WATER-MODERATED RECTANGULAR CLUSTERS OF $U(4.31)O_2$ FUEL RODS (1.892-CM PITCH) SEPARATED BY STEEL, BORAL, BOROFLEX, CADMIUM, OR COPPER PLATES, WITH STEEL REFLECTING WALLS

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1.0 DETAILED DESCRIPTION

1.1 Overview of Experiment

A series of critical-approach experiments with clusters of 36-inch-long aluminum-clad U(4.31)O_2 fuel rods in a large water-filled tank was performed over the course of several years at the Critical Mass Laboratory at the Pacific Northwest Laboratories (PNL). Experiments included square-pitch lattice clusters with pitches of 2.54 cm or 1.892 cm. Some of these experiments were simply rod clusters in water (LEU-COMP-THERM-002 and LEU-COMP-THERM-004). Others had lead, depleted-uranium, or steel reflecting walls on two opposite sides of the cluster row (LEU-COMP-THERM-010). Others had absorber plates between the clusters (LEU-COMP-THERM-009). Some circular, triangular-pitch lattices, with pitches of 2.4, 1.8, or 1.6 cm, were used to measure the effect of gadolinium dissolved in the water (LEU-COMP-THERM-005).

This evaluation documents seven water-reflected experiments, performed in 1980, with 3 rectangular clusters of 1.892-cm-pitch rods with absorber plates between clusters and steel walls on either side of the line of fuel clusters. The seven types of absorber-plate were stainless steel, borated stainless steel, Boral, Boroflex, cadmium, copper, and copper with 1% cadmium. The experimenters found that "the effectiveness of the neutron absorber plates to reduce the critical separation between fuel clusters is reduced slightly by the presence of the steel reflecting walls."[5] Worths of the absorber plates ranged from 1% to 7% of k_{eff}.

All seven experiments are judged to be acceptable as benchmark data.

1.2 Description of Experimental Configuration

Information in this section comes from References 1 - 10, which are the original PNL reports of these experiments. References 11 - 15, logbooks, and conversations with experimenters provided supplementary information. Primary references are 5 and 14. Details from specific references are so noted.

1.2.1 Experiment Tank and Surroundings - Experiments were performed in a 0.952-cm-thick, open, carbon-steel tank. (See Figures 1 and 2.) The minimum water-reflector thickness was 30.5 cm from the ends of the steel walls and from the sides of the clusters (including the steel walls) and 15 cm above and below the fuel (References 5 and 14).

The experiment tank was located in one corner of the Critical Mass Laboratory at the Pacific Northwest Laboratories, Hanford, Washington. The tank sat upon a concrete floor, which was at least 40.6 cm thick (Reference 11, p. 32). The concrete walls of the room were 5 feet thick. The concrete ceiling was 2 feet thick and approximately 20 feet high. The tank was located approximately four feet from the two closest corner walls.[a]

Nothing other than fuel rods, steel walls, absorber plates, radiation detectors, safety-blade guides, and support structures, all described below, was in the tank. Any control or safety rods or blades were withdrawn above the top water reflector.

1.2.2 Fuel-Rod Support Plate - The bottoms of the fuel rods were supported by a 2.54-cm-thick acrylic support plate. The width and length of the support plate were approximately the width and length of the clusters.[b] The plate was supported by two 15.3 x 5.08 x 0.635-cm 6061 u-shaped aluminum channels, oriented so that the bottom of the plate was 15.3 cm (width of the u) above the bottom of the tank.

1.2.3 Lattice Plates and Supports - The pitch of the fuel rods (1.892 cm) was maintained by two levels of 12.7-mm-thick polypropylene lattice plates. Holes for the fuel rods were no more than 5 mils (0.0127 cm) larger than the rod diameter.[c]

The top lattice plates were about 6 inches below the top of the fuel.[c] The bottom lattice plate rested on the acrylic support plate. There were four 51-mm-wide 6061-aluminum horizontal spacer bars between the fuel and the reflecting walls, two on each side at the level of the grid plates (References 5 and 14). In one experiment with 2.35%-enriched rods with no absorber plates or reflecting walls, the aluminum-angle grid supports were doubled, with no effect on the critical separation between clusters (Reference 1, pp. 26 and 28).

The use of shims (small pieces of aluminum or lattice-plate material) was sometimes necessary in order to accurately position the rod clusters and absorber plates.[c] The shims were used to maintain the required horizontal separation between bottom lattice plates or between lattice plates and the control/safety blade guides.

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[a] Private communication, Sid Bierman, July, 1993.

[b] There may have been a separate support plate for each cluster for the 3-cluster experiments. (Private communication, Sid Bierman, August, 1993)

[c] Private communication, Sid Bierman, August, 1993.

Figure 1. Loading a Fuel Rod.

Figure 2. Experiment Tank, Lattice Plates for 3 Clusters, and Control/Safety Blades.

1.2.4 Safety and Control Blade Guides - The aluminum control-blade and safety-blade guides were located between clusters. The guides, two for the control blade and two for the safety blade, extended from the bottom of the fuel-pin array to well above the water surface. Two slightly different sizes of guides were used at different times throughout the entire series of experiments.[a] The guides were 3.8 cm wide and were either 2.54 cm thick (Reference 5, p. 5) or 1.27 cm thick (Reference 4, p. 27), with a slot for the blades that was either 0.96 cm wide or 0.64 cm wide, respectively. The distance between the two guides for each blade could be adjusted, depending on the width of the blade.

During one experiment with 2.35%-enriched rods with no absorber plates or reflecting walls, the amount of aluminum of the control and safety blade guides was doubled. The results demonstrated "no change in the predicted critical separation between fuel-rod clusters" (Reference 1, pp. 13 and 28).

[a] Private communication, Sid Bierman, August, 1993.

1.2.5 Radiation Detectors - The boron-lined proportional counters (usually three in number) were placed symmetrically around the experiments. The detectors were kept dry by being placed in aluminum tubes that extended above the top surface of the water. The elevation of the detectors varied, depending on the buoyancy of the tube holding the detector. The aluminum tubes were approximately 1.5 inches in diameter and were placed about 30 cm from the experimental assembly, always outside a 15-cm thickness of water.[a]

1.2.6 Water Reflector - The top water surface was always at least 15 centimeters above the top of the fuel region of the rods. (Reference 14, p. 132)[b] The bottom water reflector also was at least 15 centimeters thick, since the aluminum angle supporting the fuel-rod support plate above the bottom of the tank was 15.3 cm high. Minimum water thickness at the sides of the clusters was 30.5 cm, including the steel walls, and 30.5 cm at the ends of the clusters, measured from the ends of the steel walls. (See Figure 7 in Section 3.2.)

Water temperatures were recorded in logbooks for approximately ten percent of experiments of the series reported in References 1-10, 12, and 14. Recorded temperatures ranged from 18 to 26°C, with most values between 20°C and 25°C.

1.2.7 Neutron-Absorber Plates - The neutron-absorber plates were positioned between the clusters on either side of the middle cluster, parallel to the interacting surfaces, against the fuel-rod cell boundaries of the middle cluster. "The plates were always centered on the fuel region of the fuel rods" (Reference 14, p 135). According to Reference 5 (p.x), the same absorber plates used in other experiments of this series were used for these experiments, except here the width of the plates is 302 mm, rather than 356 mm (Reference 5, p. 7). Therefore the width of all absorber plates is 302 mm. The height of all absorber plates is 915 mm.

The distance between absorber plate and center cluster was measured at several different horizontal positions to ensure that the plates were correctly positioned.[c] An experimenter remembered that for some experiments a thick Lucite shim was used, probably beneath the absorber plate, so that the absorber plate, when in place atop the shim, would be directly opposite the fuel region. Absorber plates were held in place against blade guides or lattice plates by aluminum rods, ½ inch in diameter, ~1 inch long, cut to a wedge shape and pressed into place.[d]

Thickness error limits are reported as one standard deviation.

Steel Plates. The 304L steel absorber plates were 3.02 ± 0.13 mm thick. The 304L steel plates containing 1.1 wt.% boron were 2.98 ± 0.06 mm thick.
Boral Plates. The Boral B absorber plates were 2.92 ± 0.13 mm thick including a 0.38-mm-thick

[a] Private communication, Sid Bierman, July, 1993.

[b] Confirmed by private communication, Sid Bierman, July, 1994.

[c] Private communication, Sid Bierman, June, 1998.

[d] Private communication, Sid Bierman, August, 1993.

cladding of Type 1100 aluminum on either side of the B_4C-Al core material (30.36 wt.% boron).

Boroflex Plates. The Boroflex absorber material (32.74 wt.% boron) was 2.26 ± 0.04 mm thick and was kept stiff and flat by two 1.60-mm-thick sheets of Plexiglas on either side of it.

Cadmium Plates. The thickness of the cadmium absorber plates was 0.61 ± 0.03 mm. Thicknesses were measured with a micrometer at several places along the edges of the plates.[a] To maintain their shape, the cadmium sheets were probably mounted on Plexiglas or between thin Plexiglas stiffener sheets.[b] Their probable use is indicated by the facts that in other experiments (Reference 4, p. 30) cadmium was reported as mounted on 0.296-cm-thick Plexiglas, and that 0.160-cm-thick Plexiglas was used on either side of the thin Boroflex sheets.

Copper Plates. Plates of copper and of copper containing 0.989 wt.% cadmium were used in the experiments. The copper plates without cadmium had a thickness of 3.37 ± 0.08 mm. The copper plates with cadmium were 3.57 ± 0.08 mm thick.

1.2.8 Steel Reflecting Walls - The steel walls on either side of the fuel clusters, were 1473 ± 3.2 mm long by 1219 ± 3 mm high and were 178.5 ± 0.4 mm thick (Reference 5, p. 10). The walls were "machined to obtain a plane surface within 0.127 mm" (Reference 14, p. 135). In every case, the steel walls were longer than the line of 3 clusters.

The walls were placed 19.56 ± 1.02 mm away from the outer cell boundaries of the clusters. This separation of steel walls and clusters was "near optimum for criticality with no absorber plates present" (Reference 14, p. 141).

[a] Personal communication, Sid Bierman, June, 1998.

[b] Private communication, Sid Bierman, August, 1993.

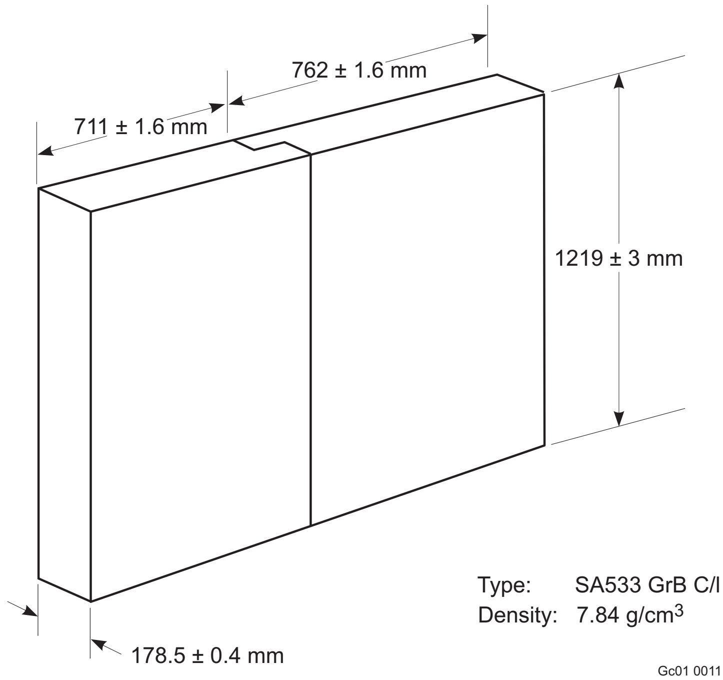

Figure 3. Steel Reflecting Walls (Reference 5, p.10, and Reference 14, p. 137).

1.2.9 Fuel Rods - Fuel-rod dimensions are given in diagrams in References 3-10. According to References 8 and 10, "error limits are one standard deviation." Figure 4 is a reproduction of the diagram from Reference 10 (p. 2.3). UO_2 fuel pellets were taken from rods "originally fabricated for Core II of the N.S. Savannah…The fuel diameter (1.265 ± 0.003 cm) ... was checked repeatedly during the reloading operations and found to agree with that quoted in the document characterizing Core II of the N.S. Savannah." (Reference 10, p. 2.4)

Diagrams in some of the earlier references showed end plugs protruding from the ends of the rod beyond the aluminum cladding, with total rod length, including protruding plugs, of 96.52 cm. However, later references showed end plugs exactly filling the ends of the clad, which had a length of 96.52 cm.

One experimenter recalls that the experimenters carefully inserted rubber plugs in the bottoms of the rods, before filling, so that the rubber plug protruded approximately 1/16 inch uniformly for all rods. Some top end plugs protruded and some were recessed, depending on slight differences between thicknesses of UO_2 pellets. Different pellet thickness was also the reason for the reported maximum and minimum lengths of 92.71 cm and 91.44 cm for the fuel region. There were no problems with water leakage into the fuel region of the rods.[a]

[a] Private communication, Sid Bierman, April, 1994.

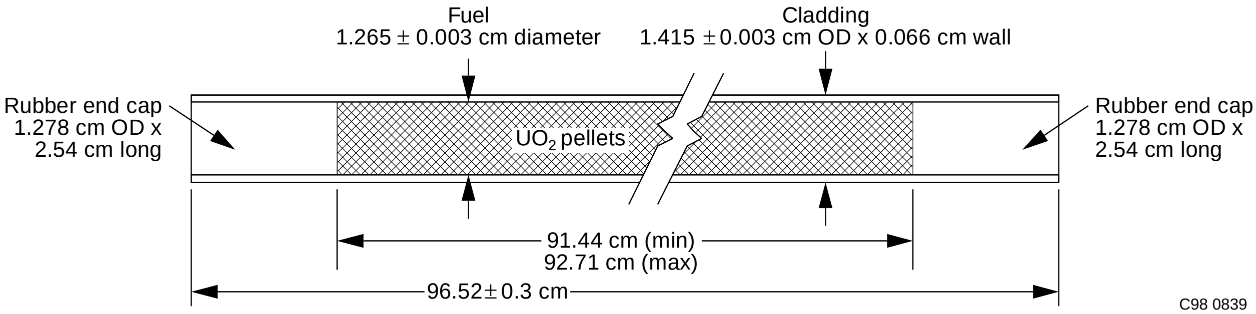

Figure 4. $U(4.31)O_2$ Fuel Rod.

Dimensions of the $U(4.31)O_2$ fuel rods are summarized in Table 1. To test the effects of small differences between rods, "experiments were repeated using alternate but identical (within the quality control applied during fabrication) fuel rods and different fuel loading arrangements on the approach to critical. ... the measurement data thus checked were reproduced to within a one-sigma limit of 0.3%" in most cases (Reference 2, p. 19). The standard deviations of a few reported critical cluster separations were greater than 0.3%.

Table 1. 4.31-Wt.%-Enriched UO_2 Fuel-Rod Dimensions.

Component	Length (cm)	Diameter (cm)
UO_2 Fuel	91.44 - 92.71	1.265 ± 0.003
Rubber End Caps	2.54	1.278
Gap (not shown)	-	1.283 ± 0.003 OD
Clad (6061 Al)	96.52 ± 0.3	1.415 ± 0.003 OD (0.066 cm thick)

1.2.10 Source - A ^{252}Cf source of approximately 0.6 micrograms was placed near the center of the experimental assembly. The source was mounted in an open acrylic tube, 0.6 cm in diameter (Reference 8, p 2.3) and two or three inches long.[a] During the triangular-pitch experiments, no measurable effect on critical size was detected with replacement-type reactivity worth measurements of the californium source (Reference 8, pp. 3.6 and 3.7).

1.2.11 Experimental Method for Determining Critical Configuration[b] **-** The critical configuration was determined by measuring neutron-detector count rates (above background)

[a] Private communication, Sid Bierman, August, 1993.

[b] This information is from the logbooks, stored at the Los Alamos National Laboratory Archives. (See Appendix B.)

produced by subcritical configurations and extrapolating to the critical condition. In general, the averages of several (usually four, five, or six) 80-second counts from each of two or three detectors were recorded for each configuration. Reference 12, describing other experiments of this series, says that the most reactive configuration measured was "taken to within 99% of the critical condition."

These experiments comprised three rectangular clusters of predetermined sizes with the neutron-absorber plates placed at the outer cell boundaries of the central cluster. The separation distance between clusters was varied. The variables plotted were [cluster separation]/[count rate] vs. [cluster separation] and [1]/[count rate] vs. [cluster separation]. At least two loadings close to critical were measured. The final result was the average predicted critical cluster separation distance.

To decrease the cluster separation, the lattice plates were not moved. Either a half row or a whole row of fuel rods was moved from the outer end of an outer cluster to the inside end of the same cluster. Moving half a row on one outer cluster was considered to be equivalent to decreasing the separation between clusters by ¼ pitch length. (See LEU-COMP-THERM-001, Section 1.2.8, for more details of this method.)

1.2.12 Critical Cluster Dimensions and Separations – A typical arrangement of fuel clusters, neutron-absorber material, and the steel reflecting walls is shown in Figure 5. The absorber plates are centered on the middle fuel cluster at the outer cell boundary.

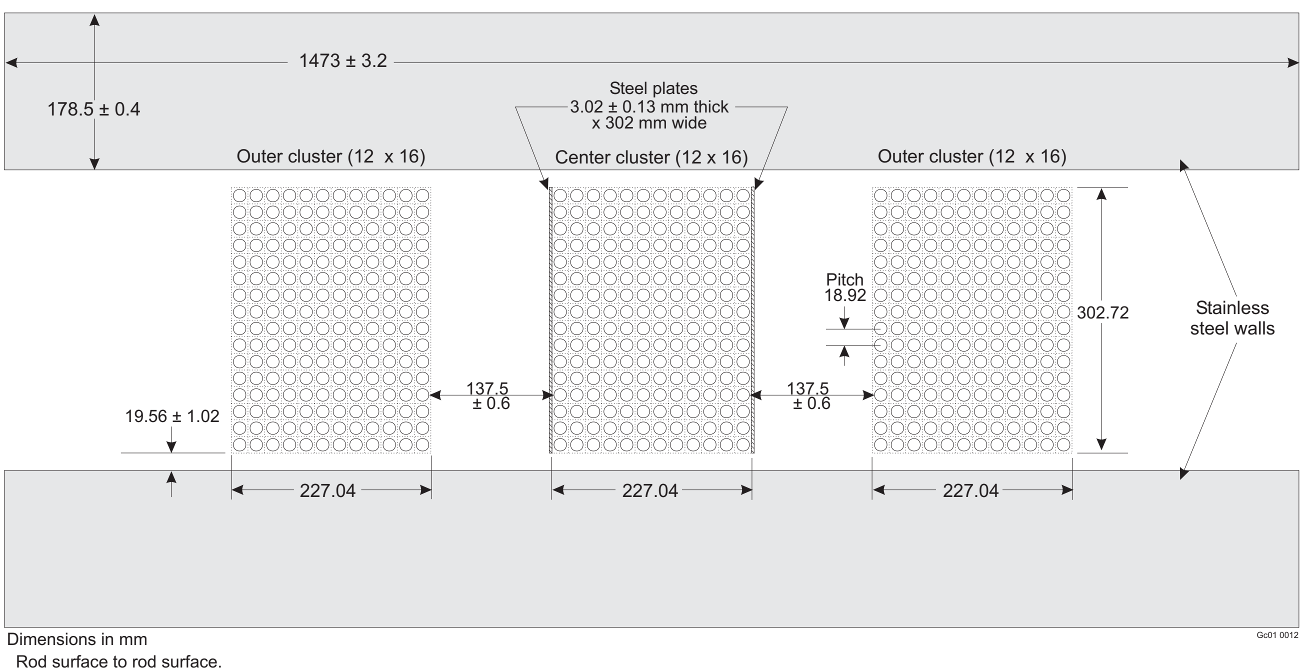

Figure 5. Critical Configuration of Case 1 (plan view).

Cluster sizes and separations for the 7 critical configurations are listed in Table 2. Error limits are one standard deviation. Each configuration consisted of a line of three clusters of fuel rods at 1.892-cm square pitch. All three clusters are 16 rods wide and 12 rods long, making the assembly 16 rods wide and 36 rods long. Cluster separations are the measured distances between the rods of two adjacent clusters, i.e. rod surface to rod surface. The absorber plates are positioned between clusters at the outer cell boundaries of the center cluster. (The cell boundary of a fuel rod is the square with side equal to the pitch centered on the axis of the fuel rod.) The distance between the steel reflecting walls and the outer cell boundaries of the fuel clusters is 19.56 ± 1.02 mm.

As an indication of the separate effects of the absorber plates and steel walls, the critical rod-surface-to-rod-surface separation between clusters was 158.4 mm with steel walls but with no absorber plates (Case 17 of LEU-COMP-THERM-010) and was 127 mm for no steel walls or absorber plates (Case 10 of LEU-COMP-THERM-004).

Table 2. $U(4.31)O_2$ Fuel-Rod Cluster Critical Configurations (Reference 5, p. 24, and Reference 14, p. 144).

Case No.	Absorber Plates		Separation of Fuel Clusters (mm) [a]
	Material	Thickness (mm)	
1	304L steel	3.02 ± 0.13	137.5 ± 0.6
2	304L steel with 1.1% B	2.98 ± 0.06	98.3 ± 0.4
3	Boral B	2.92 ± 0.13[b]	83.0 ± 0.3
4	Boroflex	5.46 ± 0.18[c]	83.7 ± 0.2
5	cadmium	0.61 ± 0.03	89.4 ± 0.6
6	copper	3.37 ± 0.08	134.7 ± 0.4
7	copper-cadmium	3.57 ± 0.08	105.7 ± 0.2

(a) Rod surface to rod surface. The distance between outer cell boundaries of clusters is obtained by subtracting 4.77 mm (pitch – rod diameter) from this value.
(b) Includes 0.38 mm of Type 1100 aluminum on either side of the B_4C-Al absorber material.
(c) Includes 1.60-mm-thick Plexiglas on either side of 2.26-mm-thick (± 0.04 mm) Boroflex.

1.3 Description of Material Data

1.3.1 Fuel Rod - UO_2 Fuel. **-** Over the course of performing the series of experiments, the experimenters improved their analyses of the fuel rods. In Reference 5, p. x, the experimenters state:

> The same UO_2 fuel, lattice grid plates, neutron absorber plates, and reflecting walls have been used throughout these experiments. However, during this period of time some of these parameters have become better defined as a result of repeated analysis. For example, the 4.31 wt.% ^{235}U enriched UO_2 rods were originally identified as having a ^{235}U enrichment of 4.29 wt.%. Multiple analysis of the rods during the course of these five sets of experiments have resulted in the more correct average of 4.31 wt.% quoted in this and some of the more recent reports. . . . the values quoted in this report should be considered the latest and, hopefully, the more correct values to use.

A similar statement is given in Reference 6 (p. xiii).

The latest reported values (Reference 10, p. 2.3-2.9) are assumed to be most accurate. In Reference 10, measurement methods are described. According to Reference 10, error limits are one standard deviation. The experimenters state (Reference 10, p. 2.4):

> The uranium assay (1059.64 ± 4.80 g/rod) and the ^{235}U enrichment (4.306 ± 0.013%)…are the average of six assays and six spectrographic analyses made on fuel pellets chosen at random during the reloading. The oxide density (10.40 ± 0.06 g UO_2/cm^3) … is based on individual volume displacement measurements with 20 pellets selected at random during the reloading operations. The mass of UO_2 per rod (1203.38 ± 4.12 g) is the average mass of the 1865 rods of this type available for use in the experiments. … The rubber end cap density (1.321 g/cm^3) …is the result of a single mass-volume measurement with six end caps selected at random. The composition of the end caps is the result of four analyses on randomly selected end caps.

Uranium isotopic composition is summarized in Table 3.

Table 3. Isotopic Composition of Uranium in
4.31%-Enriched UO_2 Fuel Rods (Reference 10, p. 2.3).

Uranium Isotope	Wt.%
^{234}U	0.022 ± 0.002
^{235}U	4.306 ± 0.013
^{236}U	0.022 ± 0.002
^{238}U	95.650 ± 0.017
Total	100.000

Rubber end-cap data[a] and 6061-aluminum tubing (clad) data are given in Table 4. The 6061-aluminum data includes the measured density and the ASTM Standard chemical composition.[b]

Table 4. Rubber End-Cap and 6061-Aluminum Clad Data.

Element	Wt.%
Rubber End Cap (density - 1.321 g/cm^3)	
C	58.0 ± 1
H	6.5 ± 0.3
Ca	11.4 ± 1.8
S	1.7 ± 0.2
Si	0.3 ± 0.1
O	22.1 (balance)
6061 Aluminum (density - 2.69 g/cm^3)	
Si	0.40-0.80 (0.6 nominal)
Fe	0.7 (maximum)
Cu	0.15-0.40 (0.25 nominal)
Mn	0.15 (maximum)
Mg	0.8-1.2 (1.0 nominal)
Cr	0.04-0.35 (0.2 nominal)
Zn	0.25 (maximum)
Ti	0.15 (maximum)
Al	remainder (96.00-98.61)

1.3.2 Support Structures - Aluminum. Experiment support structures, including lattice plate supports, spacer rods, control/safety blade guides, and tubes housing the proportional counters, were 6061 aluminum alloy.

Acrylic. The acrylic fuel-rod support plate had a density of 1.185 g/cm^3 and was 8 wt.% hydrogen, 60 wt.% carbon, and 32 wt.% oxygen (References 5 and 14). Uncertainties and methods of determination were not given.

Polypropylene. The material density of the two polypropylene (C_3H_5) lattice plates was 0.904 g/cm^3.

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[a] Reference 10, p. 2.3.

[b] Reference 10, p. A.2, and from *Alcoa Aluminum Handbook*, Aluminum Company of America, pp. 46-50, 1967.

(The impurity analysis on polypropylene lattice plates in later experiments probably does not apply to these experiments.[a])

1.3.3 Reflecting Walls - Steel Wall. The reported density of the steel wall (type SA533 GrB C/l) was 7.84 g/cm^3. The material composition (References 5 and 14) is given in Table 5.

Table 5. Material Composition of Steel Walls.

Element	Wt.% [(a)]
Fe	96.77 ± 0.13
C	0.19
Mn	1.28 ± 0.03
P	0.004
S	0.006
Si	0.22
Ni	0.79 ± 0.14
Mo	0.49 ± 0.05
Cr	0.12 ± 0.01
Cu	0.13 ± 0.01

(a) Sum of weight percents is 100.

1.3.4 Absorber Plates - The neutron-absorber plates used in the experiments were 304L stainless steel, 304L stainless steel with 1.1% boron, Boral B, Boroflex, cadmium, copper, and copper with 1% cadmium plates. The absorber-plate densities and chemical compositions given in References 5 and 14 are the same as those given in the references for other experiments of this series. Compositions are given in Tables 6-9. According to the references, "Error limits where shown are one standard deviation based on multiple chemical analyses. Impurities distribution based on spark source mass spectrographic analyses and represent best estimate of maximum concentration for each element present in significant quantity."

Boron in boron absorbers was natural boron. The isotopic composition was not measured.[b] Size distributions of B_4C particles in the Boral and Boroflex (Reference 4) are given in Appendix D.

[a] Personal communication, Sid Bierman, July 1993.

[b] Private communication, Sid Bierman, July, 1993. Bierman said that if the ^{10}B fraction had been measured, it would have been reported in the reference. No ^{10}B values were reported for these experiments.

Steel Plates. Two different types of 304L steel plates were used: without boron and with 1.1 wt.% boron. The reported density of the steel plate without boron was 7.930 g/cm^3. The density of the steel plates with 1.1% boron was 7.900 g/cm^3. Chemical compositions of the two types of the steel plates are given in Table 6.

Table 6. Compositions of Steel Plates.

Element	304L Steel Plates	
	No Boron	1.1 wt.% Boron
B	-	1.05 ± 0.08
Cr	18.56 ± 0.10	19.03 ± 0.10
Cu	0.27 ± 0.05	0.28 ± 0.05
Fe	68.24 ± 0.34	68.04 ± 0.34
Mn	1.58 ± 0.05	1.58 ± 0.05
Mo	0.26 ± 0.05	0.49 ± 0.05
Ni	11.09 ± 0.06	9.53 ± 0.05

Boral Plates. The reported density of the 2.16-mm-thick core of Boral B was 2.50 g/cm^3. The chemical composition of the B_4C-Al core is given in Table 7. (Note that the sum of weight percents is 100.05.) The ^{10}B areal density is ~33 mg/cm^2. The 0.38-mm-thick clad on both sides of the Boral B plates was Type 1100 aluminum.

Table 7. Composition of B_4C-Al Core of Boral B Plates.

Element	Wt.%
Al	61.21$^{(a)}$
B	30.36$^{(a)}$
C	8.43$^{(a)}$
Fe	0.02
Mg	0.01
Na	0.02

(a) Based on weights of mixture components at time of fabrication (References 5 and 14).

Boroflex Plates. The reported density of the 2.26-mm-thick Boroflex was 1.731 g/cm^3. The chemical composition is given in Table 8. The areal density of ^{10}B is ~25 mg/cm^3. The stiffening plates on both sides of the Boroflex were 1.60-mm-thick Plexiglas.

Table 8. Composition of Boroflex Core of Boroflex Plates.

Element	Wt.%
B	32.74 ± 0.05
C	21.13 ± 0.03
H	2.65 ± 0.31
Cr	0.03 ± 0.02
Fe	0.05 ± 0.06
O	21.01 ± 0.01
Si	22.39 ± 0.24

Cadmium Plates. The reported density of the cadmium plates was 8.650 g/cm^3. Chemical composition of the plates was 99.7 ± 0.3 wt.% Cd and 0.3 wt.% Zn.

Copper Plates. Two different types of copper plates, one with and one without cadmium, were used. The reported densities were 8.910 g/cm^3 for plates with cadmium and 8.913 g/cm^3 for plates without cadmium. Chemical compositions of the copper plates are given in Table 9.

Table 9. Compositions of Copper Plates.

Element	Copper Plates	
	No Cd (Wt.%)	With Cd (Wt.%)
B	-	0.005
C	0.340	0.002
Cd	-	0.989 ± 0.003
Cu	99.60 ± 0.14	98.685 ± 0.300
Fe	0.004	0.020
Mg	0.002	-
Mn	-	0.009
Na	0.002	-
Ni	-	0.010
O	0.030	0.019
Si	0.020	0.004
Sn	-	0.250
S	0.002	-
Zn	-	0.007

1.3.5 Water - Laboratory analyses of the water in the tank were done. The reported average impurity concentrations are given in Table 10 (Reference 5). The values shown agree with a laboratory analysis report dated August 4, 1980, from Hanford Environmental Health Sciences on two samples which were submitted on July 25, 1980, except for Zn, which is shown in the report as 0.16 mg/liter, and two values of "TDS" which average to 71.[a] No gadolinium impurity was reported.

The approximate average water temperature was 22°C.

Table 10. Water Impurities for Experiments (References 5 and 14).

Component	Concentration (ppm)
Cl	<5
NO_3^-	0.02
Cr^{+6}	<0.01
Zn	16
Mn	<0.01
Pb	<0.005
F	0.18
Fe	24
Cu	<0.01
Cd	0.001
SO_3	14.5
Dissolved Solids	61 ± 3

1.3.6 Tank - The experiment tank was carbon steel. Density and composition were not reported.

1.4 Supplemental Experimental Measurements

No supplemental experimental measurements were reported.

[a] A copy of the report was provided by Sid Bierman as applying to these experiments. Handwritten note on the report says "water samples taken 7/24/80 from SSC experiments tank, 1 sample, 2 bottles, SRB 8/6/80". ("TDS" is probably *total dissolved solids.*)

2.0 EVALUATION OF EXPERIMENTAL DATA

Experiments were well documented and carefully performed. There were no significant omissions of data.

2.1 Fuel-Rod Data

The average length of the fuel region was not given. Rather, a maximum fuel length of 92.71 cm and a minimum fuel length of 91.44 cm were reported. Using the average of the reported maximum and minimum lengths (92.075 cm), the reported fuel diameter, and the reported average mass of UO_2 per rod does give the reported average UO_2 density of 10.40 g/cm^3. A sensitivity study, with mass of UO_2 per rod held constant over this range in fuel length, gave a maximum Δk_{eff} of 0.076%, as shown in Table 11.[a] Therefore uncertainty in the fuel length contributes a small uncertainty to the benchmark-model k_{eff} value.

Reported end-plug dimensions and density were for uncompressed plugs. A sensitivity study was performed with compressed plugs that exactly filled the clad on both ends of the centered fuel region. Compressing the plugs increased k_{eff} by 10^{-4}, a negligible effect.

The uncertainty in fuel diameter was ± 0.003 cm. Varying the fuel diameter by this amount, with a corresponding change in UO_2 density, gave a maximum k_{eff} of 0.023%. The maximum reported uncertainty in pitch was ± 0.003 inch (0.0076 cm)[b], which gave a Δk_{eff} of 0.127%.

Uncertainties were also reported in average mass of UO_2 per rod (± 4.12 g), in average mass of uranium per rod (± 4.80 g), and in enrichment (± 0.013 wt.%). Eight cases were calculated for all possible combinations of the extremes of these three variables. A decrease in ^{235}U wt.% was accompanied by an equal increase in ^{238}U wt.% in the calculational models. The highest calculated k_{eff} was for the minimum UO_2 mass, the maximum U mass, and the maximum enrichment. The calculated Δk_{eff}, compared to a model having the average amounts of these variables, was +0.070%. The lowest calculated k_{eff} was for minimum UO_2, maximum U, and minimum enrichment, with a Δk_{eff} of -0.054%. The worst-case result is included in the uncertainty in the benchmark-model k_{eff}.

Results shown in Table 11 indicate that an uncertainty of ± 0.165% should be included in the benchmark-model k_{eff} to account for fuel-rod measurement uncertainties.

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[a] Sensitivity studies described in this section used ONEDANT models, with ENDF/B-IV 27-group cross sections, of a homogenized mixture representing an infinite slab of fuel rods with no absorber plates or steel walls. The calculations were P_1, S_8, with a convergence criterion of 10^{-6}. Cu was substituted for Zn, due to lack of a Zn cross section set. (See sample input in Appendix C.)

[b] Reference 8, p. E.4, corrected standard deviation of hole-spacing measurements on bottom lattice plate.

Table 11. Sensitivity of k_{eff} to Uncertainties in Fuel-Rod Characterization.

Quantity (Amount of Change)	% k_{eff} (ONEDANT)[(a)]
Fuel Length (± 0.635 cm)	±0.076
Fuel Diameter (± 0.003 cm)	±0.023
Pitch (± 0.0076 cm)[(b)]	±0.127
Combination of Enrichment (± 0.013 wt.%), UO_2 Mass Per Rod (± 4.12 g), U Mass Per Rod (± 4.80 g)	±0.070
Combined Effect[(c)]	±0.165

(a) 27-group ENDF/B-IV cross sections with homogenized lattice-cell fuel region (CSASIX); infinite slab geometry; sample input given in Appendix C.
(b) The largest standard deviation for sets of center-to-center spacing measurements for triangular-pitch lattice plates was ±0.003 inch (±0.0076 cm; last column on p. E.4, Reference 8; standard deviations were recalculated). Other references give the uncertainty in pitch as ± 0.001 cm or ± 0.005 cm. Therefore, the calculated uncertainty is conservative.
(c) Square root of sum of squares of individual effects.

2.2 Water Reflector

2.2.1 Top Reflector Thickness - The minimum thickness of the top water reflector was 15 cm above the fuel region. Assuming the average fuel length of 92.075 cm centered within the 96.52-cm-long rod, the end-plug region is slightly less than 1 inch long (2.2225 cm). Therefore, the minimum water reflector thickness above the tops of the top plugs is 12.7775 cm.

Calculations were performed for an infinite-slab fuel region with a water reflector on both sides. ONEDANT and CSAS 27-group ENDF/B-IV cross sections, with a lattice-cell fuel region homogenized by XSDRNPM, were used. The reflector thickness was varied from 15 to 30 centimeters. The effect on k_{eff} of the outermost 15 centimeters of water was less than 0.002%. Replacing the outermost 15 centimeters of water with 40 centimeters of full-density stainless steel or concrete gave similar results: the effect on k_{eff} was less than 0.004%. This value is included in the k_{eff} uncertainty.

These calculations indicate that a top water reflector with a thickness of 15 centimeters may be considered as "effectively infinite" and materials beyond the top and bottom reflectors may be neglected. Therefore, lack of data about material above the 15-cm-thick top water reflector does not affect the acceptability of these experiments as benchmark critical experiments.

2.2.2 Side Water Reflector Thickness - Additionally, ONEDANT was used to determine the effect of a water reflector outside the stainless steel wall for a slab of an XSDRN-homogenized array of pins. There was no difference in k_{eff} between a 10-cm-thick water reflector and a 30-cm-thick water reflector. Replacing the outermost 5 centimeters of the 10-cm-thick water reflector with 20% stainless steel in water also had no effect on k_{eff}. Therefore, lack of specifications about detectors, which were placed in the water reflector more than 5 centimeters away from the reflecting walls, does not affect the acceptability of these experiments.

2.3 Water Impurities

Water impurity sensitivity studies described in Appendix C of LEU-COMP-THERM-004 indicate that only gadolinium and boron impurities significantly affect k_{eff}. No gadolinium or boron impurity is reported for these configurations.

The amount of dissolved solids reported was 61 grams per cubic meter of solution. Assume that the dissolved solids have the same density as water (~1 g/cm^3) and displace water (conservative assumptions). The percentage of water volume displaced by the solute is then $61/10^6 \times 100 = 0.006$ percent. Using ONEDANT and reducing the water volume by this percentage gives a resulting change in k_{eff} of less than 0.005 percent.

The effect on k_{eff} of impurities in the water listed in Table 10 for a near-critical slab of $U(4.31)O_2$ fuel pins with stainless steel walls, was calculated using ONEDANT. The effect of the impurities is less than 0.006% of k_{eff}.

The combined effect of 0.008% for displaced water and measured impurity elements is included in the k_{eff} uncertainty.

2.4 Temperature Data

Water temperatures were recorded in logbooks for approximately ten percent of all the experiments of the series. (Other experiments in the series are mentioned in Section 1.1.) Measured temperatures ranged from 18 °C to 26 °C. ONEDANT calculations with water densities at 18 and 26 °C gave a change in k_{eff} of 0.023% for a pitch of 1.892 cm. Therefore, an estimate of the uncertainty in k_{eff} due to the effects of temperature is half this amount, namely 0.01%.

2.5 Other Sensitivity Calculations

Sensitivity studies described in this section used TWODANT models, with CSASIX ENDF/B-IV 27-group cross sections. (See sample inputs in Appendix C.) A homogeneous mixture, with macroscopic cross sections which are resonance-corrected and cell-weighted by CSASIX to account for fuel diameter, clad thickness, and fuel-rod pitch in the particular moderator, was used to model fuel-rod clusters. The TWODANT calculations were P_1, S_8, with a convergence criterion of 10^{-5}. (Cu was substituted for Zn, due to lack of a 27-group Zn cross section set.)

2.5.1 Cluster Separations - The measurement uncertainties in cluster separation (see Table 2) varied from 0.02 cm to 0.06 cm. To calculate the effect on k_{eff}, cluster separations were reduced by the particular uncertainty for each of the seven cases. Results are summarized in Table 12. The largest effect was 0.036% for Case 5.

Table 12. Uncertainties in Benchmark-Model k_{eff} Due to Cluster-Separation Measurement Uncertainty.

Case	Absorber Plate Material	Uncertainty in Cluster Separation Measurement (cm)	Δk_{eff} (%) [(a)]
1	304-L Steel	0.06	0.030
2	304-L Steel with 1.1 wt.% B	0.04	0.022
3	Boral B	0.03	0.016
4	Boroflex	0.02	0.011
5	Cadmium	0.06	0.036
6	Copper	0.04	0.020
7	Copper-Cadmium	0.02	0.011

(a) TWODANT with 27-group ENDF/B-IV cross sections.

2.5.2 Absorber Plate Thickness - The effects of the uncertainties in absorber-plate thickness on k_{eff} were calculated for all seven cases. Results in Table 13 indicate that the largest uncertainty in k_{eff} due to uncertainty in absorber plate thickness is 0.025% Δk_{eff}. This is included in the uncertainty of the benchmark-model k_{eff}.

Table 13. Uncertainties in Benchmark-Model k_{eff} Due to Absorber-Plate Thickness Uncertainty.

Case	Absorber Plate Material	Uncertainty in Absorber Plate Thickness (cm)	Δk_{eff} (%) [(a)]
1	304-L Steel	0.013	0.025
2	304-L Steel with 1.1 wt.% B	0.006	0.012
3	Boral B	0.013	0.015[(b)]
4	Boroflex	0.018[(c)]	0.011
5	Cadmium	0.003	0.002
6	Copper	0.008	0.015
7	Copper-Cadmium	0.008	0.012

(a) TWODANT with 27-group ENDF/B-IV cross sections.
(b) Includes effects of ±0.013-cm B_4C-Al core thickness change (Δk_{eff} = 0.014%) and ±0.005-cm Type 1100 aluminum clad thickness change (Δk_{eff} = 0.005%).
(c) Includes ±0.004-cm Boroflex thickness change and ± 0.007 cm change in thickness of each Plexiglas stiffener plate. The largest Δk_{eff}, included here, is for decreased Boroflex thickness and increased Plexiglas thickness.

2.5.3 Absorber-Plate Composition - The maximum effects on k_{eff} of the absorber plates' composition uncertainties were calculated. Effects of maximum and minimum amounts of components were calculated. The greater difference from k_{eff} of the base case, which has average amounts of components, is given in Tables 14 through 19. The reactivity effects of replacing the absorber plates with water were also calculated to indicate the usefulness of these benchmarks for validating calculations of configurations that include these materials.

Steel Plates. Since the steel-plate compositions were chemically analyzed (Table 6), uncertainties were relatively small compared to nominal ranges of components of the particular type of steel. For Case 1 of Table 2 the effects of maximum weight percents of iron and manganese in the non-borated steel plate were compared to effects of minimum weight percents. The differences from the base case are shown in Table 14. Similarly, for Case 2 effects of maximum and minimum weight percents of boron, iron, and manganese in the 1.1%-borated steel plate were calculated and compared to the base case. The natural variation in ^{10}B isotopic fraction[a] (± 0.8 at.%) was also calculated. Results are shown in Table 15.

[a] *Nuclides and Isotopes, Fourteenth Edition,* General Electric Company, 1989, p. 8.

Table 14. Calculated Effect of Non-Borated Steel Plate Composition Uncertainties on k_{eff}.

Case	Description	Δk_{eff} (%)
1	Fe (68.24) ± 0.34 wt.%	0.001
	Mn (1.58) ± 0.05 wt.%	0.001
	Non-Borated Steel Plates Replaced with Water	1.061

Table 15. Calculated Effect of 1.1%-Borated Steel Plate Composition Uncertainties on k_{eff}.

Case	Description	Δk_{eff} (%)
2	B (1.05) ± 0.08 wt.%	0.053
	^{10}B (19.9) ± 0.8 at.%	0.028
	Mn (1.58) ± 0.05 wt.%	0.002
	Fe (68.04) ± 0.34 wt.%	0.008
	1.1%-Borated Steel Plates Replaced with Water	4.563

Boral B Plates. Although the density and composition of the Type 1100 aluminum cladding of the Boral were not reported, it is assumed that effects on k_{eff} of variations from nominal values would be negligible. Standard density and composition from an aluminum handbook are used in the benchmark model.

Since no uncertainty in boron content was given, the uncertainty is assumed to be one in the least significant digit. For Case 3 of Table 2, the maximum and minimum wt.%'s of boron and at.%'s of ^{10}B in boron were compared to the base case, with results given in Table 16.

Table 16. Calculated Effect of Boral B Plate Composition Uncertainties on k_{eff}.

Case	Description	Δk_{eff} (%)
3	B (30.36) ±0.01 wt.%	<0.001
	^{10}B (19.9) ±0.8 at.%	0.014
	Boral B Plates Replaced with Water	7.002

Boroflex Plates. For Case 4 of Table 2, the maximum and minimum wt.%'s of B and Fe and maximum and minimum at.%'s of ^{10}B in boron were compared to the base case, with results given in Table 17.

Table 17. Calculated Effect of Boroflex Plate Composition Uncertainties on k_{eff}.

Case	Description	Δk_{eff} (%)
4	B (32.74) ± 0.05 wt.%	<0.001
	^{10}B (19.9) ± 0.8 at.%	0.015
	Fe (0.05) ± 0.06 wt.%	<0.001
	Boroflex Plates Replaced with Water	6.749

Cadmium Plates. The maximum and minimum wt.% Cd of the cadmium plate were compared for Case 5 of Table 2, with results given in Table 18.

The use of Plexiglas stiffener sheets on one or both sides of each Cd absorber plate was not reported. However, an experimenter believed that such sheets were probably used.[a] The benchmark model assumes one 0.296-cm-thick Plexiglas sheet on the outer side of each Cd plate for Case 5. The effects of no Plexiglas, of 0.16-cm Plexiglas on both sides of the cadmium, and of placing the 0.296-cm Plexiglas next to the center cluster, rather than outside of the cadmium sheets, were calculated. The largest effect was 0.256%, for 0.296-cm Plexiglas on both sides of each cadmium sheet. This effect on k_{eff} is included in the k_{eff} uncertainty for Case 5.

Table 18. Calculated Effect of Cadmium Plate Composition Uncertainties on k_{eff}.

Case	Description	Δk_{eff} (%)
5	Cd (99.7) ± 0.3 wt.%	<0.001
	Plexiglas Sheet Placement	0.256
	Cadmium Plates Replaced with Water	5.912

Copper Plates. For Cases 6 and 7 of Table 2, compositions with the maximum and minimum wt.% of copper and of cadmium for the copper plate with cadmium, were compared to the base case. Other elements (except cadmium in Case 7) were reduced or increased in proportion to their original percentages. Results are given in Table 19.

[a] Sid Bierman, private communication, July, 1999.

Table 19. Calculated Effect of Copper Plate Composition Uncertainties on k_{eff}.

Case	Description	Δk_{eff} (%)
6	Cu (99.6) ± 0.14 wt.%	0.004
	Copper Plates without Cd Replaced with Water	1.284
7	Cu (98.685) ± 0.3 wt.%	0.019
	Cd (0.989) ± 0.003 wt.%	0.017
	Copper Plates with Cd Replaced with Water	3.732

Results indicate that, except for the Plexiglas stiffener-sheet uncertainty for Case 5, the largest uncertainty in k_{eff} due to uncertainty in composition of absorber plates is 0.053% for the boron in the 1.1%-borated steel plates. This maximum effect is included in the uncertainty of the benchmark-model k_{eff} for all cases.

2.5.4 Steel Reflecting-Wall Composition and Density - For all seven cases, maximum and minimum wt.%'s of Fe in the steel walls, compensated by decreased Ni and increased Ni, respectively, were compared. Results indicate that the uncertainty in k_{eff} due to uncertainty in reflecting-wall composition is no more than 0.003% k_{eff}. (The effect on k_{eff} of replacing steel walls with water was approximately –1.9% for all cases.) The density of the walls was given as 7.84 g/cm^3, indicating an uncertainty of 0.005 g/cm^3. Case 4 was calculated with TWODANT with both increased and decreased steel-wall density. The effect on k_{eff} was 0.001%. Therefore an uncertainty of 0.003% is included in the total uncertainty of the benchmark-model k_{eff} for both of these effects.

2.5.5 Reflecting-Wall Separations - The measurements were made with the steel reflecting walls positioned at near optimum for criticality (Reference 5). The measurement uncertainty in separation of the reflecting walls from the clusters was 0.102 cm. The effect on k_{eff} of this uncertainty was calculated for each of the 7 cases by varying (increasing or decreasing) the reflecting-wall separation by the amount of the uncertainty. All of the calculated k_{eff} values increased by ~0.03% as walls were brought closer and decreased by the same amount with walls farther from the clusters.

The largest Δk_{eff} was –0.036% for walls moved 0.102 cm away from the clusters for Case 2, with borated steel absorber plates. Therefore, an additional 0.036% is included in the benchmark-model k_{eff} uncertainty.

2.6 Conclusions of Acceptability

The calculated effects of material and geometrical uncertainties are summarized in Table 20. Because the effects of some uncertainties which represent approximately the entire range of the variable (boron isotopic composition, temperature) are small, and the significant effects are from reported standard deviations, the total uncertainty represents one standard deviation (1σ).

Table 20. Summary of Effects of Material and Geometrical Uncertainties.

Measurement Uncertainty or Model Simplification	Δk_{eff} (%)
Fuel-Rod Characterization	0.165
Surroundings (steel or concrete included in additional water outside a 15-cm water reflector)	0.004
Impurities	0.008
Temperature	0.01
Cluster Separation	0.036
Absorber Plate Thickness	0.025
Absorber Plate Composition	0.053
Reflecting Wall Composition/Density	0.003
Wall Separation from Clusters	0.036
Total[(a)]	0.183[(b)]

(a) Square root of sum of squares of individual Δk_{eff} values, representing 1σ.
(b) Total is larger for Case 5 due to the additional uncertainty of 0.256 from uncertain Plexiglas stiffener-sheet placement; see Table 18. The total k_{eff} uncertainty for Case 5 is, therefore, 0.315%. Because this uncertainty includes the effect of the entire Plexiglas stiffener sheet, it is not strictly a 1σ uncertainty.

Because the effects of the non-borated steel and copper-without-cadmium plates in these experiments with water were calculated to be small (<1.3% of k_{eff}), the cases that include these plates (Cases 1 and 6) may not be considered as good tests of the ability of code packages to correctly calculate these materials. Because the required experimental data and uncertainties were measured and recorded, and because the effects of uncertainties for all cases were calculated to be small, all cases are acceptable as benchmark experiments.

3.0 BENCHMARK SPECIFICATIONS

3.1 Description of Model

The calculational models consist of square-pitch, aluminum-clad cylindrical fuel pins in water in three rectangular clusters arranged in a row with absorber plates between clusters and steel reflecting walls in place. Several sensitivity studies were performed to justify simplifications of the benchmark model.

3.1.1 Water Impurities - The calculated effect on k_{eff} of impurities in the water is less than 0.008% (Section 2.3). This effect of impurities is included in the total k_{eff} uncertainty. Impurities are not included in the benchmark model.

3.1.2 Neutron Source – As mentioned in Section 1.2.10, the californium source in a small, thin acrylic tube had no measurable effect. It is not included in the benchmark model.

3.1.3 Lattice Plates - The polypropylene lattice plates are omitted from the benchmark model. A ONEDANT sensitivity study of a slab of homogenized fuel pins reflected by water with two lattice plates gave a calculated effect on k_{eff} of the two lattice plates of 0.02%. This is included in the uncertainty of the benchmark-model k_{eff}.

3.1.4 Reflector - The model of the bottom reflector is 2.54 cm of acrylic followed by 15.3 cm of water. The effects on k_{eff} of the one-inch-thick acrylic support plate directly beneath the fuel rods and the carbon steel[a] tank 17.84 cm below the fuel rods were calculated using a ONEDANT slab model with CSAS ENDF/B-IV 27-group cross sections and a homogeneous fuel region. Results showed that the carbon steel tank has no effect and the acrylic support plate has a small effect (0.02%). Therefore the acrylic support plate is retained in the benchmark model and the tank wall is omitted.

The lateral extent of the acrylic support plate or plates is not known exactly. The model includes one support plate which extends to the edges of the array of clusters. It is judged that the effect of support plate material being replaced with water beyond the cluster array is negligible.

Because the aluminum channels supporting the acrylic support plate were placed at the edges of the clusters, the effect of omitting them is judged to be negligible. They are not included in the benchmark model. Because of the negligible effect of materials beyond the water reflector region (see Section 2.2), nothing outside the water reflector is included in the benchmark model.

The effect on k_{eff} of water reflector beyond the ends of the steel walls was calculated with TWODANT (27-group ENDF/B-IV, epsi=10^{-6}) for the three cases with largest separation between clusters. The minimum thickness of water at the ends of the clusters (S_w in Figure 7) is 26.3 cm. The calculated effect of omitting water beyond the ends of the walls was <0.001%. Therefore, there

[a] 1 wt.% Mn, 0.9 wt.% C, and remainder Fe (Robert C. Weast, ed., *CRC Handbook of Chemistry and Physics, 68th Edition*, CRC Press, 1987, p. E-114).

is nothing beyond the ends of the walls in the benchmark model.
3.1.4 Absorber Plates - Impurities Fe, Mg, and Na in the Boral B absorber plates, which totaled less than 0.06 wt.% (see Table 7), were calculated to have negligible effect (<0.001%) and were omitted. The sum of reported weight percents of other constituents, Al, B, and C, was exactly 100 wt.%.

Acrylic, which has the same wt.%'s of C, H, and O as Plexiglas ($C_5H_8O_2$), was used to model the sheets of Plexiglas used to stiffen the Boroflex (Case 4) and Cd (Case 5) plates. The effects of any small unknown differences in actual compositions are judged to be negligible.

3.1.5 Rubber End Plugs – The rubber end plugs of the fuel elements had reported density 1.321 g/cm^3 and length of 2.54 cm. In the model, the plugs are compressed to density 1.498 g/cm^3. This approximately conserves the mass of the end plugs, which have a length of 2.2225 cm in the model. A sensitivity study of the effect of compressing the plugs, mentioned in Section 2.1, showed negligible effect on k_{eff} (0.01%).

3.2 Dimensions

Fuel-rod dimensions are shown in Figure 6. The rod has an outer diameter of 1.415 cm and is 96.52 cm long. The UO_2 fuel region has a diameter of 1.265 cm and is 92.075 cm long. The clad is 0.066 cm thick. Therefore, the gap between UO_2 and clad is 0.009 cm thick with an outer diameter of 1.283 cm. The compressed rubber end plugs are 2.2225 cm long with a diameter of 1.283 cm, to fit exactly within the ends of the fuel rod.

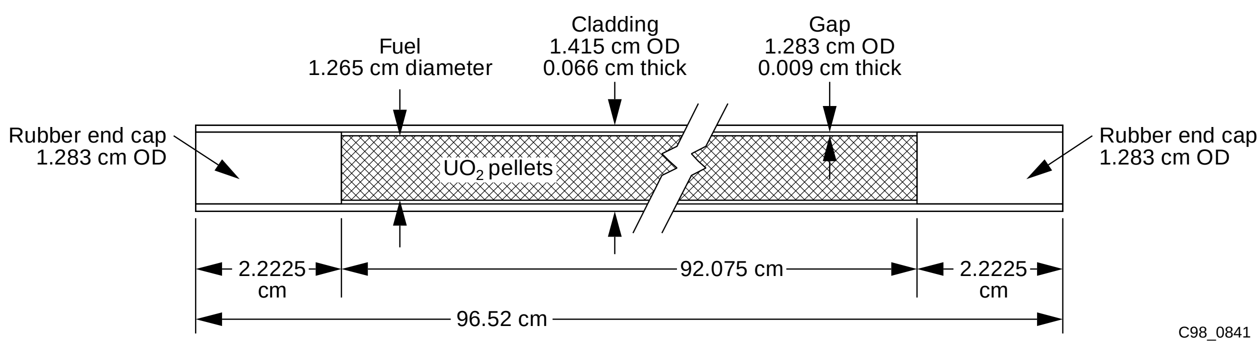

Figure 6. Fuel-Rod Model.

Each configuration comprises three clusters of fuel rods at 1.892-cm pitch, two absorber plates, and two steel reflecting walls in water. The clusters are 16 rods wide (from steel wall to steel wall) and 12 rods long, arranged in a line with absorber plates between them, as shown in Figure 7. The absorber plates are positioned at the outer cell boundary of the center fuel cluster. Separation of clusters, $\mathbf{S}_c$, is the distance between fuel-rod cell boundaries of adjacent clusters.

Dimensions are given in Table 21.

Table 21. Critical Configurations.

Case	Separation of Clusters, S_c (cm) [a]	Absorber-Plate Material	Absorber-Plate Thickness (cm)
1	13.273	304-L Steel	0.302
2	9.353	304-L Steel with 1.1 wt.% B	0.298
3	7.823	Boral B	0.216[b]
4	7.893	Boroflex	0.226[c]
5	8.463	Cadmium	0.061[d]
6	12.993	Copper	0.337
7	10.093	Copper-Cadmium	0.357

(a) Distance between outer cell boundaries of one cluster and outer cell boundaries of the next. This distance is (pitch – rod diameter) = 0.477 cm less than rod-surface-to-rod-surface separation of clusters in Table 2.
(b) Also 0.038 cm of Type 1100 aluminum on either side of the 0.216-cm-thick B_4C-Al absorber material.
(c) Also 0.16-cm-thick Plexiglas on either side of the 0.226-cm-thick Boroflex.
(d) The 0.061-cm-thick cadmium is mounted on 0.296-cm-thick Plexiglas, with the cadmium next to the center cluster.

All absorber plates are 30.2 cm wide and 91.5 cm long. The plates are parallel to the interacting faces of adjacent clusters, and are centered horizontally with respect to the cluster faces. The bottom of both absorber plates is at the same level as the bottom of the fuel regions.

The bottom reflector is a single 2.54-cm-thick acrylic plate followed by 15.3 cm of water. The acrylic plate extends horizontally to the outermost cell-boundary edges of the clusters. The water reflector containing the steel walls on the two sides of the line of clusters extends 30.5 cm from the outer cell boundaries of the clusters. The top reflector is 12.7775 cm of water above the top plugs of the fuel rods.

The two steel reflecting walls are 147.3 cm long by 121.9 cm high and 17.85 cm thick. The distance between reflecting walls and outer cell boundaries of the fuel clusters is 1.956 cm. The steel reflecting walls are centered horizontally with respect to the three clusters. The bottom of the walls is at the same level as the bottom of the water reflector, at 15.3 cm below the acrylic support plate.

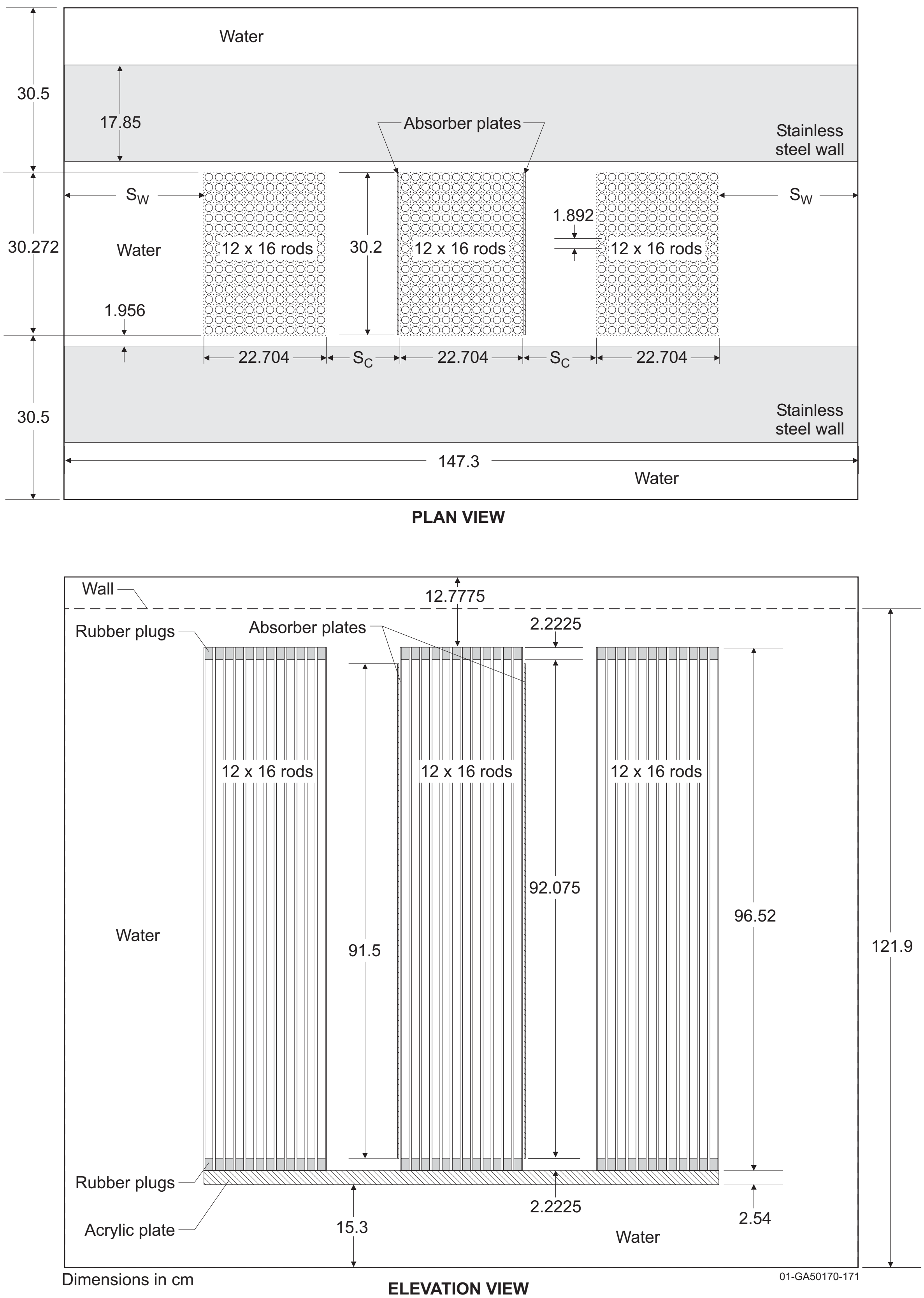

Figure 7. Benchmark Model.

3.3 Material Data

3.3.1 Fuel Rods - The fuel region consists of 1203.38 g of UO_2. The mass of uranium in each rod is 1059.64 g. The isotopic composition of the uranium is 0.022 wt.% ^{234}U, 4.306 wt.% ^{235}U, 0.022 wt.% ^{236}U, and 95.650 wt.% ^{238}U. Fuel rods have 6061-aluminum clad (average, nominal composition) and compressed rubber end plugs of density 1.498 g/cm^3.[a] Atom densities are given in Table 22.

Table 22. Fuel-Rod Atom Densities.

Material	Isotope	Atom Density (barn-cm)$^{-1}$
$U(4.306)O_2$ Fuel	^{234}U	5.1835×10^{-6}
	^{235}U	1.0102×10^{-3}
	^{236}U	5.1395×10^{-6}
	^{238}U	2.2157×10^{-2}
	O	4.6753×10^{-2}
6061-Aluminum Clad (2.69 g/cm^3)	Al	5.8433×10^{-2}
	Cr	6.2310×10^{-5}
	Cu	6.3731×10^{-5}
	Mg	6.6651×10^{-4}
	Mn	2.2115×10^{-5}
	Ti	2.5375×10^{-5}
	Zn	3.0967×10^{-5}
	Si	3.4607×10^{-4}
	Fe	1.0152×10^{-4}
Rubber End Plug (1.498 g/cm^3)	C	4.3562×10^{-2}
	H	5.8178×10^{-2}
	Ca	2.5660×10^{-3}
	S	4.7820×10^{-4}
	Si	9.6360×10^{-5}
	O	1.2461×10^{-2}

3.3.2 Reflecting Walls - Steel wall atom densities are given in Table 23.

[a] This density is more than the reported density of the plugs in Table 9 because of the compression of the plugs.

Table 23. Steel Reflecting-Wall Atom Densities.

Isotope	Wt.%	Atom Density (barn-cm)$^{-1}$
Fe	96.77	8.1810×10^{-2}
C	0.19	7.4686×10^{-4}
Mn	1.28	1.1000×10^{-3}
P	0.004	6.0971×10^{-6}
S	0.006	8.8332×10^{-6}
Si	0.22	3.6983×10^{-4}
Ni	0.79	6.3552×10^{-4}
Mo	0.49	2.4114×10^{-4}
Cr	0.12	1.0896×10^{-4}
Cu	0.13	9.6587×10^{-5}

3.3.3 Absorber Plates – Absorber-plate atom densities are given in Tables 24, 25, and 26. Boron is assumed to be 19.9 at.% ^{10}B and 80.1 at.% ^{11}B.[a]

Table 24. Steel Absorber-Plate Atom Densities.

Material	Isotope	Wt.%	Atom Density (barn-cm)$^{-1}$
304L Steel without B (7.93 g/cm^3)	Cr	18.56	1.7046×10^{-2}
	Cu	0.27	2.0291×10^{-4}
	Fe	68.24	5.8353×10^{-2}
	Mn	1.58	1.3734×10^{-3}
	Mo	0.26	1.2942×10^{-4}
	Ni	11.09	9.0238×10^{-3}
304L Steel with 1.1% B (7.9 g/cm^3)	^{10}B	1.05 wt.% boron, 19.9 at.% ^{10}B	9.1950×10^{-4}
	^{11}B	1.05 wt.% boron, 80.1 at.% ^{11}B	3.7011×10^{-3}
	Cr	19.03	1.7412×10^{-2}
	Cu	0.28	2.0963×10^{-4}
	Fe	68.04	5.7961×10^{-2}
	Mn	1.58	1.3682×10^{-3}
	Mo	0.49	2.4298×10^{-4}
	Ni	9.53	7.7251×10^{-3}

[a] *Nuclides and Isotopes, Fourteenth Edition,* General Electric Company, 1989.

Table 25. Boral, Boroflex, and Cadmium Absorber-Plate Atom Densities.

Material	Isotope	Wt.%	Atom Density
Boral B (2.5 g/cm^3)	Al	61.21	3.4154×10^{-2}
	^{10}B	30.36 wt.% boron, 19.9 at.% ^{10}B	8.4135×10^{-3}
	^{11}B	30.36 wt.% boron, 80.1 at.% ^{11}B	3.3865×10^{-2}
	C	8.43	1.0567×10^{-2}
Type 1100 Aluminum [(a)] (clad of Boral absorber plates; 2.7 g/cm^3)	Al	99.0	5.9660×10^{-2}
	Cu	0.12	3.0705×10^{-5}
	Mn	0.025	7.3991×10^{-6}
	Zn	0.05	1.2433×10^{-5}
	Si	0.4025	2.3302×10^{-4}
	Fe	0.4025	1.1719×10^{-4}
Boroflex [(b)] (1.731 g/cm^3)	^{10}B	32.74 wt.% boron, 19.9 at.% ^{10}B	6.2822×10^{-3}
	^{11}B	32.74 wt.% boron, 80.1 at.% ^{11}B	2.5287×10^{-2}
	C	21.13	1.8339×10^{-2}
	H	2.65	2.7408×10^{-2}
	Cr	0.03	6.0145×10^{-6}
	Fe	0.05	9.3329×10^{-6}
	O	21.01	1.3689×10^{-2}
	Si	22.39	8.3103×10^{-3}
Cadmium [(b)] (8.65 g/cm^3)	Cd	99.7	4.6201×10^{-2}
	Zn	0.3	2.3899×10^{-4}

(a) from *Alcoa Aluminum Handbook*, Aluminum Company of America, pp. 46-50, 1967.
(b) See Table 27 for Plexiglas stiffener material for Boroflex (Case 4) and for Cd plates (Case 5).

Table 26. Copper Absorber-Plate Atom Densities.

Material	Isotope	Wt.%	Atom Density
Copper without Cd ($8.913 g/cm^3$)	C	0.34	1.5194×10^{-3}
	Cu	99.6	8.4128×10^{-2}
	Fe	0.004	3.8444×10^{-6}
	Mg	0.002	4.4168×10^{-6}
	Na	0.002	4.6695×10^{-6}
	O	0.03	1.0064×10^{-4}
	Si	0.02	3.8223×10^{-5}
	S	0.002	3.3474×10^{-6}
Copper with Cd ($8.910 g/cm^3$)	^{10}B	0.005 wt.% boron, 19.9 at.% ^{10}B	4.9384×10^{-6}
	^{11}B	0.005 wt.% boron, 80.1 at.% ^{11}B	1.9878×10^{-5}
	C	0.002	8.9346×10^{-6}
	Cd	0.989	4.7208×10^{-4}
	Cu	98.685	8.3328×10^{-2}
	Fe	0.02	1.9216×10^{-5}
	Mn	0.009	8.7901×10^{-6}
	Ni	0.01	9.1424×10^{-6}
	O	0.019	6.3720×10^{-5}
	Si	0.004	7.6419×10^{-6}
	Sn	0.25	1.1300×10^{-4}
	Zn	0.007	5.7440×10^{-6}

3.3.4 Moderator-Reflector - The acrylic support plate has a density of 1.185 g/cm^3 and a composition of 8 wt.% hydrogen, 60 wt.% carbon, and 32 wt.% oxygen.

The moderator-reflector is water at a temperature of 22°C. This corresponds to a density of 0.997766 g/cm^3.[a] Atom densities are given in Table 27.

[a] Interpolated between densities at 20 and 25°C, CRC Handbook of Chemistry and Physics, 68th Edition, p. F-10.

Table 27. Moderator-Reflector Atom Densities.

Material	Isotope	Atom Density $(barn\text{-}cm)^{-1}$
Water	H	6.6706×10^{-2}
	O	3.3353×10^{-2}
Acrylic (Plexiglas)	H	5.6642×10^{-2}
	C	3.5648×10^{-2}
	O	1.4273×10^{-2}

3.4 Temperature Data

Temperature data for the individual experiments were not published. Logbook records give temperature data for approximately every tenth experiment. Recorded values vary between 18°C and 26°C, with most values between 20°C and 25°C. An approximate temperature of 22°C was used in the model.

3.5 Experimental and Benchmark-Model k_{eff}

The reported configurations were extrapolations to critical configurations. Therefore the experimental k_{eff} was 1.000.

Some model simplifications (no aluminum support structures; nothing beyond the water reflector, no measurement devices in the water) were judged to have negligible effect on k_{eff}. Experimental uncertainties (Section 2, Table 22) and simplifying the model by omitting the two lattice plates (Section 3.1, $\Delta k_{eff} = 0.02\%$) contribute to the estimated uncertainty in the benchmark-model k_{eff}.

Benchmark-model k_{eff}'s and uncertainties are listed in Table 28. Uncertainties are 1σ, except Case 5 which includes the entire effect of the presence of a Plexiglas stiffener plate.

Table 28. Benchmark-Model k_{eff}'s.

Case	Benchmark-Model k_{eff} and Uncertainty
1	1.0000 ± 0.0018
2	1.0000 ± 0.0018
3	1.0000 ± 0.0018
4	1.0000 ± 0.0018
5	1.0000 ± 0.0032[(a)]
6	1.0000 ± 0.0018
7	1.0000 ± 0.0018

(a) Case 5 (Cd plates) has a larger uncertainty, due to the uncertain placement of Plexiglas stiffener plates (Table 18).

4.0 RESULTS OF SAMPLE CALCULATIONS

Results of calculations representing the seven critical configurations are presented in Table 29. All results are within 0.7% of the benchmark-model k_{eff}. Typical code input listings are given in Appendix A.

Table 29. Sample Calculation Results (United States).[a]

Code (Cross Section Set) → Case ↓	KENO (44-Group ENDF/B-V)	KENO (238-Group ENDF/B-V)	MCNP (Continuous Energy ENDF/B-V)	MCNP (Continuous Energy ENDF/B-VI)
1	0.9987 ± 0.0008	0.9930 ± 0.0006	0.9981 ± 0.0006	0.9938 ± 0.0006
2	1.0011 ± 0.0006	0.9967 ± 0.0007	0.9974 ± 0.0006	0.9937 ± 0.0006
3	0.9995 ± 0.0007	0.9933 ± 0.0007	0.9975 ± 0.0006	0.9933 ± 0.0006
4	1.0016 ± 0.0007	0.9961 ± 0.0007	0.9972 ± 0.0007	0.9938 ± 0.0007
5	0.9993 ± 0.0007	0.9938 ± 0.0008	0.9973 ± 0.0007	0.9934 ± 0.0006
6	0.9992 ± 0.0006	0.9944 ± 0.0007	0.9971 ± 0.0006	0.9932 ± 0.0006
7	0.9988 ± 0.0007	0.9938 ± 0.0007	0.9966 ± 0.0007[b]	0.9933 ± 0.0007[b]

(a) Cu replaces Zn in clad and in Cd and copper-cadmium absorber plates, due to nonavailability of Zn cross sections.
(b) Sn in absorber plates is omitted, due to unavailability of cross sections.

5.0 REFERENCES

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3. S. R. Bierman, B. M. Durst, E. D. Clayton, "Criticality Experiments with Subcritical Clusters of 2.35 Wt% and 4.29 Wt% ^{235}U Enriched UO_2 Rods in Water with Uranium or Lead Reflecting Walls, Near Optimum Water-to-Fuel Volume Ratio," NUREG/CR-0796, Vol. 1, PNL-2827, Batelle Pacific Northwest Laboratories, Richland, Washington, April 1979.

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8. S. R. Bierman, E. S. Murphy, E. D. Clayton, R. T. Keay, "Criticality Experiments with Low Enriched UO_2 Fuel Rods in Water Containing Dissolved Gadolinium," PNL-4976, Batelle Pacific Northwest Laboratories, Richland, Washington, February 1984.

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11. B. M. Durst, S. R. Bierman, E. D. Clayton, J. F. Mincey, R. T. Primm III, "Summary of Experimental Data for Critical Arrays of Water Moderated Fast Test Reactor Fuel," PNL-3313, ORNL/Sub-81/97731/1, Batelle Pacific Northwest Laboratories, Richland, Washington, May 1981.

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13. R. I. Smith and G. J. Konzek, principal investigators, "Clean Critical Experiment Benchmarks for Plutonium Recycle in LWR's," NP-196, Volumes 1 and 2, Battelle Pacific Northwest Laboratories, Richland, Washington, April, 1976, and September 1978.

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15. S. R. Bierman, B. M. Durst, and E. D. Clayton, "Criticality Experiments with Subcritical Clusters of Low Enriched UO_2 Rods in Water with Uranium or Lead Reflecting Walls," Nuc. Technol., Vol. **47**, January 1980.

APPENDIX A: TYPICAL INPUT LISTINGS

A.1 KENO Input Listings

The version of KENO V.a used was SCALE4.4 provided by the Radiation Shielding Information Center. KENO V.a was run for each case using 600 active generations of 2500 neutrons each, after skipping 60 generations.

The following input listings are for the 44-group library. Input listings for the 238-group library are exactly the same except "44" is replaced by "238" in the third line.

KENO V.a Input Listing for Case 1 of Table 29 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
LCT13-1, U(4.31)O2 RODS, SS WALLS, SS ABS PLATE
44GROUPNDF5 LATTICECELL
' U(4.31)02
U-234  1 0  5.1835-6 END
U-235  1 0  1.0102-3 END
U-236  1 0  5.1395-6 END
U-238  1 0  2.2157-2 END
O  1 0  4.6753-2 END
' 6061 Al (clad)
AL  2 0  5.8433-2 END
CR  2 0  6.2310-5 END
CU  2 0  6.3731-5 END
MG  2 0  6.6651-4 END
MN  2 0  2.2115-5 END
TI  2 0  2.5375-5 END
'        (Zn replaced by Cu)
CU  2 0  3.0967-5 END
SI  2 0  3.4607-4 END
FE  2 0  1.0152-4 END
'  Rubber end plug
C  3 0   4.3562-2 END
H   3 0  5.8178-2 END
CA  3 0  2.5660-3 END
S   3 0  4.7820-4 END
SI  3 0  9.6360-5 END
O   3 0  1.2461-2 END
' water
H  4 0  6.6706-2 END
O  4 0  3.3353-2 END
'acrylic
H   5 0  5.6642-2 END
C   5 0  3.5648-2 END
O   5 0  1.4273-2 END
' SS plate
CR  6 0  1.7046-2 END
CU  6 0  2.0291-4 END
FE  6 0  5.8353-2 END
MN  6 0  1.3734-3 END
MO  6 0  1.2942-4 END
NI  6 0  9.0238-3 END
' STEEL WALLS
FE  7 0  8.1810-2 END
C   7 0  7.4686-4 END
MN  7 0  1.1000-3 END
P   7 0  6.0971-6 END
S   7 0  8.8332-6 END
SI  7 0  3.6983-4 END
NI  7 0  6.3552-4 END
MO  7 0  2.4114-4 END
CR  7 0  1.0896-4 END
CU  7 0  9.6587-5 END
' water
H  8 0  6.6706-2 END
O  8 0  3.3353-2 END
END COMP
SQUAREPITCH 1.892 1.265 1 4 1.415 2 1.283 0  END
LCT13-1, U(4.31)O2 RODS, SS WALLS, SS ABS PLATE
READ PARA TME=200 GEN=660 NPG=2500 NSK=60 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL ROD *
 CYLINDER  1 1  0.6325  92.075   0.0
 CYLINDER  0 1  0.6415  92.075   0.0
 CYLINDER  3 1  0.6415  94.2975 -2.2225
 CYLINDER  2 1  0.7075  94.2975 -2.2225
 CUBOID    4 1  4P0.946 94.2975 -2.2225
UNIT 2
```

KENO V.a Input Listing for Case 1 of Table 29 (44-Energy Group SCALE Cross Sections) (cont'd)

```
 COM=* 6X8 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
UNIT 3
 COM=* 12X8 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 13.273-0.302 CM WIDE *
 CUBOID  8 1  12.971 0.0  15.136 0.0 94.2975 -2.2225
UNIT 5
 COM=* SS POISON PLATE BETWEEN CLUSTERS, 0.302 CM THICK *
 CUBOID  6 1  0.302 0.0 15.1   0.0  91.5   0.0
 CUBOID  8 1  0.302 0.0 15.136 0.0  94.2975 -2.2225
GLOBAL
UNIT 6
 COM=* ARRAY OF CLUSTERS, 1 IN. ACRYLIC BELOW, SS WALL, WATER REFL *
 ARRAY 3 3R0
 REPLICATE 5 1  5R0 2.54 1
 REPLICATE 8 1  26.321 0 1.956 0 7.54 15.3 1
 REPLICATE 7 1  2R0 17.85 3R0 1
 REPLICATE 8 1  2R0 10.694 0 5.2375 0 1
END GEOM
READ ARRAY  ARA=1 NUX=6 NUY=8  FILL F1 END FILL
     ARA=2 NUX=12 NUY=8  FILL F1 END FILL
     ARA=3 NUX=4  FILL 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=65. ZUL=10 XLR=75.0 YLR=-2.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
READ BOUNDS -XY=REFL END BOUNDS
END DATA
END
```

KENO V.a Input Listing for Case 2 of Table 29 (44-Energy Group
SCALE Cross Sections)

```
=CSAS25
LCT13-2, U(4.31)O2 RODS, SS WALLS, SS+1.1%B ABS PLATE
44GROUPNDF5 LATTICECELL
' U(4.31)02
U-234  1 0  5.1835-6 END
U-235  1 0  1.0102-3 END
U-236  1 0  5.1395-6 END
U-238  1 0  2.2157-2 END
O  1 0  4.6753-2 END
' 6061 Al (clad)
AL  2 0  5.8433-2 END
CR  2 0  6.2310-5 END
CU  2 0  6.3731-5 END
MG  2 0  6.6651-4 END
MN  2 0  2.2115-5 END
TI  2 0  2.5375-5 END
'        (Zn replaced by Cu)
CU  2 0  3.0967-5 END
SI  2 0  3.4607-4 END
FE  2 0  1.0152-4 END
'  Rubber end plug
C  3 0   4.3562-2 END
H   3 0  5.8178-2 END
CA  3 0  2.5660-3 END
S   3 0  4.7820-4 END
SI  3 0  9.6360-5 END
O   3 0  1.2461-2 END
' water
H  4 0  6.6706-2 END
O  4 0  3.3353-2 END
'acrylic
H   5 0  5.6642-2 END
C   5 0  3.5648-2 END
O   5 0  1.4273-2 END
' SS plate with 1.1% B
B-10 6 0 9.1950-4 END
B-11 6 0 3.7011-3 END
CR  6 0  1.7412-2 END
CU  6 0  2.0963-4 END
FE  6 0  5.7961-2 END
MN  6 0  1.3682-3 END
MO  6 0  2.4298-4 END
NI  6 0  7.7251-3 END
' STEEL WALLS
FE  7 0  8.1810-2 END
C   7 0  7.4686-4 END
MN  7 0  1.1000-3 END
P   7 0  6.0971-6 END
S   7 0  8.8332-6 END
SI  7 0  3.6983-4 END
NI  7 0  6.3552-4 END
MO  7 0  2.4114-4 END
CR  7 0  1.0896-4 END
CU  7 0  9.6587-5 END
' water
H  8 0  6.6706-2 END
O  8 0  3.3353-2 END
END COMP
SQUAREPITCH 1.892 1.265 1 4 1.415 2 1.283 0  END
LCT13-2, U(4.31)O2 RODS, SS WALLS, SS+1.1%B ABS PLATE
READ PARA TME=200 GEN=660 NPG=2500 NSK=60 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL ROD *
 CYLINDER  1 1  0.6325  92.075   0.0
 CYLINDER  0 1  0.6415  92.075   0.0
 CYLINDER  3 1  0.6415  94.2975 -2.2225
 CYLINDER  2 1  0.7075  94.2975 -2.2225
```

KENO V.a Input Listing for Case 2 of Table 29 (44-Energy Group
SCALE Cross Sections) (cont'd)

```
 CUBOID    4 1  4P0.946 94.2975 -2.2225
UNIT 2
 COM=* 6X8 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
UNIT 3
 COM=* 12X8 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 9.353-0.298 CM WIDE *
 CUBOID  8 1  9.055 0.0  15.136 0.0 94.2975 -2.2225
UNIT 5
 COM=* POISON PLATE BETWEEN CLUSTERS, 0.298 CM THICK *
 CUBOID  6 1  0.298 0.0 15.1   0.0  91.5   0.0
 CUBOID  8 1  0.298 0.0 15.136 0.0  94.2975 -2.2225
GLOBAL
UNIT 6
 COM=* ARRAY OF CLUSTERS, 1 IN. ACRYLIC BELOW, SS WALL, WATER REFL *
 ARRAY 3 3R0
 REPLICATE 5 1  5R0 2.54 1
 REPLICATE 8 1  30.241 0 1.956 0 7.54 15.3 1
 REPLICATE 7 1  2R0 17.85 3R0 1
 REPLICATE 8 1  2R0 10.694 0 5.2375 0 1
END GEOM
READ ARRAY  ARA=1 NUX=6 NUY=8  FILL F1 END FILL
     ARA=2 NUX=12 NUY=8  FILL F1 END FILL
     ARA=3 NUX=4  FILL 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=55. ZUL=10 XLR=80.0 YLR=-2.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
READ BOUNDS -XY=REFL END BOUNDS
END DATA
END
```

KENO V.a Input Listing for Case 3 of Table 29 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
LCT13-3, U(4.31)O2 RODS, SS WALLS, BORAL B ABS PLATE
44GROUPNDF5 LATTICECELL
' U(4.31)02
U-234  1 0  5.1835-6 END
U-235  1 0  1.0102-3 END
U-236  1 0  5.1395-6 END
U-238  1 0  2.2157-2 END
O  1 0  4.6753-2 END
' 6061 Al (clad)
AL  2 0  5.8433-2 END
CR  2 0  6.2310-5 END
CU  2 0  6.3731-5 END
MG  2 0  6.6651-4 END
MN  2 0  2.2115-5 END
TI  2 0  2.5375-5 END
'       (Zn replaced by Cu)
CU  2 0  3.0967-5 END
SI  2 0  3.4607-4 END
FE  2 0  1.0152-4 END
'  Rubber end plug
C  3 0   4.3562-2 END
H   3 0  5.8178-2 END
CA  3 0  2.5660-3 END
S   3 0  4.7820-4 END
SI  3 0  9.6360-5 END
O   3 0  1.2461-2 END
' water
H  4 0  6.6706-2 END
O  4 0  3.3353-2 END
'acrylic
H   5 0  5.6642-2 END
C   5 0  3.5648-2 END
O   5 0  1.4273-2 END
' Boral B plate
B-10 6 0 8.4135-3 END
B-11 6 0 3.3865-2 END
AL  6 0  3.4154-2 END
C   6 0  1.0567-2 END
' STEEL WALLS
FE  7 0  8.1810-2 END
C   7 0  7.4686-4 END
MN  7 0  1.1000-3 END
P   7 0  6.0971-6 END
S   7 0  8.8332-6 END
SI  7 0  3.6983-4 END
NI  7 0  6.3552-4 END
MO  7 0  2.4114-4 END
CR  7 0  1.0896-4 END
CU  7 0  9.6587-5 END
' Type 1100 Aluminum
AL      8       0       5.9660E-02      END
CU      8       0       3.0705E-05      END
MN      8       0       7.3991E-06      END
' Cu replaces Zn, below
CU      8       0       1.2433E-05      END
SI      8       0       2.3302E-04      END
FE      8       0       1.1719E-04      END
' water
H  9 0  6.6706-2 END
O  9 0  3.3353-2 END
END COMP
SQUAREPITCH 1.892 1.265 1 4 1.415 2 1.283 0  END
LCT13-3, U(4.31)O2 RODS, SS WALLS, BORAL B ABS PLATE
READ PARA TME=200 GEN=660 NPG=2500 NSK=60 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL ROD *
 CYLINDER  1 1  0.6325  92.075   0.0
```

KENO V.a Input Listing for Case 3 of Table 29 (44-Energy Group SCALE Cross Sections) (cont'd)

```
 CYLINDER  0 1  0.6415  92.075   0.0
 CYLINDER  3 1  0.6415  94.2975 -2.2225
 CYLINDER  2 1  0.7075  94.2975 -2.2225
 CUBOID    4 1  4P0.946 94.2975 -2.2225
UNIT 2
 COM=* 6X8 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
UNIT 3
 COM=* 12X8 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 7.823-0.216-2x0.038 CM WIDE *
 CUBOID  9 1  7.531 0.0  15.136 0.0 94.2975 -2.2225
UNIT 5
 COM=* POISON PLATE BETWEEN CLUSTERS, 0.216+2x0.038 CM THICK *
 CUBOID  6 1  0.216 0.0 15.1   0.0  91.5   0.0
 CUBOID  8 1  0.254 -0.038 15.1   0.0  91.5   0.0
 CUBOID  9 1  0.254 -0.038 15.136 0.0  94.2975 -2.2225
GLOBAL
UNIT 6
 COM=* ARRAY OF CLUSTERS, 1 IN. ACRYLIC BELOW, SS WALL, WATER REFL *
 ARRAY 3 3R0
 REPLICATE 5 1  5R0 2.54 1
 REPLICATE 9 1  31.771 0 1.956 0 7.54 15.3 1
 REPLICATE 7 1  2R0 17.85 3R0 1
 REPLICATE 9 1  2R0 10.694 0 5.2375 0 1
END GEOM
READ ARRAY  ARA=1 NUX=6 NUY=8  FILL F1 END FILL
     ARA=2 NUX=12 NUY=8  FILL F1 END FILL
     ARA=3 NUX=4  FILL 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=65. ZUL=10 XLR=75.0 YLR=-2.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
READ BOUNDS -XY=REFL END BOUNDS
END DATA
END
```

KENO V.a Input Listing for Case 4 of Table 29 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
LCT13-4, U(4.31)O2 RODS, SS WALLS, BOROFLEX ABS PLATE
44GROUPNDF5 LATTICECELL
' U(4.31)02
U-234  1 0  5.1835-6 END
U-235  1 0  1.0102-3 END
U-236  1 0  5.1395-6 END
U-238  1 0  2.2157-2 END
O  1 0  4.6753-2 END
' 6061 Al (clad)
AL  2 0  5.8433-2 END
CR  2 0  6.2310-5 END
CU  2 0  6.3731-5 END
MG  2 0  6.6651-4 END
MN  2 0  2.2115-5 END
TI  2 0  2.5375-5 END
'        (Zn replaced by Cu)
CU  2 0  3.0967-5 END
SI  2 0  3.4607-4 END
FE  2 0  1.0152-4 END
'  Rubber end plug
C  3 0   4.3562-2 END
H   3 0  5.8178-2 END
CA  3 0  2.5660-3 END
S   3 0  4.7820-4 END
SI  3 0  9.6360-5 END
O   3 0  1.2461-2 END
' water
H  4 0  6.6706-2 END
O  4 0  3.3353-2 END
'acrylic
H   5 0  5.6642-2 END
C   5 0  3.5648-2 END
O   5 0  1.4273-2 END
' Boroflex
B-10 6 0 6.2822-3 END
B-11 6 0 2.5287-2 END
C    6 0 1.8339-2 END
H    6 0 2.7408-2 END
CR   6 0 6.0145-6 END
FE   6 0 9.3329-6 END
O   6 0  1.3689-2 END
SI  6 0  8.3103-3 END
' STEEL WALLS
FE  7 0  8.1810-2 END
C   7 0  7.4686-4 END
MN  7 0  1.1000-3 END
P   7 0  6.0971-6 END
S   7 0  8.8332-6 END
SI  7 0  3.6983-4 END
NI  7 0  6.3552-4 END
MO  7 0  2.4114-4 END
CR  7 0  1.0896-4 END
CU  7 0  9.6587-5 END
' water
H  8 0  6.6706-2 END
O  8 0  3.3353-2 END
END COMP
SQUAREPITCH 1.892 1.265 1 4 1.415 2 1.283 0  END
LCT13-4, U(4.31)O2 RODS, SS WALLS, BOROFLEX ABS PLATE
READ PARA TME=200 GEN=660 NPG=2500 NSK=60 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL ROD *
 CYLINDER  1 1  0.6325  92.075   0.0
 CYLINDER  0 1  0.6415  92.075   0.0
 CYLINDER  3 1  0.6415  94.2975 -2.2225
 CYLINDER  2 1  0.7075  94.2975 -2.2225
 CUBOID    4 1  4P0.946 94.2975 -2.2225
```

KENO V.a Input Listing for Case 4 of Table 29 (44-Energy Group SCALE Cross Sections) (cont'd)

```
UNIT 2
 COM=* 6X8 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
UNIT 3
 COM=* 12X8 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 7.893-0.226-2x0.16 CM WIDE *
 CUBOID  8 1  7.347 0.0  15.136 0.0 94.2975 -2.2225
UNIT 5
 COM=* POISON PLATE BETWEEN CLUSTERS, 0.226+2x0.16 CM THICK *
 CUBOID  6 1  0.226 0.0 15.1   0.0  91.5   0.0
 CUBOID  5 1  0.386 -0.16  15.1   0.0  91.5   0.0
 CUBOID  8 1  0.386 -0.16  15.136 0.0  94.2975 -2.2225
GLOBAL
UNIT 6
 COM=* ARRAY OF CLUSTERS, 1 IN. ACRYLIC BELOW, SS WALL, WATER REFL *
 ARRAY 3 3R0
 REPLICATE 5 1  5R0 2.54 1
 REPLICATE 8 1  31.701 0 1.956 0 7.54 15.3 1
 REPLICATE 7 1  2R0 17.85 3R0 1
 REPLICATE 8 1  2R0 10.694 0 5.2375 0 1
END GEOM
READ ARRAY  ARA=1 NUX=6 NUY=8  FILL F1 END FILL
     ARA=2 NUX=12 NUY=8  FILL F1 END FILL
     ARA=3 NUX=4  FILL 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=65. ZUL=10 XLR=75.0 YLR=-2.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
READ BOUNDS -XY=REFL END BOUNDS
END DATA
END
```

KENO V.a Input Listing for Case 5 of Table 29 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
LCT13-5, U(4.31)O2 RODS, SS WALLS, CD ABS PLATE
44GROUPNDF5 LATTICECELL
' U(4.31)02
U-234  1 0  5.1835-6 END
U-235  1 0  1.0102-3 END
U-236  1 0  5.1395-6 END
U-238  1 0  2.2157-2 END
O  1 0  4.6753-2 END
' 6061 Al (clad)
AL  2 0  5.8433-2 END
CR  2 0  6.2310-5 END
CU  2 0  6.3731-5 END
MG  2 0  6.6651-4 END
MN  2 0  2.2115-5 END
TI  2 0  2.5375-5 END
'        (Zn replaced by Cu)
CU  2 0  3.0967-5 END
SI  2 0  3.4607-4 END
FE  2 0  1.0152-4 END
'  Rubber end plug
C  3 0   4.3562-2 END
H   3 0  5.8178-2 END
CA  3 0  2.5660-3 END
S   3 0  4.7820-4 END
SI  3 0  9.6360-5 END
O   3 0  1.2461-2 END
' water
H  4 0  6.6706-2 END
O  4 0  3.3353-2 END
'acrylic
H   5 0  5.6642-2 END
C   5 0  3.5648-2 END
O   5 0  1.4273-2 END
' Cd plate
CD  6 0 4.6201-2 END
'          Zn replaced by Cu
CU  6 0 2.3899-4 END
' STEEL WALLS
FE  7 0  8.1810-2 END
C   7 0  7.4686-4 END
MN  7 0  1.1000-3 END
P   7 0  6.0971-6 END
S   7 0  8.8332-6 END
SI  7 0  3.6983-4 END
NI  7 0  6.3552-4 END
MO  7 0  2.4114-4 END
CR  7 0  1.0896-4 END
CU  7 0  9.6587-5 END
' water
H  8 0  6.6706-2 END
O  8 0  3.3353-2 END
END COMP
SQUAREPITCH 1.892 1.265 1 4 1.415 2 1.283 0  END
LCT13-5, U(4.31)O2 RODS, SS WALLS, CD ABS PLATE
READ PARA TME=200 GEN=660 NPG=2500 NSK=60 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL ROD *
 CYLINDER  1 1  0.6325  92.075   0.0
 CYLINDER  0 1  0.6415  92.075   0.0
 CYLINDER  3 1  0.6415  94.2975 -2.2225
 CYLINDER  2 1  0.7075  94.2975 -2.2225
 CUBOID    4 1  4P0.946 94.2975 -2.2225
UNIT 2
 COM=* 6X8 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
UNIT 3
 COM=* 12X8 ARRAY OF FUEL PINS *
```

KENO V.a Input Listing for Case 5 of Table 29 (44-Energy Group
SCALE Cross Sections) (cont'd)

```
 ARRAY 2 3R0
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 8.463-0.061-0.296 CM WIDE *
 CUBOID  8 1  8.106 0.0  15.136 0.0 94.2975 -2.2225
UNIT 5
 COM=* CD POISON PLATE BETWEEN CLUSTERS, 0.061 CM THICK *
 CUBOID  6 1  0.0 -0.061 15.1   0.0  91.5   0.0
 CUBOID  5 1  0.296 -0.061 15.1   0.0  91.5   0.0
 CUBOID  8 1  0.296 -0.061 15.136 0.0  94.2975 -2.2225
GLOBAL
UNIT 6
 COM=* ARRAY OF CLUSTERS, 1 IN. ACRYLIC BELOW, SS WALL, WATER REFL *
 ARRAY 3 3R0
 REPLICATE 5 1  5R0 2.54 1
 REPLICATE 8 1  31.131 0 1.956 0 7.54 15.3 1
 REPLICATE 7 1  2R0 17.85 3R0 1
 REPLICATE 8 1  2R0 10.694 0 5.2375 0 1
END GEOM
READ ARRAY  ARA=1 NUX=6 NUY=8  FILL F1 END FILL
     ARA=2 NUX=12 NUY=8  FILL F1 END FILL
     ARA=3 NUX=4  FILL 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=65. ZUL=10 XLR=75.0 YLR=-2.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
READ BOUNDS -XY=REFL END BOUNDS
END DATA
END
```

KENO V.a Input Listing for Case 6 of Table 29 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
LCT13-6, U(4.31)O2 RODS, SS WALLS, CU ABS PLATE
44GROUPNDF5 LATTICECELL
' U(4.31)02
U-234  1 0  5.1835-6 END
U-235  1 0  1.0102-3 END
U-236  1 0  5.1395-6 END
U-238  1 0  2.2157-2 END
O  1 0  4.6753-2 END
' 6061 Al (clad)
AL  2 0  5.8433-2 END
CR  2 0  6.2310-5 END
CU  2 0  6.3731-5 END
MG  2 0  6.6651-4 END
MN  2 0  2.2115-5 END
TI  2 0  2.5375-5 END
'        (Zn replaced by Cu)
CU  2 0  3.0967-5 END
SI  2 0  3.4607-4 END
FE  2 0  1.0152-4 END
'  Rubber end plug
C  3 0   4.3562-2 END
H   3 0  5.8178-2 END
CA  3 0  2.5660-3 END
S   3 0  4.7820-4 END
SI  3 0  9.6360-5 END
O   3 0  1.2461-2 END
' water
H  4 0  6.6706-2 END
O  4 0  3.3353-2 END
'acrylic
H   5 0  5.6642-2 END
C   5 0  3.5648-2 END
O   5 0  1.4273-2 END
' CU plate w/o Cd
C   6 0  1.5194-3 END
CU  6 0  8.4128-2 END
FE  6 0  3.8444-6 END
MG  6 0  4.4168-6 END
NA  6 0  4.6695-6 END
O   6 0  1.0064-4 END
SI  6 0  3.8223-5 END
S   6 0  3.3474-6 END
' STEEL WALLS
FE  7 0  8.1810-2 END
C   7 0  7.4686-4 END
MN  7 0  1.1000-3 END
P   7 0  6.0971-6 END
S   7 0  8.8332-6 END
SI  7 0  3.6983-4 END
NI  7 0  6.3552-4 END
MO  7 0  2.4114-4 END
CR  7 0  1.0896-4 END
CU  7 0  9.6587-5 END
' water
H  8 0  6.6706-2 END
O  8 0  3.3353-2 END
END COMP
SQUAREPITCH 1.892 1.265 1 4 1.415 2 1.283 0  END
LCT13-6, U(4.31)O2 RODS, SS WALLS, CU ABS PLATE
READ PARA TME=200 GEN=660 NPG=2500 NSK=60 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL ROD *
 CYLINDER  1 1  0.6325  92.075   0.0
 CYLINDER  0 1  0.6415  92.075   0.0
 CYLINDER  3 1  0.6415  94.2975 -2.2225
 CYLINDER  2 1  0.7075  94.2975 -2.2225
```

KENO V.a Input Listing for Case 6 of Table 29 (44-Energy Group SCALE Cross Sections) (cont'd)

```
 CUBOID    4 1  4P0.946 94.2975 -2.2225
UNIT 2
 COM=* 6X8 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
UNIT 3
 COM=* 12X8 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 12.993-0.337 CM WIDE *
 CUBOID  8 1 12.656 0.0  15.136 0.0 94.2975 -2.2225
UNIT 5
 COM=* CU POISON PLATE BETWEEN CLUSTERS, 0.337 CM THICK *
 CUBOID  6 1  0.337 0.0 15.1   0.0  91.5   0.0
 CUBOID  8 1  0.337 0.0 15.136 0.0  94.2975 -2.2225
GLOBAL
UNIT 6
 COM=* ARRAY OF CLUSTERS, 1 IN. ACRYLIC BELOW, SS WALL, WATER REFL *
 ARRAY 3 3R0
 REPLICATE 5 1  5R0 2.54 1
 REPLICATE 8 1  26.601 0 1.956 0 7.54 15.3 1
 REPLICATE 7 1  2R0 17.85 3R0 1
 REPLICATE 8 1  2R0 10.694 0 5.2375 0 1
END GEOM
READ ARRAY  ARA=1 NUX=6 NUY=8  FILL F1 END FILL
     ARA=2 NUX=12 NUY=8  FILL F1 END FILL
     ARA=3 NUX=4  FILL 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=55. ZUL=10 XLR=80.0 YLR=-2.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
READ BOUNDS -XY=REFL END BOUNDS
END DATA
END
```

KENO V.a Input Listing for Case 7 of Table 29 (44-Energy Group
SCALE Cross Sections) (cont'd)

```
=CSAS25
LCT13-7, U(4.31)O2 RODS, SS WALLS, CU+CD ABS PLATE
44GROUPNDF5 LATTICECELL
' U(4.31)02
U-234  1 0  5.1835-6 END
U-235  1 0  1.0102-3 END
U-236  1 0  5.1395-6 END
U-238  1 0  2.2157-2 END
O  1 0  4.6753-2 END
' 6061 Al (clad)
AL  2 0  5.8433-2 END
CR  2 0  6.2310-5 END
CU  2 0  6.3731-5 END
MG  2 0  6.6651-4 END
MN  2 0  2.2115-5 END
TI  2 0  2.5375-5 END
'        (Zn replaced by Cu)
CU  2 0  3.0967-5 END
SI  2 0  3.4607-4 END
FE  2 0  1.0152-4 END
'  Rubber end plug
C  3 0   4.3562-2 END
H   3 0  5.8178-2 END
CA  3 0  2.5660-3 END
S   3 0  4.7820-4 END
SI  3 0  9.6360-5 END
O   3 0  1.2461-2 END
' water
H  4 0  6.6706-2 END
O  4 0  3.3353-2 END
'acrylic
H   5 0  5.6642-2 END
C   5 0  3.5648-2 END
O   5 0  1.4273-2 END
' CU plate w/ Cd
B-10 6 0  4.9384-6 END
B-11 6 0  1.9878-5 END
C   6 0  8.9346-6 END
CD  6 0  4.7208-4 END
CU  6 0  8.3328-2 END
FE  6 0  1.9216-5 END
MN  6 0  8.7901-6 END
NI  6 0  9.1424-6 END
O   6 0  6.3720-5 END
SI  6 0  7.6419-6 END
SN-112  6       0       1.0961E-06      END
SN-114  6       0       7.3450E-07      END
SN-115  6       0       4.0680E-07      END
SN-116  6       0       1.6419E-05      END
SN-117  6       0       8.6784E-06      END
SN-118  6       0       2.7369E-05      END
SN-119  6       0       9.6954E-06      END
SN-120  6       0       3.6827E-05      END
SN-122  6       0       5.2319E-06      END
SN-123  6       0       6.5427E-06      END
'          Zn replaced by Cu
CU  6 0  5.7440-6 END
' STEEL WALLS
FE  7 0  8.1810-2 END
C   7 0  7.4686-4 END
MN  7 0  1.1000-3 END
P   7 0  6.0971-6 END
S   7 0  8.8332-6 END
SI  7 0  3.6983-4 END
NI  7 0  6.3552-4 END
MO  7 0  2.4114-4 END
CR  7 0  1.0896-4 END
CU  7 0  9.6587-5 END
' water
H  8 0  6.6706-2 END
```

KENO V.a Input Listing for Case 7 of Table 29 (44-Energy Group SCALE Cross Sections) (cont'd)

```
O  8 0  3.3353-2 END
END COMP
SQUAREPITCH 1.892 1.265 1 4 1.415 2 1.283 0  END
LCT13-7, U(4.31)O2 RODS, SS WALLS, CU+CD ABS PLATE
READ PARA TME=200 GEN=660 NPG=2500 NSK=60 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL ROD *
 CYLINDER  1 1  0.6325  92.075   0.0
 CYLINDER  0 1  0.6415  92.075   0.0
 CYLINDER  3 1  0.6415  94.2975 -2.2225
 CYLINDER  2 1  0.7075  94.2975 -2.2225
 CUBOID    4 1  4P0.946 94.2975 -2.2225
UNIT 2
 COM=* 6X8 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
UNIT 3
 COM=* 12X8 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 10.093-0.357 CM WIDE *
 CUBOID  8 1 9.736 0.0  15.136 0.0 94.2975 -2.2225
UNIT 5
 COM=* POISON PLATE BETWEEN CLUSTERS, 0.357 CM THICK *
 CUBOID  6 1  0.357 0.0 15.1   0.0  91.5   0.0
 CUBOID  8 1  0.357 0.0 15.136 0.0  94.2975 -2.2225
GLOBAL
UNIT 6
 COM=* ARRAY OF CLUSTERS, 1 IN. ACRYLIC BELOW, SS WALL, WATER REFL *
 ARRAY 3 3R0
 REPLICATE 5 1  5R0 2.54 1
 REPLICATE 8 1  29.501 0 1.956 0 7.54 15.3 1
 REPLICATE 7 1  2R0 17.85 3R0 1
 REPLICATE 8 1  2R0 10.694 0 5.2375 0 1
END GEOM
READ ARRAY  ARA=1 NUX=6 NUY=8  FILL F1 END FILL
     ARA=2 NUX=12 NUY=8  FILL F1 END FILL
     ARA=3 NUX=4  FILL 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=55. ZUL=10 XLR=80.0 YLR=-2.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
READ BOUNDS -XY=REFL END BOUNDS
END DATA
END
```

A.2 MCNP Input Listings

MCNP4c was used. MCNP k_{eff} calculations used 600 generations of 2500 neutrons each after skipping 60 generations.

Cu replaces Zn in clad and in Cd and copper-cadmium absorber plates, due to nonavailability of Zn cross sections. Sn in absorber plates is omitted, due to unavailability of cross sections.

Input listings with ENDF/B-V continuous-energy cross sections are given below, followed by input listings with ENDF/B-VI continuous-energy cross sections.

MCNP Input Listing for Case 1 (ENDF/B-V) of Table 29.

```
LCT13-1, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, ss abs plates, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2          $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(13.273 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0861284 1 -5 11 -12 30 -31  $ absorber plate
12  4 0.1000596 1 -5 12 -20 30 -31  $ water between abs plate and outer cluster
13  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
14  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
15  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
16  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
17  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
18  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
19  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
20  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
21  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
22  7 0.0851238 4 -8 10 -22 33 -34  $ wall
23  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.654   $ outer side of absorber plate    **
20   px 24.625   $ inner boundary of outer cluster **
21   px 47.329   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 21r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.50c 5.1835e-6 92235.50c 1.0102e-3
      92236.50c 5.1395e-6 92238.50c 2.2157e-2
      8016.50c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.50c  5.8433e-2  24000.50c  6.2310e-5
      29000.50c  6.3731e-5  12000.50c  6.6651e-4
      25055.50c  2.2115e-5  22000.50c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      29000.50c 3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c   m3 is rubber plug
m3    6000.50c 4.3562e-2  1001.50c 5.8178e-2
```

MCNP Input Listing for Case 1 (ENDF/B-V) of Table 29 (cont'd).

```
      20000.50c 2.5660e-3  16032.50c 4.7820e-4
      14000.50c 9.6360e-5  8016.50c 1.2461e-2
c   m4 is water
m4    8016.50c 3.3353e-2  1001.50c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
c   m6 is SS plate
m6    24000.50c  1.7046e-2  29000.50c  2.0291e-4
      26000.50c  5.8353e-2  25055.50c  1.3734e-3
      42000.50c  1.2942e-4  28000.50c  9.0238e-3
c   m7 is steel wall
m7    26000.50c 8.1810e-2  6000.50c  7.4686e-4  25055.50c  1.1e-3
      15031.50c 6.0971e-6  16032.50c 8.8332e-6  14000.50c 3.6983e-4
      28000.50c 6.3552e-4  42000.50c 2.4114e-4  24000.50c 1.0896e-4
      29000.50c 9.6587e-5
print
```

MCNP Input Listing for Case 2 (ENDF/B-V) of Table 29.

```
LCT13-2, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, ss+B abs pls, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2          $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(9.353 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0895398 1 -5 11 -12 30 -31  $ absorber plate
12  4 0.1000596 1 -5 12 -20 30 -31  $ water between abs plate and outer cluster
13  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
14  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
15  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
16  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
17  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
18  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
19  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
20  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
21  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
22  7 0.0851238 4 -8 10 -22 33 -34  $ wall
23  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.65    $ outer side of absorber plate    **
20   px 20.705   $ inner boundary of outer cluster **
21   px 43.409   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 21r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.50c 5.1835e-6 92235.50c 1.0102e-3
      92236.50c 5.1395e-6 92238.50c 2.2157e-2
      8016.50c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.50c  5.8433e-2  24000.50c  6.2310e-5
      29000.50c  6.3731e-5  12000.50c  6.6651e-4
      25055.50c  2.2115e-5  22000.50c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      29000.50c 3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c   m3 is rubber plug
m3    6000.50c 4.3562e-2  1001.50c 5.8178e-2
```

MCNP Input Listing for Case 2 (ENDF/B-V) of Table 29 (cont'd).

```
      20000.50c 2.5660e-3  16032.50c 4.7820e-4
      14000.50c 9.6360e-5  8016.50c 1.2461e-2
c   m4 is water
m4    8016.50c 3.3353e-2  1001.50c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
c   m6 is SS plate + 1.1%B
m6    24000.50c  1.7412e-2  29000.50c  2.0963e-4
      26000.50c  5.7961e-2  25055.50c  1.3682e-3
      42000.50c  2.4298e-4  28000.50c  7.7251e-3
      5010.50c   9.1950e-4  5011.50c   3.7011e-3
c   m7 is steel wall
m7    26000.50c 8.1810e-2  6000.50c  7.4686e-4  25055.50c  1.1e-3
      15031.50c 6.0971e-6  16032.50c 8.8332e-6  14000.50c 3.6983e-4
      28000.50c 6.3552e-4  42000.50c 2.4114e-4  24000.50c 1.0896e-4
      29000.50c 9.6587e-5
print
```

MCNP Input Listing for Case 3 (ENDF/B-V) of Table 29.

```
LCT13-3, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, BoralB abs pls, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2           $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(7.823 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  8 0.0600607 1 -5 11 -12 30 -31  $ Al clad of absorber plate
12  6 0.0869997 1 -5 12 -13 30 -31  $ absorber plate
13  8 0.0600607 1 -5 13 -14 30 -31  $ Al clad of absorber plate
14  4 0.1000596 1 -5 14 -20 30 -31  $ water between abs plate and outer cluster
15  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
16  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
17  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
18  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
19  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
20  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
21  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
22  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
23  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
24  7 0.0851238 4 -8 10 -22 33 -34  $ wall
25  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.39    $ side of 1100 Al clad    **
13   px 11.606   $ side of Boral B         **
14   px 11.644   $ side of 1100 Al clad    **
20   px 19.175   $ inner boundary of outer cluster **
21   px 41.879   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 23r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.50c 5.1835e-6 92235.50c 1.0102e-3
      92236.50c 5.1395e-6 92238.50c 2.2157e-2
      8016.50c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.50c  5.8433e-2  24000.50c  6.2310e-5
      29000.50c  6.3731e-5  12000.50c  6.6651e-4
      25055.50c  2.2115e-5  22000.50c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      29000.50c 3.0967e-5  14000.50c  3.4607e-4
```

MCNP Input Listing for Case 3 (ENDF/B-V) of Table 29 (cont'd).

```
      26000.50c  1.0152e-4
c   m3 is rubber plug
m3    6000.50c 4.3562e-2  1001.50c 5.8178e-2
      20000.50c 2.5660e-3  16032.50c 4.7820e-4
      14000.50c 9.6360e-5  8016.50c 1.2461e-2
c   m4 is water
m4    8016.50c 3.3353e-2  1001.50c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
c   m6 is Boral B
m6    13027.50c  3.4154e-2  6000.50c  1.0567e-2
      5010.50c   8.4135e-3  5011.60c   3.3865e-2
c   m7 is steel wall
m7    26000.50c 8.1810e-2  6000.50c  7.4686e-4  25055.50c  1.1e-3
      15031.50c 6.0971e-6  16032.50c 8.8332e-6  14000.50c 3.6983e-4
      28000.50c 6.3552e-4  42000.50c 2.4114e-4  24000.50c 1.0896e-4
      29000.50c 9.6587e-5
c   m8 is 1100 aluminum clad of Boral B plate
m8    13027.50c  5.9660e-2  29000.50c  3.0705e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      25055.50c  2.2115e-5  29000.50c  1.2433e-5
      14000.50c  2.3302e-4  26000.50c  1.1719e-4
print
```

MCNP Input Listing for Case 4 (ENDF/B-V) of Table 29.

```
LCT13-4, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, Boroflx abs pls, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2          $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(7.893 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  5 0.1065632 1 -5 11 -12 30 -31  $ Plexiglas next to absorber plate
12  6 0.0993296 1 -5 12 -13 30 -31  $ absorber plate
13  5 0.1065632 1 -5 13 -14 30 -31  $ Plexiglas next to absorber plate
14  4 0.1000596 1 -5 14 -20 30 -31  $ water between abs plate and outer cluster
15  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
16  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
17  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
18  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
19  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
20  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
21  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
22  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
23  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
24  7 0.0851238 4 -8 10 -22 33 -34  $ wall
25  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.512   $ side of Plexiglas       **
13   px 11.738   $ side of Boroflex        **
14   px 11.898   $ side of Plexiglas       **
20   px 19.245   $ inner boundary of outer cluster **
21   px 41.949   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 23r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.50c 5.1835e-6 92235.50c 1.0102e-3
      92236.50c 5.1395e-6 92238.50c 2.2157e-2
      8016.50c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.50c  5.8433e-2  24000.50c  6.2310e-5
      29000.50c  6.3731e-5  12000.50c  6.6651e-4
      25055.50c  2.2115e-5  22000.50c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      29000.50c 3.0967e-5  14000.50c  3.4607e-4
```

MCNP Input Listing for Case 4 (ENDF/B-V) of Table 29 (cont'd).

```
      26000.50c  1.0152e-4
c   m3 is rubber plug
m3    6000.50c 4.3562e-2  1001.50c 5.8178e-2
      20000.50c 2.5660e-3  16032.50c 4.7820e-4
      14000.50c 9.6360e-5  8016.50c 1.2461e-2
c   m4 is water
m4    8016.50c 3.3353e-2  1001.50c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
c   m6 is Boroflex
m6    5010.50c   6.2822e-3  5011.60c   2.5287e-2
      6012.50c   1.8339e-2  1001.50c   2.7408e-2
     24000.50c   6.0145e-6 26000.55c   9.3329e-6
      8016.50c   1.3689e-2 14000.50c   8.3103e-3
c   m7 is steel wall
m7    26000.50c 8.1810e-2  6000.50c  7.4686e-4  25055.50c  1.1e-3
      15031.50c 6.0971e-6  16032.50c 8.8332e-6  14000.50c 3.6983e-4
      28000.50c 6.3552e-4  42000.50c 2.4114e-4  24000.50c 1.0896e-4
      29000.50c 9.6587e-5
print
```

MCNP Input Listing for Case 5 (ENDF/B-V) of Table 29.

```
LCT13-5, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, Cd abs pls, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2           $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(8.463 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0464400 1 -5 11 -12 30 -31  $ absorber plate
12  5 0.1065632 1 -5 12 -13 30 -31  $ Plexiglas next to absorber plate
13  4 0.1000596 1 -5 13 -20 30 -31  $ water between abs plate and outer cluster
14  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
15  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
16  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
17  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
18  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
19  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
20  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
21  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
22  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
23  7 0.0851238 4 -8 10 -22 33 -34  $ wall
24  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0      $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.413   $ side of Cd              **
13   px 11.709   $ side of Plexiglas       **
20   px 19.815   $ inner boundary of outer cluster **
21   px 42.519   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 22r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1     92234.50c 5.1835e-6 92235.50c 1.0102e-3
       92236.50c 5.1395e-6 92238.50c 2.2157e-2
       8016.50c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2     13027.50c  5.8433e-2  24000.50c  6.2310e-5
       29000.50c  6.3731e-5  12000.50c  6.6651e-4
       25055.50c  2.2115e-5  22000.50c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
       29000.50c 3.0967e-5  14000.50c  3.4607e-4
       26000.50c  1.0152e-4
```

MCNP Input Listing for Case 5 (ENDF/B-V) of Table 29 (cont'd).

```
c   m3 is rubber plug
m3    6000.50c 4.3562e-2  1001.50c 5.8178e-2
      20000.50c 2.5660e-3  16032.50c 4.7820e-4
      14000.50c 9.6360e-5  8016.50c 1.2461e-2
c   m4 is water
m4    8016.50c 3.3353e-2  1001.50c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
c   m6 is Cd
c       Zn replaced by Cu, below
m6    48000.50c  4.6201e-2   29000.50c  2.3899e-4
c   m7 is steel wall
m7    26000.50c 8.1810e-2  6000.50c  7.4686e-4  25055.50c  1.1e-3
      15031.50c 6.0971e-6  16032.50c 8.8332e-6  14000.50c 3.6983e-4
      28000.50c 6.3552e-4  42000.50c 2.4114e-4  24000.50c 1.0896e-4
      29000.50c 9.6587e-5
print
```

MCNP Input Listing for Case 6 (ENDF/B-V) of Table 29.

```
LCT13-6, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, Cu abs plates, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2          $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(12.993 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0858030 1 -5 11 -12 30 -31  $ absorber plate
12  4 0.1000596 1 -5 12 -20 30 -31  $ water between abs plate and outer cluster
13  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
14  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
15  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
16  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
17  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
18  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
19  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
20  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
21  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
22  7 0.0851238 4 -8 10 -22 33 -34  $ wall
23  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.689   $ outer side of absorber plate    **
20   px 24.345   $ inner boundary of outer cluster **
21   px 47.049   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 21r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.50c 5.1835e-6 92235.50c 1.0102e-3
      92236.50c 5.1395e-6 92238.50c 2.2157e-2
      8016.50c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.50c  5.8433e-2  24000.50c  6.2310e-5
      29000.50c  6.3731e-5  12000.50c  6.6651e-4
      25055.50c  2.2115e-5  22000.50c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      29000.50c 3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c   m3 is rubber plug
m3    6000.50c 4.3562e-2  1001.50c 5.8178e-2
      20000.50c 2.5660e-3  16032.50c 4.7820e-4
```

MCNP Input Listing for Case 6 (ENDF/B-V) of Table 29 (cont'd).

```
      14000.50c 9.6360e-5  8016.50c 1.2461e-2
c   m4 is water
m4    8016.50c 3.3353e-2  1001.50c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
c   m6 is Cu plate
m6    6000.50c   1.5194e-3  29000.50c  8.4128e-2
      26000.50c  3.8444e-6  12000.50c  4.4168e-6
      11023.50c  4.6695e-6   8016.50c  1.0064e-4
      14000.50c  3.8223e-5  16032.50c  3.3474e-6
c   m7 is steel wall
m7    26000.50c 8.1810e-2  6000.50c  7.4686e-4  25055.50c  1.1e-3
      15031.50c 6.0971e-6  16032.50c 8.8332e-6  14000.50c 3.6983e-4
      28000.50c 6.3552e-4  42000.50c 2.4114e-4  24000.50c 1.0896e-4
      29000.50c 9.6587e-5
print
```

MCNP Input Listing for Case 7 (ENDF/B-V) of Table 29.

```
LCT13-7, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, CuCd abs plates, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2          $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(10.093 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0840606 1 -5 11 -12 30 -31  $ absorber plate
12  4 0.1000596 1 -5 12 -20 30 -31  $ water between abs plate and outer cluster
13  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
14  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
15  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
16  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
17  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
18  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
19  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
20  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
21  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
22  7 0.0851238 4 -8 10 -22 33 -34  $ wall
23  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.709   $ outer side of absorber plate    **
20   px 21.445   $ inner boundary of outer cluster **
21   px 44.149   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 21r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.50c 5.1835e-6 92235.50c 1.0102e-3
      92236.50c 5.1395e-6 92238.50c 2.2157e-2
      8016.50c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.50c  5.8433e-2  24000.50c  6.2310e-5
      29000.50c  6.3731e-5  12000.50c  6.6651e-4
      25055.50c  2.2115e-5  22000.50c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      29000.50c 3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c   m3 is rubber plug
m3    6000.50c 4.3562e-2  1001.50c 5.8178e-2
```

MCNP Input Listing for Case 7 (ENDF/B-V) of Table 29 (cont'd).

```
      20000.50c 2.5660e-3  16032.50c 4.7820e-4
      14000.50c 9.6360e-5  8016.50c 1.2461e-2
c   m4 is water
m4    8016.50c 3.3353e-2  1001.50c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
c   m6 is Cu plate
m6    5010.50c   4.9384e-6   5011.60c  1.9878e-5
      6000.50c   8.9346e-6  48000.50c  4.7208e-4
      29000.50c  8.3328e-2  26000.50c  1.9216e-5
      25055.50c  8.7901e-6  28000.50c  9.1424e-6
      8016.50c  6.3720e-5  14000.50c  7.6419e-6
c       Zn replaced by Cu, below
      29000.50c  5.7440e-6
c     50000.35c  1.1300e-4  $ Sn omitted; cross section unavailable
c   m7 is steel wall
m7    26000.50c 8.1810e-2  6000.50c  7.4686e-4  25055.50c  1.1e-3
      15031.50c 6.0971e-6  16032.50c 8.8332e-6  14000.50c 3.6983e-4
      28000.50c 6.3552e-4  42000.50c 2.4114e-4  24000.50c 1.0896e-4
      29000.50c 9.6587e-5
print
```

MCNP Input Listing for Case 1 (ENDF/B-VI) of Table 29.

```
LCT13-1, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, ss abs plates, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2          $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(13.273 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0861284 1 -5 11 -12 30 -31  $ absorber plate
12  4 0.1000596 1 -5 12 -20 30 -31  $ water between abs plate and outer cluster
13  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
14  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
15  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
16  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
17  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
18  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
19  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
20  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
21  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
22  7 0.0851238 4 -8 10 -22 33 -34  $ wall
23  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.654   $ outer side of absorber plate    **
20   px 24.625   $ inner boundary of outer cluster **
21   px 47.329   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 21r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.60c 5.1835e-6 92235.60c 1.0102e-3
      92236.60c 5.1395e-6 92238.60c 2.2157e-2
      8016.60c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.60c  5.8433e-2
      24050.60c 2.7074E-06
      24052.60c 5.2210E-05
      24053.60c 5.9195E-06
      24054.60c 1.4736E-06
      29063.60c 4.4083E-05
      29065.60c 1.9648E-05
      12000.60c  6.6651e-4
```

MCNP Input Listing for Case 1 (ENDF/B-VI) of Table 29 (cont'd).

```
      25055.60c  2.2115e-5  22000.60c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      14000.60c  3.4607e-4
      26054.60c 5.9899E-06
      26056.60c 9.3118E-05
      26057.60c 2.1320E-06
      26058.60c 2.8427E-07
c   Zn is replaced with Cu, due to no Zn cross sections
      29063.60c 2.1420E-05
      29065.60c 9.5471E-06
c   m3 is rubber plug
m3    6000.60c 4.3562e-2  1001.60c 5.8178e-2
      20000.60c 2.5660e-3  16032.60c 4.7820e-4
      14000.60c 9.6360e-5  8016.60c 1.2461e-2
c   m4 is water
m4    8016.60c 3.3353e-2  1001.60c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.60c 5.6642e-2  6000.60c 3.5648e-2
      8016.60c 1.4273e-2
c   m6 is SS plate
m6    25055.60c  1.3734e-3
      24050.60c 7.4066E-04
      24052.60c 1.4283E-02
      24053.60c 1.6194E-03
      24054.60c 4.0314E-04
      26054.60c 3.4428E-03
      26056.60c 5.3521E-02
      26057.60c 1.2254E-03
      26058.60c 1.6339E-04
      28058.60c 6.1605E-03
      28060.60c 2.3552E-03
      28061.60c 1.0197E-04
      28062.60c 3.2395E-04
      28064.60c 8.2116E-05
      29063.60c 1.4035E-04
      29065.60c 6.2556E-05
      42000.60c  1.2942e-4
c   m7 is steel wall
m7    6000.60c  7.4686e-4  25055.60c  1.1e-3
      15031.60c 6.0971e-6  16032.60c 8.8332e-6  14000.60c 3.6983e-4
      42000.60c 2.4114e-4
      24050.60c 4.7344E-06
      24052.60c 9.1299E-05
      24053.60c 1.0351E-05
      24054.60c 2.5770E-06
      26054.60c 4.8268E-03
      26056.60c 7.5036E-02
      26057.60c 1.7180E-03
      26058.60c 2.2907E-04
      28058.60c 4.3387E-04
      28060.60c 1.6587E-04
      28061.60c 7.1813E-06
      28062.60c 2.2815E-05
      28064.60c 5.7832E-06
      29063.60c 6.6809E-05
      29065.60c 2.9778E-05
print
```

MCNP Input Listing for Case 2 (ENDF/B-VI) of Table 29.

```
LCT13-2, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, ss+B abs pls, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2          $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(9.353 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0895398 1 -5 11 -12 30 -31  $ absorber plate
12  4 0.1000596 1 -5 12 -20 30 -31  $ water between abs plate and outer cluster
13  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
14  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
15  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
16  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
17  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
18  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
19  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
20  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
21  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
22  7 0.0851238 4 -8 10 -22 33 -34  $ wall
23  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0      $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.65    $ outer side of absorber plate    **
20   px 20.705   $ inner boundary of outer cluster **
21   px 43.409   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 21r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.60c 5.1835e-6 92235.60c 1.0102e-3
      92236.60c 5.1395e-6 92238.60c 2.2157e-2
      8016.60c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.60c  5.8433e-2
      24050.60c 2.7074E-06
      24052.60c 5.2210E-05
      24053.60c 5.9195E-06
      24054.60c 1.4736E-06
      29063.60c 4.4083E-05
      29065.60c 1.9648E-05
      12000.60c  6.6651e-4
```

MCNP Input Listing for Case 2 (ENDF/B-VI) of Table 29 (cont'd).

```
      25055.60c  2.2115e-5  22000.60c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      14000.60c  3.4607e-4
      26054.60c 5.9899E-06
      26056.60c 9.3118E-05
      26057.60c 2.1320E-06
      26058.60c 2.8427E-07
c   Zn is replaced with Cu, due to no Zn cross sections
      29063.60c 2.1420E-05
      29065.60c 9.5471E-06
c   m3 is rubber plug
m3    6000.60c 4.3562e-2  1001.60c 5.8178e-2
      20000.60c 2.5660e-3  16032.60c 4.7820e-4
      14000.60c 9.6360e-5  8016.60c 1.2461e-2
c   m4 is water
m4    8016.60c 3.3353e-2  1001.60c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.60c 5.6642e-2  6000.60c 3.5648e-2
      8016.60c 1.4273e-2
c   m6 is SS plate + 1.1%B
m6    25055.60c  1.3682e-3
      24050.60c 7.5654E-04
      24052.60c 1.4589E-02
      24053.60c 1.6541E-03
      24054.60c 4.1179E-04
      26054.60c 3.4197E-03
      26056.60c 5.3162E-02
      26057.60c 1.2172E-03
      26058.60c 1.6229E-04
      28058.60c 5.2739E-03
      28060.60c 2.0162E-03
      28061.60c 8.7294E-05
      28062.60c 2.7733E-04
      28064.60c 7.0298E-05
      29063.60c 1.4500E-04
      29065.60c 6.4628E-05
      42000.60c  2.4298e-4
      5010.60c   9.1950e-4  5011.60c   3.7011e-3
c   m7 is steel wall
m7    6000.60c  7.4686e-4  25055.60c  1.1e-3
      15031.60c 6.0971e-6  16032.60c 8.8332e-6  14000.60c 3.6983e-4
      42000.60c 2.4114e-4
      24050.60c 4.7344E-06
      24052.60c 9.1299E-05
      24053.60c 1.0351E-05
      24054.60c 2.5770E-06
      26054.60c 4.8268E-03
      26056.60c 7.5036E-02
      26057.60c 1.7180E-03
      26058.60c 2.2907E-04
      28058.60c 4.3387E-04
      28060.60c 1.6587E-04
      28061.60c 7.1813E-06
      28062.60c 2.2815E-05
      28064.60c 5.7832E-06
      29063.60c 6.6809E-05
      29065.60c 2.9778E-05
print
```

MCNP Input Listing for Case 3 (ENDF/B-VI) of Table 29.

```
LCT13-3, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, BoralB abs pls, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2           $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(7.823 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  8 0.0600607 1 -5 11 -12 30 -31  $ Al clad of absorber plate
12  6 0.0869997 1 -5 12 -13 30 -31  $ absorber plate
13  8 0.0600607 1 -5 13 -14 30 -31  $ Al clad of absorber plate
14  4 0.1000596 1 -5 14 -20 30 -31  $ water between abs plate and outer cluster
15  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
16  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
17  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
18  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
19  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
20  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
21  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
22  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
23  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
24  7 0.0851238 4 -8 10 -22 33 -34  $ wall
25  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.39    $ side of 1100 Al clad    **
13   px 11.606   $ side of Boral B         **
14   px 11.644   $ side of 1100 Al clad    **
20   px 19.175   $ inner boundary of outer cluster **
21   px 41.879   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 23r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.60c 5.1835e-6 92235.60c 1.0102e-3
      92236.60c 5.1395e-6 92238.60c 2.2157e-2
      8016.60c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.60c  5.8433e-2
      24050.60c 2.7074E-06
      24052.60c 5.2210E-05
      24053.60c 5.9195E-06
```

MCNP Input Listing for Case 3 (ENDF/B-VI) of Table 29 (cont'd).

```
      24054.60c 1.4736E-06
      29063.60c 4.4083E-05
      29065.60c 1.9648E-05
      12000.60c  6.6651e-4
      25055.60c  2.2115e-5  22000.60c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      14000.60c  3.4607e-4
      26054.60c 5.9899E-06
      26056.60c 9.3118E-05
      26057.60c 2.1320E-06
      26058.60c 2.8427E-07
c   Zn is replaced with Cu, due to no Zn cross sections
      29063.60c 2.1420E-05
      29065.60c 9.5471E-06
c   m3 is rubber plug
m3    6000.60c 4.3562e-2  1001.60c 5.8178e-2
      20000.60c 2.5660e-3  16032.60c 4.7820e-4
      14000.60c 9.6360e-5  8016.60c 1.2461e-2
c   m4 is water
m4    8016.60c 3.3353e-2  1001.60c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.60c 5.6642e-2  6000.60c 3.5648e-2
      8016.60c 1.4273e-2
c   m6 is Boral B
m6    13027.60c  3.4154e-2  6000.60c  1.0567e-2
      5010.60c   8.4135e-3  5011.60c   3.3865e-2
c   m7 is steel wall
m7    6000.60c  7.4686e-4  25055.60c  1.1e-3
      15031.60c 6.0971e-6  16032.60c 8.8332e-6  14000.60c 3.6983e-4
      42000.60c 2.4114e-4
      24050.60c 4.7344E-06
      24052.60c 9.1299E-05
      24053.60c 1.0351E-05
      24054.60c 2.5770E-06
      26054.60c 4.8268E-03
      26056.60c 7.5036E-02
      26057.60c 1.7180E-03
      26058.60c 2.2907E-04
      28058.60c 4.3387E-04
      28060.60c 1.6587E-04
      28061.60c 7.1813E-06
      28062.60c 2.2815E-05
      28064.60c 5.7832E-06
      29063.60c 6.6809E-05
      29065.60c 2.9778E-05
c   m8 is 1100 aluminum clad of Boral B plate
m8    13027.60c  5.9660e-2
      26056.60c 1.0748E-04
      26057.60c 2.4609E-06
      26058.60c 3.2812E-07
      28061.60c 8.7294E-05
      28062.60c 2.7733E-04
      28064.60c 7.0298E-05
      29063.60c 2.1238E-05
      29065.60c 9.4663E-06
c   Zn is replaced with Cu, due to no Zn cross sections
      29063.60c 8.5998E-06
      29065.60c 3.8330E-06
      25055.60c  2.2115e-5
      14000.60c  2.3302e-4
print
```

MCNP Input Listing for Case 4 (ENDF/B-VI) of Table 29.

```
LCT13-4, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, Boroflx abs pls, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2           $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(7.893 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  5 0.1065632 1 -5 11 -12 30 -31  $ Plexiglas next to absorber plate
12  6 0.0993296 1 -5 12 -13 30 -31  $ absorber plate
13  5 0.1065632 1 -5 13 -14 30 -31  $ Plexiglas next to absorber plate
14  4 0.1000596 1 -5 14 -20 30 -31  $ water between abs plate and outer cluster
15  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
16  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
17  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
18  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
19  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
20  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
21  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
22  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
23  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
24  7 0.0851238 4 -8 10 -22 33 -34  $ wall
25  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.512   $ side of Plexiglas       **
13   px 11.738   $ side of Boroflex        **
14   px 11.898   $ side of Plexiglas       **
20   px 19.245   $ inner boundary of outer cluster **
21   px 41.949   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 23r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.60c 5.1835e-6 92235.60c 1.0102e-3
      92236.60c 5.1395e-6 92238.60c 2.2157e-2
      8016.60c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.60c  5.8433e-2
      24050.60c 2.7074E-06
      24052.60c 5.2210E-05
      24053.60c 5.9195E-06
```

MCNP Input Listing for Case 4 (ENDF/B-VI) of Table 29 (cont'd).

```
      24054.60c 1.4736E-06
      29063.60c 4.4083E-05
      29065.60c 1.9648E-05
      12000.60c  6.6651e-4
      25055.60c  2.2115e-5  22000.60c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      14000.60c  3.4607e-4
      26054.60c 5.9899E-06
      26056.60c 9.3118E-05
      26057.60c 2.1320E-06
      26058.60c 2.8427E-07
c   Zn is replaced with Cu, due to no Zn cross sections
      29063.60c 2.1420E-05
      29065.60c 9.5471E-06
c   m3 is rubber plug
m3    6000.60c 4.3562e-2  1001.60c 5.8178e-2
      20000.60c 2.5660e-3  16032.60c 4.7820e-4
      14000.60c 9.6360e-5  8016.60c 1.2461e-2
c   m4 is water
m4    8016.60c 3.3353e-2  1001.60c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.60c 5.6642e-2  6000.60c 3.5648e-2
      8016.60c 1.4273e-2
c   m6 is Boroflex
m6    5010.60c   6.2822e-3  5011.60c   2.5287e-2
      6000.60c   1.8339e-2  1001.60c   2.7408e-2
      24050.60c 2.6133E-07
      24052.60c 5.0395E-06
      24053.60c 5.7137E-07
      24054.60c 1.4224E-07
      26054.60c 5.5064E-07
      26056.60c 8.5601E-06
      26057.60c 1.9599E-07
      26058.60c 2.6132E-08
      8016.60c   1.3689e-2 14000.60c   8.3103e-3
c   m7 is steel wall
m7    6000.60c  7.4686e-4  25055.60c  1.1e-3
      15031.60c 6.0971e-6  16032.60c 8.8332e-6  14000.60c 3.6983e-4
      42000.60c 2.4114e-4
      24050.60c 4.7344E-06
      24052.60c 9.1299E-05
      24053.60c 1.0351E-05
      24054.60c 2.5770E-06
      26054.60c 4.8268E-03
      26056.60c 7.5036E-02
      26057.60c 1.7180E-03
      26058.60c 2.2907E-04
      28058.60c 4.3387E-04
      28060.60c 1.6587E-04
      28061.60c 7.1813E-06
      28062.60c 2.2815E-05
      28064.60c 5.7832E-06
      29063.60c 6.6809E-05
      29065.60c 2.9778E-05
print
```

MCNP Input Listing for Case 5 (ENDF/B-VI) of Table 29.

```
LCT13-5, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, Cd abs pls, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2           $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(8.463 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0464400 1 -5 11 -12 30 -31  $ absorber plate
12  5 0.1065632 1 -5 12 -13 30 -31  $ Plexiglas next to absorber plate
13  4 0.1000596 1 -5 13 -20 30 -31  $ water between abs plate and outer cluster
14  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
15  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
16  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
17  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
18  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
19  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
20  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
21  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
22  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
23  7 0.0851238 4 -8 10 -22 33 -34  $ wall
24  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0      $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.413   $ side of Cd              **
13   px 11.709   $ side of Plexiglas       **
20   px 19.815   $ inner boundary of outer cluster **
21   px 42.519   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 22r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.60c 5.1835e-6 92235.60c 1.0102e-3
      92236.60c 5.1395e-6 92238.60c 2.2157e-2
      8016.60c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.60c  5.8433e-2
      24050.60c 2.7074E-06
      24052.60c 5.2210E-05
      24053.60c 5.9195E-06
      24054.60c 1.4736E-06
      29063.60c 4.4083E-05
```

MCNP Input Listing for Case 5 (ENDF/B-VI) of Table 29 (cont'd).

```
      29065.60c 1.9648E-05
      12000.60c  6.6651e-4
      25055.60c  2.2115e-5  22000.60c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      14000.60c  3.4607e-4
      26054.60c 5.9899E-06
      26056.60c 9.3118E-05
      26057.60c 2.1320E-06
      26058.60c 2.8427E-07
c   Zn is replaced with Cu, due to no Zn cross sections
      29063.60c 2.1420E-05
      29065.60c 9.5471E-06
c   m3 is rubber plug
m3    6000.60c 4.3562e-2  1001.60c 5.8178e-2
      20000.60c 2.5660e-3  16032.60c 4.7820e-4
      14000.60c 9.6360e-5  8016.60c 1.2461e-2
c   m4 is water
m4    8016.60c 3.3353e-2  1001.60c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.60c 5.6642e-2  6000.60c 3.5648e-2
      8016.60c 1.4273e-2
c   m6 is Cd
c       Zn replaced by Cu, below
m6    29063.60c 1.6531E-04
      29065.60c 7.3680E-05
      48000.50c  4.6201e-2
c   m7 is steel wall
m7    6000.60c  7.4686e-4  25055.60c  1.1e-3
      15031.60c 6.0971e-6  16032.60c 8.8332e-6  14000.60c 3.6983e-4
      42000.60c 2.4114e-4
      24050.60c 4.7344E-06
      24052.60c 9.1299E-05
      24053.60c 1.0351E-05
      24054.60c 2.5770E-06
      26054.60c 4.8268E-03
      26056.60c 7.5036E-02
      26057.60c 1.7180E-03
      26058.60c 2.2907E-04
      28058.60c 4.3387E-04
      28060.60c 1.6587E-04
      28061.60c 7.1813E-06
      28062.60c 2.2815E-05
      28064.60c 5.7832E-06
      29063.60c 6.6809E-05
      29065.60c 2.9778E-05
print
```

MCNP Input Listing for Case 6 (ENDF/B-VI) of Table 29.

```
LCT13-6, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, Cu abs plates, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2          $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(12.993 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0858030 1 -5 11 -12 30 -31  $ absorber plate
12  4 0.1000596 1 -5 12 -20 30 -31  $ water between abs plate and outer cluster
13  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
14  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
15  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
16  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
17  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
18  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
19  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
20  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
21  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
22  7 0.0851238 4 -8 10 -22 33 -34  $ wall
23  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.689   $ outer side of absorber plate    **
20   px 24.345   $ inner boundary of outer cluster **
21   px 47.049   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 21r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.60c 5.1835e-6 92235.60c 1.0102e-3
      92236.60c 5.1395e-6 92238.60c 2.2157e-2
      8016.60c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.60c  5.8433e-2
      24050.60c 2.7074E-06
      24052.60c 5.2210E-05
      24053.60c 5.9195E-06
      24054.60c 1.4736E-06
      29063.60c 4.4083E-05
      29065.60c 1.9648E-05
      12000.60c  6.6651e-4
```

MCNP Input Listing for Case 6 (ENDF/B-VI) of Table 29 (cont'd).

```
      25055.60c  2.2115e-5  22000.60c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      14000.60c  3.4607e-4
      26054.60c 5.9899E-06
      26056.60c 9.3118E-05
      26057.60c 2.1320E-06
      26058.60c 2.8427E-07
c   Zn is replaced with Cu, due to no Zn cross sections
      29063.60c 2.1420E-05
      29065.60c 9.5471E-06
c   m3 is rubber plug
m3    6000.60c 4.3562e-2  1001.60c 5.8178e-2
      20000.60c 2.5660e-3  16032.60c 4.7820e-4
      14000.60c 9.6360e-5  8016.60c 1.2461e-2
c   m4 is water
m4    8016.60c 3.3353e-2  1001.60c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.60c 5.6642e-2  6000.60c 3.5648e-2
      8016.60c 1.4273e-2
c   m6 is Cu plate
m6    6000.60c   1.5194e-3
      12000.60c  4.4168e-6
      26054.60c 2.2682E-07
      26056.60c 3.5261E-06
      26057.60c 8.0733E-08
      26058.60c 1.0764E-08
      29063.60c 5.8192E-02
      29065.60c 2.5937E-02
      11023.60c  4.6695e-6   8016.60c  1.0064e-4
      14000.60c  3.8223e-5  16032.60c  3.3474e-6
c   m7 is steel wall
m7    6000.60c  7.4686e-4  25055.60c  1.1e-3
      15031.60c 6.0971e-6  16032.60c 8.8332e-6  14000.60c 3.6983e-4
      42000.60c 2.4114e-4
      24050.60c 4.7344E-06
      24052.60c 9.1299E-05
      24053.60c 1.0351E-05
      24054.60c 2.5770E-06
      26054.60c 4.8268E-03
      26056.60c 7.5036E-02
      26057.60c 1.7180E-03
      26058.60c 2.2907E-04
      28058.60c 4.3387E-04
      28060.60c 1.6587E-04
      28061.60c 7.1813E-06
      28062.60c 2.2815E-05
      28064.60c 5.7832E-06
      29063.60c 6.6809E-05
      29065.60c 2.9778E-05
print
```

MCNP Input Listing for Case 7 (ENDF/B-VI) of Table 29.

```
LCT13-7, 12x16 U(4.31)O2 rod clusters, 1.892-cm pitch, CuCd abs plates, ss walls
1   1 0.069930423 1 -6 -44 u=1 $ fuel
2   0 1 -6 44 -45 u=1 $ gap
3   2 0.059751655  45 -46   u=1 $ clad
4   3 0.11734111 6 -45    u=1 $ top plug
5   3 0.11734111 -1 -45   u=1 $ bottom plug
6   4 0.1000596 46       u=1 $ water
7   0 -40 42 -41 43 lat=1 u=2 fill=1 $ lattice of fuel rods
8   0 10 -11 30 -32 -7 2 fill=2          $ center cluster
9   0 20 -21 30 -32 -7 2 fill=2(10.093 0 0)   $ outer cluster **
10  5 0.1065632 -2 3 10 -21 30 -32  $ acrylic support plate
11  6 0.0840606 1 -5 11 -12 30 -31  $ absorber plate
12  4 0.1000596 1 -5 12 -20 30 -31  $ water between abs plate and outer cluster
13  4 0.1000596 5 -7 11 -20 30 -31  $ water above abs plate between clusters
14  4 0.1000596 2 -1 11 -20 30 -31  $ water below abs plate between clusters
15  4 0.1000596 2 -7 11 -20 31 -32  $ water to side of abs plate
16  4 0.1000596 7 -8 10 -21 30 -32  $ water above clusters to top of wall
17  4 0.1000596 4 -3 10 -22 30 -33  $ water below level of acrylic plate between walls
18  4 0.1000596 3 -8 21 -22 30 -32  $ water at ends of cluster to top of wall
19  4 0.1000596 3 -8 10 -22 32 -33  $ water between clusters and wall to top of wall
20  4 0.1000596 4 -9 10 -22 34 -35  $ water outside steel walls
21  4 0.1000596 8 -9 10 -22 30 -34  $ water above level of top of walls, to edge of wall
22  7 0.0851238 4 -8 10 -22 33 -34  $ wall
23  0 9:-4:-10:22:-30:35  $ outside

1    pz 0.0      $ bottom of fuel
2    pz -2.2225  $ bottom of bottom plug
3    pz -4.7625  $ bottom of acrylic support plate
4    pz -20.0625 $ bottom of water reflector and walls
5    pz 91.5     $ top of absorber plate
6    pz 92.075   $ top of fuel
7    pz 94.2975  $ top of top plug
8    pz 101.8375 $ top of wall
9    pz 107.075  $ top of water reflector
*10   px 0.0     $ center of center cluster
11   px 11.352   $ edge of outer cell of center cluster
12   px 11.709   $ outer side of absorber plate    **
20   px 21.445   $ inner boundary of outer cluster **
21   px 44.149   $ outer boundary of outer cluster **
22   px 73.65    $ end of steel wall, side of water reflector
*30   py 0.0      $ centerline of clusters
31   py 15.1     $ side edge of absorber plate
32   py 15.136   $ side of clusters
33   py 17.092   $ inner side of steel wall
34   py 34.942   $ outer side of steel wall
35   py 45.636   $ side of water reflector outside walls
40   px 3.784    $ cell boundary
41   py 3.784    $ cell boundary
42   px 1.892    $ cell boundary
43   py 1.892    $ cell boundary
44   c/z  2.838 2.838 0.6325  $ fuel
45   c/z  2.838 2.838 0.6415  $ gap
46   c/z  2.838 2.838 0.7075  $ clad

imp:n  1 21r 0
kcode  2500 1 60 660 50000
ksrc  0.946 0.946 46
c   m1 is U(4.31)O2 fuel
m1    92234.60c 5.1835e-6 92235.60c 1.0102e-3
      92236.60c 5.1395e-6 92238.60c 2.2157e-2
      8016.60c  4.6753e-2
c   m2 is 6061 aluminum clad of fuel rods
m2    13027.60c  5.8433e-2
      24050.60c 2.7074E-06
      24052.60c 5.2210E-05
      24053.60c 5.9195E-06
      24054.60c 1.4736E-06
      29063.60c 4.4083E-05
      29065.60c 1.9648E-05
      12000.60c  6.6651e-4
```

MCNP Input Listing for Case 7 (ENDF/B-VI) of Table 29 (cont'd).

```
      25055.60c  2.2115e-5  22000.60c  2.5375e-5
c   Zn is replaced with Cu, due to no Zn cross sections
      14000.60c  3.4607e-4
      26054.60c 5.9899E-06
      26056.60c 9.3118E-05
      26057.60c 2.1320E-06
      26058.60c 2.8427E-07
c   Zn is replaced with Cu, due to no Zn cross sections
      29063.60c 2.1420E-05
      29065.60c 9.5471E-06
c   m3 is rubber plug
m3    6000.60c 4.3562e-2  1001.60c 5.8178e-2
      20000.60c 2.5660e-3  16032.60c 4.7820e-4
      14000.60c 9.6360e-5  8016.60c 1.2461e-2
c   m4 is water
m4    8016.60c 3.3353e-2  1001.60c 6.6706e-2
mt4   lwtr.01t
c   m5 is acrylic
m5    1001.60c 5.6642e-2  6000.60c 3.5648e-2
      8016.60c 1.4273e-2
c   m6 is Cu plate with Cd
m6    5010.60c   4.9384e-6   5011.60c  1.9878e-5
      6000.60c   8.9346e-6  48000.50c  4.7208e-4
      26054.60c 1.1337E-06
      26056.60c 1.7625E-05
      26057.60c 4.0353E-07
      26058.60c 5.3804E-08
      28058.60c 6.2415E-06
      28060.60c 2.3862E-06
      28061.60c 1.0331E-07
      28062.60c 3.2821E-07
      28064.60c 8.3196E-08
      29063.60c 5.7638E-02
      29065.60c 2.5690E-02
      25055.60c  8.7901e-6
      8016.60c  6.3720e-5  14000.60c  7.6419e-6
c       Zn replaced by Cu, below
      29063.60c 3.9731E-06
      29065.60c 1.7709E-06
c     50000.35c  1.1300e-4  $ Sn omitted; cross section unavailable
c   m7 is steel wall
m7    6000.60c  7.4686e-4  25055.60c  1.1e-3
      15031.60c 6.0971e-6  16032.60c 8.8332e-6  14000.60c 3.6983e-4
      42000.60c 2.4114e-4
      24050.60c 4.7344E-06
      24052.60c 9.1299E-05
      24053.60c 1.0351E-05
      24054.60c 2.5770E-06
      26054.60c 4.8268E-03
      26056.60c 7.5036E-02
      26057.60c 1.7180E-03
      26058.60c 2.2907E-04
      28058.60c 4.3387E-04
      28060.60c 1.6587E-04
      28061.60c 7.1813E-06
      28062.60c 2.2815E-05
      28064.60c 5.7832E-06
      29063.60c 6.6809E-05
      29065.60c 2.9778E-05
print
```

A.3 ONEDANT/TWODANT Input Listings

Because the benchmark model is 3-dimensional, ONEDANT and TWODANT models cannot be provided.

CSASIX, ONEDANT and TWODANT input listings for sensitivity studies are given in Appendix C.

APPENDIX B: LOGBOOKS

Experiment numbers were not provided in the references. These experiments are probably included in the logbooks stored at the Los Alamos National Laboratory Archives in the series SSC-4.3-137 to 151: 3/11/80 to 4/23/80 in Box 10 and series SSC-4.3-000-152 to 157: 9/2/80 to 9/22/80 in Box 11, as listed on the July 16, 1993, inventory for the shipment from Hanford to Los Alamos.

APPENDIX C: SAMPLE CSASIX, ONEDANT, AND TWODANT INPUTS FOR SENSITIVITY STUDIES USING HOMOGENIZED FUEL-ROD REGION

Note that, in the unit-cell specification at the end of the CSASIX input, the 0.009-cm gap between clad and fuel is omitted, resulting in thicker aluminum clad in these models used for sensitivity studies. Calculations show that including the gap results in a decrease of k_{eff} by about 11 pcm for all of the 7 base cases. Therefore, it is expected that this model discrepancy will not significantly affect the Δk_{eff}'s calculated in the sensitivity studies.

CSASIX and TWODANT

```
=CSASIX
LCT13
27GROUPNDF4 LATTICECELL
' U(4.31)02
U-234  1 0  5.1835-6 END
U-235  1 0  1.0102-3 END
U-236  1 0  5.1395-6 END
U-238  1 0  2.2157-2 END
O  1 0  4.6753-2 END
' water
H  2 0  6.6706-2 END
O  2 0  3.3353-2 END
' 6061 Al (clad)
AL  3 0  5.8433-2 END
CR  3 0  6.2310-5 END
CU  3 0  6.3731-5 END
MG  3 0  6.6651-4 END
MN  3 0  2.2115-5 END
TI  3 0  2.5375-5 END
'        (Zn replaced by Cu)
CU  3 0  3.0967-5 END
SI  3 0  3.4607-4 END
FE  3 0  1.0152-4 END
'  Rubber end plug
C  4 0   4.3562-2 END
H   4 0  5.8178-2 END
CA  4 0  2.5660-3 END
S   4 0  4.7820-4 END
SI  4 0  9.6360-5 END
O   4 0  1.2461-2 END
' SS plate
CR  5 0  1.7046-2 END
CU  5 0  2.0291-4 END
FE  5 0  5.8353-2 END
MN  5 0  1.3734-3 END
MO  5 0  1.2942-4 END
NI  5 0  9.0238-3 END
'acrylic
H   6 0  5.6642-2 END
C   6 0  3.5648-2 END
O   6 0  1.4273-2 END
' water
H  7 0  6.6706-2 END
O  7 0  3.3353-2 END
' SS plate
CR  8 0  1.7046-2 END
CU  8 0  2.0291-4 END
FE  8 0  5.8353-2 END
MN  8 0  1.3734-3 END
MO  8 0  1.2942-4 END
NI  8 0  9.0238-3 END
' STEEL WALLS
FE  9 0  8.1810-2 END
C   9 0  7.4686-4 END
MN  9 0  1.1000-3 END
P   9 0  6.0971-6 END
S   9 0  8.8332-6 END
SI  9 0  3.6983-4 END
```

```
NI  9 0  6.3552-4 END
MO  9 0  2.4114-4 END
CR  9 0  1.0896-4 END
CU  9 0  9.6587-5 END
' SS plate with 1.1% B
B-10 10 0 9.1950-4 END
B-11 10 3.7011-3 END
CR  10 0  1.7412-2 END
CU  10 0  2.0963-4 END
FE  10 0  5.7961-2 END
MN  10 0  1.3682-3 END
MO  10 0  2.4298-4 END
NI  10 0  7.7251-3 END
' Boral B plate
B-10 11 0 8.4135-3 END
B-11 11 0 3.3865-2 END
AL  11 0  3.4154-2 END
C   11 0  1.0567-2 END
' Boroflex
B-10 12 0 6.2822-3 END
B-11 12 0 2.5287-2 END
C    12 0 1.8339-2 END
H    12 0 2.7408-2 END
CR   12 0 6.0145-6 END
FE   12 0 9.3329-6 END
O   12 0  1.3689-2 END
SI  12 0  8.3103-3 END
' Cd plate
CD  13 0 4.6201-2 END
'          Zn replaced by Cu
CU  13 0 2.3899-4 END
' CU plate w/o Cd
C   14 0  1.5194-3 END
CU  14 0  8.4128-2 END
FE  14 0  3.8444-6 END
MG  14 0  4.4168-6 END
NA  14 0  4.6695-6 END
O   14 0  1.0064-4 END
SI  14 0  3.8223-5 END
S   14 0  3.3474-6 END
' CU plate w/ Cd
B-10 15 0  4.9384-6 END
B-11 15 0  1.9878-5 END
C   15 0  8.9346-6 END
CD  15 0  4.7208-4 END
CU  15 0  8.3328-2 END
FE  15 0  1.9216-5 END
MN  15 0  8.7901-6 END
NI  15 0  9.1424-6 END
O   15 0  6.3720-5 END
SI  15 0  7.6419-6 END
SN  15 0  1.1300-4 END
'          Zn replaced by Cu
CU  15 0  5.7440-6 END
END COMP
SQUAREPITCH 1.892 1.265 1 2 1.415 3 END
MORE DATA EPS=1.-7 PTC=1.-7
AXS=7  END MORE
END


     1     0     0
4.31 wt% rods, ss walls + ss+1%B absorber plates, LCT13, Case 2
/  Block 1
igeom=6 ngroup=27 isn=8 niso=16 mt=16 nzone=16 im=11 it=162 jm=6
jt=99  maxscm=560000 maxlcm=450000000 t

/  Block 2
xmesh=0 10 11.352 11.65 12 20.2 20.705 21 43 43.409 44 73.65
xints= 20 2 4 3 16 4 3 44 2 4 60
ymesh=0 14.8 15.136 17.092 17.4 34.942 45.636
yints= 30 4 8 2 35 20
zones=16 16 10 7 7 7 16 16 16 7 7;
      16 16 10 7 7 7 16 16 16 7 7;
      11r7;
      11r9;
```

```
      11r9;
      11r7  t

/ Block 3
 lib=bxslib
 chivec=.021 .188 .215 .125 .166 .180 .090 .014 .001 18z
 maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1   t

/ Block 4
 matls=isos  assign=matls   t

/ Block 5
 ievt=1  isct=1 ith=0 ibl=1 ibr=0 ibt=0 ibb=1
 epsi=0.00001 iitm=60 influx=0 oitm=40 bhgt=96  t

/ Block 6
 edoutf=3
 pted=1 zned=0  t
```

CSASIX and ONEDANT

```
=CSASIX
LCT13
27GROUPNDF4 LATTICECELL
' U(4.31)02
U-234  1 0  5.1835-6 END
U-235  1 0  1.0102-3 END
U-236  1 0  5.1395-6 END
U-238  1 0  2.2157-2 END
O  1 0  4.6753-2 END
' water
H  2 0  6.6706-2 END
O  2 0  3.3353-2 END
' 6061 Al (clad)
AL  3 0  5.8433-2 END
CR  3 0  6.2310-5 END
CU  3 0  6.3731-5 END
MG  3 0  6.6651-4 END
MN  3 0  2.2115-5 END
TI  3 0  2.5375-5 END
'        (Zn replaced by Cu)
CU  3 0  3.0967-5 END
SI  3 0  3.4607-4 END
FE  3 0  1.0152-4 END
'  Rubber end plug
C  4 0   4.3562-2 END
H   4 0  5.8178-2 END
CA  4 0  2.5660-3 END
S   4 0  4.7820-4 END
SI  4 0  9.6360-5 END
O   4 0  1.2461-2 END
' 80% water + 20% steel
H       5       0       5.3365E-02      END
O       5       0       2.6682E-02      END
Fe      5       0       1.6362E-02      END
C       5       0       1.4937E-04      END
MN      5       0       2.2000E-04      END
P       5       0       1.2194E-06      END
S       5       0       1.2194E-06      END
SI      5       0       7.3966E-05      END
NI      5       0       1.2710E-04      END
MO      5       0       4.8228E-05      END
CR      5       0       2.1792E-05      END
CU      5       0       1.9317E-05      END
'acrylic
H   6 0  5.6642-2 END
C   6 0  3.5648-2 END
O   6 0  1.4273-2 END
' water
H  7 0  6.6706-2 END
O  7 0  3.3353-2 END
' SS plate
CR  8 0  1.7046-2 END
CU  8 0  2.0291-4 END
FE  8 0  5.8353-2 END
```

```
MN  8 0  1.3734-3 END
MO  8 0  1.2942-4 END
NI  8 0  9.0238-3 END
' STEEL WALLS
FE  9 0  8.1810-2 END
C   9 0  7.4686-4 END
MN  9 0  1.1000-3 END
P   9 0  6.0971-6 END
S   9 0  8.8332-6 END
SI  9 0  3.6983-4 END
NI  9 0  6.3552-4 END
MO  9 0  2.4114-4 END
CR  9 0  1.0896-4 END
CU  9 0  9.6587-5 END
END COMP
SQUAREPITCH 1.892 1.265 1 2 1.415 3 END
MORE DATA EPS=1.-7 PTC=1.-7
AXS=7  END MORE
END


     1     0     0
lct13  slab with ss walls + 10-cm water
/  Block 1
igeom=1 ngroup=27 isn=8 niso=10 mt=10 nzone=10 im=7
it=120  maxscm=560000 maxlcm=4500000 t

/  Block 2
xmesh=0.0 14 15.136 17.092 18 34 34.942 44.942
xints= 28 4 8 4 32 4 40
zones=10 10 7 9 9 9 7 t

/ Block 3
 lib=c127.txt savbxs=1
 chivec=.021 .188 .215 .125 .166 .180 .090 .014 .001 18z
 maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1   t
/ Block 4
 matls=isos  assign=matls   t

/ Block 5
 ievt=1  isct=1 ith=0 ibl=1 ibr=0
 epsi=0.000001 influx=0 oitm=50 bhgt=96 bwth=26  t

/ Block 6
 edoutf=0
 pted=0 zned=0  t
!eof
     1     0     0
lct13  slab with ss walls + 30-cm water
/  Block 1
igeom=1 ngroup=27 isn=8 niso=10 mt=10 nzone=10 im=7
it=200  maxscm=560000 maxlcm=4500000 t

/  Block 2
xmesh=0.0 14 15.136 17.092 18 34 34.942 64.942
xints= 28 4 8 4 32 4 120
zones=10 10 7 9 9 9 7 t

/ Block 3
 lib=bxslib
 chivec=.021 .188 .215 .125 .166 .180 .090 .014 .001 18z
 maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1   t
/ Block 4
 matls=isos  assign=matls   t

/ Block 5
 ievt=1  isct=1 ith=0 ibl=1 ibr=0
 epsi=0.000001 influx=0 oitm=50 bhgt=96 bwth=26  t

/ Block 6
 edoutf=0
 pted=0 zned=0  t
!eof
     1     0     0
lct13  slab with ss walls + 5-cm water + 5-cm water+20%ss
/  Block 1
```

```
igeom=1 ngroup=27 isn=8 niso=10 mt=10 nzone=10 im=8
it=120  maxscm=560000 maxlcm=4500000 t

/  Block 2
xmesh=0.0 14 15.136 17.092 18 34 34.942 39.942 44.942
xints= 28 4 8 4 32 4 20 20
zones=10 10 7 9 9 9 7 5 t

/ Block 3
 lib=bxslib
 chivec=.021 .188 .215 .125 .166 .180 .090 .014 .001 18z
 maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1   t
/ Block 4
 matls=isos  assign=matls   t

/ Block 5
 ievt=1  isct=1 ith=0 ibl=1 ibr=0
 epsi=0.000001 influx=0 oitm=50 bhgt=96 bwth=26  t

/ Block 6
 edoutf=0
 pted=0 zned=0  t
!eof
```

APPENDIX D: DISTRIBUTION OF B_4C PARTICLE SIZE IN BORALS AND BOROFLEX

According to the manufacturer, B_4C was distributed uniformly throughout the aluminum matrix of the Borals and throughout the rubber matrix of the Boroflex in the weight-percent distribution shown in Table D.1. (Reference 4, p. 9)

Table D.1. Distribution of Sizes of B_4C particles in Boral and in Boroflex.

Boral		Boroflex	
Particle Size (mm)	Wt.%	Particle Size (mm)	Wt.%
>0.297	0.6	>0.149	trace
0.25-0.297	7.4	0.074-0.149	2.1
0.125-0.25	65.6	0.044-0.074	19.1
0.074-0.125	25.0	<0.044	78.8
0.044-0.074	1.4		