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Title: Godiva-IV Delayed-Critical and Static Super-Prompt-Critical Experiments

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Intended for:

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GODIVA-IV DELAYED-CRITICAL AND STATIC SUPER-PROMPT-CRITCAL EXPERIMENTS

KEY WORDS: acceptable, Godiva-IV, prompt burst, delayed-critical, experiment, highly enriched uranium, fast spectrum, metal

1.0 DETAILED DESCRIPTION

1.1 Overview of Experiments

The Godiva-IV super-prompt-critical burst experiments were conducted in Kiva 3, now called CASA 3, at the Los Alamos Critical Experiments Facility (LACEF) at Los Alamos National Laboratory (LANL) from the 1960s through 2005. The experiments supported a variety of activities at LACEF, including the testing of criticality alarms and other types of detectors. Conduct of delayed-critical experiments prior to the prompt burst was an essential part of the process. The specific experiments whose results are discussed herein were performed on April 11, 2003. Those experiments included four delayed-critical configurations and a super-prompt-critical configuration just prior to the burst.

Information on this experiment was obtained from referenced engineering drawings, discussions with experimenters and other personnel who worked at LACEF during the time of the Godiva-IV burst experiments, and examination of the Godiva-IV logbook, inspection documents, and analysis reports.

Unlike the initial Godiva experiment (HEU-MET-FAST-001), the Godiva-IV core was basically cylindrical rather than spherical. In addition, it had a hollow glory hole in the center of its core and structural restraints to keep it intact during a super-prompt-critical burst experiment. During such experiments, the resulting excursion was terminated by thermal expansion of the core. Subsequent expulsion of the bottom central part of the core known as the safety block ensured that the core remained subcritical thereafter.

Based on the information presented in this evaluation, the four Godiva-IV delayed-critical experiments and the static super-prompt-critical configuration described herein are judged to be acceptable for use as criticality-safety benchmark experiments.

1.2 Description of Experimental Configuration

1.2.1 General Description - Although hundreds of delayed-critical and super-prompt-critical burst experiments were conducted over the years that the Godiva-IV assembly was in operation, the configuration of its core changed very little. More specifically, over the last decade of its operation, the only things that distinguish the core of one experiment from that of another are the positions of its two control rods and its burst rod.

The Godiva-IV delayed-critical and super-prompt-critical burst experiments were conducted on the Godiva assembly machine inside CASA 3 at LACEF. The cylindrical core of the Godiva-IV assembly contained six stacked rings, an inner subassembly plate with two parts, a central spindle, an alignment pin, a shim ring, two control rods, a burst rod, a safety block, and a base for the safety block. Two thermocouples to measure the temperature rise during the excursion also were present. The stacked rings, the inner subassembly plates, the control rods, the burst rod, and the safety block all were made from an alloy of highly enriched uranium (HEU) and molybdenum. The spindle, the alignment pins, the shim ring and the base for the safety block were made from steel. Since the control and burst rods contained mostly HEU, they increased reactivity as they were inserted and reduced reactivity as they were withdrawn. Prior to expulsion, the safety block and its base were held in place by an electromagnet that was lifted by a cylindrical hydraulic ram. When the assembly was not in operation, the safety block and its base were withdrawn to a position such that the top of the safety block was only slightly higher than the bottom of the mounting plate, and the control and burst rods were fully withdrawn.

The hydraulic ram, which sat about 4 inches from the centerline of the Godiva-IV assembly, was attached by a metal arm to a cylindrical electromagnet centered around the support rod for the safety block. Raising the hydraulic ram lifted the electromagnet. When energized, the electromagnet magnetically held a flat steel plate that was attached to the bottom of the safety block support rod. Therefore, when the hydraulic ram lifted an energized electromagnet, the safety block was raised into the Godiva-IV core. The hydraulic ram was fully extended when the safety block was in place, and the energized electromagnet and steel plate were in tight contact. The ram was fully extended each time, and the reproducibility of the distance it traveled was quite good (about 2 thousandths of an inch).[a]

Restraints for the core included three clamps, three clamp supports (commonly referred to as legs), a circular belly band (also referred to as the Saturn ring), a subassembly cover plate, a bearing ring (sometimes referred to as a loading ring), three support pads, and various nuts and bolts. The bearing ring was placed immediately above the top fuel ring, and the pads were placed immediately below the bottom fuel ring. The subassembly cover plate sat above the upper inner subassembly plate, inside the bearing ring. It enclosed a section of the spindle and was held in place by a nut on the spindle. The top and bottom prongs of the clamps fitted onto the top of the bearing ring and the bottom of the support pads, respectively. Each of the three clamps was attached to its own clamp support. The tops of the clamp supports were held in place by the belly band, and the bottoms of the clamp supports were bolted to the mounting plate of the assembly machine. All of the restraint pieces were made of steel.

The core and its restraints were enclosed inside a cylindrical core cover that was made of aluminum. Similarly, a contamination shield made of steel and plastic enclosed the safety block and the control rods when they were withdrawn.

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[a] Personal communication from Joetta Goda of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, February 27, 2008.

The mounting plate was made of aluminum and provided structural support for the core and its restraints. As noted above, the clamp supports were bolted to the mounting plate. There was a circular hole in the middle of the mounting plate through which the safety block could move, as well as smaller holes through which the control rods and the burst rod could be inserted. A cutaway view of the Godiva-IV core and its restraints is shown in Figure 1, and photographs of the Godiva-IV assembly on top of the mounting plate are shown in Figures 2 and 3.

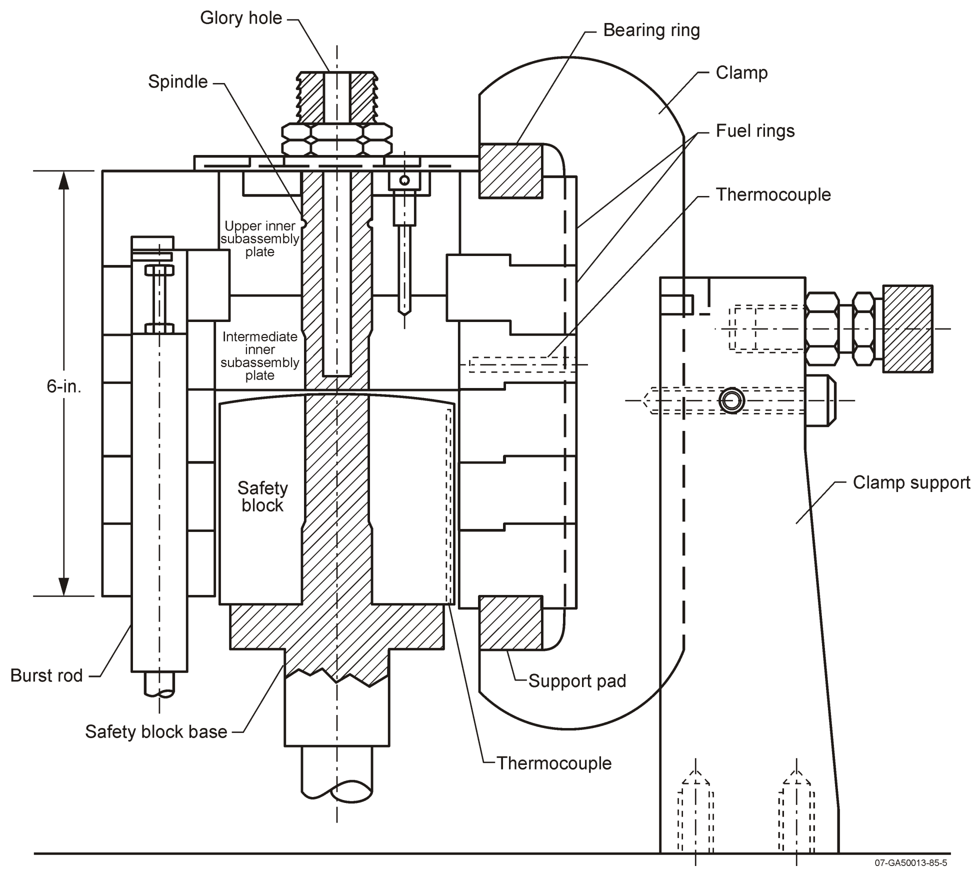

Figure 1. Cutaway View of the Godiva-IV Core and its Restraints.

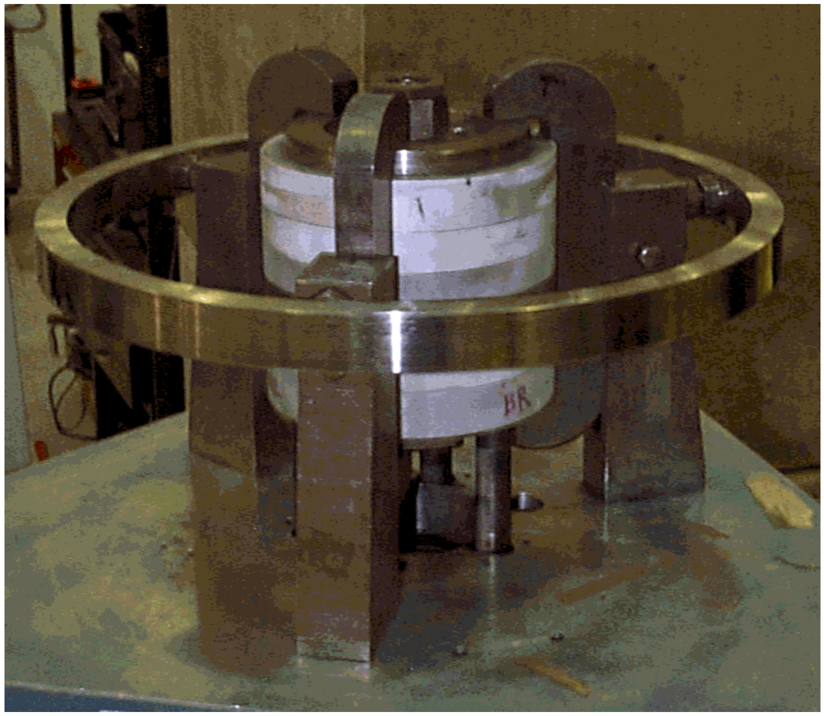

Figure 2. Side View of the Godiva-IV Assembly on Top of the Godiva Assembly Mounting Plate.

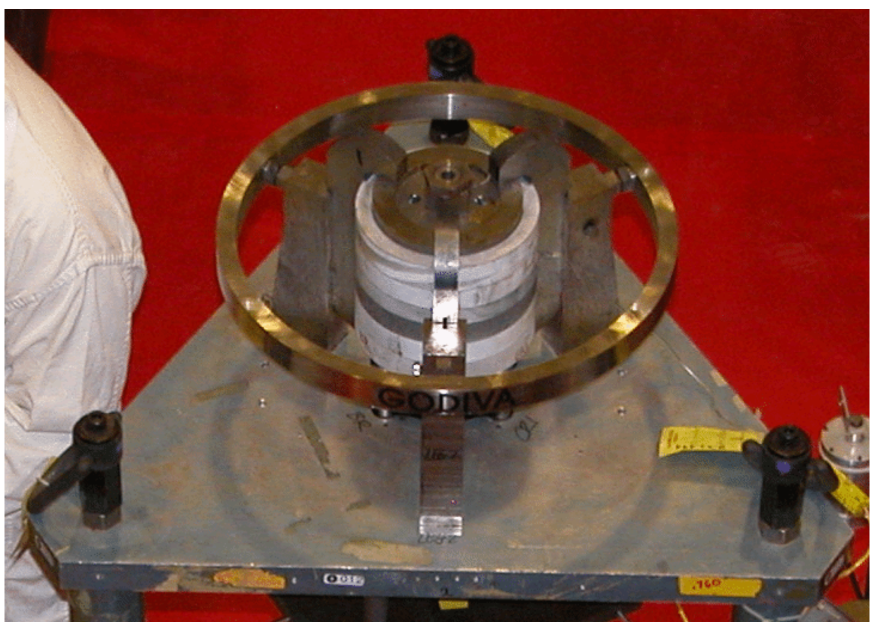

Figure 3. Top View of the Godiva-IV Assembly on Top of the Godiva Assembly Mounting Plate.

Two pairs of detectors typically were in place during the burst experiments. They were mounted on booms and usually were about a meter from the assembly, at approximately the same height as the core. They were cylindrical BF_3 detectors, with a diameter of approximately 1 inch and a length of approximately 9 inches. Each detector was fully enclosed by a layer of polyethylene, which was about an inch thick.

In addition, six safety monitors were mounted on the walls of the room. These monitors were cylindrical ^3He detectors, with a diameter of approximately 2 inches. Like the BF_3 detectors, these monitors were enclosed in a layer of polyethylene that was approximately 1 inch thick. Any one of these monitors would initiate withdrawal of the safety block, control rods, and burst rod if the measured neutron leakage exceeded a preset level. However, the response from the monitors was sufficiently slow that, for all but the very smallest bursts, the burst had been terminated before the actions they initiated even began.

CASA 3 has no windows, and its concrete walls are 18 inches thick. Its floor is a concrete slab of unspecified thickness. Its roof is made of lightweight concrete, is 3 inches thick, and is covered with tar paper. The distance from the floor to the top of the roof is 36 feet. The Godiva-IV experiments were conducted in the main experimental hall, which is 81 feet long and 39 feet wide. The effective length of the hall is somewhat shorter, however, because two vaults sit side-by-side at one end of the hall, spanning its entire width. The larger of these vaults is 23 feet 9 inches long and 19 feet 4 inches wide.

The Godiva-IV assembly was mounted on tracks so that it could be moved outside the CASA on rare occasions. However, marks on the floor ensured that the placement was reproducible, to within half an inch or less. That position was approximately in the center of the portion of the main experiment hall that did not include the vaults.

Experimental Procedure - The assembly of the critical and supercritical configurations was controlled remotely and contained no neutron source other than spontaneous fission from the HEU. Typically, the Godiva-IV core first was brought to a slightly supercritical condition, above critical but below prompt critical. In this condition, the safety block was in place, both control rods were fully inserted, and the burst rod was fully withdrawn. The delayed-critical condition then was determined by slowly withdrawing one of the control rods. For the Godiva-IV assembly with the safety block in place, the total worth of each control rod was approximately $1.5.

With the safety block in place and the control rods inserted, the worth of the burst rod was designed to be approximately $1. The burst rod could not be inserted incrementally. To confirm the worth of the burst rod, it was inserted with the safety block in place and the control rods withdrawn to their full-out position. Even when fully withdrawn, the top of the burst rod remained in the core. The full stroke of the burst rod inserted it only an additional 2.97 inches into the core. A reduction washer in the pneumatic cylinder that drove the burst rod prevented it from further insertion, and a hardened steel screw at the top of the burst rod prevented accidental overinsertion.

The worth of the burst rod was checked frequently, although not for every burst experiment. The control-rod calibration curve[a] could be used to determine the reactivity difference between the delayed-critical conditions with the burst rod out and the burst rod in. If the calculated worth of the burst rod was substantially different from $1, the experiment was terminated, and the reason for the discrepancy was investigated.

The positions of the control rods during the final stage of the burst experiment depended upon the size of the desired burst. The size of the burst was characterized by the maximum rise in temperature measured by a thermocouple in the safety block (see Figure 1). A 70 °C burst was the most common burst experiment, but bursts of 150 °C and 250 °C also were conducted from time to time.

The burst experiment itself began with the safety block, the control rods, and the burst rod fully withdrawn. The safety block was inserted first, and then one of the control rods was inserted to a predetermined position based on the size of the desired burst. Next, a delayed-critical condition was established using the other control rod. The first control rod then was inserted an additional predetermined amount that would produce the desired burst when the burst rod was inserted. This incremental insertion produced a positive period. The safety block then was lowered by about 2 inches to return the assembly to a subcritical condition.

At this point, the assembly was kept in that condition for a sufficient period of time (15 minutes or more) for the neutron population and the populations of all neutron precursors to return to levels characteristic of spontaneous fission. The purpose of this interruption was to prevent pre-initiation during the final stage of the burst experiment.

Finally, the safety block was reinserted and then the burst rod was inserted. Although this configuration placed the assembly in a super-prompt-critical position, it was often necessary to wait several seconds for a self-sustaining chain reaction to begin, because the core contained no neutron source other than spontaneous fission from the HEU. Once that chain reaction began, fissions occurred at a rate sufficient to produce heat, and consequently a thermoelastic wave from thermal expansion spread outward from the center of the core. Thermal expansion terminated the burst even before the shock wave reached the safety block. The force of the thermoelastic wave was sufficient to drive the safety-block far enough below the rest of the core that its base disengaged from the electromagnet holding it in place, and it dropped out of the core. This configuration ensured that the core did not return to a critical or supercritical condition as it cooled. Shortly thereafter, the control rods and burst rod were withdrawn to their full-out positions in response to a signal from the wall monitors, and thereafter the assembly remained in a subcritical condition.

1.2.2 Core - The cylindrical core of the Godiva-IV assembly contained six stacked fuel rings, an inner subassembly plate, a central spindle, an alignment pin, a safety block, a base for the safety

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[a] "Godiva Operator Aid: Control Rod Worth Curves," Los Alamos National Laboratory report NIS6-OP-0216 (July 2003).

block, two control rods, a burst rod, and a pin that prevented the burst rod from being over-inserted. In later years, a steel shim ring was added to compensate for gaps that were introduced by the erosion of fissile material had been oxidized during prior experiments. Table 1 contains the numbers of the drawings from which the dimensions for specific core components are taken. In addition, two thermocouples were present in the core, but a detailed description of those thermocouples is not available.

Table 1. Drawing Numbers for Core Components.

Component	Drawing Number
Fuel ring 101	128Y1719423
Fuel ring 102	128Y1719424
Fuel ring 103	128Y1719425
Fuel ring 104	128Y1719426
Fuel ring 105	128Y1719427
Fuel ring 106	128Y1719428
Upper inner subassembly plate	128Y1719429
Intermediate inner subassembly plate	128Y1719430
Shim ring	128Y1719505
Short alignment pin	128Y1719432
Long alignment pin	128Y1719433
Safety block	128Y1719441
Safety block base	128Y1719442
Control rods	128Y1719444
burst rod	128Y1719445
burst-rod pin	128Y1719394
Spindle	128Y1719431

The drawings provide tolerances for many of the dimensions of these pieces but not all of them. Where tolerances are provided, they are included in this and succeeding subsections. If no tolerance is provided, none is reported. Dimensions sometimes are given in decimal format and sometimes in fraction format. Dimensions herein are reported in the format and to the precision given in the drawings.

Fuel Rings - The core contained six fuel rings, which are numbered 101 through 106 and were stacked on top of each other. The numbers of the lower rings can be seen clearly in Figure 4.

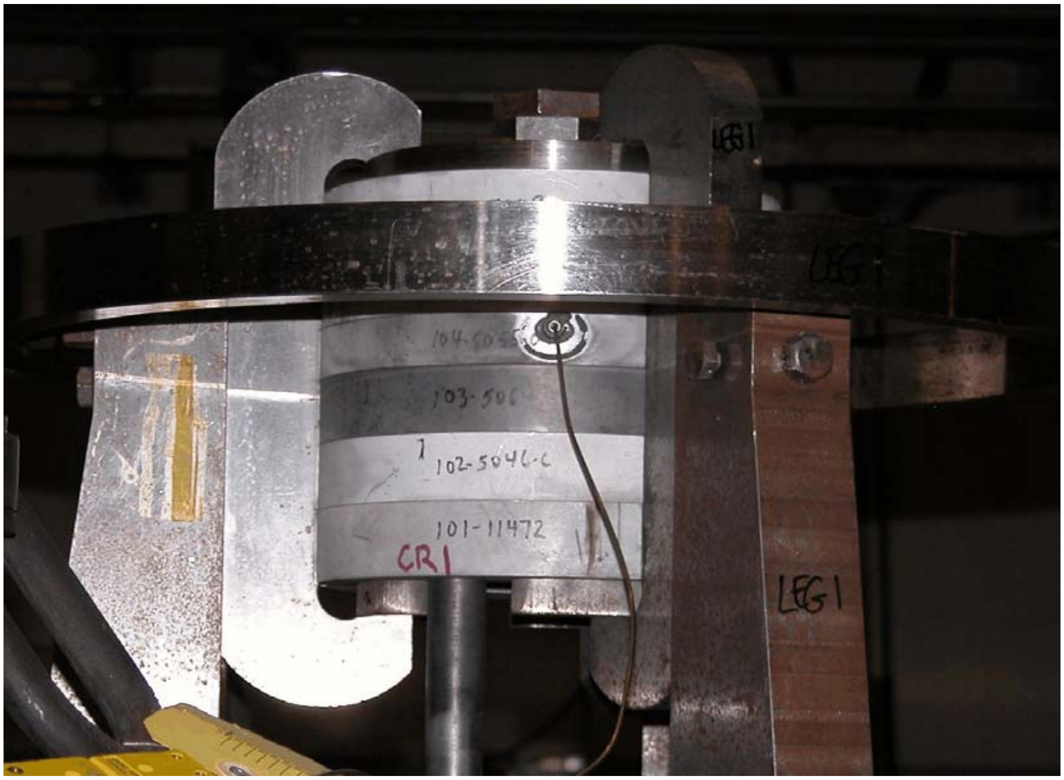

Figure 4. Numbered Godiva-IV Rings.

Overall, the six rings are quite similar. For example, they all have an outer diameter of 7.000 ± 0.001 inches.[a] However, there are small differences that make each of them unique. Consequently, they always are stacked in strict numerical order, with ring 101 at the bottom and ring 106 at the top. The rings have interlocking protrusions and depressions in their surfaces that kept them aligned after they were stacked.

The bottom five rings (101 through 105) each have three circular holes that pass completely through them to allow the entry of the two control rods and the burst rod. The holes are located symmetrically, 120° apart. The diameter of each hole is 0.875 ± 0.001 inch, and its center is 2.625 ± 0.001 inches from the center of the ring.

A picture of the bottom fuel ring, numbered 101, is shown in Figure 5, with its bottom surface facing upward. Its inner diameter is 3.500 + 0.002 / - 0.000 inches. Beyond a diameter of 5.000 + 0.002 / - 0.001 inches, the ring is 1.125 ± 0.001 inches thick. Inside that diameter the top surface is depressed by 0.125 + 0.002 / - 0.000 inch to accommodate the protrusion from the ring above it. The three slots in the bottom surface are located symmetrically between the holes and have

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[a] The drawing for ring 5 does not specify an outer diameter. Presumably, this is just an oversight.

semicircular ends. The slots are 0.100 ± 0.001 inch deep and 0.875 ± 0.001 inch wide. The radial centers of the slots are 2.438 ± 0.002 inches from the center of the ring. Omitting their semicircular ends, the slots each subtend an angle of 64°. The three full-height notches at the outer edge of the ring are located symmetrically, midway between the three holes. The full width of the notches is 0.875 ± 0.001 inch, and their half-width is 0.437 inch, with no uncertainty given.[a] At their centers, the flat inner surfaces of the notches are 0.156 ± 0.001 inch inside the outer diameter of the ring.

Figure 5. Fuel Ring 101 (Bottom View).

The geometries of the four intermediate fuel rings, numbered 102 through 105, are quite similar, although some of the dimensions vary slightly from ring to ring. A representative schematic of those rings is shown in Figure 6, with the bottom surface facing upward, and a picture of ring 104 is presented in Figure 7. Cracks are clearly visible extending inward from each of the three holes to the inner edge of the ring.

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[a] Presumably, this is not a discrepancy but instead is simply due to the fact that three digits of precision do not correspond identically to dividing the full width by two. It is not clear why both the full width and the half width of the notches need to be given, but both are specified for each ring.

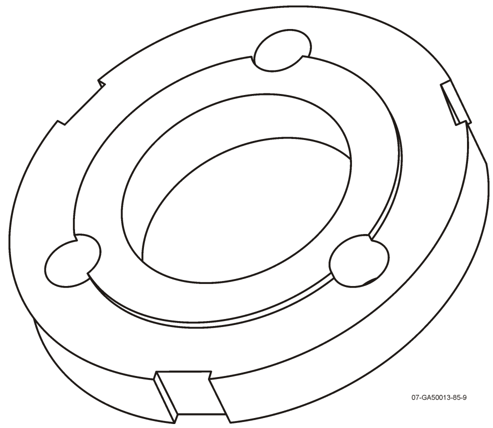

Figure 6. Schematic of Fuel Rings 102-105.

Figure 7. Fuel Ring 104.

Rings 102 through 104 have many dimensions in common with ring 101. All of them have inner diameters of 3.500 + 0.002 / - 0.000 inches. All three rings also have vertical notches at their outer edge that run the full height of the ring and are located symmetrically midway between the three holes. The notches all are 0.875 ± 0.001 inch wide, but the notches for rings 102 through 104 are slightly deeper than those for ring 101. At their centers, the flat inner surfaces of those notches are 0.170 ± 0.001 inch inside the outer diameter of the ring.

Although rings 102 and 103 have the same general shape, they have different vertical dimensions. Each ring has a bottom protrusion that fits into the depression of the ring below it, and both of them have a corresponding depression in its upper surface. For both rings, the lower protrusion extends from the inner edge of the ring out to a diameter of 4.995 + 0.000 / - 0.002, while the upper depression extends from the inner edge of the ring out to a diameter of 5.000 + 0.002 / - 0.000. In addition, the thickness of both rings from the bottom of the protrusion to the top of the outer edge of the ring is 1.125 ± 0.001 inches. However, the height of the protrusion and the depth of the depression both are 0.115 + 0.000 / - 0.002 inch for ring 102, while the corresponding distances for ring 103 are both 0.125 + 0.002 / - 0.000.

Ring 104 has two unique features. First, it is has an upper protrusion rather than an upper depression. The upper protrusion is identical to the bottom one, with an outer diameter of 4.995 + 0.000 / - 0.002 inches and a height of 0.115 + 0.000 / - 0.002 inch. Second, a small circular hole was drilled horizontally through the side of the ring to allow a thermocouple to be placed in it. The hole is 1.5 inches long, and its diameter varies with its depth. For the outermost 0.25 inch, the diameter of the hole also is 0.25 inch, and from 0.25 to 0.375 inch the diameter is 0.213 inch. The diameter then decreases with a 60° slope until it reaches a 0.067 inch, after which it remains at that diameter. The vertical position of the hole is not given, but from the drawing it appears to be about a quarter of the way between the top and bottom surfaces of the ring. The full height of ring 104, from the bottom of the bottom protrusion to the top of the top protrusion is 1.010 ± 0.010 inches.

Ring 105 is nearly identical to ring 103, with only two differences. First, its inner diameter is only 3.130 + 0.002 / - 0.000 inches. Second, its full height from the bottom of its bottom surface to the top of the protrusion is 1.082 ± 0.001 inches. Also, as noted previously, the drawing for ring 105 does not specify its outer diameter.

Ring 106, the top ring, is very similar to ring 102, with only three differences. First, it is thicker than the other rings, with a height of 1.167 ± 0.001 inches at its outer edge. Second, its notches, like those for ring 101, are only 0.156 ± 0.001 inch deep. Third, instead of a protrusion from its upper surface, it has an annular slot. The inner diameter of that slot is given as 4.000 + 0.000 / - 0.002 inches, and its outer diameter is given as 5.750 + 0.002 / - 0.000 inches. The schematic of ring 106 presented in Figure 8 is taken directly from the drawing and clearly shows a slot with uniform depth. Specifically, the drawing indicates that the slot is recessed 0.100 ± 0.001 inch below the surface. However, a photograph of ring 106 taken in 2005 and presented in Figure 9 clearly shows that some portions of the slot are deeper than the rest. Presumably, the deeper portions of the slot were added after the drawing was generated.[a] Alternatively, the deeper

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[a] Drawing 128Y1719428 states that it "reflects original design intent of a legacy drawing # 19Y-29572-D6-106." That legacy drawing was created in October 1976.

indentations may have been produced by pressure from the bearing ring, which will be described in subsection 1.2.3.

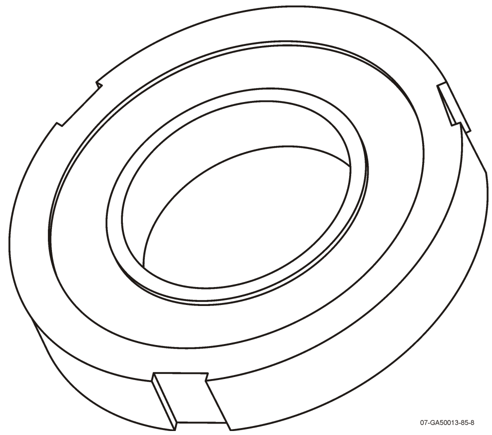

Figure 8. Schematic of Fuel Ring 106 (Top View).

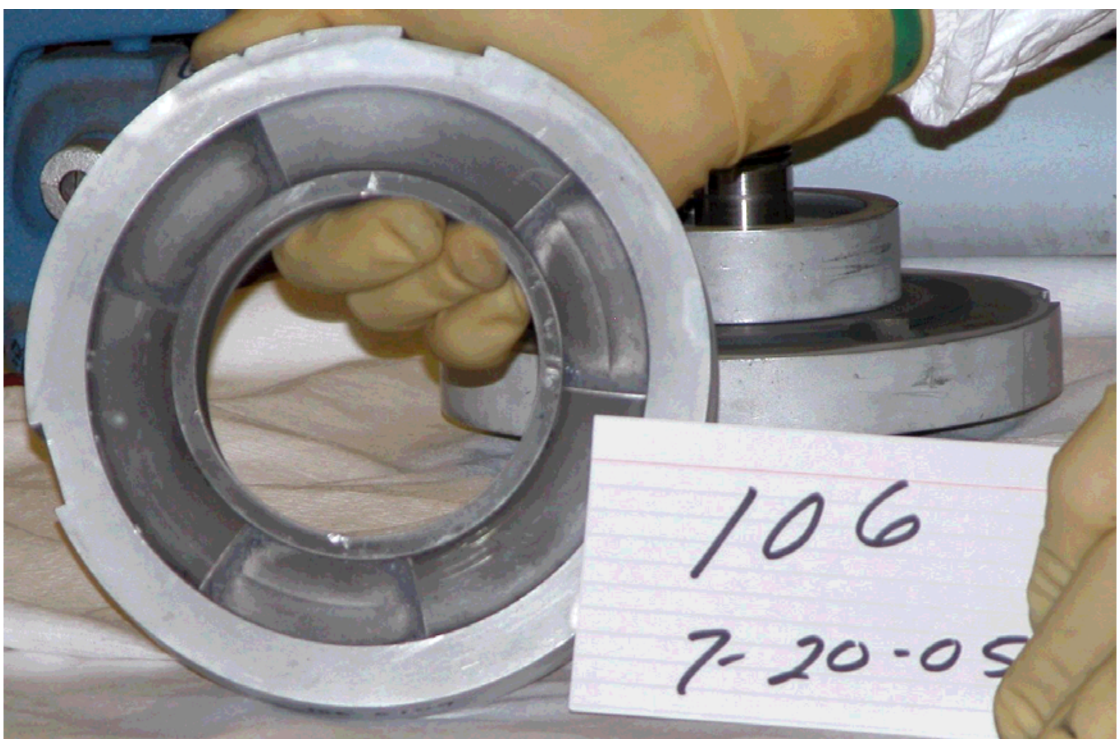

Figure 9. Picture of Fuel Ring 106 (Top View).

Subassembly Plate -The inner subassembly plate has two components, referred to as the upper plate and the intermediate plate. In later years, a thin steel shim ring was present at the outer bottom edge of the intermediate plate. Schematics of the two plates are shown in Figures 10 and 11. The dashed lines in the two schematics indicate threaded regions. A picture of all three pieces is presented in Figure 12. The intermediate inner subassembly plate is on the left, and the upper inner subassembly plate is on the right.

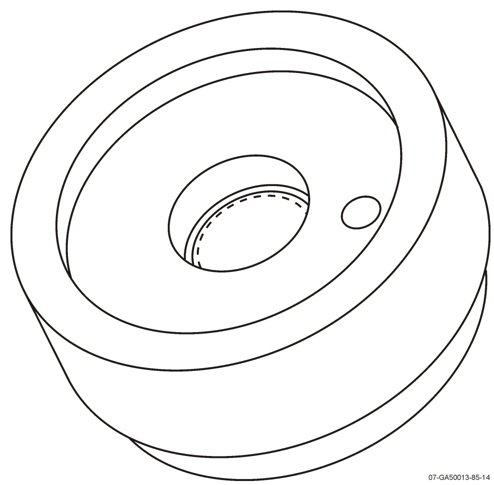

Figure 10. Schematic of the Upper Subassembly Plate.

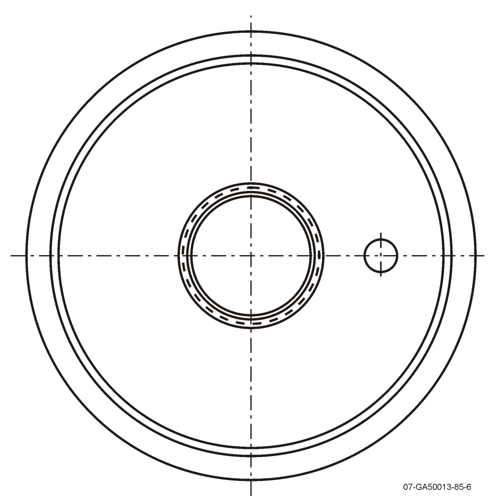

Figure 11. Schematic of the Intermediate Subassembly Plate (Top View).

Figure 12. Upper and Intermediate Inner Subassembly Plates and Steel Shim Ring.

The full height of the upper inner subassembly plate is 1.636 ± 0.002 inches. The outer diameter for the portion below 0.580 ± 0.001 inch is 3.104 + 0.000 / -0.002 inches, and, with two exceptions, the outer diameter above it is 3.4765 + 0.0000 / - 0.0020 inches. There is a semicircular indentation with a radius of 1/16 of an inch at the bottom of the upper portion of the plate (i.e., the top of the indentation is 0.580 ± 0.001 inch from the bottom of the plate), and the bottom of the plate is chamfered. The chamfered region is indented 1/16 of an inch at the very bottom of the plate, and the edge slopes upward at a 45°angle until it reaches the side of the plate.

The upper inner subassembly plate has a central opening that runs its full height. However the diameter of that opening varies. From the top of the plate to a depth of 0.2645 + 0.0000 / - 0.0030 inch, the diameter of the opening is 2.760 + 0.003 / - 0.000 inches. For the next 0.375 ± 0.002 inch, it is 1.125 + 0.002 / - 0.000 inch. Below that point, the opening is threaded and, except near the bottom surface, has a minimum diameter of 15/16 of an inch . At the very bottom, the diameter of the opening flares out at a 45° angle to an additional 1/16 of an inch.

As shown in Figure 10, the upper inner assembly plate also has a pin hole that runs completely through it. The center of the hole is 1.000 inch from the center of the plate . For the uppermost 0.375 ± 0.002 inch, the diameter of the hole is 5/16 of an inch, and below that depth the diameter is ¼ of an inch.

The full height of the intermediate inner subassembly plate is 1.375 + 0.002 / - 0.000 inches. Its basic outer diameter for the first 0.375 + 0.002 / -0.000 inch below the top surface is 3.090 + 0.000 / - 0.002 inches, and below that point it is 3.450 + 0.000 / - 0.002 inches. There are two places where the diameter is less than those basic values. The plate is chamfered at the top, with an indentation of 1/16 of an inch at the very top. The chamfered region then slopes downward at a 45° angle until it reaches the basic diameter. In addition, there is a semicircular indentation with a radius of 1/32 of an inch at the bottom of the upper portion of the plate (i.e., the bottom of the indentation is 0.375 + 0.002 / -0.000 inch below the top surface).

The intermediate subassembly plate has a central opening that runs its full height. However the diameter of that opening varies. From 0.875 inch below the top of the plate to the bottom of the plate, the diameter of the opening is 0.913 +0.002 / -0.000 inch. No diameter is given for the opening from that point to the top of the plate. However, the uppermost 0.750 inch is threaded, and the spindle that screws into the opening has no variation in its diameter over the portion of it that screws into the upper and intermediate subassembly plates. Consequently, it can be assumed that the diameter of the opening for the uppermost 0.750 inch of the intermediate plate is the same as that for the bottom portion of the upper plate. The wider opening in the upper plate extends 0.125 inch below the threaded region. From the drawing, the diameter of that portion of the opening appears to be the same as the minimum diameter in the threaded portion. In addition, the diameter of the central opening expands slightly near the top of the plate. Specifically, at the very top of the plate the diameter of the opening flares out at a 45° angle to a maximum of an additional 1/16 of an inch.

As Figure 11 indicates, the intermediate subassembly plate also has a pin hole that runs part way through it. The diameter of the hole is ¼ of an inch to a depth of ¼ of an inch and then it tapers inward to a point. Although the angle of the taper is not given, the hole must accommodate the long alignment pin described below. The bottom of that pin tapers at an angle of 45°, and therefore it is likely that the bottom of the hole does as well.

For the last several years of operation, a small steel shim ring was placed between the intermediate subassembly plate and the fuel ring that overlaps it to compensate for the erosion of oxidized material. The drawing for the shim ring gives its thickness as 0.020 inch and its inner and outer diameters as 3.090 and 3.450 inches, respectively. The Godiva Fuel Disassembly Data Sheet, dated July 20 - 21, 2005, lists its measured thickness as 0.0240 inch and its measured inner and outer diameters as 3.2590 and 3.4650 inches, respectively. These dimensions were measured with calipers.[a]

Alignment Pins - There are two stainless steel alignment pins for the subassembly plates even though they each have only a single pin hole. The short pin is 1.520 inches long, while the long pin is 1.875 inches long . The purpose of the short pin is not readily apparent, since if it were inserted into the upper plate it would not reach the intermediate plate. Nonetheless, it will be described for the sake of completeness.

Both pins have four regions: an unthreaded top with a slit in it, a threaded upper region, an unthreaded cylindrical region, and a tapered bottom. For both pins, the top has an outer diameter of 5/16 of an inch and a height of 1/16 of an inch . Both tops have a central slit that is 1/16 of an inch

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[a] Personal communication from Joetta Goda of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, January 25, 2007.

wide and extends the full width of the top. The threaded regions of the two pins have the same maximum diameter, 5/16 of an inch, but different lengths. The threaded region of the short pin is 0.625 inch long, while the threaded region of the long pin is only 0.375 inch long. The cylindrical regions of both pins have the same diameter, 0.247 + 0.000 / -0.002 inch, but the lengths of that region are not stated explicitly. The short pin tapers to a point, at a 45° angle. The long pin also tapers at a 45° angle but that tapered region is truncated to a length of only 1/32 of an inch.

Safety Block and Base - The safety block is essentially a hollow cylinder with a slightly convex upper surface and a chamfered bottom edge. A schematic of the safety block is shown in Figure 13, and a picture of the safety block with all of the core except the control rods and burst rod removed is presented in Figure 14. The safety block also has a small hole near its outer edge to accommodate a thermocouple.

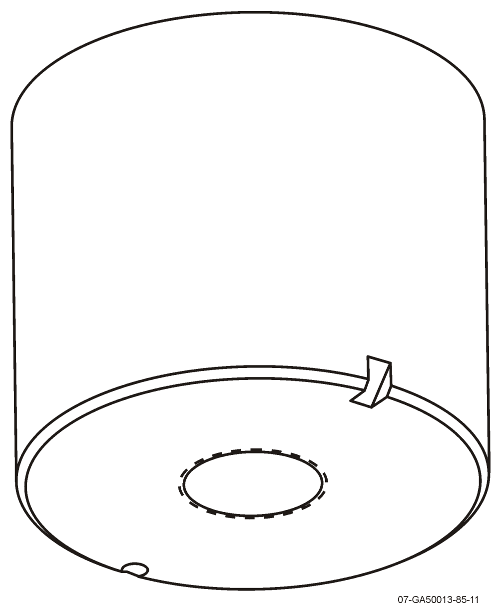

Figure 13. Schematic of the Safety Block.

Figure 14. Safety Block with Control Rods and Burst Rod.

The full height of the safety block is 3.000 + 0.000/ - 0.002 inches, and its outer diameter is 3.380 + 0.000 / - 0.002 inches. Beyond a diameter of 1.250 ± 0.005 inches, the top surface tapers downward at a 5° angle. The outermost ¼ inch of the bottom surface is chamfered at a 45° angle, and there also is a notch in the bottom surface. The width of the notch is 3/16 of an inch, but neither an angle nor a depth is provided. Based on the scale of the drawing, the depth appears to be about the same as its width, and the angle appears to be approximately 45°.

Typically there is a small gap between the top of the safety block and the bottom of the intermediate inner subassembly plate, to allow for thermal expansion on hot days. During disassembly of Godiva-IV, the maximum height of that gap was measured to be 0.10 inch.[a] Small shims were placed incrementally on top of the safety block, and it was raised into the core. The magnetic lock held the safety block in place until the total height of the shims reached 0.10 inch. The lock failed to hold for any larger stack of shims.

There are three distinct regions within the central hole of the safety block. The bottom 1 inch is threaded, and there is a "thread relief" zone immediately above it that is ⅛ of an inch long. The

[a] Personal communication from Joetta M. Goda of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, February 13, 2007.

diameter of the thread relief zone is 1 inch, and so is the minimum diameter of the threaded region. The rest of the central hole has a slightly smaller diameter, which is given as 0.875 + 0.002 / - 0.000 inch.

The hole for the thermocouple is located directly across from the bottom notch, and its center is ⅛ of an inch inside the outer diameter of the safety block. The hole extends upward from the bottom surface to a length of 2 13/16 inches. It has four distinct regions. The bottom ¼ of an inch has a diameter of 10/32 of an inch, and then the diameter is 0.161 inch up to ⅜ of an inch. The diameter then tapers at a 60° angle until it reaches 0.067 inch, after which it remains constant for the rest of the length of the hole.

The safety block base supports the safety block and screws into the bottom of the safety block. As the schematic in Figure 15 illustrates, it has a fairly complex shape.

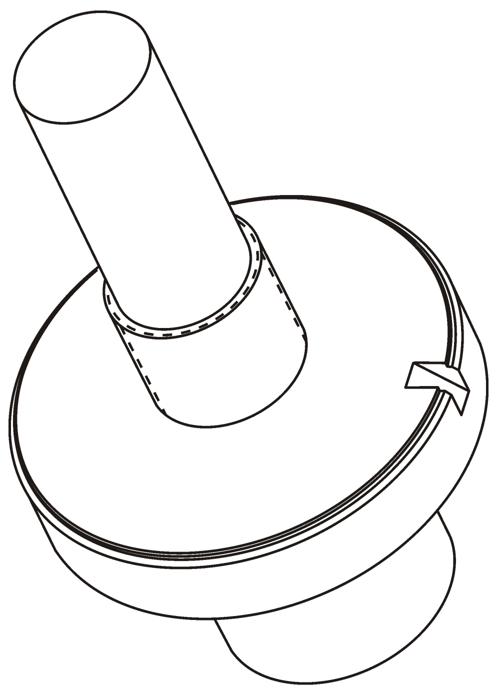

Figure 15. Schematic of the Safety Block Base.

The full height of the safety block base is 5.062 inches. Its central shaft extends 3.000 + 0.002 / - 0.000 above the top surface of the platform that supports the safety block. The upper portion of the shaft has a diameter of 0.873 + 0.000 / - 0.002 inch. The bottom 1 inch of the shaft is threaded and is slightly wider than the upper portion, but its exact diameter is not given. The shaft has a semicircular indentation where it joins the platform, with a radius of 1/16 of an inch. The top end of the shaft of the safety block base can be seen in Figure 14, surrounded by the top of the safety block.

The platform near the bottom of the base is 0.562 ± 0.002 inch thick and has a full diameter of 2.880 + 0.000 / - 0.002 inches. However, the edge of its top surface is irregular and contains a notch. At its very top, the surface of the platform has a diameter of 2.756 + 0.000 / - 0.002 inches. The edge then has a vertical drop of 0.030 + 0.002 / - 0.000 inch and thereafter is beveled at a 45° angle until it reaches its full diameter. The notch also is cut at a 45° angle, and it is ¼ of an inch deep at its ends. It is 3/16 of an inch wide.

The bottom 1 inch of the safety block base is hollow, with an outer diameter of 1.500 ± 0.003 inches and a wall thickness of ¼ inch. The bottom portion of the inside of that wall is threaded, but the uppermost ⅛ of an inch is not. The base is solid above that central hole and has a rounded edge that extends outward from the outer to the bottom of the platform. That rounded edge is in the form of a quarter circle, with a radius of ¼ of an inch.

Control and Burst Rods - The control rods are essentially solid cylinders with chamfered top and bottom edges, a notch at the edge of the top surface, and threaded central holes at the top and bottom that extend part way into the rod. The full height of the control rods is 5.000 + 0.005 / - 0.000 inches, and their outer diameter is 0.860 + 0.000 / - 0.002 inch. The top and bottom holes both are 0.75 inch long, with a diameter of 0.375 inch. The top and bottom edges of the control rods are chamfered at a 45° angle, to a maximum distance of 0.06 inch. The notch at the edge of the top surface also is cut at a 45° angle. It is 0.19 inch wide, and it extends a distance of 0.19 inch into the surface.

The burst rod differs from the control rods in only two respects. First, it does not have a notch at the edge of its top surface. Second, the top hole is deeper and tapers to a point. The top hole has a uniform diameter of 0.375 inch to a depth of 1.25 inches. Thereafter, it tapers sharply to a point. Although the angle is not given, from the drawing it would appear to be about 30° with respect what otherwise would have been a flat bottom of the hole.

The length of the steel pin that prevents the burst rod from being over-inserted is given as 1.50 inches, and its diameter is given as 0.375 inch. It extends 1.00 inch above the top of the burst rod, including its hexagonal head, and the bottom end of the pin is flat. The drawing shows the pin partially inserted inside the top threaded hole of the burst rod. The drawing for the burst rod gives the length of that hole as 1.25 inches plus a slanted tip. The pin itself is a 3/8-inch bolt, with a head that is 0.295 inches thick. The distance from one side of the hexagonal head to the side parallel to it is 0.562 inches.[a] Although Figure 1 shows another region, approximately the same size as the head, immediately above the top of the burst rod, Figure 14 confirms that no such second region is present in the current configuration.

Spindle - The spindle is essentially a hollow cylinder, but the shape of its outer surface is complex. A vertical slice through the center of the spindle is shown in Figure 16.

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[a] Personal communication from Charlene Cappiello of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, April 9, 2007.

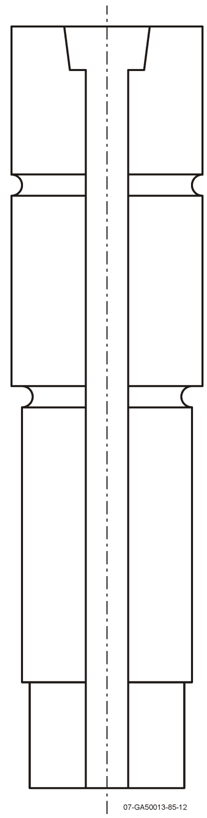

Figure 16. Vertical Slice through the Center of the Spindle.

The full height of the spindle is 4.500 + 0.005 / - 0.000 inches, and it has a central hole that runs its entire length. For most of that length the diameter of the hole is ¼ of an inch. However, it is wider near the top of the spindle. At the very top, the diameter is 9/16 of an inch, but it slopes slightly inward for the first ¼ of an inch. Unfortunately, the diameter at the bottom of the wider portion of the hole is not given, and neither is the angle of the slope.

The outer surface of the spindle has six distinct regions, but the drawing explicitly states the length of only four of the regions. However, it does give the combined height of the bottom three regions (2.375 + 0.000 / - 0.005 inches). This combination of dimensions is sufficient to allow the heights of the other two regions to be inferred.

The outer diameter of the bottom region is 0.910 + 0.000 / - 0.002 inch, and its height is 0.625 ± 0.002 inches.

The outer diameter of the threaded region immediately above the bottom region is not given, but from the drawing it is greater than that of the bottom region but less than that of the top region. Its inferred height is 1.625 inches.

The height of the third region is ⅛ of an inch. From the drawing, its maximum outer diameter is the same as the outer diameter of the second region. However, the side surface of the third region has a semicircular indentation with a radius of 1/16 of an inch (i.e., the diameter of the indentation is the same as the height of the region).

The diameter of the fourth region is 1.125 + 0.000 / - 0.005 inches. Its height is not given but can be inferred to be 1.125 inches.

The height of the fifth region is ⅛ of an inch, and its maximum outer diameter is the same as that of the fourth region; viz., 1.125 + 0.000 / - 0.005 inches. However, the side surface of the fifth region has a semicircular indentation with a radius of 1/16 of an inch (i.e., the diameter of the indentation is the same as the height of the region).

The threaded top region is 1.000 ± 0.005 inch high, and its maximum diameter is the same as that of the fourth region; viz., 1.125 + 0.000 / - 0.005 inches.

1.2.3 Restraints - Restraints for the core included three clamps, three clamp supports (commonly referred to as legs), a circular belly band (also referred to as a Saturn ring), a subassembly cover plate, a bearing ring, three support pads, and various nuts and bolts. The subassembly cover plate sat above the upper inner subassembly plate, inside the bearing ring and enclosing a section of the spindle. The bottom of the bearing ring fitted into the annular slot in the top surface of the top fuel ring, and the pads fitted into slots in the bottom surface of the bottom fuel ring. The top and bottom prongs of the clamps fitted onto the top of the bearing ring and the bottom of the pads, respectively. Each of the three clamps was attached to its own clamp support. The tops of the clamp supports were enclosed by the belly band, and the bottoms of the clamp supports were bolted to the mounting plate of the assembly machine. Table 2 contains the numbers of the drawings from which the dimensions for the restraints are taken.

Table 2. Drawing Numbers for Restraints.

Component	Drawing Number
Clamps	128Y1719437
Clamp supports Locking bolts	128Y1719438 —
Belly band Belly band bolts	128Y1719439 128Y1719440
Subassembly cover plate	128Y1719436
Bearing ring	128Y1719435
Support pads	128Y1719434

Clamps - The three clamps are similar to standard C-clamps but have been designed for this particular application. Clamps can be seen in Figures 1 through 4, and a schematic of one clamp is shown in Figure 17. The clamps are symmetrical about their vertical midplane and, except for the holes, about their horizontal midplane as well.

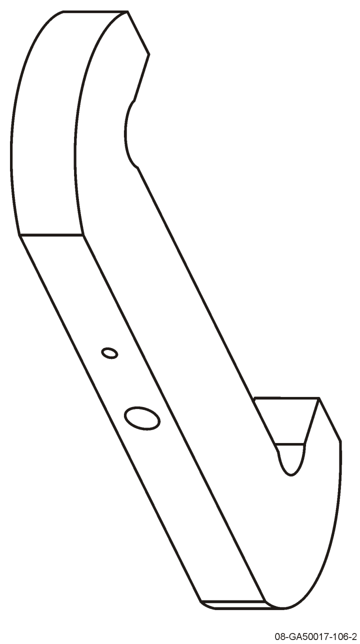

Figure 17. Schematic of a Clamp.

The clamps are made of maraging steel and were heat-treated prior to their use in the experimental assembly. Prior to heat treating, the clamps were 0.900 ± 0.005 inch wide, the distance between the flat regions of the upper and lower prongs was 0.700 inches, and the distance from the front edge of the prongs to the back edge of the clamps was 3.095 inches. After heat treating, they were 0.875 + 0.000 / - 0.002 inch wide. No similar reduction was given for the other dimensions after heat treating. The distance from the front edge of the prongs to the front edge of the flat vertical surface between them is given as 1.345 ± 0.005 inches, but the drawing does not indicate whether this was before or after heat treating.

The curved upper end of the clamp has a radius of curvature of 1⅞ inches, with the center of the curve located on the front edge of the flat vertical surface. Although information is given only for the upper end of the clamp, the bottom end presumably has the same characteristics.

Two holes were cut into the back surface of each clamp, to a depth of ½ of an inch. The larger hole has a diameter of 7/16 of an inch, and its center is at the vertical and horizontal center of the back surface of the clamp. The second hole has a diameter of 3/16 of an inch, and its center is 1.343 inches above the center of the larger hole.

The flat surfaces of the prongs do not extend all the way back to the front edge of the flat surface between them. Instead, as the schematic shows, small notches are present at the corners between the surfaces of the prongs and the flat surface that connects them. The notches were created using circular cuts with a diameter of ⅞ of an inch based on circles whose centers are 3.062 inches above and below the midpoint of the clamp. The centers of those circles are displaced on a 45° angle relative to the flat surfaces of the prongs such that at its deepest point the cut goes 0.093 inch into the clamp. The relevant portion of the drawing is shown in Figure 18.

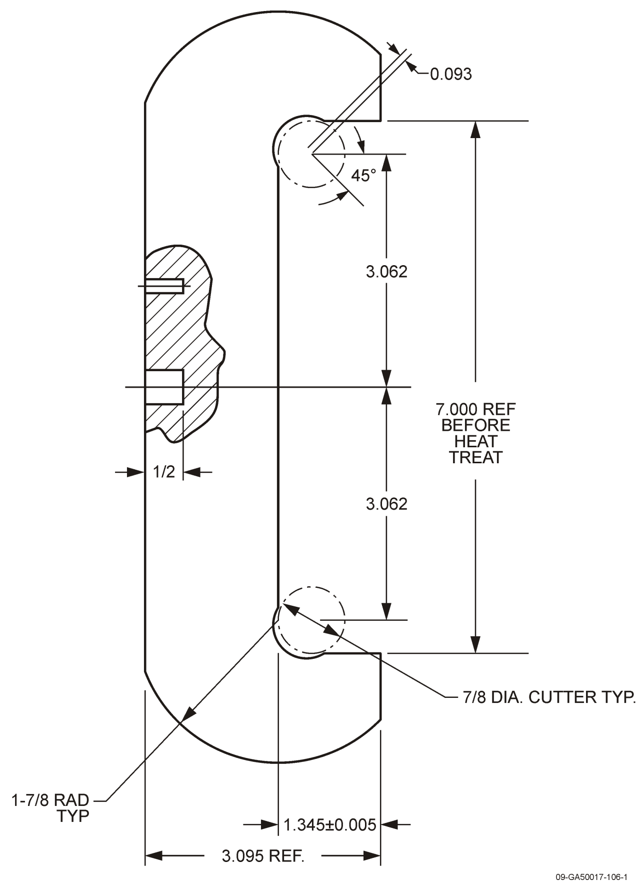

Figure 18. Side View of a Clamp with Dimensions.

Unfortunately, the drawing does not provide all of the necessary dimensions for the clamps. Consequently, those additional dimensions were obtained using a drawing to scale contained within a CAD program.[a] The full height of the clamps is 9.874 inches, and the length of the flat back

[a] Personal communication from Robert D. Garrett of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, January 3, 2007.

surface of the clamps is 7.470 inches. The distance from the top of the front edge of the top prong to the bottom of the front edge of the bottom prong is 8.737 inches.

Clamp supports - The clamp supports also have a fairly complicated shape, as shown in Figure 19. The full height of the clamp supports is 8¼ inches, and they are 1⅛ inches wide. As Figure 19 shows, however, their depth varies with axial location. They are 2 inches deep for the top 2¼ inches, and they are 2¾ inches deep for the bottom ½ inch. The depth varies linearly between those two extremes for the intervening 5½ inches.

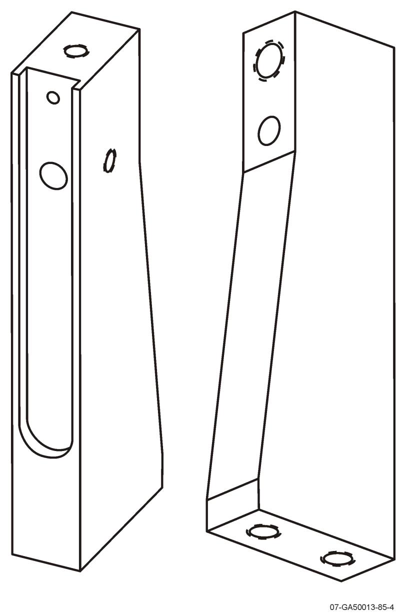

Figure 19. Schematic of Clamp Supports ("Legs").

The back edge of the clamps fitted into a slot in the front of the clamp supports. The slot is 0.250 + 0.005 / - 0.000 inches deep, and the bottom edge of the slot is a semicircle with a diameter of 0.875 inches. The width of the slot is the same as that diameter, and the center of the semicircle is 6 inches below the top of the clamp support (i.e., the bottom of the semicircle is 6.4375 inches below the top of the clamp support).

As the schematic indicates, each clamp support also contains several holes, but only one hole passes completely through it. That hole is the larger of the two holes inside the slot. The diameter of that hole is 7/16 of an inch, and its center is at the horizontal center of the slot, 1 ¾ inches below the top of the clamp support. The center of a smaller hole is located 1 11/32 inches above the center of that hole. That smaller hole has a diameter of 3/16 of an inch, but the distance it penetrates beyond the back of the slot is not given. From the drawing that distance appears to be ¼ to ⅜ of an inch.

The other five holes all are threaded. One each enters from the top, back, and side of the clamp support, and two of them enter from the bottom.

The center of the top hole is at the center of the top surface, and its diameter is ⅜ of an inch. The hole is 1⅛ inches deep and tapers to a point. Neither the length nor the angle of the pointed end is given, but the angle appears to be about 30° with respect to what otherwise would have been the flat bottom of the hole.

The center of the back hole is located ⅝ of an inch below the top of the clamp support. Its maximum diameter also is ⅝ of an inch, and it has a rounded end. The depth of that hole is not given, but from the drawing it appears to be slightly greater than 1 inch.

The side hole is located in the upper portion of the clamp support, where it is 2 inches thick. The distance from the top of the clamp support to the hole is not given, but the hole does intersect with the hole that passes completely through the clamp support. Horizontally, the center of the side hole is located 1 inch from the back of the clamp support, so it is at the horizontal center of the clamp support. The diameter of the hole is ⅜ of an inch, and it is 11/32 of an inch deep.

The centers of the two bottom holes are ⅝ of an inch from the front and back edges of the bottom surface, respectively. Their maximum diameter is ½ of an inch, and they appear to be located at the horizontal center of the surface. They are 1 inch deep, with tapered ends that come to a point. The angle of the taper is not given, but it appears to be about 30° with respect to what otherwise would have been the flat end of the hole.

The clamp supports are attached to the clamps by locking bolts, as shown in Figure 1. However, no additional information about those bolts has been found.

Belly Band and Bolts - The belly band is a circular ring with flat vertical and horizontal surfaces (i.e., a hollow cylinder). It has an inner diameter of 16.000 inches and an outer diameter of 17.500 inches. It is 1.250 inches high and contains three counter-sunk horizontal holes. Each of the three belly-band bolts screws into the back hole of a clamp support, while its head protrudes into a countersunk hole in the inner surface of the belly band. The diameter of each of the holes at the inner surface of the belly band is 0.9375 inch, and the hole tapers inward at a 45°angle for 0.125 inch. The diameter remains constant from that point out to the outer surface of the belly band.

A schematic of the threaded belly-band bolt is shown in Figure 20. The threaded shaft of the bolt is 1.750 inches long and has a maximum diameter of 0.625 inch. As the schematic indicates, there are three distinct parts of the head. The bottom part of the head is a hexagon, with a height of 0.343 inches. The distance between opposing sides of the hexagonal portion of the head is 0.938 inch, and the distance between opposing corners is 1.083 inches. The region immediately above the hexagon is circular, with a diameter of 0.9375 inch and a height of 0.063 inch. The top part of the head is 0.125 inch high. It is circular but its edge slopes inward at a 45°angle from its base to its top. The diameter at its base is the same as that of the middle part, and the top of the top part is flat.

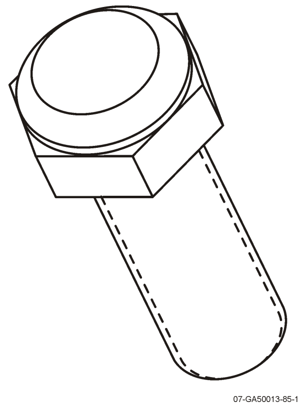

Figure 20. Schematic of Belly-Band Bolt.

Subassembly Cover Plate - The subassembly cover plate is circular, with a raised edge, a central hole, and four smaller holes. The cover plate sat inside the bearing ring, above the upper inner subassembly plate. The cover plate can be seen in Figure 3, and a schematic of it is shown in Figure 21.

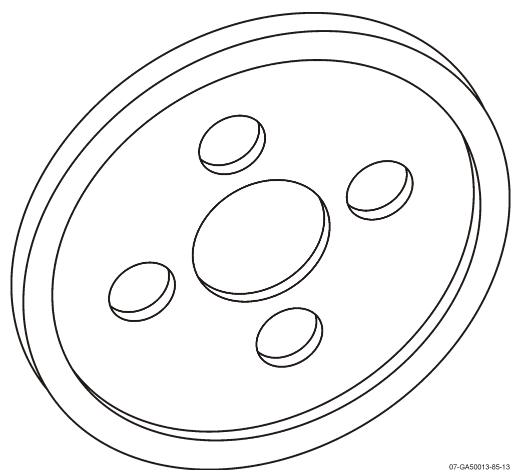

Figure 21. Schematic of Subassembly Cover Plate.

The outer diameter of the cover plate is 4.00 inches, and the inner diameter of its raised edge is 3.50 inches. The raised edge is 0.125 inch high, and the full height of the plate (including the raised edge) is 0.25 inch. The central hole has a diameter of 1.130 inches, and the four smaller holes each have a diameter of 0.537 inch. The four smaller holes are located symmetrically, with their centers 90° apart. The distance between the centers of any two of those holes that are across the center hole from each other is 2.00 inches (i.e., the center of each hole is 1 inch from the center of the central hole).

Bearing Ring - The bearing ring fitted into the annular slot on the top of the top fuel ring, which was shown in Figure 9. As Figure 22 indicates, the bearing ring has three slightly raised regions that fitted into the deeper portions of that slot.

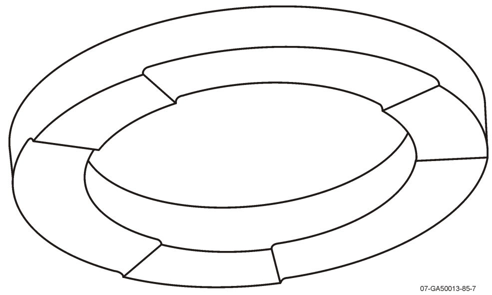

Figure 22. Schematic of Bearing Ring.

The inner diameter of the bearing ring is 4.003 + 0.002 / - 0.000 inches, and its outer diameter is 5.745 + 0.000 / - 0.002 inches. The three thicker regions are located symmetrically on the ring, and each of them subtends an angle of 40° with a separation of 80° between adjacent regions. Those thicker regions are 0.625 ± 0.001 inch thick. The surfaces of the regions between them are recessed 0.062 ± 0.001 inch above the surfaces of the thicker regions. The edges between the thicker and thinner regions slope outward from the thicker regions, with a radius of 1/16 of an inch.

Support Pads - The three support pads fitted into the slots in the bottom of the bottom fuel ring, shown in Figure 5. The pads are 0.625 ± 0.001 inch thick and have semicircular ends. With those ends omitted, the pads subtend an angle of 64°. Unfortunately, the drawing gives nominal values for the remaining dimensions that are not consistent. It is noted on the drawing that "radii shown on legacy drawing were depicted as diameters," and it appears that error has not been otherwise corrected on the current drawing. The inner diameter of the pads is given as 2.002 + 0.002 / - 0.000 inches, and their outer diameter is given as 2.872 + 0.000 / - 0.002 inches. The radius of the semicircular ends is characterized as ".437 (.435) RAD."

There is no straightforward interpretation that produces consistency among these various dimensions. Given that the support pads must fit inside the support-pad slots in the bottom of Fuel ring 101, the following interpretation appears to be the most likely. The inner *radius* of the pads is 2.002 + 0.002 / - 0.000 inches, their outer *radius* is 2.437 + 0.000 / - 0.002 inches, and the radius of curvature for the semicircular ends is 0.435 inch. This interpretation produces support pads that have a radius of curvature consistent with those for the support-pad slots and which are very slightly thinner and shorter than those slots.

1.2.4 Structural Support -There are several structural components above the mounting plate that are present during the experiment. Those pieces include the bolts that attach the mounting plate to the legs of the assembly machine, the attachment bolts that go through the mounting plate up into the clamp supports, the upper shaft for the safety-block subassembly, the lift rods and inserts for the control rods, and the burst rod extension shaft. Table 3 contains the numbers of the drawings from which the dimensions for specific components of the restraint system are taken.

Table 3. Drawing Numbers for Support Structure.

Component	Drawing Number
Mounting plate	128Y1719410
Bolts for legs of assembly machine Attachment bolts	— —
Upper shaft for safety-block subassembly	128Y1719448
Inserts for lift rods	128Y1719466
Lift rods for control rods	128Y1719465 128Y1719467
Extension shaft for burst rod	128Y1719468

The mechanical and electrical apparatus for the Godiva-IV assembly is located below the mounting plate. In addition, a contamination shield is attached to the bottom of the mounting plate and encloses the large central hole and several of the surrounding holes in the mounting plate. (The contamination shield will be described in Section 1.2.5.)

The other structural support pieces below the mounting plate are made from the same material as the mounting plate. It will be shown in Section 2 that the fraction of neutrons reflected back into the core from the mounting plate is quite small and that the fraction reflected back into the core from the contamination shield is nearly negligible. Furthermore, the structural support pieces below the mounting plate are much smaller than the contamination shield and are considerably farther from the core. Consequently, those structural support pieces do not affect the behavior of the core, and therefore none of them will be described.

Mounting Plate - The mounting plate is essentially a triangle with its tips cut off and holes drilled in it. Because the tips are cut off, it has six sides, three long ones and three short ones. In addition, it has many holes, most of which pass completely through it. The shape of the mounting plate can be seen in Figure 3, and a closer view of a portion of it is shown in Figure 23.

Figure 23. Mounting Plate with Control Rods, Burst Rod, and Safety-Block Subassembly.

The mounting plate is 1 ½ inches thick, and the distance between the centers of its parallel long and short sides is 27 ½ inches. As can be seen from Figure 23, one of its short edges is parallel to a line between the centers of the two control rods. (And therefore, because each set of short and long edges are parallel to each other, one of its long edges also is parallel to that line.) The lengths of the sides are not stated explicitly, but clipping off each tip shortened the long sides by 2 ½ inches. These dimensions, in conjunction with those given below, imply that the length of the short sides is 2.88675 inches and the length of the long sides is 29.11129 inches.

The mounting plate has a central hole through which the safety-block subassembly passes. That hole is equidistant from the centers of the long sides and also equidistant from the centers of the short sides. Its diameter is 4 ⅛ inches, and the distance from its center to the center of the short sides is 17 ½ inches. The distance to the centers of the long sides is not given. However, it easily can be inferred to be 10 inches, because the distance between the centers of the parallel long and short sides is given as 27 ½ inches.

There are three holes in the mounting plate for attaching the legs that support it. Those holes pass completely through the mounting plate. The holes are located symmetrically, with their centers on lines that pass from the central hole to the centers of the short sides. The centers of those holes are 2 ½ inches from the centers of the short sides of the plates. The diameters of the holes vary with their depth. For the uppermost ¾ of an inch, the diameter of the holes is 3 1/32 inches. From there downward, the diameter of the holes is 1 1/32 inches.

There also are three holes to accommodate the passage of the control rods and the burst rod. These holes are located along the same three lines as those for attaching the legs, but they are smaller and much closer to the central hole. They have diameters of 1.000 inch, and the half-distance between the centers of those holes is 2.273 ± 0.002 inches.

There are six holes that allow the clamp supports to be bolted to the mounting plate. These holes pass completely through the mounting plate. They are arranged in sets of two and are located on each of three lines from the center of the central hole to the center of the long sides. The diameter of each of these holes is 33/64 of an inch. For each pair, the center of the inner hole is 5.470 ± 0.005 inches from the center of the central hole, and the center of the outer hole is 1.500 ± 0.005 inches from the center of the inner hole.

In addition, there are four holes that are arranged as corners of a rectangle with the central hole in its center. The two shorter sides of the rectangle are parallel to one of the long and one of the short sides. The shorter distance between the centers of two of the holes is 8 ½ inches, and the longer distance is 10 ½ inches. These holes are open at the top of the mounting plate and are 1 1/16 inches deep. Their diameter is ⅝ of an inch.

Figures 14 and 23 show that there are three additional holes in the mounting plate that are approximately the same size as the holes for the control and burst rods. In fact, these holes are slightly larger and slightly farther away from the center hole than are the control-rod and burst-rod holes. Their diameters are 1.0273 inches, and their centers are 2.822 inches from the center of the central hole.[a] The centers of those holes fall on lines that go directly from the center of the central hole to the center of the long sides of the mounting plate.

Bolts - Drawing 128Y1719386 shows that the bolts for the legs of the assembly machine passed through the mounting plate and into those legs. The heads of those bolts screwed into the bottom of the mounting plate and appear to be hexagonal with a smaller, possibly circular, top. However, no drawings have been found that provide any dimensions for these bolts.

Figure 1 shows the tips of the attachment bolts that hold the clamp supports in place. A wider view of that same schematic shows the attachment bolts passing through the mounting plate as well as another small piece immediately below it, with the heads of the bolts underneath that second piece. However, no dimensions for the bolts or for that second piece have been found.

Upper Shaft for Safety-Block Subassembly - The upper shaft for the safety-block subassembly screwed into the central hole in the bottom of the base for the safety block. The shaft is essentially

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[a] Personal communication from Robert D. Garrett of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, April 9, 2007.

a long, narrow cylinder with a coupling at the bottom. The whole shaft is 18 ⅞ inches long, but the coupling accounts for only the bottom 1⅞ inches. Therefore, the coupling was well below the bottom of the mounting plate. The cylinder has a diameter of ⅞ of an inch, and its top 1 inch is threaded.

Inserts for Lift Rods - The control rods are driven by lift rods, which are coupled to them by the lift-rod inserts. The lift-rod inserts are simply threaded cylinders. The inserts have a diameter of 0.375 inch and are 1.50 inches long. The uppermost 0.75 inch of the insert protruded from the lift rod, and the uppermost 0.50 inch is threaded. The threaded region screwed into the bottom of the control rod.

Lift Rods for Control Rods - The lift rods are simply long, hollow cylinders. They are 59.00 inches long and have an outer diameter of 0.50 inch. Separate drawings are provided for the two lift rods, but they differ only in the specification for the inner diameter of the rod. The drawing for the lift rod for control rod 1 simply says that it should satisfy "press fit requirements" for the insert, while the drawing for the lift rod for control rod 2 gives a wall thickness of 0.063 inches. In fact, the two specifications are consistent. The outer diameter of the lift rods is 0.50 inch, and the outer diameter of the inserts is 0.375 inch. That leaves 0.125 as twice the thickness of the wall, and, with round-off, half of that number is 0.063.

Extension Shaft for Burst Rod - The extension shaft for the burst rod screwed directly into the bottom of the burst rod. The extension shaft is a solid cylinder that is 22.75 inches long and has a diameter of 0.50 inch. The top 0.50 inch of the shaft is threaded and has a maximum diameter of only 0.375 inch so that it can be screwed into the burst rod. The bottom 1 inch of the shaft also is threaded. In addition, there is a horizontal hole that passes completely through the shaft. The diameter of the hole is 0.2500 inch, and its center is 0.63 inch above the bottom end of the shaft.

1.2.5 Enclosures - In the later years of operation of Godiva-IV, enclosures were introduced to confine any particles that might be ejected from the core. There were two such enclosures, an aluminum core cover (also known as the "hood" or the "top hat") and a contamination shield subassembly (also known as the "enclosure"). Both enclosures were present for the five experiments studied in this evaluation. Bushings and guides were inserted in some of the holes in the bottom of the contamination shield to better align the magnetic drive and the support shaft of the safety-block subassembly, the lift rods for the control rods, and the extension shaft for the burst rod as they passed through it.

The core cover enclosed all of the core and restraint components of the Godiva-IV assembly that were above the top of the mounting plate. The contamination shield was attached to the bottom of the mounting plate. Figure 24 shows the core cover on top of the mounting plate, and Figure 25 shows the contamination shield below the mounting plate. Table 4 presents the numbers of the drawings from which the dimensions for the core cover and the contamination shield are taken.

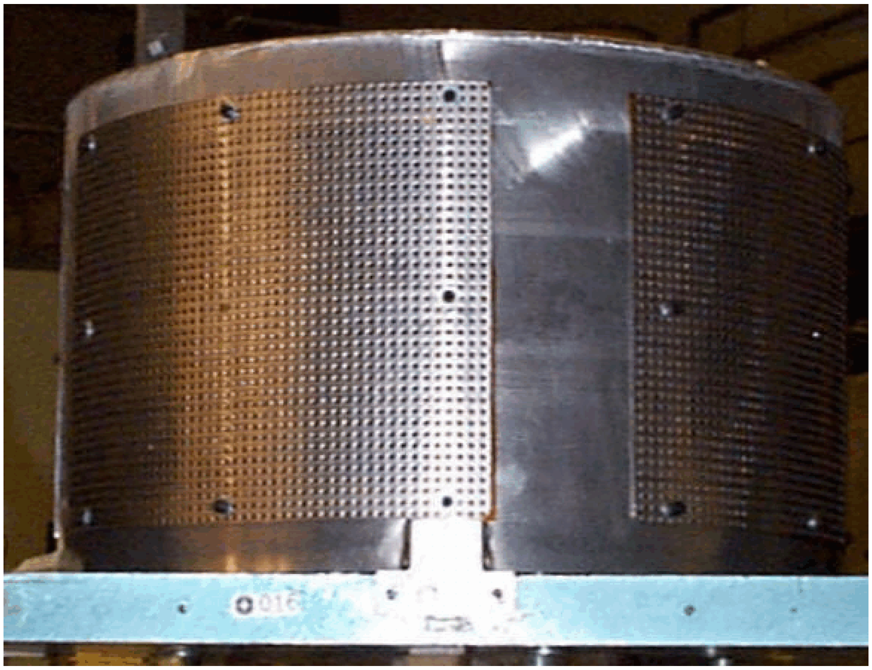

Figure 24. Core Cover on Top of the Mounting Plate.

Figure 25. Contamination Shield beneath the Mounting Plate.

Table 4. Drawing Numbers for Enclosures.

Component	Drawing Number(s)
Core cover	128Y1719409
Contamination Shield	128Y1719387 128Y1719411 128Y1719836[a] 128Y1719837[a] 128Y1719838[a] 128Y1719839[a] 128Y1719840[a] 128Y1719876[a] 128Y1719877[a] 128Y1719878[a]
Bushings	128Y1719413 128Y1719456
Guides	128Y1719414

[a] The drawings for these parts are for a replacement shield that was not used but whose design is believed to be very similar to the original one.

Core Cover - The core cover is essentially an annular cylinder with a flat, closed top. The hollow portion of the cylinder has an inner diameter of 19.87 inches and an outer diameter of 20.00 inches. The hollow portion of the core cover is 17.00 inches high, and the lid of the cover is 0.125 inch thick. The exact diameter of the lid is not given, but the drawing shows it to be very slightly less than the outer diameter of the hollow portion of the cover.

Three plates, in the shape of an inverted “T,” were attached to the bottom edge of the hollow portion of the core cover. The inverted -T plates can be seen at the bottom middle of Figure 24. Although the wide part of the “T” contains screw holes, screws were not inserted into them.

The outer diameter of the core cover is the same as the distance from the center of the central hole in the mounting plate to the centers of its long edges, and the plates are attached to the core cover at the three points where its outer edge is in contact with the edges of the mounting plate. The upper edge of the wider bottom portion of each inverted-T plate is aligned with the bottom of the core cover, and so the bottom portion of each plate hangs over the edge of the mounting plate. Each plate is nominally ⅛ inch thick and has a total height of 3.00 inches. The narrow upper portion is 1.00 inch wide, and the wide bottom portion is 3.000 inches wide and 1.00 inch high. The bottom portion of each plate has 4 holes that pass completely through it. The vertical centers of all four holes are 0.500 above the bottom edge of the plate, and the holes have diameters of 0.28 inch. The horizontal centers of the two inner holes are 0.375 inch from the horizontal center of the plate, and the horizontal centers of the two outer holes are 1.125 inches from it.

Figure 24 shows that one or more screens have been screwed onto the external surface of the core cover. The addition of those screens occurred subsequent to the initial specifications for the core cover. They are not shown in any drawings, and no documented information about them has been found. However, the experimenter who was in charge of Godiva-IV in the late 1990s recalls that pieces (probably three separate pieces) were cut from the side of the core cover and replaced with steel mesh. His best recollection is that they were approximately 0.030 inch thick and that the open holes comprised approximately 60% of the surface of the mesh.[a]

Contamination Shield - The contamination shield is essentially an open rectangular box without a top. It was formed by four plastic side plates, four plastic bottom plates, and a steel bottom plate. The bottom plastic plates fitted inside the four side plates, effectively forming a ledge at their bottom edges. The steel plate was held in place inside that ledge by screws that passed through the holes in the plastic side and bottom plates into the steel plate. There was a small gap, believed to be no more than 0.25 inch, between the top edge of the box and the bottom of the mounting plate.[b]

The drawings for the plastic parts of the original contamination shield could not be found. The drawings listed in Table 4 for those parts (drawings 128Y1719836 through 128Y1719840 and 128Y1719876 through 128Y1719878) are for a replacement shield that was not used but whose design is believed to be very similar to the original one.

The left and right side plates of the contamination shield are identical. They are 17.000 inches wide, 8.75 inches high, and 0.50 inch thick. They are solid except for three holes near the bottom of each plate that pass completely through it. The holes have diameters of 0.281 inch, and their vertical centers are 0.38 inch above the bottom edge of the plate. The horizontal center of the middle hole is at the middle of the plate, and the centers of the other two holes are 5.00 inches to either side of it.

The front side plate is very similar to the left and right side plates but not as wide. It is 14.00 inches wide, 8.75 inches high, and 0.50 inch thick. It also has three holes near its bottom edge, with diameters of 0.281 inch. The vertical centers of the holes are 0.38 inch above that bottom edge. The horizontal center of the middle hole is at the middle of the plate, and the centers of the other two holes are 4.00 inches to either side of it.

The back side plate also is 14.00 inches wide, 8.75 inches high, and 0.50 inch thick. However, it has a notch cut from its bottom edge and two holes near that bottom edge. The vertical centers of

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[a] Personal communication from Kenneth B. Butterfield of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, May 17, 2007.

[b] Personal communication from Charlene Cappiello of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, May 15, 2007.

those two holes are not specified, but they have diameters of 0.281 inch and appear to be at the same height as the holes in the other sides. Their horizontal centers are 3.00 inches from the nearest side edge of the plate. The notch is 4.75 inches wide and 1.00 inch high. It is located slightly off-center, with its left edge 5.75 inches from the left edge of the plate.

The left and right bottom plates of the contamination shield are identical. They are 16.00 inches wide, 0.75 inch high, and 1.00 inch thick. They are solid except for three holes that pass completely through each plate. The holes have diameters of 0.281 inch, and their vertical centers are 0.38 inch above the bottom edge of the plate. The horizontal center of the middle hole is at the middle of the plate, and the centers of the other two holes are 5.00 inches to either side of it.

The front bottom plate is very similar to the left and right bottom plates but not as wide. It is 12.00 inches wide, 0.75 inches high, and 1.00 inch thick. It also has three holes that pass completely through it, with diameters of 0.281 inch. The vertical centers of the holes are 0.38 inch above that bottom edge. The horizontal center of the middle hole is at the middle of the plate, and the centers of the other two holes are 4.00 inches to either side of it.

The back bottom plate also is 12.00 inches wide, but it is 3.00 inches high, and its thickness varies with its height. It has a notch cut from its bottom edge and two holes near that bottom edge. The vertical centers of those two holes are 0.38 inch above the bottom edge of the plate, and they have diameters of 0.281 inch. Their horizontal centers are 2.00 inches from the nearest side edge of the plate. The notch is 4.75 inches wide and 1.00 inch high. It is located slightly off-center, with its left edge 4.75 inches from the left edge of the plate. The front side of the plate is 1.50 inches thick except for the first 0.75 inch from the bottom edge. The precise thickness for that first 0.75 inch is not stated but appears to be 1.00 inch, which would allow it to fit together with the other bottom plates.

The steel bottom plate is 14 inches wide, 12 inches deep, and ¾ of an inch thick. Its corners are clipped at a 45° angle starting 1 inch from what would otherwise be a 90° corner. It has a total of 37 holes that pass completely or partially through it.

The left, right and front edges of the steel bottom plate each have three threaded, horizontal screw holes with a diameter of 0.250 inch that are drilled to a minimum depth of 0.62 inch. The vertical center of the holes is ⅜ of an inch from the bottom of the plate. The horizontal center of each middle hole is at the center of the relevant edge, and the two end holes are 2 inches from the side nearest the edge (i.e., 2 inches from what would have been a 90° corner if the corners hadn't been clipped). The back has no center hole, but its two end holes correspond exactly to those in the front edge.

As can be seen in Figure 25, the contamination shield is attached to the bottom of the mounting plate by four legs. The holes for those legs have a diameter of ⅝ of an inch and pass completely through the steel plate. The holes are located symmetrically and are equidistant from the horizontal center of the steel plate. The distances between the centers of the adjacent holes are 8½ inches on the left and right sides and 10½ inches on the front and back sides.

There are five holes in the steel plate to allow passage of the support shaft for the safety-block subassembly, the magnetic drive for the safety-block subassembly, the lift rods for the control rods, and the extension shaft for the burst rod. The hole for the support shaft for the safety-block subassembly is at the exact center of the steel plate and has a diameter of 1.125 inches. The hole for the magnetic drive is located on a line from the center of the center hole and the center of the left edge. Its diameter is 1.750 inches, but distance from the center of the center hole to its center is listed as both 4.755 inches and 4.745 inches. The holes for the control-rod lift rods and the burst-rod extension shaft all have diameters of 1.000 inch. The distance between the center of the center hole and the center of each of these holes is 2.625 ± 0.002 inches. One of these holes is located on a line between the center of the center hole and the center of the right edge of the plate, and the other two are rotated 120° from it, clockwise and counterclockwise about the center hole.

There are also four identical holes located symmetrically about the central hole, on a line from the center of the central hole to the center of each edge. These holes pass completely through the steel plate and have a diameter of 17/32 of an inch. Their centers are 3½ inches from the center of the central hole.

The remaining holes are much smaller, with diameters of ¼ or 10/32 of an inch. Some of them pass completely through the steel plate, while others do not.

Bushings - The bushing for the magnetic drive for the safety-block subassembly is a hollow cylinder with a wide lip. The lip is ¼ of an inch high and has an outer diameter of 3¼ inches. The total height of the cylinder, including the lip, is 2 inches. The inner diameter of the cylinder is 1¼ inches, and the outer diameter of the portion of the cylinder below the lip is 1 23/32 inches. Three holes pass through the lip in symmetric locations. The diameter of each hole is 9/32 of an inch, and the center of each of the holes is 1¼ inches from the center of the center hole. The bushing was placed with its lip above the top surface of the steel bottom plate, so that much of the lower portion of the bushing hung below the bottom surface of the plate.

In contrast, the bushing for the support shaft for the safety-block subassembly has a lip that is part-way between the top and the bottom of the bushing. The diameter of its central hole is 0.875 inch, but its outer diameter varies with height. The bottom ¼ inch of the bushing fits inside the hole in the bottom steel plate and has an outer diameter that is listed as both 1.105 and 1.095 inches. The lip extends from ¼ of an inch above the bottom of the bushing to ½ of an inch above it (i.e., the lip is ¼ of an inch thick), and its outer diameter is 2¼ inches. The lip of the bushing was placed directly on top of the top surface of the steel plate. Above the lip the bushing has an outer diameter of 1¼ inches. The full height of the bushing is 2 inches. Three symmetric holes with diameters of 9/32 of an inch pass completely through the lip. The centers of those holes are ⅞ of an inch from the center of the central hole.

Guides - The guides for the control-rod lift rods and the burst-rod extension shaft are essentially flat cylinders with three holes in them. They sat on top of the top surface of the bottom steel plate of the contamination shield. The guides are 0.250 inch high, with an inner diameter of 0.563 inch and an outer diameter of 2.00 inches. There are two other holes, placed diametrically opposite each other, that pass completely through the guides. The diameter of those holes is 0.188 inch, and the distance between their centers is 1.500 inches.

1.2.6 Critical Configurations and Prompt Burst - The control-rod and burst-rod positions recorded for the four delayed-critical conditions and for a 68 °C prompt burst on April 11, 2003, are given in Table 5. No uncertainties were given for these positions. The positions reported for the control rods are the distances withdrawn relative to full insertion. For the delayed-critical conditions, the positions of the control rods were adjusted until an effectively infinite period was observed. The configurations were assembled in the sequence shown in the table, starting in the morning and continuing into the afternoon. The ambient temperature rose slightly from one configuration to the next due to the heating of the day.

Table 5. Control-Rod and Burst-Rod Positions for Specific Conditions.

Case	Condition	Ambient Temperature (°C)	Control Rod Positions (inches withdrawn)		Burst Rod Position
			Control Rod 1	Control Rod 2	
1	Delayed critical	18.9	4.001	0.449	Fully inserted
2	Delayed critical	19.0	1.998	1.666	Fully inserted
3	Delayed critical	19.1	0.493	3.794	Fully inserted
4	Delayed critical	19.2	0.469	0.447	Fully withdrawn
5	Super-prompt-critical	20.5	0.319	0.656	Fully inserted

Table 6 provides specific information about the positions of the control and burst rods when they were fully inserted or fully withdrawn, taken from the Godiva Fuel Disassembly Data Sheet. These numbers imply that the burst-rod pin extended 1.027 inches above the top of the burst rod and that the stroke of the burst rod was 2.970 inches. The Data Sheet also states that the average time of travel for the burst rod is 91 ms, which corresponds to an average insertion speed of 32.6 inches per second. No uncertainty was given for any of these measurements.

Table 6. Fully Inserted and Withdrawn Positions of Control Rods and Burst Rod.

Item	Distance from Mounting Plate to Top of Item	
	Fully Inserted	Fully Withdrawn
Control Rod 1	7.712 in	3.703 in
Control Rod 2	7.239 in	3.512 in
Burst Rod	7.272 in	4.302 in
Burst-Rod Pin	8.299 in	5.329 in

The prompt burst produced a temperature rise of 68.4 °C. An initial period of 30.8 µs and a full width of the signal at half-maximum of 101.5 µs were reported in the logbook. A contemporaneous solution of the Inhour equation using data based on the original (spherical) Godiva configuration indicated that such a period corresponds to 103.86¢ of excess reactivity. A value for β_{eff} was not given, because β_{eff} does not appear by itself in the Inhour equation. Instead, the parameter that appears is the prompt neutron lifetime divided by β_{eff}. The value used for that ratio was reported as 1.19×10^{-6} sec.[a]

A snapshot of the detector responses for that particular burst is shown in Figure 26. In contrast to the value reported in the logbook, the detector indicates that the initial period of the burst is 33.7831 µs.

[a] Personal communication from Joetta M. Goda of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, October 4, 2006.

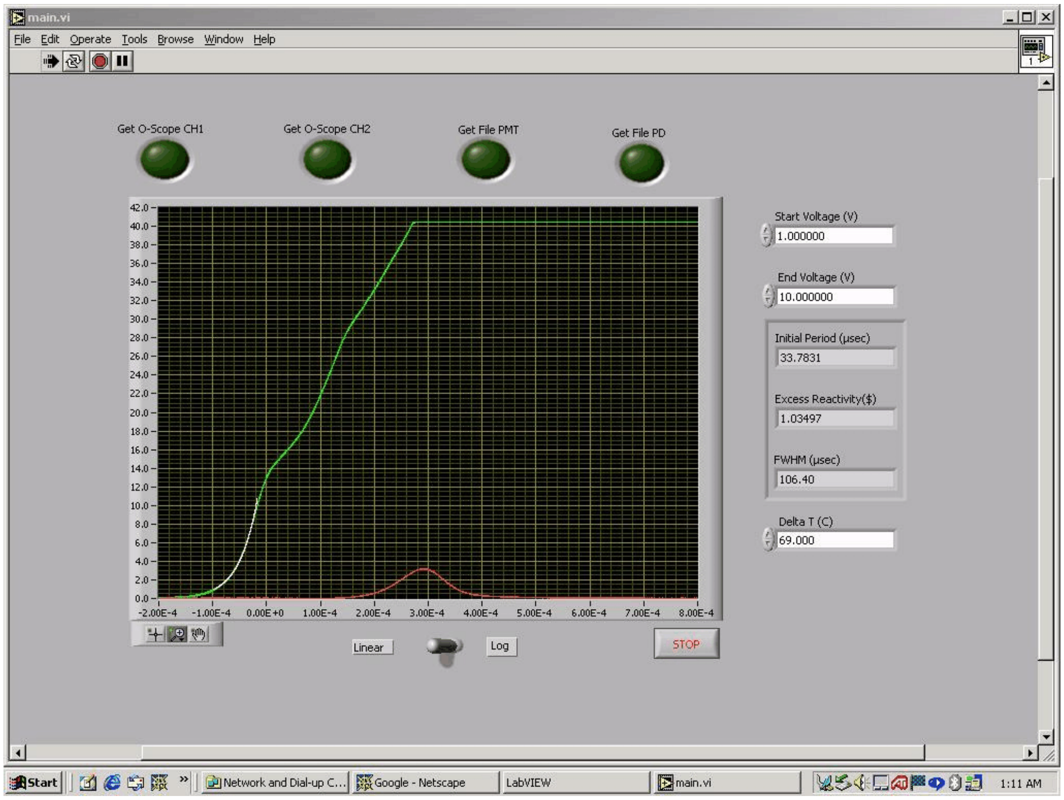

Figure 26. Detector Responses to a 68.4° C Prompt Burst on April 11, 2003.

The behavior of the neutron leakage population is shown clearly in the response from the photodiode, in red. The green line in Figure 26 is the response from the photomultiplier tube to the neutron leakage population. Fitting the beginning of the curve yields the rise time (initial period). The portion of that curve that was used to determine the initial period is shown in white. Apparently, a different portion of the curve was used for fitting at the time of the experiment, since the initial period reported in Figure 26 is different from that reported in the logbook. The initial bump in the curve is where the dynodes of the photomultiplier tube start to saturate, after which point no useful information is available.

The zero point on the time scale in Figure 26 corresponds to the time at which the trigger module triggers the capture of data into the oscilloscope, based on the time at which the voltage and /or current from the photomultiplier tube reach a preset level. The level was adjustable, but it was rarely changed. Consequently, the zero point would occur at about the same time for similar sized bursts, but it bears no relationship to the time at which the Godiva-IV configuration was fully assembled.[a]

[a] Personal communication from Joetta M. Goda of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, May 18, 2007.

Figure 27 contains the same two curves but each plotted on its own axis. Consequently, the shape of the response from the photodiode can be seen in more detail.

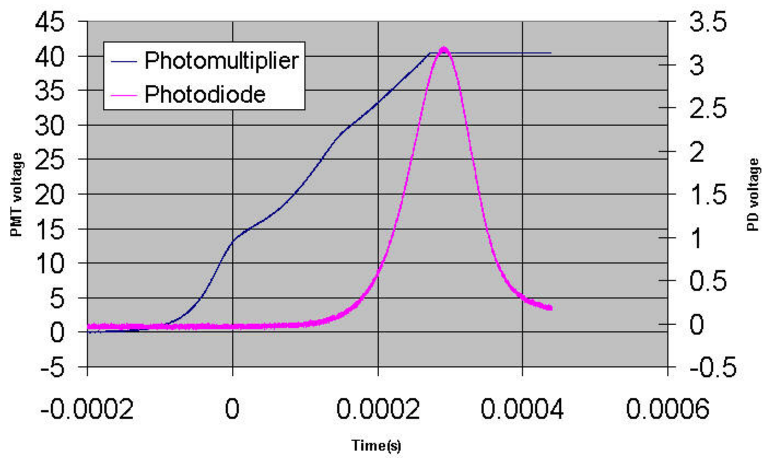

Figure 27. Detailed Response of Photodiode to a 68.4° K Prompt Burst on April 11, 2003.

1.3 <u>Description of Material Data</u>

The compositions of the various components of the Godiva-IV assembly are given on the drawings cited in Section 1.2. Masses and more detailed elemental or isotopic compositions have been obtained from other sources.

1.3.1 Core - The fuel rings, safety block, top and intermediate inner subassembly plates, and control and burst rods all were made from a compound of HEU and 1.5 ± 0.2 wt.% molybdenum.[a] All of these parts are aluminum-ion coated. The thickness of the coating was not reported, but it was known to be extremely thin. No information was found with regard to impurities in these pieces.

There are two sources of mass data for the fuel parts: the MASS database used for accountability of special nuclear materials (SNM) at LACEF, and the more recent mass measurements of the disks and rings after Godiva-IV was disassembled. The entries in the MASS database are intended to be accurate to within ± 1 g of SNM.[b] No uncertainty is reported for the measured results, but the fact that the measured values are reported to the nearest gram or tenth of a gram suggests that they

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[a] Purchase request from C. E. Cummings of LANL group N-2 to D. E. Beck and R. W. Presley of the Oak Ridge Y-12 plant, October 12, 1989.

[b] Personal communication from Roger W. Brewer of the Applied Science and Methods Development Group (X-1) at Los Alamos National Laboratory, May 13, 2008.

should be accurate to approximately that level. Furthermore, the differences between the measured results and the corresponding MASS values are small. Those masses are given in Table 7.

Table 7. Masses of Fuel Parts.

Fuel Part	Mass (g)	
	Measured	MASS
Ring 101		8378
Ring 102		8134
Ring 103		8046
Ring 104		6909
Ring 105		8166
Ring 106		9283
Upper inner subassembly plate	3502.7	3511
Intermediate inner subassembly plate	3258.2	3312
Safety block	7276.4	7288
Control rod 1 or 2	831.5	824
Control rod 1 or 2	834.1	824
Burst rod	850.4	826

Additional information about the fuel parts, taken from the MASS database, is given in Table 8. Uranium isotopic content, other than enrichment, was not reported.

Table 8. Uranium Content of Fuel Parts.

Fuel Part	Uranium Mass (g)	Enrichment (wt.%)
Ring 101	8254	93.17
Ring 102	8012	93.15
Ring 103	7926	93.08
Ring 104	6807	93.18
Ring 105	8044	93.18
Ring 106	9144	93.14
Upper inner subassembly plate	3458	93.15
Intermediate inner subassembly plate	3262	93.18
Safety block	7215	93.17
Control rod 1 or 2	813	93.16
Control rod 1 or 2	813	93.16
Burst rod	815	93.16

Furthermore, the ratios of ^{234}U to ^{235}U for five swipes taken from Godiva IV parts were determined in 2000 using an instrument identified as an Elan 6000 ICPMS.[a] Two analyses were performed for each swipe, and the average of the two ratios was reported to eight significant digits, even though the two ratios often differed in the third significant digit. One set of measurements was repeated using a slightly different dilution sequence. Those average results are presented in Table 9.

Table 9. Measured $^{234}U/^{235}U$ Atom Ratios.

Sample	$^{234}U/^{235}U$ Atom Ratios
1	0.011062133
2	0.010999371
3	0.010910976 0.010937201
4	0.010932185
5	0.011068982

[a] Informal summary of analysis performed by Kathy Lao of LANL group CST-9 on March 14, 2000.

It is not known from which part or parts the swipes were taken.

The spindle, the shim ring, and the safety-block base were made from stainless steel 303. No further information about their actual composition was found. However, representative compositions for stainless steel 303 can be obtained from a variety of sources, including MatWeb,[a] the *Metals Handbook*,[b] and the CRC *Handbook of Materials Science*.[c] The compositions given in those three sources are not entirely consistent but are generally quite close, as shown in Table 10. MatWeb gives the density of stainless steel 303 as 8 g/cm^3, without indicating a range or an uncertainty. Although neither of the other two sources provides a representative density for stainless steel 303, the *Handbook of Materials Science* gives a density of 0.29 lb$_m$/in^3 for both stainless steel 302 and stainless steel 304. That value corresponds to 8.0 g/cm^3.

Table 10. Compositions for Stainless Steel 303 (wt.%).

Element	Source		
	MatWeb	*Metals Handbook*	*Handbook of Mat. Sci.*
Carbon	0.15 (max)	0.15	0.15 (max)
Silicon	1	1.00	1.00 (max)
Phosphorus	0.2 (max)	0.2	0.20 (max)
Sulfur	0.15 (min)	0.15 (min)	0.15 (min)
Chromium	18	17 - 19	17.00 - 19.00
Manganese	2 (max)	2.00	2.00 (max)
Iron	69	Balance	Balance
Nickel	9	8 - 10	8.00 - 10.00
Zirconium			0.60 (max)
Molybdenum	0.6 (max)		0.60 (max)

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[a] Internet URL www.matweb.com.

[b] *Metals Handbook*, Tenth Ed., ASM International, Materials Park, Ohio (1990). See the table of compositions of standard stainless steels on page 843.

[c] Charles T. Lynch, Ed., Handbook of Materials Science, Vol. II: Metals, Composites, and Refractory Materials, CRC Press, Cleveland, Ohio (1975). See Table 1.1-3.

The alignment pins were to be made from "stainless, any type," and the composition for the burst-rod pin is simply stated as steel. The mass of the spindle was not measured directly, and masses are not reported for the alignment pins or the burst-rod pin.

1.3.2 Restraints - The restraints were made from various types of stainless steel. The clamps were made from a specific type of maraging steel, Vascomax 300. The bearing ring and the three support pads were made from stainless steel 4340. Although at least one informal description indicates that the belly band (which it calls a compression ring) was made from maraging steel, the drawing for the belly band states that it was made from stainless steel 303. The materials for the belly-band bolt and for the subassembly cover plate are identified merely as steel. Although the drawing for the clamp supports says they were made from aluminum, in fact they were made from steel as well.[a]

MatWeb specifies the composition of VascoMax 300, as well as its density (8 g/cm^3). The *Metals Handbook*[b] gives a composition for standard grades of commercial maraging steels, including the category in which VascoMax 300 would appear, 18Ni(300). The two specifications, shown in Table 11, are generally consistent, although the MatWeb information is more detailed.

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[a] Personal communication from Charlene Cappiello of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, April 9, 2007.

[b] *Metals Handbook*, Tenth Ed., ASM International, Materials Park, Ohio (1990). See the table of nominal compositions of commercial maraging steels on page 793.

Table 11. Compositions for Maraging Steels (wt.%).

Element	VascoMax	18Ni(300)
Carbon	0.02	
Aluminum	0.1	0.1
Silicon	0.05	
Phosphorus	0.005	
Sulfur	0.005	
Titanium	0.73	0.7
Manganese	0.05	
Iron	67	Balance
Cobalt	8.8	9.0
Nickel	18.5	18
Molybdenum	4.8	5.0

The *Handbook of Materials Science*,[a] the *Metals Handbook Desk Edition*,[b] the *ASM Metals Reference Book*,[c] and Matweb all provide compositions for SAE 4340. As shown in Table 12, the information they provide is generally consistent. MatWeb is the only source that gives a density for SAE 4340. Its value, 7.85 g/cm^3, is quite close to that given by the *Handbook of Materials Science* for a closely related steel, SAE 434. The latter value is 0.28 lb_m/in^3, which corresponds to 7.8 g/cm^3.

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[a] Charles T. Lynch, Ed., *Handbook of Materials Science*, Vol. II: Metals, Composites, and Refractory Materials, CRC Press, Cleveland, Ohio (1975). See Table 1.1-1.

[b] Howard E. Boyer and Timothy L. Gall, Eds., *Metals Handbook, Desk Edition*, American Society for Materials, Materials Park, Ohio (1985). See Table 19 on page 4-10.

[c] *ASM Metals Reference Book*, Second Ed., American Society for Metals, Metals Park, Ohio (1983). See the table of composition ranges and limits for AISI-SAE standard alloy steels — bars, billets, blooms, and slabs on page 187.

Table 12. Compositions for SAE 4340 (wt.%).

Element	Source			
	MatWeb	*Metals Handbook Desk Edition*	*ASM Metals Reference Book*	*Handbook of Mat. Sci.*
Carbon	0.37 - 0.43	0.37 - 0.44	0.38 - 0.43	0.38 - 0.43
Silicon	0.23	0.15 - 0.30	0.15 - 0.30	0.20 - 0.35
Phosphorus	0.035 (max)		0.035 (max)	0.035 (max)
Sulfur	0.04 (max)		0.040 (max)	0.04 (max)
Chromium	0.7 - 0.9	0.65 - 0.95	0.70 - 0.90	0.70 - 0.90
Manganese	0.7	0.55 - 0.90	0.65 - 0.85	0.60 - 0.80
Iron	96	Balance	Balance	Balance
Nickel	1.83	1.55 - 2.00	1.65 - 2.00	1.65 - 2.00
Molybdenum	0.2 - 0.3	0.20 - 0.30	0.20 - 0.30	
Other				0.20

1.3.3 Structural Support - The drawing for the mounting plate states that it is made of Al 6061-T6, and the drawing for the safety-block subassembly says that it is made from SAE 4340. No specific information about the composition or density of those parts has been found. Generic information about the composition and density of SAE 4340 was provided in Table 12.

Al 6061 actually is a category rather than a specification. The mounting table probably was made from Al 6061-T6, which was used for a great many structural pieces at LACEF. MatWeb gives a composition specifically for Al 6061-T6, and the *Nuclear Engineering Handbook*[a] provides a generic composition for the Al 6061 category. Those specifications, which only differ slightly in the chromium and aluminum content, are shown in Table 13.

[a] Howard Etherington, Ed., *Nuclear Engineering Handbook*, McGraw-Hill Book Company, 1958. See page 10-47.

Table 13. Compositions for Al 6061 and Al 6061-T6 (wt.%).

Element	Al 6061	Al 6061-T6
Magnesium	0.80 - 1.20	0.8 - 1.2
Aluminum	Balance	95.8 - 98.6
Silicon	0.40 - 0.80	0.4 - 0.8
Titanium	0.15 (max)	0.15 (max)
Chromium	0.15 - 0.35	0.04 - 0.35
Manganese	0.15 (max)	0.15 (max)
Iron	0.70 (max)	0.7 (max)
Copper	0.15 - 0.40	0.15 - 0.4
Zinc	0.25 (max)	0.25 (max)
Others	0.15 (max)	0.15 (max)

MatWeb gives the density of Al 6061-T6 as 2.7 g/cm^3, while the *Nuclear Engineering Handbook* gives the densities of all of the types of Al 6061, including Al 6061-T6, as 2.70 g/cm^3.

The drawings for the lift rods for the control rods, the inserts for the burst rods, and the extension shaft simply say that they were to be made from an aluminum alloy. No further information about their composition is given, and no mass measurements for them have been found.

No specific information has been found about the attachment bolts or the bolts for the legs has been found, not even the material(s) from which they were made.

1.3.4 Enclosures - The drawing for the core cover states that it is made of Al 6061-T6. The composition of Al 6061-T6 was given previously in Table 13.

The plastic portion of the contamination shield was made from Lexguard, a bullet-resistant form of Lexan. Lexguard has a specific gravity of 1.2 and is 75.58% carbon, 5.55% hydrogen, and 18.87% oxygen.[a]

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[a] Personal communication from Charlene Cappiello of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, May 15, 2007.

The steel plate for the contamination shield was made from C-1019 steel. MatWeb provides the composition given in Table 14 for AISI 1019 carbon steel, which presumably is the same as C-1019, and gives its density as 7.87 g/cm^3. The second edition of the *Metals Handbook Desk Edition*[a] gives exactly the same composition as MatWeb, while the *Handbook of Materials Science*[b] and the *ASM Metals Reference Book*[c] specify compositions that differ only in the lower limit for carbon.

Table 14. Composition for AISI 1019 Carbon Steel (wt.%).

Element	Source			
	MatWeb	*Metals Handbook Desk Edition*	*Handbook of Mat. Sci.*	*ASM Metals Reference Book*
Carbon	0.14 - 0.2	0.14 - 0.20	0.15 - 0.20	0.15 - 0.20
Phosphorus	0.04 (max)	0.04 (max)	0.040 (max)	0.040 (max)
Sulfur	0.05 (max)	0.05 (max)	0.050 (max)	0.050 (max)
Manganese	0.7 - 1.0	0.70 - 1.00	0.70 - 1.00	0.70 - 1.00
Iron	98.71 - 99.16	balance	balance	balance

1.4 Supplemental Experimental Measurements

As mentioned previously in Section 1.2.6, the prompt-burst configuration described there produced a temperature rise of 68.4 °C. The temperature increase was measured using the thermocouple inside the thermocouple hole in the safety block.

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[a] J. R. Davis, Ed., *Metals Handbook, Desk Edition*, 2nd ed., American Society for Materials, Materials Park, Ohio (1998). See page 208.

[b] Charles T. Lynch, Ed., *Handbook of Materials Science*, Vol. II: Metals, Composites, and Refractory Materials, CRC Press, Cleveland, Ohio (1975). See Table 1.1-1.

[c] *ASM Metals Reference Book*, Second Ed., American Society for Metals, Metals Park, Ohio (1983). See the table of composition ranges and limits for AISI-SAE standard alloy steels — bars, billets, blooms, and slabs on page 185.

2.0 EVALUATION OF EXPERIMENTAL DATA

Sensitivity studies were performed to determine the impact on k_{eff} of various uncertainties in the reported experimental data, and the results from those studies are reported in this section. The studies focused on the uncertainties in the material masses and compositions, fuel enrichment, geometry, and periods. Uncertainties associated with model simplifications are discussed in Section 3.

Based on the results presented below, the total experimental uncertainty is judged to be sufficiently small that the four delayed-critical experiments and the initial static condition of the super-prompt-critical burst experiment are acceptable for use as benchmarks.

The sensitivity studies employed detailed three-dimensional models that are described in Appendix B. The calculations were performed with the MCNP5 Monte Carlo code[a] and continuous-energy cross sections based on the final release of ENDF/B-VI. Each calculation employed 550 generations with 10,000 histories per generation. The first 50 generations were excluded from the statistics for each case, producing 5,000,000 active histories in each calculation. Calculated differences between results from any two of these calculations always produce an associated standard deviation of ± 0.0004 Δk. Consequently, calculated differences smaller in magnitude than 0.0004 Δk will be reported as negligible.

The five experiments are sufficiently similar that the uncertainties should not differ significantly from case to case, except for those associated with the position of the burst rod. Case 2 was chosen as the most representative case, since both control rods were inserted a substantial distance into the core and the burst rod was fully inserted. Unless otherwise noted, the results reported are for that case. Uncertainties associated with the burst rod when it was fully withdrawn were obtained from case 4.

In order to reduce the number of sensitivity calculations required to determine uncertainties, a series of calculations first was performed in which each non-fuel component was replaced by void. The results from those calculations are presented in Table 15 for components inside the core and in Table 16 for components outside it.

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[a] X-5 Monte Carlo Team, "MCNP — A General Monte Carlo N-Particle Transport Code, Version 5, Volume I: Overview and Theory," Los Alamos National Laboratory report LA-UR-03-1987 (April 2003).

Table 15. Reactivity Worth of Non-Fuel Core Components.

Component	Reactivity Worth (Δk)
Safety Block Base	0.0067 ± 0.0004
Spindle	0.0033 ± 0.0004
Burst Rod Pin (Burst Rod In)	0.0007 ± 0.0004
Alignment Pin	0.0004 ± 0.0004
Burst Rod Pin (Burst Rod Out)	Negligible
Glory Hole	Negligible

Table 16. Reactivity Worth of Restraints, Support Structure, and Enclosures.

Component	Reactivity Worth (Δk)
Clamps (3)	0.0097 ± 0.0004
Bearing Ring	0.0041 ± 0.0004
Support Pads (3)	0.0031 ± 0.0004
Mounting Plate	0.0027 ± 0.0004
Subassembly Cover Plate	0.0021 ± 0.0004
Clamp Supports (3)	0.0016 ± 0.0004
Spindle Nut	0.0010 ± 0.0004
Belly Band	0.0008 ± 0.0004
Contamination Shield	0.0005 ± 0.0004
Core Cover	0.0004 ± 0.0004

The results in Table 15 clearly indicate that the glory hole can be ignored as a source of uncertainty, and so can the pin in the burst rod when the burst rod is withdrawn. (The worth of the glory hole was determined by filling it with the same type of steel as the spindle. In practical terms, the insignificance of that change indicates that the inner dimensions of the spindle can be ignored as a source of uncertainty.) Furthermore, the reactivity worth of the alignment pin and that of the pin in the burst rod when the burst rod is inserted are so small that they would have to change by 50% or more to produce a statistically significant change in reactivity. Consequently, the pin in the burst rod and the alignment pin also can be discarded as sources of uncertainties. The results in Table 16 indicate that, although none of those components has a negligible impact on k_{eff}, several of them can be discounted as sources of uncertainty. In particular, the reactivity worth of the clamp supports, the belly band, the core cover, the contamination shield, or the spindle nut would have to change by 20% or more in order to produce a reactivity change of ± 0.0004 Δk. Such a relatively large change due to the density, composition, or dimensions of those components is highly unlikely. Consequently, they will be discarded as sources of uncertainties.

2.1 Material Mass and Composition

Fuel Pieces - For those fuel pieces for which measured masses were available, the standard deviations for their masses are taken to be equal in magnitude to the differences between the measured masses and those in the MASS database (see Table 7). Because no measured masses are available for the fuel rings, the standard deviations in their masses are assumed to be proportionally the same as those in their densities. Based on the masses of the fuel rings given in the MASS database, their average density is calculated to be 18.3751 ± 0.0849 g/cm^3. The ratio of that standard deviation to the mean density is 0.462 %.

The reactivity differences reported in Table 17 are the calculated differences between cases with the MASS mass plus one standard deviation and the MASS mass minus one standard deviation. Therefore the standard deviation in reactivity associated with the uncertainty in the mass is the calculated difference divided by two. The standard deviation for the fuel rings also has been divided by the square root of one less than the number of rings because the masses of all of them were increased or decreased at the same time.

Table 17. Reactivity Uncertainties Related to the Masses of the Fuel Pieces.

Component	Mass Variation (%)	Δk	
		Difference	Std. Deviation
Fuel Rings	± 0.462	0.0043 ± 0.0004	± 0.0010
Upper Inner Subassembly Plate	± 0.236	negligible	negligible
Intermediate Inner Subassembly Plate	± 1.624	0.0028 ± 0.0004	± 0.0014
Safety Block	± 0.159	0.0007 ± 0.0004	± 0.0004
Burst Rod	± 2.954	negligible	negligible
Control Rods	± 1.068	negligible	negligible
Cumulative			± 0.0018

The uncertainty in the mass of the uranium within each fuel piece has to be the same as that of the molybdenum, since no other elements are present in significant quantities. The nominal molybdenum content of the fuel pieces is given as 1.5 wt.%, with a tolerance of ± 0.2 wt.%. Consequently, the nominal uranium content of the fuel pieces is 98.5 wt.%, also with a tolerance of ± 0.2 wt.%. The inferred molybdenum content of the individual fuel pieces is given in Table 18, based on the information in Table 8. All of the fuel pieces have molybdenum contents within the stated tolerance except the safety block.

Table 18. Composition of Fuel Pieces.

Piece	Mass (g)			Content (wt.%)	
	Total	U	Mo	U	Mo
Ring 1	8378	8254	124	98.520	1.480
Ring 2	8134	8012	122	98.500	1.500
Ring 3	8046	7926	120	98.509	1.491
Ring 4	6909	6807	102	98.524	1.476
Ring 5	8166	8044	122	98.506	1.494
Ring 6	9283	9144	139	98.503	1.497
Safety Block	7288	7215	73	98.998	1.002
Upper Inner Subassembly Plate	3511	3458	53	98.490	1.510
Intermediate Inner Subassembly Plate	3312	3262	50	98.490	1.510
Control Rod 1 or 2	824	813	11	98.665	1.335
Control Rod 1 or 2	824	813	11	98.665	1.335
Burst Rod	826	815	11	98.668	1.332

The fuel pieces fall into three distinct categories with respect to molybdenum content. The fuel rings and the two pieces of the subassembly plate are at or very close to the nominal molybdenum content of 1.5 wt.%. The control rods and the burst rod depart significantly from the nominal value but are still within the stated tolerance. In contrast, the molybdenum content of the safety block is well outside that tolerance. Accordingly, sensitivity studies were performed for each of the three categories.

Calculations were performed that varied the molybdenum content of each fuel ring, the upper inner subassembly plate, and the intermediate inner subassembly plate by ± 0.2 wt.%. The density and enrichment of each piece was preserved in these calculations. The results are presented in Table 19. The change in k_{eff} corresponds to a change of two standard deviations in the molybdenum content. Consequently, that change must be divided by two to produce the standard deviation.

Table 19. Reactivity Uncertainties Related to the Molybdenum Content of the Fuel Rings and the Subassembly Plate.

Part	Mo Variation (wt.%)	Δk	
		Difference	Std. Deviation
Ring 1	± 0.2	negligible	negligible
Ring 2	± 0.2	negligible	negligible
Ring 3	± 0.2	-0.0008 ± 0.0004	± 0.0004
Ring 4	± 0.2	0.0004 ± 0.0004	± 0.0002
Ring 5	± 0.2	negligible	negligible
Ring 6	± 0.2	negligible	negligible
Upper Inner Subassembly Plate	± 0.2	0.0007 ± 0.0004	± 0.0003
Intermediate Inner Subassembly Plate	± 0.2	-0.0010 ± 0.0004	± 0.0005
Cumulative			± 0.0007

All of the contributions are small. Not surprisingly, the pieces closest to the center of the assembly have higher importance than those near the top or bottom.

Separate calculations were performed for the two control rods and the burst rod that increased their molybdenum content to the nominal value of 1.5 wt.%, while preserving the mass and enrichment of the rods. This change increases the molybdenum content of each rod by approximately 1.2 grams. The case with the two control rods produced a negligible change in k_{eff}, but the case with the burst rod produced a marginally significant change in reactivity, -0.0005 ± 0.0004 Δk. Strictly speaking, this change should be associated with a one-sided uncertainty. However, for convenience and because its magnitude is small, it will be treated as a double-sided uncertainty.

Increasing the molybdenum content of the safety block to the nominal value of 1.5 wt.% would increase the mass of the molybdenum by more than 30 grams. Clearly, it is unlikely that an error of that size occurred during the measurement of the uranium mass. Nonetheless, a calculation was performed in which the molybdenum content of the safety block was increased to 1.5 wt.% while preserving its mass and enrichment. The resulting change in k_{eff} is only -0.0005 ± 0.0004 Δk. Given that the actual uncertainty in the molybdenum mass is probably much smaller than 0.5 wt.%, the contribution of the uncertainty in the molybdenum mass in the safety block to the uncertainty in the overall reactivity is be taken to be negligible.

Information available for the fuel pieces does not include details about impurities in those pieces. Realistically, however, in a spectrum as hard as that produced by the Godiva-IV assembly impurities would have to be present at physically unrealistic levels to produce a statistically significant change in k_{eff}.

Spindle, Safety Block Base, and Shim Ring - The spindle, the safety block base, and the shim ring all are made from stainless steel 303. The shim ring was calculated to have negligible reactivity worth, and therefore it is not considered further as a source of uncertainty.

None of the references cited in Section 1 provide an uncertainty for the density of stainless steel 303. MatWeb[a] gives the density of stainless steel 303 as 8 g/cm^3 without indicating a range or an uncertainty. Although it doesn't provide a density for stainless steel 303, the *Handbook of Materials Science*[b] gives a density of 0.29 lb_m/in^3 for both stainless steel 302 and stainless steel 304. That value corresponds to 8.0 g/cm^3. Accordingly, a standard deviation of ± 0.1 g/cc was assumed for the density of stainless steel 303. The reactivity differences reported in Table 20 are the calculated differences between cases with densities of 8.1 and 7.9 g/cc. The standard deviation in reactivity associated with the uncertainty in the mass is that calculated difference divided by two.

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[a] Internet URL www.matweb.com.

[b] Charles T. Lynch, Ed., Handbook of Materials Science, Vol. II: Metals, Composites, and Refractory Materials, CRC Press, Cleveland, Ohio (1975).

Table 20. Reactivity Uncertainties Related to the Density of Stainless Steel 303.

Component	Mass Variation (%)	Δk	
		Difference	Std. Deviation
Spindle	± 1.250	negligible	negligible
Safety Block Base	± 1.250	0.0005 ± 0.0004	± 0.0003
Cumulative			± 0.0003

The composition of the safety block base also was explored as a possible source for reactivity uncertainties. Table 10 in Section 1 provides a range of components for stainless steel 303, and compositions that maximize and minimize the amount of iron were constructed from that table. The calculated reactivity difference between cases that employed those two compositions was only 0.0006 ± 0.0004 Δk. Although those variations probably are larger than a standard deviation, the resulting standard deviation in reactivity of ± 0.0003 is retained.

The small differences obtained indicate that the uncertainty in the density and composition of stainless steel 303 are at most marginal contributors to the overall uncertainty in reactivity. Even if those differences were doubled, their contribution still would be marginal.

Support Pads, Bearing Ring, and Subassembly Cover Plate - The bearing ring and the three support pads were made from stainless steel 4340. In addition, although the material for the subassembly cover plate is identified merely as steel, it is reasonable to assume that it was made from stainless steel 4340 as well. MatWeb gives the density for SAE 4340 as 7.85g/cm^3, with no associated uncertainty. The *Handbook of Materials Science* does not give a density for stainless steel 4340, but it does gives a density of 0.28 lb_m/in^3 for a closely related steel, SAE 434. That value corresponds to 7.8 g/cm^3. In the absence of a referenced uncertainty, the standard deviation for the density of stainless steel 4340 is assumed to be ± 0.10 g/cc.

The reactivity differences reported in Table 21 are the calculated differences between cases with densities of 7.95 g/cm^3 and 7.75 g/cm^3 for the support pads, bearing ring, or subassembly cover plate. The reactivity change is negligible for the support pads and the bearing ring, and the change for the subassembly cover plate is marginal at most.

Table 21. Reactivity Uncertainties Related to the Density of SAE 4340.

Component	Mass Variation (%)	Δk	
		Difference	Std. Deviation
Support Pads (3)	± 1.274	negligible	negligible
Bearing Ring	± 1.274	negligible	negligible
Subassembly Cover Plate	± 1.274	0.0004 ± 0.0004	± 0.0002
Cumulative			± 0.0002

The composition of SAE 4340 also was investigated as a possible source for reactivity uncertainties. Table 12 in Section 1 provides a range of components for SAE 4340, and compositions that maximize and minimize the amount of iron were constructed from that table. Calculations then were performed that used SAE 4340 with the maximum and minimum amounts of iron for the support pads, the bearing ring, and the subassembly cover plate. The results from those calculations are presented in Table 22, with the implicit assumption that the change from the nominal composition to either the maximum or minimum amount of iron corresponds to a single standard deviation.

Table 22. Reactivity Uncertainties Related to the Composition of SAE 4340.

Component	Δk	
	Difference, Minium Fe to Maximum Fe	Standard Deviation
Support Pads (3)	negligible	negligible
Bearing Ring	-0.0004 ± 0.0004	± 0.0002
Subassembly Cover Plate	negligible	negligible
Cumulative		± 0.0002

Clamps - The clamps were made from VascoMax 300, for which MatWeb specifies a density of 8 g/cm^3. Unfortunately, it does not provide a corresponding uncertainty. Accordingly, a standard deviation of 0.1 g/cm^3 was assumed, a variation of 1.250%. Calculations were performed with VascoMax densities of 8.1 and 7.9 g/cm^3, and the resulting change in reactivity was only 0.0005 ± 0.0004 Δk, which corresponds to a standard deviation of ± 0.0003 Δk in k_{eff}.

Although MatWeb also provides a composition for VascoMax 300, it does not contain ranges for any of the components. Consequently, the differences from Table 11 between the MatWeb specification for VascoMax 300 and specifications from the *Metals Handbook*[a] for 18Ni(300) were assumed to correspond to a standard deviation. The specifications from the *Metals Handbook* produced a calculated increase in reactivity of 0.0005 ± 0.0004 Δk. Strictly speaking, this uncertainty is one-sided. However, for convenience and because its magnitude is small, it will be treated as a double-sided uncertainty. Consequently, the standard deviation in the reactivity uncertainty produced by the uncertainty in the composition of VascoMax 300 will be taken to be ± 0.0005 Δk.

Mounting Plate - The mounting plate is made from Al 6061-T6, and it is assumed that the nuts and bolts that attach it to the rest of the support structure for the Godiva-IV assembly are Al 6061-T6 as well. MatWeb gives the density of Al 6061-T6 as 2.7 g/cm^3, while the *Nuclear Engineering Handbook*[b] gives the densities of all of the types of Al 6061, including Al 6061-T6, as 2.70 g/cm^3. Neither of them provides a corresponding uncertainty, however. Calculations were performed that changed the density of the Al 6061-T6 parts by ± 0.05 g/cc, a variation of 1.85% . The calculated reactivity difference between those two cases is negligible. Consequently, the standard deviation in reactivity is negligible as well.

The composition of Al 6061-T6 also was examined as a possible source of uncertainty in reactivity. Table 13 in Section 1 provides the range of compositions for Al 6061-T6, and combinations that maximize and minimize the amount of aluminum were constructed from that table. The calculated difference in k_{eff} between those two compositions was found to be 0.0004 ± 0.0004 Δk, which is only marginally significant. Those variations are assumed to correspond to changes of 1 standard deviation in each direction. Consequently, the resulting standard deviation in reactivity associated with the uncertainty in the composition of Al 6016-T6 is ± 0.0002 Δk.

Belly Band - Consistent with the discussion in Section 1.3.2, the belly band is presumed to be made from stainless steel 303, based on information in the drawing. Nevertheless, the possibility that it could have been made from maraging steel was investigated. Changing the composition of the the belly band from stainless steel 303 to VascoMax 300 produces only a negligible change in k_{eff}.

2.2 HEU Enrichment and Isotopics

A separate enrichment for each of the 12 HEU pieces is recorded in the MASS database. Unfortunately, the method of measurement and its associated uncertainty are not known.

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[a] *Metals Handbook*, Tenth Ed., ASM International, Materials Park, Ohio (1990).

[b] Howard Etherington, Ed., *Nuclear Engineering Handbook*, McGraw-Hill Company, 1958.

However, the fact that the enrichments are reported to 0.01 wt.% indicates that the expected accuracy was at or near this level. The enrichment of the individual pieces was given in Table 8.

The average enrichment for the 12 HEU pieces is 93.15 wt.%, with a standard deviation of ± 0.03 wt.% for the individual pieces. Calculations were performed that increased the enrichment of all 12 pieces by 0.05 wt.% and decreased the enrichment of all 12 pieces by 0.05 wt.%. The difference in the values of k_{eff} from those two calculations is negligible. Furthermore, to produce a standard deviation, that result would have to be reduced to account for the fact that the enrichment was increased in all of the fuel pieces. Consequently, it is clear that enrichment can be discarded as a source of uncertainty for the reactivity of the configuration.

The ratios of ^{234}U to ^{235}U from five swipes from Godiva IV fuel pieces were presented in Table 9. Unfortunately, it is not known from which piece or pieces the swipes were taken. Accordingly, the average of the six ratios from that table was applied to all 12 fuel pieces. To five significant digits, that average is 0.010985, with a standard deviation of ± 0.00007.

A calculation was performed in which the ^{234}U in the fuel was replaced by ^{238}U while preserving the mass of the fuel. The result from that calculation indicated that the reactivity worth of the ^{234}U content of the fuel is 0.0043 ± 0.0004 Δk. However, the standard deviation determined above is substantially less than 1% of the ratio. Even if the effective standard deviation were increased to 1% to account for the fact that swipes were not taken from all the fuel pieces, the resulting reactivity increment would be only marginally significant. Furthermore, that result would have to be reduced substantially to account for the fact that the change was made to all of the fuel pieces simultaneously. Consequently, it is clear that the ^{234}U content of the fuel can be discounted as a source of uncertainty in the overall reactivity of the configuration.

No measurements of the ^{233}U, ^{236}U, or ^{238}U concentrations in the fuel have been found. However, isotopic measurements for five pieces from a previous Godiva configuration similar to Godiva-IV have been located.[a] The results from those measurements are presented in Table 23.

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[a] Los Alamos Scientific Laboratory memoranda CMB-1-459, from C. F. Metz of group CMB-1 to H. C. Paxton of group N-2, and CMB-1-460, from C. F. Metz of group CMB-1 to Roger White of group N-2. Both memoranda are dated February 25, 1960.

Table 23. Isotopic Measurements for Older Godiva Pieces.

Batch Number	Isotopic Content (wt.%)				
	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U
11059	≤ 0.01	1.16	93.12	0.97	4.74
11060	≤ 0.02	1.13	93.16	0.92	4.77
11061	≤ 0.01	1.13	93.18	0.92	4.76
11080	≤ 0.01	0.99	93.18	0.34	5.48
11081	≤ 0.01	1.01	93.21	0.34	5.43
11082	≤ 0.01	1.02	93.19	0.32	5.46
11093	≤ 0.02	1.09	93.24	0.92	4.73

Given that the enrichment and the ^{234}U content of those samples are similar to those for the Godiva-IV, it is reasonable to assume that the ^{233}U and ^{236}U content are as well. The average ^{233}U content therefore is assumed to be 0.01 ± 0.01 wt.%. The ^{236}U content is assumed to be the mean of the values above with their associated standard deviation. That mean value is 0.68 wt.%, and the associated standard deviation is ± 0.28 wt.%. Similarly, the average value for the ^{238}U content of the fuel is 5.05 wt.% with an associated standard deviation of ± 0.35 wt.%.

Calculations to determine the worth of the ^{233}U and ^{236}U content of the fuel were performed by replacing those isotopes with ^{238}U while preserving the mass of the fuel. The worths of the ^{233}U and the ^{236}U were found to be 0.0006 ± 0.0004 Δk and 0.0012 ± 0.0004 Δk , respectively.

The magnitude of the standard deviation for the ^{233}U content is the same as its mean value. However, to produce a standard deviation for the uncertainty in reactivity, the mean value of 0.0006 needs to be reduced to account for the fact that in the calculation the ^{233}U content was changed uniformly throughout all of the fuel pieces. After that reduction (division by the square root of 8), the resulting uncertainty is approximately ± 0.0002 Δk.

The magnitude of the standard deviation for the ^{236}U content of the fuel is 41% of its mean value. Consequently, the reactivity uncertainty associated with a change of ± 41% in the ^{236}U content is approximately ± 0.0005 Δk. When that value is reduced to account for the fact that the ^{236}U content was changed uniformly throughout all of the fuel pieces, the resulting standard deviation is approximately ± 0.0002 Δk.

When the measured enrichments for the fuel pieces are used in conjunction with the representations described above for the ^{233}U, ^{234}U, and ^{236}U content of the fuel, the average ^{238}U

content of the fuel is 5.14 wt.%, with an associated standard deviation of ± 0.03 wt.%. Because that standard deviation is much smaller than that derived from the values in Table 22, the uncertainty in the ^{238}U content needs to be addressed. That uncertainty can be evaluated from the calculation that was previously discussed for the ^{236}U content.

The three isotopes for which there are no measurements for the Godiva-IV fuel are ^{233}U, ^{236}U, and ^{238}U. The ^{233}U content is minuscule, and therefore an increase or decrease in the ^{238}U content would have to be accompanied by a decrease or increase, respectively, in the ^{236}U content. The uncertainty of ± 0.28 wt.% in the ^{236}U content implicitly included a change of ∓ 0.28 wt.% in the ^{238}U content. Scaling that change from 0.28 wt.% to 0.35 wt.% would not change the standard deviation of ± 0.0002 Δk in reactivity associated with the uncertainty in the ^{236}U / ^{238}U content. Consequently, the reactivity impact of the uncertainty in the ^{238}U concentration already has been addressed implicitly.

2.3 Material Dimensions

As will be shown in Section 3, all of the Godiva-IV experiments had very hard spectra, with almost all interactions occurring in the fast energy range. Within that range, neutron mean free paths are much longer than the dimensions that characterize the fine details of many of the components. Consequently, uncertainties associated with chamfering, sculpted cut-outs, etc., clearly can be ignored as contributors to the uncertainty in k_{eff}.

The dimensions that can contribute to the uncertainty in k_{eff} are those that affect neutron transport between or out of the various components. In general terms, those dimensions include the overall height, length, thickness, depth, or radius of the component. Consequently, those dimensions were studied for the components that make substantial contributions to the overall reactivity of the configurations.

Fuel Pieces - Contributions to the uncertainty in reactivity from uncertainties in the dimensions of the fuel pieces were calculated using the stated tolerances for those pieces. Because tolerances are used, the standard deviation is obtained by dividing the result by the square root of three for those components that have one-sided tolerances and by dividing by two times the square root of three for those components that have double-sided tolerances. The masses of the affected fuel pieces were conserved by adjustments to their densities within each calculation. The results from those calculations are presented in Table 24.

Table 24. Reactivity Uncertainties Related to the Dimensions of the Fuel Pieces.

Component	Tolerance (cm)	Model Change (cm)	Reactivity Change (Δk_{eff})	Standard Deviation (Δk)
Fuel Ring Height (Cumulative)	±0.04064	±0.04064	0.0005 ± 0.0004	± 0.0001
Fuel Ring Inner Radius (All)	+0.00508	+0.00508	negligible	negligible
Fuel Ring Outer Radius (All)	±0.00254	±0.00254	negligible	negligible
Safety Block Height	-0.00508	-0.00508	+0.0006 ± 0.0004	± 0.0003
Safety Block Inner Radius	+0.00254	+0.00762	negligible	negligible
Safety Block Outer Radius	-0.00254	-0.00254	-0.0005 ± 0.0004	± 0.0003
UISP Height	±0.00508	±0.00508	negligible	negligible
UISP Inner Radius	+0.00254	+0.00254	negligible	negligible
UISP Outer Radius	-0.00254	-0.00254	negligible	negligible
IISP Height	+0.00508	+0.00508	-0.0004 ± 0.0004	± 0.0002
IISP Inner Radius	+0.00254	+0.00254	negligible	negligible
IISP Outer Radius	-0.00254	-0.00254	negligible	negligible
Control Rod Height	+0.01270	+0.01270	negligible	negligible
Control Rod Outer Radius	-0.00254	-0.00254	negligible	negligible
Burst Rod Height	+0.01270	+0.01270	negligible	negligible
Burst Rod Outer Radius	-0.00254	-0.00254	negligible	negligible
Cumulative				± 0.0005

As Table 24 indicates, three of the four tolerances that have statistically significant impact are one-sided. Strictly speaking, results from such cases should be preserved as one-sided standard deviations. However, for convenience and because the differences are so small, the cumulative standard deviation from Table 24 will be treated as a two-sided standard deviation.

As reported in Section 1.2.2, the gap between the bottom of the intermediate inner subassembly plate and the top of the safety block can be as much as 0.254 cm. The additional uncertainty of approximately 0.005 cm in the position of the hydraulic cylinder that holds the safety block in place is considered negligible relative to that uncertainty in the size of the gap. The detailed

MCNP model of the experiments assumes that the gap is half of the maximum distance, 0.127 cm. Calculations were performed for conditions with a gap of 0.254 cm and with no gap. It was found that the change in k_{eff} between those two conditions is 0.0038 ± 0.0004 Δk. Because the probability distribution is assumed to be uniform over the range from 0 to 0.254 cm and the nominal position is midway between those two extremes, the reactivity change must be divided by two times the square root of three. The resulting standard deviation is ± 0.0011 Δk.

The uncertainties in the positions of the burst rod and the control rods also were investigated. When the burst rod is at its fully inserted position, the nominal clearance between the top of the burst-rod pin and the fuel ring above it is only 0.16129 cm. This clearance is only slightly greater than 0.05 inch (0.127 cm). Because no uncertainties were reported for the positions of the control or burst rods, the latter distance was assumed to correspond to one standard deviation in the uncertainty for the position of the burst rod. Twice that distance was assumed to correspond to one standard deviation in the uncertainty for the positions of the control rods, which need to be assigned a larger uncertainty because they are adjusted manually. The reactivity impact of those uncertainties was found to be negligible for the burst rod, irrespective of whether it was fully inserted or fully withdrawn. The change in k_{eff} due to the combined uncertainties in the positions of the two control rods was found to be marginally significant; viz., 0.0005 ± 0.0004 Δk.

Spindle and Safety Block Base - Other than fuel, the core components that contribute significantly to the overall reactivity are the spindle and the safety block base. Contributions to the uncertainty in reactivity from uncertainties in the dimensions of those parts were calculated using the stated tolerances for the parts. Because the masses of the spindle and safety-block base were not reported, their densities were not changed in the sensitivity calculations. The results from those calculations are presented in Table 25.

Table 25. Reactivity Uncertainties Related to the Dimensions of Non-Fuel Core Components.

Component	Tolerance (cm)	Model Change (cm)	Reactivity Change (Δk_{eff})	Standard Deviation (Δk)
Spindle Height	+0.01270	+0.01270	negligible	negligible
Spindle Outer Radius	-0.00254	-0.00254	negligible	negligible
Spindle Inner Radius	Not Given	removed	negligible	negligible
Safety Block Base Height	+0.01778	+0.01778	negligible	negligible
Safety Block Base Shaft Radius	-0.00254	-0.00254	negligible	negligible
Safety Block Base Platform Radius	-0.00254	-0.00254	-0.0004 ± 0.0004	± 0.0002
Safety Block Base Cylinder Outer Radius	±0.00762	±0.00762	negligible	negligible
Cumulative				± 0.0002

The only dimension whose tolerance produces a statistically significant change in reactivity is the radius of the platform of the safety block base, and even there the change is only marginally significant. Because that dimension has a one-sided tolerance, the corresponding standard deviation in reactivity was determined by dividing the reactivity change by the square root of three. Strictly speaking, results for one-sided tolerances should be treated as one-sided uncertainties. However, for convenience and because the reactivity difference is so small, the standard deviation associated with the radius of the platform will be treated as a two-sided standard deviation.

No tolerance was given for the inner radius of the spindle, which is also the outer radius of the glory hole. However, removing the glory hole entirely — by filling it with the same material (SAE 4340) as the spindle — produced only a negligible change in reactivity.

Restraints - The support pads, bearing ring, subassembly cover plate, and the clamps are the only restraints that contribute substantially to the overall reactivity for the these experiments. Contributions to the uncertainty in reactivity from uncertainties in the dimensions of those parts were calculated using the stated tolerances for the dimensions of the support pads and bearing ring, as well as the width of the clamps. Tolerances are not given for the dimensions of the subassembly cover plate or for the other dimensions of the clamps. Consequently, modeling changes were made for those dimensions that seemed compatible with those for comparable dimensions of other parts. Most of the given tolerances are one-sided. The model change for the radius of the subassembly cover plate also is taken to be one-sided, because the nominal gap between it and the bearing ring that surrounds it is so small. Because the masses of the restraints were not reported, their densities were not changed in the sensitivity calculations.

The results from the calculations are shown in Table 26. Most of the reactivity changes are negligible, and even those that are statistically significant are small. The standard deviation in reactivity for one-sided tolerances was determined by dividing the reactivity change between cases with the nominal dimension and with the dimension at its tolerance limit by the square root of three. The standard deviation in reactivity for two-sided tolerances was obtained by dividing the reactivity change between cases with that dimension at its upper and lower tolerance limits by two times the square root of three. For convenience and because they are small, the one-sided uncertainties are treated as two-sided uncertainties in the determination of the cumulative standard deviation.

Table 26. Reactivity Uncertainties Related to the Dimensions of the Restraints.

Component	Tolerance (cm)	Model Change (cm)	Reactivity Change (Δk_{eff})	Standard Deviation (Δk)
Support Pads, Inner Radius (3)	+0.00254	+0.00254	negligible	negligible
Support Pads, Outer Radius (3)	-0.00254	-0.00254	negligible	negligible
Bearing Ring Height	±0.00254	±0.00254	negligible	negligible
Bearing Ring Inner Radius	+0.00254	+0.00254	negligible	negligible
Bearing Ring Outer Radius	-0.00254	-0.00254	-0.0007 ± 0.0004	± 0.0004
Cover Plate Height	Not Given	±0.00508	negligible	negligible
Cover Plate Inner Radius	Not Given	±0.00508	0.0004 ± 0.0004	± 0.0001
Cover Plate Outer Radius	Not Given	-0.00508	-0.0004 ± 0.0004	± 0.0002
Clamps, Width (3)	-0.00508	-0.00508	negligible	negligible
Clamps, Depth (3)	Not Given	±0.00254	negligible	negligible
Clamps, Height (3)	Not Given	±0.02540	0.0006 ± 0.0004	± 0.0002
Cumulative				± 0.0005

Mounting Plate - Horizontally, the mounting plate extends far beyond the sides of the core. Furthermore, its overall worth is small enough (see Table 16) that small variations in the size of the holes in it or in its thickness would not produce statistically significant changes in reactivity. Consequently, the impact on k_{eff} of uncertainties in the dimensions of the mounting plate can be dismissed as negligible.

2.4 Uncertainty in the Measured Period

The periods measured for the four delayed-critical conditions were effectively infinite. Consequently, the impact on k_{eff} of the uncertainty in their periods can be considered negligible.

As discussed in Section 1.2.6, a measured initial period of 30.8 microseconds for that static super-prompt-critical configuration is given in the logbook, and an initial period of 33.7831 microseconds is given in the oscilloscope display in Figure 26. These measurements are early enough in the process that they do not incorporate thermal-hydraulic feedback to any significant degree. From the Inhour equation, these periods correspond to excess reactivities of \$1.0386 and \$1.0352, respectively. Using ENDF/B-VI nuclear data, MCNP calculations for that Godiva-IV configuration estimate a value of 0.0064 +/- 0.0004 for β_{eff}.[a] The resulting value for k_{eff} is 1.0066 +/- 0.0004 for both values of excess reactivity. When those two identical values are combined statistically, the final result for k_{eff} is 1.0066 +/- 0.0003.

2.5 Combined Uncertainty

The effect of the experimental uncertainties on k_{eff} is summarized in Table 27. All five cases have a combined uncertainty of $\pm$ 0.0026 Δk. That final uncertainty is sufficiently small that these five experiments are judged to be acceptable for use as a criticality-safety benchmark experiment.

[a] β_{eff} is determined as the difference in reactivity between two otherwise identical criticality calculations, one of which excludes delayed neutrons (“no” on the TOTNU card) and the other of which includes them (blank TOTNU card).

Table 27. Impact of Experimental Uncertainties on k_{eff}.

Source of Uncertainty	Uncertainty in Reactivity (Δk)
Fuel Mass	± 0.0018
Molybdenum Content of Fuel	± 0.0009
Uranium Enrichment and Isotopics	± 0.0003
Masses of Non-Fuel Core Components	± 0.0003
Composition of Non-Fuel Core Components	± 0.0003
Restraint Masses	± 0.0004
Restraint Compositions	± 0.0005
Structural Support Masses	negligible
Structural Support Compositions	± 0.0002
Fuel Dimensions	± 0.0005
Dimensions of Non-Fuel Core Components	± 0.0002
Restraint Dimensions	± 0.0005
Structural Support Dimensions	negligible
Position of Safety Block	± 0.0011
Positions of Both Control Rods	± 0.0005
Position of Burst Rod	negligible
Period (cases 1 through 4) Period (case 5)	negligible ± 0.0003
Total (cases 1 through 5)	± 0.0026

3.0 BENCHMARK SPECIFICATIONS

3.1 Description of Models

The Godiva-IV assembly has a number of features that require a full three-dimensional benchmark model. In particular, the burst rod and the control rods are located in off-center horizontal positions, and they have vertical travel paths that do not traverse the entire height of the core. Furthermore, although the clamps and clamp supports are located symmetrically with respect to the horizontal center of the core, they subtend only relatively small transverse angles. In addition, as was shown in Table 16, the reactivity worth of the clamps is sufficiently high that they cannot be omitted from the benchmark model. Accordingly, the goal of the simplification process is to produce benchmark models for the five configurations that explicitly retain the control rods, the burst rod, the holes for the control and burst rods, the clamps, and the clamp supports but which represent the other components as cylinders or combinations of cylinders.

The development of the benchmark models for the five cases began with the construction of a very detailed model for each of them using the MCNP5 Monte Carlo code.[a] A discussion of that detailed model is provided in Appendix B.

The detailed model represents the core and restraint components in precise detail. The enclosures are present but are represented in less exact detail, because their actual structures are complex and preliminary sensitivity studies showed that they have little or negligible effect on k_{eff}.

With the following exceptions, the geometric features for the core and restraint components were modeled exactly as described in Sections 1.2.2 and 1.2.3:

(1) The nominal height of the wide part of the fifth ring is slightly higher than the combined height of the narrow portions of the intermediate and upper inner subassembly plates. Consequently, those two heights were adjusted slightly, within tolerances, to be consistent.

(2) Some of the holes, most notably those for the thermocouples, were simplified to reduce the number of regions with different radii. In all such cases, the volume of the hole was preserved.

(3) reasonable assumptions were made about the size and shape of some bolts and nuts for which the actual dimensions were not known. For example, hexagonal heads of bolts were modeled as cylinders because the exact orientation of the

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[a] X-5 Monte Carlo Team, "MCNP — A General Monte Carlo N-Particle Transport Code, Version 5, Volume I: Overview and Theory," LA-UR-03-1987, Los Alamos National Laboratory (April 2003).

heads was not known. In all such cases, however, the volume of the piece was preserved.

(4) The small shim ring was omitted from the detailed model, because the dimensions in the model are based on the drawings for the parts. Those drawings reflect the initial dimensions of the components and do not account for abrasion or oxidation. Consequently, the shim ring is not needed to preserve a tight fit between the inner subassembly plate and the fifth ring.

(5) The distance between the prongs of the clamps was taken to remain unchanged at 17.78 cm (7 inches), which means that either the bearing ring and support pads must be compressed or a small amount of fuel must be displaced. Based upon guidance provided by a LACEF staff member,[a] it was assumed that the fuel was displaced. The displaced fuel was assumed to fill the spaces surrounding the support pads and bearing ring, and the excess was assumed to be deposited on the lower surface of the bottom fuel ring and on the upper surface of the top fuel ring.

(6) The subassembly cover plate, whose composition was given simply as "steel," was assumed to be made from SAE 4340. Other components whose compositions were listed simply as "steel" were assumed to be made from stainless steel 303. In all likelihood, even if they were not made from stainless steel 303, they would have been made from a very closely related type of stainless steel.

The geometry of the support structure and the enclosures also were modeled in considerable detail, although not to the level of the core and restraints. With the exception of the contamination shield, the structure beneath the mounting plate was omitted. That structure is made of the same material as the mounting plate, and, as shown in Table 16, the mounting plate only contributes approximately 0.003 Δk to k_{eff}. Those other pieces are much farther from the core than the mounting plate, and many of them are much smaller. Furthermore, any neutrons they might have reflected back into the core first would have had to pass through the contamination shield or the mounting plate and then be reflected back through them again.

Some of the finer details of the contamination shield and the core cover also were omitted or approximated. Preliminary calculations had shown that their contributions to k_{eff} are quite small, and therefore small details such as some of the screw holes were omitted. In addition, the mesh portion of the screen around the core cover was homogenized into a single thin layer since the details of the mesh size are not known. Sensitivity calculations clearly showed that k_{eff} is

[a] Personal communication from Charlene Cappiello of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, May 1, 2007.

insensitive to the thickness and density of that layer, within the limits consistent with known information.

In addition, the long, thin aluminum tubes that support the safety block base, the control rods, and the burst rod are omitted. Although they are in direct contact with parts of the core, their areas of contact are very small, and they have relatively little mass. Furthermore, the very limited reactivity impact of the mounting plate indicates that aluminum is not an effective reflector for neutrons in the energy range for this type of configuration. Clearly, their omission does not affect k_{eff}.

Similarly, the aluminum-ion coating on the fuel pieces is clearly inconsequential. Although its actual thickness isn't known, it is very, very thin (a few atomic distances), and aluminum is essentially transparent to neutrons at these energies. For example, more than 60% of all neutrons escape from the Godiva-IV assembly, and most of them pass through the aluminum core cover. The core cover is 0.165 cm thick, which is tens to hundreds of times thicker than the aluminum-ion coating. Even so, the core cover has a negligible reactivity worth ($-0.0004 \pm 0.0004\ \Delta k$). The reactivity worth of the aluminum-ion coating clearly would be much smaller.

Finally, the detailed model ignores the effects of room return. As was discussed in Section 1.2, the Godiva-IV assembly was quite some distance from the walls, floor, and ceiling of the building. Furthermore, as shown in Table 16, the support structure and the enclosures produce relatively little neutron reflection even though they are only a short distance from the core. Consequently, it is clear that room return can be ignored.

The masses of the fuel pieces are taken to be those from the MASS database given in Table 7. There are two reasons for doing so. First, recent measurements for the fuel rings are not available, and it was felt that a (presumably) consistent set of masses would be preferable to a mix from different sources. Second, as noted above, the original dimensions of those pieces are used for the detailed model, and the MASS masses more likely are consistent with those dimensions than are the masses that were measured more recently.

The enrichments of the fuel pieces are taken from Table 8, and the average values for the ^{233}U, ^{234}U, and ^{236}U content are applied to each piece, as discussed in Section 2.2. The remainder of the uranium content in each piece was assumed to be ^{238}U.

The densities for stainless steel 303, SAE 4340, VascoMax 300, and Al 6061-T6 were discussed in Section 2.1. Consistent with that discussion, the densities for stainless steel 303 and VascoMax 300 both were taken to be 8.0 g/cm^3, the density of SAE 4340 was taken to be 7.85 g/cm^3, and the density of Al 6061-T6 was taken to be 2.70 g/cm^3.

The assumed composition of stainless steel 303 is based on the information in Table 10 from the *Handbook of Materials Science*. Elements for which a maximum content was given were taken to be at half of that value, elements for which a minimum content was given were taken to be at twice that value, and elements for which a range was provided were taken to be at the midpoint of that range. The remainder was taken to be iron.

The composition for SAE 4340 is taken to be an amalgam of the information from the *Metals Handbook Desktop Edition* and the *ASM Metals Reference Book* in Table 12. Once again, maximum values for elements were halved, elements for which a range was given were taken to be at the midpoint of that range, and the remainder was taken to be iron.

The composition of VascoMax 300 was assumed to be that given by MatWeb, which was presented in Table 11.

The composition of Al 6061-T6 also was assumed to be that given by MatWeb, which was presented in Table 13. Once again, maximum values for elements were halved, and elements for which a range was given were taken to be at the midpoint of that range. The remainder, 97.23 wt.%, was taken to be aluminum.

The development of the benchmark model thereafter proceeded in a series of sequential steps. The sensitivity studies that are summarized below were conducted in a sequence such that, at each step, all of the preceding modifications were retained. This approach permits the reactivity impact of each modification to be determined, and it also allows the cumulative reactivity effect of all of them to be ascertained by direct comparison to the detailed model. This approach has the added advantages that it requires no assumption about the mutual independence of individual modifications and that the standard deviations for each modification do not need to be compounded to produce the final standard deviation. Instead, the net reactivity change due to all of the modeling simplifications can be computed directly from the results for just the detailed and benchmark models.

Because the only differences from one configuration to another are the positions of the control rods and the burst rod, the steps in the transformation from the detailed model to the final benchmark model were performed only for one case. Case 2 was selected for that process, since the burst rod is fully inserted and both control rods are inserted a significant distance into the core. After the benchmark model for case 2 had been finalized, the same changes were applied, in a single step, to the detailed models for the other cases to transform them into benchmark models.

Ideally, the benchmark models for the Godiva-IV static super-prompt-critical configuration would be appropriate for modeling the full prompt burst experiment as well. Unfortunately, the kinetics codes used for such calculations typically are (at most) two-dimensional, and a two-dimensional cylindrical (R-Z) model has been used in the past at Los Alamos National Laboratory for that purpose.[a] A transformation of the benchmark model for the static super-prompt-critical case into a corresponding two-dimensional cylindrical model is described in Appendix C. That transformation involves a number of approximations that would not be acceptable for ICSBEP benchmark models.

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[a] R. H. Kimpland, "Preliminary Results of GODIVA-IV Prompt Burst Modeling,," Los Alamos National Laboratory report LA-UR-96-1498 (1996).

The MCNP5 calculations discussed in this section each employed 550 generations with 10,000 histories per generation. The first 50 generations were excluded from the statistics for each case, producing 5,000,000 active histories in each calculation. The calculations were performed with continuous-energy cross sections derived from the final release of ENDF/B-VI. Specifically, nuclear data were taken from the ACTI library[a] for those nuclides it contains, and nuclear data for the other nuclides were taken from the ENDF66 library.[b] For the cases in this evaluation, that combination of nuclear data corresponds to the final release of ENDF/B-VI.

3.1.1 Geometry Simplifications - As noted above, the benchmark models for the delayed-critical configurations have to be three dimensional. However, a number of simplifications can be made without substantially affecting k_{eff}. Those simplifications and their impact are summarized in Table 28. The standard deviation in the calculated reactivity difference between any two steps is ± 0.0004 Δk. Reactivity changes with a mean value whose magnitude is less than 0.0004 therefore are characterized as negligible.

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[a] S. C. Frankle, R. C. Reedy, and P. G. Young, "ACTI: An MCNP Data Library for Prompt Gamma-Ray Spectroscopy," *Proceedings of the 12th Biennial Topical Meeting of the Radiation Protection and Shielding Division*, Santa Fe, New Mexico, USA (April 2002).

[b] J . M. Campbell, S. C. Frankle, and R C. Little, "ENDF/B-VI Neutron Library for MCNP with Probability Tables," *Proceedings of the 12th Biennial Topical Meeting of the Radiation Protection and Shielding Division*, Santa Fe, New Mexico, USA (April 2002).

Table 28. Impact of Geometric Simplifications on k_{eff}.

Simplification	Incremental Δk
Remove Core Cover	-0.0004 ± 0.0004
Remove Belly Band and Belly Band Bolts	-0.0008 ± 0.0004
Remove Contamination Shield	-0.0007 ± 0.0004
Convert Mounting Plate to Flat Cylinder	Negligible
Convert Safety Block to Simple Cylinder	Negligible
Convert Safety Block Base to Set of Cylinders	Negligible
Convert Intermediate Inner Subassembly Plate to Cylinders	Negligible
Convert Spindle to Hollow, Uniform Cylinder	-0.0006 ± 0.0004
Convert Upper Inner Subassembly Plate to Cylinders	0.0004 ± 0.0004
Fill Offset Holes in Cover Plate	Negligible
Standardize Notch Depth for All Fuel Rings	Negligible
Remove Thermocouple Hole from Fourth Ring	Negligible
Fill Gaps between Fuel Rings	-0.0007 ± 0.0004
Fill Partial Control/Burst Rod Holes in Fifth Ring	Negligible
Remove Chamfering from Control Rods	0.0005 ± 0.0004
Remove Pin and Chamfering from Burst Rod	Negligible
Convert Support Pads to Ring	0.0009 ± 0.0004
Uniform Depth for Bearing Ring	0.0007 ± 0.0004
Make Internal Corners for Clamps Square	Negligible
Remove Screw Holes in Clamps	0.0004 ± 0.0004
Make Tops and Bottoms of Clamps Flat	-0.0004 ± 0.0004
Fill Holes in Clamp Supports	0.0004 ± 0.0004
Make Clamp Supports Rectangular	Negligible
Cumulative	Negligible

The cumulative change in k_{eff} from all of these geometric simplifications is negligible (specifically, -0.0003 ± 0.0004 Δk). Furthermore, no single simplification produces a change in k_{eff} whose mean value has a magnitude greater than 0.0010 Δk.

3.1.2 Material Simplifications - Some additional simplifications can be made to the composition of some of the Godiva-IV components without substantially altering k_{eff}. The compositions of the homogenized regions were obtained by volume weighting the masses and compositions of the component regions. The material simplifications that were incorporated into the benchmark model are summarized in Table 29. The cumulative change in k_{eff} from these simplifications is quite small.

Table 29. Impact of Material Simplifications on k_{eff}.

Simplification	Incremental Δk
Homogenize Fuel Rings	Negligible
Homogenize Inner Subassembly Plate	0.0008 ± 0.0004
Remove All Constituents except Aluminum from Mounting Plate	Negligible

As noted earlier, the mounting plate contains 97.23 wt.% aluminum. Consequently, a straightforward simplification is to remove its other constituents. As Table 29 indicates, removal of those elements produce a negligible change in k_{eff}.

Similar material simplifications were not attempted for the three types of steel. The content of the principal constituent, iron, in stainless steel 303 and VascoMax is only about 70 wt.%. SAE 4340 has a much higher iron content, approximately 96 wt.%, but the cumulative reactivity worth of the pieces made from SAE 4340 is considerably higher than that of the mounting plate.

After the geometric and material simplifications were evaluated, a final step was taken in which unnecessary surfaces were removed from the MCNP model. For case 2, the net change in k_{eff} between the resulting benchmark model and the initial detailed model is negligible. The corresponding changes then were made to the models for the other configurations. Three of them produced marginally significant changes in k_{eff} relative to the corresponding detailed model, and the other produced a negligible change. The largest change was only 0.0007 ± 0.0004 Δk.

The net result of these changes is to produce a core with cylindrical components and rectangular clamps and clamp supports. The control rods and burst rods are themselves cylindrical, but they remain in their physical locations, offset from the center of the core. Only five distinct fuel components remain: the safety block, the homogenized inner subassembly plate, the homogenized fuel ring, the two identical control rods, and the burst rod.

3.2 Dimensions

A vertical slice through the center of the benchmark configuration is shown in Figure 28, and the corresponding close-up of the core is shown in Figure 29. In both figures, the fully inserted burst rod can be seen on the left side of the core. A similar slice through the core that displays the partially inserted control rods is presented in Figure 30. Materials with the same composition are shown in the same color (e.g., the safety block base, the spindle, the spindle nut, and the clamp support all are made from stainless steel 303).

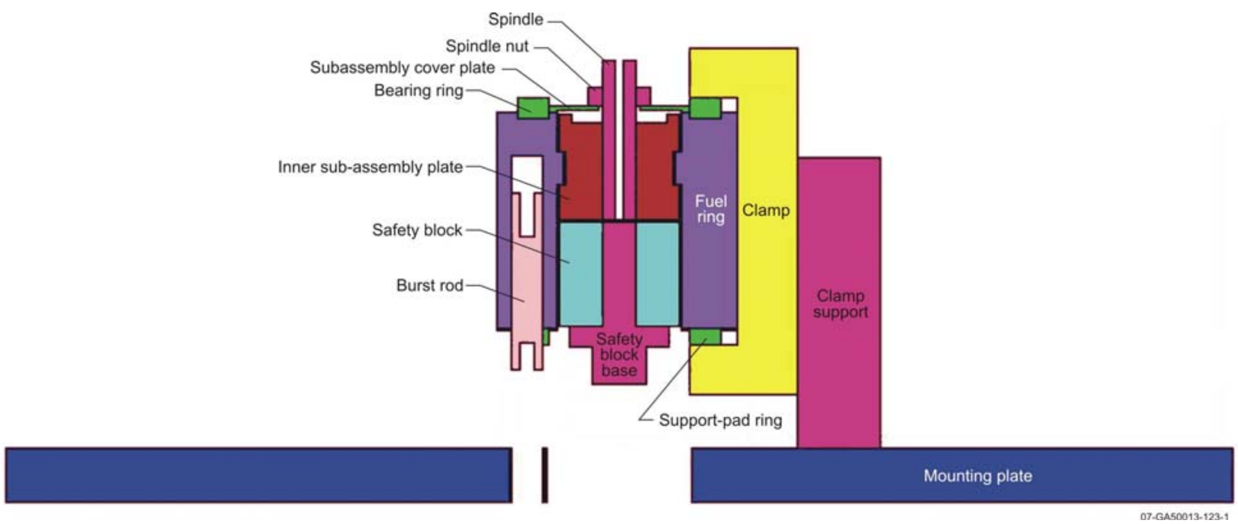

Figure 28. Vertical Slice through the Benchmark Model for Case 2.

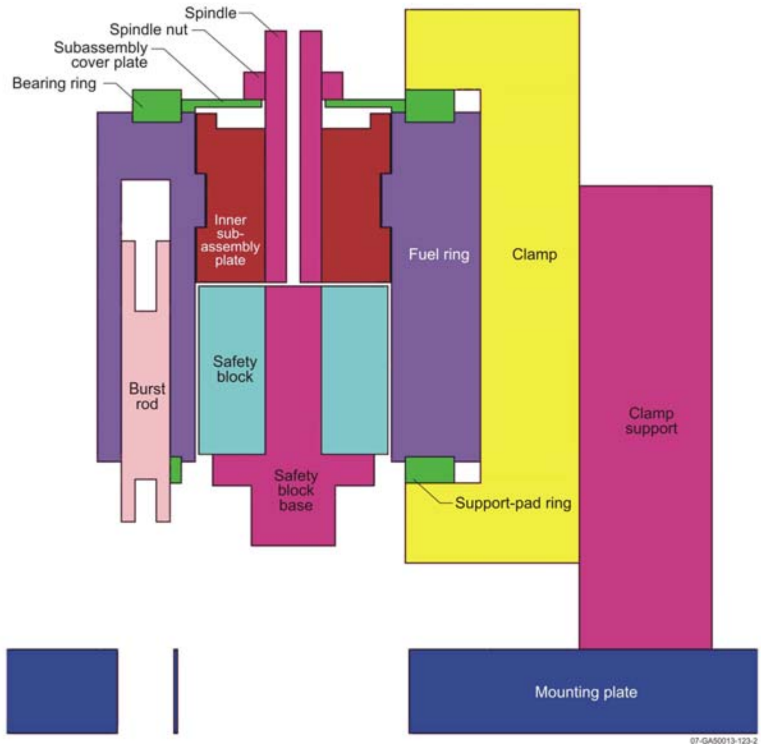

Figure 29. Vertical Slice through the Center of the Core of the Benchmark Model for Case 2.

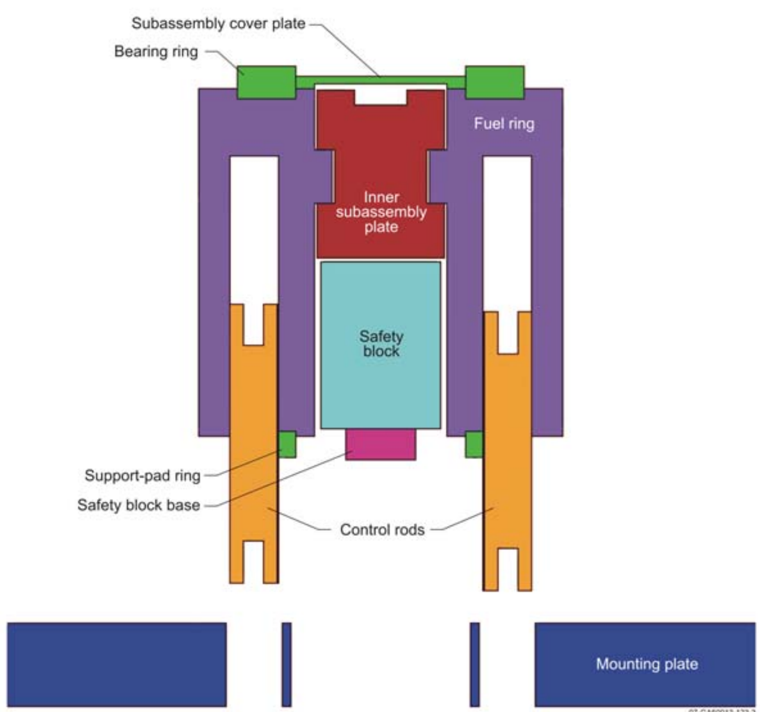

Figure 30. Off-Center Vertical Slice through the Core of the Benchmark Model for Case 2.

A horizontal slice through the mounting plate is shown in Figure 31, and progressively higher horizontal slices through the central region of the assembly are shown in Figures 32 through 41. Dimensions for the individual parts can be found in Figures 42 through 65.

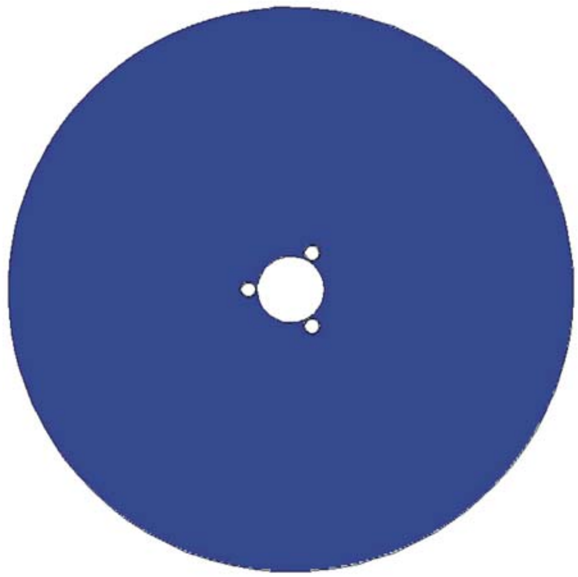

Figure 31. Horizontal Slice through the Mounting Plate in the Benchmark Model.

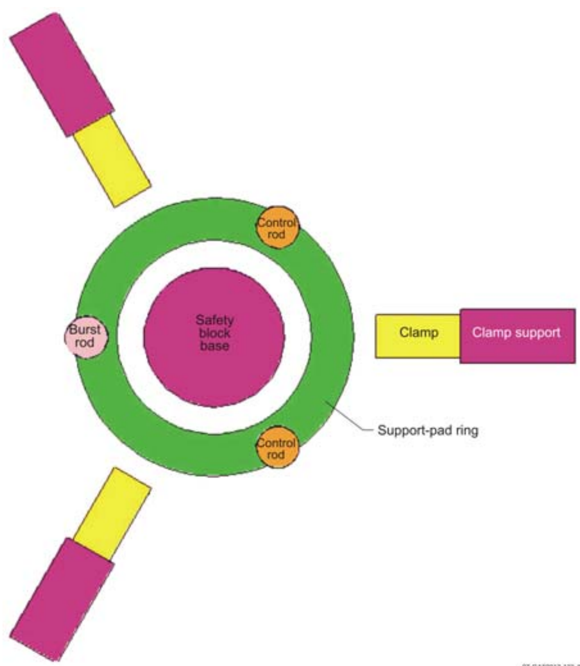

Figure 32. Horizontal Slice through the Benchmark Model for Case 2 Showing the Support-Pad Ring and the Safety Block Base.

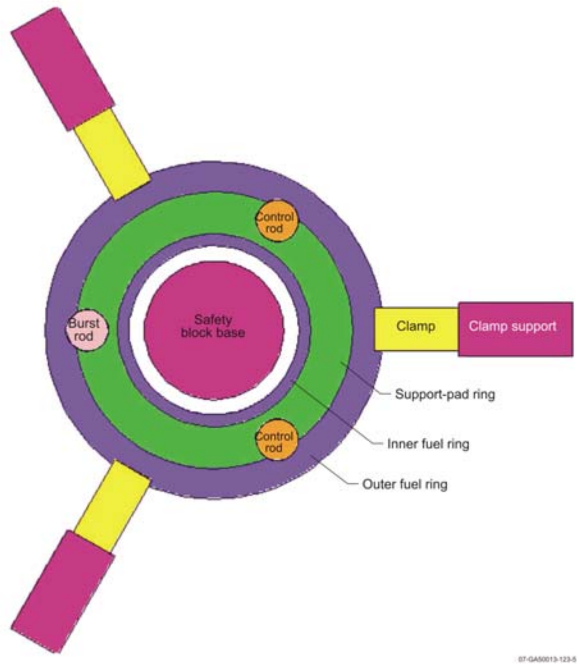

Figure 33. Horizontal Slice through the Benchmark Model for Case 2 Showing the Support-Pad Ring inside the Homogenized Fuel Ring.

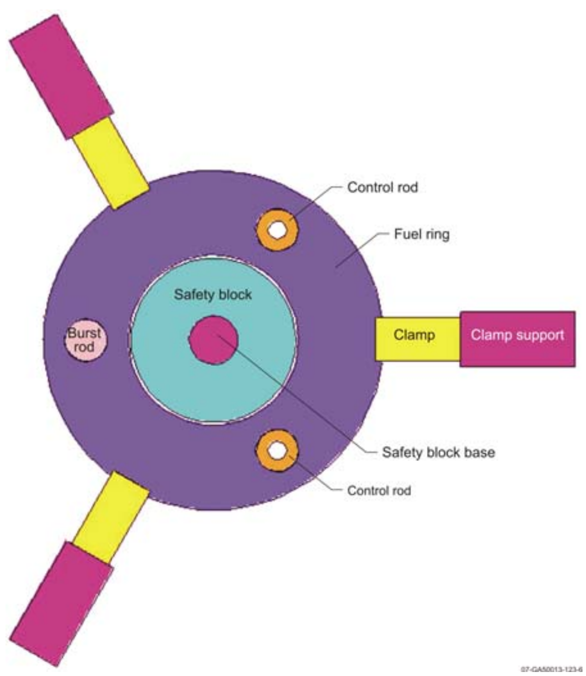

Figure 34. Horizontal Slice through the Benchmark Model for Case 2 Showing the Safety Block.

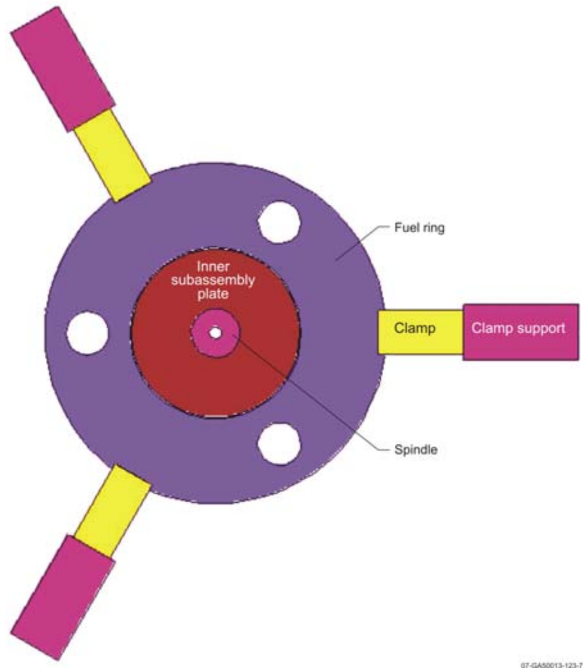

Figure 35. Horizontal Slice through the Benchmark Model for Case 2 Showing the Lower Wide Part of the Inner Subassembly Plate.

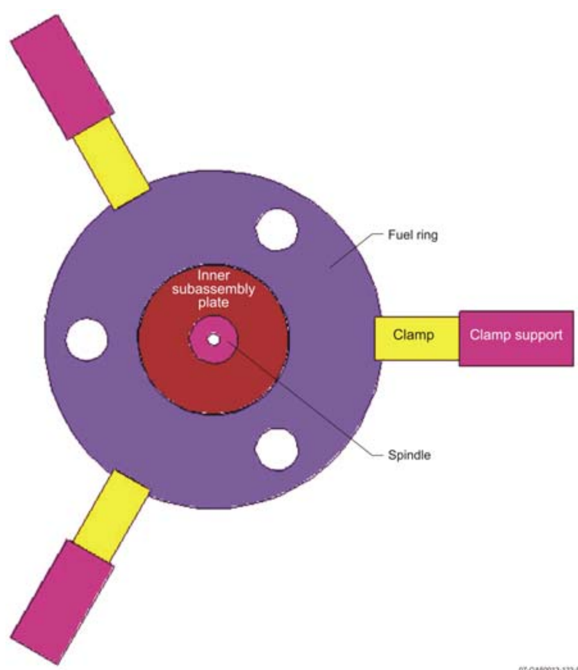

Figure 36. Horizontal Slice through the Benchmark Model for Case 2 Showing the Lower Narrow Part of the Inner Subassembly Plate.

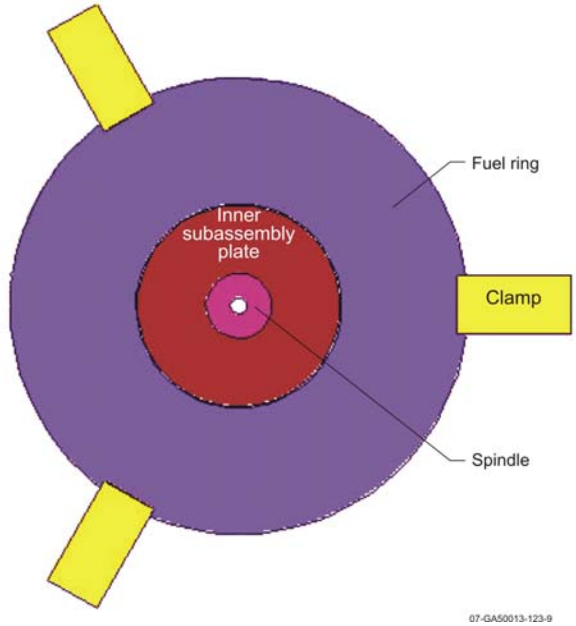

Figure 37. Horizontal Slice through the Benchmark Model for Case 2 Showing the Upper Narrow Part of the Inner Subassembly Plate.

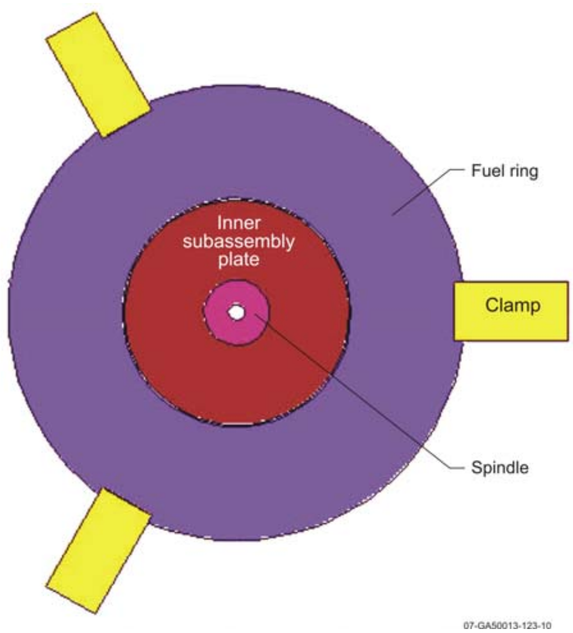

Figure 38. Horizontal Slice through the Benchmark Model for Case 2 Showing the Upper Wide Part of the Inner Subassembly Plate.

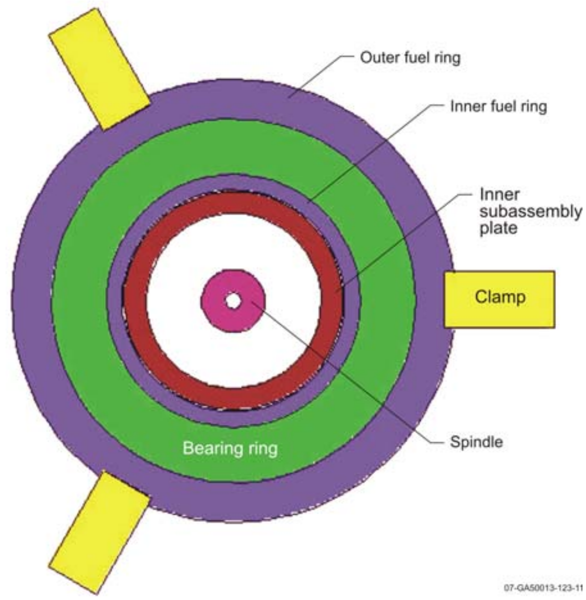

Figure 39. Horizontal Slice through the Benchmark Model for Case 2 Showing the Top Part of the Inner Subassembly Plate and the Bearing Ring inside the Homogenized Fuel Ring.

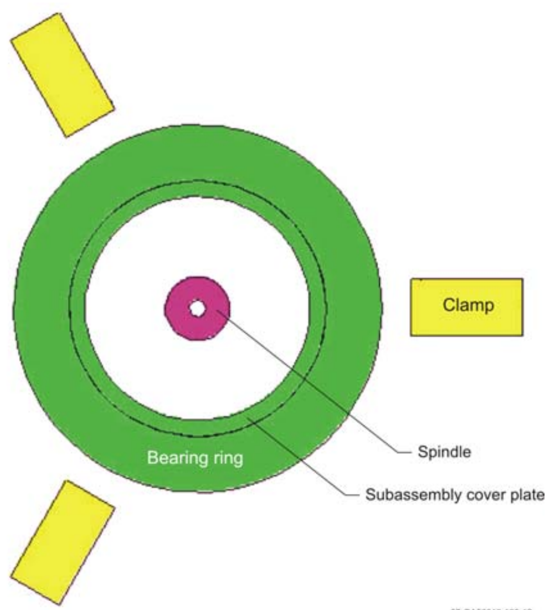

Figure 40. Horizontal Slice through the Benchmark Model for Case 2 Showing the Narrow Region of the Core Cover Plate inside the Bearing Ring.

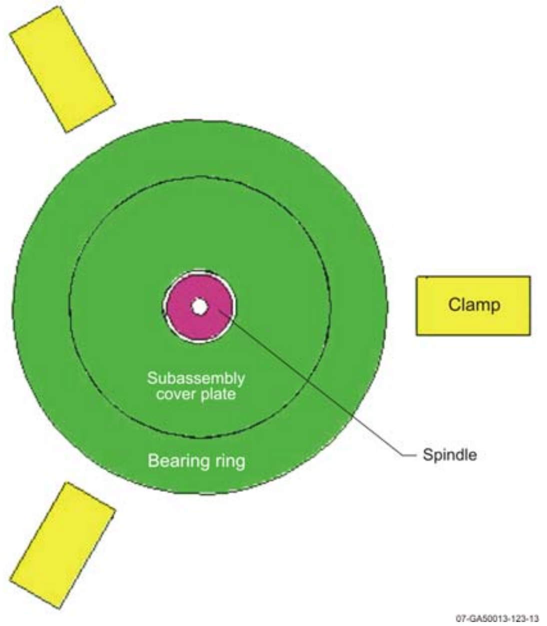

Figure 41. Horizontal Slice through the Benchmark Model for Case 2 Showing the Wide Region of the Core Cover Plate inside the Bearing Ring.

The origin for the benchmark models that are listed in Appendix A is taken to be at the center of the bottom surface of the inner subassembly plate. (Strictly speaking, it is at the center of the central void region inside that surface.) Relative to that origin, the top and bottom vertical locations of the components with fixed positions are given in Table 30, and the top and bottom locations for the control rods and burst rod are given for each case in Table 31.

Table 30. Vertical Locations of Fixed Components.

Component	Bottom (cm)	Top (cm)
Nut on Spindle	8.27278	9.54278
Subassembly Cover Plate	7.73264	8.27278
Bearing Ring	7.27160	8.75411
Spindle	0.00254	11.43254
Inner Subassembly Plate	0	7.64794
Safety Block	-7.74700	-0.12700
Homogenized Fuel Ring	-8.06553	7.73264
Support-Pad Ring	-9.02589	-7.59414
Safety Block Base	-11.85559	-0.12700
Clamps	-12.67587	12.40409
Clamp Supports	-16.56715	4.38785
Mounting Plate	-20.37715	-16.56715

Table 31. Vertical Positions of Control Rods and Burst Rod.

	Control Rod 1		Control Rod 2		Burst Rod	
Case	Bottom (cm)	Top (cm)	Bottom (cm)	Top (cm)	Bottom (cm)	Top (cm)
1	-19.84121	-7.14121	-12.02055	0.67945	-10.79627	1.90373
2	-14.75359	-2.05359	-15.11173	-2.41173	-10.79627	1.90373
3	-10.93089	1.76911	-20.51685	-7.81685	-10.79627	1.90373
4	-10.86993	1.83007	-10.81405	1.88595	-18.34007	-5.64007
5	-10.48893	2.21107	-12.54633	0.15367	-10.79627	1.90373

The length and radii of the cylindrical fuel pieces are given in Table 32.

Table 32. Dimensions of Fuel Pieces.

Component	Inner Radius (cm)	Outer Radius (cm)	Length (cm)
Inner Subassembly Plate			
Top Region	3.50520	4.38150	0.66040
Upper Middle Region	1.27000	4.38150	2.02184
Lower Middle Region	1.27000	3.92430	2.42570
Bottom Region	1.27000	4.38150	2.54000
Safety Block	1.27000	4.29260	7.62000
Homogenized Fuel Ring			
Outer Top Narrow Region	7.29615	8.89000	0.46104
Inner Top Narrow Region	4.44500	5.08381	0.46104
Upper Middle Narrow Region	4.44500	8.89000	2.30590
Upper Middle Wide Region	3.97510	8.89000	0.31750
Lower Middle Wide Region	3.97510	8.89000	2.10820
Lower Middle Narrow Region	4.44500	8.89000	10.37527
Inner Bottom Annulus	4.44500	5.08508	0.23026
Outer Bottom Annulus	7.29488	8.89000	0.23026
Control Rods			
Top Region (with Hole)	0.47625	1.09220	1.90500
Middle Region	—	1.09220	8.89000
Bottom Region (with Hole)	0.47625	1.09220	1.90500
Burst Rod			
Top Region (with Hole)	0.47625	1.09220	3.17500
Middle Region	—	1.09220	7.62000
Bottom Region	0.47625	1.09220	1.90500

The dimensions of the inner subassembly plate are shown in Figures 42 through 45, and the dimensions of the safety block are shown in Figure 46. The values on the right side of Figure 42 and on the right side of the lower portion of Figure 46 are the axial positions of those pieces relative to the origin of the coordinate system.

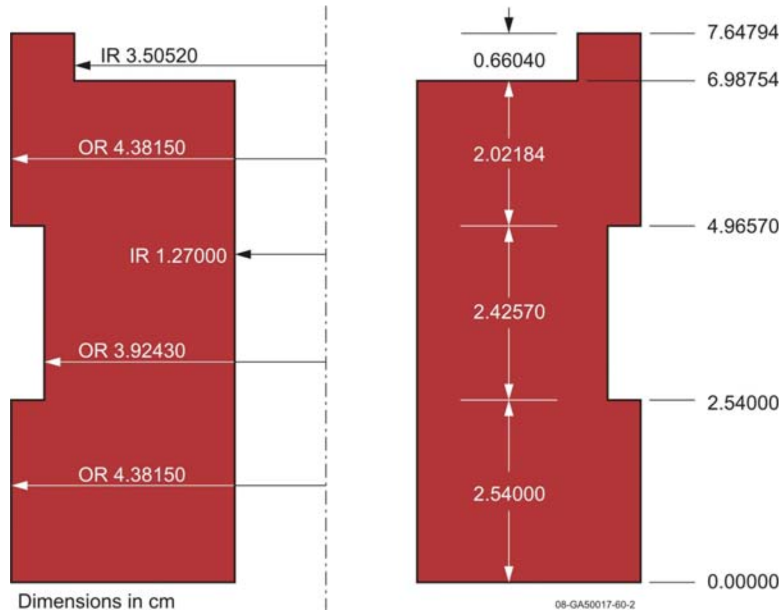

Figure 42. Vertical Slice through the Inner Subassembly Plate.

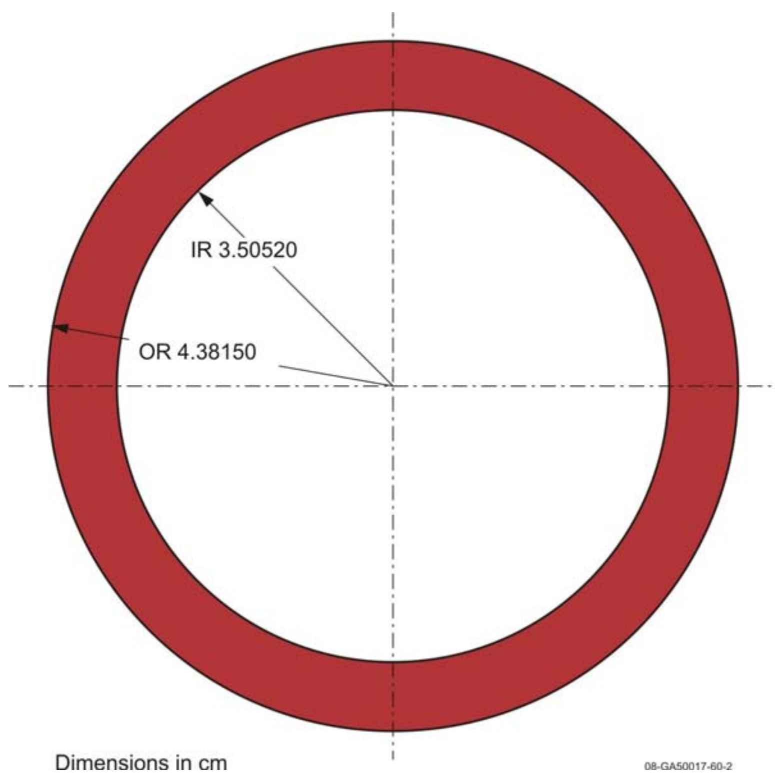

Figure 43. Horizontal Slice through the Top Portion of the Inner Subassembly Plate.

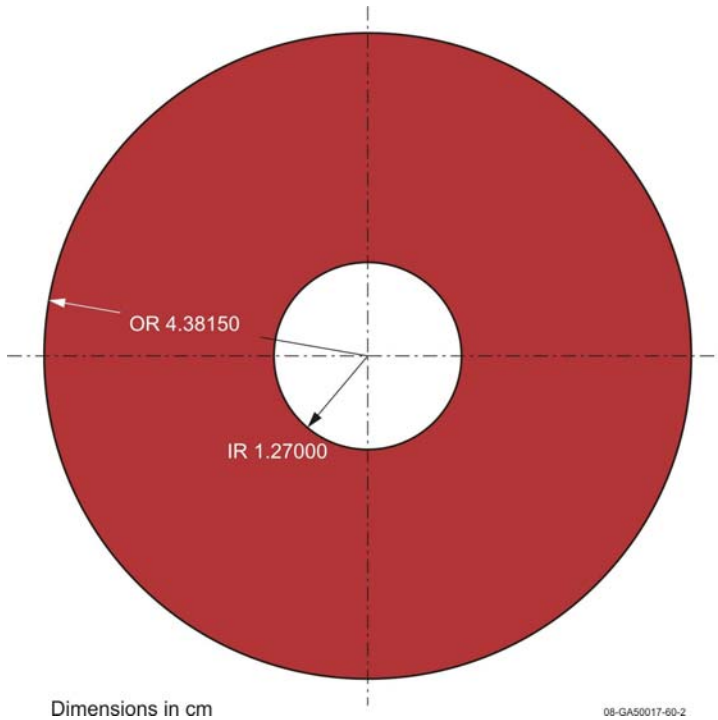

Figure 44. Horizontal Slice through the Wide Portion of the Inner Subassembly Plate.

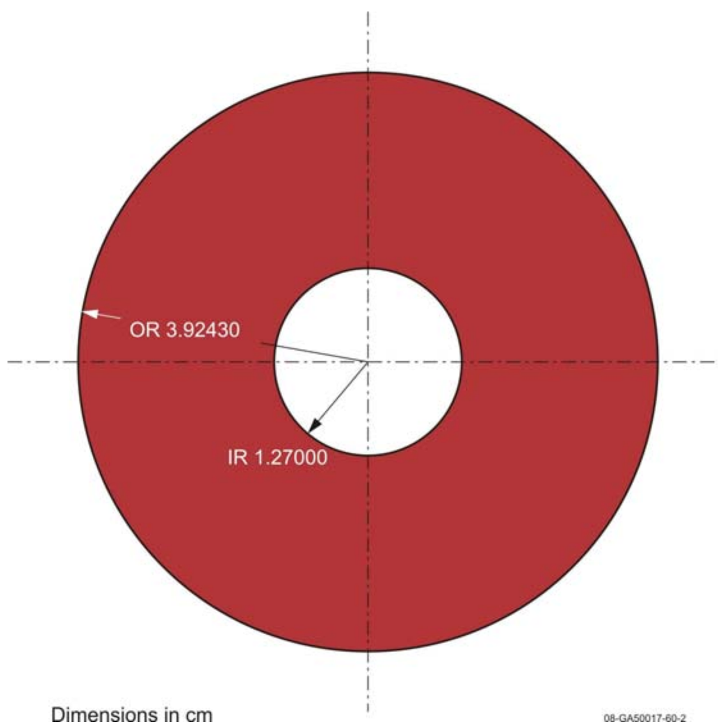

Figure 45. Horizontal Slice through the Narrow Portion of the Inner Subassembly Plate.

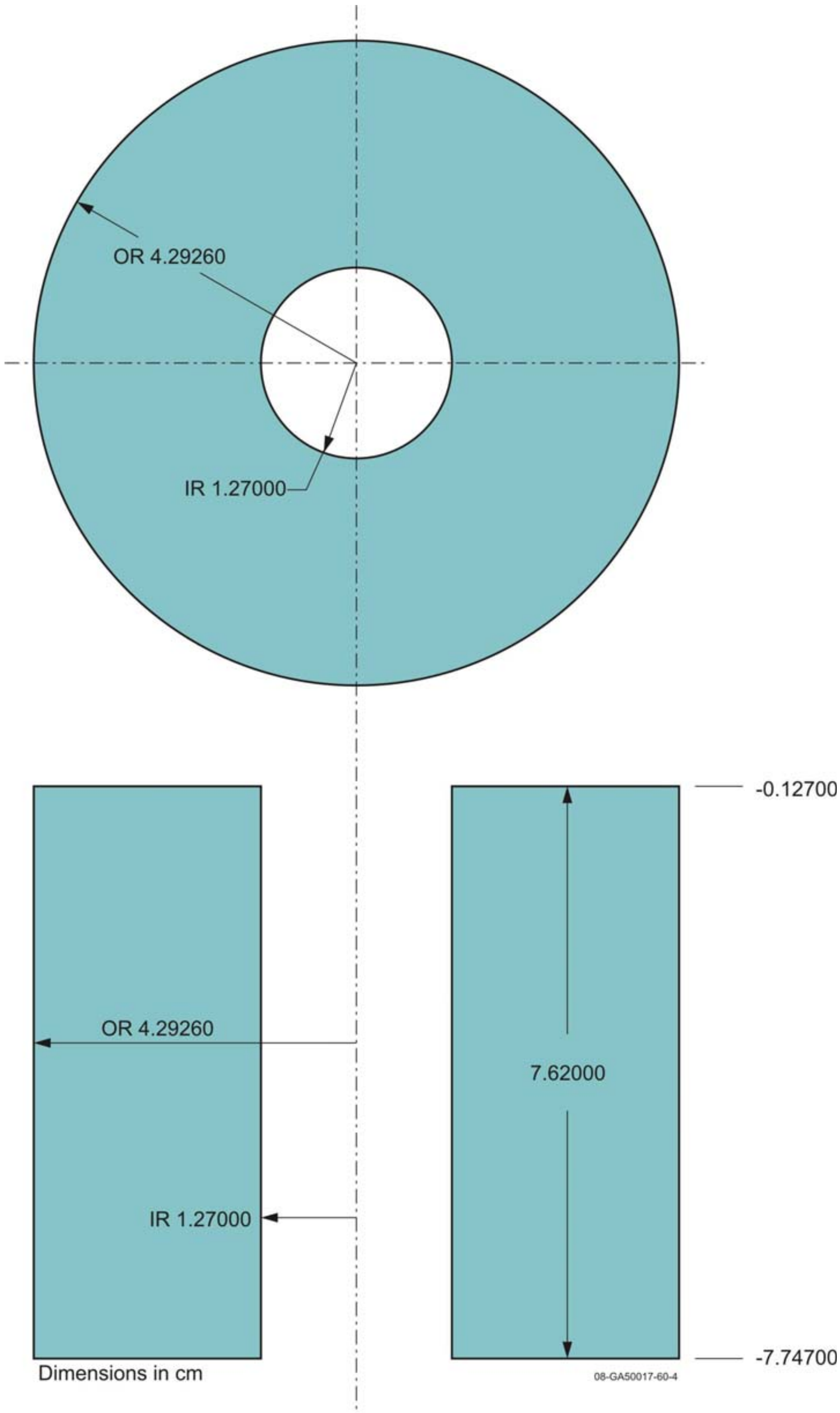

Figure 46. Horizontal and Vertical Slices through the Safety Block.

The homogenized fuel ring has internal holes to allow the passage of the control rods and the burst rod. Those holes have radii of 1.11125 cm, and their centers are 6.66750 cm from the center of the ring. The holes are located symmetrically, and the center of each hole is rotated 120° relative to the centers of the other two holes. The holes do not extend the full height of the homogenized fuel ring but instead stop 12.71373 cm above the bottom of the homogenized fuel ring.

Three notches run the entire length of the homogenized fuel ring. The notches are at the outer edge of the ring and are located symmetrically, 120° apart. One of the notches is located diametrically across from the burst rod. The notches are 2.22250 cm wide, and the horizontal distance from the center of the fuel ring to the back edge of each notch is 8.49376 cm.

Figure 47 presents a vertical slice through the homogenized fuel ring, and Figures 48 through 53 contain horizontal slices through each of the distinct axial regions of the fuel ring. The values on the right of Figures 47 and 48 are the axial elevations relative to the origin of the coordinate system.

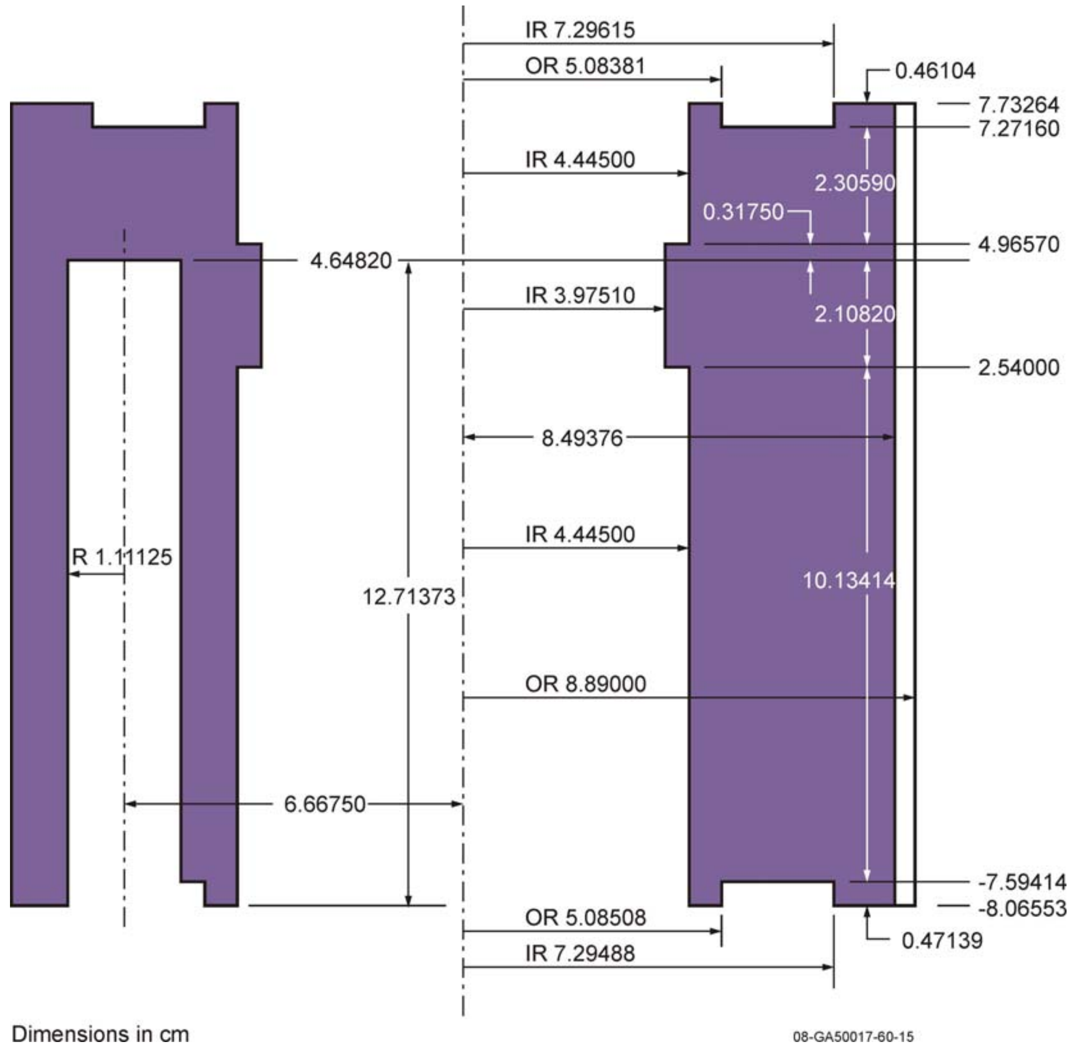

Figure 47. Vertical Slice through the Homogenized Fuel Ring.

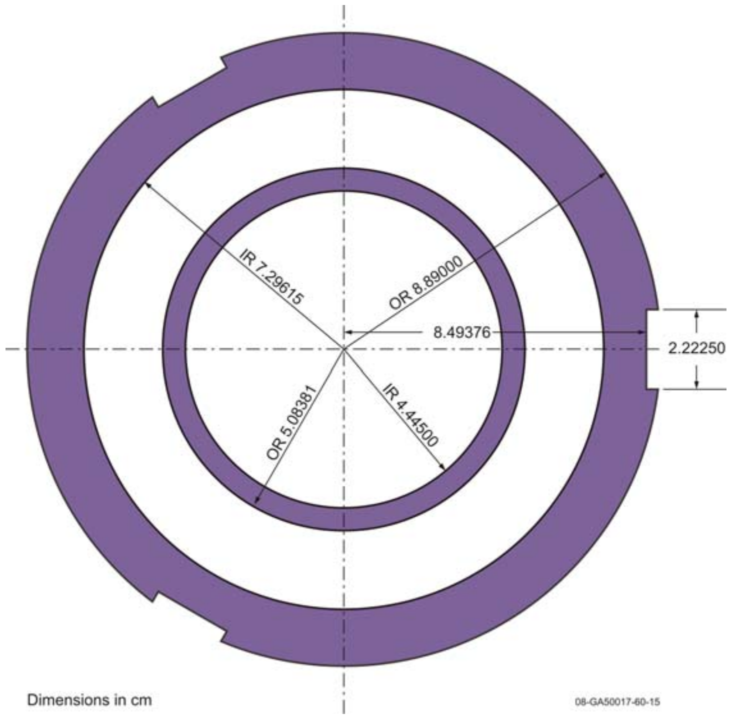

Figure 48. Horizontal Slice through the Top Region of the Homogenized Fuel Ring.

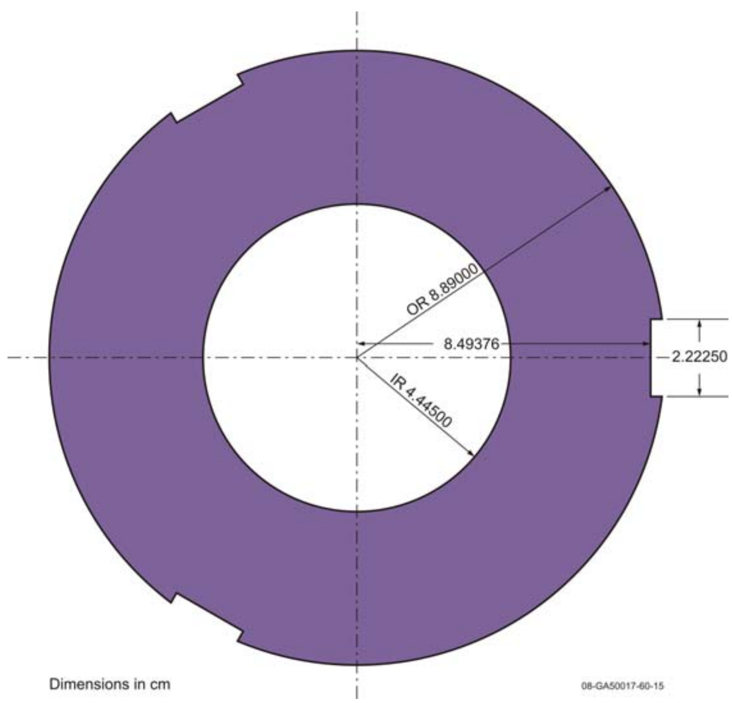

Figure 49. Horizontal Slice through the Solid Narrow Region of the Homogenized Fuel Ring.

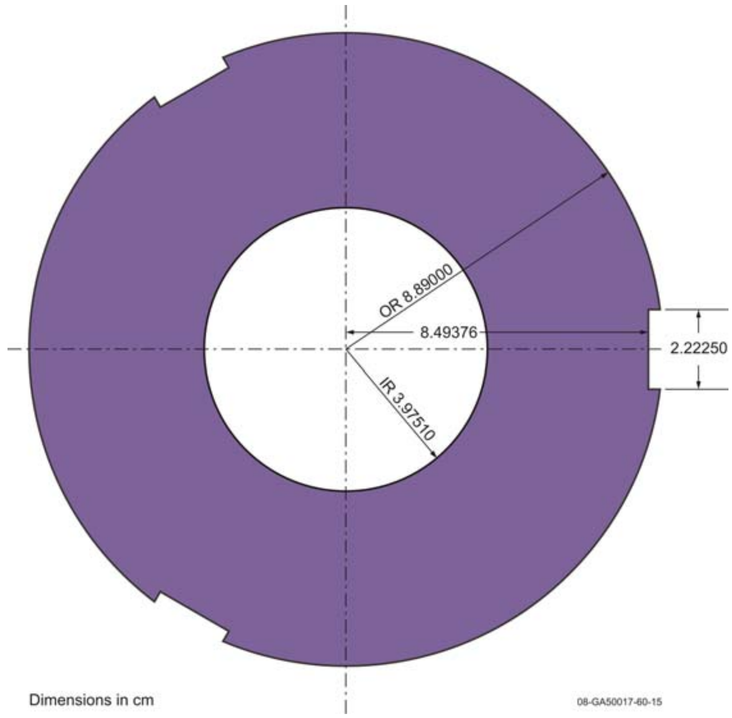

Figure 50. Horizontal Slice through the Solid Wide Region of the Homogenized Fuel Ring.

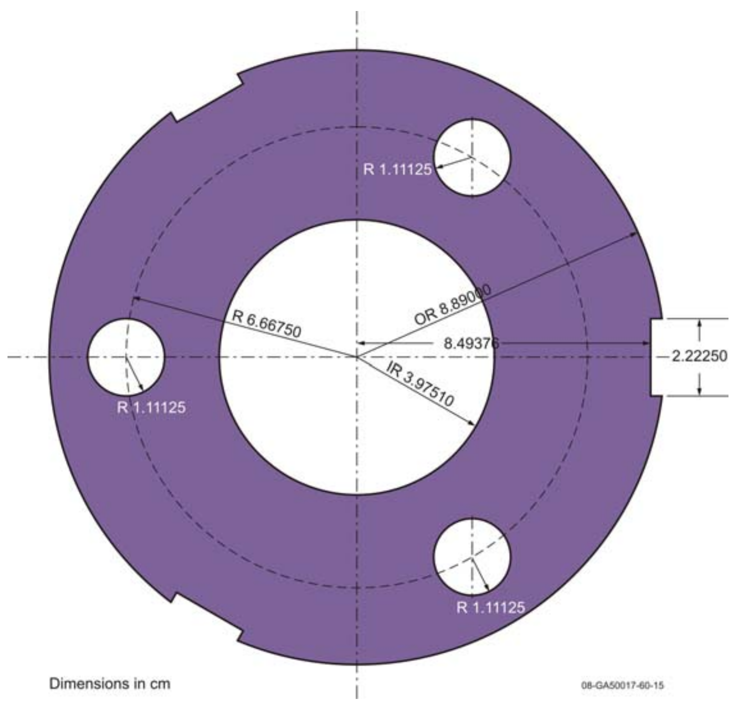

Figure 51. Horizontal Slice through the Wide Middle Region of the Homogenized Fuel Ring.

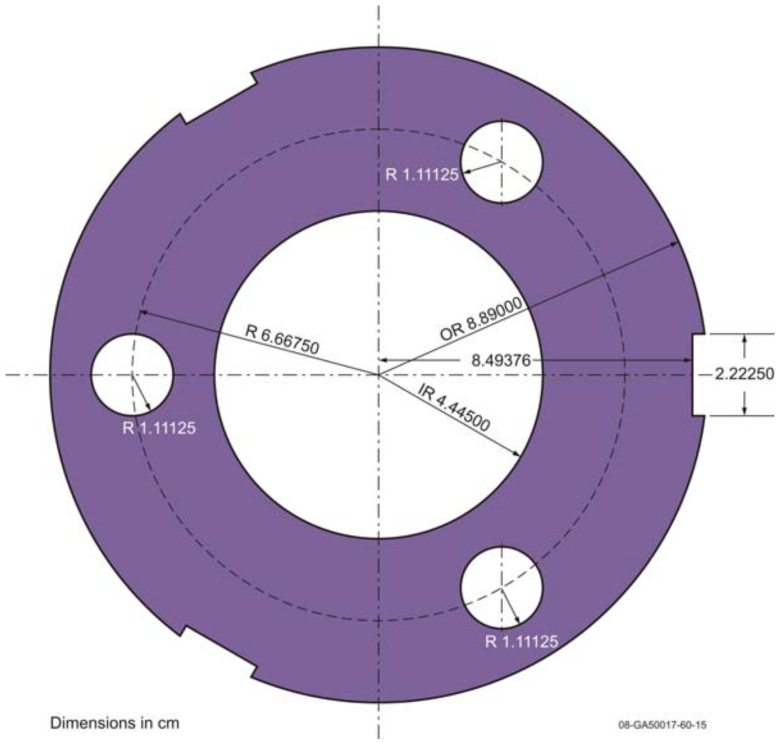

Figure 52. Horizontal Slice through the Narrow Middle Region of the Homogenized Fuel Ring.

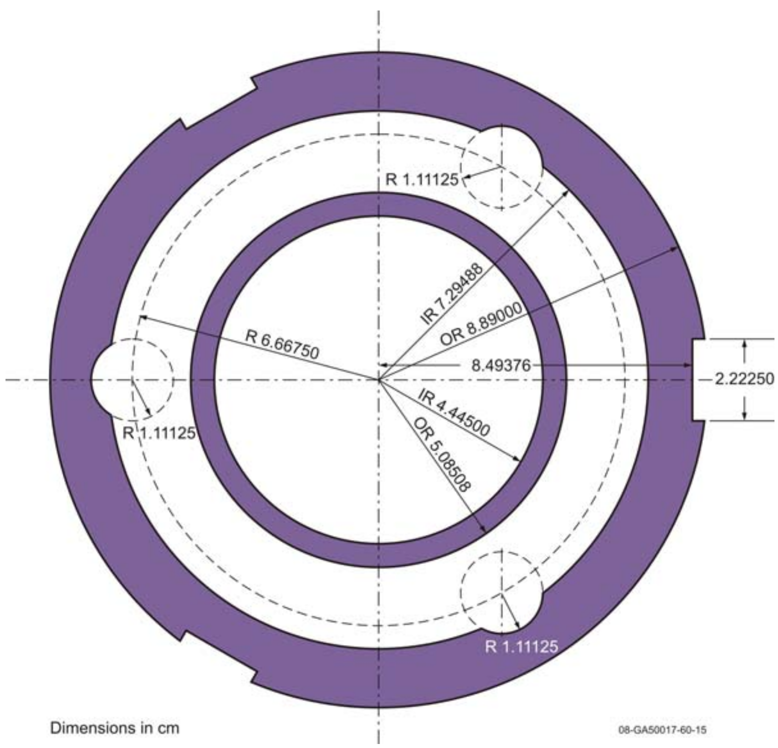

Figure 53. Horizontal Slice through the Bottom Region of the Homogenized Fuel Ring.

The horizontal locations of the control and burst rods are shown in Figure 54, along with their radial and axial dimensions.

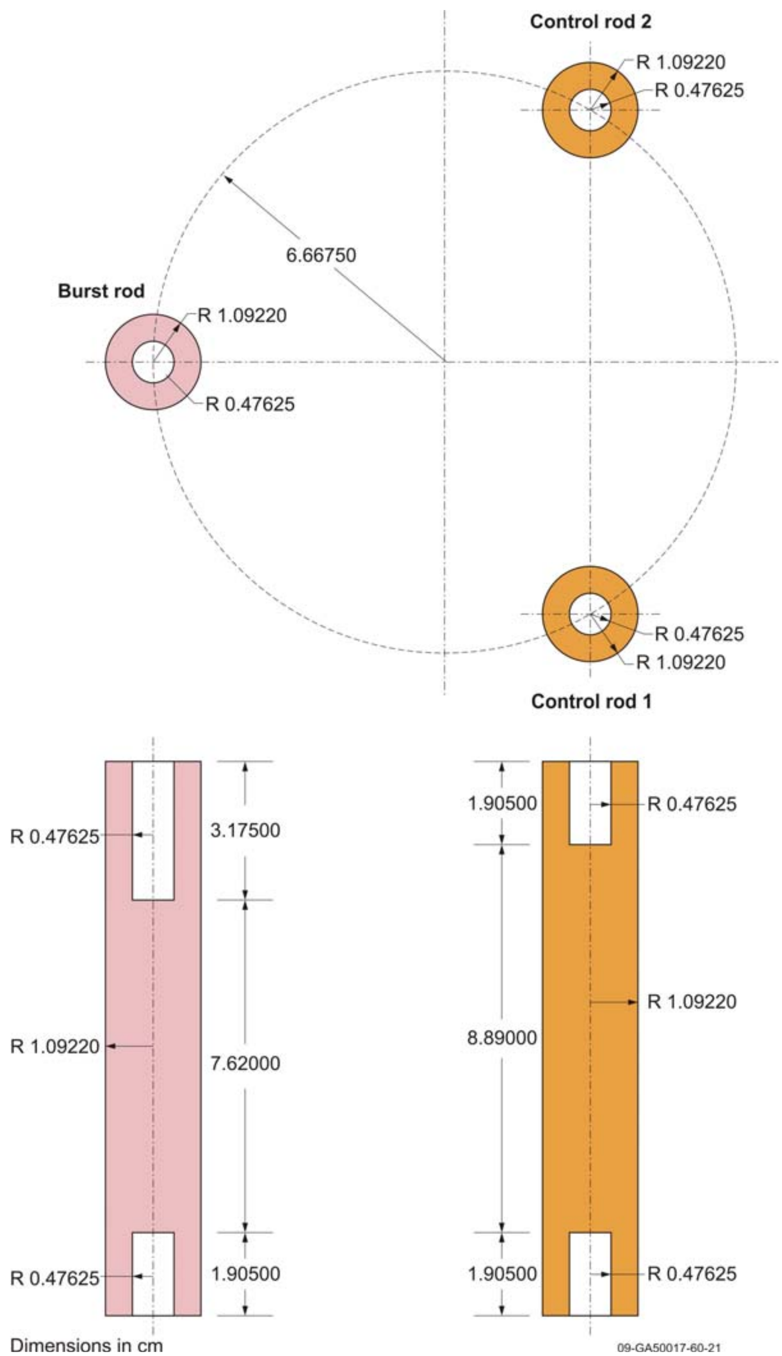

Figure 54. Horizontal and Vertical Slices through the Burst and Control Rods.

The radii and length of the cylindrical non-fuel pieces are given in Table 33. As Figures 32 and 33 indicate, portions of the circular holes for the control rods and burst rod pass through the support-pad ring. The control-rod and burst-rod holes in the support-pad ring and the mounting plate are at the same horizontal locations and have the same radii as those in the homogenized fuel ring.

Table 33. Dimensions of Cylindrical Non-Fuel Pieces.

Component	Inner Radius (cm)	Outer Radius (cm)	Length (cm)
Spindle	0.31750	1.27000	11.43000
Nut on Spindle	1.27000	2.22225	1.27000
Safety Block Base			
Top Region (Barrel)	—	1.27000	7.34300
Middle Region (Platform)	—	3.65760	1.70448
Bottom Region	—	1.90500	2.68111
Support Pad Ring	5.08508	7.29488	1.43175
Bearing Ring	5.08381	7.29615	1.48251
Subassembly Cover Plate			
Top Region	1.43510	5.08000	0.31750
Bottom Region	4.44500	5.08000	0.22264
Mounting Plate	5.23875	44.45000	3.81000

Figures 55 and 56 present vertical and horizontal slices through the spindle and the spindle nut, respectively. As usual, the values on the right side of those figures specify axial elevations relative to the origin of the coordinate system.

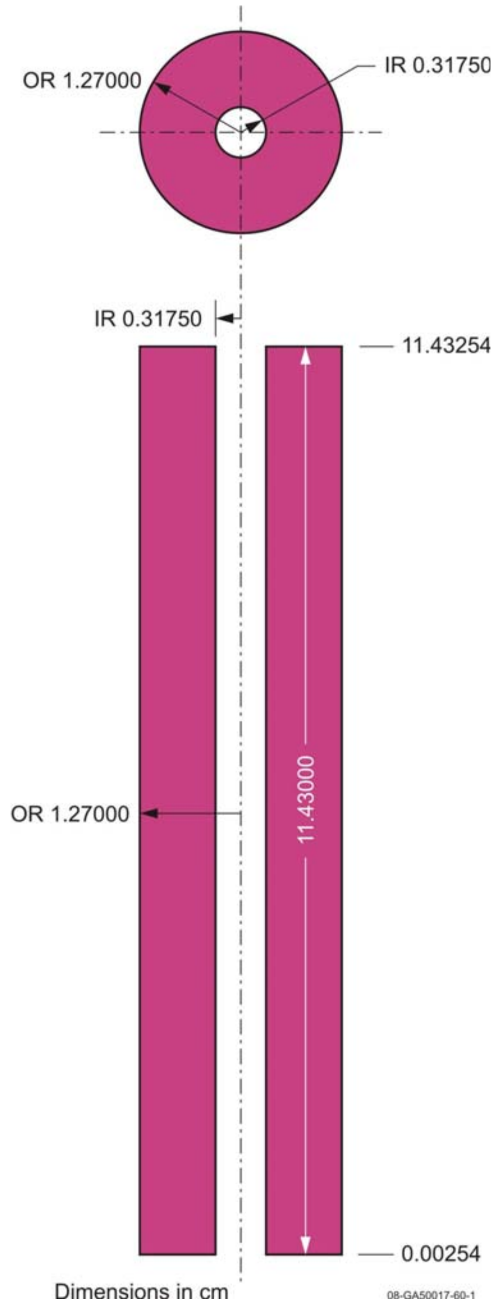

Figure 55. Horizontal and Vertical Slices through the Spindle.

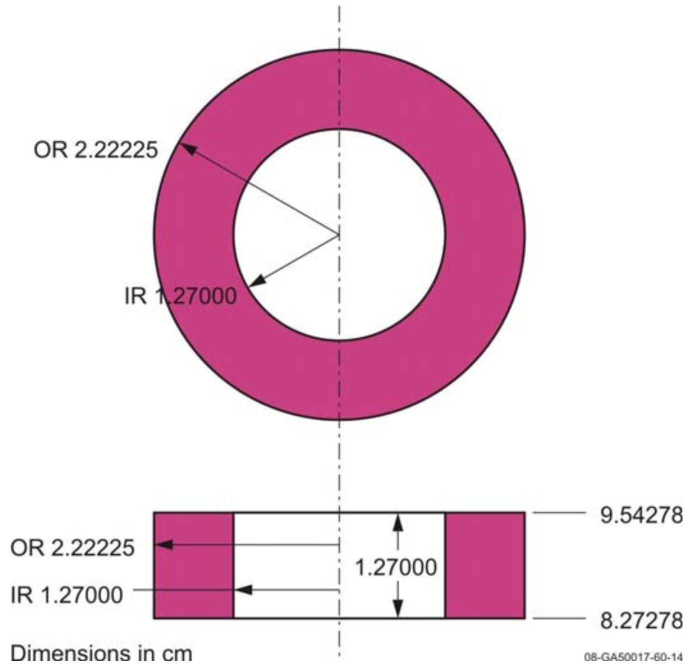

Figure 56. Horizontal and Vertical Slices through the Spindle Nut.

Figure 57 presents a collapsed horizontal depiction of the safety block base, as well as a vertical slice through it. The values to the right of the vertical slice are the axial elevations relative to the origin of the coordinate system.

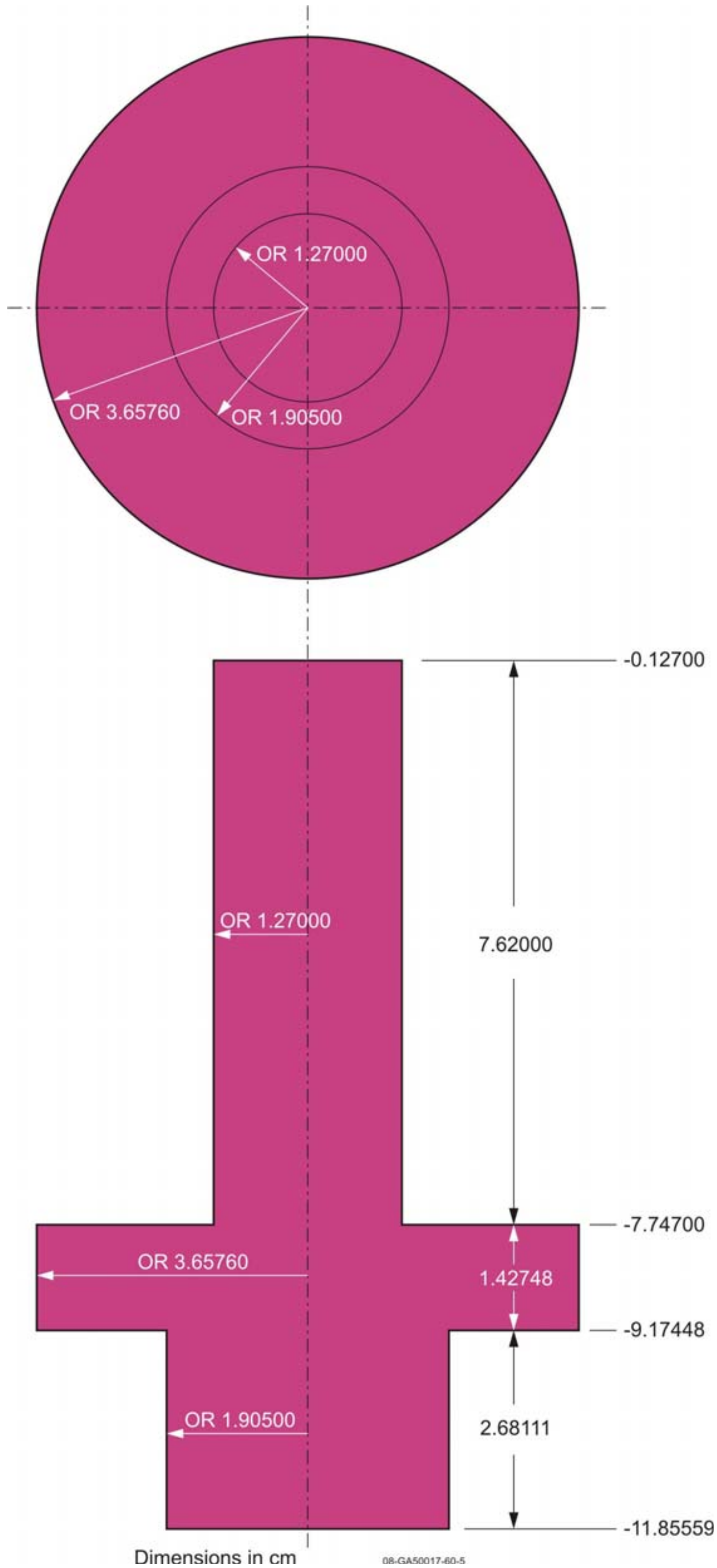

Figure 57. Compacted Horizontal View and Vertical Slice through the Safety Block Base.

Figure 58 presents horizontal and vertical slices through the support-pad ring. As the figure indicates, the ring contains holes to allow passage of the control rods and burst rod. Values to the right of the vertical slice are the axial elevations relative to the origin of the coordinate system.

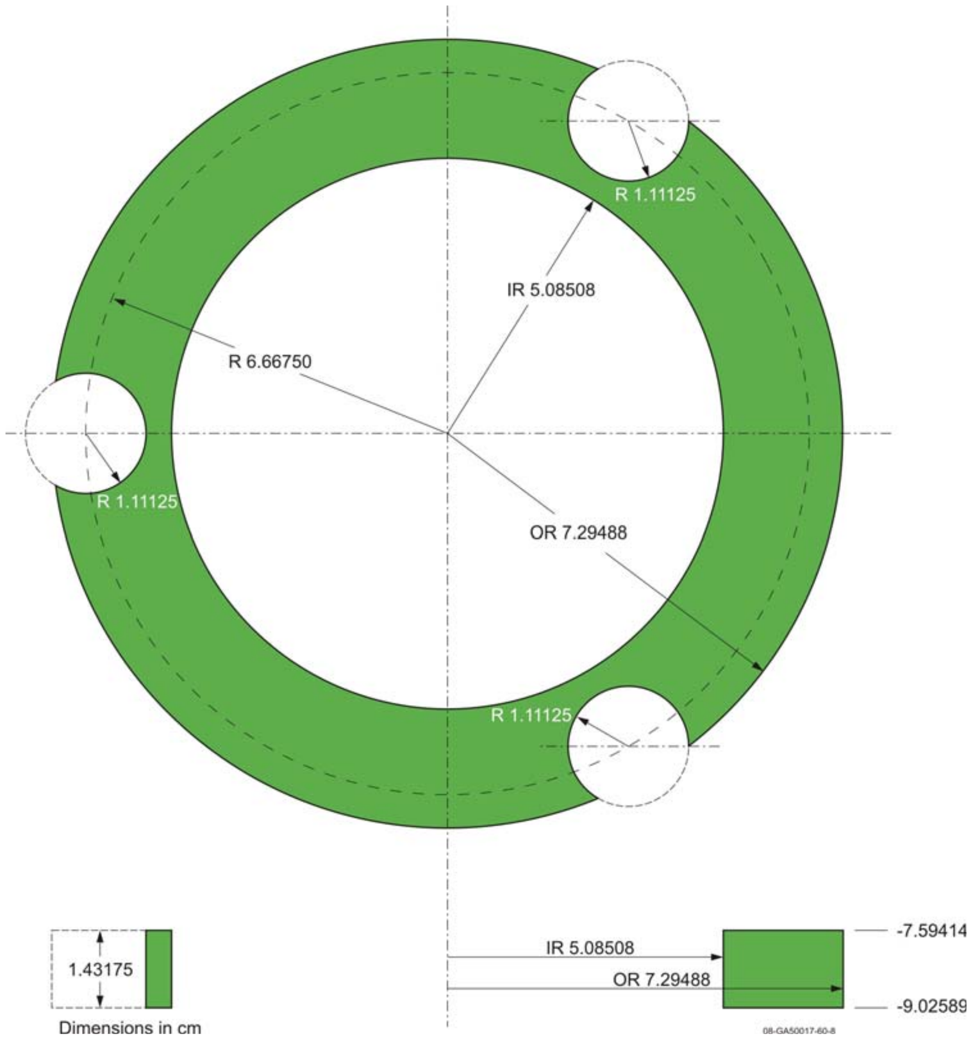

Figure 58. Horizontal and Vertical Slices through the Support Pad Ring.

Figure 59 presents vertical and horizontal slices through the bearing ring. As usual, the values to the right of the vertical slice are the axial elevations relative to the origin of the coordinate system.

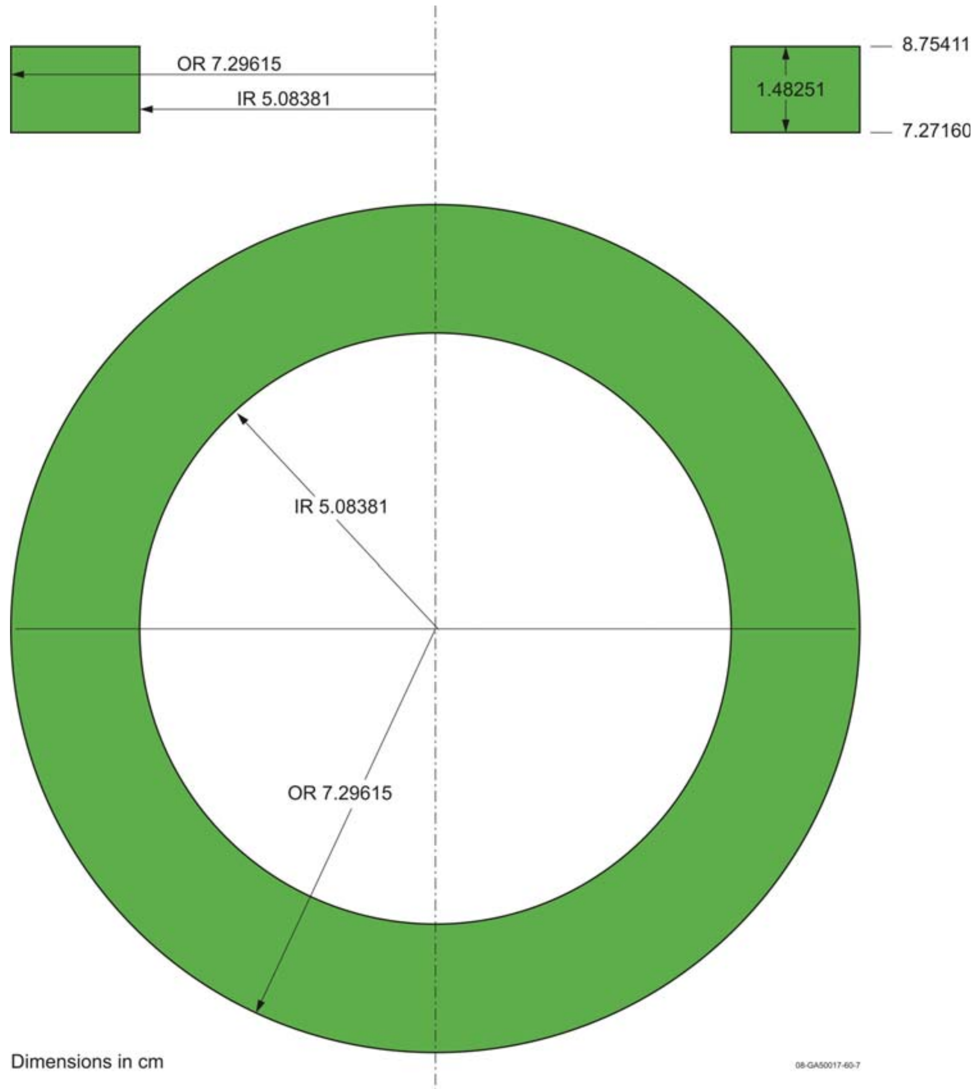

Figure 59. Vertical and Horizontal Slices through the Bearing Ring.

Figure 60 presents a vertical slice through the subassembly cover plate, while Figures 61 and 62 present horizontal slices through its two distinct axial regions. The values to the right of the vertical slice are the axial elevations relative to the origin of the coordinate system.

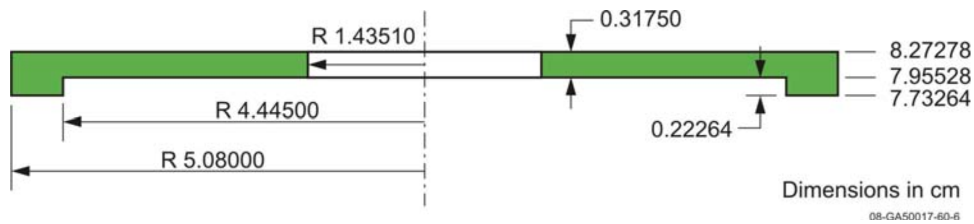

Figure 60. Vertical Slice through the Subassembly Cover Plate.

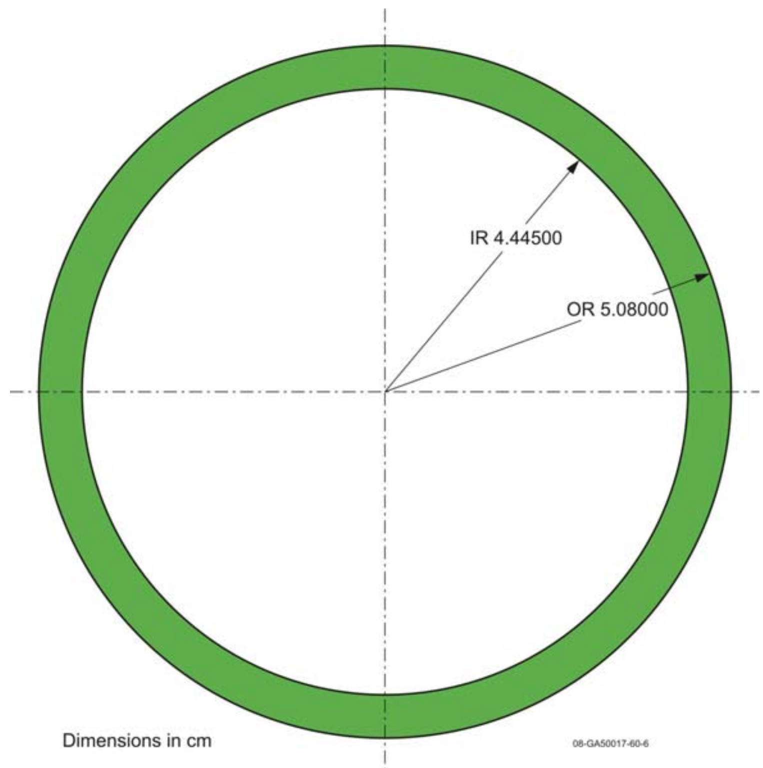

Figure 61. Horizontal Slice through the Thin Region of the Subassembly Cover Plate.

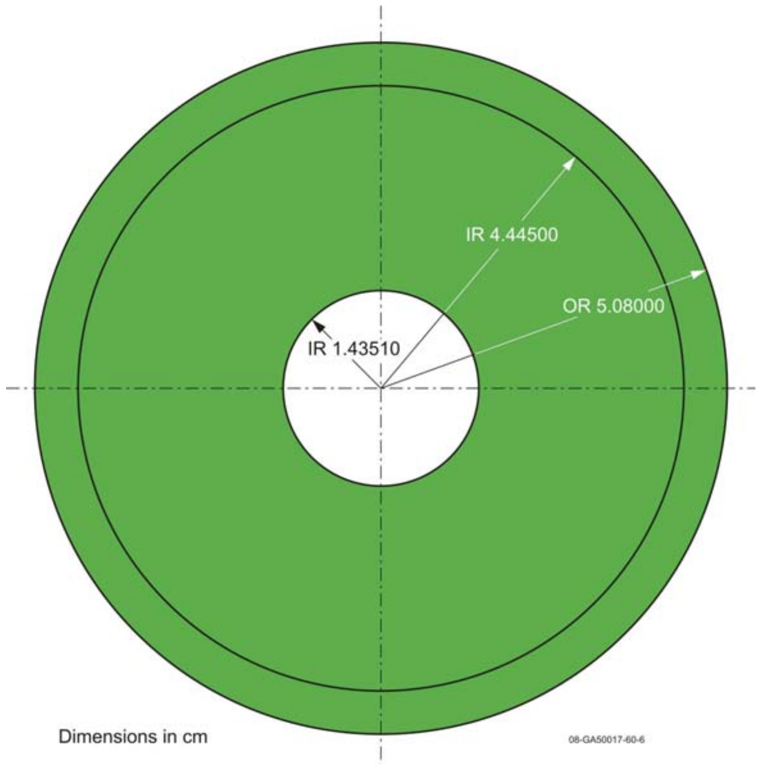

Figure 62. Horizontal Slice through the Thick Region of the Subassembly Cover Plate.

Figure 63 presents horizontal and vertical slices through the mounting plate. As the figure indicates, it contains a large central hole for the safety block to pass through as well as three smaller holes for the control and burst rods. Values to the right of the vertical slice are the axial elevations relative to the origin of the coordinate system.

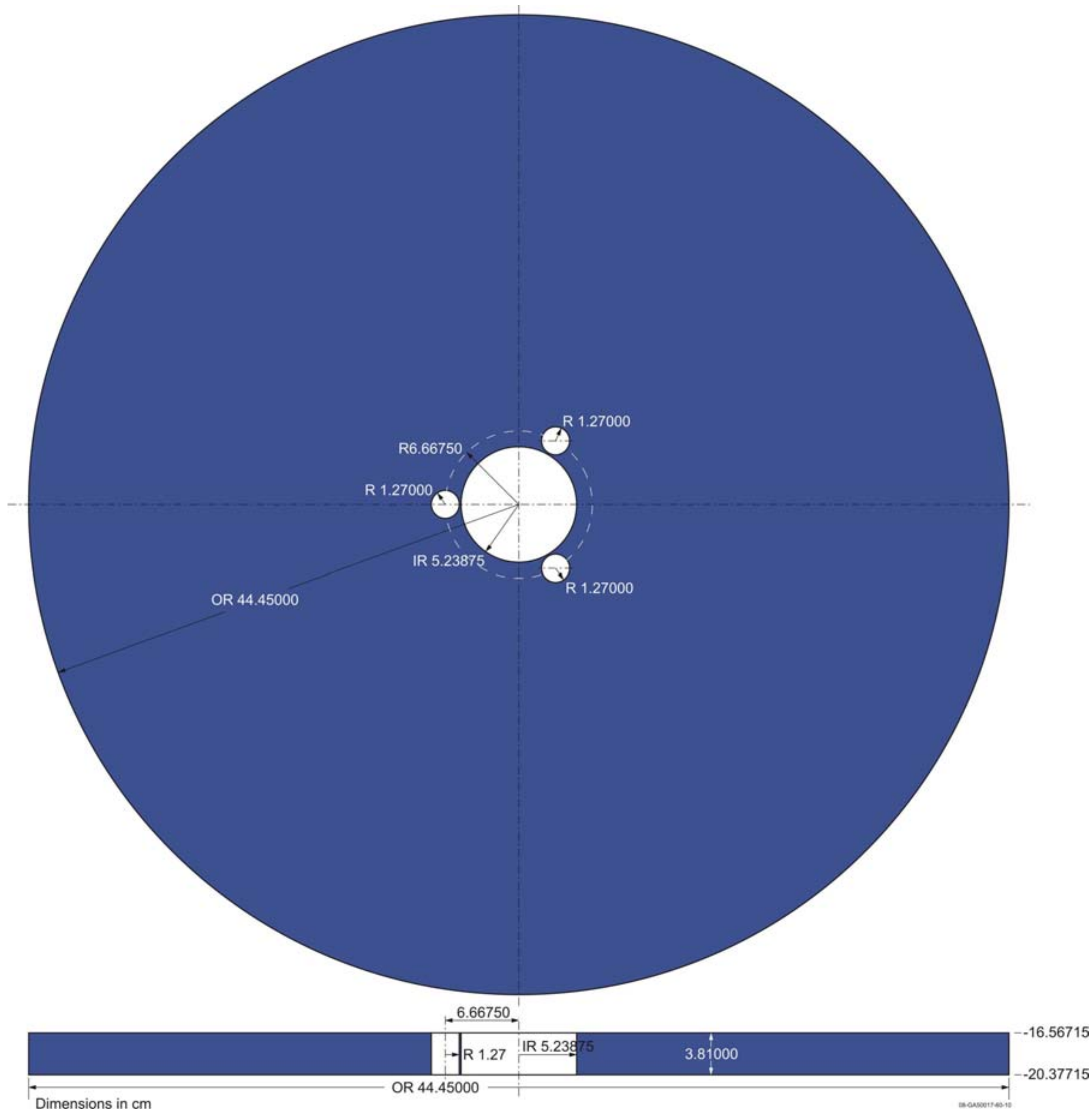

Figure 63. Horizontal and Vertical Slices through the Mounting Plate.

The dimensions for the rectangular clamps and clamp supports are given in Table 34.

Table 34. Dimensions of Clamps and Clamp Supports.

Component	Width (cm)	Thickness (cm)	Height (cm)
Clamps			
Top Prong	7.86130	2.22250	3.64998
Middle Region	4.44500	2.22250	17.78000
Bottom Prong	7.86130	2.22250	3.64998
Clamp Supports	6.00000	2.85750	20.95500

The clamps fit into the notches on the exterior surface of the homogenized fuel ring, and the clamp supports fit snugly against the back edge of the clamps. However, there is a small gap between the back of the notch and the front edge of the middle portion of the clamp. The horizontal distance from the center of the fuel ring to the flat front surface of the middle region of the clamp is 8.49630 cm. Consequently, there is a gap of 0.00254 cm between the back edge of the notch and the front edge of the middle region of the clamp.

Horizontal and vertical slices through a clamp and a clamp support are given in Figures 64 and 65, respectively. As usual, the values to the right of the vertical slices are axial elevations relative to the origin of the coordinate system.

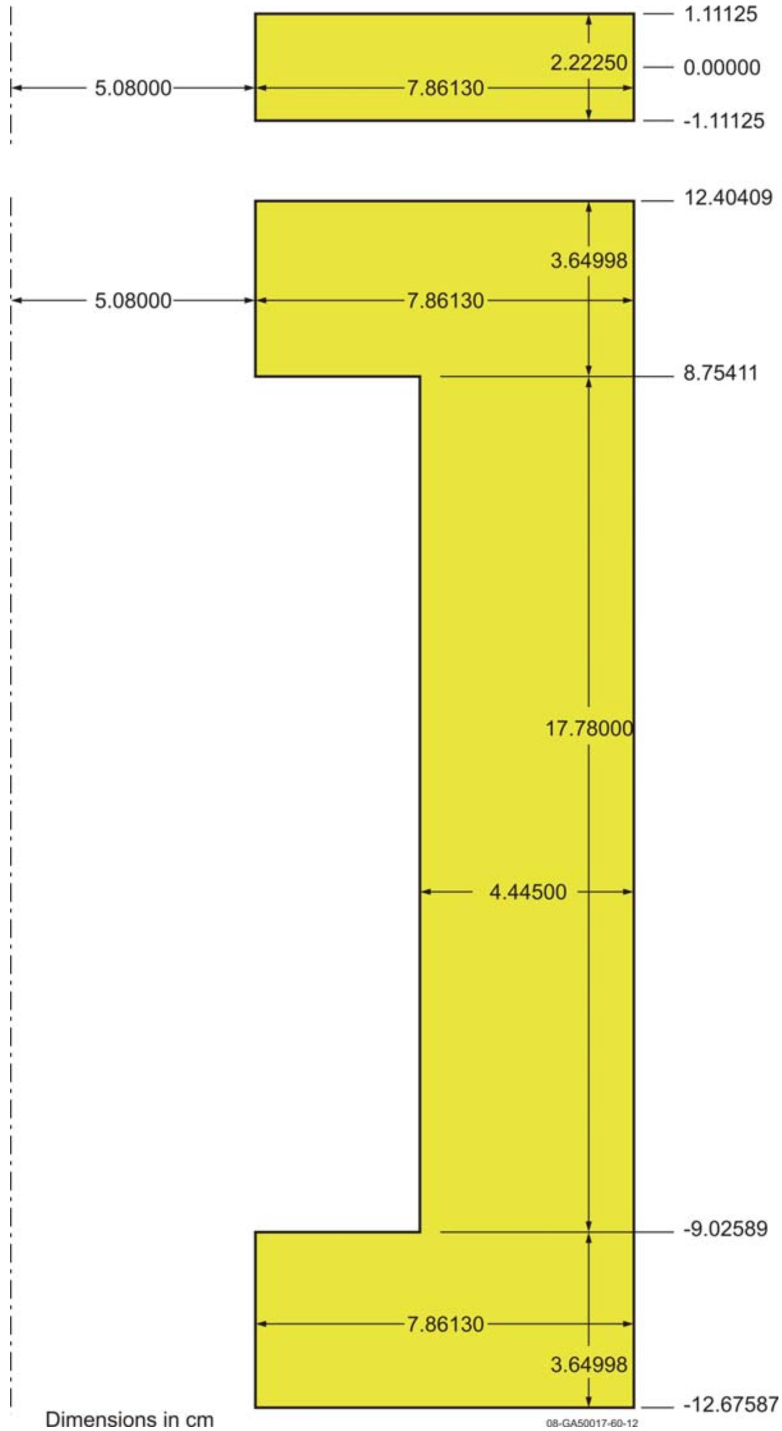

Figure 64. Horizontal and Vertical Slices through a Clamp.

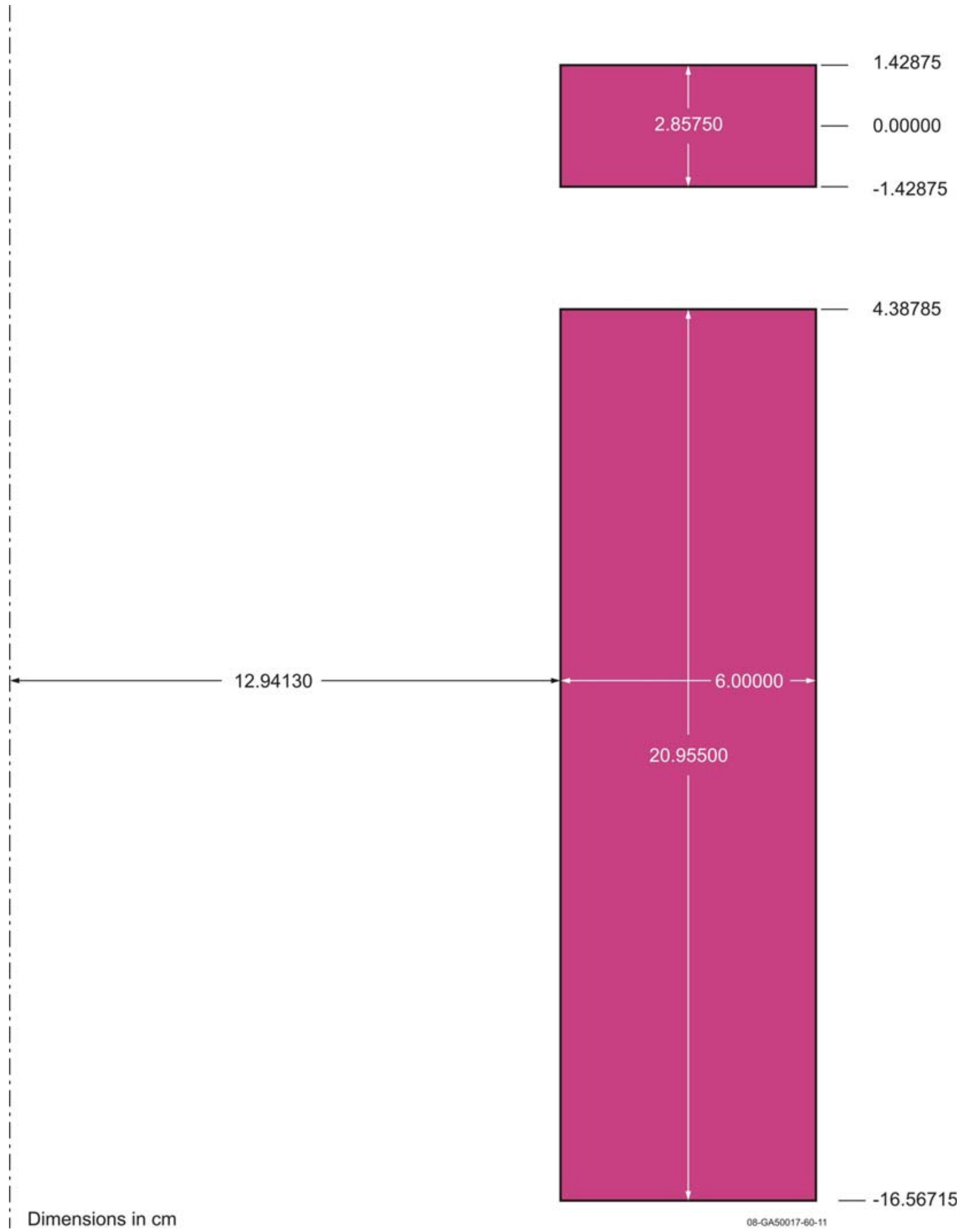

Figure 65. Horizontal and Vertical Slices through a Clamp Support.

3.3 Material Data

3.3.1 Fuel - As discussed in Section 3.1.2, the geometric and material simplifications for the benchmark model produce five distinct fuel components: the safety block, the homogenized inner subassembly plate, the homogenized fuel ring, the two identical control rods, and the burst rod. Although the densities of the components changed during that process, the masses and overall isotopic fractions have been preserved.
The mass of each fuel piece was given in Table 7, and the uranium masses and enrichments of those pieces were given in Table 8. The molybdenum masses were given in Table 18, and the basis for the isotopic content of ^{233}U, ^{234}U, ^{236}U, and ^{238}U was discussed in Section 2.2. That information, in conjunction with the volumes derived from the dimensions provided in Figures 42 through 54, produces the number densities given in Table 35.

Table 35. Concentrations for Fuel Pieces.

Region → Nuclide ↓	Number Density (atoms/b-cm)				
	Safety Block	ISP	Ring	Control Rods	Burst Rod
Molybdenum	1.1384×10^{-3}	1.7407×10^{-3}	1.7082×10^{-3}	1.5385×10^{-3}	1.5701×10^{-3}
^{233}U	4.6322×10^{-6}	4.6755×10^{-6}	4.6484×10^{-6}	4.6812×10^{-6}	4.7893×10^{-6}
^{234}U	4.7005×10^{-4}	4.7433×10^{-4}	4.7159×10^{-4}	4.7497×10^{-4}	4.8594×10^{-4}
^{235}U	4.2791×10^{-2}	4.3187×10^{-2}	4.2930×10^{-2}	4.3238×10^{-2}	4.4237×10^{-2}
^{236}U	3.1098×10^{-4}	3.1388×10^{-4}	3.1206×10^{-4}	3.1427×10^{-4}	3.2152×10^{-4}
^{238}U	2.3222×10^{-3}	2.3464×10^{-3}	2.3398×10^{-3}	2.3514×10^{-3}	2.4057×10^{-3}

3.3.2 Stainless Steel 303 - The spindle, spindle nut, safety-block base, and the clamp supports all are made of stainless steel 303. The composition of stainless steel 303 is based on the information in Table 10 from MatWeb. Elements for which a maximum content was given were taken to be at half of that value, elements for which a minimum content was given were taken to be at twice that value, and elements for which a range was provided were taken to be at the midpoint of that range.

The remainder was taken to be iron. That composition, in combination with a presumed density of 8.0 g/cm^3, produces the elemental number densities in Table 36.

Table 36. Elemental Concentrations for Stainless Steel 303.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.075	3.0083×10^{-4}
Silicon	1.00	1.7154×10^{-3}
Phosphorus	0.10	1.5554×10^{-4}
Sulfur	0.30	4.5067×10^{-4}
Chromium	18.00	1.6678×10^{-2}
Manganese	1.00	8.7693×10^{-4}
Iron	70.225	6.0580×10^{-2}
Nickel	9.00	7.3878×10^{-3}
Molybdenum	0.30	1.5065×10^{-4}

3.3.3 VascoMax 300 Maraging Steel - The clamps are made from VascoMax 300 maraging steel, and its composition was given in Table 11. When the iron concentration is reduced slightly to conserve the overall content, the concentrations in Table 37 are obtained. That composition, in combination with the given density of 8 g/cm^3, produces the elemental number densities in that same table.

Table 37. Elemental Concentrations for VascoMax 300 Maraging Steel.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.020	8.0221×10^{-5}
Aluminum	0.100	1.7855×10^{-4}
Silicon	0.050	8.5768×10^{-5}
Phosphorus	0.005	7.7770×10^{-6}
Sulfur	0.005	7.5112×10^{-6}
Ttanium	0.730	7.3453×10^{-4}
Manganese	0.050	4.3847×10^{-5}
Iron	66.940	5.7746×10^{-2}
Cobalt	8.800	7.1938×10^{-3}
Nickel	18.500	1.5186×10^{-2}
Molybdenum	4.800	2.4103×10^{-3}

3.3.4 SAE 4340 - The subassembly cover plate, the bearing ring, and the support-pad ring are made from SAE 4340. The composition for SAE 4340 is taken to be an amalgam of the information from the *Metals Handbook Desktop Edition* and the *ASM Metals Reference Book* in Table 12. Once again, maximum values for elements were halved, elements for which a range was given were taken to be at the midpoint of that range, and the remainder was taken to be iron. The resulting composition, in combination with a presumed density of 7.85 g/cm^3, produces the elemental number densities in Table 38.

Table 38. Elemental Concentrations for SAE 4340.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.405	1.5940×10^{-3}
Silicon	0.225	3.7872×10^{-4}
Phosphorus	0.018	2.7472×10^{-5}
Sulfur	0.020	2.9481×10^{-5}
Chromium	0.800	7.2734×10^{-4}
Manganese	0.725	6.2385×10^{-4}
Iron	95.757	8.1057×10^{-2}
Nickel	1.800	1.4499×10^{-3}
Molybdenum	0.250	1.2319×10^{-4}

3.3.5 Aluminum - It was shown in Section 3.1.2 that the composition of the mounting plate can be taken to be pure aluminum in place of its actual material, Al 6061-T6. The composition of Al 6061-T6 was given in Table 13, and its nominal density is 2.70 g/cm^3. If each of the components other than aluminum is taken to be at the middle of its range, aluminum constitutes 97.23 wt.% of the Al 6061-T6. Consequently, the density of the aluminum is 2.62521 g/cm^3, which corresponds to a number density of 5.8593×10^{-2} atoms/b-cm.

3.4 Temperature Data

The measured ambient temperatures for the four delayed-critical configurations ranged from 18.9 °C to 19.2 °C, while the initial temperature for super-prompt-critical configuration was 20.5 °C. Doppler effects are irrelevant for configurations with fast spectra, and the reactivity effects of thermal expansion from a temperature change of approximately 1 °C are negligible. Consequently, calculations that employ cross sections at 20°C are adequate for these benchmarks.

3.5 Experimental and Benchmark-Model k_{eff}

As discussed in Section 2.4, the measured periods for the four delayed-critical conditions were effectively infinite. Consequently, the measured value for k_{eff} for all four of those configurations is 1.0000 with negligible uncertainty.

The Godiva-IV assembly contains no neutron source, and consequently it typically sits in a static but super-prompt-critical condition for several seconds before a neutron from spontaneous fission produces a divergent chain reaction. It is that static super-prompt-critical condition that constitutes the fifth benchmark. Based on the discussion in Section 2.4, the measured value for k_{eff} for that configuration is 1.0066 ± 0.0003.

The uncertainty studies in Section 2 produce an associated uncertainty of ± 0.0026 Δk for all five configurations. Consequently, the experimental value of k_{eff} for the four delayed-critical configurations is 1.0000 ± 0.0026, and the experimental value of k_{eff} for the static super-prompt-critical configuration is 1.0066 ± 0.0026.

Table 39 compares the calculated values of k_{eff} from the detailed and benchmark models in order to obtain a bias. Cases 1, 2, and 3 produce marginally negative biases, and cases 4 and 5 produce statistically insignificant biases. However, there is no compelling reason to expect the bias between the benchmark and detailed models to be unique to each particular case. Consequently, an average bias for all five cases probably is more representative than a case-specific bias. Accordingly, a uniform bias of -0.0004 with an associated standard deviation of ± 0.0004 is applied to the difference in k_{eff} between the benchmark and detailed models. Therefore, the benchmark value of k_{eff} for the four delayed-critical cases is 0.9996 ± 0.0026, and the benchmark value of k_{eff} for the static super-prompt-critical case is 1.0062 ± 0.0026.

Table 39. Calculated Results from Detailed and Benchmark Models to Obtain Bias.

Case	Calculated k_{eff}		Δk (Bias)
	Detailed	Benchmark	
1	0.9937 ± 0.0003	0.9931 ± 0.0003	-0.0006 ± 0.0004
2	0.9939 ± 0.0003	0.9933 ± 0.0003	-0.0006 ± 0.0004
3	0.9946 ± 0.0003	0.9940 ± 0.0003	-0.0006 ± 0.0004
4	0.9952 ± 0.0003	0.9948 ± 0.0003	-0.0004 ± 0.0004
5	1.0000 ± 0.0003	1.0003 ± 0.0003	0.0003 ± 0.0004

The impact of the simplifications that produce the benchmark value for k_{eff} can be evaluated further by comparing the distributions of the neutrons that cause fission and the number of fission neutrons they produce. Such comparisons are provided in Tables 40 through 44. Those comparisons clearly demonstrate the neutronic equivalence of the corresponding benchmark and detailed models.

Table 40. Comparison of Calculated Results from Detailed and Benchmark Models for Case 1.

Parameter		Model: Detailed	Model: Benchmark
k_{eff}		0.9937 ± 0.0003	0.9931 ± 0.0003
Fission Distribution, by Energy	Fast	0.9441	0.9444
	Intermediate	0.0559	0.0556
	Thermal	0.0	0.0
Fission Fraction, by Isotope	^{233}U	0.0002	0.0002
	^{234}U	0.0084	0.0084
	^{235}U	0.9807	0.9807
	^{236}U	0.0023	0.0023
	^{238}U	0.0084	0.0084
Average Number of Neutrons Produced per Fission		2.593	2.593

Table 41. Comparison of Calculated Results from Detailed and Benchmark Models for Case 2.

Parameter		Model	
		Detailed	Benchmark
k_{eff}		0.9939 ± 0.0003	0.9933 ± 0.0003
Fission Distribution, by Energy	Fast	0.9439	0.9443
	Intermediate	0.0561	0.0557
	Thermal	0.0	0.0
Fission Fraction, by Isotope	^{233}U	0.0002	0.0002
	^{234}U	0.0084	0.0084
	^{235}U	0.9807	0.9807
	^{236}U	0.0023	0.0023
	^{238}U	0.0084	0.0084
Average Number of Neutrons Produced per Fission		2.593	2.593

Table 42. Comparison of Calculated Results from Detailed and Benchmark Models for Case 3.

Parameter		Model	
		Detailed	Benchmark
k_{eff}		0.9946 ± 0.0003	0.9940 ± 0.0003
Fission Distribution, by Energy	Fast	0.9439	0.9444
	Intermediate	0.0561	0.0556
	Thermal	0.0	0.0
Fission Fraction, by Isotope	^{233}U	0.0002	0.0002
	^{234}U	0.0084	0.0084
	^{235}U	0.9807	0.9807
	^{236}U	0.0023	0.0023
	^{238}U	0.0084	0.0084
Average Number of Neutrons Produced per Fission		2.593	2.593

Table 43. Comparison of Calculated Results from Detailed and Benchmark Models for Case 4.

Parameter		Model	
		Detailed	Benchmark
k_{eff}		0.9952 ± 0.0003	0.9948 ± 0.0003
Fission Distribution, by Energy	Fast	0.9440	0.9443
	Intermediate	0.0560	0.0557
	Thermal	0.0	0.0
Fission Fraction, by Isotope	^{233}U	0.0002	0.0002
	^{234}U	0.0084	0.0084
	^{235}U	0.9807	0.9807
	^{236}U	0.0023	0.0023
	^{238}U	0.0084	0.0084
Average Number of Neutrons Produced per Fission		2.593	2.593

Table 44. Comparison of Calculated Results from Detailed and Benchmark Models for Case 5.

Parameter		Model	
		Detailed	Benchmark
k_{eff}		1.0000 ± 0.0003	1.0003 ± 0.0003
Fission Distribution, by Energy	Fast	0.9438	0.9441
	Intermediate	0.0562	0.0559
	Thermal	0.0	0.0
Fission Fraction, by Isotope	^{233}U	0.0002	0.0002
	^{234}U	0.0084	0.0084
	^{235}U	0.9807	0.9807
	^{236}U	0.0023	0.0023
	^{238}U	0.0084	0.0084
Average Number of Neutrons Produced per Fission		2.593	2.593

4.0 RESULTS OF SAMPLE CALCULATIONS

Results from the MCNP5[a] and TRIPOLI4[b,c] Monte Carlo codes with a variety of nuclear data libraries are presented in Table 45 .

Table 45a. Sample Calculation Results (United States).

Codes (Cross-Section Library)→ Case ↓	MCNP (Continuous Energy ENDF/B-VI)	MCNP (Continuous Energy ENDF/B-VII.0)
1	0.9931 ± 0.0003	0.9960 ± 0.0003
2	0.9933 ± 0.0003	0.9962 ± 0.0003
3	0.9940 ± 0.0003	0.9970 ± 0.0003
4	0.9948 ± 0.0003	0.9979 ± 0.0003
5	1.0003 ± 0.0003	1.0028 ± 0.0003

Table 45b. Sample Calculation Results (France).

Codes (Cross-Section Library)→ Case ↓	TRIPOLI4 (Continuous Energy ENDF/B-VI)	TRIPOLI4 (Continuous Energy ENDF/B-VII.0)
1	0.9917 ± 0.0004	0.9952 ± 0.0004
2	0.9932 ± 0.0004	0.9960 ± 0.0004
3	0.9933 ± 0.0004	0.9957 ± 0.0004
4	0.9939 ± 0.0004	0.9976 ± 0.0004
5	0.9991 ± 0.0004	1.0026 ± 0.0004

---

[a] X-5 Monte Carlo Team, "MCNP — A General Monte Carlo N-Particle Transport Code, Version 5, Volume I: Overview and Theory," LA-UR-03-1987, Los Alamos National Laboratory (April 2003).

[b] O. Petit, F.- X. Hugot, Y.- K. Lee, C. Jouanne, and A. Mazzolo, "TRIPOLI-4 version 4 User Guide," CEA report CEA-R-6169, CEA/SAclay, France, 2006.

[c] Jean-Christophe Sublet, "JEFF-3.1, ENDF/B-VII and JENDL-3.3 Critical Assemblies Benchmarking with the Monte Carlo Code TRIPOLI," IEEE Transactions on Nuclear Science, Vol. 55, No. 1 (February 2008).

Table 45c. Sample Calculation Results (United States).

Codes (Cross-Section Library)→ Case ↓	MCNP (Continuous Energy JEF-3.1)	MCNP (Continuous Energy JENDL-3.3)
1	0.9919 ± 0.0003	0.9996 ± 0.0003
2	0.9924 ± 0.0003	0.9999 ± 0.0003
3	0.9935 ± 0.0003	1.0003 ± 0.0003
4	0.9941 ± 0.0003	1.0015 ± 0.0003
5	0.9990 ± 0.0003	1.0059 ± 0.0003

Table 45d. Sample Calculation Results (France).

Codes (Cross-Section Library)→ Case ↓	TRIPOLI4 (Continuous Energy JEF-3.1)	TRIPOLI4 (Continuous Energy JENDL-3.3)
1	0.9915 ± 0.0004	1.0028 ± 0.0004
2	0.9918 ± 0.0004	1.0033 ± 0.0004
3	0.9922 ± 0.0004	1.0031 ± 0.0004
4	0.9927 ± 0.0004	1.0046 ± 0.0004
5	0.9976 ± 0.0004	1.0102 ± 0.0004

The ENDF/B-VI nuclear data for the MCNP calculations are taken from a combination of the ACTI[a] and ENDF66[b] libraries that were included in the MCNP5 distribution. For these experiments, the data in the combination of those two libraries correspond to the final release of ENDF/B-VI. The ENDF/B-VII.0[c] nuclear data are taken from the ENDF/B-VII.0 library that is

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[a] S. C. Frankle, R. C. Reedy, and P. G. Young, "ACTI: An MCNP Data Library for Prompt Gamma-Ray Spectroscopy," *Proceedings of the 12th Biennial Topical Meeting of the Radiation Protection and Shielding Division*, Santa Fe, New Mexico, USA (April 2002).

[b] J . M. Campbell, S. C. Frankle, and R C. Little, "ENDF/B-VI Neutron Library for MCNP with Probability Tables," *Proceedings of the 12th Biennial Topical Meeting of the Radiation Protection and Shielding Division,* Santa Fe, New Mexico, USA (April 2002).

[c] M. B. Chadwick, et al., "ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology," *Nucl. Data Sheets*, **107**, pp. 2931-3059 (December 2006).

included in the current MCNP5 distribution. The JEF-3.1[a] and JENDL-3.3[b] nuclear data are taken from libraries prepared at the NEA Data Bank and the Japan Atomic Energy Research Institute, respectively.

The nuclear data for the TRIPOLI4 ENDF/B-VI calculations are based on interim release 4 of that nuclear data library. The nuclear data for the other TRIPOLI4 calculations are based on the final versions of the identified libraries, the same versions upon which the nuclear data for the corresponding MCNP calculations are based.

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[a] O. Cabellos, "Processing the JEF-3.1 Cross Section Library into a Continuous Energy Monte Carlo Radiation Transport and Criticality Data Library," NEA/NSC/DOC(2006)18, OECD NEA Data Bank (May 2006).

[b] K. Kosako, N. Yamano, T. Fukahori, K. Shibata, and A. Hasegawa, "The Libraries FSXLIB and MATXSLIB Based on JENDL-3.3," JAERI-Data/Code 2003-011, Japan Atomic Energy Research Institute (July 2003).

5.0 REFERENCES

None.

APPENDIX A: TYPICAL INPUT LISTINGS

A.1 <u>MCNP Input Listings</u>

The MCNP input files listed below employ continuous-energy cross sections derived from ENDF/B-VI. They are identical to MCNP input files for other nuclear data files, with two exceptions. First, of course, the suffixes of the ZAID identifiers for the various nuclides are different. Second, ENDF/B-VI contains nuclear data for the element molybdenum, while the other libraries contain nuclear data for its isotopes.

These particular cases employ 550 generations of 10,000 neutrons each, and they exclude the first 50 generations from the statistics. Consequently, the results they produce are based on 5,000,000 active histories.

```
Godiva-IV  HEU-MET-FAST-086  Case 1  Benchmark Model  DC  BR In  ENDF/B-VI  RN2
c  Spindle
1        1    0.088296      1   -2   57  -72         $ Spindle
2        0                  2   -3   64  -69
3        0                  2   -3   71  -72
c  Homogenized Subassembly Plate
4        9    0.048067      2  -12   56  -59         $ ISP Bottom Region
5        9    0.048067      2   -9   59  -63         $ ISP Middle Region
6        9    0.048067      2  -12   63  -64         $ ISP Top Region
7        9    0.048067      7  -12   64  -66         $ ISP Top Edge
c  Safety Block
8        5    0.047037      2  -11   49  -55         $ Cylindrical Safety Block
c  Safety Block Base
9        1    0.088296     -5   41  -44              $ SB Base Solid Round
10       1    0.088296     -8   44  -49              $ SB Base Platform
11       1    0.088296     -2   49  -55              $ Lower SB Base Barrel
c  Notches for HEU Rings
12       0                -20   47  -67   75  -77
                           81  #59                   $ Right Notch
13       0                -20   47  -67  -85  -87
                           88  #62                   $ Front Left Notch
14       0                -20   47  -67  -86  -89
                           90  #65                   $ Back Left Notch
c  Homogenized HEU Rings
15       8    0.047766     13  -15   25   26   27
                           47  -48                   $ Inner Bottom Annulus
16       8    0.047766     18  -20   25   26   27
                           47  -48  #12  #13  #14
                          #59  #62  #65              $ Outer Bottom Annulus
17       8    0.047766     13  -20   25   26   27
                           48  -59  #12  #13  #14
                          #59  #62  #65              $ Lower Narrow Region
18       8    0.047766     10  -20   25   26   27
                           59  -62  #12  #13  #14
                          #59  #62  #65              $ Lower Wide Region
19       8    0.047766     10  -20   62  -63  #12
                          #13  #14  #59  #62  #65    $ Upper Wide Region
20       8    0.047766     13  -20   63  -65
                          #12  #13  #14
```

```
                        #59  #62  #65                $ Upper Narrow Region
21      8    0.047766     13  -16   65  -67          $ Inr Top Narrow Region
22      8    0.047766     19  -20   65  -67
                        #12  #13  #14  #45
                        #59  #62  #65                $ Otr Top Narrow Region
c  Control and Burst Rods
23      0               -25   53  -62                $ Hole above Control Rod 1
24      0               -25   31   37  -53           $ Gap between CR1 & Rings
25      0               -22   37  -39                $ Bottom Hole, CR1
26      6    0.047922     22  -31   37  -39          $ Bottom Region, CR1
27      6    0.047922    -31   39  -51               $ Solid Middle Region, CR1
28      6    0.047922     22  -31   51  -53          $ Top Region, CR1
29      0               -22   51  -53                $ Top Hole in CR1
30      0               -27   52  -62                $ Hole above Control Rod 2
31      0               -27   32   36  -52           $ Gap between CR2 & Rings
32      0               -23   36  -38                $ Bottom Hole, CR2
33      6    0.047922     23  -32   36  -38          $ Bottom Region, CR2
34      6    0.047922    -32   38  -50               $ Solid Middle Region, CR2
35      6    0.047922     23  -32   50  -52          $ Top Region, CR2
36      0               -23   50  -52                $ Top Hole in CR2
37      0               -26   58  -62                $ Hole above Burst Rod
38      0               -26   33   47  -58           $ Gap between BR & Rings
39      0               -24   42  -46                $ Bottom Hole, Burst Rod
40      7    0.049025     24  -33   42  -46          $ Bottom Region, Burst Rod
41      7    0.049025    -33   46  -54               $ Middle Region, BR
42      7    0.049025     24  -33   54  -58          $ Top Region, Burst Rod
43      0               -24   54  -58                $ Top Hole in Burst Rod
c  Support Pads Converted to Ring
44      2    0.086011     15  -18   25   26   27
                          45  -48                    $ Support Pads as Ring
c  Bearing Ring
45      2    0.086011     16  -19   65  -70          $ Solid Bearing Ring
c  Subassembly Cover Plate
46      0                  3   -4   66  -69          $ Central Hole in SCP
47      0                  4  -13   66  -68          $ Inner Void in SCP
48      2    0.086011     13  -14   67  -69          $ Edge of SCP
49      2    0.086011      4  -13   68  -69          $ Center of SCP
c  Mounting Plate
50      0               -17   34  -35                $ Empty Central Hole
51      0                 25  -28   34  -35          $ Empty Hole for CR1
52      0                 26  -30   34  -35          $ Empty Hole for Burst Rod
53      0                 27  -29   34  -35          $ Empty Hole for CR2
54      4    0.058593     17  -21   28   29   30
                          34  -35                    $ Mounting Plate
c  Clamp Supports (Legs)
55      1    0.088296     35  -61   74  -78   83
                        -84                          $ Rectangular Right Leg
56      like 55 but trcl (0 0 0  -0.5 -0.8660254 0
                          -0.8660254 -0.5 0  0 0 1) $ Rectangular FL Leg
57      like 55 but trcl (0 0 0  -0.5  0.8660254 0
                          -0.8660254 -0.5 0  0 0 1) $ Rectanglar BL Leg
c  Clamps
58      3    0.083675     40  -45   75  -77   80
                        -83                          $ Bottom of Clamp Back
59      3    0.083675     45  -70   75  -77   82
                        -83                          $ Middle of Clamp Back
60      3    0.083675     70  -73   75  -77   80
                        -83                          $ Top of Clamp Back
61      like 58 but trcl (0 0 0  -0.5 -0.8660254 0
                          -0.8660254 -0.5 0  0 0 1) $ Bottom of Clamp Back
62      like 59  but trcl (0 0 0  -0.5 -0.8660254 0
```

```
                         -0.8660254 -0.5 0  0 0 1) $ Middle of Clamp Back
63       like 60 but trcl (0 0 0  -0.5 -0.8660254 0
                         -0.8660254 -0.5 0  0 0 1) $ Top of Clamp Back

64       like 58 but trcl (0 0 0  -0.5  0.8660254 0
                         -0.8660254  0.5 0  0 0 1) $ Bottom of Clamp Back
65       like 59  but trcl (0 0 0  -0.5  0.8660254 0
                         -0.8660254  0.5 0  0 0 1) $ Middle of Clamp Back
66       like 60 but trcl (0 0 0  -0.5  0.8660254 0
                         -0.8660254  0.5 0  0 0 1) $ Top of Clamp Back
c  Nut on Spindle
67       1    0.088296      2   -6   69  -71         $ Nut on Spindle
c  Outer Void Regions
68       0                  5  -13   43  -44         $ Cyl Gap below Platform
69       0                  5  -13   41  -43         $ Gap outside SB Base
70       0                  8  -13   44  -49         $ Gap outside Platform
71       0                 12  -13   56  -59
72       0                  9  -10   59  -60
73       0                  9  -10   60  -63     $ HEU Ring / Top ISP Gap
c  Inner Void Regions
74       0                -20   72  -73
                          #60  #63  #66
75       0                 20  -21   35  -73   76
                           79  #55  #58  #59  #60 $ BR Void above Mtng Plate
76       0                 20  -21   35  -73  -76
                           79  #55  #58  #59  #60 $ FR Void above Mntg Plate
77       0                 20  -21   35  -73  -76
                          -79  #56  #61  #62  #63 $ FL Void above Mntg Plate
78       0                 20  -21   35  -73   76
                          -79  #57  #64  #65  #66 $ BL Void above Mntg Plate
79       0                 14  -16   67  -69      $ Gap between SCP and BRing
80       0                -25   34  -37           $ Void below Control Rod 1
81       0                -27   34  -36           $ Void below Control Rod 2
82       0                -26   34  -42           $ Hole below Burst Rod
83       0                -26   33   42  -47      $ Void around Burst Rod
84       0                 13  -20   25   26   27
                           35  -45
                          #58  #61  #64           $ Void below Pads
85       0                 13  -20   25   26   27
                           45  -47
                          #44  #56  #57
                          #59  #62  #65           $ Void outside Pads
86       0                -13   35  -41           $ Void below Sfty Blk Base
87       0                 13  -16   69  -70      $ Void inside Bearing Ring
88       0                 13   19  -20   67  -70 $ Void outside Bearing Ring
                          #59  #62  #65           $ Void outside Bearing Ring
89       0                 13  -20   70  -72
                          #60  #63  #66           $ Void above Bearing Ring
90       0                 11  -13   49  -56
91       0                 12  -13   63  -66      $ Upr ISP / HEU Ring Gap
92       0                  3  -13   69  -72  #67 $ Spindle / HEU Ring Gap
93       0                -11   55  -56
94       0                 -2   56  -57           $ Space below Spindle
95       0                 -1   57  -72           $ Glory Hole
96       0                  3   -7   64  -66      $ Top ISP - Spindle Gap
c  External Void Regions
97       0                 73
98       0                 21   34  -73
99       0                -34

1     cz   0.31750                               $ Glory-Hole Radius
```

```
2      cz   1.27000                                  $ Spindle Bottom Middle OR
3      cz   1.42875                                  $ Spindle Top Middle OR
4      cz   1.43510                                  $ Radius of Central Hole in SCP
5      cz   1.90500                                  $ OR of SB Base Bottom
6      cz   2.22250                                  $ OR for Nut on Spindle

7      cz   3.50520                                  $ Upper IR of UISP
8      cz   3.65760                                  $ OR of SB Base Platform
9      cz   3.92430                                  $ OR of Upper Int Sub Plate
10     cz   3.97510                                  $ IR of Ring 5
11     cz   4.29260                                  $ Safety Block Outer Radius
12     cz   4.38150                                  $ OR of Lower Int Sub Plate
13     cz   4.44500                                  $ IR of Rings 1-4, 6
14     cz   5.08000                                  $ IR of S Pad Slots, BR Annulus
15     cz   5.08508                                  $ Inner Radius of Sprt Pad Ring
16     cz   5.08381                                  $ Inner Radius of Bearing Ring
17     cz   5.23875                                  $ Radius of Central Hole in MP
18     cz   7.29488                                  $ Outer Radius of Sprt Pad Ring
19     cz   7.29615                                  $ Outer Radius of Bearing Ring
20     cz   8.89000                                  $ OR of Rings
21     cz  44.45                                     $ Outer Radius of Mtng Plate
22     c/z  3.33375   -5.774224   0.47625            $ Control Rod 1 IR
23     c/z  3.33375    5.774224   0.47625            $ Control Rod 2 IR
24     c/z -6.66750    0.0        0.47625            $ Burst Rod IR
25     c/z  3.33375   -5.774224   1.11125            $ FR Hole, Control or Burst Rod
26     c/z -6.66750    0.0        1.11125            $ Lt Hole, Control or Burst Rod
27     c/z  3.33375    5.774224   1.11125            $ BR Hole, Control or Burst Rod
28     c/z  3.33375   -5.774224   1.27000            $ FR Hole for Control Rod 1
29     c/z  3.33375    5.774224   1.27000            $ BR Hole for Control Rod 2
30     c/z -6.66750    0.0        1.27000            $ Left Hole for Burst Rod
31     c/z  3.33375   -5.774224   1.09220            $ Control Rod 1 OR
32     c/z  3.33375    5.774224   1.09220            $ Control Rod 2 OR
33     c/z -6.66750    0.0        1.09220            $ Burst Rod OR
34     pz -20.37715                                  $ Bottom of Mounting Plate
35     pz -16.56715                                  $ Top of Mounting Plate
36     pz -12.02055                                  $ Bottom of Control Rod 2
37     pz -19.84121                                  $ Bottom of Control Rod 1
38     pz -10.11555                                  $ Top of CR2 Bottom Hole
39     pz -17.93621                                  $ Top of CR1 Bottom Hole
40     pz -12.67587                                  $ Bottom of Flat Clamp Bottom
41     pz -11.85559                                  $ Top of SB Base Bottom Hole
42     pz -10.79627                                  $ Bottom of Burst Rod (Full In)
43     pz  -9.79948                                  $ Bottom of Platform Curve
44     pz  -9.17448                                  $ Bottom of SB Base Platform
45     pz  -9.02589                                  $ Bottom of Support-Pad Ring
46     pz  -8.89127                                  $ Top of Burst Rod Bottom Hole
47     pz  -8.06553                                  $ Bottom of Ring 1
48     pz  -7.59414                                  $ Top of Ring 1 Slot for Pad Rg
49     pz  -7.74700                                  $ Bottom of Safety Block
50     pz  -1.22555                                  $ Bottom of CR2 Top Hole
51     pz  -9.04621                                  $ Bottom of CR1 Top Hole
52     pz   0.67945                                  $ Top of Control Rod 2
53     pz  -7.14121                                  $ Top of Control Rod 1
54     pz  -1.27127                                  $ Flat Bottom of BR Top Hole
55     pz  -0.12700                                  $ Top of Safety Block
56     pz   0.0                                      $ Bottom of Inter Inner SA Pl
57     pz   0.00254                                  $ Bottom of Spindle
58     pz   1.90373                                  $ Top of Burst Rod (Full In)
59     pz   2.54000                                  $ Top of IISP Wide Region
60     pz   3.49250                                  $ Top of Int Inr Subassby Plate
61     pz   4.38785                                  $ Top of Right Leg
```

```
62    pz   4.64820                               $ Top of Ring 5 Outer Edge
63    pz   4.96570                               $ Top of UISP Indentation
64    pz   6.98754                               $ Bottom of UISP Inner Annulus
65    pz   7.27160                               $ Bottom of Indent in 6
66    pz   7.64794                               $ Top of Top Inr Subasmbly Pl
67    pz   7.73264                               $ Top of HEU Ring 6
68    pz   7.95528                               $ Top of SCP Raised Edge

69    pz   8.27278                               $ Top of Subassembly Cvr Plate
70    pz   8.75411                               $ Top of Bearing Ring
71    pz   9.54278                               $ Top of Nut on Spindle
72    pz  11.43254                               $ Top of Spindle
73    pz  12.40409                               $ Top of Flat Clamp Top
74    py  -1.42875                               $ Front Edge of Right Leg
75    py  -1.11125                               $ Front Edge of Left Notch
76    py   0.0
77    py   1.11125                               $ Back Edge of Left Notch
78    py   1.42875                               $ Back Edge of Right Leg
79    px   0.0
80    px   5.08000                               $ Left Edge of Prongs
81    px   8.49376                               $ Back Edge of Left Notch(1&6)
82    px   8.49630                               $ Left Edge of Clamp Back
83    px  12.94130                               $ Right Edge of Right Leg Inset
84    px  18.94130                               $ Right Edge of Rectglar Rt Leg
85    p    1.0        1.7320508  0.0 -16.9857200 $ Back Edge, BL Notch (1 & 6)
86    p    1.0       -1.7320508  0.0 -16.9857200 $ Back Edge, BR Notch (1 & 6)
87    p    1.7320508 -1.0        0.0   1.9247415 $ Lower Edge, BL Notch
88    p    1.7320508 -1.0        0.0  -1.9247415 $ Upper Edge, BL Notch
89    p    1.7320508  1.0        0.0   1.9247415 $ Lower Edge, BR Notch
90    p    1.7320508  1.0        0.0  -1.9247415 $ Upper Edge, BR Notch

mode     n
kcode    10000    1.0    50    550
rand     hist=7314730
imp:n    1.0      95r   0.0     2r
ksrc     0.0    0.0   -1.0
c        SS 303  (8.0 g/cc)
m1        6000.66c     3.0083e-4
         14028.62c     1.5821e-3       14029.62c     8.0109e-5
         14030.62c     5.3177e-5
         15031.66c     1.5554e-4
         16000.62c     4.5067e-4
         24050.62c     7.2466e-4       24052.62c     1.3974e-2
         24053.62c     1.5844e-3       24054.62c     3.9443e-4
         25055.62c     8.7693e-4
         26054.62c     3.5742e-3       26056.62c     5.5564e-2
         26057.62c     1.2722e-3       26058.62c     1.6962e-4
         28058.62c     5.0437e-3       28060.62c     1.9282e-3
         28061.62c     8.3482e-5       28062.62c     2.6522e-4
         28064.62c     6.7229e-5
         42000.66c     1.5065e-4
c        SAE 4340  (7.85 g/cc)
m2        6000.66c     1.5940e-3
         14028.62c     3.4929e-4       14029.62c     1.7686e-5
         14030.62c     1.1740e-5
         15031.66c     2.7472e-5
         16000.62c     2.9481e-5
         24050.62c     3.1603e-5       24052.62c     6.0944e-4
         24053.62c     6.9097e-5       24054.62c     1.7202e-5
         25055.62c     6.2385e-4
         26054.62c     4.7824e-3       26056.62c     7.4345e-2
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          26057.62c     1.7022e-3       26058.62c     2.2696e-4
          28058.62c     9.8985e-4       28060.62c     3.7842e-4
          28061.62c     1.6384e-5       28062.62c     5.2051e-5
          28064.62c     1.3194e-5
          42000.66c     1.2319e-4
c         VascoMax 300  (8.0 g/cc)
m3         6000.66c     8.0221e-5
          13027.62c     1.7855e-4
          14028.62c     7.9104e-5       14029.62c     4.0054e-6

          14030.62c     2.6588e-6
          15031.66c     7.7770e-6
          16000.62c     7.5112e-6
          22000.62c     7.3453e-4
          25055.62c     4.3847e-5
          26054.62c     3.4070e-3       26056.62c     5.2965e-2
          26057.62c     1.2127e-3       26058.62c     1.6169e-4
          27059.66c     7.1938e-3
          28058.62c     1.0367e-2       28060.62c     3.9635e-3
          28061.62c     1.7160e-4       28062.62c     5.4518e-4
          28064.62c     1.3819e-4
          42000.66c     2.4103e-3
c         Pure Aluminum Mounting Plate
m4        13027.62c     5.8593e-2
c         HEU + Mo (93.17 wt.% for Safety Block), 18.1069 g/cc
m5        42000.66c     1.1384e-3
          92233.66c     4.6322e-6       92234.66c     4.7005e-4
          92235.66c     4.2791e-2       92236.66c     3.1098e-4
          92238.66c     2.3222e-3
c         HEU + Mo (93.16 wt.% for Control Rods 1 and 2)
m6        42000.66c     1.5385e-3
          92233.66c     4.6812e-6       92234.66c     4.7497e-4
          92235.66c     4.3238e-2       92236.66c     3.1427e-4
          92238.66c     2.3514e-3
c         HEU + Mo (93.16 wt.% for Burst Rod)
m7        42000.66c     1.5701e-3
          92233.66c     4.7893e-6       92234.66c     4.8594e-4
          92235.66c     4.4237e-2       92236.66c     3.2152e-4
          92238.66c     2.4057e-3
c         HEU + Mo (93.15 wt.% for Homogenized Fuel Rings)
m8        42000.66c     1.7082e-3
          92233.66c     4.6484e-6       92234.66c     4.7159e-4
          92235.66c     4.2930e-2       92236.66c     3.1206e-4
          92238.66c     2.3398e-3
c         HEU + Mo (93.15 wt.% for Homogenized IISP+UISP)
m9        42000.66c     1.7407e-3
          92233.66c     4.6755e-6       92234.66c     4.7433e-4
          92235.66c     4.3187e-2       92236.66c     3.1388e-4
          92238.66c     2.3464e-3
c
totnu
prdmp      j   575
print

 end of input
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```
Godiva-IV  HEU-MET-FAST-086  Case 2  Benchmark Model  DC  BR In  ENDF/B-VI  RN2
c  Spindle
1        1    0.088296      1   -2   57  -72          $ Spindle
2        0                  2   -3   64  -69
3        0                  2   -3   71  -72
c  Homogenized Subassembly Plate
4        9    0.048067      2  -12   56  -59          $ ISP Bottom Region
5        9    0.048067      2   -9   59  -63          $ ISP Middle Region
6        9    0.048067      2  -12   63  -64          $ ISP Top Region
7        9    0.048067      7  -12   64  -66          $ ISP Top Edge
c  Safety Block
8        5    0.047037      2  -11   49  -55          $ Cylindrical Safety Block
c  Safety Block Base
9        1    0.088296     -5   41  -44               $ SB Base Solid Round
10       1    0.088296     -8   44  -49               $ SB Base Platform
11       1    0.088296     -2   49  -55               $ Lower SB Base Barrel
c  Notches for HEU Rings
12       0                -20   47  -67   75  -77
                           81  #59                    $ Right Notch
13       0                -20   47  -67  -85  -87
                           88  #62                    $ Front Left Notch
14       0                -20   47  -67  -86  -89
                           90  #65                    $ Back Left Notch
c  Homogenized HEU Rings
15       8    0.047766     13  -15   25   26   27
                           47  -48                    $ Inner Bottom Annulus
16       8    0.047766     18  -20   25   26   27
                           47  -48  #12  #13  #14
                          #59  #62  #65               $ Outer Bottom Annulus
17       8    0.047766     13  -20   25   26   27
                           48  -59  #12  #13  #14
                          #59  #62  #65               $ Lower Narrow Region
18       8    0.047766     10  -20   25   26   27
                           59  -62  #12  #13  #14
                          #59  #62  #65               $ Lower Wide Region
19       8    0.047766     10  -20   62  -63  #12
                          #13  #14  #59  #62  #65     $ Upper Wide Region
20       8    0.047766     13  -20   63  -65
                          #12  #13  #14
                          #59  #62  #65               $ Upper Narrow Region
21       8    0.047766     13  -16   65  -67          $ Inr Top Narrow Region
22       8    0.047766     19  -20   65  -67
                          #12  #13  #14  #45
                          #59  #62  #65               $ Otr Top Narrow Region
c  Control and Burst Rods
23       0                -25   53  -62               $ Hole above Control Rod 1
24       0                -25   31   37  -53          $ Gap between CR1 & Rings
25       0                -22   37  -39               $ Bottom Hole, CR1
26       6    0.047922     22  -31   37  -39          $ Bottom Region, CR1
27       6    0.047922    -31   39  -51               $ Solid Middle Region, CR1
28       6    0.047922     22  -31   51  -53          $ Top Region, CR1
29       0                -22   51  -53               $ Top Hole in CR1
30       0                -27   52  -62               $ Hole above Control Rod 2
31       0                -27   32   36  -52          $ Gap between CR2 & Rings
32       0                -23   36  -38               $ Bottom Hole, CR2
33       6    0.047922     23  -32   36  -38          $ Bottom Region, CR2
34       6    0.047922    -32   38  -50               $ Solid Middle Region, CR2
35       6    0.047922     23  -32   50  -52          $ Top Region, CR2
36       0                -23   50  -52               $ Top Hole in CR2
37       0                -26   58  -62               $ Hole above Burst Rod
38       0                -26   33   47  -58          $ Gap between BR & Rings
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39       0                -24   42  -46               $ Bottom Hole, Burst Rod

40       7    0.049025     24  -33   42  -46          $ Bottom Region, Burst Rod
41       7    0.049025    -33   46  -54               $ Middle Region, BR
42       7    0.049025     24  -33   54  -58          $ Top Region, Burst Rod
43       0                -24   54  -58               $ Top Hole in Burst Rod
c  Support Pads Converted to Ring
44       2    0.086011     15  -18   25   26   27
                           45  -48                    $ Support Pads as Ring
c  Bearing Ring
45       2    0.086011     16  -19   65  -70          $ Solid Bearing Ring
c  Subassembly Cover Plate
46       0                  3   -4   66  -69          $ Central Hole in SCP
47       0                  4  -13   66  -68          $ Inner Void in SCP
48       2    0.086011     13  -14   67  -69          $ Edge of SCP
49       2    0.086011      4  -13   68  -69          $ Center of SCP
c  Mounting Plate
50       0                -17   34  -35               $ Empty Central Hole
51       0                 25  -28   34  -35          $ Empty Hole for CR1
52       0                 26  -30   34  -35          $ Empty Hole for Burst Rod
53       0                 27  -29   34  -35          $ Empty Hole for CR2
54       4    0.058593     17  -21   28   29   30
                           34  -35                    $ Mounting Plate
c  Clamp Supports (Legs)
55       1    0.088296     35  -61   74  -78   83
                          -84                         $ Rectangular Right Leg
56       like 55 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Rectangular FL Leg
57       like 55 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Rectanglar BL Leg
c  Clamps
58       3    0.083675     40  -45   75  -77   80
                          -83                         $ Bottom of Clamp Back
59       3    0.083675     45  -70   75  -77   82
                          -83                         $ Middle of Clamp Back
60       3    0.083675     70  -73   75  -77   80
                          -83                         $ Top of Clamp Back
61       like 58 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Bottom of Clamp Back
62       like 59  but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Middle of Clamp Back
63       like 60 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top of Clamp Back
64       like 58 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Bottom of Clamp Back
65       like 59  but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Middle of Clamp Back
66       like 60 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Top of Clamp Back
c  Nut on Spindle
67       1    0.088296      2   -6   69  -71          $ Nut on Spindle
c  Outer Void Regions
68       0                  5  -13   43  -44          $ Cyl Gap below Platform
69       0                  5  -13   41  -43          $ Gap outside SB Base
70       0                  8  -13   44  -49          $ Gap outside Platform
71       0                 12  -13   56  -59
72       0                  9  -10   59  -60
73       0                  9  -10   60  -63      $ HEU Ring / Top ISP Gap
c  Inner Void Regions
74       0                -20   72  -73
                          #60  #63  #66
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75       0                 20  -21   35  -73   76
                           79  #55  #58  #59  #60 $ BR Void above Mtng Plate
76       0                 20  -21   35  -73  -76
                           79  #55  #58  #59  #60 $ FR Void above Mntg Plate

77       0                 20  -21   35  -73  -76
                          -79  #56  #61  #62  #63 $ FL Void above Mntg Plate
78       0                 20  -21   35  -73   76
                          -79  #57  #64  #65  #66 $ BL Void above Mntg Plate
79       0                 14  -16   67  -69      $ Gap between SCP and BRing
80       0                -25   34  -37           $ Void below Control Rod 1
81       0                -27   34  -36           $ Void below Control Rod 2
82       0                -26   34  -42           $ Hole below Burst Rod
83       0                -26   33   42  -47      $ Void around Burst Rod
84       0                 13  -20   25   26   27
                           35  -45
                          #58  #61  #64           $ Void below Pads
85       0                 13  -20   25   26   27
                           45  -47
                          #44  #56  #57
                          #59  #62  #65           $ Void outside Pads
86       0                -13   35  -41           $ Void below Sfty Blk Base
87       0                 13  -16   69  -70      $ Void inside Bearing Ring
88       0                 13   19  -20   67  -70 $ Void outside Bearing Ring
                          #59  #62  #65           $ Void outside Bearing Ring
89       0                 13  -20   70  -72
                          #60  #63  #66           $ Void above Bearing Ring
90       0                 11  -13   49  -56
91       0                 12  -13   63  -66      $ Upr ISP / HEU Ring Gap
92       0                  3  -13   69  -72  #67 $ Spindle / HEU Ring Gap
93       0                -11   55  -56
94       0                 -2   56  -57           $ Space below Spindle
95       0                 -1   57  -72           $ Glory Hole
96       0                  3   -7   64  -66      $ Top ISP - Spindle Gap
c  External Void Regions
97       0                 73
98       0                 21   34  -73
99       0                -34

1     cz   0.31750                               $ Glory-Hole Radius
2     cz   1.27000                               $ Spindle Bottom Middle OR
3     cz   1.42875                               $ Spindle Top Middle OR
4     cz   1.43510                               $ Radius of Central Hole in SCP
5     cz   1.90500                               $ OR of SB Base Bottom
6     cz   2.22250                               $ OR for Nut on Spindle
7     cz   3.50520                               $ Upper IR of UISP
8     cz   3.65760                               $ OR of SB Base Platform
9     cz   3.92430                               $ OR of Upper Int Sub Plate
10    cz   3.97510                               $ IR of Ring 5
11    cz   4.29260                               $ Safety Block Outer Radius
12    cz   4.38150                               $ OR of Lower Int Sub Plate
13    cz   4.44500                               $ IR of Rings 1-4, 6
14    cz   5.08000                               $ IR of S Pad Slots, BR Annulus
15    cz   5.08508                               $ Inner Radius of Sprt Pad Ring
16    cz   5.08381                               $ Inner Radius of Bearing Ring
17    cz   5.23875                               $ Radius of Central Hole in MP
18    cz   7.29488                               $ Outer Radius of Sprt Pad Ring
19    cz   7.29615                               $ Outer Radius of Bearing Ring
20    cz   8.89000                               $ OR of Rings
21    cz  44.45                                  $ Outer Radius of Mtng Plate
22    c/z  3.33375   -5.774224   0.47625         $ Control Rod 1 IR
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23    c/z  3.33375    5.774224   0.47625         $ Control Rod 2 IR
24    c/z -6.66750    0.0        0.47625         $ Burst Rod IR
25    c/z  3.33375   -5.774224   1.11125         $ FR Hole, Control or Burst Rod
26    c/z -6.66750    0.0        1.11125         $ Lt Hole, Control or Burst Rod
27    c/z  3.33375    5.774224   1.11125         $ BR Hole, Control or Burst Rod
28    c/z  3.33375   -5.774224   1.27000         $ FR Hole for Control Rod 1

29    c/z  3.33375    5.774224   1.27000         $ BR Hole for Control Rod 2
30    c/z -6.66750    0.0        1.27000         $ Left Hole for Burst Rod
31    c/z  3.33375   -5.774224   1.09220         $ Control Rod 1 OR
32    c/z  3.33375    5.774224   1.09220         $ Control Rod 2 OR
33    c/z -6.66750    0.0        1.09220         $ Burst Rod OR
34    pz -20.37715                               $ Bottom of Mounting Plate
35    pz -16.56715                               $ Top of Mounting Plate
36    pz -15.11173                               $ Bottom of Control Rod 2
37    pz -14.75359                               $ Bottom of Control Rod 1
38    pz -13.20673                               $ Top of CR2 Bottom Hole
39    pz -12.84859                               $ Top of CR1 Bottom Hole
40    pz -12.67587                               $ Bottom of Flat Clamp Bottom
41    pz -11.85559                               $ Top of SB Base Bottom Hole
42    pz -10.79627                               $ Bottom of Burst Rod (Full In)
43    pz  -9.79948                               $ Bottom of Platform Curve
44    pz  -9.17448                               $ Bottom of SB Base Platform
45    pz  -9.02589                               $ Bottom of Support-Pad Ring
46    pz  -8.89127                               $ Top of Burst Rod Bottom Hole
47    pz  -8.06553                               $ Bottom of Ring 1
48    pz  -7.59414                               $ Top of Ring 1 Slot for Pad Rg
49    pz  -7.74700                               $ Bottom of Safety Block
50    pz  -4.31673                               $ Bottom of CR2 Top Hole
51    pz  -3.95859                               $ Bottom of CR1 Top Hole
52    pz  -2.41173                               $ Top of Control Rod 2
53    pz  -2.05359                               $ Top of Control Rod 1
54    pz  -1.27127                               $ Flat Bottom of BR Top Hole
55    pz  -0.12700                               $ Top of Safety Block
56    pz   0.0                                   $ Bottom of Inter Inner SA Pl
57    pz   0.00254                               $ Bottom of Spindle
58    pz   1.90373                               $ Top of Burst Rod (Full In)
59    pz   2.54000                               $ Top of IISP Wide Region
60    pz   3.49250                               $ Top of Int Inr Subassby Plate
61    pz   4.38785                               $ Top of Right Leg
62    pz   4.64820                               $ Top of Ring 5 Outer Edge
63    pz   4.96570                               $ Top of UISP Indentation
64    pz   6.98754                               $ Bottom of UISP Inner Annulus
65    pz   7.27160                               $ Bottom of Indent in 6
66    pz   7.64794                               $ Top of Top Inr Subasmbly Pl
67    pz   7.73264                               $ Top of HEU Ring 6
68    pz   7.95528                               $ Top of SCP Raised Edge
69    pz   8.27278                               $ Top of Subassembly Cvr Plate
70    pz   8.75411                               $ Top of Bearing Ring
71    pz   9.54278                               $ Top of Nut on Spindle
72    pz  11.43254                               $ Top of Spindle
73    pz  12.40409                               $ Top of Flat Clamp Top
74    py  -1.42875                               $ Front Edge of Right Leg
75    py  -1.11125                               $ Front Edge of Left Notch
76    py   0.0
77    py   1.11125                               $ Back Edge of Left Notch
78    py   1.42875                               $ Back Edge of Right Leg
79    px   0.0
80    px   5.08000                               $ Left Edge of Prongs
81    px   8.49376                               $ Back Edge of Left Notch(1&6)
82    px   8.49630                               $ Left Edge of Clamp Back
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83    px  12.94130                               $ Right Edge of Right Leg Inset
84    px  18.94130                               $ Right Edge of Rectglar Rt Leg
85    p    1.0        1.7320508  0.0 -16.9857200 $ Back Edge, BL Notch (1 & 6)
86    p    1.0       -1.7320508  0.0 -16.9857200 $ Back Edge, BR Notch (1 & 6)
87    p    1.7320508 -1.0        0.0   1.9247415 $ Lower Edge, BL Notch
88    p    1.7320508 -1.0        0.0  -1.9247415 $ Upper Edge, BL Notch
89    p    1.7320508  1.0        0.0   1.9247415 $ Lower Edge, BR Notch
90    p    1.7320508  1.0        0.0  -1.9247415 $ Upper Edge, BR Notch


mode     n
kcode    10000    1.0    50    550
rand     hist=7314730
imp:n    1.0      95r   0.0     2r
ksrc     0.0    0.0   -1.0
c        SS 303  (8.0 g/cc)
m1        6000.66c     3.0083e-4
         14028.62c     1.5821e-3       14029.62c     8.0109e-5
         14030.62c     5.3177e-5
         15031.66c     1.5554e-4
         16000.62c     4.5067e-4
         24050.62c     7.2466e-4       24052.62c     1.3974e-2
         24053.62c     1.5844e-3       24054.62c     3.9443e-4
         25055.62c     8.7693e-4
         26054.62c     3.5742e-3       26056.62c     5.5564e-2
         26057.62c     1.2722e-3       26058.62c     1.6962e-4
         28058.62c     5.0437e-3       28060.62c     1.9282e-3
         28061.62c     8.3482e-5       28062.62c     2.6522e-4
         28064.62c     6.7229e-5
         42000.66c     1.5065e-4
c        SAE 4340  (7.85 g/cc)
m2        6000.66c     1.5940e-3
         14028.62c     3.4929e-4       14029.62c     1.7686e-5
         14030.62c     1.1740e-5
         15031.66c     2.7472e-5
         16000.62c     2.9481e-5
         24050.62c     3.1603e-5       24052.62c     6.0944e-4
         24053.62c     6.9097e-5       24054.62c     1.7202e-5
         25055.62c     6.2385e-4
         26054.62c     4.7824e-3       26056.62c     7.4345e-2
         26057.62c     1.7022e-3       26058.62c     2.2696e-4
         28058.62c     9.8985e-4       28060.62c     3.7842e-4
         28061.62c     1.6384e-5       28062.62c     5.2051e-5
         28064.62c     1.3194e-5
         42000.66c     1.2319e-4
c        VascoMax 300  (8.0 g/cc)
m3        6000.66c     8.0221e-5
         13027.62c     1.7855e-4
         14028.62c     7.9104e-5       14029.62c     4.0054e-6
         14030.62c     2.6588e-6
         15031.66c     7.7770e-6
         16000.62c     7.5112e-6
         22000.62c     7.3453e-4
         25055.62c     4.3847e-5
         26054.62c     3.4070e-3       26056.62c     5.2965e-2
         26057.62c     1.2127e-3       26058.62c     1.6169e-4
         27059.66c     7.1938e-3
         28058.62c     1.0367e-2       28060.62c     3.9635e-3
         28061.62c     1.7160e-4       28062.62c     5.4518e-4
         28064.62c     1.3819e-4
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```
         42000.66c     2.4103e-3
c        Pure Aluminum Mounting Plate
m4       13027.62c     5.8593e-2
c        HEU + Mo (93.17 wt.% for Safety Block), 18.1069 g/cc
m5       42000.66c     1.1384e-3
         92233.66c     4.6322e-6       92234.66c     4.7005e-4
         92235.66c     4.2791e-2       92236.66c     3.1098e-4
         92238.66c     2.3222e-3
c        HEU + Mo (93.16 wt.% for Control Rods 1 and 2)
m6       42000.66c     1.5385e-3
         92233.66c     4.6812e-6       92234.66c     4.7497e-4

         92235.66c     4.3238e-2       92236.66c     3.1427e-4
         92238.66c     2.3514e-3
c        HEU + Mo (93.16 wt.% for Burst Rod)
m7       42000.66c     1.5701e-3
         92233.66c     4.7893e-6       92234.66c     4.8594e-4
         92235.66c     4.4237e-2       92236.66c     3.2152e-4
         92238.66c     2.4057e-3
c        HEU + Mo (93.15 wt.% for Homogenized Fuel Rings)
m8       42000.66c     1.7082e-3
         92233.66c     4.6484e-6       92234.66c     4.7159e-4
         92235.66c     4.2930e-2       92236.66c     3.1206e-4
         92238.66c     2.3398e-3
c        HEU + Mo (93.15 wt.% for Homogenized IISP+UISP)
m9       42000.66c     1.7407e-3
         92233.66c     4.6755e-6       92234.66c     4.7433e-4
         92235.66c     4.3187e-2       92236.66c     3.1388e-4
         92238.66c     2.3464e-3
c
totnu
prdmp     j   575
print

 end of input
```

```
Godiva-IV  HEU-MET-FAST-086  Case 3  Benchmark Model  DC  BR In  ENDF/B-VI  RN2
c  Spindle
1        1    0.088296      1   -2   57  -72          $ Spindle
2        0                  2   -3   64  -69
3        0                  2   -3   71  -72
c  Homogenized Subassembly Plate
4        9    0.048067      2  -12   56  -59          $ ISP Bottom Region
5        9    0.048067      2   -9   59  -63          $ ISP Middle Region
6        9    0.048067      2  -12   63  -64          $ ISP Top Region
7        9    0.048067      7  -12   64  -66          $ ISP Top Edge
c  Safety Block
8        5    0.047037      2  -11   49  -55          $ Cylindrical Safety Block
c  Safety Block Base
9        1    0.088296     -5   41  -44               $ SB Base Solid Round
10       1    0.088296     -8   44  -49               $ SB Base Platform
11       1    0.088296     -2   49  -55               $ Lower SB Base Barrel
c  Notches for HEU Rings
12       0                -20   47  -67   75  -77
                           81  #59                    $ Right Notch
13       0                -20   47  -67  -85  -87
                           88  #62                    $ Front Left Notch
14       0                -20   47  -67  -86  -89
                           90  #65                    $ Back Left Notch
c  Homogenized HEU Rings
15       8    0.047766     13  -15   25   26   27
                           47  -48                    $ Inner Bottom Annulus
16       8    0.047766     18  -20   25   26   27
                           47  -48  #12  #13  #14
                          #59  #62  #65               $ Outer Bottom Annulus
17       8    0.047766     13  -20   25   26   27
                           48  -59  #12  #13  #14
                          #59  #62  #65               $ Lower Narrow Region
18       8    0.047766     10  -20   25   26   27
                           59  -62  #12  #13  #14
                          #59  #62  #65               $ Lower Wide Region
19       8    0.047766     10  -20   62  -63  #12
                          #13  #14  #59  #62  #65     $ Upper Wide Region
20       8    0.047766     13  -20   63  -65
                          #12  #13  #14
                          #59  #62  #65               $ Upper Narrow Region
21       8    0.047766     13  -16   65  -67          $ Inr Top Narrow Region
22       8    0.047766     19  -20   65  -67
                          #12  #13  #14  #45
                          #59  #62  #65               $ Otr Top Narrow Region
c  Control and Burst Rods
23       0                -25   53  -62               $ Hole above Control Rod 1
24       0                -25   31   37  -53          $ Gap between CR1 & Rings
25       0                -22   37  -39               $ Bottom Hole, CR1
26       6    0.047922     22  -31   37  -39          $ Bottom Region, CR1
27       6    0.047922    -31   39  -51               $ Solid Middle Region, CR1
28       6    0.047922     22  -31   51  -53          $ Top Region, CR1
29       0                -22   51  -53               $ Top Hole in CR1
30       0                -27   52  -62               $ Hole above Control Rod 2
31       0                -27   32   36  -52          $ Gap between CR2 & Rings
32       0                -23   36  -38               $ Bottom Hole, CR2
33       6    0.047922     23  -32   36  -38          $ Bottom Region, CR2
34       6    0.047922    -32   38  -50               $ Solid Middle Region, CR2
35       6    0.047922     23  -32   50  -52          $ Top Region, CR2
36       0                -23   50  -52               $ Top Hole in CR2
37       0                -26   58  -62               $ Hole above Burst Rod
38       0                -26   33   47  -58          $ Gap between BR & Rings
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39       0                -24   42  -46               $ Bottom Hole, Burst Rod

40       7    0.049025     24  -33   42  -46          $ Bottom Region, Burst Rod
41       7    0.049025    -33   46  -54               $ Middle Region, BR
42       7    0.049025     24  -33   54  -58          $ Top Region, Burst Rod
43       0                -24   54  -58               $ Top Hole in Burst Rod
c  Support Pads Converted to Ring
44       2    0.086011     15  -18   25   26   27
                           45  -48                    $ Support Pads as Ring
c  Bearing Ring
45       2    0.086011     16  -19   65  -70          $ Solid Bearing Ring
c  Subassembly Cover Plate
46       0                  3   -4   66  -69          $ Central Hole in SCP
47       0                  4  -13   66  -68          $ Inner Void in SCP
48       2    0.086011     13  -14   67  -69          $ Edge of SCP
49       2    0.086011      4  -13   68  -69          $ Center of SCP
c  Mounting Plate
50       0                -17   34  -35               $ Empty Central Hole
51       0                 25  -28   34  -35          $ Empty Hole for CR1
52       0                 26  -30   34  -35          $ Empty Hole for Burst Rod
53       0                 27  -29   34  -35          $ Empty Hole for CR2
54       4    0.058593     17  -21   28   29   30
                           34  -35                    $ Mounting Plate
c  Clamp Supports (Legs)
55       1    0.088296     35  -61   74  -78   83
                          -84                         $ Rectangular Right Leg
56       like 55 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Rectangular FL Leg
57       like 55 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Rectanglar BL Leg
c  Clamps
58       3    0.083675     40  -45   75  -77   80
                          -83                         $ Bottom of Clamp Back
59       3    0.083675     45  -70   75  -77   82
                          -83                         $ Middle of Clamp Back
60       3    0.083675     70  -73   75  -77   80
                          -83                         $ Top of Clamp Back
61       like 58 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Bottom of Clamp Back
62       like 59  but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Middle of Clamp Back
63       like 60 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top of Clamp Back
64       like 58 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Bottom of Clamp Back
65       like 59  but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Middle of Clamp Back
66       like 60 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Top of Clamp Back
c  Nut on Spindle
67       1    0.088296      2   -6   69  -71          $ Nut on Spindle
c  Outer Void Regions
68       0                  5  -13   43  -44          $ Cyl Gap below Platform
69       0                  5  -13   41  -43          $ Gap outside SB Base
70       0                  8  -13   44  -49          $ Gap outside Platform
71       0                 12  -13   56  -59
72       0                  9  -10   59  -60
73       0                  9  -10   60  -63      $ HEU Ring / Top ISP Gap
c  Inner Void Regions
74       0                -20   72  -73
                          #60  #63  #66
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75       0                  20  -21   35  -73   76
                            79  #55  #58  #59  #60 $ BR Void above Mtng Plate
76       0                  20  -21   35  -73  -76
                            79  #55  #58  #59  #60 $ FR Void above Mntg Plate
77       0                  20  -21   35  -73  -76
                           -79  #56  #61  #62  #63 $ FL Void above Mntg Plate
78       0                  20  -21   35  -73   76
                           -79  #57  #64  #65  #66 $ BL Void above Mntg Plate
79       0                  14  -16   67  -69      $ Gap between SCP and BRing
80       0                 -25   34  -37           $ Void below Control Rod 1
81       0                 -27   34  -36           $ Void below Control Rod 2
82       0                 -26   34  -42           $ Hole below Burst Rod
83       0                 -26   33   42  -47      $ Void around Burst Rod
84       0                  13  -20   25   26   27
                            35  -45
                           #58  #61  #64           $ Void below Pads
85       0                  13  -20   25   26   27
                            45  -47
                           #44  #56  #57
                           #59  #62  #65           $ Void outside Pads
86       0                 -13   35  -41           $ Void below Sfty Blk Base
87       0                  13  -16   69  -70      $ Void inside Bearing Ring
88       0                  13   19  -20   67  -70 $ Void outside Bearing Ring
                           #59  #62  #65           $ Void outside Bearing Ring
89       0                  13  -20   70  -72
                           #60  #63  #66           $ Void above Bearing Ring
90       0                  11  -13   49  -56
91       0                  12  -13   63  -66      $ Upr ISP / HEU Ring Gap
92       0                   3  -13   69  -72  #67 $ Spindle / HEU Ring Gap
93       0                 -11   55  -56
94       0                  -2   56  -57           $ Space below Spindle
95       0                  -1   57  -72           $ Glory Hole
96       0                   3   -7   64  -66      $ Top ISP - Spindle Gap
c  External Void Regions
97       0                  73
98       0                  21   34  -73
c 99       0                  -34
99       0                  21  -34   36
100      0                 -36
101      0                 -21   27  -34   36

1     cz   0.31750                                $ Glory-Hole Radius
2     cz   1.27000                                $ Spindle Bottom Middle OR
3     cz   1.42875                                $ Spindle Top Middle OR
4     cz   1.43510                                $ Radius of Central Hole in SCP
5     cz   1.90500                                $ OR of SB Base Bottom
6     cz   2.22250                                $ OR for Nut on Spindle
7     cz   3.50520                                $ Upper IR of UISP
8     cz   3.65760                                $ OR of SB Base Platform
9     cz   3.92430                                $ OR of Upper Int Sub Plate
10    cz   3.97510                                $ IR of Ring 5
11    cz   4.29260                                $ Safety Block Outer Radius
12    cz   4.38150                                $ OR of Lower Int Sub Plate
13    cz   4.44500                                $ IR of Rings 1-4, 6
14    cz   5.08000                                $ IR of S Pad Slots, BR Annulus
15    cz   5.08508                                $ Inner Radius of Sprt Pad Ring
16    cz   5.08381                                $ Inner Radius of Bearing Ring
17    cz   5.23875                                $ Radius of Central Hole in MP
18    cz   7.29488                                $ Outer Radius of Sprt Pad Ring
19    cz   7.29615                                $ Outer Radius of Bearing Ring
20    cz   8.89000                                $ OR of Rings
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21     cz  44.45                                       $ Outer Radius of Mtng Plate
22     c/z  3.33375   -5.774224   0.47625              $ Control Rod 1 IR
23     c/z  3.33375    5.774224   0.47625              $ Control Rod 2 IR
24     c/z -6.66750    0.0        0.47625              $ Burst Rod IR
25     c/z  3.33375   -5.774224   1.11125              $ FR Hole, Control or Burst Rod

26     c/z -6.66750    0.0        1.11125              $ Lt Hole, Control or Burst Rod
27     c/z  3.33375    5.774224   1.11125              $ BR Hole, Control or Burst Rod
28     c/z  3.33375   -5.774224   1.27000              $ FR Hole for Control Rod 1
29     c/z  3.33375    5.774224   1.27000              $ BR Hole for Control Rod 2
30     c/z -6.66750    0.0        1.27000              $ Left Hole for Burst Rod
31     c/z  3.33375   -5.774224   1.09220              $ Control Rod 1 OR
32     c/z  3.33375    5.774224   1.09220              $ Control Rod 2 OR
33     c/z -6.66750    0.0        1.09220              $ Burst Rod OR
34     pz -20.37715                                    $ Bottom of Mounting Plate
35     pz -16.56715                                    $ Top of Mounting Plate
36     pz -20.51685                                    $ Bottom of Control Rod 2
37     pz -10.93089                                    $ Bottom of Control Rod 1
38     pz -18.61185                                    $ Top of CR2 Bottom Hole
39     pz  -9.02589                                    $ Top of CR1 Bottom Hole
40     pz -12.67587                                    $ Bottom of Flat Clamp Bottom
41     pz -11.85559                                    $ Top of SB Base Bottom Hole
42     pz -10.79627                                    $ Bottom of Burst Rod (Full In)
43     pz  -9.79948                                    $ Bottom of Platform Curve
44     pz  -9.17448                                    $ Bottom of SB Base Platform
45     pz  -9.02589                                    $ Bottom of Support-Pad Ring
46     pz  -8.89127                                    $ Top of Burst Rod Bottom Hole
47     pz  -8.06553                                    $ Bottom of Ring 1
48     pz  -7.59414                                    $ Top of Ring 1 Slot for Pad Rg
49     pz  -7.74700                                    $ Bottom of Safety Block
50     pz  -9.72185                                    $ Bottom of CR2 Top Hole
51     pz  -0.13589                                    $ Bottom of CR1 Top Hole
52     pz  -7.81685                                    $ Top of Control Rod 2
53     pz   1.76911                                    $ Top of Control Rod 1
54     pz  -1.27127                                    $ Flat Bottom of BR Top Hole
55     pz  -0.12700                                    $ Top of Safety Block
56     pz   0.0                                        $ Bottom of Inter Inner SA Pl
57     pz   0.00254                                    $ Bottom of Spindle
58     pz   1.90373                                    $ Top of Burst Rod (Full In)
59     pz   2.54000                                    $ Top of IISP Wide Region
60     pz   3.49250                                    $ Top of Int Inr Subassby Plate
61     pz   4.38785                                    $ Top of Right Leg
62     pz   4.64820                                    $ Top of Ring 5 Outer Edge
63     pz   4.96570                                    $ Top of UISP Indentation
64     pz   6.98754                                    $ Bottom of UISP Inner Annulus
65     pz   7.27160                                    $ Bottom of Indent in 6
66     pz   7.64794                                    $ Top of Top Inr Subasmbly Pl
67     pz   7.73264                                    $ Top of HEU Ring 6
68     pz   7.95528                                    $ Top of SCP Raised Edge
69     pz   8.27278                                    $ Top of Subassembly Cvr Plate
70     pz   8.75411                                    $ Top of Bearing Ring
71     pz   9.54278                                    $ Top of Nut on Spindle
72     pz  11.43254                                    $ Top of Spindle
73     pz  12.40409                                    $ Top of Flat Clamp Top
74     py  -1.42875                                    $ Front Edge of Right Leg
75     py  -1.11125                                    $ Front Edge of Left Notch
76     py   0.0
77     py   1.11125                                    $ Back Edge of Left Notch
78     py   1.42875                                    $ Back Edge of Right Leg
79     px   0.0
80     px   5.08000                                    $ Left Edge of Prongs
```

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81    px   8.49376                              $ Back Edge of Left Notch(1&6)
82    px   8.49630                              $ Left Edge of Clamp Back
83    px  12.94130                              $ Right Edge of Right Leg Inset
84    px  18.94130                              $ Right Edge of Rectglar Rt Leg
85    p    1.0        1.7320508  0.0 -16.9857200 $ Back Edge, BL Notch (1 & 6)
86    p    1.0       -1.7320508  0.0 -16.9857200 $ Back Edge, BR Notch (1 & 6)
87    p    1.7320508 -1.0        0.0   1.9247415 $ Lower Edge, BL Notch
88    p    1.7320508 -1.0        0.0  -1.9247415 $ Upper Edge, BL Notch
89    p    1.7320508  1.0        0.0   1.9247415 $ Lower Edge, BR Notch
90    p    1.7320508  1.0        0.0  -1.9247415 $ Upper Edge, BR Notch

mode     n
kcode    10000    1.0    50    550
rand     hist=7314730
imp:n    1.0      95r   0.0     3r    1.0
ksrc     0.0    0.0   -1.0
c        SS 303  (8.0 g/cc)
m1        6000.66c     3.0083e-4
         14028.62c     1.5821e-3       14029.62c     8.0109e-5
         14030.62c     5.3177e-5
         15031.66c     1.5554e-4
         16000.62c     4.5067e-4
         24050.62c     7.2466e-4       24052.62c     1.3974e-2
         24053.62c     1.5844e-3       24054.62c     3.9443e-4
         25055.62c     8.7693e-4
         26054.62c     3.5742e-3       26056.62c     5.5564e-2
         26057.62c     1.2722e-3       26058.62c     1.6962e-4
         28058.62c     5.0437e-3       28060.62c     1.9282e-3
         28061.62c     8.3482e-5       28062.62c     2.6522e-4
         28064.62c     6.7229e-5
         42000.66c     1.5065e-4
c        SAE 4340  (7.85 g/cc)
m2        6000.66c     1.5940e-3
         14028.62c     3.4929e-4       14029.62c     1.7686e-5
         14030.62c     1.1740e-5
         15031.66c     2.7472e-5
         16000.62c     2.9481e-5
         24050.62c     3.1603e-5       24052.62c     6.0944e-4
         24053.62c     6.9097e-5       24054.62c     1.7202e-5
         25055.62c     6.2385e-4
         26054.62c     4.7824e-3       26056.62c     7.4345e-2
         26057.62c     1.7022e-3       26058.62c     2.2696e-4
         28058.62c     9.8985e-4       28060.62c     3.7842e-4
         28061.62c     1.6384e-5       28062.62c     5.2051e-5
         28064.62c     1.3194e-5
         42000.66c     1.2319e-4
c        VascoMax 300  (8.0 g/cc)
m3        6000.66c     8.0221e-5
         13027.62c     1.7855e-4
         14028.62c     7.9104e-5       14029.62c     4.0054e-6
         14030.62c     2.6588e-6
         15031.66c     7.7770e-6
         16000.62c     7.5112e-6
         22000.62c     7.3453e-4
         25055.62c     4.3847e-5
         26054.62c     3.4070e-3       26056.62c     5.2965e-2
         26057.62c     1.2127e-3       26058.62c     1.6169e-4
         27059.66c     7.1938e-3
         28058.62c     1.0367e-2       28060.62c     3.9635e-3
         28061.62c     1.7160e-4       28062.62c     5.4518e-4
         28064.62c     1.3819e-4
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         42000.66c     2.4103e-3
c        Pure Aluminum Mounting Plate
m4       13027.62c     5.8593e-2
c        HEU + Mo (93.17 wt.% for Safety Block), 18.1069 g/cc
m5       42000.66c     1.1384e-3
         92233.66c     4.6322e-6       92234.66c     4.7005e-4
         92235.66c     4.2791e-2       92236.66c     3.1098e-4
         92238.66c     2.3222e-3
c        HEU + Mo (93.16 wt.% for Control Rods 1 and 2)
m6       42000.66c     1.5385e-3
         92233.66c     4.6812e-6       92234.66c     4.7497e-4
         92235.66c     4.3238e-2       92236.66c     3.1427e-4
         92238.66c     2.3514e-3
c        HEU + Mo (93.16 wt.% for Burst Rod)
m7       42000.66c     1.5701e-3
         92233.66c     4.7893e-6       92234.66c     4.8594e-4
         92235.66c     4.4237e-2       92236.66c     3.2152e-4
         92238.66c     2.4057e-3
c        HEU + Mo (93.15 wt.% for Homogenized Fuel Rings)
m8       42000.66c     1.7082e-3
         92233.66c     4.6484e-6       92234.66c     4.7159e-4
         92235.66c     4.2930e-2       92236.66c     3.1206e-4
         92238.66c     2.3398e-3
c        HEU + Mo (93.15 wt.% for Homogenized IISP+UISP)
m9       42000.66c     1.7407e-3
         92233.66c     4.6755e-6       92234.66c     4.7433e-4
         92235.66c     4.3187e-2       92236.66c     3.1388e-4
         92238.66c     2.3464e-3
c
totnu
prdmp     j   575
print

 end of input
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```
Godiva-IV  HEU-MET-FAST-086  Case 4  Benchmark Model  DC  BR In  ENDF/B-VI
c  Spindle
1        1    0.088296      1   -2   57  -72          $ Spindle
2        0                  2   -3   64  -69
3        0                  2   -3   71  -72
c  Homogenized Subassembly Plate
4        9    0.048067      2  -12   56  -59          $ ISP Bottom Region
5        9    0.048067      2   -9   59  -63          $ ISP Middle Region
6        9    0.048067      2  -12   63  -64          $ ISP Top Region
7        9    0.048067      7  -12   64  -66          $ ISP Top Edge
c  Safety Block
8        5    0.047037      2  -11   49  -55          $ Cylindrical Safety Block
c  Safety Block Base
9        1    0.088296     -5   41  -44               $ SB Base Solid Round
10       1    0.088296     -8   44  -49               $ SB Base Platform
11       1    0.088296     -2   49  -55               $ Lower SB Base Barrel
c  Notches for HEU Rings
12       0                -20   47  -67   75  -77
                           81  #59                    $ Right Notch
13       0                -20   47  -67  -85  -87
                           88  #62                    $ Front Left Notch
14       0                -20   47  -67  -86  -89
                           90  #65                    $ Back Left Notch
c  Homogenized HEU Rings
15       8    0.047766     13  -15   25   26   27
                           47  -48                    $ Inner Bottom Annulus
16       8    0.047766     18  -20   25   26   27
                           47  -48  #12  #13  #14
                          #59  #62  #65               $ Outer Bottom Annulus
17       8    0.047766     13  -20   25   26   27
                           48  -59  #12  #13  #14
                          #59  #62  #65               $ Lower Narrow Region
18       8    0.047766     10  -20   25   26   27
                           59  -62  #12  #13  #14
                          #59  #62  #65               $ Lower Wide Region
19       8    0.047766     10  -20   62  -63  #12
                          #13  #14  #59  #62  #65     $ Upper Wide Region
20       8    0.047766     13  -20   63  -65
                          #12  #13  #14
                          #59  #62  #65               $ Upper Narrow Region
21       8    0.047766     13  -16   65  -67          $ Inr Top Narrow Region
22       8    0.047766     19  -20   65  -67
                          #12  #13  #14  #45
                          #59  #62  #65               $ Otr Top Narrow Region
c  Control and Burst Rods
23       0                -25   53  -62               $ Hole above Control Rod 1
24       0                -25   31   37  -53          $ Gap between CR1 & Rings
25       0                -22   37  -39               $ Bottom Hole, CR1
26       6    0.047922     22  -31   37  -39          $ Bottom Region, CR1
27       6    0.047922    -31   39  -51               $ Solid Middle Region, CR1
28       6    0.047922     22  -31   51  -53          $ Top Region, CR1
29       0                -22   51  -53               $ Top Hole in CR1
30       0                -27   52  -62               $ Hole above Control Rod 2
31       0                -27   32   36  -52          $ Gap between CR2 & Rings
32       0                -23   36  -38               $ Bottom Hole, CR2
33       6    0.047922     23  -32   36  -38          $ Bottom Region, CR2
34       6    0.047922    -32   38  -50               $ Solid Middle Region, CR2
35       6    0.047922     23  -32   50  -52          $ Top Region, CR2
36       0                -23   50  -52               $ Top Hole in CR2
37       0                -26   58  -62               $ Hole above Burst Rod
38       0                -26   33   47  -58          $ Gap between BR & Rings
```

```
39       0                -24   42  -46               $ Bottom Hole, Burst Rod

40       7    0.049025     24  -33   42  -46          $ Bottom Region, Burst Rod
41       7    0.049025    -33   46  -54               $ Middle Region, BR
42       7    0.049025     24  -33   54  -58          $ Top Region, Burst Rod
43       0                -24   54  -58               $ Top Hole in Burst Rod
c  Support Pads Converted to Ring
44       2    0.086011     15  -18   25   26   27
                           45  -48                    $ Support Pads as Ring
c  Bearing Ring
45       2    0.086011     16  -19   65  -70          $ Solid Bearing Ring
c  Subassembly Cover Plate
46       0                  3   -4   66  -69          $ Central Hole in SCP
47       0                  4  -13   66  -68          $ Inner Void in SCP
48       2    0.086011     13  -14   67  -69          $ Edge of SCP
49       2    0.086011      4  -13   68  -69          $ Center of SCP
c  Mounting Plate
50       0                -17   34  -35               $ Empty Central Hole
51       0                 25  -28   34  -35          $ Empty Hole for CR1
52       0                 26  -30   34  -35          $ Empty Hole for Burst Rod
53       0                 27  -29   34  -35          $ Empty Hole for CR2
54       4    0.058593     17  -21   28   29   30
                           34  -35                    $ Mounting Plate
c  Clamp Supports (Legs)
55       1    0.088296     35  -61   74  -78   83
                          -84                         $ Rectangular Right Leg
56       like 55 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Rectangular FL Leg
57       like 55 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Rectanglar BL Leg
c  Clamps
58       3    0.083675     40  -45   75  -77   80
                          -83                         $ Bottom of Clamp Back
59       3    0.083675     45  -70   75  -77   82
                          -83                         $ Middle of Clamp Back
60       3    0.083675     70  -73   75  -77   80
                          -83                         $ Top of Clamp Back
61       like 58 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Bottom of Clamp Back
62       like 59  but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Middle of Clamp Back
63       like 60 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top of Clamp Back
64       like 58 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Bottom of Clamp Back
65       like 59  but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Middle of Clamp Back
66       like 60 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Top of Clamp Back
c  Nut on Spindle
67       1    0.088296      2   -6   69  -71          $ Nut on Spindle
c  Outer Void Regions
68       0                  5  -13   43  -44          $ Cyl Gap below Platform
69       0                  5  -13   41  -43          $ Gap outside SB Base
70       0                  8  -13   44  -49          $ Gap outside Platform
71       0                 12  -13   56  -59
72       0                  9  -10   59  -60
73       0                  9  -10   60  -63      $ HEU Ring / Top ISP Gap
c  Inner Void Regions
74       0                -20   72  -73
                          #60  #63  #66
```

```
75       0                 20  -21   35  -73   76
                           79  #55  #58  #59  #60 $ BR Void above Mtng Plate
76       0                 20  -21   35  -73  -76
                           79  #55  #58  #59  #60 $ FR Void above Mntg Plate

77       0                 20  -21   35  -73  -76
                          -79  #56  #61  #62  #63 $ FL Void above Mntg Plate
78       0                 20  -21   35  -73   76
                          -79  #57  #64  #65  #66 $ BL Void above Mntg Plate
79       0                 14  -16   67  -69      $ Gap between SCP and BRing
80       0                -25   34  -37           $ Void below Control Rod 1
81       0                -27   34  -36           $ Void below Control Rod 2
82       0                -26   34  -42           $ Hole below Burst Rod
83       0                -26   33   42  -47      $ Void around Burst Rod
84       0                 13  -20   25   26   27
                           35  -45
                          #58  #61  #64           $ Void below Pads
85       0                 13  -20   25   26   27
                           45  -47
                          #44  #56  #57
                          #59  #62  #65           $ Void outside Pads
86       0                -13   35  -41           $ Void below Sfty Blk Base
87       0                 13  -16   69  -70      $ Void inside Bearing Ring
88       0                 13   19  -20   67  -70 $ Void outside Bearing Ring
                          #59  #62  #65           $ Void outside Bearing Ring
89       0                 13  -20   70  -72
                          #60  #63  #66           $ Void above Bearing Ring
90       0                 11  -13   49  -56
91       0                 12  -13   63  -66      $ Upr ISP / HEU Ring Gap
92       0                  3  -13   69  -72  #67 $ Spindle / HEU Ring Gap
93       0                -11   55  -56
94       0                 -2   56  -57           $ Space below Spindle
95       0                 -1   57  -72           $ Glory Hole
96       0                  3   -7   64  -66      $ Top ISP - Spindle Gap
c  External Void Regions
97       0                 73
98       0                 21   34  -73
99       0                -34

1      cz   0.31750                             $ Glory-Hole Radius
2      cz   1.27000                             $ Spindle Bottom Middle OR
3      cz   1.42875                             $ Spindle Top Middle OR
4      cz   1.43510                             $ Radius of Central Hole in SCP
5      cz   1.90500                             $ OR of SB Base Bottom
6      cz   2.22250                             $ OR for Nut on Spindle
7      cz   3.50520                             $ Upper IR of UISP
8      cz   3.65760                             $ OR of SB Base Platform
9      cz   3.92430                             $ OR of Upper Int Sub Plate
10     cz   3.97510                             $ IR of Ring 5
11     cz   4.29260                             $ Safety Block Outer Radius
12     cz   4.38150                             $ OR of Lower Int Sub Plate
13     cz   4.44500                             $ IR of Rings 1-4, 6
14     cz   5.08000                             $ IR of S Pad Slots, BR Annulus
15     cz   5.08508                             $ Inner Radius of Sprt Pad Ring
16     cz   5.08381                             $ Inner Radius of Bearing Ring
17     cz   5.23875                             $ Radius of Central Hole in MP
18     cz   7.29488                             $ Outer Radius of Sprt Pad Ring
19     cz   7.29615                             $ Outer Radius of Bearing Ring
20     cz   8.89000                             $ OR of Rings
21     cz  44.45                                $ Outer Radius of Mtng Plate
22     c/z  3.33375   -5.774224   0.47625        $ Control Rod 1 IR
```

```
23    c/z  3.33375    5.774224   0.47625         $ Control Rod 2 IR
24    c/z -6.66750    0.0        0.47625         $ Burst Rod IR
25    c/z  3.33375   -5.774224   1.11125         $ FR Hole, Control or Burst Rod
26    c/z -6.66750    0.0        1.11125         $ Lt Hole, Control or Burst Rod
27    c/z  3.33375    5.774224   1.11125         $ BR Hole, Control or Burst Rod
28    c/z  3.33375   -5.774224   1.27000         $ FR Hole for Control Rod 1

29    c/z  3.33375    5.774224   1.27000         $ BR Hole for Control Rod 2
30    c/z -6.66750    0.0        1.27000         $ Left Hole for Burst Rod
31    c/z  3.33375   -5.774224   1.09220         $ Control Rod 1 OR
32    c/z  3.33375    5.774224   1.09220         $ Control Rod 2 OR
33    c/z -6.66750    0.0        1.09220         $ Burst Rod OR
34    pz -20.37715                               $ Bottom of Mounting Plate
35    pz -16.56715                               $ Top of Mounting Plate
36    pz -10.81405                               $ Bottom of Control Rod 2
37    pz -10.86993                               $ Bottom of Control Rod 1
38    pz   -8.90905                              $ Top of CR2 Bottom Hole
39    pz   -8.96493                              $ Top of CR1 Bottom Hole
40    pz -12.67587                               $ Bottom of Flat Clamp Bottom
41    pz -11.85559                               $ Top of SB Base Bottom Hole
42    pz -18.34007                               $ Btm of Burst Rod (Full Out)
43    pz   -9.79948                              $ Bottom of Platform Curve
44    pz   -9.17448                              $ Bottom of SB Base Platform
45    pz   -9.02589                              $ Bottom of Support-Pad Ring
46    pz -16.43507                               $ Top of Burst Rod Bottom Hole
47    pz   -8.06553                              $ Bottom of Ring 1
48    pz   -7.59414                              $ Top of Ring 1 Slot for Pad Rg
49    pz   -7.74700                              $ Bottom of Safety Block
50    pz   -0.01905                              $ Bottom of CR2 Top Hole
51    pz   -0.07493                              $ Bottom of CR1 Top Hole
52    pz    1.88595                              $ Top of Control Rod 2
53    pz    1.83007                              $ Top of Control Rod 1
54    pz   -8.81507                              $ Flat Bottom of BR Top Hole
55    pz   -0.12700                              $ Top of Safety Block
56    pz    0.0                                  $ Bottom of Inter Inner SA Pl
57    pz    0.00254                              $ Bottom of Spindle
58    pz   -5.64007                              $ Top of Burst Rod (Full Out)
59    pz    2.54000                              $ Top of IISP Wide Region
60    pz    3.49250                              $ Top of Int Inr Subassby Plate
61    pz    4.38785                              $ Top of Right Leg
62    pz    4.64820                              $ Top of Ring 5 Outer Edge
63    pz    4.96570                              $ Top of UISP Indentation
64    pz    6.98754                              $ Bottom of UISP Inner Annulus
65    pz    7.27160                              $ Bottom of Indent in 6
66    pz    7.64794                              $ Top of Top Inr Subasmbly Pl
67    pz    7.73264                              $ Top of HEU Ring 6
68    pz    7.95528                              $ Top of SCP Raised Edge
69    pz    8.27278                              $ Top of Subassembly Cvr Plate
70    pz    8.75411                              $ Top of Bearing Ring
71    pz    9.54278                              $ Top of Nut on Spindle
72    pz   11.43254                              $ Top of Spindle
73    pz   12.40409                              $ Top of Flat Clamp Top
74    py   -1.42875                              $ Front Edge of Right Leg
75    py   -1.11125                              $ Front Edge of Left Notch
76    py    0.0
77    py    1.11125                              $ Back Edge of Left Notch
78    py    1.42875                              $ Back Edge of Right Leg
79    px    0.0
80    px    5.08000                              $ Left Edge of Prongs
81    px    8.49376                              $ Back Edge of Left Notch(1&6)
82    px    8.49630                              $ Left Edge of Clamp Back
```

```
83    px  12.94130                                   $ Right Edge of Right Leg Inset
84    px  18.94130                                   $ Right Edge of Rectglar Rt Leg
85    p    1.0        1.7320508  0.0 -16.9857200 $ Back Edge, BL Notch (1 & 6)
86    p    1.0       -1.7320508  0.0 -16.9857200 $ Back Edge, BR Notch (1 & 6)
87    p    1.7320508 -1.0        0.0   1.9247415 $ Lower Edge, BL Notch
88    p    1.7320508 -1.0        0.0  -1.9247415 $ Upper Edge, BL Notch
89    p    1.7320508  1.0        0.0   1.9247415 $ Lower Edge, BR Notch
90    p    1.7320508  1.0        0.0  -1.9247415 $ Upper Edge, BR Notch


mode     n
kcode    10000    1.0    50    550
imp:n    1.0      95r   0.0     2r
ksrc     0.0    0.0   -1.0
c        SS 303  (8.0 g/cc)
m1        6000.66c     3.0083e-4
         14028.62c     1.5821e-3       14029.62c     8.0109e-5
         14030.62c     5.3177e-5
         15031.66c     1.5554e-4
         16000.62c     4.5067e-4
         24050.62c     7.2466e-4       24052.62c     1.3974e-2
         24053.62c     1.5844e-3       24054.62c     3.9443e-4
         25055.62c     8.7693e-4
         26054.62c     3.5742e-3       26056.62c     5.5564e-2
         26057.62c     1.2722e-3       26058.62c     1.6962e-4
         28058.62c     5.0437e-3       28060.62c     1.9282e-3
         28061.62c     8.3482e-5       28062.62c     2.6522e-4
         28064.62c     6.7229e-5
         42000.66c     1.5065e-4
c        SAE 4340  (7.85 g/cc)
m2        6000.66c     1.5940e-3
         14028.62c     3.4929e-4       14029.62c     1.7686e-5
         14030.62c     1.1740e-5
         15031.66c     2.7472e-5
         16000.62c     2.9481e-5
         24050.62c     3.1603e-5       24052.62c     6.0944e-4
         24053.62c     6.9097e-5       24054.62c     1.7202e-5
         25055.62c     6.2385e-4
         26054.62c     4.7824e-3       26056.62c     7.4345e-2
         26057.62c     1.7022e-3       26058.62c     2.2696e-4
         28058.62c     9.8985e-4       28060.62c     3.7842e-4
         28061.62c     1.6384e-5       28062.62c     5.2051e-5
         28064.62c     1.3194e-5
         42000.66c     1.2319e-4
c        VascoMax 300  (8.0 g/cc)
m3        6000.66c     8.0221e-5
         13027.62c     1.7855e-4
         14028.62c     7.9104e-5       14029.62c     4.0054e-6
         14030.62c     2.6588e-6
         15031.66c     7.7770e-6
         16000.62c     7.5112e-6
         22000.62c     7.3453e-4
         25055.62c     4.3847e-5
         26054.62c     3.4070e-3       26056.62c     5.2965e-2
         26057.62c     1.2127e-3       26058.62c     1.6169e-4
         27059.66c     7.1938e-3
         28058.62c     1.0367e-2       28060.62c     3.9635e-3
         28061.62c     1.7160e-4       28062.62c     5.4518e-4
         28064.62c     1.3819e-4
         42000.66c     2.4103e-3
```

```
c        Pure Aluminum Mounting Plate
m4       13027.62c     5.8593e-2
c        HEU + Mo (93.17 wt.% for Safety Block), 18.1069 g/cc
m5       42000.66c     1.1384e-3
         92233.66c     4.6322e-6       92234.66c     4.7005e-4
         92235.66c     4.2791e-2       92236.66c     3.1098e-4
         92238.66c     2.3222e-3
c        HEU + Mo (93.16 wt.% for Control Rods 1 and 2)
m6       42000.66c     1.5385e-3
         92233.66c     4.6812e-6       92234.66c     4.7497e-4
         92235.66c     4.3238e-2       92236.66c     3.1427e-4
         92238.66c     2.3514e-3

c        HEU + Mo (93.16 wt.% for Burst Rod)
m7       42000.66c     1.5701e-3
         92233.66c     4.7893e-6       92234.66c     4.8594e-4
         92235.66c     4.4237e-2       92236.66c     3.2152e-4
         92238.66c     2.4057e-3
c        HEU + Mo (93.15 wt.% for Homogenized Fuel Rings)
m8       42000.66c     1.7082e-3
         92233.66c     4.6484e-6       92234.66c     4.7159e-4
         92235.66c     4.2930e-2       92236.66c     3.1206e-4
         92238.66c     2.3398e-3
c        HEU + Mo (93.15 wt.% for Homogenized IISP+UISP)
m9       42000.66c     1.7407e-3
         92233.66c     4.6755e-6       92234.66c     4.7433e-4
         92235.66c     4.3187e-2       92236.66c     3.1388e-4
         92238.66c     2.3464e-3
c
totnu
prdmp     j   575
print

 end of input
```

```
Godiva-IV  HEU-MET-FAST-086  Case 5  Benchmark Model  PSCrit  BR In  E-VI  RN3
c  Spindle
1        1    0.088296      1   -2   57  -72          $ Spindle
2        0                  2   -3   64  -69
3        0                  2   -3   71  -72
c  Homogenized Subassembly Plate
4        9    0.048067      2  -12   56  -59          $ ISP Bottom Region
5        9    0.048067      2   -9   59  -63          $ ISP Middle Region
6        9    0.048067      2  -12   63  -64          $ ISP Top Region
7        9    0.048067      7  -12   64  -66          $ ISP Top Edge
c  Safety Block
8        5    0.047037      2  -11   49  -55          $ Cylindrical Safety Block
c  Safety Block Base
9        1    0.088296     -5   41  -44               $ SB Base Solid Round
10       1    0.088296     -8   44  -49               $ SB Base Platform
11       1    0.088296     -2   49  -55               $ Lower SB Base Barrel
c  Notches for HEU Rings
12       0                -20   47  -67   75  -77
                           81  #59                    $ Right Notch
13       0                -20   47  -67  -85  -87
                           88  #62                    $ Front Left Notch
14       0                -20   47  -67  -86  -89
                           90  #65                    $ Back Left Notch
c  Homogenized HEU Rings
15       8    0.047766     13  -15   25   26   27
                           47  -48                    $ Inner Bottom Annulus
16       8    0.047766     18  -20   25   26   27
                           47  -48  #12  #13  #14
                          #59  #62  #65               $ Outer Bottom Annulus
17       8    0.047766     13  -20   25   26   27
                           48  -59  #12  #13  #14
                          #59  #62  #65               $ Lower Narrow Region
18       8    0.047766     10  -20   25   26   27
                           59  -62  #12  #13  #14
                          #59  #62  #65               $ Lower Wide Region
19       8    0.047766     10  -20   62  -63  #12
                          #13  #14  #59  #62  #65     $ Upper Wide Region
20       8    0.047766     13  -20   63  -65
                          #12  #13  #14
                          #59  #62  #65               $ Upper Narrow Region
21       8    0.047766     13  -16   65  -67          $ Inr Top Narrow Region
22       8    0.047766     19  -20   65  -67
                          #12  #13  #14  #45
                          #59  #62  #65               $ Otr Top Narrow Region
c  Control and Burst Rods
23       0                -25   53  -62               $ Hole above Control Rod 1
24       0                -25   31   37  -53          $ Gap between CR1 & Rings
25       0                -22   37  -39               $ Bottom Hole, CR1
26       6    0.047922     22  -31   37  -39          $ Bottom Region, CR1
27       6    0.047922    -31   39  -51               $ Solid Middle Region, CR1
28       6    0.047922     22  -31   51  -53          $ Top Region, CR1
29       0                -22   51  -53               $ Top Hole in CR1
30       0                -27   52  -62               $ Hole above Control Rod 2
31       0                -27   32   36  -52          $ Gap between CR2 & Rings
32       0                -23   36  -38               $ Bottom Hole, CR2
33       6    0.047922     23  -32   36  -38          $ Bottom Region, CR2
34       6    0.047922    -32   38  -50               $ Solid Middle Region, CR2
35       6    0.047922     23  -32   50  -52          $ Top Region, CR2
36       0                -23   50  -52               $ Top Hole in CR2
37       0                -26   58  -62               $ Hole above Burst Rod
38       0                -26   33   47  -58          $ Gap between BR & Rings
```

```
39       0                -24   42  -46                $ Bottom Hole, Burst Rod

40       7    0.049025     24  -33   42  -46           $ Bottom Region, Burst Rod
41       7    0.049025    -33   46  -54                $ Middle Region, BR
42       7    0.049025     24  -33   54  -58           $ Top Region, Burst Rod
43       0                -24   54  -58                $ Top Hole in Burst Rod
c  Support Pads Converted to Ring
44       2    0.086011     15  -18   25   26   27
                           45  -48                     $ Support Pads as Ring
c  Bearing Ring
45       2    0.086011     16  -19   65  -70           $ Solid Bearing Ring
c  Subassembly Cover Plate
46       0                  3   -4   66  -69           $ Central Hole in SCP
47       0                  4  -13   66  -68           $ Inner Void in SCP
48       2    0.086011     13  -14   67  -69           $ Edge of SCP
49       2    0.086011      4  -13   68  -69           $ Center of SCP
c  Mounting Plate
50       0                -17   34  -35                $ Empty Central Hole
51       0                 25  -28   34  -35           $ Empty Hole for CR1
52       0                 26  -30   34  -35           $ Empty Hole for Burst Rod
53       0                 27  -29   34  -35           $ Empty Hole for CR2
54       4    0.058593     17  -21   28   29   30
                           34  -35                     $ Mounting Plate
c  Clamp Supports (Legs)
55       1    0.088296     35  -61   74  -78   83
                          -84                          $ Rectangular Right Leg
56       like 55 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Rectangular FL Leg
57       like 55 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Rectanglar BL Leg
c  Clamps
58       3    0.083675     40  -45   75  -77   80
                          -83                          $ Bottom of Clamp Back
59       3    0.083675     45  -70   75  -77   82
                          -83                          $ Middle of Clamp Back
60       3    0.083675     70  -73   75  -77   80
                          -83                          $ Top of Clamp Back
61       like 58 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Bottom of Clamp Back
62       like 59  but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Middle of Clamp Back
63       like 60 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top of Clamp Back
64       like 58 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Bottom of Clamp Back
65       like 59  but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Middle of Clamp Back
66       like 60 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Top of Clamp Back
c  Nut on Spindle
67       1    0.088296      2   -6   69  -71           $ Nut on Spindle
c  Outer Void Regions
68       0                  5  -13   43  -44           $ Cyl Gap below Platform
69       0                  5  -13   41  -43           $ Gap outside SB Base
70       0                  8  -13   44  -49           $ Gap outside Platform
71       0                 12  -13   56  -59
72       0                  9  -10   59  -60
73       0                  9  -10   60  -63       $ HEU Ring / Top ISP Gap
c  Inner Void Regions
74       0                -20   72  -73
                          #60  #63  #66
```

```
75       0                 20  -21   35  -73   76
                           79  #55  #58  #59  #60 $ BR Void above Mtng Plate
76       0                 20  -21   35  -73  -76
                           79  #55  #58  #59  #60 $ FR Void above Mntg Plate

77       0                 20  -21   35  -73  -76
                          -79  #56  #61  #62  #63 $ FL Void above Mntg Plate
78       0                 20  -21   35  -73   76
                          -79  #57  #64  #65  #66 $ BL Void above Mntg Plate
79       0                 14  -16   67  -69      $ Gap between SCP and BRing
80       0                -25   34  -37           $ Void below Control Rod 1
81       0                -27   34  -36           $ Void below Control Rod 2
82       0                -26   34  -42           $ Hole below Burst Rod
83       0                -26   33   42  -47      $ Void around Burst Rod
84       0                 13  -20   25   26   27
                           35  -45
                          #58  #61  #64           $ Void below Pads
85       0                 13  -20   25   26   27
                           45  -47
                          #44  #56  #57
                          #59  #62  #65           $ Void outside Pads
86       0                -13   35  -41           $ Void below Sfty Blk Base
87       0                 13  -16   69  -70      $ Void inside Bearing Ring
88       0                 13   19  -20   67  -70 $ Void outside Bearing Ring
                          #59  #62  #65           $ Void outside Bearing Ring
89       0                 13  -20   70  -72
                          #60  #63  #66           $ Void above Bearing Ring
90       0                 11  -13   49  -56
91       0                 12  -13   63  -66      $ Upr ISP / HEU Ring Gap
92       0                  3  -13   69  -72  #67 $ Spindle / HEU Ring Gap
93       0                -11   55  -56
94       0                 -2   56  -57           $ Space below Spindle
95       0                 -1   57  -72           $ Glory Hole
96       0                  3   -7   64  -66      $ Top ISP - Spindle Gap
c  External Void Regions
97       0                 73
98       0                 21   34  -73
99       0                -34

1     cz   0.31750                               $ Glory-Hole Radius
2     cz   1.27000                               $ Spindle Bottom Middle OR
3     cz   1.42875                               $ Spindle Top Middle OR
4     cz   1.43510                               $ Radius of Central Hole in SCP
5     cz   1.90500                               $ OR of SB Base Bottom
6     cz   2.22250                               $ OR for Nut on Spindle
7     cz   3.50520                               $ Upper IR of UISP
8     cz   3.65760                               $ OR of SB Base Platform
9     cz   3.92430                               $ OR of Upper Int Sub Plate
10    cz   3.97510                               $ IR of Ring 5
11    cz   4.29260                               $ Safety Block Outer Radius
12    cz   4.38150                               $ OR of Lower Int Sub Plate
13    cz   4.44500                               $ IR of Rings 1-4, 6
14    cz   5.08000                               $ IR of S Pad Slots, BR Annulus
15    cz   5.08508                               $ Inner Radius of Sprt Pad Ring
16    cz   5.08381                               $ Inner Radius of Bearing Ring
17    cz   5.23875                               $ Radius of Central Hole in MP
18    cz   7.29488                               $ Outer Radius of Sprt Pad Ring
19    cz   7.29615                               $ Outer Radius of Bearing Ring
20    cz   8.89000                               $ OR of Rings
21    cz  44.45                                  $ Outer Radius of Mtng Plate
22    c/z  3.33375   -5.774224   0.47625         $ Control Rod 1 IR
```

```
23    c/z  3.33375    5.774224   0.47625         $ Control Rod 2 IR
24    c/z -6.66750    0.0        0.47625         $ Burst Rod IR
25    c/z  3.33375   -5.774224   1.11125         $ FR Hole, Control or Burst Rod
26    c/z -6.66750    0.0        1.11125         $ Lt Hole, Control or Burst Rod
27    c/z  3.33375    5.774224   1.11125         $ BR Hole, Control or Burst Rod
28    c/z  3.33375   -5.774224   1.27000         $ FR Hole for Control Rod 1

29    c/z  3.33375    5.774224   1.27000         $ BR Hole for Control Rod 2
30    c/z -6.66750    0.0        1.27000         $ Left Hole for Burst Rod
31    c/z  3.33375   -5.774224   1.09220         $ Control Rod 1 OR
32    c/z  3.33375    5.774224   1.09220         $ Control Rod 2 OR
33    c/z -6.66750    0.0        1.09220         $ Burst Rod OR
34    pz -20.37715                               $ Bottom of Mounting Plate
35    pz -16.56715                               $ Top of Mounting Plate
36    pz -12.54633                               $ Bottom of Control Rod 2
37    pz -10.48893                               $ Bottom of Control Rod 1
38    pz -10.64133                               $ Top of CR2 Bottom Hole
39    pz  -8.58393                               $ Top of CR1 Bottom Hole
40    pz -12.67587                               $ Bottom of Flat Clamp Bottom
41    pz -11.85559                               $ Top of SB Base Bottom Hole
42    pz -10.79627                               $ Bottom of Burst Rod (Full In)
43    pz  -9.79948                               $ Bottom of Platform Curve
44    pz  -9.17448                               $ Bottom of SB Base Platform
45    pz  -9.02589                               $ Bottom of Support-Pad Ring
46    pz  -8.89127                               $ Top of Burst Rod Bottom Hole
47    pz  -8.06553                               $ Bottom of Ring 1
48    pz  -7.59414                               $ Top of Ring 1 Slot for Pad Rg
49    pz  -7.74700                               $ Bottom of Safety Block
50    pz  -1.75133                               $ Bottom of CR2 Top Hole
51    pz   0.30607                               $ Bottom of CR1 Top Hole
52    pz   0.15367                               $ Top of Control Rod 2
53    pz   2.21107                               $ Top of Control Rod 1
54    pz  -1.27127                               $ Flat Bottom of BR Top Hole
55    pz  -0.12700                               $ Top of Safety Block
56    pz   0.0                                   $ Bottom of Inter Inner SA Pl
57    pz   0.00254                               $ Bottom of Spindle
58    pz   1.90373                               $ Top of Burst Rod (Full In)
59    pz   2.54000                               $ Top of IISP Wide Region
60    pz   3.49250                               $ Top of Int Inr Subassby Plate
61    pz   4.38785                               $ Top of Right Leg
62    pz   4.64820                               $ Top of Ring 5 Outer Edge
63    pz   4.96570                               $ Top of UISP Indentation
64    pz   6.98754                               $ Bottom of UISP Inner Annulus
65    pz   7.27160                               $ Bottom of Indent in 6
66    pz   7.64794                               $ Top of Top Inr Subasmbly Pl
67    pz   7.73264                               $ Top of HEU Ring 6
68    pz   7.95528                               $ Top of SCP Raised Edge
69    pz   8.27278                               $ Top of Subassembly Cvr Plate
70    pz   8.75411                               $ Top of Bearing Ring
71    pz   9.54278                               $ Top of Nut on Spindle
72    pz  11.43254                               $ Top of Spindle
73    pz  12.40409                               $ Top of Flat Clamp Top
74    py  -1.42875                               $ Front Edge of Right Leg
75    py  -1.11125                               $ Front Edge of Left Notch
76    py   0.0
77    py   1.11125                               $ Back Edge of Left Notch
78    py   1.42875                               $ Back Edge of Right Leg
79    px   0.0
80    px   5.08000                               $ Left Edge of Prongs
81    px   8.49376                               $ Back Edge of Left Notch(1&6)
82    px   8.49630                               $ Left Edge of Clamp Back
```

```
83    px  12.94130                              $ Right Edge of Right Leg Inset
84    px  18.94130                              $ Right Edge of Rectglar Rt Leg
85    p    1.0        1.7320508  0.0 -16.9857200 $ Back Edge, BL Notch (1 & 6)
86    p    1.0       -1.7320508  0.0 -16.9857200 $ Back Edge, BR Notch (1 & 6)
87    p    1.7320508 -1.0        0.0   1.9247415 $ Lower Edge, BL Notch
88    p    1.7320508 -1.0        0.0  -1.9247415 $ Upper Edge, BL Notch
89    p    1.7320508  1.0        0.0   1.9247415 $ Lower Edge, BR Notch
90    p    1.7320508  1.0        0.0  -1.9247415 $ Upper Edge, BR Notch


mode     n
kcode    10000    1.0    50    550
rand     hist=1431470
imp:n    1.0      95r   0.0     2r
ksrc     0.0    0.0   -1.0
c        SS 303  (8.0 g/cc)
m1        6000.66c     3.0083e-4
         14028.62c     1.5821e-3       14029.62c     8.0109e-5
         14030.62c     5.3177e-5
         15031.66c     1.5554e-4
         16000.62c     4.5067e-4
         24050.62c     7.2466e-4       24052.62c     1.3974e-2
         24053.62c     1.5844e-3       24054.62c     3.9443e-4
         25055.62c     8.7693e-4
         26054.62c     3.5742e-3       26056.62c     5.5564e-2
         26057.62c     1.2722e-3       26058.62c     1.6962e-4
         28058.62c     5.0437e-3       28060.62c     1.9282e-3
         28061.62c     8.3482e-5       28062.62c     2.6522e-4
         28064.62c     6.7229e-5
         42000.66c     1.5065e-4
c        SAE 4340  (7.85 g/cc)
m2        6000.66c     1.5940e-3
         14028.62c     3.4929e-4       14029.62c     1.7686e-5
         14030.62c     1.1740e-5
         15031.66c     2.7472e-5
         16000.62c     2.9481e-5
         24050.62c     3.1603e-5       24052.62c     6.0944e-4
         24053.62c     6.9097e-5       24054.62c     1.7202e-5
         25055.62c     6.2385e-4
         26054.62c     4.7824e-3       26056.62c     7.4345e-2
         26057.62c     1.7022e-3       26058.62c     2.2696e-4
         28058.62c     9.8985e-4       28060.62c     3.7842e-4
         28061.62c     1.6384e-5       28062.62c     5.2051e-5
         28064.62c     1.3194e-5
         42000.66c     1.2319e-4
c        VascoMax 300  (8.0 g/cc)
m3        6000.66c     8.0221e-5
         13027.62c     1.7855e-4
         14028.62c     7.9104e-5       14029.62c     4.0054e-6
         14030.62c     2.6588e-6
         15031.66c     7.7770e-6
         16000.62c     7.5112e-6
         22000.62c     7.3453e-4
         25055.62c     4.3847e-5
         26054.62c     3.4070e-3       26056.62c     5.2965e-2
         26057.62c     1.2127e-3       26058.62c     1.6169e-4
         27059.66c     7.1938e-3
         28058.62c     1.0367e-2       28060.62c     3.9635e-3
         28061.62c     1.7160e-4       28062.62c     5.4518e-4
         28064.62c     1.3819e-4
         42000.66c     2.4103e-3
```

```
c        Pure Aluminum Mounting Plate
m4       13027.62c     5.8593e-2
c        HEU + Mo (93.17 wt.% for Safety Block), 18.1069 g/cc
m5       42000.66c     1.1384e-3
         92233.66c     4.6322e-6       92234.66c     4.7005e-4
         92235.66c     4.2791e-2       92236.66c     3.1098e-4
         92238.66c     2.3222e-3
c        HEU + Mo (93.16 wt.% for Control Rods 1 and 2)
m6       42000.66c     1.5385e-3
         92233.66c     4.6812e-6       92234.66c     4.7497e-4
         92235.66c     4.3238e-2       92236.66c     3.1427e-4
         92238.66c     2.3514e-3

c        HEU + Mo (93.16 wt.% for Burst Rod)
m7       42000.66c     1.5701e-3
         92233.66c     4.7893e-6       92234.66c     4.8594e-4
         92235.66c     4.4237e-2       92236.66c     3.2152e-4
         92238.66c     2.4057e-3
c        HEU + Mo (93.15 wt.% for Homogenized Fuel Rings)
m8       42000.66c     1.7082e-3
         92233.66c     4.6484e-6       92234.66c     4.7159e-4
         92235.66c     4.2930e-2       92236.66c     3.1206e-4
         92238.66c     2.3398e-3
c        HEU + Mo (93.15 wt.% for Homogenized IISP+UISP)
m9       42000.66c     1.7407e-3
         92233.66c     4.6755e-6       92234.66c     4.7433e-4
         92235.66c     4.3187e-2       92236.66c     3.1388e-4
         92238.66c     2.3464e-3
c
totnu
prdmp     j   575
print

 end of input
```

A.2 TRIPOLI4 Input Listings

The TRIPOLI4 input files for the five cases listed below employ continuous-energy cross sections derived from interim release 4 of ENDF/B-VI. These cases employ 550 generations of 10,000 neutrons each, and they excludes the first 50 generations from the statistics. Consequently, the results they produce are based on 5,000,000 active histories.

```
GEOMETRIE
TITRE  Godiva-IV  HEU-MET-FAST-086  Case 1  Benchmark Model  DC  BR In  ENDF/B-VI

SURF 1 CYLZ 0. 0. 0.31750 // Glory-Hole Radius
SURF 2 CYLZ 0. 0. 1.27000 // Spindle Bottom Middle OR
SURF 3 CYLZ 0. 0. 1.42875 // Spindle Top Middle OR
SURF 4 CYLZ 0. 0. 1.43510 // Radius of Central Hole in SCP
SURF 5 CYLZ 0. 0. 1.90500 // OR of SB Base Bottom
SURF 6 CYLZ 0. 0. 2.22250 // OR for Nut on Spindle
SURF 7 CYLZ 0. 0. 3.50520 // Upper IR of UISP
SURF 8 CYLZ 0. 0. 3.65760 // OR of SB Base Platform
SURF 9 CYLZ 0. 0. 3.92430 // OR of Upper Int Sub Plate
SURF 10 CYLZ 0. 0. 3.97510 // IR of Ring 5
SURF 11 CYLZ 0. 0. 4.29260 // Safety Block Outer Radius
SURF 12 CYLZ 0. 0. 4.38150 // OR of Lower Int Sub Plate
SURF 13 CYLZ 0. 0. 4.44500 // IR of Rings 1-4, 6
SURF 14 CYLZ 0. 0. 5.08000 // IR of S Pad Slots, BR Annulus
SURF 15 CYLZ 0. 0. 5.08508 // Inner Radius of Sprt Pad Ring
SURF 16 CYLZ 0. 0. 5.08381 // Inner Radius of Bearing Ring
SURF 17 CYLZ 0. 0. 5.23875 // Radius of Central Hole in MP
SURF 18 CYLZ 0. 0. 7.29488 // Outer Radius of Sprt Pad Ring
SURF 19 CYLZ 0. 0. 7.29615 // Outer Radius of Bearing Ring
SURF 20 CYLZ 0. 0. 8.89000 // OR of Rings
SURF 21 CYLZ 0. 0. 44.45 // Outer Radius of Mtng Plate
SURF 22 CYLZ 3.33375 -5.774224 0.47625 // Control Rod 1 IR
SURF 23 CYLZ 3.33375 5.774224 0.47625 // Control Rod 2 IR
SURF 24 CYLZ -6.66750 0.0 0.47625 // Burst Rod IR
SURF 25 CYLZ 3.33375 -5.774224 1.11125 // FR Hole, Control or Burst Rod
SURF 26 CYLZ -6.66750 0.0 1.11125 // Lt Hole, Control or Burst Rod
SURF 27 CYLZ 3.33375 5.774224 1.11125 // BR Hole, Control or Burst Rod
SURF 28 CYLZ 3.33375 -5.774224 1.27000 // FR Hole for Control Rod 1
SURF 29 CYLZ 3.33375 5.774224 1.27000 // BR Hole for Control Rod 2
SURF 30 CYLZ -6.66750 0.0 1.27000 // Left Hole for Burst Rod
SURF 31 CYLZ 3.33375 -5.774224 1.09220 // Control Rod 1 OR
SURF 32 CYLZ 3.33375 5.774224 1.09220 // Control Rod 2 OR
SURF 33 CYLZ -6.66750 0.0 1.09220 // Burst Rod OR
SURF 34 PLANZ -20.37715 // Bottom of Mounting Plate
SURF 35 PLANZ -16.56715 // Top of Mounting Plate
SURF 36 PLANZ -12.02055 // Bottom of Control Rod 2
SURF 37 PLANZ -19.84121 // Bottom of Control Rod 1
SURF 38 PLANZ -10.11555 // Top of CR2 Bottom Hole
SURF 39 PLANZ -17.93621 // Top of CR1 Bottom Hole
SURF 40 PLANZ -12.67587 // Bottom of Flat Clamp Bottom
SURF 41 PLANZ -11.85559 // Bottom of Safety Block Base
SURF 42 PLANZ -10.79627 // Bottom of Burst Rod (Full In)
SURF 43 PLANZ -9.79948 // Bottom of Platform Curve
SURF 44 PLANZ -9.17448 // Bottom of SB Base Platform
SURF 45 PLANZ -9.02589 // Bottom of Support-Pad Ring
SURF 46 PLANZ -8.89127 // Top of Burst Rod Bottom Hole
SURF 47 PLANZ -8.06553 // Bottom of Homog Fuel Rings
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SURF 48 PLANZ -7.59414 // Top of Support-Pad Ring
SURF 49 PLANZ -7.74700 // Bottom of Safety Block
SURF 50 PLANZ -1.22555 // Bottom of CR2 Top Hole
SURF 51 PLANZ -9.04621 // Bottom of CR1 Top Hole
SURF 52 PLANZ 0.67945 // Top of Control Rod 2
SURF 53 PLANZ -7.14121 // Top of Control Rod 1
SURF 54 PLANZ -1.27127 // Flat Bottom of BR Top Hole
SURF 55 PLANZ -0.12700 // Top of Safety Block
SURF 56 PLANZ 0.0 // Bottom of Inter Inner SA Pl
SURF 57 PLANZ 0.00254 // Bottom of Spindle
SURF 58 PLANZ 1.90373 // Top of Burst Rod (Full In)
SURF 59 PLANZ 2.54000 // Top of Upper ISP Wide Region
SURF 60 PLANZ 3.49250 // Top of Int Inr Subassby Plate
SURF 61 PLANZ 4.38785 // Top of Right Leg
SURF 62 PLANZ 4.64820 // Top of Control Rod Hole
SURF 63 PLANZ 4.96570 // Top of ISP Indentation
SURF 64 PLANZ 6.98754 // Bottom of ISP Inner Annulus
SURF 65 PLANZ 7.27160 // Bottom of Bearing ring
SURF 66 PLANZ 7.64794 // Top of Top Inr Subasmbly Pl
SURF 67 PLANZ 7.73264 // Top of Homog Fuel RingsS
SURF 68 PLANZ 7.95528 // Top of SCP Raised Edge
SURF 69 PLANZ 8.27278 // Top of Subassembly Cvr Plate
SURF 70 PLANZ 8.75411 // Top of Bearing Ring
SURF 71 PLANZ 9.54278 // Top of Nut on Spindle
SURF 72 PLANZ 11.43254 // Top of Spindle
SURF 73 PLANZ 12.40409 // Top of Flat Clamp Top
SURF 74 PLANY -1.42875 // Front Edge of Right Leg
SURF 75 PLANY -1.11125 // Front Edge of Left Notch
SURF 76 PLANY 0.0
SURF 77 PLANY 1.11125 // Back Edge of Left Notch
SURF 78 PLANY 1.42875 // Back Edge of Right Leg
SURF 79 PLANX 0.0
SURF 80 PLANX 5.08000 // Left Edge of Prongs
SURF 81 PLANX 8.49376 // Back Edge of Left Notch(1&6)
SURF 82 PLANX 8.49630 // Left Edge of Clamp Back
SURF 83 PLANX 12.94130 // Right Edge of Right Leg Inset
SURF 84 PLANX 18.94130 // Right Edge of Rectglar Rt Leg
SURF 85 PLAN 1.0 1.7320508 0.0 16.9857200 // Back Edge, BL Notch (1 & 6)
SURF 86 PLAN 1.0 -1.7320508 0.0 16.9857200 // Back Edge, BR Notch (1 & 6)
SURF 87 PLAN 1.7320508 -1.0 0.0 -1.9247415 // Lower Edge, BL Notch
SURF 88 PLAN 1.7320508 -1.0 0.0 1.9247415 // Upper Edge, BL Notch
SURF 89 PLAN 1.7320508 1.0 0.0 -1.9247415 // Lower Edge, BR Notch
SURF 90 PLAN 1.7320508 1.0 0.0 1.9247415 // Upper Edge, BR Notch

// Spindle
VOLU 1 EQUA PLUS 2 1 57 MOINS 2 2 72 FINV
VOLU 2 EQUA PLUS 2 2 64 MOINS 2 3 69 FINV
VOLU 3 EQUA PLUS 2 2 71 MOINS 2 3 72 FINV

// Homogenized Subassembly Plate
VOLU 4 EQUA PLUS 2 2 56 MOINS 2 12 59 FINV
VOLU 5 EQUA PLUS 2 2 59 MOINS 2 9 63 FINV
VOLU 6 EQUA PLUS 2 2 63 MOINS 2 12 64 FINV
VOLU 7 EQUA PLUS 2 7 64 MOINS 2 12 66 FINV

// Safety Bloc
VOLU 8 EQUA PLUS 2 2 49 MOINS 2 11 55 FINV

// Safety Bloc Base
VOLU 9  EQUA PLUS 1 41 MOINS 2 5 44 FINV
VOLU 10 EQUA PLUS 1 44 MOINS 2 8 49 FINV
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VOLU 11 EQUA PLUS 1 49 MOINS 2 2 55 FINV

// Homogenized Fuel Rings
VOLU 15 EQUA PLUS 5 13 25 26 27 47 MOINS 2 15 48 FINV

// Control and Burst Rods
VOLU 23 EQUA PLUS 1 53 MOINS 2 25 62 FINV
VOLU 24 EQUA PLUS 2 31 37 MOINS 2 25 53 FINV
VOLU 25 EQUA PLUS 1 37 MOINS 2 22 39 FINV
VOLU 26 EQUA PLUS 2 22 37 MOINS 2 31 39 FINV
VOLU 27 EQUA PLUS 1 39 MOINS 2 31 51 FINV
VOLU 28 EQUA PLUS 2 22 51 MOINS 2 31 53 FINV
VOLU 29 EQUA PLUS 1 51 MOINS 2 22 53 FINV
VOLU 30 EQUA PLUS 1 52 MOINS 2 27 62 FINV
VOLU 31 EQUA PLUS 2 32 36 MOINS 2 27 52 FINV
VOLU 32 EQUA PLUS 1 36 MOINS 2 23 38 FINV
VOLU 33 EQUA PLUS 2 23 36 MOINS 2 32 38 FINV
VOLU 34 EQUA PLUS 1 38 MOINS 2 32 50 FINV
VOLU 35 EQUA PLUS 2 23 50 MOINS 2 32 52 FINV
VOLU 36 EQUA PLUS 1 50 MOINS 2 23 52 FINV
VOLU 37 EQUA PLUS 1 58 MOINS 2 26 62 FINV
VOLU 38 EQUA PLUS 2 33 47 MOINS 2 26 58 FINV
VOLU 39 EQUA PLUS 1 42 MOINS 2 24 46 FINV
VOLU 40 EQUA PLUS 2 24 42 MOINS 2 33 46 FINV
VOLU 41 EQUA PLUS 1 46 MOINS 2 33 54 FINV
VOLU 42 EQUA PLUS 2 24 54 MOINS 2 33 58 FINV
VOLU 43 EQUA PLUS 1 54 MOINS 2 24 58 FINV

// Support Pads Converted to Ring
VOLU 44 EQUA PLUS 5 15 25 26 27 45 MOINS 2 18 48 FINV

// Bearing Ring
VOLU 45 EQUA PLUS 2 16 65 MOINS 2 19 70 FINV

// Subassembly Cover Plate
VOLU 46 EQUA PLUS 2 3 66 MOINS 2 4 69 FINV
VOLU 47 EQUA PLUS 2 4 66 MOINS 2 13 68 FINV
VOLU 48 EQUA PLUS 2 13 67 MOINS 2 14 69 FINV
VOLU 49 EQUA PLUS 2 4 68 MOINS  2 13 69 FINV

// Mounting Plate
VOLU 50 EQUA PLUS 1 34 MOINS 2 17 35 FINV
VOLU 51 EQUA PLUS 2 25 34 MOINS 2 28 35 FINV
VOLU 52 EQUA PLUS 2 26 34 MOINS 2 30 35 FINV
VOLU 53 EQUA PLUS 2 27 34 MOINS 2 29 35 FINV
VOLU 54 EQUA PLUS 5 17 28 29 30 34 MOINS 2 21 35 FINV

// Clamps supports
VOLU 550 EQUA PLUS 3 35 74 83 MOINS 3 61 78 84 FICTIF FINV
VOLU 55 ROTATION VOLU 550 0. 0. 1.    0. 0 0 0 FINV
VOLU 56 ROTATION VOLU 550 0. 0. 1. -120. 0 0 0 FINV
VOLU 57 ROTATION VOLU 550 0. 0. 1.  120. 0 0 0 FINV

// Clamps
VOLU 580 EQUA PLUS 3 40 75 80 MOINS 3 45 77 83 FICTIF FINV
VOLU 590 EQUA PLUS 3 45 75 82 MOINS 3 70 77 83 FICTIF FINV
VOLU 600 EQUA PLUS 3 70 75 80 MOINS 3 73 77 83 FICTIF FINV
VOLU 58 ROTATION VOLU 580 0 0 1    0. 0 0 0 FINV
VOLU 59 ROTATION VOLU 590 0 0 1    0. 0 0 0 FINV
VOLU 60 ROTATION VOLU 600 0 0 1    0. 0 0 0 FINV
VOLU 61 ROTATION VOLU 580 0 0 1 -120. 0 0 0 FINV
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VOLU 62 ROTATION VOLU 590 0 0 1 -120. 0 0 0 FINV
VOLU 63 ROTATION VOLU 600 0 0 1 -120. 0 0 0 FINV
VOLU 64 ROTATION VOLU 580 0 0 1  120. 0 0 0 FINV
VOLU 65 ROTATION VOLU 590 0 0 1  120. 0 0 0 FINV
VOLU 66 ROTATION VOLU 600 0 0 1  120. 0 0 0 FINV

// Nut on Spindle
VOLU 67 EQUA PLUS 2 2 69 MOINS 2 6 71 FINV

// Outer Void Regions
VOLU 68 EQUA PLUS 2 5 43 MOINS 2 13 44 FINV
VOLU 69 EQUA PLUS 2 5 41 MOINS 2 13 43 FINV
VOLU 70 EQUA PLUS 2 8 44 MOINS 2 13 49 FINV
VOLU 71 EQUA PLUS 2 12 56 MOINS 2 13 59 FINV
VOLU 72 EQUA PLUS 2 9 59 MOINS 2 10 60 FINV
VOLU 73 EQUA PLUS 2 9 60 MOINS 2 10 63 FINV

// Inner Void Regions
VOLU 74 EQUA PLUS 1 72 MOINS 2 20 73 VMOINS 3 60 63 66 FINV
VOLU 75 EQUA PLUS 4 20 35 76 79 MOINS 2 21 73 VMOINS 4 55 58 59 60 FINV
VOLU 76 EQUA PLUS 3 20 35 79 MOINS 3 21 73 76 VMOINS 4 55 58 59 60 FINV
VOLU 77 EQUA PLUS 2 20 35 MOINS 4 21 73 76 79 VMOINS 4 56 61 62 63 FINV
VOLU 78 EQUA PLUS 3 20 35 76 MOINS 3 21 73 79 VMOINS 4 57 64 65 66 FINV
VOLU 79 EQUA PLUS 2 14 67 MOINS 2 16 69 FINV
VOLU 80 EQUA PLUS 1 34 MOINS 2 25 37 FINV
VOLU 81 EQUA PLUS 1 34 MOINS 2 27 36 FINV
VOLU 82 EQUA PLUS 1 34 MOINS 2 26 42 FINV
VOLU 83 EQUA PLUS 2 33 42 MOINS 2 26 47 FINV
VOLU 84 EQUA PLUS 5 13 25 26 27 35 MOINS 2 20 45 VMOINS 3 58 61 64 FINV
VOLU 85 EQUA PLUS 5 13 25 26 27 45 MOINS 2 20 47 VMOINS 6 44 56 57 59 62 65 FINV
VOLU 86 EQUA PLUS 1 35 MOINS 2 13 41 FINV
VOLU 87 EQUA PLUS 2 13 69 MOINS 2 16 70 FINV
VOLU 88 EQUA PLUS 3 13 19 67 MOINS 2 20 70 VMOINS 3 59 62 65 FINV
VOLU 89 EQUA PLUS 2 13 70 MOINS 2 20 72 VMOINS 3 60 63 66 FINV
VOLU 90 EQUA PLUS 2 11 49 MOINS 2 13 70 FINV
VOLU 91 EQUA PLUS 2 12 63 MOINS 2 13 66 FINV
VOLU 92 EQUA PLUS 2 3 69 MOINS 2 13 72 VMOINS 1 67 FINV
VOLU 93 EQUA PLUS 1 55 MOINS 2 11 56 FINV
VOLU 94 EQUA PLUS 1 56 MOINS 2 2 57 FINV
VOLU 95 EQUA PLUS 1 57 MOINS 2 1 72 FINV
VOLU 96 EQUA PLUS 2 3 64 MOINS 2 7 66 FINV

// External Void Regions
VOLU 98 EQUA PLUS 2 21 34 MOINS 1 73 FINV

// Notches for fuel rings
VOLU 12 EQUA PLUS 3 47 75 81 MOINS 3 20 67 77 VMOINS 1 59 FINV
VOLU 13 EQUA PLUS 2 47 88 MOINS 4 20 67 85 87 VMOINS 1 62 FINV
VOLU 14 EQUA PLUS 2 47 90 MOINS 4 20 67 86 89 VMOINS 1 65 FINV

// Homogenized Fuel Rings
VOLU 16 EQUA PLUS 5 18 25 26 27 47 MOINS 2 20 48 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 17 EQUA PLUS 5 13 25 26 27 48 MOINS 2 20 59 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 18 EQUA PLUS 5 10 25 26 27 59 MOINS 2 20 62 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 19 EQUA PLUS 2 10 62 MOINS 2 20 63 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 20 EQUA PLUS 2 13 63 MOINS 2 20 65 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 21 EQUA PLUS 2 13 65 MOINS 2 16 67 FINV
VOLU 22 EQUA PLUS 2 19 65 MOINS 2 20 67 VMOINS 7 12 13 14 45 59 62 65 FINV

COLOR 10
       // void
```

```
        WHITE 53
                 2  3 12 13 14
                23 24 25 29 30
                31 32 36 37 38
                39 43 46 47 50
                51 52 53 68 69
                70 71 72 73 74
                75 76 77 78 79
                80 81 82 83 84
                85 86 87 88 89
                90 91 92 93 94
                95 96    98
        // material 1
        SALMON 8
                 1  9 10 11 55
                56 57 67
        // material 2
        GREEN 4
                44 45 48 49
        // material 3
        YELLOW 9
                58 59 60 61 62
                63 64 65 66
        // material 4
        BLUE 1
                54
        // material 5
        CYAN 1
                 8
        // material 6
        CORAL 6
                26 27 28 33 34
                35
        // material 7
        PINK 3
                40 41 42
        // material 8
        VIOLET 8
                15 16 17 18 19
                20 21 22
        // material 9
        RED 4
                4 5 6 7

COMMENT
GRAF
        -20. 0. -25.
        1 0 0
        0 0 1
        45. 45.
        3

GRAF
        -20. -20. -5.
        1 0 0
        0 1 0
        45. 45.
        3

GRAF
        3.33 -20. -20.
```

```
        0 1 0
        0 0 1
        45. 45.
        3

GRAF
        -20. -20. -8.
        1 0 0
        0 1 0
        45. 45.
        3
COMMENT
FINGEOM

COMPOSITION
        10

        PUNCTUAL 294 AIR
        2
        N14    4.1985E-5
        O16    1.1263E-5

        PUNCTUAL 294 SS303
        30
        C      3.0083e-4
        SI28   1.5821E-3
        SI29   8.0109E-5
        SI30   5.3177E-5
        P31    1.5554e-4
        S32    4.2823E-4
        S33    3.3800E-6
        S34    1.8973E-5
        S36    9.0134E-8
        CR50   7.2466e-4
        CR52   1.3974e-2
        CR53   1.5844e-3
        CR54   3.9443e-4
        MN55   8.7693e-4
        FE54   3.5742e-3
        FE56   5.5564e-2
        FE57   1.2722e-3
        FE58   1.6962e-4
        NI58   5.0437e-3
        NI60   1.9282e-3
        NI61   8.3482e-5
        NI62   2.6522e-4
        NI64   6.7229e-5
        MO92   2.2356e-5
        MO94   1.3935E-5
        MO95   2.3983E-5
        MO96   2.5128E-5
        MO97   1.4387E-5
        MO98   3.6352E-5
        MO100  1.4508E-5

        PUNCTUAL 294 SAE4340
        30
        C      1.5940e-3
        SI28   3.4929E-4
        SI29   1.7686E-5
        SI30   1.1740E-5
```

```
P31    2.7472e-5
S32    2.8013E-5
S33    2.2111E-7
S34    1.2412E-6
S36    5.8962E-9
CR50   3.1603e-5
CR52   6.0944e-4
CR53   6.9097e-5
CR54   1.7202e-5
MN55   6.2385e-4
FE54   4.7824e-3
FE56   7.4345e-2
FE57   1.7022e-3
FE58   2.2696e-4
NI58   9.8985e-4
NI60   3.7842e-4
NI61   1.6384e-5
NI62   5.2051e-5
NI64   1.3194e-5
MO92   1.8281E-5
MO94   1.1395E-5
MO95   1.9612E-5
MO96   2.0548E-5
MO97   1.1765E-5
MO98   2.9726E-5
MO100  1.1863E-5


PUNCTUAL 294 VASCOMAX300
33
C      8.0221E-5
AL27   1.7855E-4
SI28   7.9104E-5
SI29   4.0054E-6
SI30   2.6588E-6
P31    7.7770e-6
S32    7.1371E-6
S33    5.6334E-8
S34    3.1622E-7
S36    1.5022E-9
TI46   5.8762E-5
TI47   5.3621E-5
TI48   5.4208E-4
TI49   4.0399E-5
TI50   3.9665E-5
MN55   4.3847e-5
FE54   3.4070e-3
FE56   5.2965e-2
FE57   1.2127e-3
FE58   1.6169e-4
CO59   7.1938e-3
NI58   1.0367e-2
NI60   3.9635e-3
NI61   1.7160e-4
NI62   5.4518e-4
NI64   1.3819e-4
MO92   3.5769E-4
MO94   2.2295E-4
MO95   3.8372E-4
MO96   4.0204E-4
MO97   2.3018E-4
```

```
MO98   5.8161E-4
MO100  2.3211E-4

PUNCTUAL 294 ALU
1
AL27   5.8593E-2

PUNCTUAL 294 HEU_SB
12
U233   4.6322E-6
U234   4.7005E-4
U235   4.2791E-2
U236   3.1098E-4
U238   2.3222E-3
MO92   1.6894E-4
MO94   1.0530E-4
MO95   1.8123E-4
MO96   1.8989E-4
MO97   1.0872E-4
MO98   2.7470E-4
MO100  1.0963E-4

PUNCTUAL 294 HEU_ISP
12
U233   4.6755E-6
U234   4.7433E-4
U235   4.3187E-2
U236   3.1388E-4
U238   2.3464E-3
MO92   2.5832E-4
MO94   1.6101E-4
MO95   2.7712E-4
MO96   2.9035E-4
MO97   1.6624E-4
MO98   4.2003E-4
MO100  1.6763E-4

PUNCTUAL 294 HEU_RING
12
U233   4.6484E-6
U234   4.7159E-4
U235   4.2930E-2
U236   3.1206E-4
U238   2.3398E-3
MO92   2.5350E-4
MO94   1.5801E-4
MO95   2.7195E-4
MO96   2.8493E-4
MO97   1.6313E-4
MO98   4.1219E-4
MO100  1.6450E-4

PUNCTUAL 294 HEU_CTRLRODS
12
U233   4.6812E-6
U234   4.7497E-4
U235   4.3238E-2
U236   3.1427E-4
U238   2.3514E-3
MO92   2.2831E-4
MO94   1.4231E-4
```

```
        MO95   2.4493E-4
        MO96   2.5662E-4
        MO97   1.4693E-4
        MO98   3.7124E-4
        MO100  1.4816E-4

        PUNCTUAL 294 HEU_BURSTROD
        12
        U233   4.7893E-6
        U234   4.8594E-4
        U235   4.4237E-2
        U236   3.2152E-4
        U238   2.4057E-3
        MO92   2.3300E-4
        MO94   1.4523E-4
        MO95   2.4996E-4
        MO96   2.6189E-4
        MO97   1.4994E-4
        MO98   3.7887E-4
        MO100  1.5120E-4

FIN_COMPOSITION

GEOMCOMP
        AIR 53
                 2  3 12 13 14
                23 24 25 29 30
                31 32 36 37 38
                39 43 46 47 50
                51 52 53 68 69
                70 71 72 73 74
                75 76 77 78 79
                80 81 82 83 84
                85 86 87 88 89
                90 91 92 93 94
                95 96    98

        SS303 8
                 1  9 10 11 55
                56 57 67

        SAE4340 4
                44 45 48 49

        VASCOMAX300 9
                58 59 60 61 62
                63 64 65 66

        ALU 1
                54

        HEU_SB 1
                 8

        HEU_CTRLRODS 6
                26 27 28 33 34
                35

        HEU_BURSTROD 3
                40 41 42
```

```
        HEU_RING 8
                15 16 17 18 19
                20 21 22

        HEU_ISP 4
                4 5 6 7

FIN_GEOMCOMP

LIST_SOURCES
        1
        SOURCE INTENSITY 1. NEUTRON
        PUNCTUAL 0. 0. 0.
        ANGULAR_DISTRIBUTION ISOTROPIC
        ENERGETIC_DISTRIBUTION SPECTRE WATT_SPECTRE
        TIME_DISTRIBUTION DIRAC 0.
        FIN_SOURCES
FIN_LIST_SOURCES

SIMULATION
        CRITICITE
        BATCH 550 DISCARD 50
        SIZE 10000
        PARTICLE 1 NEUTRON
        ENERGY_INF NEUTRON 1.E-11
        ENERGY_SUP NEUTRON 20.
        EDITION 100
FIN_SIMULATION
```

```
GEOMETRIE
TITRE Godiva-IV  HEU-MET-FAST-086  Case 2  Benchmark Model  DC  BR In  ENDF/B-VI

SURF 1 CYLZ 0. 0. 0.31750 // Glory-Hole Radius
SURF 2 CYLZ 0. 0. 1.27000 // Spindle Bottom Middle OR
SURF 3 CYLZ 0. 0. 1.42875 // Spindle Top Middle OR
SURF 4 CYLZ 0. 0. 1.43510 // Radius of Central Hole in SCP
SURF 5 CYLZ 0. 0. 1.90500 // OR of SB Base Bottom
SURF 6 CYLZ 0. 0. 2.22250 // OR for Nut on Spindle
SURF 7 CYLZ 0. 0. 3.50520 // Upper IR of UISP
SURF 8 CYLZ 0. 0. 3.65760 // OR of SB Base Platform
SURF 9 CYLZ 0. 0. 3.92430 // OR of Upper Int Sub Plate
SURF 10 CYLZ 0. 0. 3.97510 // IR of Ring 5
SURF 11 CYLZ 0. 0. 4.29260 // Safety Block Outer Radius
SURF 12 CYLZ 0. 0. 4.38150 // OR of Lower Int Sub Plate
SURF 13 CYLZ 0. 0. 4.44500 // IR of Rings 1-4, 6
SURF 14 CYLZ 0. 0. 5.08000 // IR of S Pad Slots, BR Annulus
SURF 15 CYLZ 0. 0. 5.08508 // Inner Radius of Sprt Pad Ring
SURF 16 CYLZ 0. 0. 5.08381 // Inner Radius of Bearing Ring
SURF 17 CYLZ 0. 0. 5.23875 // Radius of Central Hole in MP
SURF 18 CYLZ 0. 0. 7.29488 // Outer Radius of Sprt Pad Ring
SURF 19 CYLZ 0. 0. 7.29615 // Outer Radius of Bearing Ring
SURF 20 CYLZ 0. 0. 8.89000 // OR of Rings
SURF 21 CYLZ 0. 0. 44.45 // Outer Radius of Mtng Plate
SURF 22 CYLZ 3.33375 -5.774224 0.47625 // Control Rod 1 IR
SURF 23 CYLZ 3.33375 5.774224 0.47625 // Control Rod 2 IR
SURF 24 CYLZ -6.66750 0.0 0.47625 // Burst Rod IR
SURF 25 CYLZ 3.33375 -5.774224 1.11125 // FR Hole, Control or Burst Rod
SURF 26 CYLZ -6.66750 0.0 1.11125 // Lt Hole, Control or Burst Rod
SURF 27 CYLZ 3.33375 5.774224 1.11125 // BR Hole, Control or Burst Rod
SURF 28 CYLZ 3.33375 -5.774224 1.27000 // FR Hole for Control Rod 1
SURF 29 CYLZ 3.33375 5.774224 1.27000 // BR Hole for Control Rod 2
SURF 30 CYLZ -6.66750 0.0 1.27000 // Left Hole for Burst Rod
SURF 31 CYLZ 3.33375 -5.774224 1.09220 // Control Rod 1 OR
SURF 32 CYLZ 3.33375 5.774224 1.09220 // Control Rod 2 OR
SURF 33 CYLZ -6.66750 0.0 1.09220 // Burst Rod OR
SURF 34 PLANZ -20.37715 // Bottom of Mounting Plate
SURF 35 PLANZ -16.56715 // Top of Mounting Plate
SURF 36 PLANZ -15.11173 // Bottom of Control Rod 2
SURF 37 PLANZ -14.75359 // Bottom of Control Rod 1
SURF 38 PLANZ -13.20673 // Top of CR2 Bottom Hole
SURF 39 PLANZ -12.84859 // Top of CR1 Bottom Hole
SURF 40 PLANZ -12.67587 // Bottom of Flat Clamp Bottom
SURF 41 PLANZ -11.85559 // Bottom of Safety Block Base
SURF 42 PLANZ -10.79627 // Bottom of Burst Rod (Full In)
SURF 43 PLANZ -9.79948 // Bottom of Platform Curve
SURF 44 PLANZ -9.17448 // Bottom of SB Base Platform
SURF 45 PLANZ -9.02589 // Bottom of Support-Pad Ring
SURF 46 PLANZ -8.89127 // Top of Burst Rod Bottom Hole
SURF 47 PLANZ -8.06553 // Bottom of Homog Fuel Rings
SURF 48 PLANZ -7.59414 // Top of Support-Pad Ring
SURF 49 PLANZ -7.74700 // Bottom of Safety Block
SURF 50 PLANZ -4.31673 // Bottom of CR2 Top Hole
SURF 51 PLANZ -3.95859 // Bottom of CR1 Top Hole
SURF 52 PLANZ -2.41173 // Top of Control Rod 2
SURF 53 PLANZ -2.05359 // Top of Control Rod 1
SURF 54 PLANZ -1.27127 // Flat Bottom of BR Top Hole
SURF 55 PLANZ -0.12700 // Top of Safety Block
SURF 56 PLANZ 0.0 // Bottom of Inter Inner SA Pl
SURF 57 PLANZ 0.00254 // Bottom of Spindle
SURF 58 PLANZ 1.90373 // Top of Burst Rod (Full In)
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SURF 59 PLANZ 2.54000 // Top of Upper ISP Wide Region
SURF 60 PLANZ 3.49250 // Top of Int Inr Subassby Plate
SURF 61 PLANZ 4.38785 // Top of Right Leg
SURF 62 PLANZ 4.64820 // Top of Control Rod Hole
SURF 63 PLANZ 4.96570 // Top of ISP Indentation
SURF 64 PLANZ 6.98754 // Bottom of ISP Inner Annulus
SURF 65 PLANZ 7.27160 // Bottom of Bearing ring
SURF 66 PLANZ 7.64794 // Top of Top Inr Subasmbly Pl
SURF 67 PLANZ 7.73264 // Top of Homog Fuel RingsS
SURF 68 PLANZ 7.95528 // Top of SCP Raised Edge
SURF 69 PLANZ 8.27278 // Top of Subassembly Cvr Plate
SURF 70 PLANZ 8.75411 // Top of Bearing Ring
SURF 71 PLANZ 9.54278 // Top of Nut on Spindle
SURF 72 PLANZ 11.43254 // Top of Spindle
SURF 73 PLANZ 12.40409 // Top of Flat Clamp Top
SURF 74 PLANY -1.42875 // Front Edge of Right Leg
SURF 75 PLANY -1.11125 // Front Edge of Left Notch
SURF 76 PLANY 0.0
SURF 77 PLANY 1.11125 // Back Edge of Left Notch
SURF 78 PLANY 1.42875 // Back Edge of Right Leg
SURF 79 PLANX 0.0
SURF 80 PLANX 5.08000 // Left Edge of Prongs
SURF 81 PLANX 8.49376 // Back Edge of Left Notch(1&6)
SURF 82 PLANX 8.49630 // Left Edge of Clamp Back
SURF 83 PLANX 12.94130 // Right Edge of Right Leg Inset
SURF 84 PLANX 18.94130 // Right Edge of Rectglar Rt Leg
SURF 85 PLAN 1.0 1.7320508 0.0 16.9857200 // Back Edge, BL Notch (1 & 6)
SURF 86 PLAN 1.0 -1.7320508 0.0 16.9857200 // Back Edge, BR Notch (1 & 6)
SURF 87 PLAN 1.7320508 -1.0 0.0 -1.9247415 // Lower Edge, BL Notch
SURF 88 PLAN 1.7320508 -1.0 0.0 1.9247415 // Upper Edge, BL Notch
SURF 89 PLAN 1.7320508 1.0 0.0 -1.9247415 // Lower Edge, BR Notch
SURF 90 PLAN 1.7320508 1.0 0.0 1.9247415 // Upper Edge, BR Notch

// Spindle
VOLU 1 EQUA PLUS 2 1 57 MOINS 2 2 72 FINV
VOLU 2 EQUA PLUS 2 2 64 MOINS 2 3 69 FINV
VOLU 3 EQUA PLUS 2 2 71 MOINS 2 3 72 FINV

// Homogenized Subassembly Plate
VOLU 4 EQUA PLUS 2 2 56 MOINS 2 12 59 FINV
VOLU 5 EQUA PLUS 2 2 59 MOINS 2 9 63 FINV
VOLU 6 EQUA PLUS 2 2 63 MOINS 2 12 64 FINV
VOLU 7 EQUA PLUS 2 7 64 MOINS 2 12 66 FINV

// Safety Bloc
VOLU 8 EQUA PLUS 2 2 49 MOINS 2 11 55 FINV

// Safety Bloc Base
VOLU 9  EQUA PLUS 1 41 MOINS 2 5 44 FINV
VOLU 10 EQUA PLUS 1 44 MOINS 2 8 49 FINV
VOLU 11 EQUA PLUS 1 49 MOINS 2 2 55 FINV

// Homogenized Fuel Rings
VOLU 15 EQUA PLUS 5 13 25 26 27 47 MOINS 2 15 48 FINV

// Control and Burst Rods
VOLU 23 EQUA PLUS 1 53 MOINS 2 25 62 FINV
VOLU 24 EQUA PLUS 2 31 37 MOINS 2 25 53 FINV
VOLU 25 EQUA PLUS 1 37 MOINS 2 22 39 FINV
VOLU 26 EQUA PLUS 2 22 37 MOINS 2 31 39 FINV
VOLU 27 EQUA PLUS 1 39 MOINS 2 31 51 FINV
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VOLU 28 EQUA PLUS 2 22 51 MOINS 2 31 53 FINV
VOLU 29 EQUA PLUS 1 51 MOINS 2 22 53 FINV
VOLU 30 EQUA PLUS 1 52 MOINS 2 27 62 FINV
VOLU 31 EQUA PLUS 2 32 36 MOINS 2 27 52 FINV
VOLU 32 EQUA PLUS 1 36 MOINS 2 23 38 FINV
VOLU 33 EQUA PLUS 2 23 36 MOINS 2 32 38 FINV
VOLU 34 EQUA PLUS 1 38 MOINS 2 32 50 FINV
VOLU 35 EQUA PLUS 2 23 50 MOINS 2 32 52 FINV
VOLU 36 EQUA PLUS 1 50 MOINS 2 23 52 FINV
VOLU 37 EQUA PLUS 1 58 MOINS 2 26 62 FINV
VOLU 38 EQUA PLUS 2 33 47 MOINS 2 26 58 FINV
VOLU 39 EQUA PLUS 1 42 MOINS 2 24 46 FINV
VOLU 40 EQUA PLUS 2 24 42 MOINS 2 33 46 FINV
VOLU 41 EQUA PLUS 1 46 MOINS 2 33 54 FINV
VOLU 42 EQUA PLUS 2 24 54 MOINS 2 33 58 FINV
VOLU 43 EQUA PLUS 1 54 MOINS 2 24 58 FINV

// Support Pads Converted to Ring
VOLU 44 EQUA PLUS 5 15 25 26 27 45 MOINS 2 18 48 FINV

// Bearing Ring
VOLU 45 EQUA PLUS 2 16 65 MOINS 2 19 70 FINV

// Subassembly Cover Plate
VOLU 46 EQUA PLUS 2 3 66 MOINS 2 4 69 FINV
VOLU 47 EQUA PLUS 2 4 66 MOINS 2 13 68 FINV
VOLU 48 EQUA PLUS 2 13 67 MOINS 2 14 69 FINV
VOLU 49 EQUA PLUS 2 4 68 MOINS  2 13 69 FINV

// Mounting Plate
VOLU 50 EQUA PLUS 1 34 MOINS 2 17 35 FINV
VOLU 51 EQUA PLUS 2 25 34 MOINS 2 28 35 FINV
VOLU 52 EQUA PLUS 2 26 34 MOINS 2 30 35 FINV
VOLU 53 EQUA PLUS 2 27 34 MOINS 2 29 35 FINV
VOLU 54 EQUA PLUS 5 17 28 29 30 34 MOINS 2 21 35 FINV

// Clamps supports
VOLU 550 EQUA PLUS 3 35 74 83 MOINS 3 61 78 84 FICTIF FINV
VOLU 55 ROTATION VOLU 550 0. 0. 1.    0. 0 0 0 FINV
VOLU 56 ROTATION VOLU 550 0. 0. 1. -120. 0 0 0 FINV
VOLU 57 ROTATION VOLU 550 0. 0. 1.  120. 0 0 0 FINV

// Clamps
VOLU 580 EQUA PLUS 3 40 75 80 MOINS 3 45 77 83 FICTIF FINV
VOLU 590 EQUA PLUS 3 45 75 82 MOINS 3 70 77 83 FICTIF FINV
VOLU 600 EQUA PLUS 3 70 75 80 MOINS 3 73 77 83 FICTIF FINV
VOLU 58 ROTATION VOLU 580 0 0 1    0. 0 0 0 FINV
VOLU 59 ROTATION VOLU 590 0 0 1    0. 0 0 0 FINV
VOLU 60 ROTATION VOLU 600 0 0 1    0. 0 0 0 FINV
VOLU 61 ROTATION VOLU 580 0 0 1 -120. 0 0 0 FINV
VOLU 62 ROTATION VOLU 590 0 0 1 -120. 0 0 0 FINV
VOLU 63 ROTATION VOLU 600 0 0 1 -120. 0 0 0 FINV
VOLU 64 ROTATION VOLU 580 0 0 1  120. 0 0 0 FINV
VOLU 65 ROTATION VOLU 590 0 0 1  120. 0 0 0 FINV
VOLU 66 ROTATION VOLU 600 0 0 1  120. 0 0 0 FINV

// Nut on Spindle
VOLU 67 EQUA PLUS 2 2 69 MOINS 2 6 71 FINV

// Outer Void Regions
VOLU 68 EQUA PLUS 2 5 43 MOINS 2 13 44 FINV
```

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VOLU 69 EQUA PLUS 2 5 41 MOINS 2 13 43 FINV
VOLU 70 EQUA PLUS 2 8 44 MOINS 2 13 49 FINV
VOLU 71 EQUA PLUS 2 12 56 MOINS 2 13 59 FINV
VOLU 72 EQUA PLUS 2 9 59 MOINS 2 10 60 FINV
VOLU 73 EQUA PLUS 2 9 60 MOINS 2 10 63 FINV

// Inner Void Regions
VOLU 74 EQUA PLUS 1 72 MOINS 2 20 73 VMOINS 3 60 63 66 FINV
VOLU 75 EQUA PLUS 4 20 35 76 79 MOINS 2 21 73 VMOINS 4 55 58 59 60 FINV
VOLU 76 EQUA PLUS 3 20 35 79 MOINS 3 21 73 76 VMOINS 4 55 58 59 60 FINV
VOLU 77 EQUA PLUS 2 20 35 MOINS 4 21 73 76 79 VMOINS 4 56 61 62 63 FINV
VOLU 78 EQUA PLUS 3 20 35 76 MOINS 3 21 73 79 VMOINS 4 57 64 65 66 FINV
VOLU 79 EQUA PLUS 2 14 67 MOINS 2 16 69 FINV
VOLU 80 EQUA PLUS 1 34 MOINS 2 25 37 FINV
VOLU 81 EQUA PLUS 1 34 MOINS 2 27 36 FINV
VOLU 82 EQUA PLUS 1 34 MOINS 2 26 42 FINV
VOLU 83 EQUA PLUS 2 33 42 MOINS 2 26 47 FINV
VOLU 84 EQUA PLUS 5 13 25 26 27 35 MOINS 2 20 45 VMOINS 3 58 61 64 FINV
VOLU 85 EQUA PLUS 5 13 25 26 27 45 MOINS 2 20 47 VMOINS 6 44 56 57 59 62 65 FINV
VOLU 86 EQUA PLUS 1 35 MOINS 2 13 41 FINV
VOLU 87 EQUA PLUS 2 13 69 MOINS 2 16 70 FINV
VOLU 88 EQUA PLUS 3 13 19 67 MOINS 2 20 70 VMOINS 3 59 62 65 FINV
VOLU 89 EQUA PLUS 2 13 70 MOINS 2 20 72 VMOINS 3 60 63 66 FINV
VOLU 90 EQUA PLUS 2 11 49 MOINS 2 13 70 FINV
VOLU 91 EQUA PLUS 2 12 63 MOINS 2 13 66 FINV
VOLU 92 EQUA PLUS 2 3 69 MOINS 2 13 72 VMOINS 1 67 FINV
VOLU 93 EQUA PLUS 1 55 MOINS 2 11 56 FINV
VOLU 94 EQUA PLUS 1 56 MOINS 2 2 57 FINV
VOLU 95 EQUA PLUS 1 57 MOINS 2 1 72 FINV
VOLU 96 EQUA PLUS 2 3 64 MOINS 2 7 66 FINV

// External Void Regions
VOLU 98 EQUA PLUS 2 21 34 MOINS 1 73 FINV

// Notches for fuel rings
VOLU 12 EQUA PLUS 3 47 75 81 MOINS 3 20 67 77 VMOINS 1 59 FINV
VOLU 13 EQUA PLUS 2 47 88 MOINS 4 20 67 85 87 VMOINS 1 62 FINV
VOLU 14 EQUA PLUS 2 47 90 MOINS 4 20 67 86 89 VMOINS 1 65 FINV

// Homogenized Fuel Rings
VOLU 16 EQUA PLUS 5 18 25 26 27 47 MOINS 2 20 48 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 17 EQUA PLUS 5 13 25 26 27 48 MOINS 2 20 59 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 18 EQUA PLUS 5 10 25 26 27 59 MOINS 2 20 62 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 19 EQUA PLUS 2 10 62 MOINS 2 20 63 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 20 EQUA PLUS 2 13 63 MOINS 2 20 65 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 21 EQUA PLUS 2 13 65 MOINS 2 16 67 FINV
VOLU 22 EQUA PLUS 2 19 65 MOINS 2 20 67 VMOINS 7 12 13 14 45 59 62 65 FINV

COLOR 10
       // void
       WHITE 53
               2  3 12 13 14
              23 24 25 29 30
              31 32 36 37 38
              39 43 46 47 50
              51 52 53 68 69
              70 71 72 73 74
              75 76 77 78 79
              80 81 82 83 84
              85 86 87 88 89
              90 91 92 93 94
```

```
        95 96    98
    // material 1
    SALMON 9
         1  9 10 11 55
        55 56 57 67
    // material 2
    GREEN 4
        44 45 48 49
    // material 3
    YELLOW 9
        58 59 60 61 62
        63 64 65 66
    // material 4
    BLUE 1
        54
    // material 5
    CYAN 1
         8
    // material 6
    CORAL 6
        26 27 28 33 34
        35
    // material 7
    PINK 3
        40 41 42
    // material 8
    VIOLET 8
        15 16 17 18 19
        20 21 22
    // material 9
    RED 4
        4 5 6 7

COMMENT
GRAF
    -20. 0. -25.
    1 0 0
    0 0 1
    45. 45.
    3

GRAF
    -20. -20. -5.
    1 0 0
    0 1 0
    45. 45.
    3

GRAF
    3.33 -20. -20.
    0 1 0
    0 0 1
    45. 45.
    3

GRAF
    -20. -20. -8.
    1 0 0
    0 1 0
    45. 45.
    3
```

```
COMMENT
FINGEOM

COMPOSITION
       10

       PUNCTUAL 294 AIR
       2
       N14    4.1985E-5
       O16    1.1263E-5

       PUNCTUAL 294 SS303
       30
       C      3.0083e-4
       SI28   1.5821E-3
       SI29   8.0109E-5
       SI30   5.3177E-5
       P31    1.5554e-4
       S32    4.2823E-4
       S33    3.3800E-6
       S34    1.8973E-5
       S36    9.0134E-8
       CR50   7.2466e-4
       CR52   1.3974e-2
       CR53   1.5844e-3
       CR54   3.9443e-4
       MN55   8.7693e-4
       FE54   3.5742e-3
       FE56   5.5564e-2
       FE57   1.2722e-3
       FE58   1.6962e-4
       NI58   5.0437e-3
       NI60   1.9282e-3
       NI61   8.3482e-5
       NI62   2.6522e-4
       NI64   6.7229e-5
       MO92   2.2356e-5
       MO94   1.3935E-5
       MO95   2.3983E-5
       MO96   2.5128E-5
       MO97   1.4387E-5
       MO98   3.6352E-5
       MO100  1.4508E-5

       PUNCTUAL 294 SAE4340
       30
       C      1.5940e-3
       SI28   3.4929E-4
       SI29   1.7686E-5
       SI30   1.1740E-5
       P31    2.7472e-5
       S32    2.8013E-5
       S33    2.2111E-7
       S34    1.2412E-6
       S36    5.8962E-9
       CR50   3.1603e-5
       CR52   6.0944e-4
       CR53   6.9097e-5
       CR54   1.7202e-5
       MN55   6.2385e-4
       FE54   4.7824e-3
```

```
FE56   7.4345e-2
FE57   1.7022e-3
FE58   2.2696e-4
NI58   9.8985e-4
NI60   3.7842e-4
NI61   1.6384e-5
NI62   5.2051e-5
NI64   1.3194e-5
MO92   1.8281E-5
MO94   1.1395E-5
MO95   1.9612E-5
MO96   2.0548E-5
MO97   1.1765E-5
MO98   2.9726E-5
MO100  1.1863E-5


PUNCTUAL 294 VASCOMAX300
33
C      8.0221E-5
AL27   1.7855E-4
SI28   7.9104E-5
SI29   4.0054E-6
SI30   2.6588E-6
P31    7.7770e-6
S32    7.1371E-6
S33    5.6334E-8
S34    3.1622E-7
S36    1.5022E-9
TI46   5.8762E-5
TI47   5.3621E-5
TI48   5.4208E-4
TI49   4.0399E-5
TI50   3.9665E-5
MN55   4.3847e-5
FE54   3.4070e-3
FE56   5.2965e-2
FE57   1.2127e-3
FE58   1.6169e-4
CO59   7.1938e-3
NI58   1.0367e-2
NI60   3.9635e-3
NI61   1.7160e-4
NI62   5.4518e-4
NI64   1.3819e-4
MO92   3.5769E-4
MO94   2.2295E-4
MO95   3.8372E-4
MO96   4.0204E-4
MO97   2.3018E-4
MO98   5.8161E-4
MO100  2.3211E-4

PUNCTUAL 294 ALU
1
AL27   5.8593E-2

PUNCTUAL 294 HEU_SB
12
U233   4.6322E-6
U234   4.7005E-4
```

```
U235   4.2791E-2
U236   3.1098E-4
U238   2.3222E-3
MO92   1.6894E-4
MO94   1.0530E-4
MO95   1.8123E-4
MO96   1.8989E-4
MO97   1.0872E-4
MO98   2.7470E-4
MO100  1.0963E-4

PUNCTUAL 294 HEU_ISP
12
U233   4.6755E-6
U234   4.7433E-4
U235   4.3187E-2
U236   3.1388E-4
U238   2.3464E-3
MO92   2.5832E-4
MO94   1.6101E-4
MO95   2.7712E-4
MO96   2.9035E-4
MO97   1.6624E-4
MO98   4.2003E-4
MO100  1.6763E-4

PUNCTUAL 294 HEU_RING
12
U233   4.6484E-6
U234   4.7159E-4
U235   4.2930E-2
U236   3.1206E-4
U238   2.3398E-3
MO92   2.5350E-4
MO94   1.5801E-4
MO95   2.7195E-4
MO96   2.8493E-4
MO97   1.6313E-4
MO98   4.1219E-4
MO100  1.6450E-4

PUNCTUAL 294 HEU_CTRLRODS
12
U233   4.6812E-6
U234   4.7497E-4
U235   4.3238E-2
U236   3.1427E-4
U238   2.3514E-3
MO92   2.2831E-4
MO94   1.4231E-4
MO95   2.4493E-4
MO96   2.5662E-4
MO97   1.4693E-4
MO98   3.7124E-4
MO100  1.4816E-4

PUNCTUAL 294 HEU_BURSTROD
12
U233   4.7893E-6
U234   4.8594E-4
U235   4.4237E-2
```

```
        U236   3.2152E-4
        U238   2.4057E-3
        MO92   2.3300E-4
        MO94   1.4523E-4
        MO95   2.4996E-4
        MO96   2.6189E-4
        MO97   1.4994E-4
        MO98   3.7887E-4
        MO100  1.5120E-4

FIN_COMPOSITION

GEOMCOMP
        AIR 53
                 2  3 12 13 14
                23 24 25 29 30
                31 32 36 37 38
                39 43 46 47 50
                51 52 53 68 69
                70 71 72 73 74
                75 76 77 78 79
                80 81 82 83 84
                85 86 87 88 89
                90 91 92 93 94
                95 96    98

        SS303 8
                 1  9 10 11 55
                56 57 67

        SAE4340 4
                44 45 48 49

        VASCOMAX300 9
                58 59 60 61 62
                63 64 65 66

        ALU 1
                54

        HEU_SB 1
                 8

        HEU_CTRLRODS 6
                26 27 28 33 34
                35

        HEU_BURSTROD 3
                40 41 42

        HEU_RING 8
                15 16 17 18 19
                20 21 22

        HEU_ISP 4
                4 5 6 7

FIN_GEOMCOMP

LIST_SOURCES
        1
```

```
        SOURCE INTENSITY 1. NEUTRON
        PUNCTUAL 0. 0. 0.
        ANGULAR_DISTRIBUTION ISOTROPIC
        ENERGETIC_DISTRIBUTION SPECTRE WATT_SPECTRE
        TIME_DISTRIBUTION DIRAC 0.
        FIN_SOURCES
FIN_LIST_SOURCES

SIMULATION
        CRITICITE
        BATCH 550 DISCARD 50
        SIZE 10000
        PARTICLE 1 NEUTRON
        ENERGY_INF NEUTRON 1.E-11
        ENERGY_SUP NEUTRON 20.
        EDITION 100
FIN_SIMULATION
```

```
GEOMETRIE
TITRE Godiva-IV  HEU-MET-FAST-086  Case 3  Benchmark Model  DC  BR In  ENDF/B-VI

SURF 1 CYLZ 0. 0. 0.31750 // Glory-Hole Radius
SURF 2 CYLZ 0. 0. 1.27000 // Spindle Bottom Middle OR
SURF 3 CYLZ 0. 0. 1.42875 // Spindle Top Middle OR
SURF 4 CYLZ 0. 0. 1.43510 // Radius of Central Hole in SCP
SURF 5 CYLZ 0. 0. 1.90500 // OR of SB Base Bottom
SURF 6 CYLZ 0. 0. 2.22250 // OR for Nut on Spindle
SURF 7 CYLZ 0. 0. 3.50520 // Upper IR of UISP
SURF 8 CYLZ 0. 0. 3.65760 // OR of SB Base Platform
SURF 9 CYLZ 0. 0. 3.92430 // OR of Upper Int Sub Plate
SURF 10 CYLZ 0. 0. 3.97510 // IR of Ring 5
SURF 11 CYLZ 0. 0. 4.29260 // Safety Block Outer Radius
SURF 12 CYLZ 0. 0. 4.38150 // OR of Lower Int Sub Plate
SURF 13 CYLZ 0. 0. 4.44500 // IR of Rings 1-4, 6
SURF 14 CYLZ 0. 0. 5.08000 // IR of S Pad Slots, BR Annulus
SURF 15 CYLZ 0. 0. 5.08508 // Inner Radius of Sprt Pad Ring
SURF 16 CYLZ 0. 0. 5.08381 // Inner Radius of Bearing Ring
SURF 17 CYLZ 0. 0. 5.23875 // Radius of Central Hole in MP
SURF 18 CYLZ 0. 0. 7.29488 // Outer Radius of Sprt Pad Ring
SURF 19 CYLZ 0. 0. 7.29615 // Outer Radius of Bearing Ring
SURF 20 CYLZ 0. 0. 8.89000 // OR of Rings
SURF 21 CYLZ 0. 0. 44.45 // Outer Radius of Mtng Plate
SURF 22 CYLZ 3.33375 -5.774224 0.47625 // Control Rod 1 IR
SURF 23 CYLZ 3.33375 5.774224 0.47625 // Control Rod 2 IR
SURF 24 CYLZ -6.66750 0.0 0.47625 // Burst Rod IR
SURF 25 CYLZ 3.33375 -5.774224 1.11125 // FR Hole, Control or Burst Rod
SURF 26 CYLZ -6.66750 0.0 1.11125 // Lt Hole, Control or Burst Rod
SURF 27 CYLZ 3.33375 5.774224 1.11125 // BR Hole, Control or Burst Rod
SURF 28 CYLZ 3.33375 -5.774224 1.27000 // FR Hole for Control Rod 1
SURF 29 CYLZ 3.33375 5.774224 1.27000 // BR Hole for Control Rod 2
SURF 30 CYLZ -6.66750 0.0 1.27000 // Left Hole for Burst Rod
SURF 31 CYLZ 3.33375 -5.774224 1.09220 // Control Rod 1 OR
SURF 32 CYLZ 3.33375 5.774224 1.09220 // Control Rod 2 OR
SURF 33 CYLZ -6.66750 0.0 1.09220 // Burst Rod OR
SURF 34 PLANZ -20.37715 // Bottom of Mounting Plate
SURF 35 PLANZ -16.56715 // Top of Mounting Plate

SURF 36 PLANZ -20.51685 // Bottom of Control Rod 2
SURF 37 PLANZ -10.93089 // Bottom of Control Rod 1
SURF 38 PLANZ -18.61185 // Top of CR2 Bottom Hole
SURF 39 PLANZ  -9.02589 // Top of CR1 Bottom Hole

SURF 40 PLANZ -12.67587 // Bottom of Flat Clamp Bottom
SURF 41 PLANZ -11.85559 // Bottom of Safety Block Base
SURF 42 PLANZ -10.79627 // Bottom of Burst Rod (Full In)
SURF 43 PLANZ -9.79948 // Bottom of Platform Curve
SURF 44 PLANZ -9.17448 // Bottom of SB Base Platform
SURF 45 PLANZ -9.02589 // Bottom of Support-Pad Ring
SURF 46 PLANZ -8.89127 // Top of Burst Rod Bottom Hole
SURF 47 PLANZ -8.06553 // Bottom of Homog Fuel Rings
SURF 48 PLANZ -7.59414 // Top of Support-Pad Ring
SURF 49 PLANZ -7.74700 // Bottom of Safety Block

SURF 50 PLANZ -9.72185 // Bottom of CR2 Top Hole
SURF 51 PLANZ -0.13589 // Bottom of CR1 Top Hole
SURF 52 PLANZ -7.81685 // Top of Control Rod 2
SURF 53 PLANZ  1.76911 // Top of Control Rod 1

SURF 54 PLANZ -1.27127 // Flat Bottom of BR Top Hole
```

```
SURF 55 PLANZ -0.12700 // Top of Safety Block
SURF 56 PLANZ 0.0 // Bottom of Inter Inner SA Pl
SURF 57 PLANZ 0.00254 // Bottom of Spindle
SURF 58 PLANZ 1.90373 // Top of Burst Rod (Full In)
SURF 59 PLANZ 2.54000 // Top of Upper ISP Wide Region
SURF 60 PLANZ 3.49250 // Top of Int Inr Subassby Plate
SURF 61 PLANZ 4.38785 // Top of Right Leg
SURF 62 PLANZ 4.64820 // Top of Control Rod Hole
SURF 63 PLANZ 4.96570 // Top of ISP Indentation
SURF 64 PLANZ 6.98754 // Bottom of ISP Inner Annulus
SURF 65 PLANZ 7.27160 // Bottom of Bearing ring
SURF 66 PLANZ 7.64794 // Top of Top Inr Subasmbly Pl
SURF 67 PLANZ 7.73264 // Top of Homog Fuel RingsS
SURF 68 PLANZ 7.95528 // Top of SCP Raised Edge
SURF 69 PLANZ 8.27278 // Top of Subassembly Cvr Plate
SURF 70 PLANZ 8.75411 // Top of Bearing Ring
SURF 71 PLANZ 9.54278 // Top of Nut on Spindle
SURF 72 PLANZ 11.43254 // Top of Spindle
SURF 73 PLANZ 12.40409 // Top of Flat Clamp Top
SURF 74 PLANY -1.42875 // Front Edge of Right Leg
SURF 75 PLANY -1.11125 // Front Edge of Left Notch
SURF 76 PLANY 0.0
SURF 77 PLANY 1.11125 // Back Edge of Left Notch
SURF 78 PLANY 1.42875 // Back Edge of Right Leg
SURF 79 PLANX 0.0
SURF 80 PLANX 5.08000 // Left Edge of Prongs
SURF 81 PLANX 8.49376 // Back Edge of Left Notch(1&6)
SURF 82 PLANX 8.49630 // Left Edge of Clamp Back
SURF 83 PLANX 12.94130 // Right Edge of Right Leg Inset
SURF 84 PLANX 18.94130 // Right Edge of Rectglar Rt Leg
SURF 85 PLAN 1.0 1.7320508 0.0 16.9857200 // Back Edge, BL Notch (1 & 6)
SURF 86 PLAN 1.0 -1.7320508 0.0 16.9857200 // Back Edge, BR Notch (1 & 6)
SURF 87 PLAN 1.7320508 -1.0 0.0 -1.9247415 // Lower Edge, BL Notch
SURF 88 PLAN 1.7320508 -1.0 0.0 1.9247415 // Upper Edge, BL Notch
SURF 89 PLAN 1.7320508 1.0 0.0 -1.9247415 // Lower Edge, BR Notch
SURF 90 PLAN 1.7320508 1.0 0.0 1.9247415 // Upper Edge, BR Notch

// Spindle
VOLU 1 EQUA PLUS 2 1 57 MOINS 2 2 72 FINV
VOLU 2 EQUA PLUS 2 2 64 MOINS 2 3 69 FINV
VOLU 3 EQUA PLUS 2 2 71 MOINS 2 3 72 FINV

// Homogenized Subassembly Plate
VOLU 4 EQUA PLUS 2 2 56 MOINS 2 12 59 FINV
VOLU 5 EQUA PLUS 2 2 59 MOINS 2 9 63 FINV
VOLU 6 EQUA PLUS 2 2 63 MOINS 2 12 64 FINV
VOLU 7 EQUA PLUS 2 7 64 MOINS 2 12 66 FINV

// Safety Bloc
VOLU 8 EQUA PLUS 2 2 49 MOINS 2 11 55 FINV

// Safety Bloc Base
VOLU 9  EQUA PLUS 1 41 MOINS 2 5 44 FINV
VOLU 10 EQUA PLUS 1 44 MOINS 2 8 49 FINV
VOLU 11 EQUA PLUS 1 49 MOINS 2 2 55 FINV

// Homogenized Fuel Rings
VOLU 15 EQUA PLUS 5 13 25 26 27 47 MOINS 2 15 48 FINV

// Control and Burst Rods
VOLU 23 EQUA PLUS 1 53 MOINS 2 25 62 FINV
```

```
VOLU 24 EQUA PLUS 2 31 37 MOINS 2 25 53 FINV
VOLU 25 EQUA PLUS 1 37 MOINS 2 22 39 FINV
VOLU 26 EQUA PLUS 2 22 37 MOINS 2 31 39 FINV
VOLU 27 EQUA PLUS 1 39 MOINS 2 31 51 FINV
VOLU 28 EQUA PLUS 2 22 51 MOINS 2 31 53 FINV
VOLU 29 EQUA PLUS 1 51 MOINS 2 22 53 FINV
VOLU 30 EQUA PLUS 1 52 MOINS 2 27 62 FINV
VOLU 31 EQUA PLUS 2 32 36 MOINS 2 27 52 FINV
VOLU 32 EQUA PLUS 1 36 MOINS 2 23 38 FINV
VOLU 33 EQUA PLUS 2 23 36 MOINS 2 32 38 FINV
VOLU 34 EQUA PLUS 1 38 MOINS 2 32 50 FINV
VOLU 35 EQUA PLUS 2 23 50 MOINS 2 32 52 FINV
VOLU 36 EQUA PLUS 1 50 MOINS 2 23 52 FINV
VOLU 37 EQUA PLUS 1 58 MOINS 2 26 62 FINV
VOLU 38 EQUA PLUS 2 33 47 MOINS 2 26 58 FINV
VOLU 39 EQUA PLUS 1 42 MOINS 2 24 46 FINV
VOLU 40 EQUA PLUS 2 24 42 MOINS 2 33 46 FINV
VOLU 41 EQUA PLUS 1 46 MOINS 2 33 54 FINV
VOLU 42 EQUA PLUS 2 24 54 MOINS 2 33 58 FINV
VOLU 43 EQUA PLUS 1 54 MOINS 2 24 58 FINV

// Support Pads Converted to Ring
VOLU 44 EQUA PLUS 5 15 25 26 27 45 MOINS 2 18 48 FINV

// Bearing Ring
VOLU 45 EQUA PLUS 2 16 65 MOINS 2 19 70 FINV

// Subassembly Cover Plate
VOLU 46 EQUA PLUS 2 3 66 MOINS 2 4 69 FINV
VOLU 47 EQUA PLUS 2 4 66 MOINS 2 13 68 FINV
VOLU 48 EQUA PLUS 2 13 67 MOINS 2 14 69 FINV
VOLU 49 EQUA PLUS 2 4 68 MOINS  2 13 69 FINV

// Mounting Plate
VOLU 50 EQUA PLUS 1 34 MOINS 2 17 35 FINV
VOLU 51 EQUA PLUS 2 25 34 MOINS 2 28 35 FINV
VOLU 52 EQUA PLUS 2 26 34 MOINS 2 30 35 FINV
VOLU 53 EQUA PLUS 2 27 34 MOINS 2 29 35 FINV
VOLU 54 EQUA PLUS 5 17 28 29 30 34 MOINS 2 21 35 FINV

// Clamps supports
VOLU 550 EQUA PLUS 3 35 74 83 MOINS 3 61 78 84 FICTIF FINV
VOLU 55 ROTATION VOLU 550 0. 0. 1.    0. 0 0 0 FINV
VOLU 56 ROTATION VOLU 550 0. 0. 1. -120. 0 0 0 FINV
VOLU 57 ROTATION VOLU 550 0. 0. 1.  120. 0 0 0 FINV

// Clamps
VOLU 580 EQUA PLUS 3 40 75 80 MOINS 3 45 77 83 FICTIF FINV
VOLU 590 EQUA PLUS 3 45 75 82 MOINS 3 70 77 83 FICTIF FINV
VOLU 600 EQUA PLUS 3 70 75 80 MOINS 3 73 77 83 FICTIF FINV
VOLU 58 ROTATION VOLU 580 0 0 1    0. 0 0 0 FINV
VOLU 59 ROTATION VOLU 590 0 0 1    0. 0 0 0 FINV
VOLU 60 ROTATION VOLU 600 0 0 1    0. 0 0 0 FINV
VOLU 61 ROTATION VOLU 580 0 0 1 -120. 0 0 0 FINV
VOLU 62 ROTATION VOLU 590 0 0 1 -120. 0 0 0 FINV
VOLU 63 ROTATION VOLU 600 0 0 1 -120. 0 0 0 FINV
VOLU 64 ROTATION VOLU 580 0 0 1  120. 0 0 0 FINV
VOLU 65 ROTATION VOLU 590 0 0 1  120. 0 0 0 FINV
VOLU 66 ROTATION VOLU 600 0 0 1  120. 0 0 0 FINV

// Nut on Spindle
```

```
VOLU 67 EQUA PLUS 2 2 69 MOINS 2 6 71 FINV

// Outer Void Regions
VOLU 68 EQUA PLUS 2 5 43 MOINS 2 13 44 FINV
VOLU 69 EQUA PLUS 2 5 41 MOINS 2 13 43 FINV
VOLU 70 EQUA PLUS 2 8 44 MOINS 2 13 49 FINV
VOLU 71 EQUA PLUS 2 12 56 MOINS 2 13 59 FINV
VOLU 72 EQUA PLUS 2 9 59 MOINS 2 10 60 FINV
VOLU 73 EQUA PLUS 2 9 60 MOINS 2 10 63 FINV

// Inner Void Regions
VOLU 74 EQUA PLUS 1 72 MOINS 2 20 73 VMOINS 3 60 63 66 FINV
VOLU 75 EQUA PLUS 4 20 35 76 79 MOINS 2 21 73 VMOINS 4 55 58 59 60 FINV
VOLU 76 EQUA PLUS 3 20 35 79 MOINS 3 21 73 76 VMOINS 4 55 58 59 60 FINV
VOLU 77 EQUA PLUS 2 20 35 MOINS 4 21 73 76 79 VMOINS 4 56 61 62 63 FINV
VOLU 78 EQUA PLUS 3 20 35 76 MOINS 3 21 73 79 VMOINS 4 57 64 65 66 FINV
VOLU 79 EQUA PLUS 2 14 67 MOINS 2 16 69 FINV
VOLU 80 EQUA PLUS 1 34 MOINS 2 25 37 FINV
VOLU 81 EQUA PLUS 1 34 MOINS 2 27 36 FINV
VOLU 82 EQUA PLUS 1 34 MOINS 2 26 42 FINV
VOLU 83 EQUA PLUS 2 33 42 MOINS 2 26 47 FINV
VOLU 84 EQUA PLUS 5 13 25 26 27 35 MOINS 2 20 45 VMOINS 3 58 61 64 FINV
VOLU 85 EQUA PLUS 5 13 25 26 27 45 MOINS 2 20 47 VMOINS 6 44 56 57 59 62 65 FINV
VOLU 86 EQUA PLUS 1 35 MOINS 2 13 41 FINV
VOLU 87 EQUA PLUS 2 13 69 MOINS 2 16 70 FINV
VOLU 88 EQUA PLUS 3 13 19 67 MOINS 2 20 70 VMOINS 3 59 62 65 FINV
VOLU 89 EQUA PLUS 2 13 70 MOINS 2 20 72 VMOINS 3 60 63 66 FINV
VOLU 90 EQUA PLUS 2 11 49 MOINS 2 13 70 FINV
VOLU 91 EQUA PLUS 2 12 63 MOINS 2 13 66 FINV
VOLU 92 EQUA PLUS 2 3 69 MOINS 2 13 72 VMOINS 1 67 FINV
VOLU 93 EQUA PLUS 1 55 MOINS 2 11 56 FINV
VOLU 94 EQUA PLUS 1 56 MOINS 2 2 57 FINV
VOLU 95 EQUA PLUS 1 57 MOINS 2 1 72 FINV
VOLU 96 EQUA PLUS 2 3 64 MOINS 2 7 66 FINV

// External Void Regions
VOLU 98 EQUA PLUS 2 21 34 MOINS 1 73 FINV

// Notches for fuel rings
VOLU 12 EQUA PLUS 3 47 75 81 MOINS 3 20 67 77 VMOINS 1 59 FINV
VOLU 13 EQUA PLUS 2 47 88 MOINS 4 20 67 85 87 VMOINS 1 62 FINV
VOLU 14 EQUA PLUS 2 47 90 MOINS 4 20 67 86 89 VMOINS 1 65 FINV

// Homogenized Fuel Rings
VOLU 16 EQUA PLUS 5 18 25 26 27 47 MOINS 2 20 48 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 17 EQUA PLUS 5 13 25 26 27 48 MOINS 2 20 59 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 18 EQUA PLUS 5 10 25 26 27 59 MOINS 2 20 62 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 19 EQUA PLUS 2 10 62 MOINS 2 20 63 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 20 EQUA PLUS 2 13 63 MOINS 2 20 65 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 21 EQUA PLUS 2 13 65 MOINS 2 16 67 FINV
VOLU 22 EQUA PLUS 2 19 65 MOINS 2 20 67 VMOINS 7 12 13 14 45 59 62 65 FINV

COLOR 10
       // void
       WHITE 53
               2  3 12 13 14
              23 24 25 29 30
              31 32 36 37 38
              39 43 46 47 50
              51 52 53 68 69
              70 71 72 73 74
```

```
                75 76 77 78 79
                80 81 82 83 84
                85 86 87 88 89
                90 91 92 93 94
                95 96    98

        // material 1
        SALMON 8
                 1  9 10 11
                55 56 57 67
        // material 2
        GREEN 4
                44 45 48 49
        // material 3
        YELLOW 9
                58 59 60 61 62
                63 64 65 66
        // material 4
        BLUE 1
                54
        // material 5
        CYAN 1
                 8
        // material 6
        CORAL 6
                26 27 28 33 34
                35
        // material 7
        PINK 3
                40 41 42
        // material 8
        VIOLET 8
                15 16 17 18 19
                20 21 22
        // material 9
        RED 4
                4 5 6 7

COMMENT
GRAF
        -20. 0. -25.
        1 0 0
        0 0 1
        45. 45.
        3

GRAF
        -20. -20. -5.
        1 0 0
        0 1 0
        45. 45.
        3

GRAF
        3.33 -25. -25.
        0 1 0
        0 0 1
        45. 45.
        3

GRAF
```

```
        -20. -20. -8.
        1 0 0
        0 1 0
        45. 45.
        3
COMMENT
FINGEOM

COMPOSITION
        10

        PUNCTUAL 294 AIR
        2
        N14     4.1985E-5
        O16     1.1263E-5

        PUNCTUAL 294 SS303
        30
        C      3.0083e-4
        SI28   1.5821E-3
        SI29   8.0109E-5
        SI30   5.3177E-5
        P31    1.5554e-4
        S32    4.2823E-4
        S33    3.3800E-6
        S34    1.8973E-5
        S36    9.0134E-8
        CR50   7.2466e-4
        CR52   1.3974e-2
        CR53   1.5844e-3
        CR54   3.9443e-4
        MN55   8.7693e-4
        FE54   3.5742e-3
        FE56   5.5564e-2
        FE57   1.2722e-3
        FE58   1.6962e-4
        NI58   5.0437e-3
        NI60   1.9282e-3
        NI61   8.3482e-5
        NI62   2.6522e-4
        NI64   6.7229e-5
        MO92   2.2356e-5
        MO94   1.3935E-5
        MO95   2.3983E-5
        MO96   2.5128E-5
        MO97   1.4387E-5
        MO98   3.6352E-5
        MO100  1.4508E-5

        PUNCTUAL 294 SAE4340
        30
        C      1.5940e-3
        SI28   3.4929E-4
        SI29   1.7686E-5
        SI30   1.1740E-5
        P31    2.7472e-5
        S32    2.8013E-5
        S33    2.2111E-7
        S34    1.2412E-6
        S36    5.8962E-9
        CR50   3.1603e-5
```

```
CR52   6.0944e-4
CR53   6.9097e-5
CR54   1.7202e-5
MN55   6.2385e-4
FE54   4.7824e-3
FE56   7.4345e-2
FE57   1.7022e-3
FE58   2.2696e-4
NI58   9.8985e-4
NI60   3.7842e-4
NI61   1.6384e-5
NI62   5.2051e-5
NI64   1.3194e-5
MO92   1.8281E-5
MO94   1.1395E-5
MO95   1.9612E-5
MO96   2.0548E-5
MO97   1.1765E-5
MO98   2.9726E-5
MO100  1.1863E-5


PUNCTUAL 294 VASCOMAX300
33
C      8.0221E-5
AL27   1.7855E-4
SI28   7.9104E-5
SI29   4.0054E-6
SI30   2.6588E-6
P31    7.7770e-6
S32    7.1371E-6
S33    5.6334E-8
S34    3.1622E-7
S36    1.5022E-9
TI46   5.8762E-5
TI47   5.3621E-5
TI48   5.4208E-4
TI49   4.0399E-5
TI50   3.9665E-5
MN55   4.3847e-5
FE54   3.4070e-3
FE56   5.2965e-2
FE57   1.2127e-3
FE58   1.6169e-4
CO59   7.1938e-3
NI58   1.0367e-2
NI60   3.9635e-3
NI61   1.7160e-4
NI62   5.4518e-4
NI64   1.3819e-4
MO92   3.5769E-4
MO94   2.2295E-4
MO95   3.8372E-4
MO96   4.0204E-4
MO97   2.3018E-4
MO98   5.8161E-4
MO100  2.3211E-4

PUNCTUAL 294 ALU
1
AL27   5.8593E-2
```

```
PUNCTUAL 294 HEU_SB
12
U233   4.6322E-6
U234   4.7005E-4
U235   4.2791E-2
U236   3.1098E-4
U238   2.3222E-3
MO92   1.6894E-4
MO94   1.0530E-4
MO95   1.8123E-4
MO96   1.8989E-4
MO97   1.0872E-4
MO98   2.7470E-4
MO100  1.0963E-4

PUNCTUAL 294 HEU_ISP
12
U233   4.6755E-6
U234   4.7433E-4
U235   4.3187E-2
U236   3.1388E-4
U238   2.3464E-3
MO92   2.5832E-4
MO94   1.6101E-4
MO95   2.7712E-4
MO96   2.9035E-4
MO97   1.6624E-4
MO98   4.2003E-4
MO100  1.6763E-4

PUNCTUAL 294 HEU_RING
12
U233   4.6484E-6
U234   4.7159E-4
U235   4.2930E-2
U236   3.1206E-4
U238   2.3398E-3
MO92   2.5350E-4
MO94   1.5801E-4
MO95   2.7195E-4
MO96   2.8493E-4
MO97   1.6313E-4
MO98   4.1219E-4
MO100  1.6450E-4

PUNCTUAL 294 HEU_CTRLRODS
12
U233   4.6812E-6
U234   4.7497E-4
U235   4.3238E-2
U236   3.1427E-4
U238   2.3514E-3
MO92   2.2831E-4
MO94   1.4231E-4
MO95   2.4493E-4
MO96   2.5662E-4
MO97   1.4693E-4
MO98   3.7124E-4
MO100  1.4816E-4

PUNCTUAL 294 HEU_BURSTROD
```

```
      12
      U233   4.7893E-6
      U234   4.8594E-4
      U235   4.4237E-2
      U236   3.2152E-4
      U238   2.4057E-3
      MO92   2.3300E-4
      MO94   1.4523E-4
      MO95   2.4996E-4
      MO96   2.6189E-4
      MO97   1.4994E-4
      MO98   3.7887E-4
      MO100  1.5120E-4

FIN_COMPOSITION

GEOMCOMP
      AIR 53
              2  3 12 13 14
             23 24 25 29 30
             31 32 36 37 38
             39 43 46 47 50
             51 52 53 68 69
             70 71 72 73 74
             75 76 77 78 79
             80 81 82 83 84
             85 86 87 88 89
             90 91 92 93 94
             95 96    98


      SS303 8
              1  9 10 11 55
             56 57 67

      SAE4340 4
             44 45 48 49

      VASCOMAX300 9
             58 59 60 61 62
             63 64 65 66

      ALU 1
             54

      HEU_SB 1
              8

      HEU_CTRLRODS 6
             26 27 28 33 34
             35

      HEU_BURSTROD 3
             40 41 42

      HEU_RING 8
             15 16 17 18 19
             20 21 22

      HEU_ISP 4
             4 5 6 7
```

```
FIN_GEOMCOMP

LIST_SOURCES
       1
       SOURCE INTENSITY 1. NEUTRON
       PUNCTUAL 0. 0. 0.
       ANGULAR_DISTRIBUTION ISOTROPIC
       ENERGETIC_DISTRIBUTION SPECTRE WATT_SPECTRE
       TIME_DISTRIBUTION DIRAC 0.
       FIN_SOURCES
FIN_LIST_SOURCES

SIMULATION
       CRITICITE
       BATCH 550 DISCARD 50
       SIZE 10000
       PARTICLE 1 NEUTRON
       ENERGY_INF NEUTRON 1.E-11
       ENERGY_SUP NEUTRON 20.
       EDITION 100
FIN_SIMULATION
```

```
GEOMETRIE
TITRE  Godiva-IV  HEU-MET-FAST-086  Case 4  Benchmark Model  DC  BR In  ENDF/B-VI

SURF 1 CYLZ 0. 0. 0.31750 // Glory-Hole Radius
SURF 2 CYLZ 0. 0. 1.27000 // Spindle Bottom Middle OR
SURF 3 CYLZ 0. 0. 1.42875 // Spindle Top Middle OR
SURF 4 CYLZ 0. 0. 1.43510 // Radius of Central Hole in SCP
SURF 5 CYLZ 0. 0. 1.90500 // OR of SB Base Bottom
SURF 6 CYLZ 0. 0. 2.22250 // OR for Nut on Spindle
SURF 7 CYLZ 0. 0. 3.50520 // Upper IR of UISP
SURF 8 CYLZ 0. 0. 3.65760 // OR of SB Base Platform
SURF 9 CYLZ 0. 0. 3.92430 // OR of Upper Int Sub Plate
SURF 10 CYLZ 0. 0. 3.97510 // IR of Ring 5
SURF 11 CYLZ 0. 0. 4.29260 // Safety Block Outer Radius
SURF 12 CYLZ 0. 0. 4.38150 // OR of Lower Int Sub Plate
SURF 13 CYLZ 0. 0. 4.44500 // IR of Rings 1-4, 6
SURF 14 CYLZ 0. 0. 5.08000 // IR of S Pad Slots, BR Annulus
SURF 15 CYLZ 0. 0. 5.08508 // Inner Radius of Sprt Pad Ring
SURF 16 CYLZ 0. 0. 5.08381 // Inner Radius of Bearing Ring
SURF 17 CYLZ 0. 0. 5.23875 // Radius of Central Hole in MP
SURF 18 CYLZ 0. 0. 7.29488 // Outer Radius of Sprt Pad Ring
SURF 19 CYLZ 0. 0. 7.29615 // Outer Radius of Bearing Ring
SURF 20 CYLZ 0. 0. 8.89000 // OR of Rings
SURF 21 CYLZ 0. 0. 44.45 // Outer Radius of Mtng Plate
SURF 22 CYLZ 3.33375 -5.774224 0.47625 // Control Rod 1 IR
SURF 23 CYLZ 3.33375 5.774224 0.47625 // Control Rod 2 IR
SURF 24 CYLZ -6.66750 0.0 0.47625 // Burst Rod IR
SURF 25 CYLZ 3.33375 -5.774224 1.11125 // FR Hole, Control or Burst Rod
SURF 26 CYLZ -6.66750 0.0 1.11125 // Lt Hole, Control or Burst Rod
SURF 27 CYLZ 3.33375 5.774224 1.11125 // BR Hole, Control or Burst Rod
SURF 28 CYLZ 3.33375 -5.774224 1.27000 // FR Hole for Control Rod 1
SURF 29 CYLZ 3.33375 5.774224 1.27000 // BR Hole for Control Rod 2
SURF 30 CYLZ -6.66750 0.0 1.27000 // Left Hole for Burst Rod
SURF 31 CYLZ 3.33375 -5.774224 1.09220 // Control Rod 1 OR
SURF 32 CYLZ 3.33375 5.774224 1.09220 // Control Rod 2 OR
SURF 33 CYLZ -6.66750 0.0 1.09220 // Burst Rod OR
SURF 34 PLANZ -20.37715 // Bottom of Mounting Plate
SURF 35 PLANZ -16.56715 // Top of Mounting Plate
SURF 36 PLANZ -10.81405 // Bottom of Control Rod 2
SURF 37 PLANZ -10.86993 // Bottom of Control Rod 1
SURF 38 PLANZ  -8.90905 // Top of CR2 Bottom Hole
SURF 39 PLANZ  -8.96493 // Top of CR1 Bottom Hole
SURF 40 PLANZ -12.67587 // Bottom of Flat Clamp Bottom
SURF 41 PLANZ -11.85559 // Bottom of Safety Block Base
SURF 42 PLANZ -18.34007 // Bottom of Burst Rod (Full In)
SURF 43 PLANZ -9.79948 // Bottom of Platform Curve
SURF 44 PLANZ -9.17448 // Bottom of SB Base Platform
SURF 45 PLANZ -9.02589 // Bottom of Support-Pad Ring
SURF 46 PLANZ -16.43507 // Top of Burst Rod Bottom Hole
SURF 47 PLANZ -8.06553 // Bottom of Homog Fuel Rings
SURF 48 PLANZ -7.59414 // Top of Support-Pad Ring
SURF 49 PLANZ -7.74700 // Bottom of Safety Block
SURF 50 PLANZ -0.01905 // Bottom of CR2 Top Hole
SURF 51 PLANZ -0.07493 // Bottom of CR1 Top Hole
SURF 52 PLANZ  1.88595 // Top of Control Rod 2
SURF 53 PLANZ  1.83007 // Top of Control Rod 1
SURF 54 PLANZ -8.81507 // Flat Bottom of BR Top Hole
SURF 55 PLANZ -0.12700 // Top of Safety Block
SURF 56 PLANZ 0.0 // Bottom of Inter Inner SA Pl
SURF 57 PLANZ 0.00254 // Bottom of Spindle
SURF 58 PLANZ -5.64007 // Top of Burst Rod (Full In)
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```
SURF 59 PLANZ 2.54000 // Top of Upper ISP Wide Region
SURF 60 PLANZ 3.49250 // Top of Int Inr Subassby Plate
SURF 61 PLANZ 4.38785 // Top of Right Leg
SURF 62 PLANZ 4.64820 // Top of Control Rod Hole
SURF 63 PLANZ 4.96570 // Top of ISP Indentation
SURF 64 PLANZ 6.98754 // Bottom of ISP Inner Annulus
SURF 65 PLANZ 7.27160 // Bottom of Bearing ring
SURF 66 PLANZ 7.64794 // Top of Top Inr Subasmbly Pl
SURF 67 PLANZ 7.73264 // Top of Homog Fuel RingsS
SURF 68 PLANZ 7.95528 // Top of SCP Raised Edge
SURF 69 PLANZ 8.27278 // Top of Subassembly Cvr Plate
SURF 70 PLANZ 8.75411 // Top of Bearing Ring
SURF 71 PLANZ 9.54278 // Top of Nut on Spindle
SURF 72 PLANZ 11.43254 // Top of Spindle
SURF 73 PLANZ 12.40409 // Top of Flat Clamp Top
SURF 74 PLANY -1.42875 // Front Edge of Right Leg
SURF 75 PLANY -1.11125 // Front Edge of Left Notch
SURF 76 PLANY 0.0
SURF 77 PLANY 1.11125 // Back Edge of Left Notch
SURF 78 PLANY 1.42875 // Back Edge of Right Leg
SURF 79 PLANX 0.0
SURF 80 PLANX 5.08000 // Left Edge of Prongs
SURF 81 PLANX 8.49376 // Back Edge of Left Notch(1&6)
SURF 82 PLANX 8.49630 // Left Edge of Clamp Back
SURF 83 PLANX 12.94130 // Right Edge of Right Leg Inset
SURF 84 PLANX 18.94130 // Right Edge of Rectglar Rt Leg
SURF 85 PLAN 1.0 1.7320508 0.0 16.9857200 // Back Edge, BL Notch (1 & 6)
SURF 86 PLAN 1.0 -1.7320508 0.0 16.9857200 // Back Edge, BR Notch (1 & 6)
SURF 87 PLAN 1.7320508 -1.0 0.0 -1.9247415 // Lower Edge, BL Notch
SURF 88 PLAN 1.7320508 -1.0 0.0 1.9247415 // Upper Edge, BL Notch
SURF 89 PLAN 1.7320508 1.0 0.0 -1.9247415 // Lower Edge, BR Notch
SURF 90 PLAN 1.7320508 1.0 0.0 1.9247415 // Upper Edge, BR Notch

// Spindle
VOLU 1 EQUA PLUS 2 1 57 MOINS 2 2 72 FINV
VOLU 2 EQUA PLUS 2 2 64 MOINS 2 3 69 FINV
VOLU 3 EQUA PLUS 2 2 71 MOINS 2 3 72 FINV

// Homogenized Subassembly Plate
VOLU 4 EQUA PLUS 2 2 56 MOINS 2 12 59 FINV
VOLU 5 EQUA PLUS 2 2 59 MOINS 2 9 63 FINV
VOLU 6 EQUA PLUS 2 2 63 MOINS 2 12 64 FINV
VOLU 7 EQUA PLUS 2 7 64 MOINS 2 12 66 FINV

// Safety Bloc
VOLU 8 EQUA PLUS 2 2 49 MOINS 2 11 55 FINV

// Safety Bloc Base
VOLU 9  EQUA PLUS 1 41 MOINS 2 5 44 FINV
VOLU 10 EQUA PLUS 1 44 MOINS 2 8 49 FINV
VOLU 11 EQUA PLUS 1 49 MOINS 2 2 55 FINV

// Homogenized Fuel Rings
VOLU 15 EQUA PLUS 5 13 25 26 27 47 MOINS 2 15 48 FINV

// Control and Burst Rods
VOLU 23 EQUA PLUS 1 53 MOINS 2 25 62 FINV
VOLU 24 EQUA PLUS 2 31 37 MOINS 2 25 53 FINV
VOLU 25 EQUA PLUS 1 37 MOINS 2 22 39 FINV
VOLU 26 EQUA PLUS 2 22 37 MOINS 2 31 39 FINV
VOLU 27 EQUA PLUS 1 39 MOINS 2 31 51 FINV
```

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VOLU 28 EQUA PLUS 2 22 51 MOINS 2 31 53 FINV
VOLU 29 EQUA PLUS 1 51 MOINS 2 22 53 FINV
VOLU 30 EQUA PLUS 1 52 MOINS 2 27 62 FINV
VOLU 31 EQUA PLUS 2 32 36 MOINS 2 27 52 FINV
VOLU 32 EQUA PLUS 1 36 MOINS 2 23 38 FINV
VOLU 33 EQUA PLUS 2 23 36 MOINS 2 32 38 FINV
VOLU 34 EQUA PLUS 1 38 MOINS 2 32 50 FINV
VOLU 35 EQUA PLUS 2 23 50 MOINS 2 32 52 FINV
VOLU 36 EQUA PLUS 1 50 MOINS 2 23 52 FINV
VOLU 37 EQUA PLUS 1 58 MOINS 2 26 62 FINV
VOLU 38 EQUA PLUS 2 33 47 MOINS 2 26 58 FINV
VOLU 39 EQUA PLUS 1 42 MOINS 2 24 46 FINV
VOLU 40 EQUA PLUS 2 24 42 MOINS 2 33 46 FINV
VOLU 41 EQUA PLUS 1 46 MOINS 2 33 54 FINV
VOLU 42 EQUA PLUS 2 24 54 MOINS 2 33 58 FINV
VOLU 43 EQUA PLUS 1 54 MOINS 2 24 58 FINV

// Support Pads Converted to Ring
VOLU 44 EQUA PLUS 5 15 25 26 27 45 MOINS 2 18 48 FINV

// Bearing Ring
VOLU 45 EQUA PLUS 2 16 65 MOINS 2 19 70 FINV

// Subassembly Cover Plate
VOLU 46 EQUA PLUS 2 3 66 MOINS 2 4 69 FINV
VOLU 47 EQUA PLUS 2 4 66 MOINS 2 13 68 FINV
VOLU 48 EQUA PLUS 2 13 67 MOINS 2 14 69 FINV
VOLU 49 EQUA PLUS 2 4 68 MOINS  2 13 69 FINV

// Mounting Plate
VOLU 50 EQUA PLUS 1 34 MOINS 2 17 35 FINV
VOLU 51 EQUA PLUS 2 25 34 MOINS 2 28 35 FINV
VOLU 52 EQUA PLUS 2 26 34 MOINS 2 30 35 FINV
VOLU 53 EQUA PLUS 2 27 34 MOINS 2 29 35 FINV
VOLU 54 EQUA PLUS 5 17 28 29 30 34 MOINS 2 21 35 FINV

// Clamps supports
VOLU 550 EQUA PLUS 3 35 74 83 MOINS 3 61 78 84 FICTIF FINV
VOLU 55 ROTATION VOLU 550 0. 0. 1.    0. 0 0 0 FINV
VOLU 56 ROTATION VOLU 550 0. 0. 1. -120. 0 0 0 FINV
VOLU 57 ROTATION VOLU 550 0. 0. 1.  120. 0 0 0 FINV

// Clamps
VOLU 580 EQUA PLUS 3 40 75 80 MOINS 3 45 77 83 FICTIF FINV
VOLU 590 EQUA PLUS 3 45 75 82 MOINS 3 70 77 83 FICTIF FINV
VOLU 600 EQUA PLUS 3 70 75 80 MOINS 3 73 77 83 FICTIF FINV
VOLU 58 ROTATION VOLU 580 0 0 1    0. 0 0 0 FINV
VOLU 59 ROTATION VOLU 590 0 0 1    0. 0 0 0 FINV
VOLU 60 ROTATION VOLU 600 0 0 1    0. 0 0 0 FINV
VOLU 61 ROTATION VOLU 580 0 0 1 -120. 0 0 0 FINV
VOLU 62 ROTATION VOLU 590 0 0 1 -120. 0 0 0 FINV
VOLU 63 ROTATION VOLU 600 0 0 1 -120. 0 0 0 FINV
VOLU 64 ROTATION VOLU 580 0 0 1  120. 0 0 0 FINV
VOLU 65 ROTATION VOLU 590 0 0 1  120. 0 0 0 FINV
VOLU 66 ROTATION VOLU 600 0 0 1  120. 0 0 0 FINV

// Nut on Spindle
VOLU 67 EQUA PLUS 2 2 69 MOINS 2 6 71 FINV

// Outer Void Regions
VOLU 68 EQUA PLUS 2 5 43 MOINS 2 13 44 FINV
```

```
VOLU 69 EQUA PLUS 2 5 41 MOINS 2 13 43 FINV
VOLU 70 EQUA PLUS 2 8 44 MOINS 2 13 49 FINV
VOLU 71 EQUA PLUS 2 12 56 MOINS 2 13 59 FINV
VOLU 72 EQUA PLUS 2 9 59 MOINS 2 10 60 FINV
VOLU 73 EQUA PLUS 2 9 60 MOINS 2 10 63 FINV

// Inner Void Regions
VOLU 74 EQUA PLUS 1 72 MOINS 2 20 73 VMOINS 3 60 63 66 FINV
VOLU 75 EQUA PLUS 4 20 35 76 79 MOINS 2 21 73 VMOINS 4 55 58 59 60 FINV
VOLU 76 EQUA PLUS 3 20 35 79 MOINS 3 21 73 76 VMOINS 4 55 58 59 60 FINV
VOLU 77 EQUA PLUS 2 20 35 MOINS 4 21 73 76 79 VMOINS 4 56 61 62 63 FINV
VOLU 78 EQUA PLUS 3 20 35 76 MOINS 3 21 73 79 VMOINS 4 57 64 65 66 FINV
VOLU 79 EQUA PLUS 2 14 67 MOINS 2 16 69 FINV
VOLU 80 EQUA PLUS 1 34 MOINS 2 25 37 FINV
VOLU 81 EQUA PLUS 1 34 MOINS 2 27 36 FINV
VOLU 82 EQUA PLUS 1 34 MOINS 2 26 42 FINV
VOLU 83 EQUA PLUS 2 33 42 MOINS 2 26 47 FINV
VOLU 84 EQUA PLUS 5 13 25 26 27 35 MOINS 2 20 45 VMOINS 3 58 61 64 FINV
VOLU 85 EQUA PLUS 5 13 25 26 27 45 MOINS 2 20 47 VMOINS 6 44 56 57 59 62 65 FINV
VOLU 86 EQUA PLUS 1 35 MOINS 2 13 41 FINV
VOLU 87 EQUA PLUS 2 13 69 MOINS 2 16 70 FINV
VOLU 88 EQUA PLUS 3 13 19 67 MOINS 2 20 70 VMOINS 3 59 62 65 FINV
VOLU 89 EQUA PLUS 2 13 70 MOINS 2 20 72 VMOINS 3 60 63 66 FINV
VOLU 90 EQUA PLUS 2 11 49 MOINS 2 13 70 FINV
VOLU 91 EQUA PLUS 2 12 63 MOINS 2 13 66 FINV
VOLU 92 EQUA PLUS 2 3 69 MOINS 2 13 72 VMOINS 1 67 FINV
VOLU 93 EQUA PLUS 1 55 MOINS 2 11 56 FINV
VOLU 94 EQUA PLUS 1 56 MOINS 2 2 57 FINV
VOLU 95 EQUA PLUS 1 57 MOINS 2 1 72 FINV
VOLU 96 EQUA PLUS 2 3 64 MOINS 2 7 66 FINV

// External Void Regions
VOLU 98 EQUA PLUS 2 21 34 MOINS 1 73 FINV

// Notches for fuel rings
VOLU 12 EQUA PLUS 3 47 75 81 MOINS 3 20 67 77 VMOINS 1 59 FINV
VOLU 13 EQUA PLUS 2 47 88 MOINS 4 20 67 85 87 VMOINS 1 62 FINV
VOLU 14 EQUA PLUS 2 47 90 MOINS 4 20 67 86 89 VMOINS 1 65 FINV

// Homogenized Fuel Rings
VOLU 16 EQUA PLUS 5 18 25 26 27 47 MOINS 2 20 48 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 17 EQUA PLUS 5 13 25 26 27 48 MOINS 2 20 59 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 18 EQUA PLUS 5 10 25 26 27 59 MOINS 2 20 62 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 19 EQUA PLUS 2 10 62 MOINS 2 20 63 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 20 EQUA PLUS 2 13 63 MOINS 2 20 65 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 21 EQUA PLUS 2 13 65 MOINS 2 16 67 FINV
VOLU 22 EQUA PLUS 2 19 65 MOINS 2 20 67 VMOINS 7 12 13 14 45 59 62 65 FINV

COLOR 10
       // void
       WHITE 53
               2  3 12 13 14
              23 24 25 29 30
              31 32 36 37 38
              39 43 46 47 50
              51 52 53 68 69
              70 71 72 73 74
              75 76 77 78 79
              80 81 82 83 84
              85 86 87 88 89
              90 91 92 93 94
```

```
        95 96    98
    // material 1
    SALMON 8
         1  9 10 11 55
        56 57 67
    // material 2
    GREEN 4
        44 45 48 49
    // material 3
    YELLOW 9
        58 59 60 61 62
        63 64 65 66
    // material 4
    BLUE 1
        54
    // material 5
    CYAN 1
         8
    // material 6
    CORAL 6
        26 27 28 33 34
        35
    // material 7
    PINK 3
        40 41 42
    // material 8
    VIOLET 8
        15 16 17 18 19
        20 21 22
    // material 9
    RED 4
        4 5 6 7

COMMENT
GRAF
    -20. 0. -25.
    1 0 0
    0 0 1
    45. 45.
    3

GRAF
    -20. -20. -5.
    1 0 0
    0 1 0
    45. 45.
    3

GRAF
    3.33 -20. -20.
    0 1 0
    0 0 1
    45. 45.
    3

GRAF
    -20. -20. -8.
    1 0 0
    0 1 0
    45. 45.
    3
```

```
COMMENT
FINGEOM

COMPOSITION
       10

       PUNCTUAL 294 AIR
       2
       N14    4.1985E-5
       O16    1.1263E-5

       PUNCTUAL 294 SS303
       30
       C      3.0083e-4
       SI28   1.5821E-3
       SI29   8.0109E-5
       SI30   5.3177E-5
       P31    1.5554e-4
       S32    4.2823E-4
       S33    3.3800E-6
       S34    1.8973E-5
       S36    9.0134E-8
       CR50   7.2466e-4
       CR52   1.3974e-2
       CR53   1.5844e-3
       CR54   3.9443e-4
       MN55   8.7693e-4
       FE54   3.5742e-3
       FE56   5.5564e-2
       FE57   1.2722e-3
       FE58   1.6962e-4
       NI58   5.0437e-3
       NI60   1.9282e-3
       NI61   8.3482e-5
       NI62   2.6522e-4
       NI64   6.7229e-5
       MO92   2.2356e-5
       MO94   1.3935E-5
       MO95   2.3983E-5
       MO96   2.5128E-5
       MO97   1.4387E-5
       MO98   3.6352E-5
       MO100  1.4508E-5

       PUNCTUAL 294 SAE4340
       30
       C      1.5940e-3
       SI28   3.4929E-4
       SI29   1.7686E-5
       SI30   1.1740E-5
       P31    2.7472e-5
       S32    2.8013E-5
       S33    2.2111E-7
       S34    1.2412E-6
       S36    5.8962E-9
       CR50   3.1603e-5
       CR52   6.0944e-4
       CR53   6.9097e-5
       CR54   1.7202e-5
       MN55   6.2385e-4
       FE54   4.7824e-3
```

```
FE56   7.4345e-2
FE57   1.7022e-3
FE58   2.2696e-4
NI58   9.8985e-4
NI60   3.7842e-4
NI61   1.6384e-5
NI62   5.2051e-5
NI64   1.3194e-5
MO92   1.8281E-5
MO94   1.1395E-5
MO95   1.9612E-5
MO96   2.0548E-5
MO97   1.1765E-5
MO98   2.9726E-5
MO100  1.1863E-5


PUNCTUAL 294 VASCOMAX300
33
C      8.0221E-5
AL27   1.7855E-4
SI28   7.9104E-5
SI29   4.0054E-6
SI30   2.6588E-6
P31    7.7770e-6
S32    7.1371E-6
S33    5.6334E-8
S34    3.1622E-7
S36    1.5022E-9
TI46   5.8762E-5
TI47   5.3621E-5
TI48   5.4208E-4
TI49   4.0399E-5
TI50   3.9665E-5
MN55   4.3847e-5
FE54   3.4070e-3
FE56   5.2965e-2
FE57   1.2127e-3
FE58   1.6169e-4
CO59   7.1938e-3
NI58   1.0367e-2
NI60   3.9635e-3
NI61   1.7160e-4
NI62   5.4518e-4
NI64   1.3819e-4
MO92   3.5769E-4
MO94   2.2295E-4
MO95   3.8372E-4
MO96   4.0204E-4
MO97   2.3018E-4
MO98   5.8161E-4
MO100  2.3211E-4

PUNCTUAL 294 ALU
1
AL27   5.8593E-2

PUNCTUAL 294 HEU_SB
12
U233   4.6322E-6
U234   4.7005E-4
```

```
U235   4.2791E-2
U236   3.1098E-4
U238   2.3222E-3
MO92   1.6894E-4
MO94   1.0530E-4
MO95   1.8123E-4
MO96   1.8989E-4
MO97   1.0872E-4
MO98   2.7470E-4
MO100  1.0963E-4

PUNCTUAL 294 HEU_ISP
12
U233   4.6755E-6
U234   4.7433E-4
U235   4.3187E-2
U236   3.1388E-4
U238   2.3464E-3
MO92   2.5832E-4
MO94   1.6101E-4
MO95   2.7712E-4
MO96   2.9035E-4
MO97   1.6624E-4
MO98   4.2003E-4
MO100  1.6763E-4

PUNCTUAL 294 HEU_RING
12
U233   4.6484E-6
U234   4.7159E-4
U235   4.2930E-2
U236   3.1206E-4
U238   2.3398E-3
MO92   2.5350E-4
MO94   1.5801E-4
MO95   2.7195E-4
MO96   2.8493E-4
MO97   1.6313E-4
MO98   4.1219E-4
MO100  1.6450E-4

PUNCTUAL 294 HEU_CTRLRODS
12
U233   4.6812E-6
U234   4.7497E-4
U235   4.3238E-2
U236   3.1427E-4
U238   2.3514E-3
MO92   2.2831E-4
MO94   1.4231E-4
MO95   2.4493E-4
MO96   2.5662E-4
MO97   1.4693E-4
MO98   3.7124E-4
MO100  1.4816E-4

PUNCTUAL 294 HEU_BURSTROD
12
U233   4.7893E-6
U234   4.8594E-4
U235   4.4237E-2
```

```
        U236   3.2152E-4
        U238   2.4057E-3
        MO92   2.3300E-4
        MO94   1.4523E-4
        MO95   2.4996E-4
        MO96   2.6189E-4
        MO97   1.4994E-4
        MO98   3.7887E-4
        MO100  1.5120E-4

FIN_COMPOSITION

GEOMCOMP
        AIR 53
                 2  3 12 13 14
                23 24 25 29 30
                31 32 36 37 38
                39 43 46 47 50
                51 52 53 68 69
                70 71 72 73 74
                75 76 77 78 79
                80 81 82 83 84
                85 86 87 88 89
                90 91 92 93 94
                95 96    98

        SS303 8
                 1  9 10 11 55
                56 57 67

        SAE4340 4
                44 45 48 49

        VASCOMAX300 9
                58 59 60 61 62
                63 64 65 66

        ALU 1
                54

        HEU_SB 1
                 8

        HEU_CTRLRODS 6
                26 27 28 33 34
                35

        HEU_BURSTROD 3
                40 41 42

        HEU_RING 8
                15 16 17 18 19
                20 21 22

        HEU_ISP 4
                4 5 6 7

FIN_GEOMCOMP

LIST_SOURCES
        1
```

```
        SOURCE INTENSITY 1. NEUTRON
        PUNCTUAL 0. 0. 0.
        ANGULAR_DISTRIBUTION ISOTROPIC
        ENERGETIC_DISTRIBUTION SPECTRE WATT_SPECTRE
        TIME_DISTRIBUTION DIRAC 0.
        FIN_SOURCES
FIN_LIST_SOURCES

SIMULATION
        CRITICITE
        BATCH 550 DISCARD 50
        SIZE 10000
        PARTICLE 1 NEUTRON
        ENERGY_INF NEUTRON 1.E-11
        ENERGY_SUP NEUTRON 20.
        EDITION 100
FIN_SIMULATION
```

```
GEOMETRIE
TITRE Godiva-IV  HEU-MET-FAST-086  Case 5  Benchmark Model  PSCrit  BR In  ENDF/B-VI

SURF 1 CYLZ 0. 0. 0.31750 // Glory-Hole Radius
SURF 2 CYLZ 0. 0. 1.27000 // Spindle Bottom Middle OR
SURF 3 CYLZ 0. 0. 1.42875 // Spindle Top Middle OR
SURF 4 CYLZ 0. 0. 1.43510 // Radius of Central Hole in SCP
SURF 5 CYLZ 0. 0. 1.90500 // OR of SB Base Bottom
SURF 6 CYLZ 0. 0. 2.22250 // OR for Nut on Spindle
SURF 7 CYLZ 0. 0. 3.50520 // Upper IR of UISP
SURF 8 CYLZ 0. 0. 3.65760 // OR of SB Base Platform
SURF 9 CYLZ 0. 0. 3.92430 // OR of Upper Int Sub Plate
SURF 10 CYLZ 0. 0. 3.97510 // IR of Ring 5
SURF 11 CYLZ 0. 0. 4.29260 // Safety Block Outer Radius
SURF 12 CYLZ 0. 0. 4.38150 // OR of Lower Int Sub Plate
SURF 13 CYLZ 0. 0. 4.44500 // IR of Rings 1-4, 6
SURF 14 CYLZ 0. 0. 5.08000 // IR of S Pad Slots, BR Annulus
SURF 15 CYLZ 0. 0. 5.08508 // Inner Radius of Sprt Pad Ring
SURF 16 CYLZ 0. 0. 5.08381 // Inner Radius of Bearing Ring
SURF 17 CYLZ 0. 0. 5.23875 // Radius of Central Hole in MP
SURF 18 CYLZ 0. 0. 7.29488 // Outer Radius of Sprt Pad Ring
SURF 19 CYLZ 0. 0. 7.29615 // Outer Radius of Bearing Ring
SURF 20 CYLZ 0. 0. 8.89000 // OR of Rings
SURF 21 CYLZ 0. 0. 44.45 // Outer Radius of Mtng Plate
SURF 22 CYLZ 3.33375 -5.774224 0.47625 // Control Rod 1 IR
SURF 23 CYLZ 3.33375 5.774224 0.47625 // Control Rod 2 IR
SURF 24 CYLZ -6.66750 0.0 0.47625 // Burst Rod IR
SURF 25 CYLZ 3.33375 -5.774224 1.11125 // FR Hole, Control or Burst Rod
SURF 26 CYLZ -6.66750 0.0 1.11125 // Lt Hole, Control or Burst Rod
SURF 27 CYLZ 3.33375 5.774224 1.11125 // BR Hole, Control or Burst Rod
SURF 28 CYLZ 3.33375 -5.774224 1.27000 // FR Hole for Control Rod 1
SURF 29 CYLZ 3.33375 5.774224 1.27000 // BR Hole for Control Rod 2
SURF 30 CYLZ -6.66750 0.0 1.27000 // Left Hole for Burst Rod
SURF 31 CYLZ 3.33375 -5.774224 1.09220 // Control Rod 1 OR
SURF 32 CYLZ 3.33375 5.774224 1.09220 // Control Rod 2 OR
SURF 33 CYLZ -6.66750 0.0 1.09220 // Burst Rod OR
SURF 34 PLANZ -20.37715 // Bottom of Mounting Plate
SURF 35 PLANZ -16.56715 // Top of Mounting Plate
SURF 36 PLANZ -12.54633 // Bottom of Control Rod 2
SURF 37 PLANZ -10.48893 // Bottom of Control Rod 1
SURF 38 PLANZ -10.64133 // Top of CR2 Bottom Hole
SURF 39 PLANZ  -8.58393 // Top of CR1 Bottom Hole
SURF 40 PLANZ -12.67587 // Bottom of Flat Clamp Bottom
SURF 41 PLANZ -11.85559 // Bottom of Safety Block Base
SURF 42 PLANZ -10.79627 // Bottom of Burst Rod (Full In)
SURF 43 PLANZ -9.79948 // Bottom of Platform Curve
SURF 44 PLANZ -9.17448 // Bottom of SB Base Platform
SURF 45 PLANZ -9.02589 // Bottom of Support-Pad Ring
SURF 46 PLANZ -8.89127 // Top of Burst Rod Bottom Hole
SURF 47 PLANZ -8.06553 // Bottom of Homog Fuel Rings
SURF 48 PLANZ -7.59414 // Top of Support-Pad Ring
SURF 49 PLANZ -7.74700 // Bottom of Safety Block

SURF 50 PLANZ -1.75133 // Bottom of CR2 Top Hole
SURF 51 PLANZ  0.30607 // Bottom of CR1 Top Hole
SURF 52 PLANZ  0.15367 // Top of Control Rod 2
SURF 53 PLANZ  2.21107 // Top of Control Rod 1

SURF 54 PLANZ -1.27127 // Flat Bottom of BR Top Hole
SURF 55 PLANZ -0.12700 // Top of Safety Block
SURF 56 PLANZ 0.0 // Bottom of Inter Inner SA Pl
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SURF 57 PLANZ 0.00254 // Bottom of Spindle
SURF 58 PLANZ 1.90373 // Top of Burst Rod (Full In)
SURF 59 PLANZ 2.54000 // Top of Upper ISP Wide Region
SURF 60 PLANZ 3.49250 // Top of Int Inr Subassby Plate
SURF 61 PLANZ 4.38785 // Top of Right Leg
SURF 62 PLANZ 4.64820 // Top of Control Rod Hole
SURF 63 PLANZ 4.96570 // Top of ISP Indentation
SURF 64 PLANZ 6.98754 // Bottom of ISP Inner Annulus
SURF 65 PLANZ 7.27160 // Bottom of Bearing ring
SURF 66 PLANZ 7.64794 // Top of Top Inr Subasmbly Pl
SURF 67 PLANZ 7.73264 // Top of Homog Fuel RingsS
SURF 68 PLANZ 7.95528 // Top of SCP Raised Edge
SURF 69 PLANZ 8.27278 // Top of Subassembly Cvr Plate
SURF 70 PLANZ 8.75411 // Top of Bearing Ring
SURF 71 PLANZ 9.54278 // Top of Nut on Spindle
SURF 72 PLANZ 11.43254 // Top of Spindle
SURF 73 PLANZ 12.40409 // Top of Flat Clamp Top
SURF 74 PLANY -1.42875 // Front Edge of Right Leg
SURF 75 PLANY -1.11125 // Front Edge of Left Notch
SURF 76 PLANY 0.0
SURF 77 PLANY 1.11125 // Back Edge of Left Notch
SURF 78 PLANY 1.42875 // Back Edge of Right Leg
SURF 79 PLANX 0.0
SURF 80 PLANX 5.08000 // Left Edge of Prongs
SURF 81 PLANX 8.49376 // Back Edge of Left Notch(1&6)
SURF 82 PLANX 8.49630 // Left Edge of Clamp Back
SURF 83 PLANX 12.94130 // Right Edge of Right Leg Inset
SURF 84 PLANX 18.94130 // Right Edge of Rectglar Rt Leg
SURF 85 PLAN 1.0 1.7320508 0.0 16.9857200 // Back Edge, BL Notch (1 & 6)
SURF 86 PLAN 1.0 -1.7320508 0.0 16.9857200 // Back Edge, BR Notch (1 & 6)
SURF 87 PLAN 1.7320508 -1.0 0.0 -1.9247415 // Lower Edge, BL Notch
SURF 88 PLAN 1.7320508 -1.0 0.0 1.9247415 // Upper Edge, BL Notch
SURF 89 PLAN 1.7320508 1.0 0.0 -1.9247415 // Lower Edge, BR Notch
SURF 90 PLAN 1.7320508 1.0 0.0 1.9247415 // Upper Edge, BR Notch

// Spindle
VOLU 1 EQUA PLUS 2 1 57 MOINS 2 2 72 FINV
VOLU 2 EQUA PLUS 2 2 64 MOINS 2 3 69 FINV
VOLU 3 EQUA PLUS 2 2 71 MOINS 2 3 72 FINV

// Homogenized Subassembly Plate
VOLU 4 EQUA PLUS 2 2 56 MOINS 2 12 59 FINV
VOLU 5 EQUA PLUS 2 2 59 MOINS 2 9 63 FINV
VOLU 6 EQUA PLUS 2 2 63 MOINS 2 12 64 FINV
VOLU 7 EQUA PLUS 2 7 64 MOINS 2 12 66 FINV

// Safety Bloc
VOLU 8 EQUA PLUS 2 2 49 MOINS 2 11 55 FINV

// Safety Bloc Base
VOLU 9  EQUA PLUS 1 41 MOINS 2 5 44 FINV
VOLU 10 EQUA PLUS 1 44 MOINS 2 8 49 FINV
VOLU 11 EQUA PLUS 1 49 MOINS 2 2 55 FINV

// Homogenized Fuel Rings
VOLU 15 EQUA PLUS 5 13 25 26 27 47 MOINS 2 15 48 FINV

// Control and Burst Rods
VOLU 23 EQUA PLUS 1 53 MOINS 2 25 62 FINV
VOLU 24 EQUA PLUS 2 31 37 MOINS 2 25 53 FINV
VOLU 25 EQUA PLUS 1 37 MOINS 2 22 39 FINV
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VOLU 26 EQUA PLUS 2 22 37 MOINS 2 31 39 FINV
VOLU 27 EQUA PLUS 1 39 MOINS 2 31 51 FINV
VOLU 28 EQUA PLUS 2 22 51 MOINS 2 31 53 FINV
VOLU 29 EQUA PLUS 1 51 MOINS 2 22 53 FINV
VOLU 30 EQUA PLUS 1 52 MOINS 2 27 62 FINV
VOLU 31 EQUA PLUS 2 32 36 MOINS 2 27 52 FINV
VOLU 32 EQUA PLUS 1 36 MOINS 2 23 38 FINV
VOLU 33 EQUA PLUS 2 23 36 MOINS 2 32 38 FINV
VOLU 34 EQUA PLUS 1 38 MOINS 2 32 50 FINV
VOLU 35 EQUA PLUS 2 23 50 MOINS 2 32 52 FINV
VOLU 36 EQUA PLUS 1 50 MOINS 2 23 52 FINV
VOLU 37 EQUA PLUS 1 58 MOINS 2 26 62 FINV
VOLU 38 EQUA PLUS 2 33 47 MOINS 2 26 58 FINV
VOLU 39 EQUA PLUS 1 42 MOINS 2 24 46 FINV
VOLU 40 EQUA PLUS 2 24 42 MOINS 2 33 46 FINV
VOLU 41 EQUA PLUS 1 46 MOINS 2 33 54 FINV
VOLU 42 EQUA PLUS 2 24 54 MOINS 2 33 58 FINV
VOLU 43 EQUA PLUS 1 54 MOINS 2 24 58 FINV

// Support Pads Converted to Ring
VOLU 44 EQUA PLUS 5 15 25 26 27 45 MOINS 2 18 48 FINV

// Bearing Ring
VOLU 45 EQUA PLUS 2 16 65 MOINS 2 19 70 FINV

// Subassembly Cover Plate
VOLU 46 EQUA PLUS 2 3 66 MOINS 2 4 69 FINV
VOLU 47 EQUA PLUS 2 4 66 MOINS 2 13 68 FINV
VOLU 48 EQUA PLUS 2 13 67 MOINS 2 14 69 FINV
VOLU 49 EQUA PLUS 2 4 68 MOINS  2 13 69 FINV

// Mounting Plate
VOLU 50 EQUA PLUS 1 34 MOINS 2 17 35 FINV
VOLU 51 EQUA PLUS 2 25 34 MOINS 2 28 35 FINV
VOLU 52 EQUA PLUS 2 26 34 MOINS 2 30 35 FINV
VOLU 53 EQUA PLUS 2 27 34 MOINS 2 29 35 FINV
VOLU 54 EQUA PLUS 5 17 28 29 30 34 MOINS 2 21 35 FINV

// Clamps supports
VOLU 550 EQUA PLUS 3 35 74 83 MOINS 3 61 78 84 FICTIF FINV
VOLU 55 ROTATION VOLU 550 0. 0. 1.    0. 0 0 0 FINV
VOLU 56 ROTATION VOLU 550 0. 0. 1. -120. 0 0 0 FINV
VOLU 57 ROTATION VOLU 550 0. 0. 1.  120. 0 0 0 FINV

// Clamps
VOLU 580 EQUA PLUS 3 40 75 80 MOINS 3 45 77 83 FICTIF FINV
VOLU 590 EQUA PLUS 3 45 75 82 MOINS 3 70 77 83 FICTIF FINV
VOLU 600 EQUA PLUS 3 70 75 80 MOINS 3 73 77 83 FICTIF FINV
VOLU 58 ROTATION VOLU 580 0 0 1    0. 0 0 0 FINV
VOLU 59 ROTATION VOLU 590 0 0 1    0. 0 0 0 FINV
VOLU 60 ROTATION VOLU 600 0 0 1    0. 0 0 0 FINV
VOLU 61 ROTATION VOLU 580 0 0 1 -120. 0 0 0 FINV
VOLU 62 ROTATION VOLU 590 0 0 1 -120. 0 0 0 FINV
VOLU 63 ROTATION VOLU 600 0 0 1 -120. 0 0 0 FINV
VOLU 64 ROTATION VOLU 580 0 0 1  120. 0 0 0 FINV
VOLU 65 ROTATION VOLU 590 0 0 1  120. 0 0 0 FINV
VOLU 66 ROTATION VOLU 600 0 0 1  120. 0 0 0 FINV

// Nut on Spindle
VOLU 67 EQUA PLUS 2 2 69 MOINS 2 6 71 FINV
```

```
// Outer Void Regions
VOLU 68 EQUA PLUS 2 5 43 MOINS 2 13 44 FINV
VOLU 69 EQUA PLUS 2 5 41 MOINS 2 13 43 FINV
VOLU 70 EQUA PLUS 2 8 44 MOINS 2 13 49 FINV
VOLU 71 EQUA PLUS 2 12 56 MOINS 2 13 59 FINV
VOLU 72 EQUA PLUS 2 9 59 MOINS 2 10 60 FINV
VOLU 73 EQUA PLUS 2 9 60 MOINS 2 10 63 FINV

// Inner Void Regions
VOLU 74 EQUA PLUS 1 72 MOINS 2 20 73 VMOINS 3 60 63 66 FINV
VOLU 75 EQUA PLUS 4 20 35 76 79 MOINS 2 21 73 VMOINS 4 55 58 59 60 FINV
VOLU 76 EQUA PLUS 3 20 35 79 MOINS 3 21 73 76 VMOINS 4 55 58 59 60 FINV
VOLU 77 EQUA PLUS 2 20 35 MOINS 4 21 73 76 79 VMOINS 4 56 61 62 63 FINV
VOLU 78 EQUA PLUS 3 20 35 76 MOINS 3 21 73 79 VMOINS 4 57 64 65 66 FINV
VOLU 79 EQUA PLUS 2 14 67 MOINS 2 16 69 FINV
VOLU 80 EQUA PLUS 1 34 MOINS 2 25 37 FINV
VOLU 81 EQUA PLUS 1 34 MOINS 2 27 36 FINV
VOLU 82 EQUA PLUS 1 34 MOINS 2 26 42 FINV
VOLU 83 EQUA PLUS 2 33 42 MOINS 2 26 47 FINV
VOLU 84 EQUA PLUS 5 13 25 26 27 35 MOINS 2 20 45 VMOINS 3 58 61 64 FINV
VOLU 85 EQUA PLUS 5 13 25 26 27 45 MOINS 2 20 47 VMOINS 6 44 56 57 59 62 65 FINV
VOLU 86 EQUA PLUS 1 35 MOINS 2 13 41 FINV
VOLU 87 EQUA PLUS 2 13 69 MOINS 2 16 70 FINV
VOLU 88 EQUA PLUS 3 13 19 67 MOINS 2 20 70 VMOINS 3 59 62 65 FINV
VOLU 89 EQUA PLUS 2 13 70 MOINS 2 20 72 VMOINS 3 60 63 66 FINV
VOLU 90 EQUA PLUS 2 11 49 MOINS 2 13 70 FINV
VOLU 91 EQUA PLUS 2 12 63 MOINS 2 13 66 FINV
VOLU 92 EQUA PLUS 2 3 69 MOINS 2 13 72 VMOINS 1 67 FINV
VOLU 93 EQUA PLUS 1 55 MOINS 2 11 56 FINV
VOLU 94 EQUA PLUS 1 56 MOINS 2 2 57 FINV
VOLU 95 EQUA PLUS 1 57 MOINS 2 1 72 FINV
VOLU 96 EQUA PLUS 2 3 64 MOINS 2 7 66 FINV

// External Void Regions
VOLU 98 EQUA PLUS 2 21 34 MOINS 1 73 FINV

// Notches for fuel rings
VOLU 12 EQUA PLUS 3 47 75 81 MOINS 3 20 67 77 VMOINS 1 59 FINV
VOLU 13 EQUA PLUS 2 47 88 MOINS 4 20 67 85 87 VMOINS 1 62 FINV
VOLU 14 EQUA PLUS 2 47 90 MOINS 4 20 67 86 89 VMOINS 1 65 FINV

// Homogenized Fuel Rings
VOLU 16 EQUA PLUS 5 18 25 26 27 47 MOINS 2 20 48 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 17 EQUA PLUS 5 13 25 26 27 48 MOINS 2 20 59 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 18 EQUA PLUS 5 10 25 26 27 59 MOINS 2 20 62 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 19 EQUA PLUS 2 10 62 MOINS 2 20 63 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 20 EQUA PLUS 2 13 63 MOINS 2 20 65 VMOINS 6 12 13 14 59 62 65 FINV
VOLU 21 EQUA PLUS 2 13 65 MOINS 2 16 67 FINV
VOLU 22 EQUA PLUS 2 19 65 MOINS 2 20 67 VMOINS 7 12 13 14 45 59 62 65 FINV

COLOR 10
       // void
       WHITE 53
               2  3 12 13 14
              23 24 25 29 30
              31 32 36 37 38
              39 43 46 47 50
              51 52 53 68 69
              70 71 72 73 74
              75 76 77 78 79
              80 81 82 83 84
```

```
            85 86 87 88 89
            90 91 92 93 94
            95 96    98
      // material 1
      SALMON 8
             1  9 10 11 55
            56 57 67
      // material 2
      GREEN 4
            44 45 48 49
      // material 3
      YELLOW 9
            58 59 60 61 62
            63 64 65 66
      // material 4
      BLUE 1
            54
      // material 5
      CYAN 1
             8
      // material 6
      CORAL 6
            26 27 28 33 34
            35
      // material 7
      PINK 3
            40 41 42
      // material 8
      VIOLET 8
            15 16 17 18 19
            20 21 22
      // material 9
      RED 4
            4 5 6 7

COMMENT
GRAF
      -20. 0. -25.
      1 0 0
      0 0 1
      45. 45.
      3

GRAF
      -20. -20. -5.
      1 0 0
      0 1 0
      45. 45.
      3

GRAF
      3.33 -20. -20.
      0 1 0
      0 0 1
      45. 45.
      3

GRAF
      -20. -20. -8.
      1 0 0
      0 1 0
```

```
       45. 45.
       3
COMMENT
FINGEOM

COMPOSITION
       10

       PUNCTUAL 294 AIR
       2
       N14    4.1985E-5
       O16    1.1263E-5

       PUNCTUAL 294 SS303
       30
       C      3.0083e-4
       SI28   1.5821E-3
       SI29   8.0109E-5
       SI30   5.3177E-5
       P31    1.5554e-4
       S32    4.2823E-4
       S33    3.3800E-6
       S34    1.8973E-5
       S36    9.0134E-8
       CR50   7.2466e-4
       CR52   1.3974e-2
       CR53   1.5844e-3
       CR54   3.9443e-4
       MN55   8.7693e-4
       FE54   3.5742e-3
       FE56   5.5564e-2
       FE57   1.2722e-3
       FE58   1.6962e-4
       NI58   5.0437e-3
       NI60   1.9282e-3
       NI61   8.3482e-5
       NI62   2.6522e-4
       NI64   6.7229e-5
       MO92   2.2356e-5
       MO94   1.3935E-5
       MO95   2.3983E-5
       MO96   2.5128E-5
       MO97   1.4387E-5
       MO98   3.6352E-5
       MO100  1.4508E-5

       PUNCTUAL 294 SAE4340
       30
       C      1.5940e-3
       SI28   3.4929E-4
       SI29   1.7686E-5
       SI30   1.1740E-5
       P31    2.7472e-5
       S32    2.8013E-5
       S33    2.2111E-7
       S34    1.2412E-6
       S36    5.8962E-9
       CR50   3.1603e-5
       CR52   6.0944e-4
       CR53   6.9097e-5
       CR54   1.7202e-5
```

```
MN55   6.2385e-4
FE54   4.7824e-3
FE56   7.4345e-2
FE57   1.7022e-3
FE58   2.2696e-4
NI58   9.8985e-4
NI60   3.7842e-4
NI61   1.6384e-5
NI62   5.2051e-5
NI64   1.3194e-5
MO92   1.8281E-5
MO94   1.1395E-5
MO95   1.9612E-5
MO96   2.0548E-5
MO97   1.1765E-5
MO98   2.9726E-5
MO100  1.1863E-5


PUNCTUAL 294 VASCOMAX300
33
C      8.0221E-5
AL27   1.7855E-4
SI28   7.9104E-5
SI29   4.0054E-6
SI30   2.6588E-6
P31    7.7770e-6
S32    7.1371E-6
S33    5.6334E-8
S34    3.1622E-7
S36    1.5022E-9
TI46   5.8762E-5
TI47   5.3621E-5
TI48   5.4208E-4
TI49   4.0399E-5
TI50   3.9665E-5
MN55   4.3847e-5
FE54   3.4070e-3
FE56   5.2965e-2
FE57   1.2127e-3
FE58   1.6169e-4
CO59   7.1938e-3
NI58   1.0367e-2
NI60   3.9635e-3
NI61   1.7160e-4
NI62   5.4518e-4
NI64   1.3819e-4
MO92   3.5769E-4
MO94   2.2295E-4
MO95   3.8372E-4
MO96   4.0204E-4
MO97   2.3018E-4
MO98   5.8161E-4
MO100  2.3211E-4

PUNCTUAL 294 ALU
1
AL27   5.8593E-2

PUNCTUAL 294 HEU_SB
12
```

```
U233   4.6322E-6
U234   4.7005E-4
U235   4.2791E-2
U236   3.1098E-4
U238   2.3222E-3
MO92   1.6894E-4
MO94   1.0530E-4
MO95   1.8123E-4
MO96   1.8989E-4
MO97   1.0872E-4
MO98   2.7470E-4
MO100  1.0963E-4

PUNCTUAL 294 HEU_ISP
12
U233   4.6755E-6
U234   4.7433E-4
U235   4.3187E-2
U236   3.1388E-4
U238   2.3464E-3
MO92   2.5832E-4
MO94   1.6101E-4
MO95   2.7712E-4
MO96   2.9035E-4
MO97   1.6624E-4
MO98   4.2003E-4
MO100  1.6763E-4

PUNCTUAL 294 HEU_RING
12
U233   4.6484E-6
U234   4.7159E-4
U235   4.2930E-2
U236   3.1206E-4
U238   2.3398E-3
MO92   2.5350E-4
MO94   1.5801E-4
MO95   2.7195E-4
MO96   2.8493E-4
MO97   1.6313E-4
MO98   4.1219E-4
MO100  1.6450E-4

PUNCTUAL 294 HEU_CTRLRODS
12
U233   4.6812E-6
U234   4.7497E-4
U235   4.3238E-2
U236   3.1427E-4
U238   2.3514E-3
MO92   2.2831E-4
MO94   1.4231E-4
MO95   2.4493E-4
MO96   2.5662E-4
MO97   1.4693E-4
MO98   3.7124E-4
MO100  1.4816E-4

PUNCTUAL 294 HEU_BURSTROD
12
U233   4.7893E-6
```

```
      U234   4.8594E-4
      U235   4.4237E-2
      U236   3.2152E-4
      U238   2.4057E-3
      MO92   2.3300E-4
      MO94   1.4523E-4
      MO95   2.4996E-4
      MO96   2.6189E-4
      MO97   1.4994E-4
      MO98   3.7887E-4
      MO100  1.5120E-4

FIN_COMPOSITION

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             23 24 25 29 30
             31 32 36 37 38
             39 43 46 47 50
             51 52 53 68 69
             70 71 72 73 74
             75 76 77 78 79
             80 81 82 83 84
             85 86 87 88 89
             90 91 92 93 94
             95 96    98

      SS303 8
              1  9 10 11 55
             56 57 67

      SAE4340 4
             44 45 48 49

      VASCOMAX300 9
             58 59 60 61 62
             63 64 65 66

      ALU 1
             54

      HEU_SB 1
              8

      HEU_CTRLRODS 6
             26 27 28 33 34
             35

      HEU_BURSTROD 3
             40 41 42

      HEU_RING 8
             15 16 17 18 19
             20 21 22

      HEU_ISP 4
             4 5 6 7

FIN_GEOMCOMP
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	ANGULAR_DISTRIBUTION ISOTROPIC
	ENERGETIC_DISTRIBUTION SPECTRE WATT_SPECTRE
	TIME_DISTRIBUTION DIRAC 0.
	FIN_SOURCES
FIN_LIST_SOURCES

SIMULATION
	CRITICITE
	BATCH 550 DISCARD 50
	SIZE 10000
	PARTICLE 1 NEUTRON
	ENERGY_INF NEUTRON 1.E-11
	ENERGY_SUP NEUTRON 20.
	EDITION 100
FIN_SIMULATION
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APPENDIX B: DETAILED MODEL

B.1 Description of Detailed Models

The detailed MCNP models for the five configurations represent the core and restraint components in precise detail. The enclosures are present but are represented in less exact detail, because their actual structures are complex and preliminary sensitivity studies showed that they have little or negligible effect on k_{eff}.

With the following exceptions, the geometric features for the core and restraint components were modeled exactly as described in Sections 1.2.2 and 1.2.3:

(1) Some of the holes, most notably those for the thermocouples, were simplified to reduce the number of regions with different radii. In all such cases, the volume of the hole was preserved.

(2) reasonable assumptions were made about the size and shape of some bolts and nuts for which the actual dimensions were not known. For example, hexagonal heads of bolts were modeled as cylinders because the exact orientation of the heads was not known. In all such cases, however, the volume of the piece was preserved.

(3) The small shim ring was omitted from the detailed model, because the dimensions in the model are based on the drawings for the parts. Those drawings reflect the initial dimensions of the components and do not account for abrasion or oxidation. Consequently, the shim ring is not needed to preserve a tight fit between the inner subassembly plate and ring 5. Furthermore, as indicated in subsection 2.1, the shim ring was calculated to have negligible reactivity worth.

(4) The distance between the prongs of the clamps was taken to remain unchanged at 17.78 cm (7 inches), which means that either that the bearing ring and support pads must be compressed or a small amount of fuel must be displaced. Based upon guidance provided by a LACEF staff member,[a] it was assumed that the fuel was displaced. The displaced fuel was assumed to fill the spaces surrounding the support pads and bearing ring, and the excess was assumed to be deposited on the lower surface of the bottom fuel ring and on the upper surface of the top fuel ring.

---

[a] Personal communication from Charlene Cappiello of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, May 1, 2007.

(5) Components whose compositions were listed simply as "steel" were assumed to be made from stainless steel 303. In all likelihood, even if they were not made from stainless steel 303, they were made from a very closely related type of stainless steel.

The geometry of the support structure and the enclosures also were modeled in considerable detail, although not to the level of the core and restraints. With the exception of the contamination shield, the structure beneath the mounting plate was omitted. That structure is made of the same material as the mounting plate, and, as shown in Table 16, the mounting plate contributes only about 0.0025 Δk to k_{eff}. Those other pieces are much farther from the core than the mounting plate, and many of them are much smaller. Furthermore, any neutrons they might reflect back into the core first would have to pass through the contamination shield or the mounting plate and then be reflected back through them again.

Some of the finer details of the contamination shield and the core cover also were omitted or approximated. Preliminary calculations had shown that their contributions to k_{eff} are quite small, and therefore small details such as some of the screw holes were omitted. In addition, the mesh portion of the screen around the core cover was homogenized into a single thin layer since the details of the mesh size are not known. Sensitivity calculations clearly showed that k_{eff} is insensitive to the thickness and density of that layer, within the limits consistent with known information.

In addition, the long, thin aluminum tubes that support the safety block base, the control rods, and the burst rod are omitted. Although they are in direct contact with parts of the core, their areas of contact are very small, and they have relatively little mass. Furthermore, the very limited impact that the mounting plate has indicates that aluminum is not an effective reflector for neutrons in the energy range for this type of configuration. Clearly, their omission does not affect k_{eff}.

Similarly, the aluminum-ion coating on the fuel pieces was ignored because it clearly is inconsequential. Although its actual thickness isn't known, it is very, very thin (a few atomic distances), and aluminum is essentially transparent to neutrons at these energies. For example, more than 60% of all neutrons escape from the Godiva-IV assembly, and most of them pass through the aluminum core cover. The core cover is 0.165 cm thick, which is tens to hundreds of times thicker than the aluminum-ion coating. Even so, as reported in Table 16, the core cover has at most only marginal reactivity worth. The reactivity worth of the aluminum-ion coating clearly would be much smaller.

Finally, the detailed model ignores the effects of room return. As was discussed in subsection 1.2, the Godiva-IV assembly was quite some distance from the walls, floor, and ceiling of the building. Furthermore, as shown in Table 16, the mounting plate and the enclosures produce relatively little neutron reflection even though they are only a short distance from the core. Consequently, it is clear that room return can be ignored.

B.2 Dimensions

The origin of the coordinate system employed for the detailed model of Godiva-IV is at the center of the bottom surface of the intermediate inner subassembly plate. The vertical line passing through that point defines the center of the fuel rings, safety block, upper inner subassembly plate, and spindle.

Two conventions will be followed for many of the diagrams that follow. First, lines represented by alternating dots (·) and vertical (|) or horizontal (—) lines indicate center lines, either for the coordinate system or for the item shown in that figure. Second, vertical distances above or below the origin will be given in cm on the right side of the figures where they appear.

B.2.1 Core - A vertical slice through the center of the benchmark configuration is shown in Figure B-1, and the corresponding close-up of the core is shown in Figure B-2. In both figures, the fully inserted burst rod can be seen on the left side of the core. A similar slice through the core that displays the partially inserted control rods is presented in Figure B-3. Materials with the same composition are shown in the same color (e.g., the safety block base, the spindle, the clamp support, the belly band, and several nuts and bolts all are made from stainless steel 303).

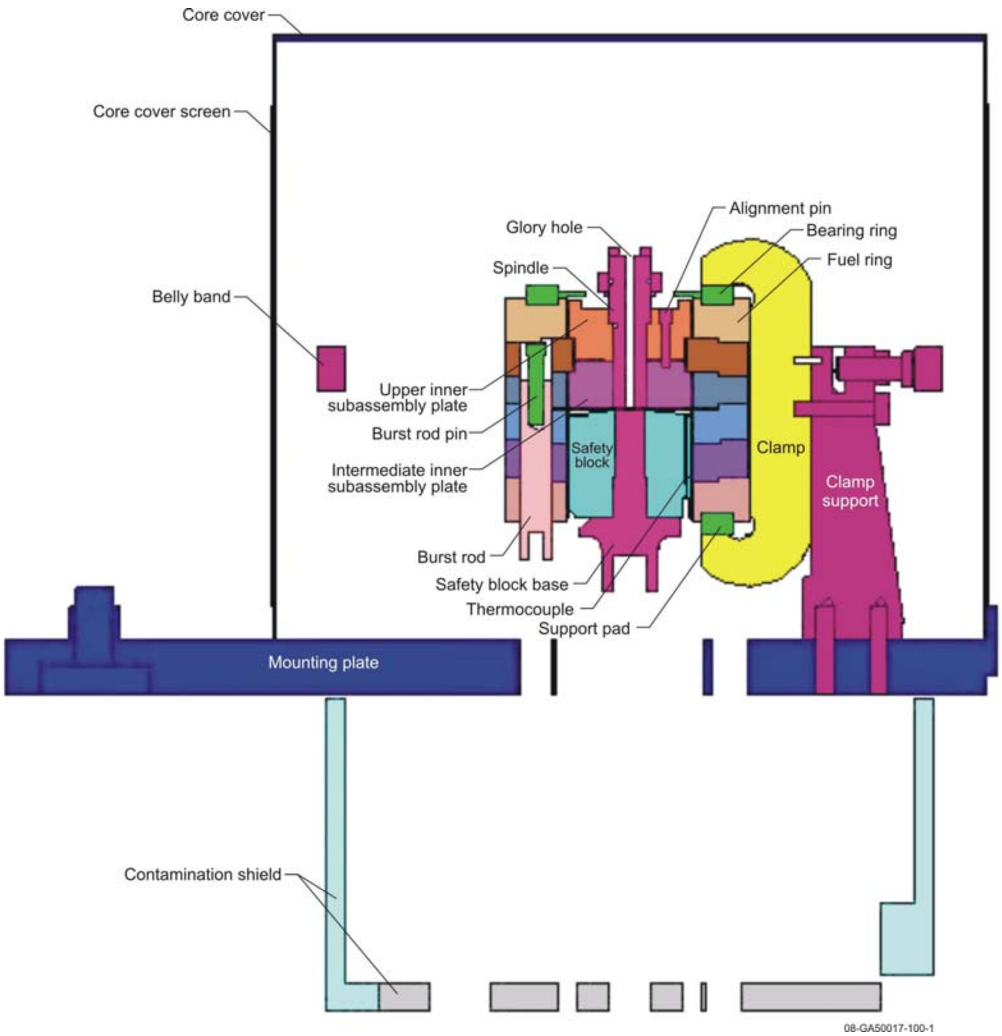

Figure B-1. Vertical Slice through the Center of the Detailed Model for Case 2.

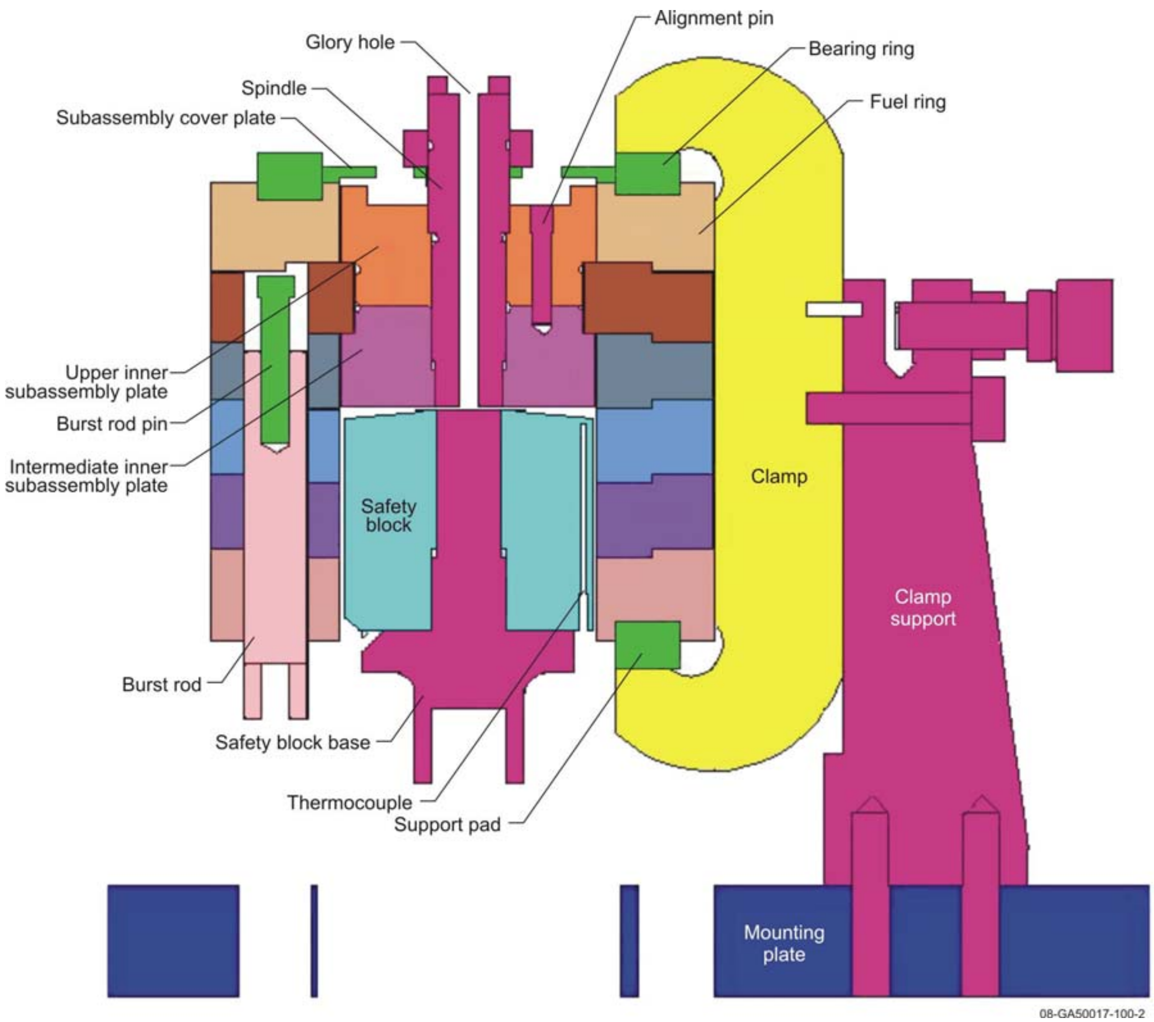

Figure B-2. Vertical Slice through the Center of the Core of the Detailed Model for Case 2.

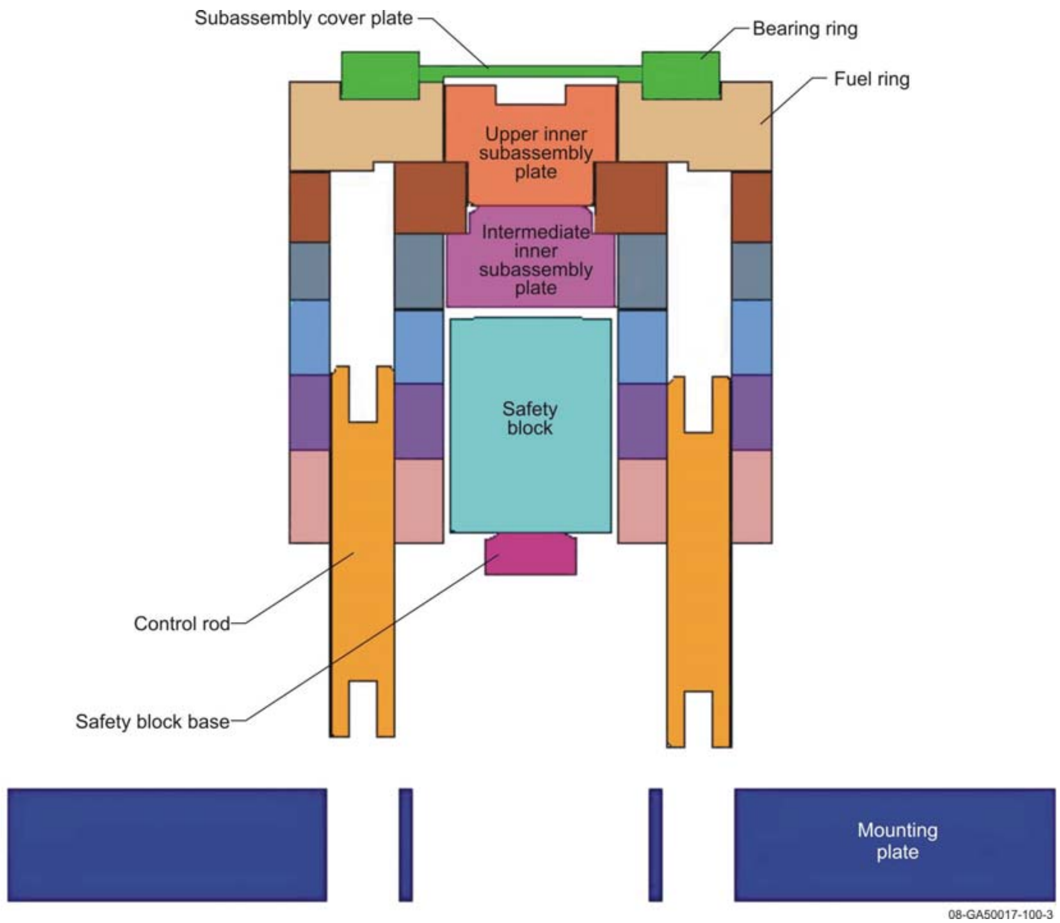

Figure B-3. Off-Center Vertical Slice through the Core of the Detailed Model for Case 2.

Two horizontal slices through the assembly are shown in Figures B-4 and B-5. The core cover appears in both figures, and the belly band and its associated hardware are shown in Figure B-5.

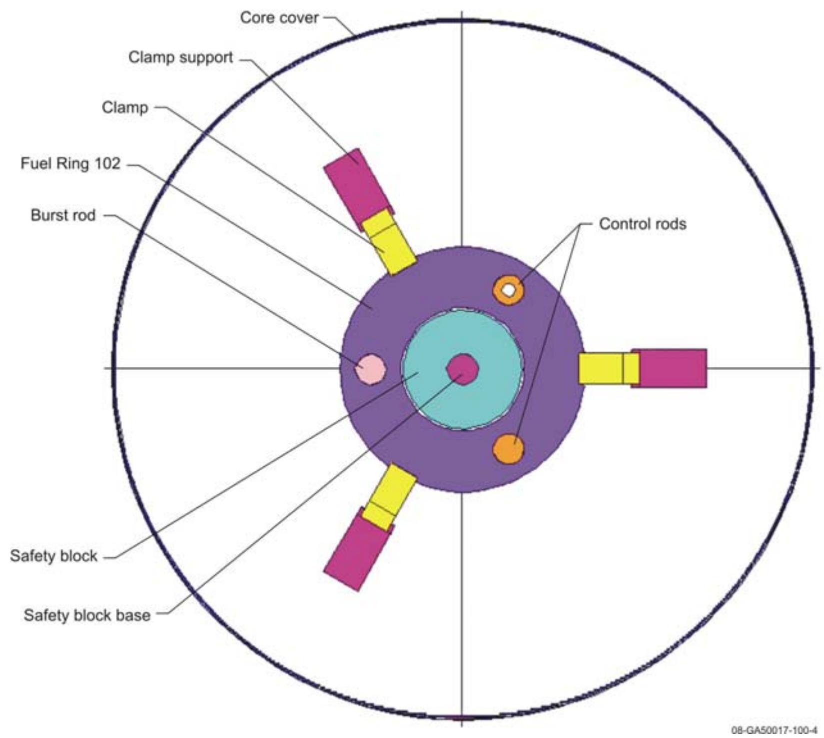

Figure B-4. Horizontal Slice through the Core and Core Cover of the Detailed Model for Case 2.

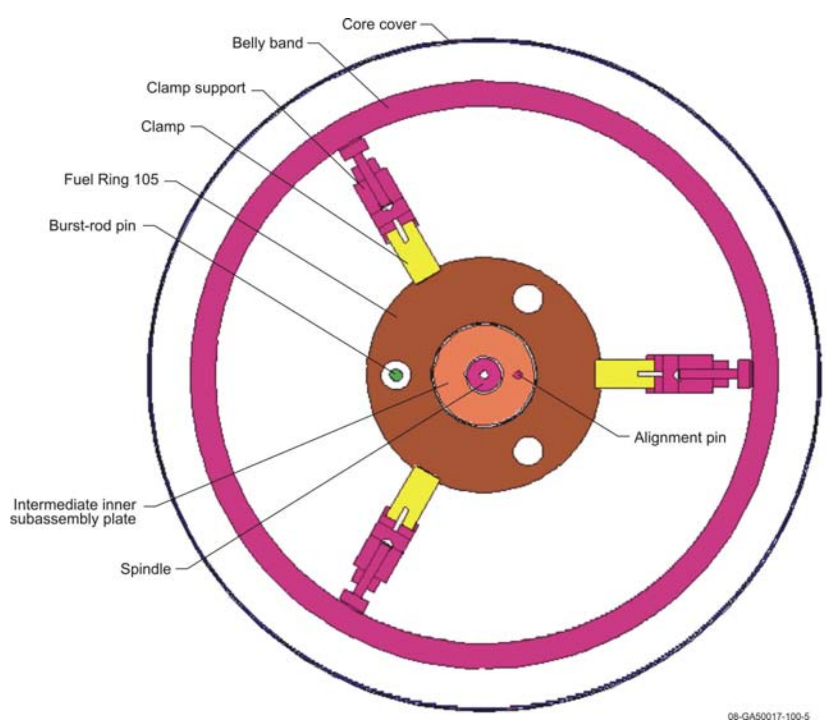

Figure B-5. Horizontal Slice through the Core, Belly Band, and Core Cover of the Detailed Model for Case 2.

The origin for the detailed models is taken to be at the center of the bottom surface of the inner subassembly plate. (Strictly speaking, it is at the center of the central void region inside that surface.) Relative to that origin, the top and bottom vertical locations of the fuel pieces with fixed positions are given in Table B-1, and the top and bottom locations for the control rods and burst rod are given for each case in Table B-2. The overlaps among the fuel rings in Table B-1 is due to the interlocking protrusions and depressions in their surfaces that kept them aligned after they were stacked.

Table B-1. Vertical Locations of Fixed Fuel Pieces.

Component	Bottom (cm)	Top (cm)
Upper Inner Subassembly Plate	3.49250	7.64794
Intermediate Inner Subassembly Plate	0	3.49250
Safety Block	-7.74700	-0.12700
Fuel Ring 106	4.67360	7.73264
Fuel Ring 105	2.21742	4.96750
Fuel Ring 104	-0.05588	2.50952
Fuel Ring 103	-2.62128	0.23622
Fuel Ring 102	-5.18668	-2.32918
Fuel Ring 101	-8.06553	-4.89458

Table B-2. Vertical Positions of Control Rods and Burst Rod.

	Control Rod 1		Control Rod 2		Burst Rod	
Case	Bottom (cm)	Top (cm)	Bottom (cm)	Top (cm)	Bottom (cm)	Top (cm)
1	-19.84121	-7.14121	-12.02055	0.67945	-10.79627	1.90373
2	-14.75359	-2.05359	-15.11173	-2.41173	-10.79627	1.90373
3	-10.93089	1.76911	-20.51685	-7.81685	-10.79627	1.90373
4	-10.86993	1.83007	-10.81405	1.88595	-18.34007	-5.64007
5	-10.48893	2.21107	-12.54633	0.15367	-10.79627	1.90373

The top and bottom vertical locations of the non-fuel pieces with fixed positions are given in Table B-3, and the top and bottom locations for the pin in the burst rod are given for each case in Table B-4.

Table B-3. Vertical Locations of Non-Fuel Pieces.

Component	Bottom (cm)	Top (cm)
Spindle	0.00254	11.43254
Nut on Spindle	8.27278	9.54278
Bearing Ring	7.27160	8.75411
Subassembly Cover Plate	7.73264	8.27278
Alignment Pin	2.619375	6.98754
Safety Block Base	-11.85559	-0.12700
Support Pads	-9.02589	-7.83527
Belly Band	1.21285	4.38785
Clamps	-12.67587	12.40409
Clamp Supports	-16.56715	4.38785
Anchor Bolts for Clamp Supports	-20.37715	-13.39215
Mounting Plate	-20.37715	-16.56715
Core Cover	-16.56715	26.61285
Core Cover Screen	-14.02715	21.53285
Core Cover T-Plates	-19.10715	-14.02715
Contamination Shield (Plastic)	-42.92965	-20.69465
Contamination Shield (Steel)	-42.92965	-41.02465

Table B-4. Vertical Positions of Burst-Rod Pin.

Case	Burst Rod	
	Bottom (cm)	Top (cm)
1	-1.27127	4.51231
2	-1.27127	4.51231
3	-1.27127	4.51231
4	-8.81507	-3.03149
5	-1.27127	4.51231

Dimensions of Fuel Pieces - Detailed diagrams of the upper and intermediate inner subassembly plate are shown in Figures B-6 and B-7. As noted previously, for these and many subsequent figures, lines represented by alternating dots (·) and vertical (|) or horizontal (—) segments indicate center lines, either for the coordinate system or for the item shown in that figure. In addition, vertical distances above or below the origin are given in cm on the right side of the figures where they appear.

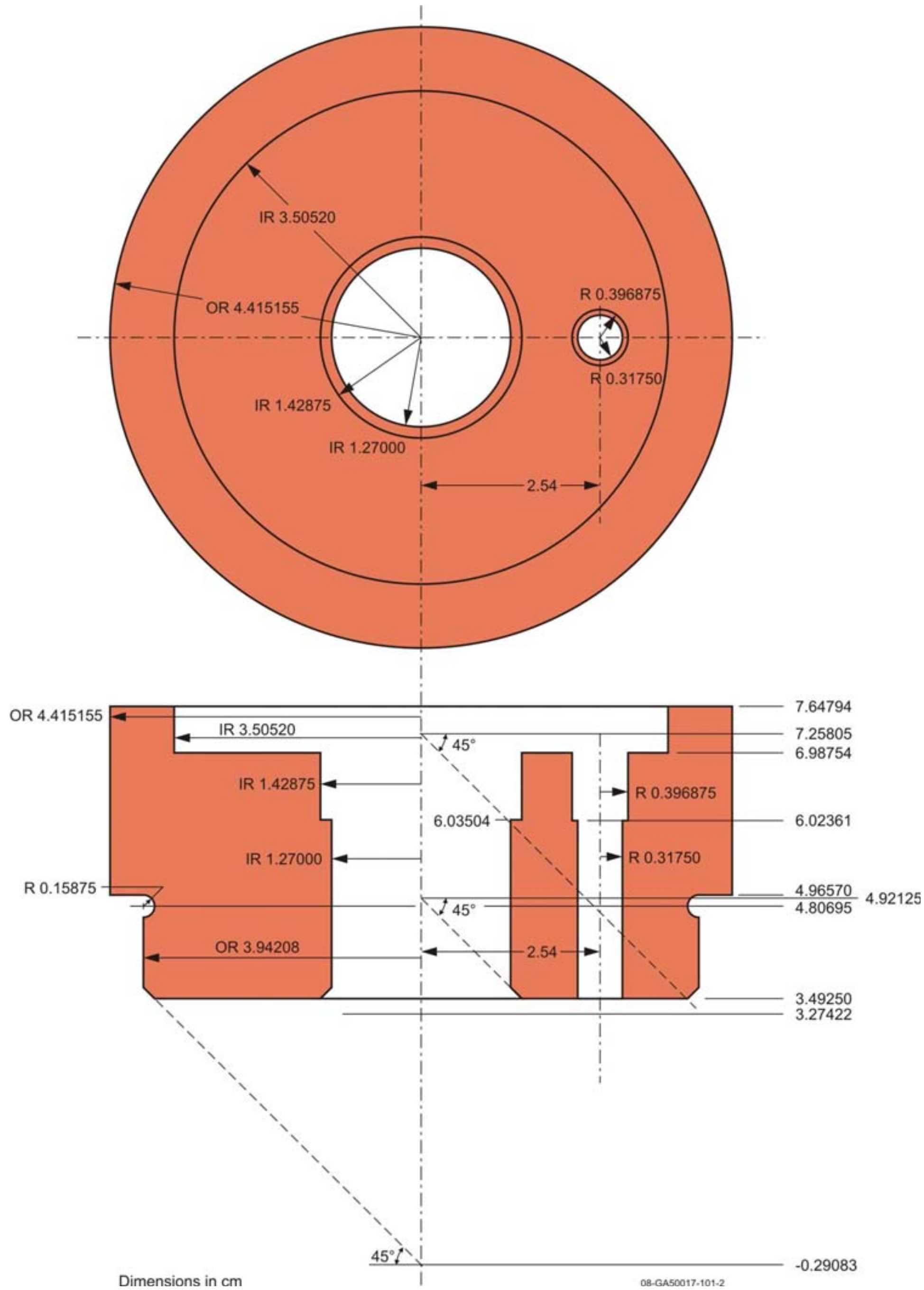

Figure B-6. Upper Inner Subassembly Plate.

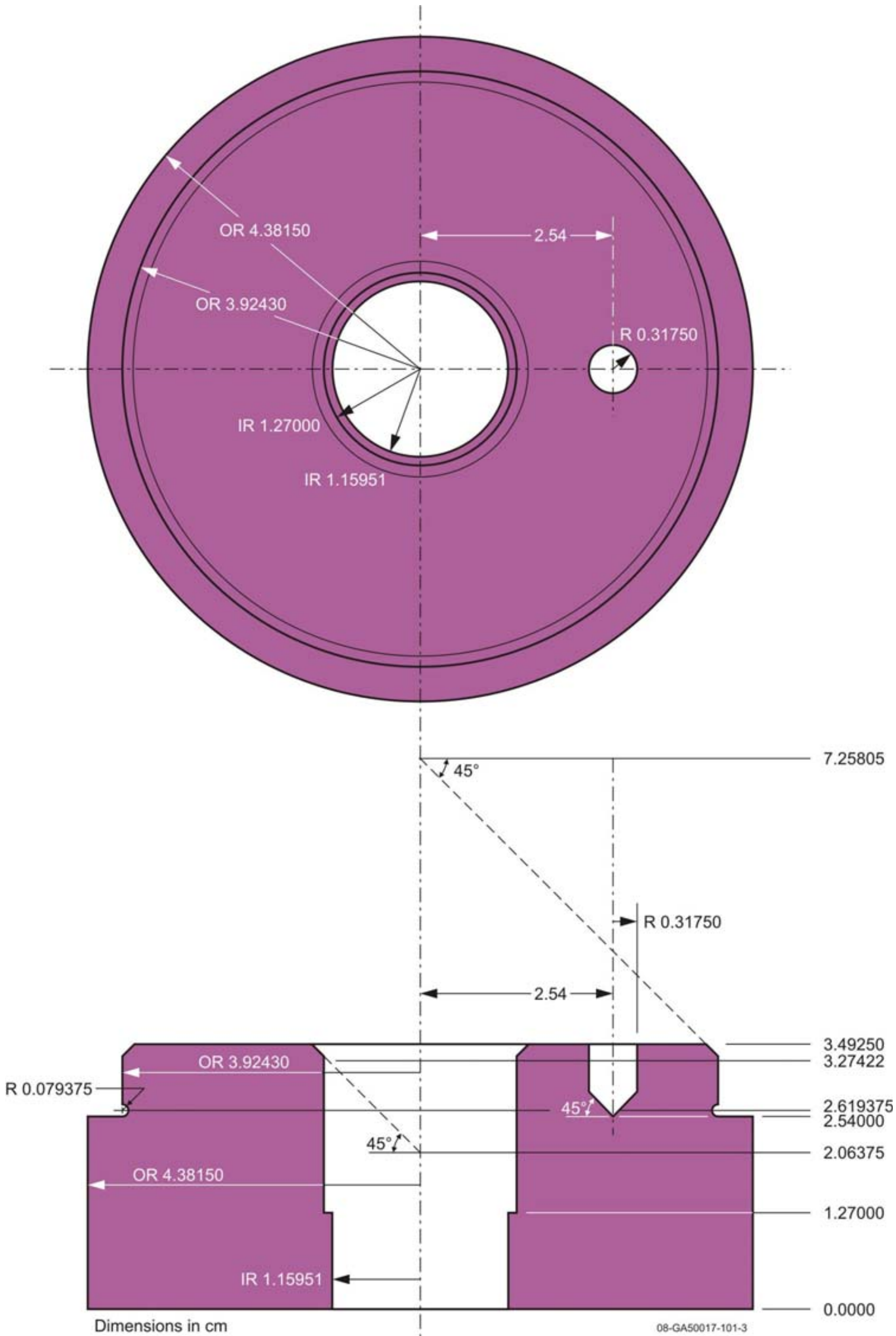

Figure B-7. Intermediate Inner Subassembly Plate.

A detailed diagram of the safety block is shown in Figure B-8. The horizontal view is from the bottom of the safety block.

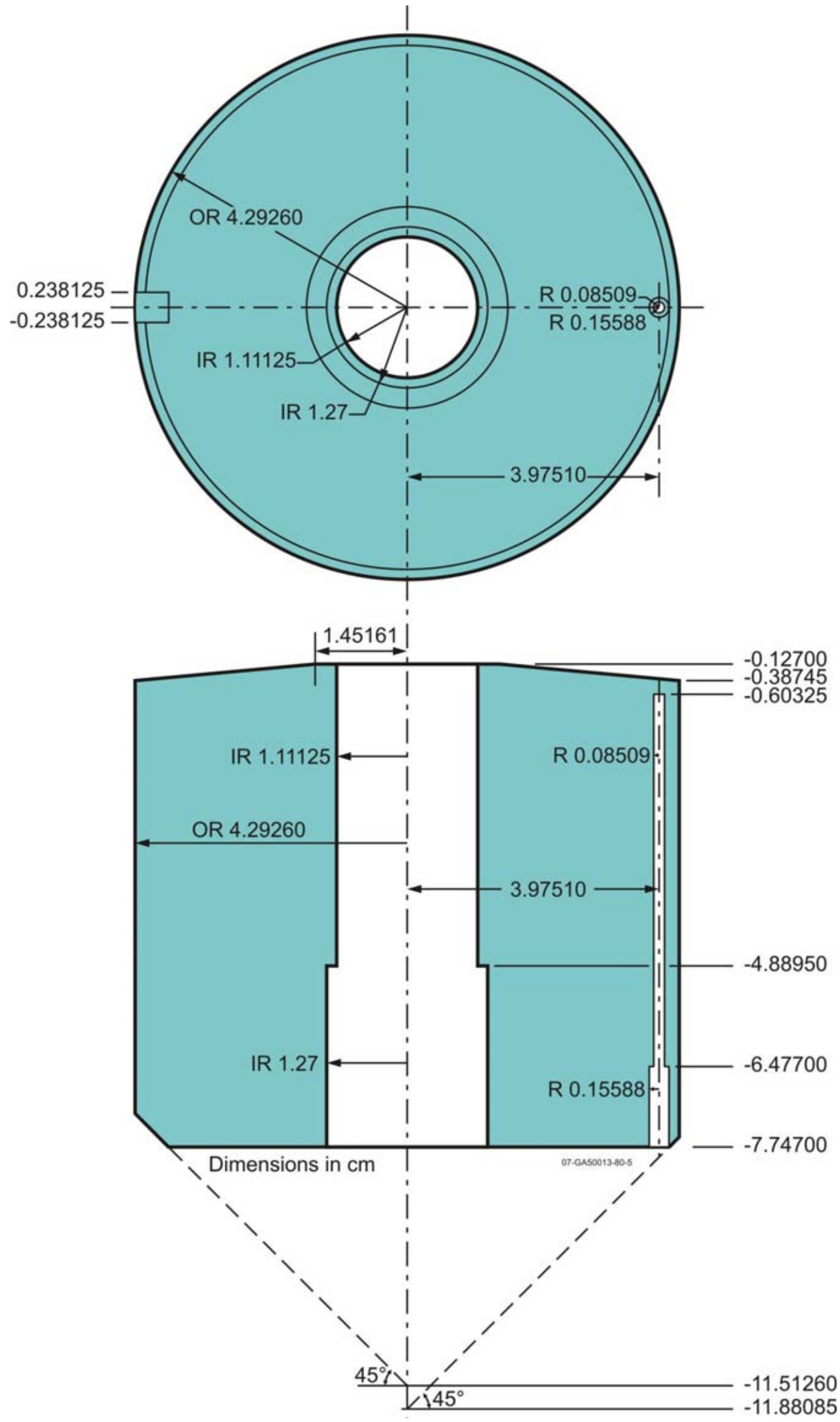

Figure B-8. Safety Block.

Diagrams of fuel rings 101 through 106 are presented in Figures B-9 through B-14, respectively.

The notches for rings 103, 104, and 105 are the same as those for ring 102, while the notches for ring 106 are the same as those for ring 101.

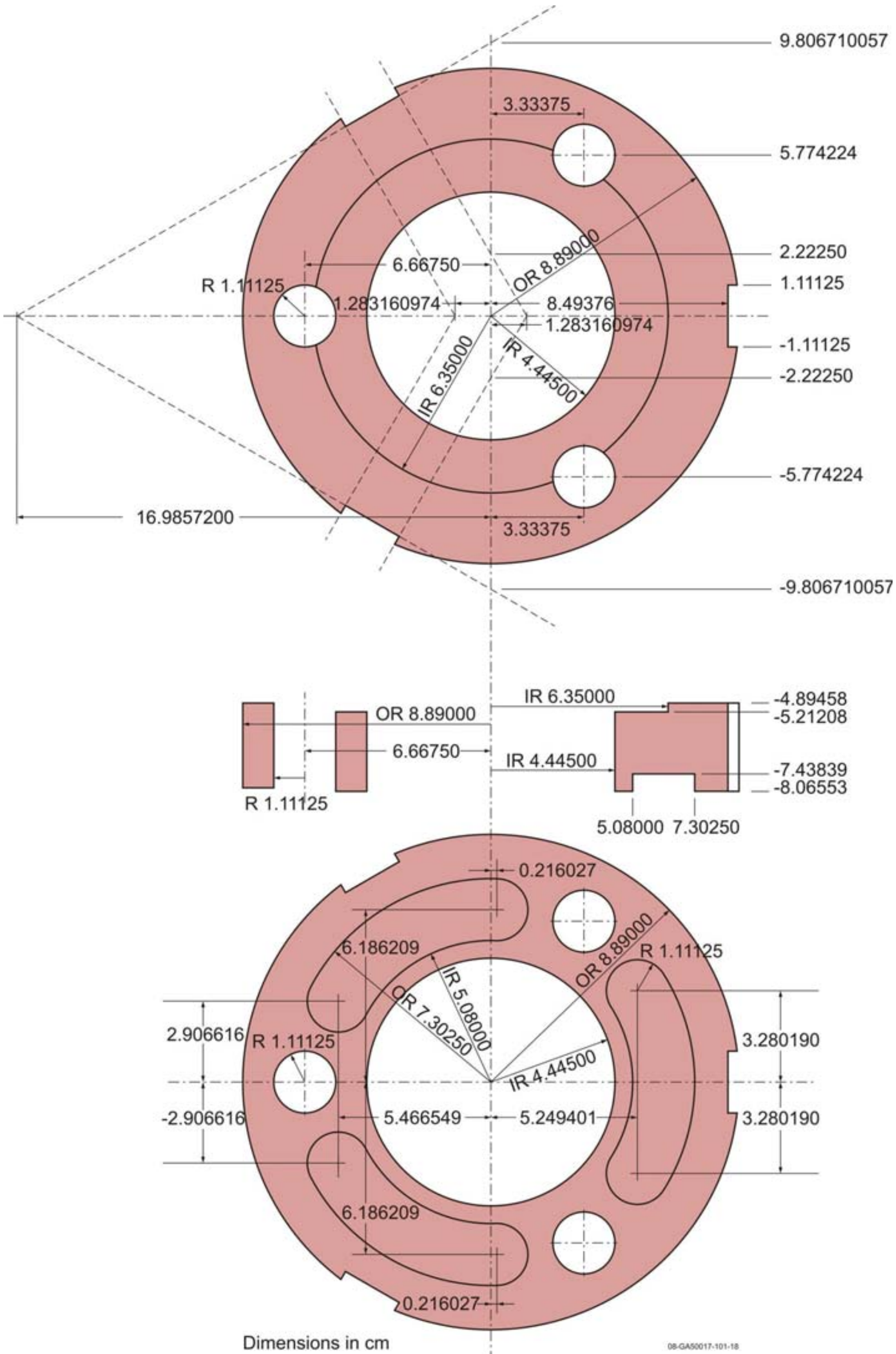

Figure B-9. Fuel Ring 101.

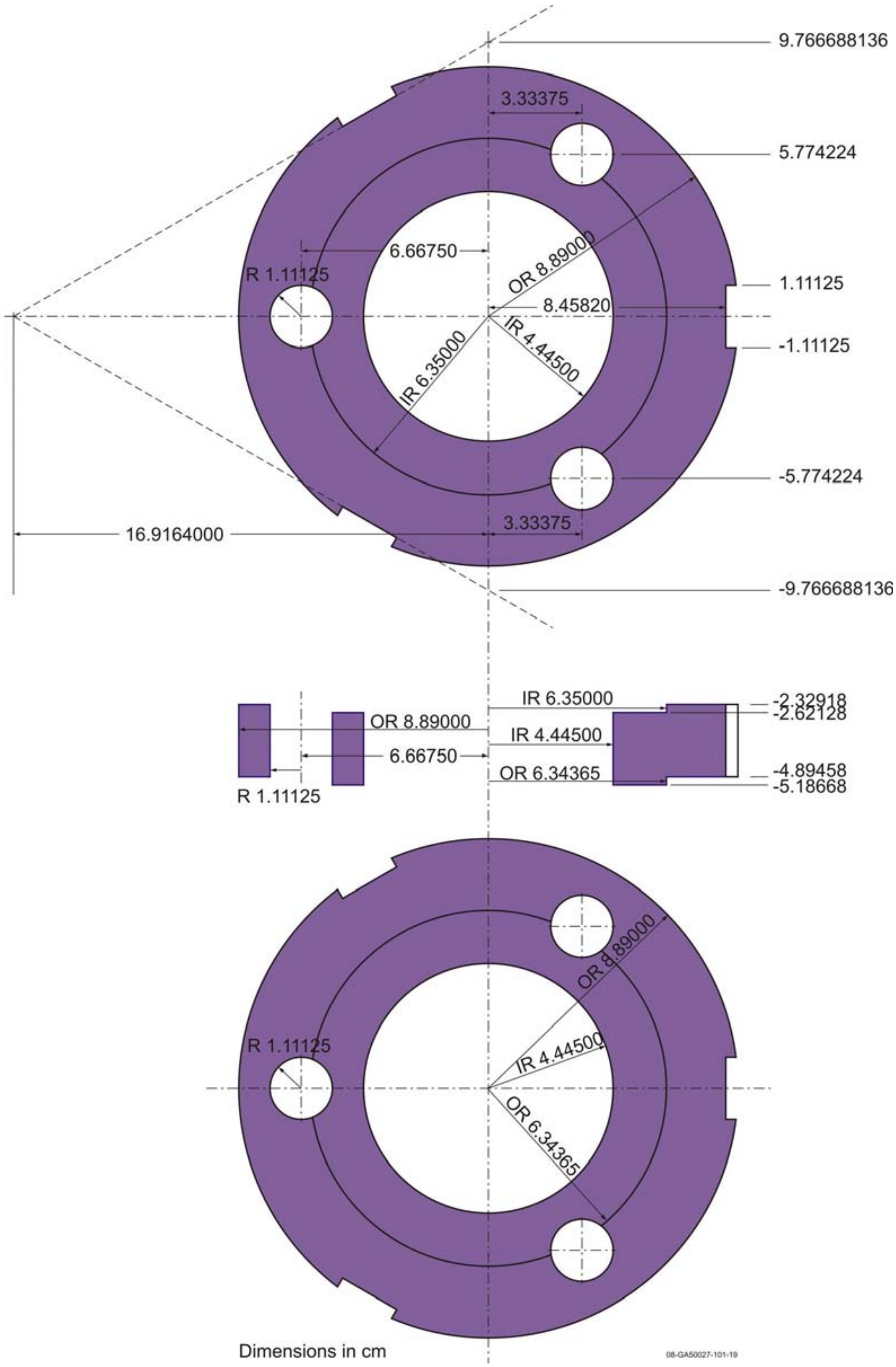

Figure B-10. Fuel Ring 102.

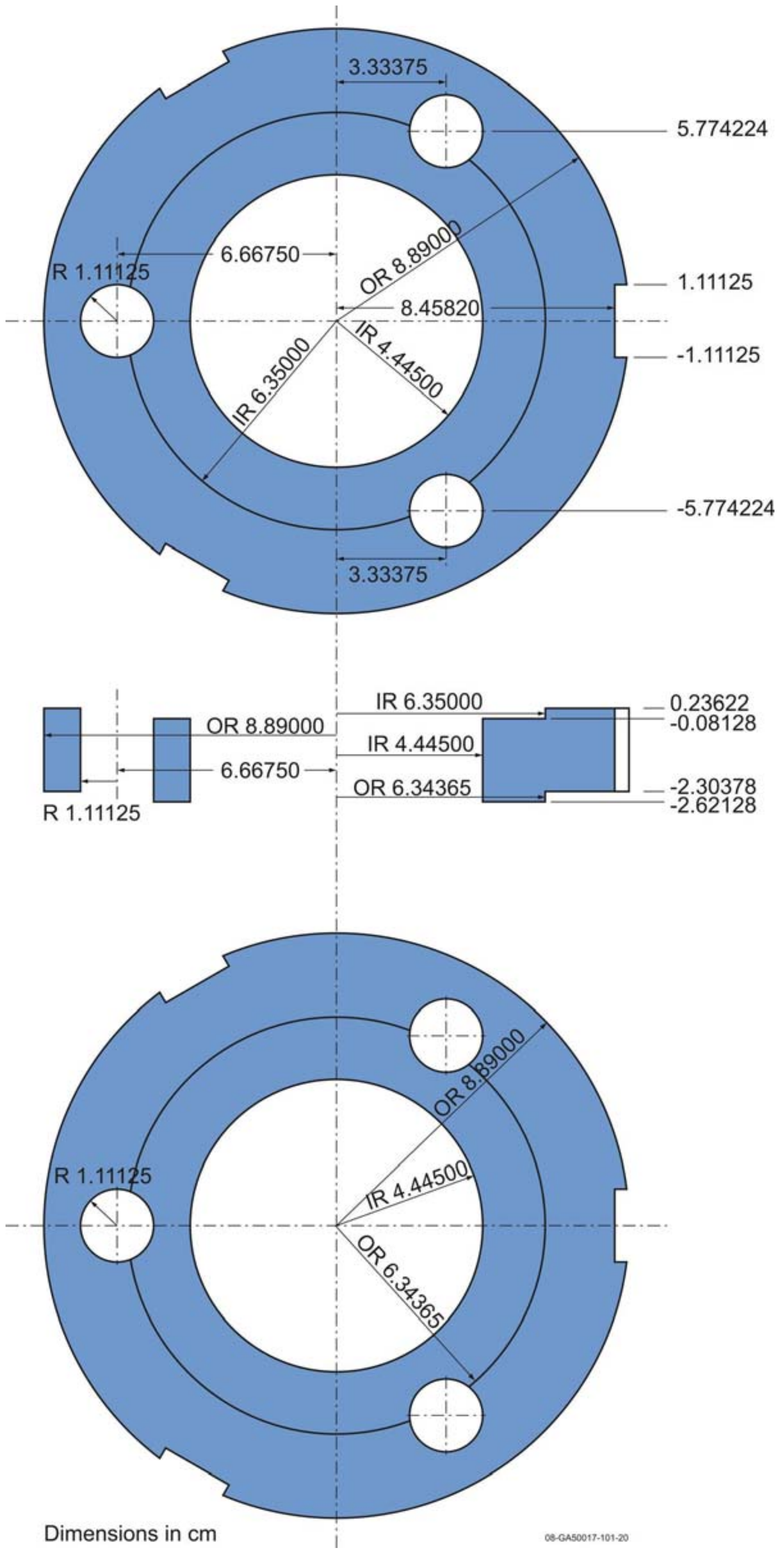

Figure B-11. Fuel Ring 103.

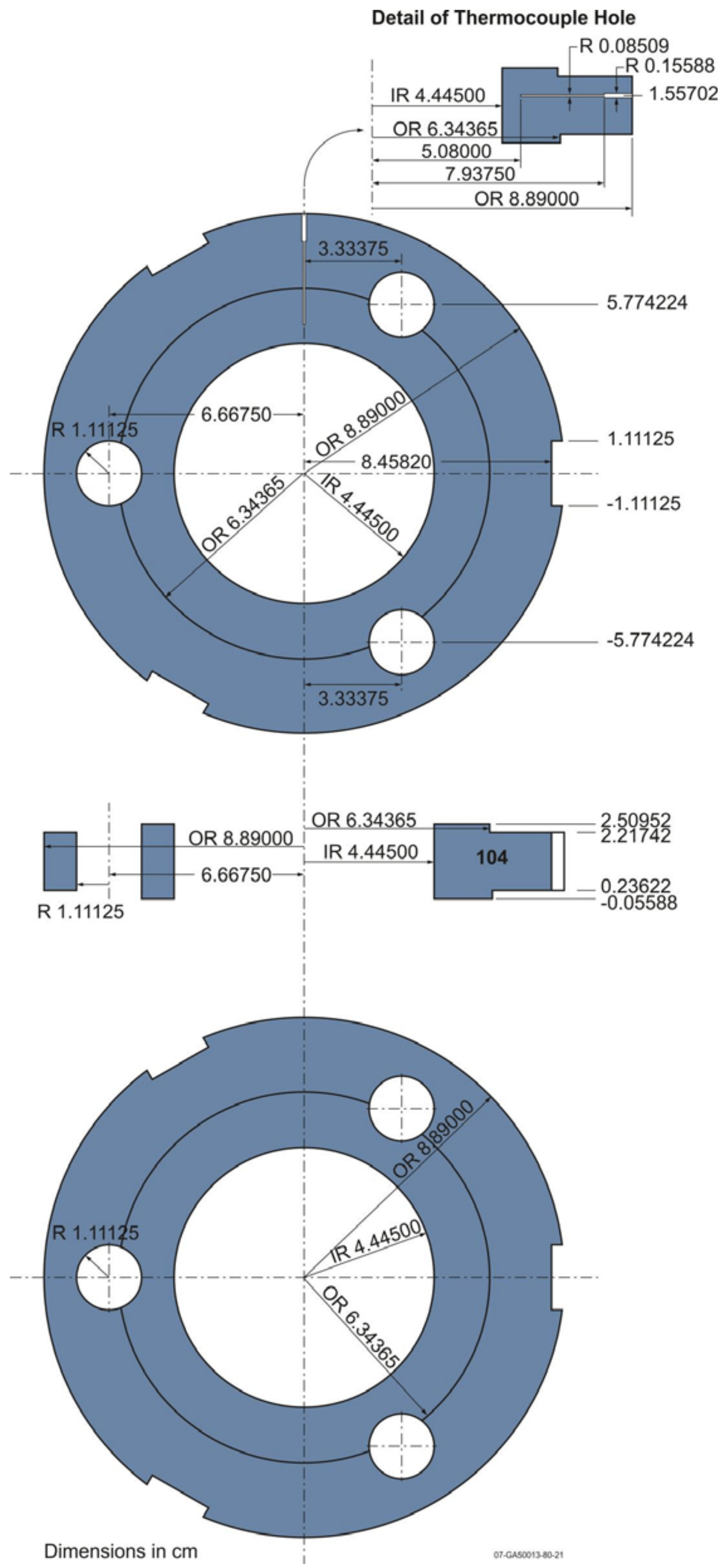

Figure B-12. Fuel Ring 104.

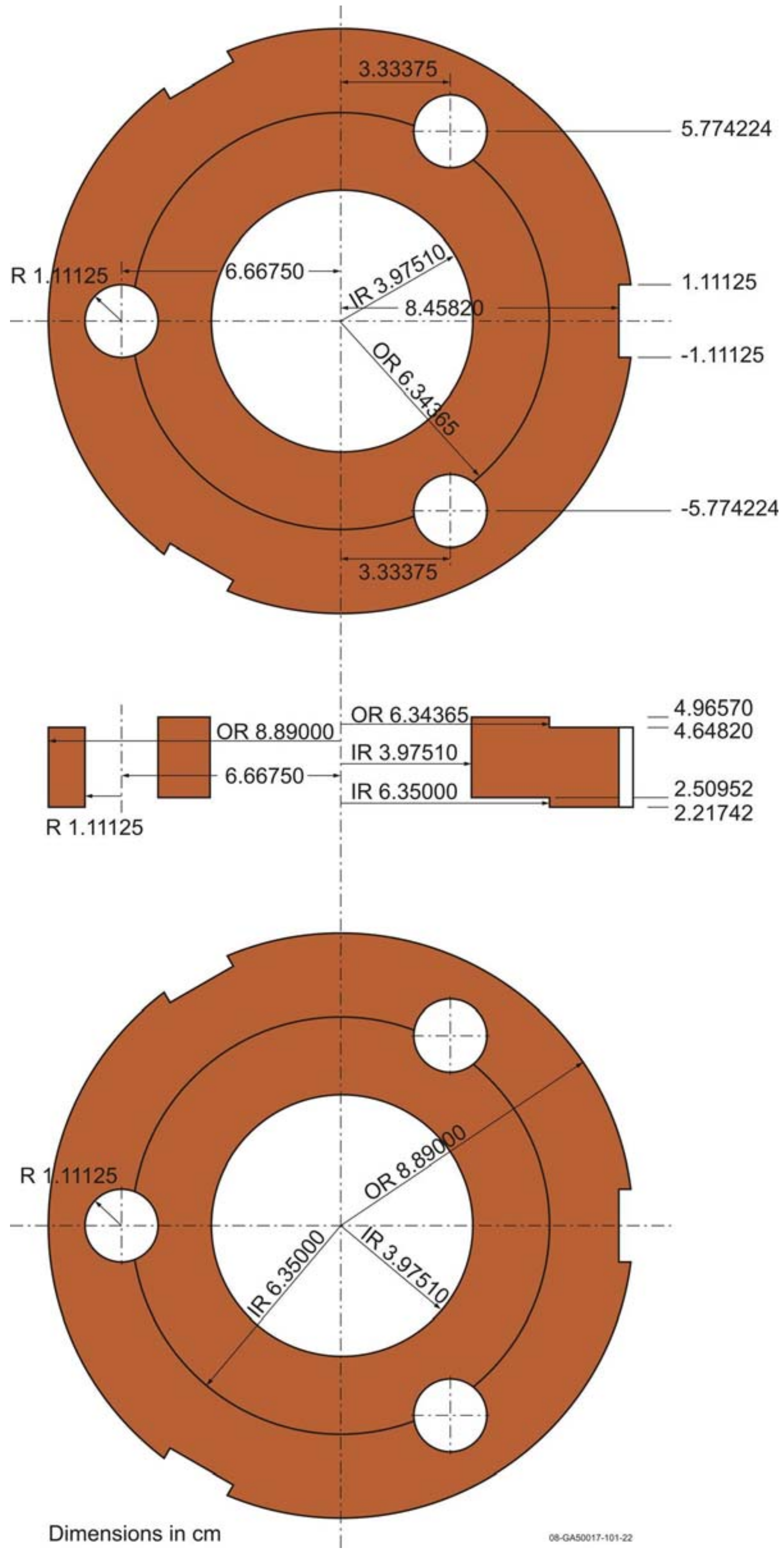

Figure B-13. Fuel Ring 105.

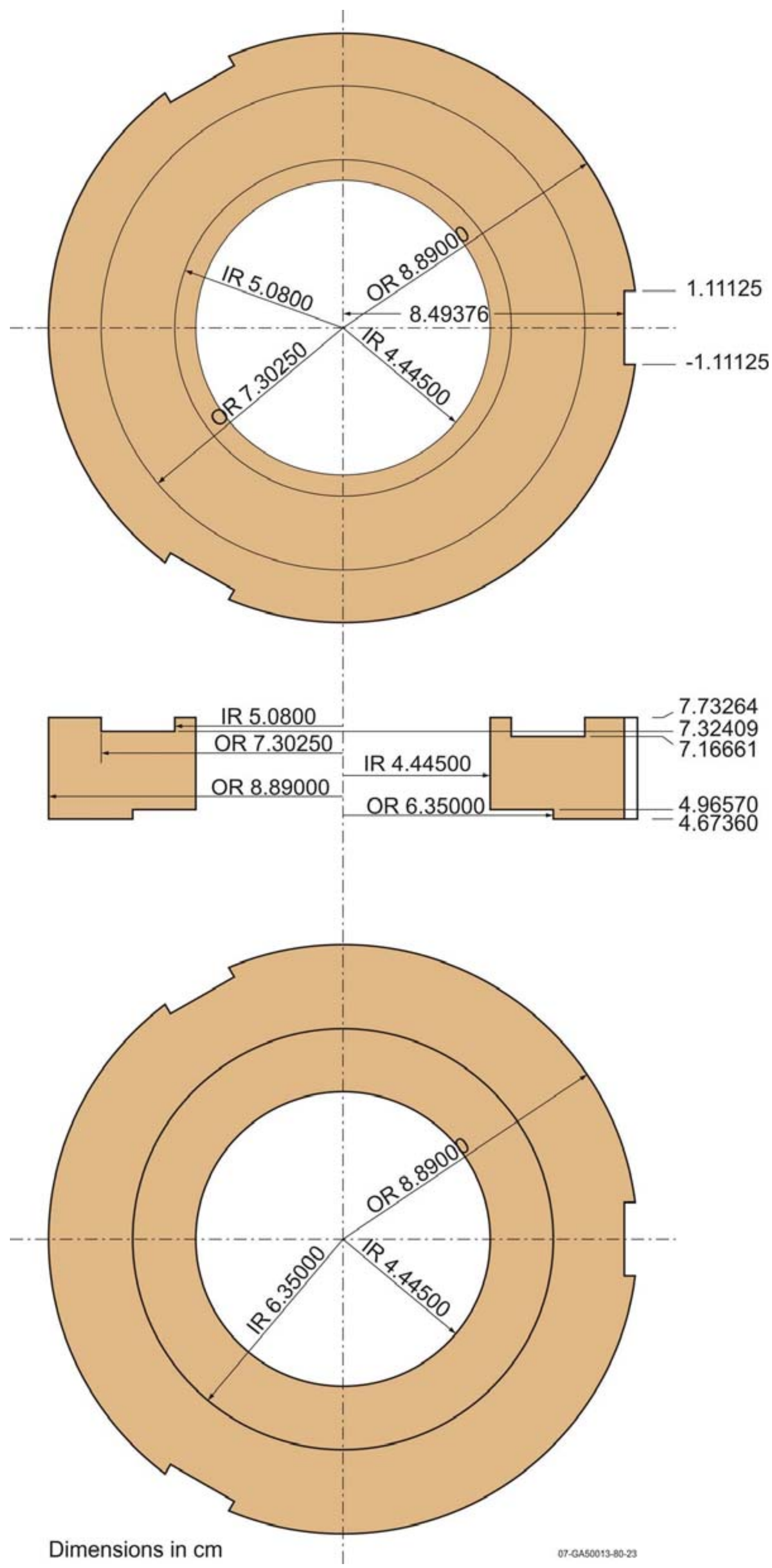

Figure B-14. Fuel Ring 106.

The locations of the control rods and the burst rod along with their radial dimensions are shown in Figure B-15. Detailed diagrams of the control rods and the burst rod are shown in Figures B-16 and B-17, respectively. The latter figure also provides the dimensions of the burst-rod pin. The notches in the control rods are shown in Figures B-15 and B-16. The numbers to the right in Figure B-17 are again the axial locations for the fully inserted burst rod relative to the origin of the coordinate system.

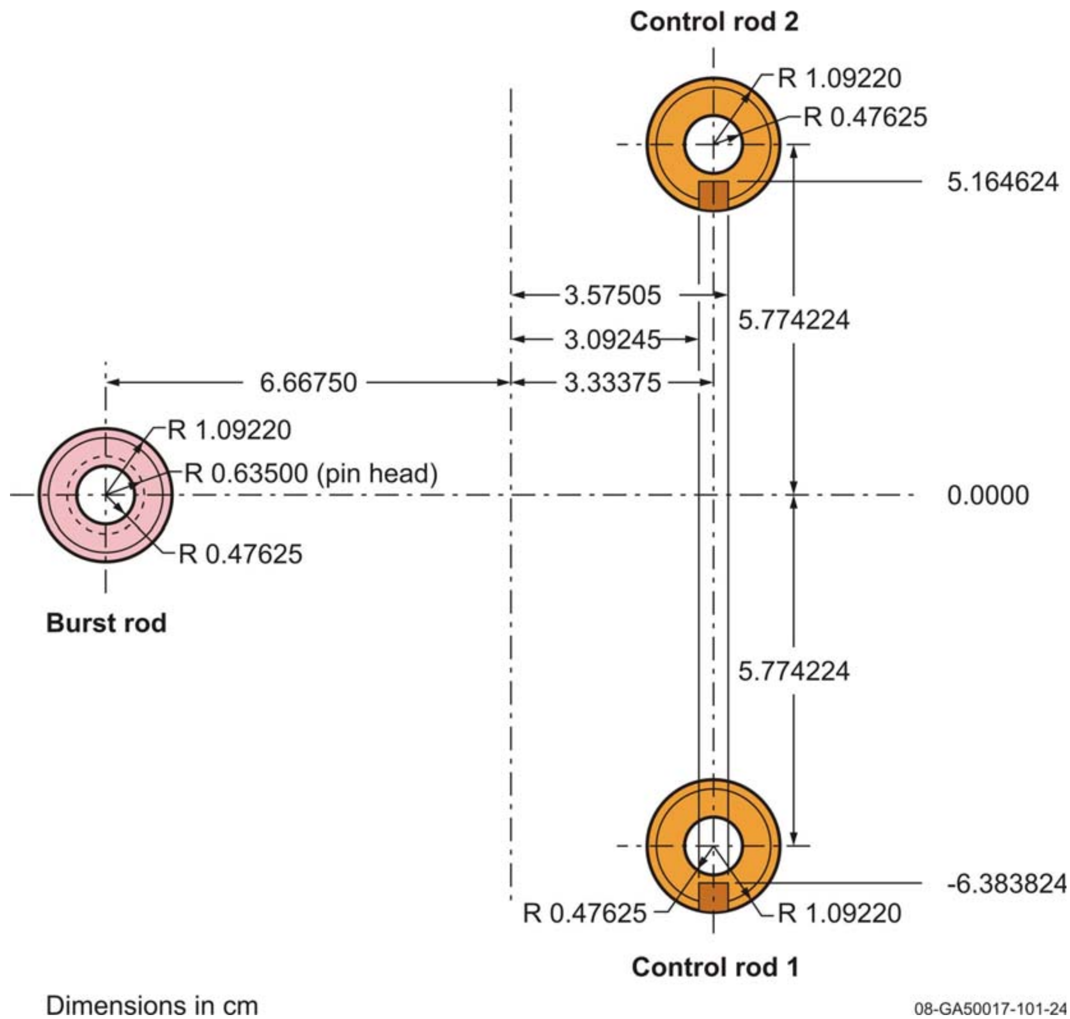

Figure B-15. Locations and Radial Dimensions of the Burst Rod and Control Rods.

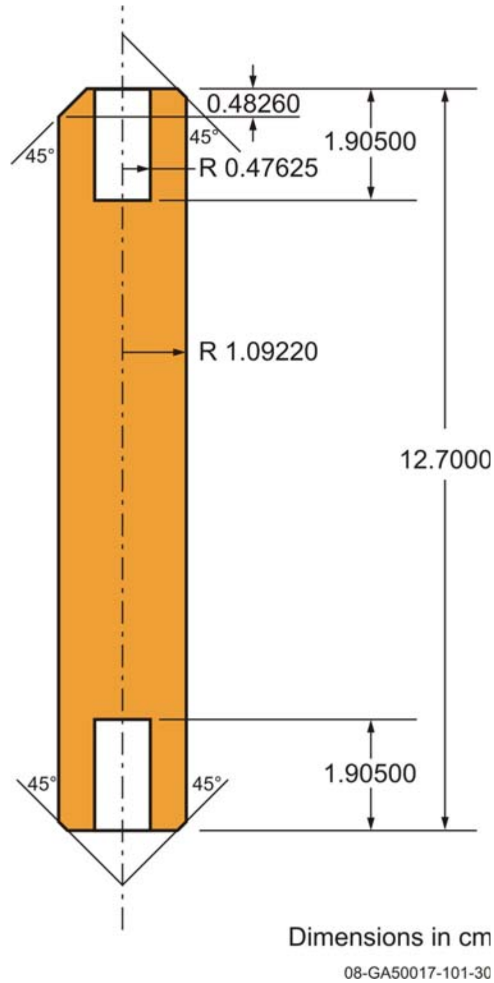

Figure B-16. Vertical Slice through the Center of a Control Rod.

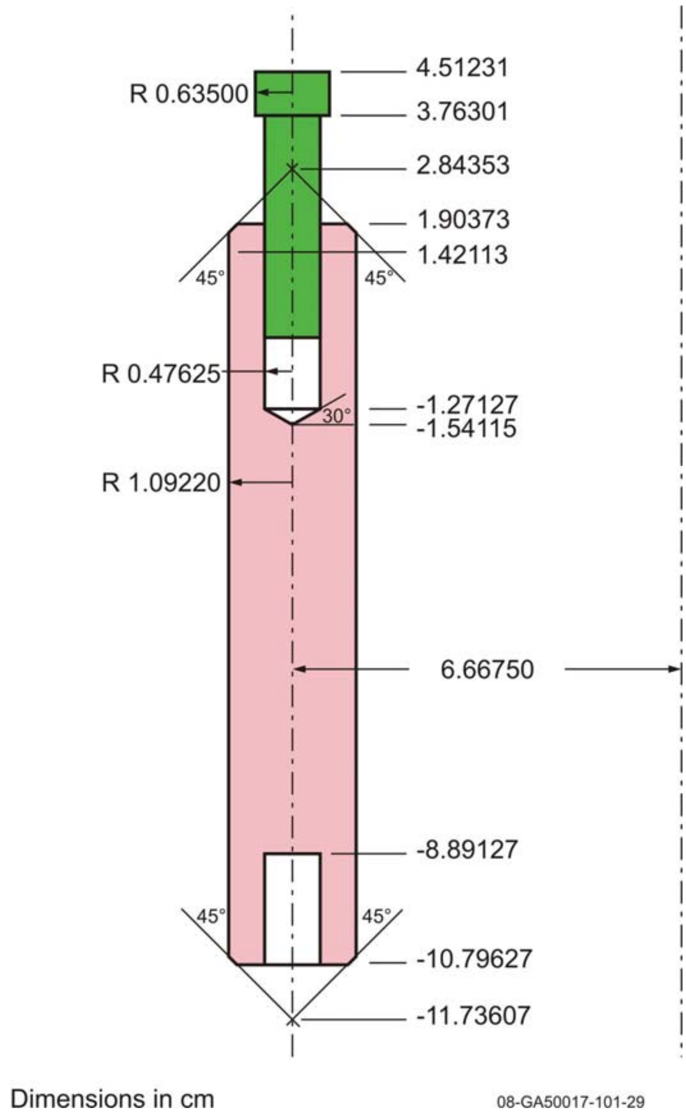

Figure B-17. Vertical Slice through the Center of the Fully Inserted Burst Rod and Burst-Rod Pin.

The radii and associated length of each region of each of the fuel rings are given in Table B-5. All of the rings have notches (see Figures B-9 through B-14), and rings 101 through 105 have interior holes for the passage of the control and burst rods (see Figures B-9 through B-13). The bottom region of ring 101 also has interior depressions for the support pads (see Figure B-9), and the top region of ring 106 has an annular interior depression for the bearing ring (see Figure B-14). In addition, ring 104 has a horizontal hole to allow a thermocouple to be inserted (see Figure B-12).

Table B-5. Basic Dimensions of Fuel Rings.

Fuel Ring	Region	Inner Radius (cm)	Outer Radius (cm)	Length (cm)
106	Top Depression	4.44500 6.35000	8.89000 8.89000	2.67208 0.29210
105	Protrusion Middle Depression	3.97510 3.97510 6.35000	6.34365 8.89000 8.89000	0.31750 2.10820 0.31750
104	Protrusion Middle Protrusion	4.44500 4.44500 4.44500	6.34365 8.89000 6.34365	0.29210 1.98120 0.29210
103	Depression Middle Protrusion	6.35000 4.44500 4.44500	8.89000 8.89000 6.34365	0.31750 2.22250 0.31750
102	Depression Middle Protrusion	6.35000 4.44500 4.44500	8.89000 8.89000 6.34365	0.29210 2.27330 0.29210
101	Depression Bottom	6.35000 4.44500	8.89000 8.89000	0.31750 2.54000

The basic inner and outer radii of the other fuel parts are given in Table B-6, along with their associated lengths. These basic radii do not account for the presence of chamfers, cut-outs, or slopes. The dimensions for those geometric features are shown in Figures B-6, B-7, and B-15.

Table B-6. Basic Dimensions of Other Fuel Pieces.

Component	Inner Radius (cm)	Outer Radius (cm)	Length (cm)
Upper Inner Subassembly Plate			
Top Region	3.50520	4.415155	0.66040
Upper Middle Region	1.42875	4.415155	0.95259
Lower Middle Region	1.27000	4.415155	0.95250
Bottom Region	1.27000	3.94208	1.46420
Intermediate Inner Subassembly Plate			
Top Region	1.27000	3.94208	0.95250
Middle Region	1.27000	4.38150	1.27000
Bottom Region	1.15951	4.38150	1.27000
Safety Block			
Top Region	1.11125	4.29260	4.76250
Bottom Region	1.27000	4.29260	2.85750
Control Rods			
Top Region (with Hole)	0.47625	1.09220	1.90500
Middle Region	—	1.09220	8.89000
Bottom Region (with Hole)	0.47625	1.09220	1.90500
Burst Rod			
Top Region (with Hole and Tip)	0.47625	1.09220	3.44488
Middle Region	—	1.09220	7.35012
Bottom Region	0.47625	1.09220	1.90500

Non-Fuel Core Pieces - Portions of the spindle and the safety block base are enclosed by fuel, as is all of the long alignment pin. A diagram of the spindle is shown in Figure B-18, and a diagram of the spindle nut is shown in Figure B-19. Diagrams of the long alignment pin and the safety block base are presented in Figures 20 and 21, respectively.

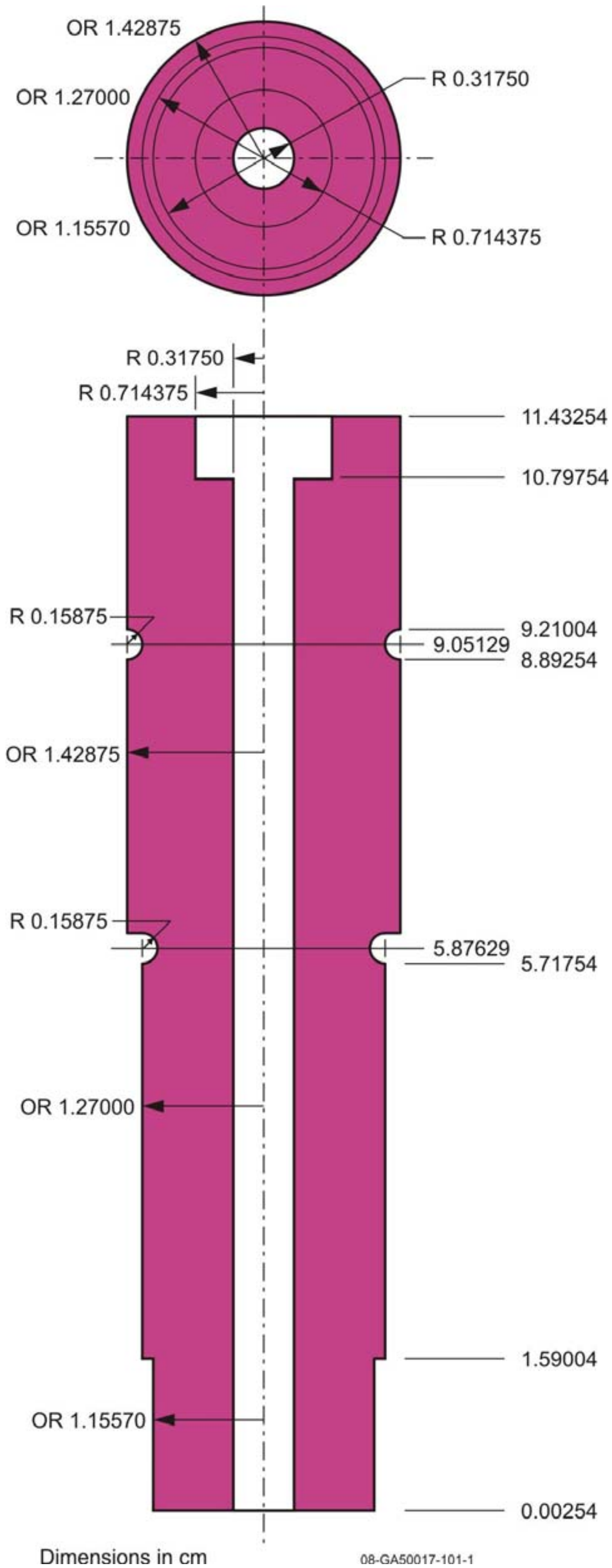

Figure B-18. Spindle.

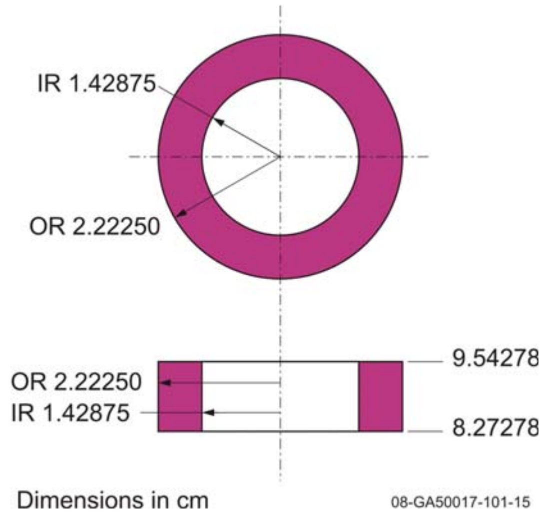

Figure B-19. Spindle Nut.

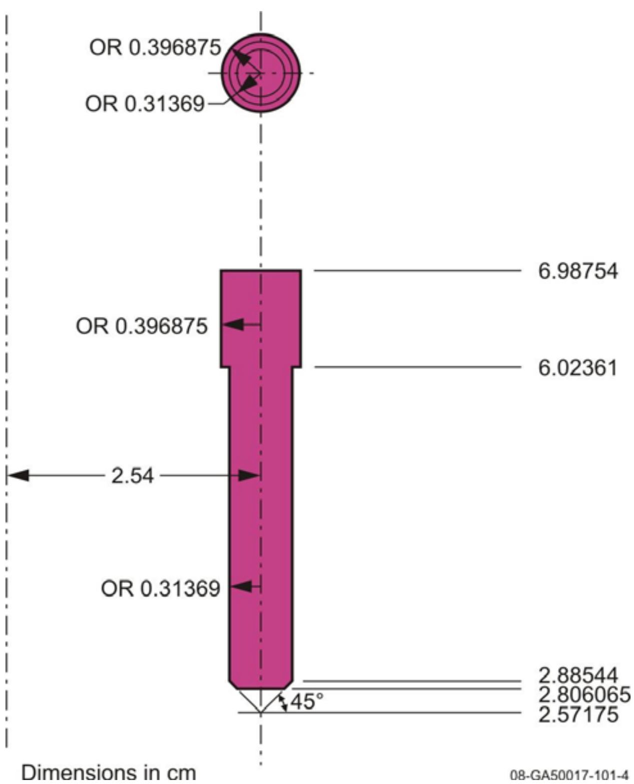

Figure B-20. Long Alignment Pin.

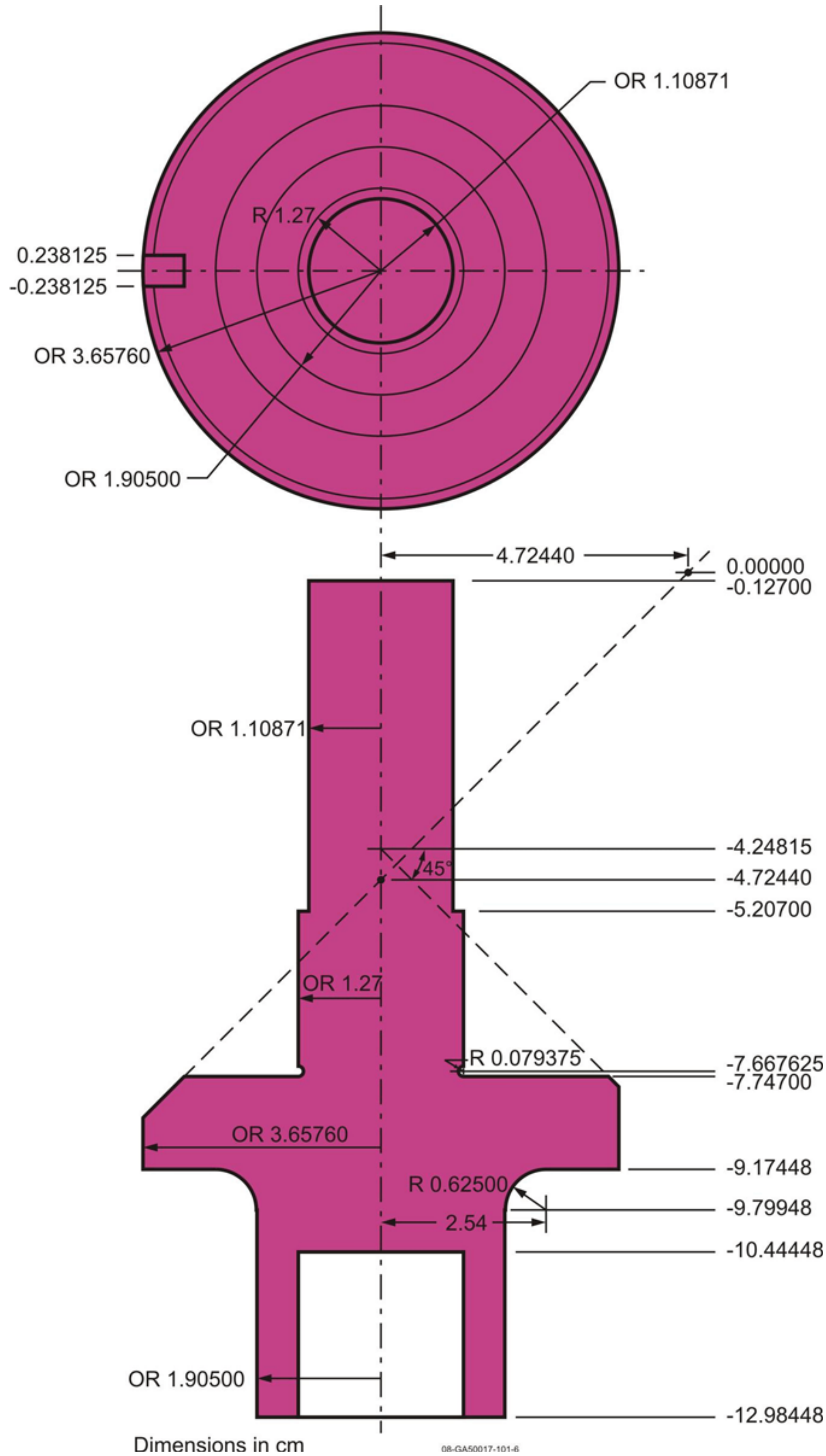

Figure B-21. Safety Block Base.

B.2.2 Restraints - Restraints for the core included three support pads, the subassembly cover plate, the bearing ring, three clamps, three clamp supports, the circular belly band, the three bolts that lock the clamps to the clamp supports, and the three bolts that connect the clamp supports to the belly band. A diagram of the support pads is given in Figure B-22, and a diagram of the subassembly cover plate is shown in Figure B-23. The diagram of the bearing ring in Figure B-24 is shown in alternating shades of green to emphasize that it has alternating regions of different thicknesses. A diagram of a clamp is presented in Figure B-25, and one of a clamp support is given in Figure B-26. Figure B-27 shows a locking bolt that holds a clamp and its clamp support together. A diagram of the belly band and one of the three bolts that connect it to a clamp support is presented in Figure B-28.

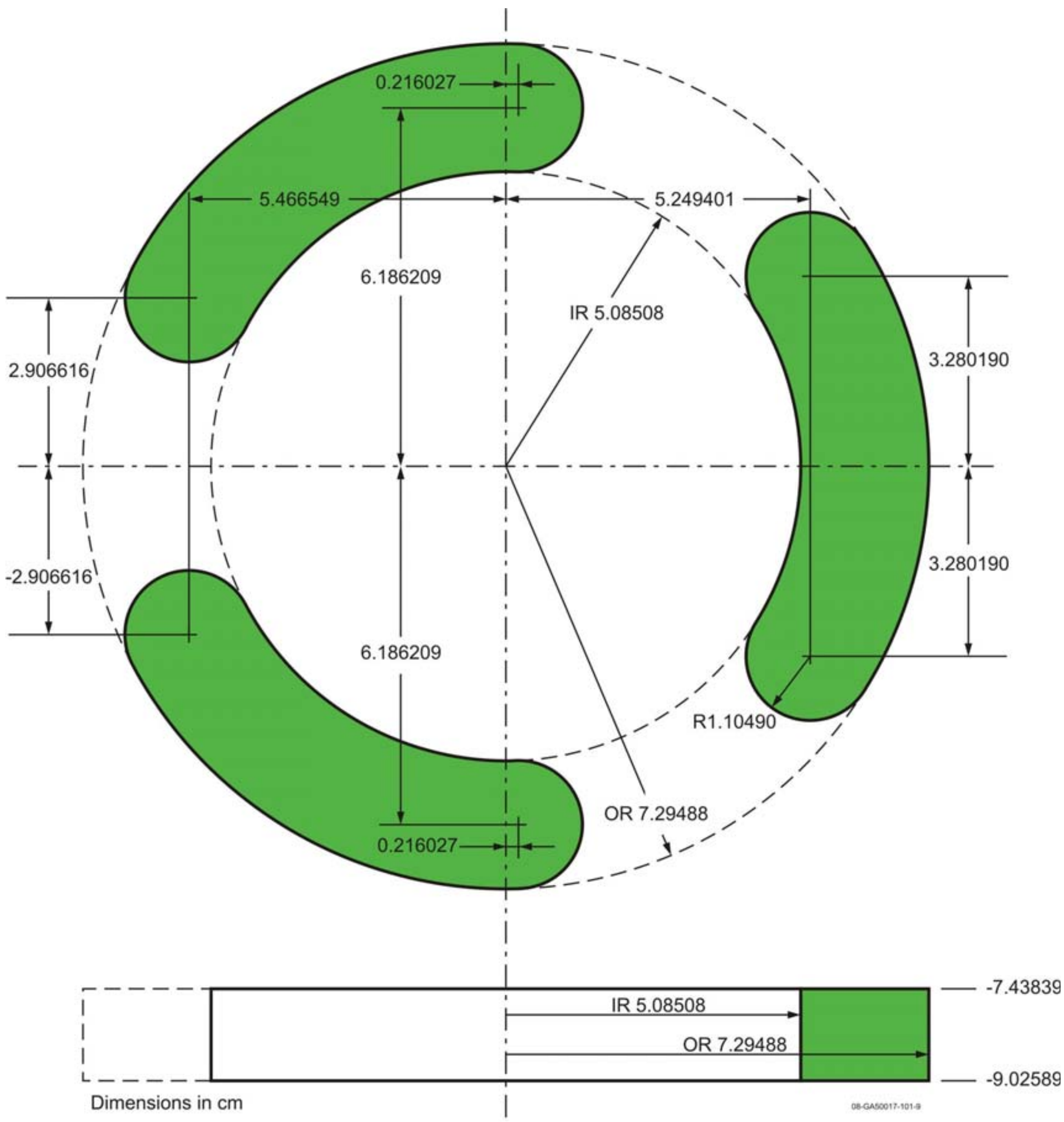

Figure B-22. Support Pads.

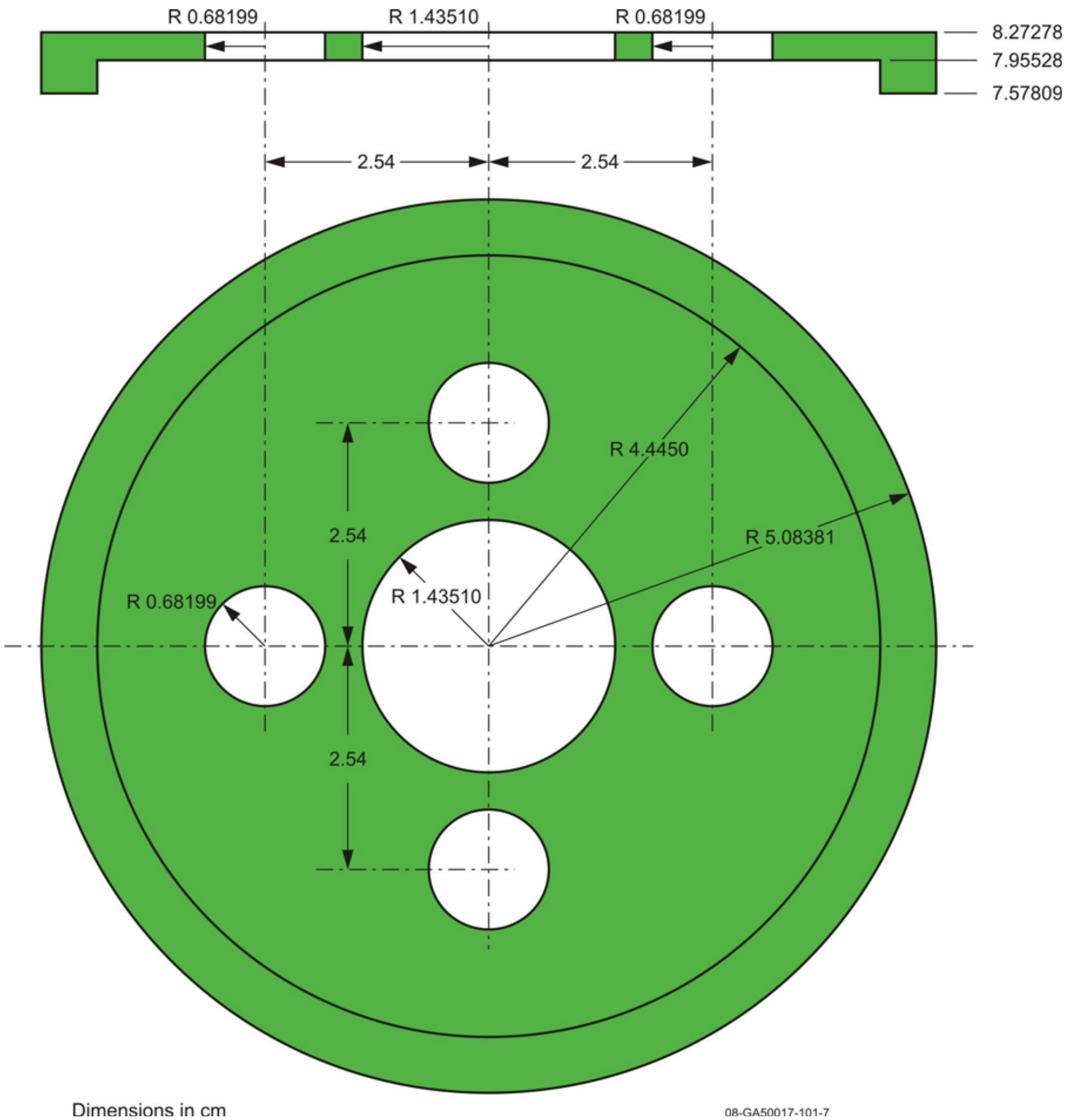

Figure B-23. Subasembly Cover Plate.

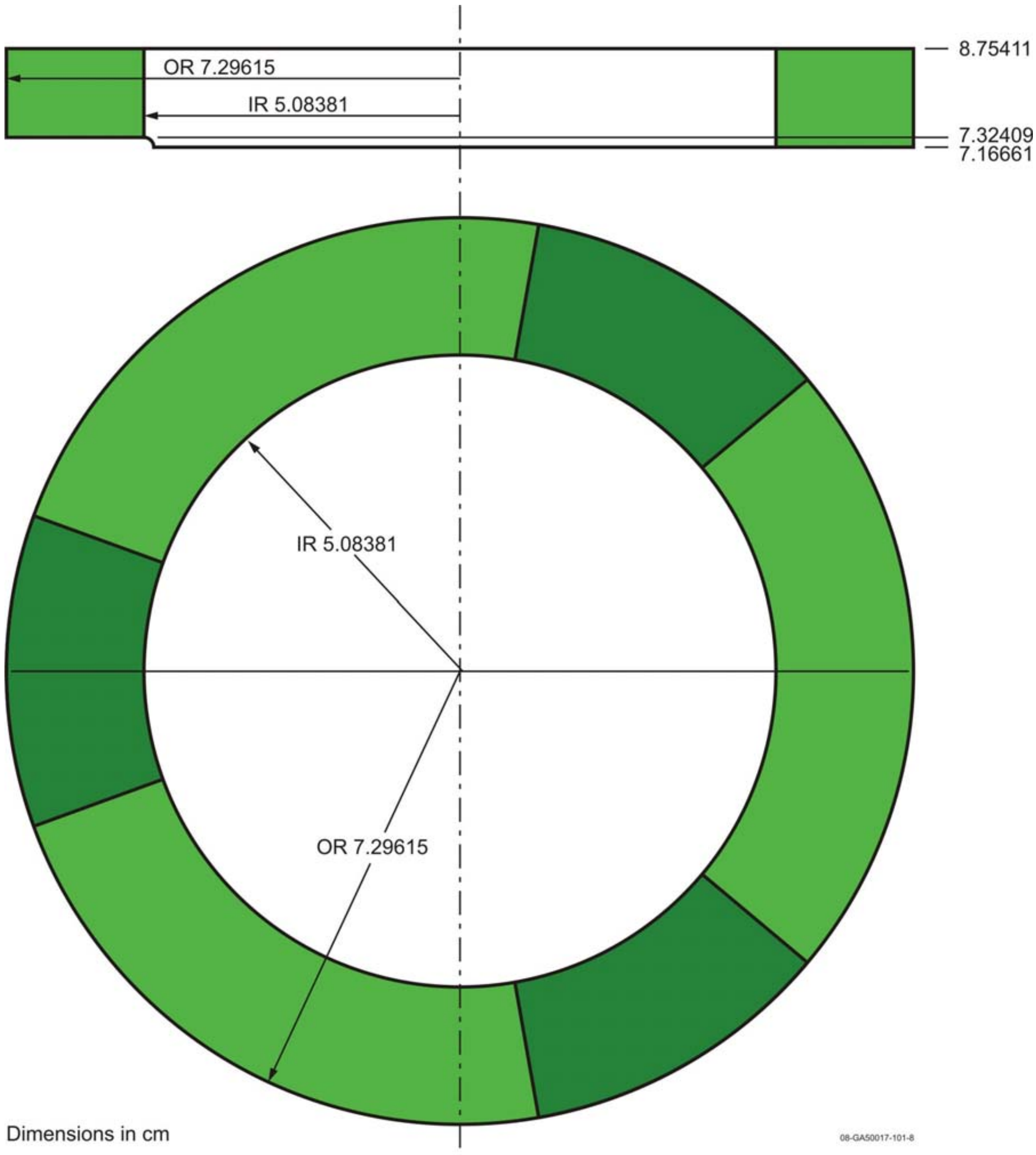

Figure B-24. Bearing Ring.

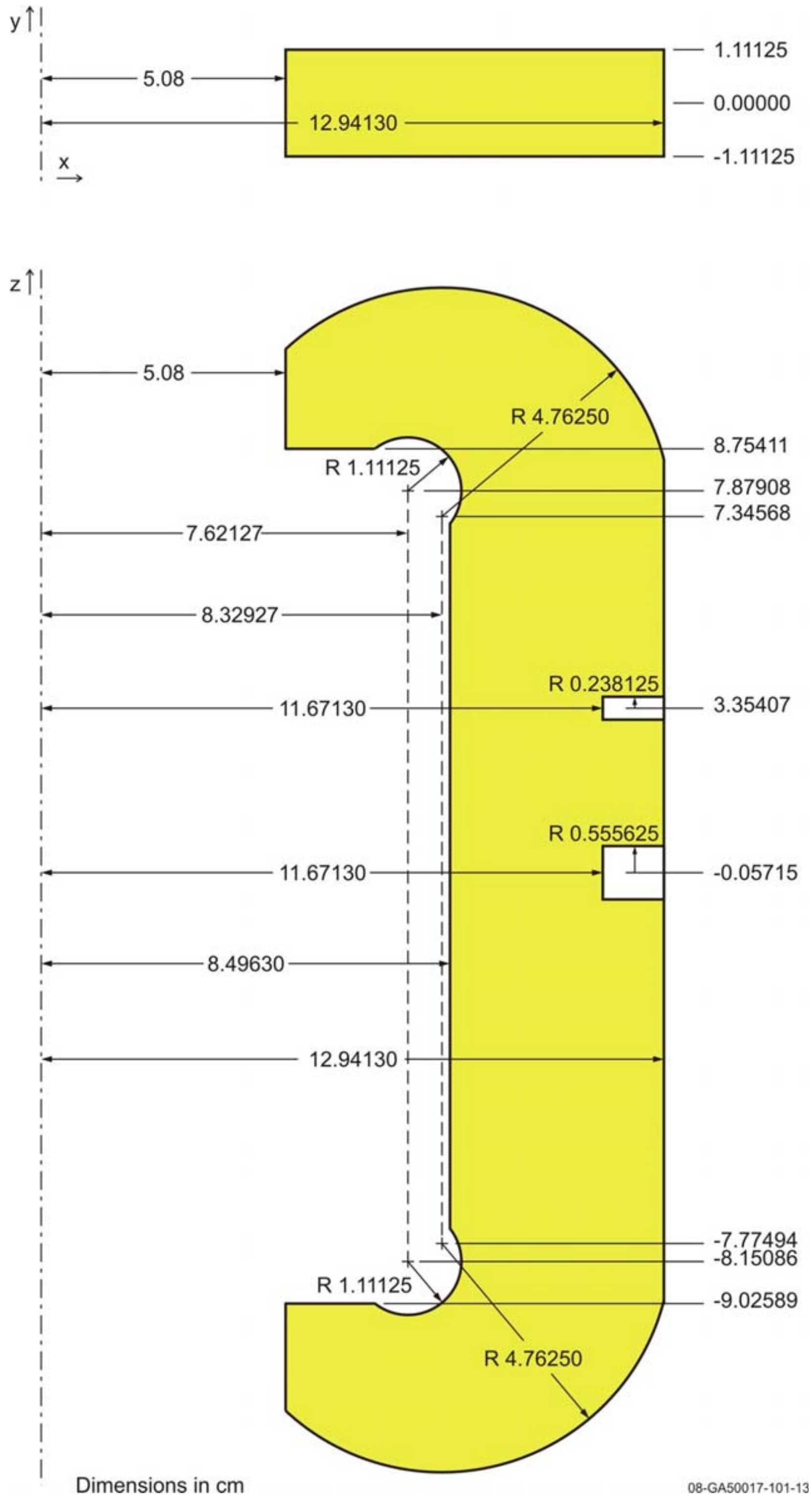

Figure B-25. Clamp.

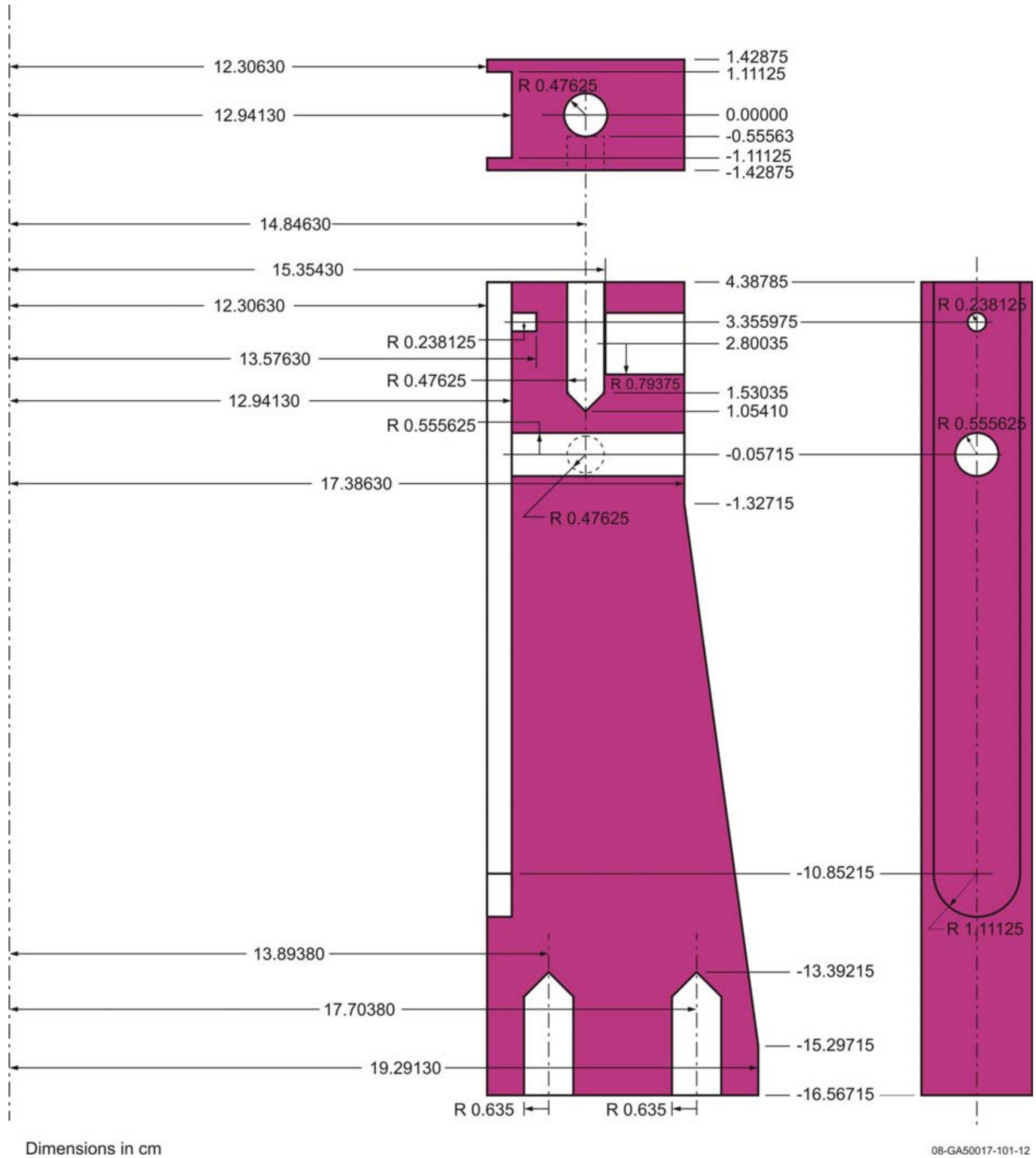

Figure B-26. Clamp Support.

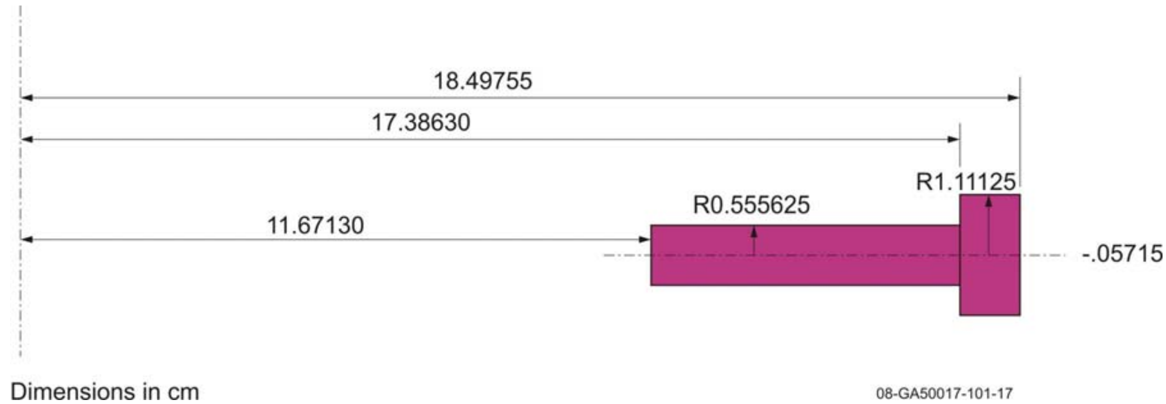

Figure B-27. Locking Bolt.

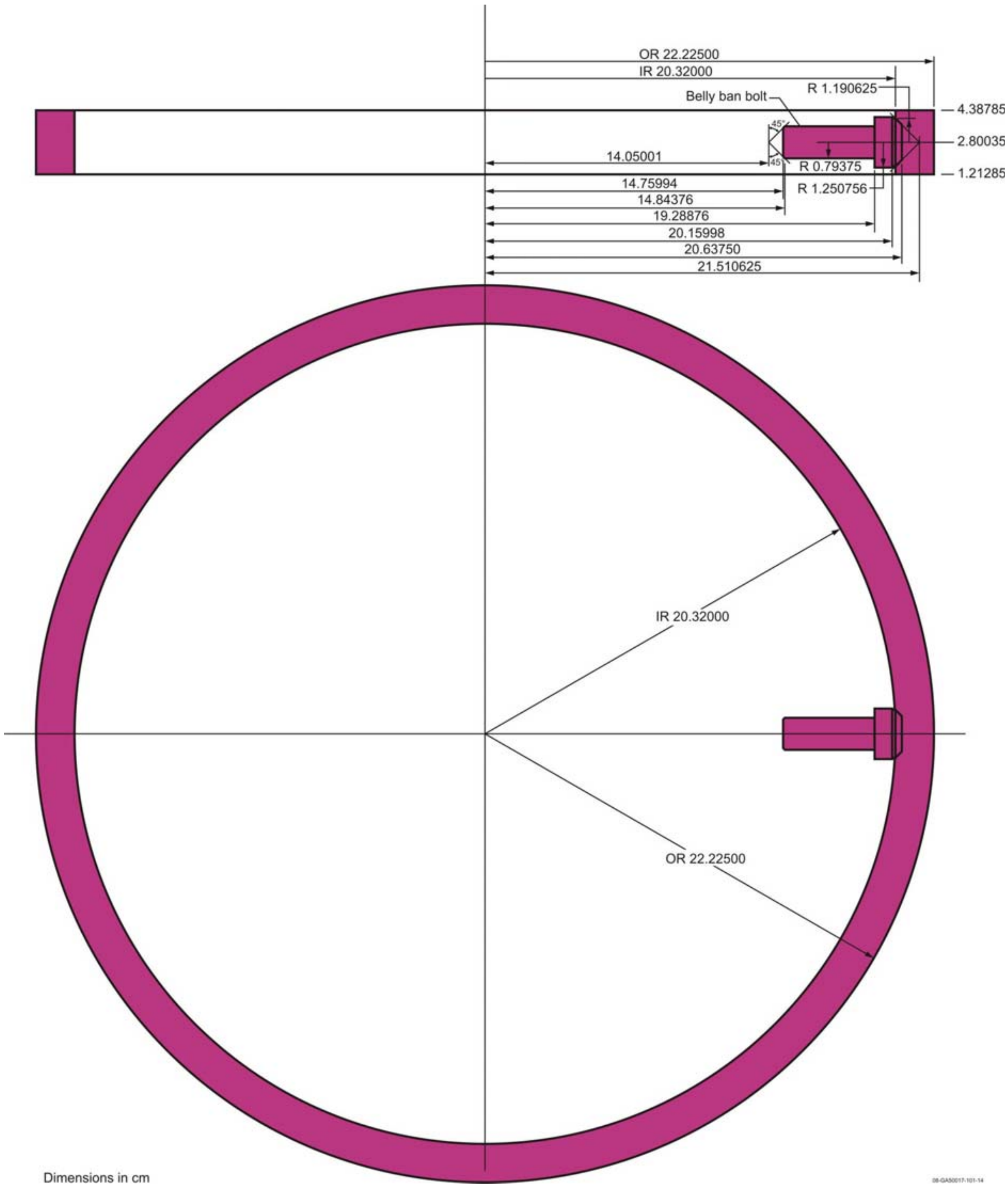

Figure B-28. Belly Band and Bolt.

B.2.3 Structural Support - Structural support for the detailed model of the Godiva-IV assembly includes the mounting plate, the six bolts that attach the clamp supports to the mounting plate, the top portions of the three screws that attach the mounting plate to the legs of the assembly machine, and the three nuts that hold those screws in place. As was noted previously, the structure beneath the mounting plate was omitted from the detailed model, with the exception of the contamination shield..

A diagram of the mounting plate is shown in Figure B-29. The horizontal view of the mounting plate has empty holes where the three bolts attach it to the rest of the assembly machine, but the vertical view includes one of the screws and the nut that holds it in place. The screw is modeled as two solid cylinders of different radii, with the narrow cylinder sitting on top of the wide cylinder. The nut is modeled as a hollow cylinder.

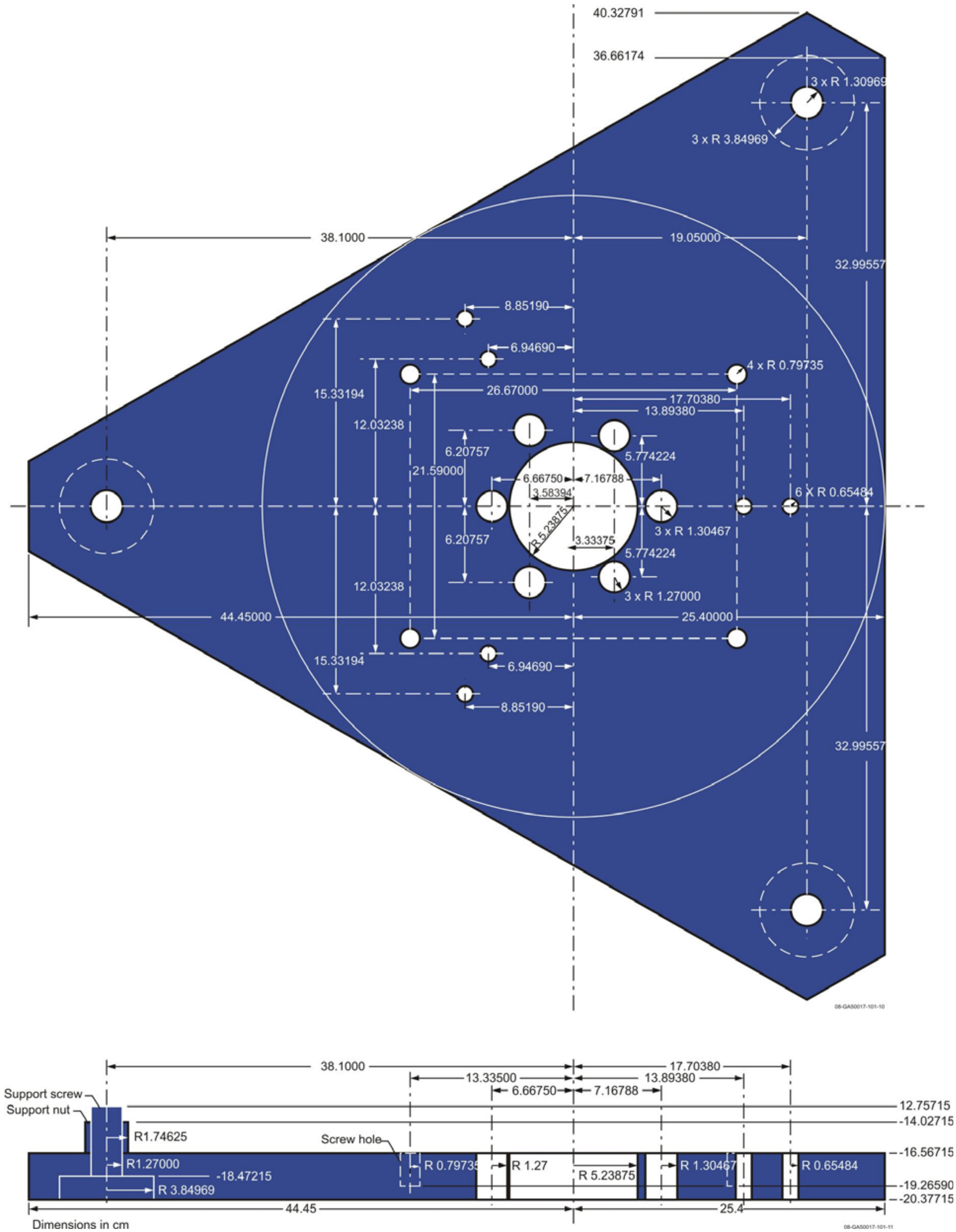

Figure B-29. Mounting Plate and Leg Bolts.

The bolts that attach the clamp supports to the mounting plate are not shown explicitly. However, they are assumed to fill the openings for them in the mounting plate and the clamp supports. Accordingly, they are modeled as cylinders with tapered upper ends. The cylindrical portion extends from -20.37715 cm to -14.02715 cm and has a radius of 0.63500 cm. Their tips taper upward at a 45° angle.

B.2.4 Enclosures - The enclosures for Godiva-IV include the core cover, the core cover screen, the inverted-T plates that hold the core cover in place on the mounting plate, and the contamination shield below the mounting plate. As was noted previously, some of the finer details of the contamination shield and the core cover are approximated or omitted entirely from the model. Preliminary calculations had shown that their contributions to k_{eff} are quite small, and therefore small details such as some of the screw holes were omitted. In addition, the mesh portion of the screen around the core cover was homogenized into a single thin layer since the details of the mesh size are not known. Sensitivity calculations clearly showed that k_{eff} is insensitive to the thickness and density of that layer, within the limits consistent with known information.

Diagrams of the core cover, the core cover screen, and one of the inverted-T plates are shown in Figures B-30 and B-31. The inverted-T plates are strictly rectangular and are not attached to the mounting plate. Instead, the lower portion of those plates fits snugly against the sides of the mounting plate and therefore prevent rotation or other movement of the core cover. Although it is not specified in those figures, the inverted-T plates are 0.635 cm thick.

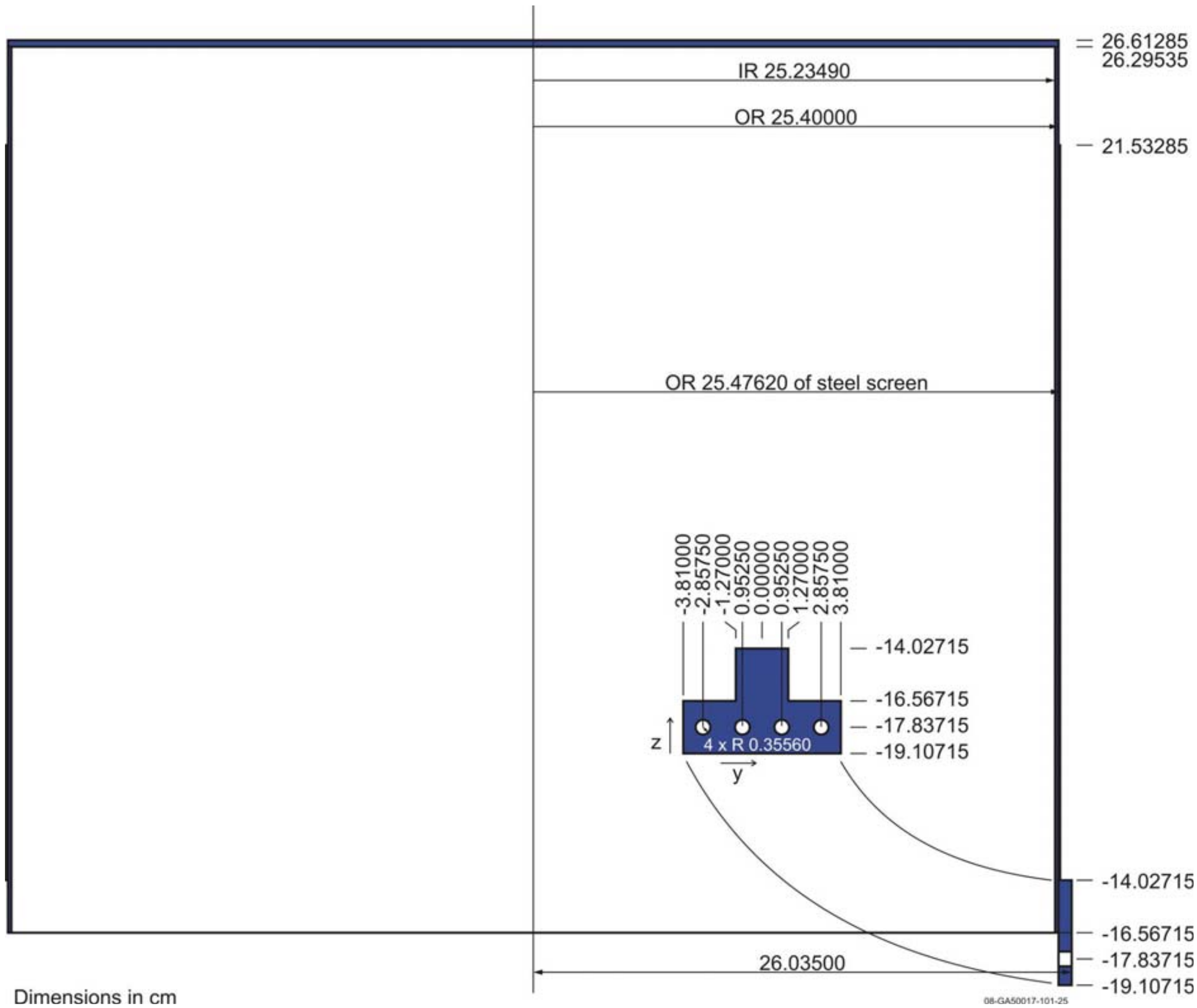

Figure B-30. Vertical Slice through Core Cover, Screen, and Inverted-T Plate.

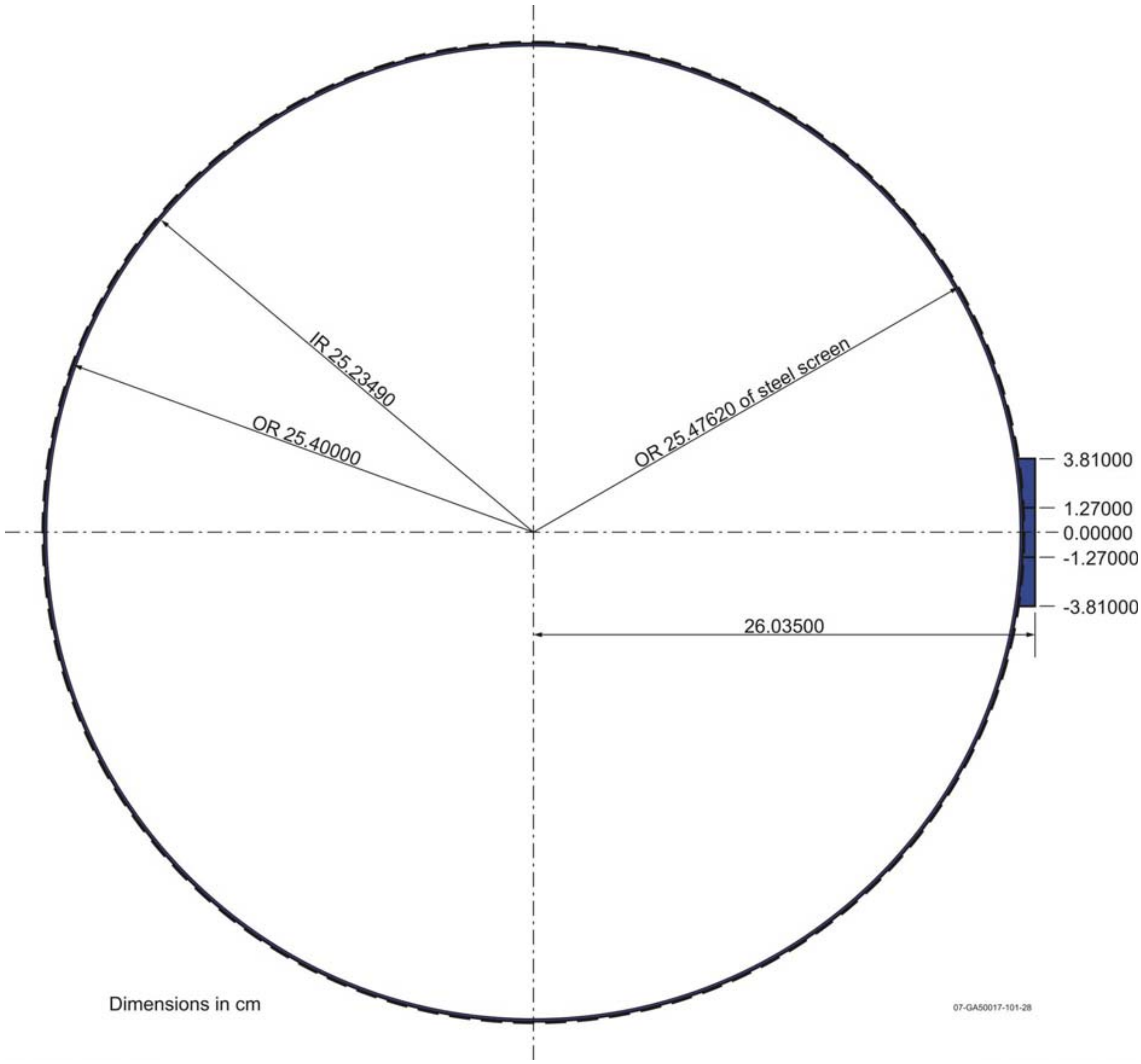

Figure B-31. Horizontal Slice through Core Cover, Screen, and Inverted-T Plate.

A diagram of the plastic sides of the contamination shield is shown in Figure B-32, and a diagram of its steel bottom is shown in Figure B-33. The locations that appear on the far right in the upper (horizontal) view in Figures B-32 and B-33 are the displacements in the y-dimension. There is a small gap between the bottom of the mounting plate and the top edge of the contamination shield.

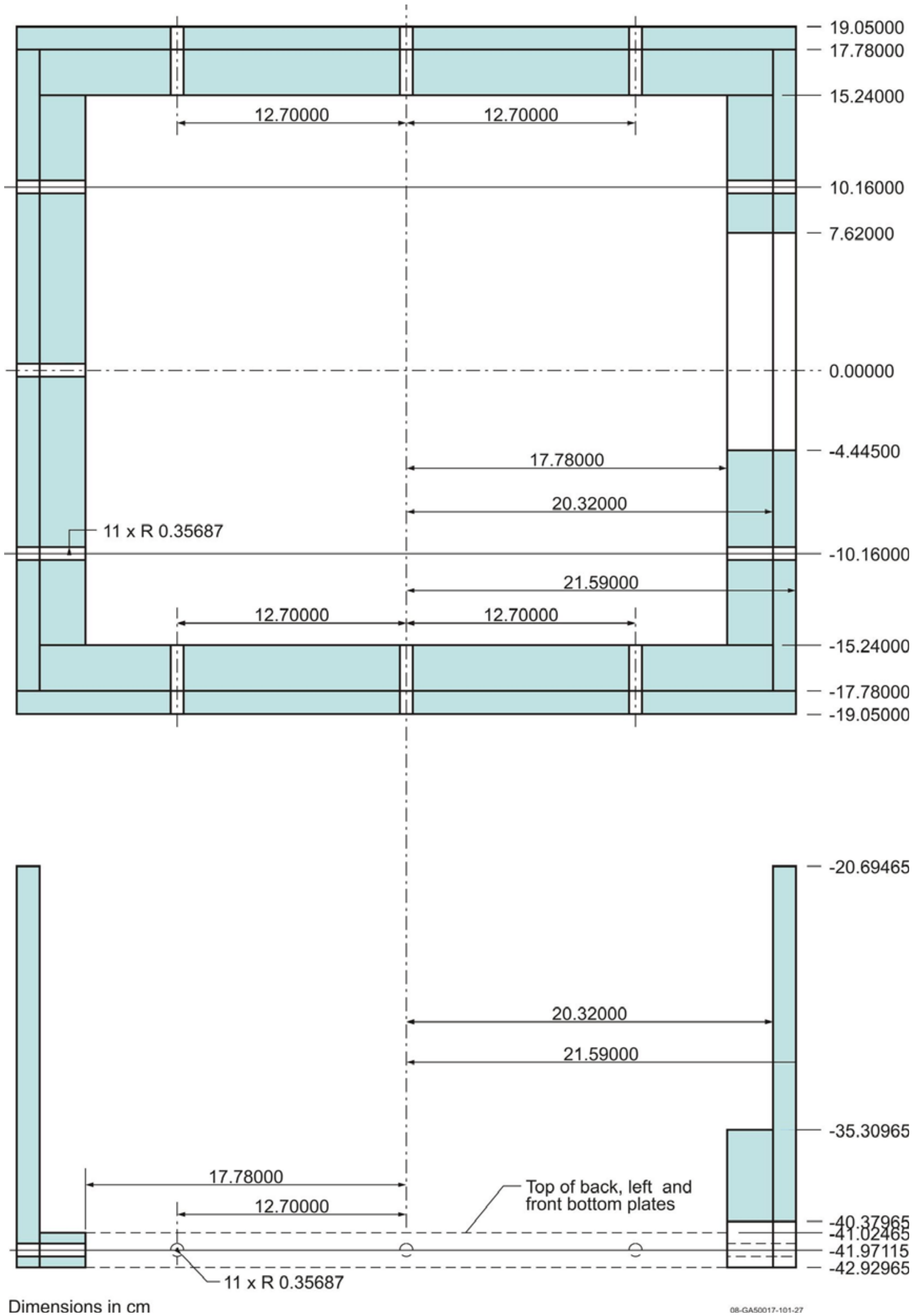

Figure 32. Plastic Portion of Contamination Shield.

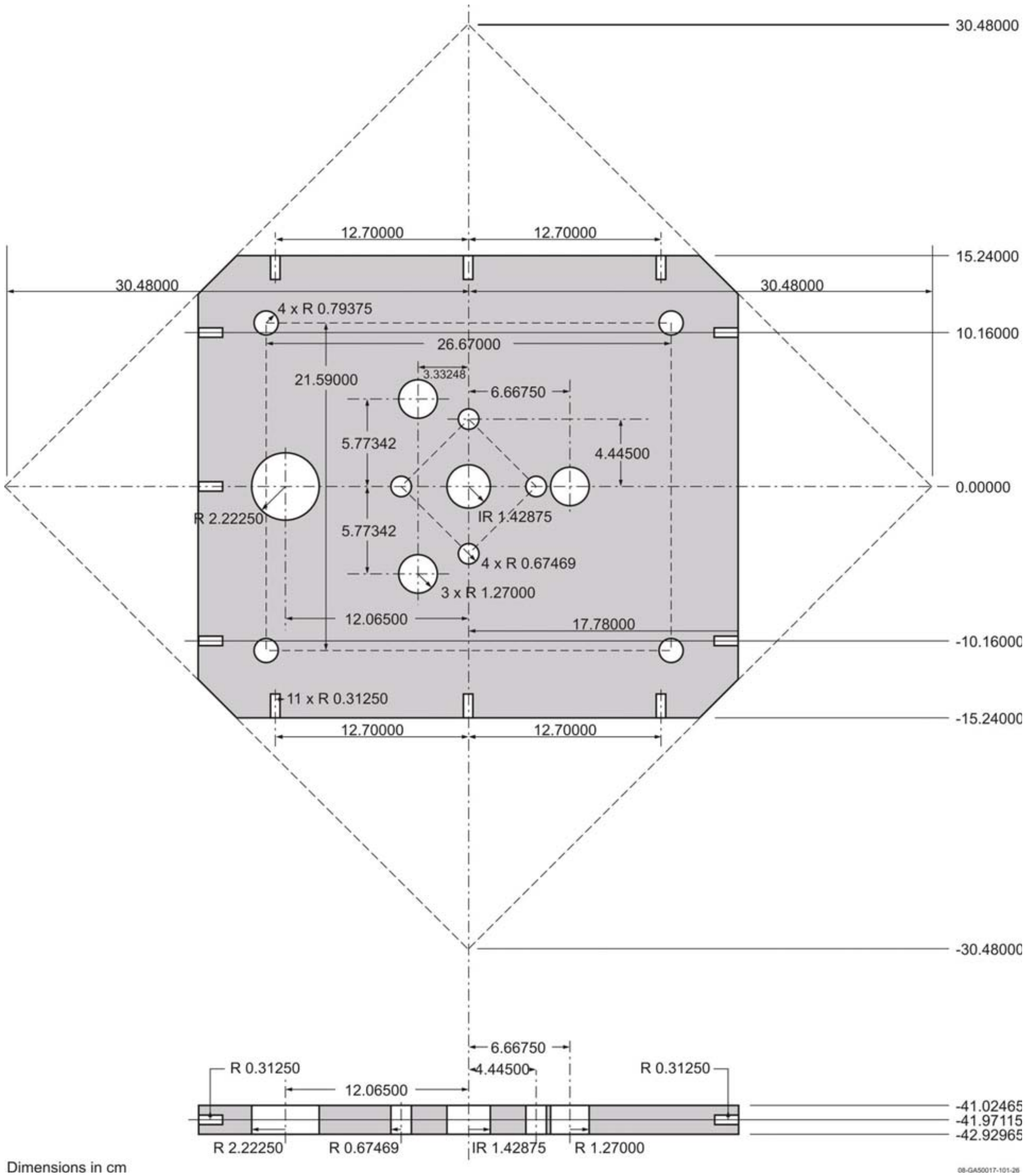

Figure 33. Steel Bottom of Contamination Shield.

B.3 Material Data

The masses of the fuel pieces are taken to be those from the MASS database given in Table 6. There are two reasons for doing so. First, definitive measurements for the fuel rings are not available, and it was felt that a (presumably) consistent set of masses would be preferable to a mix from different sources. Second, as noted above, the original dimensions of those pieces are used for the detailed model, and the MASS masses more likely are consistent with those dimensions than are the masses that were measured more recently.

B.3.1 Fuel - The enrichments of the fuel pieces are taken from Table 7, and the average values for the ^{233}U, ^{234}U, and ^{236}U content are applied to each piece, as discussed in Section 2.2. The remainder of the uranium content in each piece is assumed to be ^{238}U.

The volumes for each of the fuel pieces were obtained from detailed representations produced with CAD program,[a] because the shapes of the pieces are so complicated. Those volumes and the corresponding mass densities, based on the data from the MASS database given in Table 7, are provided in Table B-7. Because the volumes from the CAD program were given in in^3, the volumes in Table B-7 are given in both in^3 and cm^3.

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[a] Personal communication from Robert D. Garrett of the Advanced Nuclear Technology Group (N-2) at Los Alamos National Laboratory, March 19, 2007.

Table B-7. Volumes and Densities of Fuel Pieces.

Fuel Piece	Volume		Mass (g)	Density (g/cm^3)
	in^3	cm^3		
Fuel Ring 101	27.9303	457.6956	8378	18.3047
Fuel Ring 102	26.8997	440.8071	8134	18.4525
Fuel Ring 103	26.6330	436.4367	8046	18.4357
Fuel Ring 104	22.9242	375.6603	6909	18.3916
Fuel Ring 105	27.3212	447.7143	8166	18.2393
Fuel Ring 106	30.7420	503.7711	9283	18.4270
Upper Inner Subassembly Plate (UISP	11.5611	189.4525	3511	18.1715
Intermediate Inner Subassembly Plate (IISP	11.1046	181.9718	3312	18.2006
Safety Block	24.4746	401.0668	7288	18.1715
Control Rod (Each)	2.7604	45.2349	824	18.2160
Burst Rod	2.7171	44.5253	826	18.5513

The mass of each fuel piece was given in Table 7, and the uranium masses and enrichments of those pieces were given in Table 8. The inferred molybdenum masses were given in Table 18, and the basis for the isotopic content of ^{233}U, ^{234}U, ^{236}U, and $^{238}U$was discussed in Section 2.2. That information, in conjunction with the volumes from the CAD program and the masses from the MASS database, produces the number densities given in Tables B-8 through B-11.

Table B-8. Molybdenum Concentrations for Fuel Rings.

Ring	Number Density (atoms/b-cm)
101	1.7006×10^{-3}
102	1.7372×10^{-3}
103	1.7259×10^{-3}
104	1.7043×10^{-3}
105	1.7104×10^{-3}
106	1.7319×10^{-3}

Table B-9. Uranium Concentrations for Fuel Rings.

Isotope → Ring ↓	Number Density (atoms/b-cm)				
	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U
101	4.6602×10^{-6}	4.7289×10^{-4}	4.3049×10^{-2}	3.1286×10^{-4}	2.3362×10^{-3}
102	4.6969×10^{-6}	4.7651×10^{-4}	4.3378×10^{-2}	3.1532×10^{-4}	2.3639×10^{-3}
103	4.6930×10^{-6}	4.7576×10^{-4}	4.3310×10^{-2}	3.1506×10^{-4}	2.3944×10^{-3}
104	4.6825×10^{-6}	4.7521×10^{-4}	4.3260×10^{-2}	3.1436×10^{-4}	2.3428×10^{-3}
105	4.6429×10^{-6}	4.7119×10^{-4}	4.2894×10^{-2}	3.1170×10^{-4}	2.3229×10^{-3}
106	4.6905 x 10-6	4.7582×10^{-4}	4.3315×10^{-2}	3.1489 x 10-4	2.3653 x 10-3

Table B-10. Molybdenum Concentrations for Other Fuel Pieces.

Region	Number Density (atoms/b-cm)
UISP	1.7560×10^{-3}
IISP	1.7247×10^{-3}
Safety Block	1.1425×10^{-3}
Control Rods	1.5264×10^{-3}
Burst Rod	1.5507×10^{-3}

Table B-11. Uranium Concentrations for Other Fuel Pieces.

Region → Nuclide ↓	Number Density (atoms/b-cm)				
	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U
UISP	4.7168×10^{-6}	4.7853×10^{-4}	4.3562×10^{-2}	3.1665×10^{-4}	2.3739×10^{-3}
IISP	4.6323×10^{-6}	4.7011×10^{-4}	4.2796×10^{-2}	3.1099×10^{-4}	2.3176×10^{-3}
Safety Block	4.6488×10^{-6}	4.7173×10^{-4}	4.2934×10^{-2}	3.1209×10^{-4}	2.3305×10^{-3}
Control Rods	4.6445×10^{-6}	4.7124×10^{-4}	4.2889×10^{-2}	3.1180×10^{-4}	2.3329×10^{-3}
Burst Rod	4.7301×10^{-6}	4.7993×10^{-4}	4.3690×10^{-2}	3.1755×10^{-4}	2.3759×10^{-3}

B.3.2 Stainless Steel 303 - The spindle, spindle nut, safety-block base, clamp supports, alignment pin, and the various nuts and bolts all are made from stainless steel 303. The composition of stainless steel 303 is based on the information in Table 10 from MatWeb. Elements for which a maximum content was given were taken to be at half of that value, elements for which a minimum content was given were taken to be at twice that value, and elements for which a range was provided were taken to be at the midpoint of that range.

The remainder was taken to be iron. That composition, in combination with a presumed density of 8.0 g/cm^3, produces the elemental number densities in Table B-12.

Table B-12. Elemental Concentrations for Stainless Steel 303.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.075	3.0083×10^{-4}
Silicon	1.00	1.7154×10^{-3}
Phosphorus	0.10	1.5554×10^{-4}
Sulfur	0.30	4.5067×10^{-4}
Chromium	18.00	1.6678×10^{-2}
Manganese	1.00	8.7693×10^{-4}
Iron	70.225	6.0580×10^{-2}
Nickel	9.00	7.3878×10^{-3}
Molybdenum	0.30	1.5065×10^{-4}

B.3.3 VascoMax 300 Maraging Steel - The clamps are made from VascoMax 300 maraging steel, and its composition was given in Table 11. When the iron concentration is reduced slightly to conserve the overall content, the concentrations in Table B-13 are obtained. That composition, in combination with the given density of 8 g/cm^3, produces the elemental number densities in that same table.

Table B-13. Elemental Concentrations for VascoMax 300 Maraging Steel.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.020	8.0221×10^{-5}
Aluminum	0.100	1.7855×10^{-4}
Silicon	0.050	8.5768×10^{-5}
Phosphorus	0.005	7.7770×10^{-6}
Sulfur	0.005	7.5112×10^{-6}
Ttanium	0.730	7.3453×10^{-4}
Manganese	0.050	4.3847×10^{-5}
Iron	66.940	5.7746×10^{-2}
Cobalt	8.800	7.1938×10^{-3}
Nickel	18.500	1.5186×10^{-2}
Molybdenum	4.800	2.4103×10^{-3}

B.3.4 SAE 4340 - The subassembly cover plate, the bearing ring, the support-pad ring, and the pin in the burst rod are made from SAE 4340. The composition for SAE 4340 is taken to be an amalgam of the information from the *Metals Handbook Desktop Edition* and the *ASM Metals Reference Book* in Table 12. Once again, maximum values for elements were halved, elements for which a range was given were taken to be at the midpoint of that range, and the remainder was taken to be iron. The resulting composition, in combination with a presumed density of 7.85 g/cm^3, produces the elemental number densities in Table B-14.

Table B-14. Elemental Concentrations for SAE 4340.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.405	1.5940×10^{-3}
Silicon	0.225	3.7872×10^{-4}
Phosphorus	0.018	2.7472×10^{-5}
Sulfur	0.020	2.9481×10^{-5}
Chromium	0.800	7.2734×10^{-4}
Manganese	0.725	6.2385×10^{-4}
Iron	95.757	8.1057×10^{-2}
Nickel	1.800	1.4499×10^{-3}
Molybdenum	0.250	1.2319×10^{-4}

B.3.5 AISI 1019 Carbon Steel - The steel plate for the contamination shield was made from C-1019 steel, which is assumed to be the same as AISI 1019 carbon steel. The composition of AISI 1019 carbon steel is based on the information in Table 14 from the *Metals Handbook Desk Edition*. Elements for which a maximum content was given were taken to be at half of that value, and elements for which a range was provided were taken to be at the midpoint of that range. The remainder was taken to be iron. That composition, in combination with a presumed density of 7.87 g/cm^3, produces the elemental number densities in Table B-15.

Table B-15. Elemental Concentrations for AISI 1019 Carbon Steel.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.170	6.7080×10^{-4}
Phosphorus	0.020	3.0603×10^{-5}
Sulfur	0.025	3.6946×10^{-5}
Manganese	0.850	7.3328×10^{-4}
Iron	98.935	8.3960×10^{-2}

B.3.6 Lexguard - The plastic portion of the contamination shield was made from Lexguard. The information provided for Lexguard in subsection 1.3.4, including its density of 1.2 g/cm^3, produces the composition given in Table B-16.

Table B-16. Elemental Concentrations for Lexguard.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Hydrogen	5.550	3.3161×10^{-2}
Carbon	75.580	3.7894×10^{-2}
Oxygen	18.870	7.1026×10^{-3}

B.3.7 Al 6061-T6 - The mounting plate, the core cover, and the screen for the core cover are made from Al 6061-T6. The composition of Al 6061-T6 was given in Table 13, and its nominal density is 2.70 g/cm^3. Maximum values for elements were halved, elements for which a range was given were taken to be at the midpoint of that range, and the "other" constituents were replaced by void. The remainder was taken to be aluminum. The resulting composition is given in Table B-17.

Table B-17. Elemental Concentrations for Al 6061-T6.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Magnesium	1.000	6.6898×10^{-4}
Aluminum	97.230	5.8593×10^{-2}
Silicon	0.600	3.4736×10^{-4}
Titanium	0.075	2.5469×10^{-5}
Chromium	0.195	6.0978×10^{-5}
Manganese	0.075	2.2197×10^{-5}
Iron	0.350	1.0190×10^{-4}
Copper	0.275	7.0365×10^{-5}
Zinc	0.125	3.1082×10^{-5}

B.4 <u>Temperature Data</u>

The measured ambient temperatures for the four delayed-critical configurations ranged from 18.9 °C to 19.2 °C, while the initial temperature for super-prompt-critical configuration was 20.5 °C. Doppler effects are largely irrelevant for configurations with fast spectra, and the reactivity effects of thermal expansion from a temperature change of approximately 1 °C are negligible. Consequently, calculations that employ cross sections at 20°C are adequate for these benchmarks.

B.5 <u>Experimental and Detailed-Model k_{eff}</u>

As discussed in Section 2.4, the measured periods for the four delayed-critical conditions were effectively infinite. Consequently, the measured value for k_{eff} for all four of those configurations is 1.0000 with negligible uncertainty.

The Godiva-IV assembly contains no neutron source, and consequently it typically sits in a static but super-prompt-critical condition for several seconds before a neutron from spontaneous fission produces a divergent chain reaction. Based on the discussion in Section 2.4, the measured value for k_{eff} for that configuration is 1.0066 ± 0.0003.

The uncertainty studies in Section 2 produce an associated uncertainty of ± 0.0026 Δk for all five configurations. Consequently, the experimental value of k_{eff} for the four delayed-critical configurations is 1.0000 ± 0.0026, and the experimental value of k_{eff} for the static prompt supercritical configuration is 1.0066 ± 0.0026. The minor simplifications that are described in subsection B.1 and are incorporated into the detailed model are not believed to introduce any significant change in k_{eff}. Consequently, the values of k_{eff} for the detailed model are the same as the experimental values.

B.6 <u>Results of Sample Calculations</u>

Results from the MCNP5 Monte Carlo code with a variety of nuclear data libraries are presented in Table B-18. JENDL-3.3 clearly produces the best agreement with the target value for k_{eff}.

Table B-18a. Sample Calculation Results.

Codes (Cross-Section Library)→ Case ↓	MCNP (Continuous Energy ENDF/B-VI)	MCNP (Continuous Energy ENDF/B-VII.0)
1	0.9937 ± 0.0003	0.9966 ± 0.0003
2	0.9939 ± 0.0003	0.9965 ± 0.0003
3	0.9946 ± 0.0003	0.9974 ± 0.0003
4	0.9952 ± 0.0003	0.9983 ± 0.0003
5	1.0000 ± 0.0003	1.0036 ± 0.0003

Table B-18b. Sample Calculation Results (Continued).

Codes (Cross-Section Library)→ Case ↓	MCNP (Continuous Energy JEF-3.1)	MCNP (Continuous Energy JENDL-3.3)
1	0.9930 ± 0.0003	1.0001 ± 0.0003
2	0.9930 ± 0.0003	1.0004 ± 0.0003
3	0.9934 ± 0.0003	1.0010 ± 0.0003
4	0.9947 ± 0.0003	1.0017 ± 0.0003
5	0.9992 ± 0.0003	1.0069 ± 0.0003

B.7 MCNP Input Listing

The input files for the five cases are identical except for the vertical positions of the control rods and burst rods. Consequently, only the detailed model for case 2 is listed below. It employs continuous-energy cross sections derived from the final release of ENDF/B-VI. The zinc impurity in aluminum 6061-T6 is omitted, because the distributed MCNP libraries do not include ENDF/B-VI data for zinc. In addition, the other nuclear data libraries contain cross sections for the isotopes of molybdenum rather than the element. With those two exceptions, input files for other nuclear data libraries would be identical except for the suffix of the ZAID identifier for the various nuclides.

This case employs 550 generations of 10,000 neutrons each, and exclude the first 50 generations from the statistics. Consequently, the results it produces are based on 5,000,000 active histories.

```
Godiva-IV  HEU-FAST-MET-086  Case 2 DC  BR In  MASS Masses  Detailed  ENDF/B-VI
c  Core
c  Spindle
1        1    0.088296      1   -3    6   -7          $ Spindle Bottom
2        1    0.088296      1   -4    7   -8          $ Spindle Bottom Middle
3        1    0.088296      1   -4    8   14  -39     $ Spindle Bottom Indented
4        1    0.088296      1   -5  -10   39          $ Spindle Top Middle
5        1    0.088296      1   -5   10  -11   15     $ Spindle Top Indented
6        1    0.088296      1   -5   11  -12          $ Spindle Top Part 1
7        1    0.088296      2   -5   12  -13          $ Spindle Top Part 2
c  Intermediate Inner Subassembly Plate
8       14    0.047624     16  -18   20  -21          $ ISP Bottom Region
9       14    0.047624      4  -18   21  -22          $ ISP Lwr Middle Region
10       0                -19  -38   54   56          $ Align Pin Hole Cylinder
11       0                -19  -29  -56  #23          $ Align Pin Hole Tip Gap
12      14    0.047624      4  -17   22  -24   26
                          #10  #11  #22  #23          $ ISP Top Middle Region
13      14    0.047624      4  -17   19   24  -25
                          -27   28  #10               $ ISP Top Region
c  Shim Ring
c 14       1    0.088296      22   30  -31  -32          $ Shim Ring
c Upper Inner Subassembly Plate
15      15    0.048492      4   19   25  -34  -37
                          -42   43   44               $ Lower Part of Top ISP
16      15    0.048492      4   19  -35   37  -38     $ Lwr Mdl Part of Top ISP
17      15    0.048492      4  -35   36   38  -39     $ Middle Part of Top ISP
18      15    0.048492      5  -35   36   39  -40     $ Upr Mdl Part of Top ISP
19      15    0.048492     33  -35   40  -41          $ Upper Part of Top ISP
c  Long Alignment Pin
20       0                -36  -40   57   58  -59     $ Slit in Align Pin Cap
21       1    0.088296    -36   38  -40  #20          $ Alignment Pin Cap
22       1    0.088296    -38  -54   56               $ Alignment Pin Barrel
23       1    0.088296     55  -56  -60               $ Alignment Pin Tip
c  Safety Block
24       0                 -4  -67   75   83          $ Lwr SB/Base Gap
25       0                -64   65  -66               $ Lwr Thermocouple Hole
26       0                -63   66  -68               $ Upr Thermocouple Hole
27       0                -62   65   70  -71  -72
                          -73                         $ Safety Block Notch
28      13    0.047205      4  -62   64   65  -66
                          -73  #27                    $ Safety Block Bottom
29      13    0.047205      4  -62   63   66  -67     $ Safety Blk Lwr Middle
30      13    0.047205     61  -62   63   67  -68     $ Safety Blk Upr Middle
31      13    0.047205     61  -62   68  -69  -74     $ Safety Block Top
c  Safety Block Base
32       0                 -4  -87                    $ Indentation in SB Base
33       0                 -4   79  -80               $ SB Base Bottom Hole
34       0                -65   70  -71  -78   82
                          -84  -85                    $ SB Base Notch
35       1    0.088296      4  -76   79  -80          $ SB Base Bottom
36       1    0.088296    -76   80  -81               $ SB Base Solid Round
37       1    0.088296    -77   81  -82   86          $ Curved SB Base
38       1    0.088296    -65  -78   82  -85  #34     $ SB Base Platform
39       1    0.088296     -4   65  -83   87          $ Lower SB Base Barrel
40       1    0.088296    -69  -75   83               $ Upper SB Base Barrel
c  Notches for Fuel Rings
41       0                -94  108 -117  123 -124
                          125 #591                    $ Right Notch, Rings 2-5
42       0                -94  108 -117 -141 -143
                          144 #691                    $ FL Notch, Rings 2-5
43       0                -94  108 -117 -142 -145
```

```
                         146 #791                   $ BL Notch, Rings 2-5
c  Fuel Ring 1 (101)
44       7    0.047876    90  -93  104 -105 -137
                         138 #125                   $ Middle, Right Pad Slot
45       7    0.047876    90  -93  -99  104 -105
                         137 #126                   $ Front End, Rt Pad Slot
46       7    0.047876    90  -93  -98  104 -105
                        -138 #127                   $ Back End, Rt Pad Slot
47       7    0.047876    90  -93  104 -105 -133
                        -134 #128                   $ Middle, FL Pad Slot
48       7    0.047876    90  -93 -100  104 -105
                         133 #129                   $ Rt End, FL Pad Slot
49       7    0.047876    90  -93 -102  104 -105
                         134 #130                   $ Lt End, FL Pad Slot
50       7    0.047876    90  -93  104 -105  136
                         135 #131                   $ Middle, BL Pad Slot
51       7    0.047876    90  -93 -101  104 -105
                        -136 #132                   $ Rt End, BL Pad Slot
52       7    0.047876    90  -93 -103  104 -105
                        -135 #133                   $ Lt End, BL Pad Slot
53       0               -94  104 -108  123 -124
                         126 #199 #591              $ Right Notch, Ring 1
54       0               -94  104 -108 -139 -143
                         144 #241 #691              $ Front Left Notch, Ring 1
55       0               -94  104 -108 -140 -145
                         146 #276 #791              $ Back Left Notch, Ring 1
56       7    0.047876    89  -94   95   96   97
                         104 -105
                         #44  #45  #46  #47  #48
                         #49  #50  #51  #52
                         #53  #54  #55
                        #125 #126 #127 #128 #129
                        #130 #131 #132 #133
                        #199 #591 #241 #691 #276
                        #791                        $ Bottom Annulus, Ring 1
57       7    0.047876    89  -94   95   96   97
                         105 -106  #53  #54  #55
                        #591  #691 #791             $ Middle Annulus, Ring 1
58       7    0.047876    92  -94   95   96   97
                         106 -108  #53  #54  #55
                        #591  #691 #791             $ Top Annulus, Ring 1
c  Fuel Ring 2 (102)
59       0                89  -92   95   96   97
                         106 -107                   $ Gap inside Ring 2
60       0                91  -92   95   96   97
                         107 -108                   $ Internal Gap, Rings 1, 2
61       8    0.048276    89  -91   95   96   97
                         107 -108                   $ Bottom Annulus, Ring 2
62       8    0.048276    89  -94   95   96   97
                         108 -109  #41  #42  #43
                        #591 #691 #791              $ Middle Annulus, Ring 3
63       8    0.048276    92  -94   95   96   97
                         109 -110  #41  #42  #43
                        #591 #691 #791              $ Top Annulus, Ring 2
c  Fuel Ring 3 (103)
64       0                91  -94   95   96   97
                         110 -111  #41  #42  #43
                        #591 #691 #791              $ Outer Edge Gap, Rng 2, 3
65       0                91  -92   95   96   97
                         109 -110                   $ Internal Gap, Rings 2, 3
66       9    0.048226    89  -91   95   96   97
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                         109 -111                        $ Bottom Annulus, Ring 3
67       9    0.048226    89  -94   95   96   97
                         111 -112  #41  #42  #43
                        #591 #691 #791                   $ Middle Annulus, Ring 3
68       9    0.048226    92  -94   95   96   97
                         112 -114  #41  #42  #43
                        #591 #691 #791                   $ Top Annulus, Ring 3
c  Fuel Ring 4 (104)
69       0                91  -92   95   96   97
                         113 -114                        $ Gap, Rings 3 and 4
70       0                89  -92   95   96   97
                         112 -113                        $ Gap Inside Ring 4
721      0               -720  722 -723                  $ Smaller Ring 4 TC Hole
722      0                -94 -721  723                  $ Larger Ring 4 TC Hole
71       10   0.048101    89  -91   95   96   97
                         113 -114                        $ Bottom Annulus, Ring 4
72       10   0.048101    89  -94   95   96   97
                         114 -115  #41  #42  #43
                        #591 #691 #791 #721 #722         $ Middle Annulus, Ring 4
73       10   0.048101    89  -91   95   96   97
                         115 -116                        $ Top Annulus, Ring 4
c  Fuel Ring 5 (105)
74       0                91  -92   95   96   97
                         115 -116                        $ Gap inside Ring 5 Slot
75       0               -22   89  -92   95   96
                          97  116                        $ Gap inside Ring 5
76       11   0.047715   -22   92  -94   95   96
                          97  115  #41  #42  #43
                        #591 #691 #791                   $ Bottom Annulus, Ring 5
77       11   0.047715    22   88  -94   95   96
                          97 -117  #41  #42  #43
                        #591 #691 #791                   $ Middle Annulus, Ring 5
78       11   0.047715    88  -91   95   96   97
                         117 -119                        $ Top Annulus, Ring 5
c  Fuel Ring 6 (106)
79       0                91  -94   95   96   97
                         117 -118 #591 #691 #791         $ Gap inside Ring 6 Slot
80       0               -37   91  -92  118              $ Gap, Rings 5 and 6
81       0               -37  -91  -95  118              $ Left Hole above C/B Rod
82       0               -37  -91  -96  118              $ Back Hole above C/B Rod
83       0               -37  -91  -97  118              $ Right Hole above C/B Rod
84       0               -94  118 -122  123 -124
                         126 #201 #591                   $ Right Notch, Ring 6
85       0               -94  118 -122 -139 -143
                         144 #243 #691                   $ Fr Left Notch, Ring 6
86       0               -94  118 -122 -140 -145
                         146 #278 #791                   $ Bk Left Notch, Ring 6
87       0                90  -93  121 -122 #139         $ Shallow Indent, Ring 6
88       12   0.048208   -37   92  -94  118
                         #84  #85  #86 #591 #691
                        #791                             $ Bottom Annulus, Ring 6
89       12   0.048208    37   89  -94 -121  #84
                         #85  #86 #136 #137 #138
                        #201 #243 #278 #591 #691
                        #791                             $ Middle Annulus, Ring 6
90       12   0.048208    89  -90  121 -122              $ Inr Top Annulus, Ring 6
91       12   0.048208    93  -94  121 -122
                         #84  #85  #86 #201 #591
                        #243 #691 #278 #791              $ Otr Top Annulus, Ring 6
c  Control and Burst Rods
92       0               -95  166 -118                   $ Hole above Control Rod 1
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93       0               -95  148  156 -166          $ Gap between CR1 & Rings
94       0              -147  164 -166               $ Top Hole in CR1
95       0              -148 -166  168 -170  171     $ Control Rod 1 Notch
96       0              -148  156  174               $ Gap for Lower CR1 Slant
97       0              -148 -166  175  #95          $ Gap for Upper CR1 Slant
98       16    0.047546  147 -148  156 -159 -174     $ Bottom Region, CR1
99       16    0.047546 -148  159 -164               $ Solid Middle Region, CR1
100      16    0.047546  147 -148  164 -166 -175
                         #95                         $ Top Region, CR1
101      0               -97  167 -118               $ Hole above Control Rod 2
102      0               -97  153  157 -167          $ Gap between CR2 & Rings
103      0              -152  165 -167               $ Top Hole in CR2
104      0              -153 -167  169 -172  173     $ Control Rod 2 Notch
105      0              -153  157  179               $ Gap for Lower CR1 Slant
106      0              -153 -167  180 #104          $ Gap for Upper CR1 Slant
107      16    0.047546  152 -153  157 -160 -179     $ Bottom Region, CR2
108      16    0.047546 -153  160 -165               $ Solid Middle Region, CR2
109      16    0.047546  152 -153  165 -167 -180
                        #104                         $ Top Region, CR2
110      0               -96  163 -118               $ Hole above Burst Rod
111      0               -96  150  162 -163          $ Gap, BR Pin Head & Fuel
112      0               -96  149  161 -162          $ Gap, BR Pin Cyl & Fuel
113      0               -96  151  104 -161          $ Gap between BR & Rings
114      0              -151  154  176               $ Gap for Lower BR Slant
115      0              -151 -161  177               $ Gap for Upper BR Slant
116      17    0.048419  149 -151  154 -155 -176     $ Bottom Region, Burst Rod
117      17    0.048419 -151  155 -158  178          $ Middle Region, BR
118      17    0.048419  149 -151  158 -161 -177     $ Top Region, Burst Rod
119      0              -158 -178                    $ Tip of BR Pin Hole
120      2     0.087654 -149  158 -162               $ Cylinder, BR Pin
121      2     0.087654 -150  162 -163               $ Head, BR Pin
122      0              -147  156 -159               $ Bottom Hole, CR1
123      0              -152  157 -160               $ Bottom Hole, CR2
124      0              -149  154 -155               $ Bottom Hole, Burst Rod
c  Support Pads
125      2     0.087654 -105 -137  138  181 -182
                         189                         $ Middle, Right Pad
126      2     0.087654 -105  137  181 -182 -184
                         189                         $ Back End, Right Pad
127      2     0.087654 -105 -138  181 -182 -183
                         189                         $ Front End, Right Pad
128      2     0.087654 -105 -133 -134  181 -182
                         189                         $ Middle, Front Pad
129      2     0.087654 -105  133  181 -182 -185
                         189                         $ Right End, Front Pad
130      2     0.087654 -105  134  181 -182 -187
                         189                         $ Left End, Front Pad
131      2     0.087654 -105  135  136  181 -182
                         189                         $ Middle, Back Pad
132      2     0.087654 -105 -136  181 -182 -186
                         189                         $ Right End, Back Pad
133      2     0.087654 -105 -135  181 -182 -188
                         189                         $ Left End, Back Pad
c  Bearing Ring
c 134
c 135
136      2     0.087654   90  -93  120 -121  127
                        -128                         $ Left Deep Indent, Ring 6
137      2     0.087654   90  -93  120 -121 -129
                         130                         $ Bk Rt Deep Indent, Ring 6
138      2     0.087654   90  -93  120 -121  131
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                        -132                         $ FR Rt Deep Indent, Ring 6
139      2    0.087654    121  190 -191 -192         $ Solid Bearing Ring
c  Subassembly Cover Plate
140      0                  5   41 -193 -199         $ Central Hole in SCP
141      0                 41  -89  193 -198         $ Inner Void in SCP
142      0               -194  198 -199              $ Back Hole in SCP
143      0               -195  198 -199              $ Right Hole in SCP
144      0               -196  198 -199              $ Front Hole in SCP
145      0               -197  198 -199              $ Left Hole in SCP
146      2    0.087654     89  122  -90 -199         $ Edge of SCP
147      2    0.087654    -89  193  194  195  196
                          197  198 -199              $ Center of SCP
c  Mounting Plate
148      0               -200  226 -229              $ Empty Central Hole
149      0                 95 -201  226 -229         $ Empty Hole for CR1
150      0                 96 -202  226 -229         $ Empty Hole for Burst Rod
151      0                 97 -203  226 -229         $ Empty Hole for CR2
152      0               -204  226 -229              $ Empty Right Hole
153      0               -205  226 -229              $ Empty Front Left Hole
154      0               -206  226 -229              $ Empty Back Left Hole
155      1    0.088296   -216  226 -229              $ Front Bolt for FL Leg
156      1    0.088296   -217  226 -229              $ Front Bolt for Rt Leg
157      1    0.088296   -218  226 -229              $ Front Bolt for BL Leg
158      1    0.088296   -219  226 -229              $ Back Bolt for FL Leg
159      1    0.088296   -220  226 -229              $ Back Bolt for Rt Leg
160      1    0.088296   -221  226 -229              $ Back Bolt for BL Leg
161      0               -222  227 -229              $ Front Right Screw Hole
162      0               -223  227 -229              $ Front Left Screw Hole
163      0               -224  227 -229              $ Back Left Screw Hole
164      0               -225  227 -229              $ Back Right Screw Hole
165      4    0.059890   -207  228 -231              $ BR Support Bolt (Upper)
166      4    0.059890   -208  228 -231              $ Lt Support Bolt (Upper)
167      4    0.059890   -209  228 -231              $ FR Support Bolt (Upper)
168      4    0.059890   -213  226 -228              $ FR Support Bolt (Lower)
169      4    0.059890   -214  226 -228              $ Lt Support Bolt (Lower)
170      4    0.059890   -215  226 -228              $ BR Support Bolt (Lower)
171      4    0.059890    207 -210  229 -230         $ BR Support Nut
172      4    0.059890    208 -211  229 -230         $ Lt Support Nut
173      4    0.059890    209 -212  229 -230         $ FR Support Nut
174      4    0.059890    200  201  202  203  204
                          205  206  213  214  215
                          216  217  218  219  220
                          221  226 -227  232 -233
                          234  235 -236 -237         $ Mounting Plate (Bottom)
175      4    0.059890    200  201  202  203  204
                          205  206  213  214  215
                          216  217  218  219  220
                          221  222  223  224  225
                          227 -228  232 -233  234
                          235 -236 -237
                         #313 #314 #315 #316 #318
                         #319 #320 #321 #322 #324    $ Mounting Plate (Middle)
176      4    0.059890    200  201  202  203  204
                          205  206  207  208  209
                          216  217  218  219  220
                          221  222  223  224  225
                          228 -229  232 -233  234
                          235 -236 -237
                         #313 #314 #315 #316 #318
                         #319 #320 #321 #322 #324    $ Mounting Plate (Top)
c  Right Clamp Support (Leg)
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177      1    0.088296    229 -230 -239              $ Front Bolt for Right Leg
178      1    0.088296    230 -264 -403              $ Front Bolt Tip, Rt Leg
179      1    0.088296    229 -230 -240              $ Back Bolt for Right Leg
180      1    0.088296    230 -266 -403              $ Back Bolt Tip, Right Leg
181      0                248  253 -255  257 -258
                          269 -275                   $ Upper Inset below Clamp
182      0               -243 -248  257 -258         $ Inset Bottom for Rt Leg
183      1    0.088296   -244  258 -261              $ Locking Bolt
c 184
185      0               -238 -298                   $ Lt End of BB Bolt Hole
186      0               -246  258 -259              $ Left Hole in Rt Leg
187      0               -241  250 -251  238 -298    $ Left Top End of Top Hole
590      0               -241  245  250 -251  238
                          298                        $ Top End of Top Hole
188      0               -250 -265  404              $ Tip of Top Hole, Rt Leg
189      0               -242  252 -254              $ Front Hole, Right Leg
190      1    0.088296    229  239  240 -247  252
                         -256  257 -262              $ Bottom Region, Right Leg
191      1    0.088296    243  247 -248  252 -256
                          257 -258                   $ Region below Insert
192      1    0.088296    248 -251  252 -253  257
                         -258                        $ Left Side of Insert
193      1    0.088296    248 -251  255 -256  257
                         -258                        $ Right Side of Insert
501      1    0.088296   -230  239  240  247  252
                         -256  258 -263              $ Btm Lwr Mdl, Right Leg
502      1    0.088296    230  252 -256  258 -263
                          264  266 -403              $ Mdl Lwr Mdl, Right Leg
194      1    0.088296    403 -248  252 -256  258
                         -263                        $ Top Lwr Mdl, Right Leg
195      1    0.088296    248 -249  252 -256  258
                         -263                        $ Upr Mdl Region, Rt Leg
503      1    0.088296    242  249  252 -254  258
                         -261 -404                   $ Btm Top Region, Rt Leg
504      1    0.088296    244  249  254 -256  258
                         -261 -404                   $ Btm Top Region, Rt Leg
505      1    0.088296   -250  252 -256  258 -261
                          265  404                   $ Mdl Top Region, Rt Leg
506      1    0.088296    246  250 -251  252 -256
                          258 -259                   $ UL Top Region, Rt Leg
196      1    0.088296    238  241  250 -251  252
                         -256  259 -298              $ Top Region, Right Leg
197      1    0.088296    241  245  250 -251  252
                         -256  298 -261              $ UR Top Region, Rt Leg
c  Right Clamp
198      0                253 -255 -267 -275         $ Void in Btm Inside Crnr
199      0                253 -255 -267  284         $ Void in Btm Inside Crnr
200      0                253 -255 -268  278         $ Void in Top Inside Crnr
201      0                253 -255 -268  284         $ Void in Top Inside Crnr
c 202
c 203
204      1    0.088296   -244 -258  285              $ Locking Bolt
205      0               -271 -258  285              $ Hole for Long Roll Pin
206      3    0.083675    253 -255 -258  267 -269
                         -275  284                   $ Bottom of Clamp Back
591      3    0.083675    253 -255 -258  267  268
                          275 -278  284 -285         $ Middle of Clamp Back
592      3    0.083675    253 -255 -258  267  268
                          275 -278  285  244  271    $ Middle of Clamp Back
208      3    0.083675    253 -255 -258  268 -270
                          278  284                   $ Top of Clamp Back
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209      3    0.083675    253 -255  267 -269 -275
                          282 -284                    $ Bottom Prong
210      3    0.083675    253 -255  267  275 -276
                          283 -284                    $ Crnr Fill for Btm Prong
211      3    0.083675    253 -255  268 -270  278
                          282 -284                    $ Top Prong
212      3    0.083675    253 -255  268  277 -278
                          283 -284                    $ Crnr Fill for Top Prong
c  Belly Band
c 213
c 214
c 215
216      1    0.088296    286 -287  288 -289          $ Solid Belly Band
c  Nuts and Bolts
217      1    0.088296      5  199 -292 -293          $ Nut on Spindle
218      1    0.088296    261 -294 -295               $ Cap of Rt Locking Bolt
c  Front Left Clamp Support (Leg)
219      like 177 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Front Bolt for FL Leg
220      like 178 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Front Bolt Tip for FL Leg
221      like 179 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Back Bolt for FL Leg
222      like 180 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Back Bolt Tip for FL Leg
223      like 181 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Upper Inset for FL Leg
224      like 182 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Inset Bottom for FL Leg
225      like 183 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Locking Bolt for FL Leg
c 226
227      like 185 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Rt End of BB Bolt Hole
228      like 186 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Right Hole in FL Leg
229      like 187 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top End of Top Hole
690      like 590 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top End of Top Hole
230      like 188 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Tip of Tope Hole, FL Leg
231      like 189 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Front Hole for FL Leg
232      like 190 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Bottom Region for FL Leg
233      like 191 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Region below Inset FL Lg
234      like 192 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ BL Side of Insert FL Leg
235      like 193 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ FL Side of Insert FL Leg
601      like 501 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Lwr Mdl Region, FL Leg
602      like 502 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Lwr Mdl Region, FL Leg
236      like 194 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Lwr Mdl Region, FL Leg
237      like 195 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Upr Mdl Region, FL Leg
603      like 503 but trcl (0 0 0  -0.5 -0.8660254 0
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                            -0.8660254 -0.5 0  0 0 1) $ Lwr Mdl Region, FL Leg
604      like 504 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Lwr Mdl Region, FL Leg
605      like 505 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Lwr Mdl Region, FL Leg
606      like 506 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Lwr Mdl Region, FL Leg
238      like 196 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top Region, FL Leg
239      like 197 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top Region, FL Leg
c  Front Left Clamp
240      like 198 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Void in Btm Inside Crnr
241      like 199 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Void in Btm Inside Crnr
242      like 200 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Void in Top Inside Crnr
243      like 201 but trcl (0 0 0  -0.5 -0.8660254 0
                           -0.8660254 -0.5 0  0 0 1) $ Void in Btm Inside Crnr
244      like 204 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Locking Bolt
245      like 205 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Hole for Long Roll Pin
246      like 206 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Bottom of Clamp Back
691      like 591  but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Middle of Clamp Back
692      like 592  but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Middle of Clamp Back
247      like 208 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top of Clamp Back
248      like 209 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Bottom Prong, FL Leg
249      like 210 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Crnr Fill for Btm Prong
250      like 211 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Top Prong, FL Leg
251      like 212 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Crnr Fill for Top Prong
c  Nuts and Bolts
252      like 218 but trcl (0 0 0  -0.5 -0.8660254 0
                            -0.8660254 -0.5 0  0 0 1) $ Crnr Fill for Top Prong
253      like 218 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Crnr Fill for Top Prong
c  Back Left Clamp Support (Leg)
254      like 177 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Front Bolt for BL Leg
255      like 178 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Front Bolt Tip for BL Leg
256      like 179 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Back Bolt for BL Leg
257      like 180 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Back Bolt Tip for BL Leg
258      like 181 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Upper Inset for BL Leg
259      like 182 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Inset Bottom for BL Leg
260      like 183 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Locking Bolt for BL Leg
c 261
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```
262      like 185 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Rt End of BB Bolt Hole
263      like 186 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Right Hole in BL Leg
264      like 187 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Top End of Top Hole
790      like 590 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Top End of Top Hole
265      like 188 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Tip of Tope Hole, BL Leg
266      like 189 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Front Hole for BL Leg
267      like 190 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Bottom Region for BL Leg
268      like 191 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Region below Inset BL Lg
269      like 192 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ BL Side of Insert BL Leg
270      like 193 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ BL Side of Insert BL Leg
701      like 501 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Lwr Mdl Region, BL Leg
702      like 502 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Lwr Mdl Region, BL Leg
271      like 194 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Lwr Mdl Region, BL Leg
272      like 195 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Upr Mdl Region, BL Leg
703      like 503 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Lwr Mdl Region, BL Leg
704      like 504 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Lwr Mdl Region, BL Leg
705      like 505 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Lwr Mdl Region, BL Leg
706      like 506 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Lwr Mdl Region, BL Leg
273      like 196 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Top Region, BL Leg
274      like 197 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Top Region, BL Leg
c  Back Left Clamp
275      like 198 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Void in Btm Inside Crnr
276      like 199 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Void in Btm Inside Crnr
277      like 200 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Void in Top Inside Crnr
278      like 201 but trcl (0 0 0  -0.5  0.8660254 0
                            -0.8660254  0.5 0  0 0 1) $ Void in Btm Inside Crnr
279      like 204 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Locking Bolt
280      like 205 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Hole for Long Roll Pin
281      like 206 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Bottom of Clamp Back
791      like 591  but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Middle of Clamp Back
792      like 592  but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Middle of Clamp Back
282      like 208 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Top of Clamp Back
```

```
283       like 209 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Bottom Prong, FL Leg
284       like 210 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Crnr Fill for Btm Prong
285       like 211 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Top Prong, FL Leg
286       like 212 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Crnr Fill for Top Prong
c  Belly Band Bolts
287       0                -245  298 -299  303          $ Void around Chamfer End
288       1    0.088296     298 -299 -303               $ Chamfer End of BB Bolt
289       1    0.088296    -245  299 -300               $ Cylinder of Rt BB Bolt
290       1    0.088296    -297  300 -301               $ Hex Head of Rt BB Bolt
291       1    0.088296    -296  301 -405               $ Cyl Head of Rt BB Bolt
292       like 287 but trcl (0 0 0  -0.5 -0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Void around Chamfer End
293       like 288 but trcl (0 0 0  -0.5 -0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Chamfer End of BB Bolt
294       like 289 but trcl (0 0 0  -0.5 -0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Cylinder of FL BB Bolt
295       like 290 but trcl (0 0 0  -0.5 -0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Hex Head of FL BB Bolt
296       like 291 but trcl (0 0 0  -0.5 -0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Cyl Head of FL BB Bolt
297       like 287 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Void around Chamfer End
298       like 288 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Chamfer End of BB Bolt
299       like 289 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Cylinder of BL BB Bolt
300       like 290 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Hex Head of BL BB Bolt
301       like 291 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Cyl Head of BL BB Bolt
302       1    0.088296     245  261 -295 -296          $ Cyl Nut on Rt BB Bolt
303       like 302 but trcl (0 0 0  -0.5 -0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Cyl Nut on FL BB Bolt
304       like 302 but trcl (0 0 0  -0.5  0.8660254 0
                             -0.8660254  0.5 0  0 0 1) $ Cly Nut on BL BB Bolt
c  See cells 213, 214, and 215 for slanted ends of bolt heads
c
c  Core Cover (Top Hat)
305       0                 233 -307 -320            $ Ft Hole in Right T Plate
306       0                 233 -308 -320            $ FM Hole in Right T Plate
307       0                 233 -309 -320            $ BM Hole in Right T Plate
308       0                 233 -310 -320            $ Bk Hole in Right T Plate
309       4    0.059890     229  304 -305 -314
                           #311 #317                 $ Side of Core Cover
310       4    0.059890    -305  314 -315            $ Core Cover Lid
311       4    0.059890     229  233 -312  317
                           -318 -320                 $ Top of Right T Plate
312       4    0.059890    -229  233  307  308
                            309  310  311  316
                           -319 -320                 $ Bottom of Right T Plate
313       like 305 but trcl (0 0 0  -0.5 -0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Hole in FL T Plate
314       like 306 but trcl (0 0 0  -0.5 -0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Hole in FL T Plate
315       like 307 but trcl (0 0 0  -0.5 -0.8660254 0
                             -0.8660254 -0.5 0  0 0 1) $ Hole in FL T Plate
316       like 308 but trcl (0 0 0  -0.5 -0.8660254 0
```

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                        -0.8660254 -0.5 0  0 0 1) $ Hole in FL T Plate
317      like 311 but trcl (0 0 0  -0.5 -0.8660254 0
                        -0.8660254 -0.5 0  0 0 1) $ Top of FL T Plate
318      like 312 but trcl (0 0 0  -0.5 -0.8660254 0
                        -0.8660254 -0.5 0  0 0 1) $ Bottom of FL T Plate
319      like 305 but trcl (0 0 0  -0.5  0.8660254 0
                        -0.8660254 -0.5 0  0 0 1) $ Hole in BL T Plate
320      like 306 but trcl (0 0 0  -0.5  0.8660254 0
                        -0.8660254 -0.5 0  0 0 1) $ Hole in BL T Plate
321      like 307 but trcl (0 0 0  -0.5  0.8660254 0
                        -0.8660254 -0.5 0  0 0 1) $ Hole in BL T Plate
322      like 308 but trcl (0 0 0  -0.5  0.8660254 0
                        -0.8660254 -0.5 0  0 0 1) $ Hole in BL T Plate
323      like 311 but trcl (0 0 0  -0.5  0.8660254 0
                        -0.8660254 -0.5 0  0 0 1) $ Top of BL T Plate
324      like 312 but trcl (0 0 0  -0.5  0.8660254 0
                        -0.8660254 -0.5 0  0 0 1) $ Bottom of BL T Plate
325      1    0.035318    305 -306  312 -313          $ Core Cover Screen
c
c  Contamination Shield (Enclosure)
c  Positions are rotated 90 degrees clockwise relative to description in Sec 1
c  viz., "front" becomes "left", "left" becomes "back," etc.
348      0                333 -335  341 -342  349
                         -351                      $ Notch in Right Plates
349      5    0.078158    333 -337  338 -339  346
                         -351                      $ Front Plate
350      5    0.078158    333 -337  339 -344  346
                         -347                      $ Left Plate
351      5    0.078158    333 -337  344 -345  346
                         -351                      $ Back Plate
352      5    0.078158    333 -335  339 -341  350
                         -351                      $ Front Lwr Part of Right Pl
353      5    0.078158    333 -335  342 -344  350
                         -351                      $ Back Lower Part of Right Pl
354      5    0.078158    335 -337  339 -344  350
                         -351                      $ Upper Part of Right Plate
355      5    0.078158    333 -334  339 -340  347
                         -350                      $ Front Bottom Plate
356      5    0.078158    333 -334  340 -343  347
                         -348                      $ Left Bottom Plate
357      5    0.078158    333 -334  343 -344  347
                         -350                      $ Back Bottom Plate
358      5    0.078158    333 -335  340 -341  349
                         -350                      $ Fr Lwr Part of Right Btm Pl
359      5    0.078158    333 -335  342 -343  349
                         -350                      $ Bk Lwr Part of Right Btm Pl
360      5    0.078158    335 -336  340 -343  349
                         -350                      $ Upper Part of Right Btm Pl
361      6    0.085432    333 -334  340 -343  348
                         -349  352  353  354  355
                          356  357  358  359  360
                          361  362  363  364 -365
                         -366  367  368            $ Bottom Steel Plate
c  Outer Void Regions
395      0                 77   81  -82  -89       $ Cyl Gap below Platform
396      0                -77   81  -82  -86       $ Crv Gap below Platform
397      0                 76   79  -81  -89       $ Gap outside SB Base
398      0                -65   78   82  -89       $ Gap outside Platform
399      0                -65  -78   82   85       $ Slanted Platform Inset
c
781      0                -62  -69   74
```

```
782       0                 -62   65   73
793       0                  18   20  -22  -89
794       0                 -17  -26
795       0                 -17   24  -25   27
796       0                  17   22  -25  -88
797       0                 -34  -44                  $ Torus Gap for Top ISP
798       0                  25  -34   42             $ Outer Slant Gap for UISP
799       0                  25   34  -37  -88        $ Fuel Ring 5 / Top ISP Gap
c  Inner Void Regions
868       0                  13 -315 -400
                           #208 #211 #247 #250 #282
                           #285 #309 #310 #325
869       0                -226  333 -400
                           #348 #349 #350 #351 #352
                           #353 #354 #355 #356 #357
                           #358 #359 #360 #361
870       0                 -13   94  229 -400  401
                            402
                           #165 #170 #171 #177 #178
                           #179 #180 #181 #182 #183
                                #185 #186 #187 #590
                           #188 #189 #190 #191 #192
                           #193 #194 #195 #196 #197
                           #204 #205 #206 #591 #592
                           #208 #210      #216 #218
                           #501 #502 #503 #504 #505
                           #506
                           #287 #288 #289 #290 #291
                           #302 #309 #311 #325        $ BR Void above Mntg Plate
871       0                 -13   94  229 -400 -401
                            402
                           #167 #168 #173 #177 #178
                           #179 #180 #181 #182 #183
                                #185 #186 #187 #590
                           #188 #189 #190 #191 #192
                           #193 #194 #195 #196 #197
                           #204 #205 #206 #591 #592
                           #208 #210      #216 #218
                           #501 #502 #503 #504 #505
                           #506
                           #287 #288 #289 #290 #291
                           #302 #309 #311 #325        $ FR Void above Mntg Plate
872       0                 -13   94  229 -400 -401
                           -402
                           #166 #169 #172
                                #216 #219 #220 #221
                           #222 #223 #224 #225
                           #227 #228 #229 #690 #230
                           #231 #232 #233 #234 #235
                           #236 #237 #238 #239 #240
                           #241 #242 #243 #244 #245
                           #246 #691 #692 #247 #248
                           #249 #250 #251 #252 #601
                           #602 #603 #604 #605 #606
                           #292 #293 #294 #295 #296
                           #303 #309 #317 #325        $ FL Void above Mntg Plate
873       0                 -13   94  229 -400  401
                           -402
                           #166 #169 #172
                                #216 #218
                           #253 #254 #255 #256 #257
```

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                                #258 #259 #260      #262
                                #263 #264 #790 #265 #266
                                #267 #268 #269 #270 #701
                                #702 #271 #272 #703 #704
                                #705 #706 #273 #274 #275
                                #276 #277 #278 #279 #280
                                #281 #791 #792 #282 #283
                                #284 #285 #286
                                #297 #298 #299 #300 #301
                                #304 #309 #323 #325       $ BL Void above Mntg Plate
874      0                       226 -229 -400
                                #305 #306 #307 #308 #311
                                #312 #313 #314 #315 #316
                                #318 #319 #320 #321 #322
                                #324
                             (-232:233:-234:-235:236:237) $ Void around Mounting Plate
875      0                        90  122 -190 -199       $ Gap between SCP and BRing
876      0                       -95  226 -156            $ Void below Control Rod 1
877      0                       -97  226 -157            $ Void below Control Rod 2
878      0                       -96  226 -154            $ Hole below Burst Rod
879      0                       -96 -104  151  154       $ Void around Burst Rod
880      0                        89  -94   95   96   97
                                -189  229
                                #198 #199 #206 #209
                                #240 #241 #246 #248
                                #275 #276 #281 #283       $ Void below Pads
881      0                        89  -94 -104   95   96
                                  97  189
                                #125 #126 #127 #128 #129
                                #130 #131 #132 #133
                                #198 #199 #591 #210
                                #239 #241 #691 #249
                                #274 #276 #791 #284      $ Void outside Pads
882      0                       -79  -89  229           $ Void below Sfty Blk Base
883      0                        89 -190 -192  199      $ Void inside Bearing Ring
884      0                        89  -94  122  191 -192 $ Void outside Bearing Ring
                                #200 #201 #591 #212
                                #241 #243 #691 #251
                                #277 #278 #791 #286      $ Void outside Bearing Ring
885      0                       -13   89  -94  192
                                #200 #208 #211
                                #242 #247 #250
                                #277 #282 #285           $ Void above Bearing Ring
886      0                       -20   62   65  -89
887      0                        35   37  -41  -89      $ Upr IISP / Fuel Ring Gap
888      0                         5  -13  -89  199 #217 $ Spindle / Fuel Ring Gap
889      0                       -61   75  -69   67      $ Upr SB/SB Base Gap
890      0                       -20  -62   69
891      0                        -3   -6   20           $ Space below Spindle
892      0                        -1    6  -12           $ Lower Glory Hole
893      0                        -2   12  -13           $ Upper Glory Hole
894      0                         5  -33   40  -41      $ Top ISP - Spindle Gap
895      0                        -4  -14                $ Bot Spindle Half Torus
896      0                        -5  -15                $ Top Spindle Half Torus
897      0                         3  -16   20  -21      $ Inter ISP-Spindle Gap
898      0                         4  -28  -43           $ TopInt ISP-Spindle Gap
899      0                         3   -4   -7   21      $ IISP-Spindle Gap
c  External Void Regions
997      0                       315
998      0                      -315  333  400
999      0                      -333
```

```
c  Surfaces for Spindle
1     cz   0.31750                               $ Glory-Hole Radius
2     cz   0.714375                              $ Glory-Hole Top Radius
3     cz   1.15570                               $ Spindle Bottom OR
4     cz   1.27000                               $ Spindle Bottom Middle OR
5     cz   1.42875                               $ Spindle Top Middle OR
6     pz   0.00254                               $ Bottom of Spindle
7     pz   1.59004                               $ Top of Spindle Bottom
8     pz   5.71754                               $ Top of Spindle Bot Middle
10    pz   8.89254                               $ Top of Spindle Top Middle
11    pz   9.21004                               $ Bottom of Spindle Top
12    pz  10.79754                               $ Bottom of Wide Glory Hole
13    pz  11.43254                               $ Top of Spindle
14    tz   0.0  0.0  5.87629  1.27000  0.15875  0.15875  $ Bottom Spindle Torus
15    tz   0.0  0.0  9.05129  1.42875  0.15875  0.15875  $ Top Spindle Torus
c  Surfaces for Intermediate Inner Subassembly Plate
16    cz   1.15951                               $ OR of Bottom IISP Hole
17    cz   3.92430                               $ OR of Upper Int Sub Plate
18    cz   4.38150                               $ OR of Lower Int Sub Plate
19    c/z  2.54000  0.0  0.31750                 $ OR of Alignment Pin Hole
20    pz   0.0                                   $ Bottom of Inter Inner SA Pl
21    pz   1.27000                               $ Top of Bottom IISP Hole
22    pz   2.54000                               $ Top of IISP Wide Region
24    pz   3.27422                               $ Bot of IISP Hole Slant
25    pz   3.49250                               $ Top of Int Inr Subassby Plate
26    tz   0.0  0.0  2.619375  3.92430  0.079375  0.079375 $ Int Sub Plate Torus
27    kz   7.25805   1  -1                       $ Outer Slant for Int ISP
28    kz   2.06375   1   1                       $ Inner Slant for Int ISP
29    k/z  2.54000  0.0  2.5400   1  1           $ Tip of Alignment Pin Hole
c  Surfaces for Shim Ring
30    cz   4.13893                               $ Shim Ring IR
31    cz   4.40055                               $ Shim Ring OR
32    pz   2.60096                               $ Top of Shim Ring
c  Surfaces for Top Inner Subassembly Plate
33    cz   3.50520                               $ Upper IR of UISP
34    cz   3.94208                               $ Lower OR of UISP
35    cz   4.415155                              $ Upper OR of UISP
36    c/z  2.54000  0.0  0.396875                $ OR of Alignment Pin Cap Hole
37    pz   4.96570                               $ Top of UISP Indentation
38    pz   6.02361                               $ Bottom of Alignment Pin Cap
39    pz   6.03504                               $ Bottom of UISP Middle IR
40    pz   6.98754                               $ Bottom of UISP Inner Annulus
41    pz   7.64794                               $ Top of Top Inr Subasmbly Pl
42    kz  -0.29083   1   1                       $ Outer Slant for Top ISP
43    kz   4.92125   1  -1                       $ Inner Slant for Top ISP
44    tz   0.0  0.0  4.80695  3.94208  0.15875  0.15875  $ Torus for Top ISP
c  Unused Surfaces
c 45
c 46
c 47
c 48
c 49
c 50
c 51
c 52
c 53
c  Surfaces for Long Alignment Pin
54    c/z  2.54000  0.0  0.31369                 $ OR of Alignment Pin Barrel
55    pz   2.806065                              $ Bottom of Alignment Pin
56    pz   2.88544                               $ Bottom of Align Pin Barrel
57    pz   7.568565                              $ Bottom of Slit in Align Pin
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58    px  -0.079375                               $ Left Edge of Align Pin Slot
59    px   0.079375                               $ Right Edge of Align Pin Slot
60    k/z  2.54000  0.0  2.57175  1  1            $ Tip of Alignment Pin
c  Surfaces for Safety Block
61    cz   1.11125                                $ SB Hole Upper Radius
62    cz   4.29260                                $ Safety Block Outer Radius
63    c/z  3.97510  0.0  0.08509                  $ Smaller SB TC Outer Radius
64    c/z  3.97510  0.0  0.15588                  $ Larger SB TC Outer Radius
65    pz  -7.74700                                $ Bottom of Safety Block
66    pz  -6.47700                                $ Interface between TC ORs
67    pz  -4.88950                                $ Interface between SB Hole ORs
68    pz  -0.60325                                $ Top of Thermocouple Hole
69    pz  -0.12700                                $ Top of Safety Block
70    py  -0.238125                               $ Front of Safety Block Notch
71    py   0.238125                               $ Back of Safety Block Notch
72    p    1.0    0.0    1.0    -11.51260         $ Bottom of Safety Block Notch
73    kz -11.88085   1   1                        $ Slant for Safety Block Bottom
74    kz   0.01189   130.646     -1               $ Slant for Saftey Bock Top
c  Surfaces for Safety Block Base
75    cz   1.10871                                $ OR of Upper SB Base
76    cz   1.90500                                $ OR of SB Base Bottom
77    cz   2.54000                                $ OR of Platform Curve
78    cz   3.65760                                $ OR of SB Base Platform
79    pz -12.98448                                $ Bottom of SB Base
80    pz -10.44448                                $ Top of SB Base Bottom Hole
81    pz  -9.79948                                $ Bottom of Platform Curve
82    pz  -9.17448                                $ Bottom of SB Base Platform
83    pz  -5.20700                                $ Top of Threaded SB Base
84    p    1.0    0.0   -1.0      4.72440         $ Slant for SB Base Notch
85    kz  -4.24815   1  -1                        $ Slant for SB Base Platform
86    tz   0.0  0.0 -9.79948   2.54000  0.62500   0.62500  $ Platform Crv Torus
87    tz   0.0  0.0 -7.667625  1.27000  0.079375  0.079375 $ Torus for SB Base
c  Surfaces for Fuel Rings
88    cz   3.97510                                $ IR of Ring 5
89    cz   4.44500                                $ IR of Rings 1-4, 6
90    cz   5.08000                                $ IR of S Pad Slots, BR Annulus
91    cz   6.34365                                $ OR of Protrusions
92    cz   6.35000                                $ IR of Slots
93    cz   7.30250                                $ OR of S Pad Slots, BR Annulus
94    cz   8.89000                                $ OR of Rings
95    c/z  3.33375   -5.774224   1.11125          $ FR Hole, Control or Burst Rod
96    c/z -6.66750    0.0        1.11125          $ Lt Hole, Control or Burst Rod
97    c/z  3.33375    5.774224   1.11125          $ BR Hole, Control or Burst Rod
98    c/z  5.249401  -3.280190   1.11125          $ Front End of Right Pad Slot
99    c/z  5.249401   3.280190   1.11125          $ Back End of Right Pad Slot
100   c/z  0.216027  -6.186209   1.11125          $ Right End of Front Pad Slot
101   c/z  0.216027   6.186209   1.11125          $ Right End of Back Pad Slot
102   c/z -5.466549  -2.906616   1.11125          $ Left End of Front Pad Slot
103   c/z -5.466549   2.906616   1.11125          $ Left End of Back Pad Slot
720   c/y  0.0        1.55702    0.08509          $ Smaller FR4 TC Outer Radius
721   c/y  0.0        1.55702    0.15588          $ Larger FR4 TC Outer Radius
104   pz  -8.06553                                $ Bottom of Ring 1
105   pz  -7.43839                                $ Top of Ring 1 Slots for Pads
106   pz  -5.21208                                $ Bottom of Ring 1 Slot
107   pz  -5.18668                                $ Bottom of Ring 2
108   pz  -4.89458                                $ Bottom of Ring 2 Outer Edge
109   pz  -2.62128                                $ Bottom of Ring 3
110   pz  -2.32918                                $ Top of Ring 2
111   pz  -2.30378                                $ Bottom of Ring 3 Outer Edge
112   pz  -0.08128                                $ Bottom of Ring 3 Slot
113   pz  -0.05588                                $ Bottom of Fuel Ring 4
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114   pz   0.23622                               $ Bottom of Ring 4 Outer Edge
115   pz   2.21742                               $ Bottom of Ring 5 Outer Edge
116   pz   2.50952                               $ Top of Fuel Ring 4
117   pz   4.64820                               $ Top of Ring 5 Outer Edge
118   pz   4.67360                               $ Bottom of Ring 6 Outer Edge
119   pz   4.96570                               $ Top of Ring 6 Slot
120   pz   7.16661                               $ Bottom of Deep Indent in 6
121   pz   7.32409                               $ Bottom of Shallow Indent in 6
122   pz   7.73264                               $ Top of Fuel Ring 6
123   py  -1.11125                               $ Front Edge of Left Notch
124   py   1.11125                               $ Back Edge of Left Notch
722   py   5.08000                               $ End of Small TC Hole
723   py   7.93750                               $ End of Larger TC Hole
125   px   8.45820                               $ Back Edge of Left Notch(2-5)
126   px   8.49376                               $ Back Edge of Left Notch(1&6)
127   p   -0.3639702  1.0        0.0   0.0       $ Left Edge of Top Deep Indent
128   p    0.3639702  1.0        0.0   0.0       $ Right Edge of Top Deep Indent
129   p   -5.6712818  1.0        0.0   0.0       $ Top Edge of BR Deep Indent
130   p   -0.8390996  1.0        0.0   0.0       $ Bottom Edge of BR Deep Indent
131   p    5.6712818  1.0        0.0   0.0       $ Top Edge of BL Deep Indent
132   p    0.8390996  1.0        0.0   0.0       $ Bottom Edge of BL Deep Indent
133   p   28.6362533  1.0        0.0   0.0       $ Rt Flat Edge, Front Pad Slot
134   p   -0.5317094  1.0        0.0   0.0       $ Lt Flat Edge, Front Pad Slot
135   p    0.5317094  1.0        0.0   0.0       $ Lt Flat Edge, Back Pad Slot
136   p  -28.6362533  1.0        0.0   0.0       $ Rt Flat Edge, Back Pad Slot
137   p   -0.6248694  1.0        0.0   0.0       $ Bk Flat Edge, Right Pad Slot
138   p    0.6248694  1.0        0.0   0.0       $ Fr Flat Edge, Right Pad Slot
139   p    1.0        1.7320508  0.0 -16.9857200 $ Back Edge, BL Notch (1 & 6)
140   p    1.0       -1.7320508  0.0 -16.9857200 $ Back Edge, BR Notch (1 & 6)
141   p    1.0        1.7320508  0.0 -16.9164000 $ Back Edge, BL Notch (2 - 5)
142   p    1.0       -1.7320508  0.0 -16.9164000 $ Back Edge, BR Notch (2 - 5)
143   p    1.7320508 -1.0        0.0   1.9247415 $ Lower Edge, BL Notch
144   p    1.7320508 -1.0        0.0  -1.9247415 $ Upper Edge, BL Notch
145   p    1.7320508  1.0        0.0   1.9247415 $ Lower Edge, BR Notch
146   p    1.7320508  1.0        0.0  -1.9247415 $ Upper Edge, BR Notch
c  Surfaces for Control Rods and Burst Rod
147   c/z  3.33375   -5.774224   0.47625         $ Control Rod 1 IR
148   c/z  3.33375   -5.774224   1.09220         $ Control Rod 1 OR
149   c/z -6.66750    0.0        0.47625         $ Burst Rod IR
150   c/z -6.66750    0.0        0.63500         $ BR Pin Head OR (Est.)
151   c/z -6.66750    0.0        1.09220         $ Burst Rod OR
152   c/z  3.33375    5.774224   0.47625         $ Control Rod 2 IR
153   c/z  3.33375    5.774224   1.09220         $ Control Rod 2 OR
154   pz -10.79627                               $ Bottom of Burst Rod (Full In)
155   pz  -8.89127                               $ Top of Burst Rod Bottom Hole
156   pz -14.75359                               $ Bottom of Control Rod 1
157   pz -15.11173                               $ Bottom of Control Rod 2
158   pz  -1.27127                               $ Flat Bottom of BR Top Hole
159   pz -12.84859                               $ Top of CR1 Bottom Hole
160   pz -13.20673                               $ Top of CR2 Bottom Hole
161   pz   1.90373                               $ Top of Burst Rod (Full In)
162   pz   3.76301                               $ Bottom of BR Pin Head
163   pz   4.51231                               $ Top of BR Pin
164   pz  -3.95859                               $ Bottom of CR1 Top Hole
165   pz  -4.31673                               $ Bottom of CR2 Top Hole
166   pz  -2.05359                               $ Top of Control Rod 1
167   pz  -2.41173                               $ Top of Control Rod 2
168   p    1.0       -1.7320508  2.0  10.46988   $ Back Edge, CR1 Notch
169   p    1.0        1.7320508  2.0   9.75360   $ Back Edge, CR2 Notch
170   p    1.7320508  1.0        0.0   0.4179439 $ Lower Edge, CR1 Notch
171   p    1.7320508  1.0        0.0  -0.4179439 $ Upper Edge, CR1 Notch
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172   p    1.7320508 -1.0        0.0   0.4179439 $ Lower Edge, CR2 Notch
173   p    1.7320508 -1.0        0.0  -0.4179439 $ Upper Edge, CR2 Notch
174   k/z  3.33375 -5.774224 -15.69339   1  1    $ Lower Slant for Control Rod 1
175   k/z  3.33375 -5.774224  -1.11379   1 -1    $ Upper Slant for Control Rod 1
176   k/z -6.66750  0.0      -11.73607   1  1    $ Lower Slant for Burst Rod
177   k/z -6.66750  0.0        2.84353   1 -1    $ Upper Slant for Burst Rod
178   k/z -6.66750  0.0       -1.54115   3  1    $ Tip of Burst Rod
179   k/z  3.33375  5.774224 -16.05153   1  1    $ Lower Slant for Control Rod 2
180   k/z  3.33375  5.774224  -1.47193   1 -1    $ Upper Slant for Control Rod 2
c  Surfaces for Support Pads
181   cz   5.08508                               $ Inner Radius of Support Pads
182   cz   7.29488                               $ Outer Radius of Support Pads
183   c/z  5.249401  -3.280190   1.10490         $ Left End of Front Pad
184   c/z  5.249401   3.280190   1.10490         $ Right End of Front Pad
185   c/z  0.216027  -6.186209   1.10490         $ Front End of Left Pad
186   c/z  0.216027   6.186209   1.10490         $ Front End of Right Pad
187   c/z -5.466549  -2.906616   1.10490         $ Back End of Left Pad
188   c/z -5.466549   2.906616   1.10490         $ Back End of Right Pad
189   pz  -9.02589                               $ Bottom of Support Pads
c  Surfaces for Bearing Ring
190   cz   5.08381                               $ Inner Radius of Bearing Ring
191   cz   7.29615                               $ Outer Radius of Bearing Ring
192   pz   8.75411                               $ Top of Bearing Ring
c  Surfaces for Subassembly Cover Plate
193   cz   1.43510                               $ Radius of Central Hole in SCP
194   c/z  0.0        2.54       0.68199         $ Back Hole, Subassby Cvr Plate
195   c/z  2.54       0.0        0.68199         $ Right Hole, Subassby Cvr Plat
196   c/z  0.0       -2.54       0.68199         $ Front Hole, Subassby Cvr Plat
197   c/z -2.54       0.0        0.68199         $ Left Hole, Subassby Cvr Plate
198   pz   7.95528                               $ Top of SCP Raised Edge
199   pz   8.27278                               $ Top of Subassembly Cvr Plate
c  Surfaces for Mounting Plate
200   cz   5.23875                               $ Radius of Central Hole in MP
201   c/z  3.33375   -5.774224   1.27000         $ FR Hole for Control Rod 1
202   c/z -6.66750    0.0        1.27000         $ Left Hole for Burst Rod
203   c/z  3.33375    5.774224   1.27000         $ BR Hole for Control Rod 2
204   c/z  7.16788    0.0        1.30467         $ Open Right Hole
205   c/z -3.58394   -6.20757    1.30467         $ Open Front Left Hole
206   c/z -3.58394    6.20757    1.30467         $ Open Back Left Hole
207   c/z  19.05000  32.99557    1.30969         $ BR Support Hole (Upper)
208   c/z -38.10000   0.0        1.30969         $ Left Support Hole (Upper)
209   c/z  19.05000 -32.99557    1.30969         $ FR Support Hole (Upper)
210   c/z  19.05000  32.99557    1.74625         $ BR Support Nut OR
211   c/z -38.10000   0.0        1.74625         $ Left Support Nut OR
212   c/z  19.05000 -32.99557    1.74625         $ FR Support Nut OR
213   c/z  19.05000 -32.99557    3.84969         $ FR Support Hole (Lower)
214   c/z -38.10000   0.0        3.84969         $ Left Support Hole (Lower)
215   c/z  19.05000  32.99557    3.84969         $ BR Support Hole (Lower)
216   c/z  -6.94690 -12.03238    0.65484         $ Front Hole for FL Leg Bolt
217   c/z  13.89380   0.0        0.65484         $ Front Hole for Rt Leg Bolt
218   c/z  -6.94690  12.03238    0.65484         $ Front Hole for BL Leg Bolt
219   c/z  -8.85190 -15.33194    0.65484         $ Back Hole for FL Leg Bolt
220   c/z  17.70380   0.0        0.65484         $ Back Hole for Rt Leg Bolt
221   c/z  -8.85190  15.33194    0.65484         $ Back Hole for BL Leg Bolt
222   c/z  13.33500 -10.79500    0.79735         $ Front Right Screw Hole
223   c/z -13.33500 -10.79500    0.79735         $ Front Left Screw Hole
224   c/z -13.33500  10.79500    0.79735         $ Back Left Screw Hole
225   c/z  13.33500  10.79500    0.79735         $ Back Right Screw Hole
226   pz  -20.37715                              $ Bottom of Mounting Plate
227   pz  -19.26590                              $ Bottom of Screw Holes
228   pz  -18.47215                              $ Middle of Mounting Plate
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229   pz  -16.56715                                    $ Top of Mounting Plate
230   pz  -14.02715                                    $ Top of Support Nuts
231   pz  -12.75715                                    $ Top of Support Bolts
232   px  -44.45000                                    $ Left (short) Edge of Mntg Pl
233   px   25.40000                                    $ Right (long) Edge of Mtng Pl
234   p    1.0       -1.7320508  0.0 -50.80000         $ BL (long) Edge of Mntg Plate
235   p    1.0        1.7320508  0.0 -50.80000         $ FL (long) Edge of Mntg Plate
236   p    1.0       -1.7320508  0.0  88.90000         $ FR (short) Edge of Mntg Plate
237   p    1.0        1.7320508  0.0  88.90000         $ BR (short) Edge of Mntg Plate
c  Surfaces for Clamp Support (Leg)
238   s    15.35430   0.0     2.80035  0.79375         $ End for BB Bolt Hole, Rt Leg
239   c/z  13.89380   0.0         0.63500              $ Front Hole for Rt Leg Bolt
240   c/z  17.70380   0.0         0.63500              $ Back Hole for Rt Leg Bolt
241   c/z  14.84630   0.0         0.47625              $ Top Hole for Right Leg
242   c/y  14.84630  -0.05715     0.47625              $ Front Hole for Right Leg
243   c/x   0.0     -10.85215     1.11125              $ Bottom Edge of Rt Leg Insert
244   c/x   0.0      -0.05715     0.555625             $ Hole for Locking Bolt
245   c/x   0.0       2.80035     0.79375              $ Belly Band Bolt Cylinder
246   c/x   0.0       3.355975    0.238125             $ Left Hole for Right Leg
247   pz  -15.29715                                    $ Bottom of Slant for Right Leg
248   pz  -10.85215                                    $ Flat Bottom of Rt Leg Inset
249   pz   -1.32715                                    $ Top of Slant for Right Leg
250   pz    1.53035                                    $ Flat Bottom of Top Hole Rt Lg
251   pz    4.38785                                    $ Top of Right Leg
252   py   -1.42875                                    $ Front Edge of Right Leg
253   py   -1.11125                                    $ Front Edge of Right Leg Inset
254   py   -0.55563                                    $ Back Edge of Front Hole Rt Lg
255   py    1.11125                                    $ Back Edge of Right Leg Inset
256   py    1.42875                                    $ Back Edge of Right Leg
257   px   12.30630                                    $ Left Edge of Right Leg
258   px   12.94130                                    $ Right Edge of Right Leg Inset
259   px   13.57630                                    $ Right Edge of Left Pin Hole
260   px   15.35430                                    $ Lt Flat Edge of BB Bolt Hole
261   px   17.38630                                    $ Right Edge of Right Leg Top
262   px   19.29130                                    $ Right Edge of Right Leg Base
263   p   22.0    0.0    3.0   378.51715               $ Slant for Right Leg
264   k/z 13.89380  0.0      -13.39215   1             $ Tip of Fr Hole, Rt Leg Bolt
265   k/z 14.84630  0.0        1.05410   1             $ Tip of Top Hole, Rt Leg Bolt
266   k/z 17.70380  0.0      -13.39215   1             $ Tip of Bk Hole, Rt Leg Bolt
c  Surfaces for Clamp
267   c/y   7.62127  -8.15086     1.11125              $ Rounded Btm Corner of Clamp
268   c/y   7.62127   7.87908     1.11125              $ Rounded Top Corner of Clamp
269   c/y   8.32927  -7.77494     4.76250              $ Curved Bottom of Clamp
270   c/y   8.32927   7.34568     4.76250              $ Curved Top of Clamp
271   c/x   0.0       3.35407     0.238125             $ Hole for Long Roll Pin
272   pz  -13.78839                                    $ Bottom Peak of Clamp
273   pz  -11.23188                                    $ Bottom of Btm Prong Edge
274   pz   -9.83597                                    $ Bottom of Straight Back
275   pz   -9.02589                                    $ Top of Bottom Prong
276   pz   -8.15086                                    $ Top of Bottom Corner Fill
277   pz    7.87908                                    $ Bottom of Top Corner Fill
278   pz    8.75411                                    $ Bottom of Top Prong
279   pz    9.56419                                    $ Top of Straight Back
280   pz   10.96010                                    $ Top of Top Prong Edge
281   pz   13.51653                                    $ Top Peak of Clamp
282   px    5.08000                                    $ Left Edge of Prongs
283   px    7.62127                                    $ Left Edge of Corner Fill
284   px    8.49630                                    $ Left Edge of Clamp Back
285   px   11.67130                                    $ Front Edge of Holes
c  Surfaces for Belly Band
286   cz   20.32000                                    $ IR for Belly Band
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287   cz   22.22500                               $ OR for Belly Band
288   pz    1.21285                               $ Bottom of Belly Band
289   pz    4.38785                               $ Top of Belly Band
290   px   20.63750                               $ Right Edge of Rt BB Bolt Hole
291   k/x  21.510625 0.0        2.80035   1       $ Slant for Right BB Bolt Hole
c  Surfaces for Nuts and Bolts
292   cz    2.22250                               $ OR for Nut on Spindle
293   pz    9.54278                               $ Top of Nut on Spindle
294   c/x   0.0       -0.05715    1.11125         $ OR of Rt Locking Bolt Cap
295   px   18.49755                               $ Rt Edge of Rt Locking Blt Cap
c  Surfaces for Right Belly Band Bolt
296   c/x   0.0       2.80035    1.190625         $ Cyl Head for Belly Band Bolt
297   c/x   0.0       2.80035    1.250786         $ Hex Head for Belly Band Bolt
298   px   14.75994                               $ Left Edge of BB Chamfer
299   px   14.84376                               $ Right Edge of BB Chamfer
300   px   19.28876                               $ Left Edge of BB Head
301   px   20.15998                               $ Right Edge of BB Hex Head
302   px   20.32000                               $ Right Edge of BB Bolt Cyl Hd
303   k/x  14.05001  0.0        2.80035   1       $ Slant for Right BB Bolt Hole
c  Surfaces for Core Cover
304   cz   25.23490                               $ IR of Core Cover
305   cz   25.40000                               $ OR of Core Cover
306   cz   25.47620                               $ OR of Steel Screen
307   c/x  -2.85750 -17.83715    0.35560          $ Front Hole on T Plate
308   c/x  -0.95250 -17.83715    0.35560          $ Front Middle Hole on T Plate
309   c/x   0.95250 -17.83715    0.35560          $ Back Middle Hole on T Plate
310   c/x   2.85750 -17.83715    0.35560          $ Back Hole on T Plate
311   pz  -19.10715                               $ Bottom of T Plate
312   pz  -14.02715                               $ Top of T-Plate
313   pz   21.53285                               $ Top of Steel Screen
314   pz   26.29535                               $ Bottom of Core Cover Lid
315   pz   26.61285                               $ Top of Core Cover Lid
316   py   -3.81000                               $ Front Edge of T Plate Bottom
317   py   -1.27000                               $ Front Edge of T Plate Top
318   py    1.27000                               $ Back Edge of T Plate Top
319   py    3.81000                               $ Back Edge of T Plate Bottom
320   px   26.03500                               $ Right Edge of Rt T Plate
c  Surfaces for Contamination Shield (Lexguard)
c  Positions are rotated 90 degrees clockwise relative to description in Sec 1
c  viz., "front" becomes "left", "left" becomes "back," etc.
321   c/y -12.70000 -41.97115    0.35687          $ Lft Screw Hole in F&B Plates
322   c/y   0.0     -41.97115    0.35687          $ Ctr Screw Hole in F&B Plates
323   c/y  12.70000 -41.97115    0.35687          $ Rht Screw Hole in F&B Plates
324   c/x -10.16000 -41.97115    0.35687          $ Fnt Screw Hole in L&R Plates
325   c/x   0.0     -41.97115    0.35687          $ Ctr Screw Hole in Left Plate
326   c/x  10.16000 -41.97115    0.35687          $ Bck Screw Hole in L&R Plates
327   c/y -12.70000 -41.97115    0.31250          $ Lft F&B Screw Holes in SS Pl
328   c/y   0.0     -41.97115    0.31250          $ Ctr F&B Screw Holes in SS Pl
329   c/y  12.70000 -41.97115    0.31250          $ Rht F&B Screw Holes in SS Pl
330   c/x -10.16000 -41.97115    0.31250          $ Fnt L&R Screw Holes in SS Pl
331   c/x   0.0     -41.97115    0.31250          $ Ctr Left Screw Hole in SS Pl
332   c/x  10.16000 -41.97115    0.31250          $ Bck L&R Screw Holes in SS Pl
333   pz  -42.92965                               $ Bottom of Contam Shield
334   pz  -41.02465                               $ Top of R, L, F Bottom Plates
335   pz  -40.37965                               $ Top of Notch in Contam Shield
336   pz  -35.30965                               $ Top of Back Bottom Plate
337   pz  -20.69465                               $ Top of Contamination Shield
338   py  -19.05000                               $ Front Edge of Front Plate
339   py  -17.78000                               $ Back Edge of Front Plate
340   py  -15.24000                               $ Back Edge of Front Btm Plate
341   py   -4.44500                               $ Front Edge of Right Pl Notch
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342   py    7.62000                                $ Back Edge of Right Pl Notch
343   py   15.24000                                $ Front Edge of Back Btm Plate
344   py   17.78000                                $ Front Edge of Back Plate
345   py   19.05000                                $ Back Edge of Back Plate
346   px  -21.59000                                $ Left Edge of Left Plate
347   px  -20.32000                                $ Left Edge of Left Btm Plate
348   px  -17.78000                                $ Right Edge of Left Btm Plate
349   px   17.78000                                $ Left Edge of Right Btm Plate
350   px   20.32000                                $ Right Edge of Right Btm Plate
351   px   21.59000                                $ Right Edge of Right Plate
c  Surfaces for Bottom Steel Plate in Contamination Shield
352   cz    1.42875                                $ Central Hole in Steel Plate
353   c/z -12.06500   0.0        2.22250           $ Magnet Drive Hole in Steel Pl
354   c/z   6.66750   0.0        1.27000           $ Hole in Steel Plate
355   c/z  -3.33248  -5.77342    1.27000           $ Hole in Steel Plate
356   c/z  -3.33248   5.77342    1.27000           $ Hole in Steel Plate
357   c/z   4.44500   0.0        0.67469           $ Hole in Steel Plate
358   c/z   0.0      -4.44500    0.67469           $ Hole in Steel Plate
359   c/z  -4.44500   0.0        0.67469           $ Hole in Steel Plate
360   c/z   0.0       4.44500    0.67469           $ Hole in Steel Plate
361   c/z  13.33500  10.79500    0.79375           $ Bk Rt Crnr Hole in Steel Pl
362   c/z  13.33500 -10.79500    0.79375           $ Fr Rt Crnr Hole in Steel Pl
363   c/z -13.33500  10.79500    0.79375           $ Fr Lt Crnr Hole in Steel Pl
364   c/z -13.33500 -10.79500    0.79375           $ Bk Lt Crnr Hole in Steel Pl
365   p    1.0        1.0        0.0  30.48000     $ Back Right Crnr of Steel Pl
366   p    1.0       -1.0        0.0  30.48000     $ Front Right Crnr of Steel Pl
367   p    1.0        1.0        0.0 -30.48000     $ Front Left Crnr of Steel Pl
368   p    1.0       -1.0        0.0 -30.48000     $ Back Left Crnr of Steel Plate
c
400   cz   45.0                                    $ Radius for imp=1 Regions
401   py    0.0
402   px    0.0
403   pz  -13.39215                                $ Top of Leg Bolts
404   pz    1.05410                                $ Bottom of Top Leg Hole Tip
405   cz   20.31900                                $ OR for Cyl Head of BB Bolt

mode     n
kcode    10000    1.0    50    550
imp:n    1.0   401r    0.0     2r
ksrc     0.0    0.0   -1.0
c        SS 303  (8.0 g/cc)
m1        6000.66c     3.0083e-4
         14028.62c     1.5821e-3       14029.62c     8.0109e-5
         14030.62c     5.3177e-5
         15031.66c     1.5554e-4
         16000.62c     4.5067e-4
         24050.62c     7.2466e-4       24052.62c     1.3974e-2
         24053.62c     1.5844e-3       24054.62c     3.9443e-4
         25055.62c     8.7693e-4
         26054.62c     3.5742e-3       26056.62c     5.5564e-2
         26057.62c     1.2722e-3       26058.62c     1.6962e-4
         28058.62c     5.0437e-3       28060.62c     1.9282e-3
         28061.62c     8.3482e-5       28062.62c     2.6522e-4
         28064.62c     6.7229e-5
         42000.66c     1.5065e-4
c        SAE 4340  (8.0 g/cc)
m2        6000.66c     1.6245e-3
         14028.62c     3.5597e-4       14029.62c     1.8024e-5
         14030.62c     1.1965e-5
         15031.66c     2.7997e-5
         16000.62c     3.0045e-5
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          24050.62c     3.2207e-5       24052.62c     6.2108e-4
          24053.62c     7.0418e-5       24054.62c     1.7530e-5
          25055.62c     6.3577e-4
          26054.62c     4.8737e-3       26056.62c     7.5765e-2
          26057.62c     1.7347e-3       26058.62c     2.3129e-4
          28058.62c     1.0088e-3       28060.62c     3.8565e-4
          28061.62c     1.6697e-5       28062.62c     5.3046e-5
          28064.62c     1.3446e-5
          42000.66c     1.2554e-4
c         VascoMax 300  (7.85 g/cc)
m3         6000.66c     8.0221e-5
          13027.62c     1.7855e-4
          14028.62c     7.9104e-5       14029.62c     4.0054e-6
          14030.62c     2.6588e-6
          15031.66c     7.7770e-6
          16000.62c     7.5112e-6
          22000.62c     7.3453e-4
          25055.62c     4.3847e-5
          26054.62c     3.4070e-3       26056.62c     5.2965e-2
          26057.62c     1.2127e-3       26058.62c     1.6169e-4
          27059.66c     7.1938e-3
          28058.62c     1.0367e-2       28060.62c     3.9635e-3
          28061.62c     1.7160e-4       28062.62c     5.4518e-4
          28064.62c     1.3819e-4
          42000.66c     2.4103e-3
c         Aluminum 6061-T6 (2.70 g/cc * 0.99925)
m4        12000.62c     6.6898e-4
          13027.62c     5.8593e-2
          14028.62c     3.2037e-4       14029.62c     1.6222e-5
          14030.62c     1.0768e-5
          22000.62c     2.5469e-5
          24050.62c     2.6495e-6       24052.62c     5.1093e-5
          24053.62c     5.7929e-6       24054.62c     1.4421e-6
          25055.62c     2.2197e-5
          26054.62c     6.0121e-6       26056.62c     9.3463e-5
          26057.62c     2.1399e-6       26058.62c     2.8532e-7
          29063.62c     4.8671e-5       29065.62c     2.1695e-5
c *****   Zinc not available in ACTI or ENDF66
c           30000.nnc     3.1082e-5
c         Lexguard  (1.2 g/cc)
m5         1001.62c     3.3161e-2
           6000.66c     3.7894e-2
           8016.62c     7.1026e-3
c         AISI 1019 Carbon Steel  (7.87 g/cc)
m6         6000.66c     6.7080e-4
          15031.66c     3.0603e-5
          16000.62c     3.6946e-5
          25055.62c     7.3328e-4
          26054.62c     4.9536e-3       26056.62c     7.7008e-2
          26057.62c     1.7632e-3       26058.62c     2.3509e-4
c         HEU + Mo (93.17 wt.% for Ring 101)
m7        42000.66c     1.7006e-3
          92233.66c     4.6602e-6       92234.66c     4.7290e-4
          92235.66c     4.3049e-2       92236.66c     3.1286e-4
          92238.66c     2.3362e-3

c         HEU + Mo (93.15 wt.% for Ring 102)
m8        42000.66c     1.7372e-3
          92233.66c     4.6969e-6       92234.66c     4.7652e-4
          92235.66c     4.3378e-2       92236.66c     3.1532e-4
          92238.66c     2.3639e-3
```

```
c        HEU + Mo (93.08 wt.% for Ring 103)
m9       42000.66c     1.7259e-3
         92233.66c     4.6930e-6       92234.66c     4.7577e-4
         92235.66c     4.3310e-2       92236.66c     3.1506e-4
         92238.66c     2.3944e-3
c        HEU + Mo (93.18 wt.% for Ring 104)
m10      42000.66c     1.7043e-3
         92233.66c     4.6825e-6       92234.66c     4.7522e-4
         92235.66c     4.3260e-2       92236.66c     3.1436e-4
         92238.66c     2.3427e-3
c        HEU + Mo (93.18 wt.% for Ring 105)
m11      42000.66c     1.7104e-3
         92233.66c     4.6429e-6       92234.66c     4.7120e-4
         92235.66c     4.2894e-2       92236.66c     3.1170e-4
         92238.66c     2.3229e-3
c        HEU + Mo (93.14 wt.% for Ring 106)
m12      42000.66c     1.7319e-3
         92233.66c     4.6905e-6       92234.66c     4.7583e-4
         92235.66c     4.3315e-2       92236.66c     3.1489e-4
         92238.66c     2.3653e-3
c        HEU + Mo (93.17 wt.% for Safety Block)
m13      42000.66c     1.1425e-3
         92233.66c     4.6488e-6       92234.66c     4.7174e-4
         92235.66c     4.2943e-2       92236.66c     3.1209e-4
         92238.66c     2.3305e-3
c        HEU + Mo (93.18 wt.% for IISP)
m14      42000.66c     1.7247e-3
         92233.66c     4.6323e-6       92234.66c     4.7012e-4
         92235.66c     4.2796e-2       92236.66c     3.1099e-4
         92238.66c     2.3176e-3
c        HEU + Mo (93.15 wt.% for TISP)
m15      42000.66c     1.7560e-3
         92233.66c     4.7168e-6       92234.66c     4.7854e-4
         92235.66c     4.3562e-2       92236.66c     3.1665e-4
         92238.66c     2.3739e-3
c        HEU + Mo (93.16 wt.% for Control Rods 1 and 2)
m16      42000.66c     1.5264e-3
         92233.66c     4.6445e-6       92234.66c     4.7126e-4
         92235.66c     4.2899e-2       92236.66c     3.1180e-4
         92238.66c     2.3329e-3
c        HEU + Mo (93.16 wt.% for Burst Rod)
m17      42000.66c     1.5507e-3
         92233.66c     4.7301e-6       92234.66c     4.7994e-4
         92235.66c     4.3690e-2       92236.66c     3.1755e-4
         92238.66c     2.3759e-3
c
totnu
prdmp     j   575
print

 end of input
```

APPENDIX C: CYLINDRICAL BURST MODEL

C.1 Description of Model

Ideally, the benchmark model for the static prompt supercritical configuration of the Godiva-IV assembly would be appropriate for modeling the prompt burst experiment as well. Unfortunately, the kinetics codes that are employed for such calculations typically are (at most) two-dimensional. This appendix describes the transformation of the benchmark model for that configuration into a two-dimensional cylindrical model and provides specifications for the materials and dimensions of that cylindrical model. It should be noted, however, that the cylindrical model obtained is only for the initial condition of the burst. Additional information would be required to model the actual burst with a kinetics code.

The starting point for the cylindrical burst model is the benchmark model for case 5, described in Section 3. The development of the benchmark model thereafter proceeds in a series of sequential steps. The sensitivity studies that are summarized below were conducted in a sequence such that, at each step, all of the preceding modifications were retained. This approach permits the reactivity impact of each modification to be determined, and it also allows the cumulative reactivity effect of all of them to be ascertained by direct comparison to the benchmark model. This approach has the added advantages that no assumptions are required concerning the mutual independence of individual modifications and that the standard deviations for each modification do not need to be compounded to produce the overall standard deviation. Instead, the net reactivity change due to all of the modeling simplifications can be computed directly from the results for just the benchmark and cylindrical burst models.

The MCNP5 calculations discussed in this appendix each employed 550 generations with 10,000 histories per generation. The first 50 generations were excluded from the statistics for each case, producing 5,000,000 active histories in each calculation. The calculations were performed with continuous-energy cross sections derived from the final release of ENDF/B-VI. Specifically, nuclear data were taken from the ACTI library[a] for those nuclides it contains, and nuclear data for the other nuclides were taken from the ENDF66 library.[b] For the case of interest herein, that combination of nuclear data corresponds to the final release of ENDF/B-VI.

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[a] S. C. Frankle, R. C. Reedy, and P. G. Young, "ACTI: An MCNP Data Library for Prompt Gamma-Ray Spectroscopy," *Proceedings of the 12th Biennial Topical Meeting of the Radiation Protection and Shielding Division*, Santa Fe, New Mexico, USA (April 2002).

[b] J . M. Campbell, S. C. Frankle, and R C. Little, "ENDF/B-VI Neutron Library for MCNP with Probability Tables," *Proceedings of the 12th Biennial Topical Meeting of the Radiation Protection and Shielding Division*, Santa Fe, New Mexico, USA (April 2002).

C.1.1 Geometry Simplifications - A vertical slice through the final cylindrical configuration for case 5 is shown in Figure C-1. Regions with the same relative isotopic composition are shown in the same color, even though they may have different densities as a result of fuel regions being homogenized with different void regions.

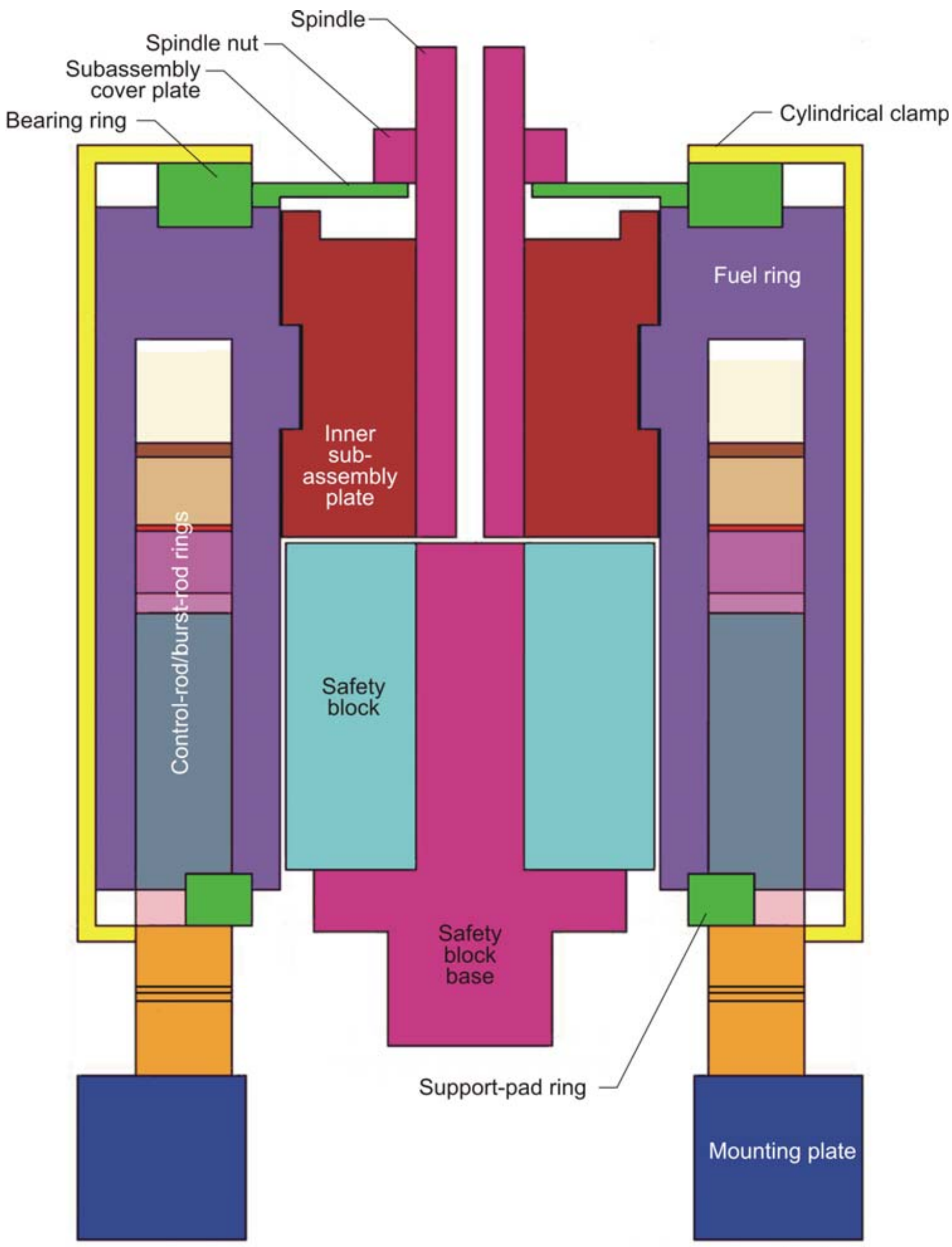

Figure C-1. Vertical Slice through the Cylindrical Burst Model for Case 5.

The individual simplifications and their impact on k_{eff} are summarized in Table C-1. The standard deviation in the calculated reactivity difference between any two steps is ± 0.0004 Δk. Reactivity changes with a mean value whose magnitude is less than 0.0004 therefore are characterized as negligible.

Table C-1. Impact of Geometric Simplifications on k_{eff}.

Modification	Δk	
	Incremental	Cumulative
Remove Holes and Gaps Associated with Control and Safety Rods:		
Remove Internal Holes from Control Rods	Negligible	0
Remove Internal Hole from Burst Rod	Negligible	0
Remove Gaps between Control Rods or Burst Rod and Fuel Ring	Negligible	0
Remove Control-Rod and Burst-Rod Holes from Mounting Plate	Negligible	0
Convert Control Rods and Burst Rods into Rings:		
Homogenize Control Rods and Burst Rod with Fuel Ring (above Support-Pad Ring)	0.0017 ± 0.0004	0.0017 ± 0.0004
Homogenize Control Rods and Burst Rod with Voids (below Support-Pad Ring)	-0.0006 ± 0.0004	0.0011 ± 0.0004
Shorten Inner Edge of Lower Clamp Prongs to be at Outer Edge of Control-Rod/Burst-Rod Ring	-0.0004 ± 0.0004	0.0007 ± 0.0004
Convert Support-Pad Ring and Enclosed Control Rods and Burst Rods to Concentric Rings	-0.0008 ± 0.0004	-0.0001 ± 0.0004
Remove Clamp Supports and Notches in Fuel Rings:		
Remove Clamp Supports	-0.0005 ± 0.0004	-0.0006 ± 0.0004
Remove Notches in Fuel Rings	-0.0088 ± 0.0004	-0.0094 ± 0.0004
Convert Clamps to Cylinder:		
Convert Top Prongs of Clamps to Cylinder	0.0008 ± 0.0004	-0.0086 ± 0.0004
Convert Bottom Prongs of Clamps to Cylinder	Negligible	-0.0086 ± 0.0004
Convert Backs of Clamps to Cylinder	0.0010 ± 0.0004	-0.0076 ± 0.0004
Produce Single Outer Radius for Cylindrical Clamp	0.0079 ± 0.0004	0.0003 ± 0.0004
Simplify Mounting Plate:		
Reduce Outer Radius of Mounting Plate to Match Cylindrical Clamp	-0.0021 ± 0.0004	-0.0018 ± 0.0004
Eliminate Gap between Mounting Plate and Control-Rod Ring	0.0012 ± 0.0004	-0.0006 ± 0.0004

The first major step in the transformation was the elimination of the internal holes in the control rods and the burst rod, as well as the gaps around them. This objective was accomplished by homogenizing the holes with the portion of the control rod or burst rod that encloses them and homogenizing the gaps with the control or burst rod that they surround. Each homogenization was performed in such a way that the overall mass is preserved. These changes produce three distinct vertical regions for each control rod and two such regions for the burst rod. None of these changes, either individually or collectively, produces a significant change in k_{eff}.

Similarly, the control-rod and burst-rod holes were removed from the mounting plate. In this case, however, those holes were removed simply by filling those holes with aluminum of the same density as the rest of the mounting plate. The actual density of the mounting plate is not known, and its reactivity worth is small (see Table 16). Not surprisingly, this change also produces a negligible change in k_{eff}.

The next major step was to combine the control and burst rods with intervening portions of the fuel rings, where present, into a series of stacked cylindrical rings. Although the philosophy for the creation of these rings is the same everywhere, its specific implementation varies depending on the presence of the fuel ring and the support-pad ring.

Between the top of the support-pad ring and the tops of the insertion holes for the control and burst rods, the inner radius of those rings was taken to be the same as the horizontal distance from the center of the core to the front of the physical holes for the control rods and the burst rod. Similarly, their outer radius was taken to be the same as the horizontal distance to the back of those holes. The height of each ring corresponds to a distance over which the contents of each of the three holes is uniform. Within that distance, the contents were homogenized with the portion of the fuel ring contained within the annulus in such a way that the mass and the average isotopics are preserved. A total of seven separate rings is required to accommodate the vertical variations in the positions of the control-rod and burst-rod regions. As Table C-1 indicates, this process produces a small increase in k_{eff}.

From the bottom of the lowest physical control rod to the bottom of the support-pad ring, there are additional rings that homogenize the control rods and burst rod, if present, with void to produce rings with the same inner and outer radii as those above the support-pad ring. A total of four such rings is required to accommodate the vertical variations in the positions of the control-rod and burst-rod regions. The homogenization process preserves both the mass and the average isotopics within each of those four rings, and it produces a marginal decrease in k_{eff}.

The creation of the rings below the support-pad ring produces a conflict with the bottom prongs of the three clamps. Those prongs simply were shortened to eliminate that conflict. As Table C-1 indicates, this change has at most a marginal impact on k_{eff}.

As Figures 32 and 33 in Section 3 indicate, the combination of the support-pad ring and the control and burst rods produces a complicated geometry even within the benchmark model. There is one annulus of fuel inside the support-pad ring and another outside it. Furthermore, the control and burst rods displace portions of both the support-pad ring and the fuel annulus outside it. In order to produce a strictly cylindrical geometry, this region was converted into four concentric rings. The innermost ring is identical to the inner fuel annulus in the benchmark model. The second ring has the same mass and volume as the support-pad ring, but its outer radius has been shrunk to exclude the control and burst rods. The outer radius of the third ring is the same as that of the homogenized control-rod/burst-rod/fuel rings above it, and its composition is a homogeneous average of the control rods, the burst rod, and the portion of the fuel ring contained within that annulus. The composition of the outermost annulus is the same as that of the fuel ring. This conversion reduces k_{eff} slightly.

It should be noted, however, that the heights of those four rings are not all the same. The innermost and outermost rings only extend down to the bottom of the original fuel ring, while the height of the two middle rings is the same as that of the support-pad ring.

The transformation of the portions of the control and burst rods inside the fuel ring increases k_{eff} by 0.0017 ± 0.0004, while the remaining transformations cumulatively reduce it by 0.0018 ± 0.0004. Consequently, the overall transformation of the control and burst rods has essentially no impact on k_{eff}.

The third major step was the elimination of the clamp supports and the notches in the fuel rings. Eliminating the clamp supports has only a marginal impact on k_{eff}, because they sit directly behind the clamps and are far enough from the fuel rings that they reflect only a very small fraction of the neutrons that leak from the fuel. In contrast, removing the notches produces the largest change in k_{eff} of any of the changes made during the transformation. Removing the notches while preserving the mass and density of the fuel rings requires reducing the outer radius of the fuel rings and shifting the clamps outward so that they do not penetrate the fuel rings. These two changes substantially reduce the amount of contact between the fuel and the only reflectors on the sides of the configuration. The result is a reduction in k_{eff} of nearly 0.009 Δk.

The fourth major step was to convert the clamps into a smooth cylinder. The conversions of the top prongs, bottom prongs, and backs of the clamps into cylinders were performed separately. The inner radius of the top prongs was chosen to correspond to the physical location of its front edge, while the inner radius of the bottom prongs was taken to be the outer radius of the revised support-pad ring. The common outer radius of the top and bottom prongs was chosen to be the same as the physical back edge of the clamps. Their thicknesses then were chosen to preserve the mass and density of the prongs, which produces two fairly thin disks. The inner radius of the middle part of the cylinder that corresponds to the backs of the clamps between the prongs was chosen to be the same as the outer radius of the fuel rings, and its top and bottom edges remained the same as the bottom edge of the top prongs and the top edge of the bottom prongs, respectively. The outer radius of the middle part of the cylinder was determined by preserving the cumulative mass and volume of the middle portions of the backs of the clamps. This last transformation produces a very thin layer of VascoMax 300 around the outer edges of the fuel rings.

To this point, the transformation of the clamps into cylinders has produced only a small increase in k_{eff} (approximately 0.002 Δk). It also has produced a cylinder with a very wide top and bottom and a very thin annular region between them.

The creation of the cylindrical burst model has two objectives: to produce a simplified cylindrical model and to preserve k_{eff}, at least approximately. Fortunately, insofar as the clamps are concerned, both of these objectives can be satisfied by a single further transformation. A common outer radius was determined for the top, middle, and bottom regions of the cylindrical clamp that preserves the cumulative mass and volume of those three components. Because it thickens the middle region of the cylindrical clamp, this change increases neutron reflection and produces a substantial increase in k_{eff} (approximately 0.008 Δk). That change happens to be approximately equal in magnitude but opposite in sign to the reactivity effect of removing the notches.

The final major step in the creation of the cylindrical burst model was to simplify the mounting plate further. Because the reactivity worth of the mounting plate is approximately 0.003 Δk, simply removing it was not considered acceptable. Reducing the plate's outer radius to be the same as that of the cylindrical clamp and moving it upward so that it is in contact with the bottom control-rod/burst-rod ring produces a net change in k_{eff} of approximately -0.001 Δk, which is considered an acceptably small change.

C.1.2 Material Simplifications - The bottom four control-rod/burst-rod rings (i.e., those below the support ring) were assumed to have the same atom fractions as the control rods, even though they are combinations of the burst rod and one or both of the control rods. This simplification does not produce a significant change in k_{eff}.

No specific material simplifications were made for any other regions . Different materials were combined when the regions containing them were homogenized or transformed as part of the geometric simplifications, but the reactivity impact of those changes is included in the results reported in Table C-1.

C.2 Dimensions

The dimensions of the non-fuel components of the cylindrical burst model are given in Table C-2, the dimensions of the control-rod/burst-rod rings are given in Table C-3, and those of the fuel-ring regions, inner subassembly plate, and safety block are given in Table C-4. The control-rod/burst-rod rings, of course, are homogenized composites of the control rods, burst rod, open holes, and fuel rings at the appropriate heights. Those rings, as well as the fuel-ring regions, are numbered sequentially downward from the top of the assembly. The origin of the coordinate system is at the center of the bottom surface of the inner subassembly plate.

Table C-2. Dimensions of Non-Fuel Components.

Component	Inner Radius (cm)	Outer Radius (cm)	Height (cm)	Top (cm)	Bottom (cm)
Spindle	0.31750	1.27000	11.43000	11.43254	0.00254
Nut on Spindle	1.27000	2.22225	1.27000	9.54278	8.27278
Subassembly Cover Plate					
Inner Region	1.43510	4.44500	0.31750	8.27278	7.95528
Outer Region	4.44500	5.08000	0.54014	8.27278	7.73264
Bearing Ring	5.08381	7.29615	1.48251	8.75411	7.27160
Safety Block Base					
Top Region (Barrel)	—	1.27000	7.62000	-0.12700	-7.74700
Middle Region (Platform)	—	3.65760	1.42748	-7.74700	-9.17448
Bottom Region	—	1.90500	4.02032	-9.17448	-11.85559
Support Pad Ring	5.08508	6.64161	1.19062	-7.59414	-9.02589
Clamp					
Top Region	5.08000	9.13706	0.42985	9.18396	8.75411
Middle Region	8.74898	9.13706	0.27278	8.75411	-9.02589
Bottom Region	7.77875	9.13706	0.37386	-9.02589	-9.39975
Mounting Plate	5.23875	9.13706	3.81000	-12.54633	-16.35633

Table C-3. Dimensions of Control-Rod/Burst-Rod Rings.

Ring	Inner Radius (cm)	Outer Radius (cm)	Height (cm)	Top (cm)	Bottom (cm)
1	5.55625	7.77875	2.43713	4.64820	2.21107
2	5.55625	7.77875	0.30734	2.21107	1.90373
3	5.55625	7.77875	1.59766	1.90373	0.30607
4	5.55625	7.77875	0.15240	0.30607	0.15367
5	5.55625	7.77875	1.42494	0.15367	-1.27127
6	5.55625	7.77875	0.48006	-1.27127	-1.75133
7	5.55625	7.77875*	6.08394	-1.75133	-8.18014*
8	6.64161	7.77875	1.19062	-8.18014	-9.02589
9	5.55625	7.77875	1.46304	-9.02589	-10.48893
10	5.55625	7.77875	0.15240	-10.48893	-10.64133
11	5.55625	7.77875	0.15494	-10.64133	-10.79627
12	5.55625	7.77875	1.75006	-10.79627	-12.54633

* Ring 7 has a jagged bottom edge. From its inner radius to a radius of 6.64161 cm its bottom edge
is at -7.59414 cm, and from that point outward its bottom edge is at -8.18014 cm.

Table C-4. Dimensions of Fuel Rings, Inner Subassembly Plate, and Safety Block.

Component	Inner Radius (cm)	Outer Radius (cm)	Height (cm)	Top (cm)	Bottom (cm)
Inner Subassembly Plate					
Region 1 (Top)	3.50520	4.38150	0.66040	7.64794	6.98754
Region 2 (Upper Middle)	1.27000	4.38150	2.02184	6.98754	4.96570
Region 3 (Lower Middle)	1.27000	3.92430	2.42570	4.96570	2.54000
Region 4 (Bottom)	1.27000	4.38150	2.54000	2.54000	0.0
Safety Block	1.27000	4.29260	7.62000	-0.12700	-7.74700
Fuel Rings					
Ring 1 (Inner Top)	4.44500	5.08381	0.46104	7.73264	7.27160
Ring 2 (Outer Top)	7.29615	8.74898	0.46104	7.73264	7.27160
Ring 3 (Narrow Upper Middle)	4.44500	8.74898	2.30590	7.27160	4.96570
Ring 4 (Wide Upper Middle)	3.97510	8.74898	0.31750	4.96570	4.64820
Ring 5 (Inner Wide Middle)	7.77875	8.74898	12.48347	4.64820	-7.59414
Ring 6 (Inner Narrow Middle)	3.97510	5.55625	2.10820	4.64820	2.54000
Ring 7 (Outer Middle)	4.44500	5.55625	10.37527	2.54000	-7.59414
Ring 8 (Inner Bottom)	4.44500	5.08508	0.34487	-7.59414	-8.18014
Ring 9 (Outer Bottom)	7.77875	8.74898	0.34487	-7.59414	-8.18014

C.3 Material Data

C.3.1 Fuel - As discussed in Section 3.1.2, the geometric simplifications for the cylindrical burst model produce several distinct fuel components: the safety block, the homogenized inner subassembly plate, nine individually homogenized fuel rings, and twelve individually homogenized control-rod/burst-rod rings. The homogenized fuel rings all have exactly the same density and composition, but each control-rod/burst-rod ring has its own composition and density based upon the regions of the control rods and burst rod it contains. The molybdenum atom densities are given in Table C-5, and the corresponding uranium isotopic number densities are given in Table C-6.

Table C-5. Molybdenum Concentrations for Fuel Pieces.

Component	Molybdenum Concentration (atoms/b-cm)
Safety Block	1.1384×10^{-3}
Inner Subassembly Plate	1.7407×10^{-3}
Fuel Rings	1.7082×10^{-3}
Control-Rod/Burst-Rod Rings	
1	1.5214×10^{-3}
2	1.5652×10^{-3}
3	1.6100×10^{-3}
4	1.6203×10^{-3}
5	1.6642×10^{-3}
6	1.6747×10^{-3}
7	1.6850×10^{-3}
8	2.1461×10^{-4}
9	1.6187×10^{-4}
10	1.1211×10^{-4}
11	1.0043×10^{-4}
12	4.9758×10^{-5}

Table C-6. Uranium Isotopic Concentrations for Fuel Pieces.

Isotope→ Region ↓	Number Density (atoms/b-cm)				
	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U
Safety Block	4.6322×10^{-6}	4.7005×10^{-4}	4.2791×10^{-2}	3.1098×10^{-4}	2.3222×10^{-3}
ISP	4.6755×10^{-6}	4.7433×10^{-4}	4.3180×10^{-2}	3.1388×10^{-4}	2.3534×10^{-3}
Fuel Rings	4.6484×10^{-6}	4.7161×10^{-4}	4.2932×10^{-2}	3.1206×10^{-4}	2.3379×10^{-3}
CR/BR					
Rings	4.1400×10^{-6}	4.2003×10^{-4}	3.8236×10^{-2}	2.7793×10^{-4}	2.0822×10^{-3}
1	4.2735×10^{-6}	4.3358×10^{-4}	3.9470×10^{-2}	2.8689×10^{-4}	2.1493×10^{-3}
2	4.4101×10^{-6}	4.4744×10^{-4}	4.0731×10^{-2}	2.9606×10^{-4}	2.2179×10^{-3}
3	4.4415×10^{-6}	4.5062×10^{-4}	4.1021×10^{-2}	2.9817×10^{-4}	2.2336×10^{-3}
4	4.5750×10^{-6}	4.6416×10^{-4}	4.2254×10^{-2}	3.0713×10^{-4}	2.3007×10^{-3}
5	4.6070×10^{-6}	4.6742×10^{-4}	4.2550×10^{-2}	3.0928×10^{-4}	2.3168×10^{-3}
6	4.6384×10^{-6}	4.7060×10^{-4}	4.2840×10^{-2}	3.1139×10^{-4}	2.3325×10^{-3}
7	6.5462×10^{-7}	6.6420×10^{-5}	6.0465×10^{-3}	4.3946×10^{-5}	3.2882×10^{-4}
8	4.9252×10^{-7}	4.9972×10^{-5}	4.5491×10^{-3}	3.3065×10^{-5}	2.4740×10^{-4}
9	3.4112×10^{-7}	3.4611×10^{-5}	3.1508×10^{-3}	2.2901×10^{-5}	1.7135×10^{-4}
10	3.0558×10^{-7}	3.1005×10^{-5}	2.8225×10^{-3}	2.0515×10^{-5}	1.5439×10^{-4}
11	1.5140×10^{-7}	1.5361×10^{-5}	1.3984×10^{-3}	1.0164×10^{-5}	7.6046×10^{-5}
12					

C.3.2 Stainless Steel 303 - The spindle and the base for the safety block are made from stainless steel 303. The density and composition of those two components are unchanged from the benchmark model discussed in Section 3. The elemental number densities for stainless steel 303 were presented in Table 38 and are repeated in Table C-7 for convenience.

Table C-7. Elemental Concentrations for Stainless Steel 303.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.075	3.0083×10^{-4}
Silicon	1.00	1.7154×10^{-3}
Phosphorus	0.10	1.5554×10^{-4}
Sulfur	0.30	4.5067×10^{-4}
Chromium	18.00	1.6678×10^{-2}
Manganese	1.00	8.7693×10^{-4}
Iron	70.225	6.0580×10^{-2}
Nickel	9.00	7.3878×10^{-3}
Molybdenum	0.30	1.5065×10^{-4}

C.3.3 VascoMax 300 Maraging Steel - The cylindrical clamp is made of VascoMax 300 maraging steel, and its density and composition are the same as for the benchmark model discussed in Section 3. The elemental number densities for the clamp were given in Table 39, which is reproduced here as Table C-8.

Table C-8. Elemental Concentrations for VascoMax 300 Maraging Steel.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.020	8.0221×10^{-5}
Aluminum	0.100	1.7855×10^{-4}
Silicon	0.050	8.5768×10^{-5}
Phosphorus	0.005	7.7770×10^{-6}
Sulfur	0.005	7.5112×10^{-6}
Ttanium	0.730	7.3453×10^{-4}
Manganese	0.050	4.3847×10^{-5}
Iron	66.940	5.7746×10^{-2}
Cobalt	8.800	7.1938×10^{-3}
Nickel	18.500	1.5186×10^{-2}
Molybdenum	4.800	2.4103×10^{-3}

C.3.4 SAE 4340 - The bearing ring, the subassembly cover plate, and the support-pad ring are made of SAE 4340. The density and composition of those three components are unchanged from the benchmark model discussed in Section 3. The elemental number densities for SAE 4340 were presented in Table 40 and are repeated in Table C-9 for convenience.

Table C-9. Elemental Concentrations for SAE 4340.

Element	Content (wt.%)	Number Density (atoms/b-cm)
Carbon	0.405	1.5940×10^{-3}
Silicon	0.225	3.7872×10^{-4}
Phosphorus	0.018	2.7472×10^{-5}
Sulfur	0.020	2.9481×10^{-5}
Chromium	0.800	7.2734×10^{-4}
Manganese	0.725	6.2385×10^{-4}
Iron	95.757	8.1057×10^{-2}
Nickel	1.800	1.4499×10^{-3}
Molybdenum	0.250	1.2319×10^{-4}

C.3.5 Aluminum - The composition of the mounting plate is pure aluminum. In Section 3, the density of the aluminum was determined to be 2.62521 g/cm^3, which corresponds to a number density of 5.8593×10^{-2} atoms/b-cm. The same composition and concentration are retained for the cylindrical burst model.

C.4 <u>Temperature Data</u>

The measured ambient temperature prior to the initiation of the burst was 20.5 °C. Doppler effects are irrelevant for configurations with fast spectra, and the reactivity effects of thermal expansion from approximately 20°C to 20.5°C are negligible. Consequently, calculations that employ cross sections at 20°C are adequate for the initial condition that this model represents.

C.5 <u>Experimental and Burst-Model k_{eff}</u>

In Section 3.5, the measured and experimental values for k_{eff} for the static prompt supercritical configuration are given as 1.0066 ± 0.0003 and 1.0066 ± 0.0026, respectively. Those values are not affected by the transformation described in this appendix.

Table C-10 compares the calculated results from the detailed, benchmark, and cylindrical burst models. It is clear that the three models produce essentially identical results, at least as far as reactivity and isotopic fission rates are concerned. The difference between the calculated values of k_{eff} for the detailed and burst models is -0.0010 ± 0.0004 Δk. Consequently, the target value of k_{eff} for the cylindrical burst model is 1.0056 ± 0.0026.

Table C-10. Comparison of Results from Detailed, Benchmark, and Cylindrical Models for Case 5.

Parameter		Model		
		Detailed	Benchmark	Cylindrical
k_{eff}		1.0000 ± 0.0003	1.0003 ± 0.0003	0.9990 ± 0.0003
Fission Distribution, by Energy	Fast	0.9438	0.9441	0.9438
	Intermediate	0.0562	0.0559	0.0562
	Thermal	0.0	0.0	0.0
Fission Fraction, by Isotope	^{233}U	0.0002	0.0002	0.0002
	^{234}U	0.0084	0.0084	0.0084
	^{235}U	0.9807	0.9807	0.9807
	^{236}U	0.0023	0.0023	0.0023
	^{238}U	0.0084	0.0084	0.0084
Average Number of Neutrons Produced per Fission		2.593	2.593	2.593

The difference in the levels of complexity among the three models for case is indicated in Table C-11, along with their relative MCNP5 execution times.

Table C-11. Comparison of MCNP Models for Case 5.

Model	Cells	Surfaces	Materials	Relative Run Time
Detailed	405	365	17	1.00
Benchmark	99	90	9	0.31
Cylindrical	66	58	16	0.23

Results from the MCNP5 Monte Carlo code with a variety of nuclear data libraries are presented in Table C-12. JENDL-3.3 clearly produces the best agreement with the target value for k_{eff}.

Table C-12. MCNP5 Results for Cylindrical Burst Model of Godiva-IV Case 5.

Calculated k_{eff}			
ENDF/B-VI	ENDF/B-VII.0	JEFF-3.1	JENDL-3.3
0.9990 ± 0.0003	1.0026 ± 0.0003	0.9984 ± 0.0003	1.0060 ± 0.0003

C.6 <u>MCNP Input Listing</u>

The MCNP input file listed below employs continuous-energy cross sections derived from ENDF/B-VI. The corresponding MCNP input files for other nuclear data libraries would be identical except for the suffix of the ZAID identifier for the various nuclides.

This particular case employs 550 generations of 10,000 neutrons each, and exclude the first 50 generations from the statistics. Consequently, the results it produces are based on 5,000,000 active histories.

```
 Godiva-IV  HEU-MET-FAST-086  Case 5  Burst Model  Final Model  ENDF/B-VI
c  Spindle
1       1    0.088296      1   -2   40  -58          $ Spindle
2       0                  2   -3   49  -54
3       0                  2   -3   57  -58
c  Homogenized Subassembly Plate
4       9    0.048067      2  -12   39  -45          $ ISP Bottom Region
5       9    0.048067      2   -9   45  -48          $ ISP Middle Region
6       9    0.048067      2  -12   48  -49          $ ISP Top Region
7       9    0.048067      7  -12   49  -51          $ ISP Top Edge
c  Safety Block
```

```
8        5    0.047037      2  -11   35  -38          $ Cylindrical Safety
Block
c  Safety Block Base
9        1    0.088296     -5   26  -31               $ SB Base Solid Round
10       1    0.088296     -8   31  -35               $ SB Base Platform
11       1    0.088296     -2   35  -38               $ Lower SB Base Barrel

c  Homogenized HEU Rings
12       8    0.047766     13  -16   33  -34          $ Inner Bottom Annulus
13       8    0.047766     21  -22   33  -34  #42     $ Outer Bottom Annulus
14       8    0.047766     13  -18   34  -45          $ Lower Narrow Inr
Region
15       8    0.047766     10  -18   45  -47          $ Lower Wide Inner
Region
16       8    0.047766     21  -22   34  -47  #42     $ Lower Outer Region
17      10    0.047644     18  -21   33  -36  #33     $ Ctr Region  2CR, BR
18      15    0.047323     18  -21   36  -37          $ Ctr Region  CR, CRH,
BR
19      14    0.046995     18  -21   37  -41          $ Ctr Region  CR, CRH,
BRH
20      13    0.045628     18  -21   41  -42          $ Ctr Region  1CR, BRH
21      12    0.045307     18  -21   42  -43          $ Ctr Region  1CRH, BRH
22      11    0.043909     18  -21   43  -44          $ Ctr Region  1CRH
23      16    0.042542     18  -21   44  -47          $ Ctr Region  3 Holes
24       8    0.047766     10  -22   47  -48  #42     $ Upper Wide Region
25       8    0.047766     13  -22   48  -50  #42     $ Upper Narrow Region
26       8    0.047766     13  -15   50  -52          $ Inr Top Narrow Region
27       8    0.047766     20  -22   50  -52
                          #34  #42                    $ Otr Top Narrow Region
c  Control and Burst Rods
28       6    0.0015499    18  -21   25  -27          $ Ring with Homog
CR+Hole
29       6    0.0031282    18  -21   27  -28          $ Ring with Homog CRH,
BRH
30       6    0.0034921    18  -21   28  -29          $ Ring with Homog CR,
BRH
31       6    0.0050419    18  -21   29  -32          $ Ring with Hom
CR,CRH,BRH
32       7    0.0067009    19  -21   32  -33          $ Homog Ring outsd SP
Ring
c  Support Pads Converted to Ring
33       2    0.086011     16  -19   32  -34          $ Support Pads as Ring
c  Bearing Ring
34       2    0.086011     15  -20   50  -55          $ Solid Bearing Ring
c  Subassembly Cover Plate
35       0                  3   -4   51  -54          $ Central Hole in SCP
36       0                  4  -13   51  -53          $ Inner Void in SCP
37       2    0.086011     13  -14   52  -54          $ Edge of SCP
38       2    0.086011      4  -13   53  -54          $ Center of SCP
c  Mounting Plate
39       0                -17   24  -25               $ Empty Central Hole
40       4    0.058593     17  -23   24  -25          $ Mounting Plate
c  Clamps
41       3    0.083675     21  -23   30  -32          $ Btm of Cylindrical
Clamp
42       3    0.083675     22  -23   32  -55          $ Mdl of Cylindrical
Clamp
43       3    0.083675     14  -23   55  -56          $ Top of Cylindrical
```

```
Clamp
c  Nut on Spindle
44       1    0.088296      2   -6   54  -57          $ Nut on Spindle
c  Outer Void Regions
45       0                  5  -13   26  -31          $ Gap below SB Platform
46       0                  8  -13   31  -35          $ Gap outside SB
Platform
47       0                 12  -13   39  -45
48       0                  9  -10   45  -46
49       0                  9  -10   46  -48      $ HEU Ring / Top ISP Gap
c  Inner Void Regions
50       0                 14  -15   52  -54      $ Gap between SCP and BRing
51       0                 13  -23   25  -32
                          #28  #29  #30  #31
                          #41  #42                $ Void below Pads
52       0                 13  -23   32  -33
                          #32  #33  #42           $ Void outside Pads
53       0                -13   25  -26           $ Void below Sfty Blk Base
54       0                 13  -15   54  -55      $ Void inside Bearing Ring

55       0                 13   20  -23   52  -55
                          #42                     $ Void outside Bearing Ring
56       0                 13  -23   55  -58
                          #43                     $ Void above Bearing Ring
57       0                 11  -13   35  -39
58       0                 12  -13   48  -51      $ Upr ISP / HEU Ring Gap
59       0                  3  -13   54  -58  #44 $ Spindle / HEU Ring Gap
60       0                -11   38  -39
61       0                 -2   39  -40           $ Space below Spindle
62       0                 -1   40  -58           $ Glory Hole
63       0                  3   -7   49  -51      $ Top ISP - Spindle Gap
c  External Void Regions
64       0                -24
65       0                 23   24  -58
66       0                 58

1      cz   0.31750                              $ Glory-Hole Radius
2      cz   1.27000                              $ Spindle Bottom Middle OR
3      cz   1.42875                              $ Spindle Top Middle OR
4      cz   1.43510                              $ Radius of Central Hole in
SCP
5      cz   1.90500                              $ OR of SB Base Bottom
6      cz   2.22250                              $ OR for Nut on Spindle
7      cz   3.50520                              $ Upper IR of UISP
8      cz   3.65760                              $ OR of SB Base Platform
9      cz   3.92430                              $ OR of Upper Int Sub Plate
10     cz   3.97510                              $ Narrow IR of Fuel Ring
11     cz   4.29260                              $ Safety Block Outer Radius
12     cz   4.38150                              $ OR of Lower Int Sub Plate
13     cz   4.44500                              $ Inner Radius of Fuel Rings
14     cz   5.08000                              $ IR of S Pad Slots, BR
Annulus
15     cz   5.08381                              $ Inner Radius of Bearing
Ring
16     cz   5.08508                              $ Inner Radius of Sprt Pad
Ring
17     cz   5.23875                              $ Radius of Central Hole in
MP
```

```
18    cz   5.55625                                 $ Inner Radius of CR/BR Ring
19    cz   6.64161                                 $ Outer Radius of Sprt Pad
Ring
20    cz   7.29615                                 $ Outer Radius of Bearing
Ring
21    cz   7.77875                                 $ Outer Radius of CR/BR Ring
22    cz   8.74898                                 $ Outer Radius of Fuel Ring
23    cz   9.13706                                 $ OR of Cylindrical Clamp
24    pz -16.35633                                 $ Bottom of Mounting Plate
25    pz -12.54633                                 $ Bottom of Control Rod 2
26    pz -11.85559                                 $ Top of SB Base Bottom Hole
27    pz -10.79627                                 $ Bottom of Burst Rod (Full
In)
28    pz -10.64133                                 $ Top of CR2 Bottom Hole
29    pz -10.48893                                 $ Bottom of Control Rod 1
30    pz  -9.39975                                 $ Bottom of Cylindrical Clamp
31    pz  -9.17448                                 $ Bottom of SB Base Platform
32    pz  -9.02589                                 $ Bottom of Support-Pad Ring
33    pz  -8.18014                                 $ Bottom of Homog Fuel Ring
34    pz  -7.59414                                 $ Top of Bottom Fuel Ring
Slot
35    pz  -7.74700                                 $ Bottom of Safety Block
36    pz  -1.75133                                 $ Bottom of CR2 Top Hole
37    pz  -1.27127                                 $ Flat Bottom of BR Top Hole
38    pz  -0.12700                                 $ Top of Safety Block
39    pz   0.0                                     $ Bottom of Inter Inner SA Pl
40    pz   0.00254                                 $ Bottom of Spindle
41    pz   0.15367                                 $ Top of Control Rod 2
42    pz   0.30607                                 $ Bottom of CR1 Top Hole
43    pz   1.90373                                 $ Top of Burst Rod (Full In)

44    pz   2.21107                                 $ Top of Control Rod 1
45    pz   2.54000                                 $ Top of IISP Wide Region
46    pz   3.49250                                 $ Top of Int Inr Subassby
Plate
47    pz   4.64820                                 $ Top of Ring 5 Outer Edge
48    pz   4.96570                                 $ Top of UISP Indentation
49    pz   6.98754                                 $ Bottom of UISP Inner
Annulus
50    pz   7.27160                                 $ Bottom of Bearing Ring
51    pz   7.64794                                 $ Top of Top Inr Subasmbly Pl
52    pz   7.73264                                 $ Top of Fuel Ring
53    pz   7.95528                                 $ Top of SCP Raised Edge
54    pz   8.27278                                 $ Top of Subassembly Cvr
Plate
55    pz   8.75411                                 $ Top of Bearing Ring
56    pz   9.18396                                 $ Top of Cylindrical Clamp
57    pz   9.54278                                 $ Top of Nut on Spindle
58    pz  11.43254                                 $ Top of Spindle

mode      n
kcode     10000    1.0    50    550
imp:n     1.0      62r   0.0     2r
ksrc      0.0    0.0   -1.0
c         SS 303  (8.0 g/cc)
m1         6000.66c     3.0083e-4
          14028.62c     1.5821e-3       14029.62c     8.0109e-5
          14030.62c     5.3177e-5
```

```
         15031.66c     1.5554e-4
         16000.62c     4.5067e-4
         24050.62c     7.2466e-4       24052.62c     1.3974e-2
         24053.62c     1.5844e-3       24054.62c     3.9443e-4
         25055.62c     8.7693e-4
         26054.62c     3.5742e-3       26056.62c     5.5564e-2
         26057.62c     1.2722e-3       26058.62c     1.6962e-4
         28058.62c     5.0437e-3       28060.62c     1.9282e-3
         28061.62c     8.3482e-5       28062.62c     2.6522e-4
         28064.62c     6.7229e-5
         42000.66c     1.5065e-4
c        SAE 4340  (7.85 g/cc)
m2        6000.66c     1.5940e-3
         14028.62c     3.4929e-4       14029.62c     1.7686e-5
         14030.62c     1.1740e-5
         15031.66c     2.7472e-5
         16000.62c     2.9481e-5
         24050.62c     3.1603e-5       24052.62c     6.0944e-4
         24053.62c     6.9097e-5       24054.62c     1.7202e-5
         25055.62c     6.2385e-4
         26054.62c     4.7824e-3       26056.62c     7.4345e-2
         26057.62c     1.7022e-3       26058.62c     2.2696e-4
         28058.62c     9.8985e-4       28060.62c     3.7842e-4
         28061.62c     1.6384e-5       28062.62c     5.2051e-5
         28064.62c     1.3194e-5
         42000.66c     1.2319e-4
c        VascoMax 300  (8.0 g/cc)
m3        6000.66c     8.0221e-5
         13027.62c     1.7855e-4
         14028.62c     7.9104e-5       14029.62c     4.0054e-6
         14030.62c     2.6588e-6
         15031.66c     7.7770e-6
         16000.62c     7.5112e-6
         22000.62c     7.3453e-4
         25055.62c     4.3847e-5
         26054.62c     3.4070e-3       26056.62c     5.2965e-2
         26057.62c     1.2127e-3       26058.62c     1.6169e-4
         27059.66c     7.1938e-3
         28058.62c     1.0367e-2       28060.62c     3.9635e-3
         28061.62c     1.7160e-4       28062.62c     5.4518e-4
         28064.62c     1.3819e-4
         42000.66c     2.4103e-3
c        Pure Aluminum Mounting Plate
m4       13027.62c     5.8593e-2
c        HEU + Mo (93.17 wt.% for Safety Block), 18.1069 g/cc
m5       42000.66c     1.1384e-3
         92233.66c     4.6322e-6       92234.66c     4.7005e-4
         92235.66c     4.2791e-2       92236.66c     3.1098e-4
         92238.66c     2.3222e-3
c        HEU + Mo (93.16 wt.% for Control Rods 1 and 2)
m6       42000.66c     1.5385e-3
         92233.66c     4.6812e-6       92234.66c     4.7497e-4
         92235.66c     4.3238e-2       92236.66c     3.1427e-4
         92238.66c     2.3514e-3
c        HEU + Mo (93.16 wt.% for Burst Rod)
m7       42000.66c     1.5701e-3
         92233.66c     4.7893e-6       92234.66c     4.8594e-4
         92235.66c     4.4237e-2       92236.66c     3.2152e-4
```

```
          92238.66c     2.4057e-3
c         HEU + Mo (93.15 wt.% for Homogenized Fuel Rings)
m8        42000.66c     1.7082e-3
          92233.66c     4.6484e-6       92234.66c     4.7159e-4
          92235.66c     4.2930e-2       92236.66c     3.1206e-4
          92238.66c     2.3398e-3
c         HEU + Mo (93.15 wt.% for Homogenized IISP+UISP)
m9        42000.66c     1.7407e-3
          92233.66c     4.6755e-6       92234.66c     4.7433e-4
          92235.66c     4.3180e-2       92236.66c     3.1388e-4
          92238.66c     2.3534e-3
c         HEU + Mo (Fuel Ring Combined with 2 Control Rods and Burst Rod)
m10       42000.66c     1.6850e-3
          92233.66c     4.6384e-6       92234.66c     4.7058e-4
          92235.66c     4.2838e-2       92236.66c     3.1139e-4
          92238.66c     2.3342e-3
c         HEU + Mo (Fuel Ring Combined with 1 Control Rod and Hole)
m11       42000.66c     1.5652e-3
          92233.66c     4.2735e-6       92234.66c     4.3356e-4
          92235.66c     3.9468e-2       92236.66c     2.8689e-4
          92238.66c     2.1510e-3
c         HEU + Mo (Fuel Ring combined with 1 CR, 1 BR, and Holes)
m12       42000.66c     1.6100e-3
          92233.66c     4.4101e-6       92234.66c     4.4742e-4
          92235.66c     4.0730e-2       92236.66c     2.9606e-4
          92238.66c     2.2196e-3
c         HEU + Mo (Fuel Ring combined with 1 CR and 1 BR with Hole)
m13       42000.66c     1.6203e-3
          92233.66c     4.4415e-6       92234.66c     4.5060e-4
          92235.66c     4.1019e-2       92236.66c     2.9817e-4
          92238.66c     2.2353e-3
c         HEU + Mo (Fuel Ring combined with 1 CR and 1 CR and 1 BR with Holes)
m14       42000.66c     1.6642e-3
          92233.66c     4.5750e-6       92234.66c     4.6415e-4
          92235.66c     4.2252e-2       92236.66c     3.0713e-4
          92238.66c     2.3024e-3
c         HEU + Mo (Fuel Ring combined with 1 CR, 1 BR, and 1 CR with Hole)
m15       42000.66c     1.6747e-3

          92233.66c     4.6070e-6       92234.66c     4.6740e-4
          92235.66c     4.2549e-2       92236.66c     3.0928e-4
          92238.66c     2.3185e-3
c         HEU + Mo (Fuel Ring combined with 3 CR/BR Holes)
m16       42000.66c     1.5214e-3
          92233.66c     4.1400e-6       92234.66c     4.2001e-4
          92235.66c     3.8235e-2       92236.66c     2.7793e-4
          92238.66c     2.0839e-3
c
totnu
prdmp      j   575
print

 end of input
```