Critical Configuration for Beryllium Reflected Assemblies of U(93.15)O₂ Fuel Rods (1.506-CM Pitch and 7-Tube Clusters)

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**Prepared for the
U.S. Department of Energy
Office of National Nuclear Security Administration
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517**

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CRITICAL CONFIGURATION FOR BERYLLIUM REFLECTED ASSEMBLIES OF U(93.15)O₂ FUEL RODS (1.506-CM PITCH AND 7-TUBE CLUSTERS)

IDENTIFICATION NUMBER: HEU-COMP-FAST-004

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

1.0 DETAILED DESCRIPTION

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

Initial experiments, performed in November and December of 1962, consisted of a core of 253 unmoderated stainless steel tubes, each containing 26 UO₂ fuel pellets, surrounded by a graphite reflector. Measurements were made to determine critical reflector arrangements, fission-rate distributions, and cadmium ratio distributions. "The [assemblies were built] on [a] vertical assembly machine so that the movable part was the core and bottom reflector." The first two experiments in the series were evaluated in [HEU-COMP-FAST-001 \(SCCA-FUND-EXP-001\)](#) and [HEU-COMP-FAST-002 \(SCCA-FUND-EXP-002\)](#).^b

The first experiment had the 253 fuel tubes packed tightly into a 22.87 cm outside diameter (OD) core tank (References 1 and 2). The second experiment in the series, performed in early 1963, had the 253 fuel tubes at a 1.506-cm triangular lattice in a 25.96 cm OD core tank and graphite reflectors on all sides. The third set of experiments in the series, performed in mid-1963, used beryllium reflectors and is the subject of this evaluation. The beryllium reflected system was the preferred reactor configuration for this application because of the small thickness of the reflector. The two core configurations had the 253 fuel tubes at a 1.506-cm triangular lattice and arranged in 7-tube clusters. The experiments have been determined to represent acceptable benchmark experiments.

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

^b Reports with SCCA identification are location in the International Handbook of Evaluations Reactor Physics Benchmark Experiments, NEA/NSC/DOC(2006)1, OECD-NEA, Paris, France (2012).

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Information for this evaluation was compiled from published reports on all three parts of the experimental series (Reference 1-5) and the experimental logbook^a as well as from communication with the experimenter, Dr. John T. Mihalcz.

1.1 Overview of Experiment

Upon completion of the part two of the three part series the 1.506-cm pitch core arrangement was moved into a shorter core tank and the graphite reflectors were switched out for beryllium reflectors. The same grid plates, spacer tubes and fuel clips were used to maintain the fuel tube spacing. The thicknesses of beryllium reflector on the top, side and bottom of the core were varied to obtain the critical configurations. For the initial trials, a Pu-Be source was placed on top of the top reflector. The source was withdrawn into a shield for the final critical measurements and had negligible reflection contribution to k_{eff} .^b The core tank was raised stepwise into the reflector as each configuration was tested. The core was then rearranged into the 7-tube cluster assembly and the reactivity change was measured.

The uncertainty in both mass and size measurements was “one in the last significant digit given”.^c

1.2 Description of Experimental Configuration

The assemblies were built on a vertical assembly machine in the east experimental cell of the Oak Ridge Critical Experiments Facility (ORCEF). Safety mechanisms of the device and facility are discussed in the facility safety review.^d The machine was located such that the center of the core was 3.67 m from the 1.5-m-thick west wall, 3.9 m from the 0.6-m-thick north wall, and 2.8 m above the concrete floor in the 10.7×10.7-m-square, 9.1-m-tall room (Reference 2). Figure 1-1 is a photograph of the vertical assembly machine.

^a Radiation Safety Information Computation Center (RSICC), The ORNL Critical Experiments Logbooks, Book 75r, <http://rsicc.ornl.gov/RelatedLinks.aspx?t=criticallist>, logbook page 10-60 (PDF page 3-43).

^b Personal email communication with J.T. Mihalcz, September 29, 2011.

^c Personal email communication with J. T. Mihalcz, May 23, 2011.

^d *Safety Review of the Oak Ridge Critical Experiments Facility*, Union Carbide Nuclear Corporation, Oak Ridge National Laboratory (1962).

Figure 1-1. Photograph of the Vertical Assembly Machine.²

² *Safety Review of the Oak Ridge Critical Experiments Facility*, Union Carbide Nuclear Corporation, Oak Ridge National Laboratory (1962).

Revision: 0

Date: September 30, 2012

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The top and side reflectors were on an aluminum table mounted from the four poles of the vertical assembly machine. The bottom reflector and the core were placed on the moveable table and raised into the side reflector such that the bottom reflector came into contact with the bottom of the aluminum table. The core and bottom reflector were on the Type 304 Stainless Steel moveable platform of the vertical assembly machine. The side and top reflector sat on a Type 1100 Aluminum plate. Figure 1-2 shows the arrangement of the core and reflectors on the vertical assembly machine.

Figure 1-2. Core and Reflector Placement for the Vertical Assembly Machine.^a

^a ORNL Photograph 39873.

1.2.1 The Fuel

The critical core assemblies consisted of 253 1.27 cm-outside-diameter^a fuel tubes in a Type 1100 Aluminum cylindrical core tank. Pellets were packed into Type 347 Stainless Steel tubes and held in place using end caps. The tubes were made of standard commercially available tubing.^b The end caps created small wells at the top and bottom of the fuel tubes as can be seen in Figure 1-3.^c Dimensions and a photograph of the fuel pellets and tubes as taken from Reference 1 and 4 can be found in Figure 1-3 and Tables 1-1 and 1-2.

Figure 1-3. Stainless Steel Tube (with one end Cap Removed) and Fuel Pellets.^{d,e}

^a Reference 1 and 2 only gives two significant digits but according to the experimenter the diameter was measured to three significant digits (September 19, 2011). A value of 1.27 cm, as reported in Reference 1, 2 and 4, has been used in this evaluation.

^b Personal email communication with J.T. Mihalczo, June 28, 2012.

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

^d "The edges of the pellets were chipped during their removal from the tube preparatory to this photograph." (Reference 1).

^e ORNL Photograph 39309.

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Table 1-1. Fuel Pellet Dimensions
(References 1, 2 and 4)

Number of Pellets per Tube	26	
UO ₂ Density	9.71	g/cm ³
UO ₂ Mass per Tube	295.8	g
Pellet Diameter	1.141	cm
Length of One Pellet	1.145	cm
Length of 26 Pellets	29.88	cm ^(a)

(a) This length “includes 0.110 cm of void or ~0.0044 cm of void between each pellet” (Reference 2).

Table 1-2. Fuel Tube Dimensions
(References 1, 2 and 4)

Length	30.48	cm
Outside Diameter	1.27	cm
Wall Thickness	0.051	cm
Weight with End Caps	45.37	g ^(a)
Weight of One End Cap	0.64	g

(a) Compared to values in the logbook this weight is too low by the weight of one end cap (see [HEU-COMP-FAST-001](#)).

The mass of the fuel tube given in Table 1-2 is the mass of the tube and one end cap, not two end caps. Using logbook data, the fuel tube and end cap mass can be calculated as being 44.729 and 0.64107 g, respectively (see [HEU-COMP-FAST-001](#)).

1.2.2 The Core

The center to center spacing between fuel pins was 1.506 cm in the first assembly. The fuel pins were in a Type 1100 Aluminum, 25.96-cm-OD tank. Fuel tubes were held in place within the core tank using grid plates, grid plate spacer tubes, shims and fuel tube clips. Twelve of the fuel tubes at the periphery of the core were moved inward until they were nearly in contact with adjacent fuel rods in order to reduce the size of the core. This can be seen in a photograph of the grid plate (see Figure 1-4). Twenty of the fuel tubes at the periphery of the core were held at the proper pitch using shims, because the grid plate had been cutaway. These 20 fuel pins were moved outward until they were in contact with the core tank during physics measurements to obtain a reactivity coefficient associated with the outward movement of the fuel pins.^a Two grid plates were used; one was adjacent to the bottom of the core tank and the other was held in place by the four grid plate spacer tubes. The grid plate spacer tubes were 90 degrees apart and “fit into a recess on the inner sides of the grid plates.”^b The fuel tube clips “snapped around and fit on more than half way around

^a Personal communication with J.T. Mihalcz, March 21, 2012.

^b Personal email communication with J.T. Mihalcz, December 17, 2011.

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each of the 2 fuel tubes whose spacing they were maintaining.”^b According to the experimenter aluminum shims were used in this experiment and the fuel tube clips were only used during reactivity effect measurements.^b No dimensions for the aluminum shims were given in References 3 and 4 or the logbook. The dimensions of the core tank, grid plates, spacer tubes, and fuel clips are given in Table 1-3.

For the second, 7-tube cluster, assembly, 217 fuel tubes were in 7-tube clusters, 30 fuel tubes were in 5-tube clusters around the edge of the core, and 6 single fuel tubes were around the edge of the core (retaining the total of 253 fuel tubes). This configuration was maintained using two grid plates which were held in place by the same grid plate spacer tubes. The grid plates for the 7-cluster assembly were the same thickness and material as the grid plates used in the first assembly. The grid plate spacer tubes were placed around four of the single fuel pins in the assembly.^a Figure 1-5 is a photograph of a grid plate for the core with the clustered fuel pins.

Figure 1-4. Grid Plate for 1.506-cm Spacing.^b

^a Personal email communication with J.T. Mihalcz, May 2, 2012.

^b ORNL Photograph 39521.

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Table 1-3. Core Dimensions (Reference 4).

Core Tank (Open Top)	
Material	Type 1100 Aluminum
Side Wall Thickness (cm)	0.254
Bottom Thickness (cm)	0.33
Outside Diameter (cm)	25.96
Outside Length (cm)	31.04
Mass (kg)	2.125
Grid Plates (2)	
Material	Type 1100 Aluminum
Thickness (cm)	0.317
Mass (g)	139 (each) ^(b)
Grid Plate Spacer Tubes (4)	
Material	Type 347 Stainless Steel
Outside Diameter (cm)	1.37
Wall Thickness (cm)	0.076
Length (cm)	27.94
Weight (g)	37.5 (each)
Fuel Tube Clips ^(a)	
Material	Type 1100 Aluminum
Mass (g)	2.3 (each)

(a) These clips were at the core midplane to hold outer fuel elements in position. According to the experimenter these clips were not used for the critical configuration but only during reactivity effect measurements for the unclustered core.

(b) The mass of the grid plates for the second assembly was not given.

Figure 1-5. Grid Plate for 7-Cluster Assembly.^a

1.2.3 The Reflectors

The core was reflected by beryllium. The side reflector was composed of annuli of unknown height and 11.37 cm radial thickness. The total height of the side reflector was 30.63 cm. The top and bottom reflectors were made of 7.3- and 3.65-cm-square, 2.54- or 0.635-cm-thick, blocks and some triangular pieces. Square blocks had 0.476-cm-diameter holes through the square faces. The beryllium blocks were machined at “Y-12 to 0.001 inches”.^b According to the experimenter the beryllium annuli of the side reflector were used only for these experiments. The blocks for the bottom and top reflector were used previously for experiments in support of aircraft nuclear propulsion (ANP) research ([HEU-MET-THERM-025](#)).^c Discrepancies between Reference 4 and 5 beryllium block dimensions and those given in [HEU-MET-THERM-025](#) and associated reports^{d,e} are discussed in Section 2.2.1.

^a ORNL Photograph 39874.

^b Personal communication with J.T. Mihalczo, April 8, 2012. Y-12 is the facility where many experiment parts were manufactured.

^c Personal email communication with J.T. Mihalczo, April 15, 2012.

^d E.L. Zimmerman, “Two Beryllium-Moderated Critical Assemblies,” ORNL-2201, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 6, 1958.

^e F.T. Bly, “The NEPA Critical Experiment Facility, Materials For ANP Zero Power Reactor Experiments (Appendix C of NEPA-1769),” NEPA-1829, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 16, 1951.

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The different layers of square reflector blocks were aligned so that the holes went from the bottom to the top of the top and the bottom reflectors. Blocks were arranged such that the top and bottom reflectors were 6.985 and 7.62 cm thick, respectively. The arrangement of the blocks is shown in Figure 1-6. Octagonal reflector tanks were used to contain both the top and the bottom reflectors. The beryllium blocks were held tightly in place using aluminum screws. The reflector tanks, tightening screws, and the side reflector can be seen in Figures 1-2 and 1-7. The dimensions of the reflectors are given in Table 1-4. Figure 1-8 shows the arrangement of the cores and reflectors for the critical assemblies but uses a nominal diameter for the top and bottom reflectors.

Figure 1-6. Arrangement of Top and Bottom Reflectors (Redrawn from Reference 4).

Figure 1-7. Radial and Top Beryllium Reflectors.^a

^a ORNL Photograph 39876.

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Table 1-4. Reflector Dimensions (Reference 3 and 4).

Side Reflector	
Height (cm)	30.63
Thickness (cm)	11.37
Inside Diameter (cm)	26.16
Mass (kg)	75.7
Top Reflector	
Thickness (cm)	6.985
Nominal Diameter (cm) ^(a)	41.2
Mass (kg)	17.13
Top Reflector Tank-Aluminum (Type 1100)	
Side Wall Thickness (cm)	0.635
Height (cm)	12.95
Bottom Thickness (cm)	0.22
Mass (kg)	4.38
Bottom Reflector	
Thickness (cm)	7.62
Nominal Diameter (cm) ^(a)	41.2
Mass (kg)	18.7
Bottom Reflector Tank-Aluminum (Type 1100)	
Side Wall Thickness (cm)	0.635
Height (cm)	8.51
Bottom Thickness (cm)	0.89
Mass (kg)	5.75
Additional Reflectors	
Support Plates	
Beryllium Support Plate - Aluminum (Type 1100)	
Thickness (cm)	0.635
Outside Dimensions (cm)	75 × 75
Inside Diameter (cm)	27.9
Mass (kg)	8.7
Bottom Reflector Support Plate - Stainless Steel (Type 304)	
Thickness (cm)	2.38
Diameter (cm)	45.72
Mass (kg)	31.2

(a) This nominal diameter was given in Reference 1. The top and bottom reflector were composed of 7.3- and 3.65-cm-square blocks, 2.54- or 0.635-cm-thick, and some triangular shaped pieces (see Figure 1-6).

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Figure 1-8. Reactor-Core Assembly (Side view, redrawn from Reference 4).

1.2.4 Reactivity of the Final Configuration

The reactivity of the final near-critical configuration for the first assembly was given as $+11.8 \phi$ with a repeatability of 1.2ϕ in Reference 4. In the repeat measurement the fuel pins were all removed from the core and reinserted randomly into core locations.^a The change in reactivity from the first assembly to the second assembly was $+10.5 \phi$. This small change is believed to be the overall effect of two competing effects; the “negative effect of the increased streaming out of the core and the positive effect caused by peaking of the fast neutron flux within the fuel clusters” (Reference 4).

^a Personal communication with J.T. Mihalczo, May 12, 2012.

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The effective delayed neutron fraction, β_{eff} , for the system was 0.0068. (This β_{eff} value is an approximation made by the experimenter.)^a

1.3 Description of Material Data

An impurity analysis for the uranium oxide and an isotopic analysis for the uranium were performed and reported in Reference 1 and 4. No analysis results were given for the beryllium but, according to the experimenter, the impurities would have been similar to those given in [HEU-COMP-FAST-069](#).^b The fuel tubes and grid plate spacer tubes were made of Type 347 Stainless Steel; the core tank, reflector tanks, grid plates, and fuel tube clips were made of Type 1100 Aluminum; and the vertical assembly machine support structures were made of Type 1100 Aluminum and Type 304 Stainless Steel (Reference 4). The compositions for these materials were not given. The type of aluminum and/or composition of the aluminum shims were not given in the references or the logbook.

The core was reported to contain a ^{235}U mass of 61.15 kg, UO_2 mass of 74.54 kg, and a stainless steel mass of 11.43 kg^c (Reference 4).

1.3.1 Fuel Composition

The basic fuel units were pellets of UO_2 with a density of 9.71 g/cm^3 . The pellets were pressed and sintered at the Oak Ridge Y-12 Plant (Reference 2). An impurity analysis is in Table 1-5 and the uranium isotopic distribution is in Table 1-6. The uncertainty in the isotopic distribution was $\pm 0.005 \text{ wt. \%}$ for ^{234}U , ^{235}U , and ^{236}U .^d

^a Personal email communication with J.T. Mihalczo, May 23, 2011, August 19, 2011, and November 14, 2011.

^b Personal email communication with J.T. Mihalczo, March 2, 2012.

^c The UO_2 mass is based off of a fuel mass of 295.8 g per tube, 252 fuel tubes in the core rather than 253, and disregards fuel impurities. Total stainless steel mass is incorrect due to the incorrect fuel tube mass given in Table 1-2.

^d According to J.T. Mihalczo (personal email communication, August 19, 2011), the uncertainty in the isotopic was the same as those given in [HEU-MET-FAST-051](#). This report gives the isotopic uncertainties stated above.

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Table 1-5. Mass Spectrographic Analysis of Uranium Oxide (Reference 1 and 4).^(a)

Silver, Ag	< 40	ppm ^(b)
Beryllium, Be	< 0.3	ppm
Chromium, Cr	6 to 40	ppm
Lithium, Li	< 1.5	ppm
Nickel, Ni	< 25	ppm
Tin, Sn	5 to 25	ppm
Aluminum, Al	3 to 30	ppm
Calcium, Ca	50	ppm
Copper, Cu	3 to 35	ppm
Magnesium, Mg	< 12	ppm
Phosphorous, P	< 100	ppm
Boron, B	< 1	ppm
Iron, Fe	10 to 250	ppm
Manganese, Mn	< 8	ppm
Barium, Ba	< 10	ppm
Potassium, K	< 50	ppm
Sodium, Na	< 10	ppm
Silicon, Si	10 to 50	ppm

- (a) Reference 1 reports these as results of spectrochemical analysis.
(b) These were measured by weight.

Table 1-6. Uranium Isotopic Composition (wt.%), (References 1, 2, and 4).^(a)

²³⁴ U	1.01
²³⁵ U	93.15
²³⁶ U	0.47
²³⁸ U	5.37

- (a) Isotopic uncertainty of ± 0.005 wt. % in ²³⁴U, ²³⁵U, and ²³⁶U.

1.3.2 Beryllium

The reflectors were beryllium. Reference 4 and the logbook did not give a composition analysis for the beryllium. The beryllium blocks were used previously during ANP research and an impurity analysis of the beryllium was provided in [HEU-MET-THERM-025](#). The beryllium annuli were used only for these experiments and no impurity analysis was provided. According to the experimenter the impurity analysis for the beryllium used in [HEU-MET-FAST-069](#) should be used for the annuli.^a

1.4 Temperature

The temperature of the experiment was 72°F (22°C).^b

1.5 Supplemental Experimental Measurements

Reactivity effect measurements, relative axial and radial fission rate distribution measurements, and axial and radial cadmium ratio measurements were performed for the critical configuration. These measurements are documented and evaluated in [SCCA-FUND-EXP-003](#).^c

^a Personal email communication with J.T. Mihalczo, April 17, 2012.

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

^c International Handbook of Evaluated Reactor Physics Benchmark Experiments, NEA/NSC/DOC(2006)1, OECD-NEA, Paris, France (2013).

2.0 EVALUATION OF EXPERIMENTAL DATA

The critical configurations were evaluated using Monte Carlo N-Particle (MCNP) versions 5-1.60^a and ENDF/B-VII.0^b neutron cross section libraries. Unless stated otherwise, the simple or detailed benchmark models, as described in Section 3, were used for the uncertainty analyses. The effect of the uncertainty in all measured parameters was found individually by increasing and decreasing the specified value by a given amount; the Δk_{eff} for that uncertainty was found by taking one half the difference between the k_{eff} values for the upper and lower perturbed models. The magnitude of most perturbations was increased from the 1σ uncertainties in order to obtain statistically significant results. The ratio of the perturbation to the 1σ uncertainty for the parameter was used as a “scaling factor” to convert the calculated Δk_{eff} to a 1σ uncertainty in k_{eff} . All models were calculated such that the statistical uncertainty, σ_{MC} , was no more than ± 0.00006 , although some calculations had a σ_{MC} of 0.00002. An uncertainty was considered to have a negligible effect (NEG) when the magnitude of the $1\sigma \Delta k_{\text{eff}}$ was ≤ 0.00010 .

Henceforth, the 1.506-cm-triangular pitch core will be referred to as Case 1 and the 7-tube cluster core will be referred to as Case 2.

2.1 Evaluation of Critical Measurement

The reactivity of the final-near-critical configuration was given as $+11.8 \text{ } \phi$ with a repeatability of $1.2 \text{ } \phi$ for Case 1 in Reference 4. The reactivity of Case 2 was given as being $10.5 \text{ } \phi$ higher than the reactivity of Case 1 or $22.3 \text{ } \phi$. Case 2 was assumed to have a repeatability of $1.2 \text{ } \phi$. The experimenter estimated the β_{eff} for the system to be 0.0068. The β_{eff} also was calculated using two methods. The first method used k_{prompt} , calculated by MCNP5, and compared it to k_{eff} to calculate β_{eff} ($\beta_{\text{eff}} = 1 - k_{\text{prompt}}/k_{\text{eff}}$) (HEU-MET-FAST-059). The second method used MCNP5 to calculate β_{eff} directly. The two methods were used to calculate β_{eff} for both the detailed and simple benchmark models; all four values were averaged to obtain a β_{eff} of 0.0073. This value was used for this evaluation.^c An uncertainty in the reactivity measurements of 10% and 5% in the β_{eff} value (1σ uncertainties) are typical for this facility (HEU-MET-FAST-059 and HEU-MET-FAST-069) and were used in this evaluation. The measured reactivity in cents, β_{eff} , and the calculated measured reactivity in terms of Δk_{eff} are given in Table 2-1.

Table 2-1. Uncertainty in Reactivity Measurement of Critical Configurations.

Case	Measured Reactivity (ϕ)	$\pm 1\sigma$	$\beta_{\text{eff}} \pm 5\% (1\sigma)$	Repeatability ($\phi/\Delta k_{\text{eff}}$)	Reactivity (Δk_{eff})	$\pm \sigma_{\text{statistical}}$
1	11.8	± 1.18	0.0073 ± 0.00037	1.2/0.00009	0.00086	± 0.00013
2	22.3	± 2.23	0.0073 ± 0.00037	1.2/0.00009	0.00163	± 0.00020

^a F.B. Brown, R.F. Barrett, T.E. Booth, J.S. Bull, L.J. Cox, R.A. Forster, T.J. Goorley, R.D. Mosteller, S.E. Post, R.E. Prael, E.C. Selcow, A. Sood, and J. Sweezy, “MCNP Version 5,” LA-UR-02-3935, Los Alamos National Laboratory (2002).

^b M.B. Chadwick, et al., “ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology,” *Nucl. Data Sheets*, **107**: 2931-3060 (2006).

^c B.C. Kiedrowski, et al., “MCNP5-1.60 Feature Enhancements and Manual Clarifications,” LA-UR-10-06217, Los Alamos National Laboratory (2010).

2.2 Evaluation of Dimension and Mass Uncertainties

According to the experimenter the uncertainty in the dimension and mass measurements was plus or minus one in the last significant digit. This uncertainty was assumed to be a 1σ uncertainty unless stated otherwise.

2.2.1 Beryllium Reflector Dimension and Mass Uncertainties

The beryllium blocks used in the top and bottom reflector were used previously in ANP research experiments. Engineering drawings give the block dimensions as 2.875 in. square and 1.436 in. square with 1 in. and 1/4 in. thicknesses.^a The hole diameters were not readable on the engineering drawings but another report gives them as 0.196-in.-diameter center holes to allow for the 3/16-in.-diameter aluminum skewers that held the assemblies together.^b These blocks were machined at the Oak Ridge Y-12 plant to 0.001 in. (0.00254 cm).^c Reference 4 gives the large block dimensions as 7.3 cm square and the small block dimensions as 3.65 cm square with 0.467-cm-diameter holes. The dimensions of the blocks agree but the diameter of the holes does not. It is believed that the 0.467 cm diameter given in Reference 4 was actually the dimension of the aluminum skewer and thus the hole diameter should actually be 0.498 cm. In the detailed benchmark model, the dimensions of the large and small blocks are 7.303 ± 0.00254 cm square and 3.647 ± 0.00254 cm square with a 0.498 ± 0.02 cm hole centered through the square face. The uncertainty in the hole diameter was increased from ± 0.00254 cm to ± 0.02 cm to match the difference in diameter between the Reference 4 value and the ANP reports value.

The uncertainty in the square dimension of the blocks was evaluated separately for the two sizes of blocks. The 7.303-cm-square block was perturbed by ± 0.0127 cm and the 3.647-cm-square-blocks were perturbed by ± 0.0127 cm. The reflector tank dimensions were adjusted as the block dimensions were changed. All blocks of the same size were perturbed simultaneously. Since the tolerance was given to three significant digits the systematic uncertainty in the block size was taken to be ± 0.001 in. (0.00254 cm), which would be bounding with a uniform distribution. The random component of the uncertainty was taken to be $\pm 0.001/3$ in. (0.00085 cm) because the tolerance is a bounding uncertainty with a normal distribution. Using Equation 2.1, which combines the systematic and random uncertainties for the total 1σ uncertainty, the uncertainty in both block sizes was 0.00148 cm. (For the 7.303 cm block perturbation N was 20. For the 3.647 cm block perturbation N was 24 since the dimensions of the triangular blocks were also perturbed.) The results of these analyses are given in Table 2-2.

$$1\sigma_{total} = \sqrt{\left(\frac{0.00254}{\sqrt{3}}\right)^2 + \frac{(0.00254/3)^2}{N}} \quad \text{Equation 2.1}$$

The thickness of the blocks, according to Reference 4, was 2.54 cm and 0.635 cm thick. The thickness of the blocks used in the ANP experiments were 1 in. (2.54 cm) and 1/4 in (0.635 cm). The tolerance of the thickness was 0.010 in.^d The thickness of the top reflector was most likely a combination of 2 of the 2.54-cm-thick blocks and 3 of the 0.635-cm-thick blocks. The bottom reflector was most likely made up of 3 2.54-cm-thick blocks. Since the tolerance was given to three significant digits, the systematic uncertainty

^a F.T. Bly, "The NEPA Critical Experiment Facility, Materials For ANP Zero Power Reactor Experiments (Appendix C of NEPA-1769)," NEPA-1829, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 16, 1951.

^b E.L. Zimmerman, "Two Beryllium-Moderated Critical Assemblies," ORNL-2201, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 6, 1958.

^c Personal communication with J.T. Mihalczo, April 8, 2012.

^d F.T. Bly, "The NEPA Critical Experiment Facility, Materials For ANP Zero Power Reactor Experiments (Appendix C of NEPA-1769)," NEPA-1829, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 16, 1951.

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in the reflector thickness was taken to be ± 0.001 in. (0.00254 cm), which would be bounding with a uniform distribution. The random component of the uncertainty was taken to be $\pm 0.010/3$ in (0.0085 cm) because the tolerance is a bounding uncertainty with a normal distribution. Equation 2.2 gives the combination of the systematic and random uncertainties for the total 1σ uncertainty.

$$1\sigma_{total} = \sqrt{\left(\frac{0.00254}{\sqrt{3}}\right)^2 + \frac{(0.0254/3)^2}{N}} \quad \text{Equation 2.2}$$

N is the total number of blocks that make up a stack. The fact that there are multiple stacks of blocks is neglected. For the top reflector, the total uncertainty is ± 0.004 cm. For the bottom reflector, the total uncertainty is ± 0.005 cm.

No dimensions for the triangular pieces of the top and bottom reflector were given. It was assumed that the triangular pieces were isosceles triangles with two sides equal to the dimensions of the 3.647 cm squares. It is assumed that the uncertainty in height for the triangular pieces is the same as the uncertainty in the height of the stacked blocks for respective top and bottom reflectors.

The effect of the uncertainty in the height of the top and bottom reflector was evaluated by perturbing the top and bottom reflector thicknesses by 0.1 and 0.01 cm and then scaling the resulting Δk_{eff} to 1σ . Results are in Table 2-2.

Table 2-2. Uncertainty in Top and Bottom Reflector Dimensions.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
7.303-cm Block								
1	± 0.0127 cm	-0.00021	$\pm$	0.00004	8.58	-0.00002	$\pm$	0.00000
2		-0.00020	$\pm$	0.00004	8.58	-0.00002	$\pm$	0.00000
3.647-cm Block								
1	± 0.0127 cm	0.00009	$\pm$	0.00004	8.58	0.00001	$\pm$	0.00000
2		0.00009	$\pm$	0.00004	8.58	0.00001	$\pm$	0.00000
Bottom Reflector Height								
1	± 0.1 cm	0.00020	$\pm$	0.00004	20	0.00001	$\pm$	<0.00001
2		0.00012	$\pm$	0.00004	20	0.00001	$\pm$	<0.00001
Top Reflector Height								
1	± 0.01 cm	0.00002	$\pm$	0.00004	2.5	0.00001	$\pm$	0.00002
2		-0.00006	$\pm$	0.00004	2.5	-0.00003	$\pm$	0.00002

The height, thickness, and inside diameter of the side reflector were perturbed by ± 0.1 cm (10σ). When the inside diameter was varied, the thickness was held constant thus the outer diameter also varied. When the thickness was varied, the outer diameter was varied accordingly and the inside diameter was held constant. The Δk_{eff} results of these perturbations are summarized in Table 2-3.

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Table 2-3. Uncertainty in Side Reflector Dimensions.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Side Reflector Height								
1	± 0.1 cm	-0.00123	$\pm$	0.00004	10	-0.00012	$\pm$	<0.00001
2		-0.00125	$\pm$	0.00004	10	-0.00012	$\pm$	<0.00001
Side Reflector Thickness								
1	± 0.1 cm	-0.00209	$\pm$	0.00004	10	-0.00021	$\pm$	<0.00001
2		-0.00214	$\pm$	0.00004	10	-0.00021	$\pm$	<0.00001
Side Reflector Inside Diameter								
1	± 0.1 cm	-0.00192	$\pm$	0.00004	10	-0.00019	$\pm$	<0.00001
2		-0.00229	$\pm$	0.00004	10	-0.00023	$\pm$	<0.00001

The total masses of the side, top and bottom reflectors were 75.7, 17.13, and 18.7 kg. The 1σ uncertainty in the masses was one in the last significant digit. The effect of the uncertainty in the reflector mass is summarized in Table 2-4.

Table 2-4. Uncertainty in Reflector Mass.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Top Reflector Mass								
1	± 0.2 kg	0.00067	$\pm$	0.00004	20	0.00003	$\pm$	<0.00001
2		0.00072	$\pm$	0.00004	20	0.00004	$\pm$	<0.00001
Bottom Reflector Mass								
1	± 0.2 kg	0.00069	$\pm$	0.00004	20	0.00003	$\pm$	<0.00001
2		0.00066	$\pm$	0.00004	20	0.00003	$\pm$	<0.00001
Side Reflector Mass								
1	± 0.2 kg	0.00084	$\pm$	0.00004	2	0.00042	$\pm$	0.00002
2		0.00087	$\pm$	0.00004	2	0.00043	$\pm$	0.00002

2.2.2 Reflector Tank Dimensions and Mass Uncertainties

Dimensions for the reflector tanks were not given in the references or the logbook. The dimensions were derived using Figures 1-2 and 1-7 and the block sizes. A gap between the reflector blocks and the reflector tank of 3/16 in. (0.47625 cm) was arbitrarily assumed. The dimensions of the reflector tanks are given in Table 1-4 and Figure 2-1.

All components of the tank, including the tightening screws were made of type 1100 aluminum. The tank was modeled as an octagonal tank with sharp, non-rounded, corners. The mass and calculated volumes were used to calculate atom densities for the tanks. It is believed that the mass given in Reference 4 includes the mass of the tightening screws. Because of the small bias associated with simplifying the reflector tanks to cylindrical tanks with a nominal diameter, it is believed that any uncertainty associated with the derived model dimensions of the reflector tanks would be negligible.

Figure 2-1. Derived Reflector Tank Dimensions.

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The reflector tank wall thickness, bottom thickness, and height were varied for the bottom and top reflector tanks. The tank wall thickness and bottom thickness were perturbed simultaneously on the top and bottom tank. The results of these uncertainty analyses are summarized in Table 2-5.

Table 2-5. Uncertainty in Reflector Tank Dimensions.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Tank Wall Thickness								
1	± 0.02 cm	0.00001	$\pm$	$0.00004^{(a)}$	20	<0.00001	$\pm$	<0.00001
2		-0.00002	$\pm$	$0.00004^{(a)}$	20	<0.00001	$\pm$	<0.00001
Tank Bottom Thickness								
1	± 0.1 cm	-0.00063	$\pm$	0.00004	10	-0.00006	$\pm$	<0.00001
2		-0.00048	$\pm$	0.00004	10	-0.00005	$\pm$	<0.00001
Bottom Tank Height								
1	± 0.1 cm	-0.00061	$\pm$	0.00004	10	-0.00006	$\pm$	<0.00001
2		-0.00065	$\pm$	0.00004	10	-0.00006	$\pm$	<0.00001
Top Tank Height								
1	± 0.1 cm	-0.00001	$\pm$	$0.00004^{(a)}$	10	<0.00001	$\pm$	<0.00001
2		-0.00005	$\pm$	0.00004	10	<0.00001	$\pm$	<0.00001

(a) Despite using a scaling factor, the Δk_{eff} is less than σ_{MC} , which is small, thus this uncertainty has a negligible effect, as is seen in Table 2-28.

The mass of the top and bottom reflector tanks was 4.38 and 5.75 kg. These masses are believed to include the mass of the aluminum tightening screws. The effect of the uncertainty in the reflector tank masses are given in Table 2-6.

Table 2-6. Uncertainty in Reflector Tank Mass.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Top Reflector Tank Mass								
1	± 0.2 kg	0.00007	$\pm$	0.00004	20	<0.00001	$\pm$	<0.00001
2		0.00009	$\pm$	0.00004	20	<0.00001	$\pm$	<0.00001
Bottom Reflector Tank Mass								
1	± 0.2 kg	0.00018	$\pm$	0.00030	20	0.00001	$\pm$	0.00002
2		<0.00001	$\pm$	0.00004 ^(a)	20	<0.00001	$\pm$	<0.00001

(a) Despite using a scaling factor, the Δk_{eff} is less than σ_{MC} , which is small, thus this uncertainty has a negligible effect, as is seen in Table 2-28.

2.2.3 Fuel and Fuel Tube Dimensions and Mass Uncertainties

A total of 253 fuel tubes were used in the experiments. It is not known whether or not the dimensions of the fuel tubes were measured for multiple fuel tubes. The total uncertainty in the dimensions was given by the experimenter as plus or minus the last reported significant digit. This would have been ± 0.01 cm for the fuel and fuel tube length.

Measurements in the logbook are often reported in inches to three significant digits. This would correspond to an uncertainty of ± 0.001 in (or 0.00254 cm). This value is taken to be the systematic component of the total uncertainty and is about 25% of the total. Thus, the 0.01 cm uncertainty in the fuel and fuel tube lengths was split 25%/75% systematic/random uncertainties using Equation 2.1. When fuel-tube dimensions were perturbed, all 253 fuel tubes were perturbed simultaneously,

$$\Delta k_{eff,1\sigma} = \frac{1}{Scaling\ Factor} \cdot \sqrt{(\Delta k_{eff} \cdot 25\%)^2 + \frac{(\Delta k_{eff} \cdot 75\%)^2}{N}}, \quad \text{Equation 2.3}$$

where $\Delta k_{eff,1\sigma}$ is the combined 1σ effect on k_{eff} and Δk_{eff} is the change in k_{eff} when all N components were perturbed simultaneously.

The tolerance on the outside diameter of half-inch-stainless-steel tubing sold today (2011) is ± 0.005 in (± 0.0127 cm).^a This is taken to be a bounding uncertainty with an equal probable distribution thus the 1σ uncertainty for the fuel tube outside diameter is ± 0.00733 cm ($\pm 0.0127/\sqrt{3}$ cm). The thickness of the fuel tube was held constant when the outer diameter was varied; thus the inside diameter was also varied. The thickness of the fuel tube could have varied by a maximum of $+0.012$ cm based on the pellet diameters; this value was taken to be a 3σ uncertainty thus the 1σ uncertainty would be $+0.004$ cm ($+0.012/3$ cm). This uncertainty, 0.004 cm, was also used for the fuel pellet diameter uncertainty. Although the derivation of the uncertainty for the fuel tube diameter, fuel tube thickness, and fuel tube pellet diameter differed from the fuel and fuel tube length it is judged that Equation 2.1 can still be used to account for systematic and random components of the uncertainty. The outer diameter of the fuel tube was held constant while varying the thickness of the fuel tube. The effects of these uncertainties are summarized in Table 2-7.

^a <http://www.speedymetals.com/information/Material82.html#Tolerances> (accessed November 12, 2011).

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Table 2-7. Uncertainty in Fuel and Fuel Tube Dimensions.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}}^{(a)}$ (1 σ)	$\pm$	$\sigma_{\text{statistical}}$
Fuel Length								
1	± 0.05 cm	-0.00003	$\pm$	0.00004 ^(b)	5	<0.00001	$\pm$	0.00001
2		-0.00004	$\pm$	0.00004	5	<0.00001	$\pm$	0.00001
Fuel Diameter								
1	± 0.020	-0.00026	$\pm$	0.00004	5	0.00001	$\pm$	0.00001
2		-0.00023	$\pm$	0.00004	5	0.00001	$\pm$	0.00001
Fuel Tube Wall Thickness								
1	± 0.012 cm	0.00018	$\pm$	0.00004	3	0.00002	$\pm$	0.00001
2		0.00011	$\pm$	0.00004	3	0.00001	$\pm$	0.00001
Fuel Tube Length								
1	± 0.1 cm	-0.00013	$\pm$	0.00004	10	<0.00001	$\pm$	<0.00001
2		-0.00016	$\pm$	0.00004	10	<0.00001	$\pm$	<0.00001
Fuel Tube Outside Diameter								
1	± 0.0423	0.00003	$\pm$	0.00004 ^(b)	5.77	<0.00001	$\pm$	<0.00001
2		-0.00054	$\pm$	0.00004 ^(c)	5.77	0.00001	$\pm$	<0.00001

- (a) Random and systematic components of the uncertainty were taken into account using Equation 2.1.
(b) Despite using a scaling factor, the Δk_{eff} is less than σ_{MC} , which is small, thus this uncertainty has a negligible effect, as is seen in Table 2-28.
(c) The uncertainty effect of fuel tube outside diameter is much larger for Case 2 than Case 1 because fuel tubes within tube clusters in Case 2 are tightly packed thus the spacing of fuel is affected when the fuel tube diameter is changed. The fuel tubes are not touching in Case 1 thus the diameter of the fuel tube has little effect.

The fuel tube outside diameter uncertainty has a much larger effect (prior to scaling) in Case 2 because the clusters of fuel tubes are tightly packed.

As discussed in [HEU-COMP-FAST-001](#), the mass of the fuel per tube was 295.818 ± 0.063 g and the mass of the fuel tube with end caps was 46.011 ± 0.032 g. These uncertainties are the total uncertainties and account for the systematic and random components of the uncertainty in the fuel and tube masses, respectively. The effects of these mass uncertainties are summarized in Table 2-8.

It should be noted that the mass of fuel per tube that is calculated using the reported density of 9.71 g/cm^3 and the pellet dimensions is 295.57 g, which does not agree with the reported mass per tube of 295.818 g. Since a density is a derived value, the reported density of 9.71 g/cm^3 is not used in the benchmark model and the measured mass and dimensions were used in the calculation of atom densities instead.

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Table 2-8. Uncertainty in Fuel and Fuel Tube Mass.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Mass of Fuel per Tube								
1	± 1.26 g	0.00205	$\pm$	0.00004	20	0.00010	$\pm$	<0.00001
2		0.00206	$\pm$	0.00004	20	0.00010	$\pm$	<0.00001
Mass of Fuel Tube								
1	± 0.32 g	-0.00057	$\pm$	0.00004	10	-0.00006	$\pm$	<0.00001
2		-0.00048	$\pm$	0.00003	10	-0.00005	$\pm$	<0.00001

2.2.4 Fuel Tube Placement Uncertainty

For Case 1, the fuel tubes were in a 1.506-cm triangular lattice. The uncertainty in the pitch was taken to be ± 0.001 cm. This uncertainty was taken to be 25% systematic and 75% random with an N of 253 thus Equation 2.3 was used to find the 1σ uncertainty effect on Δk_{eff} .

For Case 2, the pitch of the cluster was estimated as being 3.95656 cm using Figure 1-5. The uncertainty in the pitch was taken to be ± 0.001 cm. This uncertainty was taken to be 25% systematic and 75% random with an N of 37, the total number of clusters, thus Equation 2.3 was used to find the 1σ uncertainty effect on Δk_{eff} .

The position of fuel tubes for Case 1 and the clusters for Case 2 was also varied using the URAN analysis in MCNP5.^a This card allows for the stochastic sampling of components with random locations in a lattice. Fuel rod position was randomly varied by ± 0.086 cm in the x- and y-directions for Case 1. Fuel rods at the periphery of the core that were in contact with the fuel rods that had been moved in were not varied in the URAN analysis. The cluster position was randomly varied by ± 0.12 cm in the x- and y-directions for Case 2. The single fuel rods at the periphery of the core were not moved in the URAN analysis. These large variations are an overestimate of the true uncertainty.

The results of these analyses are given in Table 2-9. Analysis using the URAN method confirms that the uncertainty obtained by simultaneously perturbing the pitch of all fuel rods is negligible.

^a X-5 Monte Carlo Team, "MCNP – A General Monte Carlo N-Particle Transport Code, Version 5, Volume II: User's Guide," LA-CP-03-0245, Los Alamos National Laboratory (October 3, 2005).

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Table 2-9. Uncertainty in Fuel Pitch and Fuel Placement.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Fuel Pitch								
1	± 0.003 cm	-0.00039	$\pm$	0.00004	3	0.00003	$\pm$	0.00001 ^(a)
2		-0.00013	$\pm$	0.00004	3	0.00001	$\pm$	0.00001 ^(a)
Fuel Placement								
1	URAN ^(b)	-0.00007	$\pm$	0.00003	1	-0.00007	$\pm$	0.00003
2		0.00008	$\pm$	0.00003	1	0.00008	$\pm$	0.00003

(a) Random and systematic components of the uncertainty were taken into account using Equation 2.1.

(b) Fuel placement within the 1.506-cm triangular lattice was randomly varied using the URAN analysis in MCNP5. The maximum movement of the rods was ± 0.086 cm in the x and y directions.

2.2.5 Core Tank Dimensions and Mass Uncertainties

The dimensions and mass of the core tank were perturbed individually. The thickness of the side wall was varied by holding the outside diameter of the tank constant while varying the inside diameter. The outside diameter was varied while holding the wall thickness constant thus the inside diameter was also varied. Mass was conserved during the perturbations for the dimensions. Results are summarized in Table 2-10.

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Table 2-10. Uncertainty in Core Tank Dimensions.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Core Tank Mass								
1	± 0.01 kg	0.00004	$\pm$	0.00004	10	<0.00001	$\pm$	<0.00001
2		-0.00001	$\pm$	$0.00004^{(a)}$	10	<0.00001	$\pm$	<0.00001
Core Tank Side Wall Thickness								
1	± 0.025 cm	-0.00001	$\pm$	0.00004	25	<0.00001	$\pm$	<0.00001
2		-0.00007	$\pm$	0.00004	25	<0.00001	$\pm$	<0.00001
Core Tank Bottom Thickness								
1	± 0.1 cm	-0.00012	$\pm$	0.00004	10	-0.00001	$\pm$	<0.00001
2		-0.00023	$\pm$	0.00004	10	-0.00002	$\pm$	<0.00001
Core Tank Outside Diameter								
1	± 0.05 cm	-0.00006	$\pm$	0.00004	5	-0.00001	$\pm$	0.00001
2		$-0.00003^{(a)}$	$\pm$	0.00004	5	-0.00001	$\pm$	0.00001
Core Tank Outside Length								
1	± 0.05 cm	$<0.00001^{(a)}$	$\pm$	0.00004	5	<0.00001	$\pm$	0.00001
2		-0.00006	$\pm$	0.00004	5	-0.00001	$\pm$	0.00001

(a) Despite using a scaling factor, the Δk_{eff} is less than σ_{MC} , which is small, thus this uncertainty has a negligible effect, as is seen in Table 2-28.

2.2.6 Core Support Structure

Two grid plates, four grid plate spacer tubes, ten fuel clips, and five aluminum shims were used to hold the fuel in place within the core. The experimenter believes that aluminum shims rather than fuel clips were used to hold the outermost fuel tubes in place in Case 1. Case 2 only used the two grid plates and four grid plate spacer tubes.

The grid plates were included in the detailed benchmark models. For Case 1, the uncertainty in the grid plate mass, thickness, and diameter of the grid plate holes was evaluated. The 1σ uncertainty in the mass was ± 1 g. The 1σ uncertainty in the thickness was ± 0.001 cm. The diameter of the grid plate holes was not given but was modeled as being 1.284 cm. (This diameter is equal to the arbitrarily chosen inside diameter of the grid plate spacer tubes, see below.) The grid plate hole diameter could have been as little as 1.27 cm, the outside diameter of the fuel tubes, thus the uncertainty in the grid plate hole diameter was taken to be ± 0.014 cm, bounding with a uniform distribution. Mass was conserved when evaluating the uncertainty in the plate thickness and the hole diameter.

For Case 2, no dimensions of the grid plates were given in any of the References but the experimenter has said that they were the same material and thickness as the grid plates in Case 1. The grid plate was modeled as having nominal Type 1100 Aluminum density, 2.70 g/cm^3 , a thickness of 0.317 cm and a hole diameter of 1.284 cm. The same uncertainties were used for the grid plate thickness and hole diameter as in Case 1. The aluminum density was conserved during dimension perturbations. The density was varied between 2.55 and 2.85 g/cm^3 , $\pm 0.15 \text{ g/cm}^3$. This uncertainty was taken to be a bounding uncertainty. The effect of these uncertainties for Case 1 and 2 are given in Table 2-11.

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Table 2-11. Uncertainty in Grid Plate Dimensions.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Grid Plate Mass								
1	± 10 g	0.00007	$\pm$	0.00004	10	0.00001	$\pm$	<0.00001
Grid Plate Density								
2	± 0.15 g/cm ³	0.00004	$\pm$	0.00004	$\sqrt{3}$	0.00002	$\pm$	0.00002
Grid Plate Thickness								
1	± 0.01	0.00004	$\pm$	0.00004	10	<0.00001	$\pm$	<0.00001
2		0.00002	$\pm$	0.00004 ^(a)	10	<0.00001	$\pm$	<0.00001
Grid Plate Hole Diameter								
1	± 0.014	-0.00001	$\pm$	0.00004 ^(b)	1	-0.00001	$\pm$	0.00004
2		0.00001	$\pm$	0.00004 ^(b)	1	0.00001	$\pm$	0.00004

(a) Despite using a scaling factor, the Δk_{eff} is less than σ_{MC} , which is small, thus this uncertainty has a negligible effect, as is seen in Table 2-28.

(b) Due to the geometry a scaling factor could not be used to obtain a Δk_{eff} greater than σ_{MC} .

For Case 1, the placement of the grid plate spacer tube was of some concern. Based on the distribution of fuel in the core tank, there was no space for the 1.37-cm-OD spacer tubes and the inside diameter of the tubes would have been too small for them to fit around fuel tubes. It is believed that the wall thickness of the spacer tubes was incorrectly reported. In the detailed model the spacer tubes had an outside diameter of 1.37 cm. The wall thickness was arbitrarily decreased to 0.043 cm so that the inside diameter of the tubes was 1.284 cm and the spacer tubes would fit around the fuel tubes. The 4 spacer tubes were modeled as being 90° apart at a radius of 10.433 cm. For Case 2, the grid plate spacer tubes were modeled as having the same dimensions as in Case 1. They were modeled as being around four of the six individual fuel pins at the periphery of the core. The effect of removing the grid plate spacer tubes was small for Case 1 and 2 (see Section 3.1.2); thus, it was judged that the uncertainty in the spacer tube dimensions, mass, and placement would be negligible.

There were no dimensions or masses provided for the five aluminum shims used in Case 1 to hold the fuel tubes in place. The shims would have been approximately 270 segments to fit tightly between the core tank and the fuel tubes. The aluminum shims were assumed to be the same material as the core tank (Type 1100 Aluminum). A nominal density of 2.70 g/cm³ was used in the model. The height of the shims was assumed to be the same as the height of the shims used in part one of the experimental series (Reference 1). Because the effect of removing the shims was negligible (see Section 3.1.2) it was judged that the uncertainty in the aluminum shim dimensions and density would also have been negligible.

2.2.7 Support Plate Dimensions and Mass Uncertainties

The support structure of the vertical assembly machine provided some additional reflection to the core. The dimensions of the support plates are given in Table 1-4. Each dimension was perturbed by 10 times the uncertainty (10 σ). Results are given in Table 2-12.

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Table 2-12. Uncertainty in Support Plate Dimensions.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Beryllium Support Plate Thickness								
1	± 0.01 cm	-0.00010	$\pm$	0.00004	10	-0.00001	$\pm$	<0.00001
2		-0.00013	$\pm$	0.00004	10	-0.00001	$\pm$	<0.00001
Beryllium Support Plate Outside Dimensions								
1	± 10 cm	-0.00062	$\pm$	0.00004	10	-0.00006	$\pm$	<0.00001
2		-0.00056	$\pm$	0.00004	10	-0.00006	$\pm$	<0.00001
Beryllium Support Plate Inside Diameter								
1	± 1 cm	-0.00011	$\pm$	0.00004	10	-0.00001	$\pm$	<0.00001
2		-0.00013	$\pm$	0.00004	10	-0.00001	$\pm$	<0.00001
Beryllium Support Plate Mass								
1	± 1 kg	0.00023	$\pm$	0.00004	10	0.00002	$\pm$	<0.00001
2		0.00026	$\pm$	0.00004	10	0.00003	$\pm$	<0.00001
Bottom Reflector Support Plate Thickness								
1	± 0.1 cm	0.00002	$\pm$	0.00004 ^(a)	10	<0.00001	$\pm$	<0.00001
2		-0.00007	$\pm$	0.00004	10	-0.00001	$\pm$	<0.00001
Bottom Reflector Support Plate Diameter								
1	± 0.1 cm	-0.00004	$\pm$	0.00004	10	<0.00001	$\pm$	<0.00001
2		0.00004	$\pm$	0.00004	10	<0.00001	$\pm$	<0.00001
Bottom Reflector Support Plate Mass								
1	± 1 kg	0.00021	$\pm$	0.00004	10	0.00002	$\pm$	<0.00001
2		0.00021	$\pm$	0.00004	10	0.00002	$\pm$	<0.00001

(a) Despite using a scaling factor, the Δk_{eff} is less than σ_{MC} , which is small, thus this uncertainty has a negligible effect, as is seen in Table 2-28.

2.3 Evaluation of Material Properties

Material impurities reported in References 1 and 4 were used for the uranium oxide and the uranium isotopic composition. The beryllium impurity composition was taken from ANP experiment reports^a and HEU-MET-FAST-069. ASTM standards were used for all other material compositions. When calculating atom densities, measured masses and calculated volumes were always used to find the material density even if a density was reported. When calculating atom densities from material impurity data and composition data, typically three types of values were given: a single value (i.e., 15 ppm or 20 wt.%), which gives the actual content of the element in the material, a maximum value (i.e., < 15 ppm or < 20 wt.%), which gives the maximum amount of an element present in the material, and a range of values (i.e., 15 -17 ppm or 20 – 22 wt.%), which gives the minimum and maximum amount of an element present in the material. When calculating atom densities for models, the actual content of the element, one half of the maximum element

^a F.T. Bly, "The NEPA Critical Experiment Facility, Materials For ANP Zero Power Reactor Experiments (Appendix C of NEPA-1769)," NEPA-1829, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 16, 1951.

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content, and/or the middle of the range of element content were used for the material composition, respectively. When perturbing compositions, single values were perturbed by plus or minus the square root of the value,^a maximum values were varied between zero and the maximum, and range values were varied between the top and bottom of the range. These uncertainties are assumed to be bounding with uniform distribution probability. This method could lead to an over estimate but was used as a best estimate of the true uncertainty.

2.3.1 Side Reflector Beryllium Composition

The beryllium annuli for the side reflector had the same impurity content as the beryllium used in [HEU-MET-FAST-069](#). These impurities are given in Table 2-13. The effect of uncertainty in the impurity content on k_{eff} was evaluated by varying all impurities simultaneously using methods described in Section 2.3. The beryllium content was adjusted to maintain unity. Results are summarized in Table 2-14.

Table 2-13. Side Reflector Beryllium Composition.

Element	wt. % ^(a)
O	1.23458 ^(b)
Al	0.06
C	0.12
Fe	0.13
Mg	0.02
Bi	0.05
B	0.001
Cd	0.0002
Dy	0.0001
Br	0.00005
Gd	0.0001
Ni	0.0001
Sm	0.0001
Total	1.61623

(a) Beryllium impurities from [HEU-MET-FAST-069](#).

(b) The oxygen content was originally given as BeO content (1.93 wt.%).

^a Using the square root of the content as the uncertainty was used because compositions come from spectrographic results, which report contents in 'counts'. The uncertainty in the composition can then be defined as the square root of the value, as is commonly assumed for spectrographic measurements with a Poisson distribution. It is believed that this method provides an overestimate of the actual uncertainty.

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Table 2-14. Uncertainty in Side Reflector Beryllium Impurity Content.

Case	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
1	-0.00056	$\pm$	0.00004	$\sqrt{3}$	-0.00032	$\pm$	0.00002
2	-0.00057	$\pm$	0.00004	$\sqrt{3}$	-0.00033	$\pm$	0.00002

2.3.2 Top and Bottom Reflector Beryllium Composition

The beryllium for the bottom and top reflector was the same beryllium used in the ANP experiments. The impurity content of significant neutron absorbers was measured but the impurity content of non-neutron absorbers was not measured. For the detailed benchmark model, the impurity content from the ANP experiments plus an assumed oxygen content of 1.23458 wt.%, the oxygen content of the side reflector, was used.^a The beryllium composition is given in Table 2-15. The impurity content was perturbed using methods described in Section 2.3, except for the oxygen content. The oxygen content was varied between 1 wt.% and 2 wt.%. The impurities were all perturbed simultaneously in the top and bottom reflector. The results are in Table 2-16.

Table 2-15. Top and Bottom Reflector Beryllium Composition.

Li	0.3	ppm
B	1.2	ppm
Mg	80	ppm
Al	800	ppm
Si	700	ppm
Ca	10	ppm
Cr	140	ppm
Mn	100	ppm
Co	1	ppm
Ni	180	ppm
Cu	90	ppm
Zn	30	ppm
Ag	3	ppm
Cd	0.2	ppm
O	1.23458	wt. % ^(a)
Be	98.55185	wt. %

(a) Oxygen content from side reflector was used in the top and bottom reflector.

^a F.T. Bly, "The NEPA Critical Experiment Facility, Materials For ANP Zero Power Reactor Experiments (Appendix C of NEPA-1769)," NEPA-1829, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 16, 1951.

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Table 2-16. Uncertainty in Top and Bottom Reflector Beryllium Impurity Content.

Case	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
1	0.00072	$\pm$	0.00004	$\sqrt{3}$	0.00042	$\pm$	0.00002
2	0.00061	$\pm$	0.00004	$\sqrt{3}$	0.00035	$\pm$	0.00002

2.3.3 Uranium Oxide Composition

The fuel was pellets of uranium oxide, UO_2 . A spectrochemical analysis of the fuel is given in Table 1-5. The impurity content was calculated and perturbed using methods described in Section 2.3 while holding the total fuel mass constant. All impurities were varied simultaneously and results are summarized in Table 2-17.

Table 2-17. Uncertainty in Fuel Composition.

Case	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
1	-0.00014	$\pm$	0.00004	$\sqrt{3}$	-0.00008	$\pm$	0.00002
2	-0.00013	$\pm$	0.00004	$\sqrt{3}$	-0.00008	$\pm$	0.00002

The oxygen to uranium ratio in the fuel would have been 2.0. The ratio could not have been less than 2.0 and no more than 2.02.^a The uranium to oxygen ratio was $2.0 + 0.02$, which is a one-sided bounding uncertainty. Results are summarized in Table 2-18.

Table 2-18. Uncertainty in Oxygen to Uranium Ratio.

Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
1	± 0.05	-0.00057	$\pm$	0.00004	$2.5 \cdot 2\sqrt{3}$	-0.00007	$\pm$	0.00001
2		-0.00048	$\pm$	0.00004	$2.5 \cdot 2\sqrt{3}$	-0.00005	$\pm$	0.00001

The uncertainty in the isotopic distribution of uranium was also evaluated. According to the experimenter, the uncertainty in the ^{234}U , ^{235}U , and ^{236}U content was ± 0.005 wt.%; however, typical uncertainties for this time period at Oak Ridge National Laboratory would have been 0.0017 wt.%, 0.0177 wt.%, 0.0130 wt.% for the ^{234}U , ^{235}U , and ^{236}U , respectively. These typical values were used for the uranium isotopic uncertainties rather than the values given by the experimenter. It was assumed that the ^{238}U content was found by subtracting the ^{234}U , ^{235}U , and ^{236}U contents from unity; thus, when the content of a single isotope was perturbed the ^{238}U content was varied to maintain unity. ^{234}U and ^{235}U were varied individually by ± 0.5 wt.% and ^{236}U was varied by ± 0.45 wt.%. Total fuel mass was maintained when perturbing the uranium isotopic. Results are summarized in Table 2-19.

^a Personal communication between J.T. Mihalczo and a Y-12 chemist, August 14, 2012.

Table 2-19. Uncertainty in Uranium Isotopic Distribution.

	Case	Deviation	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
^{234}U	1	$\pm 0.5 \text{ wt.}\%$	0.00068	$\pm$	0.00004	294.12	<0.00001	$\pm$	<0.00001
	2		0.00073	$\pm$	0.00004	294.12	<0.00001	$\pm$	<0.00001
^{235}U	1	$\pm 0.5 \text{ wt.}\%$	0.00201	$\pm$	0.00004	28.25	0.00007	$\pm$	<0.00001
	2		0.00198	$\pm$	0.00004	28.25	0.00007	$\pm$	<0.00001
^{236}U	1	$\pm 0.45 \text{ wt.}\%$	-0.00008	$\pm$	0.00004	34.62	<0.00001	$\pm$	<0.00001
	2		-0.00014	$\pm$	0.00004	34.62	<0.00001	$\pm$	<0.00001

2.3.4 Fuel Tube Composition

The fuel pellets were in Type 347 Stainless Steel tubes. The composition of the Type 347 Stainless Steel was not given, so a standard composition was used. The standard composition and the model composition, as determined using methods described in Section 2.3, are given in Table 2-20. The perturbation of the composition was performed on all elements simultaneously using the method described in Section 2.3. When the composition was varied, iron content was varied to maintain a balance. The results of the perturbation of the composition are given in Table 2-21.

Table 2-20. Type 347 Stainless Steel Composition.

Element	Standard Composition ^{(a)(b)}	Model Composition
Iron, Fe	Balance	68.7225 wt.%
Carbon, C	0.08 wt.%	0.04 wt.%
Manganese, Mn	2.00 wt.%	1.00 wt.%
Silicon, Si	1.00 wt.%	0.50 wt.%
Chromium, Cr	17.0-19.0 wt.%	18.0 wt.%
Nickel, Ni	9.0-13.0 wt.%	11.0 wt.%
Phosphorus, P	0.045 wt.%	0.0225 wt.%
Sulfur, S	0.030 wt.%	0.0150 wt.%
Tantalum+Niobium, Ta + Nb	10×C min., 1.0 wt.% max	0.7 wt.% total 0.644 wt.% Nb, 0.056 wt.% Ta ^(c)

(a) R.H. Perry and D.W. Green, editors, "Perry's Chemical Engineers' Handbook," McGraw-Hill, 7th ed. (1997) .

(b) Single values are maximum values.

(c) The split between Nb and Ta was determined based on the natural abundances of Nb and Ta in the earth's crust, 8 and 0.7 ppm, respectively. Shaw, R., Goodenough, K., et. al., "Niobium-tantalum," British Geological Survey, April 2011, www.MineralsUK.com, (accessed June 8, 2012).

Table 2-21. Uncertainty in Fuel Tube Composition.

Case	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
1	-0.00043	$\pm$	0.00004	$\sqrt{3}$	-0.00025	$\pm$	0.00002
2	-0.00048	$\pm$	0.00004	$\sqrt{3}$	-0.00027	$\pm$	0.00002

2.3.5 Core Tank Composition

The core tank was made of Type 1100 Aluminum. The composition of the aluminum was not given, so a standard composition was used. Silicon and iron content was given as a maximum of the sum of the two elements. For the model, one half the maximum was assumed as the total for both elements thus one quarter of the maximum content was used for silicon and iron. All other element contents were found using methods described in Section 2.3. Aluminum was varied to maintain unity. For all elements except silicon and iron, perturbation methods described in Section 2.3 were used. For the uncertainty perturbation of iron and silicon, the iron content was set to the maximum, (0.95 wt. %) for the upper uncertainty and silicon was set to zero and vice versa for the lower uncertainty. The standard composition and the model composition are given in Table 2-22. The results of the perturbation of the composition are given in Table 2-23.

Table 2-22. Type 1100 Aluminum Composition.

Element	Standard Composition ^{(a)(b)}	Model Composition
Aluminum, Al	99.00 wt.% minimum	99.325 wt. %
Copper, Cu	0.05-0.20 wt. %	0.125 wt. %
Silicon, Si	0.95 wt. %	0.2375 wt. %
Iron, Fe	Si + Fe	0.2375 wt. %
Manganese, Mn	0.05 wt. %	0.025 wt. %
Zinc, Zn	0.1 wt. %	0.05 wt. %
Other ^(c)	0.03 wt. % each 0.015 wt. total	0.00 wt. %

(a) ASTM Standard B 209 - 07.

(b) Single values are maximum values.

(c) 'Other' impurities were assumed have a negligible effect on k_{eff} and thus were not included in the benchmark model.

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Table 2-23. Uncertainty in Core Tank Composition.

Case	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
1	-0.00001	$\pm$	0.00004 ^(a)	$\sqrt{3}$	-0.00001	$\pm$	0.00002
2	-0.00005	$\pm$	0.00004	$\sqrt{3}$	-0.00003	$\pm$	0.00002

(a) Despite using a scaling factor, the Δk_{eff} is less than σ_{MC} , which is small, thus this uncertainty has a negligible effect, as is seen in Table 2-28.

2.3.6 Composition of Top and Bottom Reflector Tanks

The reflector tanks for the top and bottom reflector were composed of Type 1100 Aluminum. The composition was varied by the same method used for the evaluation of the core tank composition. The effect of the uncertainty in the grid plates is given in Table 2-25.

Table 2-24. Uncertainty in Reflector Tank Composition.

Case	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
1	-0.00002	$\pm$	0.00004	$\sqrt{3}$	-0.00001	$\pm$	0.00002
2	-0.00002	$\pm$	0.00004	$\sqrt{3}$	-0.00001	$\pm$	0.00002

2.3.7 Composition of Core Support Structure

The grid plates were composed of Type 1100 Aluminum. The standard composition of Type 1100 Aluminum is given in Table 2-22. The composition was varied by the same method used for the evaluation of the core tank composition. The effect of the uncertainty in the grid plates is given in Table 2-25.

Table 2-25. Uncertainty in Grid Plate Composition.

Case	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
1	0.00005	$\pm$	0.00004	$\sqrt{3}$	0.00003	$\pm$	0.00002
2	0.00002	$\pm$	0.00004	$\sqrt{3}$	0.00001	$\pm$	0.00002

The grid plate spacer tubes were made of Type 347 Stainless Steel (standard composition given in Table 2-20). It was judged that the uncertainty in the grid plate spacer tube composition would have a negligible (see Section 3.1.2) effect based on the small bias for removing the tubes.

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According to the experimenter, five shims, similar to the shims used in the first experiment, were used to hold the fuel in place for Case 1. The shims were included in the detailed model as 1.91-cm tall 27° sections of Type 1100 Aluminum. Because the effect of removing these shims from the model is negligible (see Section 3.1.2), it is assumed that the uncertainty in the shim composition is also negligible.

2.3.8 Composition of Support Plates

The support plates were composed of Type 304 Stainless Steel and Type 1100 Aluminum. The standard compositions for these materials are given in Tables 2-22 and 2-26, respectively. The composition for the plates was perturbed using methods described in Sections 2.3 and 2.3.4 for the aluminum composition. The results of these perturbations are summarized in Table 2-27.

Table 2-26. Type 304 Stainless Steel Composition.

Element	Standard Composition ^{(a)(b)}	Model Composition
Iron, Fe	Balance	69.9225 wt. %
Carbon, C	0.08 wt. %	0.04 wt. %
Manganese, Mn	2.00 wt. %	1.00 wt. %
Silicon, Si	1.00 wt. %	0.50 wt. %
Chromium, Cr	18.0-20.0 wt. %	19.00 wt. %
Nickel, Ni	8.0-11.0 wt. %	9.50 wt. %
Phosphorus, P	0.045 wt. %	0.0225 wt. %
Sulfur, S	0.03 wt. %	0.015 wt. %

(a) ASTM Standard A 312/A 312M-09.

(b) Single values are maximum values.

Table 2-27. Uncertainty in Support Plate Compositions.

Case	Δk_{eff}	$\pm$	σ_{MC}	Scaling Factor	$\Delta k_{\text{eff}} (1\sigma)$	$\pm$	$\sigma_{\text{statistical}}$
Type 1100 Aluminum							
1	-0.00005	$\pm$	0.00004	$\sqrt{3}$	-0.00003	$\pm$	0.00002
2	-0.00007	$\pm$	0.00004	$\sqrt{3}$	-0.00004	$\pm$	0.00002
Type 304 Stainless Steel							
1	0.00019	$\pm$	0.00004	$\sqrt{3}$	0.00011	$\pm$	0.00002
2	0.00026	$\pm$	0.00004	$\sqrt{3}$	0.00015	$\pm$	0.00002

2.4 Temperature Uncertainty

The experiments were carried out at 22°C or 295.15 K. The temperature in the facility could have varied a few degrees (1 °C is 1 σ). The temperature coefficient for bare, highly enriched uranium metal experiments at this facility was -0.3 ϕ /ΔT(°C). The temperature coefficient for this experiment would have been less than this because of the reflector and thus the effect of the uncertainty in the temperature on k_{eff} would have been negligible.^a

2.5 Total Uncertainty in Critical Configuration

All 1 σ uncertainties were compiled and are summarized in Table 2-28. An uncertainty is considered to have a negligible effect (NEG) when the magnitude of the 1 σ Δk_{eff} is ≤ 0.00010 . The total uncertainty were 0.00066 and 0.00060 Δk_{eff} for Case 1 and Case 2, respectively. The experimental uncertainties in HEU-COMP-FAST-001 and HEU-COMP-FAST-002 were approximately 0.0005 and 0.00065 Δk_{eff} , respectively. The statistical uncertainties in the Monte Carlo calculation were not preserved in Table 2-28, as they were all considered negligible, but can be found in the preceding sections if necessary.

The described configurations are judged to be acceptable as a criticality safety benchmark experiments.

Table 2-28. Total Uncertainty in Experimental Configuration.

	Case 1			Case 2		
	Parameter Value ^(a)		$\pm \Delta k_{\text{eff}}$ (1 σ)	Parameter Value ^(a)		$\pm \Delta k_{\text{eff}}$ (1 σ)
Configuration Reactivity	11.8	$\pm 1.18 \phi$	0.00013	22.3	$\pm 2.23 \phi$	0.00020
7.303-cm Block	7.303	$\pm 0.00148 \text{ cm}$	NEG	7.303	$\pm 0.00148 \text{ cm}$	NEG
3.647-cm Block	3.647	$\pm 0.00148 \text{ cm}$	NEG	3.647	$\pm 0.00148 \text{ cm}$	NEG
Bottom Reflector Height	7.62	$\pm 0.005 \text{ cm}$	NEG	7.62	$\pm 0.005 \text{ cm}$	NEG
Top Reflector Height	6.985	$\pm 0.004 \text{ cm}$	NEG	6.985	$\pm 0.004 \text{ cm}$	NEG
Side Reflector Height	30.63	$\pm 0.01 \text{ cm}$	-0.00012	30.63	$\pm 0.01 \text{ cm}$	-0.00012
Side Reflector Thickness	11.37	$\pm 0.01 \text{ cm}$	-0.00021	11.37	$\pm 0.01 \text{ cm}$	-0.00021
Side Reflector Inside Diameter	26.16	$\pm 0.01 \text{ cm}$	-0.00019	26.16	$\pm 0.01 \text{ cm}$	NEG
Top Reflector Mass	17.13	$\pm 0.01 \text{ kg}$	NEG	17.13	$\pm 0.01 \text{ kg}$	NEG
Bottom Reflector Mass	5.75	$\pm 0.01 \text{ kg}$	NEG	5.75	$\pm 0.01 \text{ kg}$	NEG
Side Reflector Mass	75.7	$\pm 0.1 \text{ kg}$	0.00042	75.7	$\pm 0.1 \text{ kg}$	0.00043
Reflector Tank Wall Thickness	0.635	$\pm 0.001 \text{ cm}$	NEG	0.635	$\pm 0.001 \text{ cm}$	NEG
Reflector Tank Bottom Thickness	0.22/ 0.89	$\pm 0.01 \text{ cm}$	NEG	0.22/ 0.89	$\pm 0.01 \text{ cm}$	NEG
Bottom Reflector Tank Height	8.51	$\pm 0.01 \text{ cm}$	NEG	8.51	$\pm 0.01 \text{ cm}$	NEG
Top Reflector Tank Height	12.95	$\pm 0.01 \text{ cm}$	NEG	12.95	$\pm 0.01 \text{ cm}$	NEG

^a Personal email communication with J.T. Mihalcz, November 14, 2011

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Table 2-28. Total Uncertainty in Experimental Configuration.

Top Reflector Tank Mass	4.38	±	0.01 kg	NEG	4.38	±	0.01 kg	NEG
Bottom Reflector Tank Mass	5.75	±	0.01 kg	NEG	5.75	±	0.01 kg	NEG
Fuel Length	29.88	±	0.01 cm ^(b)	NEG	29.88	±	0.01 cm ^(b)	NEG
Fuel Diameter	1.141	±	0.004 cm ^(b)	NEG	1.141	±	0.004 cm ^(b)	NEG
Fuel Tube Wall Thickness	0.051	±	0.004 cm ^(b)	NEG	0.051	±	0.004 cm ^(b)	NEG
Fuel Tube Length	30.48	±	0.01 cm ^(b)	NEG	30.48	±	0.01 cm ^(b)	NEG
Fuel Tube Outside Diameter	1.27	±	0.00733 cm ^(b)	NEG	1.27	±	0.00733 cm ^(b)	NEG
Mass of Fuel per Tube	295.818	±	0.063 g	0.00010	295.818	±	0.063 g	0.00010
Mass of Fuel Tube	46.011	±	0.032 g	NEG	46.011	±	0.032 g	NEG
Fuel Pitch	1.506	±	0.001cm	NEG	3.96565	±	0.001 cm	NEG
Fuel Placement	Section 2.2.4			NEG	Section 2.2.4			NEG
Core Tank Mass	2.125	±	0.001 kg	NEG	2.125	±	0.001 kg	NEG
Core Tank Side Wall Thickness	0.254	±	0.001 cm	NEG	0.254	±	0.001 cm	NEG
Core Tank Bottom Thickness	0.33	±	0.01 cm	NEG	0.33	±	0.01 cm	NEG
Core Tank Outside Diameter	25.96	±	0.01 cm	NEG	25.96	±	0.01 cm	NEG
Core Tank Outside Length	31.04	±	0.01 cm	NEG	31.04	±	0.01 cm	NEG
Grid Plate Mass/Density	37.5	±	1 kg	NEG	2.70	±	0.087 g/cm ³	NEG
Grid Plate Thickness	0.317	±	0.001 cm	NEG	0.317	±	0.001 cm	NEG
Grid Plate Hole Diameter	1.284	±	0.014 cm	NEG	1.284	±	0.014 cm	NEG
Beryllium Support Plate Thickness	0.635	±	0.001 cm	NEG	0.635	±	0.001 cm	NEG
Beryllium Support Plate Outside Dimensions	75	±	1 cm	NEG	75	±	1 cm	NEG
Beryllium Support Plate Inside Diameter	27.9	±	0.1 cm	NEG	27.9	±	0.1 cm	NEG
Beryllium Support Plate Mass	8.7	±	0.1 kg	NEG	8.7	±	0.1 kg	NEG
Bottom Reflector Support Plate Thickness	2.38	±	0.01 cm	NEG	2.38	±	0.01 cm	NEG
Bottom Reflector Support Plate Diameter	45.72	±	0.01 cm	NEG	45.72	±	0.01 cm	NEG
Bottom Reflector Support Plate Mass	31.2	±	0.1 kg	NEG	31.2	±	0.1 kg	NEG
Side Reflector Impurity Content	Section 2.3.1			-0.00032	Section 2.3.1			-0.00033
Top and Bottom Reflector Impurity Content	Section 2.3.2			0.00042	Section 2.3.2			0.00035

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Table 2-28. Total Uncertainty in Experimental Configuration.

Fuel Composition	Section 2.3.3		NEG	Section 2.3.3		NEG
Oxygen to Uranium Ratio	2	$\pm 0.02/2\sqrt{3}$	NEG	2	$\pm 0.02/2\sqrt{3}$	NEG
²³⁴ U Isotopic Distribution	1.01	± 0.0017 wt. %	NEG	1.01	± 0.0017 wt. %	NEG
²³⁵ U Isotopic Distribution	93.15	± 0.0177 wt. %	NEG	93.15	± 0.0177 wt. %	NEG
²³⁶ U Isotopic Distribution	0.47	± 0.013 wt. %	NEG	0.47	± 0.013 wt. %	NEG
Fuel Tube Composition	Section 2.3.4		-0.00025	Section 2.3.4		-0.00027
Core Tank Composition	Section 2.3.5		NEG	Section 2.3.5		NEG
Top and Bottom Reflector Tank Composition	Section 2.3.6		NEG	Section 2.3.6		NEG
Grid Plate Composition	Section 2.3.7		NEG	Section 2.3.7		NEG
Aluminum Support Table Composition	Section 2.3.8		NEG	Section 2.3.8		NEG
Stainless Steel Support Plate Composition	Section 2.3.8		0.00011	Section 2.3.8		0.00015
Temperature	Section 2.4		NEG	Section 2.4		NEG
Total Experimental Uncertainty	Case 1	0.00080		Case 2	0.00082	

- (a) Uncertainty is 1 σ uncertainty unless stated otherwise
(b) This uncertainty is 25% systematic and 75% random (see Section 2.2.3).

3.0 BENCHMARK SPECIFICATIONS

Detailed and simple benchmark models were created with MCNP5 using ENDF/B-VII.0 neutron cross section libraries. The biases of any simplifications or assumptions were calculated for both the detailed and simple models. All models were run in MCNP5 such that the statistical uncertainty (1σ) of k_{eff} was not more than 0.00006 and for some cases it was 0.00002. Benchmark specifications for both the detailed and simple model are described in Sections 3.2 and 3.3.

The method for determining the simplification bias was as follows. First, the detailed benchmark model was created. The biases of simplifications in the detailed benchmark model were calculated. This included the bias of room return, replacing air with void, and the modeling of the grid plates (Case 1). Next, the biases of individual simplifications used to obtain the simple benchmark model were calculated. This included the bias of removal of the support structures within the core, homogenization of the fuel and fuel tubes, and the removal of material impurities. The overall biases for the detailed and simple benchmark models were found by comparing the benchmark models to a model with no simplifications.

A simplification is considered negligible if the effect on k_{eff} is ≤ 0.00010 .

3.1 Description of Model

3.1.1 Description of the Detailed Benchmark Model Simplifications

3.1.1.1 Room Return and Effect of Air

As stated in Reference 2, the vertical assembly machine was located in the experiment cell such that the center of the core was 12.336 ft (3.760 m) from the 4.92-ft-thick west wall (1.50 m), 12.79 ft (5.42 m) from the 1.97-ft-thick (0.60 m) north wall and 9.19 ft (2.80 m) above the concrete floor in the 35.10×35.10-ft-square (10.7×0.7 m) 29.86-ft-tall (9.10 m) room. The walls were modeled as described (the east and south walls were modeled as being 2 ft (0.6 m) thick) with a 2-ft-thick (0.6 m) concrete floor and ceiling, using Oak Ridge concrete (HEU-MET-FAST-081).^a The results of this simplification bias are in Table 3-1.

The simplification bias of removing air (density of 1.19 kg/m³) from the model and replacing it with void is summarized in Table 3-1.

3.1.1.2 Grid Plates

For the grid plate in Case 1, as can be seen in Figure 1-4, the grid plate holes were cut through the edge of the grid plate in twenty locations. Rather than model each cut out explicitly, a modeling simplification was used. The cut outs were modeled as being five circle segments removed from the grid plate flush with the surface of the 4 fuel tubes. The circle segments were 27° sections, and mass was conserved. This simplification is shown in Figure 3-1.

^a SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, ORNL/TM-2005/39 Version 5, Volume III, Section M.8, Oak Ridge National Laboratory, April 2005.

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Figure 3-1. Detailed Benchmark Model of Grid Plates, Case 1.

To determine the bias associated with this modeling simplification, a second grid plate geometry was modeled, as is shown in Figure 3-2. In this model, the mass of the grid plate was spread over the area of the cut outs.

Figure 3-2. Model of Grid Plates for Homogenization Bias, Case 1.

It was found that the effect of modeling the cut out had an effect of $-0.00040 \pm 0.00008 \Delta k_{\text{eff}}$. This approach was used due to the uncertainty in the exact dimensions of the grid plate at the edges. The reactivity of the true grid plate would have been somewhere between the reactivity of the models shown in Figures 3-1 and 3-2 thus the $-0.00040 \pm 0.00008 \Delta k_{\text{eff}}$ was taken to be half bias and half uncertainty. Thus the modeling bias for the grid plates was $-0.00020 \pm 0.00021 \Delta k_{\text{eff}}$.

The grid plate for Case 2 is shown in Figure 1-5. The thickness of the plates was the same as the Case 1 plate thickness. No mass was given for the grid plates, so a nominal type 1100 aluminum density of 2.70 g/cm^3 was used in the detailed benchmark model. A modeling simplification was made by modeling the grid plate as shown in Figure 3-3. A small amount of aluminum was present within the cluster in the detailed benchmark model that was not present in the actual grid plate. This simplification is believed to have a negligible effect.

Figure 3-3. Detailed Benchmark Model of Grid Plates, Case 2.

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The grid plates were supported with four stainless steel grid plate support tubes. The positions of these tubes were chosen arbitrarily in the detailed benchmark model. It is believed that the arbitrary placement of these tubes would have a negligible bias.

3.1.1.3 Fuel Tube End Caps

The end caps in the fuel tubes were not solid cylinders but rather cup like, which created wells. The end caps were modeled as solid plugs with a reduced density. The height of each plug was found by taking half the difference between the fuel tube length (30.48 cm) and the length of 26 stacked pellets (29.88 cm). This bias of this model simplification was believed to be negligible.

3.1.1.4 Reflector Tank Modeling Simplifications

For the detailed benchmark model, the reflector tanks were modeled as described in Section 2.2.2. Because of the small bias associated with simplifying the reflector tanks to cylindrical tanks with a nominal diameter, it is believed that any modeling biases associated with the detailed benchmark model would have been negligible.

3.1.1.5 Temperature

The experiments were performed at 22°C or 295.15 K. The model temperature was 293.6 K. The bias of this temperature change is negligible.

3.1.1.6 Summary of Simplification Biases for Detailed Benchmark Model

The overall simplification bias was found by comparing the most detailed model to the detailed benchmark model. The overall simplification bias is given in Table 3-1. The biases associated with individual simplifications are also given in Table 3-1 for reference.

Table 3-1. Summary of Simplification Biases for the Detailed Benchmark Model.

	Case 1	Case 2
Room Return	-0.00034 ± 0.00008	-0.00018 ± 0.00008
Replacing Air with Void	-0.00022 ± 0.00008	NEG
Grid Plate Simplification	-0.00020 ± 0.00021	-
Fuel Tube End Cap Simplification	NEG	NEG
Grid Plate Spacer Tube Position	NEG	NEG
Reflector Tank Simplifications	NEG	NEG
Temperature Bias	NEG	NEG
Overall Simplification Bias	-0.00060 ± 0.00023 ^(a)	-0.00048 ± 0.00008 ^(a)

(a) Found by comparing the detailed benchmark model against a model with no simplifications and then adding the bias and uncertainty in the grid plate simplification.

(b) Found by comparing the detailed benchmark model against a model with no simplifications. No simplifications were made to the grid plate in Case 2

3.1.2 Description of the Simple Benchmark Model Simplifications

The simplification biases applied to the detailed benchmark model would also have applied to the simple benchmark model. These are included in Table 3-2.

3.1.2.1 Simplification of Top and Bottom Reflectors

The top and bottom reflector were modeled as cylinders of nominal diameter 41.3 cm in the simple benchmark model. The nominal diameter of 41.3 cm is the diagonal distance across the reflector ($4 \cdot \sqrt{2 \cdot 7.303^2}$). The bias of this simplification was evaluated in the top and bottom reflector separately. The reflector tanks were modeled as having a 41.3 cm inner diameter to match the reflector geometry. The bias of this simplification was evaluated independently. The results are given in Table 3-2.

3.1.2.2 Simplification of Core Region

The support structure for the fuel tubes in the core was removed in the simple benchmark model. The five aluminum shims were removed (Case 1), the grid plate spacer tubes were removed, and the grid plates were removed. The biases of these simplifications are given in Table 3-2.

3.1.2.3 Simplification of Fuel

The fuel tube geometry was simplified by homogenizing the mass of the fuel tube and two end caps (46.01114 g) over the entire fuel tube volume rather than having separate material densities for the fuel tube and the two end caps.

The mass of the fuel (295.818 g) was homogenized over the length of the fuel (1.141-cm diameter, 29.88-cm long).

The biases of the simplifications are given in Table 3-2.

3.1.2.4 Removal of Impurities

The impurities, as given in Tables 1-5, 2-13, and 2-15, were replaced with void in the fuel and the beryllium. This reduced the total material weight percentage for the fuel and beryllium. The effect on k_{eff} of removing these impurities is given in Table 3-2.

3.1.2.5 Summary of Simplification Biases for Simple Benchmark Model

The overall simplification bias was found by comparing the simple benchmark model against a model with no simplifications. Because the bias was of a relatively larger magnitude the bias was also calculated using other cross section libraries (Jeff-3.1 and JENDL-3.3). The overall simplification bias is given in Table 3-2. The biases associated with individual simplifications are also given in Table 3-2 for reference.

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Table 3-2. Summary of Simplification Biases for Simple Benchmark Model.

	Case 1	Case 2
Room Return	-0.00037 ± 0.00008	-0.00016 ± 0.00008
Replacing Air with Void	-0.00045 ± 0.00008	-0.00035 ± 0.00008
Temperature Bias	NEG	NEG
Nominal Diameter for Top Reflector	0.00061 ± 0.00008	0.00042 ± 0.00008
Nominal Inner Diameter for Top Reflector Tank	0.00020 ± 0.00008	0.00026 ± 0.00008
Nominal Diameter for Bottom Reflector	0.00079 ± 0.00008	0.00075 ± 0.00008
Nominal Inner Diameter for Bottom Reflector Tank	0.00019 ± 0.00008	0.00010 ± 0.00008
Removing Shims	NEG	-
Removing Grid Plate Spacer Tubes	-0.00011 ± 0.00008	NEG
Remove Grid Plates	-0.00099 ± 0.00008	-0.00122 ± 0.00008
Grid Plate Simplifications	-0.00020 ± 0.00021	-
Fuel Tube End Cap Simplifications	NEG	NEG
Simplification of Fuel Tube	-0.00017 ± 0.00008	-0.00023 ± 0.00008
Homogenization of Fuel	-0.00011 ± 0.00008	NEG
Removing Fuel Impurities	NEG	NEG
Removing Side Reflector Impurities	-0.00131 ± 0.00008	-0.00116 ± 0.00008
Removing Top and Bottom Reflector Impurities	NEG	NEG
Overall Simplification Bias^{(a)(b)(c)}	-0.00194 ± 0.00025	-0.00185 ± 0.00009
ENDF/B-VII.0	-0.00182 ± 0.00008	-0.00189 ± 0.00008
JEFF3.1	-0.00178 ± 0.00008	-0.00185 ± 0.00008
JENDL-3.3	-0.00162 ± 0.00008	-0.000181 ± 0.00008

- (a) Found by comparing the simple benchmark model against a model with no simplifications.
(b) Overall simplification bias found by averaging of the three cross section library results. Uncertainty is the standard deviation of the results and the statistical uncertainty added in quadrature.
(c) For Case 1 the grid plate simplification bias and associated uncertainty was also added to the overall simplification bias. There was no grid plate simplification bias for Case 2.

3.1.3 Total Bias for Detailed and Simple Benchmark Models

In addition to the simplification bias discussed in Sections 3.1.1 and 3.1.2, there is an experimental bias from the measured reactivity of the critical configuration. The experimental bias and the simplification biases were added to obtain the total bias. The total bias of the benchmark model is given in Table 3-3.

Table 3-3. Summary of Benchmark Model Biases.

	Case 1			Case 2		
Experimental Bias (ϵ)	11.8	$\pm$	1.18	22.3	$\pm$	2.23
Experimental Bias (Δk_{eff})	0.00086	$\pm$	0.00013 ^(a)	0.00163	$\pm$	0.00020 ^(a)
Overall Simplification Bias ^(b)						
Detailed Benchmark Model	-0.00060	$\pm$	0.00023	-0.00048	$\pm$	0.00008
Simple Benchmark Model	-0.00194	$\pm$	0.000025	-0.00185	$\pm$	0.00009
Total Bias						
Detailed Benchmark Model	0.00026	$\pm$	0.00023	0.00115	$\pm$	0.00008
Simple Benchmark Model	-0.00108	$\pm$	0.00025	-0.00022	$\pm$	0.00009

- (a) The uncertainty in the measured reactivity of the critical configuration was included in the measurement uncertainty given in Section 2.
- (b) Found by comparing the detailed or simple benchmark model against a model with no simplifications.

3.2 Benchmark Model Dimensions

3.2.1 Detailed Benchmark Model Dimensions

3.2.1.1 Top and Bottom Reflectors and Tanks

The top and bottom reflectors were modeled as square and triangular blocks 6.985 and 7.62 cm thick, respectively. A gap of 0.47625 cm was modeled between the reflector tank walls and the outermost beryllium blocks. The dimensions of the blocks and reflector tank for the top and bottom reflector are given in Figure 3-4. The volume and mass of the top and bottom reflector were 9,259.848 cm³, 17.13 kg, 10,101.65 cm³, and 18.7 kg respectively. The volume and mass of the top and bottom reflector tanks were 1,540.063 cm³, 4.38 kg, 2,166.843 cm³, and 7.303 kg respectively.

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Figure 3-4. Beryllium Blocks and Reflector Tank for Top and Bottom Reflector, Detailed Model.

3.2.1.2 Side Reflector

The side reflector was modeled as a single annulus of inner diameter 26.16 cm, outer diameter 48.9 cm, and height 30.63 cm.

3.2.1.3 Fuel and Fuel Tubes

The fuel tubes were modeled as 1.27-cm-OD stainless steel tubes with a 0.3 cm tall end caps. The fuel region was made up of 26, 1.141-cm-diameter, 1.145-cm-tall pellets. Small voids between each pellet yielded a total fuel length of 29.88 cm. The dimensions of the fuel and fuel tubes are given in Figure 3-5. The volume of each pellet was 1.17076 cm³ and the mass of 26 pellets was 295.818 g. The mass and volume of the fuel tube were 44.729 g and 5.95304 cm³ and for one end cap 0.64107 g and 0.321438 cm³.

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Figure 3-5. Fuel and Fuel Tube Dimensions in the Detailed Benchmark Model.

3.2.1.4 The Core, Case 1

The core consisted of a 253 fuel tube array, 1.506-cm-triangular pitch lattice for Case 1. Grid plates, grid plate spacer tubes, and aluminum shims were used to hold the fuel tubes in place. The core support structure is shown in Figure 3-6.

The fuel tubes were held in place with two 0.317-cm-thick aluminum grid plates. The holes in the grid plates for the detailed benchmark model had a diameter of 1.284 cm and 27° circle segments on five sides of the grid plate represented the cutouts in the grid plate (see Figure 3-1). Each grid plate weighed 139 g and had a volume of 44.098 cm³. Dimensions of the grid plate are given in Figure 3-1.

The lower grid plate sat on the bottom of the core tank and four grid plate spacer tubes, 27.94-cm long, supported the upper grid plate. The grid plate spacer tubes have an outside diameter of 1.37 cm and a wall thickness of 0.043 cm. Each grid plate spacer tube had a mass and volume of 37.5 g and 5.0086 cm³.

On the five sides where the grid plate was cut out, aluminum shims were used to hold in the four corresponding fuel tubes. The aluminum shims were modeled as 27° circle segments, 1.941-cm tall, located at the midplane of the core. The volume of each shim was 2.667 cm³ and the nominal density of 2.70 g/cm³ was used.

The core tank had an outside diameter of 25.96 cm, a side-wall thickness of 0.254 cm, a bottom thickness of 0.33 cm and an outside length of 31.04 cm. The mass and volume of the core tank was 2.125 kg and 804.6061 cm³.

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Figure 3-6. Core Support Structure Dimensions in the Detailed Benchmark Model, Case 1.

3.2.1.5 The Core, Case 2

In Case 2, the 253 fuel tubes were arranged in 5- and 7-tube cluster assemblies. Within the clusters, fuel tubes were touching and the pitch of the clusters was 3.95656 cm. Six individual fuel tubes were equally spaced around the periphery of the core. Two grid plates and four grid plate spacer tubes were used to hold the fuel tubes in place. The core support structure is shown in Figure 3-7.

The two grid plates were 0.317-cm-thick aluminum. The holes in the grid plates had a diameter of 1.284 cm. The grid plates had a nominal density of 2.70 g/cm³. Dimensions of the grid plates are given in Figure 3-3.

The lower grid plate sat on the bottom of the core tank and four grid plate spacer tubes identical to those used in Case 1 supported the upper grid plate.

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3.2.1.6 Support Plates and Table

The bottom reflector as on the steel top of the vertical lift and the side and top reflector were placed on the aluminum support table. The dimensions of the support plate and table are given in Table 3-4. The locations of the support plate and table can be seen in Figures 3-8 and 3-9.

Table 3-4. Support Plate Dimensions.

2.38-cm-Thick Type 304 Stainless Steel Plate	45.72-cm-OD, 31.2 kg.
0.635-cm-Thick Type 1100 Aluminum Table	75×75 cm square table with 27.9 cm diameter cutout ^(a) , 8.7 kg

(a) A cut out in the middle of the table allowed the core and bottom reflector to be lifted into the side reflector.

Figure 3-8. Detailed Benchmark Model, Case 1.

Figure 3-9. Detailed Benchmark Model, Case 2.

3.2.2 Simple Benchmark Model Dimensions

3.2.2.1 Reflectors and Reflector Tanks

The reflectors in the simple benchmark model were solid masses of beryllium. The top and bottom reflector and reflector tanks were modeled using a nominal diameter. The dimensions of the reflectors and reflector tanks are given in Figure 3-10.

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Figure 3-10. Dimensions of the Simple Benchmark Model, Case 1.

Figure 3-11. Dimensions of the Simple Benchmark Model, Case 2.

3.2.2.2 Fuel and Fuel Tubes

The fuel was modeled as solid 1.141-cm-diameter, 29.88-cm-tall fuel rods in the simple benchmark model. The fuel tubes were modeled as 1.27-cm-OD, 0.051-cm-thick-wall stainless steel tubes with 0.3 cm tall end caps. The dimensions of the fuel and fuel tubes can be seen in Figures 3-10 and 3-11.

3.2.2.3 The Core

The core for Case 1 consisted of a 253 fuel tube array, 1.506-cm-triangular lattice. The core for Case 2 consisted of 253 fuel tubes arranged in 5- and 7-tube cluster assemblies with a pitch of 3.95656. Both cores were held in a core tank with an outside diameter of 25.96 cm, a side-wall thickness of 0.254 cm, a bottom thickness of 0.33 cm and an outside length of 31.04 cm.

3.2.2.4 Support Plate and Table

The dimensions of the support plate and table were the same as in the detailed benchmark model (see Section 3.2.1.6).

3.3 Benchmark Model Material Data

Atomic masses from the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Document Content and Format Guide were used to derive atom densities for all material.

3.3.1 Detailed Benchmark Material Data

3.3.1.1 Top and Bottom Reflectors

The composition of the top and bottom reflectors is given in Table 3-5.

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Table 3-5. Top and Bottom Reflector Composition.

Element	Wt. %	Top Reflector Atoms/b-cm	Bottom Reflector Atoms/b-cm
Be	98.55185	1.2182E-01	1.2191E-01
Li	0.00003	4.8150E-08	4.8183E-08
B	0.00012	1.2366E-07	1.2374E-07
Mg	0.00800	3.6669E-06	3.6694E-06
Al	0.08000	3.3031E-05	3.3054E-05
Si	0.07000	2.7766E-05	2.7785E-05
Ca	0.00100	2.7797E-07	2.7816E-07
Cr	0.01400	2.9996E-06	3.0016E-06
Mn	0.01000	2.0278E-06	2.0292E-06
Co	0.00010	1.8903E-08	1.8916E-08
Ni	0.01800	3.4167E-06	3.4191E-06
Cu	0.00900	1.5778E-06	1.5789E-06
Zn	0.00300	5.1111E-07	5.1145E-07
Ag	0.00030	3.0983E-08	3.1005E-08
Cd	0.00002	1.9821E-09	1.9835E-09
O	1.23458	8.5964E-04	8.6023E-04
Total	100 wt. %	1.2190E-01	1.2198E-01

3.3.1.2 Top and Bottom Reflector Tanks

The composition of the top and bottom reflector tanks is given in Table 3-6.

Table 3-6. Top and Bottom Reflector Tank Composition.

Element	wt. %	Top Reflector Tank Atom/b-cm	Bottom Reflector Tank Atom/b-cm
Al	99.325	6.3077E-02	5.8854E-02
Cu	0.125	3.3690E-05	3.1435E-05
Si	0.2375	1.4483E-04	1.3514E-04
Fe	0.2375	7.2631E-05	6.7768E-05
Mn	0.025	7.7938E-06	7.2720E-06
Zn	0.050	1.3096E-06	1.2219E-06
Total	100 wt. %	6.3338E-02	5.9097E-02

3.3.1.3 Side Reflectors

The composition of the side reflector is given in Table 3-7.

Table 3-7. Side Reflector Composition.

Element	Wt. %	Side Reflector Atom/b-cm
Be	98.38377	1.2120E-01
O	1.23458	8.5669E-04
Al	0.06	2.4688E-05
C	0.12	1.1092E-04
Fe	0.13	2.5844E-05
Mg	0.02	9.1357E-06
Bi	0.05	2.6563E-06
B	0.001	1.0269E-06
Cd	0.0002	1.9753E-08
Dy	0.0001	6.8321E-09
Br	0.00005	6.9472E-09
Gd	0.0001	7.0602E-09
Ni	0.0001	1.8917E-08
Sm	0.0001	7.3837E-09
Total	100 wt. %	1.2223E-01

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3.3.1.4 Fuel

The composition of the fuel is given in Table 3-8.

Table 3-8. Fuel Composition.

Element/Isotope	wt. %	Atom/barn-cm
²³⁴ U	0.8887	2.2222E-04
²³⁵ U	81.9608	2.0407E-02
²³⁶ U	0.4135	1.0253E-04
²³⁸ U	4.7250	1.1616E-03
O	11.9708	4.3788E-02
Ag	1.9992E-03	1.0847E-06
Be	1.4994E-05	9.7367E-08
Cr	2.2991E-03	2.5877E-06
Li	7.4969E-05	6.3211E-07
Ni	1.2495E-03	1.2251E-06
Sn	1.4994E-03	7.3919E-07
Al	1.6493E-03	3.5774E-06
Ca	4.9979E-03	7.2982E-06
Cu	1.8992E-03	1.7491E-06
Mg	5.9975E-04	1.4441E-06
P	4.9979E-03	9.4434E-06
B	4.9979E-05	2.7056E-07
Fe	1.2995E-02	1.3617E-05
Mn	3.9984E-04	4.2593E-07
Ba	4.9979E-04	2.1299E-07
K	2.4990E-03	3.7406E-06
Na	4.9979E-04	1.2723E-06
Si	2.9988E-03	6.2487E-06
Total	100 wt. %	6.5737E-02

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3.3.1.5 Fuel Tubes

The compositions of the fuel tubes and end caps are given in Table 3-9.

Table 3-9. Fuel Tube and End Cap Composition.

Element	wt. %	Fuel Tube Atom/barn-cm	End Caps Atom/barn-cm
Fe	68.7225	5.5680E-02	1.4779E-02
C	0.04	1.5069E-04	3.9998E-05
Mn	1.00	8.2362E-04	2.1862E-04
Si	0.50	8.0554E-04	2.1382E-04
Cr	18.00	1.5664E-02	4.1578E-03
Ni	11.00	8.4806E-03	2.2511E-03
P	0.0225	3.2869E-05	8.7246E-06
S	0.0150	2.1164E-05	5.6176E-06
Nb	0.644	3.1349E-04	8.3211E-05
Ta	0.056	1.4084E-05	3.7383E-06
Total	100 wt. %	8.1986E-02	2.1762E-02

3.3.1.6 The Core Tank

The composition of the core tank is given in Table 3-10.

Table 3-10. Core Tank Composition.

Element	wt. %	Atom/barn-cm
Al	99.325	5.85485E-02
Cu	0.125	3.12857E-05
Si	0.2375	1.34495E-04
Fe	0.2375	6.74467E-05
Mn	0.025	7.23754E-06
Zn	0.050	1.21614E-05
Total	100 wt. %	5.88012E-02

3.3.1.7 Grid Plates

The composition of the grid plates is given in Table 3-11.

Table 3-11. Grid Plate Composition.

Element	wt. %	Case 1 Atom/barn-cm	Case 2 Atom/barn-cm
Al	99.325	6.9878E-02	5.9856E-02
Cu	0.125	3.7339E-05	3.1984E-05
Si	0.2375	1.6052E-04	1.3750E-04
Fe	0.2375	8.0725E-05	6.9147E-05
Mn	0.025	8.6380E-06	7.3991E-06
Zn	0.050	1.4515E-05	1.2433E-05
Total	100 wt. %	7.0179E-02	6.0114E-02

3.3.1.8 Grid Plate Spacer Tubes

The composition of the grid plate spacer tubes is given in Table 3-12.

Table 3-12. Grid Plate Spacer Tube Composition.

Element	wt. %	Atom/barn-cm
Fe	68.7225	5.5483E-02
C	0.04	1.5016E-04
Mn	1.00	8.2071E-04
Si	0.50	8.0270E-04
Cr	18.00	1.5609E-02
Ni	11.00	8.4507E-03
P	0.0225	3.2753E-05
S	0.0150	2.1089E-05
Nb	0.644	3.1238E-04
Ta	0.056	1.4034E-05
Total	100 wt. %	8.1697E-02

3.3.1.9 Aluminum Shims

The composition of the aluminum shims is given in Table 3-13.

Table 3-13. Aluminum Shim Composition.

Element	wt. %	Atom/barn-cm
Al	99.325	5.9856E-02
Cu	0.125	3.1984E-05
Si	0.2375	1.3750E-04
Fe	0.2375	6.8952E-05
Mn	0.025	7.3991E-06
Zn	0.050	1.2433E-05
Total	100 wt. %	6.0114E-02

3.3.1.10 Support Plate and Table

The composition of the aluminum table is given in Table 3-14.

Table 3-14. Aluminum Table Composition

Element	wt. %	Atoms/barn-cm
Al	99.325	6.0608E-02
Cu	0.125	3.2371E-05
Si	0.2375	1.3916E-04
Fe	0.2375	6.9788E-05
Mn	0.025	7.4887E-06
Zn	0.050	1.2583E-06
Total	100 wt. %	6.0858E-02

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The stainless steel plate composition is given in Table 3-15.

Table 3-15. Stainless Steel Plate Composition.

Element	wt. %	Atoms/barn-cm
Fe	69.9225	6.0206E-02
C	0.04	1.6014E-04
Mn	1.00	8.7529E-04
Si	0.50	8.5607E-04
Cr	19.00	1.7571E-02
Ni	9.50	7.7836E-03
P	0.0225	3.4931E-05
S	0.015	2.2491E-05
Total	100 wt. %	8.7510E-02

3.3.2 Simple Benchmark Material Data

3.3.2.1 Reflectors

A nominal diameter for the top and bottom reflector was used in the simple benchmark model. Impurities in the beryllium were replaced with void in the simple benchmark model. The composition of the beryllium for the side, top and bottom reflectors are given in Table 3-16.

Table 3-16. Reflector Composition.

Element	Side Reflector Atom/barn-cm	Top Reflector Atom/barn-cm	Bottom Atom/barn-cm
Be ^(a)	1.2120E-01	1.2055E-01	1.2064E-01

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

3.3.2.2 Reflector Tank Composition

A nominal diameter was used for the reflector tanks in the simple benchmark model. The composition of the reflector tanks in the simple benchmark model are given in Table 3-17.

Table 3-17. Top and Bottom Reflector Tank Composition.

Element	wt. %	Top Reflector Tank Atom/b-cm	Bottom Reflector Tank Atom/b-cm
Al	99.325	7.0492E-02	6.6972E-02
Cu	0.125	3.7651E-05	3.5770E-05
Si	0.2375	1.6186E-04	1.5377E-04
Fe	0.2375	8.1168E-05	7.7115E-05
Mn	0.025	8.7100E-06	8.2750E-06
Zn	0.050	1.4636E-06	1.3905E-06
Total	100 wt.%	7.0783E-02	6.7248E-02

3.3.2.3 Fuel

Impurities in the fuel were replaced with void in the simple benchmark model. The composition of the fuel is given in Table 3-18.

Table 3-18. Fuel Composition.

Element/Isotope	wt. %	Atom/barn-cm
²³⁴ U	0.8887	2.2140E-04
²³⁵ U	81.9608	2.0332E-02
²³⁶ U	0.4135	1.0215E-04
²³⁸ U	4.7250	1.1573E-03
O	11.9708	4.3627E-02
Total	99.9588 wt.%(a)	6.5440E-02

(a) Impurities were replaced with void.

3.3.2.4 Fuel Tubes and End Caps

The mass of the fuel tubes plus the end caps was averaged over the volume of the fuel tubes and end caps. The composition of the fuel tubes and end caps is given in Table 3-19.

Table 3-19. Fuel Tube and End Cap Composition.

Element	wt. %	Atom/barn-cm
Fe	68.7225	5.1693E-02
C	0.04	1.3990E-04
Mn	1.00	7.6465E-04
Si	0.50	7.4787E-04
Cr	18.00	1.4542E-02
Ni	11.00	7.8734E-03
P	0.0225	3.0516E-05
S	0.0150	1.9648E-05
Nb	0.644	2.9104E-04
Ta	0.056	1.3076E-05
Total	100%	7.6116E-02

3.3.2.5 The Core Tank

The composition of the core tank was the same in the simple benchmark model as in the detailed benchmark model (see Table 3-10).

3.3.2.6 Support Plates and Table

The composition of the support plates and table was the same in the simple benchmark model as in the detailed benchmark model (see Tables 3-14 and 3-15).

3.4 Benchmark Model Temperature Data

The benchmark model temperature is 293.6 K.

3.5 Benchmark Model k_{eff} and Uncertainties

The experimental configurations had an excess reactivity of 11.8 and 22.3 β for Case 1 and 2. This bias and the simplification bias were applied to obtain the detailed and simple benchmark model k_{eff} values found in Table 3-20. The uncertainty in the benchmark models was found by adding in quadrature the uncertainty derived in Section 2 and the uncertainty in the bias derived in Section 3.1.

Table 3-20. Benchmark Experiment Eigenvalues.

	Detailed Benchmark Model, $k_{\text{eff}} \pm 1\sigma$	Simple Benchmark Model, $k_{\text{eff}} \pm 1\sigma$
Case 1	1.0003 $\pm$ 0.0008	0.9989 $\pm$ 0.0008
Case 2	1.0011 $\pm$ 0.0008	0.9998 $\pm$ 0.0008

4.0 RESULTS OF SAMPLE CALCULATIONS

Models were created with MCNP5 and KENO-VI^a using ENDF/B-VII.0 continuous energy neutron cross section libraries. Thermal scattering treatments, $S(\alpha, \beta)$, were used for the uranium dioxide fuel, the aluminum, and the beryllium reflectors. Cross section data were not available for ytterbium (Yb) so it was replaced with void in the fuel. Example input files for the benchmark model can be found in Appendix A. Results of the MCNP5 sample calculations range from 0.50 to 0.62%, or about 6.0–7.2 σ less than the benchmark value for the detailed and simple benchmark models. Results are summarized in Tables 4-1 and 4-2. KENO-VI results for the simple benchmark model were also presented in Table 4.2; these results were 8.1 and 6.8 σ below the benchmark value for Case 1 and 2 respectively.

Table 4-1. Sample Results for the Detailed Benchmark Model, ENDF/B-VII.0.

Model	Benchmark			Calculated			
				MCNP5 ENDF/B-VII.0 ^(a)			$\frac{C - E^{(b)}}{E}$
	k _{eff}	±	σ	k _{eff}	±	σ	
Case 1	1.0003	±	0.0008	0.99435	±	0.00006	-0.60%
Case 2	1.0011	±	0.0008	0.99615	±	0.00006	-0.50%

(a) Results obtained using 100,000 histories for 2150 cycles, skipping the first 150 cycles.

(b) 'E' is the expected or benchmark value. 'C' is the calculated value.

Table 4-2. Sample Results for the Simple Benchmark Model, ENDF/B-VII.0.

Model	Benchmark			Calculated								
				MCNP5 ENDF/B-VII.0 ^(a)			$\frac{C - E^{(d)}}{E}$	KENO-VI ENDF/B-VII.0 ^(b,c)			$\frac{C - E^{(d)}}{E}$	
	k _{eff}	±	σ	k _{eff}	±	σ		k _{eff}	±	σ		
Case 1	0.9989	±	0.0008	0.99293	±	0.00006	-0.60%		0.99211	±	0.00009	-0.68%
Case 2	0.9998	±	0.0008	0.99474	±	0.00006	-0.50%		0.99422	±	0.00009	-0.56%

(a) Results obtained using 100,000 histories for 2150 cycles, skipping the first 150 cycles.

(b) Results provided by John D. Bess from Idaho National Laboratory.

(c) Results obtained using 100,000 histories for 1150 cycles, skipping the first 150 cycles.

(d) 'E' is the expected or benchmark value. 'C' is the calculated value.

^a D.F. Hollenbach, L.M. Petrie, S. Goluoglu, N.F. Landers, and M.E. Dunn, "KENO-VI: A General Quadratic Version of the KENO Program," ORNL/TM-2005/39 Version 6 Vol. II, Sect. F17, Oak Ridge National Laboratory (January 2009).

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Sample calculation results for the simple benchmark model are also provided using JEFF-3.1 and JENDL-3.3 cross section libraries in Table 4.3. Isotopes that were not available in the respective cross section libraries were replaced with void. For JEFF-3.1 strontium-64, dysprosium-156 and -168, lutetium-175 and 176 were replaced with void. For JENDL-3.3 dysprosium-156, -168, -160, -162, -163, and -164 were replaced with void and oxygen-17 was converted to oxygen-16. Thermal scattering treatments for ENDF/B-VII.0 were used when they were not available.

Table 4-3. Sample Results for the Simple Benchmark Model, JEFF3.1 and JENDL-3.3.

Model	Benchmark			Calculated							
				JEFF-3.1 ^{(a)(b)}			$\frac{C - E^{(c)}}{E}$	JENDL-3.3 ^{(a)(b)}			$\frac{C - E^{(c)}}{E}$
	k _{eff}	±	σ	k _{eff}	±	σ		k _{eff}	±	σ	
Case 1	0.9989	±	0.0008	0.99396	±	0.00006	-0.50%	0.99726	±	0.00006	-0.17%
Case 2	0.9998	±	0.0008	0.99581	±	0.00006	-0.40%	0.99914	±	0.00006	-0.06%

(a) Results obtained using 100,000 histories for 2150 cycles, skipping the first 150 cycles.

(b) Results provided by John D. Bess from Idaho National Laboratory.

(c) 'E' is the expected or benchmark value. 'C' is the calculated value.

5.0 REFERENCES

1. J. T. Mihalcz, "A Small Graphite-Reflected UO_2 Critical Assembly," ORNL-TM-450, Oak Ridge National Laboratory (1962).
2. J.T. Mihalcz, "A Small Graphite-Reflected UO_2 Assembly," *Proc. 5th Int. Conf. Nucl. Crit. Safety*, Albuquerque, NM, September 17-21 (1995).
3. J.T. Mihalcz, "A Small Graphite-Reflected UO_2 Critical Assembly, Part II," ORNL-TM-561, Oak Ridge National Laboratory (1963).
4. J.T. Mihalcz, "A Small Beryllium-Reflected UO_2 Assembly," ORNL-TM-655, Oak Ridge National Laboratory (1963).
5. J.T. Mihalcz, "A Small, Beryllium-Reflected UO_2 Critical Assembly," *Trans. Am. Nucl. Soc.*, **72**, 196-198 (1995).

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APPENDIX A: TYPICAL INPUT LISTINGS

Models were created using Monte Carlo n-Particle, version 5-1.60, (MCNP) and ENDF/B-VII.0 neutron cross section libraries. Isotopic abundances for all elements except uranium were taken from "Nuclides and Isotopes: Chart of the Nuclides," Sixteenth Edition, KAPL, 2002. MCNP5.1.60 models were run for 2000 active cycles (150 inactive cycles) with 100,000 histories per cycle.

MCNP5 Input Deck for Detailed Benchmark Models:

Case 1

SCCA-FUND-EXP-002-001 and HEU-COMP-FAST-002

```
C
C
C Cell Cards
1 1 6.57372E-02 (-25 22 -26) u=10 imp:n=1 $fuel pellet
2 0 -22:(25 22 -26):26 u=10 imp:n=1 $void around pellet
3 0 -28 lat=1 u=11 imp:n=1 fill= 0:0 0:0 -1:26
    11 10 10 10 10 10 10 10 10 10 10 10
    10 10 10 10 10 10 10 10 10 10 10 11
4 0 -21 22 -23 fill=11 u=12 imp:n=1
C
C BASIC FUEL TUBE W/ GRID PLATE
15 15 8.19858E-02 (1 -24 -20 21) u=12 imp:n=1 $Fuel tube
16 16 2.17619E-02 (1 -22 -21):(23 -24 -21) u=12 imp:n=1 $end caps
17 20 7.01794E-02 -60 66 u=12 imp:n=1 $Grid Plate
18 20 7.01794E-02 -61 66 u=12 imp:n=1 $Grid Plate
19 0 -60 -66 20 u=12 imp:n=1
20 0 -61 -66 20 u=12 imp:n=1
21 0 -1:(1 60 61 20 -24):24 u=12 imp:n=1
C BASIC FUEL TUBES FOR TUBES WHICH ARE MOVED IN
22 0 -21 22 -23 fill=11 u=13 imp:n=1
23 15 8.19858E-02 (21) u=13 imp:n=1 $Fuel tube
24 16 2.17619E-02 (-22 -21):(23 -21) u=13 imp:n=1 $end caps
C FUEL TUBES WITH SPACER TUBES
29 0 -21 22 -23 fill=11 u=14 imp:n=1
30 15 8.19858E-02 (1 -24 -20 21) u=14 imp:n=1 $Fuel tube
31 16 2.17619E-02 (1 -22 -21):(23 -24 -21) u=14 imp:n=1 $end caps
32 20 7.01794E-02 -60 66 u=14 imp:n=1 $Grid Plate
33 20 7.01794E-02 -61 66 u=14 imp:n=1 $Grid Plate
34 0 -60 -66 20 u=14 imp:n=1
35 0 -61 -66 20 u=14 imp:n=1
36 0 20 -63 64 -65 u=14 imp:n=1
37 21 8.16965E-02 -62 63 u=14 imp:n=1 $Spacer Tube
38 0 -1:(64 62 -65):(65 61 20 -24):24 u=14 imp:n=1
C BASIC FUEL TUBES
40 0 -12 fill=12 u=1 imp:n=1
C FUEL TUBES WHICH ARE MOVED IN
41 0 -13 fill=13 (-3.766 -11.458 0) imp:n=1
42 0 -14 fill=13 (3.766 -11.458 0) imp:n=1
43 0 -15 fill=13 (3.766 11.458 0) imp:n=1
44 0 -16 fill=13 (-3.766 11.458 0) imp:n=1
45 0 -17 fill=13 (-8.039 -8.989 0) imp:n=1
46 0 -18 fill=13 (8.039 -8.989 0) imp:n=1
47 0 -19 fill=13 (-8.039 8.989 0) imp:n=1
48 0 -30 fill=13 (8.039 8.989 0) imp:n=1
49 0 -31 fill=13 (-11.805 -2.467 0) imp:n=1
```

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111 0 -157 fill=21 (10.9545 10.9545 0) u=45 imp:n=1
 112 0 -158 fill=21 (3.6515 10.9545 0) u=45 imp:n=1
 113 0 -159 fill=21 (-3.6515 10.9545 0) u=45 imp:n=1
 114 0 -160 fill=21 (-10.9545 10.9545 0) u=45 imp:n=1
 115 0 -161 fill=21 (-10.9545 3.6515 0) u=45 imp:n=1
 116 0 -162 fill=21 (-10.9545 -3.6515 0) u=45 imp:n=1
 117 0 -163 fill=21 (-10.9545 -10.9545 0) u=45 imp:n=1
 118 0 -164 fill=21 (-3.6515 -10.9545 0) u=45 imp:n=1
 119 0 -165 fill=21 (3.6515 -10.9545 0) u=45 imp:n=1
 120 0 -166 fill=21 (10.9545 -10.9545 0) u=45 imp:n=1
 121 0 -167 -168 fill=21 u=45 imp:n=1
 122 0 -167 168 u=45 imp:n=1
 123 0 -169 fill=21 (16.4295 -9.122 0) u=45 imp:n=1
 124 0 -170 fill=21 (16.4295 -5.475 0) u=45 imp:n=1
 125 0 -171 fill=21 (18.2575 0 0) u=45 imp:n=1
 126 0 -172 fill=21 (16.4295 5.475 0) u=45 imp:n=1
 127 0 -173 fill=21 (16.4295 9.122 0) u=45 imp:n=1
 128 0 -174 -175 fill=21 u=45 imp:n=1
 129 0 -174 175 u=45 imp:n=1
 130 0 -176 -177 fill=21 u=45 imp:n=1
 131 0 -176 177 u=45 imp:n=1
 132 0 -178 fill=21 (9.122 16.4295 0) u=45 imp:n=1
 133 0 -179 fill=21 (5.475 16.4295 0) u=45 imp:n=1
 134 0 -180 fill=21 (0 18.2575 0) u=45 imp:n=1
 135 0 -181 fill=21 (-5.475 16.4295 0) u=45 imp:n=1
 136 0 -182 fill=21 (-9.122 16.4295 0) u=45 imp:n=1
 167 0 -183 -184 fill=21 u=45 imp:n=1
 168 0 -183 184 u=45 imp:n=1
 169 0 -185 -186 fill=21 u=45 imp:n=1
 170 0 -185 186 u=45 imp:n=1
 171 0 -187 fill=21 (-16.4295 9.122 0) u=45 imp:n=1
 172 0 -188 fill=21 (-16.4295 5.475 0) u=45 imp:n=1
 173 0 -189 fill=21 (-18.2575 0 0) u=45 imp:n=1
 174 0 -190 fill=21 (-16.4295 -5.475 0) u=45 imp:n=1
 175 0 -191 fill=21 (-16.4295 -9.122 0) u=45 imp:n=1
 176 0 -192 -193 fill=21 u=45 imp:n=1
 177 0 -192 193 u=45 imp:n=1
 178 0 -194 -195 fill=21 u=45 imp:n=1
 179 0 -194 195 u=45 imp:n=1
 180 0 -196 fill=21 (-9.122 -16.4295 0) u=45 imp:n=1
 181 0 -197 fill=21 (-5.475 -16.4295 0) u=45 imp:n=1
 182 0 -198 fill=21 (0 -18.2575 0) u=45 imp:n=1
 183 0 -199 fill=21 (5.475 -16.4295 0) u=45 imp:n=1
 184 0 -200 fill=21 (9.122 -16.4295 0) u=45 imp:n=1
 185 0 -148 -149 fill=21 u=45 imp:n=1
 186 0 -148 149 u=45 imp:n=1
 187 0 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167
 169 170 171 172 173 174 176 178 179 180 181 182 183 185 187 188 189 190
 191 192 194 196 197 198 199 200 148 u=45 imp:n=1
 C Top Reflector and Tank
 192 0 -201 -202 -203 -204 -205 -206 -207 -208 301 -302 fill= 45 imp:n=1
 193 13 6.33375E-02 #192 -211 -212
 -213 -214 -215 -216 -217 -218 300 -302 imp:n=1
 194 0 -201 -202 -203 -204 -205 -206 -207 -208 302 -303 imp:n=1
 195 13 6.33375E-02 #194 -211 -212
 -213 -214 -215 -216 -217 -218 302 -303 imp:n=1
 196 0 -999 300 (211:212:213:214:215:216:217:218):(-999 303) imp:n=1
 C Bottom Reflector
 200 10 1.21983E-01 150 u=22 imp:n=1
 201 0 -150 u=22 imp:n=1
 C blocks beginning quadrant 1 block working out counter clockwise

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205 0 -151 fill=22 (3.6515 3.6515 0) u=65 imp:n=1
 206 0 -152 fill=22 (-3.6515 3.6515 0) u=65 imp:n=1
 207 0 -153 fill=22 (-3.6515 -3.6515 0) u=65 imp:n=1
 208 0 -154 fill=22 (3.6515 -3.6515 0) u=65 imp:n=1
 209 0 -155 fill=22 (10.9545 -3.6515 0) u=65 imp:n=1
 210 0 -156 fill=22 (10.9545 3.6515 0) u=65 imp:n=1
 211 0 -157 fill=22 (10.9545 10.9545 0) u=65 imp:n=1
 212 0 -158 fill=22 (3.6515 10.9545 0) u=65 imp:n=1
 213 0 -159 fill=22 (-3.6515 10.9545 0) u=65 imp:n=1
 214 0 -160 fill=22 (-10.9545 10.9545 0) u=65 imp:n=1
 215 0 -161 fill=22 (-10.9545 3.6515 0) u=65 imp:n=1
 216 0 -162 fill=22 (-10.9545 -3.6515 0) u=65 imp:n=1
 217 0 -163 fill=22 (-10.9545 -10.9545 0) u=65 imp:n=1
 218 0 -164 fill=22 (-3.6515 -10.9545 0) u=65 imp:n=1
 219 0 -165 fill=22 (3.6515 -10.9545 0) u=65 imp:n=1
 220 0 -166 fill=22 (10.9545 -10.9545 0) u=65 imp:n=1
 221 0 -167 -168 fill=22 u=65 imp:n=1
 222 0 -167 168 u=65 imp:n=1
 223 0 -169 fill=22 (16.4295 -9.122 0) u=65 imp:n=1
 224 0 -170 fill=22 (16.4295 -5.475 0) u=65 imp:n=1
 225 0 -171 fill=22 (18.2575 0 0) u=65 imp:n=1
 226 0 -172 fill=22 (16.4295 5.475 0) u=65 imp:n=1
 227 0 -173 fill=22 (16.4295 9.122 0) u=65 imp:n=1
 228 0 -174 -175 fill=22 u=65 imp:n=1
 229 0 -174 175 u=65 imp:n=1
 230 0 -176 -177 fill=22 u=65 imp:n=1
 231 0 -176 177 u=65 imp:n=1
 232 0 -178 fill=22 (9.122 16.4295 0) u=65 imp:n=1
 233 0 -179 fill=22 (5.475 16.4295 0) u=65 imp:n=1
 234 0 -180 fill=22 (0 18.2575 0) u=65 imp:n=1
 235 0 -181 fill=22 (-5.475 16.4295 0) u=65 imp:n=1
 236 0 -182 fill=22 (-9.122 16.4295 0) u=65 imp:n=1
 267 0 -183 -184 fill=22 u=65 imp:n=1
 268 0 -183 184 u=65 imp:n=1
 269 0 -185 -186 fill=22 u=65 imp:n=1
 270 0 -185 186 u=65 imp:n=1
 271 0 -187 fill=22 (-16.4295 9.122 0) u=65 imp:n=1
 272 0 -188 fill=22 (-16.4295 5.475 0) u=65 imp:n=1
 273 0 -189 fill=22 (-18.2575 0 0) u=65 imp:n=1
 274 0 -190 fill=22 (-16.4295 -5.475 0) u=65 imp:n=1
 275 0 -191 fill=22 (-16.4295 -9.122 0) u=65 imp:n=1
 276 0 -192 -193 fill=22 u=65 imp:n=1
 277 0 -192 193 u=65 imp:n=1
 278 0 -194 -195 fill=22 u=65 imp:n=1
 279 0 -194 195 u=65 imp:n=1
 280 0 -196 fill=22 (-9.122 -16.4295 0) u=65 imp:n=1
 281 0 -197 fill=22 (-5.475 -16.4295 0) u=65 imp:n=1
 282 0 -198 fill=22 (0 -18.2575 0) u=65 imp:n=1
 283 0 -199 fill=22 (5.475 -16.4295 0) u=65 imp:n=1
 284 0 -200 fill=22 (9.122 -16.4295 0) u=65 imp:n=1
 285 0 -148 -149 fill=22 u=65 imp:n=1
 286 0 -148 149 u=65 imp:n=1
 287 0 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167
 169 170 171 172 173 174 176 178 179 180 181 182 183 185 187 188 189 190
 191 192 194 196 197 198 199 200 148 u=65 imp:n=1
 C Bottom Reflector and Tank
 305 0 -201 -202 -203 -204 -205 -206 -207 -208 305 -304 fill= 65 imp:n=1
 306 14 5.90971E-02 #305 -211 -212
 -213 -214 -215 -216 -217 -218 306 -304 imp:n=1
 307 0 (211:212:213:214:215:216:217:218) -304 306 -999 imp:n=1
 C Side Reflector

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320 9 1.22230E-01 320 -321 322 -323 imp:n=1
321 0 -300 53 -320 imp:n=1
322 0 -53 50 -320 322 imp:n=1
323 0 -322 50 -326 304 imp:n=1
324 0 -300 52 321 325 -999 imp:n=1
325 0 -306 327 -999 imp:n=1
C Support Structure/Additional Reflectors
350 30 6.08580E-02 -325 326 imp:n=1 \$Support Plate for Be
351 31 8.75101E-02 -327 imp:n=1 \$SS304 Plate
999 0 999 imp:n=0

C Surface Cards

1 pz 0. \$bottom of fuel
11 rhp 0 0 -10 0 0 50 0.753 0 0
12 rhp 0 0 -11 0 0 52 1 0 0
13 rcc -3.766 -11.458 0 0 0 30.48 0.635
14 rcc 3.766 -11.458 0 0 0 30.48 0.635
15 rcc 3.766 11.458 0 0 0 30.48 0.635
16 rcc -3.766 11.458 0 0 0 30.48 0.635
17 rcc -8.039 -8.989 0 0 0 30.48 0.635
18 rcc 8.039 -8.989 0 0 0 30.48 0.635
19 rcc -8.039 8.989 0 0 0 30.48 0.635
20 cz 0.635 \$OR Clad
21 cz 0.584 \$IR Clad
22 pz 0.3 \$top of bottom cap
23 pz 30.18 \$bottom of top cap
24 pz 30.48 \$Top of fuel tube
25 cz 0.5705 \$OR of Pellet
26 pz 1.445 \$Top of bottom fuel pellet
27 pz 1.4494 \$bottom of 2nd fuel pellet
28 rpp -0.9 0.9 -0.9 0.9 0.2978 1.4472 \$pellet lattice box
30 rcc 8.039 8.989 0 0 0 30.48 0.635
31 rcc -11.805 -2.467 0 0 0 30.48 0.635
32 rcc 11.805 -2.467 0 0 0 30.48 0.635
33 rcc -11.805 2.467 0 0 0 30.48 0.635
34 rcc 11.805 2.467 0 0 0 30.48 0.635

C Core Tank

50 cz 12.98 \$OR Core Tank
51 cz 12.726 \$IR Core Tank
52 pz -0.33 \$Bottom of Core Tank
53 pz 30.71 \$Top of Core Tank

C Grid Plate

60 rcc 0 0 0 0 0 0.317 12.8 \$bottom grid plate
61 rcc 0 0 28.257 0 0 0.317 12.8 \$top grip plate
66 cz 0.642

C Grid Plate Spacer Tubes

62 rcc 0 0 0.317 0 0 27.94 0.685
63 cz 0.642
64 pz 0.317
65 pz 28.257

C Al Shims

71 p -2.9708 12.3744 15 0.0000 12.3744 30 2.9708 12.3744 15
72 p 2.9708 12.3744 15 6.1010 10.5672 30 9.2311 8.7600 15
73 p 9.2311 8.7600 15 10.7165 6.1872 30 12.2019 3.6144 15
74 p 12.2019 3.6144 15 12.2019 0.0000 30 12.2019 -3.6144 15
75 p 12.2019 -3.6144 15 10.7165 -6.1872 30 9.2311 -8.7600 15
76 p 9.2311 -8.7600 15 6.1010 -10.5672 30 2.9708 -12.3744 15
77 p 2.9708 -12.3744 15 0.0000 -12.3744 30 -2.9708 -12.3744 15
78 p -2.9708 -12.3744 15 -6.1010 -10.5672 30 -9.2311 -8.7600 15
79 p -9.2311 -8.7600 15 -10.7165 -6.1872 30 -12.2019 -3.6144 15
80 p -12.2019 -3.6144 15 -12.2019 0.0000 30 -12.2019 3.6144 15

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81 p -12.2019 3.6144 15 -10.7165 6.1872 30 -9.2311 8.7600 15
82 p -9.2311 8.7600 15 -6.1010 10.5672 30 -2.9708 12.3744 15
83 pz 14.4
84 pz 16.31
C Reflector
C
150 cz 0.249
151 box 0 0 0 7.303 0 0 0 7.303 0
152 box 0 0 0 -7.303 0 0 0 7.303 0
153 box 0 0 0 -7.303 0 0 0 -7.303 0
154 box 0 0 0 7.303 0 0 0 -7.303 0
155 box 7.303 -7.303 0 7.303 0 0 0 7.303 0
156 box 7.303 0 0 7.303 0 0 0 7.303 0
157 box 7.303 7.303 0 7.303 0 0 0 7.303 0
158 box 0 7.303 0 7.303 0 0 0 7.303 0
159 box -7.303 7.303 0 7.303 0 0 0 7.303 0
160 box -14.606 7.303 0 7.303 0 0 0 7.303 0
161 box -14.606 0 0 7.303 0 0 0 7.303 0
162 box -14.606 -7.303 0 7.303 0 0 0 7.303 0
163 box -14.606 -14.606 0 7.303 0 0 0 7.303 0
164 box -7.303 -14.606 0 7.303 0 0 0 7.303 0
165 box 0 -14.606 0 7.303 0 0 0 7.303 0
166 box 7.303 -14.606 0 7.303 0 0 0 7.303 0
167 box 14.606 -14.5925 0 3.647 0 0 0 3.647 0
168 p 14.606 -14.5925 5 18.253 -10.9455 0 16.4295 -12.769 14
169 box 14.606 -10.9455 0 3.647 0 0 0 3.647 0
170 box 14.606 -7.2985 0 3.647 0 0 0 3.647 0
171 box 14.606 -3.6515 0 7.303 0 0 0 7.303 0
172 box 14.606 3.6515 0 3.647 0 0 0 3.647 0
173 box 14.606 7.2985 0 3.647 0 0 0 3.647 0
174 box 14.606 10.9455 0 3.647 0 0 0 3.647 0
175 p 14.606 14.5925 5 18.253 10.9455 0 16.4295 12.769 14
176 box 10.9455 14.606 0 3.647 0 0 0 3.647 0
177 p 10.9455 18.253 5 14.5925 14.606 0 12.769 16.4295 14
178 box 7.2985 14.606 0 3.647 0 0 0 3.647 0
179 box 3.6515 14.606 0 3.647 0 0 0 3.647 0
180 box -3.6515 14.606 0 7.303 0 0 0 7.303 0
181 box -7.2985 14.606 0 3.647 0 0 0 3.647 0
182 box -10.9455 14.606 0 3.647 0 0 0 3.647 0
183 box -14.5925 14.606 0 3.647 0 0 0 3.647 0
184 p -14.5925 14.606 5 -10.9455 18.253 0 -12.769 16.4295 14
185 box -18.253 10.9455 0 3.647 0 0 0 3.647 0
186 p -18.253 10.9455 5 -14.606 14.5925 0 -16.4295 12.769 14
187 box -18.253 7.2985 0 3.647 0 0 0 3.647 0
188 box -18.253 3.6515 0 3.647 0 0 0 3.647 0
189 box -21.909 -3.6515 0 7.303 0 0 0 7.303 0
190 box -18.253 -7.2985 0 3.647 0 0 0 3.647 0
191 box -18.253 -10.9455 0 3.647 0 0 0 3.647 0
192 box -18.253 -14.5925 0 3.647 0 0 0 3.647 0
193 p -18.253 -10.9455 5 -14.606 -14.5925 0 -16.4295 -12.769 14
194 box -14.5925 -18.253 0 3.647 0 0 0 3.647 0
195 p -14.606 -14.5925 5 -10.9455 -18.253 0 -12.77575 -16.42275 14
196 box -10.9455 -18.253 0 3.647 0 0 0 3.647 0
197 box -7.2985 -18.253 0 3.647 0 0 0 3.647 0
198 box -3.6515 -21.909 0 7.303 0 0 0 7.303 0
199 box 3.6515 -18.253 0 3.647 0 0 0 3.647 0
200 box 7.2985 -18.253 0 3.647 0 0 0 3.647 0
148 box 10.9455 -18.253 0 3.647 0 0 0 3.647 0
149 p 10.9455 -18.253 5 14.5925 -14.606 0 12.769 -16.4295 14
C Reflector Tanks
201 p -7.2985 22.3853 5 0 22.3853 5 7.2985 22.3853 10

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202 p 7.2985 22.3853 10 14.8419 14.8419 5 22.3853 7.2985 5
203 p 22.3853 7.2985 5 22.3853 0 5 22.3853 -7.2985 10
204 p 22.3853 -7.2985 10 14.8419 -14.8419 5 7.2985 -22.3853 5
205 p 7.2985 -22.3853 5 0 -22.3853 5 -7.2985 -22.3853 10
206 p -7.2985 -22.3853 10 -14.8419 -14.8419 5 -22.3853 -7.2985 5
207 p -22.38525 -7.2985 5 -22.3853 0 5 -22.3853 7.2985 10
208 p -22.38525 7.2985 10 -14.8419 14.8419 5 -7.2985 22.3853 5
211 p -7.562 23.0203 5 0 23.0203 5 7.5615 23.0203 10
212 p 7.562 23.0203 10 15.2909 15.2909 5 23.0203 7.5615 5
213 p 23.0203 7.562 5 23.0203 0 5 23.0203 -7.5615 10
214 p 23.0203 -7.562 10 15.2909 -15.2909 5 7.5615 -23.0203 5
215 p 7.562 -23.0203 5 0 -23.0203 5 -7.5615 -23.0203 10
216 p -7.562 -23.0203 10 -15.2909 -15.2909 5 -23.0203 -7.5615 5
217 p -23.0203 -7.562 5 -23.0203 0 5 -23.0203 7.5615 10
218 p -23.0203 7.562 10 -15.2909 15.2909 5 -7.5615 23.0203 5

C

300 pz 30.935
301 pz 31.155
302 pz 38.14
303 pz 43.885

C

304 pz -0.33
305 pz -7.95
306 pz -8.84

C Side Reflector

320 cz 13.08
321 cz 24.45
322 pz 0.305
323 pz 30.935

C

C Be Support Plate

325 rpp -37.5 37.5 -37.5 37.5 -0.33 0.305
326 cz 13.95

C SS304 Plate

327 rcc 0. 0. -11.22 0. 0. 2.38 22.86

C

999 rpp -500 500 -500 500 -500 500

C Data Cards

m1 92234.70c 2.22221E-04
92235.70c 2.04075E-02
92236.70c 1.02532E-04
92238.70c 1.16161E-03
8016.70c 4.36813E-02
8017.70c 1.06404E-04
47107.70c 5.62272E-07
47109.70c 5.22379E-07
4009.70c 9.73675E-08
24050.70c 1.12435E-07
24052.70c 2.16820E-06
24053.70c 2.45856E-07
24054.70c 6.11987E-08
3006.70c 4.74083E-08
3007.70c 5.84702E-07
28058.70c 8.33992E-07
28060.70c 3.21252E-07
28061.70c 1.39646E-08
28062.70c 4.45253E-08
28064.70c 1.13393E-08
50112.70c 7.17017E-09
50114.70c 4.87867E-09

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50115.70c	2.51325E-09	
50116.70c	1.07479E-07	
50117.70c	5.67700E-08	
50118.70c	1.79032E-07	
50119.70c	6.34966E-08	
50120.70c	2.40829E-07	
50122.70c	3.42246E-08	
50124.70c	4.27992E-08	
13027.70c	3.57743E-06	
20040.70c	7.07498E-06	
20042.70c	4.72195E-08	
20043.70c	9.85261E-09	
20044.70c	1.52241E-07	
20046.70c	2.91929E-10	
20048.70c	1.36477E-08	
29063.70c	1.20986E-06	
29065.70c	5.39253E-07	
12024.70c	1.14073E-06	
12025.70c	1.44414E-07	
12026.70c	1.59000E-07	
15031.70c	9.44341E-06	
5010.70c	5.38407E-08	
5011.70c	2.16716E-07	
26054.70c	7.95942E-07	
26056.70c	1.24946E-05	
26057.70c	2.88555E-07	
26058.70c	3.84013E-08	
25055.70c	4.25932E-07	
56130.70c	2.25774E-10	
56132.70c	2.15124E-10	
56134.70c	5.14807E-09	
56135.70c	1.40406E-08	
56136.70c	1.67286E-08	
56137.70c	2.39235E-08	
56138.70c	1.52713E-07	
19039.70c	3.48837E-06	
19040.70c	4.37645E-10	
19041.70c	2.51747E-07	
11023.70c	1.27230E-06	
14028.70c	5.76320E-06	
14029.70c	2.92641E-07	
14030.70c	1.92911E-07	\$ TOT 6.57372E-02
C Fuel Clad		
m15 26054.70c	3.25448E-03	
26056.70c	5.10884E-02	
26057.70c	1.17985E-03	
26058.70c	1.57017E-04	
6000.70c	1.50688E-04	
25055.70c	8.23618E-04	
14028.70c	7.42946E-04	
14029.70c	3.77250E-05	
14030.70c	2.48686E-05	
24050.70c	6.80598E-04	
24052.70c	1.31247E-02	
24053.70c	1.48823E-03	
24054.70c	3.70452E-04	
28058.70c	5.77334E-03	
28060.70c	2.22388E-03	
28061.70c	9.66705E-05	
28062.70c	3.08228E-04	
28064.70c	7.84965E-05	

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15031.70c	3.28690E-05	
16032.70c	2.00907E-05	
16033.70c	1.60844E-07	
16034.70c	9.07921E-07	
16036.70c	4.23273E-09	
41093.70c	3.13488E-04	
73181.70c	1.40839E-05	\$ tot 8.19858E-02
C End Caps		
m16	26054.70c	8.63854E-04
	26056.70c	1.35607E-02
	26057.70c	3.13175E-04
	26058.70c	4.16778E-05
	6000.70c	3.99979E-05
	25055.70c	2.18617E-04
	14028.70c	1.97204E-04
	14029.70c	1.00135E-05
	14030.70c	6.60099E-06
	24050.70c	1.80655E-04
	24052.70c	3.48374E-03
	24053.70c	3.95029E-04
	24054.70c	9.83310E-05
	28058.70c	1.53245E-03
	28060.70c	5.90295E-04
	28061.70c	2.56597E-05
	28062.70c	8.18144E-05
	28064.70c	2.08357E-05
	15031.70c	8.72458E-06
	16032.70c	5.33276E-06
	16033.70c	4.26936E-08
	16034.70c	2.40994E-07
	16034.70c	1.12352E-09
	41093.70c	8.32108E-05
	73181.70c	3.73835E-06 \$ tot 2.17619E-02
C Core Tank		
m2	13027.70c	5.85485E-02
	29063.70c	2.16403E-05
	29065.70c	9.64537E-06
	14028.70c	1.24044E-04
	14029.70c	6.29865E-06
	14030.70c	4.15212E-06
	26054.70c	3.95341E-06
	26056.70c	6.20601E-05
	26057.70c	1.43324E-06
	26058.70c	1.90738E-07
	25055.70c	7.23754E-06
	30000.70c	1.21614E-05 \$ Tot 5.88014E-02
C Grid Plate		
m20	13027.70c	0.069877686
	29063.70c	2.58277E-05
	29065.70c	1.15117E-05
	14028.70c	1.48047E-04
	14029.70c	7.51744E-06
	14030.70c	4.95555E-06
	26054.70c	4.71840E-06
	26056.70c	7.40687E-05
	26057.70c	1.71057E-06
	26058.70c	2.27645E-07
	25055.70c	8.63800E-06
	30000.70c	1.45146E-05 \$ Tot 7.01794E-02
C Grid Plate Spacer Tube		
m21	26054.70c	3.24300E-03

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26056.70c	5.09082E-02	
26057.70c	1.17569E-03	
26058.70c	1.56463E-04	
6000.70c	1.50157E-04	
25055.70c	8.20712E-04	
14028.70c	7.40325E-04	
14029.70c	3.75919E-05	
14030.70c	2.47808E-05	
24050.70c	6.78197E-04	
24052.70c	1.30784E-02	
24053.70c	1.48298E-03	
24054.70c	3.69145E-04	
28058.70c	5.75297E-03	
28060.70c	2.21603E-03	
28061.70c	9.63294E-05	
28062.70c	3.07140E-04	
28064.70c	7.82196E-05	
15031.70c	3.27530E-05	
16032.70c	2.00198E-05	
16033.70c	1.60276E-07	
16034.70c	9.04718E-07	
16036.70c	4.21780E-09	
41093.70c	3.12383E-04	
73181.70c	1.40342E-05	\$ tot 8.16965E-02
C Al Shim		
m22	13027.70c	5.98555E-02
	29063.70c	2.21234E-05
	29065.70c	9.86068E-06
	14028.70c	1.26813E-04
	14029.70c	6.43926E-06
	14030.70c	4.24481E-06
	26054.70c	4.04166E-06
	26056.70c	6.34455E-05
	26057.70c	1.46523E-06
	25055.70c	7.39910E-06
	30000.70c	1.24328E-05 \$ Tot 6.01138E-02
C Al Fuel Tube Clips		
m23	13027.70c	7.73726E-03
	29063.70c	2.85979E-06
	29065.70c	1.27465E-06
	14028.70c	1.63926E-05
	14029.70c	8.32374E-07
	14030.70c	5.48707E-07
	26054.70c	5.22448E-07
	26056.70c	8.20131E-06
	26057.70c	1.89404E-07
	25055.70c	9.56449E-07
	30000.70c	1.60714E-06 \$ Tot 7.77064E-03
C Reflectors		
C *****		
C Top Reflector		
m8	4009.70c	1.21825E-01
	3006.70c	3.61129E-09
	3007.70c	4.45392E-08
	5010.70c	2.46076E-08
	5011.70c	9.90488E-08
	12024.70c	2.89646E-06
	12025.70c	3.66687E-07
	12026.70c	4.03723E-07
	13027.70c	3.30313E-05
	14028.70c	2.56087E-05

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14029.70c	1.30035E-06	
14030.70c	8.57200E-07	
20040.70c	2.69465E-07	
20042.70c	1.79846E-09	
20043.70c	3.75257E-10	
20044.70c	5.79842E-09	
20046.70c	1.11187E-11	
20048.70c	5.19801E-10	
24050.70c	1.30331E-07	
24052.70c	2.51331E-06	
24053.70c	2.84990E-07	
24054.70c	7.09399E-08	
25055.70c	2.02782E-06	
27059.70c	1.89035E-08	
28058.70c	2.32600E-06	
28060.70c	8.95971E-07	
28061.70c	3.89472E-08	
28062.70c	1.24181E-07	
28064.70c	3.16252E-08	
29063.70c	1.09137E-06	
29065.70c	4.86440E-07	
30000.70c	5.11106E-07	
47107.70c	1.60615E-08	
47109.70c	1.49219E-08	
48106.70c	2.47763E-11	
48108.70c	1.76407E-11	
48110.70c	2.47565E-10	
48111.70c	2.53709E-10	
48112.70c	4.78282E-10	
48113.70c	2.42213E-10	
48114.70c	5.69459E-10	
48116.70c	1.48460E-10	
8016.70c	8.57552E-04	
8017.70c	2.08893E-06	\$ total 1.21900E-01

C

C Side Reflector

m9 4009.70c	1.21199E-01	
8016.70c	8.54608E-04	
8017.70c	2.08176E-06	
13027.70c	2.46884E-05	
6000.70c	1.10920E-04	
26054.70c	1.51055E-06	
26056.70c	2.37125E-05	
26057.70c	5.47624E-07	
26058.70c	7.28787E-08	
12024.70c	7.21630E-06	
12025.70c	9.13571E-07	
12026.70c	1.00584E-06	
83209.70c	2.65627E-06	
5010.70c	2.04360E-07	
5011.70c	8.22573E-07	
48106.70c	2.46912E-10	
48108.70c	1.75802E-10	
48110.70c	2.46715E-09	
48111.70c	2.52838E-09	
48112.70c	4.76640E-09	
48113.70c	2.41382E-09	
48114.70c	5.67504E-09	
48116.70c	1.47950E-09	
66156.70c	4.09926E-12	
66158.70c	6.83211E-12	

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66160.70c	1.59871E-10	
66161.70c	1.29195E-09	
66162.70c	1.74287E-09	
66163.70c	1.70119E-09	
66164.70c	1.92529E-09	
35079.70c	3.52153E-09	
35081.70c	3.42566E-09	
64152.70c	1.41204E-11	
64154.70c	1.53912E-10	
64155.70c	1.04491E-09	
64156.70c	1.44522E-09	
64157.70c	1.10492E-09	
64158.70c	1.75375E-09	
64160.70c	1.54336E-09	
28058.70c	1.28779E-08	
28060.70c	4.96053E-09	
28061.70c	2.15631E-10	
28062.70c	6.87525E-10	
28064.70c	1.75092E-10	
62144.70c	2.26680E-10	
62147.70c	1.10682E-09	
62148.70c	8.29931E-10	
62149.70c	1.02043E-09	
62150.70c	5.44919E-10	
62152.70c	1.97515E-09	
62154.70c	1.67980E-09	\$ Total 1.22230E-01
C Bottom Reflector		
m10 4009.70c	1.21908E-01	
3006.70c	3.61375E-09	
3007.70c	4.45695E-08	
5010.70c	2.46244E-08	
5011.70c	9.91163E-08	
12024.70c	2.89844E-06	
12025.70c	3.66937E-07	
12026.70c	4.03998E-07	
13027.70c	3.30538E-05	
14028.70c	2.56262E-05	
14029.70c	1.30123E-06	
14030.70c	8.57784E-07	
20040.70c	2.69649E-07	
20042.70c	1.79968E-09	
20043.70c	3.75513E-10	
20044.70c	5.80237E-09	
20046.70c	1.11263E-11	
20048.70c	5.20155E-10	
24050.70c	1.30420E-07	
24052.70c	2.51502E-06	
24053.70c	2.85184E-07	
24054.70c	7.09882E-08	
25055.70c	2.02920E-06	
27059.70c	1.89163E-08	
28058.70c	2.32758E-06	
28060.70c	8.96581E-07	
28061.70c	3.89738E-08	
28062.70c	1.24265E-07	
28064.70c	3.16467E-08	
29063.70c	1.09212E-06	
29065.70c	4.86771E-07	
30000.70c	5.11455E-07	
47107.70c	1.60724E-08	
47109.70c	1.49321E-08	

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48106.70c 2.47932E-11
48108.70c 1.76527E-11
48110.70c 2.47733E-10
48111.70c 2.53882E-10
48112.70c 4.78608E-10
48113.70c 2.42378E-10
48114.70c 5.69846E-10
48116.70c 1.48561E-10
8016.70c 8.58136E-04
8017.70c 2.09035E-06 \$ total 1.21983E-01
C *****
C Upper reflector tank
m13 13027.70c 6.30773E-02
29063.70c 2.33036E-05
29065.70c 1.03867E-05
14028.70c 1.33578E-04
14029.70c 6.78278E-06
14030.70c 4.47126E-06
26054.70c 4.25728E-06
26056.70c 6.68301E-05
26057.70c 1.54340E-06
25055.70c 7.79383E-06
30000.70c 1.30961E-06 \$ Tot 6.33375E-02
C lower reflector tank
m14 13027.70c 5.88542E-02
29063.70c 2.17434E-05
29065.70c 9.69134E-06
14028.70c 1.24635E-04
14029.70c 6.32867E-06
14030.70c 4.17191E-06
26054.70c 3.97225E-06
26056.70c 6.23559E-05
26057.70c 1.44007E-06
25055.70c 7.27203E-06
30000.70c 1.22193E-06 \$ Tot 5.90971E-02
C *****
C Additional Bottom Reflectors
C Be Support Plate (A11100)
m30 13027.70c 6.06080E-02
29063.70c 2.23913E-05
29065.70c 9.98012E-06
14028.70c 1.28349E-04
14029.70c 6.51725E-06
14030.70c 4.29622E-06
26054.70c 4.09062E-06
26056.70c 6.42139E-05
26057.70c 1.48298E-06
25055.70c 7.48872E-06
30000.70c 1.25834E-06 \$ Tot 6.08580E-02
C SS304 Support Plate
m31 26054.70c 3.51905E-03
26056.70c 5.52415E-02
26057.70c 1.27577E-03
26058.70c 1.69781E-04
6000.70c 1.60142E-04
25055.70c 8.75287E-04
14028.70c 7.89554E-04
14029.70c 4.00916E-05
14030.70c 2.64287E-05
24050.70c 7.63478E-04
24052.70c 1.47229E-02

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24053.70c 1.66946E-03
24054.70c 4.15564E-04
28058.70c 5.29886E-03
28060.70c 2.04111E-03
28061.70c 8.87257E-05
28062.70c 2.82896E-04
28064.70c 7.20454E-05
15031.70c 3.49310E-05
16032.70c 2.13510E-05
16033.70c 1.70934E-07
16034.70c 9.64879E-07
16034.70c 4.49827E-09 \$ tot 8.75101E-02
C Scattering Cards
mt1 o2/u.10t u/o2.10t
mt2 al27.12t
mt8 be.10t
mt9 be.10t
mt10 be.10t
mt13 al27.12t
mt14 al27.12t
mt20 al27.12t
mt22 al27.12t
mt30 al27.12t
C
kcode 100000 1 150 2150
ksrc 0.0692 4.5245 0.77787 0 8.8072 0.7787
0.0692 -4.3864 0.77787 0 -8.7382 0.7787
3.8736 0 0.7787 7.6780 0 0.7787
-3.7353 0 0.7787 -7.8510 0 0.7787

Case 2

SCCA-FUND-EXP-002-001 and HEU-COMP-FAST-002

C
C
C Cell Cards
1 1 6.57372E-02 (-25 22 -26) u=10 imp:n=1 \$fuel pellet
2 0 -22:(25 22 -26):26 u=10 imp:n=1 \$void around pellet
3 0 -28 lat=1 u=11 imp:n=1 fill= 0:0 0:0 -1:26
11 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10 10 11
4 0 -21 22 -23 fill=11 u=12 imp:n=1
C
C BASIC FUEL TUBE W/ GRID PLATE
15 15 8.19858E-02 (1 -24 -20 21) u=12 imp:n=1 \$Fuel tube
16 16 2.17619E-02 (1 -22 -21):(23 -24 -21) u=12 imp:n=1 \$end caps
17 20 6.01140E-02 -60 66 u=12 imp:n=1 \$Grid Plate
18 20 6.01140E-02 -61 66 u=12 imp:n=1 \$Grid Plate
19 0 -60 -66 20 u=12 imp:n=1
20 0 -61 -66 20 u=12 imp:n=1
21 0 -1:(1 60 61 20 -24):24 u=12 imp:n=1
C BASIC FUEL TUBES FOR TUBES WHICH ARE MOVED IN
22 0 -21 22 -23 fill=11 u=13 imp:n=1
23 15 8.19858E-02 (21) u=13 imp:n=1 \$Fuel tube
24 16 2.17619E-02 (-22 -21):(23 -21) u=13 imp:n=1 \$end caps
C VOID WITH GRID PLATE
40 20 6.01140E-02 -60 u=20 imp:n=1
41 20 6.01140E-02 -61 u=20 imp:n=1
42 0 -999 61 60 u=20 imp:n=1
C BASIC FUEL TUBES
43 0 -12 fill=12 u=1 imp:n=1
C
60 0 -11 lat=2 u=2 imp:n=1 fill=-2:2 -2:2 0:0

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```
20 20 20 20 20
20 20 1 1 20
20 1 1 1 20
20 1 1 20 20
20 20 20 20 20
61 0 -11 lat=2 u=3 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 1 1 20
20 20 1 1 20
20 20 1 20 20
20 20 20 20 20
62 0 -11 lat=2 u=4 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 20 1 20
20 20 1 1 20
20 1 1 20 20
20 20 20 20 20
63 0 -11 lat=2 u=5 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 1 1 20
20 1 1 1 20
20 20 20 20 20
20 20 20 20 20
64 0 -11 lat=2 u=6 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 20 20 20
20 1 1 1 20
20 1 1 20 20
20 20 20 20 20
65 0 -11 lat=2 u=7 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 1 1 20
20 1 1 20 20
20 1 20 20 20
20 20 20 20 20
66 0 -11 lat=2 u=8 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 1 20 20
20 1 1 20 20
20 1 1 20 20
20 20 20 20 20
67 0 -13 lat=2 u=9 imp:n=1 fill=-4:4 -4:4 0:0
20 20 20 20 20 20 20 20 20
20 20 20 20 3 2 2 4 20
20 20 20 2 2 2 2 20
20 20 2 2 2 2 2 20
20 5 2 2 2 2 2 6 20
20 2 2 2 2 2 2 20 20
20 2 2 2 2 2 20 20 20
20 7 2 2 8 20 20 20 20
20 20 20 20 20 20 20 20
C
C
70 0 -14 fill=13 (0 12.02 0) imp:n=1
71 0 -15 fill=13 (0 -12.02 0) imp:n=1
72 0 -16 fill=13 (10.4 6.0 0) imp:n=1
73 0 -17 fill=13 (-10.4 6.0 0) imp:n=1
74 0 -18 fill=13 (-10.4 -6.0 0) imp:n=1
75 0 -19 fill=13 (10.4 -6.0 0) imp:n=1
80 21 8.16965E-02 31 -37 imp:n=1
81 0 -31 15 imp:n=1
```

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82 21 8.16965E-02 30 -36 imp:n=1
83 0 -30 14 imp:n=1
84 21 8.16965E-02 32 -38 imp:n=1
85 0 -32 16 imp:n=1
86 21 8.16965E-02 34 -40 imp:n=1
87 0 -34 18 imp:n=1
C
C Core Tank
77 0 -51 1 -53 14 36 15 37 16 38 17 18 40 19 fill=9 imp:n=1
C 133 0 -151 1 -113 #131 14 15 16 17 18 19 imp:n=1
C 134 0 -151 114 -153 #131 14 15 16 17 18 19 imp:n=1
C 135 0 150 -210 -153 213 imp:n=1
C 136 0 -152 -150 220 213 250 imp:n=1
76 2 5.88014E-02 (-53 1 -50 51):(-1 52 -50) imp:n=1 \$Core Tank
C
C
C
C Top Reflector
C Infinite Be around void hole
100 8 1.21900E-01 150 u=21 imp:n=1
101 0 -150 u=21 imp:n=1
C blocks begining quadrant 1 block working out counter clockwise
105 0 -151 fill=21 (3.6515 3.6515 0) u=45 imp:n=1
106 0 -152 fill=21 (-3.6515 3.6515 0) u=45 imp:n=1
107 0 -153 fill=21 (-3.6515 -3.6515 0) u=45 imp:n=1
108 0 -154 fill=21 (3.6515 -3.6515 0) u=45 imp:n=1
109 0 -155 fill=21 (10.9545 -3.6515 0) u=45 imp:n=1
110 0 -156 fill=21 (10.9545 3.6515 0) u=45 imp:n=1
111 0 -157 fill=21 (10.9545 10.9545 0) u=45 imp:n=1
112 0 -158 fill=21 (3.6515 10.9545 0) u=45 imp:n=1
113 0 -159 fill=21 (-3.6515 10.9545 0) u=45 imp:n=1
114 0 -160 fill=21 (-10.9545 10.9545 0) u=45 imp:n=1
115 0 -161 fill=21 (-10.9545 3.6515 0) u=45 imp:n=1
116 0 -162 fill=21 (-10.9545 -3.6515 0) u=45 imp:n=1
117 0 -163 fill=21 (-10.9545 -10.9545 0) u=45 imp:n=1
118 0 -164 fill=21 (-3.6515 -10.9545 0) u=45 imp:n=1
119 0 -165 fill=21 (3.6515 -10.9545 0) u=45 imp:n=1
120 0 -166 fill=21 (10.9545 -10.9545 0) u=45 imp:n=1
121 0 -167 -168 fill=21 u=45 imp:n=1
122 0 -167 168 u=45 imp:n=1
123 0 -169 fill=21 (16.4295 -9.122 0) u=45 imp:n=1
124 0 -170 fill=21 (16.4295 -5.475 0) u=45 imp:n=1
125 0 -171 fill=21 (18.2575 0 0) u=45 imp:n=1
126 0 -172 fill=21 (16.4295 5.475 0) u=45 imp:n=1
127 0 -173 fill=21 (16.4295 9.122 0) u=45 imp:n=1
128 0 -174 -175 fill=21 u=45 imp:n=1
129 0 -174 175 u=45 imp:n=1
130 0 -176 -177 fill=21 u=45 imp:n=1
131 0 -176 177 u=45 imp:n=1
132 0 -178 fill=21 (9.122 16.4295 0) u=45 imp:n=1
133 0 -179 fill=21 (5.475 16.4295 0) u=45 imp:n=1
134 0 -180 fill=21 (0 18.2575 0) u=45 imp:n=1
135 0 -181 fill=21 (-5.475 16.4295 0) u=45 imp:n=1
136 0 -182 fill=21 (-9.122 16.4295 0) u=45 imp:n=1
167 0 -183 -184 fill=21 u=45 imp:n=1
168 0 -183 184 u=45 imp:n=1
169 0 -185 -186 fill=21 u=45 imp:n=1
170 0 -185 186 u=45 imp:n=1
171 0 -187 fill=21 (-16.4295 9.122 0) u=45 imp:n=1
172 0 -188 fill=21 (-16.4295 5.475 0) u=45 imp:n=1
173 0 -189 fill=21 (-18.2575 0 0) u=45 imp:n=1

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174 0 -190 fill=21 (-16.4295 -5.475 0) u=45 imp:n=1
175 0 -191 fill=21 (-16.4295 -9.122 0) u=45 imp:n=1
176 0 -192 -193 fill=21 u=45 imp:n=1
177 0 -192 193 u=45 imp:n=1
178 0 -194 -195 fill=21 u=45 imp:n=1
179 0 -194 195 u=45 imp:n=1
180 0 -196 fill=21 (-9.122 -16.4295 0) u=45 imp:n=1
181 0 -197 fill=21 (-5.475 -16.4295 0) u=45 imp:n=1
182 0 -198 fill=21 (0 -18.2575 0) u=45 imp:n=1
183 0 -199 fill=21 (5.475 -16.4295 0) u=45 imp:n=1
184 0 -200 fill=21 (9.122 -16.4295 0) u=45 imp:n=1
185 0 -148 -149 fill=21 u=45 imp:n=1
186 0 -148 149 u=45 imp:n=1
187 0 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167
169 170 171 172 173 174 176 178 179 180 181 182 183 185 187 188 189 190
191 192 194 196 197 198 199 200 148 u=45 imp:n=1

C Top Reflector and Tank

192 0 -201 -202 -203 -204 -205 -206 -207 -208 301 -302 fill= 45 imp:n=1
193 13 6.33375E-02 #192 -211 -212
-213 -214 -215 -216 -217 -218 300 -302 imp:n=1
194 0 -201 -202 -203 -204 -205 -206 -207 -208 302 -303 imp:n=1
195 13 6.33375E-02 #194 -211 -212
-213 -214 -215 -216 -217 -218 302 -303 imp:n=1
196 0 -999 300 (211:212:213:214:215:216:217:218):(-999 303) imp:n=1

C Bottom Reflector

200 10 1.21983E-01 150 u=22 imp:n=1
201 0 -150 u=22 imp:n=1
C blocks beginning quadrant 1 block working out counter clockwise

205 0 -151 fill=22 (3.6515 3.6515 0) u=65 imp:n=1
206 0 -152 fill=22 (-3.6515 3.6515 0) u=65 imp:n=1
207 0 -153 fill=22 (-3.6515 -3.6515 0) u=65 imp:n=1
208 0 -154 fill=22 (3.6515 -3.6515 0) u=65 imp:n=1
209 0 -155 fill=22 (10.9545 -3.6515 0) u=65 imp:n=1
210 0 -156 fill=22 (10.9545 3.6515 0) u=65 imp:n=1
211 0 -157 fill=22 (10.9545 10.9545 0) u=65 imp:n=1
212 0 -158 fill=22 (3.6515 10.9545 0) u=65 imp:n=1
213 0 -159 fill=22 (-3.6515 10.9545 0) u=65 imp:n=1
214 0 -160 fill=22 (-10.9545 10.9545 0) u=65 imp:n=1
215 0 -161 fill=22 (-10.9545 3.6515 0) u=65 imp:n=1
216 0 -162 fill=22 (-10.9545 -3.6515 0) u=65 imp:n=1
217 0 -163 fill=22 (-10.9545 -10.9545 0) u=65 imp:n=1
218 0 -164 fill=22 (-3.6515 -10.9545 0) u=65 imp:n=1
219 0 -165 fill=22 (3.6515 -10.9545 0) u=65 imp:n=1
220 0 -166 fill=22 (10.9545 -10.9545 0) u=65 imp:n=1
221 0 -167 -168 fill=22 u=65 imp:n=1
222 0 -167 168 u=65 imp:n=1
223 0 -169 fill=22 (16.4295 -9.122 0) u=65 imp:n=1
224 0 -170 fill=22 (16.4295 -5.475 0) u=65 imp:n=1
225 0 -171 fill=22 (18.2575 0 0) u=65 imp:n=1
226 0 -172 fill=22 (16.4295 5.475 0) u=65 imp:n=1
227 0 -173 fill=22 (16.4295 9.122 0) u=65 imp:n=1
228 0 -174 -175 fill=22 u=65 imp:n=1
229 0 -174 175 u=65 imp:n=1
230 0 -176 -177 fill=22 u=65 imp:n=1
231 0 -176 177 u=65 imp:n=1
232 0 -178 fill=22 (9.122 16.4295 0) u=65 imp:n=1
233 0 -179 fill=22 (5.475 16.4295 0) u=65 imp:n=1
234 0 -180 fill=22 (0 18.2575 0) u=65 imp:n=1
235 0 -181 fill=22 (-5.475 16.4295 0) u=65 imp:n=1
236 0 -182 fill=22 (-9.122 16.4295 0) u=65 imp:n=1
267 0 -183 -184 fill=22 u=65 imp:n=1

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268 0 -183 184 u=65 imp:n=1
269 0 -185 -186 fill=22 u=65 imp:n=1
270 0 -185 186 u=65 imp:n=1
271 0 -187 fill=22 (-16.4295 9.122 0) u=65 imp:n=1
272 0 -188 fill=22 (-16.4295 5.475 0) u=65 imp:n=1
273 0 -189 fill=22 (-18.2575 0 0) u=65 imp:n=1
274 0 -190 fill=22 (-16.4295 -5.475 0) u=65 imp:n=1
275 0 -191 fill=22 (-16.4295 -9.122 0) u=65 imp:n=1
276 0 -192 -193 fill=22 u=65 imp:n=1
277 0 -192 193 u=65 imp:n=1
278 0 -194 -195 fill=22 u=65 imp:n=1
279 0 -194 195 u=65 imp:n=1
280 0 -196 fill=22 (-9.122 -16.4295 0) u=65 imp:n=1
281 0 -197 fill=22 (-5.475 -16.4295 0) u=65 imp:n=1
282 0 -198 fill=22 (0 -18.2575 0) u=65 imp:N=1
283 0 -199 fill=22 (5.475 -16.4295 0) u=65 imp:n=1
284 0 -200 fill=22 (9.122 -16.4295 0) u=65 imp:n=1
285 0 -148 -149 fill=22 u=65 imp:n=1
286 0 -148 149 u=65 imp:n=1
287 0 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167
169 170 171 172 173 174 176 178 179 180 181 182 183 185 187 188 189 190
191 192 194 196 197 198 199 200 148 u=65 imp:n=1

C Bottom Reflector and Tank

305 0 -201 -202 -203 -204 -205 -206 -207 -208 305 -304 fill= 65 imp:n=1
306 14 5.90971E-02 #305 -211 -212
-213 -214 -215 -216 -217 -218 306 -304 imp:n=1
307 0 (211:212:213:214:215:216:217:218) -304 306 -999 imp:n=1

C Side Reflector

320 9 1.22230E-01 320 -321 322 -323 imp:n=1
321 0 -300 53 -320 imp:n=1
322 0 -53 50 -320 322 imp:n=1
323 0 -322 50 -326 304 imp:n=1
324 0 -300 52 321 325 -999 imp:n=1
325 0 -306 327 -999 imp:n=1

C Support Structure/Additional Reflectors

350 30 6.08580E-02 -325 326 imp:n=1 \$Support Plate for Be
351 31 8.75101E-02 -327 imp:n=1 \$SS304 Plate
999 0 999 imp:n=0

C Surface Cards

1 pz 0. \$bottom of fuel
11 rhp 0 0 -10 0 0 50 0 0.63501 0
12 rhp 0 0 -11 0 0 52 1 0 0
13 rhp 0 0 -11 0 0 52 1.982826 0 0
14 rcc 0 12.02 0 0 0 30.48 0.635
15 rcc 0 -12.02 0 0 0 30.48 0.635
16 rcc 10.4 6.0 0 0 0 30.48 0.635
17 rcc -10.4 6.0 0 0 0 30.48 0.635
18 rcc -10.4 -6.0 0 0 0 30.48 0.635
19 rcc 10.4 -6.0 0 0 0 30.48 0.635

C Spacer Tubes

30 rcc 0 12.02 0.317 0 0 27.94 0.642
31 rcc 0 -12.02 0.317 0 0 27.94 0.642
32 rcc 10.4 6.0 0.317 0 0 27.94 0.642
33 rcc -10.4 6.0 0.317 0 0 27.94 0.642
34 rcc -10.4 -6.0 0.317 0 0 27.94 0.642
35 rcc 10.4 -6.0 0.317 0 0 27.94 0.642

C

36 rcc 0 12.02 0.317 0 0 27.94 0.685
37 rcc 0 -12.02 0.317 0 0 27.94 0.685
38 rcc 10.4 6.0 0.317 0 0 27.94 0.685

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39 rcc -10.4 6.0 0.317 0 0 27.94 0.685
40 rcc -10.4 -6.0 0.317 0 0 27.94 0.685
41 rcc 10.4 -6.0 0.317 0 0 27.94 0.685
20 cz 0.635 \$OR Clad
21 cz 0.584 \$IR Clad
22 pz 0.3 \$Top of bottom cap
23 pz 30.18 \$Bottom of top cap
24 pz 30.48 \$Top of fuel tube
25 cz 0.5705 \$OR of Pellet
26 pz 1.445 \$Top of bottom fuel pellet
27 pz 1.4494 \$Bottom of 2nd fuel pellet
28 rpp -0.9 0.9 -0.9 0.9 0.2978 1.4472 \$pellet lattice box
C Core Tank
50 cz 12.98 \$OR Core Tank
51 cz 12.726 \$IR Core Tank
52 pz -0.33 \$Bottom of Core Tank
53 pz 30.71 \$Top of Core Tank
C Grid Plate
60 rcc 0 0 0 0 0 0.317 12.8 \$bottom grid plate
61 rcc 0 0 28.257 0 0 0.317 12.8 \$top grip plate
66 cz 0.642
C Grid Plate Spacer Tubes
62 rcc 0 0 0.317 0 0 27.94 0.685
63 cz 0.642
64 pz 0.317
65 pz 28.257
C
C Reflector
C
150 cz 0.249
151 box 0 0 0 7.303 0 0 0 7.303 0
152 box 0 0 0 -7.303 0 0 0 7.303 0
153 box 0 0 0 -7.303 0 0 0 -7.303 0
154 box 0 0 0 7.303 0 0 0 -7.303 0
155 box 7.303 -7.303 0 7.303 0 0 0 7.303 0
156 box 7.303 0 0 7.303 0 0 0 7.303 0
157 box 7.303 7.303 0 7.303 0 0 0 7.303 0
158 box 0 7.303 0 7.303 0 0 0 7.303 0
159 box -7.303 7.303 0 7.303 0 0 0 7.303 0
160 box -14.606 7.303 0 7.303 0 0 0 7.303 0
161 box -14.606 0 0 7.303 0 0 0 7.303 0
162 box -14.606 -7.303 0 7.303 0 0 0 7.303 0
163 box -14.606 -14.606 0 7.303 0 0 0 7.303 0
164 box -7.303 -14.606 0 7.303 0 0 0 7.303 0
165 box 0 -14.606 0 7.303 0 0 0 7.303 0
166 box 7.303 -14.606 0 7.303 0 0 0 7.303 0
167 box 14.606 -14.5925 0 3.647 0 0 0 3.647 0
168 p 14.606 -14.5925 5 18.253 -10.9455 0 16.4295 -12.769 14
169 box 14.606 -10.9455 0 3.647 0 0 0 3.647 0
170 box 14.606 -7.2985 0 3.647 0 0 0 3.647 0
171 box 14.606 -3.6515 0 7.303 0 0 0 7.303 0
172 box 14.606 3.6515 0 3.647 0 0 0 3.647 0
173 box 14.606 7.2985 0 3.647 0 0 0 3.647 0
174 box 14.606 10.9455 0 3.647 0 0 0 3.647 0
175 p 14.606 14.5925 5 18.253 10.9455 0 16.4295 12.769 14
176 box 10.9455 14.606 0 3.647 0 0 0 3.647 0
177 p 10.9455 18.253 5 14.5925 14.606 0 12.769 16.4295 14
178 box 7.2985 14.606 0 3.647 0 0 0 3.647 0
179 box 3.6515 14.606 0 3.647 0 0 0 3.647 0
180 box -3.6515 14.606 0 7.303 0 0 0 7.303 0
181 box -7.2985 14.606 0 3.647 0 0 0 3.647 0

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182 box -10.9455 14.606 0 3.647 0 0 0 3.647 0
183 box -14.5925 14.606 0 3.647 0 0 0 3.647 0
184 p -14.5925 14.606 5 -10.9455 18.253 0 -12.769 16.4295 14
185 box -18.253 10.9455 0 3.647 0 0 0 3.647 0
186 p -18.253 10.9455 5 -14.606 14.5925 0 -16.4295 12.769 14
187 box -18.253 7.2985 0 3.647 0 0 0 3.647 0
188 box -18.253 3.6515 0 3.647 0 0 0 3.647 0
189 box -21.909 -3.6515 0 7.303 0 0 0 7.303 0
190 box -18.253 -7.2985 0 3.647 0 0 0 3.647 0
191 box -18.253 -10.9455 0 3.647 0 0 0 3.647 0
192 box -18.253 -14.5925 0 3.647 0 0 0 3.647 0
193 p -18.253 -10.9455 5 -14.606 -14.5925 0 -16.4295 -12.769 14
194 box -14.5925 -18.253 0 3.647 0 0 0 3.647 0
195 p -14.606 -14.5925 5 -10.9455 -18.253 0 -12.77575 -16.42275 14
196 box -10.9455 -18.253 0 3.647 0 0 0 3.647 0
197 box -7.2985 -18.253 0 3.647 0 0 0 3.647 0
198 box -3.6515 -21.909 0 7.303 0 0 0 7.303 0
199 box 3.6515 -18.253 0 3.647 0 0 0 3.647 0
200 box 7.2985 -18.253 0 3.647 0 0 0 3.647 0
148 box 10.9455 -18.253 0 3.647 0 0 0 3.647 0
149 p 10.9455 -18.253 5 14.5925 -14.606 0 12.769 -16.4295 14
C Reflector Tanks
201 p -7.3 22.3763 5 0 22.3763 5 7.3 22.3763 10
202 p 7.3 22.3763 10 14.8381 14.8381 5 22.3763 7.3 5
203 p 22.3763 7.3 5 22.3763 0 5 22.3763 -7.3 10
204 p 22.3763 -7.3 10 14.8381 -14.8381 5 7.3 -22.3763 5
205 p 7.3 -22.3763 5 0 -22.3763 5 -7.3 -22.3763 10
206 p -7.3 -22.3763 10 -14.8381 -14.8381 5 -22.3763 -7.3 5
207 p -22.37625 -7.3 5 -22.3763 0 5 -22.3763 7.3 10
208 p -22.37625 7.3 10 -14.8381 14.8381 5 -7.3 22.3763 5
211 p -7.563 23.0113 5 0 23.0113 5 7.5630 23.0113 10
212 p 7.563 23.0113 10 15.2871 15.2871 5 23.0113 7.5630 5
213 p 23.0113 7.563 5 23.0113 0 5 23.0113 -7.5630 10
214 p 23.0113 -7.563 10 15.2871 -15.2871 5 7.5630 -23.0113 5
215 p 7.563 -23.0113 5 0 -23.0113 5 -7.5630 -23.0113 10
216 p -7.563 -23.0113 10 -15.2871 -15.2871 5 -23.0113 -7.5630 5
217 p -23.0113 -7.563 5 -23.0113 0 5 -23.0113 7.5630 10
218 p -23.0113 7.563 10 -15.2871 15.2871 5 -7.5630 23.0113 5
C
300 pz 30.935
301 pz 31.155
302 pz 38.14
303 pz 43.885
C
304 pz -0.33
305 pz -7.95
306 pz -8.84
C Side Reflector
320 cz 13.08
321 cz 24.45
322 pz 0.305
323 pz 30.935
C
C Be Support Plate
325 rpp -37.5 37.5 -37.5 37.5 -0.33 0.305
326 cz 13.95
C SS304 Plate
327 rcc 0. 0. -11.22 0. 0. 2.38 22.86
C
999 rpp -500 500 -500 500 -500 500

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C Data Cards

m1 92234.70c 2.22221E-04
92235.70c 2.04075E-02
92236.70c 1.02532E-04
92238.70c 1.16161E-03
8016.70c 4.36813E-02
8017.70c 1.06404E-04
47107.70c 5.62272E-07
47109.70c 5.22379E-07
4009.70c 9.73675E-08
24050.70c 1.12435E-07
24052.70c 2.16820E-06
24053.70c 2.45856E-07
24054.70c 6.11987E-08
3006.70c 4.74083E-08
3007.70c 5.84702E-07
28058.70c 8.33992E-07
28060.70c 3.21252E-07
28061.70c 1.39646E-08
28062.70c 4.45253E-08
28064.70c 1.13393E-08
50112.70c 7.17017E-09
50114.70c 4.87867E-09
50115.70c 2.51325E-09
50116.70c 1.07479E-07
50117.70c 5.67700E-08
50118.70c 1.79032E-07
50119.70c 6.34966E-08
50120.70c 2.40829E-07
50122.70c 3.42246E-08
50124.70c 4.27992E-08
13027.70c 3.57743E-06
20040.70c 7.07498E-06
20042.70c 4.72195E-08
20043.70c 9.85261E-09
20044.70c 1.52241E-07
20046.70c 2.91929E-10
20048.70c 1.36477E-08
29063.70c 1.20986E-06
29065.70c 5.39253E-07
12024.70c 1.14073E-06
12025.70c 1.44414E-07
12026.70c 1.59000E-07
15031.70c 9.44341E-06
5010.70c 5.38407E-08
5011.70c 2.16716E-07
26054.70c 7.95942E-07
26056.70c 1.24946E-05
26057.70c 2.88555E-07
26058.70c 3.84013E-08
25055.70c 4.25932E-07
56130.70c 2.25774E-10
56132.70c 2.15124E-10
56134.70c 5.14807E-09
56135.70c 1.40406E-08
56136.70c 1.67286E-08
56137.70c 2.39235E-08
56138.70c 1.52713E-07
19039.70c 3.48837E-06
19040.70c 4.37645E-10
19041.70c 2.51747E-07

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11023.70c	1.27230E-06	
14028.70c	5.76320E-06	
14029.70c	2.92641E-07	
14030.70c	1.92911E-07	\$ TOT 6.57372E-02
C Fuel Clad		
m15 26054.70c	3.25448E-03	
26056.70c	5.10884E-02	
26057.70c	1.17985E-03	
26058.70c	1.57017E-04	
6000.70c	1.50688E-04	
25055.70c	8.23618E-04	
14028.70c	7.42946E-04	
14029.70c	3.77250E-05	
14030.70c	2.48686E-05	
24050.70c	6.80598E-04	
24052.70c	1.31247E-02	
24053.70c	1.48823E-03	
24054.70c	3.70452E-04	
28058.70c	5.77334E-03	
28060.70c	2.22388E-03	
28061.70c	9.66705E-05	
28062.70c	3.08228E-04	
28064.70c	7.84965E-05	
15031.70c	3.28690E-05	
16032.70c	2.00907E-05	
16033.70c	1.60844E-07	
16034.70c	9.07921E-07	
16036.70c	4.23273E-09	
41093.70c	3.13488E-04	
73181.70c	1.40839E-05	\$ tot 8.19858E-02
C End Caps		
m16 26054.70c	8.63854E-04	
26056.70c	1.35607E-02	
26057.70c	3.13175E-04	
26058.70c	4.16778E-05	
6000.70c	3.99979E-05	
25055.70c	2.18617E-04	
14028.70c	1.97204E-04	
14029.70c	1.00135E-05	
14030.70c	6.60099E-06	
24050.70c	1.80655E-04	
24052.70c	3.48374E-03	
24053.70c	3.95029E-04	
24054.70c	9.83310E-05	
28058.70c	1.53245E-03	
28060.70c	5.90295E-04	
28061.70c	2.56597E-05	
28062.70c	8.18144E-05	
28064.70c	2.08357E-05	
15031.70c	8.72458E-06	
16032.70c	5.33276E-06	
16033.70c	4.26936E-08	
16034.70c	2.40994E-07	
16034.70c	1.12352E-09	
41093.70c	8.32108E-05	
73181.70c	3.73835E-06	\$ tot 2.17619E-02
C Core Tank		
m2 13027.70c	5.85485E-02	
29063.70c	2.16403E-05	
29065.70c	9.64537E-06	
14028.70c	1.24044E-04	

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14029.70c	6.29865E-06	
14030.70c	4.15212E-06	
26054.70c	3.95341E-06	
26056.70c	6.20601E-05	
26057.70c	1.43324E-06	
26058.70c	1.90738E-07	
25055.70c	7.23754E-06	
30000.70c	1.21614E-05	\$ Tot 5.88014E-02
C Grid Plate		
m20 13027.70c	0.05985552	
29063.70c	2.21234E-05	
29065.70c	9.86068E-06	
14028.70c	1.26813E-04	
14029.70c	6.43926E-06	
14030.70c	4.24481E-06	
26054.70c	4.04166E-06	
26056.70c	6.34455E-05	
26057.70c	1.46523E-06	
26058.70c	1.94996E-07	
25055.70c	7.39910E-06	
30000.70c	1.24328E-05	\$ Tot 6.01140E-02
C Grid Plate Spacer Tube		
m21 26054.70c	3.24300E-03	
26056.70c	5.09082E-02	
26057.70c	1.17569E-03	
26058.70c	1.56463E-04	
6000.70c	1.50157E-04	
25055.70c	8.20712E-04	
14028.70c	7.40325E-04	
14029.70c	3.75919E-05	
14030.70c	2.47808E-05	
24050.70c	6.78197E-04	
24052.70c	1.30784E-02	
24053.70c	1.48298E-03	
24054.70c	3.69145E-04	
28058.70c	5.75297E-03	
28060.70c	2.21603E-03	
28061.70c	9.63294E-05	
28062.70c	3.07140E-04	
28064.70c	7.82196E-05	
15031.70c	3.27530E-05	
16032.70c	2.00198E-05	
16033.70c	1.60276E-07	
16034.70c	9.04718E-07	
16036.70c	4.21780E-09	
41093.70c	3.12383E-04	
73181.70c	1.40342E-05	\$ tot 8.16965E-02
C Al Shim		
m22 13027.70c	5.98555E-02	
29063.70c	2.21234E-05	
29065.70c	9.86068E-06	
14028.70c	1.26813E-04	
14029.70c	6.43926E-06	
14030.70c	4.24481E-06	
26054.70c	4.04166E-06	
26056.70c	6.34455E-05	
26057.70c	1.46523E-06	
25055.70c	7.39910E-06	
30000.70c	1.24328E-05	\$ Tot 6.01138E-02
C Al Fuel Tube Clips		
m23 13027.70c	7.73726E-03	

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```
29063.70c 2.85979E-06
29065.70c 1.27465E-06
14028.70c 1.63926E-05
14029.70c 8.32374E-07
14030.70c 5.48707E-07
26054.70c 5.22448E-07
26056.70c 8.20131E-06
26057.70c 1.89404E-07
25055.70c 9.56449E-07
30000.70c 1.60714E-06 $ Tot 7.77064E-03
C Reflectors
C *****
C Top Reflector
m8 4009.70c 1.21825E-01
3006.70c 3.61129E-09
3007.70c 4.45392E-08
5010.70c 2.46076E-08
5011.70c 9.90488E-08
12024.70c 2.89646E-06
12025.70c 3.66687E-07
12026.70c 4.03723E-07
13027.70c 3.30313E-05
14028.70c 2.56087E-05
14029.70c 1.30035E-06
14030.70c 8.57200E-07
20040.70c 2.69465E-07
20042.70c 1.79846E-09
20043.70c 3.75257E-10
20044.70c 5.79842E-09
20046.70c 1.11187E-11
20048.70c 5.19801E-10
24050.70c 1.30331E-07
24052.70c 2.51331E-06
24053.70c 2.84990E-07
24054.70c 7.09399E-08
25055.70c 2.02782E-06
27059.70c 1.89035E-08
28058.70c 2.32600E-06
28060.70c 8.95971E-07
28061.70c 3.89472E-08
28062.70c 1.24181E-07
28064.70c 3.16252E-08
29063.70c 1.09137E-06
29065.70c 4.86440E-07
30000.70c 5.11106E-07
47107.70c 1.60615E-08
47109.70c 1.49219E-08
48106.70c 2.47763E-11
48108.70c 1.76407E-11
48110.70c 2.47565E-10
48111.70c 2.53709E-10
48112.70c 4.78282E-10
48113.70c 2.42213E-10
48114.70c 5.69459E-10
48116.70c 1.48460E-10
8016.70c 8.57552E-04
8017.70c 2.08893E-06 $ total 1.21900E-01
C
C Side Reflector
m9 4009.70c 1.21199E-01
8016.70c 8.54608E-04
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8017.70c	2.08176E-06	
13027.70c	2.46884E-05	
6000.70c	1.10920E-04	
26054.70c	1.51055E-06	
26056.70c	2.37125E-05	
26057.70c	5.47624E-07	
26058.70c	7.28787E-08	
12024.70c	7.21630E-06	
12025.70c	9.13571E-07	
12026.70c	1.00584E-06	
83209.70c	2.65627E-06	
5010.70c	2.04360E-07	
5011.70c	8.22573E-07	
48106.70c	2.46912E-10	
48108.70c	1.75802E-10	
48110.70c	2.46715E-09	
48111.70c	2.52838E-09	
48112.70c	4.76640E-09	
48113.70c	2.41382E-09	
48114.70c	5.67504E-09	
48116.70c	1.47950E-09	
66156.70c	4.09926E-12	
66158.70c	6.83211E-12	
66160.70c	1.59871E-10	
66161.70c	1.29195E-09	
66162.70c	1.74287E-09	
66163.70c	1.70119E-09	
66164.70c	1.92529E-09	
35079.70c	3.52153E-09	
35081.70c	3.42566E-09	
64152.70c	1.41204E-11	
64154.70c	1.53912E-10	
64155.70c	1.04491E-09	
64156.70c	1.44522E-09	
64157.70c	1.10492E-09	
64158.70c	1.75375E-09	
64160.70c	1.54336E-09	
28058.70c	1.28779E-08	
28060.70c	4.96053E-09	
28061.70c	2.15631E-10	
28062.70c	6.87525E-10	
28064.70c	1.75092E-10	
62144.70c	2.26680E-10	
62147.70c	1.10682E-09	
62148.70c	8.29931E-10	
62149.70c	1.02043E-09	
62150.70c	5.44919E-10	
62152.70c	1.97515E-09	
62154.70c	1.67980E-09	\$ Total 1.22230E-01
C Bottom Reflector		
m10 4009.70c	1.21908E-01	
3006.70c	3.61375E-09	
3007.70c	4.45695E-08	
5010.70c	2.46244E-08	
5011.70c	9.91163E-08	
12024.70c	2.89844E-06	
12025.70c	3.66937E-07	
12026.70c	4.03998E-07	
13027.70c	3.30538E-05	
14028.70c	2.56262E-05	
14029.70c	1.30123E-06	

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14030.70c 8.57784E-07
20040.70c 2.69649E-07
20042.70c 1.79968E-09
20043.70c 3.75513E-10
20044.70c 5.80237E-09
20046.70c 1.11263E-11
20048.70c 5.20155E-10
24050.70c 1.30420E-07
24052.70c 2.51502E-06
24053.70c 2.85184E-07
24054.70c 7.09882E-08
25055.70c 2.02920E-06
27059.70c 1.89163E-08
28058.70c 2.32758E-06
28060.70c 8.96581E-07
28061.70c 3.89738E-08
28062.70c 1.24265E-07
28064.70c 3.16467E-08
29063.70c 1.09212E-06
29065.70c 4.86771E-07
30000.70c 5.11455E-07
47107.70c 1.60724E-08
47109.70c 1.49321E-08
48106.70c 2.47932E-11
48108.70c 1.76527E-11
48110.70c 2.47733E-10
48111.70c 2.53882E-10
48112.70c 4.78608E-10
48113.70c 2.42378E-10
48114.70c 5.69846E-10
48116.70c 1.48561E-10
8016.70c 8.58136E-04
8017.70c 2.09035E-06 \$ total 1.21983E-01

C *****

C Upper reflector tank

m13 13027.70c 6.30773E-02
29063.70c 2.33036E-05
29065.70c 1.03867E-05
14028.70c 1.33578E-04
14029.70c 6.78278E-06
14030.70c 4.47126E-06
26054.70c 4.25728E-06
26056.70c 6.68301E-05
26057.70c 1.54340E-06
25055.70c 7.79383E-06
30000.70c 1.30961E-06 \$ Tot 6.33375E-02

C lower reflector tank

m14 13027.70c 5.88542E-02
29063.70c 2.17434E-05
29065.70c 9.69134E-06
14028.70c 1.24635E-04
14029.70c 6.32867E-06
14030.70c 4.17191E-06
26054.70c 3.97225E-06
26056.70c 6.23559E-05
26057.70c 1.44007E-06
25055.70c 7.27203E-06
30000.70c 1.22193E-06 \$ Tot 5.90971E-02

C *****

C Additional Bottom Reflectors

C Be Support Plate (All100)

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m30 13027.70c 6.06080E-02
29063.70c 2.23913E-05
29065.70c 9.98012E-06
14028.70c 1.28349E-04
14029.70c 6.51725E-06
14030.70c 4.29622E-06
26054.70c 4.09062E-06
26056.70c 6.42139E-05
26057.70c 1.48298E-06
25055.70c 7.48872E-06
30000.70c 1.25834E-06 \$ Tot 6.08580E-02

C SS304 Support Plate

m31 26054.70c 3.51905E-03
26056.70c 5.52415E-02
26057.70c 1.27577E-03
26058.70c 1.69781E-04
6000.70c 1.60142E-04
25055.70c 8.75287E-04
14028.70c 7.89554E-04
14029.70c 4.00916E-05
14030.70c 2.64287E-05
24050.70c 7.63478E-04
24052.70c 1.47229E-02
24053.70c 1.66946E-03
24054.70c 4.15564E-04
28058.70c 5.29886E-03
28060.70c 2.04111E-03
28061.70c 8.87257E-05
28062.70c 2.82896E-04
28064.70c 7.20454E-05
15031.70c 3.49310E-05
16032.70c 2.13510E-05
16033.70c 1.70934E-07
16034.70c 9.64879E-07
16034.70c 4.49827E-09 \$ tot 8.75101E-02

C Scattering Cards

mt1 o2/u.10t u/o2.10t
mt2 al27.12t
mt8 be.10t
mt9 be.10t
mt10 be.10t
mt13 al27.12t
mt14 al27.12t
mt20 al27.12t
mt22 al27.12t
mt30 al27.12t

C

kcode 100000 1 150 2150
ksrc 0.0692 4.5245 0.77787 0 8.8072 0.7787
0.0692 -4.3864 0.77787 0 -8.7382 0.7787
3.8736 0 0.7787 7.6780 0 0.7787
-3.7353 0 0.7787 -7.8510 0 0.7787

MCNP5 Input Deck for Simple Benchmark Models:

Case 1

SCCA-FUND-EXP-002-001 and HEU-COMP-FAST-002

C

C

C Cell Cards

1 1 6.54398E-02 (-25 22 -24) u=11 imp:n=1 \$fuel pellet
2 0 -22:(25 22 -24):24 u=11 imp:n=1 \$void around pellet

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103 13 7.07826E-02 (301 -303 57 -58):(300 -301 -58) imp:n=1
196 0 -999 300 (58):(-999 303) imp:n=1
C Bottom Reflector
300 10 1.20636E-01 -57 -304 305 imp:n=1
301 14 6.72481E-02 (57 -58 -304 305):(-305 306 -58) imp:n=1
307 0 58 -304 306 -999 imp:n=1
C Side Reflector
320 9 1.21199E-01 320 -321 322 -323 imp:n=1
321 0 -300 53 -320 imp:n=1
322 0 -53 50 -320 322 imp:n=1
323 0 -322 50 -326 304 imp:n=1
324 0 -300 52 321 325 -999 imp:n=1
325 0 -306 327 -999 imp:n=1
C Support Structure/Additional Reflectors
350 30 6.08580E-02 -325 326 imp:n=1 \$Support Plate for Be
351 31 8.75101E-02 -327 imp:n=1 \$SS304 Plate
999 0 999 imp:n=0

C Surface Cards
1 pz 0. \$bottom of fuel
11 rhp 0 0 -10 0 0 50 0.753 0 0
12 rhp 0 0 -11 0 0 52 1 0 0
13 rcc -3.766 -11.458 0 0 0 30.48 0.635
14 rcc 3.766 -11.458 0 0 0 30.48 0.635
15 rcc 3.766 11.458 0 0 0 30.48 0.635
16 rcc -3.766 11.458 0 0 0 30.48 0.635
17 rcc -8.039 -8.989 0 0 0 30.48 0.635
18 rcc 8.039 -8.989 0 0 0 30.48 0.635
19 rcc -8.039 8.989 0 0 0 30.48 0.635
20 cz 0.635 \$OR Clad
21 cz 0.584 \$IR Clad
22 pz 0.3 \$top of bottom cap
23 pz 30.18 \$bottom of top cap
24 pz 30.48 \$Top of fuel tube
25 cz 0.5705 \$OR of Pellet
30 rcc 8.039 8.989 0 0 0 30.48 0.635
31 rcc -11.805 -2.467 0 0 0 30.48 0.635
32 rcc 11.805 -2.467 0 0 0 30.48 0.635
33 rcc -11.805 2.467 0 0 0 30.48 0.635
34 rcc 11.805 2.467 0 0 0 30.48 0.635

C Core Tank
50 cz 12.98 \$OR Core Tank
51 cz 12.726 \$IR Core Tank
52 pz -0.33 \$Bottom of Core Tank
53 pz 30.71 \$Top of Core Tank
C simple model to preflector
57 cz 20.65 \$Ir upper and lower tank
58 cz 21.285 \$OR upper and lower tank

C
300 pz 30.935
301 pz 31.155
302 pz 38.14
303 pz 43.885

C
304 pz -0.33
305 pz -7.95
306 pz -8.84
C Side Reflector
320 cz 13.08
321 cz 24.45
322 pz 0.305

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323 pz 30.935
C
C Be Support Plate
325 rpp -37.5 37.5 -37.5 37.5 -0.33 0.305
326 cz 13.95
C SS304 Plate
327 rcc 0. 0. -11.22 0. 0. 2.38 22.86
C
999 rpp -500 500 -500 500 -500 500

C Data Cards
m1 92234.70c 2.21403E-04
92235.70c 2.03324E-02
92236.70c 1.02154E-04
92238.70c 1.15733E-03
8016.70c 4.35205E-02
8017.70c 1.06012E-04 \$ Tot 6.54398E-02
C Fuel Clad
m15 26054.70c 3.02148E-03
26056.70c 4.74308E-02
26057.70c 1.09538E-03
26058.70c 1.45775E-04
6000.70c 1.39900E-04
25055.70c 7.64651E-04
14028.70c 6.89755E-04
14029.70c 3.50241E-05
14030.70c 2.30881E-05
24050.70c 6.31871E-04
24052.70c 1.21850E-02
24053.70c 1.38168E-03
24054.70c 3.43930E-04
28058.70c 5.35999E-03
28060.70c 2.06466E-03
28061.70c 8.97493E-05
28062.70c 2.86160E-04
28064.70c 7.28766E-05
15031.70c 3.05157E-05
16032.70c 1.86523E-05
16033.70c 1.49328E-07
16034.70c 8.42918E-07
16036.70c 3.92969E-09
41093.70c 2.91044E-04
73181.70c 1.30755E-05 \$tot 7.61160E-02
C Core Tank
m2 13027.70c 5.85485E-02
29063.70c 2.16403E-05
29065.70c 9.64537E-06
14028.70c 1.24044E-04
14029.70c 6.29865E-06
14030.70c 4.15212E-06
26054.70c 3.95341E-06
26056.70c 6.20601E-05
26057.70c 1.43324E-06
26058.70c 1.90738E-07
25055.70c 7.23754E-06
30000.70c 1.21614E-05 \$ Tot 5.88014E-02
C Reflectors
C *****
C Top Reflector
m8 4009.70c 1.20554E-01
C Side Reflector

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m9 4009.70c 1.21199E-01
C Bottom Reflector
m10 4009.70c 1.20636E-01
C *****
C Upper reflector tank
m13 13027.70c 7.04918E-02
29063.70c 2.60429E-05
29065.70c 1.16077E-05
14028.70c 1.49280E-04
14029.70c 7.58007E-06
14030.70c 4.99684E-06
26054.70c 4.75770E-06
26056.70c 7.46858E-05
26057.70c 1.72482E-06
25055.70c 8.70996E-06
30000.70c 1.46355E-06 \$ Tot 7.07826E-02
C lower reflector tank
m14 13027.70c 6.69718E-02
29063.70c 2.47424E-05
29065.70c 1.10280E-05
14028.70c 1.41826E-04
14029.70c 7.20156E-06
14030.70c 4.74732E-06
26054.70c 4.52013E-06
26056.70c 7.09564E-05
26057.70c 1.63869E-06
25055.70c 8.27504E-06
30000.70c 1.39047E-06 \$ Tot 6.72481E-02
C *****
C Additional Bottom Reflectors
C Be Support Plate (Al1100)
m30 13027.70c 6.06080E-02
29063.70c 2.23913E-05
29065.70c 9.98012E-06
14028.70c 1.28349E-04
14029.70c 6.51725E-06
14030.70c 4.29622E-06
26054.70c 4.09062E-06
26056.70c 6.42139E-05
26057.70c 1.48298E-06
25055.70c 7.48872E-06
30000.70c 1.25834E-06 \$ Tot 6.08580E-02
C SS304 Support Plate
m31 26054.70c 3.51905E-03
26056.70c 5.52415E-02
26057.70c 1.27577E-03
26058.70c 1.69781E-04
6000.70c 1.60142E-04
25055.70c 8.75287E-04
14028.70c 7.89554E-04
14029.70c 4.00916E-05
14030.70c 2.64287E-05
24050.70c 7.63478E-04
24052.70c 1.47229E-02
24053.70c 1.66946E-03
24054.70c 4.15564E-04
28058.70c 5.29886E-03
28060.70c 2.04111E-03
28061.70c 8.87257E-05
28062.70c 2.82896E-04
28064.70c 7.20454E-05

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15031.70c 3.49310E-05
16032.70c 2.13510E-05
16033.70c 1.70934E-07
16034.70c 9.64879E-07
16034.70c 4.49827E-09 \$tot 8.75101E-02
C Scattering Cards
mt1 o2/u.10t u/o2.10t
mt2 al27.12t
mt8 be.10t
mt9 be.10t
mt10 be.10t
mt13 al27.12t
mt14 al27.12t
mt20 al27.12t
mt22 al27.12t
m23 al27.12t
mt30 al27.12t
C
kcode 100000 1 150 2150
ksrc 0.0692 4.5245 0.77787 0 8.8072 0.7787
0.0692 -4.3864 0.77787 0 -8.7382 0.7787
3.8736 0 0.7787 7.6780 0 0.7787
-3.7353 0 0.7787 -7.8510 0 0.7787

Case 2

SCCA-FUND-EXP-002-001 and HEU-COMP-FAST-002

C
C
C Cell Cards
1 1 6.54398E-02 (-25 22 -24) u=11 imp:n=1 \$fuel pellet
2 0 -22:(25 22 -24):24 u=11 imp:n=1 \$void around pellet
4 0 -21 22 -23 fill=11 u=12 imp:n=1
C
C BASIC FUEL TUBE W/ GRID PLATE
15 15 7.61160E-02 (1 -24 -20 21) u=12 imp:n=1 \$Fuel tube
16 15 7.61160E-02 (1 -22 -21):(23 -24 -21) u=12 imp:n=1 \$end caps
21 0 -1:20:24 u=12 imp:n=1
C BASIC FUEL TUBES FOR TUBES WHICH ARE MOVED IN
22 0 -21 22 -23 fill=11 u=13 imp:n=1
23 15 7.61160E-02 (21) u=13 imp:n=1 \$Fuel tube
24 15 7.61160E-02 (-22 -21):(23 -21) u=13 imp:n=1 \$end caps
C VOID
42 0 -999 u=20 imp:n=1
C BASIC FUEL TUBES
43 0 -12 fill=12 u=1 imp:n=1
C
60 0 -11 lat=2 u=2 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 1 1 20
20 1 1 1 20
20 1 1 20 20
20 20 20 20 20
61 0 -11 lat=2 u=3 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 1 1 20
20 20 1 1 20
20 20 1 20 20
20 20 20 20 20
62 0 -11 lat=2 u=4 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 20 1 20
20 20 1 1 20

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```

20 1 1 20 20
20 20 20 20 20
63 0 -11 lat=2 u=5 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 1 1 20
20 1 1 1 20
20 20 20 20 20
20 20 20 20 20
64 0 -11 lat=2 u=6 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 20 20 20
20 1 1 1 20
20 1 1 20 20
20 20 20 20 20
65 0 -11 lat=2 u=7 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 1 1 20
20 1 1 20 20
20 1 20 20 20
20 20 20 20 20
66 0 -11 lat=2 u=8 imp:n=1 fill=-2:2 -2:2 0:0
20 20 20 20 20
20 20 1 20 20
20 1 1 20 20
20 1 1 20 20
20 20 20 20 20
67 0 -13 lat=2 u=9 imp:n=1 fill=-4:4 -4:4 0:0
20 20 20 20 20 20 20 20 20
20 20 20 20 3 2 2 4 20
20 20 20 2 2 2 2 2 20
20 20 2 2 2 2 2 2 20
20 5 2 2 2 2 2 6 20
20 2 2 2 2 2 2 20 20
20 2 2 2 2 2 20 20 20
20 7 2 2 8 20 20 20 20
20 20 20 20 20 20 20 20
C
C
70 0 -14 fill=13 (0 12.02 0) imp:n=1
71 0 -15 fill=13 (0 -12.02 0) imp:n=1
72 0 -16 fill=13 (10.4 6.0 0) imp:n=1
73 0 -17 fill=13 (-10.4 6.0 0) imp:n=1
74 0 -18 fill=13 (-10.4 -6.0 0) imp:n=1
75 0 -19 fill=13 (10.4 -6.0 0) imp:n=1
C
C Core Tank
77 0 -51 1 -53 14 15 16 17 18 19 fill=9 imp:n=1
76 2 5.88014E-02 (-53 1 -50 51):(-1 52 -50) imp:n=1 $Core Tank
C
C Reflectors
C Top Reflector
100 8 1.20554E-01 301 -57 -302 imp:n=1
102 0 302 -57 -303 imp:n=1
103 13 7.07826E-02 (301 -303 57 -58):(300 -301 -58) imp:n=1
196 0 -999 300 (58):(-999 303) imp:n=1
C Bottom Reflector
300 10 1.20636E-01 -57 -304 305 imp:n=1
301 14 6.72481E-02 (57 -58 -304 305):(-305 306 -58) imp:n=1
307 0 58 -304 306 -999 imp:n=1
C Side Reflector
320 9 1.21199E-01 320 -321 322 -323 imp:n=1

```

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321 0 -300 53 -320 imp:n=1
322 0 -53 50 -320 322 imp:n=1
323 0 -322 50 -326 304 imp:n=1
324 0 -300 52 321 325 -999 imp:n=1
325 0 -306 327 -999 imp:n=1
C Support Structure/Additional Reflectors
350 30 6.08580E-02 -325 326 imp:n=1 \$Support Plate for Be
351 31 8.75101E-02 -327 imp:n=1 \$SS304 Plate
999 0 999 imp:n=0

C Surface Cards

1 pz 0. \$bottom of fuel
11 rhp 0 0 -10 0 0 50 0 0.63501 0
12 rhp 0 0 -11 0 0 52 1 0 0
13 rhp 0 0 -11 0 0 52 1.982826 0 0
14 rcc 0 12.02 0 0 0 30.48 0.635
15 rcc 0 -12.02 0 0 0 30.48 0.635
16 rcc 10.4 6.0 0 0 0 30.48 0.635
17 rcc -10.4 6.0 0 0 0 30.48 0.635
18 rcc -10.4 -6.0 0 0 0 30.48 0.635
19 rcc 10.4 -6.0 0 0 0 30.48 0.635
20 cz 0.635 \$OR Clad
21 cz 0.584 \$IR Clad
22 pz 0.3 \$top of bottom cap
23 pz 30.18 \$bottom of top cap
24 pz 30.48 \$Top of fuel tube
25 cz 0.5705 \$OR of Pellet

C Core Tank

50 cz 12.98 \$OR Core Tank
51 cz 12.726 \$IR Core Tank
52 pz -0.33 \$Bottom of Core Tank
53 pz 30.71 \$Top of Core Tank

C Top and bottom reflector for simple model

57 cz 20.65
58 cz 21.285
C top reflector
300 pz 30.935
301 pz 31.155
302 pz 38.14
303 pz 43.885

C

304 pz -0.33
305 pz -7.95
306 pz -8.84

C Side Reflector

320 cz 13.08
321 cz 24.45
322 pz 0.305
323 pz 30.935

C

C Be Support Plate

325 rpp -37.5 37.5 -37.5 37.5 -0.33 0.305
326 cz 13.95

C SS304 Plate

327 rcc 0. 0. -11.22 0. 0. 2.38 22.86

C

999 rpp -500 500 -500 500 -500 500

C Data Cards

m1 92234.70c 2.21403E-04
92235.70c 2.03324E-02

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92236.70c 1.02154E-04
92238.70c 1.15733E-03
8016.70c 4.35205E-02
8017.70c 1.06012E-04 \$ Tot 6.54398E-02
C Fuel Clad
m15 26054.70c 3.02148E-03
26056.70c 4.74308E-02
26057.70c 1.09538E-03
26058.70c 1.45775E-04
6000.70c 1.39900E-04
25055.70c 7.64651E-04
14028.70c 6.89755E-04
14029.70c 3.50241E-05
14030.70c 2.30881E-05
24050.70c 6.31871E-04
24052.70c 1.21850E-02
24053.70c 1.38168E-03
24054.70c 3.43930E-04
28058.70c 5.35999E-03
28060.70c 2.06466E-03
28061.70c 8.97493E-05
28062.70c 2.86160E-04
28064.70c 7.28766E-05
15031.70c 3.05157E-05
16032.70c 1.86523E-05
16033.70c 1.49328E-07
16034.70c 8.42918E-07
16036.70c 3.92969E-09
41093.70c 2.91044E-04
73181.70c 1.30755E-05 \$tot 7.61160E-02
C Core Tank
m2 13027.70c 5.85485E-02
29063.70c 2.16403E-05
29065.70c 9.64537E-06
14028.70c 1.24044E-04
14029.70c 6.29865E-06
14030.70c 4.15212E-06
26054.70c 3.95341E-06
26056.70c 6.20601E-05
26057.70c 1.43324E-06
26058.70c 1.90738E-07
25055.70c 7.23754E-06
30000.70c 1.21614E-05 \$ Tot 5.88014E-02
C Reflectors
C *****
C Top Reflector
m8 4009.70c 1.20554E-01
C Side Reflector
m9 4009.70c 1.21199E-01
C Bottom Reflector
m10 4009.70c 1.20636E-01
C *****
C Upper reflector tank
m13 13027.70c 7.04918E-02
29063.70c 2.60429E-05
29065.70c 1.16077E-05
14028.70c 1.49280E-04
14029.70c 7.58007E-06
14030.70c 4.99684E-06
26054.70c 4.75770E-06
26056.70c 7.46858E-05

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26057.70c 1.72482E-06
25055.70c 8.70996E-06
30000.70c 1.46355E-06 \$ Tot 7.07826E-02
C lower reflector tank
m14 13027.70c 6.69718E-02
29063.70c 2.47424E-05
29065.70c 1.10280E-05
14028.70c 1.41826E-04
14029.70c 7.20156E-06
14030.70c 4.74732E-06
26054.70c 4.52013E-06
26056.70c 7.09564E-05
26057.70c 1.63869E-06
25055.70c 8.27504E-06
30000.70c 1.39047E-06 \$ Tot 6.72481E-02
C *****
C Additional Bottom Reflectors
C Be Support Plate (Al1100)
m30 13027.70c 6.06080E-02
29063.70c 2.23913E-05
29065.70c 9.98012E-06
14028.70c 1.28349E-04
14029.70c 6.51725E-06
14030.70c 4.29622E-06
26054.70c 4.09062E-06
26056.70c 6.42139E-05
26057.70c 1.48298E-06
25055.70c 7.48872E-06
30000.70c 1.25834E-06 \$ Tot 6.08580E-02
C SS304 Support Plate
m31 26054.70c 3.51905E-03
26056.70c 5.52415E-02
26057.70c 1.27577E-03
26058.70c 1.69781E-04
6000.70c 1.60142E-04
25055.70c 8.75287E-04
14028.70c 7.89554E-04
14029.70c 4.00916E-05
14030.70c 2.64287E-05
24050.70c 7.63478E-04
24052.70c 1.47229E-02
24053.70c 1.66946E-03
24054.70c 4.15564E-04
28058.70c 5.29886E-03
28060.70c 2.04111E-03
28061.70c 8.87257E-05
28062.70c 2.82896E-04
28064.70c 7.20454E-05
15031.70c 3.49310E-05
16032.70c 2.13510E-05
16033.70c 1.70934E-07
16034.70c 9.64879E-07
16034.70c 4.49827E-09 \$ tot 8.75101E-02
C Scattering Cards
mt1 o2/u.10t u/o2.10t
mt2 al27.12t
mt8 be.10t
mt9 be.10t
mt10 be.10t
mt13 al27.12t
mt14 al27.12t

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mt20 al27.12t
mt22 al27.12t
m23 al27.12t
mt30 al27.12t
C
kcode 100000 1 150 2150
ksrc 0.0692 4.5245 0.77787 0 8.8072 0.7787
0.0692 -4.3864 0.77787 0 -8.7382 0.7787
3.8736 0 0.7787 7.6780 0 0.7787
-3.7353 0 0.7787 -7.8510 0 0.7787

KENO Input Deck for Simple Benchmark Models:

Case 1

'Input generated by GeeWiz SCALE 6.1 Compiled on Mon Jun 6 11:04:33 2011

=csas6

scca-002 simple

ce_v7_endf

read composition

be 1 0 0.1212 293.6 end
be 2 0 0.12055 293.6 end
be 3 0 0.12064 293.6 end
al 4 0 0.070492 293.6 end
cu 4 0 3.7651e-05 293.6 end
si 4 0 0.00016186 293.6 end
fe 4 0 8.1168e-05 293.6 end
mn 4 0 8.71e-06 293.6 end
zn 4 0 1.4636e-06 293.6 end
al 5 0 0.066972 293.6 end
cu 5 0 3.577e-05 293.6 end
si 5 0 0.00015377 293.6 end
fe 5 0 7.7115e-05 293.6 end
mn 5 0 8.275e-06 293.6 end
zn 5 0 1.3905e-06 293.6 end
u-234 6 0 0.0002222 293.6 end
u-235 6 0 0.020407 293.6 end
u-236 6 0 0.00010253 293.6 end
u-238 6 0 0.0011616 293.6 end
o 6 0 0.043788 293.6 end
fe 7 0 0.05222 293.6 end
c 7 0 0.0001399 293.6 end
mn 7 0 0.00076465 293.6 end
si 7 0 0.00074787 293.6 end
cr 7 0 0.014542 293.6 end
ni 7 0 0.0078734 293.6 end
p 7 0 3.0516e-05 293.6 end
s 7 0 1.9648e-05 293.6 end
al 9 0 0.058549 293.6 end
cu 9 0 3.1286e-05 293.6 end
si 9 0 0.0001345 293.6 end
fe 9 0 6.7447e-05 293.6 end
mn 9 0 7.2375e-06 293.6 end
zn 9 0 1.2161e-05 293.6 end
al 13 0 0.060608 293.6 end
cu 13 0 3.2371e-05 293.6 end
si 13 0 0.00013916 293.6 end
fe 13 0 6.9788e-05 293.6 end
mn 13 0 7.4887e-06 293.6 end
zn 13 0 1.2583e-05 293.6 end
fe 15 0 0.060206 293.6 end
c 15 0 0.00016014 293.6 end
mn 15 0 0.00087529 293.6 end

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```

si      15 0 0.00085607 293.6 end
cr      15 0 0.017571 293.6 end
ni      15 0 0.0077836 293.6 end
p       15 0 3.4931e-05 293.6 end
s       15 0 2.2491e-05 293.6 end
end composition
read parameter
gen=1150
npg=100000
nsk=150
htm=yes
end parameter
read geometry
global unit 1
com="global unit 1 references array 1"
cylinder 34 12.726 41.7 11.22
array 1 34 -35 -36 -37 -38 -39 -40 -41 -42 -43 -44 -45 -46 place 11 11 1 0 0 0
cylinder 35 0.635 41.7 11.22 origin x=3.766 y=-11.458 z=0
array 2 35 place 2 2 1 3.766 -11.458 0
cylinder 36 0.635 41.7 11.22 origin x=8.039 y=-8.989 z=0
array 2 36 place 2 2 1 8.039 -8.989 0
cylinder 37 0.635 41.7 11.22 origin x=11.805 y=-2.467 z=0
array 2 37 place 2 2 1 11.805 -2.467 0
cylinder 38 0.635 41.7 11.22 origin x=11.805 y=2.467 z=0
array 2 38 place 2 2 1 11.805 2.467 0
cylinder 39 0.635 41.7 11.22 origin x=8.039 y=8.989 z=0
array 2 39 place 2 2 1 8.039 8.989 0
cylinder 40 0.635 41.7 11.22 origin x=3.766 y=11.458 z=0
array 2 40 place 2 2 1 3.766 11.458 0
cylinder 41 0.635 41.7 11.22 origin x=-3.766 y=11.458 z=0
array 2 41 place 2 2 1 -3.766 11.458 0
cylinder 42 0.635 41.7 11.22 origin x=-8.039 y=8.989 z=0
array 2 42 place 2 2 1 -8.039 8.989 0
cylinder 43 0.635 41.7 11.22 origin x=-11.805 y=2.467 z=0
array 2 43 place 2 2 1 -11.805 2.467 0
cylinder 44 0.635 41.7 11.22 origin x=-11.805 y=-2.467 z=0
array 2 44 place 2 2 1 -11.805 -2.467 0
cylinder 45 0.635 41.7 11.22 origin x=-8.039 y=-8.989 z=0
array 2 45 place 2 2 1 -8.039 -8.989 0
cylinder 46 0.635 41.7 11.22 origin x=-3.766 y=-11.458 z=0
array 2 46 place 2 2 1 -3.766 -11.458 0
cylinder 47 12.726 41.93 11.22
cylinder 48 12.98 41.93 10.89
cylinder 49 13.08 42.155 10.89
cylinder 50 13.95 11.525 10.89
cuboid 51 75 -75 75 -75 11.525 10.89
cuboid 52 75 -75 75 -75 55.105 0
cylinder 53 22.86 2.38 0
cylinder 54 20.65 10.89 3.27
cylinder 55 21.285 10.89 2.38
cylinder 56 24.45 42.155 11.525
cylinder 57 20.65 49.36 42.375
cylinder 58 20.65 55.105 42.375
cylinder 59 21.285 55.105 42.155
media 0 1 -34 47 -35 -36 -37 -38 -39 -40 -41 -42 -43 -44 -45 -46
media 9 1 -47 48 -35 -36 -37 -38 -39 -40 -41 -42 -43 -44 -45 -46
media 0 1 -48 49
media 0 1 -49 50
media 13 1 -50 51
media 15 1 53
media 1 1 54

```

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```

media 4 1 -54 55
media 3 1 56 -49
media 2 1 57
media 0 1 -57 58
media 5 1 -58 59
media 0 1 52 -51 -55 -59 -56 -53
boundary 52
unit 3
com="fuel tube position"
cylinder 1 0.635 41.7 11.22
cylinder 2 0.584 41.4 11.52
cylinder 3 0.5705 41.4 11.52
hexprism 31 0.753 41.7 11.22
media 7 1 1 -2
media 0 1 2 -3
media 0 1 -1 31
media 6 1 3
boundary 31
unit 5
com="empty fuel tube position (void)"
hexprism 31 0.753 41.7 11.22
media 0 1 31
boundary 31
end geometry
read array
ara=1 nux=21 nuy=21 nuz=1 typ=shexagonal gbl=1
com="
fill
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 3 3 3 3 3 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 5 5 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 5 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 3 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 3 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 3 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 3 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 5 5 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 5 5 5 3 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 5 5 5 5 3 3 3 3 3 3 3 3 3 3 5 5 5 5
5 5 5 5 5 5 5 5 3 3 3 3 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 end fill
ara=2 nux=3 nuy=3 nuz=1 typ=shexagonal
com="
fill
5 5 5
5 3 5
5 5 5 end fill
end array
end data
end

```

Case 2

'Input generated by GeeWiz SCALE 6.1 Compiled on Mon Jun 6 11:04:33 2011
=csas6

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```
scca-002 simple
ce_v7_endf
read composition
be 1 0 0.1212 293.6 end
be 2 0 0.12055 293.6 end
be 3 0 0.12064 293.6 end
al 4 0 0.070492 293.6 end
cu 4 0 3.7651e-05 293.6 end
si 4 0 0.00016186 293.6 end
fe 4 0 8.1168e-05 293.6 end
mn 4 0 8.71e-06 293.6 end
zn 4 0 1.4636e-06 293.6 end
al 5 0 0.066972 293.6 end
cu 5 0 3.577e-05 293.6 end
si 5 0 0.00015377 293.6 end
fe 5 0 7.7115e-05 293.6 end
mn 5 0 8.275e-06 293.6 end
zn 5 0 1.3905e-06 293.6 end
u-234 6 0 0.0002222 293.6 end
u-235 6 0 0.020407 293.6 end
u-236 6 0 0.00010253 293.6 end
u-238 6 0 0.0011616 293.6 end
o 6 0 0.043788 293.6 end
fe 7 0 0.05222 293.6 end
c 7 0 0.0001399 293.6 end
mn 7 0 0.00076465 293.6 end
si 7 0 0.00074787 293.6 end
cr 7 0 0.014542 293.6 end
ni 7 0 0.0078734 293.6 end
p 7 0 3.0516e-05 293.6 end
s 7 0 1.9648e-05 293.6 end
al 9 0 0.058549 293.6 end
cu 9 0 3.1286e-05 293.6 end
si 9 0 0.0001345 293.6 end
fe 9 0 6.7447e-05 293.6 end
mn 9 0 7.2375e-06 293.6 end
zn 9 0 1.2161e-05 293.6 end
al 13 0 0.060608 293.6 end
cu 13 0 3.2371e-05 293.6 end
si 13 0 0.00013916 293.6 end
fe 13 0 6.9788e-05 293.6 end
mn 13 0 7.4887e-06 293.6 end
zn 13 0 1.2583e-05 293.6 end
fe 15 0 0.060206 293.6 end
c 15 0 0.00016014 293.6 end
mn 15 0 0.00087529 293.6 end
si 15 0 0.00085607 293.6 end
cr 15 0 0.017571 293.6 end
ni 15 0 0.0077836 293.6 end
p 15 0 3.4931e-05 293.6 end
s 15 0 2.2491e-05 293.6 end
end composition
read parameter
gen=1150
npg=100000
nsk=150
htm=yes
end parameter
read geometry
global unit 1
com="global unit 1 references array 1"
```

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cylinder 34 12.726 41.7 11.22
array 1 34 -35 -36 -37 -38 -39 -40 place 5 5 1 0 0 0
cylinder 35 0.635 41.7 11.22 origin x=0 y=12.02 z=0
array 2 35 place 2 2 1 0 12.02 0
cylinder 36 0.635 41.7 11.22 origin x=10.4 y=6 z=0
array 2 36 place 2 2 1 10.4 6 0
cylinder 37 0.635 41.7 11.22 origin x=10.4 y=-6 z=0
array 2 37 place 2 2 1 10.4 -6 0
cylinder 38 0.635 41.7 11.22 origin x=0 y=-12.02 z=0
array 2 38 place 2 2 1 0 -12.02 0
cylinder 39 0.635 41.7 11.22 origin x=-10.4 y=-6 z=0
array 2 39 place 2 2 1 -10.4 -6 0
cylinder 40 0.635 41.7 11.22 origin x=-10.4 y=6 z=0
array 2 40 place 2 2 1 -10.4 6 0
cylinder 47 12.726 41.93 11.22
cylinder 48 12.98 41.93 10.89
cylinder 49 13.08 42.155 10.89
cylinder 50 13.95 11.525 10.89
cuboid 51 75 -75 75 -75 11.525 10.89
cuboid 52 75 -75 75 -75 55.105 0
cylinder 53 22.86 2.38 0
cylinder 54 20.65 10.89 3.27
cylinder 55 21.285 10.89 2.38
cylinder 56 24.45 42.155 11.525
cylinder 57 20.65 49.36 42.375
cylinder 58 20.65 55.105 42.375
cylinder 59 21.285 55.105 42.155
media 0 1 -34 47 -35 -36 -37 -38 -39 -40
media 9 1 -47 48 -35 -36 -37 -38 -39 -40
media 0 1 -48 49
media 0 1 -49 50
media 13 1 -50 51
media 15 1 53
media 1 1 54
media 4 1 -54 55
media 3 1 56 -49
media 2 1 57
media 0 1 -57 58
media 5 1 -58 59
media 0 1 52 -51 -55 -59 -56 -53
boundary 52
unit 3
com="fuel tube position"
cylinder 1 0.635 41.7 11.22
cylinder 2 0.584 41.4 11.52
cylinder 3 0.5705 41.4 11.52
rhexprism 31 0.635 41.7 11.22
media 7 1 1 -2
media 0 1 2 -3
media 0 1 -1 31
media 6 1 3
boundary 31
unit 5
com="empty fuel tube position (void)"
rhexprism 31 0.635 41.7 11.22
media 0 1 31
boundary 31
unit 6
com="flower fuel cluster"
hexprism 31 1.97828 41.7 11.22
array 3 31 place 3 3 1 0 0 0

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boundary 31
unit 7
com="empty flower cluster position"
hexprism 31 1.97828 41.7 11.22
media 0 1 31
boundary 31
unit 8
com="w flower fuel cluster"
hexprism 31 1.97828 41.7 11.22
array 4 31 place 3 3 1 0 0 0
boundary 31
unit 9
com="nw flower fuel cluster"
hexprism 31 1.97828 41.7 11.22
array 5 31 place 3 3 1 0 0 0
boundary 31
unit 10
com="ne flower fuel cluster"
hexprism 31 1.97828 41.7 11.22
array 6 31 place 3 3 1 0 0 0
boundary 31
unit 11
com="e flower fuel cluster"
hexprism 31 1.97828 41.7 11.22
array 7 31 place 3 3 1 0 0 0
boundary 31
unit 12
com="se flower fuel cluster"
hexprism 31 1.97828 41.7 11.22
array 8 31 place 3 3 1 0 0 0
boundary 31
unit 13
com="sw flower fuel cluster"
hexprism 31 1.97828 41.7 11.22
array 9 31 place 3 3 1 0 0 0
boundary 31
end geometry
read array
ara=1 nux=9 nuy=9 nuz=1 typ=shexagonal gbl=1
com='core'
fill
  7 7 7 7 7 7 7 7 7
  7 7 13 6 6 12 7 7 7
  7 7 6 6 6 6 6 7 7
  7 6 6 6 6 6 6 7 7
  7 8 6 6 6 6 6 11 7
  7 6 6 6 6 6 6 7 7
  7 7 6 6 6 6 6 7 7
  7 7 9 6 6 10 7 7 7
  7 7 7 7 7 7 7 7 7 end fill
ara=2 nux=3 nuy=3 nuz=1 typ=rhexagonal
com='single pin'
fill
  5 5 5
  5 3 5
  5 5 5 end fill
ara=3 nux=5 nuy=5 nuz=1 typ=rhexagonal
com='flower fuel cluster'
fill
  5 5 5 5 5
  5 3 3 3 5

```

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5 3 3 3 5
5 5 3 5 5
5 5 5 5 5 end fill
ara=4 nux=5 nuy=5 nuz=1 typ=rhexagonal
com='w cluster'
fill
5 5 5 5 5
5 5 3 3 5
5 5 3 3 5
5 5 3 5 5
5 5 5 5 5 end fill
ara=5 nux=5 nuy=5 nuz=1 typ=rhexagonal
com='nw cluster'
fill
5 5 5 5 5
5 3 3 3 5
5 5 3 3 5
5 5 5 5 5
5 5 5 5 5 end fill
ara=6 nux=5 nuy=5 nuz=1 typ=rhexagonal
com='ne cluster'
fill
5 5 5 5 5
5 3 3 3 5
5 3 3 5 5
5 5 5 5 5
5 5 5 5 5 end fill
ara=7 nux=5 nuy=5 nuz=1 typ=rhexagonal
com='e cluster'
fill
5 5 5 5 5
5 3 3 5 5
5 3 3 5 5
5 5 3 5 5
5 5 5 5 5 end fill
ara=8 nux=5 nuy=5 nuz=1 typ=rhexagonal
com='se cluster'
fill
5 5 5 5 5
5 3 5 5 5
5 3 3 3 5
5 5 3 5 5
5 5 5 5 5 end fill
ara=9 nux=5 nuy=5 nuz=1 typ=rhexagonal
com='sw cluster'
fill
5 5 5 5 5
5 5 5 3 5
5 3 3 3 5
5 5 3 5 5
5 5 5 5 5 end fill
end array
end data
end

```