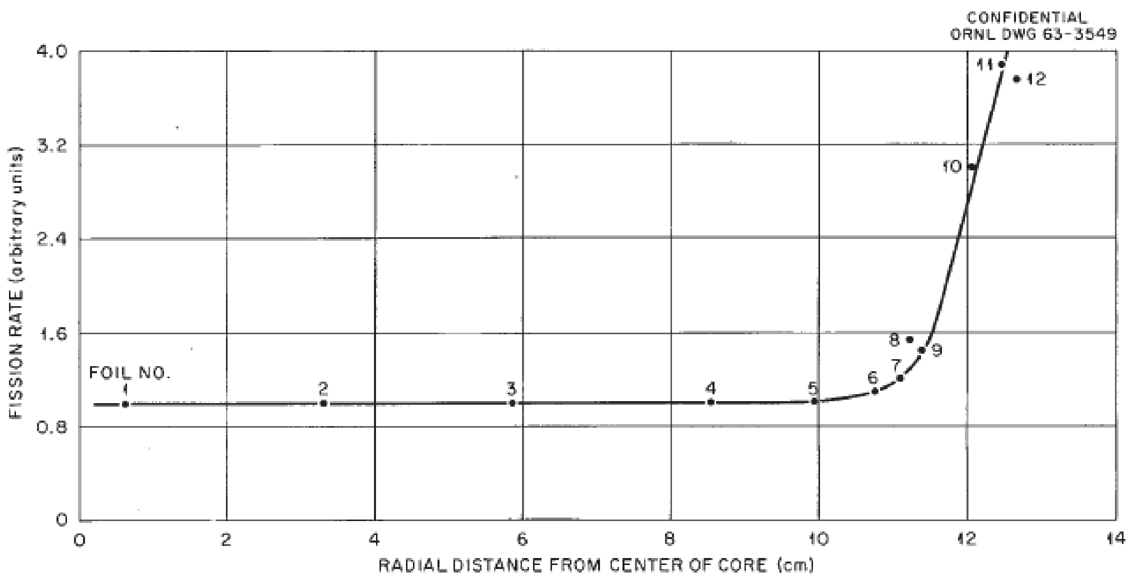

Figure 1.7-2. Plot of Radial Relative Activation of ^{235}U Fission Foils at the Core Midplane (see Reference 4).

1.7.3 Material Data

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

1.7.4 Temperature Data

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

1.7.5 Additional Information Relevant to Reaction-Rate Distribution Measurements

Additional information is not available.

1.8 Description of Power Distribution Measurements

The axial and radial relative power distribution is the same as the relative fission rate that was measured in the core region of 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.

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

2.0 EVALUATION OF EXPERIMENTAL DATA

2.1 Evaluation of Critical and/or Subcritical Configuration Data

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

2.2 Evaluation of Buckling and Extrapolation Length Data

Buckling and extrapolation-length measurements were not performed.

2.3 Evaluation of Spectral Characteristics Data

Spectra characteristics measurements were not evaluated.

2.4 Evaluation of Reactivity Effects Data

Reactivity effects measurements were not evaluated.

2.5 Evaluation of Reactivity Coefficient Data

Reactivity coefficient measurements were not evaluated.

2.6 Evaluation of Kinetics Measurements Data

Kinetics measurements were not performed.

2.7 Evaluation of Reaction-Rate Distributions

Reaction-rate distribution measurements were not evaluated.

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

2.8 Evaluation of Power Distribution Data

The relative power distribution in the core is the same as the relative fission rate as was measured in the core region of the assembly. These measurements were not evaluated (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

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

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

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

Buckling and extrapolation-length measurements were not performed.

3.3 Benchmark-Model Specifications for Spectral Characteristics Measurements

The spectral characteristic measurements were not evaluated.

3.4 Benchmark-Model Specifications for Reactivity Effects Measurements

The reactivity effect measurements were not evaluated.

3.5 Benchmark-Model Specifications for Reactivity Coefficient Measurements

Reactivity coefficient measurements were not evaluated.

3.6 Benchmark-Model Specifications for Kinetics Measurements

Kinetics measurements were not performed.

3.7 Benchmark-Model Specifications for Reaction-Rate Distribution Measurements

The reaction-rate distribution measurements were not evaluated.

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

3.8 Benchmark-Model Specifications for Power Distribution Measurements

The relative power distribution is the same as the relative fission rate as was measured in the core region of assembly. These measurements were not evaluated (see Section 3.7).

3.9 Benchmark-Model Specifications for Isotopic Measurements

Isotopic measurements were not performed.

3.10 Benchmark-Model Specifications for Other Miscellaneous Types of Measurements

Other miscellaneous types of measurements were not performed.

4.0 RESULTS OF SAMPLE CALCULATIONS

4.1 Results of Calculations of the Critical or Subcritical Configurations

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

4.2 Results of Buckling and Extrapolation Length Calculations

Buckling and extrapolation-length measurements were not performed.

4.3 Results of Spectral-Characteristics Calculations

The spectral characteristic measurements were not evaluated.

4.4 Results of Reactivity-Effects Calculations

The reactivity effect measurements were not evaluated.

4.5 Results of Reactivity Coefficient Calculations

Reactivity coefficient measurements were not evaluated.

4.6 Results of Kinetics Parameter Calculations

Kinetics measurements were not performed.

4.7 Results of Reaction-Rate Distribution Calculations

The reaction-rate distribution measurements were not evaluated.

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

4.8 Results of Power Distribution Calculations

The relative power distribution is the same as the relative fission rate as was measured in the core region of assembly. These measurements were not evaluated (see Section 4.7).

4.9 Results of Isotopic Calculations

Isotopic measurements were not performed.

4.10 Results of Calculations for Other Miscellaneous Types of Measurements

Other miscellaneous types of measurements were not performed.

5.0 REFERENCES

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

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

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

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

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

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

A.1 Critical/Subcritical Configurations

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

A.2 Buckling and Extrapolation Length Configurations

Buckling and extrapolation-length measurements were not performed.

A.3 Spectral-Characteristics Configurations

The spectral-characteristics measurements were not evaluated.

A.4 Reactivity-Effects Configurations

The reactivity-effect measurements were not evaluated.

A.5 Reactivity Coefficient Configurations

Reactivity coefficient measurements were not evaluated.

A.6 Kinetics Parameter Configurations

Kinetics measurements were not performed.

A.7 Reaction-Rate Configurations

The reaction-rate measurements were not evaluated.

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

A.8 Power Distribution Configurations

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

A.9 Isotopic Configurations

Isotopic measurements were not performed.

A.10 Configurations of Other Miscellaneous Types of Measurements

Other miscellaneous types of measurements were not performed.