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LEU-COMP-THERM-096

PARTIALLY-REFLECTED WATER-MODERATED SQUARE-PITCHED U(6.90)O_2 FUEL ROD LATTICES WITH 0.67 FUEL TO WATER VOLUME RATIO (0.800 CM PITCH)

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IDENTIFICATION NUMBER: LEU-COMP-THERM-096 SPECTRA

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1.0 DETAILED DESCRIPTION

1.1 Overview of Experiment

The US Department of Energy (DOE) Nuclear Energy Research Initiative funded the design and construction of the Seven Percent Critical Experiment (7uPCX) at Sandia National Laboratories. The start-up of the experiment facility and the execution of the experiments described here were funded by the DOE Nuclear Criticality Safety Program. The 7uPCX is designed to investigate critical systems with fuel for light water reactors in the enrichment range above 5% ^{235}U. The 7uPCX assembly is a water-moderated and -reflected array of aluminum-clad square-pitched U(6.90%)O_2 fuel rods.

The fuel used in these experiments was fabricated using unirradiated 6.90% enriched UO_2 fuel pellets from fuel elements designed to be used in the internal nuclear superheater section of the Pathfinder boiling water reactor operated in South Dakota by the Northern States Power Company in the 1960s. The fuel elements were obtained from The Pennsylvania State University where they had been stored for many years. The fuel pellets in those fuel elements were removed from the original Incoloy cladding and reclad in 3003 aluminum tubes and end caps for use in the experiments reported here.

The nominal outside diameter of the fuel pellets is 0.207 in (0.52578 cm). The nominal outside diameter of the fuel rod cladding is 0.250 in (0.635 cm). The distance between the fuel rods in the square-pitched array is 0.315 in (0.8001 cm). This geometry gives a fuel-to-water volume ratio of 0.67 in the array. In the configurations examined, the arrays are significantly undermoderated in that an increased amount of moderator in the array, such as might be caused by an increased pitch of the array or an increased density of the moderator, results in an increase in the reactivity of the system.

The nineteen critical experiments in this series were performed in 2014 and 2015 in the Sandia Critical Experiments at the Sandia Pulsed Reactor Facility.

The first of the experiments had the critical assembly core fully loaded with a 45x45 array of 2025 fuel rods with no water holes and was intended to provide a baseline against which the remaining experiments could be compared. The remaining eighteen critical experiments contained various configurations of the fuel in the assembly. The purpose of these experiments was to measure the critical water height in the assembly for the nineteen experiment configurations. The case-to-case variations involved 1) the number of fuel rods in the array (Cases 1, and 4 through 9); 2) the number and location of water holes in the array (Cases 1 through 3); and 3) the width of water-filled gaps between two or four identical fuel rod subarrays (Cases 10 through 19).

All nineteen critical experiments are judged to be acceptable as benchmark experiments.

1.2 Description of Experimental Configuration

1.2.1 Design of the Critical Assembly – A schematic of the critical assembly as it was configured for the experiments evaluated in LEU-COMP-THERM-079 is shown in Figure 1. The same assembly tank was used for the experiments evaluated here though the assembly core was modified. Figure 2 shows a view of the critical assembly configured for the current experiments. The assembly core resides in an elevated assembly core tank that is connected to a moderator dump tank at a lower elevation. When the assembly is not being operated, the moderator resides in the dump tank. When the assembly is being brought to delayed critical, the moderator is pumped from the dump tank into the core tank. The moderator can be released by gravity to the dump tank through two large-diameter normally-open pneumatically operated dump valves. A heater is included in the dump tank to keep the moderator at a constant temperature set by a controller at the assembly control system. During operation, the moderator is continually circulated between the dump tank and the assembly tank. During initial filling of the core tank, the moderator/reflector water is pumped from the dump tank through the “fast fill” system that fills the core tank in about 15 minutes. The fast fill system operates until a float switch in the core tank is actuated. Actuation of the float switch prohibits the operation of the fast fill system. Further filling of the core tank is done using the “slow fill” system. The slow fill system is designed to provide moderator/reflector to the core tank in a controlled manner to limit the maximum reactivity addition rate during this part of the operation. During experiments in which the reactivity of the critical assembly is controlled by the level of moderator/reflector in the core tank, the float switch is typically set at the level that causes it to actuate when the k_{eff} of the system is about 0.9.

Figure 3 shows a cut-away view of the critical assembly core tank with the moderator drained from the core tank. The inset shows the core tank with the moderator at the critical level as it was during the experiments. The assembly fuel rods are described in detail in a subsequent section. The assembly is driven by a small ^{252}Cf source that is located in the assembly grid or immediately adjacent to the assembly fuel array. The assembly fuel is supported in the assembly tank by two 1 in (2.54 cm) thick aluminum grid plates. A guide plate, used to align the fuel rods in the assembly during insertion, is located above the upper grid plate. The grid and guide plates are separated by aluminum support posts. The assembly core is situated in the tank to provide a 6.5 in (16.51 cm) thick water reflector below the lower grid plate. The diameter of the tank provides a radial water reflector around the assembly greater than 6 in (15.24 cm).

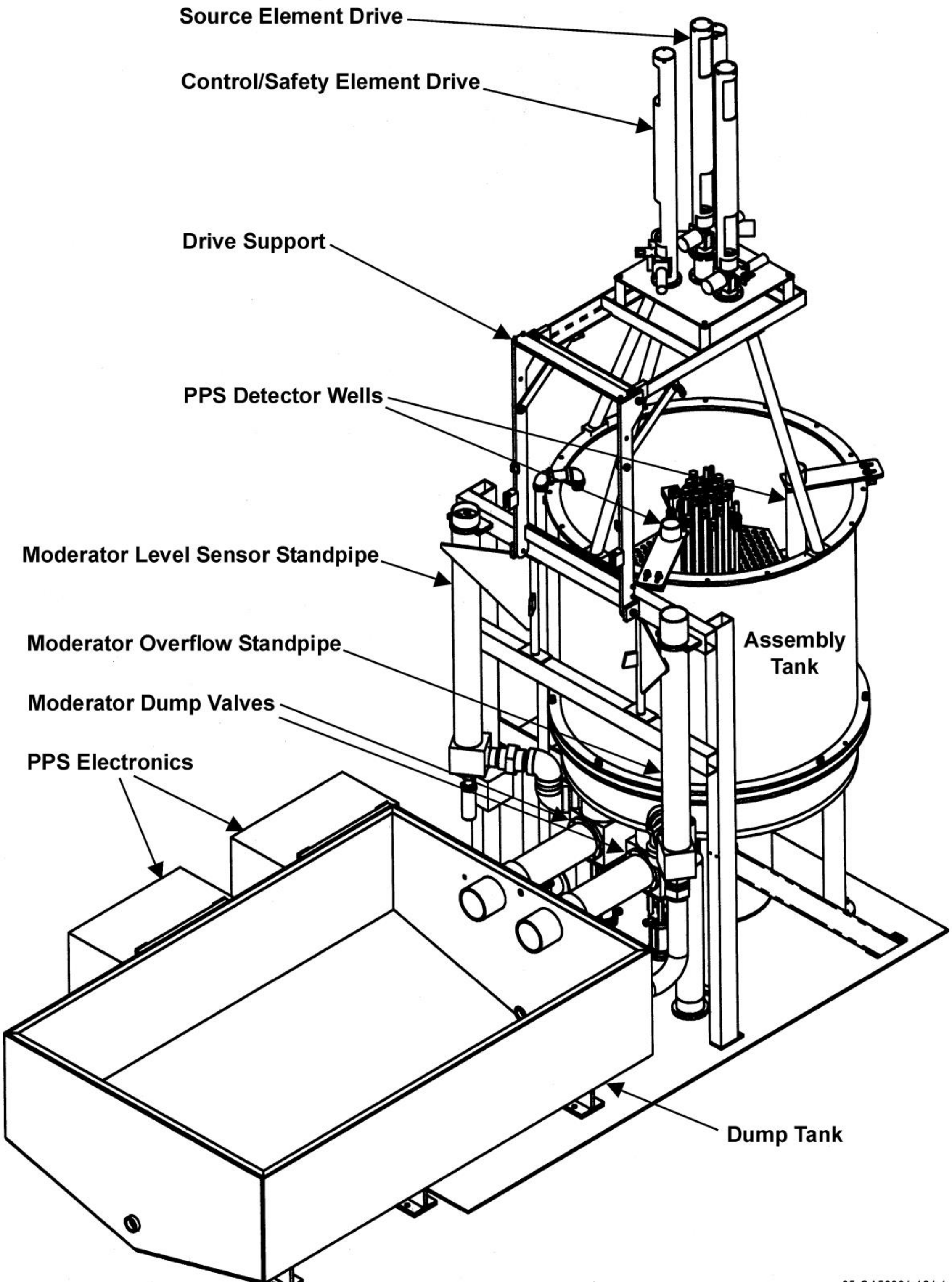

Figure 1. A Schematic of the Critical Assembly.

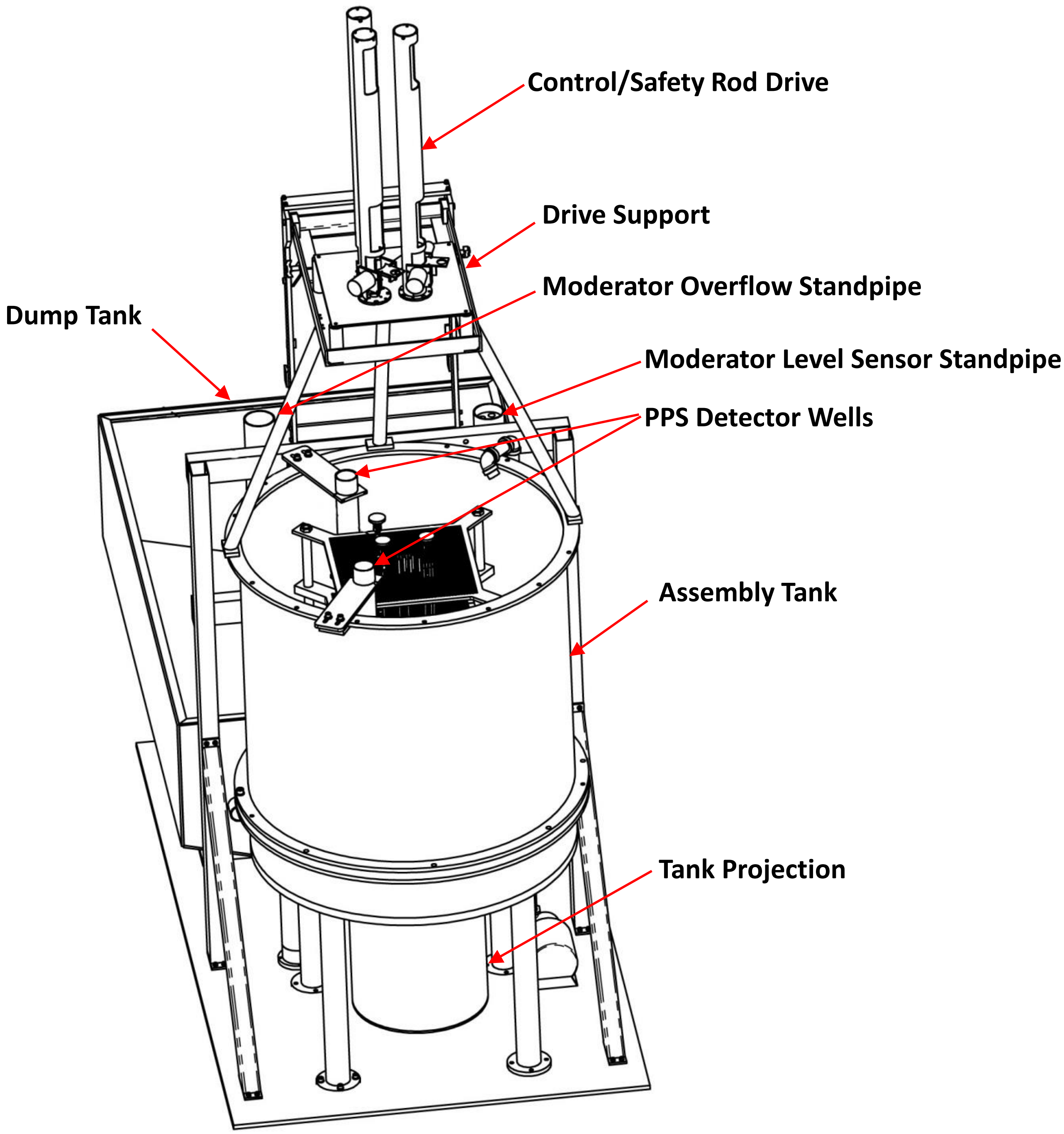

Figure 2. View of the Critical Assembly.

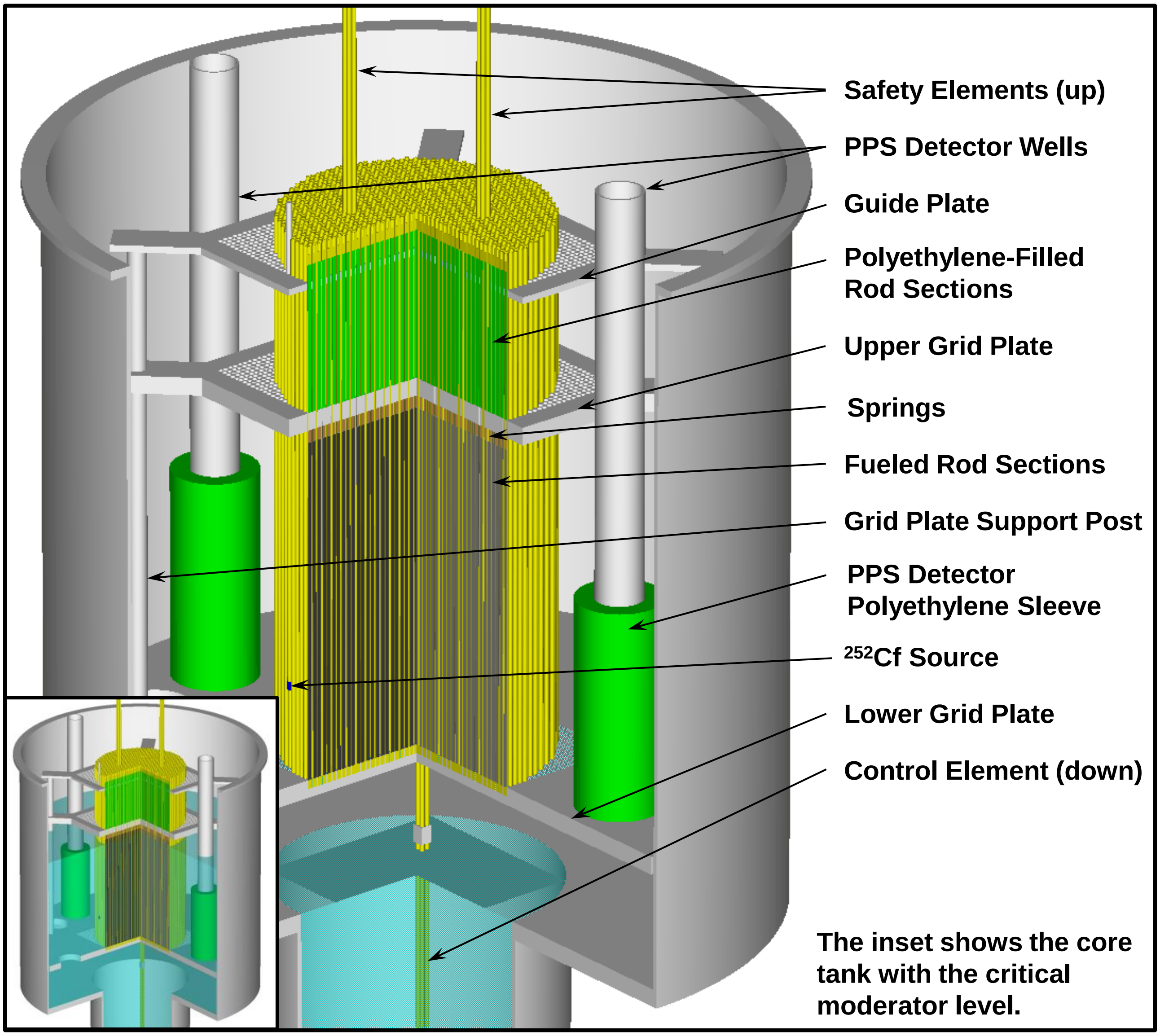

Figure 3. Cut-away view of the critical assembly core tank (Case 8).

The assembly has one control and two safety elements of identical design. Each consists of a ganged four-rod assembly that passes through the grid and guide plates. Each of the rods in these elements has a B_4C-filled absorber section separated from a fuel follower by a polyethylene-filled decoupler section. When each of the elements is fully withdrawn, the fuel follower is in the assembly and the absorber is above the surface of the assembly moderator. The two types of elements are differentiated by the way in which they are used. During operations, the two safety elements are held in the most reactive position and provide a redundant shutdown mechanism that can be rapidly inserted by gravity drop. The control element is used to make fine adjustments to the reactivity of the assembly during operations. During the measurements reported here, all three elements were fully withdrawn to their most reactive positions. The three control/safety elements are attached to the control/safety element drives through electromagnets. The control/safety element drives are supported above the assembly tank by the drive support.

During operation of the critical assembly, water is continuously pumped from the dump tank to the core tank. The level of the moderator in the assembly tank is maintained by overflow into one of two overflow standpipes. One overflow standpipe (the fixed standpipe) is set at a level that allows the core tank to fill until the fuel in the critical assembly is fully reflected, a level about 6 inches above the upper grid plate. A second overflow standpipe (the remotely adjustable standpipe or RASP) is, as the name implies, adjustable from the control console of the critical assembly. The RASP limits the reactivity available in the assembly during an approach-to-critical experiment with the level of the moderator/reflector in the core tank as the approach variable. Figure 4 shows the two overflow standpipes on the critical assembly.

The level of the moderator/reflector in the core tank is monitored by an uncalibrated linear level measurement system located in a standpipe outside the core tank and by a calibrated system that uses four ultrasonic distance measurement devices in still tubes around the periphery of the core tank. The ultrasonic sensors operate by emitting a pulse ultrasound and measuring the time required to receive an echo from a surface. The still tubes restrict the field of view of the ultrasonic sensors to an area in which surface disturbances of the moderator are limited by the presence of the tube. Each still tube has a hinged door on the side that allows placement of the length standards used to calibrate the system. The air temperature in each still tube was monitored by a high-precision platinum resistance temperature detector (RTD) to allow corrections to be made for the temperature-dependent velocity of sound in the tubes. The ultrasonic sensors are operated in sets of two with the still tubes for the two sensors in a set positioned in diametrically-opposed locations across the critical assembly core from one another. The moderator/reflector level in the center of the assembly core is obtained by averaging the measured levels of the two sensors in a set. Two measurements of the level of the moderator/reflector at the center of the core are thus provided by the two sets of two ultrasonic level sensors.

Figures 5 and 6 show photographs of two of the cores in the assembly. At the time that both photographs were taken, the moderator had been drained from the core tank. Figure 5 shows an overall view of the critical assembly core in the assembly tank. In this view, the control and safety elements are down and attached to the respective drives. The lower grid plate is visible at the bottom of the tank with the upper grid plate above it. The guide plate is visible above the upper grid plate. The upper grid plate and the guide plate have checkerboard markings to aid in the placement of the fuel rods in the assembly grid. The guide plate has each column and row in the grid pattern identified. The two dry wells that house the fission chambers for the assembly instrumentation are visible in the picture as are the four still tubes for the ultrasonic level sensors.

Figure 6 shows a view of the top of the core for a different configuration. In this view, the control and safety elements are withdrawn from the core to their most reactive positions with the fueled sections in the core. The handle of the neutron source, which stands above the tops of the fuel rods, is visible at the center of the fuel array. The four still tubes for the ultrasonic sensors and two of the detector drywells are visible in the figure.

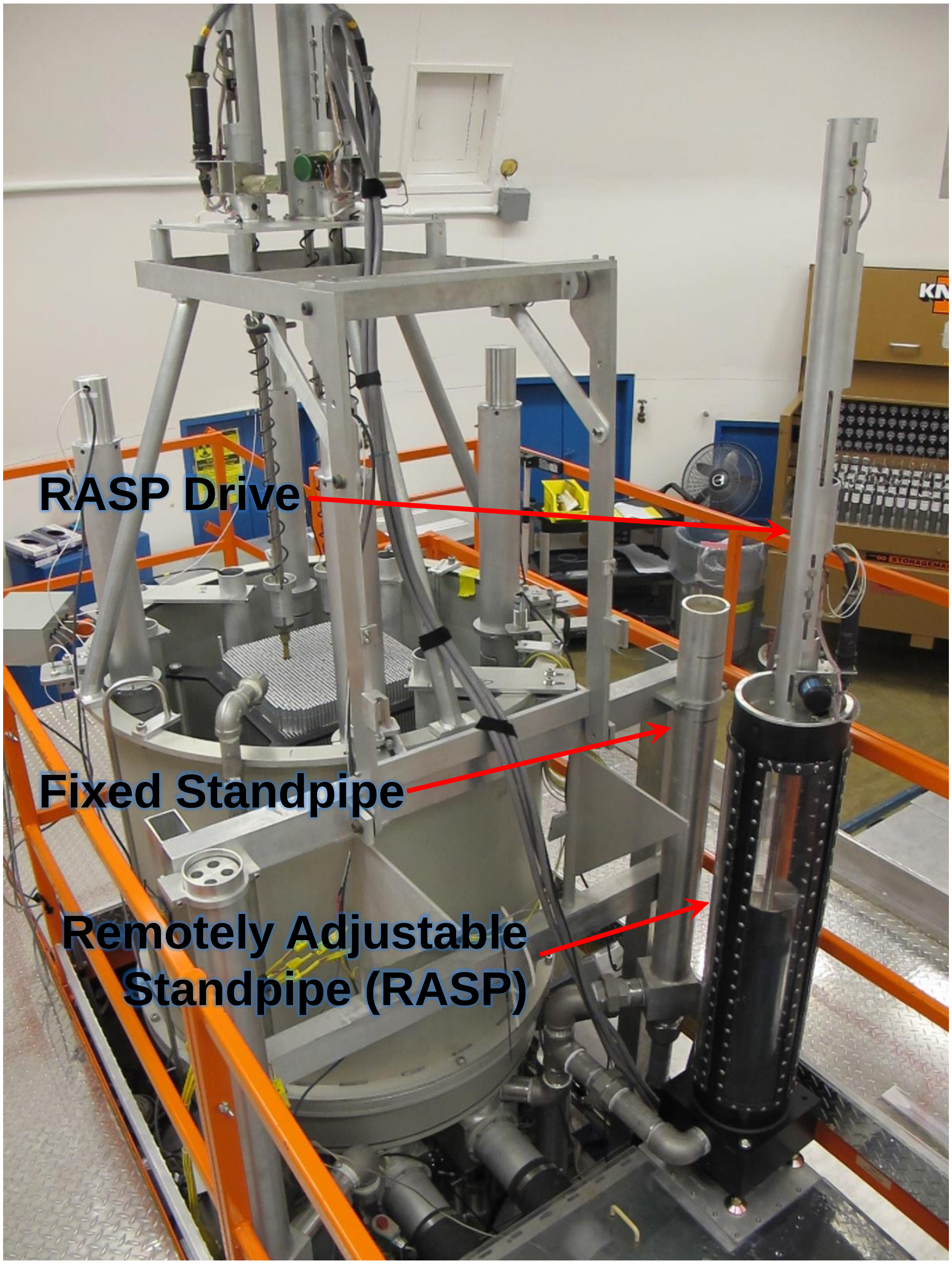

Figure 4. View of the Critical Assembly Showing the Overflow Standpipes (Case 4).

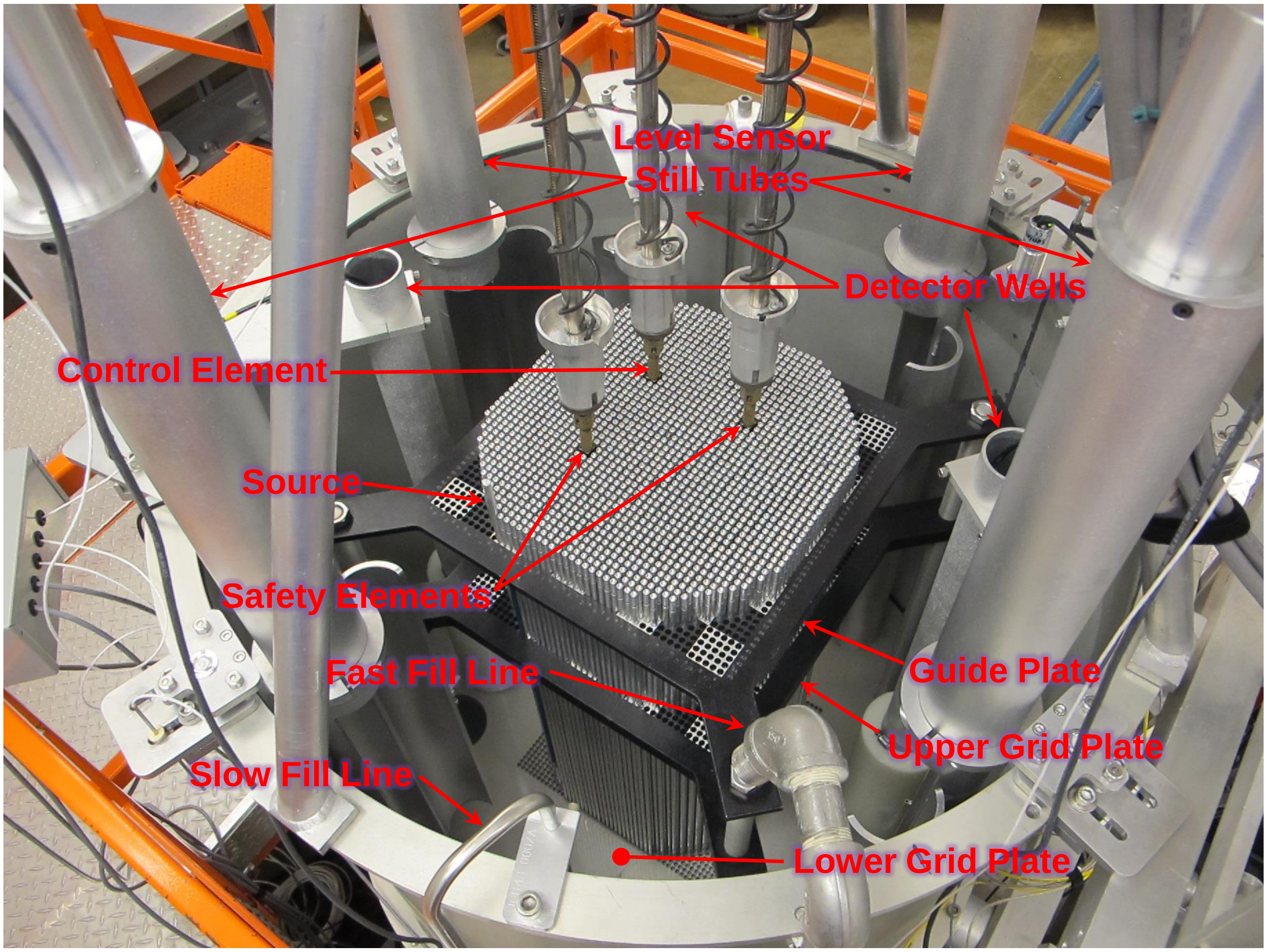

Figure 5. View of One of the Critical Configurations (Case 6).

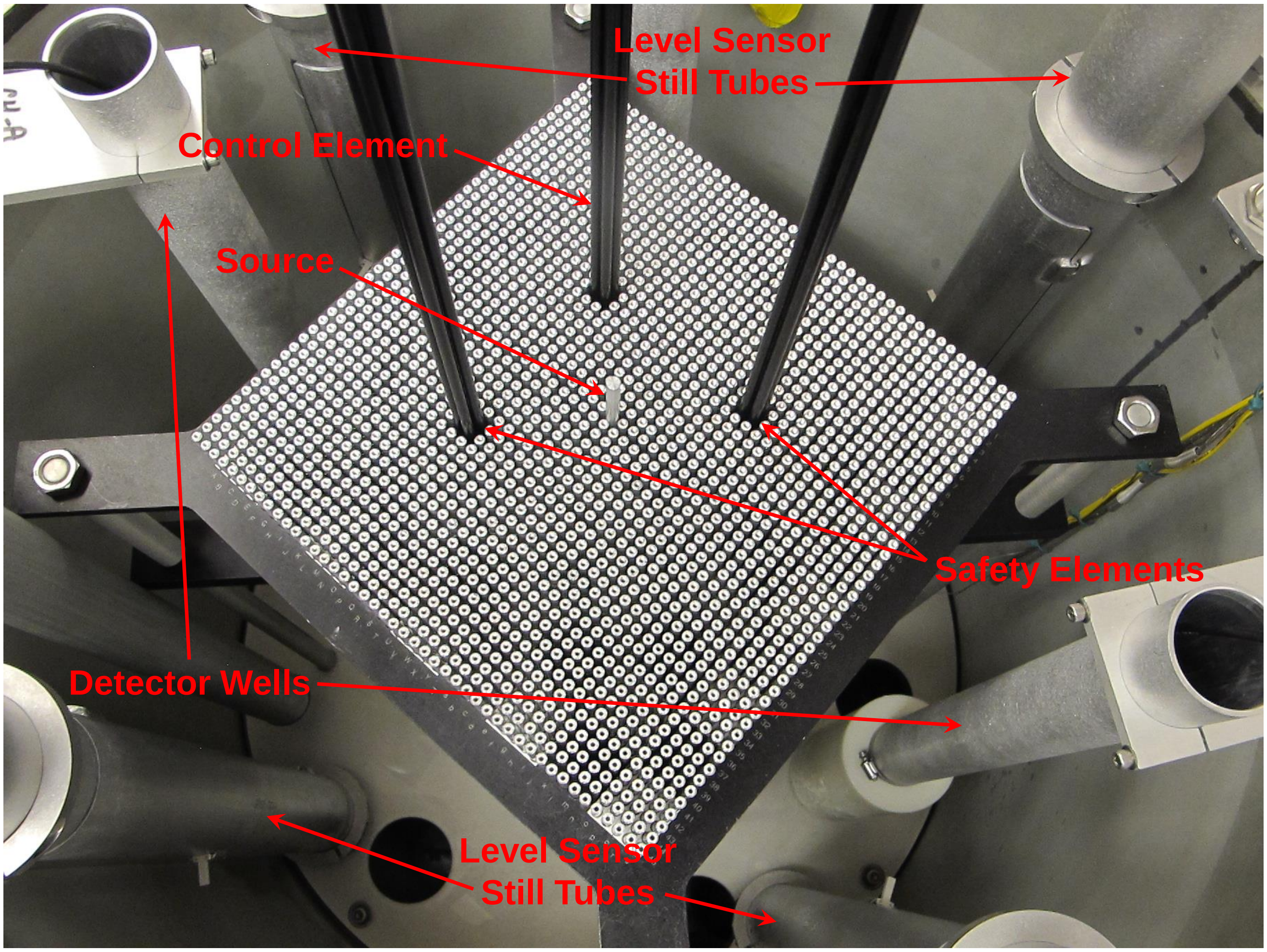

Figure 6. View of One of the Critical Configurations (Case 2).

1.2.2 Reactor Room – The critical experiments were performed in the reactor building at the Sandia Pulsed Reactor Facility. The reactor building is a large thick-walled, steel-reinforced concrete structure with a base in the shape of a cylinder having an inside diameter of approximately 30 ft (9.1 m) and capped with a hemispherical shell. A large steel and concrete door is present in the wall. Inside the building, the reactor room is lined on the walls and the dropped ceiling by 8 in (20.32 cm) of gypsum. The 4 in (10.16 cm) of gypsum that is nearest the concrete walls is borated. The floor is an 8 in (20.32 cm) thick concrete slab, the upper 4 in (10.16 cm) of which is borated. The ceiling is about 12 ft 5 in (378.46 cm) above the floor. A view of the critical assembly in the reactor room is shown in Figure 7.

Figure 7. View of the Critical Assembly in the Reactor Room.

1.2.3 Assembly Tank - The assembly tank supports the assembly and contains the moderator during approach-to-critical experiments. The tank is cylindrical with a coaxial cylindrical projection out the bottom to accommodate the motion of the fuel-followed control/safety elements. The assembly tank consists of two welded flanged sections joined through a ring that supports the lower grid plate of the assembly. All parts of the tank were fabricated from 6061 aluminum.

The upper tank section is essentially a flanged tube. The inside dimensions of the upper tank are 40 in (101.6 cm) tall by 36.88 in (93.6752 cm) diameter. The upper tank is 6061 aluminum. It has a radial wall thickness of 0.25 in (0.635 cm). The lower flange is drilled to match the flange on the lower tank section and the grid plate support ring. The upper flange is drilled to connect to the support structure for the control/safety and source element drives.

The lower tank section has the same inner diameter and wall thickness as the upper tank section and has a 1 in (2.54 cm) thick floor that provides support for the assembly tank. The floor is drilled and tapped to accommodate the tank supports and has holes to connect to the two moderator dump valves. The floor also has a large central hole for the projection. The inside dimensions of the projection are 21.75 in (55.25 cm) tall by 15 in (38.1 cm) diameter. The radial wall thickness and floor thickness of the projection are both 0.25 in (0.635 cm). The lower tank section has a flange at the top with an O-ring groove used for connection to the grid plate support ring. The flange is drilled and tapped to match the lower flange in the upper tank section and the grid plate support ring.

The grid plate support ring fits between the upper and lower tank sections and has an O-ring groove in the surface that mates with the lower flange on the upper tank section. The lower grid plate attaches to the grid plate support ring.

The assembly tank is connected to three different standpipes. One standpipe contains a linear moderator level sensor and is shown in Figures 1 and 2. The second contains a fixed overflow pipe that determines the moderator level when the assembly is fully reflected. The third standpipe is the RASP used to set the moderator/reflector level during approach-to-critical experiments with moderator/reflector level as the approach variable. The assembly tank also has a float switch used to indicate the moderator/reflector level at a fixed point.

1.2.4 Grid Plates – The two 6061 aluminum grid plates support and maintain the spacing of the fuel rods in the critical assembly. A third guide plate, similar to but thinner than the upper grid plate, is located above the upper grid plate. The guide plate was fabricated from cast aluminum tooling plate, a standard aluminum product known for its dimensional stability. Both grid plates are 1 in (2.54 cm) thick while the guide plate is 0.375 in (0.9525 cm) thick. The lower grid plate is circular, 36.5 in (92.71 cm) in diameter, and is supported by the grid plate support ring that is part of the assembly tank. The lower grid plate has six 4.00 in (10.16 cm) diameter holes in it equally spaced on a 28 in (71.12 cm) diameter circle to allow passage of the moderator when the dump valves are opened. The upper grid plate is a 16.50 ± 0.06 in (41.91 ± 0.1524 cm) square with four support bosses at the corners. The support bosses are rectangular projections of the grid plates and are visible in Figures 5 and 6. The upper grid plate is supported above the lower grid plate by four 1 in (2.54 cm) diameter threaded aluminum standoffs that attach to the bosses. The standoffs maintain a spacing of 19.88 ± 0.02 in (50.4952 ± 0.0508 cm) between the top of the lower grid plate and the bottom of the upper grid plate. The standoffs are placed on a 28 in (71.12 cm) diameter circle centered on the center of the grid plates. Similar standoffs maintain a 7.00 ± 0.02in (17.78 ± 0.0508 cm) spacing between the top of the upper grid plate and the bottom of the guide plate.

A set of three grid plates – lower, upper, and guide – was fabricated for the experiments. These plates have provisions for 2025 fuel rods in the 45 × 45 square-pitched critical array. The array has a pitch of 0.3150 in (0.8001 cm). The tolerance on the absolute location of each fuel rod position in the grid is 0.005 in (0.0127 cm). The lower grid plate has 2013 0.5 in (1.27 cm) deep holes bored in it to support and locate the bottom of the fuel rods. The upper grid plate and guide plate have matching through holes in them to locate the top of the fuel rods. The diameter of the grid plate holes is 0.260 +0.005/–0.000 in (0.6604 + 0.0127/–0.0000 cm). All three plates have three through holes – square in shape with rounded corners – machined in them to allow for passage of the four-rod control/safety elements. An excerpt from the design drawing for the upper grid plate is shown in Figure 8.

The rows and columns of holes in the guide plate are marked for identification. The guide plate and the upper grid plate are anodized in a checkerboard pattern to assist in identifying the grid locations.

Table 1 shows the axial locations of the grid/guide plates under the assumption that the origin is at the top of the lower grid plate.

Table 1. Axial Locations of the Grid and Guide Plate Surfaces as Installed in the Critical Assembly.

Part	**Location**	**Axial Position Relative to the Top of the Lower Grid Plate**	
		Position (in)	**Position (cm)**
Lower Grid Plate	Bottom of the lower grid plate	-1	-2.54
	Bottom of the fuel rod support holes	-0.5	-1.27
	Top of the lower grid plate	0	0
Upper Grid Plate	Bottom of the upper grid plate	19.88	50.4952
	Top of the upper grid plate	20.88	53.0352
Guide Plate	Bottom of the guide plate	27.88	70.8152
	Top of the guide plate	28.255	71.7677

1.2.5 Radiation Detectors – Two cylindrical fission chambers that are part of the facility plant protection system were used to obtain count-rate data during the experiments. These detectors were placed in dry wells outside the fuel array. The dry wells were fabricated from aluminum 6061-T6511 tubing 2.50 in (6.35 cm) OD with 0.125 in (0.3175 cm) wall. The bottom of the tube was closed with a 0.250 in (0.635 cm) thick welded aluminum 6061-T6 or –T651 plate. The bottom of the tube was in contact with the top of the lower grid plate. The detector tubes were surrounded by an annulus of polyethylene 11.82 in (30.0228 cm) tall with an inner diameter of 2.603 in (6.61162 cm) and an outer diameter of 4.535 in (11.5189 cm). The bottom of the polyethylene was 0.3 in (0.762 cm) above the top surface of the lower grid plate. The mass of each of the polyethylene annuli was measured on a balance with the following specifications given by the manufacturer: repeatability 0.01 g, linearity 0.02 g, readability 0.01 g. The average mass of the two annuli was 2017.28 g. The vertical axis of one detector tube, using the orientation of the upper grid plate shown in Figure 8, was 32.385 cm to the right of and 6.4 cm above the center of the grid plate. The second detector was 32.385 cm to the left of and 6.4 cm below the center of the grid plate, as shown in the figure. The detectors were placed axially at the bottom of the dry wells with the axes of the detectors parallel to the axis of the tank. A third fission chamber, located below and immediately adjacent to the bottom core tank, was used in some of the experiments.

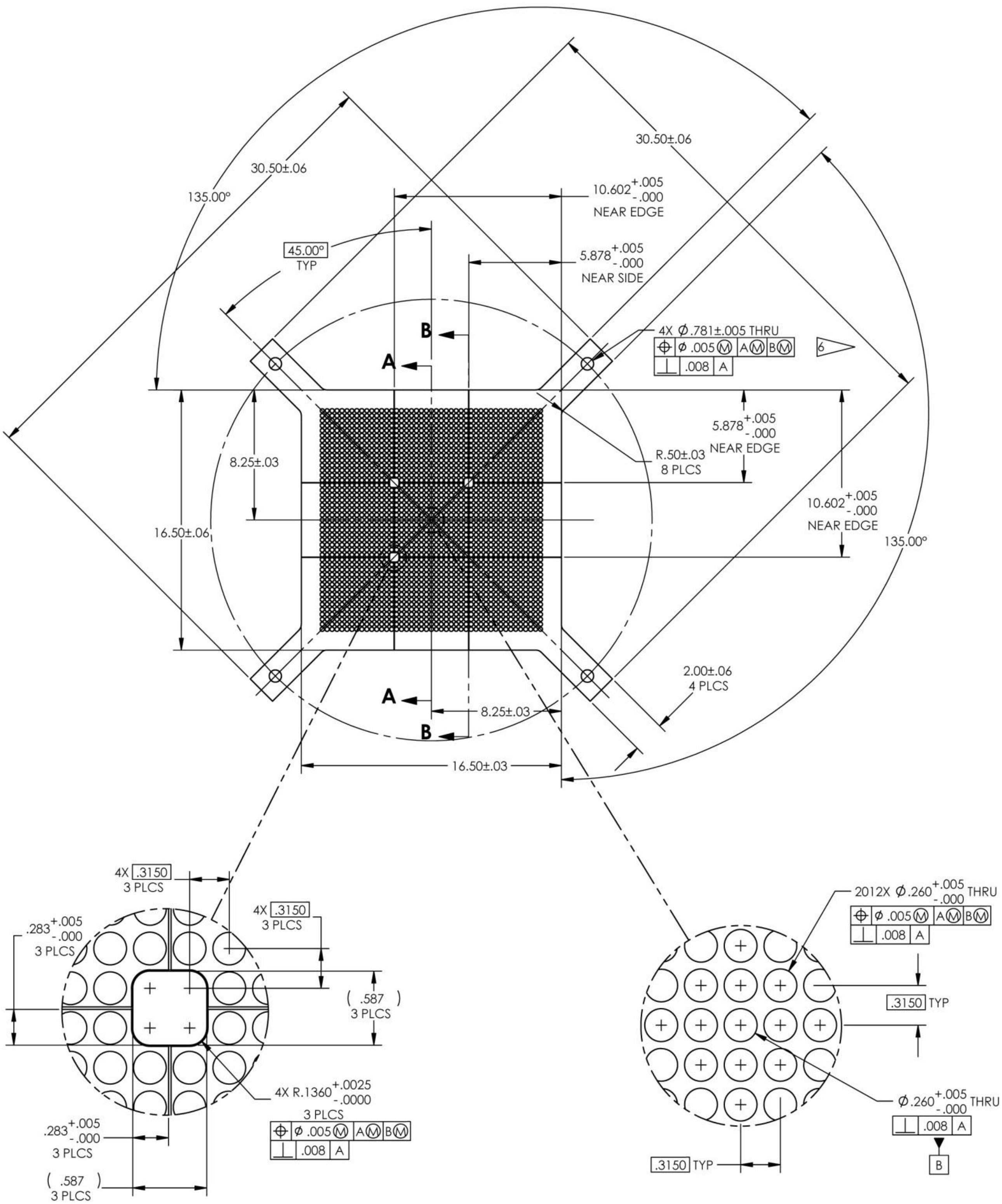

Figure 8. Excerpt From the Design Drawing for the Upper Grid Plate.

1.2.6 Water Moderator and Reflector – As noted above, the lower grid plate was supported in the core tank so that the core was reflected on the bottom by a 6.5 in (16.51 cm) thick layer of water. The bottom surface of the water in the core tank is 7.5 in (19.05 cm) below the upper surface of the lower grid plate. The diameter of the core tank was sufficient that the core was reflected radially by more than 6 in (15.24 cm) of water for all cores. There was nothing that is not described above within 6 in (15.24 cm) of the fuel rods.

During the experiments, water was continuously pumped from the dump tank to the core tank. The level of the moderator/reflector in the core tank was controlled by the remotely adjustable standpipe. The level was monitored by four ultrasonic distance measurement instruments operated as two pairs of diametrically-opposed instruments. Averaging the measured level from a pair of detectors gives the level at the center of the core. Each instrument was calibrated using a set of length standards with known lengths. Based on many measurements of each standard, the uncertainty in the measured level in each instrument is estimated to be 0.35 mm at the one-standard-deviation level.

1.2.7 Fuel Rods – With the exception of the fueled sections of the control and safety elements, the fuel rods in the critical assembly were all of the same design. The design of the fuel rods is shown in Figure 9. The fuel rods were fabricated in 2004 at Sandia National Laboratories from existing UO_2 fuel pellets removed from “Pathfinder” fuel assemblies obtained from The Pennsylvania State University. The fuel rods in the Pathfinder fuel assemblies were separated from the assemblies and the fuel pellets were removed from the original cladding tubes and fabricated into new fuel rods using 3003 aluminum tubing welded to end plugs of the same aluminum alloy.

The cladding tubes are welded to the lower caps. During fabrication, each weld was subjected to and certified to have passed a helium leak test. Passing the helium leak test assured that the water moderator would not enter the fuel rods. The material stack in the fuel rods, starting at the bottom, is as follows: a 0.500 in (1.270 cm) aluminum 3003 lower cap; a nominal 19.257 in (48.91278 cm) stack of fuel pellets; a corrosion-resistant steel compression spring 0.180 in (0.4572 cm) outside diameter, 0.138 in (0.35052 cm) inside diameter, 0.875 in (2.2225 cm) uncompressed length whose length adjusts according to the actual length of the fuel stack; a 1.000 in (2.540 cm) aluminum 6061 spacer 0.207 ± 0.010 in (0.52578 ± 0.02540 cm) diameter, an 8.38 ± 0.02 in (21.2852 ± 0.0508 cm) long high-density polyethylene spacer also 0.207 ± 0.010 in (0.52578 ± 0.02540 cm) diameter, and a 1.000 inch (2.540 cm) aluminum 3003 top cap. Table 2 lists the axial locations of the interfaces between the fuel rod components when the fuel rods are installed in the critical assembly.

The cladding tubes used in the fuel rods have a nominal outer diameter of 0.250 in (0.635 cm) with a nominal 0.014 in (0.03556 cm) wall. The lower cap of the fuel rods is 0.500 in (1.270 cm) long.

Table 2. Axial Locations of the Interfaces in the Fuel Rods as Installed in the Critical Assembly.

Location	**Axial Position Relative to the Top of the Lower Grid Plate**	
	Position (in)	**Position (cm)**
Bottom of the lower grid plate	-1.00	-2.54
Bottom of the fuel rod	-0.50	-1.27
Bottom of the fuel pellet stack	0.00	0.00
Top of the fuel pellet stack (measured)	19.2045	48.780 [(a)]
Bottom of the aluminum spacer	19.894	50.53076
Top of the aluminum spacer	20.894	53.07076
Top of the polyethylene spacer	29.274	74.35596
Top of the fuel rod	30.274	76.89596

(a) This is the mean measured fuel column length, different from the 19.257 in (48.91278 cm) nominal length. The measured length in inches is this value (48.780) divided by 2.54.

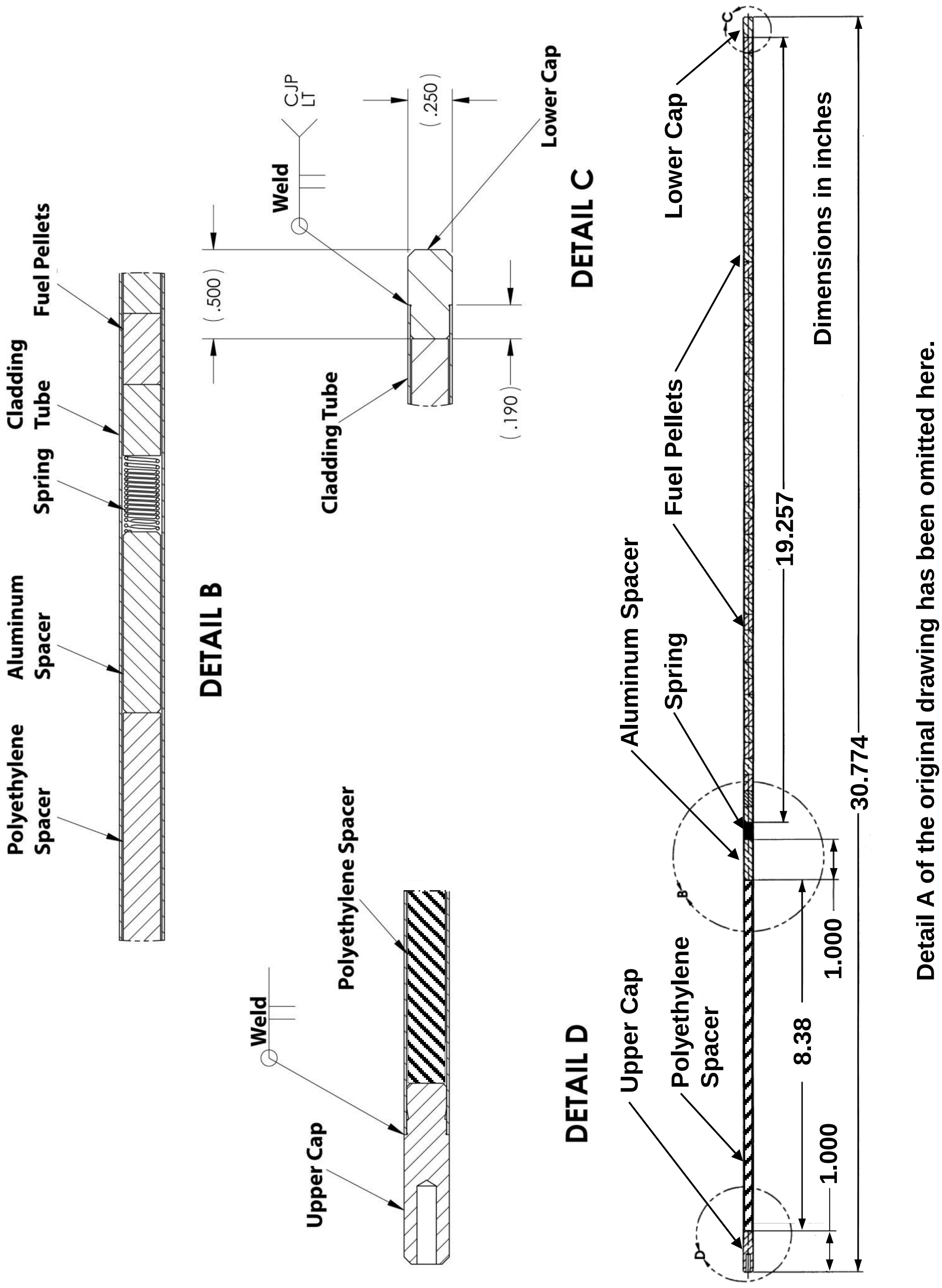

Figure 9. Design of the Fuel Rod.

Before the fuel rods were fabricated, the masses of 100 of each non-fuel components of the fuel rods were measured. The mass measurements were made on a balance with the following specifications given by the manufacturer: repeatability 0.01 g, linearity 0.02 g, readability 0.01 g. The results of the mass measurements are summarized in Table 3. The sixth row in the table gives the results for 100 sets of all five parts. It can be seen that the variability in the mass sum is dominated by the variability in the mass of the polyethylene spacer. The variability is attributed to the manufacturing process used to fabricate the polyethylene spacers. The last (seventh) row in the table gives the results for 100 sets of parts without the polyethylene spacers.

Table 3. Measured Mass Data for the Fuel Rod Components.

Component	Average Mass (g)	Standard Deviation (g)
Cladding Tube/Lower Cap Assembly	13.824	0.027
Corrosion-Resistant Steel Springs	0.1923	0.0095
Aluminum Spacer	1.4368	0.0043
Polyethylene Spacer	4.524	0.094
Upper Cap	1.8350	0.0052
Sum of Five Parts for 100 Sets	21.813	0.094
Sum Without Polyethylene Spacer	17.289	0.027

During the fabrication of the 2199 fuel rods available for the experiments, the following quantities were measured for each fuel rod: total rod mass, polyethylene spacer mass, and fuel pellet column length. The mass measurements were made on a balance with the following specifications given by the manufacturer: repeatability 0.01 g, linearity 0.02 g, readability 0.01 g. The length measurements were made to the nearest 0.1 cm. The values of the measured masses and lengths were preserved for each fuel rod. The mass of the fuel pellets in each rod was obtained by subtracting the measured mass of the polyethylene spacer plus the 17.289 g average mass of the remaining hardware given in Table 3 from the total mass of the fuel rod. Table 4 lists average values of UO_2 fuel mass and fuel pellet stack length for the entire population of 2199 fuel rods. The linear fuel mass in each fuel rod was obtained from the UO_2 mass and the fuel pellet stack length for each fuel rod. The average value of the linear fuel mass is also listed in the table as is the average polyethylene spacer mass.

Table 4. Population Averages for the 2199 Fuel Rods

Characteristic	Average Value	Standard Deviation
UO_2 Mass (g)	108.7165	0.323
Fuel Pellet Stack Length (cm)	48.780	0.125
Linear Fuel Mass (g/cm)	2.2287	0.0050
Polyethylene Spacer Mass (g)	4.454	0.102

After the fuel rods were fabricated, the outer diameter of each fuel rod was measured using a high-precision laser micrometer system. The system consisted of three micrometer heads and the hardware required to position the fuel rods in the micrometer heads. The micrometer heads were located to measure the fuel rod outside diameter at 6.4 in (16.256 cm), 10.15 in (25.781 cm), and 13.9 in (35.306 cm) above the bottom end of the fuel rod. This gave a fuel rod outer diameter measurement at about the midplane of the fuel pellet stack and 3.75 in (9.525 cm) above and below the midplane. Each micrometer made two simultaneous orthogonal diameter measurements. For each fuel rod, a measurement was taken, the fuel rod was rotated by 45°, and another measurement was taken. Thus, the outer diameter of each fuel rod was measured at three axial locations in four azimuthal orientations. The manufacturer's specifications indicated that the laser micrometers had a resolution of 0.000001 in (0.00000254 cm) and a repeatability of 0.000005 in (0.0000127 cm). The bias in the micrometer measurements was established using a pin gage standard with a calibration traceable to the US National Institute of Standards and Technology. The diameter measurements had a systematic uncertainty of 0.000022 in (0.00005588 cm) which is the sum in quadrature of the 0.000015 in (0.0000381 cm) uncertainty in the pin gage standard with the maximum in the random variations in the measurement of the standard on any axis for the three micrometers. The fuel rod diameter measurements were made in a number of sessions over the course of several months. The stability of the measurement system was monitored by repeatedly measuring two 12 in (30.48 cm) long pin gages during each of the sessions. These measurements also showed that the diameter measurements had a random reproducibility uncertainty of about 0.000030 in (0.0000762 cm). Of the 2199 fuel rods fabricated for the experiment, five were removed from service and not used. The average measured fuel rod diameter for the remaining population of 2194 fuel rods is 0.249980 in (0.634948 cm as rounded from the original data) with a standard deviation of 0.000086 in (0.000218 cm).

The design documents for the fuel elements from which the fuel pellets were removed specified the diameter of the fuel pellets as 0.207 in (0.52578 cm). The outer diameter of a sample of 123 fuel pellets, drawn randomly from the fuel pellet stock used in the fuel rods, was measured using one of the laser micrometers described above. The average measured diameter was 0.20694 in (0.52563 cm) with a standard deviation of the 123 measurements of 0.00019 in (0.00048 cm).

The fuel rods were designed to be supported by the two 1 in (2.54 cm) thick grid plates. The lower cap fits in a 0.5 in (1.27 cm) deep blind hole in the lower grid plate. The top of the lower cap is then aligned with the top of the grid plate to make the combination appear as a solid sheet of metal. With the appropriate grid plate spacing, the top and bottom of the aluminum spacers in the fuel rods are nearly aligned with the top and bottom of the upper grid plate.

1.2.8 Control and Safety Elements - The critical assembly has three identical fuel-followed control/safety elements, two operated as safety elements and one operated as a control element. Each control/safety element occupies four adjacent fuel rod positions in the critical assembly. Each element consists of four B_4C-loaded absorber sections followed by four polyethylene-filled decoupler sections followed by four fueled rod sections. These sections are joined into four-rod bundles by 6061 aluminum bundle plates. The three sections use the same 3003 aluminum tubing as the fuel rods. Each section has 3003 aluminum end caps at the top and bottom of identical design. When a control/safety element is fully withdrawn from the assembly, the fueled rod sections are in the core and are nearly identical neutronically to the other fueled positions in the critical assembly. The design of the control and safety elements is shown in Figure 10. The design of the lower bundle plate is shown in Figure 11. The design of the middle bundle plate, of which there are two in each control or safety element, is shown in Figure 12. The design of the upper bundle plate is shown in Figure 13. All of the bundle plates were fabricated from 6061 aluminum.

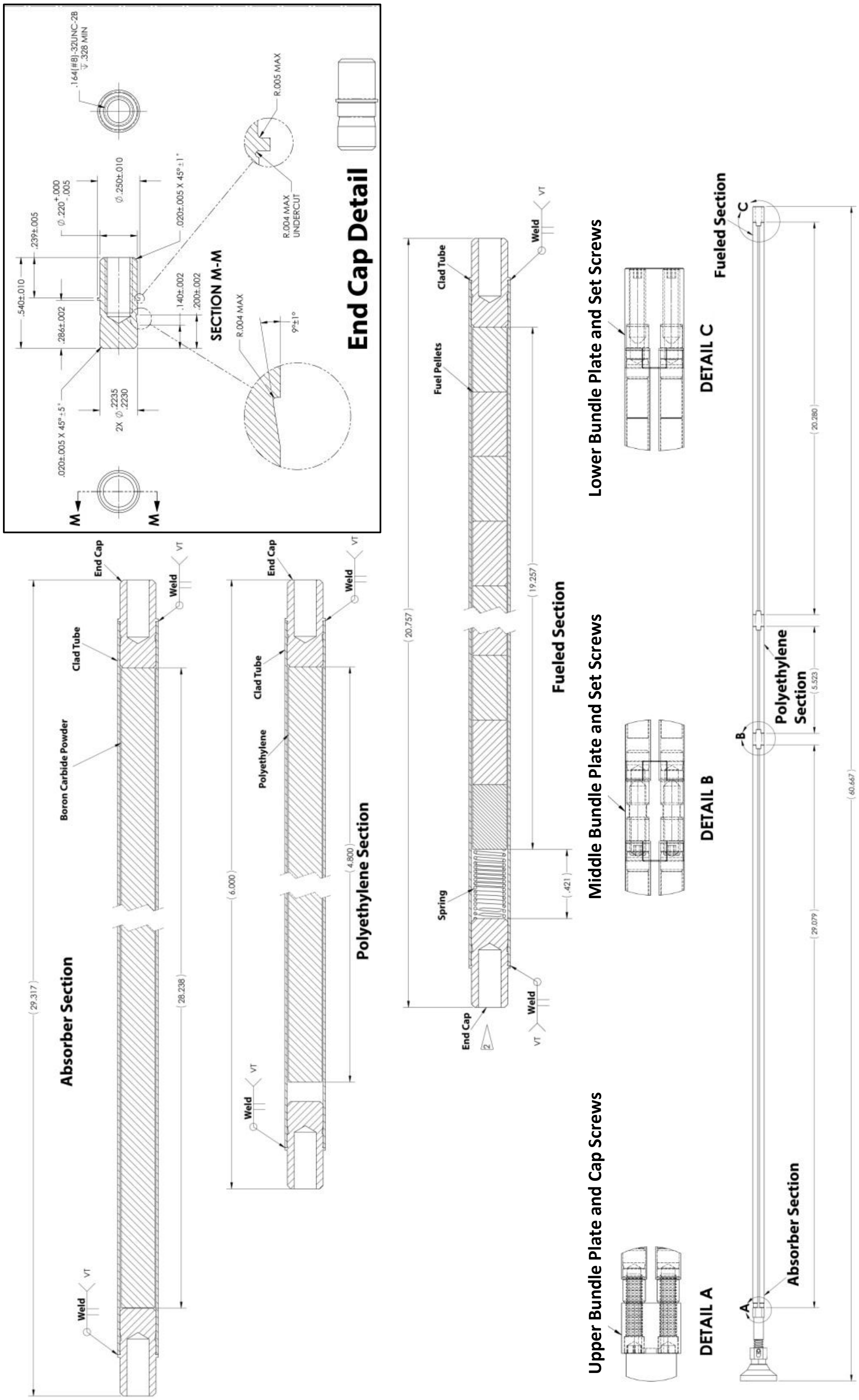

Figure 10. Design of the Control and Safety Elements.

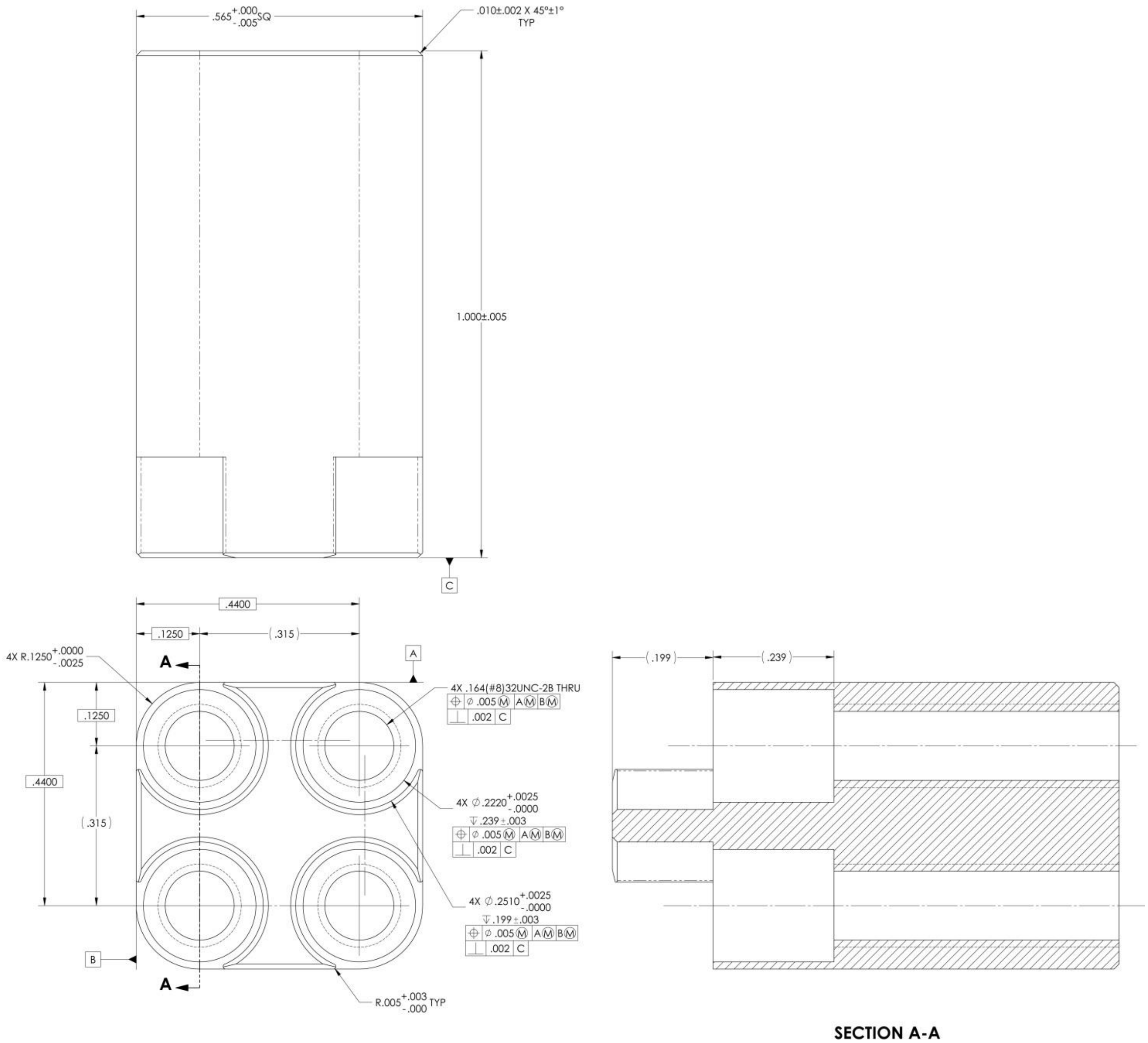

Figure 11. Excerpt From the Design Drawing for the Lower Bundle Plate.

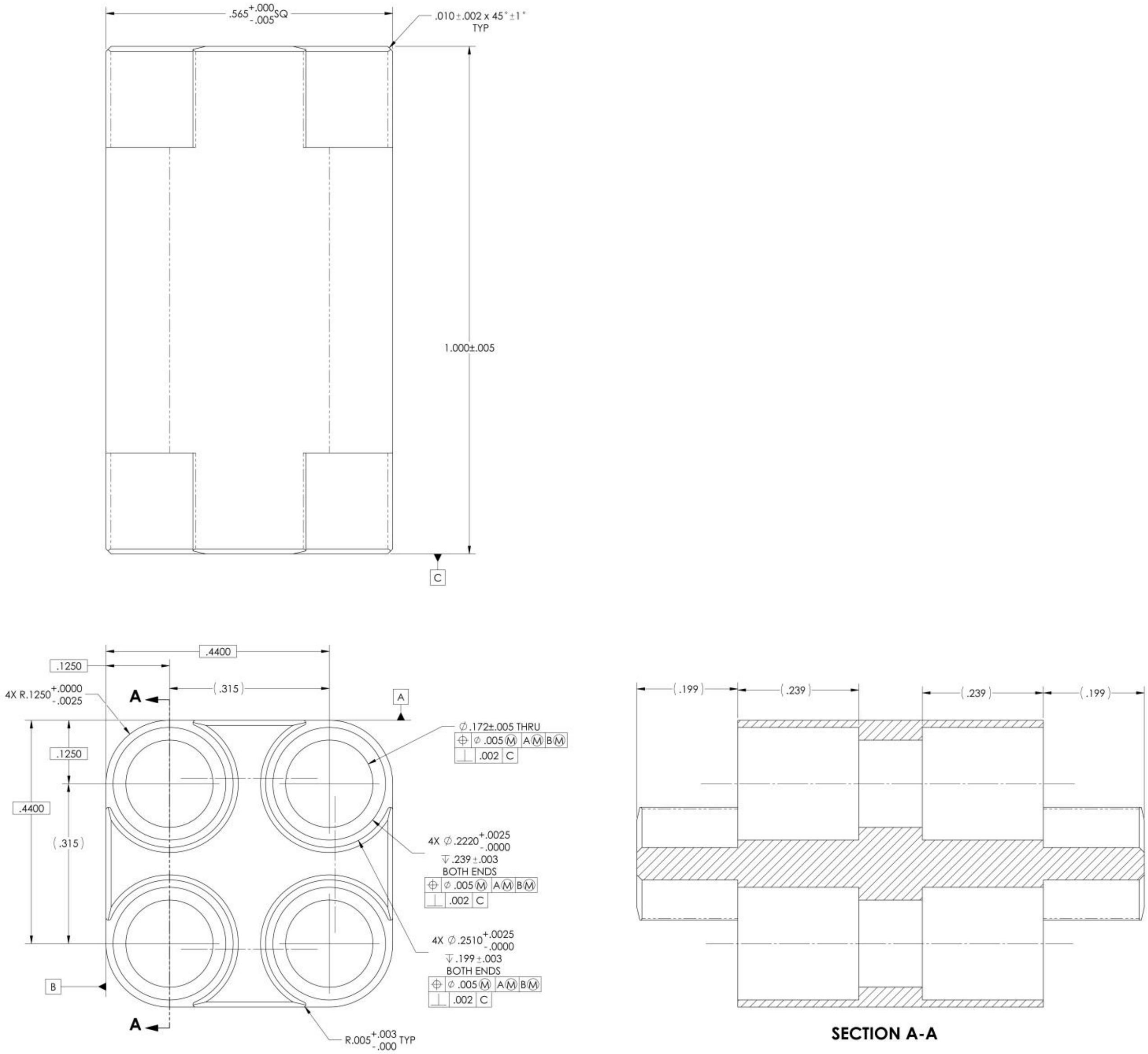

Figure 12. Excerpt From the Design Drawing for the Middle Bundle Plate.

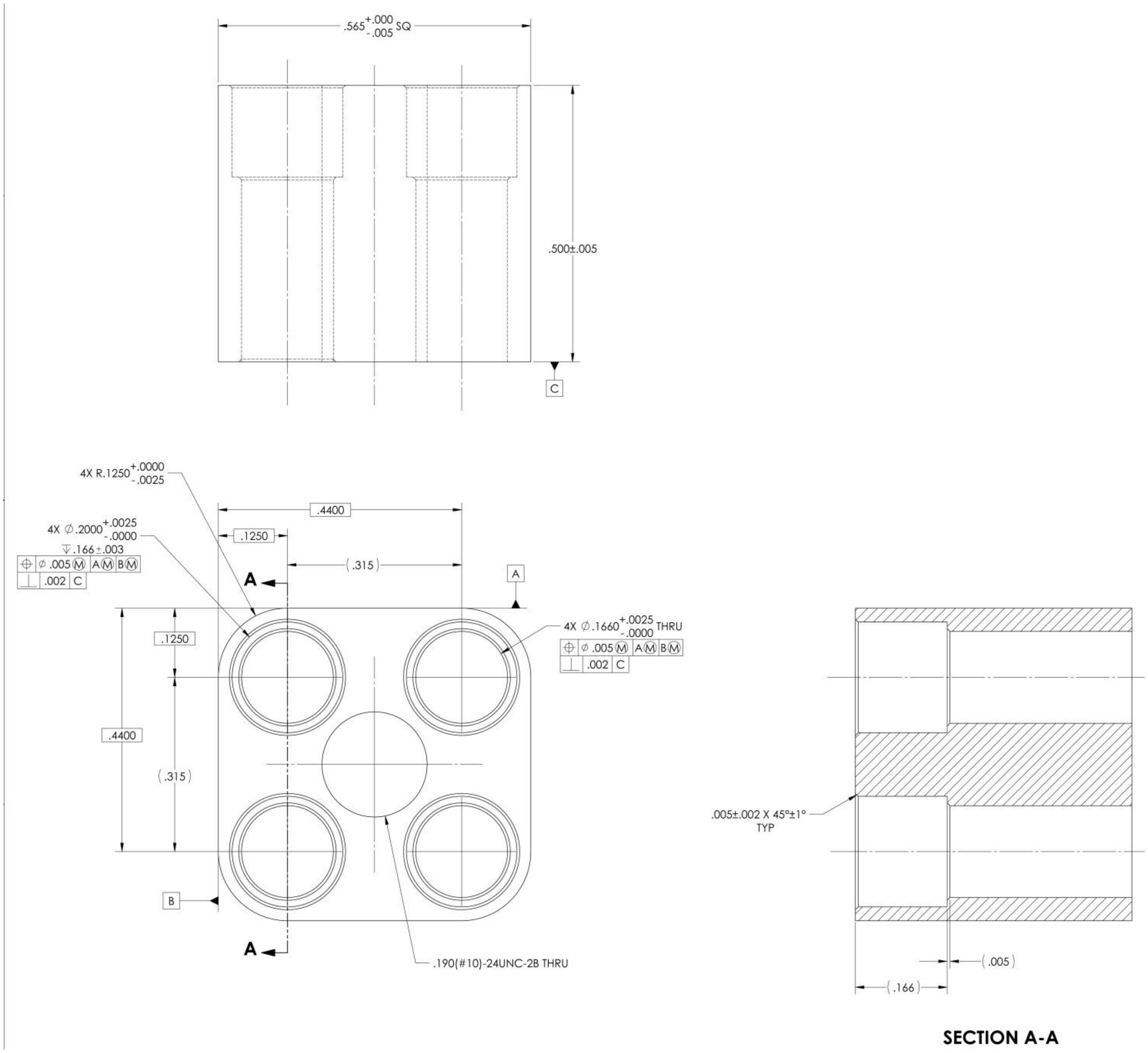

Figure 13. Excerpt From the Design Drawing for the Upper Bundle Plate.

The fueled section of the control/safety elements is similar to the fueled section of a fuel rod. The 3003 aluminum cladding tubes and end cap material are the same as were used in the fuel rods. In order to allow the elements to be lowered from the assembly, the lower grid plate has four-position through holes at the control/safety element positions as described above. The end caps on the fueled sections of the control/safety elements mate with a 6061 aluminum lower bundle plate that fills the hole in the lower grid plate. An 8-32 corrosion-resistant steel set screw 0.750 in (1.905 cm) long joins each fueled section to the bundle plate. Above the bottom end cap is a stack of fuel pellets and a spring similar to those in a fuel rod. The length and mass of the fuel pellet stack is known for each of the 23 fueled sections that were fabricated to the same precision as for the fuel rods. The relevant data on the fuel pellet stack for the population of 23 fueled sections is given in Table 5. The total mass of the UO_2 in the twelve fueled sections used in the experiments reported here is 1303.79 g and the total stack length is 584.7 cm.

Table 5. Population Averages for the 23 Control/Safety Element Fueled Sections.

Characteristic	Average Value	Standard Deviation
UO_2 Mass (g)	108.62	0.13
Fuel Pellet Stack Length (cm)	48.717	0.049
Linear Fuel Mass (g/cm)	2.2295	0.0020

The top end caps of the fueled sections are joined to the bottom end caps of the polyethylene-filled decoupler sections through a middle bundle plate using the same set screws as in the lower bundle plates. The length of the fueled sections is set so that, when the lower bundle plate upper and lower surfaces are in line with the surfaces of the lower grid plate, the upper and lower surfaces of the middle bundle plate are nearly in line with the upper and lower surfaces of the upper grid plate.

The decoupler sections contain 4.800 in (12.192 cm) long 0.207 in (0.52578 cm) diameter polyethylene rods inside the same 3003 aluminum tubes used for the fuel rod cladding. The average polyethylene mass in the population of 24 decoupler sections is 2.531 g with a standard deviation of 0.037 g. The end caps on the decoupler sections are identical to those on the fueled section.

The bottoms of the absorber sections are joined to the tops of the decoupler sections through a middle bundle plate. The same corrosion-resistant set screws are used. The absorber sections are filled with boron carbide powder. Two lots of boron carbide powder, each with a different average particle size, were mixed in equal parts prior to loading into the absorber sections. During loading, the powder was compacted by vibrating the tubes. The loading procedure specified that the absorber sections be filled to within about 0.3 in of the top of the tube. The top caps of the sections extend 0.286 in into the tubes. Thus the gap between the bottom of the cap and the top of the powder was small. The average boron carbide mass in the population of 23 absorber sections that were fabricated is 26.37 g with a standard deviation of 0.22 g. After filling, the top caps were welded to the absorber section tubes.

The top of each absorber section is joined to the upper bundle plate by a modified 8-32 socket head cap screw 1.125 in (2.8575 cm) tall. Table 6 lists the axial positions of the interfaces in the control and safety elements when the elements are fully withdrawn from the assembly to the positions in which the measurements reported here were made.

Table 6. Axial Locations of the Interfaces in the Control and Safety Elements when the Elements are Fully Withdrawn from the Critical Assembly.

Part	Location	Axial Position Relative to the Top of the Lower Grid Plate	
		Position (in)	Position (cm)
Lower Bundle Plate	Bottom of the lower bundle plate	-1	-2.54
	Bottom of the 0.222 in ID hole	-0.438	-1.11252
	Bottom of the 0.251 in ID hole	-0.199	-0.50546
	Top of the lower bundle plate	0	0
Fueled Section	Bottom of the fueled section	-0.438	-1.11252
	Bottom of the full-diameter clad	-0.199	-0.50546
	Bottom of the fuel pellet stack	0.102	0.25908
	Top of the fuel pellet stack	19.282	48.97608
	Bottom of the top end cap	19.78	50.2412
	Top of the full-diameter clad	20.081	51.00574
	Top of the fueled section	20.32	51.6128
Middle Bundle Plate 1	Bottom of the middle bundle plate 1	19.882	50.50028
	Top of the lower 0.251 in ID hole	20.081	51.00574
	Top of the lower 0.222 in ID hole	20.32	51.6128
	Bottom of the upper 0.222 in ID hole	20.444	51.92776
	Bottom of the upper 0.251 in ID hole	20.683	52.53482
	Top of the middle bundle plate 1	20.882	53.04028
Polyethylene Decoupler Section	Bottom of the decoupler section	20.444	51.92776
	Bottom of the full-diameter clad	20.683	52.53482
	Bottom of the polyethylene	20.984	53.29936
	Top of the polyethylene	25.784	65.49136
	Bottom of the top end cap	25.905	65.7987
	Top of the full-diameter clad	26.206	66.56324
	Top of the decoupler section	26.445	67.1703
Middle Bundle Plate 2	Bottom of the middle bundle plate 2	26.007	66.05778
	Top of the lower 0.251 in ID hole	26.206	66.56324
	Top of the lower 0.222 in ID hole	26.445	67.1703
	Bottom of the upper 0.222 in ID hole	26.569	67.48526
	Bottom of the upper 0.251 in ID hole	26.808	68.09232
	Top of the middle bundle plate 2	27.007	68.59778
Absorber Section	Bottom of the absorber section	26.569	67.48526
	Bottom of the full-diameter clad	26.808	68.09232
	Bottom of the absorber	27.109	68.85686
	Bottom of the top end cap	55.347	140.58138
	Top of the full-diameter clad	55.648	141.34592
	Top of the absorber section	55.887	141.95298
Upper Bundle Plate	Bottom of the upper bundle plate	55.887	141.95298
	Bottom of the 0.200 in ID hole	56.221	142.80134
	Top of the upper bundle plate	56.387	143.22298

Whenever moderator is present in the core tank during the execution of a critical experiment, the safety elements are held at their most reactive position with the absorber above the surface of the water and the fueled sections in the assembly core. In this position, a large negative reactivity is available to quickly shut down the assembly should the need arise. The absorber section in the elements is also well away from the assembly core and does not significantly affect the reactivity of the system. The control element is used during critical assembly operations to make fine adjustments in the reactivity of the assembly. When data are taken during an approach-to-critical experiment, the control element is also fully withdrawn to its most reactive position so the absorber does not affect the system neutronically.

1.2.9 Neutron Source – The neutron source in the assembly is a small double-sealed 316L stainless steel capsule containing a ^{252}Cf spontaneous fission source. The source is attached to a fixture designed to be placed in a fuel rod location in the assembly grid structure or in a mounting location outside the grid plates. The source and fixture are shown in Figure 14. The bottom (source) end of the fixture is the bottom end cap, essentially a cylinder of aluminum 3003 0.540 in (1.3716 cm) long and 0.220 in (0.5588 cm) diameter that is drilled and tapped to accommodate a 3-48 steel set screw that is 0.313 in (0.79502 cm) long. The bottom of the source fixture and top of the source capsule are 5.099 in (12.95146 cm) above the top of the lower grid plate. An aluminum 3003 tube identical to the fuel rod cladding tubes (nominally 0.250 in outer diameter, 0.0014 in wall) covers the top 0.254 in (0.64516 cm) of the bottom end cap and extends above the moderator where it connects to a handle that rests on the guide plate. The tube is slotted at the ends so that it fills with moderator when the critical assembly is filled.

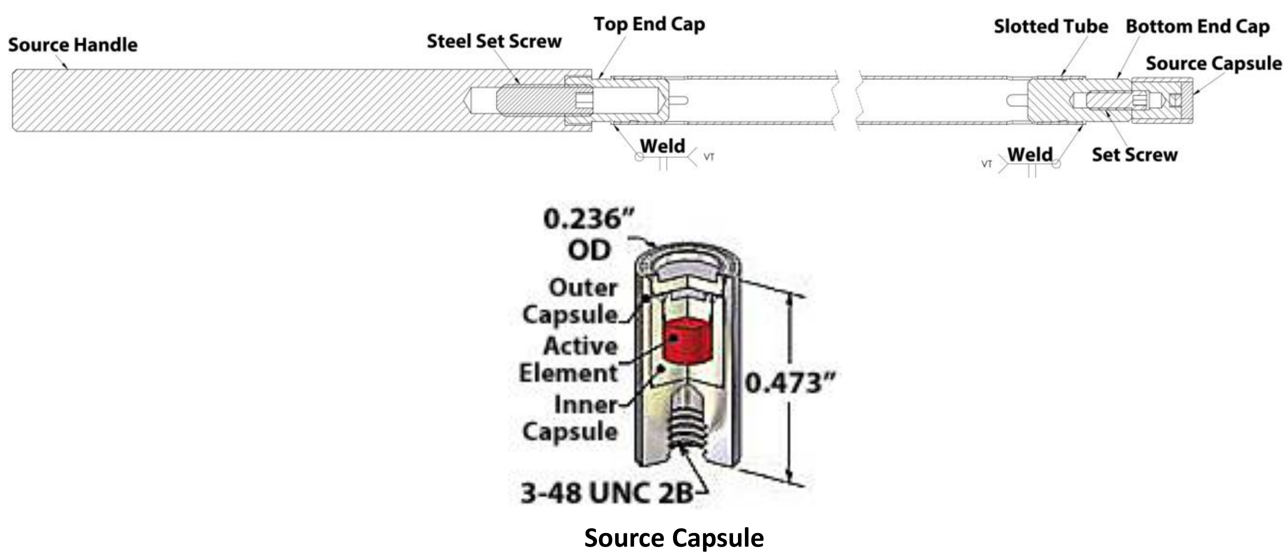

Figure 14. The neutron source and supporting fixture.

Table 7 shows the axial locations of the surfaces of the neutron source under the assumption that the origin is at the top of the lower grid plate.

Table 7. Axial Locations of the Interfaces in the Neutron Source as Installed in the Critical Assembly.

Part	Location	Axial Position Relative to the Top of the Lower Grid Plate	
		Position (in)	Position (cm)
Source Capsule	Bottom of the source capsule	4.626	11.75004
	Bottom of the set screw hole	5.016	12.74064
	Top of the source capsule	5.099	12.95146
Lower Set Screw	Bottom of the set screw	5.016	12.74064
	Top of the set screw	5.329	13.53566
Bottom End Cap	Bottom of the bottom end cap	5.099	12.95146
	Top of the set screw hole	5.586	14.18844
	Top of the bottom end cap	5.94	15.0876
Slotted Tube	Bottom of the slotted tube	5.382	13.67028
	Top of the slotted tube	28.156	71.51624
Top End Cap	Bottom of the top end cap	27.855	70.7517
	Bottom of the hole in the top end cap	27.908	70.88632
	Top of the top end cap	28.395	72.1233
Upper Set Screw	Bottom of the upper set screw	28.255	71.7677
	Top of the upper set screw	28.755	73.0377
Handle	Bottom of the handle	28.255	71.7677
	Top of the end cap hole in the handle	28.395	72.1233
	Top of the set screw hole in the handle	28.885	73.3679
	Top of the handle	32.255	81.9277

1.2.10 Experimental Method – The focus of these critical experiments was to explore partially reflected arrays.

The critical moderator/reflector height for each configuration was determined in an approach-to-critical experiment with the moderator/reflector height as a free parameter. The inverse count rate at successive moderator levels for two or three detectors as a function of the height of the moderator was linearly extrapolated to zero inverse count rate to obtain an estimate of the critical moderator height. During all measurements the control and safety elements were in their fully withdrawn or most reactive positions During the experiments, water was continuously pumped from the dump tank to the core tank. The height of the moderator in the core tank was determined by the setting of the remotely adjustable overflow standpipe.

The arrays addressed in the first three cases completely filled the 45x45 array of holes in the grid plates. The differences among these arrays were in the number of water holes – Case 1 had none, Case 2 had one in the central location, and Case 3 had 189 holes distributed around the core. The arrays addressed in Cases 4 through 9 had decreasing numbers of fuel rods with no internal water holes.

Cases 10 through 19 all included the same 1600 fuel rods. Case 10 had a 40x40 array of fuel rods. In the arrays in Cases 11 through 15, the 1600-rod core was divided into two 20x40 halves with an internal water-filled linear slot between the two halves. The width of the slot varies from one to five fuel rod rows.

In Cases 16 through 19, the 1600-rod array was divided into 20x20 400-rod quarters with cruciform slots between the quarters. The width of the slot varied from one to four fuel rod rows.

Each of the configurations was addressed with a full approach-to-critical experiment. The initial moderator level in these configurations had a calculated effective multiplication factor of about 0.9 and the second level had a calculated effective multiplication factor of about 0.95. Subsequent measurements were guided by the count rate results. Early in each approach, the water height increments were several millimeters. The water height increments decreased during the approach until the last few count rate measurements were made at increments of a small number of millimeters.

All of the final configurations had subcritical multiplications that significantly exceeded 100.

1.2.11 Experiment Arrays – During the approach-to-critical experiments, detailed records were kept of the location and identity of each fuel rod in each core. In Cases 1 through 10, a given fuel rod was placed in the same grid location in each core in which it was used. The slots in the arrays of Cases 11 through 19 were created by moving fuel rod rows from the inside to the outside of the array. The total number of fuel rod positions occupied, the mass of UO_2 in the core, and the total length of the fuel columns in all the fuel rods for the array measured in each of the nineteen configurations are listed in Table 8. Also listed in the table is the extrapolated water height at delayed critical, the temperature at which the experimental measurements were made, and the last water level that was used in the extrapolation to delayed critical. The uncertainties in the extrapolated critical water heights are attributed only to the uncertainties in the count-rate measurements propagated through the linear extrapolation to delayed critical. The difference between the extrapolated critical water height and the last water level used in the extrapolation ranged from a maximum of 0.33 cm (Case 15) to a minimum of 0.15 cm (Case 6).

Table 9 lists the average fuel rod diameter with standard deviation for the set of fuel rods used in each benchmark experiment. The fuel rod arrangement in the array measured for each of the nineteen cores is shown in Figures 15 through 33.

In Cases 2 through 19, the source was in the fuel grid as shown in the figures. For Case 1, the source was located in a fixture outside the grid. In this case, the source was located 21.6205 cm to the right and 4.0005 cm above the center of the array oriented as shown in Figure 15.

Table 8. Extrapolated Critical Water Height, Total UO2 Mass and Column Length, and Assembly Temperature for the 19 Cases.

Case	Array Size (rods) [a]	UO_2 Mass (g) [b]	Fuel Column Length (cm) [c]	Extrapolated Critical Water Height (cm) [d]		Temper-ature (ºC)	Highest Water Level (cm) [f]
				Value	Uncertainty [e]		
1	2025	220168.44	98774.9	36.54	0.00037	24.7	36.36
2	2024	220059.58	98726.1	36.49	0.00038	24.8	36.24
3	1836	199602.57	89543.4	31.55	0.00036	24.9	31.33
4	1977	214954.67	96431.8	37.12	0.00051	24.8	36.91
5	1873	205602.56	91355.7	38.65	0.00032	24.8	38.48
6	1781	193663.26	86871.1	40.39	0.00025	25.0	40.24
7	1673	181933.94	81602.9	43.10	0.00073	24.9	42.83
8	1573	171072.87	76725.0	46.57	0.00049	25.1	46.34
9	1525	165860.08	74381.2	48.70	0.00063	25.0	48.42
10	1600	174006.02	78040.8	46.79	0.00059	25.1	46.51
11	1600	174006.02	78040.8	42.19	0.00039	25.2	41.93
12	1600	174006.02	78040.8	39.60	0.00056	25.2	39.31
13	1600	174006.02	78040.8	39.03	0.00063	25.2	38.71
14	1600	174006.02	78040.8	39.98	0.00037	25.2	39.74
15	1600	174006.02	78040.8	42.57	0.00066	25.3	42.24
16	1600	174006.02	78040.8	38.69	0.00033	25.4	38.45
17	1600	174006.02	78040.8	35.31	0.00053	25.5	35.03
18	1600	174006.02	78040.8	35.10	0.00026	25.0	34.91
19	1600	174006.02	78040.8	37.50	0.00037	25.0	37.24

(a) Includes the twelve fueled sections in the control element and the two safety elements.
(b) Sum of the UO_2 masses in the rods included in the configuration.
(c) Sum of the fuel column lengths in the rods included in the configuration.
(d) The water depth is measured from the top of the lower grid plate.
(e) The uncertainties listed in the extrapolated critical water height are those attributed only to the stochastic nature of the radiation detection process at each moderator height used in the extrapolation. The stochastic uncertainties have been propagated through the linear extrapolation.
(f) The highest water level in the approach-to-critical experiment that was used in the extrapolation to the critical moderator height.

Table 9. Average Fuel Rod Diameter and Standard Deviation of the Distribution For the Fuel Rods in Each Case.

Case	Array Size (rods)	Average Fuel Rod Outside Diameter (cm)	Standard Deviation (cm)	Number of Fuel Rods [(a)]
1	2025	0.634955	0.000217	2013
2	2024	0.634955	0.000217	2012
3	1836	0.634955	0.000217	1824
4	1977	0.634957	0.000217	1965
5	1873	0.634961	0.000217	1861
6	1781	0.634963	0.000217	1769
7	1673	0.634970	0.000215	1661
8	1573	0.634975	0.000214	1561
9	1525	0.634977	0.000215	1513
10	1600	0.634973	0.000216	1588
11	1600	0.634973	0.000216	1588
12	1600	0.634973	0.000216	1588
13	1600	0.634973	0.000216	1588
14	1600	0.634973	0.000216	1588
15	1600	0.634973	0.000216	1588
16	1600	0.634973	0.000216	1588
17	1600	0.634973	0.000216	1588
18	1600	0.634973	0.000216	1588
19	1600	0.634973	0.000216	1588

(a) Each configuration also included 12 fueled sections in the control and safety elements.

During the course of the critical experiments, reproducibility data were taken for two of the configurations investigated (cases 1 and 3). The maximum deviation from the mean critical moderator level was about 0.2 mm..

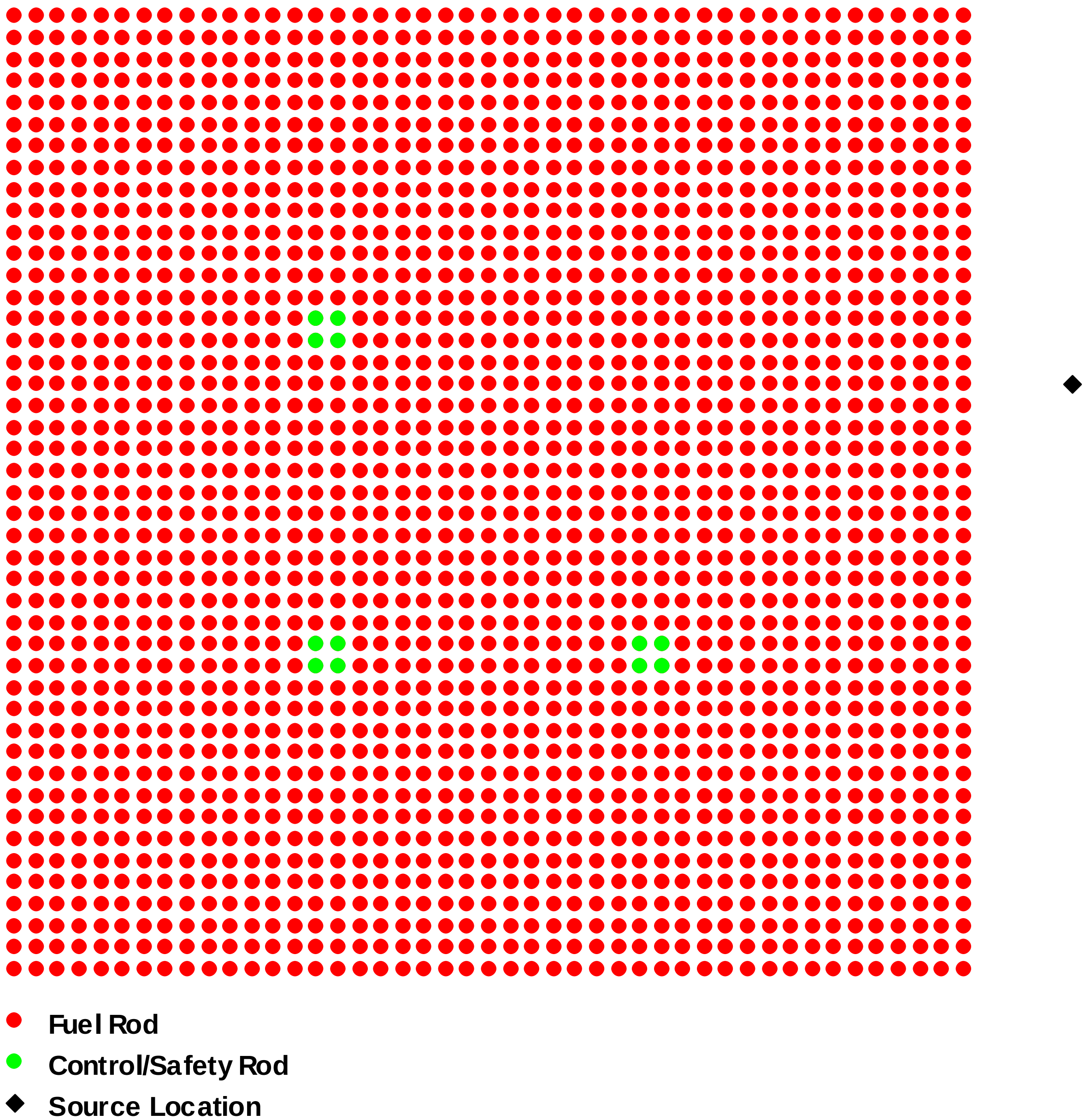

Figure 15. Fuel Rod Layout of the Array Measured for Case 1.

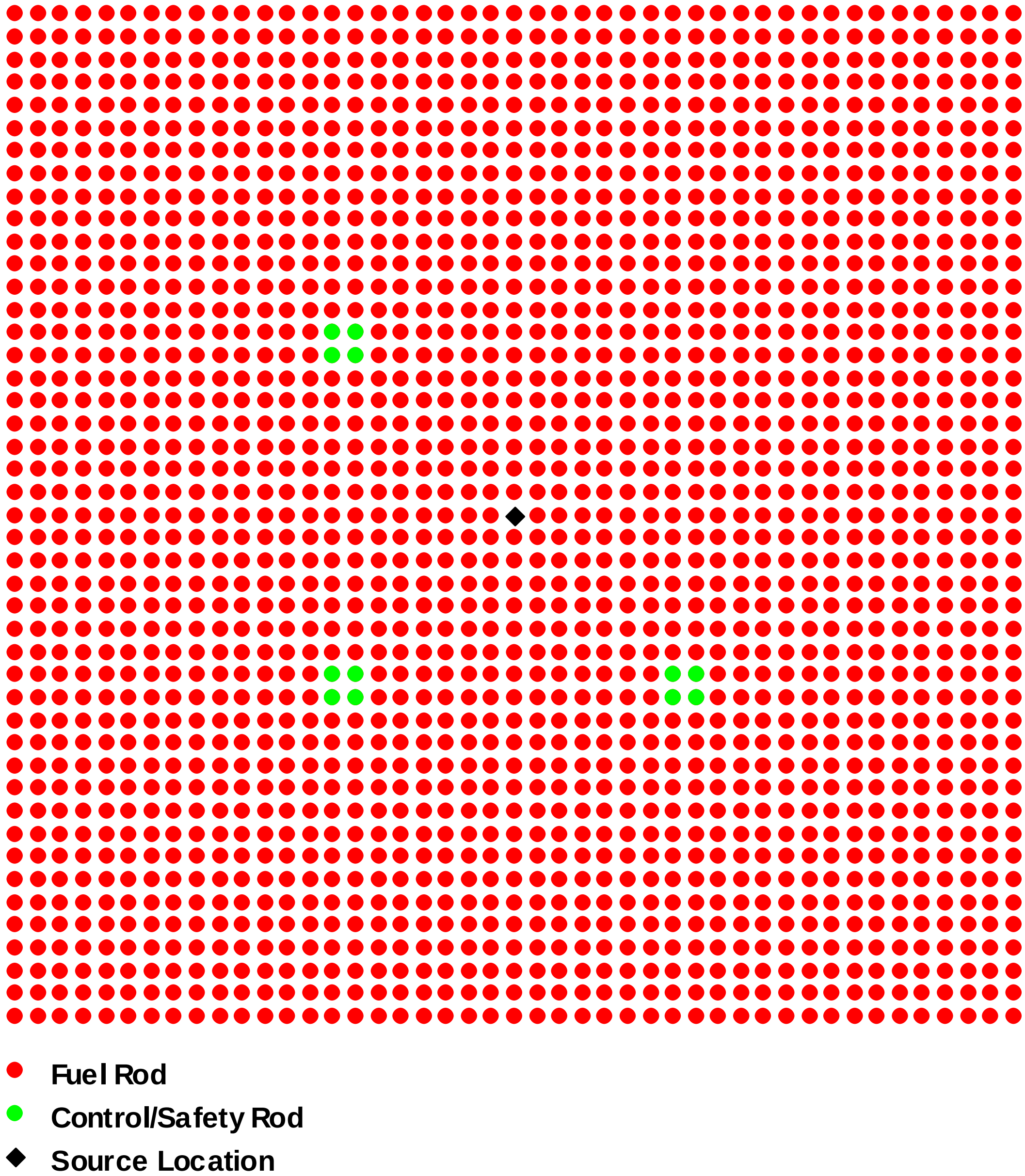

Figure 16. Fuel Rod Layout of the Array Measured for Case 2.

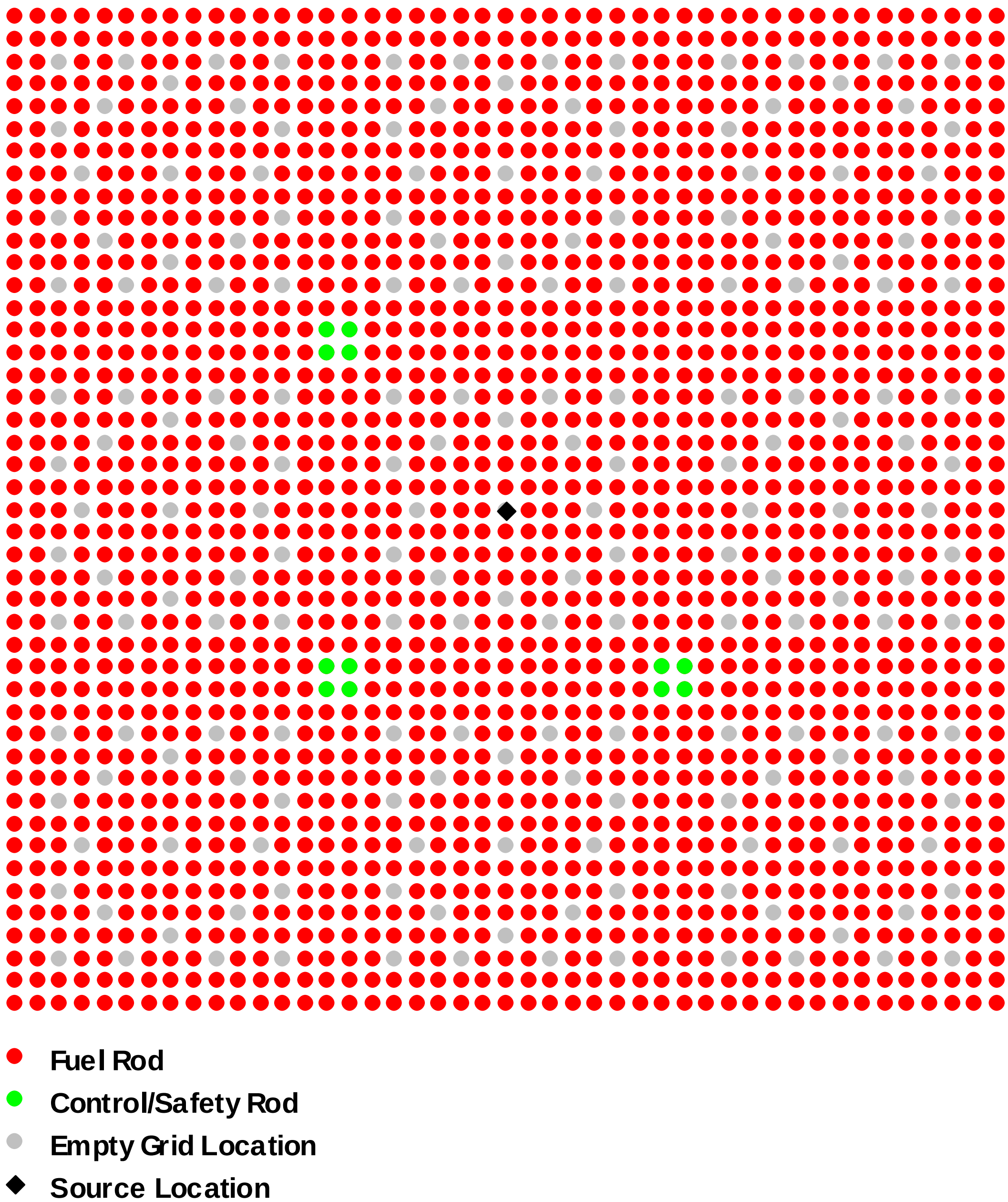

Figure 17. Fuel Rod Layout of the Array Measured for Case 3.

Figure 18. Fuel Rod Layout of the Array Measured for Case 4.

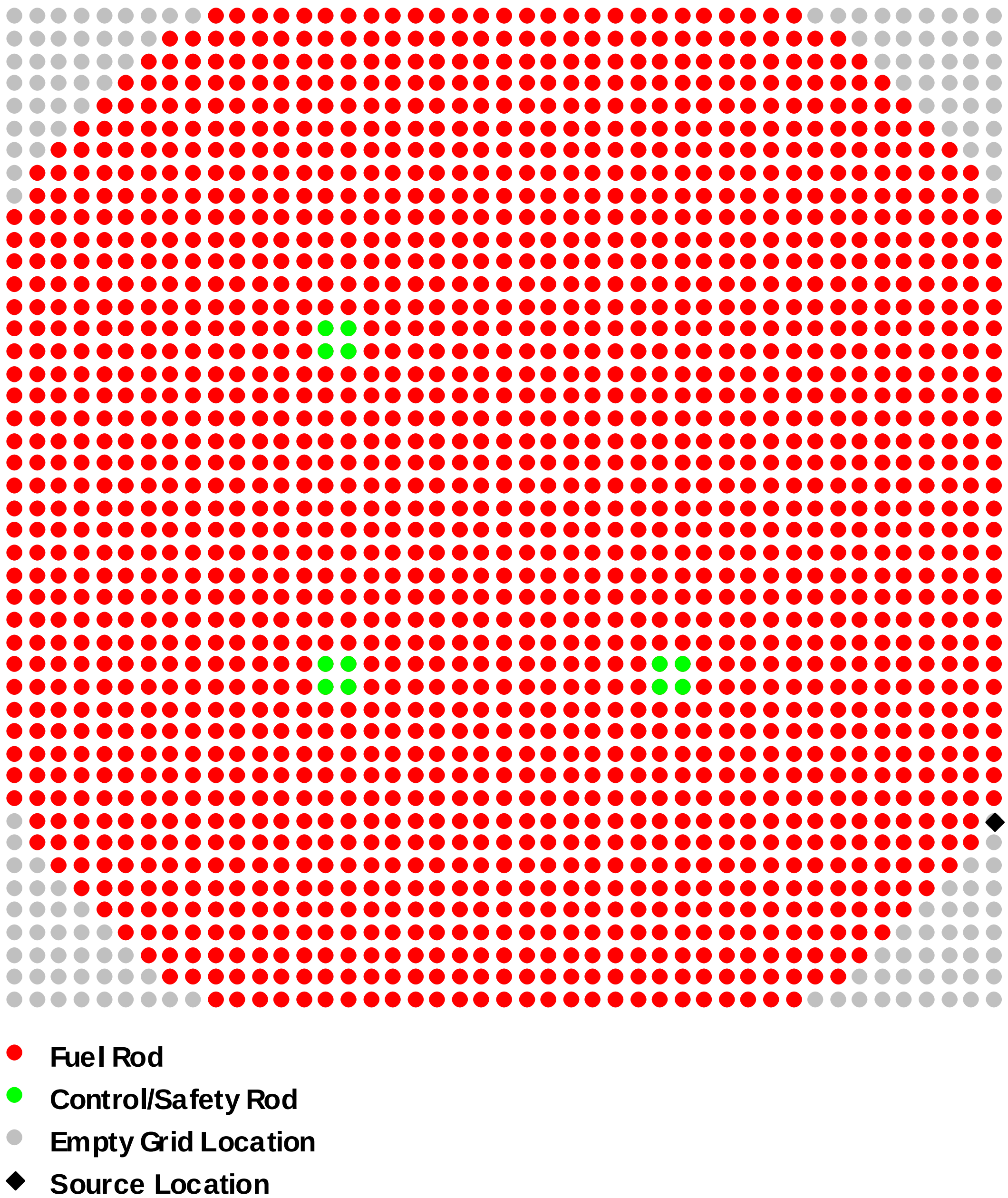

Figure 19. Fuel Rod Layout of the Array Measured for Case 5.

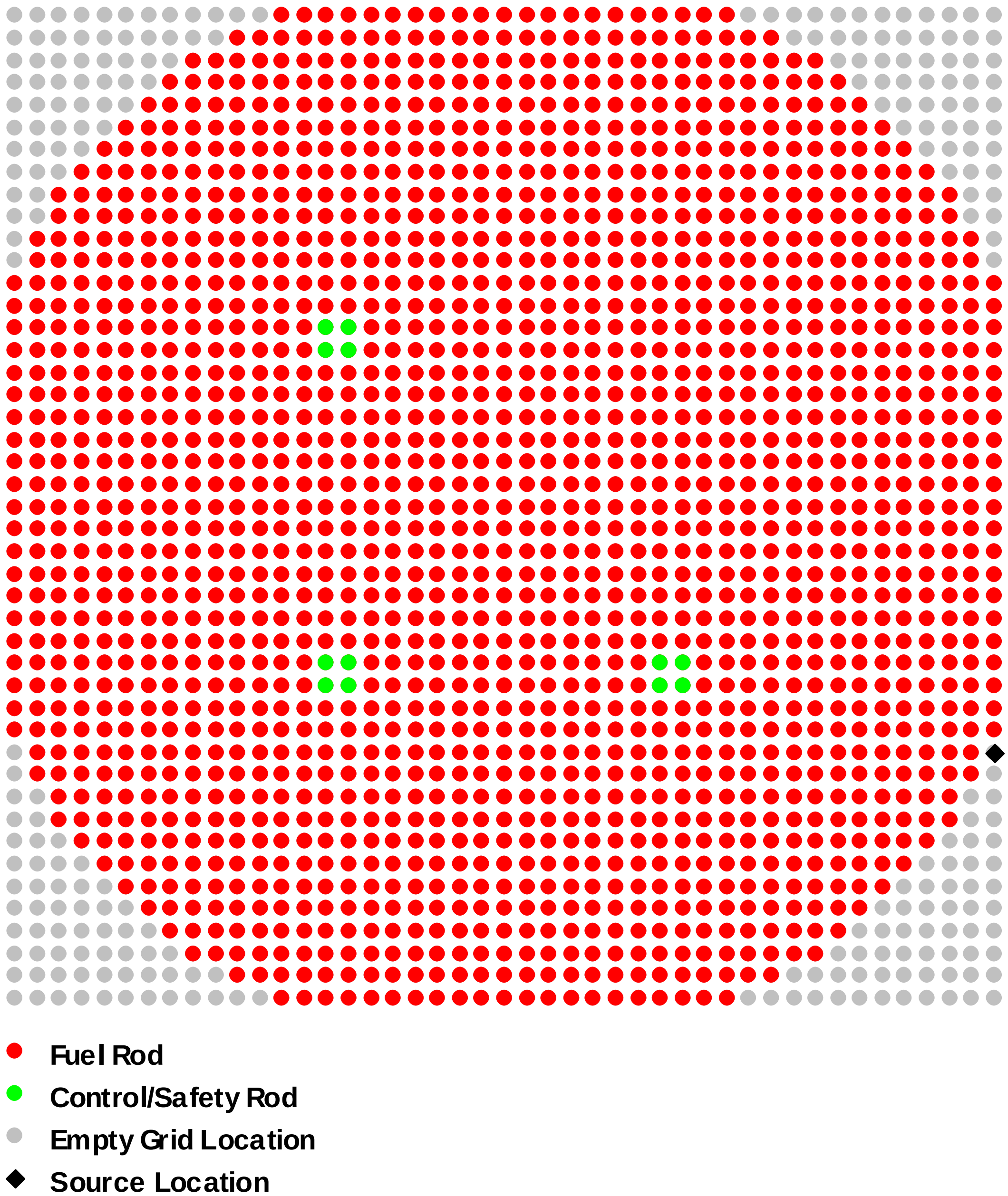

Figure 20. Fuel Rod Layout of the Array Measured for Case 6.

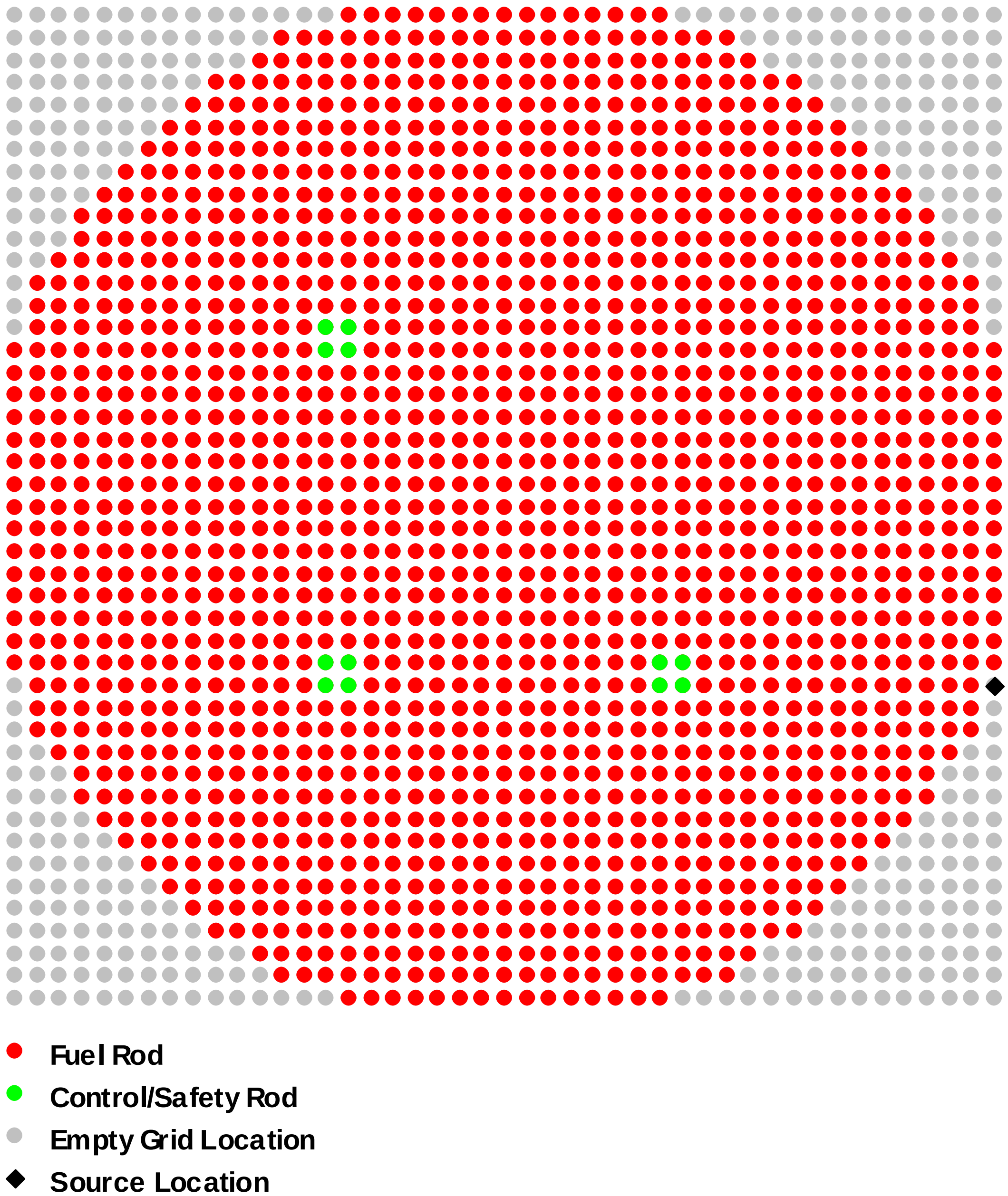

Figure 21. Fuel Rod Layout of the Array Measured for Case 7.

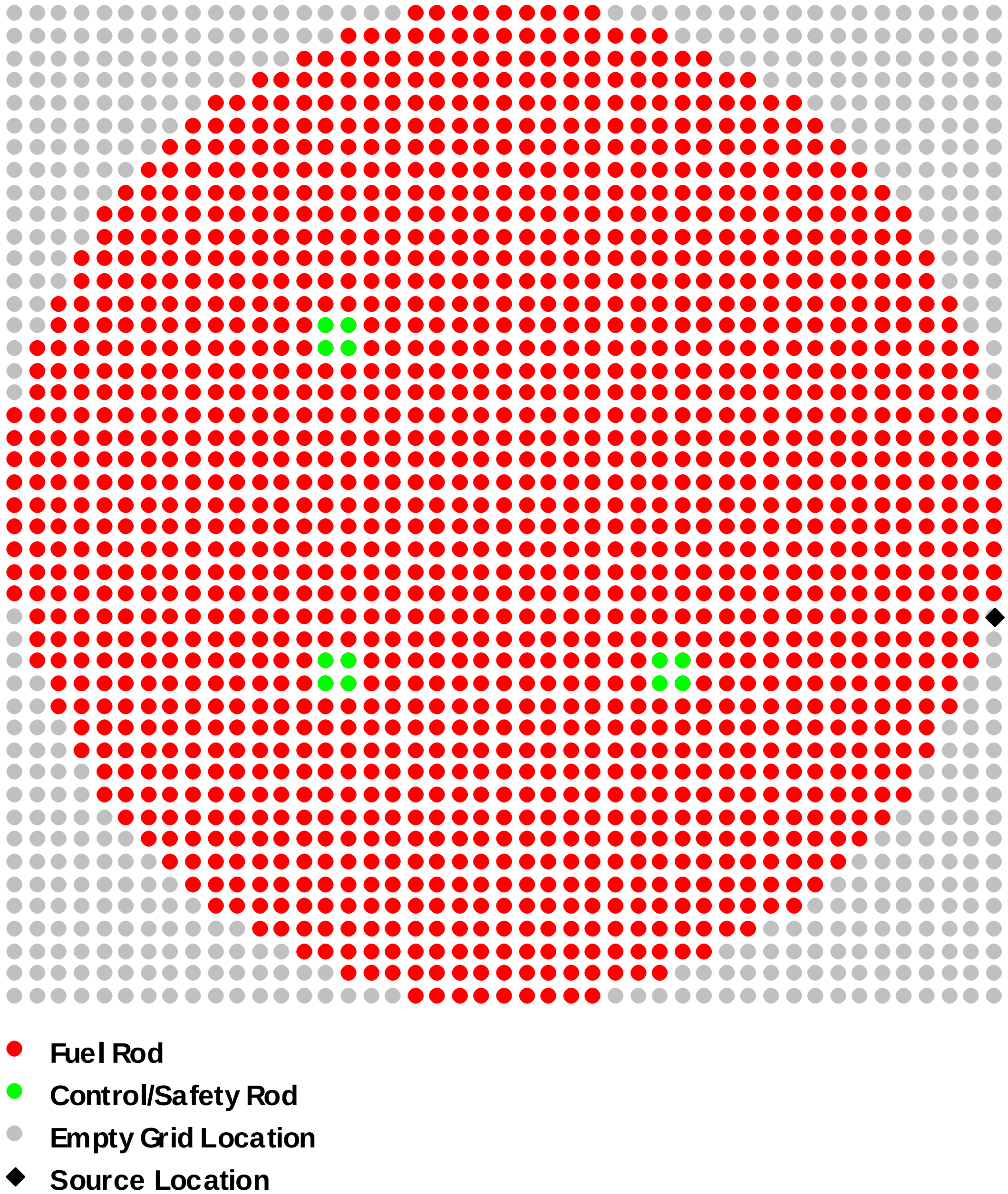

Figure 22. Fuel Rod Layout of the Array Measured for Case 8.

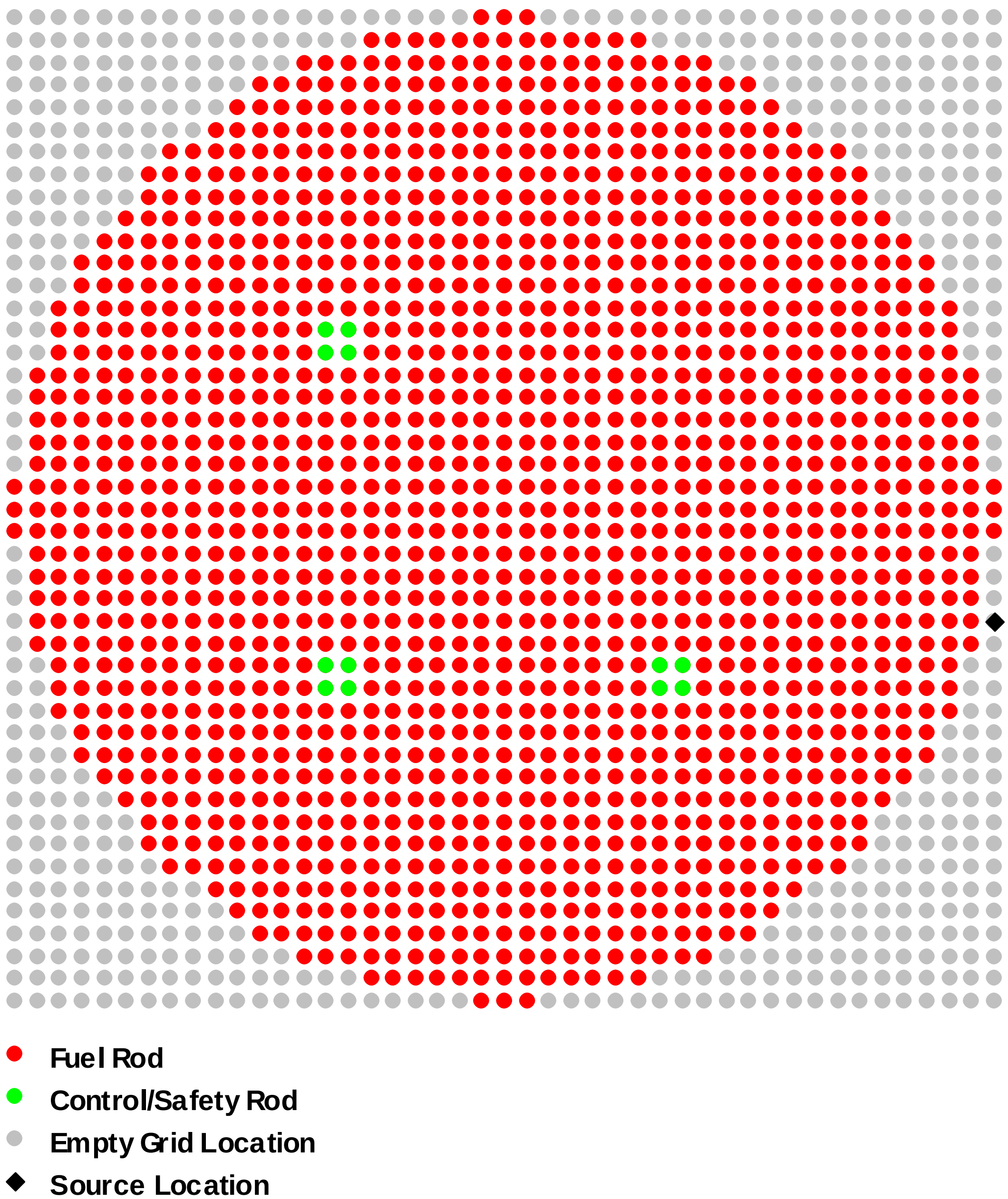

Figure 23. Fuel Rod Layout of the Array Measured for Case 9.

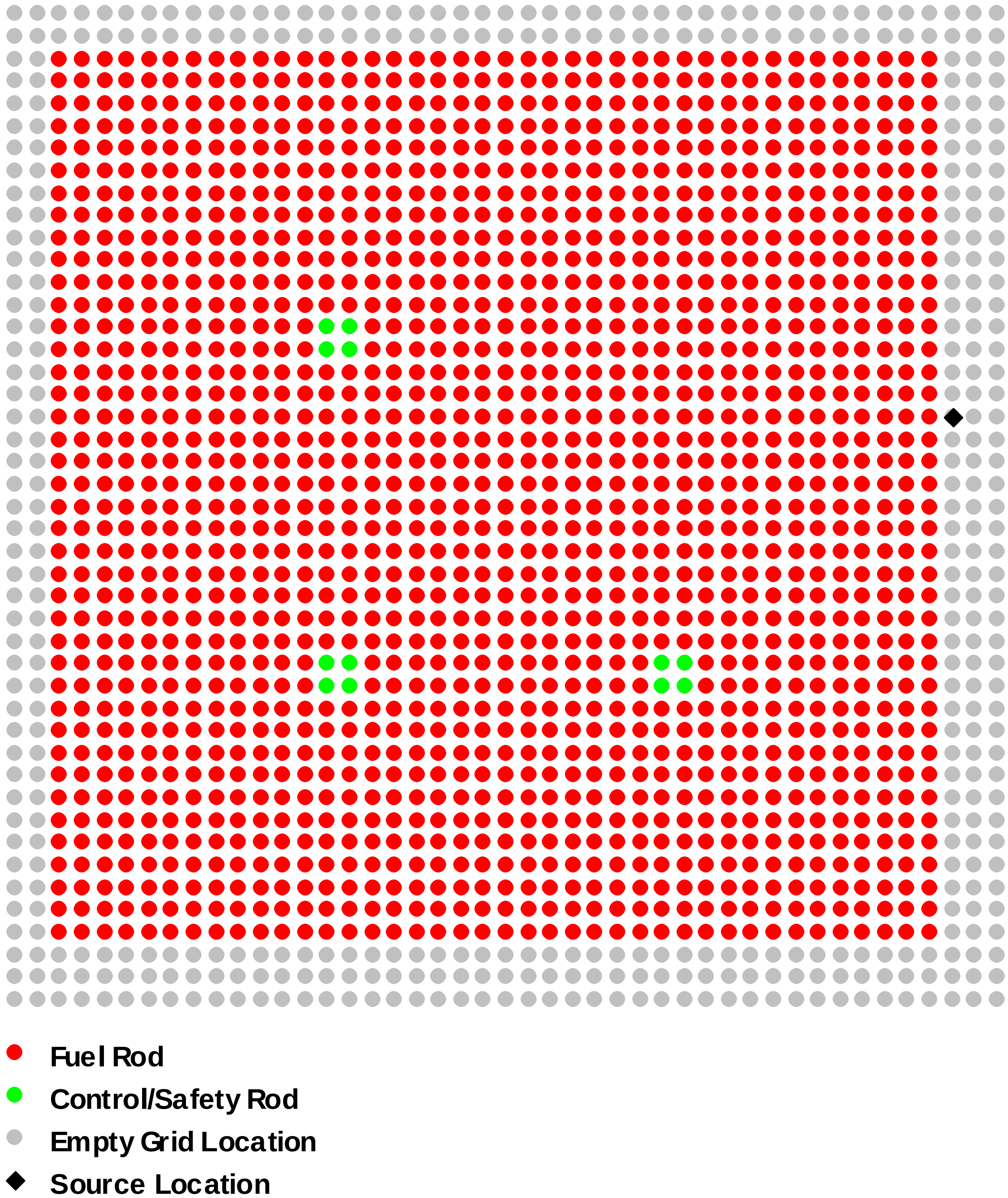

Figure 24. Fuel Rod Layout of the Array Measured for Case 10.

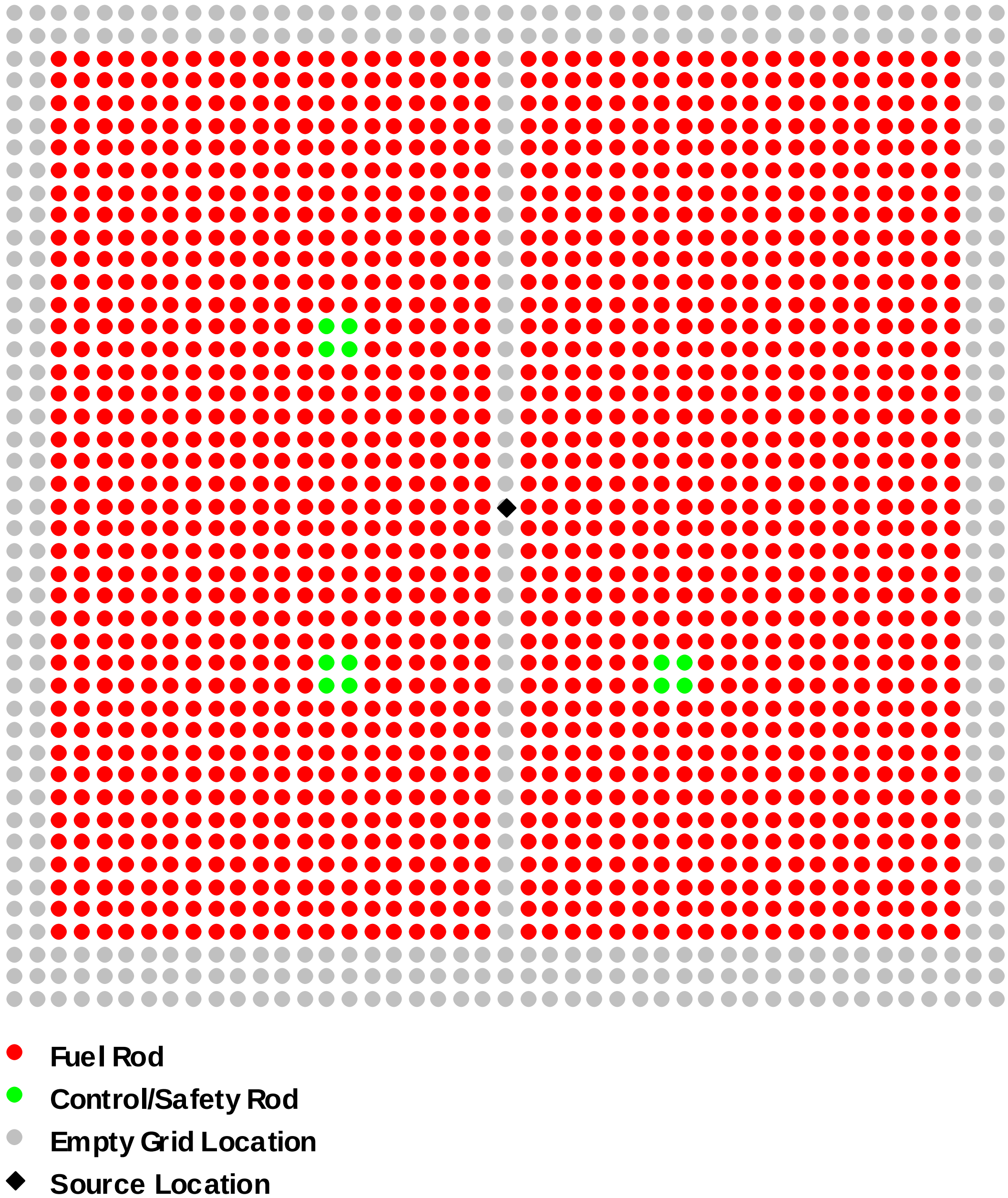

Figure 25. Fuel Rod Layout of the Array Measured for Case 11.

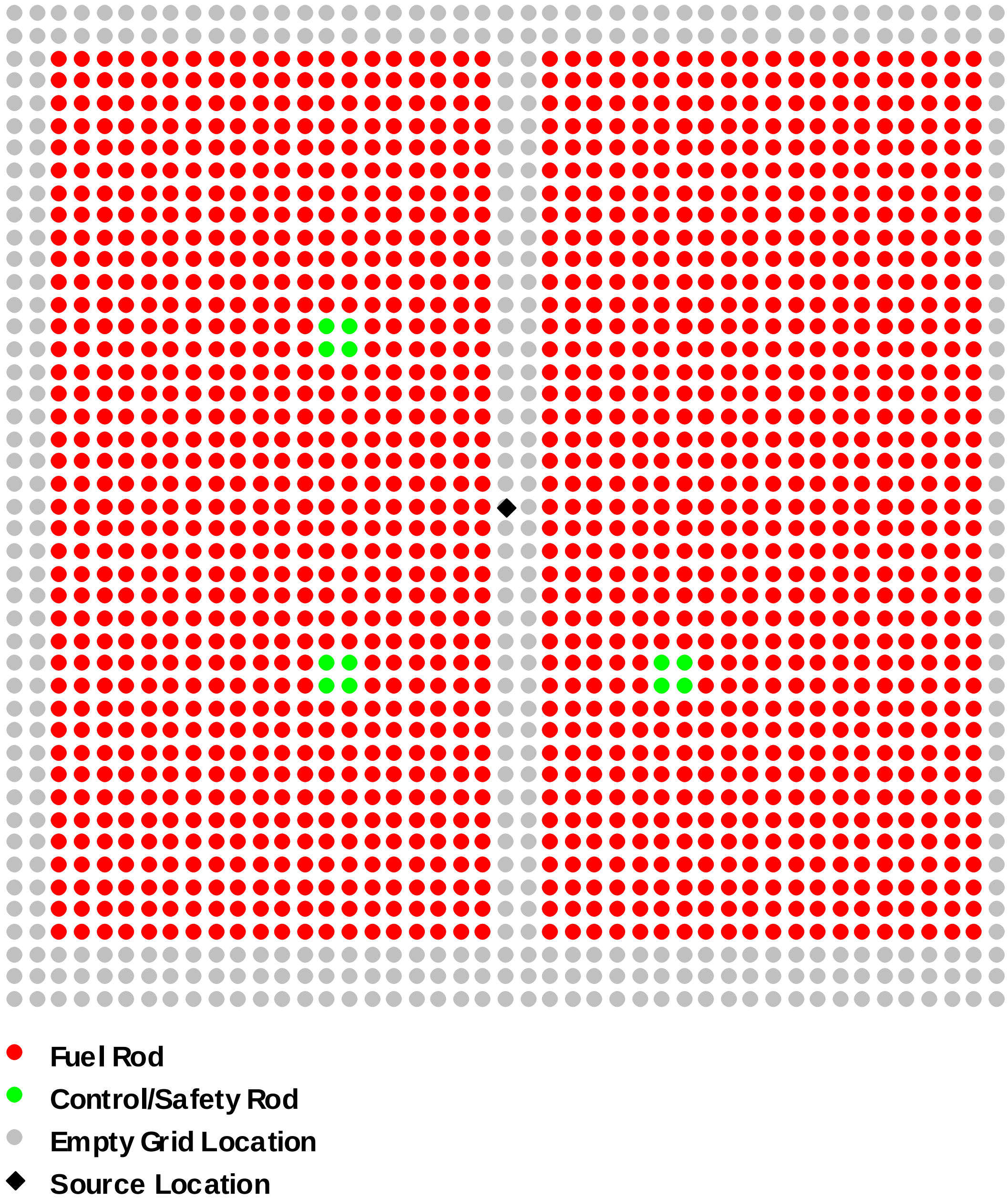

Figure 26. Fuel Rod Layout of the Array Measured for Case 12.

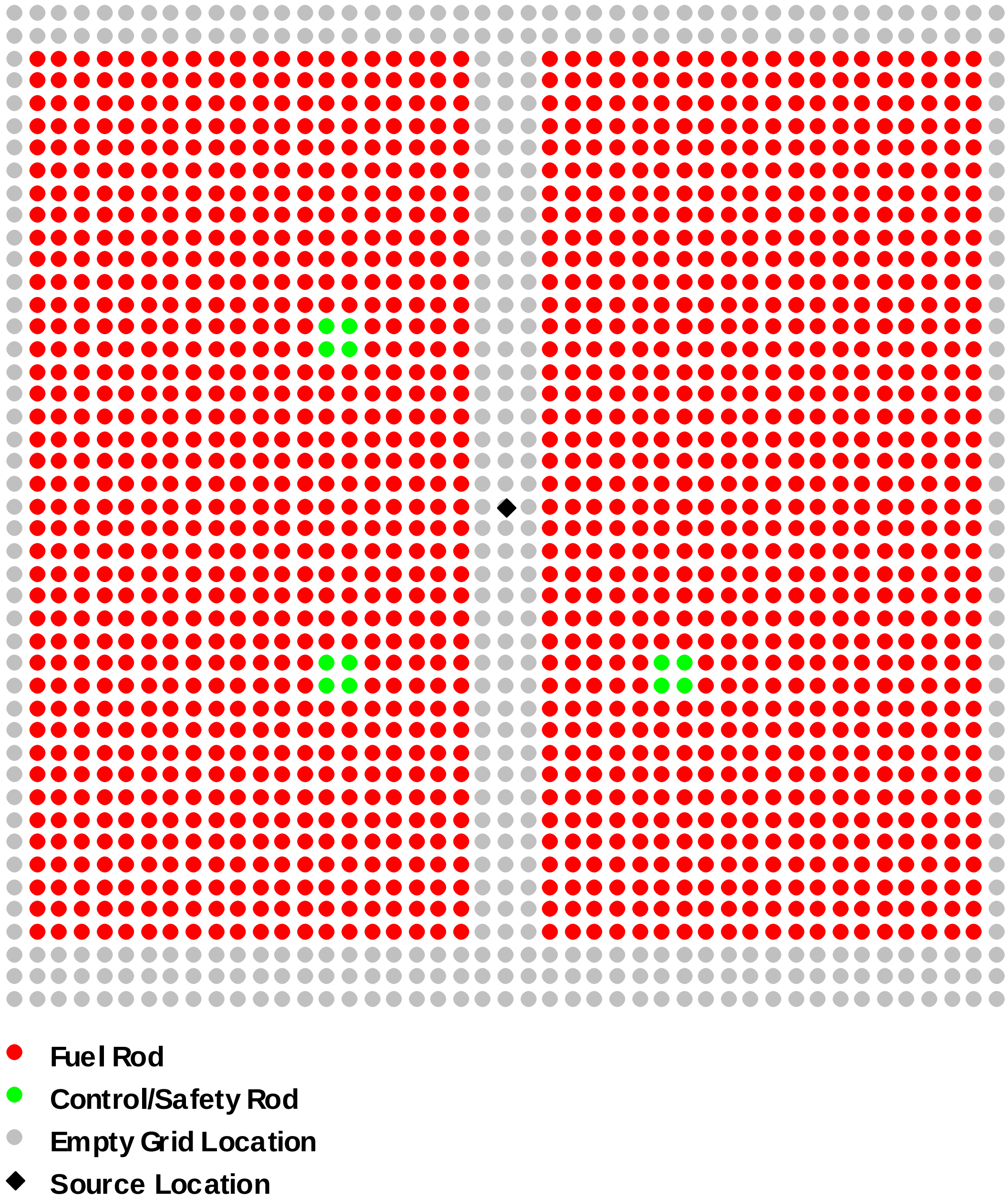

Figure 27. Fuel Rod Layout of the Array Measured for Case 13.

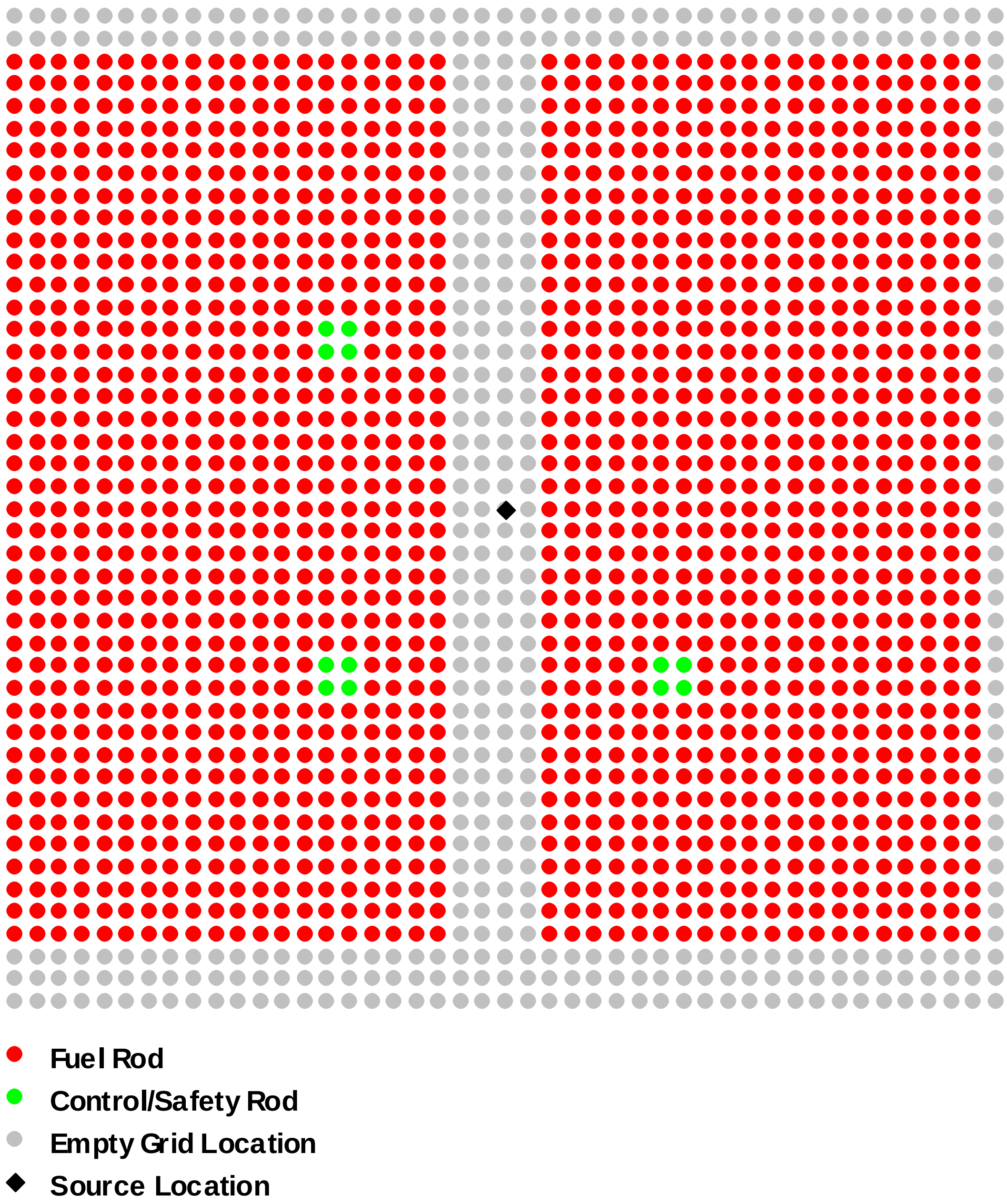

Figure 28. Fuel Rod Layout of the Array Measured for Case 14.

Figure 29. Fuel Rod Layout of the Array Measured for Case 15.

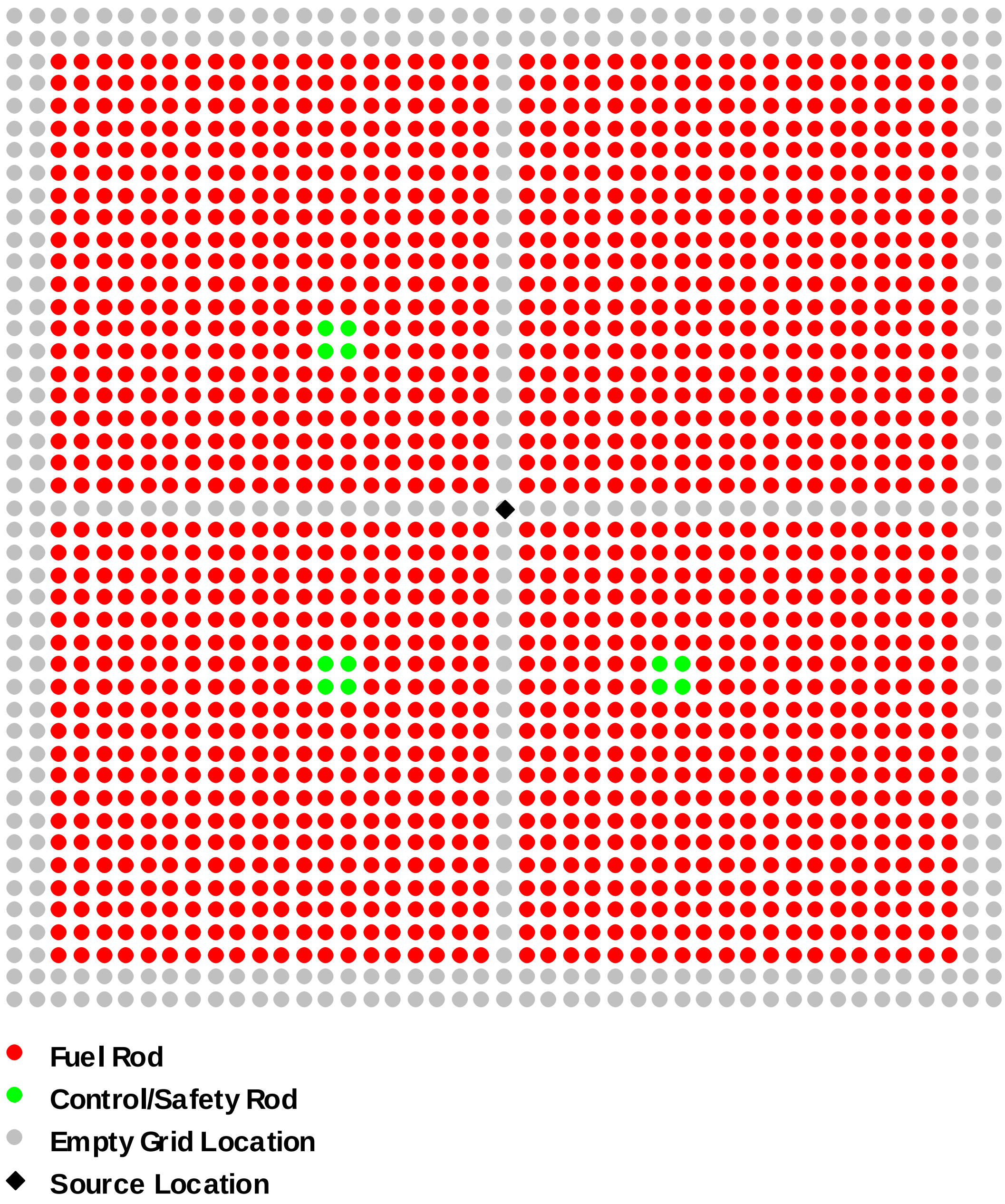

Figure 30. Fuel Rod Layout of the Array Measured for Case 16.

Figure 31. Fuel Rod Layout of the Array Measured for Case 17.

Figure 32. Fuel Rod Layout of the Array Measured for Case 18.

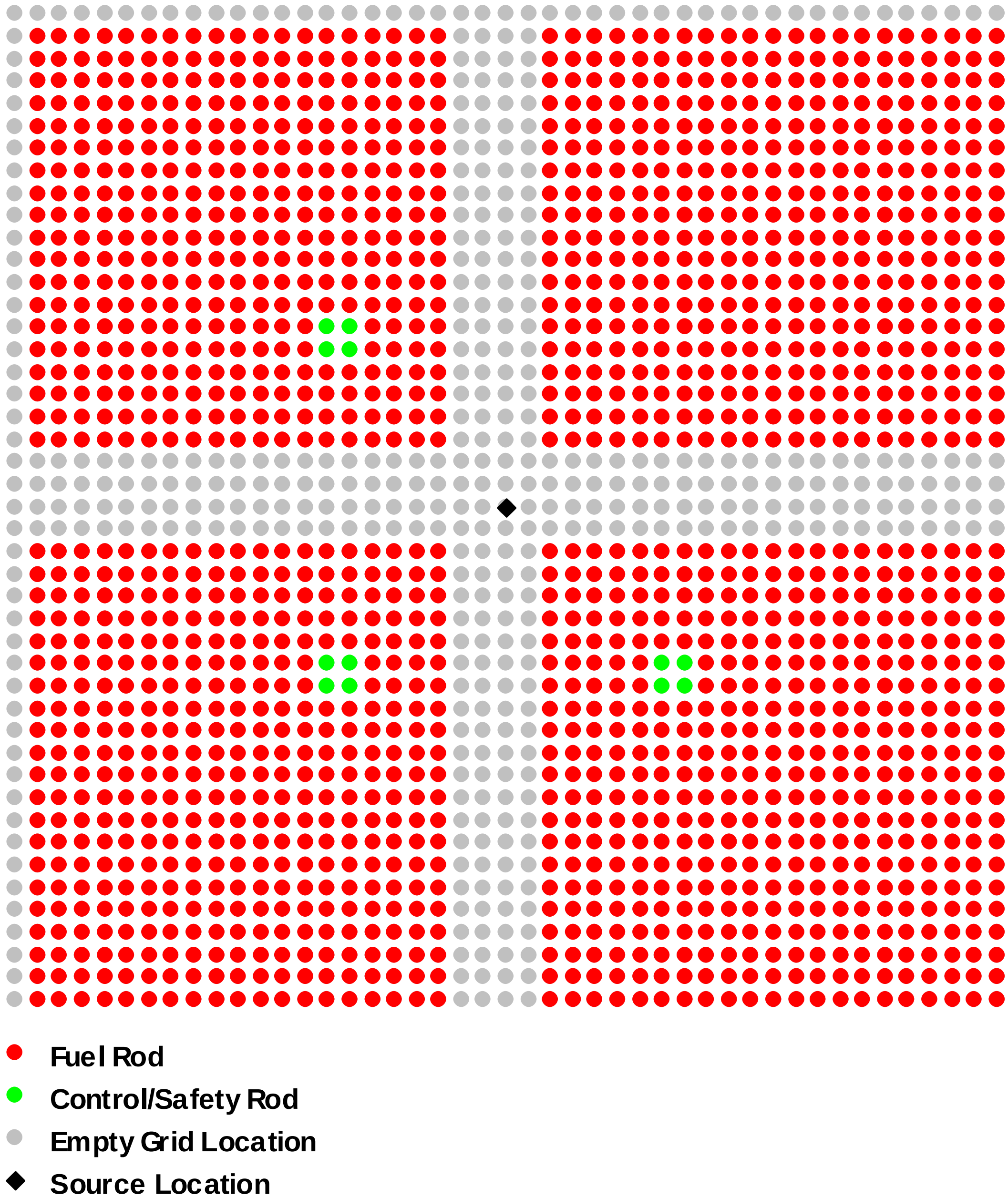

Figure 33. Fuel Rod Layout of the Array Measured for Case 19.

1.3 Description of Material Data

1.3.1 UO_2 Fuel – The fuel pellets used in the fuel rods were drawn from the fuel stock that was removed from fuel elements obtained from The Pennsylvania State University. The uranium isotopic data were measured for ten randomly-selected fuel pellets from the pool of fuel pellets used in the fuel rod fabrication using a high-resolution multi-collector inductively coupled plasma mass spectrometer (ICP-MS). The measured uranium isotopic data are given in Table 10. The uncertainties shown with the mass fractions are the standard deviations for the ten measurements. The systematic uncertainties were estimated by the laboratory that made the isotopic measurements.

Table 10. Isotopic Composition of Uranium in 6.90% Enriched UO_2 Fuel Pellets.

Uranium Isotope	Wt.%[(a)]	Systematic Uncertainty (Wt.%)[(b)]
^{234}U	0.02814 ± 0.00008	0.00013
^{235}U	6.9034 ± 0.0046	0.0069
^{236}U	0.06336 ± 0.00012	0.00063
^{238}U	93.0051 ± 0.0046	-
Total	100.000	-

(a) The uncertainties given are the standard deviations for ten measurements.
(b) The systematic uncertainties are given at the one-standard-deviation level.

The oxygen to uranium ratio was not measured.

Metallic impurities were also obtained during the ICP-MS measurements of the ten fuel pellets. The results of the impurity measurements are shown in Table 11.

Table 11. Results of the Fuel Impurity Measurements.

Element	Average [(a)] (g/g)	Standard Deviation [(a)] (g/g)	Maximum [(b)] (g/g)	Minimum [(c)] (g/g)	Reported Detection Limit [(d)] (g/g)	Measurements Above Detection Limit
Ag	1.61E-07	2.19E-07	6.67E-07	2.24E-08	2.24E-08	9
B	4.17E-07	4.73E-07	1.56E-06	2.24E-08	2.24E-08	9
Cd	2.25E-07	3.98E-07	9.36E-07	2.21E-08	2.27E-08	5
Co	2.06E-07	5.67E-08	3.13E-07	1.27E-07	-	10
Cr	2.11E-05	1.06E-05	4.03E-05	1.31E-05	-	10
Cu	2.19E-06	1.59E-06	4.95E-06	2.26E-07	2.26E-07	9
Fe	9.31E-05	4.31E-05	1.79E-04	5.27E-05	-	10
Mn	2.52E-06	1.04E-06	4.51E-06	1.50E-06	-	10
Mo	1.93E-06	1.85E-06	5.19E-06	6.34E-07	-	10
Ni	3.32E-05	1.13E-05	5.73E-05	2.31E-05	-	10
V	1.22E-07	2.33E-08	1.56E-07	9.71E-08	-	10
W	1.07E-07	1.14E-08	1.23E-07	8.53E-08	-	10
Sm	5.31E-08	-	5.31E-08	2.21E-08	2.27E-08	1
Dy	-	-	-	-	2.27E-08	0
Eu	-	-	-	-	2.27E-08	0
Gd	-	-	-	-	2.27E-08	0

(a) The impurities were reported as mass of impurity per unit UO_2 fuel pellet mass. Averages and standard deviations are reported for the measurements that were above the detection limit for the element. Measurements at the detection limits were not included in the averages or the calculation of the standard deviations. Because only one measurement was above the detection limit for Sm, no value is reported for the standard deviation.
(b) Reported maximum measured value. No value is included when all measurements were at the detection limit.
(c) Reported minimum measured value when all ten measurements were above the detection limit. Minimum of the reported detection limits when one or more measurements were below the detection limit. No value is included when all measurements were at the detection limit.
(d) The detection limit varied slightly from sample to sample. The maximum detection limit is recorded. Where all measurements were above the detection limit, no value is entered.

1.3.2 Fuel Rod Cladding – The fabrication drawings for the fuel rods specify the material for the clad tubing and end plugs as aluminum alloy 3003. The composition of the material used was not measured. The specification for the composition of aluminum alloy 3003 is given in Table 12. The density of the cladding material was not measured.

Table 12. Chemical Composition Limits of Aluminum Alloy 3003.

Element	Weight % [(a)]
Si	0.6 max
Fe	0.7 max
Cu	0.05 – 0.20
Mn	1.0 – 1.5
Zn	0.10 max
Other Elements Each	0.05 max
Other Elements Total	0.15 max
Al	Remainder

(a) From ASTM B210-04

1.3.3 Aluminum Grid Plates – The upper and lower grid plates were fabricated from 1.00 in (2.54 cm) thick plates of aluminum alloy 6061-T651. The measured composition of the grid plates is compared with the 6061 aluminum specification in Table 13. The density of the grid plate material was not measured.

Table 13. Chemical Composition Limits of Aluminum Alloy 6061 Compared to the Measured Composition of the Grid Plates.

Element	Weight %	
	6061 spec.[(a)]	Measured
Si	0.40 – 0.8	0.72
Fe	0.7 max	0.62
Cu	0.15 – 0.40	0.31
Mn	0.15 max	0.09
Mg	0.8 – 1.2	1.04
Cr	0.04 – 0.35	0.20
Zn	0.25 max	0.12
Ti	0.15 max	0.02
V	–	0.01
Zr	–	0.00
Other Elements Each	0.05 max	–
Other Elements Total	0.15 max	0.06
Al	Remainder	Remainder

(a) From ASTM B209-10

1.3.4 Aluminum Guide Plates – The composition of the aluminum tooling plate used in the guide plate was also measured. That composition is given Table 14. The density of the guide plate material was not measured.

Table 14. Chemical Composition of the Aluminum Tooling Plate used in the Guide Plate.

Element	Weight %
Si	0.50
Fe	0.60
Cu	1.2
Mn	0.75
Mg	1.6
Cr	0.06
Zn	3.00
Other Elements Total	0.06
Al	Remainder

1.3.5 Water – The water moderator in the assembly was taken from the de-ionized water supply in the facility. Samples of the moderator were taken during the experiment and archived. No chemical analysis was done on the water samples.

The facility water is taken from the Albuquerque municipal water supply. The deionizer is fed from that source. The Albuquerque municipal water system is divided into nineteen distribution regions. The water quality is monitored in each distribution region. Table 15 lists the impurities detected in the water for the year 2003. Both the city-wide average and the maximum level across the system are listed in the table.

Table 15. Impurities Measured in the Albuquerque Municipal Water Supply in the Year 2003.

Element[(a)]	Units[(b)]	City-Wide Average[(c)]	Maximum Detected in the Water System[(c)]
As	PPB	12	33
Ba	PPM	0.09	0.19
B	PPM	0.11	0.31
Cr	PPB	2	19
Fe	PPM	0.08	0.096
Mn	PPM	ND[(d)]	0.019
Se	PPB	ND	3
Zn	PPM	0.49	0.321
Ca	PPM	36	57
Mg	PPM	5.5	9.6
K	PPM	4.9	8.2
Na	PPM	46	128

(a) Elements tested but not detected in any distribution region: Cd, Sb, Be, Hg, Tl
(b) Parts Per Million (PPM) or Parts Per Billion (PPB) by mass.
(c) From http://www.cabq.gov/waterquality
(d) ND: Not Detected

1.3.6 Stainless Steel – The source capsule was fabricated from 316L stainless steel. The specific composition of the material used in the source was not measured. The specification for the composition 316L stainless steel is listed in Table 16. The density of the stainless steel was not measured.

Table 16. Composition of 316L Stainless Steel.

Element	Weight % [(a)]
C	0.030 max
Mn	2.00 max
P	0.045 max
S	0.030 max
Si	1.00 max
Cr	16.0 – 18.0
Ni	10.0 – 14.0
Mo	2.00 – 3.00
Fe	Remainder

(a) From ASTM A276-10

The composition of the corrosion-resistant steel springs in the fuel rods is listed in the manufacturer's catalog as "stainless steel." No further composition data were available on the springs.

1.3.7 Polyethylene – The fuel rods included polyethylene in the part of the rod that was in the reflector. The annuli surrounding the radiation detector dry wells were also polyethylene. Polyethylene has the basic molecular formula CH_2.

1.3.8 Boron Carbide – The boron carbide powder used to fill the absorber sections of the control and safety elements was mixed from two lots of powder mixed equally before loading into the absorber sections. The composition data for the two lots of boron carbide are given in Table 17.

Table 17. Composition and Particle Size Data for the Boron Carbide.

Quantity		Lot 1	Lot 2
Boron Mass Fraction (%)		77.0	77.0
Carbon Mass Fraction (%)		21.7	21.6
B_2O_3 Mass Fraction (%)		0.1	0.1
Silicon Mass Fraction (%)		<0.010	<0.010
Iron Mass Fraction (%)		0.10	0.10
Nitrogen Mass Fraction (%)		0.04	0.07
^{10}B Isotopic Abundance (atom %)		20.02	20.01
Particle Size Distribution (micron) [(a)]	3%	11.23	158.2
	50%	7.251	80.13
	94%	3.140	40.47

(a) The particle size above which the specified fraction of the material falls.
(b) The mass fractions do not sum to 100%. The remainder is unknown and is treated as void.

1.4 Temperature Data

The water temperature in the experiment was measured at at three different heights in the reflector of the assembly with thermocouples. The average measured temperature for each case is shown in Table 8.

1.5 Supplemental Experimental Measurements

Additional experimental measurements were not performed.

2.0 EVALUATION OF EXPERIMENTAL DATA

This section provides interpretation of some of the experiment material data, translates the experiment projections to delayed critical into k_{eff} for the benchmark experiment configurations, details adjustments to the k_{eff} data to a common temperature of 25ºC, and provides an analysis of the uncertainties in the experimental configurations. The uncertainties associated with all these factors are small.

2.1 Material Data

2.1.1 Fuel Rod UO_2 Mass – The UO_2 fuel pellet mass in each fuel rod (2199 total) and control/safety element fueled section (23 total) was measured. Records were kept of these data as well as the location and identity of every rod in all configurations. As a result, the fuel mass in each configuration was available. The average fuel mass in the entire population of 2222 fuel rods and control/safety element fueled sections was 108.7165 g with a standard deviation of 0.322 g. The average UO_2 mass for the fuel rods in each configuration is listed in Table 18.

Table 18. Average UO_2 Mass in Each Configuration

Case	Number of Fuel Rods and Control/Safety Rod Sections	Average UO_2 Mass (g)	
		Value	Standard Deviation
1	2025	108.7252	0.313
2	2024	108.7251	0.313
3	1836	108.7160	0.314
4	1977	108.7277	0.315
5	1873	108.7269	0.320
6	1781	108.7385	0.310
7	1673	108.7471	0.296
8	1573	108.7558	0.294
9	1525	108.7607	0.296
10	1600	108.7538	0.309
11	1600	108.7538	0.309
12	1600	108.7538	0.309
13	1600	108.7538	0.309
14	1600	108.7538	0.309
15	1600	108.7538	0.309
16	1600	108.7538	0.309
17	1600	108.7538	0.309
18	1600	108.7538	0.309
19	1600	108.7538	0.309

2.1.2 Fuel Impurities – The fuel pellets were fresh UO_2 with measured enrichment and impurity content for ten randomly-chosen fuel pellets. Twelve impurity elements were measured above the detection limit in at least five of the measurements. The measured impurity content and standard deviation of the ten measurements is shown in Table 19. The standard deviations shown for three of the listed elements are larger than the average mass fraction for three impurities – Ag, B, and Cd. This is because each of these species had one measurement that was much higher than the others. Also shown in the table are the thermal absorption cross section for each impurity species and the fraction of the impurity thermal macroscopic absorption cross section contributed by each species. The uncertainty in the impurity macroscopic cross section is dominated by the contribution from boron which is in turn dominated by the fact that one of the measurements is an outlier compared to the rest of the measurements.

Table 19. Fuel Impurity Analysis.

Species	Mass Fraction(a)	Standard Deviation(b)	Thermal Absorption Cross Section(c) (barns)	Fractional Macroscopic Absorption Cross Section(d)	Fractional Contribution to the Macroscopic Absorption Cross Section Uncertainty(e)
Ag	1.61E-07	2.19E-07	63	0.0022	0.0037
B	4.17E-07	4.73E-07	760	0.6744	0.9789
Cd	2.25E-07	3.98E-07	2520	0.1160	0.1928
Co	2.06E-07	5.67E-08	37.2	0.0030	0.0011
Cr	2.11E-05	1.06E-05	3.1	0.0289	0.0190
Cu	2.19E-06	1.59E-06	3.8	0.0030	0.0029
Fe	9.31E-05	4.31E-05	2.56	0.0982	0.0594
Mn	2.52E-06	1.04E-06	13.3	0.0140	0.0076
Mo	1.93E-06	1.85E-06	2.5	0.0012	0.0014
Ni	3.32E-05	1.13E-05	4.5	0.0586	0.0261
V	1.22E-07	2.33E-08	5.0	0.0003	6.9E-05
W	1.07E-07	1.14E-08	18.2	0.0002	3.4E-05
Sum	1.55E-04(f)	–	–	1.0000(f)	1.0000(g)

(a) The average of the reported impurity mass fractions that were above the detection limit.
(b) The standard deviation of the reported impurity mass fractions that were above the detection limit.
(c) Thermal neutron (2200 m/s) absorption cross section from E. M. Baum, et al., Nuclides and Isotopes Sixteenth Edition, KAPL, Inc., 2002.
(d) The impurity macroscopic absorption cross section is the sum of the [product of the species atom density and the species absorption cross section] having a value of 0.00024 cm^{-1}.
(e) The uncertainty in the impurity macroscopic absorption cross section is the sum in quadrature of the [product of the uncertainty in the species atom density and the species absorption cross section] and has a value of 0.00021 cm^{-1}.
(f) Arithmetic sum.
(g) Sum in quadrature.

2.1.3 Fuel Rod Cladding – The clad tubes and end caps for the fuel rods were fabricated from 3003 aluminum. The elemental composition of the 3003 aluminum was not measured. For the work documented here, the composition of the tubes and end caps is assumed to be at the mid-range value where an elemental content is specified as a range and as half of the maximum value where one is given for an element. The composition specification for 3003 aluminum and the composition chosen here are shown in Table 20. The density of the 3003 aluminum was taken as 2.73 g/cm^3.[1]

Table 20. Elemental Composition Specification for Aluminum Alloy 3003 and the Composition Used for the Fuel Rod Cladding in the Analyses.

Element	Specification Composition (Weight %) [(a)]	Assumed Composition (Weight %)
Si	0.6 max	0.3
Fe	0.7 max	0.35
Cu	0.05 – 0.20	0.125
Mn	1.0 – 1.5	1.25
Zn	0.10 max	0.05
Other Elements Each	0.05 max	0
Other Elements Total	0.15 max	0
Al	Remainder	97.925

(a) From ASTM B210-04

2.1.4 Source Capsule Composition – The material in the source capsule was specified as 316L stainless steel. The elemental composition was not measured. The composition for the 316L stainless steel is assumed to be at the mid-range value where an elemental content is specified as a range and as half of the maximum value where one is given for an element. The composition specification for 316L stainless steel and the derived composition used here are shown in Table 21. The density of the 316L stainless steel was taken as 8.0 g/cm^3.[2]

[1] From http://matweb.com/search/DataSheet.aspx?MatGUID=fd4a40f87d3f4912925e5e6eab1fbc40 accessed on May 29, 2012.. From http://matweb.com search for key word "3003" and choose the "Aluminum 3003-O" option.
[2] From http://matweb.com/search/DataSheet.aspx?MatGUID=a2d0107bf958442e9f8db6dc9933fe31 accessed on May 29, 2012. From http://matweb.com search for key word "316L" and choose the "AISI Type 316L Stainless Steel, annealed bar" option.

Table 21. Elemental Composition Specification for 316L Stainless Steel and the Composition Used for the Source Capsule in the Analyses.

Element	Specification Composition (Weight %) [(a)]	Assumed Composition (Weight %)
C	0.030 max	0.015
Mn	2.00 max	1.00
P	0.045 max	0.0225
S	0.030 max	0.015
Si	1.00 max	0.50
Cr	16.0 – 18.0	17.0
Ni	10.0 – 14.0	12.0
Mo	2.00 – 3.00	2.50
Fe	Remainder	66.9475

(a) From ASTM A276-10

2.1.5 Fuel Rod Spring Composition – The composition of the springs in the fuel rods and control/safety rod fueled sections was specified in the manuracturer’s catalog as stainless steel. The composition of 304 stainless steel, treated as described above, will be used. Table 22 lists the composition specification for 304 stainless steel spring wire with the derived composition. The springs, as manufactured, had an specified inner diameter of 0.138 in (0.35052 cm) and outer diameter of 0.180 in (0.4572 cm). Where they were included, the springs were modeled as annuli of inner diameter 0.35052 cm and outer diameter 0.4572 cm. The average spring mass was measured as 0.1923 ± 0.0095 g. As used in the fuel rods, the springs are compressed to a length of 1.75076 cm. The density of the springs in each model was obtained from the dimensions of the annulus and the average spring mass.

Table 22. Elemental Composition Specification for 304 Stainless Steel Spring Wire and the Composition Used for the Fuel Rod Springs in the Analyses.

Element	Specification Composition (Weight %) [(a)]	Assumed Composition (Weight %)
C	0.08 max	0.04
Mn	2.00 max	1.00
P	0.045 max	0.0225
S	0.030 max	0.015
Si	1.00 max	0.50
Cr	18.0 – 20.0	19.0
Ni	8.0 – 10.5	9.25
N	0.10 max	0.05
Fe	Remainder	70.1225

(a) From ASTM A313-10. Note that the composition differs slightly from the composition for bars and shapes given in ASTM A276-10.

2.1.6 Boron Carbide Composition – The boron carbide used in the absorber sections of the control and safety elements was mixed from two batches of boron carbide powder with slightly different compositions. The two batches were mixed equally so the appropriate composition to use is the average of the values for the two batches. The specifications for the two batches included mass fractions for boron and for B_2O_3. It is assumed that the boron included in the B_2O_3 is included in the given boron mass fraction leaving the oxygen at a mass fraction of 0.069% rounded to two significant figures. Because a maximum value is specified for silicon, half that value is assumed to be present. The elemental mass fractions in the boron carbide powder are shown in Table 23. The ^{10}B isotopic atom fraction in the boron is 20.015%.

Table 23. Composition Data for the Boron Carbide Powder

Quantity	Value
Boron Mass Fraction (%)	77.0
Carbon Mass Fraction (%)	21.65
Oxygen Mass Fraction (%)	0.069
Silicon Mass Fraction (%)	0.005
Iron Mass Fraction (%)	0.10
Nitrogen Mass Fraction (%)	0.055
Sum (%) [(a)]	98.879

(a) The mass fractions do not sum to 100%. The remainder (1.121%) is unknown and is treated as void.

2.2 Geometric Data

2.2.1 Fuel Rod Pellet Stack Height – The fuel pellet stack height in each fuel rod and control/safety element fueled section was also measured during fabrication. The average fuel pellet stack length for the entire population of 2222 fuel rods and control/safety element fueled sections was 48.7789 cm with a standard deviation of 0.125 cm. The average fuel pellet stack height for the specific fuel rods included in the benchmark experiment configurations is listed in Table 24.

Table 24. Average Fuel Pellet Stack Height in Each Configuration

Case	Number of Fuel Rods and Control/Safety Rod Sections	Average Fuel Pellet Stack Height (cm)	
		Value	Standard Deviation
1	2025	48.7777	0.120
2	2024	48.7777	0.120
3	1836	48.7709	0.119
4	1977	48.7768	0.120
5	1873	48.7751	0.121
6	1781	48.7766	0.118
7	1673	48.7764	0.116
8	1573	48.7762	0.114
9	1525	48.7746	0.115
10	1600	48.7755	0.117
11	1600	48.7755	0.117
12	1600	48.7755	0.117
13	1600	48.7755	0.117
14	1600	48.7755	0.117
15	1600	48.7755	0.117
16	1600	48.7755	0.117
17	1600	48.7755	0.117
18	1600	48.7755	0.117
19	1600	48.7755	0.117

2.2.2 Fuel Rod Diameter – The outer diameter of each fuel rod was measured. The average for the population of 2199 fuel rods was 0.634948 cm with a standard deviation of 0.000218 cm. The average outer diameter of the fuel rods for the specific fuel rods included in the benchmark experiment configurations is listed in Table 25.

Table 25. Average Fuel Rod Outer Diameter in Each Configuration

Case	Number of Fuel Rods	Average Fuel Rod Outer Diameter (cm)	
		Value	Standard Deviation
1	2013	0.634955	0.000217
2	2012	0.634955	0.000217
3	1824	0.634955	0.000217
4	1965	0.634957	0.000217
5	1861	0.634961	0.000217
6	1769	0.634963	0.000217
7	1661	0.634970	0.000215
8	1561	0.634975	0.000214
9	1513	0.634977	0.000215
10	1588	0.634973	0.000216
11	1588	0.634973	0.000216
12	1588	0.634973	0.000216
13	1588	0.634973	0.000216
14	1588	0.634973	0.000216
15	1588	0.634973	0.000216
16	1588	0.634973	0.000216
17	1588	0.634973	0.000216
18	1588	0.634973	0.000216
19	1588	0.634973	0.000216

2.2.3 Fuel Rod Cladding Inner Diameter – The mass of the assembled clad tube and lower end cap was measured for 100 samples during the fabrication of the fuel rods. The average mass was 13.824 g with a standard deviation of 0.027 g. The volume of the lower end cap was calculated from the dimensions given in the design drawings as 0.354 cm^3. Using the tolerances given on the drawing, the uncertainty in the volume is 0.010 cm^3. Using a density for 3003 aluminum of 2.73 g/cm^3, the calculated mass of the lower end cap is 0.967 g with a one-standard-deviation uncertainty based on drawing tolerances of 0.027 g. The mass of the 29.75 in (75.565 cm) long clad tube is then 12.857 g with an uncertainty of 0.027 g. The average measured outside diameter of the fuel rods is 0.249980 in (0.634948 cm as rounded from the original data) with standard deviation for 2194 measurements of 0.000086 in (0.000218 cm) and an overall uncertainty of 0.000023 in (0.000058 cm) including systematic uncertainties. From these data and using a density of 2.73 g/cm^3, an inner diameter of 0.569038 cm (0.224031 in) is obtained with an uncertainty of 0.000164 cm (0.000065 in).

2.2.4 Polyethylene Density – The average mass of the polyethylene spacers in the 2199 fuel rods is 4.454 g. The polyethylene spacer is designed as a cylinder 0.207 in (0.52578 cm) diameter and 8.38 in (21.2852 cm) long. This gives an average density of the polyethylene in the spacer of 0.96377 g/cm^3.

The average mass of the polyethylene annuli on the radiation detector dry wells is 2017.28 g. The annuli are 11.82 in (30.0228 cm) tall and have inner diameters of 2.603 in (6.61162 cm) and outer diameters of 4.535 in (11.5189 cm). The average mass and dimensions of the annuli give a polyethylene density of 0.9612 g/cm^3. Because this density is nearly the same as the density obtained for the polyethylene spacers in the fuel rods, the density derived for the spacers in the fuel rods (0.96377 g/cm^3) will be used for both types of polyethylene.

2.2.5 Boron Carbide Powder Density – The average mass of boron carbide powder in the 23 absorber sections that were fabricated is 26.37 g. With an inner diameter of the cladding of 0.569038 cm (0.224031 in) and a height for the absorber of 28.238 in (71.72452 cm), the average density of the boron carbide power is 1.4457 g/cm^3 as loaded.

2.3 Uncertainty Analyses

A number of uncertainty analyses were done. The analyses were done with KENO V.a using the 238-group ENDF/B-VII.0 cross section set from SCALE 6 or, in a few cases as noted below, with MCNP6.1 using continuous-energy ENDF/B-VII.1 cross sections. The results of the uncertainty analyses for four cases are given in Tables 28 through 31.

Where uncertainties are given below, the method of handling the uncertainties by type as defined in the *ICSBEP Guide to the Expression of Uncertainties* is followed. Where the uncertainty is given at the one-standard-deviation level, the uncertainty is used as-is. Where an uncertainty is given as a tolerance or a bounding value, it is assumed to specify an outer limit with a constant probability distribution between the limits. The value of the tolerance is divided by the square root of 3 to get the one-standard-deviation uncertainty in the nominal value. This treatment is used in the determination of the uncertainty of the fuel rod pitch and in the uncertainty of the composition of the fuel rod cladding.

In each of the following cases, the sensitivity of the assembly to a given uncertainty was determined by analyzing arrays in which the parameter varied over a range. Except as noted below, a least-squares fit of the k_{eff} data to a line was done. The stochastic uncertainties from the Monte Carlo calculations were propagated through the least-squares equations used in the fit. The sensitivity of the array to the parameter was the slope of the line. The uncertainty in the sensitivity was the uncertainty in the slope. The relative uncertainty in the sensitivity gives a measure of the statistical significance of the fit.

2.3.1 Fuel Rod Pitch – The uncertainty in the fuel rod pitch contributes to the uncertainty in the amount of water moderator in the core. This uncertainty is related to the uncertainty in the placement of the holes in the grid plates during fabrication, to the width of the nominal gap between the outside of the fuel rods and the inside of the grid plate holes, to the uncertainty in the diameter of the holes in the grid plates, to the uncertainty in the outside diameter of the fuel rods, and to the number of rows of fuel rods in the core. The fabrication tolerance in the placement of each hole is that it be within ±0.005 in (0.0127 cm) of its intended location relative to the center of the grid plate. The gap between the outside of the fuel rods and the inside of the grid plate holes is 0.00631 in (0.0160 cm). The uncertainty in the diameter of the grid plate holes is one-sided (+0.005/−0.000 in). Assuming that the nominal value of hole diameter falls at the center of this range, the tolerance is then ±0.0025 in (0.00635 cm). The outer diameters of the fuel rods were measured. The uncertainty in the average value for the configuration with the fewest rods (Case 9 with 1525 rods) is 0.0000022 in (0.000085 divided by the square root of 1525) added in quadrature to the systematic uncertainty in the diameter measurements of 0.000022 in resulting in a one-standard-deviation uncertainty of 0.000022 in (0.000056 cm). Multiplying this value by the square root of 3 to get 0.000038 in (0.000097 cm) maintains the level of significance associated with the tolerances. Summing these four values in quadrature yields

$$\sqrt{0.005^2 + 0.00631^2 + 0.0025^2 + 0.000038^2} = 0.00843 \text{ in (0.02141 cm).}$$

The tolerance in the fuel rod pitch is twice this value divided by [the diameter of the core divided by the fuel rod pitch]. Note that this last factor reduces to one less than the number of fuel rods on a chord across the core.

For Cases 1 through 9, there were 45 fuel rods on a chord across the core. In this case, the diameter of the core divided by the fuel rod pitch is 44. By the above method, the tolerance in the pitch is

$$(2 \times 0.00843 \text{ in})/44 = 0.000383 \text{ in (0.000973 cm).}$$

For Cases 10 through 19, there were at least 40 fuel rods on a chord across the core. In this case, the diameter of the core divided by the fuel rod pitch is 39. The tolerance on the pitch is then

$$(2 \times 0.00843 \text{ in})/39 = 0.000432 \text{ in (0.001098 cm).}$$

Dividing the above tolerances by the square root of three gives the one-standard-deviation value for the uncertainty in the fuel rod pitch. The values so obtained are 0.000221 in (0.000562 cm) for Cases 1 through 9 and 0.000250 in (0.000634 cm) for Cases 10 through 19.

Arrays with fuel rod pitch up to 0.01 cm on either side of the nominal value in 0.005 cm increments were analyzed to obtain the effect of pitch on k_{eff}. The results were used in a least-squares linear fit to determine the sensitivity of the experiment to the fuel rod pitch. The sensitivity was combined with the pitch uncertainty to obtain the uncertainty in the benchmark experiment k_{eff}.

2.3.2 Clad Outer Diameter – The outer diameter of the fuel rod clad tubes was measured for the 2194 rods available for the experiments. The population average for the measurements was 0.249980 in (0.634948 cm as rounded from the original data) with a standard deviation of 0.000086 in (0.000218 cm). The uncertainty in the mean value is 0.0000022 in (0.0000056 cm), the standard deviation divided by the square root of 1525, the lowest number of fuel rods in any of the benchmark experiment configurations. Because the outside diameter was known for each fuel rod and the identity of each fuel rod in every configuration was known, the distribution of the fuel rod diameters does not contribute to the uncertainty in the experiments. The systematic uncertainty in the measurements was 0.000022 in (0.000056 cm). The resolution of the instruments used was 0.000001 in (0.00000254 cm) and the repeatability was 0.000005 in (0.0000127 cm). The random uncertainty in the diameter measurements was 0.000030 in (0.0000762 cm) and will be treated as a systematic uncertainty. The sum in quadrature of the systematic uncertainties (0.000022 in, 0.000001 in, 0.000005 in, and 0.000030 in) is 0.0000375 in (0.0000954 cm). Arrays with fuel rod clad diameters up to 0.00508 cm on either side of the nominal value were analyzed to determine the sensitivity of the experiments to the clad tube diameter. The mass of the clad tube was kept constant during these variations.

2.3.3 Clad Inner Diameter – The method of obtaining the inside diameter of the fuel clad tubes based on the tube outer diameter and the measured mass of the assembly of the clad tube and the lower end cap is described above. Using that method, the uncertainty in the inner diameter of the clad tube is 0.000164 cm. Arrays with fuel rod clad inside diameters up to 0.04 cm on either side of the nominal value were analyzed. The outside diameter of the fuel rod clad tubes was held constant for these calculations.

2.3.4 Fuel Outer Diameter – The outer diameter of 123 randomly-selected fuel pellets was measured. The average diameter was 0.20694 in (0.52563 cm) with a standard deviation of 0.00019 in (0.00048 cm). The systematic uncertainties in the fuel pellet outer diameter measurements are 0.000001 in resolution, 0.000005 in repeatability, 0.000022 in absolute uncertainty, and 0.000030 in reproducibility. Considering the number of measurements and the systematic uncertainties in the measurements, the uncertainty in the average diameter is 0.000041 in (0.000105 cm). Arrays with fuel pellet diameters up to 0.004 in on either side of nominal were analyzed. The density of the fuel was modified in the analysis to keep the fuel mass in the fuel rods constant.

2.3.5 Moderator/Reflector Height – The height of the water in the core tank is set by the remotely adjustable overflow standpipe. The water height was measured by four ultrasonic sensors operated in two sets of two sensors located in diametrically opposed positions across the assembly core. Averaging the measurements from the two sensors in a set gives the height of the moderator at the center of the core.

The random uncertainty in the extrapolated critical water height contributed by the stochastic nature of the radiation detection process is listed for each case in Table 8. All values are less than 0.001 mm.

The ultrasonic sensors were read to 0.1 mm. This will be treated as the systematic uncertainty in the measurement.

A set of eleven precicely measured length standards with lengths covering the range of moderator heights encountered in the experiments was available to calibrate the ultrasonic sensors. Based on over 400 measurements in each of the still tubes, the lengths of the standards measured by the ultrasonic sensors scattered around the actual lengths of the standards with a standard deviation of about 0.35 mm. For a pair of ultrasonic sensors measuring the water height at the center of the core, the random uncertainty in the measurement is 0.35 mm divided by the square root of two. With two sets of two ultrasonic sensors, the random uncertainty at the center of the core becomes 0.5x0.35 mm. Summing the random and systematic uncertainties in quadrature gives an overall uncertainty in the water level measurement of

$$\sqrt{\left[\frac{0.35mm}{2}\right]^2 + [0.1mm]^2 + [0.001mm]^2} = 0.20mm$$

2.3.6 Fuel Rod UO_2 Mass – The UO_2 fuel mass in the driver fuel rods was measured giving a standard deviation for 2222 measurements of 0.322 g. Because the fuel mass was known for each fuel rod and the identity of each fuel rod in every configuration was known, the distribution of the fuel rod UO_2 mass does not contribute to the uncertainty in the experiments. The fuel mass measurements were made using an instrument with a repeatability of 0.01 g, linearity of 0.02 g, and readability of 0.01 g. The uncertainty in the fuel mass is the sum in quadrature of the systematic uncertainties in the mass measurements (0.01 g, 0.02 g, and 0.01 g) and is 0.024 g. Arrays with the fuel rod UO_2 mass varying from 1 g below to 1 g above the nominal value were analyzed to determine the sensitivity of the experiments to this uncertainty. The variations were done by changing the fuel density while keeping the fuel dimensions constant.

2.3.7 Fuel Rod Pellet Stack Height – The fuel pellet stack height was measured during fabrication for all fuel rods to the nearest millimeter. The systematic uncertainty in this measurement is estimated to be 0.5 mm. The standard deviation for 2222 fuel columns was 0.125 cm. Because the pellet stack height was known for each fuel rod and the identity of each fuel rod in every configuration was known, the distribution of the fuel rod UO_2 column height does not contribute to the uncertainty in the experiments. The uncertainty in the average fuel pellet stack height is the estimated systematic uncertainty in the measurement or 0.05 cm. Arrays with fuel pellet stack heights 1 cm on either side of the nominal value were analyzed to determine the sensitivity of the experiments to the uncertainty in the pellet stack height. The mass of fuel in the fuel rods was held constant by varying the fuel density to compensate for pellet stack height changes.

2.3.8 Fuel Enrichment – The fuel isotopics were measured on ten randomly-selected fuel pellet samples drawn from the pellet stock used in the experiment fuel rods. The standard deviation of the ^{235}U enrichment measurements was 0.0046 wt%. The systematic uncertainty was 0.0069 wt%. Considering the random uncertainty and the number of measurements and adding in quadrature to the systematic uncertainty, the uncertainty in the ^{235}U enrichment of the fuel is 0.0071 wt%. Arrays with the uranium enrichment varied from 0.2% below nominal to 0.2% above nominal were analyzed to determine the sensitivity of the system to the uranium enrichment. The fuel mass and volume were held constant with changes in the ^{235}U mass fraction compensated by changes in the ^{238}U mass fraction.

2.3.9 Fuel ^{234}U Content – The ^{234}U content of the fuel was also measured. The standard deviation of the ten ^{234}U measurements was 0.00008 wt%. The systematic uncertainty was 0.00013 wt%. Considering the random uncertainty and the number of measurements and adding in quadrature to the systematic uncertainty, the uncertainty in the ^{234}U content of the fuel is 0.00013 wt%. Arrays with the ^{234}U mass fraction varied from zero to twice the nominal value were analyzed to determine the sensitivity of the system to the ^{234}U mass fraction. The fuel mass and volume were held constant with changes in the ^{234}U mass fraction compensated by changes in the ^{238}U mass fraction.

2.3.10 Fuel ^{236}U Content – The ^{236}U content of the fuel was also measured. The standard deviation of the ten ^{236}U measurements was 0.00012 wt%. The systematic uncertainty was 0.00063 wt%.

Considering the random uncertainty and the number of measurements and adding in quadrature to the systematic uncertainty, the uncertainty in the ^{236}U content of the fuel is 0.00063 wt%. Arrays with the ^{236}U mass fraction varied from zero to twice the nominal value were analyzed to determine the sensitivity of the system to the ^{236}U mass fraction. The fuel mass and volume were held constant with changes in the ^{236}U mass fraction compensated by changes in the ^{238}U mass fraction.

2.3.11 Fuel Stoichiometry – The oxygen-to-uranium ratio in the fuel was not measured and was assumed to be 2.00. A range of 0.1 was assumed to bound the uncertainty in the oxygen-to-uranium ratio. Arrays with fuel of $UO_{1.8}$ to $UO_{2.2}$ were analyzed to determine the sensitivity of the assembly to this parameter. During the variations, the fuel density was adjusted to hold the fuel mass and volume constant in the fuel rods.

2.3.12 Impurities in the UO_2 Fuel – The impurities in the fuel fell into two classes – those for which a definite value was measured and those that were determined to be less than the detection limit for the analysis system. For this analysis, an “impurity unit” – i.u. – will be defined as the level of impurities detected. For the impurities that were detected, an uncertainty at the one-standard-deviation level of 50% of the detected value (0.5 i.u.) was assumed. The arrays were analyzed with fuel containing none of this class of impurities (0 i.u.), the reported level (1 i.u.), and twice the reported level with all impurities (2 i.u.). The fuel mass and volume were held constant during the variations.

For the impurities that were below the detection limit, the fuel content was varied in integral multiples of the detection limit from 0 to 4. Here, the i.u. is defined as the composition of this class of impurities, each at its detection level. The uncertainty was assumed to be the detection limit or 1 i.u.. The fuel mass and volume were held constant during the variations.

2.3.13 Fuel Clad Composition – The composition range for 3003 aluminum tubing is shown in Table 20 above. The effect of changes in the concentration of any given element depends on the absorption cross section of the element relative to that of aluminum. Table 26 lists the thermal neutron absorption cross section for each element listed in the composition of 3003 aluminum. Most of the elements listed have a larger absorption cross section than aluminum. The exception is Si. The maximum absorption cross section for 3003 aluminum occurs for the composition that has the maximum concentration of all elements except Si. The content of Si is minimized, replaced by aluminum, to obtain the maximum absorption cross section.

Table 26. Thermal Neutron Absorption Cross Sections for All Elements Listed in the Composition for 3003 Aluminum.

Element	σ_a (barn)[(a)]	Element	σ_a (barn)[(a)]
Al	0.230		
Si	0.168	Mn	13.3
Fe	2.56	Zn	1.1
Cu	3.8		

(a) Thermal neutron (2200 m/s) absorption cross section from J. R. Parrington, et al., Nuclides and Isotopes Fifteenth Edition, General Electric, Co., 1996.

The sensitivity of the experiment to the composition of the 3003 aluminum was obtained by calculating the k_{eff} for three compositions of 3003 aluminum. The nominal composition is described above. The composition with minimum absorption cross section was formulated by including all elements at the minimum concentration except Si, which was included at the maximum concentration. The composition with maximum absorption cross section was formulated inversely with all elements included at maximum concentration except Si, which were included at the minimum concentration.

The change from one composition to the nominal composition can be defined as one "composition unit" (c.u.). In this case, the composition unit is the change of the composition by half the range for elements given as a range of values and half of the maximum for elements with maximum content given, all elements being changed in concert. Because the composition is specified as limits, the one-standard-deviation variation of the composition is assumed to be one "composition unit" divided by the square root of three or 0.577 "composition units."

2.3.14 Aluminum Grid Plate Composition – The elemental composition of the 6061 aluminum grid plates was measured and reported by the supplier of the grid plates. No uncertainties were given for the measurements. The measured composition for the aluminum grid plates is shown in Table 13 above. The aluminum was treated in a manner similar to the 3003 aluminum cladding. Table 27 lists the thermal neutron absorption cross sections for the measured constituents of the aluminum. All of the listed elements have larger absorption cross sections than aluminum except Si and Mg.

Table 27. Thermal Neutron Absorption Cross Sections for All Elements Listed in the Composition for the Aluminum Grid Plates.

Element	σ_a (barn)[(a)]	Element	σ_a (barn)[(a)]	Element	σ_a (barn)[(a)]
Al	0.230				
Si	0.168	Mn	13.3	Zn	1.1
Fe	2.56	Mg	0.066	Ti	6.1
Cu	3.8	Cr	3.1	V	5.0

(a) Thermal neutron (2200 m/s) absorption cross section from J. R. Parrington, et al., Nuclides and Isotopes Fifteenth Edition, General Electric, Co., 1996.

The sensitivity of the arrays to the composition of the aluminum grid plates was obtained by calculating the k_{eff} of the array with two aluminum compositions in addition to the nominal composition. For this analysis, the bounding composition for low absorption had the content of all constituents reduced 50% from the measured value except Si and Mg, which were at increased by 50%. The bounding composition for high absorption had the reverse – all elements at increased 50% except Si and Mg, which were reduced 50%.

The variation was over one half of one "composition unit" where a composition unit is defined here as modifying the constituents by 100% of the measured value. A somewhat arbitrary but bounding assumption was made that the uncertainty in the measured composition of the aluminum was 0.25 "composition units."

2.3.15 Water Composition – The impurities measured in the municipal water supply that feeds the facility are listed in Table 15 above. The sensitivity of the experiments to the water composition was determined by analyzing arrays containing no impurities, the city-wide average impurities and the city-wide maximum impurities. For conservatism, the maximum impurity levels were assumed to be the 1-σ uncertainties.

2.3.16 Temperature – The experiments were run near a temperature of 25°C and the data were corrected to that temperature. A bounding estimate of the uncertainty in the measured experiment temperature is 1 C. The sensitivity of the arrays to moderator/reflector temperature was determined by analyzing arrays at temperatures from 5 to 45 C in 5 C increments using MCNP6.1 and ENDF/B-VII.1 cross sections. In the analysis, the water temperature was varied as well as the water density. Thermal scattering kernel data appropriate for each water temperature were used during the variations. The sensitivity of the arrays to fuel temperature was also computed with the same code/cross sections using the temperature-dependent uranium cross sections included with the code. The variations in the calculated k_{eff} data in both cases necessitated the use of a second-order polynomial fit. The sensitivity was taken as the slope of the polynomial at the experiment temperature. The stochastic uncertainties in the Monte Carlo calculations were propagated through the fit. The two sensitivities were combined to obtain the overall temperature sensitivity of the assemblies. The uncertainties in the two sensitivities were combined in quadrature.

2.3.17 Uncertainty Values – The results of the sensitivity studies were combined with the uncertainties in the various parameters to determine the contribution of each uncertainty source to the overall uncertainty in the experiments. The results are shown in Table 28 for Case 1, in Table 29 for Case 3, in Table 30 for Case 8, and in Table 31 for Case 13. For each array, the uncertainty contribution from each source is listed. Also listed is the total uncertainty for each configuration which is the sum in quadrature of the various uncertainty components. This value represents the uncertainty in the experiments at the one-standard-deviation level.

Table 28. Results of the Uncertainty Analysis for Case 1.

Uncertainty Source	Uncertainty Value	Sensitivity Value[a]	Sensitivity Unc.[b]	Δk_{eff}
Pitch of Fuel Rods (cm)	0.000562	1.2559	0.0023	0.00071
Clad OD (cm)	0.0000954	-1.2794	0.0044	-0.00012
Clad ID (cm)	0.000164	-0.1215	0.0005	-0.00002
Fuel Pellet OD (cm)	0.000105	-0.05143	0.0014	-0.00001
Water Depth (mm)	0.20	0.0005286	0.0000004	0.00011
Rod Fuel Mass (g)	0.024	0.000818	0.000015	0.00002
Rod Fuel Length (cm)	0.05	-0.001517	0.000022	-0.00008
Enrichment (wt %)	0.0071%	1.644	0.011	0.00012
^{234}U (wt %)	0.00013%	-4.911	0.065	-0.00001
^{236}U (wt %)	0.00063%	-1.838	0.023	-0.00001
UO_2 Stoichiometry (O per U)	0.1	-0.00526	0.00010	-0.00053
Measured Fuel Impurities (i.u.)[c]	0.5	-0.000184	0.000007	-0.00009
Undetected Fuel Impurities (i.u.)[c]	1.0	-0.000036	0.000009	-0.00004
Clad Composition (c.u.)[d]	0.577	-0.000389	0.000014	-0.00022
Grid Plate Composition (c.u.)[d]	0.25	-0.000626	0.000027	-0.00016
Water Impurities (w.u.)[e]	1.0	-0.000009	0.000007	-0.00001
Temperature (K)	1	-0.0000465	0.0000015	-0.00005
			Sum in Quadrature	0.00095

(a) The sensitivity analysis for assembly temperature was done with the code MCNP6.1 using continuous-energy ENDF/B-VII.1 cross sections. The remaining sensitivity analyses were done with the code KENO V.a using the 238-group ENDF/B-VII.0 cross section set from SCALE6.

(b) 1-σ uncertainty due to the stochastic uncertainties contributed by the Monte Carlo calculations done for the sensitivity studies.

(c) The “impurity unit” (i.u.) is defined as the measured level of all measured impurities or as the detection limit for all undetected impurities.

(d) A “composition unit” (c.u.) is defined as described in the text.

(e) The “water impurity unit” (w.u.) is defined as the change from pure water to the maximum impurity level given in Table 15.

Table 29. Results of the Uncertainty Analysis for Case 3.

Uncertainty Source	Uncertainty Value	Sensitivity		Δk_{eff}
		Value[(a)]	Unc.[(b)]	
Pitch of Fuel Rods (cm)	0.000552	1.0659	0.0023	0.00060
Clad OD (cm)	0.0000954	-1.0953	0.0045	-0.00010
Clad ID (cm)	0.000164	-0.1153	0.0005	-0.00002
Fuel Pellet OD (cm)	0.000105	-0.0369	0.0014	0.00000
Water Depth (mm)	0.20	0.0007164	0.0000013	0.00014
Rod Fuel Mass (g)	0.024	0.000926	0.000015	0.00002
Rod Fuel Length (cm)	0.05	-0.001929	0.000022	-0.00010
Enrichment (wt %)	0.0071%	1.716	0.011	0.00012
^{234}U (wt %)	0.00013%	-4.615	0.064	-0.00001
^{236}U (wt %)	0.00063%	-1.630	0.024	-0.00001
UO_2 Stoichiometry (O per U)	0.1	-0.00584	0.00009	-0.00058
Measured Fuel Impurities (i.u.)[(c)]	0.5	-0.000199	0.000007	-0.00010
Undetected Fuel Impurities (i.u.)[(c)]	1.0	-0.000038	0.000009	-0.00004
Clad Composition (c.u.)[(d)]	0.577	-0.000401	0.000014	-0.00023
Grid Plate Composition (c.u.)[(d)]	0.25	-0.000739	0.000028	-0.00018
Water Impurities (w.u.)[(e)]	1.0	-0.000028	0.000007	-0.00003
Temperature (K)	1	-0.0000526	0.0000014	-0.00005
			Sum in Quadrature	0.00093

(a) The sensitivity analysis for assembly temperature was done with the code MCNP6.1 using continuous-energy ENDF/B-VII.1 cross sections. The remaining sensitivity analyses were done with the code KENO V.a using the 238-group ENDF/B-VII.0 cross section set from SCALE6.

(b) 1-σ uncertainty due to the stochastic uncertainties contributed by the Monte Carlo calculations done for the sensitivity studies.

(c) The "impurity unit" (i.u.) is defined as the measured level of all measured impurities or as the detection limit for all undetected impurities.

(d) A "composition unit" (c.u.) is defined as described in the text.

(e) The "water impurity unit" (w.u.) is defined as the change from pure water to the maximum impurity level given in Table 15.

Table 30. Results of the Uncertainty Analysis for Case 8.

Uncertainty Source	Uncertainty Value	Sensitivity		Δk_{eff}
		Value[(a)]	Unc.[(b)]	
Pitch of Fuel Rods (cm)	0.000562	1.3140	0.0022	0.00074
Clad OD (cm)	0.0000954	-1.2670	0.0050	-0.00012
Clad ID (cm)	0.000164	-0.1085	0.0006	-0.00002
Fuel Pellet OD (cm)	0.000105	-0.0546	0.0025	-0.00001
Water Depth (mm)	0.20	0.0002891	0.0000007	0.00006
Rod Fuel Mass (g)	0.024	0.000690	0.000026	0.00002
Rod Fuel Length (cm)	0.05	-0.000735	0.000023	-0.00004
Enrichment (wt %)	0.0071%	1.602	0.012	0.00011
^{234}U (wt %)	0.00013%	-4.953	0.089	-0.00001
^{236}U (wt %)	0.00063%	-1.832	0.040	-0.00001
UO_2 Stoichiometry (O per U)	0.1	-0.00457	0.00011	-0.00046
Measured Fuel Impurities (i.u.)[(c)]	0.5	-0.000193	0.000010	-0.00010
Undetected Fuel Impurities (i.u.)[(c)]	1.0	-0.000018	0.000014	-0.00002
Clad Composition (c.u.)[(d)]	0.577	-0.000335	0.000025	-0.00019
Grid Plate Composition (c.u.)[(d)]	0.25	-0.000384	0.000051	-0.00010
Water Impurities (w.u.) [(e)]	1.0	-0.000030	0.000014	-0.00003
Temperature (K)	1	-0.0000380	0.0000013	-0.00004
			Sum in Quadrature	0.00092

(a) The sensitivity analysis for assembly temperature was done with the code MCNP6.1 using continuous-energy ENDF/B-VII.1 cross sections. The remaining sensitivity analyses were done with the code KENO V.a using the 238-group ENDF/B-VII.0 cross section set from SCALE6.

(b) 1-σ uncertainty due to the stochastic uncertainties contributed by the Monte Carlo calculations done for the sensitivity studies.

(c) The "impurity unit" (i.u.) is defined as the measured level of all measured impurities or as the detection limit for all undetected impurities.

(d) A "composition unit" (c.u.) is defined as described in the text.

(e) The "water impurity unit" (w.u.) is defined as the change from pure water to the maximum impurity level given in Table 15.

Table 31. Results of the Uncertainty Analysis for Case 13.

Uncertainty Source	Uncertainty Value	Sensitivity		Δk_{eff}
		Value[(a)]	Unc.[(b)]	
Pitch of Fuel Rods (cm)	0.000634	1.0181	0.0038	0.00065
Clad OD (cm)	0.0000954	-1.0471	0.0086	-0.00010
Clad ID (cm)	0.000164	-0.1029	0.0010	-0.00002
Fuel Pellet OD (cm)	0.000105	-0.0420	0.0031	0.00000
Water Depth (mm)	0.20	0.0004637	0.00000095	0.00009
Rod Fuel Mass (g)	0.024	0.000909	0.000030	0.00002
Rod Fuel Length (cm)	0.05	-0.001728	0.000039	-0.00009
Enrichment (wt %)	0.0071%	1.762	0.022	0.00012
^{234}U (wt %)	0.00013%	-4.42	0.11	-0.00001
^{236}U (wt %)	0.00063%	-1.570	0.049	-0.00001
UO_2 Stoichiometry (O per U)	0.1	-0.00593	0.00014	-0.00059
Measured Fuel Impurities (i.u.)[(c)]	0.5	-0.000270	0.000014	-0.00014
Undetected Fuel Impurities (i.u.)[(c)]	1.0	-0.000085	0.000017	-0.00009
Clad Composition (c.u.)[(d)]	0.577	-0.000359	0.000031	-0.00021
Grid Plate Composition (c.u.)[(d)]	0.25	-0.000528	0.000063	-0.00013
Water Impurities (w.u.) [(e)]	1.0	-0.000139	0.000020	-0.00014
Temperature (K)	1	0.0000040	0.0000023	0.00000
			Sum in Quadrature	0.00095

(a) The sensitivity analysis for assembly temperature was done with the code MCNP6.1 using continuous-energy ENDF/B-VII.1 cross sections. The remaining sensitivity analyses were done with the code KENO V.a using the 238-group ENDF/B-VII.0 cross section set from SCALE6.
(b) 1-σ uncertainty due to the stochastic uncertainties contributed by the Monte Carlo calculations done for the sensitivity studies.
(c) The "impurity unit" (i.u.) is defined as the measured level of all measured impurities or as the detection limit for all undetected impurities.
(d) A "composition unit" (c.u.) is defined as described in the text.
(e) The "water impurity unit" (w.u.) is defined as the change from pure water to the maximum impurity level given in Table 15.

The fuel configurations in Cases 1, 2, 4, and 5 are square or nearly square and almost completely fill the 45x45 grid plate. The uncertainties obtained for Case 1 will be used for these cases. The uncertainties obtained for Case 3 will be used only for that case. The cross sections of the fuel configurations for Cases 6 through 9 are more circular and leave a significant number of grid plate locations open outside the array. The fuel configuration of case 10 is square but does not fill the grid plate. The uncertainties calculated for Case 8 will be used for Cases 6 through 10. The fuel configurations for Cases 11 through 19 have water-filled internal slots. The uncertainties calculated for Case 13 will be used for cases 11 through 19.

3.0 BENCHMARK SPECIFICATIONS

3.1 Description of Model

The models of the experiments consist of square-pitched arrays of UO_2 fuel rods supported by aluminum grid plates and completely submerged in water. The arrays are centered in a 93.6752 cm diameter cylinder of water with 16.51 cm of water below the lower grid plate. The height of the water moderator/reflector above was varied to determine the level that made the experiment configuration critical. This section first describes the reactivity effects of several simplifications of the array configurations that are included in the benchmark models and evaluates the bias introduced by the model simplifications. The simplifications are examined individually to determine the magnitude of the reactivity effect due to each. The reactivity effect of each simplification is small and the aggregate effects are also small. The overall model bias is determined by the comparison of the results for the benchmark model with the results for a detailed model with no simplifications of each case. The section concludes with an analysis of temperature corrections necessary to account for the differences between the experiment temperatures and the benchmark model temperature of 25 ºC.

3.1.1 Modeling Approximations – The fuel rods in the benchmark models will be modeled set at the nominal dimensions averaged over the entire population of fuel rods. This creates slight discrepancies between the averages of the fuel UO_2 mass, fuel pellet stack height, and average fuel rod outside diameter and the values of these quantities for each benchmark configuration. The sensitivity of the configurations to each of these parameters was determined as part of the uncertainty analysis using KENOV.a and ENDF/B-VII.0 cross sections. The biases introduced by the modeling approximations can therefore be obtained and taken into account in the benchmark model k_{eff}. The sensitivity obtained for case 1 will be used for cases 1, 2, 4, and 5. The sensitivity obtained for Case 8 will be used for Cases 6 through 10. The sensitivity obtained for Case 13 will be used for Cases 11 through 19. Table 32 lists the biases associated with using the average fuel rod UO_2 mass, Table 33 lists the biases associated with using the average fuel pellet stack height, and Table 34 lists the biases associated with using the average fuel rod outside diameter.

Table 32. Bias Introduced by Using the Population Average Value for the UO_2 Fuel Mass.

	Sensitivity	Uncertainty
Cases 1, 2, 4, and 5	0.000818	0.000015
Case 3	0.000926	0.000015
Cases 6 through 10	0.000690	0.000026
Cases 11 through 19	0.000909	0.000030

	Fuel Rod UO_2 Mass (g)	Model UO_2 Mass Difference (g)	Bias	Uncertainty
Benchmark Model	108.7165	–	–	–
Case 1	108.7252	-0.0087	-0.000007	0.000000
Case 2	108.7251	-0.0086	-0.000007	0.000000
Case 3	108.7160	0.0005	0.000000	0.000000
Case 4	108.7277	-0.0112	-0.000009	0.000000
Case 5	108.7269	-0.0104	-0.000008	0.000000
Case 6	108.7385	-0.0220	-0.000015	0.000000
Case 7	108.7471	-0.0306	-0.000021	0.000000
Case 8	108.7558	-0.0393	-0.000027	0.000000
Case 9	108.7607	-0.0442	-0.000030	0.000000
Case 10	108.7538	-0.0373	-0.000026	0.000000
Case 11	108.7538	-0.0373	-0.000034	0.000000
Case 12	108.7538	-0.0373	-0.000034	0.000000
Case 13	108.7538	-0.0373	-0.000034	0.000000
Case 14	108.7538	-0.0373	-0.000034	0.000000
Case 15	108.7538	-0.0373	-0.000034	0.000000
Case 16	108.7538	-0.0373	-0.000034	0.000000
Case 17	108.7538	-0.0373	-0.000034	0.000000
Case 18	108.7538	-0.0373	-0.000034	0.000000
Case 19	108.7538	-0.0373	-0.000034	0.000000

Table 33. Bias Introduced by Using the Population Average Value for the Fuel Pellet Stack Height.

	Sensitivity	Uncertainty
Cases 1, 2, 4, and 5	-0.001517	0.000022
Case 3	-0.001929	0.000022
Cases 6 through 10	-0.000735	0.000023
Cases 11 through 19	-0.001728	0.000039

	Fuel Pellet Stack Height (cm)	Model Stack Height Difference (cm)	Bias	Uncertainty
Benchmark Model	48.780	–	–	–
Case 1	48.7777	0.0023	-0.000003	0.000000
Case 2	48.7777	0.0023	-0.000003	0.000000
Case 3	48.7709	0.0091	-0.000018	0.000000
Case 4	48.7768	0.0032	-0.000005	0.000000
Case 5	48.7751	0.0049	-0.000007	0.000000
Case 6	48.7766	0.0034	-0.000003	0.000000
Case 7	48.7764	0.0036	-0.000003	0.000000
Case 8	48.7762	0.0038	-0.000003	0.000000
Case 9	48.7746	0.0054	-0.000004	0.000000
Case 10	48.7755	0.0045	-0.000003	0.000000
Case 11	48.7755	0.0045	-0.000008	0.000000
Case 12	48.7755	0.0045	-0.000008	0.000000
Case 13	48.7755	0.0045	-0.000008	0.000000
Case 14	48.7755	0.0045	-0.000008	0.000000
Case 15	48.7755	0.0045	-0.000008	0.000000
Case 16	48.7755	0.0045	-0.000008	0.000000
Case 17	48.7755	0.0045	-0.000008	0.000000
Case 18	48.7755	0.0045	-0.000008	0.000000
Case 19	48.7755	0.0045	-0.000008	0.000000

Table 34. Bias Introduced by Using the Population Average Value for the Fuel Rod Outer Diameter.

	Sensitivity	Uncertainty
Cases 1, 2, 4, and 5	-1.2794	0.0044
Case 3	-1.0953	0.0045
Cases 6 through 10	-1.2670	0.0050
Cases 11 through 19	-1.0471	0.0086

	Fuel Rod Outer Diameter (cm)	Model Rod OD Difference (cm)	Bias	Uncertainty
Benchmark Model	0.634948	–	–	–
Case 1	0.634955	-0.000007	0.000009	0.000000
Case 2	0.634955	-0.000007	0.000009	0.000000
Case 3	0.634955	-0.000007	0.000008	0.000000
Case 4	0.634957	-0.000009	0.000011	0.000000
Case 5	0.634961	-0.000013	0.000016	0.000000
Case 6	0.634963	-0.000015	0.000019	0.000000
Case 7	0.634970	-0.000022	0.000028	0.000000
Case 8	0.634975	-0.000027	0.000034	0.000000
Case 9	0.634977	-0.000029	0.000037	0.000000
Case 10	0.634973	-0.000025	0.000032	0.000000
Case 11	0.634973	-0.000025	0.000026	0.000000
Case 12	0.634973	-0.000025	0.000026	0.000000
Case 13	0.634973	-0.000025	0.000026	0.000000
Case 14	0.634973	-0.000025	0.000026	0.000000
Case 15	0.634973	-0.000025	0.000026	0.000000
Case 16	0.634973	-0.000025	0.000026	0.000000
Case 17	0.634973	-0.000025	0.000026	0.000000
Case 18	0.634973	-0.000025	0.000026	0.000000
Case 19	0.634973	-0.000025	0.000026	0.000000

3.1.2 Align Axial Dimensions – The fuel rods are designed with an aluminum spacer in them to fill the space at the level of the upper grid plate with the same metal as the grid plate. In the execution of the design, the spacer is displaced upward slightly by about 0.036 cm. In the benchmark model, the spacer is placed at the level of the upper grid plate which changed the length of the spring from 1.75076 cm to 1.7152 cm. This small displacement is judged to have an insignificant reactivity impact. This was verified by comparing the results of a detailed MCNP6.1 model using continuous-energy ENDF/B-VII.1 cross sections in which the axial positioning of all parts was as described in Section 1 with the results of the same model in which the spacers had been moved in line with the upper grid plate for Cases 1, 3, 8, 10, and 13. In the modified models, the space for the springs was changed slightly and the density of the spring material was adjusted to preserve the measured mass of the springs. The uncertainty-weighted average difference for the five cases was 0.00000 ± 0.00002.

3.1.3 Experiment Parts Above the Reflector – The benchmark model does not include the parts of the configuration that fall more than 68.2752 cm above the top of the bottom grid plate. The same detailed MCNP6.1 model was used to estimate the bias contributed by this change. The uncertainty-weighted average difference for Cases 1, 3, 8, 10, and 13 was -0.00011 ± 0.00002.

3.1.4 Upper Grid Plate Support Bosses and Posts – The upper grid plate is supported by four aluminum posts that attach to support bosses at the corners of the grid plate. The guide plate is similarly supported by four aluminum posts. The bosses and posts were removed from the detailed MCNP6.1 model of the assembly. The uncertainty-weighted average reactivity change was -0.00010 ± 0.00002 for Cases 1, 3, 8, 10, and 13.

3.1.5 Convert Control and Safety Elements to Fuel Rods – The fueled sections and polyethylene decoupler sections of the control and safety elements were designed to be similar to the design of the fuel rods. Replacing the control and safety elements in the benchmark configurations was judged to have small reactivity impact. This was again verified through the use of the detailed MCNP6.1 model and ENDF/B-VII.1 cross sections. The uncertainty-weighted average reactivity change for Cases 1, 3, 8, 10, and 13 was 0.00003 ± 0.00002.

3.1.6 Remove the Neutron Source – The benchmark model was simplified by removing the neutron source and replacing it with an unfueled position. The detailed MCNP6.1 model with ENDF/B-VII.1 cross sections was used to investigate the effect for five cases. Case 1, Case 8, and Case 10 had the source on the periphery of the fuel array. Cases 3 and 13 had the source in the center of the fuel array. The reactivity change associated with the removal of the source and replacement with water below the moderator level and void above is shown for the five cases investigated in Table 35.

Table 35. Calculated Reactivity Change Caused by Removal of the Source

Case	Reactivity Change	Uncertainty
1	0.00001	0.00003
3	0.00017	0.00003
8	0.00002	0.00003
10	-0.00001	0.00003
13	0.00005	0.00003
Weighted Average [(a)]	0.00005	0.00001

(a) The uncertainty-weighted average for all five cases.

3.1.7 Remove the Tank Walls, Floor, and the Lower Projection – The effect of the removal of the core tank walls and floor and the removal of the projection below the core tank was investigated as described above. The uncertainty-weighted average reactivity change caused by this change was -0.00008 ± 0.00002 for Cases 1, 3, 8, 10, and 13.

3.1.8 Effect of Materials Outside the Core Tank – The effect of return from the reactor room walls was investigated by comparing the results of MCNP6.1 calculations using the detailed model of the assembly with and without the inclusion of a model of the reactor room. The uncertainty-weighted average reactivity change for removal of the reactor room model in Cases 1, 3, 8, 10, and 13 was -0.00003 ± 0.00002.

3.1.9 Effect of Polyethylene Density Simplification – The critical experiments included polyethylene in the fuel rods, the control and safety elements, and surrounding the detectors outside the core. Based on the dimensions and average measured mass of the polyethylene sections in the fuel rods, the density of the polyethylene was calculated as 0.96377 g/cm^3. The density of the polyethylene annuli around the detectors was derived as 0.9612 g/cm^3 based on the measured dimensions and masses of the two annuli. The effect of using the density of the polyethylene in the fuel rods for the polyethylene around the detectors was investigated by comparing the results of MCNP6.1 calculations using the the different polyethylene densities and using uniform densities. The uncertainty-weighted average reactivity change for the uniform densities for cases 1, 3, 8, 10, and 13 was -0.00003 ± 0.00002.

3.1.10 Integral Calculation of the Benchmark Model Bias – The k_{eff} for all cases was calculated using the detailed MCNP6.1 model and compared to the calculated k_{eff} for a model in which the simplifications described in sections 3.1.1 through 3.1.8 had been made. Table 36 lists the biases attributable to the model simplifications. The bias associated with simplification of the benchmark model is small in all cases. The biases listed in the table will be applied to the benchmark model k_{eff}.

Table 36. Benchmark Model Bias and Uncertainty

Case	Benchmark Model Bias	Uncertainty in the Bias
1	-0.00016	0.00003
2	-0.00007	0.00003
3	-0.00013	0.00003
4	-0.00016	0.00003
5	-0.00014	0.00003
6	-0.00019	0.00003
7	-0.00014	0.00003
8	-0.00013	0.00003
9	-0.00006	0.00003
10	-0.00012	0.00003
11	-0.00002	0.00003
12	0.00000	0.00003
13	-0.00010	0.00003
14	-0.00008	0.00003
15	-0.00011	0.00003
16	-0.00006	0.00003
17	-0.00008	0.00003
18	-0.00006	0.00003
19	-0.00013	0.00003

3.1.11 Temperature Corrections to k_{eff} – The benchmark experiments were run near a temperature of 25°C and this temperature was chosen as the benchmark model temperature. The experiment k_{eff} for all cases was 1.0. A correction to the experiment k_{eff}, Δk_T, for a temperature difference ΔT between the experiment temperature and the benchmark model temperature is given by

$$\Delta k_T = \Delta T \bullet S_T$$

where S_T is the temperature sensitivity of the configuration involved.

Detailed models of all cases were analyzed for moderator temperatures in 5°C increments from 5°C to 45°C using MCNP6.1 with continuous-energy ENDF/B-VII.1 cross sections using thermal scattering data and water densities appropriate to each temperature. The moderator temperature sensitivity of each model was determined by fitting a second-order polynomial to the k_{eff} results as a function of moderator temperature and finding the slope of the fitting function at 25°C.

Detailed models of the same cases were analyzed at fuel temperatures of 250, 293, 600, 900, and 1200 K using MCNP6.1 with continuous-energy uranium cross sections at those temperatures. Thermal expansion of the UO_2 was included in the analysis. As for the moderator, the temperature sensitivity of each model was determined by fitting a second-order polynomial to the k_{eff} result and finding the slope of the fitting function at 25°C. The overall temperature sensitivity S_T was taken as the sum of the moderator and fuel sensitivities. The combined temperature sensitivity S_T, the experiment temperature, and the Δk_T correction to the benchmark model k_{eff} are shown in Table 37.

Table 37. Temperature Corrections to the Benchmark Model k_{eff}

Case	Temperature Sensitivity S_T ($\times10^{-5}$ °C^{-1})		Experiment Temperature (°C)	Temperature Correction Δk_T to Benchmark Model k_{eff}	
	Value	σ		Value	σ
1	-4.65	0.15	24.7	0.00001	0.00000
2	-4.65	0.15	24.8	0.00001	0.00000
3	-5.26	0.14	24.9	0.00001	0.00000
4	-4.04	0.35	24.8	0.00001	0.00000
5	-4.34	0.21	24.8	0.00001	0.00000
6	-4.82	0.17	25.0	0.00000	0.00000
7	-3.46	0.21	24.9	0.00000	0.00000
8	-3.80	0.13	25.1	0.00000	0.00000
9	-2.80	0.18	25.0	0.00000	0.00000
10	-2.24	0.23	25.1	0.00000	0.00000
11	-2.52	0.21	25.2	-0.00001	0.00000
12	-2.00	0.19	25.2	0.00000	0.00000
13	0.41	0.23	25.2	0.00000	0.00000
14	3.68	0.18	25.2	0.00001	0.00000
15	8.15	0.20	25.3	0.00002	0.00000
16	-2.85	0.21	25.4	-0.00001	0.00000
17	-1.28	0.21	25.5	-0.00001	0.00000
18	3.26	0.20	25.0	0.00000	0.00000
19	10.14	0.18	25.0	0.00000	0.00000

3.2 Dimensions

The critical assembly can be modeled as a cylinder of water with two grid plates in it supporting a 45×45 square-pitched array of fuel rods centered on the axis of the cylinder. The water only partially covers the fuel in the experiment. Except in Case 1, not all of the array positions are fueled – some have no fuel rod. The model includes two dry wells surrounded by polyethylene outside of the fuel array that were used for radiation detection instruments. A cut-away perspective view of the benchmark model for Case 5 is shown in Figure 34. A layout of the Benchmark model for Case 13 with the water removed is shown in Figure 35.

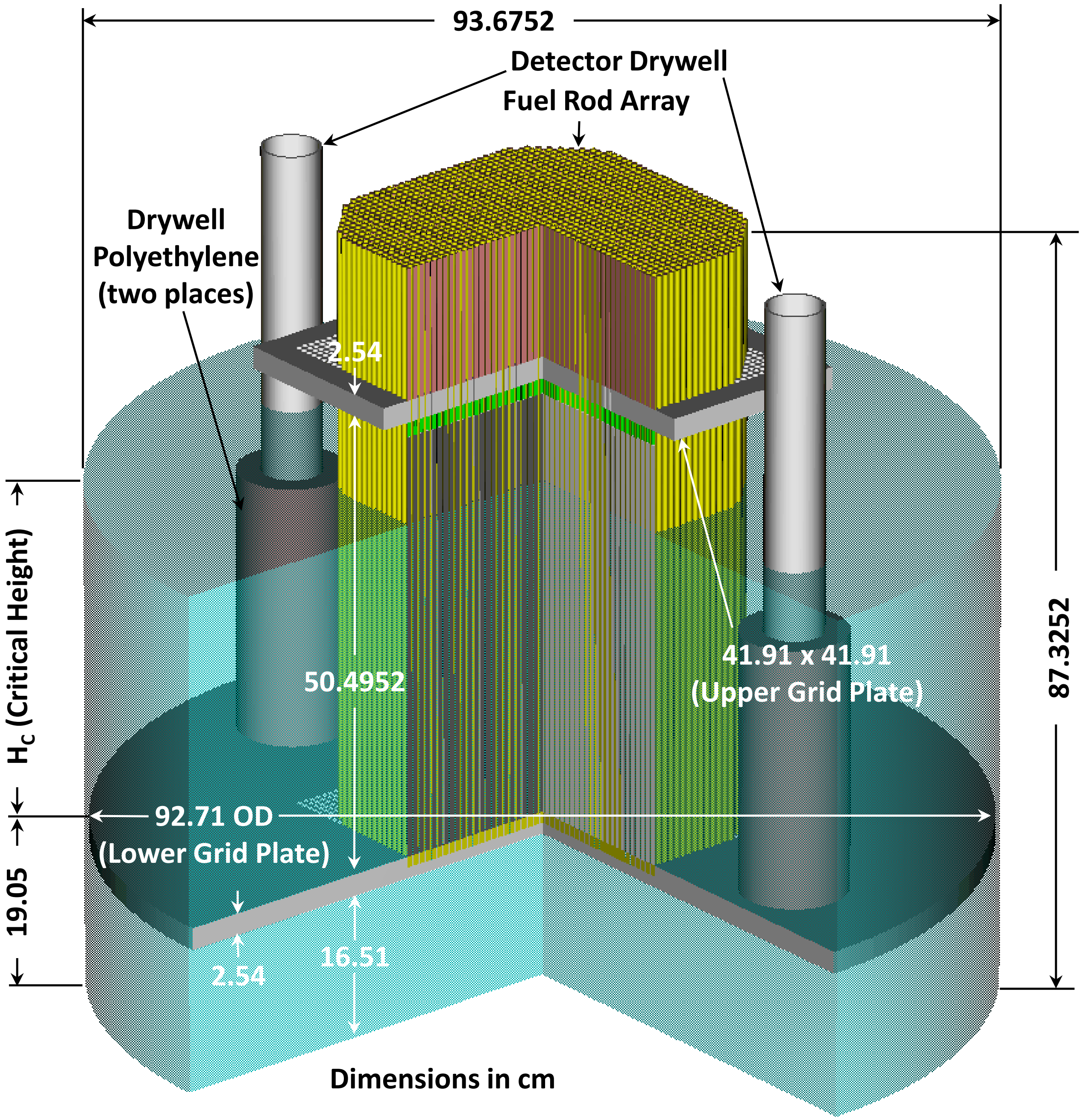

Figure 34. Cut-Away Perspective View of the Benchmark Model of Case 5.

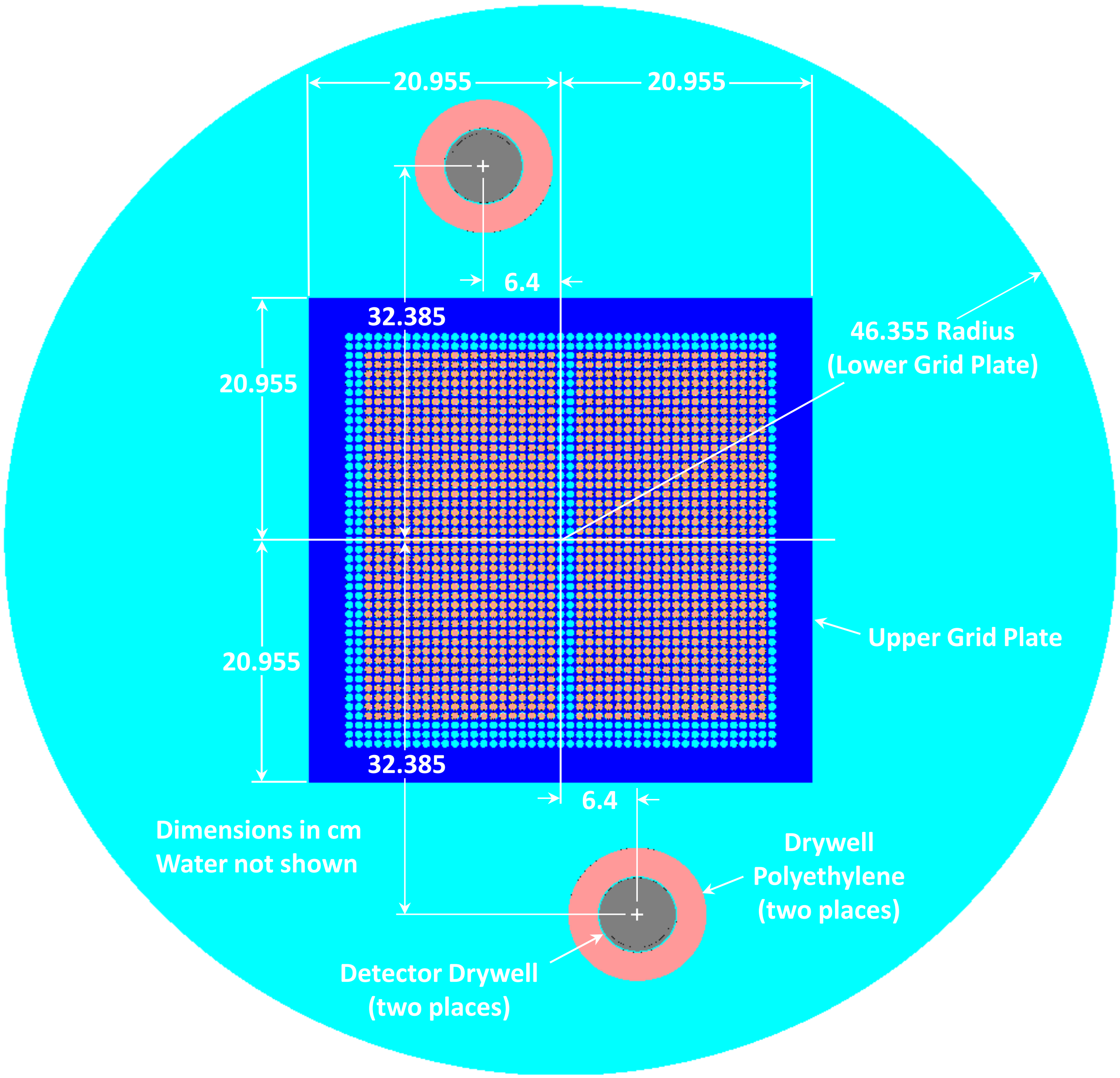

Figure 35. Layout of the Benchmark Model of Case 12.

The water moderator and reflector is a right circular cylinder 93.6752 cm in diameter and height that depends on the configuration. The benchmark model water heights, referenced to the top of the lower grid plate, are given in Table 38. The table lists the measured critical water heights from Table 8 and the benchmark model water heights which are identical to the measured water heights.

Table 38. Measured Critical Water Heights and Benchmark Model Water Heights.

Case	Measured Critical Water Height (cm)		Benchmark Model Water Height H_C (cm)
	Value	σ [(a)]	
1	36.54	0.00037	36.54
2	36.49	0.00038	36.49
3	31.55	0.00036	31.55
4	37.12	0.00051	37.12
5	38.65	0.00032	38.65
6	40.39	0.00025	40.39
7	43.10	0.00073	43.10
8	46.57	0.00049	46.57
9	48.70	0.00063	48.70
10	46.79	0.00059	46.79
11	42.19	0.00039	42.19
12	39.60	0.00056	39.60
13	39.03	0.00063	39.03
14	39.98	0.00037	39.98
15	42.57	0.00066	42.57
16	38.69	0.00033	38.69
17	35.31	0.00053	35.31
18	35.10	0.00026	35.10
19	37.50	0.00037	37.50

(a) The uncertainties given are due to the stochastic nature of the radiation detection process used in the experiments from Table 8.

The lower grid plate is a 6061 aluminum cylinder 92.71 cm diameter and 2.54 cm thick centered on the axis of the moderator cylinder. The top of the lower grid plate is 19.05 cm above the bottom of the water cylinder. The lower grid plate has a 45×45 square-pitched array of blind 0.333375 cm radius cylindrical holes bored from the top surface 1.27 cm deep that support the fuel rods from the bottom. The upper grid plate is a 41.91cm square 2.54 cm thick centered on the axis of the water cylinder. The bottom of the upper grid plate is 50.4952 cm above the top surface of the lower grid plate. The upper grid plate has a 45×45 square-pitched array of 0.333375 cm radius through holes bored in it to locate the fuel rods in the array. The pitch of the fuel rod array is 0.8001 cm.

The fuel rods in the model extend from the bottom of the holes in the lower grid plate to the surface of the water. In the description that follows, the upper surface of the lower grid plate, also the axial location of the bottom of the fuel in the fuel rods, is the origin of the axial coordinates. The fuel rods are 0.317474 cm radius right-circular cylinders. Figure 36 shows a schematic of several fuel rods in the model. Table 39 lists modeling information by axial interval for the fuel rods. Table 40 lists similar information for array positions that are unfueled.

Table 39. Axial and Radial Modeling Information for a Fuel Rod

Position (cm)				Material
Axial[(a)]		Radial[(b)]		
From	To	From	To	
-2.54	-1.27	0.0	Cell[(c)]	Grid Plate 6061 Aluminum
-1.27	0.0	0.0	0.317474	Cladding 3003 Aluminum
		0.317474	0.333375	Water
		0.333375	Cell	Grid Plate 6061 Aluminum
0.0	48.780	0.0	0.262814	UO_2
		0.262814	0.284519	Void
		0.284519	0.317474	Cladding 3003 Aluminum
		0.317474	Cell	Water to H_c, Void Above
48.780	50.4952	0.0	0.17526	Void
		0.17526	0.2286	Spring 304 Stainless Steel
		0.2286	0.284519	Void
		0.284519	0.317474	Cladding 3003 Aluminum
		0.317474	Cell	Void
50.4952	53.0352	0.0	0.26289	6061 Aluminum
		0.26289	0.284519	Void
		0.284519	0.317474	Cladding 3003 Aluminum
		0.317474	0.333375	Void
		0.333375	Cell	Grid Plate 6061 Aluminum
53.0352	68.2752	0.0	0.26289	Polyethylene
		0.26289	0.284519	Void
		0.284519	0.317474	Cladding 3003 Aluminum
		0.317474	Cell	Void

(a) The origin of the axial coordinates is the top of the lower grid plate.
(b) The origin of the radial coordinates is the axial center of the 0.8001×0.8001 cm square cell
(c) "Cell" refers to the boundary of the square cell in the array. Each surface of the cell is 0.40005 cm from the central axis of the cell.

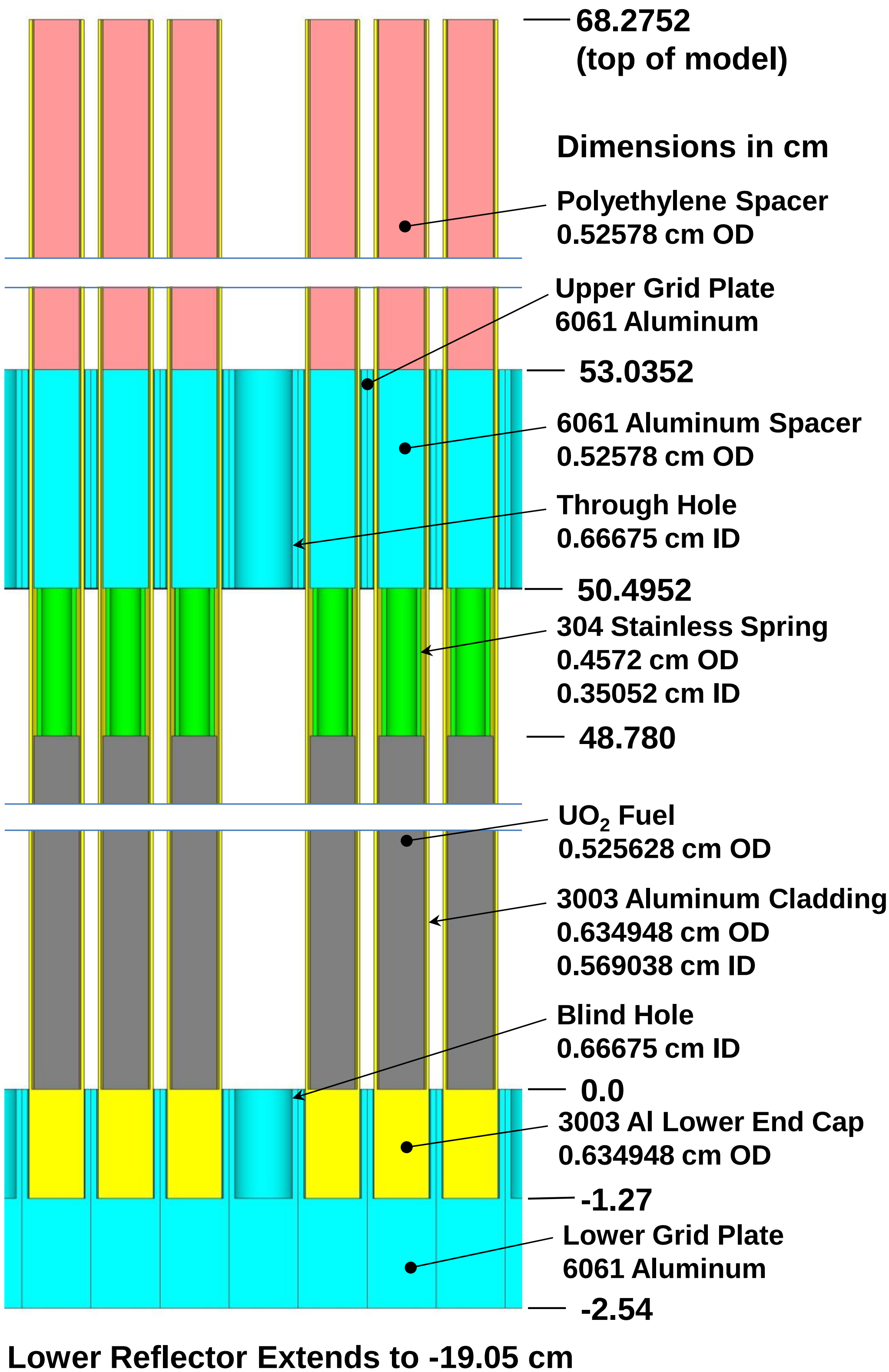

Figure 36. Schematic of the Fuel Rods in the Model.

Table 40. Axial and Radial Modeling Information for an Empty Grid Location

Position (cm)				Material
Axial(a)		Radial(b)		
From	To	From	To	
-2.54	-1.27	0.0	Cell(c)	Grid Plate 6061 Aluminum
-1.27	0.0	0.0	0.333375	Water
		0.333375	Cell	Grid Plate 6061 Aluminum
0.0	50.4952	0.0	Cell	Water to H_c, Void Above
50.4952	53.0352	0.0	0.333375	Void
		0.333375	Cell	Grid Plate 6061 Aluminum
53.0352	68.2752	0.0	Cell	Void

(a) The origin of the axial coordinates is the top of the lower grid plate.
(b) The origin of the radial coordinates is the axial center of the 0.8001×0.8001 cm square cell
(c) "Cell" refers to the boundary of the square cell in the array. Each surface of the cell is 0.40005 cm from the central axis of the cell.

All configurations include two 6.35 cm outside diameter 6061 aluminum tubes surrounded by polyethylene that function as dry wells for the assembly instrumentation. With the origin of the coordinate system at the center of the top surface of the lower grid plate and the z-axis aligned with the axis of the water cylinder, the axis of one of the dry wells is located at x=32.385 cm, y=6.4 cm while the axis of the other is located at x=-32.385 cm, y=-6.4 cm. Figure 37 shows an elevation view of the assembly with a cut-away view of one of the detector wells. Table 41 gives modeling details for the dry wells.

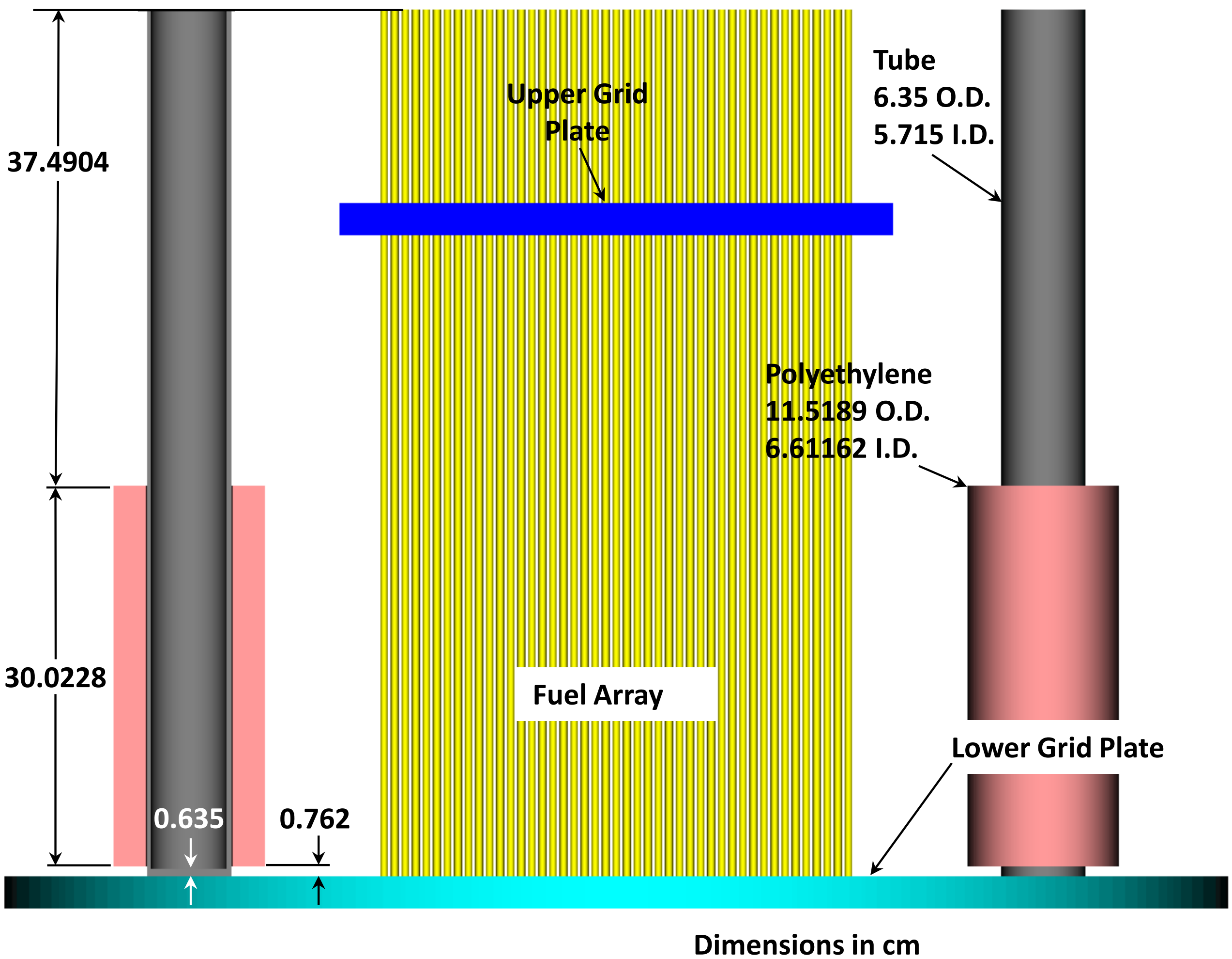

Figure 37. Elevation View of the Benchmark Model Showing a Cut-Away View of One of the Detector Wells

Table 41. Axial and Radial Modeling Information for a Dry Well

Position (cm)				Material
Axial[a]		Radial[b]		
From	To	From	To	
0.0	0.635	0.0	3.175	6061 Aluminum
0.635	0.762	0.0	2.8575	Void
		2.8575	3.175	6061 Aluminum
0.762	30.7848	0.0	2.8575	Void
		2.8575	3.175	6061 Aluminum
		3.175	3.30581	Water
		3.30581	5.75945	Polyethylene
30.7848	68.2752	0.0	2.8575	Void
		2.8575	3.175	6061 Aluminum

(a) The origin of the axial coordinates is the top of the lower grid plate.
(b) The origin of the radial coordinates is the axial center of the dry well

The layout of the fuel rods in the 45×45 array in Cases 1 through 19 are shown in Figures 38 through 56.

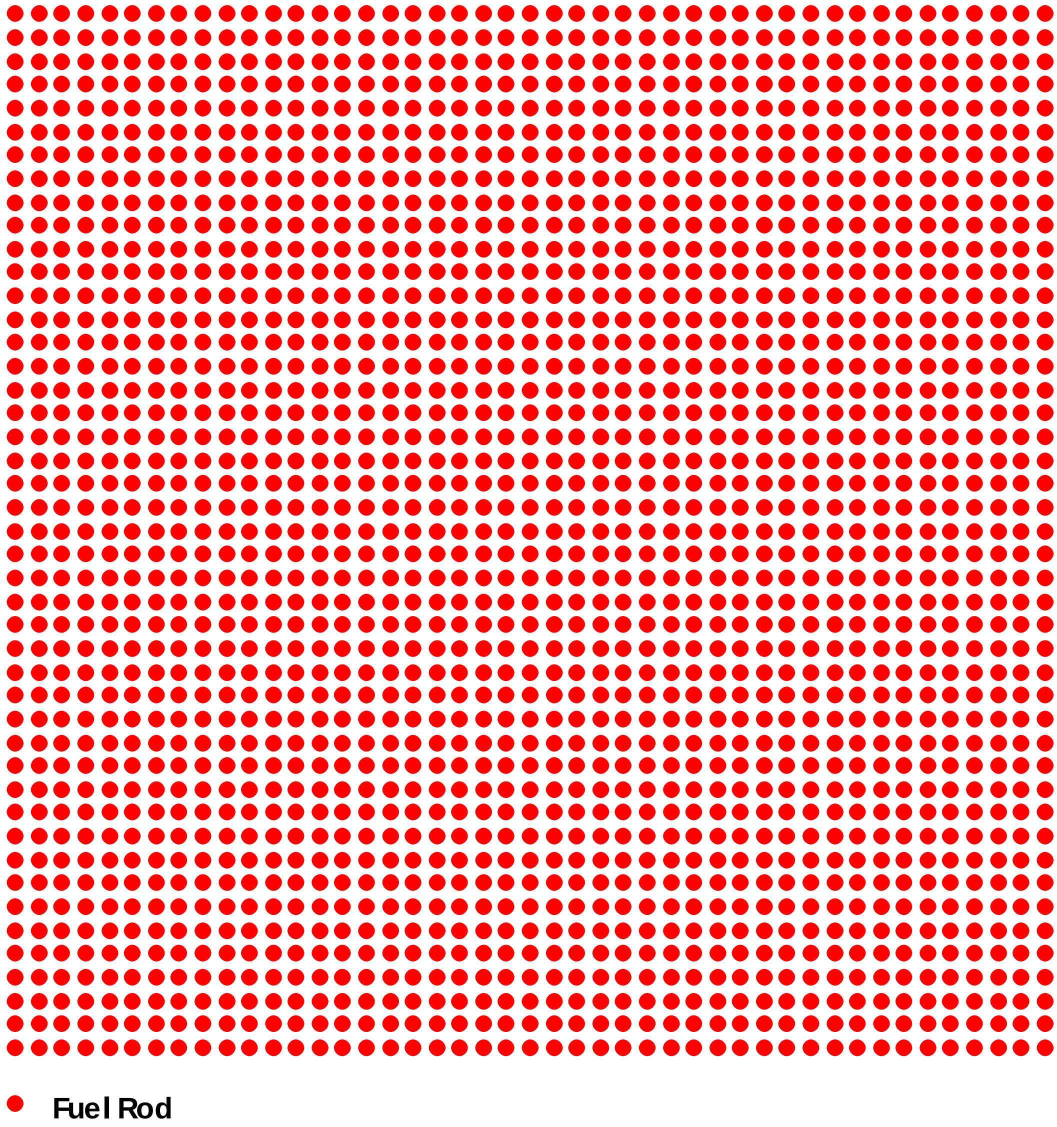

Figure 38. Fuel Rod Layout for Case 1 (2025 fuel rods).

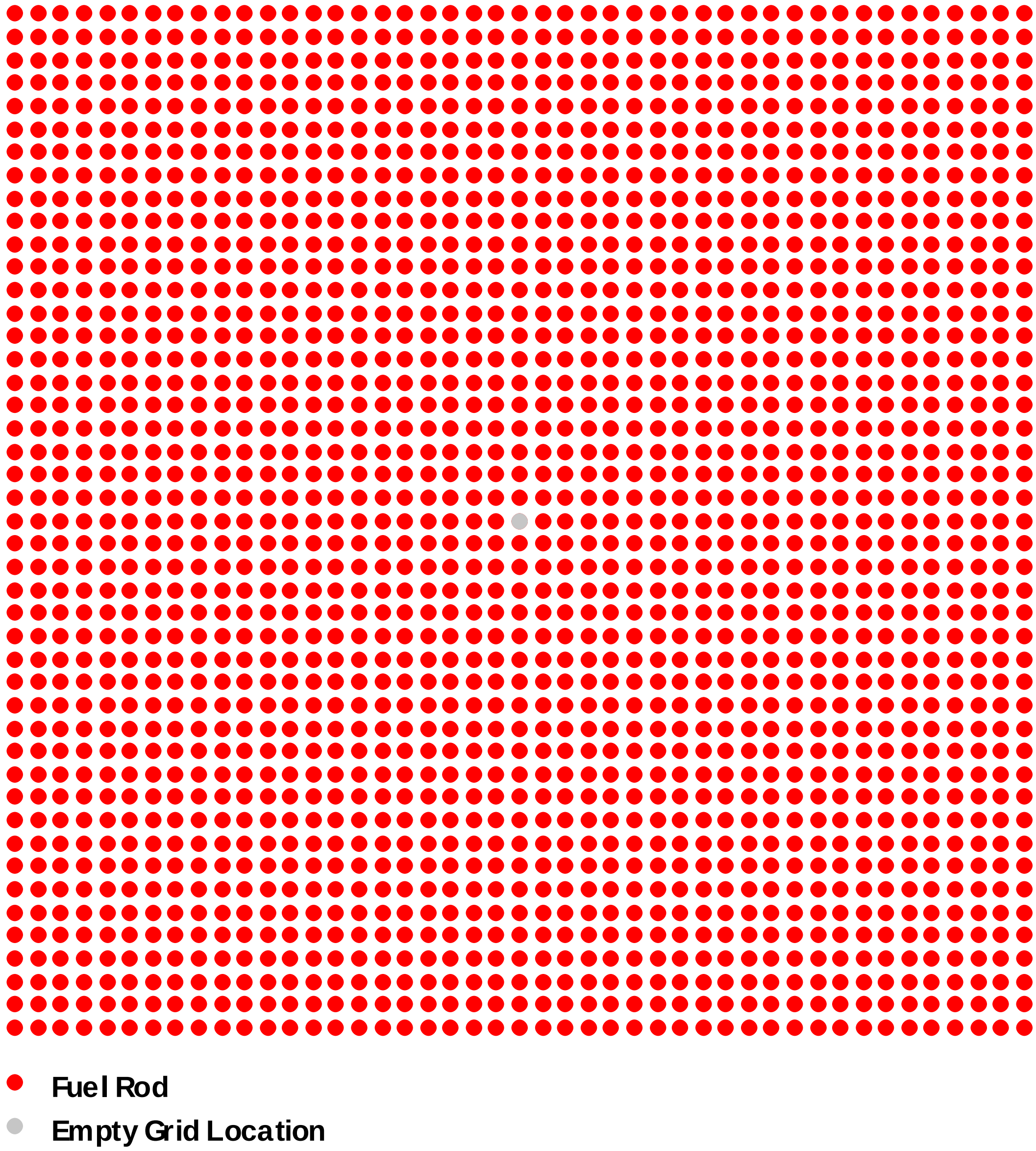

Figure 39. Fuel Rod Layout for Case 2 (2024 fuel rods).

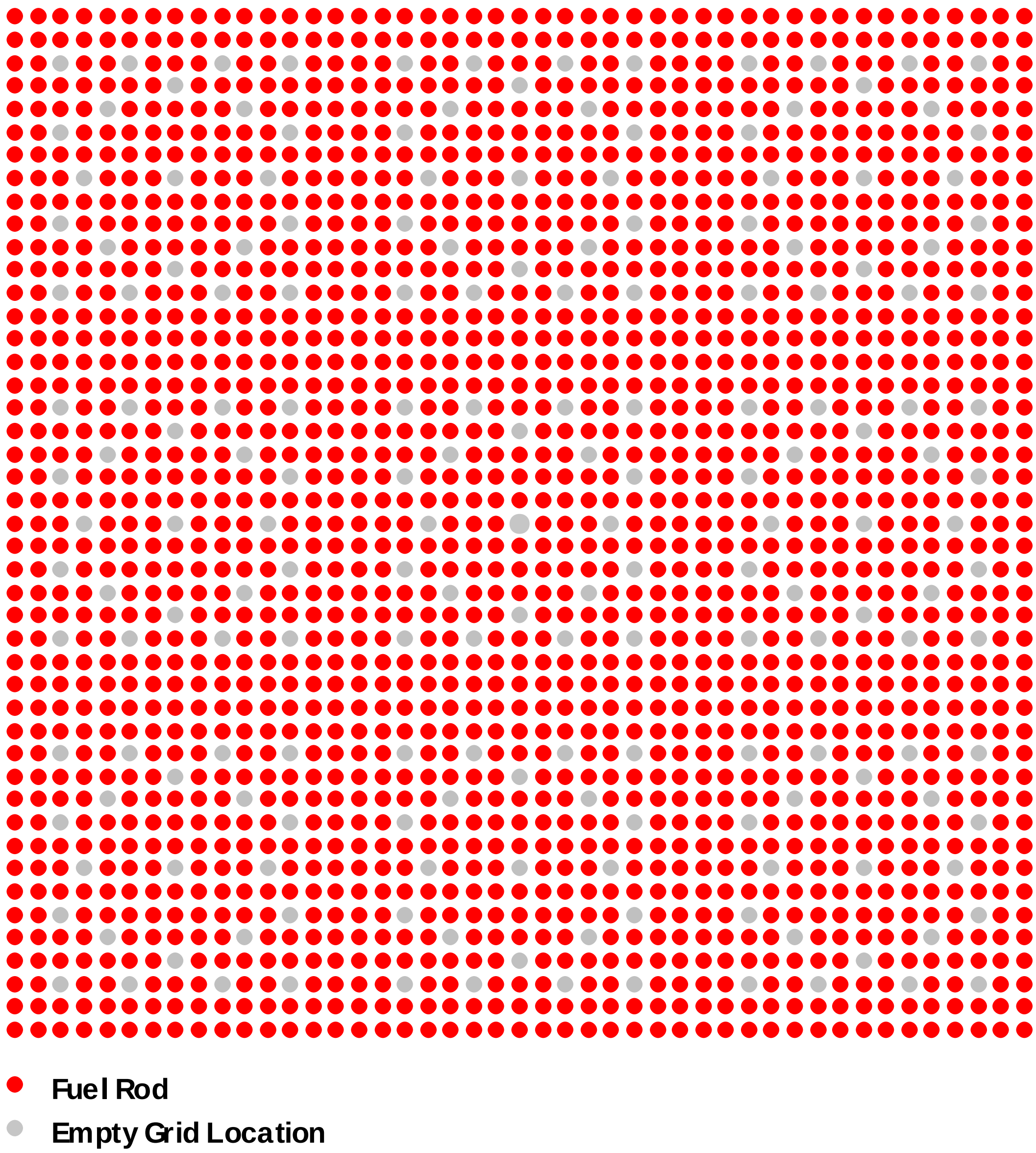

Figure 40. Fuel Rod Layout for Case 3 (1836 fuel rods).

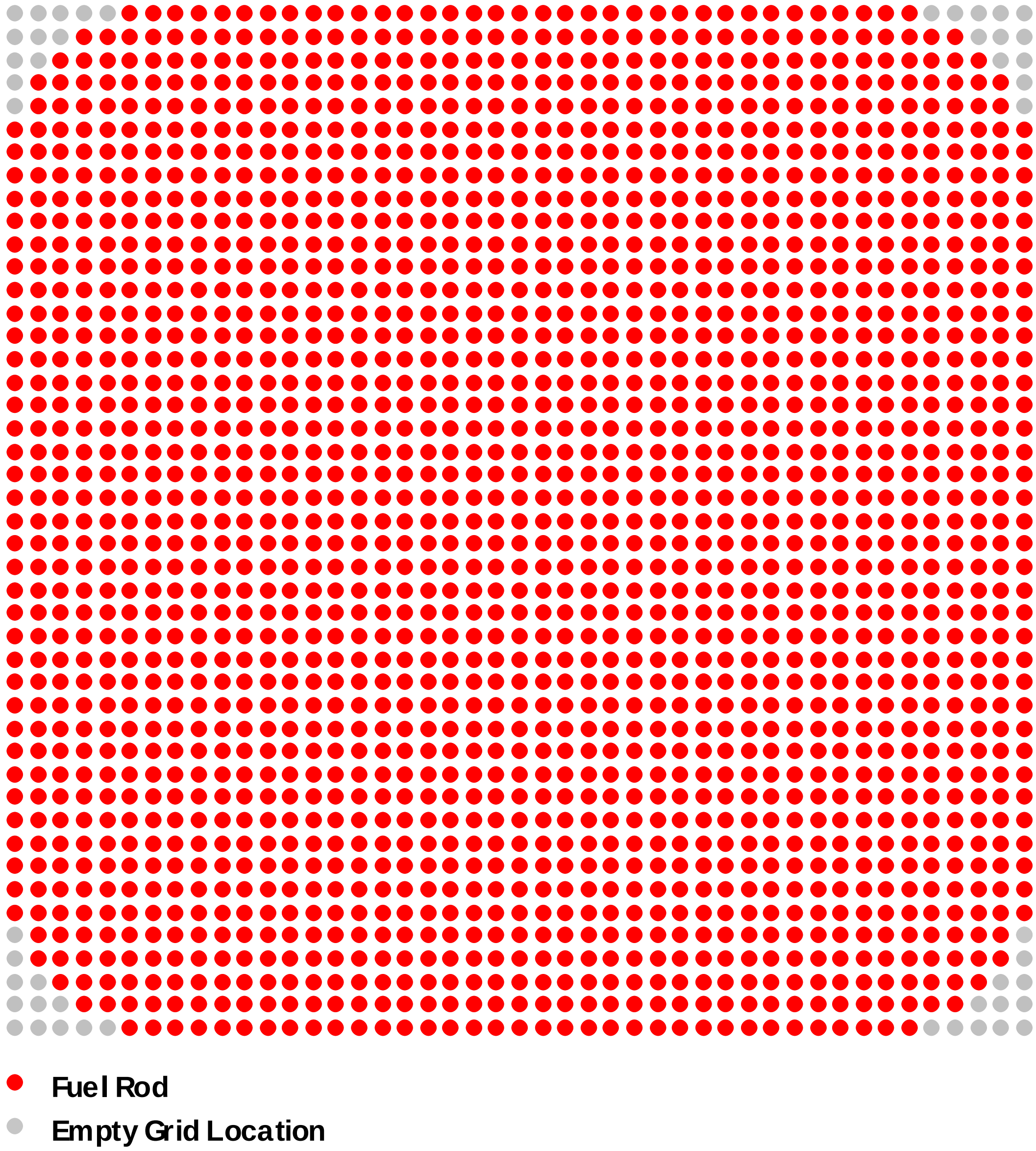

Figure 41. Fuel Rod Layout for Case 4 (1977 fuel rods).

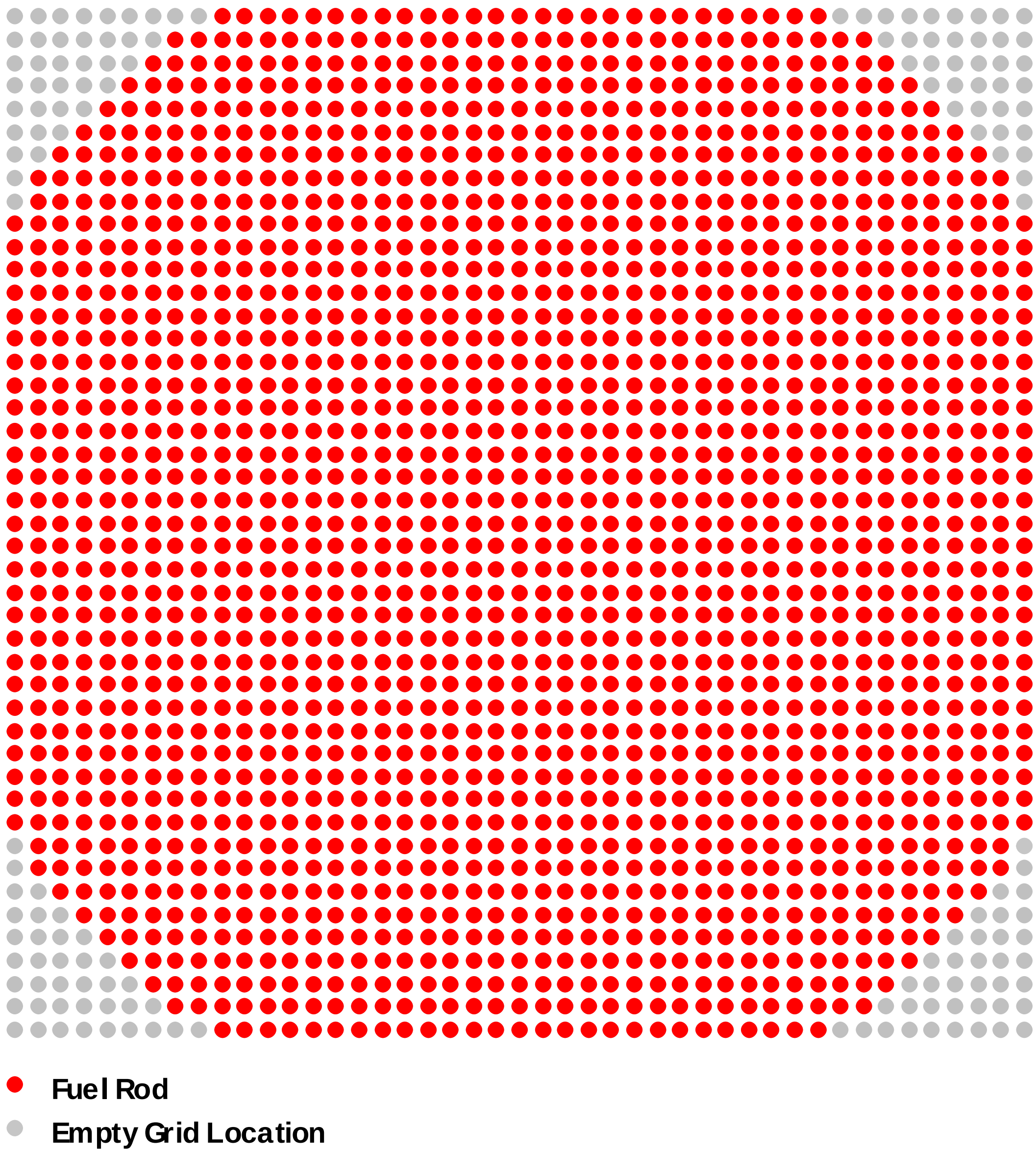

Figure 42. Fuel Rod Layout for Case 5 (1873 fuel rods).

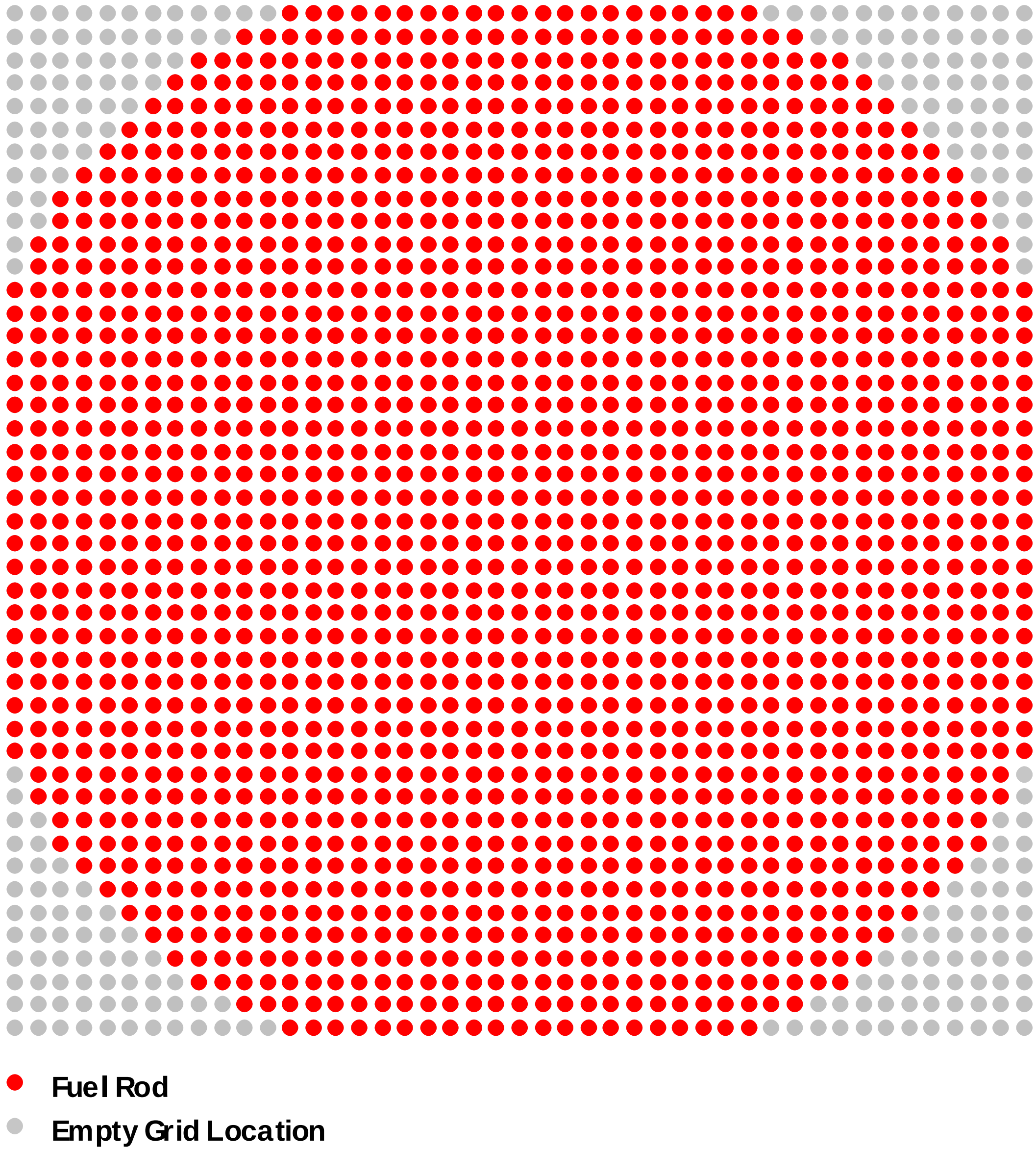

Figure 43. Fuel Rod Layout for Case 6 (1781 fuel rods).

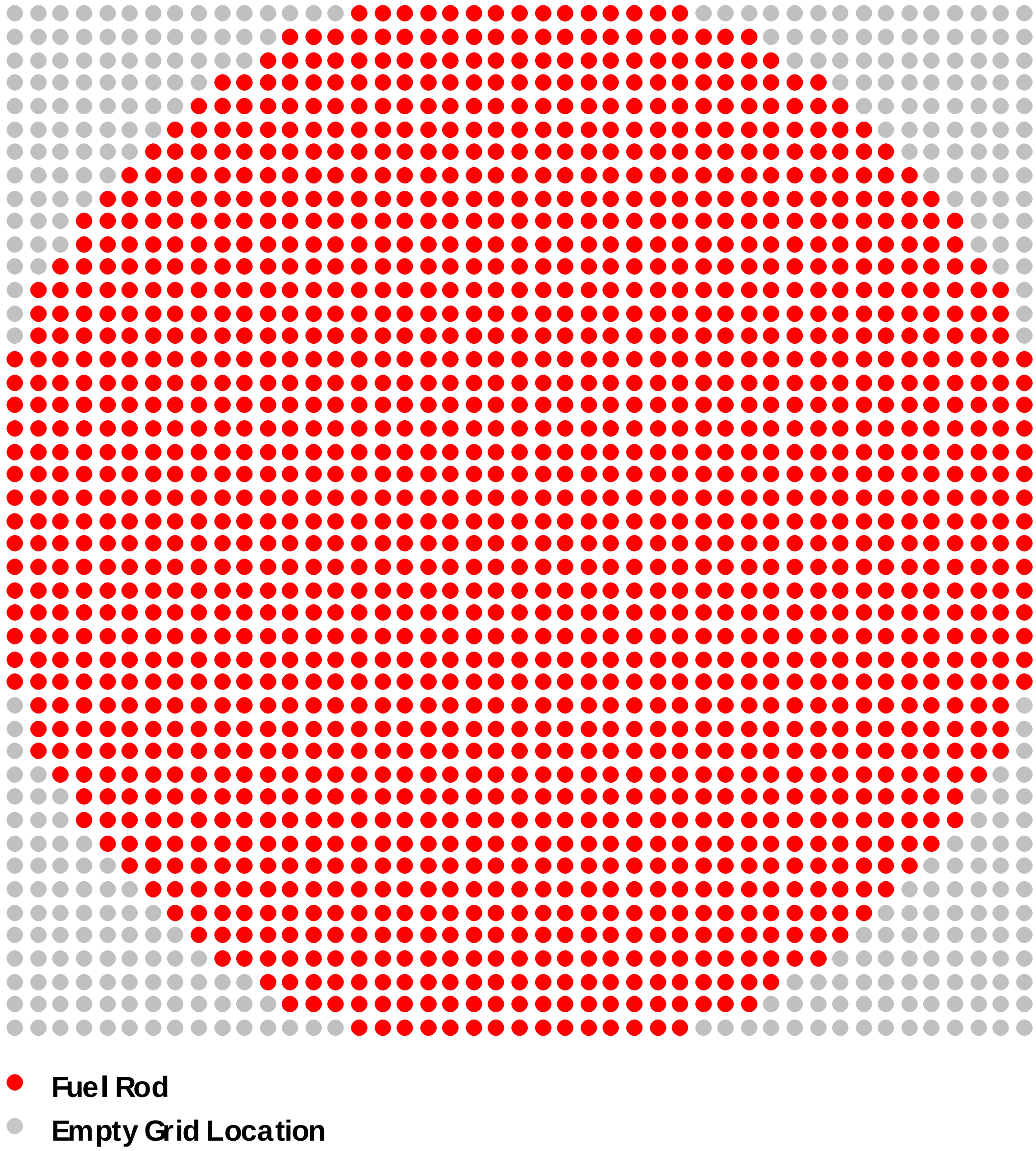

Figure 44. Fuel Rod Layout for Case 7 (1673 fuel rods).

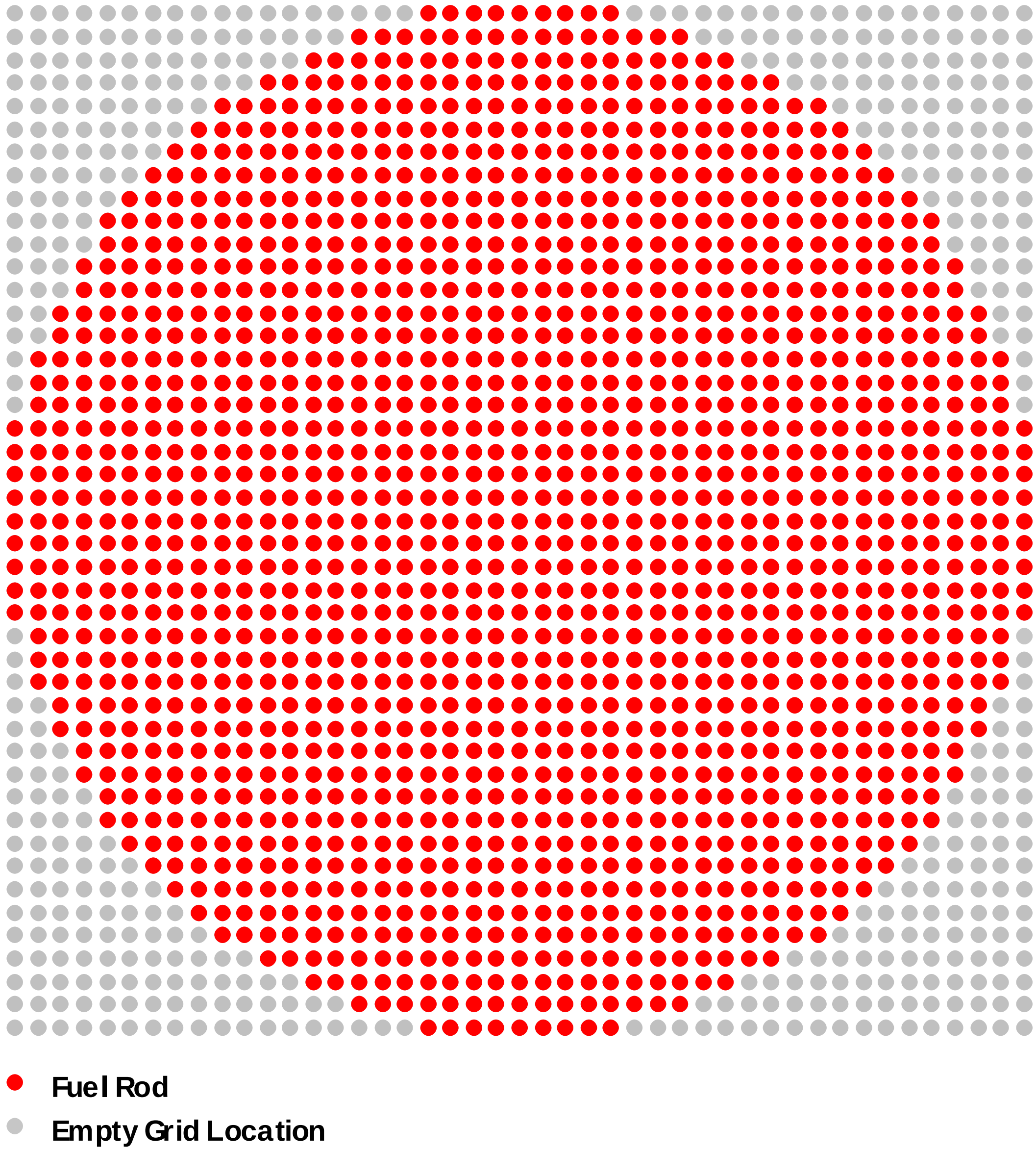

Figure 45. Fuel Rod Layout for Case 8 (1573 fuel rods).

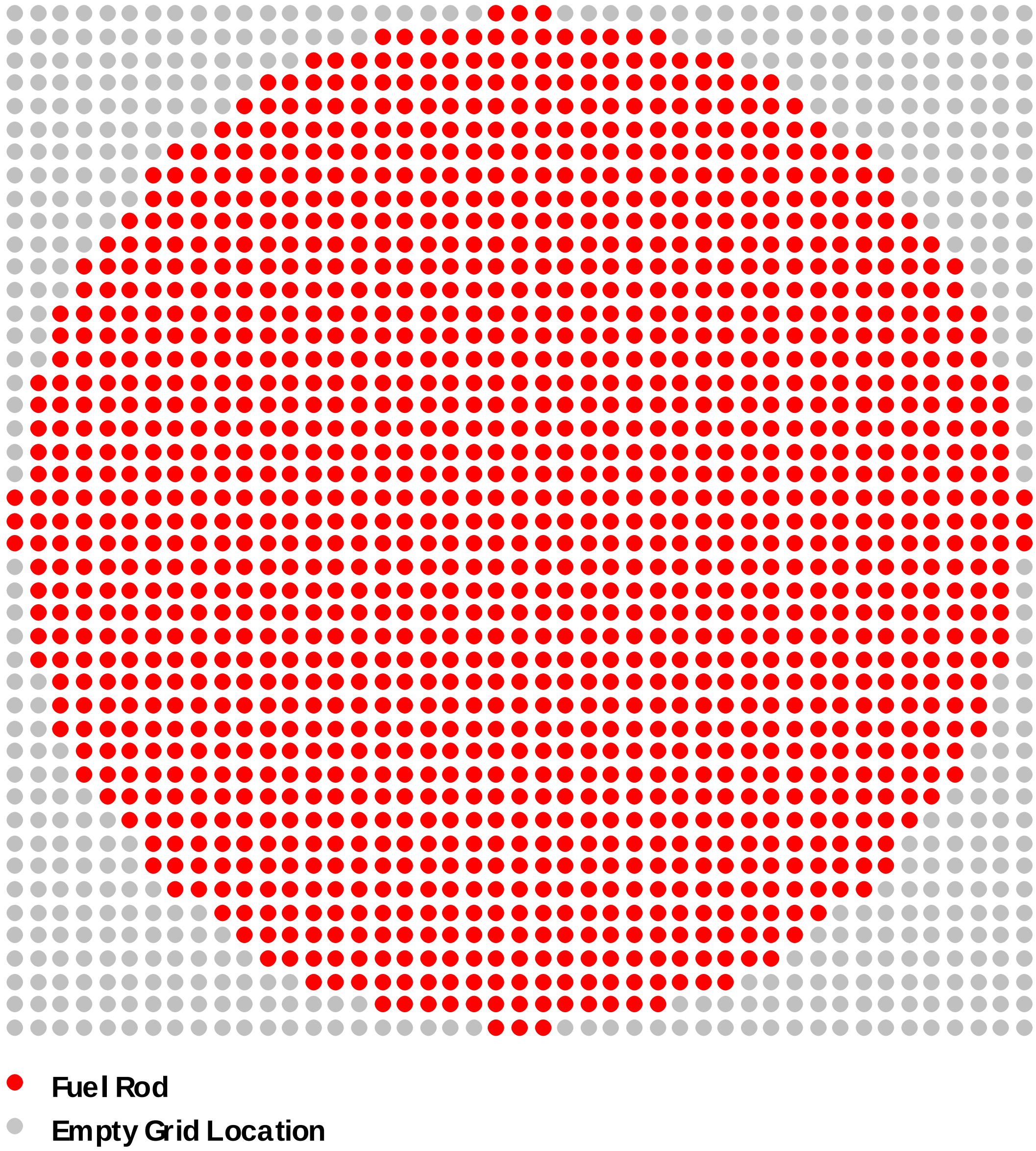

Figure 46. Fuel Rod Layout for Case 9 (1525 fuel rods).

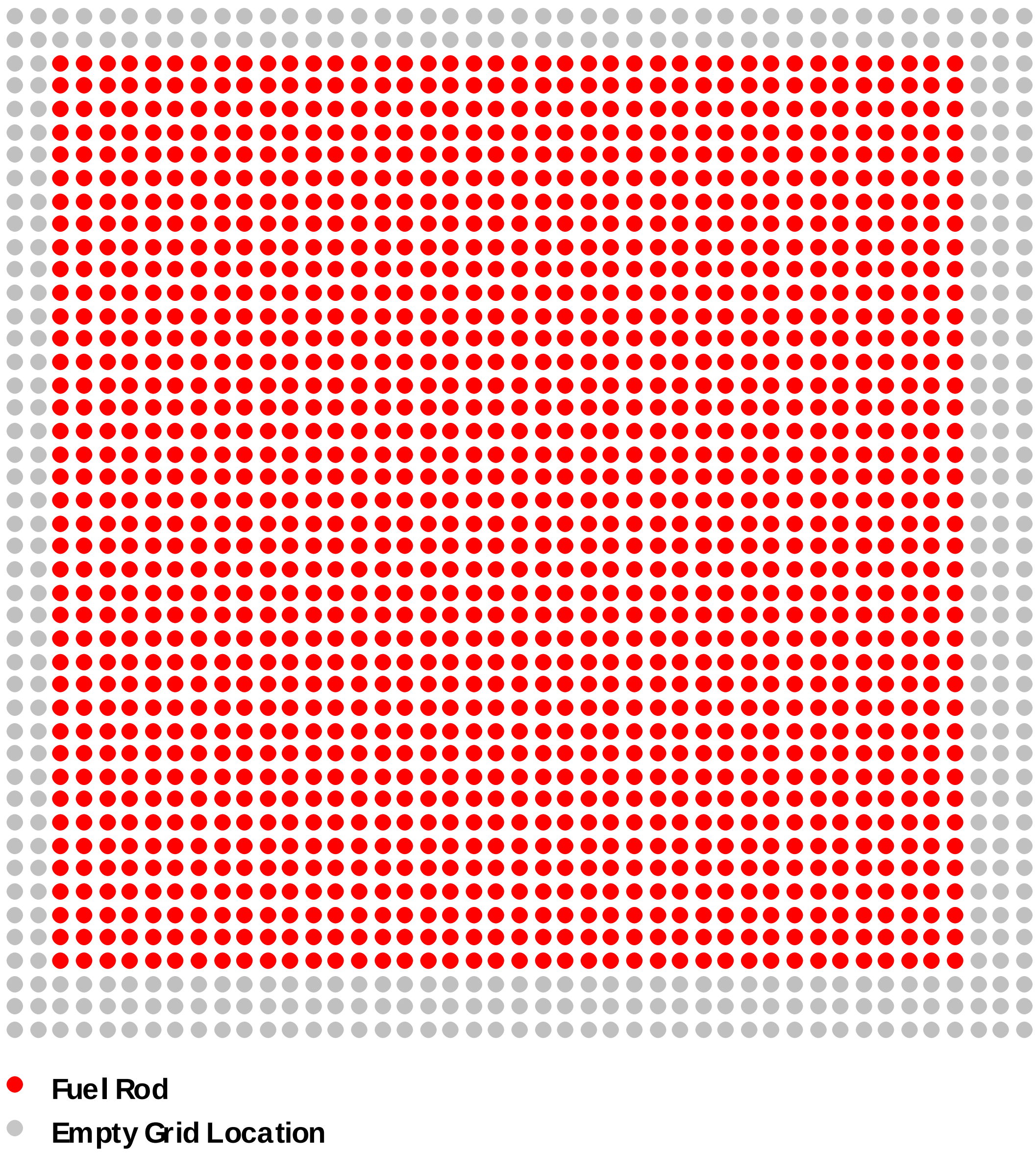

Figure 47. Fuel Rod Layout for Case 10 (1600 fuel rods).

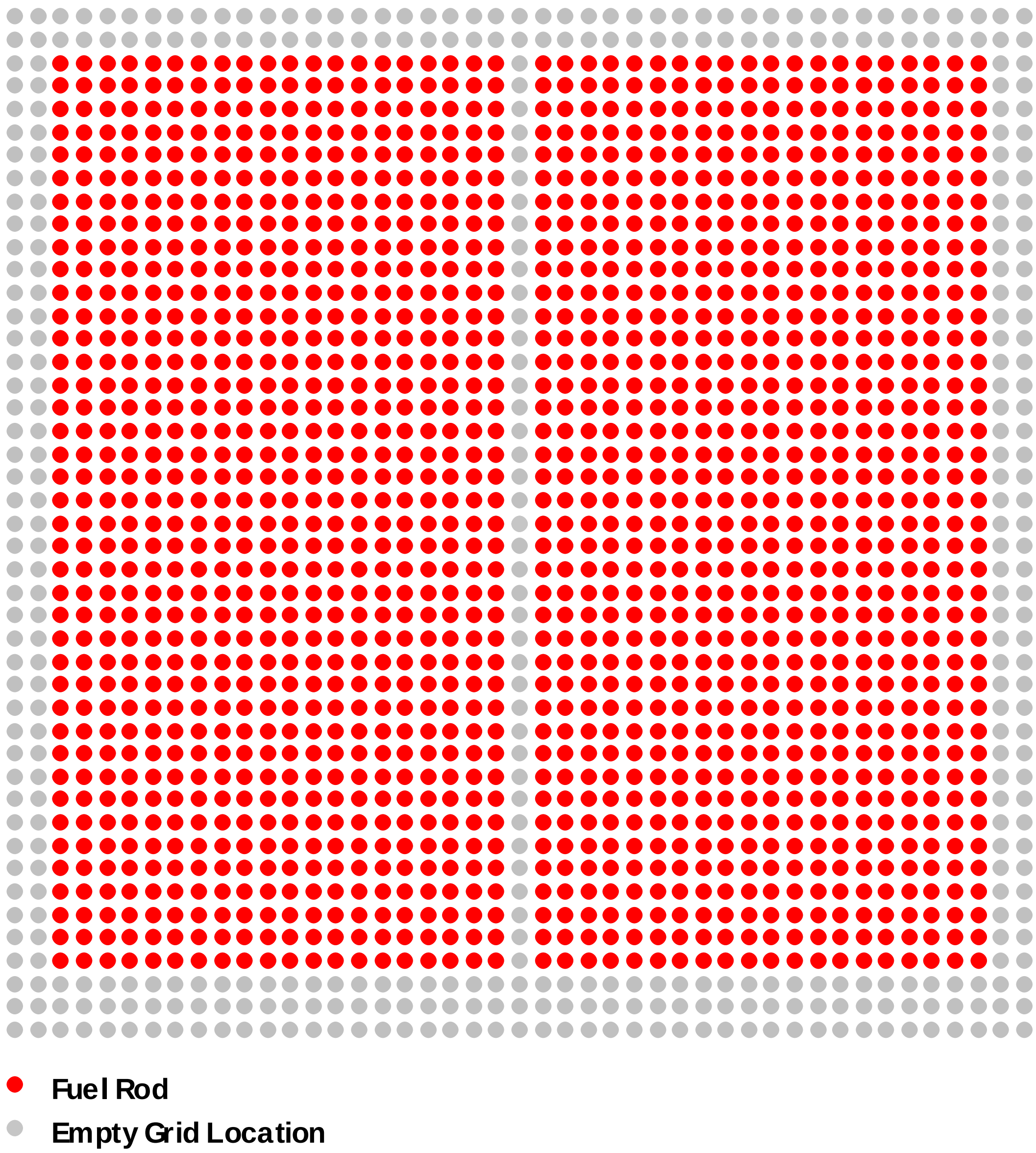

Figure 48. Fuel Rod Layout for Case 11 (1600 fuel rods).

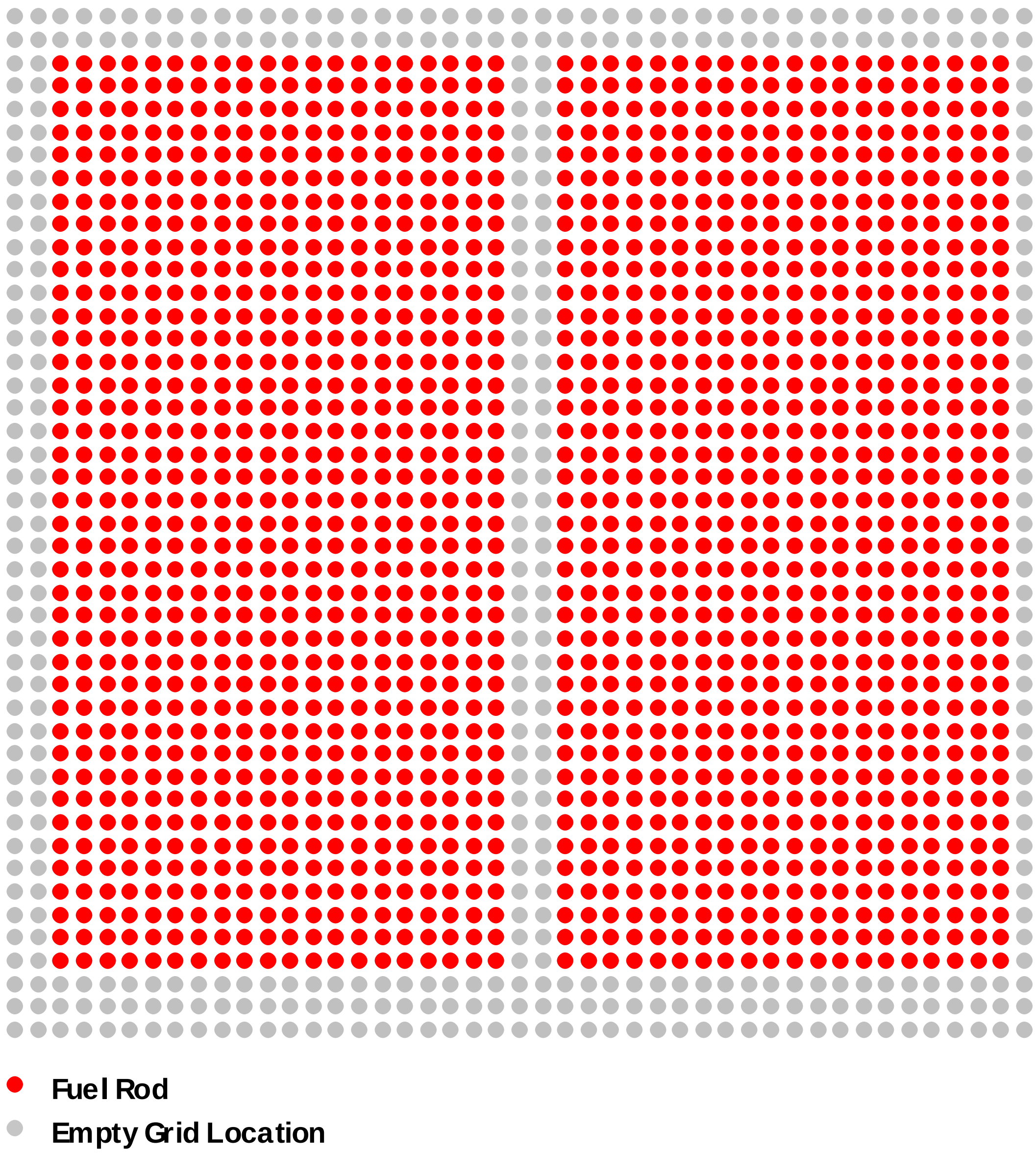

Figure 49. Fuel Rod Layout for Case 12 (1600 fuel rods).

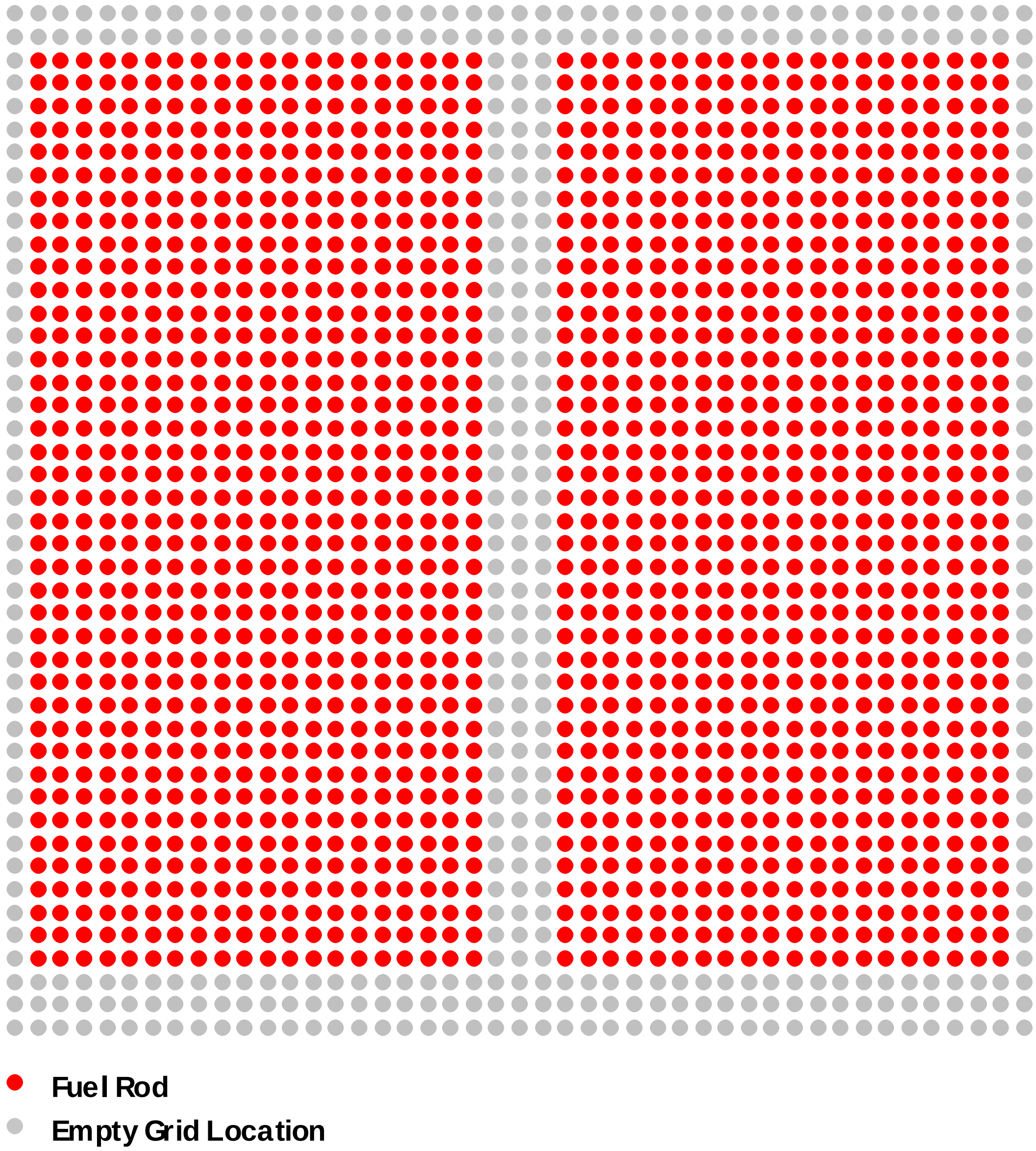

Figure 50. Fuel Rod Layout for Case 13 (1600 fuel rods).

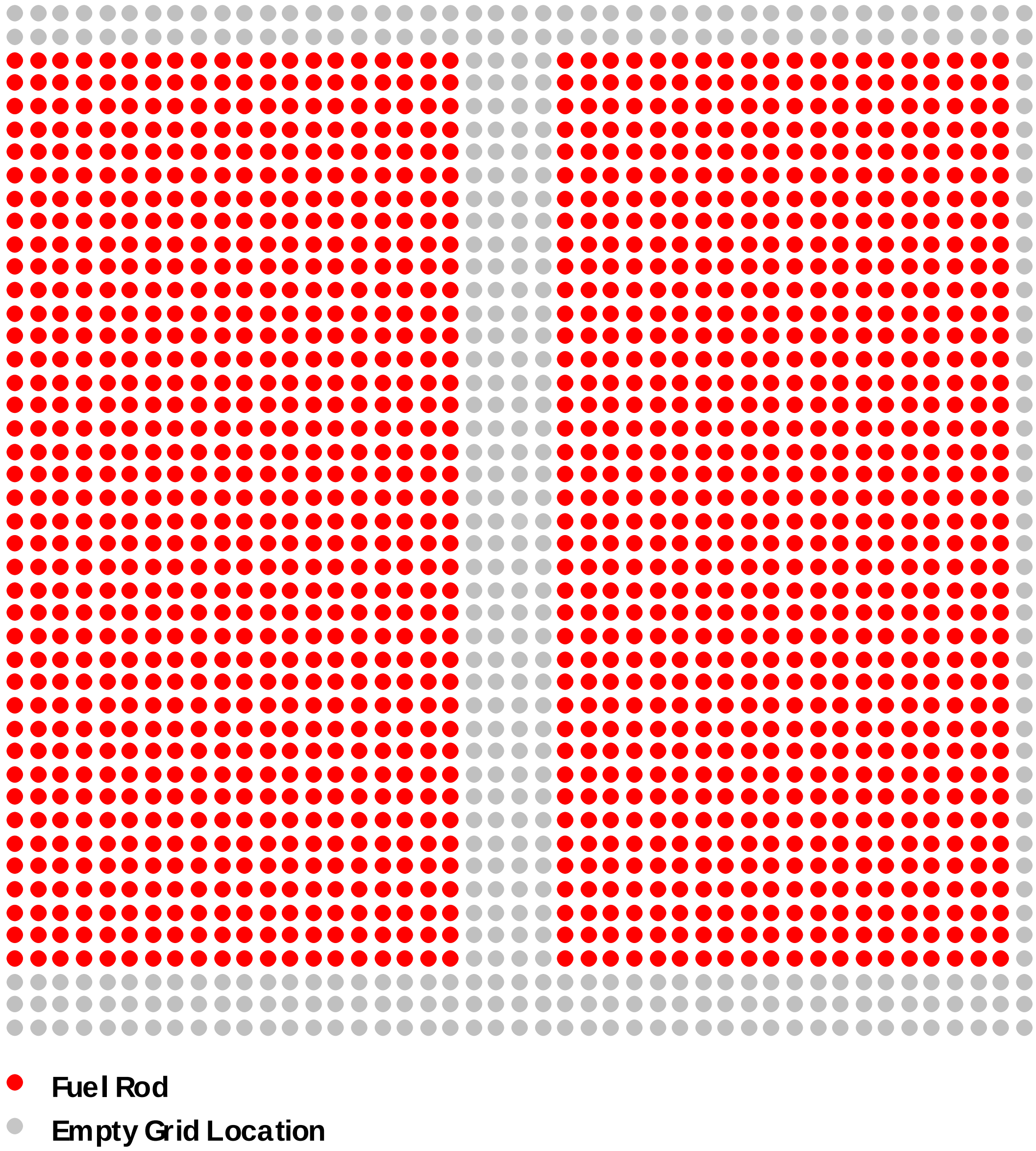

Figure 51. Fuel Rod Layout for Case 14 (1600 fuel rods).

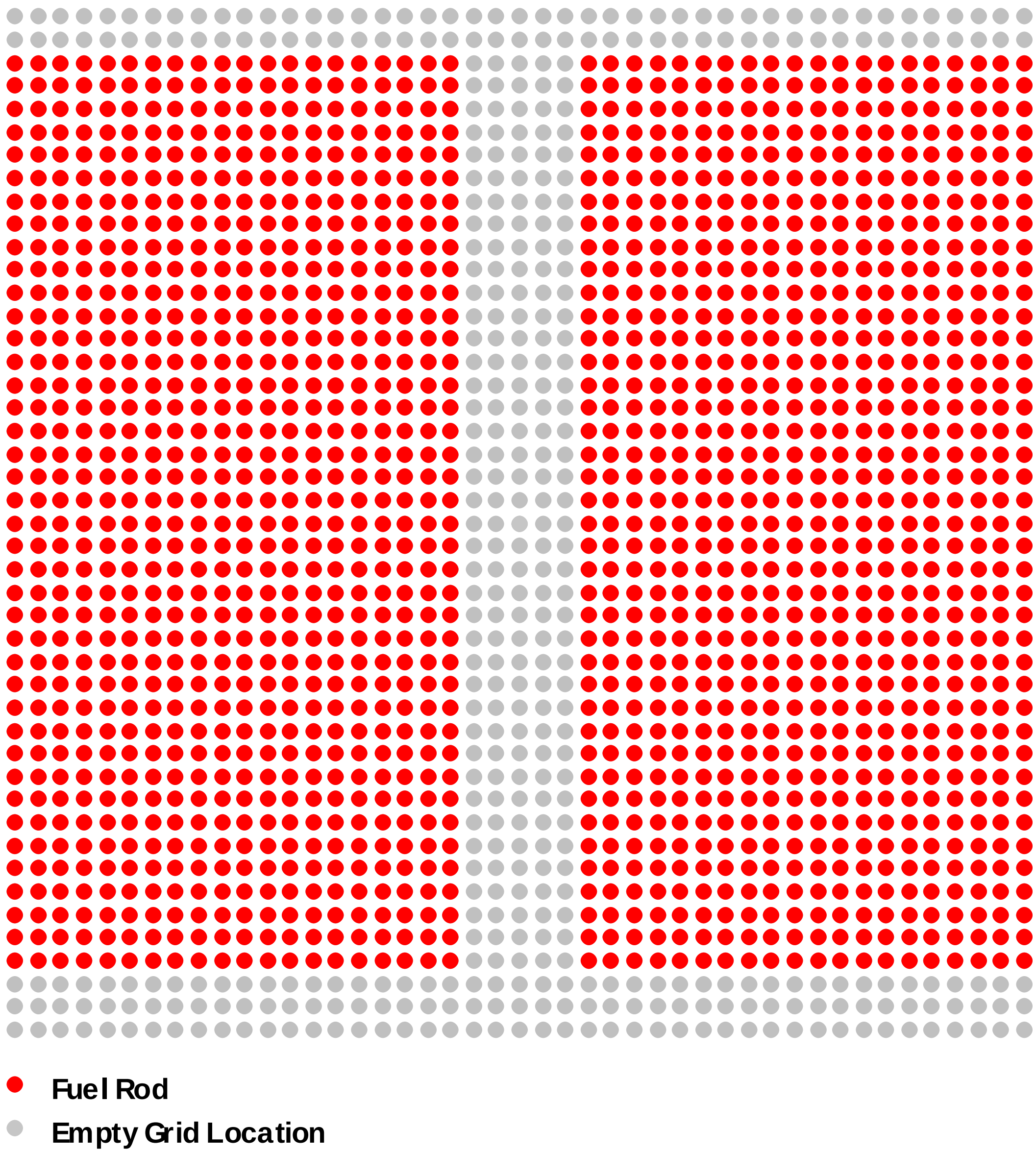

Figure 52. Fuel Rod Layout for Case 15 (1600 fuel rods).

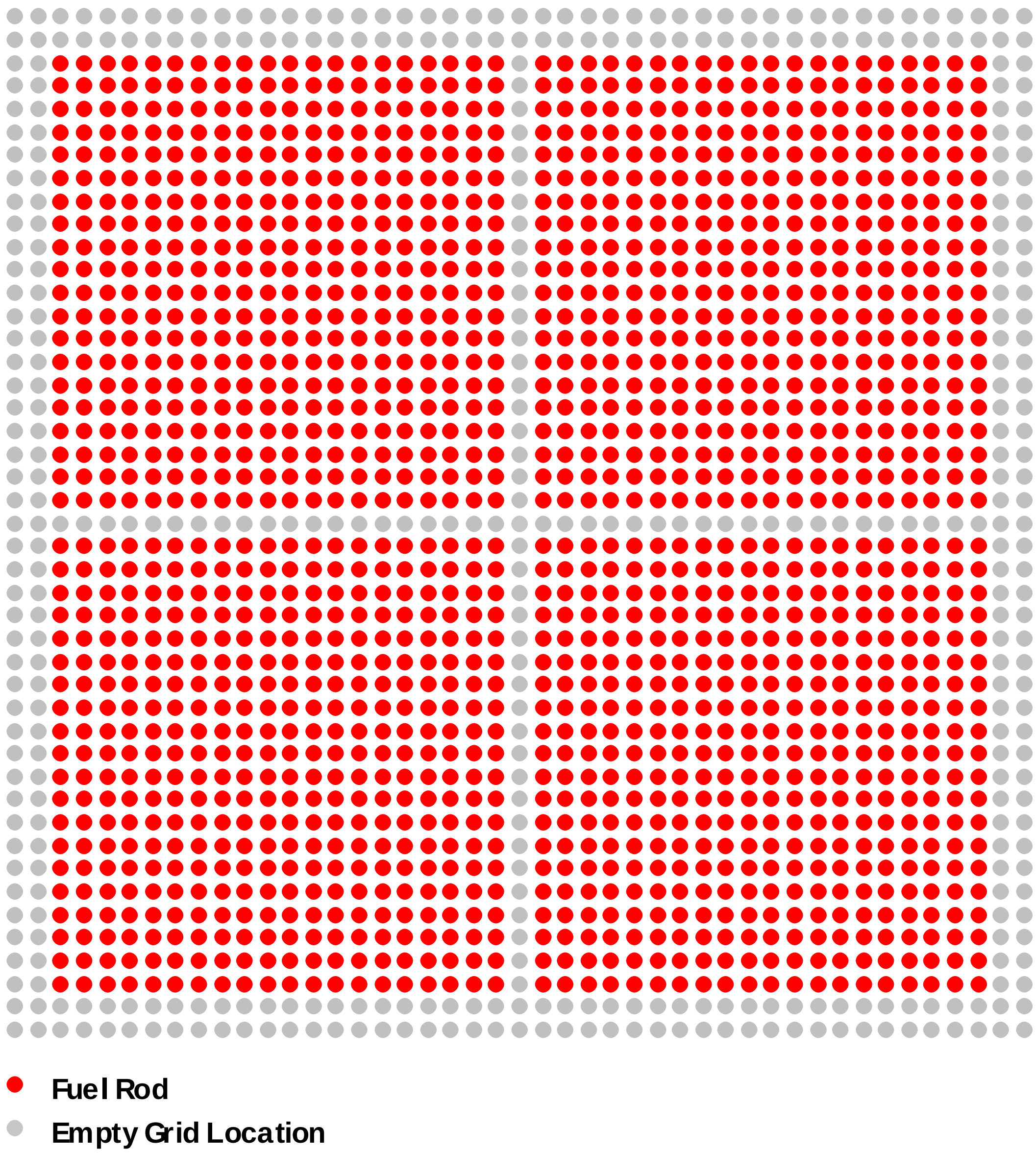

Figure 53. Fuel Rod Layout for Case 16 (1600 fuel rods).

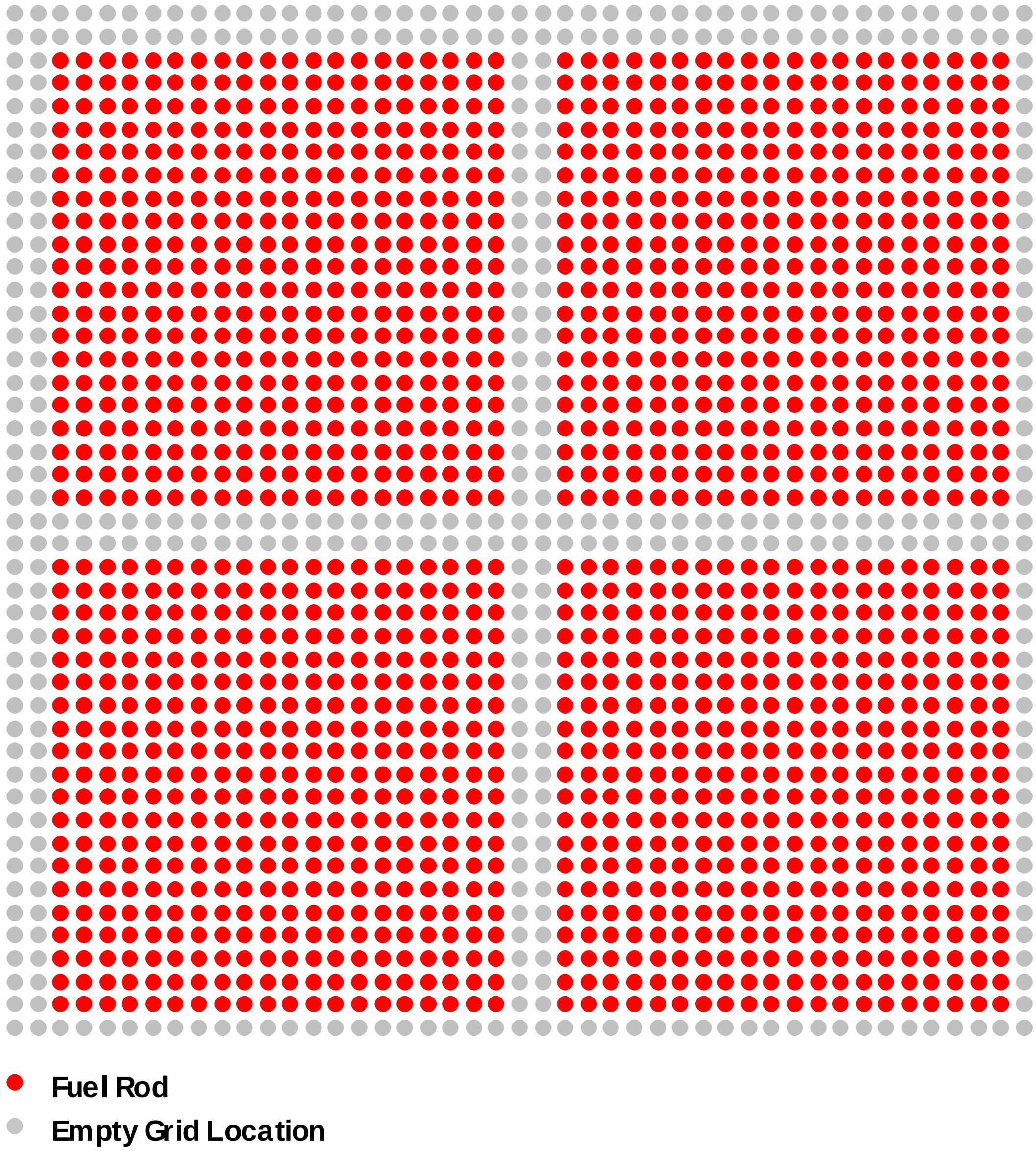

Figure 54. Fuel Rod Layout for Case 17 (1600 fuel rods).

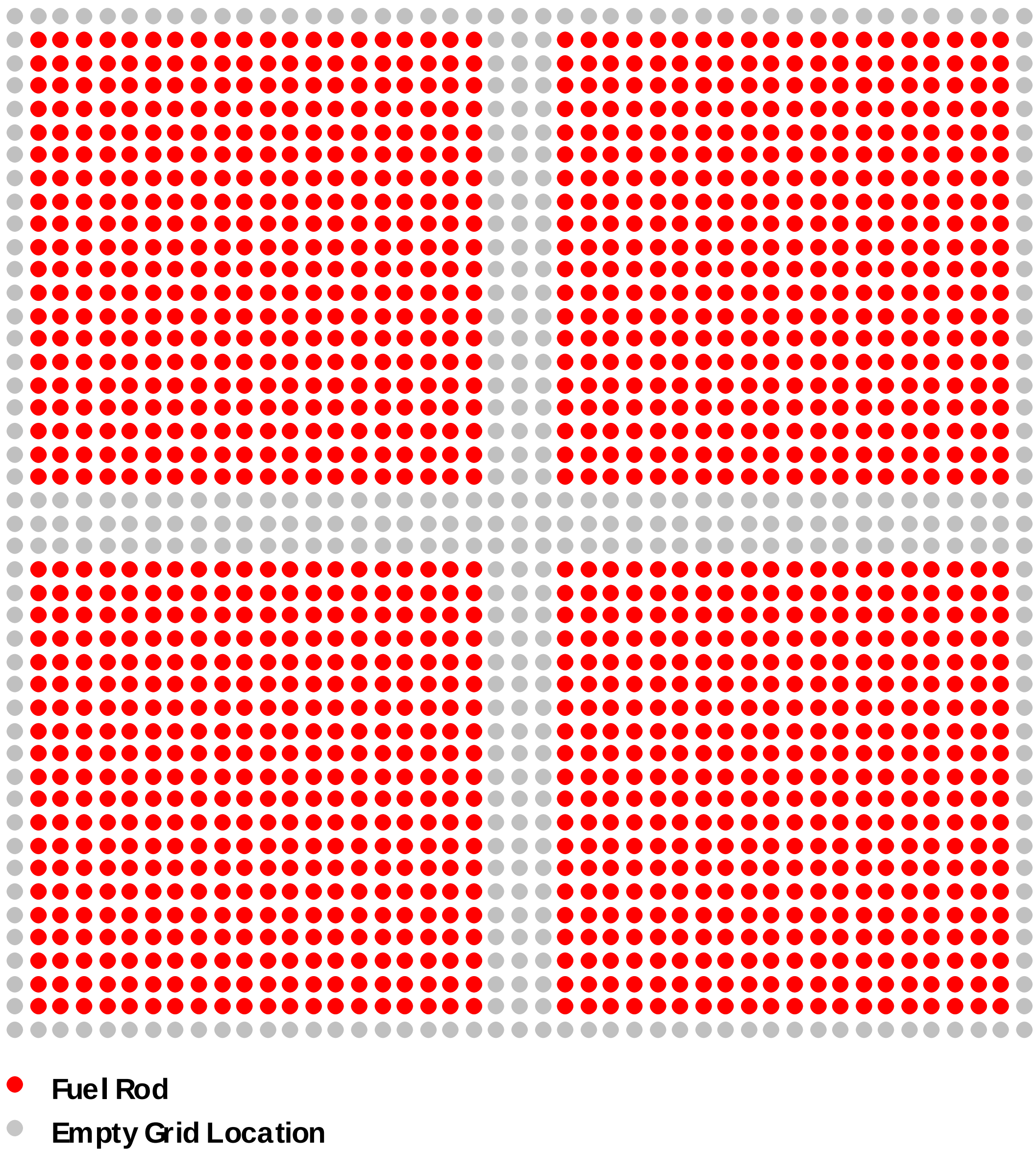

Figure 55. Fuel Rod Layout for Case 18 (1600 fuel rods).

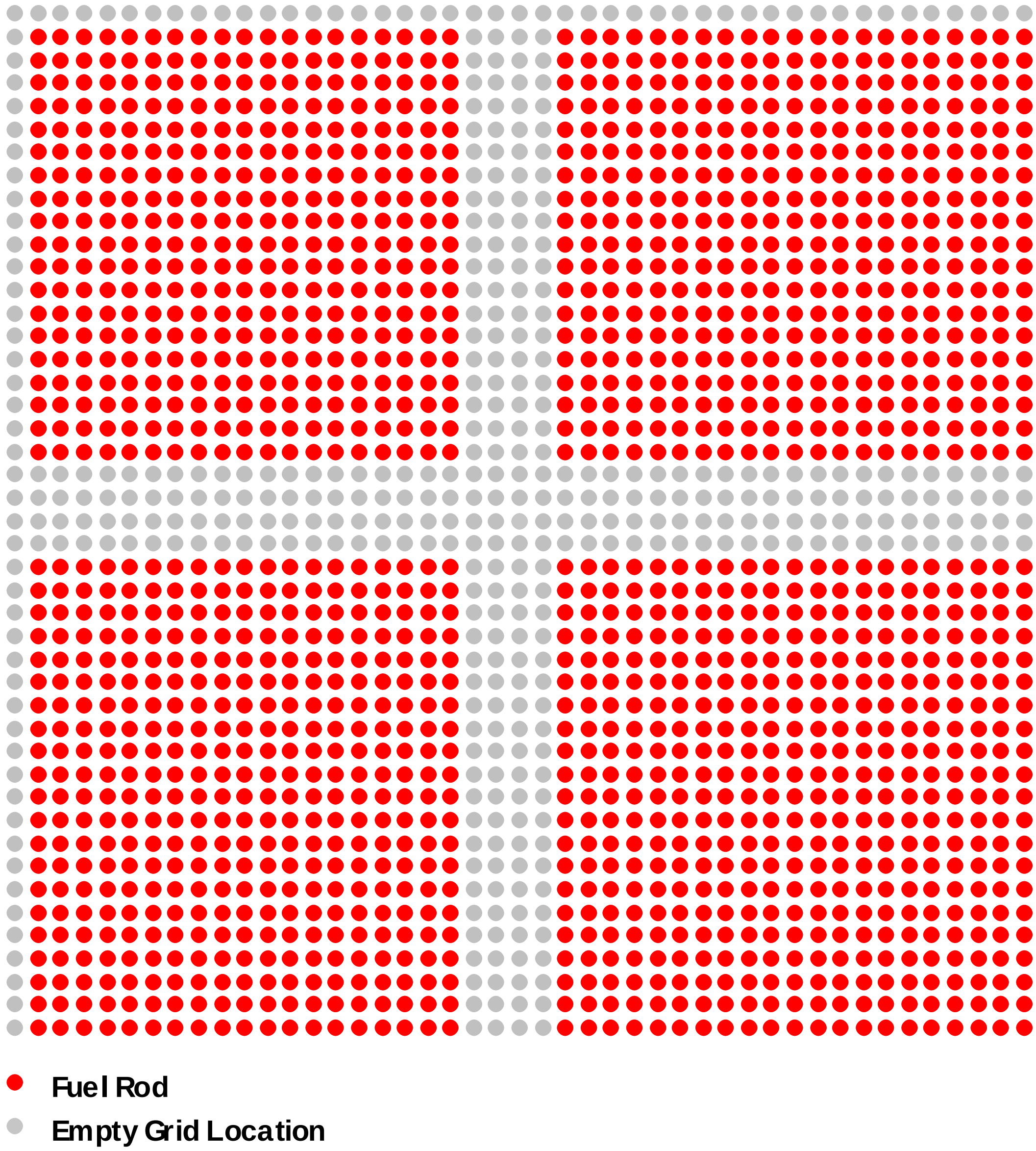

Figure 56. Fuel Rod Layout for Case 19 (1600 fuel rods).

3.3 Material Data

The atom densities for the materials in the critical experiment models are listed in Table 42.

Table 42. Composition of the Materials in the Critical Experiment Models.

Material	Element or Isotope	Atom Number Density (barn^{-1}cm^{-1})
UO_2 Fuel (108.7165 g of fuel [$UO_{2.00}$ + impurities] in a cylinder 0.525628 cm diameter, 48.780 cm long)	^{234}U	6.5539E-06
	^{235}U	1.6010E-03
	^{236}U	1.4632E-05
	^{238}U	2.1296E-02
	O	4.5837E-02
	Ag	9.2319E-09
	B	2.3858E-07
	Cd	1.2380E-08
	Co	2.1620E-08
	Cr	2.5100E-06
	Cu	2.1316E-07
	Fe	1.0311E-05
	Mn	2.8372E-07
	Mo	1.2443E-07
	Ni	3.4989E-06
	V	1.4813E-08
	W	3.5998E-09
3003 Aluminum Cladding (2.73 g/cm^3)[(a)]	Al	5.9668E-02
	Si	1.7561E-04
	Fe	1.0303E-04
	Cu	3.2339E-05
	Mn	3.7407E-04
	Zn	1.2571E-05
Water (0.99705 g/cm^3)[(b)]	H	6.6659E-02
	O	3.3329E-02
6061 Aluminum Grid Plates (2.70 g/cm^3)[(c)] Also Used in Dry Well Tubes	Al	5.8376E-02
	Si	4.1683E-04
	Fe	1.8051E-04
	Cu	7.9320E-05
	Mn	2.6637E-05
	Mg	6.9574E-04
	Cr	6.2542E-05
	Zn	2.9839E-05
	Ti	6.7918E-06
	V	3.1918E-06

(a) Density from http://matweb.com/search/DataSheet.aspx?MatGUID=fd4a40f87d3f4912925e5e6eab1fbc40 accessed on May 29, 2012.
(b) This density is from the National Institute of Standards and Technology Chemistry WebBook, http://webbook.nist.gov/chemistry/.
(c) Density from http://matweb.com/search/DataSheet.aspx?MatGUID=1b8c06d0ca7c456694c7777d9e10be5b accessed on May 29, 2012.

Table 42. Composition of the Materials in the Critical Experiment Models (continued).

Material	Element or Isotope	Atom Number Density ($barn^{-1}cm^{-1}$)
304 Stainless Steel Springs (0.1923 g in an annulus 0.35052 cm ID, 0.45720 cm OD and 1.7152 cm tall)	Fe	1.2527E-02
	Cr	3.6455E-03
	Ni	1.5724E-03
	Mn	1.8160E-04
	C	3.3225E-05
	P	7.2471E-06
	S	4.6663E-06
	Si	1.7761E-04
	N	3.5613E-05
Polyethylene in Fuel Rods (4.454 g in a cylinder 0.52578 cm OD and 21.2852 cm long) Also Used in Dry Well Annuli	H	8.2755E-02
	C	4.1377E-02

3.4 Temperature Data

The temperature of the moderator was maintained near 25°C. The critical data were corrected to 25°C as noted above. The model temperature is therefore 25°C.

3.5 Experimental and Benchmark-Model k_{eff}

The approach-to-critical experiments were done by varying the height of the moderator/reflector in the critical assembly. The projected critical moderator height was determined by extrapolation of inverse detector count rates from two moderator heights within a few millimeters of critical to zero. The experimental k_{eff} under the conditions of the experiment was thus 1.0000.

Several simplifications were made to the benchmark model. These simplifications resulted in a small bias in the benchmark model that is listed in Table 36. The bias in the benchmark model k_{eff} caused by the difference between the experiment temperatures listed in Table 8 and the benchmark model temperature of 25°C is listed in Table 37. The experiment uncertainties were estimated in Section 2.3. Table 43 summarizes these data and lists the benchmark model k_{eff} and its uncertainty.

Table 43. Simplification Bias, Water Height Uncertainty, Water Height Sensitivity, Experiment Uncertainty, and Benchmark-Model k_{eff} and Uncertainty for the Nineteen Cases.

Case	Simplification Bias [a]		Temperature Correction Δk_T to Benchmark Model k_{eff} [b]		Experiment Uncertainty [c]	Bench Model k_{eff}	
	Value	σ	Value	σ		Value [d]	σ [e]
1	-0.00016	0.00003	0.00001	0.00000	0.00095	0.99985	0.00095
2	-0.00007	0.00003	0.00001	0.00000	0.00095	0.99994	0.00095
3	-0.00013	0.00003	0.00001	0.00000	0.00093	0.99988	0.00093
4	-0.00016	0.00003	0.00001	0.00000	0.00095	0.99985	0.00095
5	-0.00014	0.00003	0.00001	0.00000	0.00095	0.99987	0.00095
6	-0.00019	0.00003	0.00000	0.00000	0.00092	0.99981	0.00092
7	-0.00014	0.00003	0.00000	0.00000	0.00092	0.99986	0.00092
8	-0.00013	0.00003	0.00000	0.00000	0.00092	0.99987	0.00092
9	-0.00006	0.00003	0.00000	0.00000	0.00092	0.99994	0.00092
10	-0.00012	0.00003	0.00000	0.00000	0.00092	0.99988	0.00092
11	-0.00002	0.00003	-0.00001	0.00000	0.00095	0.99997	0.00096
12	0.00000	0.00003	0.00000	0.00000	0.00095	1.00000	0.00096
13	-0.00010	0.00003	0.00000	0.00000	0.00095	0.99990	0.00096
14	-0.00008	0.00003	0.00001	0.00000	0.00095	0.99993	0.00096
15	-0.00011	0.00003	0.00002	0.00000	0.00095	0.99991	0.00096
16	-0.00006	0.00003	-0.00001	0.00000	0.00095	0.99993	0.00096
17	-0.00008	0.00003	-0.00001	0.00000	0.00095	0.99991	0.00096
18	-0.00006	0.00003	0.00000	0.00000	0.00095	0.99994	0.00096
19	-0.00013	0.00003	0.00000	0.00000	0.00095	0.99987	0.00096

(a) From Table 36.
(b) From Table 37.
(c) From Tables 28, 29, 30, and 31 as described in Section 2.3.17.
(d) The benchmark model k_{eff} is the sum of the experiment k_{eff} (1.0000) and the two biases listed in the table.
(e) The uncertainty in the benchmark model k_{eff} is the sum in quadrature of the uncertainty in the simplification bias, the uncertainty in the temperature correction, and the experiment uncertainty.

4.0 RESULTS OF SAMPLE CALCULATIONS

The results of sample calculations using KENO V.a and MCNP5 for the nineteen cases are shown in Table 44. The input listings used in some of the calculations are shown in Appendix A.

Table 44. Sample Calculation Results (United States).

Code (Cross Section Set) → Case ↓	KENO V.a (238-group ENDF/B-VII.0 SCALE6.1 Library)		KENO V.a (Continuous-Energy ENDF/B-VII.0 SCALE6.1 Library)		MCNP 6.1 (Continuous-Energy ENDF/B-VII.1)	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
1	0.99653	0.00022	0.99788	0.00020	0.99878	0.00019
2	0.99735	0.00020	0.99824	0.00018	0.99915	0.00019
3	0.99963	0.00019	0.99941	0.00022	1.00013	0.00019
4	0.99703	0.00021	0.99777	0.00023	0.99852	0.00019
5	0.99713	0.00019	0.99820	0.00020	0.99878	0.00019
6	0.99672	0.00020	0.99746	0.00021	0.99855	0.00018
7	0.99661	0.00020	0.99740	0.00017	0.99870	0.00019
8	0.99654	0.00017	0.99747	0.00027	0.99809	0.00018
9	0.99644	0.00018	0.99787	0.00023	0.99805	0.00019
10	0.99604	0.00019	0.99727	0.00022	0.99769	0.00018
11	0.99745	0.00021	0.99825	0.00019	0.99842	0.00018
12	0.99763	0.00018	0.99761	0.00021	0.99837	0.00019
13	0.99763	0.00020	0.99808	0.00019	0.99890	0.00018
14	0.99768	0.00020	0.99750	0.00019	0.99825	0.00019
15	0.99721	0.00019	0.99776	0.00020	0.99825	0.00019
16	0.99789	0.00019	0.99804	0.00023	0.99851	0.00019
17	0.99827	0.00018	0.99869	0.00022	0.99873	0.00019
18	0.99873	0.00022	0.99821	0.00020	0.99906	0.00018
19	0.99867	0.00019	0.99837	0.00020	0.99908	0.00019

Figure 57 shows the reactivity offset ρ of the multigroup KENO V.a calculations, defined as

$$\rho = \frac{k_c - k_b}{k_c k_b} ,$$

where k_c is the calculated k_{eff} for the benchmark model of a given configuration and k_b is the evaluated benchmark model k_{eff} for the same configuration. The red error bars shown in the figure represent the uncertainty in the evaluated benchmark model k_{eff}. The smaller black error bars shown in the figure represent the stochastic uncertainties in the Monte Carlo calculations. The calculations underpredict the benchmark model k_{eff} by about one to four times the benchmark model uncertainty for all cases except Case 3 where the calculated k_{eff} very nearly matches the benchmark model k_{eff}. The unweighted average reactivity offset for all cases is -0.0025.

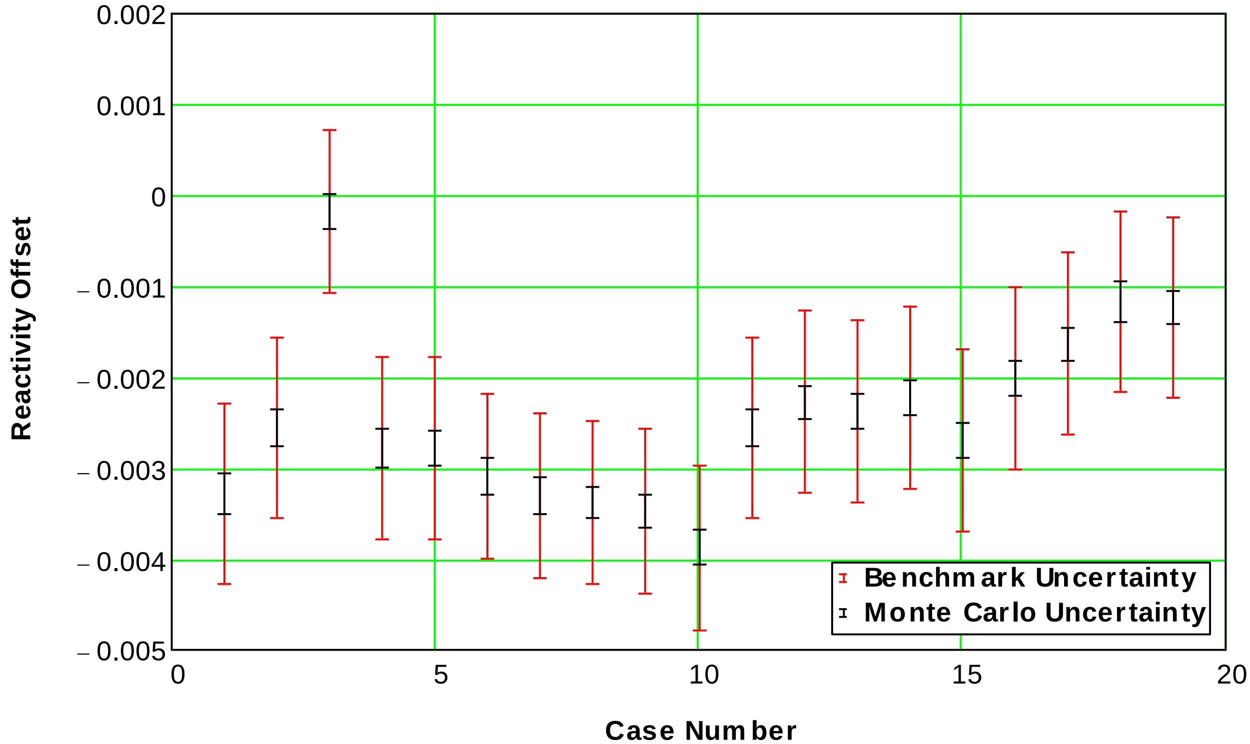

Figure 57. Reactivity Offset for KENO V.a Calculations Using Cross Sections from the 238-Group ENDF/B-VII.0 SCALE6.1 Library.

Figure 58 shows the reactivity offset for the continuous-energy KENO V.a calculations. The calculations underpredict the benchmark model k_{eff} by about one to three times the benchmark model uncertainty for all cases. The unweighted average reactivity offset for all cases is -0.0019.

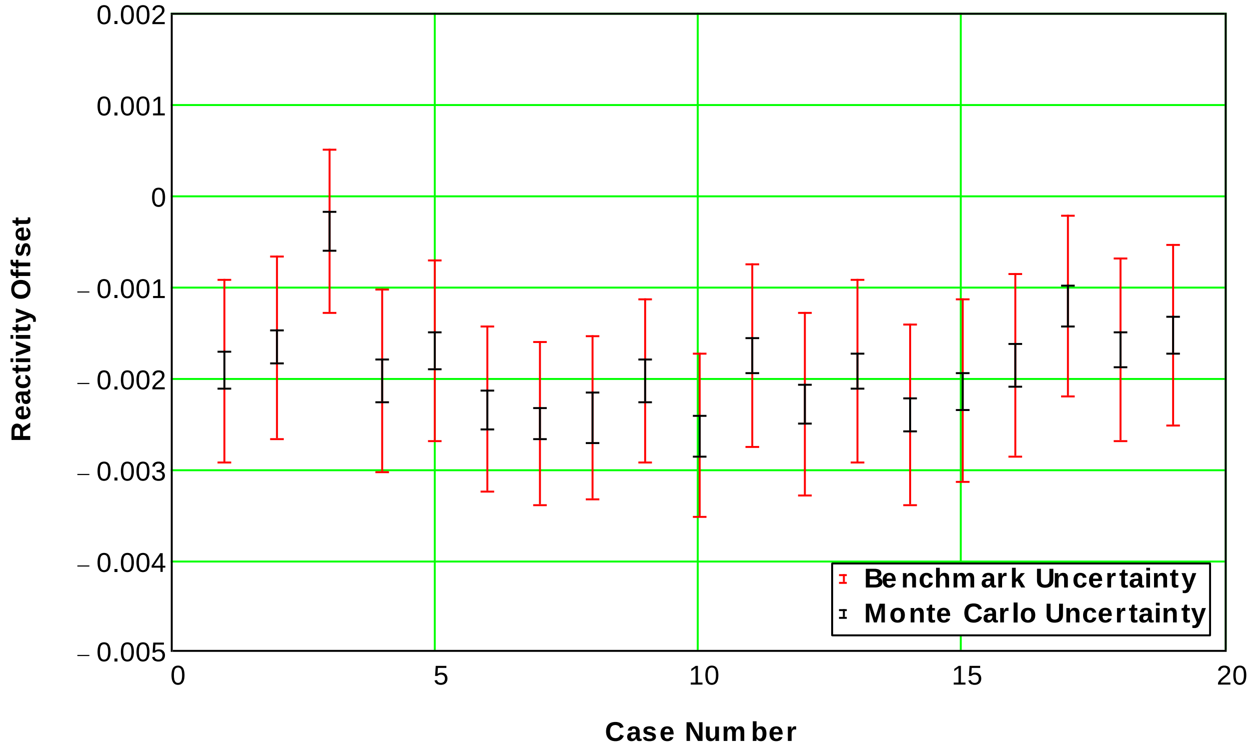

Figure 58. Reactivity Offset for KENO V.a Calculations Using Cross Sections from the Continuous-Energy ENDF/B-VII.0 SCALE6.1 Library.

Figure 59 shows the relative reactivity offset for the continuous-energy MCNP6.1 calculations. The calculations underpredict the benchmark model k_{eff} by about zero to two times the benchmark model uncertainty for all cases. The unweighted average reactivity offset for all cases is -0.0013.

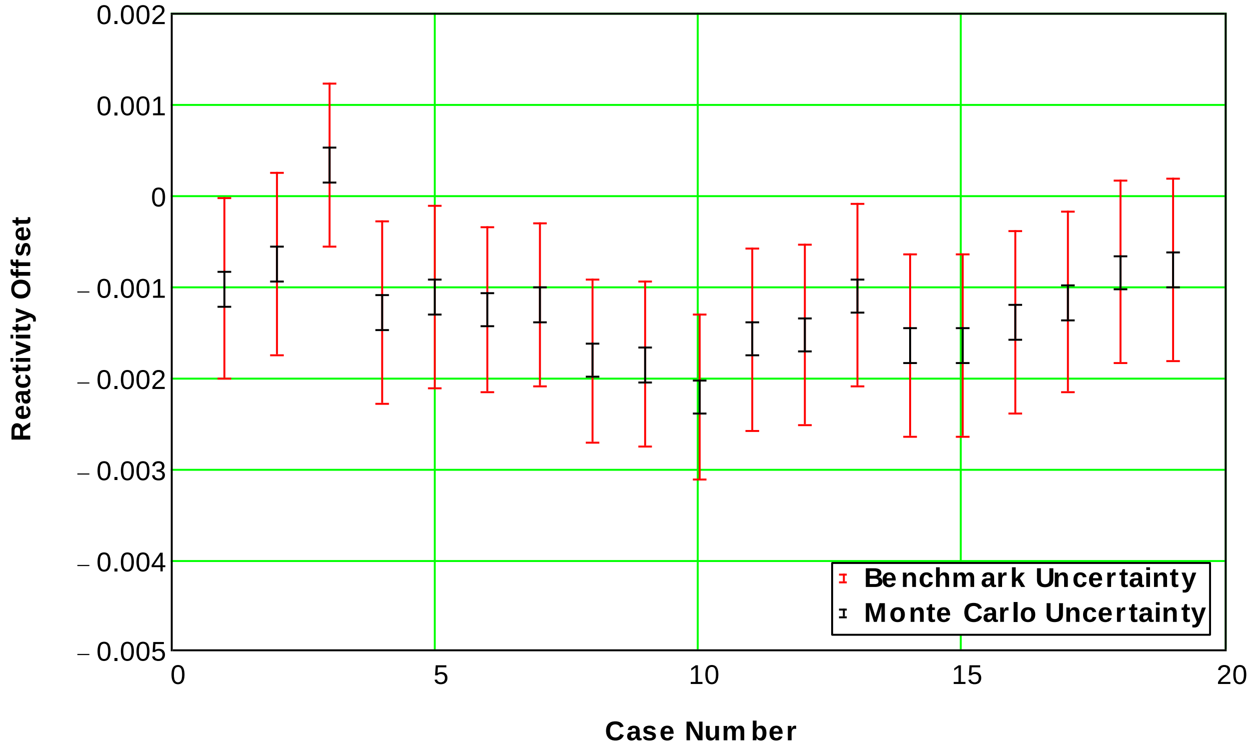

Figure 59. Reactivity Offset for MCNP6.1 Calculations Using Continuous-Energy ENDF/B-VII.0 Cross Sections.

The results of APOLLO2-MORET 5 and MORET 5 calculations for the nineteen cases are shown in Table 45. The APOLLO-MORET 5 calculations are run in two steps using the CRISTAL V2.0 package. The MORET 5 calculations are run in one step. The input listings used in some of the calculations are shown in Appendix A.3 (APOLLO2-MORET 5) and Appendix A.4 (MORET 5).

1. APOLLO2 2.8.3 release is a one-dimensional multi-group cell code. It is used to determine material buckling B^2_m, $k_{infinite}$, and homogeneous macroscopic self-shielded cross-section. It uses CEAV5.1.2, 281-group cross section library (coming from JEFF-3.1).

2. MORET 5 can be used in two calculation routes:

- Either coupled with the APOLLO2 deterministic code in a multi-group APOLLO2-MORET 5 route. It uses macroscopic cross sections from APOLLO2 and calculates k_{eff} through a 3D simulation.
- Or in a Monte Carlo MORET 5 continuous energy code. MORET uses cross sections in the ACE format based on the ENDF/B-VII.0 evaluation or the JEFF-3.1 evaluation and performs the 3D simulation to determine k_{eff}.

Table 45. Sample Calculation Results (France).

Code (Cross Section Set) → Case ↓	APOLLO2-MORET 5 (CEAV5.1.2 281-Group JEFF3.1) [(a)]		Continuous Energy MORET 5.B.2 (ENDF/B-VII.0) [(a)]		Continuous Energy MORET 5.B.2 (JEFF3.1) [(a)]	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
1	1.00192	0.00030	0.99819	0.00029	0.99729	0.00027
2	1.00224	0.00030	0.99823	0.00028	0.99780	0.00029
3	1.00355	0.00030	0.99930	0.00031	0.99884	0.00028
4	1.00090	0.00030	0.99778	0.00031	0.99712	0.00030
5	1.00133	0.00030	0.99852	0.00029	0.99813	0.00029
6	1.00123	0.00030	0.99785	0.00029	0.99734	0.00029
7	1.00136	0.00030	0.99794	0.00029	0.99631	0.00030
8	1.00155	0.00030	0.99776	0.00029	0.99679	0.00029
9	1.00193	0.00030	0.99745	0.00033	0.99774	0.00037
10	1.00134	0.00030	0.99733	0.00031	0.99684	0.00035
11	1.00156	0.00030	0.99797	0.00033	0.99691	0.00029
12	1.00110	0.00030	0.99731	0.00034	0.99738	0.00032
13	1.00125	0.00030	0.99802	0.00034	0.99736	0.00033
14	1.00078	0.00030	0.99762	0.00032	0.99644	0.00032
15	1.00072	0.00030	0.99735	0.00028	0.99602	0.00030
16	1.00199	0.00030	0.99832	0.00031	0.99744	0.00033
17	1.00195	0.00030	0.99853	0.00033	0.99785	0.00035
18	1.00127	0.00030	0.99893	0.00034	0.99733	0.00034
19	1.00081	0.00030	0.99753	0.00032	0.99595	0.00030

(a) Results provided by Nicolas Leclaire and Mathieu Monestier (France)

Figure 60 shows the reactivity offset for the multigroup APOLLO2 MORET 5 calculations using cross sections from the CEAV5.1.2, 281-group library from JEFF-3.1. The calculations overpredict the benchmark model k_{eff} by about one to four times the benchmark model uncertainty for all cases. The unweighted average reactivity offset for all cases is 0.0016.

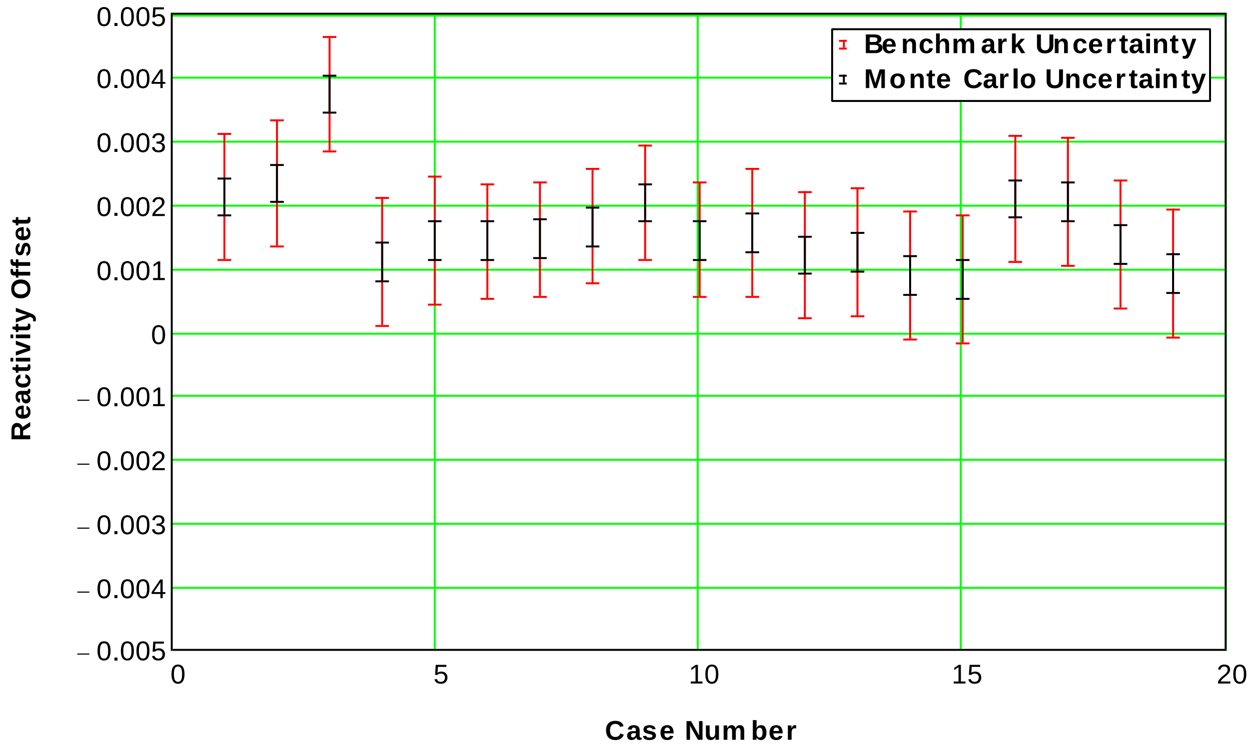

Figure 60. Reactivity Offset for APOLLO2 MORET 5 Calculations Using Cross Sections from the 238-Group ENDF/B-VII.0 SCALE6.1 Library.

Figure 61 shows the reactivity offset for the continuous-energy MORET 5 calculations using ENDF/B-VII.0 cross sections. The calculations underpredict the benchmark model k_{eff} by about zero to three times the benchmark model uncertainty for all cases. The unweighted average reactivity offset for all cases is -0.0019.

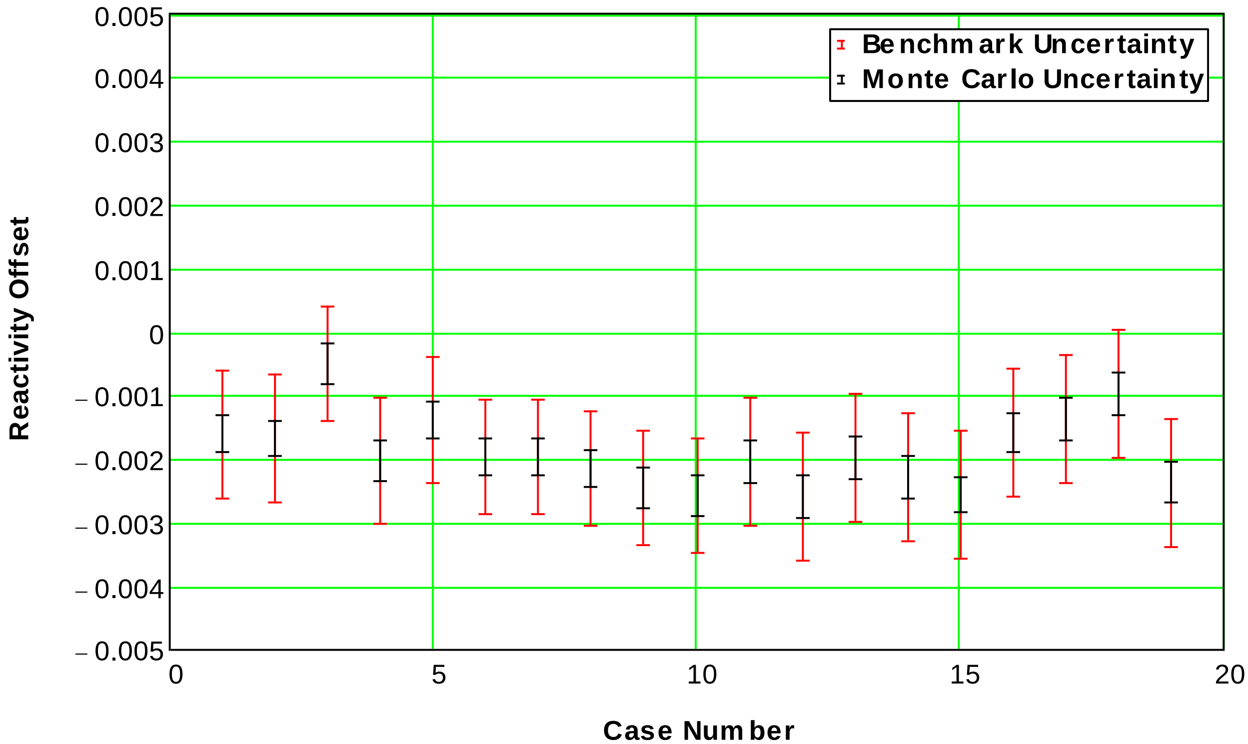

Figure 61. Reactivity Offset for Continuous-Energy MORET 5 Calculations Using Cross Sections from ENDF/B-VII.0.

Figure 62 shows the reactivity offset for the continuous-energy MORET 5 calculations using JEFF3.1 cross sections. The calculations underpredict the benchmark model k_{eff} by about one to four times the benchmark model uncertainty for all cases. The unweighted average reactivity offset for all cases is -0.0027.

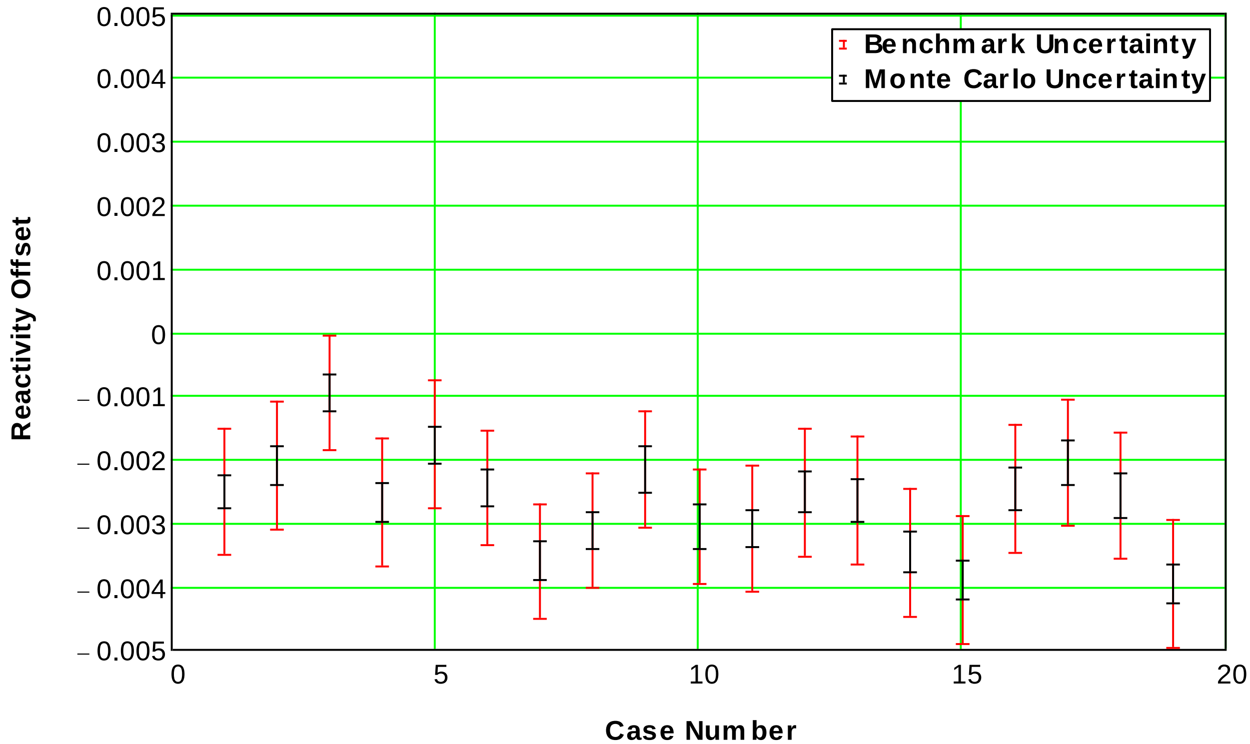

Figure 62. Reactivity Offset for Continuous-Energy MORET 5 Calculations Using Cross Sections from JEFF3.1.

5.0 REFERENCES

There are no published references.

APPENDIX A. TYPICAL INPUT LISTINGS

A.1 KENO INPUT LISTINGS

KENO V.a and the 238-group ENDF/B-VII.0 cross section set from SCALE 6.1.3 were used. A total of 550 batches of 40,000 neutrons were run. The first 50 batches were skipped.

KENO V.a input for Case 1

```
=csas25
LCT096 case 01, 2025 rods, Water at 36.540 cm
v7-238
read comp
'
' UO2 fuel
'
U-234  1 0  6.5539E-06 298.15 end
U-235  1 0  1.6010E-03 298.15 end
U-236  1 0  1.4632E-05 298.15 end
U-238  1 0  2.1296E-02 298.15 end
O      1 0  4.5837E-02 298.15 end
Ag     1 0  9.2319E-09 298.15 end
B      1 0  2.3858E-07 298.15 end
Cd     1 0  1.2380E-08 298.15 end
Co     1 0  2.1620E-08 298.15 end
Cr     1 0  2.5100E-06 298.15 end
Cu     1 0  2.1316E-07 298.15 end
Fe     1 0  1.0311E-05 298.15 end
Mn     1 0  2.8372E-07 298.15 end
Mo     1 0  1.2443E-07 298.15 end
Ni     1 0  3.4989E-06 298.15 end
V      1 0  1.4813E-08 298.15 end
' W      1 0  3.5998E-09 298.15 end
' Neither natural W nor W-180 are in the SCALE 238-group ENDF/B-VII.0 set
'  Source for Isotopic Atom Fractions:  Chart of the Nuclides 16th ed.
' W-180  1 0  4.31976e-12 298.15 end
W-182  1 0  9.53947e-10 298.15 end
W-183  1 0  5.15131e-10 298.15 end
W-184  1 0  1.10298e-09 298.15 end
W-186  1 0  1.02342e-09 298.15 end
'
' 3003 aluminum
'
Al  2 0  5.9668E-02 298.15 end
Si  2 0  1.7561E-04 298.15 end
Fe  2 0  1.0303E-04 298.15 end
Cu  2 0  3.2339E-05 298.15 end
Mn  2 0  3.7407E-04 298.15 end
Zn  2 0  1.2571E-05 298.15 end
'
'  water @ 25 C in core
'
H   3 0  6.6659E-02 298.15 end
O   3 0  3.3329E-02 298.15 end
```

```
'
' 6061 aluminum
'
Al  5 0  5.8376E-02 298.15 end
Si  5 0  4.1683E-04 298.15 end
Fe  5 0  1.8051E-04 298.15 end
Cu  5 0  7.9320E-05 298.15 end
Mn  5 0  2.6637E-05 298.15 end
Mg  5 0  6.9574E-04 298.15 end
Cr  5 0  6.2542E-05 298.15 end
Zn  5 0  2.9839E-05 298.15 end
Ti  5 0  6.7918E-06 298.15 end
V   5 0  3.1918E-06 298.15 end
'
' polyethylene
'
H-POLY 6 0  8.2755E-02 298.15 end
C   6 0  4.1377E-02 298.15 end
'
' SS-304 for springs
'
Fe  8 0  1.2527E-02 298.15 end
Cr  8 0  3.6455E-03 298.15 end
Ni  8 0  1.5724E-03 298.15 end
Mn  8 0  1.8160E-04 298.15 end
C   8 0  3.3225E-05 298.15 end
P   8 0  7.2471E-06 298.15 end
S   8 0  4.6663E-06 298.15 end
Si  8 0  1.7761E-04 298.15 end
N   8 0  3.5613E-05 298.15 end
'
'  water for reflector
'
H  10 0  6.6659E-02 298.15 end
O  10 0  3.3329E-02 298.15 end
'
' UO2 fuel
'
U-234 11 0  6.5539E-06 298.15 end
U-235 11 0  1.6010E-03 298.15 end
U-236 11 0  1.4632E-05 298.15 end
U-238 11 0  2.1296E-02 298.15 end
O     11 0  4.5837E-02 298.15 end
Ag    11 0  9.2319E-09 298.15 end
B     11 0  2.3858E-07 298.15 end
Cd    11 0  1.2380E-08 298.15 end
Co    11 0  2.1620E-08 298.15 end
Cr    11 0  2.5100E-06 298.15 end
Cu    11 0  2.1316E-07 298.15 end
Fe    11 0  1.0311E-05 298.15 end
Mn    11 0  2.8372E-07 298.15 end
Mo    11 0  1.2443E-07 298.15 end
Ni    11 0  3.4989E-06 298.15 end
V     11 0  1.4813E-08 298.15 end
' W     11 0  3.5998E-09 298.15 end
' Neither natural W nor W-180 are in the SCALE 238-group ENDF/B-VII.0 set
```

```
'  Source for Isotopic Atom Fractions:  Chart of the Nuclides 16th ed.
' W-180 11 0  4.31976e-12 298.15 end
W-182 11 0  9.53947e-10 298.15 end
W-183 11 0  5.15131e-10 298.15 end
W-184 11 0  1.10298e-09 298.15 end
W-186 11 0  1.02342e-09 298.15 end
'
' 3003 aluminum
'
Al 12 0  5.9668E-02 298.15 end
Si 12 0  1.7561E-04 298.15 end
Fe 12 0  1.0303E-04 298.15 end
Cu 12 0  3.2339E-05 298.15 end
Mn 12 0  3.7407E-04 298.15 end
Zn 12 0  1.2571E-05 298.15 end
end comp
read celldata
  latticecell squarepitch fuelr=0.262814 1 gapr=0.284519 0 cladr=0.317474 2
hpitch=0.40005 3 end
  latticecell squarepitch fuelr=0.262814 11 gapr=0.284519 0 cladr=0.317474 12
hpitch=0.40005 0 end
end celldata
read param
 npg=40000 gen=550 tme=500 htm=no
 nsk=50 run=yes flx=yes plt=no
 wrs=35 res=10000
end param
read geom
unit 1
  com=' bottom of driver rod in grid plate '
  cylinder  2 1  0.317474 0.0  -1.27
  cylinder  3 1  0.333375 0.0  -1.27
  cuboid    5 1 4p0.40005 0.0  -2.54
unit 2
  com=' submerged fueled section of driver rod '
  cylinder  1 1  0.262814 36.540      0.0
  cylinder  0 1  0.284519 36.540      0.0
  cylinder  2 1  0.317474 36.540      0.0
  cuboid    3 1 4p0.40005 36.540      0.0
unit 301
  com=' dry fueled section of driver rod '
  cylinder 11 1  0.262814 48.780     36.540
  cylinder  0 1  0.284519 48.780     36.540
  cylinder 12 1  0.317474 48.780     36.540
  cuboid    0 1 4p0.40005 48.780     36.540
unit 302
  com=' driver rod spring '
  cylinder  0 1  0.17526  50.4952    48.780
  cylinder  8 1  0.22860  50.4952    48.780
  cylinder  0 1  0.284519 50.4952    48.780
  cylinder  2 1  0.317474 50.4952    48.780
  cuboid    0 1 4p0.40005 50.4952    48.780
unit 3
  com=' dry fueled section and spring '
  array    301   -0.40005 -0.40005   36.540
  cuboid    3 1 4p0.40005 50.4952    36.540
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unit 4
  com=' top of driver rod in grid plate '
  cylinder  5 1  0.26289  53.0352    50.4952
  cylinder  0 1  0.284519 53.0352    50.4952
  cylinder  2 1  0.317474 53.0352    50.4952
  cylinder  0 1  0.333375 53.0352    50.4952
  cuboid    5 1 4p0.40005 53.0352    50.4952
unit 5
  com=' poly section of fuel rod in reflector '
  cylinder  6 1  0.26289  68.2752    53.0352
  cylinder  0 1  0.284519 68.2752    53.0352
  cylinder  2 1  0.317474 68.2752    53.0352
  cuboid    0 1 4p0.40005 68.2752    53.0352
unit 11
  com=' bottom grid plate without rod'
  cylinder  3 1  0.333375 0.0  -1.27
  cuboid    5 1 4p0.40005 0.0  -2.54
unit 12
  com=' submerged fueled section without rod '
  cuboid    3 1 4p0.40005 36.540      0.0
unit 13
  com=' dry fueled section without rod '
  cuboid    0 1 4p0.40005 50.4952    36.540
unit 14
  com=' grid plate without rod'
  cylinder  0 1  0.333375 53.0352    50.4952
  cuboid    5 1 4p0.40005 53.0352    50.4952
unit 15
  com=' poly section without rod '
  cuboid    0 1 4p0.40005 68.2752    53.0352
unit 51
  com=' bottom grid plate without rod'
  cylinder 10 1  0.333375 0.0  -1.27
  cuboid    5 1 4p0.40005 0.0  -2.54
unit 52
  com=' submerged fueled section without rod '
  cuboid   10 1 4p0.40005 36.540      0.0
unit 53
  com=' dry fueled section without rod '
  cuboid    0 1 4p0.40005 50.4952    36.540
unit 54
  com=' grid plate without rod'
  cylinder  0 1  0.333375 53.0352    50.4952
  cuboid    5 1 4p0.40005 53.0352    50.4952
unit 55
  com=' poly section without rod '
  cuboid    0 1 4p0.40005 68.2752    53.0352
unit 210
  com=' water under lower grid plate '
  cylinder 10 1  46.8376   16.51     0.0
  cuboid    0 1  46.9  -46.9   46.9  -46.9   16.51     0.0
unit 211
  com=' lower grid plate with rod ends '
  array   11    -18.00225 -18.00225  0.0
  cylinder  5 1  46.355     2.54     0.0
  cylinder 10 1  46.8376    2.54     0.0
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  cuboid    0 1  46.9  -46.9   46.9  -46.9    2.54     0.0
unit 151
  com=' bottom section of detector tube '
  cylinder  0 1  2.8575    0.762      0.635
  cylinder  5 1  3.175     0.762      0.0
unit 152
  com=' poly section of detector tube '
  cylinder  0 1  2.875    30.7848     0.762
  cylinder  5 1  3.175    30.7848     0.762
  cylinder 10 1  3.30581  30.7848     0.762
  cylinder  6 1  5.75945  30.7848     0.762
unit 153
  com=' submerged section of detector tube above poly in fuel '
  cylinder  0 1  2.875    36.540     30.7848
  cylinder  5 1  3.175    36.540     30.7848
unit 212
  com=' model above lower GP underwater '
  array   12    -18.00225 -18.00225    0.0
  cylinder 10 1  46.8376   36.540      0.0
  hole    151    32.385     6.4        0.0
  hole    152    32.385     6.4        0.0
  hole    153    32.385     6.4        0.0
  hole    151   -32.385    -6.4        0.0
  hole    152   -32.385    -6.4        0.0
  hole    153   -32.385    -6.4        0.0
  cuboid    0 1  46.9  -46.9   46.9  -46.9   36.540       0.0
unit 154
  com=' dry section of detector tube above poly in fuel '
  cylinder  0 1  2.875    50.4952    36.540
  cylinder  5 1  3.175    50.4952    36.540
unit 213
  com=' model below upper GP above water level '
  array   13    -18.00225 -18.00225   36.540
  cylinder  0 1  46.8376   50.4952    36.540
  hole    154    32.385     6.4        0.0
  hole    154   -32.385    -6.4        0.0
  cuboid    0 1  46.9  -46.9   46.9  -46.9   50.4952     36.540
unit 155
  com=' section of detector tube at grid plate '
  cylinder  0 1  2.875    53.0352    50.4952
  cylinder  5 1  3.175    53.0352    50.4952
unit 214
  com=' model at upper grid plate '
  array   14    -18.00225 -18.00225 50.4952
  cuboid    5 1  4p20.955  53.0352    50.4952
  cylinder  0 1  46.8376   53.0352    50.4952
  hole    155    32.385     6.4        0.0
  hole    155   -32.385    -6.4        0.0
  cuboid    0 1  46.9  -46.9   46.9  -46.9   53.0352    50.4952
unit 156
  com=' bottom section of detector tube '
  cylinder  0 1  2.875    68.2752    53.0352
  cylinder  5 1  3.175    68.2752    53.0352
unit 215
  com=' model above upper grid plate '
  array   15    -18.00225 -18.00225 53.0352
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  cylinder  0 1  46.8376   68.2752    53.0352
  hole    156    32.385     6.4        0.0
  hole    156   -32.385    -6.4        0.0
  cuboid    0 1  46.9  -46.9   46.9  -46.9   68.2752    53.0352
global unit 999
  array    1    -46.9     -46.9    -19.05
end geom
read array
  ara=1
  com=' the whole shebang '
  nux=1   nuy=1   nuz=6
  fill   210  211  212  213  214  215  end fill
  ara=301
  com=' fueled section of fuel rod '
  nux=1   nuy=1   nuz=2
  fill   301  302  end fill
' 2025 fuel rods 2025 total positions
ara= 11
nux= 45 nuy= 45 nuz= 1 fill
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end fill
end array
read plot
  ttl='central few rods'
  xul=-2.  yul= 2.   zul=24.39
  xlr= 2.  ylr=-2.   zlr=24.39
  uax=1    vax=0    wax=0
  udn=0    vdn=-1   wdn=0
  nax=600  ndn=600
  end plt0
  ttl='central "element"'
  xul=-7.7  yul=7.7  zul=24.39
  xlr= 7.7 ylr=-7.7  zlr=24.39
  uax=1    vax=0    wax=0
  udn=0    vdn=-1   wdn=0
  nax=600  ndn=600
  end plt1
  ttl='whole core - midplane'
  xul=-22  yul= 22   zul=24.39
  xlr= 22  ylr=-22   zlr=24.39
  uax=1    vax=0    wax=0
  udn=0    vdn=-1   wdn=0
```

```
nax=600  ndn=600
end plt2
ttl='whole core - bottom gridplate'
xul=-22  yul= 22   zul=-1.2
xlr= 22  ylr=-22   zlr=-1.2
uax=1    vax=0    wax=0
udn=0    vdn=-1   wdn=0
nax=600  ndn=600
end plt3
ttl='whole core - top gridplate'
xul=-22  yul= 22   zul=51.7
xlr= 22  ylr=-22   zlr=51.7
uax=1    vax=0    wax=0
udn=0    vdn=-1   wdn=0
nax=600  ndn=600
end plt4
ttl='big look - midplane'
xul=-50  yul= 50   zul=24.39
xlr= 50  ylr=-50   zlr=24.39
uax=1    vax=0    wax=0
udn=0    vdn=-1   wdn=0
nax=600  ndn=600
end plt5
ttl='big look - bottom gridplate'
xul=-50  yul= 50   zul=-1.2
xlr= 50  ylr=-50   zlr=-1.2
uax=1    vax=0    wax=0
udn=0    vdn=-1   wdn=0
nax=600  ndn=600
end plt6
ttl='big look - top gridplate'
xul=-50  yul= 50   zul=51.7
xlr= 50  ylr=-50   zlr=51.7
uax=1    vax=0    wax=0
udn=0    vdn=-1   wdn=0
nax=600  ndn=600
end plt7
ttl='central few rods'
xul=-2.  yul=0     zul= 26.7
xlr= 2.  ylr=0     zlr= 22.7
uax=1    vax=0    wax=0
udn=0    vdn=0    wdn=-1
nax=600  ndn=600
end plt8
ttl='central few rods - top'
xul=-4.  yul=0     zul= 53.7
xlr= 4.  ylr=0     zlr= 45.7
uax=1    vax=0    wax=0
udn=0    vdn=0    wdn=-1
nax=600  ndn=600
end plt9
ttl='central few rods - bottom'
xul=-4.  yul=0     zul= 4.7
xlr= 4.  ylr=0     zlr=-3.3
uax=1    vax=0    wax=0
udn=0    vdn=0    wdn=-1
```

```
  nax=600  ndn=600
  end plt10
  ttl='central "element"'
  xul=-7.7 yul= 0.   zul=32.4
  xlr= 7.7 ylr= 0.   zlr=17.0
  end plt11
  ttl='big look'
  xul=-50.  yul=0   zul=  75.
  xlr= 50.  ylr=0   zlr= -25.
  uax=1    vax=0    wax=0
  udn=0    vdn=0    wdn=-1
  nax=600  ndn=600
  end plt12
  ttl='top of core'
  xul=-25.  yul=0   zul=  70.
  xlr= 25.  ylr=0   zlr=  20.
  uax=1    vax=0    wax=0
  udn=0    vdn=0    wdn=-1
  nax=600  ndn=600
  end plt13
  ttl='left detector y=6.4'
  xul=-50.  yul= 6.4 zul= 75.
  xlr= 50.  ylr= 6.4 zlr=-25.
  uax=1    vax=0    wax=0
  udn=0    vdn=0    wdn=-1
  nax=600  ndn=600
  end plt14
  ttl='right detector y=-6.4'
  xul=-50.  yul=-6.4 zul= 75.
  xlr= 50.  ylr=-6.4 zlr=-25.
  uax=1    vax=0    wax=0
  udn=0    vdn=0    wdn=-1
  nax=600  ndn=600
  end plt15
end plot
end data
end
```

A.2 MCNP INPUT LISTINGS

MCNP6.1 and the continuous-energy cross section set based on ENDF/B-VII.1 were used. A total of 550 batches of 40,000 neutrons were run. The first 50 batches were skipped.

MCNP6.1 input for Case 1

```
LCT096 case 01 2025 rod assembly
c
c   fuel rod with grid plates
c
 1     1  6.8772E-02  -1    12   -13       u=1 $ fuel
 2     0              -5    13   -14       u=1 $ inside spring
 3     5  1.8185E-02  -6     5    13   -14 u=1 $ spring
 4     2  5.9877E-02  -7    14   -15       u=1 $ Al spacer
 5     7  1.2236E-01  -7    15   -101      u=1 $ polyethylene spacer
 6     0              -2    12   -101          $ void in clad
                     (1 : 13)                  $ fuel
                     (6 : -13 : 14)            $ spring
                     (7 : -14 : 15)            $ Al spacer
                     (7 : -15 : 101)       u=1   $ poly spacer
 7     3  6.0366E-02  -3    11   -101          $ clad
                     (2 : -12)             u=1   $ void in rod
 8     4  9.9988E-02  -4     3    11   -12 u=1 $ water in lower GP
 9     2  5.9877E-02  10   -12                 $ lower grid plate
                     (4 : -11)              u=1   $ hole
10     4  9.9988E-02 -10                   u=1 $ water below lower GP
11     4  9.9988E-02   3    12   -14  -100 u=1 $ water between GPs
12     4  9.9988E-02  -4     3    14   -15     $ water in upper GP
                                      -100 u=1
13     2  5.9877E-02   4    14   -15       u=1 $ upper grid plate
14     4  9.9988E-02   3    15   -101 -100 u=1 $ water above upper GP
15     0               3    12   -14   100 u=1 $ void between GPs
16     0              -4     3    14   -15     $ void in upper GP
                                       100 u=1
17     0               3    15   -101  100 u=1 $ void above upper GP
c
c  a water cell
c
114    4  9.9988E-02 -10 -100             u=7 $ water below grid plate
115    2  5.9877E-02  10   -11 :  4   11      $ bottom grid plate
                     -12                  u=7
116    4  9.9988E-02  -4   11  -12        u=7 $ water in lower grid plate
117    4  9.9988E-02  12   -14 -100       u=7 $ water between grid plates
118    4  9.9988E-02  -4   14  -15 -100   u=7 $ water in upper grid plate
119    2  5.9877E-02   4   14  -15        u=7 $ upper grid plate
120    4  9.9988E-02  15 -100 -101        u=7 $ water above grid plate
121    0              12   -14  100       u=7 $ void between grid plates
122    0              -4   14  -15  100   u=7 $ void in upper grid plate
123    0              15  100 -101        u=7 $ void above grid plate
c
c  the array
c
```

```
999    4  -0.99705  901  -902   903  -904  lat=1  u=10
                    fill -22:23 -22:22  0:0
c  2025 fuel rods 2025 total positions
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
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      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
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      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
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      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
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      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
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      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
```

```
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
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      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7
c
c
1000   4  9.9988E-02 921  -101   913  -914   915  -916 $ bounds on upper array
           fill=10
1002   2  5.9877E-02 10   -12  -932                     $ bottom grid plate
              (-921 : 912 : -913 : 914 : -915 : 916)      $ the array
1003   2  5.9877E-02 961 -962  963 -964   14   -15      $ top grid plate
              (-921 : 912 : -913 : 914 : -915 : 916)      $ the array
1007   4  9.9988E-02 921 -922 -923 -100                 $ reflector below water level
              (-921 : 912 : -913 : 914 : -915 : 916)      $ the array
                      (-10 : 12 : 932)                    $ bottom grid plate
              (-961 : 962 : -963 : 964 : -14 : 15)        $ top grid plate
              (-803 : 804)                                $-x+y detector tube
              (-803 : 806)                                $+x+y detector tube
              (810 : -811 : 812 : -814)                   $-x+y detector poly
              (810 : -811 : 813 : -815)                   $+x+y detector poly
1008   0              921 -922 -923  100 -101           $ reflector above water level
              (-921 : 912 : -913 : 914 : -915 : 916)      $ the array
                      (-10 : 12 : 932)                    $ bottom grid plate
```

```
            (-961 : 962 : -963 : 964 : -14 : 15)       $ top grid plate
            (-803 : 804)                               $-x+y detector tube
            (-803 : 806)                               $+x+y detector tube
            (810 : -811 : 812 : -814)                  $-x+y detector poly
            (810 : -811 : 813 : -815)                  $+x+y detector poly
1030   0           -101   802 -805                   $ -x+y detector well
1031   2  5.9877E-02 -101   803 -804                 $ -x+y detector tube
                   (-802 : 805)                        $-x+y well
1032   7  1.2236E-01 -810   811 -812  814            $ -x+y detector poly
1033   0           -101   802 -807                   $ +x+y detector well
1034   2  5.9877E-02 -101   803 -806                 $ +x+y detector tube
                   (-802 : 807)                        $+x+y well
1035   7  1.2236E-01 -810   811 -813  815            $ +x+y detector poly
1100   0                                             $ external void
                   (-921 : 101 : 923)                $ water in upper tank

c
c fuel rod surfaces
c
1    cz    0.262814 $ fuel OD
2    cz    0.284519 $ clad ID
3    cz    0.317474 $ clad OD
4    cz    0.333375 $ ID of hole in grid plate at fuel
5    cz    0.17526  $ ID of spring
6    cz    0.22860  $ OD of spring
7    cz    0.26289  $ intermediate plug OD
8    cz    0.26289  $ poly OD
10   pz   -2.54     $ bottom of bottom grid plate
11   pz   -1.27     $ bottom of rod
12   pz    0.0      $ bottom of fuel
13   pz   48.780    $ top of fuel
14   pz   50.4952   $ bottom of upper grid plate
15   pz   53.0352   $ top of upper grid plate
c
c     water level
c
100   pz    36.54        $ top of the water
c
c     top of the model
101   pz    68.2752      $ top of the model - 68.2752 gives 6" above grid plate
c
c   detector wells
c
802   pz     0.635     $ bottom inside of tube
803   pz     0.0       $ bottom of tube
804   c/z   32.385    6.400   3.175  $ OD tube outside
805   c/z   32.385    6.400   2.8575 $ ID of tube
806   c/z  -32.385   -6.400   3.175  $ OD tube
807   c/z  -32.385   -6.400   2.8575 $ ID of tube
810   pz    30.7848                  $ top of poly
811   pz     0.762                   $ bottom of poly
812   c/z   32.385    6.400   5.75945 $ OD poly
813   c/z  -32.385   -6.400   5.75945 $ OD poly
814   c/z   32.385    6.400   3.30581 $ ID poly
815   c/z  -32.385   -6.400   3.30581 $ ID poly
c
```

```
c cell boundaries
c
901  px   -0.40005
902  px    0.40005
903  py   -0.40005
904  py    0.40005
c
c array boundaries
c
911  pz  -16.00001
912  pz  145.00001
913  px  -18.00225
914  px   18.00225
915  py  -18.00225
916  py   18.00225
c
c     the water
c
921   pz   -19.05      $ bottom of reflector
922   pz    82.55      $ top of reflector
923   cz    46.83125   $ outside of reflector
932   cz    46.355     $ outside curve of lower grid plate
c
c   upper grid plate
c
961   px   -20.955
962   px    20.955
963   py   -20.955
964   py    20.955

c  Source for Isotopic Atom Fractions:  Chart of the Nuclides 16th ed.
c
c UO2 fuel
c
m1
     92234.80c  6.5539E-06
     92235.80c  1.6010E-03
     92236.80c  1.4632E-05
     92238.80c  2.1296E-02
      8016.80c  4.5837E-02
c     47000.xxc  9.2319E-09  $Ag
     47107.80c 4.78572e-09
     47109.80c 4.44618e-09
c      5000.xxc  2.3858E-07  $B
      5010.80c 4.74774e-08
      5011.80c 1.91103e-07
c     48000.xxc  1.2380E-08  $Cd
     48106.80c 1.54750e-10
     48108.80c 1.10182e-10
     48110.80c 1.54626e-09
     48111.80c 1.58464e-09
     48112.80c 2.98729e-09
     48113.80c 1.51284e-09
     48114.80c 3.55677e-09
     48116.80c 9.27262e-10
     27059.80c 2.1620E-08  $Co
```

```
c      24000.xxc  2.5100E-06  $Cr
     24050.80c 1.0906e-07
     24052.80c 2.1031e-06
     24053.80c 2.38475e-07
     24054.80c 5.93615e-08
c      29000.xxc  2.1316E-07  $Cu
     29063.80c 1.47443e-07
     29065.80c 6.57172e-08
c      26000.xxc  1.0311E-05  $Fe
     26054.80c 6.02678e-07
     26056.80c 9.46075e-06
     26057.80c 2.18490e-07
     26058.80c 2.90770e-08
     25055.80c  2.8372E-07  $Mn
c  Molybdenum 1.2443E-07
     42092.80c 1.84654e-08
     42094.80c 1.15098e-08
     42095.80c 1.98093e-08
     42096.80c 2.07549e-08
     42097.80c 1.18831e-08
     42098.80c 3.00250e-08
     42100.80c 1.19826e-08
c      28000.xxc  3.4989E-06  $Ni
     28058.80c 2.38194e-06
     28060.80c 9.17520e-07
     28061.80c 3.98840e-08
     28062.80c 1.27168e-07
     28064.80c 3.23858e-08
c      23000.XXX  1.4813E-08  $V
      23050.80c 3.70325E-11
      23051.80c 1.4776E-08
c      74000.xxc  3.5998E-09  $W
     74180.80c 4.31976e-12
     74182.80c 9.53947e-10
     74183.80c 5.15131e-10
     74184.80c 1.10298e-09
     74186.80c 1.02342e-09
c
c    6061 aluminum
c
m2   13027.80c  5.8376E-02
c      14000.xxx  4.1683E-04
     14028.80c 3.84441e-04
     14029.80c 1.95210e-05
     14030.80c 1.28684e-05
c      26000.xxx  1.8051E-04
     26054.80c 1.05508e-05
     26056.80c 1.65625e-04
     26057.80c 3.82501e-06
     26058.80c 5.09038e-07
c      29000.xxx  7.9320E-05
     29063.80c 5.48656e-05
     29065.80c 2.44544e-05
     25055.80c  2.6637E-05
c  Magnesium  6.9574E-04
     12024.80c 5.49565e-04
```

```
     12025.80c 6.9574e-05
     12026.80c 7.6601e-05
c     24000.xxx  6.2542E-05
     24050.80c 2.71745e-06
     24052.80c 5.24033e-05
     24053.80c 5.94212e-06
     24054.80c 1.47912e-06
c     30000.XXX  2.9839e-05
     30064.80c 1.45107E-05
     30066.80c 8.32508E-06
     30067.80c 1.2234E-06
     30068.80c 5.59481E-06
     30070.80c 1.85002E-07
c  Titanium 6.7918e-006
     22046.80c 5.60324e-07
     22047.80c 5.05310e-07
     22048.80c 5.00691e-06
     22049.80c 3.67436e-07
     22050.80c 3.51815e-07
c     23000.XXX  3.1918E-06
     23050.80c 7.9795E-09
     23051.80c 3.18382E-06
c
c    3003 aluminum
c
m3   13027.80c  5.9668E-02
c     14000.xxx  1.7561E-04
     14028.80c 1.61965e-04
     14029.80c 8.22417e-06
     14030.80c 5.42143e-06
c     26000.xxx  1.0303E-04
     26054.80c 6.02210e-06
     26056.80c 9.45341e-05
     26057.80c 2.18321e-06
     26058.80c 2.90545e-07
c     29000.xxx  3.2339E-05
     29063.80c 2.23689e-05
     29065.80c 9.97011e-06
     25055.80c  3.7407E-04
c     30000.XXX  1.2571e-05
     30064.80c 6.11328E-06
     30066.80c 3.50731E-06
     30067.80c 5.15411E-07
     30068.80c 2.35706E-06
     30070.80c 7.79402E-08
c
c    water
c
m4    1001.80c  6.6659E-02
      8016.80c  3.3329E-02
mt4   lwtr.20t
c
c    stainless steel 304
c
m5
c  Iron 1.2527e-02
```

```
     26054.80c 7.32203e-04
     26056.80c 1.14940e-02
     26057.80c 2.65447e-04
     26058.80c 3.53261e-05
c  Chromium 3.6455E-03
     24050.80c 1.58397e-04
     24052.80c 3.05453e-03
     24053.80c 3.46359e-04
     24054.80c 8.62161e-05
c  Nickel 1.5724E-03
     28058.80c 1.07044e-03
     28060.80c 4.12332e-04
     28061.80c 1.79238e-05
     28062.80c 5.71489e-05
     28064.80c 1.45541e-05
     25055.80c  1.8160E-04  $Mn
      6000.80c  3.3225E-05  $C
     15031.80c  7.2471E-06  $P
c  Sulfur 4.6663e-006
     16032.80c 4.42972e-06
     16033.80c 3.54639e-08
     16034.80c 2.00184e-07
     16036.80c 9.33260e-10
c  Silicon 1.7761e-04
     14028.80c 1.63809e-04
     14029.80c 8.31783e-06
     14030.80c 5.48318e-06
c  Nitrogen 3.5613e-005
      7014.80c 3.54819e-05
      7015.80c 1.31056e-07
c
c    polyethylene (CH2)
c
m7
      1001.80c  8.2755E-02
      6000.80c  4.1377E-02
mt7   poly.20t
c
c
imp:n    1 38r 0
mode   n
kcode  40000  1  50  550
ksrc   0 0 24.4
prdmp    0  0  0  1
print    -128
lost   1000 10
tr4   0.   0.   0.  $ SE1 0=up  -68.57746=down
tr5   0.   0.   0.  $ SE2 0=up  -68.57746=down
tr6   0.   0.   0.  $ CE  0=up  -68.57746=down
kopts  kinetics=yes
```

A.3 APOLLO2-MORET 5 INPUT LISTINGS

APOLLO2-MORET 5 and the 281-group CEAV5.1.2 281-group JEF-3.1 cross section set were used. A total of 1590 batches of 6000 neutrons were run. The first 100 batches were skipped.

Case 1

```
********************************************************
*          281 groups APOLLO2-MORET 5.B.1 Code         *
*               CRISTAL V2.0 package                   *
********************************************************
*                LEU-COMP-THERM-096                    *
*                  ICSBEP Volume IV                    *
*                     CASE 1                           *
*                   revision 0                         *
********************************************************
*                  BENCHMARK SNL                       *
*  partially reflected water-moderated square-pitched  *
*  U(6.90)O2 fuel rod lattices with 0.67 fuel to water *
*            volume ratio (0.800 cm pitch)             *
*                           CAS 1                      *
********************************************************
*          array  2025 rods  - Pitch = 0.8 cm          *
*                  Hc = 36.54  cm                      *
*                  T = 25 C                            *
********************************************************
*    Keff(exp) +/- 1s =0.99985 +/- 0.00095             *
********************************************************
* writer:   M. Monestier reviewer : N.  leclaire       *
********************************************************
DEBUT_APOLLO2
*=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
*     LATEC version 1.2.0 - 16.04.2015
*     Creation du fichier le Monday, April 20, 2015
*=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
*            -=- INITIALISATION - CALCUL Geometrie_3D-=-

TOPT = TABLE:                                                       ;
TRES = TABLE:                                                       ;
TSTR = TABLE:                                                       ;
TOPT.'CALCUL_CRISTAL' = 1                                           ;
REPPROC            = OUVRIR: 22 'VARIABLE' 1024 10000
                                'ADRESSE' 'aprocristal'             ;
CHARGE_APROCRISTAL = LIRE: REPPROC 'APROC' 'CHARGE_APROCRISTAL'     ;
FERMER: REPPROC                                                     ;
EXECUTER CHARGE_APROCRISTAL                                         ;
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES               ;
*            -=- OPTIONS -=-
*
TOPT.'STCRI'.'NGROUP_FINAL' = 281 ;
TOPT.'STCRI'.'ANISOTROPIE' = 'P5' ;
*
*===============================================================
* APOLLO PIJ CALCUL 1
*
```

```
ANISO = CONCAT: '&' TOPT.'STCRI'.'ANISOTROPIE' ;
*===============================================================
* AIR
TITRE: 'AIR' ;
CALCUL_AP2 =  1 ;
*
*            -=- Description des milieux -=-

nom_calc = 'AIR' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                            ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                   ;
TSTR.nom_calc = TABLE:                                              ;

*AIR
nom_mil = 'STRUC AIR ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                         ;
TOPT.'STMIL'.nom_mil.'N14     ' = 4.19850E-05 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 1.12630E-05 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'AIR' ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                         -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )             ;

*
*            -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES              ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*            -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil            ;
DETRUIRE:   TSTR.'APOLIB'                                           ;

*===============================================================
```

```
* APOLLO PIJ CALCUL 2
*
*===============================================================
* WATER_LCT080
TITRE: 'WATER_LCT080' ;
CALCUL_AP2 =  2 ;
*
*            -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES               ;
nom_calc = 'WATER_LCT080' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                            ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                   ;
TSTR.nom_calc = TABLE:                                              ;

*WATER_LCT080
nom_mil = 'STRUC WATER_LCT080 ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                         ;
TOPT.'STMIL'.nom_mil.'H1_H2O  ' = 6.66580E-02 ;
TOPT.'STMIL'.nom_mil.'O17     ' = 1.26650E-05 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 3.33163E-02 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'WATER_LCT080' ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                         -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )             ;

*
*            -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES              ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*            -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
```

```
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil             ;
DETRUIRE:   TSTR.'APOLIB'                                            ;

*==============================================================
* APOLLO PIJ CALCUL 3
*
*==============================================================
* GRID_PLATE_6061_ALUMINUM_2
TITRE: 'GRID_PLATE_6061_ALUMINUM_2' ;
CALCUL_AP2 =  3 ;
*
*             -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES                ;
nom_calc = 'GRID_PLATE_6061_ALUMINUM_2' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                             ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                    ;
TSTR.nom_calc = TABLE:                                               ;

*GRID_PLATE_6061_ALUMINUM_2
nom_mil = 'STRUC GRID_PLATE_6061_ALUMINUM_2 ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                          ;
TOPT.'STMIL'.nom_mil.'FE56    ' = 1.65625E-04 ;
TOPT.'STMIL'.nom_mil.'FE57    ' = 3.82501E-06 ;
TOPT.'STMIL'.nom_mil.'FE58    ' = 5.09038E-07 ;
TOPT.'STMIL'.nom_mil.'VNAT    ' = 3.19180E-06 ;
TOPT.'STMIL'.nom_mil.'TI46    ' = 5.60323E-07 ;
TOPT.'STMIL'.nom_mil.'CR54    ' = 1.47912E-06 ;
TOPT.'STMIL'.nom_mil.'CR53    ' = 5.94212E-06 ;
TOPT.'STMIL'.nom_mil.'CR52    ' = 5.24033E-05 ;
TOPT.'STMIL'.nom_mil.'SI30    ' = 1.29217E-05 ;
TOPT.'STMIL'.nom_mil.'CR50    ' = 2.71745E-06 ;
TOPT.'STMIL'.nom_mil.'TI49    ' = 3.67436E-07 ;
TOPT.'STMIL'.nom_mil.'TI48    ' = 5.00691E-06 ;
TOPT.'STMIL'.nom_mil.'TI47    ' = 5.05310E-07 ;
TOPT.'STMIL'.nom_mil.'MN55    ' = 2.66370E-05 ;
TOPT.'STMIL'.nom_mil.'AL27    ' = 5.83760E-02 ;
TOPT.'STMIL'.nom_mil.'CU65    ' = 2.44544E-05 ;
TOPT.'STMIL'.nom_mil.'CU63    ' = 5.48656E-05 ;
TOPT.'STMIL'.nom_mil.'ZN      ' = 2.98390E-05 ;
TOPT.'STMIL'.nom_mil.'TI50    ' = 3.51815E-07 ;
TOPT.'STMIL'.nom_mil.'MG24    ' = 5.49565E-04 ;
TOPT.'STMIL'.nom_mil.'MG25    ' = 6.95740E-05 ;
TOPT.'STMIL'.nom_mil.'MG26    ' = 7.66010E-05 ;
TOPT.'STMIL'.nom_mil.'SI28    ' = 3.84442E-04 ;
TOPT.'STMIL'.nom_mil.'SI29    ' = 1.94660E-05 ;
TOPT.'STMIL'.nom_mil.'FE54    ' = 1.05508E-05 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'GRID_PLATE_6061_ALUMINUM_2' ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
```

```
*                        -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*             -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )              ;

*
*             -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES               ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*             -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil             ;
DETRUIRE:   TSTR.'APOLIB'                                            ;

*===============================================================
* APOLLO PIJ CALCUL 4
*
*===============================================================
* GRID_PLATE_6061_ALUMINUM
TITRE: 'GRID_PLATE_6061_ALUMINUM' ;
CALCUL_AP2 =  4 ;
*
*             -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES                ;
nom_calc = 'GRID_PLATE_6061_ALUMINUM' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                             ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                    ;
TSTR.nom_calc = TABLE:                                               ;

*GRID_PLATE_6061_ALUMINUM
nom_mil = 'STRUC GRID_PLATE_6061_ALUMINUM ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                          ;
TOPT.'STMIL'.nom_mil.'FE56    ' = 1.65625E-04 ;
TOPT.'STMIL'.nom_mil.'FE57    ' = 3.82501E-06 ;
TOPT.'STMIL'.nom_mil.'FE58    ' = 5.09038E-07 ;
TOPT.'STMIL'.nom_mil.'VNAT    ' = 3.19180E-06 ;
TOPT.'STMIL'.nom_mil.'TI46    ' = 5.60323E-07 ;
TOPT.'STMIL'.nom_mil.'CR54    ' = 1.47912E-06 ;
```

```
TOPT.'STMIL'.nom_mil.'CR53    ' = 5.94212E-06 ;
TOPT.'STMIL'.nom_mil.'CR52    ' = 5.24033E-05 ;
TOPT.'STMIL'.nom_mil.'SI30    ' = 1.29217E-05 ;
TOPT.'STMIL'.nom_mil.'CR50    ' = 2.71745E-06 ;
TOPT.'STMIL'.nom_mil.'TI49    ' = 3.67436E-07 ;
TOPT.'STMIL'.nom_mil.'TI48    ' = 5.00691E-06 ;
TOPT.'STMIL'.nom_mil.'TI47    ' = 5.05310E-07 ;
TOPT.'STMIL'.nom_mil.'MN55    ' = 2.66370E-05 ;
TOPT.'STMIL'.nom_mil.'AL27    ' = 5.83760E-02 ;
TOPT.'STMIL'.nom_mil.'CU65    ' = 2.44544E-05 ;
TOPT.'STMIL'.nom_mil.'CU63    ' = 5.48656E-05 ;
TOPT.'STMIL'.nom_mil.'ZN      ' = 2.98390E-05 ;
TOPT.'STMIL'.nom_mil.'TI50    ' = 3.51815E-07 ;
TOPT.'STMIL'.nom_mil.'MG24    ' = 5.49565E-04 ;
TOPT.'STMIL'.nom_mil.'MG25    ' = 6.95740E-05 ;
TOPT.'STMIL'.nom_mil.'MG26    ' = 7.66010E-05 ;
TOPT.'STMIL'.nom_mil.'SI28    ' = 3.84442E-04 ;
TOPT.'STMIL'.nom_mil.'SI29    ' = 1.94660E-05 ;
TOPT.'STMIL'.nom_mil.'FE54    ' = 1.05508E-05 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'GRID_PLATE_6061_ALUMINUM' ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                         -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )             ;

*
*            -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES              ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*            -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil             ;
DETRUIRE:   TSTR.'APOLIB'                                            ;

*==============================================================
```

```
* APOLLO PIJ CALCUL 5
*
*==============================================================
* POLYETTHYLENE
TITRE: 'POLYETTHYLENE' ;
CALCUL_AP2 =  5 ;
*
*            -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES               ;
nom_calc = 'POLYETTHYLENE' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                            ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                   ;
TSTR.nom_calc = TABLE:                                              ;

*POLYETTHYLENE
nom_mil = 'STRUC POLYETTHYLENE ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                         ;
TOPT.'STMIL'.nom_mil.'CNAT    ' = 4.13770E-02 ;
TOPT.'STMIL'.nom_mil.'H1_CH2  ' = 8.27540E-02 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'POLYETTHYLENE' ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                         -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )             ;

*
*            -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES              ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO     ;
*
*            -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil            ;
```

```
DETRUIRE:   TSTR.'APOLIB'                                           ;

*==============================================================
* APOLLO PIJ CALCUL 6
*
*==============================================================
* AIR
TITRE: 'AIR' ;
CALCUL_AP2 =  6 ;
*
*            -=- Description des milieux -=-

***********************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES               ;
nom_calc = 'AIR' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                            ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                   ;
TSTR.nom_calc = TABLE:                                              ;

*AIR
nom_mil = 'STRUC AIR ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                         ;
TOPT.'STMIL'.nom_mil.'N14     ' = 4.19850E-05 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 1.12630E-05 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'AIR' ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                         -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )             ;

*
*            -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES              ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*            -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
```

```
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil             ;
DETRUIRE:   TSTR.'APOLIB'                                            ;

*===============================================================
* APOLLO PIJ CALCUL 7
*
*===============================================================
* CLADDING_+_AIR_+_GRID_PLATE
TITRE: 'CLADDING_+_AIR_+_GRID_PLATE' ;
CALCUL_AP2 =  7 ;
*
*            -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES                ;
nom_calc = 'CLADDING_+_AIR_+_GRID_PLATE' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                             ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                    ;
TSTR.nom_calc = TABLE:                                               ;

*CLADDING_+_AIR_+_GRID_PLATE
nom_mil = 'STRUC CLADDING_+_AIR_+_GRID_PLATE ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                          ;
TOPT.'STMIL'.nom_mil.'FE56    ' = 1.14498E-06 ;
TOPT.'STMIL'.nom_mil.'FE57    ' = 2.64425E-08 ;
TOPT.'STMIL'.nom_mil.'FE58    ' = 3.51901E-09 ;
TOPT.'STMIL'.nom_mil.'VNAT    ' = 1.36120E-08 ;
TOPT.'STMIL'.nom_mil.'TI46    ' = 2.38960E-09 ;
TOPT.'STMIL'.nom_mil.'CR54    ' = 6.30798E-09 ;
TOPT.'STMIL'.nom_mil.'CR53    ' = 2.53413E-08 ;
TOPT.'STMIL'.nom_mil.'CR52    ' = 2.23484E-07 ;
TOPT.'STMIL'.nom_mil.'SI30    ' = 8.03667E-08 ;
TOPT.'STMIL'.nom_mil.'CR50    ' = 1.15891E-08 ;
TOPT.'STMIL'.nom_mil.'TI49    ' = 1.56700E-09 ;
TOPT.'STMIL'.nom_mil.'TI48    ' = 2.13529E-08 ;
TOPT.'STMIL'.nom_mil.'TI47    ' = 2.15499E-09 ;
TOPT.'STMIL'.nom_mil.'MN55    ' = 1.84926E-06 ;
TOPT.'STMIL'.nom_mil.'AL27    ' = 5.25811E-04 ;
TOPT.'STMIL'.nom_mil.'CU65    ' = 1.50551E-07 ;
TOPT.'STMIL'.nom_mil.'CU63    ' = 3.37775E-07 ;
TOPT.'STMIL'.nom_mil.'ZN      ' = 1.85582E-07 ;
TOPT.'STMIL'.nom_mil.'TI50    ' = 1.50038E-09 ;
TOPT.'STMIL'.nom_mil.'MG24    ' = 2.34372E-06 ;
TOPT.'STMIL'.nom_mil.'MG25    ' = 2.96711E-07 ;
TOPT.'STMIL'.nom_mil.'MG26    ' = 6.03569E-02 ;
TOPT.'STMIL'.nom_mil.'SI28    ' = 2.39104E-06 ;
TOPT.'STMIL'.nom_mil.'SI29    ' = 1.21068E-07 ;
TOPT.'STMIL'.nom_mil.'FE54    ' = 7.29384E-08 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'CLADDING_+_AIR_+_GRID_PLATE' ;
*

*
```

```
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                          -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*             -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )              ;

*
*             -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES               ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*             -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil             ;
DETRUIRE:   TSTR.'APOLIB'                                            ;

*===============================================================
* APOLLO PIJ CALCUL 8
*
*===============================================================
* CLADDING_+_WATER_+_GRID_PLATE
TITRE: 'CLADDING_+_WATER_+_GRID_PLATE' ;
CALCUL_AP2 =  8 ;
*
*             -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES                ;
nom_calc = 'CLADDING_+_WATER_+_GRID_PLATE' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                             ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                    ;
TSTR.nom_calc = TABLE:                                               ;

*CLADDING_+_WATER_+_GRID_PLATE
nom_mil = 'STRUC CLADDING_+_WATER_+_GRID_PLATE ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                          ;
TOPT.'STMIL'.nom_mil.'FE56    ' = 1.22050E-04 ;
TOPT.'STMIL'.nom_mil.'FE57    ' = 2.81867E-06 ;
TOPT.'STMIL'.nom_mil.'FE58    ' = 3.75114E-07 ;
TOPT.'STMIL'.nom_mil.'VNAT    ' = 1.45099E-06 ;
```

```
TOPT.'STMIL'.nom_mil.'TI46    ' = 2.54723E-07 ;
TOPT.'STMIL'.nom_mil.'CR54    ' = 6.72407E-07 ;
TOPT.'STMIL'.nom_mil.'CR53    ' = 2.70129E-06 ;
TOPT.'STMIL'.nom_mil.'CR52    ' = 2.38226E-05 ;
TOPT.'STMIL'.nom_mil.'SI30    ' = 8.56679E-06 ;
TOPT.'STMIL'.nom_mil.'CR50    ' = 1.23535E-06 ;
TOPT.'STMIL'.nom_mil.'TI49    ' = 1.67036E-07 ;
TOPT.'STMIL'.nom_mil.'TI48    ' = 2.27614E-06 ;
TOPT.'STMIL'.nom_mil.'TI47    ' = 2.29714E-07 ;
TOPT.'STMIL'.nom_mil.'MN55    ' = 1.97124E-04 ;
TOPT.'STMIL'.nom_mil.'AL27    ' = 5.60495E-02 ;
TOPT.'STMIL'.nom_mil.'CU65    ' = 1.60482E-05 ;
TOPT.'STMIL'.nom_mil.'CU63    ' = 3.60055E-05 ;
TOPT.'STMIL'.nom_mil.'H1_H2O  ' = 3.38622E-03 ;
TOPT.'STMIL'.nom_mil.'O17     ' = 6.43382E-07 ;
TOPT.'STMIL'.nom_mil.'ZN      ' = 1.97824E-05 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 1.69247E-03 ;
TOPT.'STMIL'.nom_mil.'TI50    ' = 1.59935E-07 ;
TOPT.'STMIL'.nom_mil.'MG24    ' = 2.49832E-04 ;
TOPT.'STMIL'.nom_mil.'MG25    ' = 3.16283E-05 ;
TOPT.'STMIL'.nom_mil.'MG26    ' = 3.48228E-05 ;
TOPT.'STMIL'.nom_mil.'SI28    ' = 2.54876E-04 ;
TOPT.'STMIL'.nom_mil.'SI29    ' = 1.29055E-05 ;
TOPT.'STMIL'.nom_mil.'FE54    ' = 7.77496E-06 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'CLADDING_+_WATER_+_GRID_PLATE' ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                         -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*             -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )              ;

*
*             -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES               ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*             -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
*
```

```
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil             ;
DETRUIRE:   TSTR.'APOLIB'                                            ;

*===============================================================
* APOLLO PIJ CALCUL 9
*
*===============================================================
* ROD_air
TITRE: 'ROD_air' ;
CALCUL_AP2 =  9 ;
WRITE: TOPT.'RESU' 'Dimensions of the cell : ' ''
'Absciss1      : 0.262814'
'Absciss2      : 0.284519'
'Absciss3      : 0.317474'
'Square pitch4 : 0.8001'
 ;
WRITE: TOPT.'RESU' 'ROD_air' ;
*
*            -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES                ;
*===============================================================
* ROD_air
nom_calc = 'ROD_air' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                             ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                    ;
TSTR.nom_calc = TABLE:                                               ;

*UO2_FUEL
nom_mil = 'FISSIL1_1 ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'FE56    ' = 9.46075E-06 ;
TOPT.'STMIL'.nom_mil.'CD110   ' = 1.54626E-09 ;
TOPT.'STMIL'.nom_mil.'FE57    ' = 2.18490E-07 ;
TOPT.'STMIL'.nom_mil.'FE58    ' = 2.90770E-08 ;
TOPT.'STMIL'.nom_mil.'VNAT    ' = 1.48130E-08 ;
TOPT.'STMIL'.nom_mil.'U238    ' = 2.12970E-02 ;
TOPT.'STMIL'.nom_mil.'U236    ' = 1.46320E-05 ;
TOPT.'STMIL'.nom_mil.'CO59    ' = 2.16200E-08 ;
TOPT.'STMIL'.nom_mil.'W186    ' = 1.02342E-09 ;
TOPT.'STMIL'.nom_mil.'CR54    ' = 5.93615E-08 ;
TOPT.'STMIL'.nom_mil.'NI60    ' = 9.17520E-07 ;
TOPT.'STMIL'.nom_mil.'CR53    ' = 2.38475E-07 ;
TOPT.'STMIL'.nom_mil.'NI61    ' = 3.98840E-08 ;
TOPT.'STMIL'.nom_mil.'CR52    ' = 2.10310E-06 ;
TOPT.'STMIL'.nom_mil.'NI62    ' = 1.27168E-07 ;
TOPT.'STMIL'.nom_mil.'CR50    ' = 1.09059E-07 ;
TOPT.'STMIL'.nom_mil.'MO94    ' = 1.15098E-08 ;
TOPT.'STMIL'.nom_mil.'MO95    ' = 1.98093E-08 ;
TOPT.'STMIL'.nom_mil.'CD116   ' = 9.27262E-10 ;
TOPT.'STMIL'.nom_mil.'MO96    ' = 2.07549E-08 ;
TOPT.'STMIL'.nom_mil.'CD114   ' = 3.55677E-09 ;
TOPT.'STMIL'.nom_mil.'W182    ' = 9.53947E-10 ;
TOPT.'STMIL'.nom_mil.'NI64    ' = 3.23858E-08 ;
```

```
TOPT.'STMIL'.nom_mil.'CD113   ' = 1.51284E-09 ;
TOPT.'STMIL'.nom_mil.'W183    ' = 5.15131E-10 ;
TOPT.'STMIL'.nom_mil.'CD112   ' = 2.98729E-09 ;
TOPT.'STMIL'.nom_mil.'W184    ' = 1.10730E-09 ;
TOPT.'STMIL'.nom_mil.'MO92    ' = 1.84654E-08 ;
TOPT.'STMIL'.nom_mil.'CD111   ' = 1.58464E-09 ;
TOPT.'STMIL'.nom_mil.'AG109   ' = 4.44618E-09 ;
TOPT.'STMIL'.nom_mil.'B10     ' = 4.74774E-08 ;
TOPT.'STMIL'.nom_mil.'B11     ' = 1.91103E-07 ;
TOPT.'STMIL'.nom_mil.'MO97    ' = 1.18831E-08 ;
TOPT.'STMIL'.nom_mil.'MN55    ' = 2.83720E-07 ;
TOPT.'STMIL'.nom_mil.'MO98    ' = 3.00250E-08 ;
TOPT.'STMIL'.nom_mil.'AG107   ' = 4.78572E-09 ;
TOPT.'STMIL'.nom_mil.'CU65    ' = 6.57172E-08 ;
TOPT.'STMIL'.nom_mil.'MO100   ' = 1.19826E-08 ;
TOPT.'STMIL'.nom_mil.'CU63    ' = 1.47443E-07 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 4.58370E-02 ;
TOPT.'STMIL'.nom_mil.'CD108   ' = 1.10182E-10 ;
TOPT.'STMIL'.nom_mil.'U235    ' = 1.60100E-03 ;
TOPT.'STMIL'.nom_mil.'CD106   ' = 1.54750E-10 ;
TOPT.'STMIL'.nom_mil.'U234    ' = 6.55400E-06 ;
TOPT.'STMIL'.nom_mil.'NI58    ' = 2.38194E-06 ;
TOPT.'STMIL'.nom_mil.'FE54    ' = 6.02678E-07 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
*

TOPT.'STMIL'.'FISSIL1_2' = TOPT.'STMIL'.'FISSIL1_1' ;
TOPT.'STMIL'.'FISSIL1_3' = TOPT.'STMIL'.'FISSIL1_1' ;
TOPT.'STMIL'.'FISSIL1_4' = TOPT.'STMIL'.'FISSIL1_1' ;
*AIR
nom_mil = 'STRUCT0' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'N14     ' = 4.19850E-05 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 1.12630E-05 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
*

*ALUMINUM_3003_114
nom_mil = 'STRUCT1' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'FE56    ' = 9.45341E-05 ;
TOPT.'STMIL'.nom_mil.'CU63    ' = 2.23689E-05 ;
TOPT.'STMIL'.nom_mil.'FE57    ' = 2.18321E-06 ;
TOPT.'STMIL'.nom_mil.'FE58    ' = 2.90545E-07 ;
TOPT.'STMIL'.nom_mil.'ZN      ' = 1.25710E-05 ;
TOPT.'STMIL'.nom_mil.'SI30    ' = 5.44391E-06 ;
TOPT.'STMIL'.nom_mil.'MN55    ' = 3.74070E-04 ;
TOPT.'STMIL'.nom_mil.'SI28    ' = 1.61965E-04 ;
TOPT.'STMIL'.nom_mil.'SI29    ' = 8.20099E-06 ;
TOPT.'STMIL'.nom_mil.'AL27    ' = 5.96680E-02 ;
TOPT.'STMIL'.nom_mil.'FE54    ' = 6.02210E-06 ;
TOPT.'STMIL'.nom_mil.'CU65    ' = 9.97011E-06 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
*

*AIR
```

```
nom_mil = 'STRUCT2' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'N14     ' = 4.19850E-05 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 1.12630E-05 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                         -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM: &CELL &CARR &CYLI &COTE 0.8001 &MAIL
4
 .185838 .235068 .256159 .262814
1 &EQD .284519
1 &EQD .317474
1 &EQD .451408
&MILI
TSTR.'MILREF'.'FISSIL1_1' 1
TSTR.'MILREF'.'FISSIL1_2' 2
TSTR.'MILREF'.'FISSIL1_3' 3
TSTR.'MILREF'.'FISSIL1_4' 4
TSTR.'MILREF'.'STRUCT0' 5
TSTR.'MILREF'.'STRUCT1' 6
TSTR.'MILREF'.'STRUCT2' 7
;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )             ;

*
*            -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES              ;

*
*            -=- Flux a B2 nul -=-
*
TOPT.'TYPE_B2' = 'NUL'                                              ;
TOPT.'STPIJ' = TABLE: ;
TOPT.'STPIJ'.'UP' = 'LINEAIRE' ;
TRES TSTR TOPT = CALFLUX_PIJ_CRI_S 1 TSTR TOPT TRES                 ;
*
*            -=- Flux a B2 critique -=-
*
SI ( TRES.'KINF' GT 1. )                                            ;
TOPT.'TYPE_B2' = 'CRITIQUE'                                         ;
TRES TSTR TOPT = CALFLUX_PIJ_CRI_S 1 TSTR TOPT TRES                 ;
FINSI                                                               ;
*
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc.'B2' = TRES.'B2'           ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc.'KINF' = TRES.'KINF'       ;
```

```
*
*            -=- Sorties CARA Etendues -=-
*
TRES TSTR TOPT = SORTIE_FCARA_S  1 TSTR TOPT TRES                     ;
*

*            -=- Condensation homogeneisation -=-
*
TRES TSTR TOPT = HOMOGE_COND_S  1 TSTR TOPT TRES                      ;
*
*            -=- Creation de la Macrolib pour CELLUL1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47  &NOMMIL TSTR.nom_calc.'MILEQ' nom_calc              ;
DETRUIRE:   TSTR.'APOLIB'                                             ;

*==============================================================
* APOLLO PIJ CALCUL 10
*
*==============================================================
* ROD_eau
TITRE: 'ROD_eau' ;
CALCUL_AP2 =  10 ;
WRITE: TOPT.'RESU' 'Dimensions of the cell : ' ''
'Absciss1      : 0.262814'
'Absciss2      : 0.284519'
'Absciss3      : 0.317474'
'Square pitch4 : 0.8001'
 ;
WRITE: TOPT.'RESU' 'ROD_eau' ;
*
*            -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES                 ;
*==============================================================
* ROD_eau
nom_calc = 'ROD_eau' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                              ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                     ;
TSTR.nom_calc = TABLE:                                                ;

*UO2_FUEL
nom_mil = 'FISSIL1_1 ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'FE56    ' = 9.46075E-06 ;
TOPT.'STMIL'.nom_mil.'CD110   ' = 1.54626E-09 ;
TOPT.'STMIL'.nom_mil.'FE57    ' = 2.18490E-07 ;
TOPT.'STMIL'.nom_mil.'FE58    ' = 2.90770E-08 ;
TOPT.'STMIL'.nom_mil.'VNAT    ' = 1.48130E-08 ;
TOPT.'STMIL'.nom_mil.'U238    ' = 2.12970E-02 ;
TOPT.'STMIL'.nom_mil.'U236    ' = 1.46320E-05 ;
TOPT.'STMIL'.nom_mil.'CO59    ' = 2.16200E-08 ;
TOPT.'STMIL'.nom_mil.'W186    ' = 1.02342E-09 ;
TOPT.'STMIL'.nom_mil.'CR54    ' = 5.93615E-08 ;
TOPT.'STMIL'.nom_mil.'NI60    ' = 9.17520E-07 ;
```

```
TOPT.'STMIL'.nom_mil.'CR53      ' = 2.38475E-07 ;
TOPT.'STMIL'.nom_mil.'NI61      ' = 3.98840E-08 ;
TOPT.'STMIL'.nom_mil.'CR52      ' = 2.10310E-06 ;
TOPT.'STMIL'.nom_mil.'NI62      ' = 1.27168E-07 ;
TOPT.'STMIL'.nom_mil.'CR50      ' = 1.09059E-07 ;
TOPT.'STMIL'.nom_mil.'MO94      ' = 1.15098E-08 ;
TOPT.'STMIL'.nom_mil.'MO95      ' = 1.98093E-08 ;
TOPT.'STMIL'.nom_mil.'CD116     ' = 9.27262E-10 ;
TOPT.'STMIL'.nom_mil.'MO96      ' = 2.07549E-08 ;
TOPT.'STMIL'.nom_mil.'CD114     ' = 3.55677E-09 ;
TOPT.'STMIL'.nom_mil.'W182      ' = 9.53947E-10 ;
TOPT.'STMIL'.nom_mil.'NI64      ' = 3.23858E-08 ;
TOPT.'STMIL'.nom_mil.'CD113     ' = 1.51284E-09 ;
TOPT.'STMIL'.nom_mil.'W183      ' = 5.15131E-10 ;
TOPT.'STMIL'.nom_mil.'CD112     ' = 2.98729E-09 ;
TOPT.'STMIL'.nom_mil.'W184      ' = 1.10730E-09 ;
TOPT.'STMIL'.nom_mil.'MO92      ' = 1.84654E-08 ;
TOPT.'STMIL'.nom_mil.'CD111     ' = 1.58464E-09 ;
TOPT.'STMIL'.nom_mil.'AG109     ' = 4.44618E-09 ;
TOPT.'STMIL'.nom_mil.'B10       ' = 4.74774E-08 ;
TOPT.'STMIL'.nom_mil.'B11       ' = 1.91103E-07 ;
TOPT.'STMIL'.nom_mil.'MO97      ' = 1.18831E-08 ;
TOPT.'STMIL'.nom_mil.'MN55      ' = 2.83720E-07 ;
TOPT.'STMIL'.nom_mil.'MO98      ' = 3.00250E-08 ;
TOPT.'STMIL'.nom_mil.'AG107     ' = 4.78572E-09 ;
TOPT.'STMIL'.nom_mil.'CU65      ' = 6.57172E-08 ;
TOPT.'STMIL'.nom_mil.'MO100     ' = 1.19826E-08 ;
TOPT.'STMIL'.nom_mil.'CU63      ' = 1.47443E-07 ;
TOPT.'STMIL'.nom_mil.'O16       ' = 4.58370E-02 ;
TOPT.'STMIL'.nom_mil.'CD108     ' = 1.10182E-10 ;
TOPT.'STMIL'.nom_mil.'U235      ' = 1.60100E-03 ;
TOPT.'STMIL'.nom_mil.'CD106     ' = 1.54750E-10 ;
TOPT.'STMIL'.nom_mil.'U234      ' = 6.55400E-06 ;
TOPT.'STMIL'.nom_mil.'NI58      ' = 2.38194E-06 ;
TOPT.'STMIL'.nom_mil.'FE54      ' = 6.02678E-07 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
*

TOPT.'STMIL'.'FISSIL1_2' = TOPT.'STMIL'.'FISSIL1_1' ;
TOPT.'STMIL'.'FISSIL1_3' = TOPT.'STMIL'.'FISSIL1_1' ;
TOPT.'STMIL'.'FISSIL1_4' = TOPT.'STMIL'.'FISSIL1_1' ;
*AIR
nom_mil = 'STRUCT0' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'N14       ' = 4.19850E-05 ;
TOPT.'STMIL'.nom_mil.'O16       ' = 1.12630E-05 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
*

*ALUMINUM_3003_114
nom_mil = 'STRUCT1' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'FE56      ' = 9.45341E-05 ;
TOPT.'STMIL'.nom_mil.'CU63      ' = 2.23689E-05 ;
TOPT.'STMIL'.nom_mil.'FE57      ' = 2.18321E-06 ;
TOPT.'STMIL'.nom_mil.'FE58      ' = 2.90545E-07 ;
```

```
TOPT.'STMIL'.nom_mil.'ZN      ' = 1.25710E-05 ;
TOPT.'STMIL'.nom_mil.'SI30    ' = 5.44391E-06 ;
TOPT.'STMIL'.nom_mil.'MN55    ' = 3.74070E-04 ;
TOPT.'STMIL'.nom_mil.'SI28    ' = 1.61965E-04 ;
TOPT.'STMIL'.nom_mil.'SI29    ' = 8.20099E-06 ;
TOPT.'STMIL'.nom_mil.'AL27    ' = 5.96680E-02 ;
TOPT.'STMIL'.nom_mil.'FE54    ' = 6.02210E-06 ;
TOPT.'STMIL'.nom_mil.'CU65    ' = 9.97011E-06 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
*

*WATER_LCT080
nom_mil = 'STRUCT2' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'H1_H2O  ' = 6.66580E-02 ;
TOPT.'STMIL'.nom_mil.'O17     ' = 1.26650E-05 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 3.33163E-02 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                          -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM: &CELL &CARR &CYLI &COTE 0.8001 &MAIL
4
 .185838 .235068 .256159 .262814
1 &EQD .284519
1 &EQD .317474
1 &EQD .451408
&MILI
TSTR.'MILREF'.'FISSIL1_1' 1
TSTR.'MILREF'.'FISSIL1_2' 2
TSTR.'MILREF'.'FISSIL1_3' 3
TSTR.'MILREF'.'FISSIL1_4' 4
TSTR.'MILREF'.'STRUCT0' 5
TSTR.'MILREF'.'STRUCT1' 6
TSTR.'MILREF'.'STRUCT2' 7
;
*
*             -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )              ;

*
*             -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES               ;

*
*             -=- Flux a B2 nul -=-
*
TOPT.'TYPE_B2' = 'NUL'                                               ;
```

```
TOPT.'STPIJ' = TABLE: ;
TOPT.'STPIJ'.'UP' = 'LINEAIRE' ;
TRES TSTR TOPT = CALFLUX_PIJ_CRI_S 1 TSTR TOPT TRES                    ;
*
*            -=- Flux a B2 critique -=-
*
SI ( TRES.'KINF' GT 1. )                                               ;
TOPT.'TYPE_B2' = 'CRITIQUE'                                            ;
TRES TSTR TOPT = CALFLUX_PIJ_CRI_S 1 TSTR TOPT TRES                    ;
FINSI                                                                  ;
*
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc.'B2' = TRES.'B2'              ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc.'KINF' = TRES.'KINF'          ;
*
*            -=- Sorties CARA Etendues -=-
*
TRES TSTR TOPT = SORTIE_FCARA_S  1 TSTR TOPT TRES                      ;
*

*            -=- Condensation homogeneisation -=-
*
TRES TSTR TOPT = HOMOGE_COND_S  1 TSTR TOPT TRES                       ;
*
*            -=- Creation de la Macrolib pour CELLUL1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47  &NOMMIL TSTR.nom_calc.'MILEQ' nom_calc               ;
DETRUIRE:   TSTR.'APOLIB'                                              ;

*===============================================================
* APOLLO PIJ CALCUL 11
*
*===============================================================
* VOID_+_SPRING_+_ALUMINUM_+_AIR
TITRE: 'VOID_+_SPRING_+_ALUMINUM_+_AIR' ;
CALCUL_AP2 =  11 ;
*
*            -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES                  ;
nom_calc = 'VOID_+_SPRING_+_ALUMINUM_+_AIR' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                               ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                      ;
TSTR.nom_calc = TABLE:                                                 ;

*VOID_+_SPRING_+_ALUMINUM_+_AIR
nom_mil = 'STRUC VOID_+_SPRING_+_ALUMINUM_+_AIR ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                            ;
TOPT.'STMIL'.nom_mil.'FE56    ' = 1.30355E-03 ;
TOPT.'STMIL'.nom_mil.'CNAT    ' = 3.73973E-06 ;
TOPT.'STMIL'.nom_mil.'FE57    ' = 3.01046E-05 ;
TOPT.'STMIL'.nom_mil.'FE58    ' = 4.00637E-06 ;
TOPT.'STMIL'.nom_mil.'CR54    ' = 9.70428E-06 ;
TOPT.'STMIL'.nom_mil.'NI60    ' = 4.64113E-05 ;
```

```
TOPT.'STMIL'.nom_mil.'CR53    ' = 3.89854E-05 ;
TOPT.'STMIL'.nom_mil.'NI61    ' = 2.01747E-06 ;
TOPT.'STMIL'.nom_mil.'CR52    ' = 3.43811E-04 ;
TOPT.'STMIL'.nom_mil.'NI62    ' = 6.43256E-06 ;
TOPT.'STMIL'.nom_mil.'SI30    ' = 1.18437E-06 ;
TOPT.'STMIL'.nom_mil.'CR50    ' = 1.78288E-05 ;
TOPT.'STMIL'.nom_mil.'NI64    ' = 1.63818E-06 ;
TOPT.'STMIL'.nom_mil.'MN55    ' = 5.92387E-05 ;
TOPT.'STMIL'.nom_mil.'AL27    ' = 6.18872E-03 ;
TOPT.'STMIL'.nom_mil.'CU65    ' = 1.03409E-06 ;
TOPT.'STMIL'.nom_mil.'P31     ' = 8.15717E-07 ;
TOPT.'STMIL'.nom_mil.'N14     ' = 1.70456E-05 ;
TOPT.'STMIL'.nom_mil.'CU63    ' = 2.32009E-06 ;
TOPT.'STMIL'.nom_mil.'S33     ' = 3.99174E-09 ;
TOPT.'STMIL'.nom_mil.'S32     ' = 4.98599E-07 ;
TOPT.'STMIL'.nom_mil.'ZN      ' = 1.30386E-06 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 1.78937E-02 ;
TOPT.'STMIL'.nom_mil.'S34     ' = 2.25323E-08 ;
TOPT.'STMIL'.nom_mil.'S36     ' = 1.05046E-10 ;
TOPT.'STMIL'.nom_mil.'SI28    ' = 3.52370E-05 ;
TOPT.'STMIL'.nom_mil.'NI58    ' = 1.20487E-04 ;
TOPT.'STMIL'.nom_mil.'SI29    ' = 1.78420E-06 ;
TOPT.'STMIL'.nom_mil.'FE54    ' = 8.30398E-05 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'VOID_+_SPRING_+_ALUMINUM_+_AIR' ;
*

*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                          -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*             -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )              ;

*
*             -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES               ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*             -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
```

```
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil             ;
DETRUIRE:   TSTR.'APOLIB'                                            ;

*==============================================================
* APOLLO PIJ CALCUL 12
*
*==============================================================
* CH2_+_VOID_+_3003_ALUMINUM_+_AIR
TITRE: 'CH2_+_VOID_+_3003_ALUMINUM_+_AIR' ;
CALCUL_AP2 =  12 ;
*
*            -=- Description des milieux -=-

************************************************************
TRES TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT TRES                ;
nom_calc = 'CH2_+_VOID_+_3003_ALUMINUM_+_AIR' ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                             ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                    ;
TSTR.nom_calc = TABLE:                                               ;

*CH2_+_VOID_+_3003_ALUMINUM_+_AIR
nom_mil = 'STRUC CH2_+_VOID_+_3003_ALUMINUM_+_AIR ' ;
TOPT.'STMIL'.nom_mil = TABLE: ;
TOPT.'STMIL'.nom_mil.'U235'     =    1.E-10                          ;
TOPT.'STMIL'.nom_mil.'FE56    ' = 9.72024E-06 ;
TOPT.'STMIL'.nom_mil.'CNAT    ' = 1.46048E-02 ;
TOPT.'STMIL'.nom_mil.'FE57    ' = 2.24483E-07 ;
TOPT.'STMIL'.nom_mil.'FE58    ' = 2.98745E-08 ;
TOPT.'STMIL'.nom_mil.'MN55    ' = 3.84629E-05 ;
TOPT.'STMIL'.nom_mil.'H1_CH2  ' = 2.92097E-02 ;
TOPT.'STMIL'.nom_mil.'AL27    ' = 6.13522E-03 ;
TOPT.'STMIL'.nom_mil.'CU65    ' = 1.02515E-06 ;
TOPT.'STMIL'.nom_mil.'N14     ' = 2.57514E-06 ;
TOPT.'STMIL'.nom_mil.'CU63    ' = 2.30003E-06 ;
TOPT.'STMIL'.nom_mil.'ZN      ' = 1.29259E-06 ;
TOPT.'STMIL'.nom_mil.'O16     ' = 1.77362E-02 ;
TOPT.'STMIL'.nom_mil.'SI30    ' = 5.59757E-07 ;
TOPT.'STMIL'.nom_mil.'SI28    ' = 1.66537E-05 ;
TOPT.'STMIL'.nom_mil.'SI29    ' = 8.43247E-07 ;
TOPT.'STMIL'.nom_mil.'FE54    ' = 6.19208E-07 ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE' = 21.0 ;
WRITE: TOPT.'RESU' 'CH2_+_VOID_+_3003_ALUMINUM_+_AIR' ;
*


*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT TRES ;
*
*                          -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM:  &CYLI &MAIL
 1 &EQD 1.0
&MILI TSTR.'MILREF'.nom_mil 1 ;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
```

```
                                &SFIN &TP
                                ( TEXTE TOPT.'REPBIB' )             ;

*
*            -=- Autoprotection -=-
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT TRES               ;

*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
              TSTR.'MILREF'.nom_mil
              &TOTA &SELF &ABSO &ENER
              &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*            -=- Creation de la Macrolib pour le milieu MILHOM1 -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47  &NOMMIL TSTR.'MILREF'.nom_mil nom_mil             ;
DETRUIRE:   TSTR.'APOLIB'                                            ;

*
EDTIME: ;
ARRET: ;
FIN_APOLLO2

*=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
*     JDD MORET
*=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
DEBUT_MORET
TITRE TITRE

ARRE
  ETAP
    ACTI 150
    PASS 100
  KEFF
    SIGM 0.00030
FARR

GEOM

* Module 0 (LATEC name)
MODU 0

* DESCRIPTION DES TYPES

TYPE 1 CYLZ 46.8376 46.8376

TYPE 2 CYLZ 46.8376 27.795

TYPE 3 CYLZ 46.8376 8.255

TYPE 4 CYLZ 46.355 1.27

TYPE 5 BOIT 20.955 20.955 1.27
```

```
TYPE 6 CYLZ 5.75945 15.0114

TYPE 7 CYLZ 3.30581 15.0114

TYPE 8 CYLZ 3.175 34.0741

TYPE 9 CYLZ 2.8575 33.7566

TYPE 10 CYLZ 3.175 34.0741

TYPE 11 CYLZ 2.8575 33.7566

TYPE 12 CYLZ 5.75945 15.0114

TYPE 13 CYLZ 3.30581 15.0114


* DESCRIPTION DES VOLUMES


* Volume : 0_1 (LATEC name)
VOLU 0_1 0 1 1 0.0 0.0 46.8376
* Trou : 0__1 (LATEC name)

TYPE 14 BOIT 18.00225 18.00225 35.4076

TROU 1 0_1 14 1 0.0 0.0 51.9176 ECRA 4 0_3 0_4 0_2 0_5

* Volume : 0_2 (LATEC name)
VOLU 0_2 0_1 2 2 0.0 0.0 27.795

* Volume : 0_3 (LATEC name)
VOLU 0_3 0_2 3 2 0.0 0.0 8.255

* Volume : 0_4 (LATEC name)
VOLU 0_4 0_2 4 3 0.0 0.0 17.78

* Volume : 0_5 (LATEC name)
VOLU 0_5 0_1 5 4 0.0 0.0 70.8152

* Volume : 0_6 (LATEC name)
VOLU 0_6 0_1 6 5 32.385 6.4 34.6964 ECRA 1 0_2

* Volume : 0_7 (LATEC name)
VOLU 0_7 0_6 7 6 32.385 6.4 34.6964

* Volume : 0_12 (LATEC name)
VOLU 0_12 0_1 8 4 -32.385 -6.4 53.1241 ECRA 3 0_2 0_10 0_11

* Volume : 0_13 (LATEC name)
VOLU 0_13 0_12 9 6 -32.385 -6.4 53.4416

* Volume : 0_8 (LATEC name)
VOLU 0_8 0_1 10 4 32.385 6.4 53.1241 ECRA 3 0_2 0_6 0_7
```

```
* Volume : 0_9 (LATEC name)
VOLU 0_9 0_8 11 6 32.385 6.4 53.4416

* Volume : 0_10 (LATEC name)
VOLU 0_10 0_1 12 5 -32.385 -6.4 34.6964 ECRA 1 0_2

* Volume : 0_11 (LATEC name)
VOLU 0_11 0_10 13 6 -32.385 -6.4 34.6964

FINM


* Module 1 (LATEC name)
MODU 1

* DESCRIPTION DES TYPES

TYPE 14 BOIT 18.00225 18.00225 35.4076

TYPE 15 BOIT 18.00225 18.00225 35.4076

TYPE 16 BOIT 18.00225 18.00225 1.27

TYPE 17 BOIT 18.00225 18.00225 0.635

TYPE 18 BOIT 18.00225 18.00225 0.635

TYPE 19 BOIT 18.00225 18.00225 24.39

TYPE 20 BOIT 18.00225 18.00225 18.27

TYPE 21 BOIT 18.00225 18.00225 0.8576

TYPE 22 BOIT 18.00225 18.00225 7.62



* DESCRIPTION DES VOLUMES


* Volume : 1_1 (LATEC name)
VOLU 1_1 0 14 1 0.0 0.0 35.4076

* Volume : 1_2 (LATEC name)
VOLU 1_2 1_1 15 1 0.0 0.0 35.4076

* Volume : 1_16 (LATEC name)
VOLU 1_16 1_2 16 7 0.0 0.0 54.3052

* Volume : 1_3 (LATEC name)
VOLU 1_3 1_2 17 3 0.0 0.0 0.635

* Volume : 1_4 (LATEC name)
VOLU 1_4 1_2 18 8 0.0 0.0 1.905

* Volume : 1_7 (LATEC name)
```

```
VOLU 1_7 1_2 19 9 0.0 0.0 26.93

* Volume : 1_71 (LATEC name)
VOLU 1_71 1_7 20 10 0.0 0.0 20.815

* Volume : 1_11 (LATEC name)
VOLU 1_11 1_2 21 11 0.0 0.0 52.1776

* Volume : 1_21 (LATEC name)
VOLU 1_21 1_2 22 12 0.0 0.0 63.1952

FINM

FING

CHIM
  MULT
  APO2 8 NORD 8
  APO2 9 NORD 9
  APO2 2 NORD 2
  APO2 6 NORD 6
  APO2 12 NORD 12
  APO2 3 NORD 3
  APO2 10 NORD 10
  APO2 4 NORD 4
  APO2 11 NORD 11
  APO2 1 NORD 1
  APO2 5 NORD 5
  APO2 7 NORD 7

FINC


SORT

  SCORe
    ACTIve SEUL 1 CARA
  FSCOres

FSOR

SOUR
UNIF 2000
  MODU 1
FUNI
FINS

GRAP Z 40 FGRAPH
GRAP Z 29 FGRAPH
GRAP Z 22 FGRAPH
GRAP X 0.0 FGRAPH
GRAP Y 0.0 FGRA


SIMU
NATU
```

```
FSIM


FIND
FIN_MORET
```

A.4 MORET 5 INPUT LISTINGS

MORET 5.B.2 and the continuous-energy cross section set based on ENDF/B-VII.0 were used. A total of 100 batches of 80,000 neutrons were run. The first 3 batches were skipped.

Case 1

```
*******************************************************
*           I.R.S.N MORET 5.B.2 Code                  *
*******************************************************
*                 LEU-COMP-THERM-096                  *
*                   ICSBEP Volume IV                  *
*                      CASE 1                         *
*                     revision 0                      *
*******************************************************
*                   BENCHMARK SNL                     *
*  partially reflected water-moderated square-pitched  *
*  U(6.90)O2 fuel rod lattices with 0.67 fuel to water *
*            volume ratio (0.800 cm pitch)            *
*                             CAS 1                   *
*******************************************************
*           array  2025 rods  - Pitch = 0.8 cm        *
*                   Hc = 36.54  cm                    *
*                   T = 25 C                          *
*******************************************************
*    Keff(exp) +/- 1s =0.99985 +/- 0.00095            *
*******************************************************
* writer:   M. Monestier reviewer : N.  leclaire      *
*******************************************************

DEBUT_MORET
LEU-COMP-THERM-096


ARRE
  KEFF SIGM 0.00050
FARR

CHIM
PONC
BIBL endf70.xml
TEMP 294

COMP UO2_Fuel CONC
  U234     6.5539E-06
  U235     1.6010E-03
  U236     1.4632E-05
  U238     2.1296E-02
  O16      4.5837E-02
  AG       9.2319E-09
  B        2.3858E-07
  CD       1.2380E-08
  CO       2.1620E-08
  CR       2.5100E-06
  CU       2.1316E-07
```

```
  FE       1.0311E-05
  MN       2.8372E-07
  MO       1.2443E-07
  NI       3.4989E-06
  V        1.4813E-08
  W182   9.53947e-10
  W183     5.15131e-10
  W184     1.10298e-09
  W186     1.02342e-09
FINC

COMP 3003_Al CONC
  AL       5.9668E-02
  SI       1.7561E-04
  FE        1.0303E-04
  CU       3.2339E-05
  MN       3.7407E-04
  ZN       1.2571E-05
FINC

COMP Eau CONC
  H1-H2O         6.6659E-02
  O16       3.3329E-02
FINC

COMP 6061_Al CONC
      AL              5.8376E-02
      SI      4.1683E-04
      FE      1.8051E-04
      CU      7.9320E-05
      MN      2.6637E-05
      MG      6.9574E-04
      CR      6.2542E-05
      ZN      2.9839E-05
      TI      6.7918E-06
      V       3.1918E-06
FINC


COMP POLYETHYLENE CONC
   H1-CH2       8.2755E-02
   C            4.1377E-02
FINC

COMP SS-304 CONC
      FE             1.2527E-02
      CR      3.6455E-03
      NI      1.5724E-03
      MN      1.8160E-04
      C       3.3225E-05
      P       7.2471E-06
      S       4.6663E-06
      SI      1.7761E-04
      N       3.5613E-05
FINC
```

```
COMP Air CONC
  N        4.1985E-10
  O16      1.1263E-10
FINC


FINChimie

*  ---------------------------------------------------------------------
* MatÃ©riaux
*  1 - Combustible UO2
*  2 - Aluminium 3003
*  3 - Eau
*  4 - Aluminium 6061
*  5 - PolyÃ©thylÃ¨ne
*  6 - SS-304
*  ---------------------------------------------------------------------

GEOM
MODU 0

*intÃ©rieur cuve (totale)
TYPE 1 CYLZ 46.8376 46.8376
VOLU 1 0 1 7 0. 0. 46.8376

*intÃ©rieur cuve immergÃ©
*HAUTEUR D'EAU************************************************
TYPE 2 CYLZ 46.8376 27.795
VOLU 2 1 2 3 0. 0. 27.795

*RÃ©flecteur bas
TYPE 3 CYLZ 46.8376 8.255
VOLU 3 2 3 3 0. 0. 8.255

*Plaque infÃ©rieure
TYPE 4 CYLZ 46.355 1.27
VOLU 4 2 4 4 0. 0. 17.78

*Plaque supÃ©rieure
TYPE 5 BOITE 20.955 20.955 1.27
VOLU 5 1 5 4 0. 0. 70.8152

*détecteurs
TYPE 6 CYLZ 5.75945 15.0114
TYPE 7 CYLZ 3.30581 15.0114
TYPE 8 CYLZ 3.175 34.0741
TYPE 9 CYLZ 2.8575 33.7566

VOLU 6 1 6 5 32.385 6.4 34.6964 ECRASE 1 2
VOLU 7 6 7 7 32.385 6.4 34.6964
VOLU 8 1 8 4 32.385 6.4 53.1241 ECRASE 3 2 6 7
VOLU 9 8 9 7 32.385 6.4 53.4416

VOLU 10 1 6 5 -32.385 -6.4 34.6964 ECRASE 1 2
VOLU 11 10 7 7 -32.385 -6.4 34.6964
VOLU 12 1 8 4 -32.385 -6.4 53.1241 ECRASE 3 2 10 11
```

```
VOLU 13 12 9 7 -32.385 -6.4 53.4416

*Crayons combustibles
TYPE 14 BOIT 18.00225 18.00225 35.4076
TROU 1 1 14 1 0.0 0.0 51.9176 ECRASE 4 3 4 2 5

FINM

MODU 1
* universe
TYPE 1 BOITE 18.00225 18.00225 35.4076
VOLU 1 0 1 7 0. 0. 35.4076

*Volume Maille
TYPE 2 BOITE 0.40005 0.40005 35.4076
VOLU 2 1 2 7 -17.6022 -17.6022 35.4076

*Zone 1
TYPE 3 BOITE 0.40005 0.40005 0.635
VOLU 3 2 3 4 -17.6022 -17.6022 0.635

*Zone 2
*ALU
TYPE 4 BOITE 0.40005 0.40005 0.635
VOLU 4 2 4 4 -17.6022 -17.6022 1.905
*EAU
TYPE 5 CYLZ 0.333375 0.635
VOLU 5 4 5 3 -17.6022 -17.6022 1.905
*ALU3003
TYPE 6 CYLZ 0.317474 0.635
VOLU 6 5 6 2 -17.6022 -17.6022 1.905

*Zone 3
*AIR
TYPE 7 BOITE 0.40005 0.40005 24.39
VOLU 7 2 7 7 -17.6022 -17.6022 26.93
*EAU************************************************************
TYPE 71 BOITE 0.40005 0.40005 18.27
VOLU 71 7 71 3 -17.6022 -17.6022 20.81
*3003 ALU
TYPE 8 CYLZ 0.317474 24.39
VOLU 8 7 8 2 -17.6022 -17.6022 26.93 ECRASE 1 71
*VIDE
TYPE 9 CYLZ 0.284519 24.39
VOLU 9 8 9 7 -17.6022 -17.6022 26.93
*UO2
TYPE 10 CYLZ 0.262814 24.39
VOLU 10 9 10 1 -17.6022 -17.6022 26.93

*Zone 4
*VIDE
TYPE 11 BOITE 0.40005 0.40005 0.8576
VOLU 11 2 11 7 -17.6022 -17.6022 52.1776
*3003 ALU
TYPE 12 CYLZ 0.317474 0.8576
VOLU 12 11 12 2 -17.6022 -17.6022 52.1776
```

```
*VIDE
TYPE 13 CYLZ 0.284519 0.8576
VOLU 13 12 13 7 -17.6022 -17.6022 52.1776
*303 SS
TYPE 14 CYLZ 0.2286 0.8576
VOLU 14 13 14 6 -17.6022 -17.6022 52.1776
*VIDE
TYPE 15 CYLZ 0.17526 0.8576
VOLU 15 14 15 7 -17.6022 -17.6022 52.1776

*zone 5
*6061 Al
TYPE 16 BOITE 0.40005 0.40005 1.27
VOLU 16 2 16 4 -17.6022 -17.6022 54.3052
*VIDE
TYPE 17 CYLZ 0.333375 1.27
VOLU 17 16 17 7 -17.6022 -17.6022 54.3052
*3003 AL
TYPE 18 CYLZ 0.317474 1.27
VOLU 18 17 18 2 -17.6022 -17.6022 54.3052
*VIDE
TYPE 19 CYLZ 0.284519 1.27
VOLU 19 18 19 7 -17.6022 -17.6022 54.3052
*6061 AL
TYPE 20 CYLZ 0.26289 1.27
VOLU 20 19 20 4 -17.6022 -17.6022 54.3052


*zone 6
*VIDE
TYPE 21 BOITE 0.40005 0.40005 7.62
VOLU 21 2 21 7 -17.6022 -17.6022 63.1952
*3003 AL
TYPE 22 CYLZ 0.317474 7.62
VOLU 22 21 22 2 -17.6022 -17.6022 63.1952
*VIDE
TYPE 23 CYLZ 0.284519 7.62
VOLU 23 22 23 7 -17.6022 -17.6022 63.1952
*CH2
TYPE 24 CYLZ 0.26289 7.62
VOLU 24 23 24 5 -17.6022 -17.6022 63.1952



RESC
 MPRI 2
 DIMR 45 45 1
FINR

FINM


FING


GRAP X 0.44 FGRA
```

```
PEIN X 0.44 FGRA
GRAP Y 6.4 FGRA
PEIN Y 6.4 FGRA
GRAP Y -6.4 FGRA
PEIN Y -6.4 FGRA
GRAP Z 30 FGRA
PEIN Z 30 FGRA



SORTies
  SCORes
    ANNUle TOUS
  FSCOres
FSORties


SOUR
 UNIF 50 MODU 1 VOLU 10 FUNI
FINS


FIND

FIN_MORET
```