

*Benchmark Critical Experiments of
Highly Enriched Uranium-233
Spheres Reflected by Normal Uranium*

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**BENCHMARK CRITICAL EXPERIMENTS OF HIGHLY ENRICHED
URANIUM-233 SPHERES REFLECTED BY NORMAL URANIUM**

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BENCHMARK CRITICAL EXPERIMENTS OF HIGHLY ENRICHED URANIUM-233 SPHERES REFLECTED BY NORMAL URANIUM

IDENTIFICATION NUMBER: U233-MET-FAST-003

KEY WORDS: acceptable, critical experiment, metal, normal uranium reflected, reflected ^{233}U sphere, sphere, ^{233}U

1.0 DETAILED DESCRIPTION

1.1 Overview of Experiment

Evaluated in this report are two critical experiments. Both critical experiments were performed using spherical masses of ^{233}U reflected by normal uranium at Los Alamos Scientific Laboratory. The first experiment was performed using a core mass of 10.012 kg and will be referred to as the 10 kg experiment. The second experiment was performed using a core mass of 7.601 kg and will be referred to as the 7.6 kg experiment. These experiments are considered to be acceptable as benchmark critical experiments. This series is covered by PU-MET-FAST-005, PU-MET-FAST-010, PU-MET-FAST-018, U233-MET-FAST-002, U233-MET-FAST-004, U233-MET-FAST-005, and MIX-MET-FAST-001.

1.2 Description of Experimental Configuration

Both the 7.6 kg and 10 kg experiments were performed in 1958 using the Planet universal assembly machine (Reference 1). The core was composed of two hemispheres with a 0.85-inch-diameter central source cavity. The hemispheres were constructed of uranium highly enriched in ^{233}U and plated with 0.005 inches of nickel. Hemishells of various thicknesses of normal uranium were constructed to enclose the ^{233}U hemishells (Reference 1).

A drawing of the Planet assembly machine is shown in Figure 1, and the core setup is shown in Figure 2. The top half of the core rested on a 0.015-inch-thick stainless-steel diaphragm. The lower half of the core rode on a hydraulic lift. The lift that supported the lower half of the assembly was a hollow cylinder made of aluminum. Assembly was accomplished by raising the hydraulic lift which supported the lower half of the core. Rapid disassembly was accomplished by dropping the lift that supported the lower half of the core (Reference 1).



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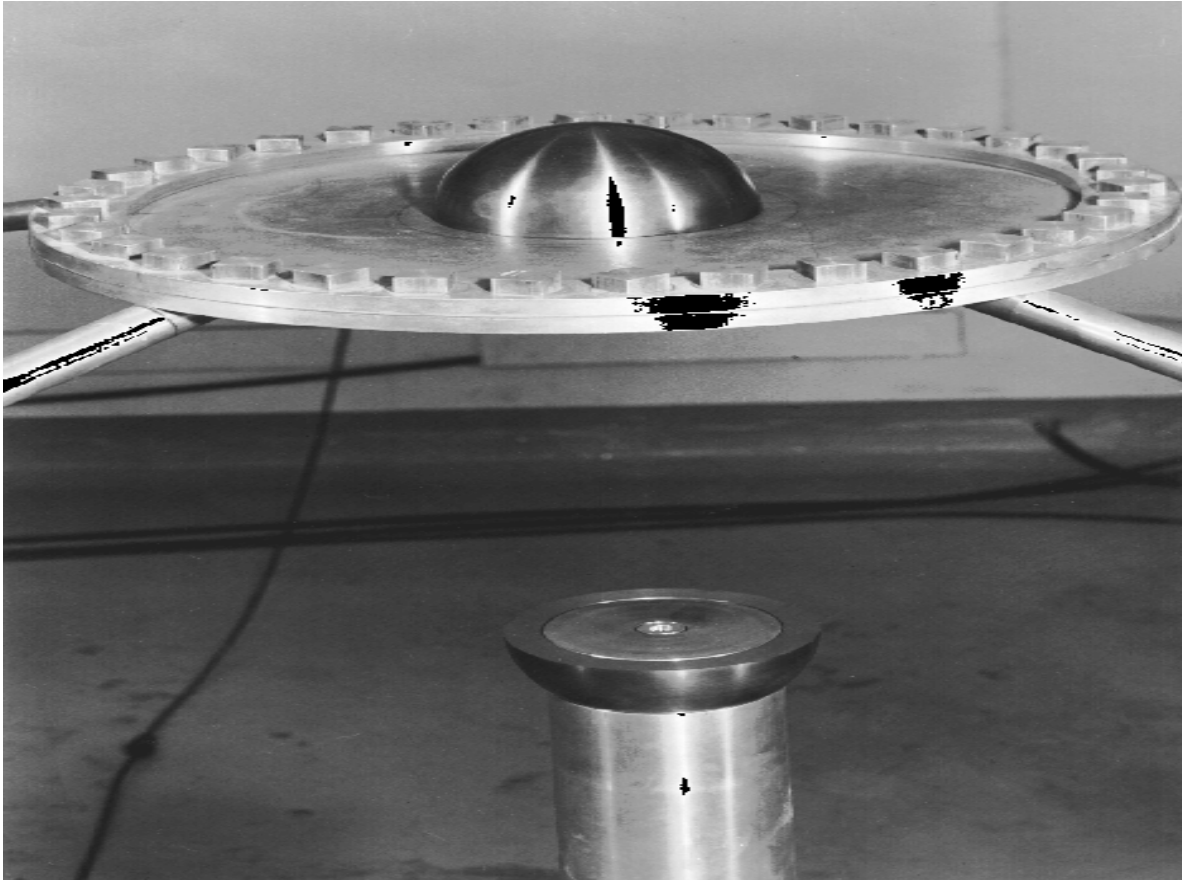


Figure 2. The Core Setup.

Four BF₃ detectors encased in polyethylene were mounted on the assembly lift in such a way as to adequately monitor neutron leakage. A ²¹⁰PoBe neutron source with a strength of approximately 10⁵ neutrons/sec was placed inside of the source cavity in the upper half of the core. The experiments were performed on the same day such that the short half-life of the source (138 days) was not a factor.^a

Hemishells were fabricated of normal uranium to enclose the ²³³U hemispheres, and the multiplication of the assembled system was measured. The procedure was followed for (1) the bare core, (2) an intermediate thickness of normal uranium, and (3) a final normal uranium thickness. For the 7.6 kg experiment, measurements were made with a 42.52 g close-fitting hemispherical ²³³U filler piece in the lower source cavity (Reference 2). For the 10 kg experiment, measurements were made with a 29.64 g close-fitting hemispherical plutonium filler piece in the lower source cavity (Reference 3).

Table 1 shows the actual experimental results for the 10 kg and 7.6 kg experiments. The multiplication^b measurements were obtained with the filler piece in place, and both halves of the core in direct contact with the diaphragm (References 2 and 3).

Table 1. Multiplication Measurements.

U Thickness (inches)	Core Reflector Clearance (inches)	Multiplication with filler piece
10 kg Experiment		
0.0	-	6.31
0.769	0.006	31.11
0.960	0.009	88.24
7.6 kg Experiment		
0.0	-	4.560
2.098	0.002	64.54
2.299	0.002	172.1

^a The PoBe source neutron spectrum and strength changes over time because of radioactive decay, chemical and physical changes, such as recrystallization of the beryllium. If measurements are taken with the same source over a relatively long period of time, the measured multiplication and, therefore, the critical characteristic dimension determination can be affected.

^b Multiplication, in simple terms, is the ratio of the neutron count rates as measured by external neutron counters, with and without fissile material present. That is, in a subcritical system with a neutron source, multiplication is the equilibrium ratio of the total number of fission and source neutrons to the total number of source neutrons.

Additional experimental measurements and corrections were made to the experimental configuration to obtain the critical mass of a solid sphere of uranium highly enriched in ^{233}U with a close-fitting spherical normal uranium reflector. These corrections and measurements are described in Section 2.

1.3 Description of Material Data

The core composition is given in Table 2. The core composition as described in Reference 5 is used. The core specifications from Reference 5 apply to ^{233}U cores surrounded by HEU, but it was determined that the same two cores were used for the two experiments in this evaluation. The isotopic compositions are the same for both cores (Reference 5). The density of the 7.6 kg core was 18.644 g/cm^3 and 18.621 g/cm^3 for the 10 kg core.

Table 2. Core Composition.

Isotope	Wt. %
^{233}U	98.2
^{234}U	1.1
^{238}U	0.7

The normal uranium reflector composition is given in Table 3. The reflector is the same for both experiments. The density of the reflector was 18.92 g/cm^3 for both experiments (Reference 1).

Table 3. Reflector Composition.

Isotope	Wt. %
^{235}U	0.72
^{238}U	99.28

1.4 Supplemental Experimental Measurements

No additional experimental measurements were performed with the exception of those described in Section 2.

2.0 EVALUATION OF EXPERIMENTAL DATA

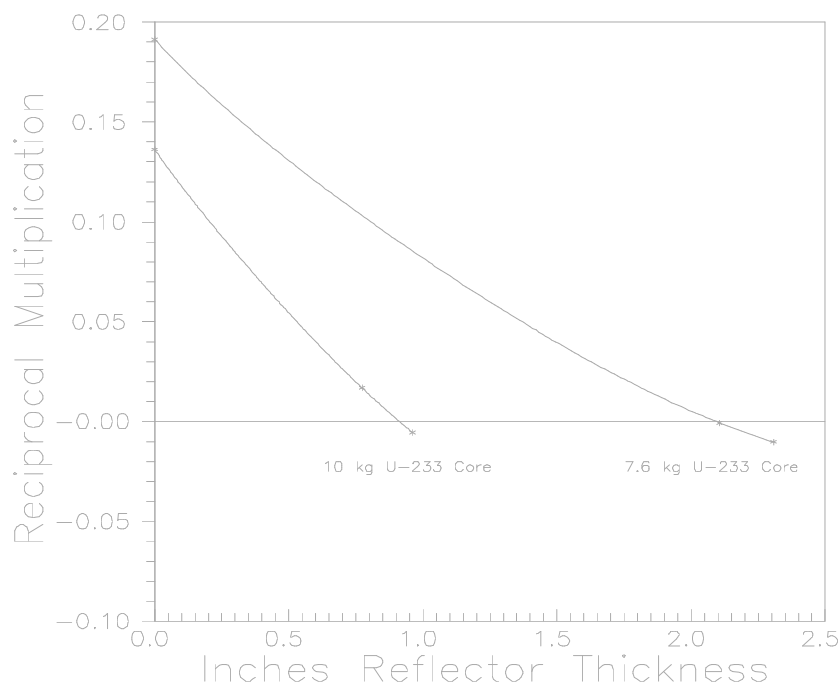
The need and value of solid spherical critical assemblies was foreseen by the experimenters, and, thus, the experimenters made some additional corrections and measurements to obtain solid spherical core-reflector critical masses.

First, the experimenters determined the effect of the 0.015-inch-thick diaphragm. The results of the study indicated that the steel diaphragm had little effect other than maintaining a gap between the two halves of the assembly. The measured $\Delta 1/M$ effect of the diaphragm was approximately -0.0036.

"A plot of reciprocal multiplication ($1/M$) was extrapolated for an additional 0.015 inches past the closure point to obtain the effect of the diaphragm on the multiplication of the system. The validity of this extrapolation was verified by increasing the thickness of the diaphragm with an additional 0.015-inch sheet of stainless steel. The multiplication thus obtained agreed with what could have been predicted from the $1/M$ closure curve . . ." (Reference 1)

Figure 3 was reproduced from Reference 1 and shows the plot of reciprocal multiplication versus reflector thickness.

Next, the change in multiplication was measured when a close-fitting filler piece was added to the bottom half of the central source cavity. From this measurement, a good estimate was made of the expected change in multiplication when the source cavity was completely filled (i.e., solid spherical core-reflector critical masses) (References 6 and 7). The $\Delta 1/M$ correction for the



central void was -0.0100. This value includes the correction for the nickel on the source cavity surface.

The effect of the 0.005-inch-thick nickel plating on the hemisphere parting plane and the source cavity surface was determined using material replacement data made on the ^{239}Pu Jezebel bare critical assembly. The worth of the nickel on the interior of the surface cavity was previously mentioned, and the $\Delta 1/M$ for the nickel on the parting plane was determined to be -0.0040. The effect of the nickel on the surface of the ^{233}U core was estimated using data from the Topsy critical assembly for which the 0.005-inch thick nickel plating is equivalent to a 0.005-inch thick layer of uranium (Reference 1).

The magnitudes of the previously described corrections made for the diaphragm, source cavity, and internal nickel are applicable only to the 10 kg experiment. The magnitudes of these corrections for the 7.6 kg experiment were not given in the references.

An approximate correction was made for clearances between the core and reflector as described below. Explicit values for this correction in terms of $\Delta 1/M$ were not given in the references.

"A suitable correction for the clearance between the core and reflector material, which was present in the experimental setup, was deduced from the slope of the measured curve of reciprocal multiplication versus reflector thickness. The slope at zero thickness is interpreted as giving the change in $1/M$ per unit thickness which would have occurred had the clearance void been filled with reflector. The external reflector radius was reduced to produce this same $\Delta(1/M)$ as indicated by the slope of the curve in this region." (Reference 1)

Care was taken by the experimenters to ensure that the equatorial surfaces of the lower core hemisphere and the lower reflector hemishell were flush by placing small pieces of shim stock between the polar surfaces of the lower core and reflector parts (Reference 8). This was done to ensure that both pieces (core and reflector) were in direct contact with the diaphragm.

With the above measurements and corrections, the experimenters were able to correct their inverse multiplication versus reflector thickness curve to that for solid spherical cores of ^{233}U surrounded by a close-fitting normal uranium reflector. The resulting critical uranium thicknesses were found to be 2.090 inches and 0.906 inches for the two cores (Reference 1). These thicknesses were found by interpolating between the data shown in Figure 3.

Later efforts made corrections to account for reflection by the Planet assembly machine and the surrounding room walls. This correction increased the HEU thickness by 0.0003 inches (Reference 3).

It was observed that the experimenters used many corrections particular to ^{239}Pu metal (^{239}Pu Jezebel and Topsy) for the ^{233}U metal systems. The experimenters also used a plutonium filler piece when measurements were taken to reduce the 10 kg experiment to a solid sphere. This is the reason why the multiplications reported in Reference 3 differ from those in Reference 6. Previous experiments indicated that ^{239}Pu and ^{233}U critical assemblies are similar (Reference 9).

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Another indication of the validity of this substitution can be seen in the similar critical masses of the two isotopes: 17.02 kg for ^{239}Pu metal (PU-MET-FAST-001) and 16.53 kg for ^{233}U metal (U233-MET-FAST-001). A small correction was applied to correct for using plutonium instead of ^{233}U .

The reported core densities, core masses, and core enrichments are different for the three primary references (References 1, 4, and 5). The information given for Reference 5 was taken from the specifications of the $^{233}\text{U}/\text{HEU}$ experiment. It was deduced from References 1, 4, and 5 that the same two cores were used for several experiments performed to determine critical thicknesses of various reflector materials. The reported data are summarized in Table 4. The reported critical masses in Reference 4 are believed to be typographical errors because the masses correspond to the uncorrected core masses. Furthermore, the masses are not consistent with the reported core diameter and the reported core densities in that reference, and the core diameters and densities in Reference 4 correspond to the masses reported in References 1 and 5. The discrepancies between core enrichments were studied, and the enrichments reported in Reference 5 are used for the benchmark model. Besides the fact that Reference 5 is the most recent reevaluation of these experiments, it also contains the most complete and most consistent data, as shown in Table 4.

Table 4. Differences Between the Reported Specifications of the Three Primary References.

Parameter	Reference 1	Reference 5	Reference 4
^{233}U wt. %	98.25	98.2	98.2
^{234}U wt. %	none given	1.1	1.1
^{235}U wt. %	none given	none given	none given
^{238}U wt. %	none given	0.7	0.7
10 kg Density (g/cm^3)	18.62	18.621	18.62
10 kg Mass (g)	10012	10012	9840
7.6 kg Density (g/cm^3)	18.62	18.644	18.64
7.6 kg Mass (g)	7601	7601	7470

The 10 kg idealized critical experiment, as corrected, consists of a 3.972-inch-diameter ^{233}U spherical core (density = $18.621 \text{ g}/\text{cm}^3$) intimately surrounded by a spherical shell of normal uranium, 0.906-inches thick, with a density of $18.92 \text{ g}/\text{cm}^3$. The 7.6 kg idealized critical experiment, as corrected, consists of a 3.622-inch-diameter ^{233}U spherical core (density = $18.644 \text{ g}/\text{cm}^3$) intimately surrounded by a spherical shell of normal uranium, 2.090-inches thick, with a density of $18.92 \text{ g}/\text{cm}^3$. The experimental uncertainty was given as $\pm 1.0\%$ in the thickness of the

normal uranium reflector for both experiments. The core specifications as described in the reevaluation efforts of Reference 5 are what is described in this report. It is these descriptions that we accept as the benchmark models. The sensitivity of the calculational benchmark models to various parameters is studied in Appendix B.

3.0 BENCHMARK SPECIFICATIONS

3.1 Description of Model

3.1.1 The 10 kg Model - The benchmark model is a simple highly enriched ^{233}U sphere with a density of 18.621 g/cm^3 and a mass of 10012 grams uranium with $2.3012 \text{ cm} \pm 1\%$ normal uranium reflection at a density of 18.92 g/cm^3 . The model is an idealized configuration derived by the experimenters.

3.1.2 The 7.6 kg Model - The benchmark model is a simple highly enriched ^{233}U sphere with a density of 18.644 g/cm^3 and a mass of 7601 grams uranium with $5.3086 \text{ cm} \pm 1\%$ normal uranium reflection at a density of 18.92 g/cm^3 . The model is an idealized configuration derived by the experimenters.

3.2 Dimensions

3.2.1 The 10 kg Dimensions - The radius of the core, a 10012 gram uranium sphere at a density of 18.621 g/cm^3 , was 5.0444 cm. The sphere was reflected by 2.3012 cm of normal uranium (outer radius of 7.3456 cm).

3.2.2 The 7.6 kg Dimensions - The radius of the core, a 7601 gram uranium sphere at a density of 18.644 g/cm^3 , was 4.5999 cm. The sphere was reflected by 5.3086 cm of normal uranium (outer radius of 9.9085 cm).

3.3 Material Data

The calculated atomic number densities of the uranium cores for the isotopic compositions given previously in Tables 2 and 3 are shown in Table 5 using the densities given in Section 3.2.

Table 5. Atom Densities for Uranium Sphere.

Isotope	Atom Density, 10 kg (atoms/barn-cm)	Atom Density, 7.6 kg (atoms/barn-cm)
²³³ U Core		
²³³ U	4.7253×10^{-2}	4.7312×10^{-2}
²³⁴ U	5.2705×10^{-4}	5.2770×10^{-4}
²³⁸ U	3.2975×10^{-4}	3.3015×10^{-4}
Normal Uranium Reflector		
²³⁵ U	3.4902×10^{-4}	3.4902×10^{-4}
²³⁸ U	4.7518×10^{-2}	4.7518×10^{-2}

3.4 Temperature Data

No mention was made in the references in regard to experimental temperature. The experimental temperature was assumed to be room temperature (293 kelvin).

3.5 Experimental and Benchmark-Model k_{eff}

3.5.1 The 10 kg Model - At a thickness of 0.960 inches, the measured multiplication for this experiment was 88.24 and the corrected inverse multiplication -0.0056 (Reference 3). The difference between quoted (-0.0056) and inferred (-0.0063) inverse multiplications is 0.0007, which is less than the experimental uncertainty, ± 0.0009 (see Appendix B). Corrections were also made for external nickel and for clearances between core and reflector. The correction for external nickel was +0.005 inches. The correction for clearances between core and reflector was -0.005 inches. These effects would cancel each other.

The benchmark model k_{eff} is 1.000 ± 0.001 , where the uncertainty in k_{eff} is due to the $\pm 1.0\%$ uncertainty in the thickness of the reflector. The uncertainty in k_{eff} is derived from a ONEDANT calculation shown in Appendix B.

3.5.2 The 7.6 kg Model - At a thickness of 2.299 inches, the measured multiplication for this experiment was 172.1 and the corrected inverse multiplication -0.0104 (Reference 2). Differences between quoted and inferred inverse multiplications are not shown here because the magnitude of the corrections were not given in the references. The experimental k_{eff} was 1.0000, which includes experimental corrections made for the diaphragm, the source cavity, and internal

and external nickel.^a The benchmark-model k_{eff} is 1.000 ± 0.001 , where the uncertainty in k_{eff} is due to the $\pm 1.0\%$ uncertainty in the thickness of the reflector. The uncertainty in k_{eff} is derived from a ONEDANT calculation shown in Appendix B.

^a Inverse multiplication, $1/M$, is related to k_{eff} by: $1/M = 1 - k_{\text{eff}}$. This relationship is valid if the system is near critical.

4.0 RESULTS OF SAMPLE CALCULATIONS

In this section, results of calculations using various criticality codes and cross section sets are given. The results of these calculations using the models which were described previously in Section 3.2 are shown in Table 6. The calculations using 27-group SCALE cross sections significantly underpredict k_{eff} , as seen in Table 6. This misprediction is due to known deficiencies in the ^{233}U cross sections for this library.^a

Table 6. Sample Calculation Results (United States).

Code (Cross Section Set) Case Number ↓	KENO (Hansen-Roach)	KENO (27-Group ENDF/B-IV)	MCNP (Continuous Energy (ENDF/B-V)	ONEDANT (27-Group ENDF/B-IV)
1 (10 kg)	1.0029 ± 0.0013	0.9715 ± 0.0011	1.0003 ± 0.0009	0.9717
2 (7.6 kg)	1.0018 ± 0.0013	0.9734 ± 0.0012	0.9956 ± 0.0010	0.9749

^a Personal communication, L. M. Petrie and R. M. Westfall, ORNL, September 1993.

5.0 REFERENCES

1. E. A. Plassmann and D. P. Wood, "Critical Reflector Thicknesses for U²³³ and Pu²³⁹ Systems," Nucl. Sci. Eng., **8**, pp. 615-620, 1960.
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3. E. A. Plassmann, N-Division Progress Report for October 21 - November 20, 1957, pp. 22-26, Los Alamos National Laboratory Archives A-86-016, 202-6.
4. H. C. Paxton, "Los Alamos Critical - Mass Data," LA-3067-MS, December 1975.
5. G. E. Hansen and H. C. Paxton, "Reevaluated Critical Specifications of Some Los Alamos Fast-Neutron Systems," LA-4208, p. 8, September 1969.
6. E. A. Plassmann and D. P. Wood, N-Division Progress Report for July 21 - August 20, 1957, pp. 15-18, Los Alamos National Laboratory Archives A-86-016, 200-12.
7. E. A. Plassmann, D. P. Wood and R. E. White, N-Division Progress Report for March 21 - April 20, 1957, pp. 21-23, Los Alamos National Laboratory Archives A-86-016, 200-8.
8. E. A. Plassmann and D. P. Wood, N-Division Progress Report for April 21 - May 20, 1957, pp. 15-18, Los Alamos National Laboratory Archives A-86-016, 200-9.
9. H. C. Paxton, "Critical Masses of Fissionable Metals as Basic Nuclear Safety Data," LA-1958, January 1955.

APPENDIX A: TYPICAL INPUT LISTINGS**A.1 KENO Input Listings**Hansen-Roach Cross Sections and 27-Group ENDF/B-IV Cross Sections

Listed below are the input files for KENO V.a with 16 group Hansen-Roach and 27-group SCALE4 ENDF/B-IV cross sections for the one-dimensional models (both experiments). The models use 300 active generations with 1500 histories per generation while skipping the first ten generations.

In the parameter section of the input file, "lib=40" is specified. This is the Los Alamos version in AMPX format of the 16-group Hansen-Roach cross-section library.

KENO-V.a Input Listing for Table 6 (16-Energy-Group Hansen-Roach Cross Sections).

```
=kenova
10 KG EXP, U-233 SPHERE, NU REFLECTOR
READ PARAMETERS
  RUN=YES FAR=YES LIB=40
  TME=1000 TBA=10
  GEN=310 NPG=1500 NSK=10
END PARAMETERS
READ MIXT SCT=1
MIX=1 92300 .047253
      92400 .00052705
      92800 .00032975
MIX=2 92800 .047518
      92500 .00034902
END MIXT
READ GEOM
UNIT 1
  SPHERE 1 1 5.0444
  SPHERE 2 1 7.3456
END GEOM
END DATA
END
```

```
=kenova
U-233 SPHERE, NU REFLECTED, 7.6 KG EXP
READ PARAMETERS
  RUN=YES FAR=YES LIB=40
  TME=1000 TBA=10
  GEN=310 NPG=1500 NSK=10
END PARAMETERS
READ MIXT SCT=1
MIX=1 92300 .047312
      92400 .00052770
      92800 .00033015
MIX=2 92800 .047518
      92500 .00034902
END MIXT
READ GEOM
UNIT 1
  SPHERE 1 1 4.5999
  SPHERE 2 1 9.9085
END GEOM
END DATA
END
```

KENO-V.a Input Listing for Table 6 (27-Energy-Group SCALE4 Cross Sections).

```
=CSAS25
U-233 SPHERE, NU REFLECTED, 10 KG EXP
27GROUPNDF4 INFHOMMEDIUM
U-233 1 0.0 0.047253 END
U-234 1 0.0 0.00052705 END
U-238 1 0.0 0.00032975 END
U-235 2 0.0 0.00034902 END
U-238 2 0.0 0.047518 END
END COMP
U-233 SPHERE
READ PARAMETERS
  TME=1000 TBA=10
  GEN=310 NPG=1500 NSK=10
END PARAMETERS
READ GEOM
UNIT 1
  SPHERE 1 1 5.0444
  SPHERE 2 1 7.3456
END GEOM
END DATA
END
```

```
=CSAS25
7.6 KG EXP, U-233/NU SPHERE
27GROUPNDF4 INFHOMMEDIUM
U-233 1 0.0 0.047312 END
U-234 1 0.0 0.00052770 END
U-238 1 0.0 0.00033015 END
U-235 2 0.0 0.00034902 END
U-238 2 0.0 0.047518 END
END COMP
U-233/NU SPHERE
READ PARAMETERS
  TME=1000 TBA=10
  GEN=310 NPG=1500 NSK=10
END PARAMETERS
READ GEOM
UNIT 1
  SPHERE 1 1 4.5999
  SPHERE 2 1 9.9085
END GEOM
END DATA
```

A.2 MCNP Input Listing

Listed below are the input files for MCNP 4.2 with ENDF/B-V continuous-energy cross sections for the one-dimensional models (both experiments). The listing designates 300 active generations to be run with 1500 histories per generation while skipping the first ten generations.

MCNP Input Listing for Table 6.

NU REFLECTED U-233 SPHERE, 10 KG EXP

```
1 1 0.0481098 -1 imp:n=1
2 2 0.04786702 1 -2 imp:n=1
3 0 2 imp:n=0
```

```
1 so 5.0444
2 so 7.3456
```

```
m1 92233.50c 0.047253
    92234.50c 0.00052705
    92238.50c 0.00032975
```

```
m2 92238.50c 0.047518
    92235.50c 0.00034902
```

```
kcode 1500 1.0 10 310
```

```
ksrc 0. 0. 0.
```

```
print
```

NU REFLECTED U-233 SPHERE, 7.6 KG EXP

```
1 1 0.04816985 -1 imp:n=1
2 2 0.04786702 1 -2 imp:n=1
3 0 2 imp:n=0
```

```
1 so 4.5999
2 so 9.9085
```

```
m1 92233.50c 0.047312
    92234.50c 0.00052770
    92238.50c 0.00033015
```

```
m2 92238.50c 0.047518
    92235.50c 0.00034902
```

```
kcode 1500 1.0 10 310
```

```
ksrc 0. 0. 0.
```

```
print
```

A.3 ONEDANT Input Listing

Listed below are the input files for ONEDANT version 2.3e (both experiments). The first file listed in the set is used to generate the SCALE4 ENDF/B-IV 27-group cross sections and the second is the ONEDANT input. The 27-group cross sections have P_3 scatter data. The quadrature set is S_{48} . The convergence criteria for the eigenvalue and flux is 10^{-4} by default. The mesh size is approximately 20 mesh/cm for the core and reflector.

ONEDANT Input Listing for Table 6.

```
=CSASI
ICE RUN TO GET XSECTS FOR U-233/NU SPHERE, 10 Kg
EXP
27GROUPNDF4 INFHOMMEDIUM
U-233 1 0.0 0.047253 END
U-234 1 0.0 0.00052705 END
U-238 1 0.0 0.00032975 END
U-235 2 0.0 0.00034902 END
U-238 2 0.0 0.047518 END
END COMP
END

2
U233 sphere with a NU reflector, 10 kg Exp
Simplified model
/BLOCK 1
igeom=sph ngroup=27 niso=2 isn=48 mt=2 nzone=2 im=2 it=157
t
/BLOCK 2
xmesh=0.0,5.0444,7.3456 xints=101,46 zones=1,2 t
/BLOCK 3
lib=xs27
maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1 t
/BLOCK 4
matls=isos
assign=matls t
/BLOCK 5
chi=.020 .195 .219 .126 .164 .172 .088 .014 .001 18z;
ievt=1 isct=3 t
```

```
=CSASI
ICE RUN TO GET XSECTS FOR U-233/NU SPHERE
27GROUPNDF4 INFHOMMEDIUM
U-233 1 0.0 0.047312 END
U-234 1 0.0 0.00052770 END
U-238 1 0.0 0.00033015 END
U-235 2 0.0 0.00034902 END
U-238 2 0.0 0.047518 END
END COMP
END

2
U233 sphere with a NU reflector, 7.6 kg Exp
Simplified model
/BLOCK 1
igeom=sph ngroup=27 niso=2 isn=48 mt=2 nzone=2 im=2 it=198
t
/BLOCK 2
xmesh=0.0,4.5999,9.9085 xints=92,106 zones=1,2 t
/BLOCK 3
lib=xs27
maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1 t
/BLOCK 4
matls=isos
assign=matls t
/BLOCK 5
chi=.020 .195 .219 .126 .164 .172 .088 .014 .001 18z;
ievt=1 isct=3 t
```

APPENDIX B: SENSITIVITY STUDIES

The results of calculations to determine the experimental uncertainties of the calculation models are reported in this Appendix. An experimental uncertainty of $\pm 1\%$ in the HEU thickness was given by the experimenters. Calculations were performed to determine the Δk associated with this uncertainty for the 10 kg experiment. The result of this calculation is given below in Table B.1 (± 0.0009).

ONEDANT/TWODANT with Hansen-Roach cross sections was used for the sensitivity studies. The results are shown in Table B.1.

Table B.1. Sensitivity Studies.

Effect	Δk_{eff}
10 kg Experiment	
$\pm 1\%$ of Normal uranium thickness ^(a)	$\pm 0.0009^{(b)}$
7.6 kg Experiment	
$\pm 1\%$ of Normal uranium thickness ^(a)	$\pm 0.0010^{(c)}$

- (a) The uncertainty is given as $\pm 1\%$ in the thickness of the ^{235}U surroundings.
 (b) The Δk_{eff} is relative to a base case of 1.0008.
 (c) The Δk_{eff} is relative to a base case of 1.0022.

