WATER-MODERATED RECTANGULAR CLUSTERS OF $U(2.35)O_2$ FUEL RODS(1.684-CM PITCH) SEPARATED BY STEEL, BORAL, BOROFLEX, CADMIUM,OR COPPER PLATES (GADOLINIUM WATER IMPURITY)

Evaluators

Soon S. Kim
Virginia F. Dean
Idaho National Engineering and Environmental Laboratory

Internal Reviewer
Virginia F. Dean

Independent Reviewer

Nigel R. Smith
AEA Technology

ACKNOWLEDGMENTS

The authors wish to thank three of the experimenters, Sid Bierman, Duane Clayton, and Michael Durst, who provided valuable additional information about how the experiments were conducted. They would also like to thank Roger Meade and Linda Sandoval of the Los Alamos National Laboratory Archives, who assisted in finding stored logbooks, and Pam A. Thurman of Environmental Health Sciences of the Hanford Environmental Health Foundation, who found the worksheet verifying the Gd impurity data.

WATER-MODERATED RECTANGULAR CLUSTERS OF $U(2.35)O_2$ FUEL RODS (1.684-CM PITCH) SEPARATED BY STEEL, BORAL, BOROFLEX, CADMIUM, OR COPPER PLATES (GADOLINIUM WATER IMPURITY)

IDENTIFICATION NUMBER: LEU-COMP-THERM-012 SPECTRA

KEY WORDS: absorber, acceptable, Boral, borated stainless steel, Boroflex, cadmium, compound, copper, fuel rods, gadolinium, Gd, low-enriched, plates, PNL, poison, stainless steel, thermal, ^{235}U, uranium, uranium dioxide, water-moderated, water-reflected

1.0 DETAILED DESCRIPTION

1.1 Overview of Experiment

A series of critical-approach experiments with clusters of 36-inch-long aluminum-clad $U(2.35)O_2$ 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-pitched lattice clusters with pitches of 2.032 cm (LEU-COMP-THERM-001, no Gd water impurity) or 1.684 cm (LEU-COMP-THERM-003, with Gd water impurity). Some experiments had lead, depleted-uranium, or steel reflecting walls on two opposite sides of the cluster row (LEU-COMP-THERM-017, no Gd impurity). Some circular, triangular-pitched lattices with pitches of 1.6 cm or 1.9 cm were used to measure the effect of gadolinium dissolved in the water (LEU-COMP-THERM-005). The effects of absorber plates for 2.032-cm-pitch rod clusters were also studied (LEU-COMP-THERM-016, no Gd impurity).

This evaluation documents water-reflected experiments performed in late 1979 with 3 rectangular clusters of 1.684-cm-pitched rods with neutron-absorber plates between clusters with a reported small Gd impurity in the water moderator-reflector. The absorber plates were stainless steel, borated stainless steel, Boral, Boroflex, copper, or copper with 1% cadmium. The effect of the absorber plates was 1% to 7% of k_{eff}.

Four-cluster experiments with rods at this pitch and with perpendicular absorber plates separating the four clusters were also performed, but only with the less effective absorbers, due to insufficient available fuel. They are not included in this evaluation.

A total of 10 experiments were evaluated and found to be acceptable as benchmark data. Similar experiments with steel reflecting walls and no Gd impurity are documented in LEU-COMP-THERM-042.

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. This particular set of 10 configurations is described in Reference 4.

1.2.1 Experiment Tank and Surroundings - Figures 1 and 2 show the experiment tank and surroundings. Experiments were performed in an open carbon-steel tank with a minimum water-reflector thickness of 30 cm at the sides and 15 cm at the ends of the line of 3 clusters. Tank walls were 9.52-mm thick.[a] The experiments were centered in the tank to within one-quarter inch. Nothing other than fuel rods, absorber plates, radiation detectors, and support structures (acrylic support and lattice plates, aluminum rod and angle supports, and control/safety-blade guides, all described below) was in the tank. Any control or safety rods or blades were withdrawn above the top water reflector.

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] Reference 4, pp. 10 and 27. Other information in this section is from personal communication, Sid Bierman, July, 1993.

Figure 1. Loading a Fuel Rod.

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

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. The plate was supported by two 15.3 x 5.08 x 0.635-cm 6061 aluminum channels oriented so that the bottom of the plate was 15.3 cm above the bottom of the tank.[a]

1.2.3 Lattice Plates and Supports - The pitch of the fuel rods was maintained by two levels of 1.27±0.4-cm-thick polypropylene lattice plates. Holes for the fuel rods were specified to be no more than 5 mils (0.0127 cm) larger than the rod diameter.

The top lattice plates were approximately 15 cm below the top of the fuel region. The bottom lattice plates rested on the acrylic support plate. The plates were joined by half-inch-diameter aluminum rods to 5.08 x 5.08 x 0.635-cm aluminum angles, which were attached at their ends to the walls of the tank. In one experiment at 2.032-cm pitch, these aluminum supports were doubled, with no effect on the critical separation between clusters (Reference 1, pp. 26 and 28).

---

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

The same lattice plates used for the 4-cluster experiments (Reference 4) were cut up to form lattice plates for the 3-cluster experiments. Slots were cut in the lattice plates for the four-cluster experiments, with slots just wide enough to accommodate the thickest absorber plate. Absorber plates were pressed against one side of the slot by polypropylene shims stuck in the slots.[a]

Slots for absorber plates were not used in the 3-cluster experiments. Figure 7 in Reference 4 shows a 2-cluster flux-trap experiment rotated 90° from the normal orientation with lattice plates with slots. This was not the orientation of these 3-cluster experiments, which used 6 separate lattice plates.[a]

A polypropylene shim was placed between the bottom lattice plates (or between a bottom lattice plate and the control/safety-blade guides) in order to more accurately determine the cluster separation, since the shim-plate width could be more accurately measured than separation of the lattice plates. Shims (small pieces of aluminum or lattice-plate material) were used to accurately position the rod clusters and absorber plates.[b]

1.2.4 Safety and Control Blade Guides - The aluminum control and safety blade guides were located between clusters. The blade 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. The guides were 38 mm wide and 12.7 mm thick with a 6.4-mm slot for the blades (Reference 4, p. 27). The distance between the two guides for each blade could be adjusted, depending on the width of the blade.

During one experiment from the set of experiments at 2.032-cm pitch with no absorber plates, 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).

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.[c]

1.2.6 Water Reflector - The top water surface was at least 15 cm above the top of the fuel region of the rods. (Reference 4, p. 27)[d] The bottom water reflector was at least 15 cm thick, since the aluminum angle supporting the fuel-rod support plate above the bottom of the tank was 153 mm high. The longer side of the experiment was parallel to the longer side of the tank[e] so that the minimum reflector thickness in the horizontal direction for these experiments was about 90 cm.

---

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

[b] Personal communication, Sid Bierman, July and August, 1993.

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

[d] Confirmed by personal communication, Sid Bierman, July, 1994.

[e] Personal communication, Sid Bierman, August, 1993.

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 to 25°C.

1.2.7 Neutron-Absorber Plates - The 2 neutron-absorber plates were positioned between the 3 clusters, parallel to their interacting surfaces, against the fuel-rod cell boundaries of the middle cluster. The absorber plates rested on the shim plates between bottom lattice plates. (The shim plates were made from the same sheets that the lattice plates were made of and, therefore, were the same thickness.) Absorber plates were held in place against the center lattice plate with shims of lattice-plate material or aluminum. Each plate was slightly longer and wider than the fuel length and width of the clusters and was "centered on the fuel region of the fuel rods" (Reference 14).[a]

All absorber plates were 91.5 cm long and 35.6 cm wide except both types of copper plates, which were 91.5 cm long and 30.6 cm wide.[a]

<u>Steel Plates</u>. The 304L steel plates had thicknesses of 0.298 ± 0.006 cm and 0.302 ± 0.013 cm. The critical separation between fuel-rod clusters was determined for steel without boron and steel with two boron contents: 1.05 and 1.62 wt.% boron.

<u>Boral Plates</u>. The Boral B plates were 0.292 ± 0.013 cm thick. The 0.292-cm thickness included 0.038-cm-thick cladding of Type 1100 aluminum on either side of the B_4C-Al core material. The Boral C plates were 0.231 ± 0.013 cm thick, including a 0.025-cm-thick cladding of Type 1100 aluminum on both sides.

<u>Boroflex Plates</u>. Two types of Boroflex plates were used. One type was 0.546 ± 0.018 cm thick, which included 0.160-cm-thick sheets of Plexiglas on either side of the borated-rubber core material. The other type was 0.408 ± 0.034 cm thick, which included 0.091±0.023-cm-thick Type 304-L steel on either side of the borated-rubber core.

<u>Cadmium Plates</u>. The thickness of the cadmium plates was 0.061 ± 0.003 cm. Thicknesses were measured with a micrometer at several places along the edges of the plates.[b] The cadmium was probably mounted on a sheet of 0.296-cm-thick Plexiglas or between two such sheets.[c]

<u>Copper Plates</u>. 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 0.337 ± 0.008 cm. The copper plates with cadmium were 0.357 ± 0.008 cm thick.

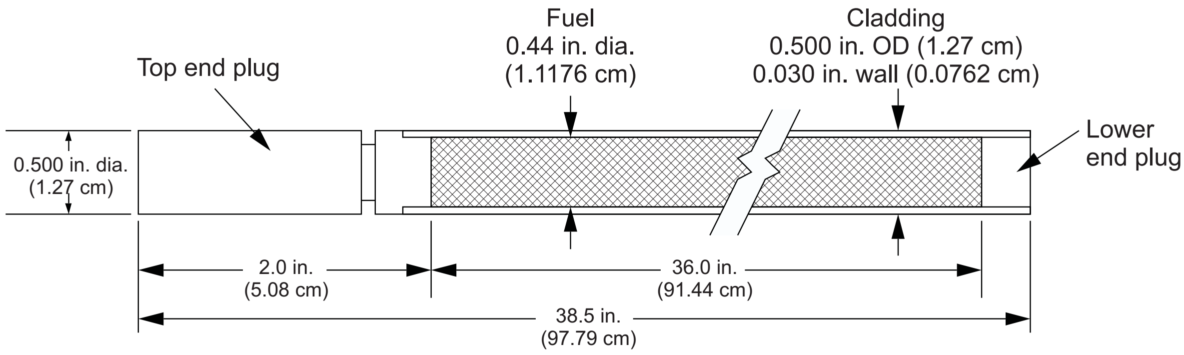
1.2.8 Fuel Rods - Fuel-rod dimensions are given in diagrams in References 1, 3-6, and 8. These diagrams are the same as Figure 3, which is a reproduction of an annotated diagram from Reference 13 (Vol 1, p. 29). Reference 13 is cited by Reference 8, p. 2.7, as the source of fuel-rod data.

---

[a] Confirmed by personal communication, Sid Bierman, March 4, 1993.
[b] Personal communication, Sid Bierman, June, 1998.
[c] Personal communication, Sid Bierman, August, 1993.

Fuel specifications: 2.35% enriched UO_2

Fuel rods
1. Rod dimensions



2. Cladding: 6061 Aluminum tubing seal welded with a lower end plug of 5052-H32 Aluminum and a top plug of 1100 Aluminum.
3. Total weight of loaded fuel rods: 917 g (average)

Fuel loading
1. Fuel mixture vibrationally compacted.
2. 825 g of UO_2 powdered/rod, 726 g of U/rod, 17.08 g of U-235/rod.
3. Enrichment = 2.35 ± 0.05 w/o U-235.
4. Fuel density = 9.20 g/cm (84% theoretical density).

C98 0171

Figure 3. $U(2.35)O_2$ Fuel Rod.

Dimensions of the $U(2.35)O_2$ fuel rods are summarized in Table 1. The total rod length is 97.79 cm. The clad length is an approximation from measuring Figure B-1 in Reference 13 (Vol 1, p. 29). The clad envelops the lower end plug, fuel, and ~0.48 cm of the top end plug. Dimensions of the notch shown in the top end plug are not known. When the fuel rods were fabricated, end plugs were pushed in (or on) for a tight fit, then were cut off; so the lengths of the plugs are only approximate.[a]

Table 1. 2.35-Wt.%-Enriched UO_2 Fuel-Rod Dimensions.

Component	Length (cm)	Diameter (cm)
UO_2 fuel	91.44	1.1176
Top end plug(1100 Al)	5.08	1.27
Lower end plug (5052-H32 Al)	1.27	1.1176
Clad (6061 Al)	~93.19	1.270 OD (0.0762 cm thick)

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

1.2.9 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-pitched 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).

1.2.10 Experimental Method for Determining Critical Configuration[b] **-** The critical configuration was determined by measuring neutron-detector count rates (above background) produced by subcritical configurations and extrapolating to the critical condition. In particular, the averages of several (usually four, five, or six) 80-second counts from each of two or three detectors were recorded for each configuration. Generally, the most reactive configuration measured was "taken to within 99% of the critical condition" (Reference 12).

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. Moving half a row on one outer cluster was considered to be equivalent to decreasing the separation between clusters by ¼ pitch length. The variables plotted were [cluster separation]/[count rate] vs. [cluster separation] and [1]/[count rate] vs. [cluster separation].[c] At least two loadings close to critical were measured. The final result was the average predicted critical cluster separation distance.
(See LEU-COMP-THERM-003, Section 1.2.8, for an example of this method.)

1.2.11 Critical Cluster Dimensions and Separations - Typical arrangements of fuel clusters and the neutron-absorber material are shown in Figure 4.

Cluster sizes and separations for the ten critical configurations are listed in Table 2 (Reference 4, p. 41). Error limits are one standard deviation. Each configuration consisted of three clusters of fuel rods at 1.684-cm square pitch. Cluster dimensions are given in rods: the first dimension is along the direction of cluster placement; the second dimension is the width of facing sides, as shown in Figure 4. Note that clusters of the last two cases are only 18 rods wide, due to the narrower copper plates.

---

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

[b] This information is from the logbooks, stored at the Los Alamos National Laboratory Archives.

[c] Plots of both [separation]/[count rate] vs. [separation] and 1/[count rate] vs. [separation]) were used because one tended to overestimate the critical parameter variation and the other to underestimate it. As criticality was approached, both curves tended to predict the same critical configuration. (Personal communication, Duane Clayton, August, 1993.)

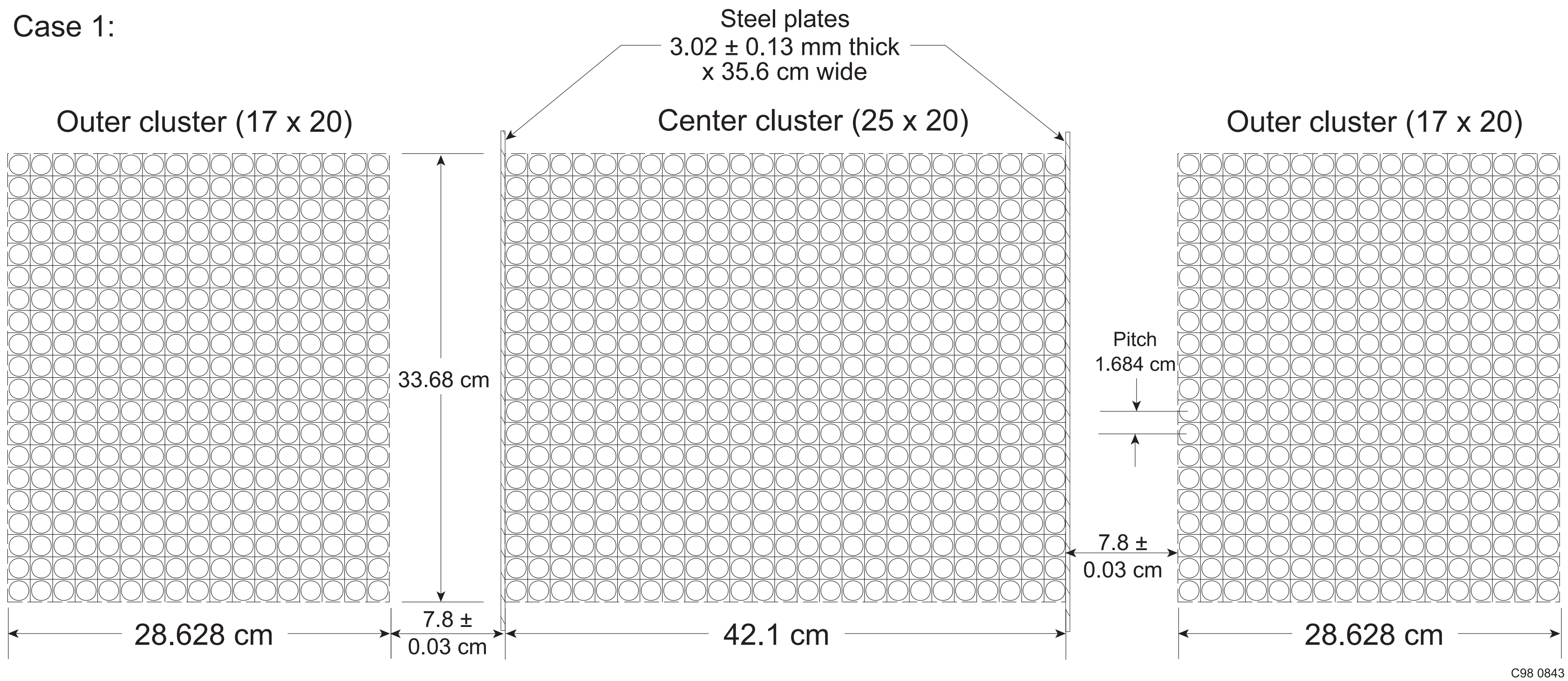


Figure 4. Typical Configuration (Case 1).

Table 2. $U(2.35)O_2$ Fuel-Rod Cluster Critical Configurations.

Case	Cluster Dimensions (number of rods)	Absorber Plates		Separation of Fuel Clusters (cm)	Expt. No.
		Material	Thickness (cm)		
1	25 x 20 (center) 17 x 20 (two outer)	304-L Steel	0.302 ± 0.013	7.80 ± 0.03	113
2	25 x 20 (center) 17 x 20 (two outer)	304-L Steel with 1.1 wt% B	0.298 ± 0.006	3.86 ± 0.02	114
3	25 x 20 (center) 17 x 20 (two outer)	304-L Steel with 1.6 wt% B	0.298 ± 0.006	3.46 ± 0.02	115
4	25 x 20 (center) 17 x 20 (two outer)	Boral B	0.292 ± 0.013[a]	1.68 ± 0.09	117
5	25 x 20 (center) 17 x 20 (two outer)	Boral C	0.231 ± 0.013[b]	1.93 ± 0.07	116
6	25 x 20 (center) 17 x 20 (two outer)	Boroflex	0.546 ± 0.018[c]	1.84 ± 0.05	118
7	25 x 20 (center) 17 x 20 (two outer)	Boroflex	0.408 ± 0.034[d]	1.73 ± 0.07	119
8	25 x 20 (center) 17 x 20 (two outer)	Cadmium	0.061 ± 0.003[e]	3.04 ± 0.02	123
9	25 x 18 (center) 20 x 18 (two outer)[f]	Copper	0.337 ± 0.008	5.24 ± 0.02	121
10	25 x 18 (center) 20 x 18 (two outer)[f]	Copper-Cadmium	0.357 ± 0.008	2.60 ± 0.02	122

(a) Includes 0.038 cm of Type 1100 aluminum on either side of the B_4C-Al absorber material.
(b) Includes 0.025 cm of Type 1100 aluminum on either side of the B_4C-Al absorber material.
(c) Includes 0.160-cm-thick Plexiglas on either side of 0.226±0.004-cm-thick Boroflex.
(d) Includes 0.091±0.023-cm-thick Type 304-L steel on either side of 0.226±0.004-cm-thick Boroflex.
(e) Cadmium was probably mounted on 0.296-cm-thick Plexiglas. (Personal communication, Sid Bierman, August, 1993)
(f) These clusters are 18 instead of 20 rods wide because the copper absorber plates were only 30.6 cm wide, while other absorber plates were 35.6 cm wide.

In Table 2 “Separation of Fuel Clusters” is the measured distance between the closest cell boundaries of rods of the center cluster and rods of a side cluster. (The cell boundary of each fuel rod is the square with side equal to the pitch centered on the axis of the fuel rod.) The inner surfaces of the absorber plates are positioned at the cell boundaries of the outer fuel rods on either side of the center fuel cluster. Therefore there was essentially no separation between the two absorber plates and the center cluster.

As an indication of the effects of the absorber plates, the critical separation of clusters without absorber plates corresponding to Cases 1 – 8, with 17 × 20-rod clusters at the ends and a 25 × 20-rod center cluster, is 9.88 cm (Case 20 of LEU-COMP-THERM-003). The critical separation of clusters without absorber plates corresponding to Cases 9 and 10, with 20 × 18-rod clusters at the ends and a 25 × 18-rod center cluster, is 6.78 cm (Case 21 of LEU-COMP-THERM-003)

1.3 Description of Material Data

1.3.1 Fuel Rod - UO_2 Fuel. Figure 3 (from Reference 13, Vol. 1, p. 29) and results of a fuel-rod sample analysis (Reference 13, Vol. 2, p. 3) are the bases for the fuel material characterization. As also stated in Reference 1, a fuel rod contains 825 g of UO_2 powder, 726 g of 2.35 wt.% enriched uranium, and 17.08 g of ^{235}U, at an oxide density of 9.20 g/cm^3.[a] The isotopic content of the uranium is given in Table 3.

Table 3. Isotopic Composition of Uranium in 2.35%-Enriched UO_2 Fuel Rods.
(Reference 8, p. 2.8)

Uranium Isotope	Wt.%[(a)]
^{234}U	0.0137 ± 0.0003
^{235}U	2.350 ± 0.003
^{236}U	0.0171 ± 0.0003
^{238}U	97.62 ± 0.003

(a) Values are originally from Reference 13, Vol 2, p. 3. Uncertainties are 1σ. (Note that the total of weight percents is 100.008.)

Aluminum Alloys. Aluminum components of the fuel rods are the top (longer) end plug of 1100 aluminum, the lower end plug of 5052 aluminum, and the clad of 6061 aluminum. Measured densities and ASTM Standard chemical compositions of these three types of aluminum are given in Table 4.[b] The ASTM Standard for these three aluminum alloys includes limits on impurities to maximums of 0.05 wt.% each and 0.15 wt.% total.

[a] These values are not self-consistent. See discussion in Section 2.1.

[b] ASTM Standard, from Reference 8, pp. A.2-A.4, and from *Alcoa Aluminum Handbook*, Aluminum Company of America, 1967, pp. 46-50. About the densities, Appendix A of Reference 8 says, "(Not part of standard – measured by volume displacement)".

Table 4. Measured Densities and Standard Compositions of Aluminum Alloys.

Element	Wt.%
1100 Aluminum (density - 2.70 g/cm^3)	
Si, Fe	1.0 (combined maximum)
Cu[(a)]	0.05-0.20 (0.12 nominal)
Mn	0.05 (maximum)
Zn	0.10 (maximum)
Al	99.00 (minimum)
5052 Aluminum (density - 2.69 g/cm^3)	
Si, Fe	0.45 (combined maximum)
Cu	0.10 (maximum)
Mn	0.10 (maximum)
Mg	2.2-2.8 (2.5 nominal)
Cr	0.15-0.35 (0.25 nominal)
Zn	0.10 (maximum)
Al	remainder (96.10-97.65)
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)

(a) reported as Cr in Reference 8; composition given as coming from ASTM standard B210-78; two handbooks gave Cu, rather than Cr, with this wt.%.

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

Polypropylene. The material density of the two polypropylene (C_3H_5) lattice plates was 0.904 g/cm^3. (The impurity analysis on polypropylene lattice plates in later experiments probably does not apply to these experiments.[a])

Acrylic. The acrylic fuel-rod support plate had a density of 1.185 g/cm^3 and was 8 wt.% hydrogen,

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

60 wt.% carbon, and 32 wt.% oxygen (References 4 and 14). Uncertainties and methods of determination were not given.

1.3.3 Absorber Plates - The neutron absorbers used in the experiments were steel, Boral, Boroflex, cadmium, and copper plates. The chemical compositions from References 1, 4, 12, and 14 are given in Tables 5-8. According to Reference 4, "Error limits where shown are one standard deviation based on multiple chemical analyses. Error limits not shown for minor impurities. 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.[a]

Steel Plates. Three different types of 304L steel plates were used: without boron, with 1.1 wt.% boron, and with 1.6 wt.% boron. The reported density of the steel plate without boron is 7.930 g/cm^3. The densities of the steel plates with 1.1 and 1.6 wt.% boron are 7.900 and 7.770 g/cm^3, respectively. Chemical compositions of the three types of the steel plates are given in Table 5.

Table 5. Compositions of Steel Plates (Wt.%'s).

Element	304L Steel Plates		
	No Boron	1.1 wt.% Boron	1.6 wt.% Boron
B	-	1.05 ± 0.08	1.62 ± 0.10
Cr	18.56 ± 0.10	19.03 ± 0.10	19.60 ± 0.10
Cu	0.27 ± 0.05	0.28 ± 0.05	0.26 ± 0.05
Fe	68.24 ± 0.34	68.04 ± 0.34	66.40 ± 0.33
Mn	1.58 ± 0.05	1.58 ± 0.05	1.69 ± 0.05
Mo	0.26 ± 0.05	0.49 ± 0.05	0.31 ± 0.05
Ni	11.09 ± 0.06	9.53 ± 0.05	10.12 ± 0.05

Boral Plates. The reported densities of the 0.216-cm-thick and the 0.181-cm-thick cores of Boral B and Boral C are, respectively, 2.50 and 2.47 g/cm^3. Their chemical compositions are given in Table 6. The distribution of sizes of the B_4C particles in the aluminum matrix of the Boral, as provided by the manufacturer, is given in Appendix D. The 0.038-cm-thick clad on both sides of the Boral B plates and the 0.025-cm-thick clad on both sides of the Boral C plates are Type 1100 aluminum.

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

Table 6. Composition of B_4C-Al Cores of Boral Plates (Wt.%'s).

Element	Boral Plates	
	Boral B	Boral C
Al	61.21[(a)]	59.26[(a)]
B	30.36[(a)]	31.88[(a)]
C	8.43[(a)]	8.86[(a)]
Fe	0.02	0.05
Mg	0.01	0.01
Na	0.02	0.02
Si	-	0.06

(a) Based on weights of mixture components at time of fabrication (References 4 and 14).

Boroflex Plates. The reported density of the 0.226-cm-thick Boroflex was 1.731 g/cm^3. The chemical composition is given in Table 7. The distribution of sizes of the B_4C particles in the rubber matrix of the Boroflex, as provided by the manufacturer, is given in Appendix D. The stiffening plates on both sides of the Boroflex were 0.16-cm-thick Plexiglas (Case 6) or 0.091-cm-thick steel (Case 7).

Table 7. Composition of Boroflex.

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 8.

Table 8. Compositions of Copper Plates.

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

1.3.4 Water - Laboratory analyses of the water in the tank were done. The reported average impurity concentrations are given in Table 9 (Reference 4). The approximate average water temperature was 22°C.

Table 9. Water Impurities for Experiments (Reference 4).

Component	Concentration (ppm)[(a)]
Cl	1.7 ± 0.6
NO_3^-	0.02 ± 0.01
Cr^{+6}	<0.01
Zn	0.9 ± 1.1
Mn	<0.01
Pb	0.008 ± 0.001
F	0.15 ± 0.04
Fe	<0.03
Cu	<0.01
Cd	0.020 ± 0.006
Gd	10.4 ± 3.6
SO_3	13.4 ± 5.0

(a) Error limits are standard deviations observed in 3 samples.

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

1.4 Supplemental Experimental Measurements

Neutron count rate as a function of cluster separation (no absorber plates) was plotted. The plot indicated that clusters were essentially isolated from each other at a cluster separation of 12 cm.

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

$\underline{UO_2}$. Some uncertainty exists in the characterization of the fuel rods. Dimensions and masses are stated in the source document (Reference 13, Vol. 1, p. 29) with no mention of measurement techniques or uncertainties. The 3σ-uncertainty in enrichment is stated as 0.01 wt.% without further discussion (Reference 13, Vol. 2, p. 3).

Quantities characterizing the fuel are not self-consistent. Table 10 gives the mass of ^{235}U derived in different ways from the given quantities. The highest and lowest uranium masses represent a difference of less than 0.2% (727.22 g vs. 726 g).

Table 10. Mass of ^{235}U Per Fuel Rod Derived from Different Reported Sets of Quantities.

Reported Quantities	Derived ^{235}U Mass (g)
^{235}U mass[(a)]	17.08
Mass of U (726 g)[(b)] and 2.35 wt.% ^{235}U	17.0610
Mass of UO_2 (825 g)[(c)] and 2.07 wt.% ^{235}U in UO_2 [(d)]	17.0775[(e)]
UO_2 density (9.20 g/cm^3)[(c)], volume of fuel[(f)], and 2.07 wt.% ^{235}U in UO_2 [(d)]	17.0827
Mass of UO_2 (825 g)[(c)], 2.35 wt.% ^{235}U, and 2-to-1 ratio of O atoms to U atoms in UO_2	17.0896
Total rod mass (917 g)[(a)], volume[(f)] and density of aluminum, and 2.07 wt.% ^{235}U in UO_2 [(d)]	17.0775

(a) Given only in Reference 1.
(b) Given in References 1 and 8.
(c) Given in all reports on experiments with 2.35 wt.% enriched rods. (References 1, 3-6, and 8.)
(d) Reference 13, Vol. 2, p. 3.
(e) This mass and the given wt.%'s of the uranium isotopes result in a formula for uranium dioxide of $UO_{2.012}$. This is within the typical range for UO_2 powders of $UO_{2.005}$ and $UO_{2.129}$.[a]
(f) Calculated from reported dimensions.

[a] C.R. Tipton, Jr., ed., *Reactor Handbook, Second Edition*, Interscience Publishers, Inc., N.Y., vol. I, p. 292.

An experimenter recommended that mass of the UO_2 powder be used as the basic quantity for characterizing the fuel, rather than grams of U per rod, average weight of the rod, or reported fuel density.[a] Therefore to determine atom densities of the fuel for the benchmark model, the reported masses of UO_2 (825 g) and of ^{235}U (17.08 g), with uranium enrichment of 2.35% and the reported fuel-region dimensions are used.

There is a possibility of axial variation of fuel-powder density, perhaps due to settling of the powder during handling of the fuel rods. Therefore, the effect of uneven fuel density is an additional uncertainty.

Aluminum Alloys. In order to test the sensitivity of the critical configurations to the small amounts of alloying substances in the aluminum, four cases were calculated with ONEDANT of a near-critical, cylindrical, water-reflected lattice of rods at pitch 1.684 cm. Each case used only one of the three aluminum alloys or pure aluminum for clad. Results are given in Table 11. The greatest difference is 0.16%, between pure aluminum clad and 6061 aluminum clad. Therefore, to more accurately represent the fuel rods for this benchmark, the specified aluminum alloys with nominal amounts of all constituents are included. (The effect of the uncertainty from approximating clad length from a diagram of the fuel rod is judged to be negligible.)

Table 11. Calculated Effects of Different Aluminum Claddings.(a)

Clad Material	Δk_{eff} (%)(b)
6061 aluminum(c)	-
1100 aluminum(c)	0.01
5052 aluminum(c)	0.10
aluminum(d)	0.16

(a) Clad thickness was increased by 28% to include the amount of aluminum in the endplugs.
(b) homogenized fuel-rod mixture, SCALE 27-group ENDF/B-IV cross sections created by CSASIX.
(c) Minimum amounts of aluminum and maximum amounts of other components (see Table 4).
(d) Density is the nominal ^{27}Al density in 6061 aluminum alloy (97.325 wt.% of 2.69 g/cm^3).

The magnitudes of other uncertainties in fuel-rod data are taken as half the value of the least significant digit, when the uncertainty is not given. The effects on k_{eff} of the uncertainties in enrichment, fuel diameter, fuel length, clad thickness, pitch, and uranium mass for a near-critical configuration are summarized in Table 12. Effects were calculated with ONEDANT and CSAS ENDF/B-IV 27-group cross sections using an infinite-slab homogeneous mixture representing the fuel rods. The calculations were P_3, S_{16}, with a convergence criterion of 10^{-6}.

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

To check the effect of possible uneven density of the fuel powder, MCNP calculations of five of the ten cases were run with the upper third of the fuel at 95% of nominal density, the middle third at nominal density, and the bottom third of the fuel at 105% of nominal density. Results were compared to base cases with fuel at uniform nominal density. Calculated effects of uneven density were both positive and negative, with three of the five Δk_{eff}'s within the standard deviation of the differences, which was 0.10% of k_{eff}. The two larger Δk_{eff}'s, one positive and one negative, were within two standard deviations. (ONEDANT and TWODANT calculations confirmed that effects were small, with $\Delta k_{eff} < 0.0001$.) To account for effects of possible uneven fuel density, an additional 0.10% uncertainty is included in fuel-rod uncertainties of Table 12.

Results indicate that effects on k_{eff} of uncertainties in fuel-rod characterization and pitch are 0.15%.

Table 12. Sensitivity of k_{eff} to Uncertainties in Fuel-Rod Characterization.

Quantity (Amount of Change)	% Δk_{eff} (ONEDANT)[(a)]
Enrichment (± 0.003 wt.%[(b)])	±0.04
Fuel Diameter (± 0.0127 cm)	±0.03
Fuel Length (± 0.127 cm)	±0.02
Clad Diameter (± 0.00127 cm)	±0.02
Pitch (± 0.0076 cm[(c)])	±0.09
Uranium Mass (-0.81 g and +0.41 g)	±0.01
Uneven Fuel Density (±5%)	±0.10[(d)]
Combined Effect	±0.15

(a) 27-group ENDF/B-IV cross sections with homogenized lattice-cell fuel region (CSASIX); sample input given in Appendix C.
(b) The 3σ uncertainty (Reference 13, Vol. 2, p. 3) was 0.01%.
(c) The largest standard deviation for sets of center-to-center spacing measurements for triangular-pitch lattice plates of Reference 8 (Appendix E) was 0.003 inch (0.0076 cm). References 7 (p. 2) and 8 (p. 36) give the uncertainty in pitch as ± 0.005 cm. Reference 9 (p. 3.2) and Appendix D of Reference 10 give the uncertainty in pitch as ± 0.001 cm. Therefore, the calculated uncertainty for ±0.0076 cm is conservative.
(d) MCNP calculations.

2.2 <u>Water Reflector Thickness</u>

The minimum thickness of the top water reflector is 15 cm above the fuel region. Since the top end plug is 2 inches (5.08 cm) long, the minimum water reflector thickness above the rods is 9.92 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.

Additionally ONEDANT was used to determine the effect of radial-reflector thickness for a near-critical, cylindrical, XSDRN-homogenized array of pins. The difference in k_{eff} between a 15-cm-thick side reflector and a 30-cm-thick side reflector is less than 0.001%. Replacing the outermost 15 cm of the 30-cm-thick water with 20% stainless steel in water affects k_{eff} by less than 0.002%. Therefore, lack of specifications about detectors, which were placed in the water reflector more than 15 cm away from the clusters, does not affect acceptability of these experiments.

2.3 Gadolinium Impurity

Water impurity sensitivity studies in Appendix C of LEU-COMP-THERM-003 indicate that the only significant reported impurity is the gadolinium. As shown in Table 9, a gadolinium concentration of 10.4 ± 3.6 g/m^3 is reported to be present in the water moderator and reflector, and is assumed to be dissolved in the water.

One experimenter[a] provided the results of the water sample analyses for experiments reported in Reference 4. A letter from Loren J. Maas of the Hanford Environmental Health Foundation to B. M. Durst dated August 31, 1979, stated the results of analyses of three water samples from the set of experiments from Reference 4. The gadolinium results were stated in the letter as 12.0, 6.3, and 13.0 mg/liter of Gd. The average value is 10.4 g/m with a standard deviation of 3.6 g/m , as reported in Reference 4. The three Gd sample values were verified by P. A. Thurman of the water analysis laboratory, who checked the original laboratory worksheet. Recorded values were 12.3, 6.3, and 12.6 mg/l of gadolinium. (Apparently these values were rounded to two significant figures in the letter reporting results.) Ms. Thurman said[b] such small amounts could be detected because the sample was concentrated by evaporation before analysis. Another experimenter[c] reported information from a recent discussion with Maureen K. Hamilton, Laboratory Director, Environmental Sciences, the Hanford Environmental Health Foundation. Ms. Hamilton said that the 1979 analysis was made just after a new water analysis standard was issued that required analysis for gadolinium. At that time, the

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

[b] Personal communication, Pam Thurman, April 1994.

[c] Personal communication, Michael Durst, October 1994.

standard required analysis of the exact amount of gadolinium present. (Later, the standard was revised to require only a determination that the amount of gadolinium was less than 40 ppm.) Ms. Hamilton stated that the analysis was made using emission and/or absorption spectroscopy.

A letter dated August 4, 1980, reporting the analyses of samples from the later experiments in Reference 5, which were similar except for the addition of steel reflecting walls, did not report a value for gadolinium.[a]

Possible sources of the gadolinium are paint on the tank inner wall,[b] breach of cladding on gadolinium safety rods used in experiments that were alternated with these experiments,[c] and gadolinium solution that was present in the same laboratory at that time. Although all water was replaced as experiments were alternated and precautions were taken to contain gadolinium solutions, the presence of gadolinium impurity is not impossible.[d] (The natural abundance of gadolinium in the earth's crust is 6.1 ppm.[e] Several gadolinium compounds are soluble in room-temperature water.[f])

Although calculational results of this set of experiments are significantly low, as discussed in Section 4, evidence indicates that gadolinium impurity at the reported concentration was indeed present.

The effects on k_{eff} of impurities in the water moderator-reflector for a near-critical cylindrical cluster of $U(2.35)O_2$ fuel pins are given in Appendix C of LEU-COMP-THERM-003. All impurities except boron and gadolinium affect the calculated value of k_{eff} by less than 0.005%. The reported gadolinium concentration of 10.4 g/m^3 causes a significant reduction (~0.8%) in k_{eff}. The sensitivity study in LEU-COMP-THERM-003 indicates that the effect of the 3.6 g/m^3 standard deviation in gadolinium concentration is 0.29% for 1.684-cm-pitch rods. This is added to the uncertainty in k_{eff} for the benchmark model. (If the entire 10.4 g/m^3 Gd impurity concentration from Reference 4 is considered to be an uncertainty, the uncertainty in k_{eff} due to gadolinium impurity is 0.79%.)

2.4 <u>Temperature Data</u>

Water temperatures were recorded in logbooks for approximately ten percent of the experiments. Measured temperatures ranged from 18°C to 26°C. ONEDANT calculations with 27-group cross sections, for an infinite slab of fuel pins reflected on both sides by 15 cm of water, gave a change in k_{eff} of 0.04% between these two extremes of temperature. (The gadolinium impurity was not included in

---

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

[b] Personal communication, B. M. Durst, September 1994.

[c] B. M. Durst and James Mincey, personal communication, September 1994.

[d] Personal communication, B. M. Durst, February 1995. Although Mr. Durst believes that results of the water sample analyses cannot be discounted, he believes that it is unlikely that such a large amount of Gd could have been present in the tank. (The 10.4 g/m represents about 60 grams of gadolinium in the tank.)

[e] N. N. Greenwood and A. Earnshaw, Chemistry of the Elements, Pergamon Press, New York, p. 1426, 1984.

[f] In particular, gadolinium bromide, chloride, fluoride, iodide, dimethylphosphate, nitrate, selenate, and sulfate. (CRC Handbook of Chemistry and Physics, R.C. Weast, ed., CRC Press, Inc., Boca Raton, Florida, 68th edition, p. B-91, 1987.)

this sensitivity study.) Therefore, an estimate of the uncertainty in k_{eff} due to the effect of temperature is half this amount, namely 0.02%.

2.5 Other Sensitivity Calculations

Sensitivity studies described in this section used TWODANT models, with CSAS ENDF/B-IV 27-group cross sections. A homogeneous mixture was used to model fuel rod clusters. The calculations were P_1, S_8, with a convergence criterion of 10^{-5}.

2.5.1 Cluster Separations - The measurement uncertainties in cluster separation (see Tables 2 through 7) vary from 0.02 cm to 0.09 cm. To calculate the effect on k_{eff}, cluster separations were reduced by the particular uncertainty for all ten cases. Results are summarized in Table 13. The largest effect was 0.049% for Case 4. This value may be used as the k_{eff} uncertainty due to uncertainty in cluster separation.

Table 13. Uncertainties in Benchmark-Model k_{eff} Due to Cluster Separation Measurement Uncertainty.

Case	Absorber Plate Material	Uncertainty in Cluster Separation Measurement (cm)	Δk_{eff} (%)
1	304-L Steel	0.03	0.018
2	304-L Steel with 1.1 wt% B	0.02	0.018
3	304-L Steel with 1.6 wt% B	0.02	0.017
4	Boral B	0.09	0.049
5	Boral C	0.07	0.044
6	Boroflex	0.05	0.028
7	Boroflex	0.07	0.039
8	Cadmium	0.02	0.017
9	Copper	0.02	0.023
10	Copper-Cadmium	0.02	0.018

2.5.2 Absorber Plate Thickness - The effects of the uncertainties in absorber plate thickness on k_{eff} were calculated for all of the ten cases. Results in Table 14 indicate that the uncertainty in k_{eff} due to uncertainty in absorber plate thickness is less than 0.033% Δk_{eff}. This is included in the uncertainty of the benchmark-model k_{eff}.

Table 14. Uncertainties in Benchmark-Model k_{eff} Due to Absorber Plate Thickness Uncertainty.

Case	Absorber Plate Material	Uncertainty in Absorber Plate Thickness (cm)	Δk_{eff} (%)
1	304-L Steel	0.013	0.033
2	304-L Steel with 1.1 wt% B	0.006	0.024
3	304-L Steel with 1.6 wt% B	0.006	0.022
4	Boral B	0.013	0.002
5	Boral C	0.013	0.002
6	Boroflex	0.018	0.005
7	Boroflex	0.034	0.018
8	Cadmium	0.003	0.001
9	Copper	0.008	0.029
10	Copper-Cadmium	0.008	0.027

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 (average amounts of components) is given in Tables 15 through 21. 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. For Case 1 of Table 2 the effects of maximum weight percents of iron and manganese in the non-borated steel plate were individually compared to effects of minimum weight percents. The difference from the base case is shown in Table 15. Similarly, for Case 2 effects of maximum and minimum weight percents of boron, iron, and manganese in the 1.1%-borated steel plate were individually calculated and compared to the base case. A ±0.8 at.% variation in ^{10}B isotopic fraction in natural boron was also calculated. Results are shown in Table 16. Similar sensitivity calculations were performed for the 1.6%-borated steel plate (Case 3), and results are given in Table 17.

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

Case	Description	Δk_{eff} (%)
1	Fe, (68.24) ± 0.34 wt.%	0.002
	Mn, (1.58) ± 0.05 wt.%	0.002
	Non-Borated Steel Plates Replaced with Water	0.966

Table 16. Calculated Effect of Composition Uncertainties of 1.1%-Borated Steel Plate on k_{eff}.

Case	Description	Δk_{eff} (%)
2	B, (1.05) ± 0.08 wt.%	0.074
	^{10}B, (19.9) ±0.8 at.%	0.042
	Mn, (1.58) ± 0.05 wt.%	<0.001
	Fe, (68.04) ± 0.34 wt.%	<0.001
	1.1%-Borated Steel Plates Replaced with Water	4.994

Table 17. Calculated Effect of Composition Uncertainties of 1.6%-Borated Steel Plate on k_{eff}.

Case	Description	Δk_{eff} (%)
3	B, (1.62) ± 0.10 wt.%	0.061
	^{10}B, (19.9) ±0.8 at.%	0.039
	Mn, (1.69) ± 0.05 wt.%	<0.001
	Fe, (66.40) ± 0.33 wt.%	<0.001
	1.6%-Borated Steel Plates Replaced with Water	5.570

Boral Plates. For Cases 4 and 5 of Table 2, the maximum and minimum at.%'s of ^{10}B in boron were compared to the base case, with results given in Table 18.

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

Case	Description	Δk_{eff} (%)
4	^{10}B, (19.9) ±0.8 at.%	0.035
	Boral B Plates Replaced with Water	7.280
5	^{10}B, (19.9) ±0.8 at.%	0.034
	Boral C Plates Replaced with Water	7.171

Boroflex Plates. For Cases 6 and 7 the maximum and minimum at.%'s of ^{10}B in boron were compared to the base case, with results given in Table 19.

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

Case	Description	Δk_{eff} (%)
6	B, (32.74) ± 0.05 wt.%	0.001
	^{10}B, (19.9) ±0.8 at.%	0.035
	Fe, (0.05) ± 0.06 wt.%	<0.001
	Boroflex Plates Replaced with Water	7.028
7	B, (32.74) ± 0.05 wt.%	0.001
	^{10}B, (19.9) ±0.8 at.%	0.035
	Fe, (0.05) ± 0.06 wt.%	<0.001
	Boroflex Plates Replaced with Water	7.031

Cadmium Plates. The maximum and minimum wt.% Cd of the cadmium plate were compared for Case 8 with results given in Table 20. Because absorber plates were reported to be at the outer cell boundaries of rods of the center cluster, in the benchmark model the Cd plates are next to the center fuel-rod cluster, with a Plexiglas stiffener sheet against the outer side of each Cd plate. However, placement of the 0.296-cm-thick Plexiglas sheet was not specified. It is possible that the Plexiglas sheets were next to the center fuel-rod cluster, that two Plexiglas sheets were used for each sheet of cadmium, or that no Plexiglas was used. The effect of Plexiglas instead of Cd placed next to the center cluster is 0.0030. The effect on k_{eff} of no Plexiglas stiffener sheet was -0.0004. The effect of two (rather than one) 0.296-cm-thick Plexiglas sheets for each Cd sheet is given in Table 20.

Table 20. Calculated Effect of Cadmium Plate Composition Uncertainties on k_{eff}.

Case	Description	Δk_{eff} (%)
8	Cd, (99.7) ± 0.3 wt.%	0.002
	Plexiglas Sheet Placement	0.346
	Cadmium Plates Replaced with Water	6.025

Copper Plates. For Cases 9 and 10, compositions with the maximum and minimum wt.% of cadmium of the copper plate with cadmium were compared to the base case, with results given in Table 21.

Table 21. Calculated Effect of Copper Plate Composition Uncertainties on k_{eff}.

Case	Description	Δk_{eff} (%)
9	Cu, (99.6) ± 0.14 wt.%	0.003
	Copper Plates without Cd Replaced with Water	1.451
10	Cu, (98.685) ± 0.3 wt.%	0.002
	Cd, (0.989) ± 0.003 wt.%	0.003
	Copper Plates with Cd Replaced with Water	4.413

Results indicate that the maximum uncertainty in k_{eff} due to uncertainty in composition of absorber plates (not including the larger effect of Plexiglas-stiffener-sheet placement for Case 8) is 0.085%, the effect of combining the two boron uncertainties for Case 2 (Table 16). This 0.085% maximum effect is included in the uncertainty of the benchmark-model k_{eff} for all cases.

2.6 Conclusions of Acceptability

Because the effects of the non-borated steel and copper without cadmium plates in these experiments with water were calculated to be small (1-1.5% of k_{eff}), the cases that include these plates (Cases 1 and 9) 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-pitched, aluminum-clad cylindrical fuel pins in water in three rectangular clusters arranged in a row with absorber plates between clusters. Several sensitivity studies were performed to justify simplifications of the benchmark model.

3.1.1 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 <0.01%. This is included in the uncertainty of the benchmark-model k_{eff}.

3.1.2 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 are shown in Table 22. The conclusions are that the carbon steel tank has no effect and the acrylic support plate has a small effect (0.06%). Therefore the support plate is retained in the benchmark model and the tank wall is omitted.

Table 22. Calculated Effect of Bottom Reflector Materials on k_{eff}.

Reflector			Δk_{eff} (%)
Inner 2.54 cm	Middle 15.3 cm	Outer 0.952 cm	
acrylic	water	carbon steel	-
acrylic	water	water	+0.00
water	water	water	-0.06

Because of the negligible effect of materials beyond the water reflector region (Section 2.2), nothing outside the water reflector is included in the benchmark model.

The sensitivity study in LEU-COMP-THERM-003, which were the same rods at the same pitch, indicates that the reported gadolinium impurity in the water causes a significant effect (~0.8%) on k_{eff}. Therefore the 10.4 g/m^3 gadolinium concentration is included in the water moderator-reflector.

[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).

Table 23 gives Monte Carlo calculated results for the ten configurations with and without 10.4 g/m^3 gadolinium in water of the reflector and moderator. As expected, gadolinium reduces k_{eff} by approximately 0.8%. Recall (Section 2.3) that the magnitude of the calculated uncertainty in the benchmark-model k_{eff} due to the reported uncertainty in gadolinium (±3.6 g/m^3) was 0.29%.

Table 23. Calculated Results[(a)] for Cases 1-10, U(2.35)O_2 Fuel Rods, 1.684-cm Pitch in Water, with and without Gadolinium Impurities in Water.

Code (Cross Section Set) → Case ↓	KENO (44-Group ENDF/B-V)	KENO (44-Group ENDF/B-V) w/o Gd in Water	MCNP (Continuous Energy ENDF/B-V)	MCNP (Continuous Energy ENDF/B-V) w/o Gd in Water
1	0.9864	0.9954	0.9845	0.9961
2	0.9864	0.9954	0.9829	0.9940
3	0.9830	0.9898	0.9839	0.9941
4	0.9792	0.9916	0.9854	0.9916
5	0.9849	0.9892	0.9849	0.9949
6	0.9884	0.9910	0.9881	0.9950
7	0.9857	0.9933	0.9858	0.9921
8	0.9877	0.9931	0.9856	0.9956
9	0.9872	0.9910	0.9835	0.9940
10	0.9863	0.9916	0.9867	0.9900
Average of the above ten cases	0.9855	0.9921	0.9851	0.9937
Average change in k_{eff} when Gd is removed	-	0.66%	-	0.86%

(a) Standard deviations of calculations ranged from 0.0015 to 0.0019.

3.1.3 Absorber Plates - Impurities Fe, Mg, Na, and Si in the Boral absorber plates, which were each measured as no more than 0.06 wt.% (see Table 6), were judged to have negligible effect 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 6) and Cd (Case 8) plates. The 304L steel composition of the absorber plates for Case 1 was used to model the 0.091-cm-thick 304L steel stiffener plate used for the Boroflex for Case 7. The effects of any small unknown differences in actual compositions are judged to be negligible.

3.2 Dimensions

Fuel-rod dimensions, as modeled, are shown in Figure 5. The entire rod has a diameter of 1.27 cm and is 97.79 cm long. The UO_2 fuel region has a diameter of 1.1176 cm and is 91.44 cm long. The clad is 0.0762 cm thick and 93.19 cm long. The clad surrounds the fuel, the lower end plug, and 0.48 cm of the top end plug. There is no gap between the clad and fuel or end plugs. The top end plug is 5.08 cm long. The lower end plug is 1.27 cm long.

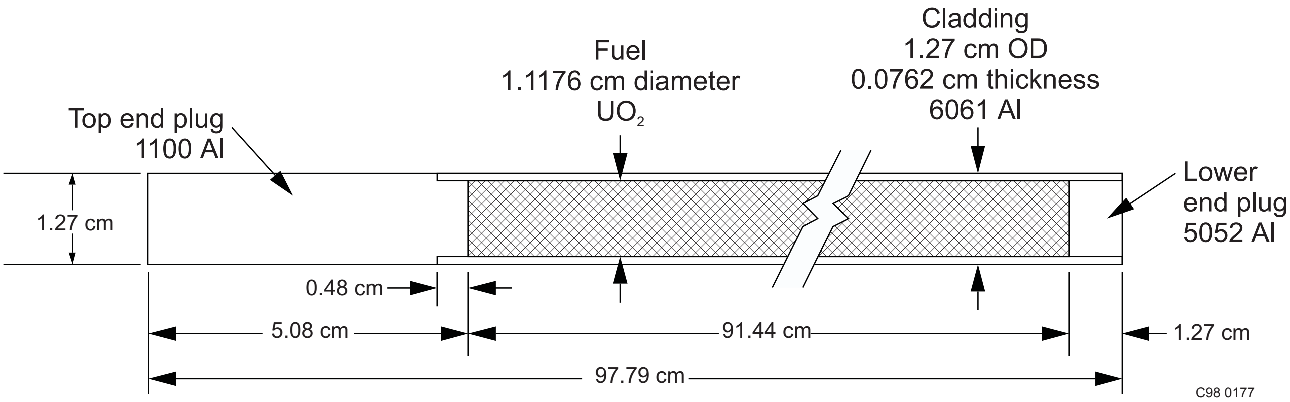


Figure 5. Model of Fuel Rod.

The fuel rods are arranged in rectangular clusters at a square pitch of 1.684 cm. Each configuration includes 3 clusters and 2 absorber plates as shown in Figure 6. The absorber plates are between clusters at the outer fuel-rod cell boundary of the middle cluster. The plates are parallel to the interacting faces of adjacent clusters, and are centered horizontally with respect to the fuel region of the cluster faces. All absorber plates are 91.5 cm long and extend upward from the bottom of the fuel region.

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 four side reflectors are 30-cm-thick water. The top reflector is 9.92 cm of water above the top plugs of the fuel rods.

Cluster and absorber-plate dimensions are given in Table 24. Cluster dimensions are given as rods along the direction of cluster placement followed by the width of all three clusters, in rods. Separation of clusters, S_c, is the distance between closest fuel-rod cell boundaries of adjacent clusters.

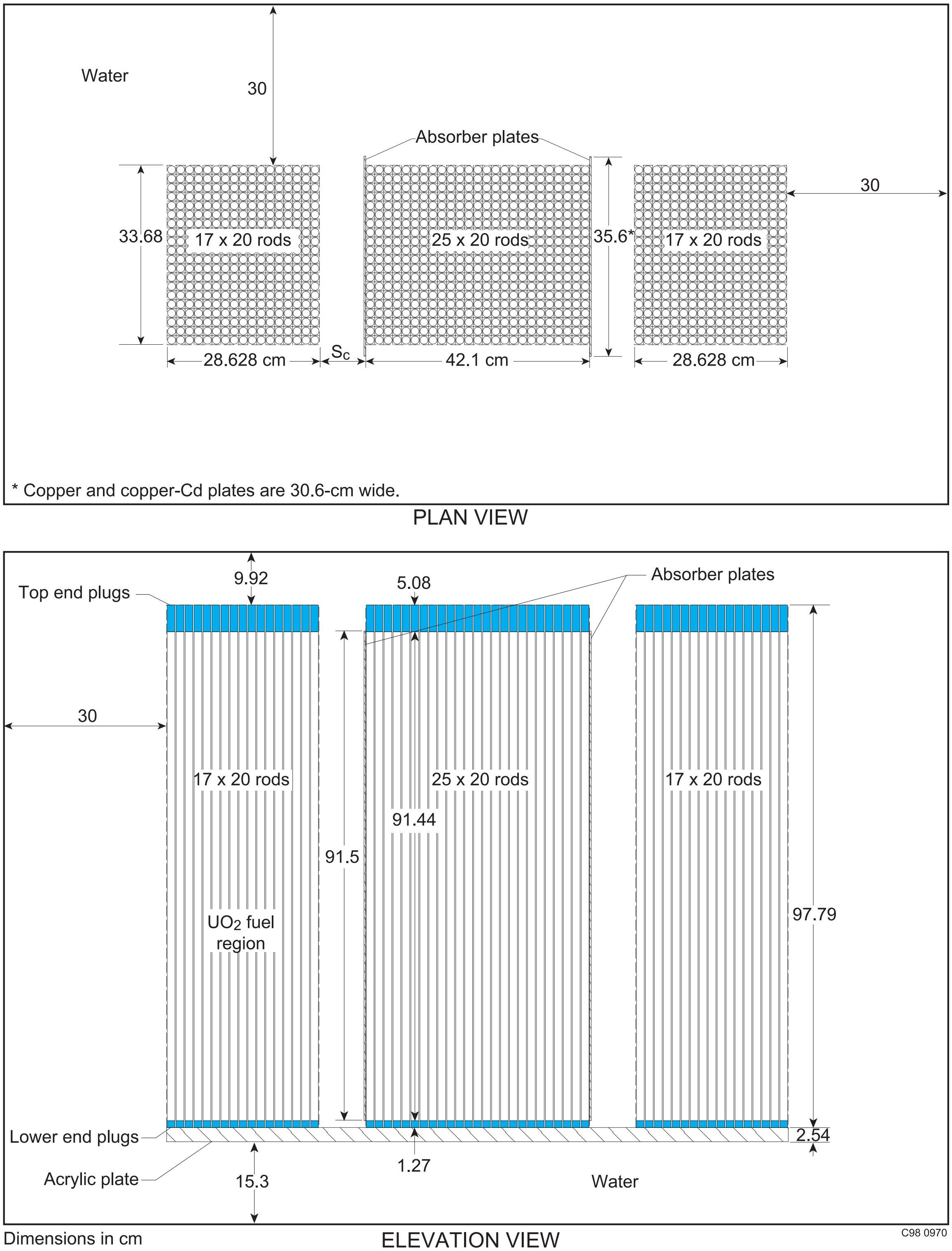


Figure 6. Example of Benchmark Model (Case 1).

Table 24. Critical Configurations.

Case	Cluster Dimensions (rods)	Separation of Clusters, S_c (cm)	Absorber-Plate Material	Absorber-Plate Thickness (cm)	Width of Plates (cm)
1	25 x 20 (center) 17 x 20 (two outer)	7.80	304-L Steel	0.302	35.6
2	25 x 20 (center) 17 x 20 (two outer)	3.86	304-L Steel with 1.1 wt% B	0.298	35.6
3	25 x 20 (center) 17 x 20 (two outer)	3.46	304-L Steel with 1.6 wt% B	0.298	35.6
4	25 x 20 (center) 17 x 20 (two outer)	1.68	Boral B	0.292[(a)]	35.6
5	25 x 20 (center) 17 x 20 (two outer)	1.93	Boral C	0.231[(b)]	35.6
6	25 x 20 (center) 17 x 20 (two outer)	1.84	Boroflex	0.546[(c)]	35.6
7	25 x 20 (center) 17 x 20 (two outer)	1.73	Boroflex	0.408[(d)]	35.6
8	25 x 20 (center) 17 x 20 (two outer)	3.04	Cadmium	0.061[(e)]	35.6
9	25 x 18 (center) 20 x 18 (two outer)	5.24	Copper	0.337	30.6
10	25 x 18 (center) 20 x 18 (two outer)	2.60	Copper-Cadmium	0.357	30.6

(a) Includes 0.038 cm of Type 1100 aluminum on either side of the B_4C-Al absorber material.
(b) Includes 0.025 cm of Type 1100 aluminum on either side of the B_4C-Al absorber material.
(c) Includes 0.160-cm-thick Plexiglas on either side of 0.226-cm-thick Boroflex.
(d) Includes 0.091-cm-thick Type 304-L steel on either side of 0.226-cm-thick Boroflex.
(e) Cadmium mounted on 0.296-cm-thick Plexiglas, with the cadmium closer to the center cluster.

3.3 Material Data

3.3.1 Fuel Rods - The fuel region, as shown in Figures 5 and 6, consists of 825 g of UO_2. The mass of ^{235}U in each rod is 17.08 g. The isotopic composition of the uranium is 0.0137 wt.% ^{234}U, 2.35 wt.% ^{235}U, 0.0171 wt.% ^{236}U, and balance (97.6192 wt.%) ^{238}U.

Fuel rods have 6061 aluminum clad, with a 5052 aluminum lower end plug and a 1100 aluminum top end plug, as shown in Figure 5. Aluminum clad and end-plug weight percents and fuel-rod atom densities are given in Table 25. Weight percents are the approximate average values (see Table 4).

Table 25. Fuel-Rod Atom Densities.

Material	Isotope	Wt.%	Atom Density (barn-cm)$^{-1}$
$U(2.35)O_2$ Fuel	^{234}U		2.8563×10^{-6}
	^{235}U		4.8785×10^{-4}
	^{236}U		3.5348×10^{-6}
	^{238}U		2.0009×10^{-2}
	O		4.1202×10^{-2}
1100 Aluminum (top end plug, clad of Boral absorber plates ; 2.70 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}
5052 Aluminum (lower end plug; 2.69 g/cm^3)	Al	96.65	5.8028×10^{-2}
	Cr	0.25	7.7888×10^{-5}
	Cu	0.05	1.2746×10^{-5}
	Mg	2.5	1.6663×10^{-3}
	Mn	0.05	1.4743×10^{-5}
	Zn	0.05	1.2387×10^{-5}
	Si	0.225	1.2978×10^{-4}
	Fe	0.225	6.5265×10^{-5}
6061 Aluminum (clad; 2.69 g/cm^3)	Al	97.325	5.8433×10^{-2}
	Cr	0.2	6.2310×10^{-5}
	Cu	0.25	6.3731×10^{-5}
	Mg	1.0	6.6651×10^{-4}
	Mn	0.075	2.2115×10^{-5}
	Ti	0.075	2.5375×10^{-5}
	Zn	0.125	3.0967×10^{-5}
	Si	0.6	3.4607×10^{-4}
	Fe	0.35	1.0152×10^{-4}

3.3.2 Absorber Plates – Steel, Boral, Boroflex, cadmium, and copper plate atom densities are given in Tables 26 and 27. Boron is assumed to be 19.9 at.% ^{10}B and 80.1 at.% ^{11}B.[a]

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

Table 26. Steel Absorber-Plate Atom Densities.

Material	Isotope	Wt.%	Atom Density $(\text{barn-cm})^{-1}$
304L Steel without B[(a)] (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 wt.% 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}
304L Steel with 1.6 wt.% B (7.77 g/cm^3)	^{10}B	1.62 wt.% boron, 19.9 at.% ^{10}B	1.3953×10^{-3}
	^{11}B	1.62 wt.% boron, 80.1 at.% ^{11}B	5.6163×10^{-3}
	Cr	19.6	1.7638×10^{-2}
	Cu	0.26	1.9145×10^{-4}
	Fe	66.4	5.5634×10^{-2}
	Mn	1.69	1.4394×10^{-3}
	Mo	0.31	1.5119×10^{-4}
	Ni	10.12	8.0684×10^{-3}

(a) also used for 304L steel stiffener plate of Boroflex in Case 7.

Table 27. Boral, Boroflex, Cadmium, and Copper Absorber-Plate Atom Densities.

Material	Isotope	Wt.%	Atom Density
Boral B[(a)] (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}
Boral C[(a)] (2.47 g/ cm^3)	Al	59.26	3.2669×10^{-2}
	^{10}B	31.88 wt.% boron, 19.9 at.% ^{10}B	8.7288×10^{-3}
	^{11}B	31.88 wt.% boron, 80.1 at.% ^{11}B	3.5134×10^{-2}
	C	8.86	1.0972×10^{-2}
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[(c)] (8.65 g/cm^3)	Cd	99.7	4.6201×10^{-2}
	Zn	0.3	2.3899×10^{-4}
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}

(a) See Table 25 for atom densities of the type 1100 aluminum clad of the Boral plates.
(b) See Table 26 for 304L stiffener-plate material for Boroflex of Case 7, and see Table 28 for Plexiglas material for Boroflex of Case 6.
(c) See Table 28 for Plexiglas stiffener material for Cd plates (Case 8).

3.3.3 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 28.

Table 28. Moderator-Reflector Atom Densities.

Material	Isotope	Atom Density (barn-cm)$^{-1}$
Water	H	6.6706 x 10^{-2}
	O	3.3353 x 10^{-2}
	Gd	3.9828 x 10^{-8}
Acrylic (Plexiglas[(a)])	H	5.6642 x 10^{-2}
	C	3.5648 x 10^{-2}
	O	1.4273 x 10^{-2}

(a) stiffener-plate material for absorber plates in Cases 6 and 8.

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 models.

A sensitivity study of temperature variation (see Section 2.4) demonstrated that the effects on k_{eff} of temperature were small (~0.005% per degree C). The effect of ± 4 °C is included in the uncertainty of the benchmark-model k_{eff}. Therefore, any reasonable approximation to room temperature may be 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, no notch in the top end plug) were judged to have negligible effect on k_{eff}. However, experimental uncertainties (Section 2) and simplifying the model by omitting the two lattice plates (Section 3.1.1) contribute to the estimated uncertainty in the benchmark-model k_{eff}.

---

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

The included uncertainties are listed in Table 29.

Table 29. Uncertainty in Benchmark-Model k_{eff}.

Measurement Uncertainty or Model Simplification	Δk_{eff}
Fuel-Rod Characterization	0.0015
Surroundings	0.00004
Temperature	0.0002
Cluster Separation	0.0005
Gadolinium impurity uncertainty (±3.6 g/m^3) [(a)]	0.0029
Absorber Plate Thickness	0.00033
Absorber Plate Composition	0.00085
No Lattice Plates	0.0001
Total Uncertainty in k_{eff}[(b)]	0.0034

(a) If the entire 10.4 g/m^3 Gd impurity concentration from Reference 4 is considered to be the uncertainty, as discussed in Section 2.3, the uncertainty in k_{eff} due to gadolinium impurity is 0.0079.

(b) Square root of sum of squares of individual Δk_{eff}'s. Including the uncertainty from the entire 10.4 g/m^3 Gd impurity in the total uncertainty in k_{eff} gives 0.0081 rather than 0.0034.

An additional k_{eff} uncertainty of 0.0035 for uncertain placement of the Plexiglas stiffener sheets next to the Cd plates (Table 20) increases the total uncertainty for Case 8 to 0.0049. Therefore the benchmark-model k_{eff} is 1.0000 ± 0.0034, except for Case 8, for which it is 1.0000 ± 0.0049.

4.0 RESULTS OF SAMPLE CALCULATIONS

Results of calculations of the ten critical configurations are presented in Table 30. Code versions and modelling options are discussed briefly in paragraphs preceding the input listings in Appendix A.

All results are below the benchmark-model k_{eff} of 1.0000. In fact, all results of all three codes are below the range of k_{eff} that includes the estimated uncertainty. Even considering the entire reported amount of gadolinium impurity as an uncertainty, so that the uncertainty in k_{eff} is ±0.0089, all results are outside the uncertainty in k_{eff}. Both code – cross section packages underpredict k_{eff} by 1½%.

Table 30. Sample Calculation Results (United States).[(a)]

Code (Cross Section Set) → Case ↓	KENO (44-Group ENDF/B-V)	MCNP (Continuous Energy ENDF/B-V)
1	0.9864 ± 0.0016	0.9845 ± 0.0019
2	0.9864 ± 0.0018	0.9829 ± 0.0016
3	0.9830 ± 0.0016	0.9839 ± 0.0018
4	0.9792 ± 0.0016	0.9854 ± 0.0019
5	0.9849 ± 0.0016	0.9849 ± 0.0018
6	0.9884 ± 0.0016	0.9881 ± 0.0016
7	0.9857 ± 0.0019	0.9858 ± 0.0017
8	0.9877 ± 0.0016	0.9856 ± 0.0018
9	0.9872 ± 0.0017	0.9835 ± 0.0017
10	0.9863 ± 0.0017	0.9867 ± 0.0017

(a) Zn replaced by Cu, due to unavailability of Zn cross sections.

5.0 REFERENCES

1. S. R. Bierman, E. D. Clayton, B. M. Durst, “Critical Separation Between Subcritical Clusters of 2.35 Wt% ^{235}U Enriched UO_2 Rods in Water with Fixed Neutron Poisons,” PNL-2438, Batelle Pacific Northwest Laboratories, Richland, Washington, October 1977.

2. S. R. Bierman, B. M. Durst, E. D. Clayton, “Critical Separation Between Subcritical Clusters of 4.29 Wt% ^{235}U Enriched UO_2 Rods in Water with Fixed Neutron Poisons,” NUREG/CR-0073, Batelle Pacific Northwest Laboratories, Richland, Washington, May 1978.

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.

4. S. R. Bierman, E. D. Clayton, “Criticality Experiments with Subcritical Clusters of 2.35 Wt% and 4.31 Wt% ^{235}U Enriched UO_2 Rods in Water at a Water-to-Fuel Volume Ratio of 1.6,” NUREG/CR-1547, PNL-3314, Batelle Pacific Northwest Laboratories, Richland, Washington, July 1980.

5. S. R. Bierman, E. D. Clayton, “Criticality Experiments with Subcritical Clusters of 2.35 Wt% and 4.31 Wt% ^{235}U Enriched UO_2 Rods in Water with Steel Reflecting Walls,” NUREG/CR-1784, PNL-3602, Batelle Pacific Northwest Laboratories, Richland, Washington, April 1981.

6. S. R. Bierman, B. M. Durst, E. D. Clayton, “Criticality Experiments with Subcritical Clusters of 2.35 Wt% and 4.31 Wt% ^{235}U Enriched UO_2 Rods in Water with Uranium or Lead Reflecting Walls, Undermoderated Water-to-Fuel Volume Ratio of 1.6,” NUREG/CR-0796, PNL-3926, Vol. 2, Batelle Pacific Northwest Laboratories, Richland, Washington, December 1981.

7. B. M. Durst, S. R. Bierman, E. D. Clayton, “Critical Experiments with 4.31 Wt% ^{235}U Enriched UO_2 Rods in Highly Borated Water Lattices,” NUREG/CR-2709, PNL-4267, Batelle Pacific Northwest Laboratories, Richland, Washington, August 1982.

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.

9. S. R. Bierman, “Criticality Experiments to Provide Benchmark Data on Neutron Flux Traps,” PNL-6205, UC-714, Batelle Pacific Northwest Laboratories, Richland, Washington, June 1988.

10. S. R. Bierman, Criticality Experiments with Neutron Flux Traps Containing Voids,” PNL-7167, TTC-0969, UC-722, Batelle Pacific Northwest Laboratories, Richland, Washington, April 1990.

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.

12. S. R. Bierman, B. M. Durst, E. D. Clayton, "Critical Separation between Subcritical Clusters of Low Enriched UO_2 Rods in Water with Fixed Neutron Poisons," Nuc. Technol., Vol. **42**, pp. 237-249, March 1979.

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.

14. S. R. Bierman and E. D. Clayton, "Criticality Experiments with Subcritical Clusters of 2.35 and 4.31 wt% ^{235}U-Enriched UO_2 Rods in Water with Steel Reflecting Walls," Nuc. Technol., Vol. **54**, August 1981.

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 SCALE (SCALE 4.3, creation date 12/23/97, for KENO V.a with CSAS 44-group ENDF/B-V cross sections) provided by the Radiation Shielding Information Center.

KENO V.a was run using 110 active generations of 1500 neutrons each, after skipping 50 generations. Zn was replaced by Cu, due to unavailability of ENDF/B-V Zn cross sections.

KENO V.a Input Listing for Case 1 of Table 30 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
ks1-k CASE 1  THREE 20X16 CLUSTERS, 7.8  CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
```

KENO V.a Input Listing for Case 1 of Table 30 (44-Energy Group SCALE Cross Sections) (cont'd)

```
' SS plate
CR  8 0  1.7046-2 295 END
CU  8 0  2.0291-4 295 END
FE  8 0  5.8353-2 295 END
MN  8 0  1.3734-3 295 END
MO  8 0  1.2942-4 295 END
NI  8 0  9.0238-3 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS1-k  CASE 1  one 25x20, two 17x20, 7.8 CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X20 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 3
 COM=* 17X20 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 7.498CM WIDE *
 CUBOID  7 1  7.498 0.0  34.64 -0.96   96.52 -1.27
 CUBOID  6 1  7.498 0.0  34.64 -0.96   96.52 -3.81
UNIT 5
 COM=* SS POISON PLATE BETWEEN CLUSTERS, 0.302CM WIDE *
 CUBOID  8 1  0.302 0.0 34.64 -0.96   91.5   0.0
 CUBOID  7 1  0.302 0.0 34.64 -0.96   96.52 -1.27
 CUBOID  6 1  0.302 0.0 34.64 -0.96   96.52 -3.81
GLOBAL
UNIT 6
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=20  FILL F1 END FILL
           ARA=2 NUX=17 NUY=20  FILL F1 END FILL
           ARA=3 NUX=7  FILL 3 4 5 2 5 4 3  END FILL
END ARRAY
READ PLOT
  XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
  ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

KENO V.a Input Listing for Case 2 of Table 30 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
ks2-k CASE 2  one 25x20, two 17x20, 3.86 CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
' SS plate
B-10 8 0 9.9150-4 295 END
```

KENO V.a Input Listing for Case 2 of Table 30 (44-Energy Group SCALE Cross Sections) (cont'd)

```
B-11 8 0 3.7011-3 295 END
CR  8 0  1.7412-2 295 END
CU  8 0  2.0963-4 295 END
FE  8 0  5.7961-2 295 END
MN  8 0  1.3682-3 295 END
MO  8 0  2.4298-4 295 END
NI  8 0  7.7251-3 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS2-k  CASE 1  one 25x20, two 17x20, 3.86 CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X20 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 3
 COM=* 17X20 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 3.562CM WIDE *
 CUBOID  7 1  3.562 0.0  34.64 -0.96   96.52 -1.27
 CUBOID  6 1  3.562 0.0  34.64 -0.96   96.52 -3.81
UNIT 5
 COM=* SS POISON PLATE BETWEEN CLUSTERS, 0.298CM WIDE *
 CUBOID  8 1  0.298 0.0 34.64 -0.96   91.5   0.0
 CUBOID  7 1  0.298 0.0 34.64 -0.96   96.52 -1.27
 CUBOID  6 1  0.298 0.0 34.64 -0.96   96.52 -3.81
GLOBAL
UNIT 6
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=20  FILL F1 END FILL
    ARA=2 NUX=17 NUY=20  FILL F1 END FILL
    ARA=3 NUX=7  FILL 3 4 5 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

KENO V.a Input Listing for Case 3 of Table 30 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
ks3-k CASE 3  one 25x20, two 17x20, 3.46 CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
' SS plate
B-10 8 0 1.3953-3 295 END
```

KENO V.a Input Listing for Case 3 of Table 30 (44-Energy Group SCALE Cross Sections) (cont'd)

```
B-11 8 0 5.6163-3 295 END
CR  8 0  1.7638-2 295 END
CU  8 0  1.9145-4 295 END
FE  8 0  5.5634-2 295 END
MN  8 0  1.4394-3 295 END
MO  8 0  1.5119-4 295 END
NI  8 0  8.0684-3 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS3-k  CASE 1  one 25x20, two 17x20, 3.46 CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X20 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 3
 COM=* 17X20 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 3.162CM WIDE *
 CUBOID  7 1  3.162 0.0  34.64 -0.96   96.52 -1.27
 CUBOID  6 1  3.162 0.0  34.64 -0.96   96.52 -3.81
UNIT 5
 COM=* SS POISON PLATE BETWEEN CLUSTERS, 0.298CM WIDE *
 CUBOID  8 1  0.298 0.0 34.64 -0.96   91.5  0.0
 CUBOID  7 1  0.298 0.0 34.64 -0.96   96.52 -1.27
 CUBOID  6 1  0.298 0.0 34.64 -0.96   96.52 -3.81
GLOBAL
UNIT 6
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=20  FILL F1 END FILL
    ARA=2 NUX=17 NUY=20  FILL F1 END FILL
    ARA=3 NUX=7  FILL 3 4 5 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

KENO V.a Input Listing for Case 4 of Table 30 (44-Energy Group
SCALE Cross Sections)

```
=CSAS25
ks4-k CASE 4  one 25x20, two 17x20, 1.68 CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
' Boral B plate
B-10 8 0 8.4135-3 295 END
```

KENO V.a Input Listing for Case 4 of Table 30 (44-Energy Group SCALE Cross Sections) (cont'd)

```
B-11 8 0 3.3865-2 295 END
AL  8 0  3.4154-2 295 END
C   8 0  1.0567-2 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS4-k  CASE 4  one 25x20, two 17x20, 1.68 CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X20 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 3
 COM=* 17X20 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 1.388CM WIDE *
 CUBOID  7 1  1.388 0.0  34.64 -0.96   96.52 -1.27
 CUBOID  6 1  1.388 0.0  34.64 -0.96   96.52 -3.81
UNIT 5
 COM=* BORAL B POISON PLATE BETWEEN CLUSTERS, 0.292CM WIDE *
 CUBOID  4 1  0.038 0.0 34.64 -0.96   91.5    0.0
 CUBOID  8 1  0.254 0.0 34.64 -0.96   91.5    0.0
 CUBOID  4 1  0.292 0.0 34.64 -0.96   91.5    0.0
 CUBOID  7 1  0.292 0.0 34.64 -0.96   96.52 -1.27
 CUBOID  6 1  0.292 0.0 34.64 -0.96   96.52 -3.81
GLOBAL
UNIT 6
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=20  FILL F1 END FILL
    ARA=2 NUX=17 NUY=20  FILL F1 END FILL
    ARA=3 NUX=7  FILL 3 4 5 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

KENO V.a Input Listing for Case 5 of Table 30 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
ks5-k CASE 5  one 25x20, two 17x20, 1.93 CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
' Boral c plate
B-10 8 0 8.7288-3 295 END
```

KENO V.a Input Listing for Case 5 of Table 30 (44-Energy Group
SCALE Cross Sections) (cont'd)

```
B-11 8 0 3.5134-2 295 END
AL  8 0  3.2669-2 295 END
C   8 0  1.0972-2 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS5-k  CASE 5  one 25x20, two 17x20, 1.93 CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X20 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 3
 COM=* 17X20 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 1.699CM WIDE *
 CUBOID  7 1  1.699 0.0  34.64 -0.96   96.52 -1.27
 CUBOID  6 1  1.699 0.0  34.64 -0.96   96.52 -3.81
UNIT 5
 COM=* Boral C POISON PLATE BETWEEN CLUSTERS, 0.231CM WIDE *
 CUBOID  4 1  0.025 0.0 34.64 -0.96   91.5   0.0
 CUBOID  8 1  0.206 0.0 34.64 -0.96   91.5   0.0
 CUBOID  4 1  0.231 0.0 34.64 -0.96   91.5   0.0
 CUBOID  7 1  0.231 0.0 34.64 -0.96   96.52 -1.27
 CUBOID  6 1  0.231 0.0 34.64 -0.96   96.52 -3.81
GLOBAL
UNIT 6
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=20  FILL F1 END FILL
    ARA=2 NUX=17 NUY=20  FILL F1 END FILL
    ARA=3 NUX=7  FILL 3 4 5 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

KENO V.a Input Listing for Case 6 of Table 30 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
ks6-k CASE 6  one 25x20, two 17x20, 1.84 CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
' Boroflex
B-10 8 0 6.2822-3 295 END
```

KENO V.a Input Listing for Case 6 of Table 30 (44-Energy Group SCALE Cross Sections) (cont'd)

```
B-11 8 0 2.5287-2 295 END
C    8 0 1.8339-2 295 END
H    8 0 2.7408-2 295 END
CR   8 0 6.0145-6 295 END
FE   8 0 9.3329-6 295 END
O   8 0  1.3689-2 295 END
SI  8 0  8.3103-3 295 END
' PLEXIGLASS
H  9 0  5.6819-2 295 END
O  9 0  1.4205-2 295 END
C  9 0  3.5512-2 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS6-k  CASE 6  one 25x20, two 17x20, 1.84 CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X20 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 3
 COM=* 17X20 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 1.294CM WIDE *
 CUBOID  7 1  1.294 0.0  34.64 -0.96   96.52 -1.27
 CUBOID  6 1  1.294 0.0  34.64 -0.96   96.52 -3.81
UNIT 5
 COM=* Boroflex POISON PLATE BETWEEN CLUSTERS, 0.546CM WIDE *
 CUBOID  9 1  0.16 0.0 34.64 -0.96    91.5   0.0
 CUBOID  8 1  0.386 0.0 34.64 -0.96    91.5   0.0
 CUBOID  9 1  0.546 0.0 34.64 -0.96    91.5   0.0
 CUBOID  7 1  0.546 0.0 34.64 -0.96   96.52 -1.27
 CUBOID  6 1  0.546 0.0 34.64 -0.96   96.52 -3.81
GLOBAL
UNIT 6
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=20  FILL F1 END FILL
    ARA=2 NUX=17 NUY=20  FILL F1 END FILL
    ARA=3 NUX=7  FILL 3 4 5 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

KENO V.a Input Listing for Case 7 of Table 30 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
ks7-k CASE 7  one 25x20, two 17x20, 1.73 CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
' Boroflex
B-10 8 0 6.2822-3 295 END
```

KENO V.a Input Listing for Case 7 of Table 30 (44-Energy Group
SCALE Cross Sections) (cont'd)

```
B-11 8 0 2.5287-2 295 END
C    8 0 1.8339-2 295 END
H    8 0 2.7408-2 295 END
CR   8 0 6.0145-6 295 END
FE   8 0 9.3329-6 295 END
O   8 0  1.3689-2 295 END
SI  8 0  8.3103-3 295 END
' SS plate
CR  9 0  1.7046-2 295 END
CU  9 0  2.0291-4 295 END
FE  9 0  5.8353-2 295 END
MN  9 0  1.3734-3 295 END
MO  9 0  1.2942-4 295 END
NI  9 0  9.0238-3 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS7-k  CASE 7  one 25x20, two 17x20, 1.78 CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X20 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 3
 COM=* 17X20 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 1.322CM WIDE *
 CUBOID  7 1  1.322 0.0  34.64 -0.96   96.52 -1.27
 CUBOID  6 1  1.322 0.0  34.64 -0.96   96.52 -3.81
UNIT 5
 COM=* BOROFLEX POISON PLATE BETWEEN CLUSTERS, 0.408CM WIDE *
 CUBOID  9 1  0.091 0.0 34.64 -0.96   91.5    0.0
 CUBOID  8 1  0.317 0.0 34.64 -0.96   91.5    0.0
 CUBOID  9 1  0.408 0.0 34.64 -0.96   91.5    0.0
 CUBOID  7 1  0.408 0.0 34.64 -0.96   96.52 -1.27
 CUBOID  6 1  0.408 0.0 34.64 -0.96   96.52 -3.81
GLOBAL
UNIT 6
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=20  FILL F1 END FILL
    ARA=2 NUX=17 NUY=20  FILL F1 END FILL
    ARA=3 NUX=7  FILL 3 4 5 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

KENO V.a Input Listing for Case 8 of Table 30 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
ks8-k CASE 8  one 25x20, two 17x20, 3.04 CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
' Cd plate
CD  8 0 4.6201-2 295 END
```

KENO V.a Input Listing for Case 8 of Table 30 (44-Energy Group SCALE Cross Sections) (cont'd)

```
CU  8 0 2.3899-4 295 END
' PLEXIGLASS
H  9 0  5.6819-2 295 END
O  9 0  1.4205-2 295 END
C  9 0  3.5512-2 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS8-k  CASE 8  one 25x20, two 17x20, 3.04 CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X20 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 3
 COM=* 17X20 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.96  0.96  0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 2.683CM WIDE *
 CUBOID  7 1  2.683 0.0  34.64 -0.96   96.52 -1.27
 CUBOID  6 1  2.683 0.0  34.64 -0.96   96.52 -3.81
UNIT 5
 COM=* CD POISON PLATE BETWEEN CLUSTERS, 0.061CM WIDE *
 CUBOID  9 1  0.296 0.0 34.64 -0.96   91.5   0.0
 CUBOID  8 1  0.357 0.0 34.64 -0.96   91.5   0.0
 CUBOID  7 1  0.357 0.0 34.64 -0.96   96.52 -1.27
 CUBOID  6 1  0.357 0.0 34.64 -0.96   96.52 -3.81
UNIT 6
 COM=* CD POISON PLATE BETWEEN CLUSTERS, 0.061CM WIDE *
 CUBOID  8 1  0.061 0.0 34.64 -0.96   91.5   0.0
 CUBOID  9 1  0.357 0.0 34.64 -0.96   91.5   0.0
 CUBOID  7 1  0.357 0.0 34.64 -0.96   96.52 -1.27
 CUBOID  6 1  0.357 0.0 34.64 -0.96   96.52 -3.81
GLOBAL
UNIT 7
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=20  FILL F1 END FILL
    ARA=2 NUX=17 NUY=20  FILL F1 END FILL
    ARA=3 NUX=7  FILL 3 4 5 2 6 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

KENO V.a Input Listing for Case 9 of Table 30 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
ks9-k CASE 9  one 25x18, two 20x18, 5.24 CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
' CU plate w/o Cd
C   8 0  1.5194-3 295 END
```

KENO V.a Input Listing for Case 9 of Table 30 (44-Energy Group
SCALE Cross Sections) (cont'd)

```
CU  8 0  8.4128-2 295 END
FE  8 0  3.8444-6 295 END
MG  8 0  4.4168-6 295 END
NA  8 0  4.6695-6 295 END
O   8 0  1.0064-4 295 END
SI  8 0  3.8223-5 295 END
S   8 0  3.3474-6 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS9-k  CASE 9  one 25x18, two 20x18, 5.24 CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X20 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.144 0.144 0.0 0.0  1
UNIT 3
 COM=* 17X20 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.144 0.144 0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 4.903CM WIDE *
 CUBOID  7 1  4.903 0.0  30.456 -0.144 96.52 -1.27
 CUBOID  6 1  4.903 0.0  30.456 -0.144 96.52 -3.81
UNIT 5
 COM=* CU  POISON PLATE BETWEEN CLUSTERS, 0.337CM WIDE *
 CUBOID  8 1  0.337 0.0 30.456 -0.144 91.5   0.0
 CUBOID  7 1  0.337 0.0 30.456 -0.144 96.52 -1.27
 CUBOID  6 1  0.337 0.0 30.456 -0.144 96.52 -3.81
GLOBAL
UNIT 6
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=18  FILL F1 END FILL
    ARA=2 NUX=20 NUY=18  FILL F1 END FILL
    ARA=3 NUX=7  FILL 3 4 5 2 5 4 3  END FILL
END ARRAY
READ PLOT
 XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

KENO V.a Input Listing for Case 10 of Table 30 (44-Energy Group SCALE Cross Sections)

```
=CSAS25
ks10-k CASE 10  one 25x18, two 20x18, 2.6  CM SEPARATION
44GROUPNDF5 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD-152 2 0  7.9656-11 295 END
GD-154 2 0  8.6825-10 295 END
GD-155 2 0  5.8946-9  295 END
GD-156 2 0  8.1528-9  295 END
GD-157 2 0  6.2331-9  295 END
GD-158 2 0  9.8933-9  295 END
GD-160 2 0  8.7064-9  295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'       (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'       (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'       (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD-152 7 0  7.9656-11 295 END
GD-154 7 0  8.6825-10 295 END
GD-155 7 0  5.8946-9  295 END
GD-156 7 0  8.1528-9  295 END
GD-157 7 0  6.2331-9  295 END
GD-158 7 0  9.8933-9  295 END
GD-160 7 0  8.7064-9  295 END
' CU plate w/ Cd
B-10 8 0  4.9384-6 295 END
```

KENO V.a Input Listing for Case 10 of Table 30 (44-Energy Group SCALE Cross Sections) (cont'd)

```
B-11 8 0  1.9878-5 295 END
C   8 0  8.9346-6 295 END
CD  8 0  4.7208-4 295 END
CU  8 0  8.3328-2 295 END
FE  8 0  1.9216-5 295 END
MN  8 0  8.7901-6 295 END
NI  8 0  9.1424-6 295 END
O   8 0  6.3742-5 295 END
SI  8 0  7.6419-6 295 END
SN-112  8 0  1.0328-6 295 END
SN-114  8 0  7.0512-7 295 END
SN-115  8 0  3.9324-7 295 END
SN-116  8 0  1.6030-5 295 END
SN-117  8 0  8.5462-6 295 END
SN-118  8 0  2.7182-5 295 END
SN-119  8 0  9.7112-6 295 END
SN-120  8 0  3.7196-5 295 END
SN-122  8 0  5.3732-6 295 END
SN-124  8 0  6.8286-6 295 END
'         Zn replaced by Cu
CU  8 0  5.7440-6 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
KS10-k  CASE 10  one 25x18, two 20x18, 2.6  CM SEPARATION
READ PARA TME=200 GEN=160 NPG=1500 NSK=50 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* FUEL PIN *
 CYLINDER  1 1  0.5588 91.44 0.0
 CYLINDER  4 1  0.5588 91.92 0.0
 CYLINDER  5 1  0.5588 91.92 -1.27
 CYLINDER  3 1  0.635  91.92 -1.27
 CYLINDER  4 1  0.635  96.52 -1.27
 CUBOID  2 1  4P0.842 96.52 -1.27
UNIT 2
 COM=* 25X18 ARRAY OF FUEL PINS *
 ARRAY 1 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.144 0.144 0.0 0.0  1
UNIT 3
 COM=* 20x18 ARRAY OF FUEL PINS *
 ARRAY 2 3R0
 REPLICATE 6 1 5R0.0 2.54 1
 REPLICATE 7 1  0.0 0.0 0.144 0.144 0.0 0.0  1
UNIT 4
 COM=* WATER BETWEEN CLUSTERS, 2.243CM WIDE *
 CUBOID  7 1  2.243 0.0  30.456 -0.144 96.52 -1.27
 CUBOID  6 1  2.243 0.0  30.456 -0.144 96.52 -3.81
UNIT 5
 COM=* CU w/ Cd POISON PLATE BETWEEN CLUSTERS, 0.357CM WIDE *
 CUBOID  8 1  0.357 0.0 30.456 -0.144 91.5    0.0
 CUBOID  7 1  0.357 0.0 30.456 -0.144 96.52 -1.27
 CUBOID  6 1  0.357 0.0 30.456 -0.144 96.52 -3.81
GLOBAL
UNIT 6
 COM=* ARRAY OF 3 CLUSTERS, 1 IN. ACRYLIC BELOW, WATER REFLECTOR *
 ARRAY 3 3R0
 REPLICATE 7 1  2R30.0 2R29.04  9.92 15.3  1
END GEOM
READ ARRAY  ARA=1 NUX=25 NUY=18  FILL F1 END FILL
    ARA=2 NUX=20 NUY=18  FILL F1 END FILL
    ARA=3 NUX=7  FILL 3 4 5 2 5 4 3  END FILL
```

KENO V.a Input Listing for Case 10 of Table 30 (44-Energy Group SCALE Cross Sections) (cont'd)

```
END ARRAY
READ PLOT
 XUL=0.0 YUL=40. ZUL=10 XLR=155.0 YLR=-5.0
 ZLR=10  UAX=1  VDN=-1 NAX=130  NCH=' 12*45678' END
END PLOT
END DATA
END
```

A.2 MCNP Input Listings

MCNP4 was used. MCNP k_{eff} calculations used 110 generations of 1500 neutrons each after skipping 50 generations. Zn was replaced by Cu, due to unavailability of ENDF/B-V Zn cross sections.

MCNP Input Listing for Case 1 of Table 30

```
message:    outp=ks1-m.o  runtpe=ks1-m.r  srctp=ks1-m.s

ks1-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 7.8 CM SEPR, PITCH 1.684 CM
1    1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2    3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3    4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4    4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5    5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6    2 .100059  2 u=1 imp:n=1 $ water
7    0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8    0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9    0 -13 12 -20 21 -22 23 fill=2(36.428 0 0) imp:n=1  $ second rod cluster
10   0 -15 14 -20 21 -22 23 fill=2(86.328 0 0) imp:n=1  $ third rod cluster
11   7 .08612853 33 -34 31 -32 7  -37  imp:n=1  $ SS plate
12   7 .08612853 35 -36 31 -32 7  -37  imp:n=1  $ SS plate
13   6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
14   2 .100059  -12 10 -20 21  -22 23 #11  imp:n=1  $ water between clusters
15   2 .100059  -14 13 -20 21  -22 23 #12  imp:n=1  $ water between clusters
16   2 .100059 (-11:15:20:-21:22:-29)
           #11 #12 -24 25 -26 27 -28 30 imp:n=1 $ water
17   0  24:-25:26:-27:28:-30  imp:n=0

1    c/z 0.842 0.842 .5588  $ fuel cylinder
2    c/z 0.842 0.842 .635  $ clad cylinder
3    px  0.0  $ fuel rod cell boundary
4    px  1.684  $ fuel rod cell boundary
5    py  0.0  $ fuel rod cell boundary
6    py  1.684  $ fuel rod cell boundary
7    pz  0.0  $ bottom of fuel
8    pz  91.44  $ top of fuel
9    pz  91.92  $ top of clad
10   px  28.6279  $ farthest edge of closest cluster
11   px  .0001  $ closest edge of closest cluster
12   px  36.4281  $ closest edge of center cluster **
13   px  78.5279  $ farthest edge of center cluster
14   px  86.3281  $ closest edge of farthest cluster **
15   px  114.9559  $ farthest end of clusters
20   py  33.6799  $ sides of clusters
21   py  .0001  $ sides of clusters
22   pz  96.52  $ top of fuel rod
23   pz  -1.27  $ bottom of fuel rod
24   px  144.956  $ side of water reflector
25   px  -30.0   $ side of water reflector
26   py  63.68   $ side of water reflector
27   py  -30.0   $ side of water reflector
28   pz  106.44  $ top of water
29   pz  -3.81  $ bottom of acrylic support plate
30   pz  -19.11  $ bottom of water
c    plates
31   py  -0.96   $ plate bottom
32   py  34.64   $ plate top
33   px  36.126  $ 1st plate
34   px  36.428  $ 1st plate
35   px  78.528  $ 2st plate
36   px  78.83   $ 2st plate
37   pz  91.5    $ plate top

kcode  1500 1 50 160 50000
c    kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
```

MCNP Input Listing for Case 1 of Table 30 (cont'd)

```
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is SS plate
m7    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
```

MCNP Input Listing for Case 2 of Table 30

```
message:     outp=ks2-m.o  runtpe=ks2-m.r  srctp=ks2-m.s

ks2-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 3.86CM SEPR, PITCH 1.684 CM
1    1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2    3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3    4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4    4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5    5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6    2 .100059  2 u=1 imp:n=1 $ water
7    0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8    0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9    0 -13 12 -20 21 -22 23 fill=2(32.488 0 0) imp:n=1  $ second rod cluster
10   0 -15 14 -20 21 -22 23 fill=2(78.448 0 0) imp:n=1  $ third rod cluster
11   7 .0895395 33 -34 31 -32 7  -37  imp:n=1  $ SS w/ 1.1% B plate
12   7 .0895395 35 -36 31 -32 7  -37  imp:n=1  $ SS  w/ 1.1% B plate
13   6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
14   2 .100059  -12 10 -20 21  -22 23 #11  imp:n=1  $ water between clusters
15   2 .100059  -14 13 -20 21  -22 23 #12  imp:n=1  $ water between clusters
16   2 .100059 (-11:15:20:-21:22:-29)
          #11 #12 -24 25 -26 27 -28 30 imp:n=1 $ water
17   0  24:-25:26:-27:28:-30  imp:n=0

1    c/z 0.842 0.842 .5588  $ fuel cylinder
2    c/z 0.842 0.842 .635  $ clad cylinder
3    px  0.0  $ fuel rod cell boundary
4    px  1.684  $ fuel rod cell boundary
5    py  0.0  $ fuel rod cell boundary
6    py  1.684  $ fuel rod cell boundary
7    pz  0.0  $ bottom of fuel
8    pz  91.44  $ top of fuel
9    pz  91.92  $ top of clad
10   px  28.6279  $ farthest edge of closest cluster
11   px  .0001  $ closest edge of closest cluster
12   px  32.4881  $ closest edge of center cluster **
13   px  74.5879  $ farthest edge of center cluster
14   px  78.4481  $ closest edge of farthest cluster **
15   px  107.0759  $ farthest end of clusters
20   py  33.6799  $ sides of clusters
21   py  .0001  $ sides of clusters
22   pz  96.52  $ top of fuel rod
23   pz  -1.27  $ bottom of fuel rod
24   px  137.076  $ side of water reflector
25   px  -30.0   $ side of water reflector
26   py  63.68   $ side of water reflector
27   py  -30.0   $ side of water reflector
28   pz  106.44  $ top of water
29   pz  -3.81  $ bottom of acrylic support plate
30   pz  -19.11  $ bottom of water
c    plates
31   py  -0.96   $ plate bottom
32   py  34.64   $ plate top
33   px  32.19    $ 1st plate
34   px  32.488  $ 1st plate
35   px  74.588  $ 2st plate
36   px  74.886  $ 2st plate
37   pz  91.5    $ plate top

kcode  1500 1 50 160 50000
c    kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
```

MCNP Input Listing for Case 2 of Table 30 (cont'd)

```
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is SS plate w/ 1.05 wtB
m7    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  5011.56c   3.7011e-3
```

MCNP Input Listing for Case 3 of Table 30

```
message:      outp=ks3-m.o  runtpe=ks3-m.r  srctp=ks3-m.s

ks3-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 3.46CM SEPR, PITCH 1.684 CM
1    1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2    3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3    4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4    4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5    5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6    2 .100059  2 u=1 imp:n=1 $ water
7    0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8    0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9    0 -13 12 -20 21 -22 23 fill=2(32.088 0 0) imp:n=1  $ second rod cluster
10    0 -15 14 -20 21 -22 23 fill=2(77.648 0 0) imp:n=1  $ third rod cluster
11    7 .09013404 33 -34 31 -32 7  -37  imp:n=1  $ SS w/ 1.6% B plate
12    7 .09013404 35 -36 31 -32 7  -37  imp:n=1  $ SS  w/ 1.6% B plate
13    6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
14    2 .100059  -12 10 -20 21  -22 23 #11  imp:n=1  $ water between clusters
15    2 .100059  -14 13 -20 21  -22 23 #12  imp:n=1  $ water between clusters
16    2 .100059 (-11:15:20:-21:22:-29)
           #11 #12 -24 25 -26 27 -28 30 imp:n=1 $ water
17    0  24:-25:26:-27:28:-30  imp:n=0

1    c/z 0.842 0.842 .5588  $ fuel cylinder
2    c/z 0.842 0.842 .635  $ clad cylinder
3    px  0.0  $ fuel rod cell boundary
4    px  1.684  $ fuel rod cell boundary
5    py  0.0  $ fuel rod cell boundary
6    py  1.684  $ fuel rod cell boundary
7    pz  0.0  $ bottom of fuel
8    pz  91.44  $ top of fuel
9    pz  91.92  $ top of clad
10    px  28.6279  $ farthest edge of closest cluster
11    px  .0001  $ closest edge of closest cluster
12    px  32.0881  $ closest edge of center cluster **
13    px  74.1879  $ farthest edge of center cluster
14    px  77.6481  $ closest edge of farthest cluster **
15    px  106.2759  $ farthest end of clusters
20    py  33.6799  $ sides of clusters
21    py  .0001  $ sides of clusters
22    pz  96.52  $ top of fuel rod
23    pz  -1.27  $ bottom of fuel rod
24    px  136.276  $ side of water reflector
25    px  -30.0   $ side of water reflector
26    py  63.68   $ side of water reflector
27    py  -30.0   $ side of water reflector
28    pz  106.44  $ top of water
29    pz  -3.81  $ bottom of acrylic support plate
30    pz  -19.11  $ bottom of water
c     plates
31    py  -0.96   $ plate bottom
32    py  34.64   $ plate top
33    px  31.79    $ 1st plate
34    px  32.088  $ 1st plate
35    px  74.188  $ 2st plate
36    px  74.486  $ 2st plate
37    pz  91.5    $ plate top

kcode  1500 1 50 160 50000
c    kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
```

MCNP Input Listing for Case 3 of Table 30 (cont'd)

```
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is SS plate w/ 1.6 wt%B
m7    24000.50c  1.7638e-2  29000.50c  1.9145e-4
      26000.50c  5.5634e-2  25055.50c  1.4394e-3
      42000.50c  1.5119e-4  28000.50c  8.0684e-3
      5010.50c   1.3953e-3  5011.56c   5.6163e-3
```

MCNP Input Listing for Case 4 of Table 30

```
message:      outp=ks4-m.o  runtpe=ks4-m.r  srctp=ks4-m.s

ks4-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 1.68CM SEPR, PITCH 1.684 CM
1    1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2    3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3    4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4    4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5    5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6    2 .100059  2 u=1 imp:n=1 $ water
7    0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8    0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9    0 -13 12 -20 21 -22 23 fill=2(30.308 0 0) imp:n=1  $ second rod cluster
10    0 -15 14 -20 21 -22 23 fill=2(74.088 0 0) imp:n=1  $ third rod cluster
11    4 .06006075  33 -34 31 -32 7  -37 imp:n=1  $ Boral B - Al
12    7 .0869995  34 -35 31 -32 7  -37  imp:n=1  $ Boral B - Core
13    4 .06006075  35 -36 31 -32 7  -37 imp:n=1  $ Boral B - Al
14     4 .06006075  43 -44 31 -32 7  -37 imp:n=1  $ Boral B - Al
15    7 .0869995  44 -45 31 -32 7  -37  imp:n=1  $ Boral B - Core
16    4 .06006075  45 -46 31 -32 7  -37 imp:n=1  $ Boral B - Al
17    6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
18    2 .100059  -12 10 -20 21  -22 23 #11 #12 #13  imp:n=1  $ water between clusters
19    2 .100059  -14 13 -20 21  -22 23 #14 #15 #16  imp:n=1  $ water between clusters
20    2 .100059 (-11:15:20:-21:22:-29)
          #11 #12 #13 #14 #15 #16 -24 25 -26 27 -28 30 imp:n=1 $ water
21    0  24:-25:26:-27:28:-30  imp:n=0

1     c/z 0.842 0.842 .5588  $ fuel cylinder
2     c/z 0.842 0.842 .635  $ clad cylinder
3     px  0.0  $ fuel rod cell boundary
4     px  1.684  $ fuel rod cell boundary
5     py  0.0  $ fuel rod cell boundary
6     py  1.684  $ fuel rod cell boundary
7     pz  0.0  $ bottom of fuel
8     pz  91.44  $ top of fuel
9     pz  91.92  $ top of clad
10    px  28.6279  $ farthest edge of closest cluster
11    px  .0001  $ closest edge of closest cluster
12    px  30.3081  $ closest edge of center cluster **
13    px  72.4079  $ farthest edge of center cluster
14    px  74.0881  $ closest edge of farthest cluster **
15    px  102.7159  $ farthest end of clusters
20    py  33.6799  $ sides of clusters
21    py  .0001  $ sides of clusters
22    pz  96.52  $ top of fuel rod
23    pz  -1.27  $ bottom of fuel rod
24    px  132.716  $ side of water reflector
25    px  -30.0   $ side of water reflector
26    py  63.68   $ side of water reflector
27    py  -30.0   $ side of water reflector
28    pz  106.44  $ top of water
29    pz  -3.81  $ bottom of acrylic support plate
30    pz  -19.11  $ bottom of water
c     plates
31    py  -0.96   $ plate bottom
32    py  34.64   $ plate top
33    px  30.016   $ 1st plate
34    px  30.054  $ 1st plate
35    px  30.27   $ 1st plate
36    px  30.308  $ 1st plate
43    px  72.408  $ 2st plate
44    px  72.446  $ 2st plate
45    px  72.662  $ 2st plate
46    px  72.70   $ 2st plate
37    pz  91.5    $ plate top

kcode  1500 1 50 160 50000
```

MCNP Input Listing for Case 4 of Table 30 (cont'd)

```
c     kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is Boral B Plate
m7    5010.50c   8.4135e-3  5011.56c   3.3865e-2
      6012.50c   1.0567e-2  13027.50c  3.4154e-2
```

MCNP Input Listing for Case 5 of Table 30

```
message:      outp=ks5-m.o  runtpe=ks5-m.r  srctp=ks5-m.s

ks5-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 1.93CM SEPR, PITCH 1.684 CM
1    1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2    3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3    4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4    4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5    5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6    2 .100059  2 u=1 imp:n=1 $ water
7    0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8    0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9    0 -13 12 -20 21 -22 23 fill=2(30.558 0 0) imp:n=1  $ second rod cluster
10   0 -15 14 -20 21 -22 23 fill=2(74.588 0 0) imp:n=1  $ third rod cluster
11   4 .06006075  33 -34 31 -32 7  -37 imp:n=1  $ Boral c - Al
12   7 .0875038  34 -35 31 -32 7  -37  imp:n=1  $ Boral c plate
13   4 .06006075  35 -36 31 -32 7  -37 imp:n=1  $ Boral c - Al
14   4 .06006075  43 -44 31 -32 7  -37 imp:n=1  $ Boral c - Al
15   7 .0875038  44 -45 31 -32 7  -37  imp:n=1  $ Boral c plate
16   4 .06006075  45 -46 31 -32 7  -37 imp:n=1  $ Boral c - Al
17   6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
18   2 .100059  -12 10 -20 21  -22 23 #11 #12 #13  imp:n=1  $ water between clusters
19   2 .100059  -14 13 -20 21  -22 23 #14 #15 #16  imp:n=1  $ water between clusters
20   2 .100059 (-11:15:20:-21:22:-29)
          #11 #12 #13 #14 #15 #16 -24 25 -26 27 -28 30 imp:n=1 $ water
21   0  24:-25:26:-27:28:-30  imp:n=0

1    c/z 0.842 0.842 .5588  $ fuel cylinder
2    c/z 0.842 0.842 .635  $ clad cylinder
3    px  0.0  $ fuel rod cell boundary
4    px  1.684  $ fuel rod cell boundary
5    py  0.0  $ fuel rod cell boundary
6    py  1.684  $ fuel rod cell boundary
7    pz  0.0  $ bottom of fuel
8    pz  91.44  $ top of fuel
9    pz  91.92  $ top of clad
10   px  28.6279  $ farthest edge of closest cluster
11   px  .0001  $ closest edge of closest cluster
12   px  30.5581  $ closest edge of center cluster **
13   px  72.6579  $ farthest edge of center cluster
14   px  74.5881  $ closest edge of farthest cluster **
15   px  103.2159  $ farthest end of clusters
20   py  33.6799  $ sides of clusters
21   py  .0001  $ sides of clusters
22   pz  96.52  $ top of fuel rod
23   pz  -1.27  $ bottom of fuel rod
24   px  133.216  $ side of water reflector
25   px  -30.0   $ side of water reflector
26   py  63.68   $ side of water reflector
27   py  -30.0   $ side of water reflector
28   pz  106.44  $ top of water
29   pz  -3.81  $ bottom of acrylic support plate
30   pz  -19.11  $ bottom of water
c    plates
31   py  -0.96   $ plate bottom
32   py  34.64   $ plate top
33   px  30.327   $ 1st plate
34   px  30.352   $ 1st plate
35   px  30.533   $ 1st plate
36   px  30.558  $ 1st plate
43   px  72.658  $ 2st plate
44   px  72.683  $ 2st plate
45   px  72.864  $ 2st plate
46   px  72.889  $ 2st plate
37   pz  91.5    $ plate top

kcode  1500 1 50 160 50000
```

MCNP Input Listing for Case 5 of Table 30 (cont'd)

```
c     kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is Boral c Plate
m7    5010.50c   8.7288e-3  5011.56c   3.5134e-2
      6012.50c   1.0972e-2  13027.50c  3.2669e-2
```

MCNP Input Listing for Case 6 of Table 30

```
message:     outp=ks6-m.o  runtpe=ks6-m.r  srctp=ks6-m.s

ks6-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 1.84CM SEPR, PITCH 1.684 CM
1    1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2    3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3    4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4    4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5    5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6    2 .100059  2 u=1 imp:n=1 $ water
7    0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8    0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9    0 -13 12 -20 21 -22 23 fill=2(30.468 0 0) imp:n=1  $ second rod cluster
10    0 -15 14 -20 21 -22 23 fill=2(74.408 0 0) imp:n=1  $ third rod cluster
11    8  .106545  33 -34 31 -32 7  -37  imp:n=1  $ plexiglas
12    7 .09933085 34 -35 31 -32 7  -37  imp:n=1  $ Boroflex
13    8  .106545  35 -36 31 -32 7  -37  imp:n=1  $ plexiglas
14    8  .106545  43 -44 31 -32 7  -37  imp:n=1  $ plexiglas
15    7 .09933085 44 -45 31 -32 7  -37  imp:n=1  $ Boroflex
16    8  .106545  45 -46 31 -32 7  -37  imp:n=1  $ plexiglas
17    6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
18    2 .100059  -12 10 -20 21  -22 23 #11 #12 #13  imp:n=1  $ water between clusters
19    2 .100059  -14 13 -20 21  -22 23 #14 #15 #16  imp:n=1  $ water between clusters
20    2 .100059 (-11:15:20:-21:22:-29)
          #11 #12 #13 #14 #15 #16 -24 25 -26 27 -28 30 imp:n=1 $ water
21    0  24:-25:26:-27:28:-30  imp:n=0

1     c/z 0.842 0.842 .5588  $ fuel cylinder
2     c/z 0.842 0.842 .635  $ clad cylinder
3     px  0.0  $ fuel rod cell boundary
4     px  1.684  $ fuel rod cell boundary
5     py  0.0  $ fuel rod cell boundary
6     py  1.684  $ fuel rod cell boundary
7     pz  0.0  $ bottom of fuel
8     pz  91.44  $ top of fuel
9     pz  91.92  $ top of clad
10    px  28.6279  $ farthest edge of closest cluster
11    px  .0001  $ closest edge of closest cluster
12    px  30.4681  $ closest edge of center cluster **
13    px  72.5679  $ farthest edge of center cluster
14    px  74.4081  $ closest edge of farthest cluster **
15    px  103.0359  $ farthest end of clusters
20    py  33.6799  $ sides of clusters
21    py  .0001  $ sides of clusters
22    pz  96.52  $ top of fuel rod
23    pz  -1.27  $ bottom of fuel rod
24    px  133.036  $ side of water reflector
25    px  -30.0   $ side of water reflector
26    py  63.68   $ side of water reflector
27    py  -30.0   $ side of water reflector
28    pz  106.44  $ top of water
29    pz  -3.81  $ bottom of acrylic support plate
30    pz  -19.11  $ bottom of water
c     plates
31    py  -0.96   $ plate bottom
32    py  34.64   $ plate top
33    px  29.922   $ 1st plate
34    px  30.082   $ 1st plate
35    px  30.308   $ 1st plate
36    px  30.468  $ 1st plate
43    px  72.568  $ 2st plate
44    px  72.728  $ 2st plate
45    px  72.954  $ 2st plate
46    px  73.114  $ 2st plate
37    pz  91.50   $ plate top

kcode  1500 1 50 160 50000
```

MCNP Input Listing for Case 6 of Table 30 (cont'd)

```
c     kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is Boroflex Plate
m7    5010.50c   6.2822e-3  5011.56c   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
mt7   poly.01t
c     plexiglas
m8    8016.50c 1.4206e-2  1001.50c 5.6824e-2
      6012.50c 3.5515e-2
mt8   poly.01t
```

MCNP Input Listing for Case 7 of Table 30
message: outp=ks7-m.o runtpe=ks7-m.r srctp=ks7-m.s

```
ks6-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 1.73CM SEPR, PITCH 1.684 CM
1     1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2     3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3     4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4     4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5     5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6     2 .100059  2 u=1 imp:n=1 $ water
7     0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8     0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9     0 -13 12 -20 21 -22 23 fill=2(30.358 0 0) imp:n=1  $ second rod cluster
10    0 -15 14 -20 21 -22 23 fill=2(74.188 0 0) imp:n=1  $ third rod cluster
11    8 .08612853 33 -34 31 -32 7  -37  imp:n=1  $ SS
12    7 .09933085 34 -35 31 -32 7  -37  imp:n=1  $ Boroflex
13    8 .08612853 35 -36 31 -32 7  -37  imp:n=1  $ SS
14    8 .08612853 43 -44 31 -32 7  -37  imp:n=1  $ SS
15    7 .09933085 44 -45 31 -32 7  -37  imp:n=1  $ Boroflex
16    8 .08612853 45 -46 31 -32 7  -37  imp:n=1  $ SS
17    6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
18    2 .100059  -12 10 -20 21  -22 23 #11 #12 #13  imp:n=1  $ water between clusters
19    2 .100059  -14 13 -20 21  -22 23 #14 #15 #16  imp:n=1  $ water between clusters
20    2 .100059 (-11:15:20:-21:22:-29)
           #11 #12 #13 #14 #15 #16 -24 25 -26 27 -28 30 imp:n=1 $ water
21    0  24:-25:26:-27:28:-30  imp:n=0

1     c/z 0.842 0.842 .5588  $ fuel cylinder
2     c/z 0.842 0.842 .635  $ clad cylinder
3     px  0.0  $ fuel rod cell boundary
4     px  1.684  $ fuel rod cell boundary
5     py  0.0  $ fuel rod cell boundary
6     py  1.684  $ fuel rod cell boundary
7     pz  0.0  $ bottom of fuel
8     pz  91.44  $ top of fuel
9     pz  91.92  $ top of clad
10    px  28.6279  $ farthest edge of closest cluster
11    px  .0001  $ closest edge of closest cluster
12    px  30.3581  $ closest edge of center cluster **
13    px  72.4579  $ farthest edge of center cluster
14    px  74.1881  $ closest edge of farthest cluster **
15    px  102.8159  $ farthest end of clusters
20    py  33.6799  $ sides of clusters
21    py  .0001  $ sides of clusters
22    pz  96.52  $ top of fuel rod
23    pz  -1.27  $ bottom of fuel rod
24    px  132.816  $ side of water reflector
25    px  -30.0   $ side of water reflector
26    py  63.68   $ side of water reflector
27    py  -30.0   $ side of water reflector
28    pz  106.44  $ top of water
29    pz  -3.81  $ bottom of acrylic support plate
30    pz  -19.11  $ bottom of water
c     plates
31    py  -0.96   $ plate bottom
32    py  34.64   $ plate top
33    px  29.95    $ 1st plate
34    px  30.041   $ 1st plate
35    px  30.267   $ 1st plate
36    px  30.358  $ 1st plate
43    px  72.458  $ 2st plate
44    px  72.549  $ 2st plate
45    px  72.775  $ 2st plate
46    px  72.866  $ 2st plate
37    pz  91.5    $ plate top

kcode  1500 1 50 160 50000
```

MCNP Input Listing for Case 7 of Table 30 (cont'd)

```
c     kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is Boroflex Plate
m7    5010.50c   6.2822e-3  5011.56c   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
mt7   poly.01t
c     m8 is SS plate
m8    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
```

MCNP Input Listing for Case 8 of Table 30

```
message:     outp=ks8-m.o  runtpe=ks8-m.r  srctp=ks8-m.s

ks8-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 3.04CM SEPR, PITCH 1.684 CM
1    1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2    3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3    4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4    4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5    5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6    2 .100059  2 u=1 imp:n=1 $ water
7    0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8    0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9    0 -13 12 -20 21 -22 23 fill=2(31.668 0 0) imp:n=1  $ second rod cluster
10    0 -15 14 -20 21 -22 23 fill=2(76.808 0 0) imp:n=1  $ third rod cluster
11    8 .106545   33 -34 31 -32 7  -37  imp:n=1  $ Plexiglas
12    7 .04643999 34 -35 31 -32 7  -37  imp:n=1  $ Cd plates
13    7 .04643999 43 -44 31 -32 7  -37  imp:n=1  $ Cd plates
14    8 .106545   44 -45 31 -32 7  -37  imp:n=1  $ Plexiglas
15    6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
16    2 .100059  -12 10 -20 21  -22 23 #11 #12 imp:n=1  $ water between clusters
17    2 .100059  -14 13 -20 21  -22 23 #13 #14 imp:n=1  $ water between clusters
18    2 .100059 (-11:15:20:-21:22:-29)
           #11 #12 #13 #14 -24 25 -26 27 -28 30 imp:n=1 $ water
19    0  24:-25:26:-27:28:-30  imp:n=0

1    c/z 0.842 0.842 .5588  $ fuel cylinder
2    c/z 0.842 0.842 .635  $ clad cylinder
3    px  0.0  $ fuel rod cell boundary
4    px  1.684  $ fuel rod cell boundary
5    py  0.0  $ fuel rod cell boundary
6    py  1.684  $ fuel rod cell boundary
7    pz  0.0  $ bottom of fuel
8    pz  91.44  $ top of fuel
9    pz  91.92  $ top of clad
10    px  28.6279  $ farthest edge of closest cluster
11    px  .0001  $ closest edge of closest cluster
12    px  31.6681  $ closest edge of center cluster **
13    px  73.7679  $ farthest edge of center cluster
14    px  76.8081  $ closest edge of farthest cluster **
15    px  105.4359  $ farthest end of clusters
20    py  33.6799  $ sides of clusters
21    py  .0001  $ sides of clusters
22    pz  96.52  $ top of fuel rod
23    pz  -1.27  $ bottom of fuel rod
24    px  135.436  $ side of water reflector
25    px  -30.0   $ side of water reflector
26    py  63.68   $ side of water reflector
27    py  -30.0   $ side of water reflector
28    pz  106.44  $ top of water
29    pz  -3.81  $ bottom of acrylic support plate
30    pz  -19.11  $ bottom of water
c     plates
31    py  -0.96   $ plate bottom
32    py  34.64   $ plate top
33    px  31.015   $ 1st plate
34    px  31.311   $ 1st plate
35    px  31.372  $ 1st plate
43    px  73.768  $ 2st plate
44    px  73.829  $ 2st plate
45    px  74.055  $ 2st plate
37    pz  91.5    $ plate top

kcode  1500 1 50 160 50000
c    kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
```

MCNP Input Listing for Case 8 of Table 30 (cont'd)

```
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is Cd plates
m7    48000.50c  4.6201-2   29000.50c  2.3899-4
c     plexiglas
m8    8016.50c 1.4206e-2  1001.50c 5.6824e-2
      6012.50c 3.5515e-2
mt8   poly.01t
```

MCNP Input Listing for Case 9 of Table 30

```
message:    outp=ks9-m.o  runtpe=ks9-m.r  srctp=ks9-m.s

ks9-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 5.24CM SEPR, PITCH 1.684 CM
1    1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2    3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3    4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4    4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5    5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6    2 .100059  2 u=1 imp:n=1 $ water
7    0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8    0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9    0 -13 12 -20 21 -22 23 fill=2(38.92  0 0) imp:n=1  $ second rod cluster
10   0 -15 14 -20 21 -22 23 fill=2(86.26  0 0) imp:n=1  $ third rod cluster
11   7 .0858025  33 -34 31 -32 7  -37  imp:n=1  $ Cu plates
12   7 .0858025  35 -36 31 -32 7  -37  imp:n=1  $ Cu plates
13   6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
14   2 .100059  -12 10 -20 21  -22 23 #11  imp:n=1  $ water between clusters
15   2 .100059  -14 13 -20 21  -22 23 #12  imp:n=1  $ water between clusters
16   2 .100059 (-11:15:20:-21:22:-29)
          #11 #12 -24 25 -26 27 -28 30 imp:n=1 $ water
17   0  24:-25:26:-27:28:-30  imp:n=0

1    c/z 0.842 0.842 .5588  $ fuel cylinder
2    c/z 0.842 0.842 .635  $ clad cylinder
3    px  0.0  $ fuel rod cell boundary
4    px  1.684  $ fuel rod cell boundary
5    py  0.0  $ fuel rod cell boundary
6    py  1.684  $ fuel rod cell boundary
7    pz  0.0  $ bottom of fuel
8    pz  91.44  $ top of fuel
9    pz  91.92  $ top of clad
10   px  33.6798  $ farthest edge of closest cluster
11   px  .0001  $ closest edge of closest cluster
12   px  38.9201  $ closest edge of center cluster **
13   px  81.0199  $ farthest edge of center cluster
14   px  86.2601  $ closest edge of farthest cluster **
15   px  119.9399  $ farthest end of clusters
20   py  30.3119  $ sides of clusters
21   py  .0001  $ sides of clusters
22   pz  96.52  $ top of fuel rod
23   pz  -1.27  $ bottom of fuel rod
24   px  149.94   $ side of water reflector
25   px  -30.0   $ side of water reflector
26   py  60.312  $ side of water reflector
27   py  -30.0   $ side of water reflector
28   pz  106.44  $ top of water
29   pz  -3.81  $ bottom of acrylic support plate
30   pz  -19.11  $ bottom of water
c    plates
31   py  -0.144  $ plate bottom
32   py  30.456  $ plate top
33   px  38.583   $ 1st plate
34   px  38.92   $ 1st plate
35   px  81.02   $ 2st plate
36   px  81.357  $ 2st plate
37   pz  91.5    $ plate top

kcode  1500 1 50 160 50000
c    kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
```

MCNP Input Listing for Case 9 of Table 30 (cont'd)

```
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is Cu plate w/o Cd
m7    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
```

MCNP Input Listing for Case 10 of Table 30

```
message:      outp=ks10-m.o  runtpe=ks10-m.r  srctp=ks10-m.s

ks10-m  ONE 25X20, TWO 17x20,U(2.35)O2 RODS, 2.6 CM SEPR, PITCH 1.684 CM
1    1 .06170524 -1 7 -8 u=1 imp:n=1 $ uo2 fuel
2    3 .0597516   1 -2 -9 u=1 imp:n=1 $ clad
3    4 .06006075  -1 8 -9 u=1 imp:n=1 $ top end plug (lower piece)
4    4 .06006075  -2 9 u=1 imp:n=1 $ top end plug (top piece)
5    5 .06000711  -1 -7 u=1 imp:n=1 $ lower end plug
6    2 .100059  2 u=1 imp:n=1 $ water
7    0  -4 3 -6 5  imp:n=1 lat=1 u=2 fill=1  $ lattice of fuel rods
8    0 -10 11 -20 21 -22 23 fill=2 imp:n=1  $ first rod cluster
9    0 -13 12 -20 21 -22 23 fill=2(36.28  0 0) imp:n=1  $ second rod cluster
10   0 -15 14 -20 21 -22 23 fill=2(80.98  0 0) imp:n=1  $ third rod cluster
11   7 .0840611  33 -34 31 -32 7  -37  imp:n=1  $ Cu w/ Cd plates
12   7 .0840611  35 -36 31 -32 7  -37  imp:n=1  $ Cu w/ Cd plates
13   6 .106563  -23 29 -15 11 -20 21 imp:n=1  $ acrylic support plate
14   2 .100059  -12 10 -20 21  -22 23 #11  imp:n=1  $ water between clusters
15   2 .100059  -14 13 -20 21  -22 23 #12  imp:n=1  $ water between clusters
16   2 .100059 (-11:15:20:-21:22:-29)
          #11 #12 -24 25 -26 27 -28 30 imp:n=1 $ water
17   0  24:-25:26:-27:28:-30  imp:n=0

1    c/z 0.842 0.842 .5588  $ fuel cylinder
2    c/z 0.842 0.842 .635  $ clad cylinder
3    px  0.0  $ fuel rod cell boundary
4    px  1.684  $ fuel rod cell boundary
5    py  0.0  $ fuel rod cell boundary
6    py  1.684  $ fuel rod cell boundary
7    pz  0.0  $ bottom of fuel
8    pz  91.44  $ top of fuel
9    pz  91.92  $ top of clad
10   px  33.6798  $ farthest edge of closest cluster
11   px  .0001  $ closest edge of closest cluster
12   px  36.2801  $ closest edge of center cluster **
13   px  78.3799  $ farthest edge of center cluster
14   px  80.9801  $ closest edge of farthest cluster **
15   px  114.6599  $ farthest end of clusters
20   py  30.3119  $ sides of clusters
21   py  .0001  $ sides of clusters
22   pz  96.52  $ top of fuel rod
23   pz  -1.27  $ bottom of fuel rod
24   px  144.66   $ side of water reflector
25   px  -30.0   $ side of water reflector
26   py  60.312  $ side of water reflector
27   py  -30.0   $ side of water reflector
28   pz  106.44  $ top of water
29   pz  -3.81  $ bottom of acrylic support plate
30   pz  -19.11  $ bottom of water
c    plates
31   py  -0.144  $ plate bottom
32   py  30.456  $ plate top
33   px  35.923   $ 1st plate
34   px  36.28   $ 1st plate
35   px  78.38   $ 2st plate
36   px  78.737  $ 2st plate
37   pz  91.5    $ plate top

kcode  1500 1 50 160 50000
c    kcode  100 1 1 5 50000
sdef  x=d1 y=d2 z=d3 cel=d4
si1   0 150
sp1   0 1
si2   0 100
sp2   0 1
si3   0 100
```

MCNP Input Listing for Case 10 of Table 30 (cont'd)

```
sp3   0 1
si4   l 8 9 10
sp4   v
print
c     m1 is UO2 fuel
m1    92234.50c 2.8563e-6 92235.50c 4.8785e-4
      92236.50c 3.5348e-6 92238.50c 2.0009e-2
      8016.50c  4.1202e-2
c     m2 is water
m2    8016.50c 3.3353e-2  1001.50c 6.6706e-2
      64152.50c 7.9656-11 64154.50c 8.6825-10
      64155.50c 5.8946-9  64156.50c 8.1528-9
      64157.50c 6.2331-9  64158.50c 9.8933-9
      64160.50c 8.7064-9
mt2   lwtr.01t
c     m3 is 6061 Al (clad)
m3    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 replaced by Cu, below
      29000.50c  3.0967e-5  14000.50c  3.4607e-4
      26000.50c  1.0152e-4
c     m4 is 1100 aluminum (top end plug)
m4   13027.50c  5.9660e-2  29000.50c  3.0705e-5
      25055.50c  7.3991e-6
c       Zn replaced by Cu, below
      29000.50c  1.2433e-5  14000.50c  2.3302e-4
      26000.50c  1.1719e-4
c     m5 is 5052 aluminum (lower end plug)
m5   13027.50c  5.8028e-2  24000.50c  7.7888e-5
      29000.50c  1.2746e-5  12000.50c  1.6663e-3
      25055.50c  1.4743e-5
c       Zn replaced by Cu, below
      29000.50c  1.2387e-5  14000.50c  1.2978e-4
      26000.50c  6.5265e-5
c     m6 is acrylic (support plate)
m6    1001.50c 5.6642e-2  6000.50c 3.5648e-2
      8016.50c 1.4273e-2
mt6   poly.01t
c     m7 is Cu plate w/ Cd
m7    5010.50c   4.9384e-6   5011.56c  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  6.3742e-5  14000.50c  7.6419e-6
      50000.35c  1.1300e-4  29000.50c  5.7440e-6
```

A.3 ONEDANT/TWODANT Input Listings

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

APPENDIX B: LOGBOOKS

Logbooks are stored at the Los Alamos National Laboratory Archives under the original experiment number. Logbooks for these experiments from the Plutonium Critical Mass Laboratory at Hanford were listed on the July 16, 1993, inventory for the shipment from Hanford to Los Alamos as being in Box 11. These experiments at 0.663" sq. pitch are numbered SSC (Simulated Shipping Cask) 2.35-000-110 to 123 dated 12/20/79 to 1/17/80.

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

```
=CSASIX
GENERATE 27-GRP LIB FOR 2.35 WT% UO2 PNL FUEL PINS IN WATER
27GROUPNDF4 LATTICECELL
U-234  1 0  2.85626-6 291 END
U-235  1 0  4.87852-4 291 END
U-236  1 0  3.53484-6 291 END
U-238  1 0  2.00094-2 291 END
O  1 0  4.12021-2 291 END
H  2 0  6.67619-2 291 END
O  2 0  3.33809-2 291 END
Al  3 0  6.01507-2 291 END
H  4 0  6.67619-2 291 END
O  4 0  3.33809-2 291 END
END COMP
SQUAREPITCH 2.032 1.1176 1 2 1.27 3 END
END


1    0    0
SLAB OF U(2.35)O2 FUEL PINS IN WATER, BASE CASE
/  Block 1
igeom=slab ngroup=27 isn=16 niso=5 mt=5 nzone=5 im=4 it=251  T

/  Block 2
xmesh= 0 44.72 45.72 46.72 60.72
xints= 179    8     8     56
zones=   5    5     4      4 T

/  Block 3
lib=xs27.p3
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=3 ibl=1 ibr=0 epsi=.000001  T

/  Block 6
pted=0 zned=1  T
```

```
=CSASIX
dss1 CASE 1  1 25x20, 2 17x20  7.8      CM SEPARATION
27GROUPNDF4 LATTICECELL
' U(2.35)02
U-234  1 0  2.8563-6 295 END
U-235  1 0  4.8785-4 295 END
U-236  1 0  3.5348-6 295 END
U-238  1 0  2.0009-2 295 END
O  1 0  4.1202-2 295 END
' water
H  2 0  6.6706-2 295 END
O  2 0  3.3353-2 295 END
GD 2 0  3.9828-8 295 END
' 6061 Al (clad)
AL  3 0  5.8433-2 295 END
CR  3 0  6.2310-5 295 END
CU  3 0  6.3731-5 295 END
MG  3 0  6.6651-4 295 END
MN  3 0  2.2115-5 295 END
TI  3 0  2.5375-5 295 END
'        (Zn replaced by Cu)
CU  3 0  3.0967-5 295 END
SI  3 0  3.4607-4 295 END
FE  3 0  1.0152-4 295 END
'  1100 Al (top end plug)
AL  4 0  5.9660-2 295 END
CU  4 0  3.0705-5 295 END
MN  4 0  7.3991-6 295 END
'        (Zn replaced by Cu)
CU  4 0  1.2433-5 295 END
SI  4 0  2.3302-4 295 END
FE  4 0  1.1719-4 295 END
' 5052 Al (lower end plug)
AL  5 0  5.8028-2 295 END
CR  5 0  7.7888-5 295 END
CU  5 0  1.2746-5 295 END
MG  5 0  1.6663-3 295 END
MN  5 0  1.4743-5 295 END
'        (Zn replaced by Cu)
CU  5 0  1.2387-5 295 END
SI  5 0  1.2978-4 295 END
FE  5 0  6.5265-5 295 END
' acrylic
H   6 0  5.6642-2 295 END
C   6 0  3.5648-2 295 END
O   6 0  1.4273-2 295 END
' water
H  7 0  6.6706-2 295 END
O  7 0  3.3353-2 295 END
GD 7 0  3.9828-8 295 END
' SS plate
CR  8 0  1.7046-2 295 END
CU  8 0  2.0291-4 295 END
FE  8 0  5.8353-2 295 END
MN  8 0  1.3734-3 295 END
MO  8 0  1.2942-4 295 END
NI  8 0  9.0238-3 295 END
END COMP
SQUAREPITCH 1.684 1.1176 1 2 1.27 3 END
MORE DATA EPS=1.-7 PTC=1.-7 END MORE
END
```

```
 1     0     0
doct1, 2.35 wt% 1 25x20, 2 17x20, 7.8  cm separation,
/      SS plates
/  Block 1
igeom=6 ngroup=27 isn=8 niso=9 mt=9 nzone=9 im=5 it=151 jm=5
jt=134  maxscm=560000 maxlcm=4500000 t
```

```
/  Block 2
xmesh=0 21.05 21.352 28.85 57.478 87.478xints= 40 3 12 56 40
ymesh=0.0 29.04  30.0 63.68 64.64 93.68
yints= 30 4 66 4  30
zones=5r7; 7 8 3r7; 9 8 7 9 7;
      7 8 3r7; 5r7  t

/ Block 3
 lib=xs27.p3
 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=0
 epsi=0.00001 iitm=60 influx=0 oitm=40 bhgt=110.33  t

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

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		