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Nuclear Criticality Safety Evaluation of the 9965, 9968, 9972, 9973, 9974, and 9975 Shipping Casks

by

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ABSTRACT

A Nuclear Criticality Safety Evaluation (NCSE) has been performed for the 9965, 9968, 9972, 9973, 9974, and 9975 SRS-designed shipping casks. This was done in support of the recertification effort for the 9965 and 9968, and the certification of the newly designed 9972-9975 series. The analysis supports the use of these packages as Fissile Class I for shipment of fissionable material from the SRS FB-line, HB-Line, and from Lawrence Livermore National Laboratory. Six different types of material were analyzed with varying isotopic composition, of both oxide and metallic form. The mass limits required to support the Fissile Class I rating for each of the envelopes are given in the Table below. These mass limits apply if DOE approves an exception as described in 10 CFR 71.55(c), such that water leakage into the primary containment vessel does not need to be considered in the criticality analysis. If this exception is not granted, the mass limits are lower than those shown below. This issue is discussed in detail in sections 5 and 6 of the report.

One finding from this work is important enough to highlight in the abstract. The fire tests performed for this family of shipping casks indicates only minimal charring of the Celotex thermal insulation. Analysis of the casks with no Celotex insulation (assuming it has all burned away), results in values of k-eff that exceed 1.0. Therefore, the Celotex insulation must remain intact in order to guarantee subcriticality of the 9972-9975 family of shipping casks.

Envelope Mass Limits for Each Cask

Cask	Envelope Mass Limit (kg)					
	A	B	C	D	E	F
9972	-	-	-	-	4.4	13.5
9973	-	-	4.4	-	-	-
9974	-	-	4.4	-	-	-
9975	4.4	4.4	4.4	4.3	-	-

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1.0 INTRODUCTION

The purpose of this work is to establish criticality safety limits for the 9965, 9968, 9972, 9973, 9974, and 9975 shipping casks. These casks were designed at the Savannah River Site for use in the transportation of solid form uranium and/or plutonium materials between DOE sites. The criticality safety aspects of the 9965, 9966, 9967, and 9968 shipping casks were evaluated in support of the original Safety Analysis Report Packages (SARP). The license granted based on that SARP is up for renewal. As regulations have changed, it was determined that the criticality analysis in support of the SARP should be re-analyzed in order to demonstrate full compliance with current regulations and requirements (as outlined in Section 3.0). In addition, the Packaging and Transportation Group decided to make design improvements to the packages. The result is the new generation of casks designated 9972, 9973, 9974, and 9975. From a criticality standpoint, the only difference between the 9972-9975 casks and the original 9965-9968 series is in the use of a stainless steel drum in the former as opposed to carbon steel in the latter. Because the drum walls are thin and because few neutrons make it through the containment vessel walls and Celotex to reach the drum wall, this difference has no effect on the criticality safety of the casks. In this work the 9965 and 9972 cask are assumed to be identical, as are the 9968 and 9975. Note that the 9965 and 9968 are being recertified because there are so many of them already in use. They will be used in conjunction with the newly designed 9972 and 9975. The 9966 and 9967 will be completely replaced with the newly designed 9973 and 9974.

This report is a Nuclear Criticality Safety Evaluation (NCSE) written to the specifications of the WSRC Nuclear Criticality Safety Manual (Ref. 1). This document is meant to support the SARP, but is not written in the format of a SARP chapter. The SARP chapter should be based on the results reported in this NCSE and should reference it as well.

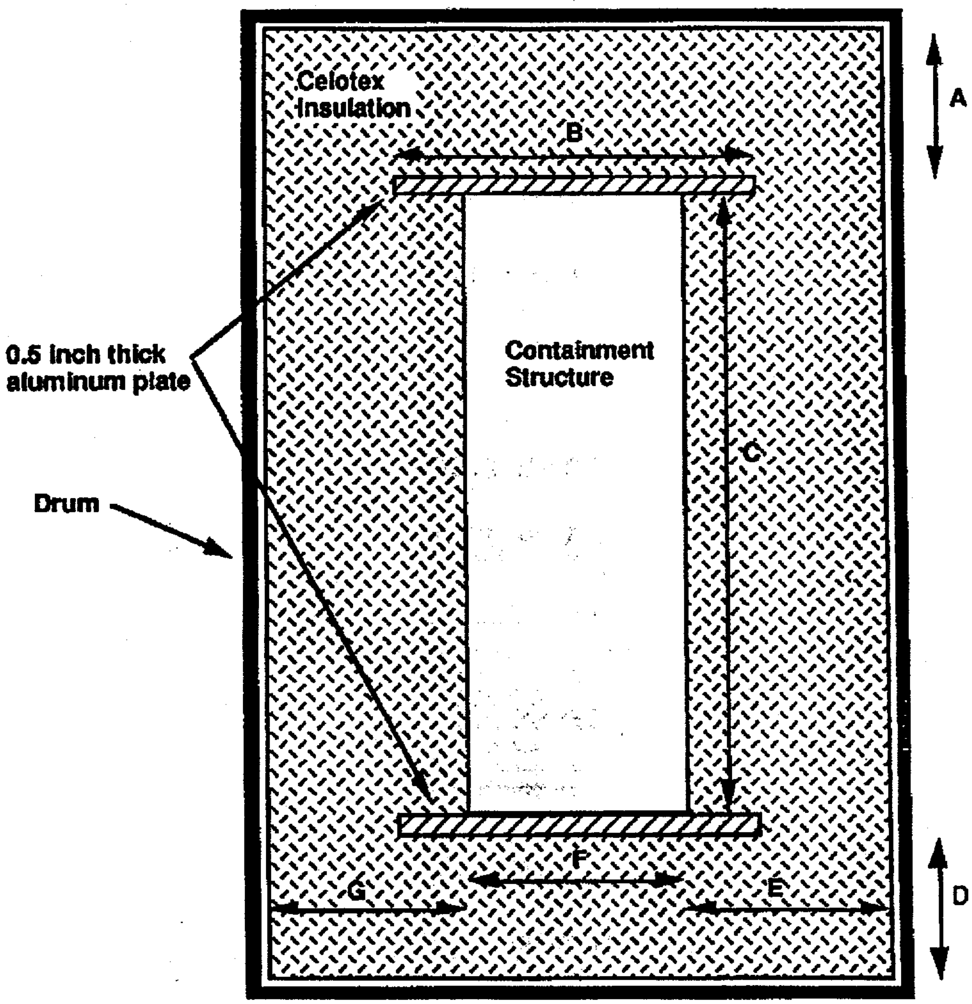
2.0 DESCRIPTION

2.1 Cask Geometry

The 9972-9975 shipping casks are all of the "pipe and drum" type of design. Each cask contains, as a minimum, a primary containment vessel, which is approximately centered inside a 30, 35, or 55 gallon drum and surrounded by Celotex fiberboard insulation. The primary containment vessel (PCV) is constructed of 5 inch schedule 40 stainless steel pipe. A bottom piece is welded in place, and the top is sealed with a thick plug and locking nut. Since the bottom piece is rounded (it is convex in shape), a small length of 4 inch schedule 40 pipe is welded to the bottom of the PCV to provide a flat surface such that the PCV can be stood on its bottom. For the 9972 cask, the PCV is loaded directly into a cavity in the Celotex insulation, which is contained inside a standard 30 gallon drum. Figure 1 illustrates the general cask geometry, applicable for all of the casks. The term containment structure is used to define the structure that is loaded into the Celotex insulation. In the case of the 9972 cask, the containment structure consists simply of the PCV. Figure 2 illustrates the Primary Containment Vessel geometry.

The 9972 cask is designed to carry uranium materials or metallic plutonium. For this reason, a single containment design is sufficient. For transport of plutonium bearing materials in non-metallic form, a double containment design is required (10 CFR 71.63). The 9973 cask was designed to carry this type of material. The 9973 is identical in design to the 9972 with the exception that the primary containment vessel is placed inside a secondary containment vessel (SCV) before loading into a slightly larger cavity in the Celotex insulation. The SCV is designed from 6 inch schedule 40 stainless steel pipe, and, similar to the PCV, has a welded bottom and a plug and nut seal at the top. Geometry and dimensions for the SCV are shown in Figure 2. The containment structure for the 9973 cask consists of a PCV loaded into an SCV.

A minimal amount of radiation shielding is obtained from the drum and containment vessel walls of the 9972 and 9973 casks. However, this shielding is not sufficient to lower the radiation dose rate to acceptable levels for some of the material identified for shipment. The 9974 cask was designed to meet this challenge. The 9974 consists of a PCV and SCV identical to those used in the 9973 loaded into a shielding sub-assembly before being placed inside the cavity in the Celotex. The shielding sub-assembly consists of a 0.25 inch thick stainless steel sleeve and a 1.25 inch thick lead shield (1.5 inches at top and bottom). Because of the size and mass of the shielding sub-assembly, a 55 gallon drum is used in the 9974 design.



Note: total height of celotex insulation = A+C+D+2*0.5.

	Dimension in Centimeters						
Package	A	B	C	D	E	F	G
9972	17.22	25.40	34.62	16.11	16.04	14.29	16.04
9973	10.27	25.40	47.83	9.73	14.77	16.83	14.77
9974	13.40	-	55.75	13.56	15.52	26.11	15.52
9975	12.96	28.59	63.07	7.99	12.39	21.59	12.39

Figure 1. General configuration for all packages (NCT). Dimensions in inches. Derived from Ref. 2. See Table 2 for drum specifications.

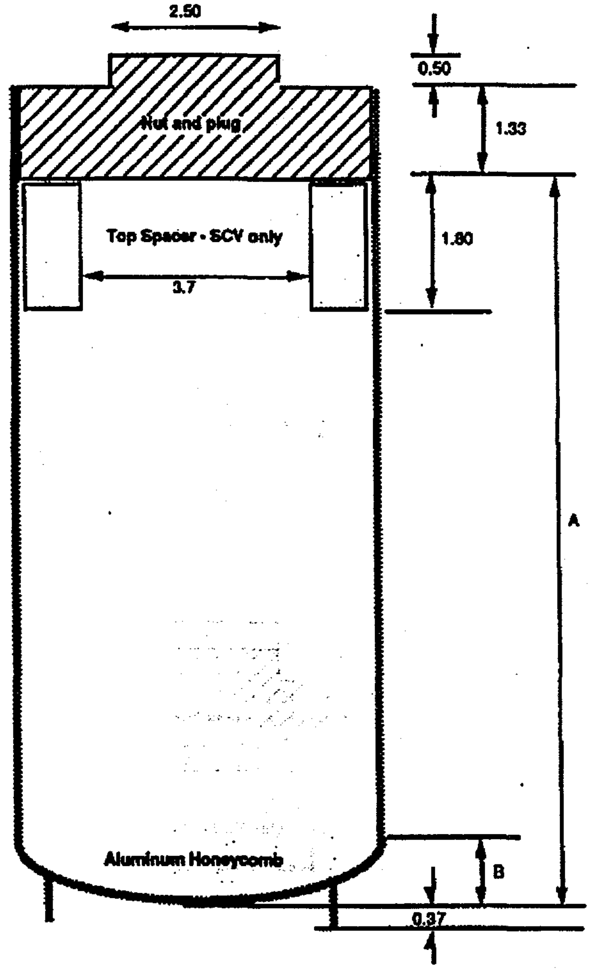


		Table Values in Inches			
				Nominal Pipe Size (Schedule 40)	
Cask	Vessel	A	B	Vessel	Legs
9972, 9973, and 9974	PCV	11.38	0.8	5	4
9975	PCV	16.38	0.8	5	4
9972, 9973, and 9974	SCV	16.75	1.0	6	5
9975	SCV	21.75	1.0	6	5

Figure 2. Primary and Secondary Containment Vessel. Derived from Refs. 3-5. Pipe specifications are listed in Table 1. All table and figures values are in inches.

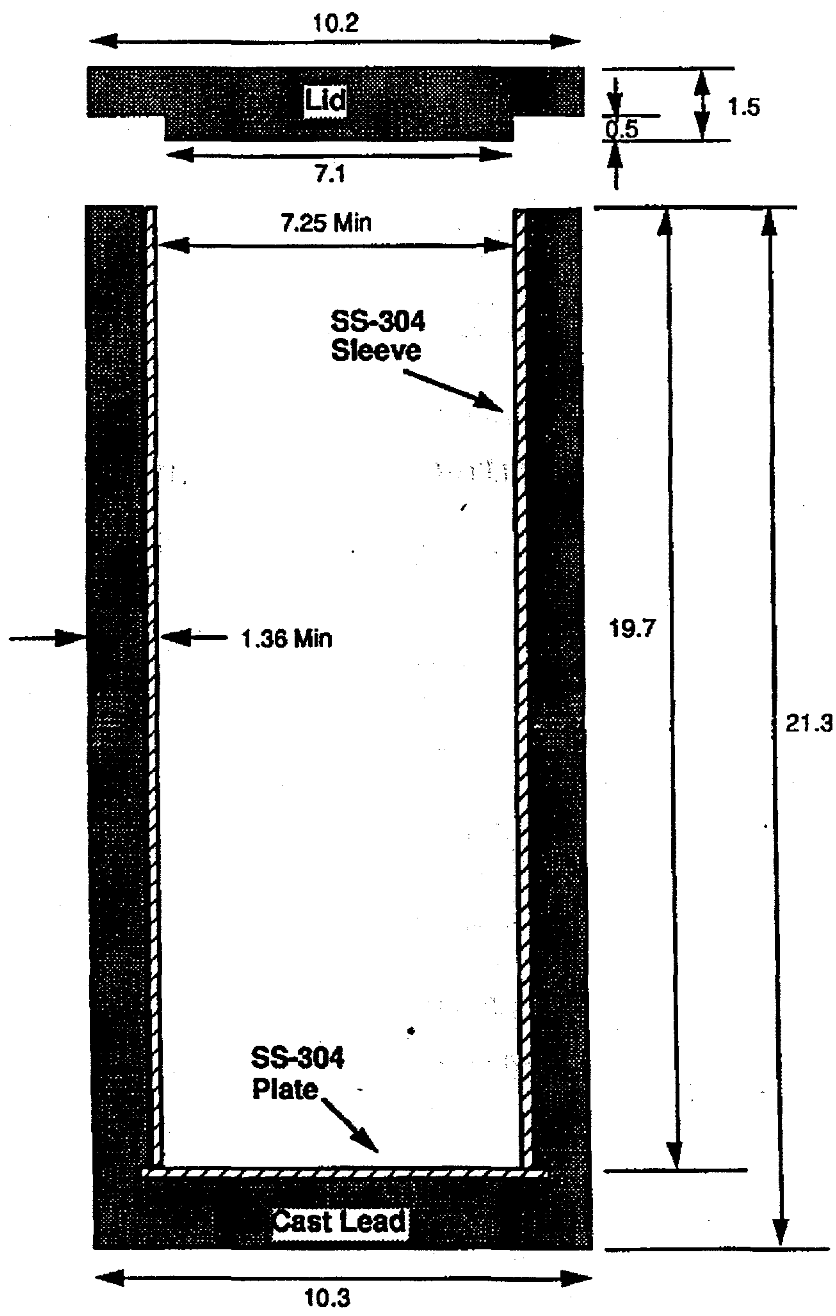


Figure 3. Lead shield design for the 9974 cask. Derived from Ref. 7. All values in inches.

Figure 3 illustrates the shield assembly design. Note that for the 9974, the containment structure consists of the PCV, SCV, and shield sub-assembly.

The final cask to be discussed is the 9975. This cask was designed to carry materials that need more shielding than what the containment vessel walls provide, but not as much as the heavily shielded 9974. It was also designed to carry lower density material, and thus incorporates "stretched" versions of the PCV and SCV. The containment vessels for this cask differ from the ones used in the 9972, 9973, and 9974 only in length. The shielding sub-assembly is constructed of 0.5 inch thick lead, with an aluminum top, as illustrated in Figure 4.

Figure 5 shows the containment structure for the 9974 cask, with the shield sub-assembly containing the SCV and PCV. The containment structure for the 9975 is put together in a similar manner.

Fissionable materials are pre-packed before loading into the PCV. At the time of writing, the type of pre-pack had not been finalized. Originally, fissionable material was to be packaged in either tin cans or, in the case of oxide powders, a 500 ml polyethylene bottle. Each bottle/can would be individually sealed in a plastic bag. In some cases, fissionable material was to be placed into a can, which is then wrapped in a plastic bag and placed in another can, which is subsequently wrapped in another plastic bag. Unfortunately, the plastics cause problems in the thermal analysis. When the PCV is heated, the plastics decompose and emit gases. This offgasing limits the mass of plastic that can be used inside the PCV. Currently, the Packaging and Transportation Group is performing experiments to determine the properties of the plastics to be used. From this, a limit will be set on the amount of plastic that can be contained inside the PCV. Current indications are that the limit will be 100 grams total plastic inside the PCV. The original plans for pre-packs are described in Ref. 6.

The pre-packs do not rest on the bottom of the PCV. A 0.8 inch thick aluminum honeycomb spacer, shaped to fit the rounded bottom of the PCV, separates the pre-pack from the PCV bottom.

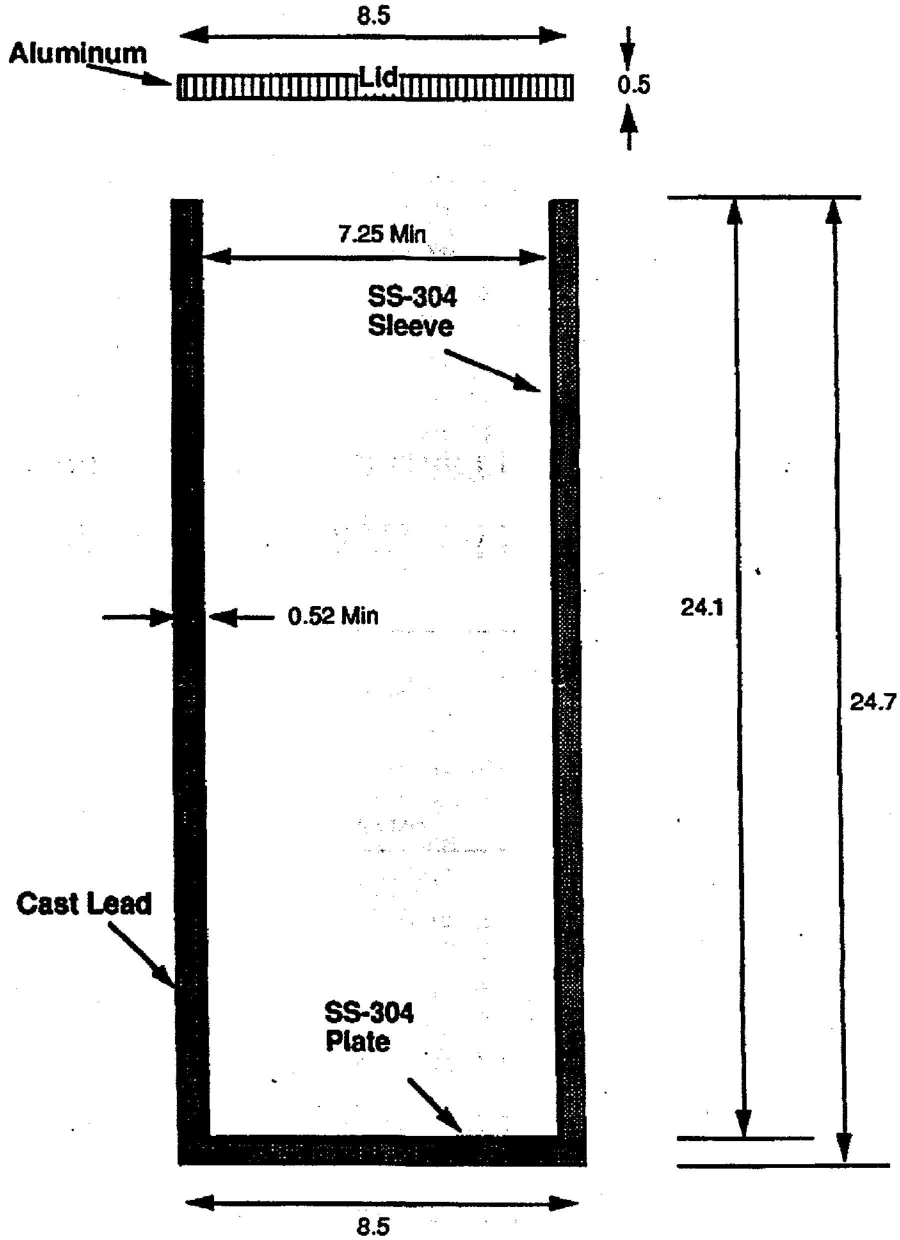


Figure 4. Lead shield design for the 9975 cask. Derived from Ref. 7. All values in inches.

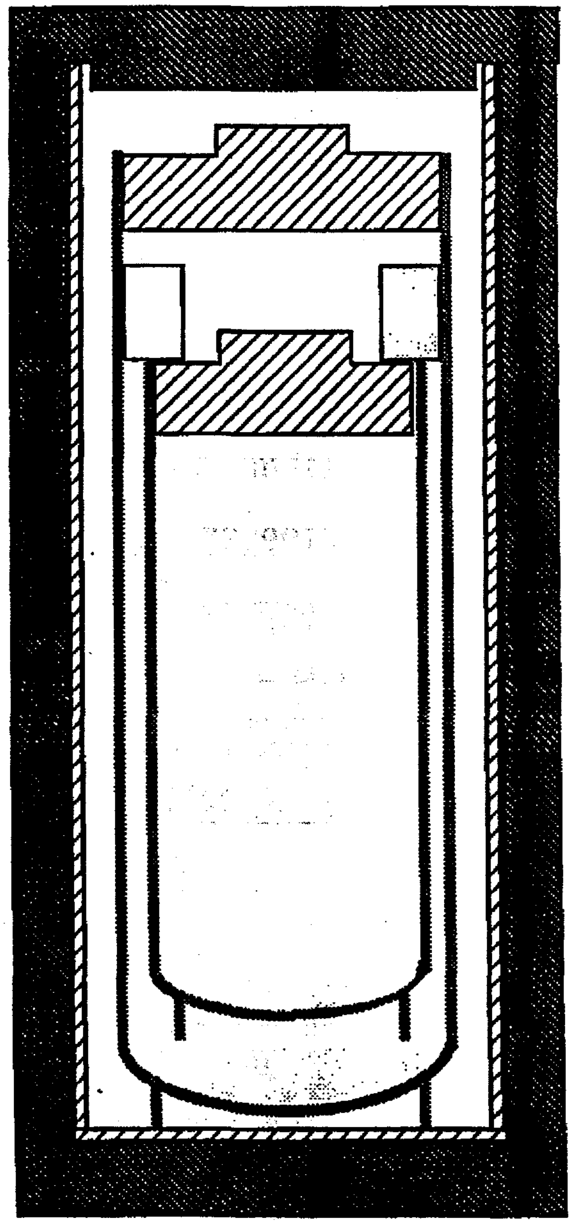


Figure 5. The 9974 containment structure: PCV is loaded inside SCV, which is then loaded inside the shielding subassembly. This entire structure is loaded into the cavity in the Celotex insulation inside the 55 gallon drum. Drawing is approximately to scale.

TABLE 1

Specifications for Schedule 40 Pipe

Nominal Pipe Size	Nominal O.D.	Nominal Wall Thickness	Nominal I.D.	Max. O.D.	Min. Wall Thickness	Max. I.D.
	Inches					
4"	4.500	0.237	4.026	4.563	0.207	4.148
5"	5.563	0.258	5.047	5.626	0.226	5.174
6"	6.625	0.280	6.065	6.688	0.245	6.198
	Centimeters					
4"	11.430	0.602	10.226	11.590	0.526	10.536
5"	14.130	0.655	12.819	14.290	0.574	13.142
6"	16.828	0.711	15.405	16.988	0.622	15.743

2.1.1 Dimensions and Tolerances

Table 1 lists dimensions and tolerances for schedule 40 stainless steel pipe derived from ASTM A 530/A 530M-91a. There is a tolerance of 12.5% on the wall thickness and a tolerance on the outer diameter of $^{+\frac{1}{16}}/_{-\frac{1}{32}}$ inches. Specifications for the drums are given in Table 2. The drum diameter and height, with associated tolerances, are from Ref. 8. The drawing also gives gauge requirements for the drum wall. Nominal and minimal thicknesses for standard gauges can be found in ANSI MH2.5. The dimensions of the drum rolling hoops are not provided on the drawings. However, the drums were basically designed to meet ANSI MH2.x requirements, and the standard specifies the diameter over rolling hoops for a 55 gallon drum (MH2.5) to be 23.8437±.0625 inches, and for a 30 gallon drum (MH2.13) 19.5938±.0625 inches. Since the only difference between the 30 and 35 gallon drums used for these casks is in the height, the same rolling hoop diameter is assumed to hold for the 35 gallon drum. The drums also have bolted closure rings at the top to seal the lid. No specifications could be found for these rings, but measurement of two of the casks used in the certification testing indicated the diameter around the closure ring was approximately 3/4 inch larger than the diameter around the rolling hoops.

TABLE 2

Specifications for Drums

Cask	Drum Size (Gallons)	Inner Diameter	Internal Height	Wall Thickness		
				Gauge	Nominal	Minimum
		±0.13	±0.25	Inches		
9972, 9973	30	18.25	27.25	18	0.0478	0.0428
9974	55	22.50	32.88	16	0.0598	0.0533
9975	35	18.25	34.00	18	0.0478	0.0428
		±0.33	±0.64	Centimeters		
9972, 9973	30	46.36	69.22	18	0.1214	0.1087
9974	55	57.15	83.52	16	0.1519	0.1354
9975	35	46.36	86.36	18	0.1214	0.1087

The 9974 and 9975 (9968) cask designs include lead shielding subassemblies as shown in Figures 3 and 4. Both designs utilize cast lead, such that the sub-assembly consists of only two pieces: the shield body and the shield lid. The lead is cast around a stainless steel sleeve and bottom disk, which are welded together prior to casting. For the 9974 cask, the sleeve is constructed of SS-304 tubing, with an OD of 8.0 inches, and a wall thickness of 0.25±0.01 inches. The plate has a diameter of 8.5 inches and a thickness of 0.25±0.01 inches. The thickness of lead is not directly specified. Rather, the minimum thickness from the inside of the stainless steel sleeve to the outside surface of the lead is specified. The minimum lead thickness is found when the steel sleeve thickness is maximum (0.26 inches), and is 1.10 inches. The thickness of lead at the bottom (from the bottom of the steel plate to outside of lead bottom) is nominally 1.35 inches. The drawing quotes a tolerance of ±0.25 inches on dimensions given to 1 decimal place. The minimum lead thickness at the bottom then is (21.3-.05)-(19.7+.05)-(.25+.01) = 1.24 inches. The nominal and minimal lead thickness at the top is 1.5 and 1.45 inches, respectively. These results are summarized in Table 3.

The shield design for the 9975 cask is similar to that of the 9974. The design of the shield body differs only in dimensions and thicknesses. The lid designs differ significantly, though. The 9974 shield has a 1.5 inch thick lead lid, while the 9975 uses a 0.5 inch thick aluminum lid. For the 9975, the steel tube has an OD of 7.5

inches and a wall thickness of 0.06 ± 0.01 inches. The steel plate has a diameter of 8 inches and the same thickness as the tube. The minimum lead wall thickness is 0.52-0.26=0.26 inches, while the minimum lead thickness at the bottom is (24.7-.05)-(24.1+.05)-(0.25+.01)=0.24 inches. These results are summarized in Table 3.

TABLE 3

Minimum Thicknesses for 9974 and 9975 Shield Assemblies

	Minimum Thickness (inches)		Minimum Thickness (cm)	
Component	9974	9975	9974	9975
Steel Tube and Plate	0.24	0.05	0.61	0.13
Lead Side Wall	1.10	0.26	2.79	0.66
Lead Bottom	1.24	0.24	3.15	0.61
Lead Top	1.45	NA	3.68	NA

2.2 Materials of Construction

The drawings specify structural materials as conforming to specific ASTM or ASME standards. The composition of the materials is specified in these standards, but no density requirements are given. Thus, densities were obtained from the CRC Handbook of Chemistry and Physics, 74th Edition. The composition and density information is compiled in Table 4. The Al 1100 is used for the top and bottom plates, and the lead for the shield subassemblies. Note that the steel for the drum adheres to a different standard than that for the containment vessel, but the differences in composition are minor.

The Celotex insulation is required to meet ASTM specification C-208. That standard is for insulating board (cellulosic fiber), and gives a density requirement of between 10 and 31 pounds per cubic foot. However, the drawing (Ref. 2) specifies that the density will be between 14 and 16 pounds per cubic foot (0.224 and 0.256 g/cc). With regards to composition, the standard only states that the material be manufactured from "...refined or partly refined ligno-cellulosic (wood or cane) fibers...into homogeneous panels." This indicates that the composition is probably accurately represented by cellulose ($C_6H_{10}O_5$). The standard also specifies the water absorption,

TABLE 4

Composition and Density for Structural Materials

	Al 1100	Lead	Drum Steel	Containment Steel
Standard	ASTM B-209	ASTM B-749	ASME SA-240 Type 304	ASME SA-312 Grade TP304
Density (g/cc)	2.7	11.34	7.9	7.9
Al	99.00 Min	-	-	
Pb	-	99.94 Min	-	
Fe	.95†	.002 Max	Difference	Difference
Ni	-	-	8.00-10.50	8.00-11.0
Cr	-	-	18.00-20.00	18.0-20.0
Mn	0.05	-	2	2
Mg	-	-	-	-
Cu	.05-.20	.0015 Max	-	-
Zn	0.10	.001 Max	-	-
Ag*	-	0.005	-	-
Bi*	-	0.05	-	-
C*	-	-	0.08	0.08
Si*	-	-	0.75	0.75
P*	-	-	0.045	0.04
S*	-	-	0.03	0.03
N*	-	-	0.1	-
Others*	0.15	0.002	-	-

*Maximum

by volume, as 7% for the grade and thickness specified on the drawing. Finally, the aluminum honeycomb spacer is specified as aluminum tube honeycomb, pre-crushed, 3 mil minimum foil, with a crush strength of 1500±500 PSI.

2.3 Description of Fissionable Material Loading

The 9972-9975 casks were designed to transport material originating from three sources at SRS as well as Lawrence Livermore National Laboratory (LLNL). The three SRS sources are HB-Line, FB-Line, and M-area. A large variety of material types and compositions exist at these facilities. The Packaging and Transportation Group of SRTC originally sought input from all of the package users listed above in order to try to characterize the fissionable material. In order to reduce the number of calculations that would be needed, they combined user inputs to create artificial materials containing conservative maximum ranges of isotopes. For example, a material containing, among others, 10% ^{239}Pu and 50% ^{240}Pu might be combined with a material containing 90% ^{239}Pu and 3% ^{240}Pu. The resulting specification would be for an artificial material containing as much as 90% ^{239}Pu, and as much as 50% ^{240}Pu. These artificial materials are referred to in the remainder of this document as "content envelopes," since they really represent multidimensional bounds that "envelope" permitted contents.

Ref. 8 describes 13 different content envelopes developed as described above by the Packaging and Transportation Group. At a meeting in July of 1994, it was realized that the basis for some of these content groups was no longer apparent. The specifications for the first six content envelopes are given in Table 5. The current criticality evaluation only considers these six content envelopes; the other seven envelopes are to be addressed at a later date. In addition to content envelopes, Table 5 indicates which package is to be used for shipping that particular content envelope, and the physical form of the material.

Oxides in both loose powder and pressed pellet form are to be shipped. The metals are not small pieces but instead are ingots. A maximum of two ingots will be loaded into each cask, with each ingot separately packaged in a food pack can (pre-pack). The ingots have no concave surfaces.

Studies have indicated that the maximum moisture absorption for plutonium oxides is near 30 mg water per gram oxide (Ref. 9). This is a worst case value corresponding to 100% humidity and very fine particulate plutonium oxide. Jeffery Schaade of the SRS Nuclear Materials Production Division feels that a value of 15 mg water per gram oxide is conservative considering typical facility requirements for oxide production and storage.

TABLE 5

Fissionable Material Description

Envelope	A	B	C	D	E	F
User	LLNL	LLNL	Unknown	HB-Line	Unknown	FB-Line
Cask	9975	9975	9973, 74, 75	9975	9972	9972
Form	oxide	oxide	oxide	oxide	metal	oxide & metal
Am-241	5.00%	50.00%	0.50%	1.00%	5.00%	-
Am-243	0.00%	0.00%	0.00%	0.00%	0.00%	-
Cm-244	0.00%	0.00%	0.00%	0.00%	0.00%	-
Np-237	2.00%	2.00%	2.00%	0.50%	2.00%	-
Pu-236	-	-	-	0.00%	0.00%	-
Pu-238	0.40%	0.40%	0.10%	100.00%	0.40%	-
Pu-239	95.00%	95.00%	100.00%	40.00%	95.00%	-
Pu-240	50.00%	50.00%	50.00%	13.00%	50.00%	-
Pu-241	2.00%	2.00%	2.00%	1.00%	2.00%	-
Pu-242	5.00%	5.00%	5.00%	1.50%	5.00%	-
Th-232	-	-	-	10.00%	-	-
U-232	-	-	-	-	-	0.00%
U-233	-	-	-	-	-	0.10%
U-234	-	-	-	-	-	2.00%
U-235	-	-	95.00%	0.50%	-	100.00%
U-236	-	-	-	-	-	40.00%
U-238	-	-	100.00%	0.50%	-	100.00%

3.0 REQUIREMENTS DOCUMENTATION

The Department of Transportation (DOT) is the principle agency for regulating shipments of radioactive material. However, in 49 CFR 173.7(d), DOT delegates to the Department of Energy (DOE) the authority to approve DOE packages using standards equivalent to those in 10 CFR 71, "Packaging and Transportation of Radioactive Materials." The specific requirements investigated for compliance in this work are 10 CFR 71.55, "General Requirements for Fissile Material Packages," and 10 CFR 71.57, "Specific Standards for a Fissile Class I Package." Section 71.55 requires that a package be subcritical if water leaks into the containment system or liquid contents leak out, under the most reactive fuel, moderator, and reflector conditions. The 9972-9975 casks are designed to carry fuel in solid form only, so the condition of liquid fuel leaking out of the containment system need not be addressed. In order for a package to receive a Fissile Class I rating, section 71.57 requires that any number of undamaged packages be subcritical in any arrangement with optimum interspersed hydrogenous moderation, and that 250 damaged packages, stacked together in any arrangement, with optimum interspersed hydrogenous moderation and closely reflected by water, also be subcritical. The analysis described in this NCSE satisfies the requirements of both of these sections.

One of the requirements of 10 CFR 71.55 is of particular importance to the 9972-9975 criticality evaluation. Paragraph (a) states that a package used for the shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water leaked into the containment system under the most reactive conditions. The requirement seems to specifically address the case of water leaking into a single package, but reviewers at Lawrence Livermore have stated that current NRC interpretation (which is emulated by DOE) is that it applies to both single units and arrays. Meeting this requirement for arrays of damaged packages can result in undesirable reductions in the allowable safe mass in some instances. Fortunately, an exemption is provided (paragraph c) if the package incorporates special design features that ensure that no single packaging error would permit leakage, and if appropriate measures are taken before each shipment to ensure the containment system does not leak. The 9972-9975 shipping casks were subjected to all of the drop and fire tests required in 10 CFR 71, and the containment system was leak tested after each test. It was found that both the primary and secondary containment vessel (when present) remained leak tight after all tests. In addition, each package is subjected to a leak test with sensitivity 10^{-3} cm^3/sec following fuel loading and assembly. Since the 9973, 9974, and 9975 casks all have a double containment structure, a single packaging error would, at worst, allow water leakage into the SCV but not into the PCV. Although the 9972 cask has only single containment, it has a double O-ring design on that containment. Failure of either one of the two O-rings would not be sufficient to allow water flooding of the PCV. Admittedly, this is not as strong a double contingency defense as a double containment structure, but it is deemed adequate. On this basis, the SRS Packaging and Transportation Group (P&TG) feel the 9972-9975 casks qualify for exemption from the requirement of being subcritical with the PCV flooded. The strategy in the criticality analysis is to first calculate mass limits without taking the paragraph c exemption. If the resulting mass limit does not match operational needs, a new limit is calculated assuming the paragraph c exemption will be granted by the licenser.

4.0 METHODOLOGY

The LAW (Library to Analyze Waste) 44-energy group cross section library (Ref. 10), recently released by Oak Ridge National Laboratory, was used for all calculations. All cross sections were processed with the AMPX-77 system (Ref. 11), with resonance treatment provided by the BONAMI and NITAWL modules when applicable. BONAMI treats unresolved resonances using the Bondarenko method, while NITAWL treats resolved resonances using the Nordheim integral method. Bondarenko and Nordheim treatments were applied to ^{235}U and ^{239}Pu; only the Nordheim treatment was performed for Fe, Mn, Cr and Ni (there is no Bondarenko factor data in the library for these isotopes).

Single unit analysis was performed using the discrete ordinates code TWODANT (Ref. 12). All calculations employed S_8 quadrature, P_3 Legendre expansion, and mesh spacing chosen to ensure spatial convergence. The convergence criteria for eigenvalues and fluxes was 1×10^{-4}. All jobs were run to full convergence of eigenvalues and fluxes. TWODANT was used for the single unit analysis rather than KENO V.a because it is more economical to run, and because it provides a deterministic rather than stochastic solution, which means that statistical uncertainties need not be folded into the k-safe calculation. Input for the most limiting cases are given in Appendix A.

Array analyses were performed with the KENO V.a (Ref. 13) Monte Carlo code (note that it is not possible to build arrays of cylindrical objects in TWODANT). All calculations employed a P_5 Legendre expansion. All calculations except the final runs used 300 generations, with 330 particles per generation, for a total of 99,000 histories. The first 32 generations were discarded. For the final calculations, 1200 generations were used for a total of 396,000 histories. In all cases, convergence of the fission source was checked by viewing the graph of average k-eff by generation; in addition, the k-eff histogram was checked to verify that a normal distribution was produced in the Monte Carlo simulation. Both KENO V.a and TWODANT provide the user with plots showing the geometry of the system and the distribution of materials. In all cases, these plots were examined to ensure the model was as intended. KENO V.a input files for the most limiting cases are provided in Appendix A.

The array calculations were performed using a square lattice. A square lattice produces approximately the same value of k-eff as a hexagonal lattice, if the square lattice pitch is adjusted such that the number of packages per unit area is the same in both lattices. This can be accomplished by reducing the pitch by a factor of $\sqrt{\sqrt{3}/2}$, approximately 7%. In the 9972-9975 analyses, the rolling hoops and closure ring were ignored, which effectively reduces the lattice pitch by more than 7%. Therefore, the square lattice array calculations are conservative.

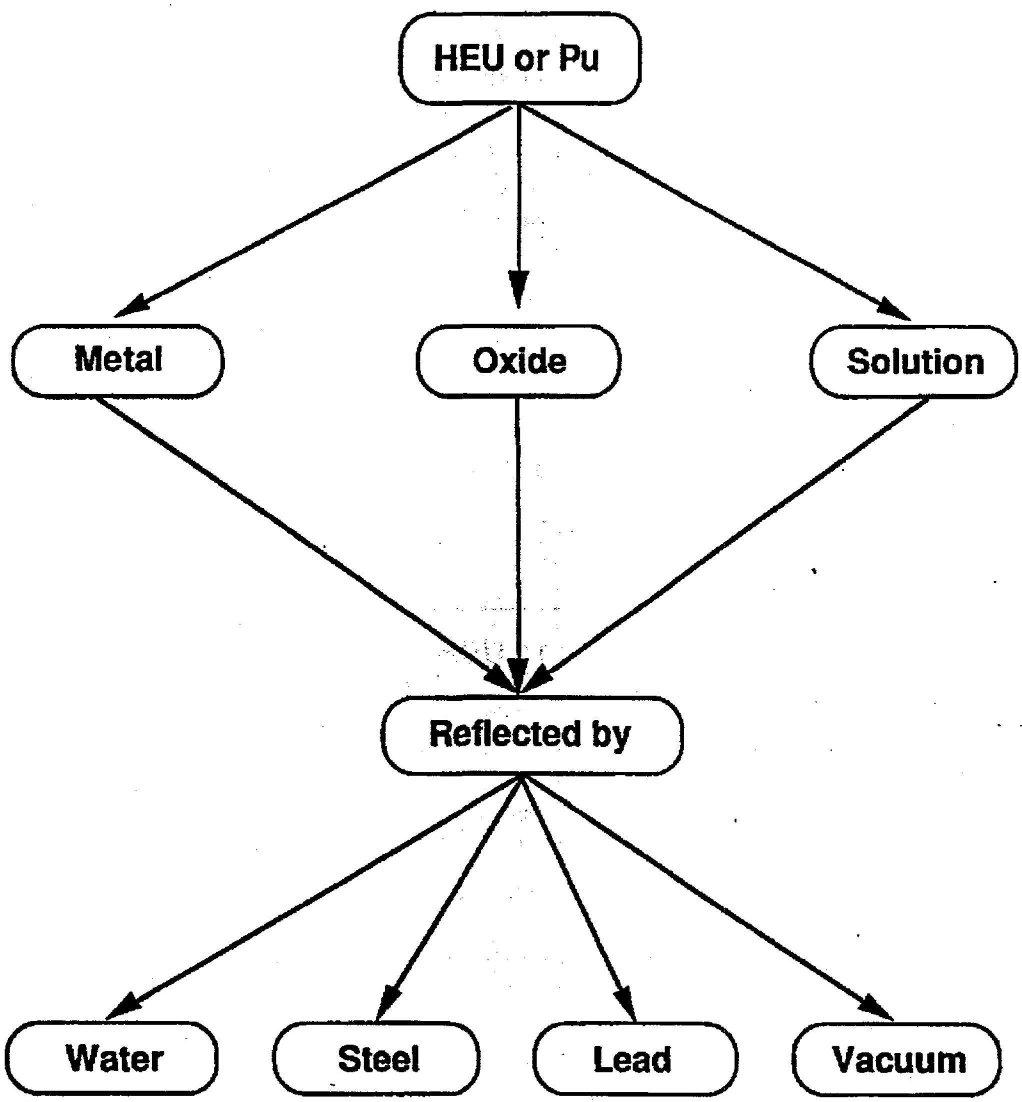
4.1 Computer Code Quality Assurance

The AMPX-77, KENO V.a, and TWODANT computer codes have been certified at SRS in accordance with 1Q34, which implements the requirements of the site 1Q manual. Refs. 14, 15, and 16 are the certification packages for AMPX-77, KENO V.a, and TWODANT, respectively. The controlled versions of these codes reside on three different computing platforms. The AMPX-77 controlled version resides in the data set USCS.SCMS.LOAD on the IBM 3090. The TWODANT controlled version resides on the SRS Cray in the directory /usr/local/scms/bin. These data sets are both part of the Scientific Configuration Management System (SCMS), administered by the Engineering and Scientific Computing Section. The KENO V.a controlled version utilized in this work is from the SCALE 4.2 system, which is maintained on the Andrew File Server for the RS-6000 workstation cluster. Access control and security are provided through the use of access control lists managed by the code proprietor. The executable is located in the directory /afs/srtc.srs.gov/project/crit/scale. Only controlled code versions were used in this work.

4.2 Validation

4.2.1 Benchmark Experiments and Applicability

Validation of the LAW 44 group library suitable for the 9972-9975 shipping casks has been completed using the same computer codes (TWODANT, KENO V.a, and AMPX-77) as were used in the criticality analysis. When selecting benchmark experiments, the fuel composition and physical state, as well as the geometry and components of construction for the shipping casks, must be considered. The fissionable material in this work is uranium and or plutonium of various isotopic content, in either oxide or metal form. However, it is necessary in the analysis to calculate the effect of water leaking into the containment system. This means that uranium and plutonium solution systems must also be considered. The shipping casks are constructed primarily of steel, lead, and Celotex. No criticality studies of these types of shipping casks carrying high enriched fuel have been performed. The best alternative is to analyze simple systems reflected by one of these components, and then add the biases together. Thus, a desirable list of validation experiments is described by the diagram on the following page. For example, highly enriched uranium metal reflected by water, and plutonium solution at a specified H/X ratio with no reflector would be included in the list. The most important of these validations have been completed. No oxide validation has been performed. However, the k-eff corresponding to the oxide cases is very low (<0.80), so a large bias can be assumed with no effect on the mass limit. Therefore, a bias of 0.05 has been adopted for all oxide cases. The oxide validation will be addressed in the future. For the metal validations, unreflected, water reflected, and iron reflected systems were investigated. No lead-reflected criticals have been identified at this point. For the solution validation, both bare and water-reflected spheres were investigated. This set of validation experiments is sufficient for the criticality safety analysis of the 9972-9975 shipping casks.


HEU or Pu
Metal
Oxide
Solution
Reflected by
Water
Steel
Lead
Vacuum

A weakness in the validation is the lack of benchmark experiments involving arrays of HEU and/or plutonium. These experiments, for both metal and solution forms, need to be identified and validated.

4.2.2. Details of the Benchmark Calculations

To simplify the validation process, spherical benchmark experiments were investigated. All cross section processing was done with the BONAMI and NITAWL modules of the SCALE 4.2 system. The transport analysis was performed using both ONEDANT and KENO V.a. In the ONEDANT analysis, care was taken to ensure convergence was achieved on the spatial mesh. A convergence criteria of 1×10^{-4} was used for all calculations. For KENO V.a analyses, each problem was run 10 times with a different random seed. The average and standard deviation were then calculated from the 10 calculated values of k-eff.

Biases were conservatively calculated by considering the experimental uncertainty in critical mass, and rounding the resulting bias down, maintaining three significant figures. For the KENO V.a bias, three standard deviations were subtracted from the k-eff result before the bias was determined. For example, if k-eff was calculated as 1.0031 +- .0024, the bias would be calculated as (1.0031 - 3*0.0024) - 1.0 = -0.0041, which would be rounded down to -0.005. Any reported uncertainty in the experimental configuration was also included in the bias. In most cases, the reported uncertainty was in the critical mass. Since the KENO V.a bias is made more negative by the subtraction of the three standard deviations, it is always more conservative than the TWODANT bias. For simplicity, only the KENO V.a biases were used in the calculation of the k-safe values.

A total of eight uranium metal validation experiments were analyzed. All consisted of a highly enriched uranium metal core. One experiment had no reflector (bare sphere), while the others had reflectors of water, natural uranium, and cast iron to varying thicknesses. The most negative bias calculated was -0.013. This value includes uncertainties in the experimental results as well as statistical uncertainties. This maximum calculated bias was used for all uranium metal cases. The uranium metal validation is detailed in Ref. 7.

Four plutonium metal validation experiments were analyzed. Two of the plutonium metal cores were bare, but with differing Pu-240 content. One of the cores was reflected by water, and the last was reflected by natural uranium. The maximum bias calculated, including all uncertainties, was -0.023. This maximum calculated bias was used for all plutonium metal cases. The plutonium metal validation is detailed in Ref. 8.

Twenty-four uranium solution validation experiments were analyzed. These experiments span the H/fissile range from 30 to 1400, and include bare and water reflected spheres. Most of the solutions are uranyl fluoride; a few are uranyl nitrate. Most of the experiments were performed at or near room temperature. In all cases, the spherical container was constructed with thin aluminum walls. The ^{235}U enrichment was approximately 93% in 19 of the experiments. Four experiments used an approximate ^{235}U enrichment of 30%, and one used 5%. The range of values of k-eff calculated by TWODANT, using S_8P_3 quadrature/Legendre order, is 0.998 to 1.012. The linear regression best fit to all 24 data points is:

$$k\text{-eff} = 1.0065 - 1.7\text{X}10^{-6} * (\text{H/fissile}) \quad (1)$$

As there was some concern that some of the experiments (including the five low enrichment experiments) might follow a different trend than the others, ten experiments were removed from the data set and a new regression fit was calculated. There was no change in the intercept and only a small change in the slope, so it was concluded that all of the data was consistent and the full set could be used for the validation.

The full data set was analyzed to determine if it represented a normal distribution by performing a t-test on the slope of the regression line. If the slope is sufficiently close to zero, then the data set represents a normal distribution around a mean value of k-eff. It was found that this was the case. A lower tolerance limit was then calculated for which there is 99% confidence that 99% of the values will fall above the tolerance limit. This lower tolerance limit is 0.992. Therefore, the bias used for uranium solution calculations is -0.008. Details of the uranium solution validation can be found in Ref. 19.

Eight plutonium solution validation experiments were analyzed, with the H/fissile value ranging from 700 to 1060. All of the solutions were plutonium nitrate at room temperature, and all of the spheres had thin stainless steel or aluminum walls. The plutonium was approximately 97% ^{239}Pu. All eight of the spheres were water reflected. It was not possible to demonstrate that the data set represented a normal distribution due to the fact that only 8 data points were analyzed. A functional representation of a 99% lower tolerance limit is given by Eq. 2 for the KENO V.a, which are more conservative than the TWODANT results:

$$k_{lower} = 0.96845 + 7.8694 \times 10^{-5} *(H/fissile) - 5.3206 \times 10^{-8} * (H/fissile)^2 \quad (2)$$

This function is valid over an H/fissile range of 700 to 1060 and has a minimum value of 0.992; thus the bias used for plutonium solutions in the SARP analysis is -0.008. (Note: the 99% tolerance limit assuming a normal distribution is k_{lower}=1.000; so not assuming a normal distribution has little effect on the bias used.) The plutonium solution validation is detailed in Ref. 20.

4.2.3. Results of the Benchmark Calculations

The bias results from the benchmark calculations are presented above. Values of k-safe were calculated utilizing the bias values and a subcritical margin. For this work, a subcritical margin of 0.03 was used. In the Draft DOE Standard, Calvin Hopper recommends using a subcritical margin of 0.05 when possible, but states that a smaller value may be used if justifiable, as long as it is at least 0.02. In the 9972-9975 SARP work, use of a smaller subcritical margin is justified for the following reasons:

1. The calculated biases are extremely conservative, including experimental uncertainties as well as statistical uncertaintes. The latter were considered by subtracting three standard deviations from the calculated value of k-eff, a very conservative approach.

2. Three standard deviations were added to all values of k-eff calculated in the SARP work. Again, this is very conservative.

3. The calculational models employed in the SARP work were extremely conservative.

There is one exception to the above: a subcritical margin of 0.05 was used for both the uranium and plutonium oxides. This was necessary due to the lack of validation for these types of systems.

The final k-safe values used in the criticality analysis are listed in Table 6. All k-eff values calculated in the criticality analysis for a particular class of problems must be less than the applicable k-safe value.

TABLE 6

K-Safe Values Used in the Criticality Analysis

System	Bias	Subcrit Margin	k-safe
U-235 Metal	-0.013	-0.03	0.957
U-235 Solution	-0.008	-0.03	0.962
U-235 Oxide	-0.050	-0.05	0.900
Pu-239 Metal	-0.023	-0.03	0.947
Pu-239 Solution	-0.008	-0.03	0.962
Pu-239 Oxide	-0.050	-0.05	0.900

4.3 Equivalence Relations

The fissionable material to be transported in the 9972-9975 casks may contain a wide variety of fissile and fissionable isotopes. In order to determine a mass limit for a particular content envelope†, the most reactive permissible combination of isotopes from that envelope must be considered. In the current work, the most reactive combination of isotopes was determined by using the Rule of Fractions extended to include non-thermal systems.

The Rule of Fractions from ANSI/ANS 8.15 assumes that when two fissile isotopes are combined in solution, the resulting solution will be subcritical if the sum of the ratio of the actual mass of each fissile

† See section 2.3 for a definition of the term envelope.

isotope to its known critical mass is less then 1.0. This can be expressed mathematically as:

$$\frac{m_i}{M_i}+\frac{m_r}{M_r}\leq 1.0 \tag{3}$$

where M represents the critical mass for isotope i or r and m the actual mass present. Eq. (3) can be re-written as:

$$m_i EF_i + m_r \leq M_r \tag{4}$$

where $EF_i = M_r / M_i$ is defined as the equivalency factor for isotope i, with respect to reference isotope r. Eq. (4) has been shown to be valid for well-moderated, water-reflected systems. ANSI/ANS 8.15 endorses its use with subcritical mass limits supplied in Table 2 of that reference for ^{239}Pu, ^{241}Pu, ^{242m}Am, ^{243}Cm, ^{245}Cm, ^{247}Cm, ^{249}Cf, and ^{251}Cf. Unfortunately, the existing information is not sufficient for the 9972-9975 SARP work, for the following reasons:

1. The equivalency factors are valid only for well-moderated, water-reflected systems. The SARP analysis must consider dry metallic systems, and both water and steel reflectors.

2. No information is available linking the isotopes listed above to others that must be considered in the SARP analysis. Specifically, these include ^{238}Pu, ^{240}Pu, ^{242}Pu, ^{235}U, and ^{241}Am.

For these reasons, it was necessary to develop equivalence relations applicable to the SARP analysis. The LAW 44-group cross section library was used in conjunction with the ONEDANT code to perform the analysis. This work is an extension of equivalence relations to include well-moderated systems with steel reflectors, and, as a serious departure from existing work, to include fast metal systems.

The necessary equivalence relations were determined by considering binary mixtures of two isotopes, using ^{239}Pu as the reference isotope. The critical masses used for ^{235}U and ^{239}Pu were those masses that resulted in a k-eff equivalent to that found in the validation work (see Refs. 17-20) for the particular system of interest. For the other isotopes, the mass that resulted in a k-eff of 1.0 for the system of interest was used as the critical mass. The binary system was then analyzed by calculating mixtures of the two isotopes, using fractions of the critical mass of each isotope that summed to 1.0, *e.g.*, 25% of the critical mass of ^{240}Pu with 75% of the critical mass of ^{239}Pu. The resulting values of k-eff were compared to the values expected from the Rule of Fractions, calculated as:

$$k_{ROF} = \frac{m_i}{M_i}k_i + \frac{m_r}{M_r}k_r \qquad (5)$$

where k_i is the value of k-eff calculated with mass M_i of pure isotope i. If the calculated value of k-eff is less than or equal to the Rule-of-Fractions value, the Rule-of-Fractions is validated for that system, and EF_i is simply the ratio of the calculated critical mass of the reference isotope r to the critical mass of the isotope i. If the calculated value is greater than the Rule-of-Fractions value, then the equivalence factor for the isotope i is increased until the maximum calculated k-eff value is less than the Rule-of-Fractions value. Note that increasing the equivalence factor is the same as decreasing the critical mass M_i in Eq. 5. Figures 6 and 7 show examples of cases where the calculated values of k-eff are less than or equal to the Rule-of-Fractions values and where they exceed the Rule-of-Fractions values, respectively.

The calculation of equivalence factors for the criticality analysis of the 9972-9975 casks is detailed in Ref. 23. Equivalence factors were calculated for binary metal systems containing fissile-fissile, fissile-fissionable, and fissionable-fissionable isotopic combinations. Only fissile-fissile combinations were considered for solution systems. It is not necessary to consider solution systems for binary combinations in which one or both of the isotopes is fissionable (but not fissile). By definition, such an isotope has a capture to fission ratio in the thermal energy range greater than 1.0 Thus, adding a fissionable isotope to a fissile solution will always reduce the value of k-eff. For solution systems, only infinite water reflectors were considered, but both infinite water and infinite steel reflectors were considered for the metal systems. In metal systems, steel is often a better reflector than water, due to the shape of the neutron energy distribution in relation to the iron scattering resonance. The results of the

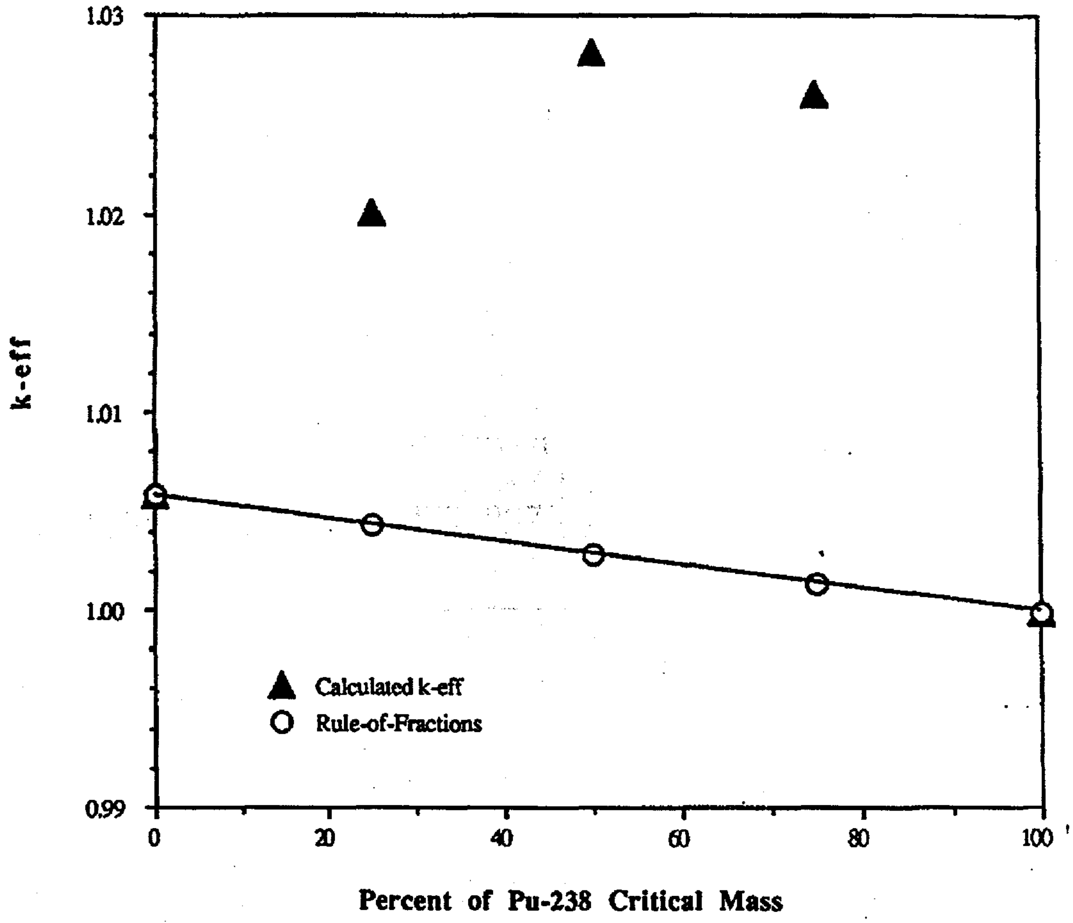


Figure 6. Example of case where calculated k-eff's exceed the Rule-of-Fractions values. This particular example is for ^{238}Pu referenced to ^{239}Pu.

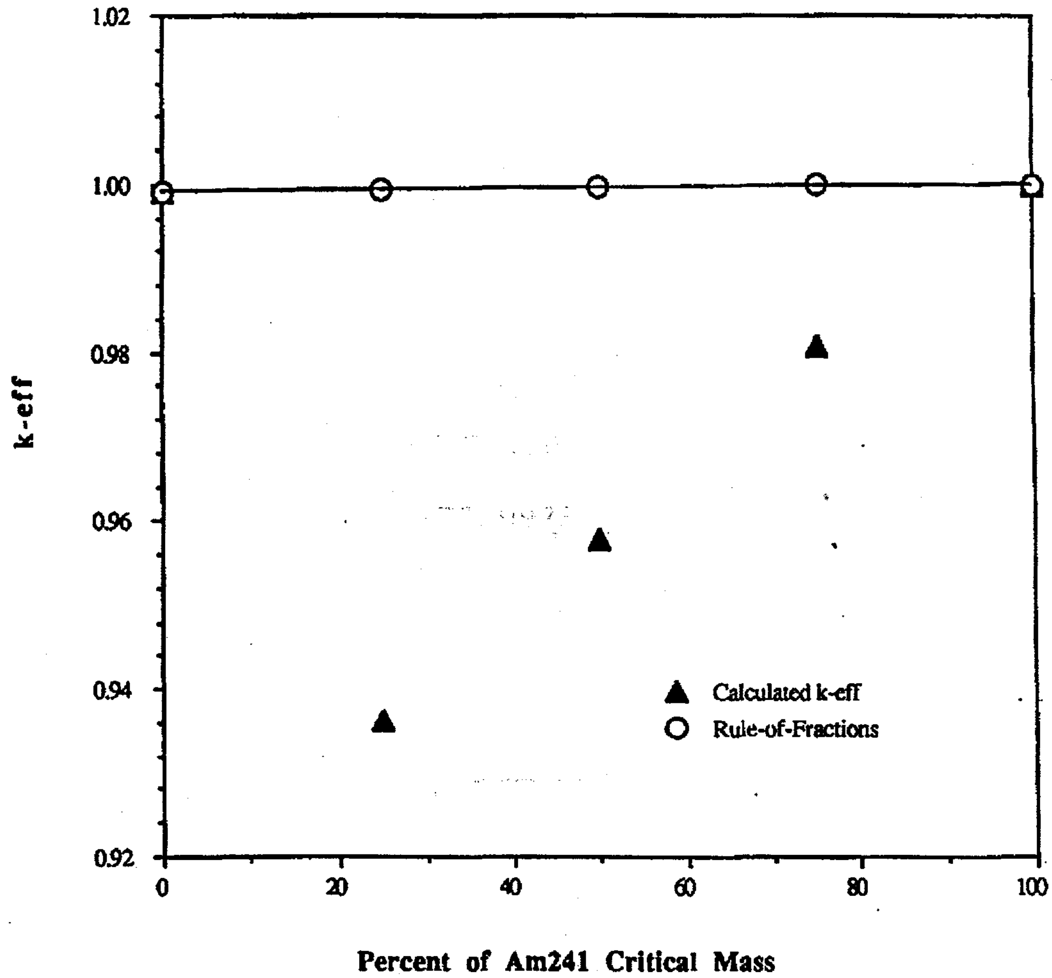


Figure 7. Example of case where the calculated k-eff's are less than the Rule-of-Fraction values. This particular case is for ^{241}Am referenced to ^{239}Pu.

equivalence studies are listed in Table 7. Note that if the equivalence factor for isotope *i* is less than 1.0, the mass limit of isotope *i* exceeds that of the reference isotope. In this case, the mass limit of the reference isotope is used as the content envelope mass limit. On the other hand, if the equivalence factor is greater than 1.0, the mass limit for the mixture of isotopes *i* and *r* is less than that for the reference isotope *r*. The actual calculation of mass limits is detailed in the next section.

In the calculation of equivalence factors for metal systems, the heterogeneity of the systems can play a crucial role. The equivalence relations in Table 7 were developed assuming a homogeneous distribution of the fissile and fissionable isotopes. If the materials are heterogeneously distributed, the results listed in Table 7 are no longer valid. The worst case scenario involves a ball and shell configuration, in which a plutonium ball is surrounded by a shell of some uranium, plutonium or americium isotope. In such a case, very large equivalence values can result, which would reduce the envelope mass limits by a very large amount. Fortunately, the material to be shipped in the 9972-9975 shipping casks is homogeneously distributed, so heterogeneity does not need to be accounted for.

TABLE 7

Equivalence Factors

Isotope	Reference Isotope	Equivalence Factor	
		Water Reflected	SS-304 Reflected
Am-241	Pu-239	0.07	0.09
Pu-238	Pu-239	0.90	1.01
Pu-240	Pu-239	0.19	0.25
Pu-241	Pu-239	1.00	0.89
Pu-241*	Pu-239	1.86	--
Pu-242	Pu-239	0.11	0.12
U-235	Pu-239	0.25	0.25
U-235*	Pu-239	0.65	--

*Aqueous solution.

4.3.1. Calculation of Envelope Mass Limits

4.3.1.1 Procedure/Theory

The discussion in section 4.3 concerned binary systems of fissile or fissionable isotopes. The content envelopes described in Table 5 contain as many as 7 fissile or fissionable isotopes present in sufficient quantity to warrant consideration in the calculation of the mass limit. Eq. (4) can be extended to multi-component systems as follows:

$$M \le \frac{M_r}{\sum_i x_i EF_i} \qquad (6)$$

where M is the envelope mass limit, x_i is the weight fraction of isotope i in the mixture, and M_r is the mass limit for the reference isotope in the cask. The latter value is the one found from the criticality safety analysis. Since the weight fraction of the isotopes within the content envelope can vary over a wide range, the problem is to find the combination of weight fractions and equivalence factors that optimize the sum of the products of x_i and EF_i. This will give the most conservative envelope mass limit, since Eq. (6) can be re-arranged as:

$$M \le \frac{M_r}{\sum_i x_i EF_i} \qquad (7)$$

It is apparent that the denominator in Eq. 7 is maximized by first selecting the isotope with the largest value of EF_i, and including it to the maximum value of x_i permitted (from Table 5). Next, the isotope with the second largest value of EF_i is included to its maximum permissible extent, and so on, until the x_i sum to 1.0.

4.3.1.2 Calculations

In this section the mass limits for each content envelope by cask are calculated. Note that these calculations utilize the results from section 6 (*i.e.*, the mass limit of pure ^{239}Pu and ^{235}U in each cask).

The Packaging and Transportation Group has designated one or more of the cask designs (9972, 9973, 9974, or 9975) to carry material characterized by each of the content envelopes. These designations were included in Table 5 and are summarized below:

9972: Envelopes E and F

9973: Envelope C

9974: Envelope C

9975: Envelopes A, B, C, and D

The mass limits can be calculated using the information in Table 5, the mass limits by cask for the reference isotopes ^{239}Pu and ^{235}U from section 6, and the procedure described in section 4.3.1.1. The mass limits for the reference isotopes calculated in section 6 are summarized below:

	With Exemption		Without Exemption	
Cask	^{239}Pu	^{235}U	^{239}Pu	^{235}U
9972	4.4 kg	13.5 kg	4.0 kg	13.5 kg
9973	4.4 kg	14.5 kg	4.4 kg	14.5 kg
9974	4.4 kg	13.5 kg	4.4 kg	11.5 kg
9975	4.4 kg	11.5 kg	3.5 kg	3.5 kg

The mass limits depend on whether or not a paragraph c exemption is granted by DOE. This is discussed in detail in sections 5 and 6. If the paragraph c exemption is granted, water leakage into the PCV does not need to be considered; if it is denied, water in-leakage must be considered.

Envelope A - The isotopes to be considered are: ^{241}Am, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu (^{237}Np was not considered because it is present in such small quantities and is known to have a very large critical mass). First, assume the paragraph c exemption is granted. The equivalence factors from Table 7, with ^{239}Pu as the reference isotope, are: 0.07, 1.01, 1.0, 0.25, 1.0, and 0.12, respectively. Note that when selecting the equivalence factors from Table 7, the largest value for each isotope is selected. Employing the procedure from section 4.3.1.1, ^{238}Pu is included to its maximum allowable extent (0.40%), then ^{241}Pu to its maximum permissible extent; the remainder is assumed to be ^{239}Pu. The envelope mass limit is then:

$$M = \frac{M_r}{\sum_i x_i EF_i} = \frac{4.4\text{ kg}}{(.004)\bullet(1.01)+(.02)\bullet(1.0)+(0.976)\bullet(1.0)} = 4.3998 \approx 4.4\text{ kg}$$

If the paragraph c exemption is denied, water leakage into the PVC must be considered. Then, the equivalence value used for ^{241}Pu is 1.86, and the envelope mass limit is:

$$M = \frac{M_r}{\sum_i x_i EF_i} = \frac{3.5\text{ kg}}{(.004)\bullet(1.01)+(.02)\bullet(1.86)+(0.976)\bullet(1.0)} = 3.44 \approx 3.4\text{ kg}$$

Envelope B - The specifications in Table 5 for envelope B differ from those in Envelope A only by the amount of ^{241}Am permitted. ^{241}Am does not come into play in determination of the envelope mass limit, since its equivalence factor is less than 1.0. Therefore, the envelope B mass limits are identical to those for envelope A.

Envelope C - Compared to envelope A, envelope C is restricted to less ^{241}Am and ^{238}Pu, but can include ^{235}U. Since the equivalence factor for ^{235}U is less than 1.0, the mass limits for envelope C in the 9975 cask are unchanged from those for envelope A. Materials characterized by envelope C may also be carried in the 9973 and 9974 casks. The mass limit in these casks for envelope C material is the same as for envelope A if the paragraph c exemption is granted. If it is not granted, the mass limit is:

$$M = \frac{M_r}{\sum_i x_i EF_i} = \frac{4.4\text{ kg}}{(.004)\bullet(1.01)+(.02)\bullet(1.86)+(0.976)\bullet(1.0)} = 4.33 \approx 4.3\text{ kg}$$

Envelope D - For envelope D, using the procedure of section 4.3.1.1, 100% ^{238}Pu is used if the paragraph c exemption is granted. The mass limit is then:

$$M = \frac{M_r}{\sum_i x_i EF_i} = \frac{4.4\text{ kg}}{(1.0)\bullet(1.01)} = 4.36 \approx 4.4\text{ kg}$$

If the paragraph c exemption is not granted, ^{241}Pu must be included in the calculation:

$$M = \frac{M_r}{\sum_i x_i EF_i} = \frac{3.5\ \text{kg}}{(0.99) \bullet (1.01) + (.01) \bullet (1.86)} = 3.44 \approx 3.4\ \text{kg}$$

Envelope E - The contents are identical to envelope A (the difference is that envelope A is an oxide material, while envelope E is a metal). The mass limit is calculated in the same manner as for envelope A, except that the reference isotope mass limit without a paragraph c exemption is different :

$$M = \frac{M_r}{\sum_i x_i EF_i} = \frac{4.0\ \text{kg}}{(.004) \bullet (1.01) + (.02) \bullet (1.86) + (0.976) \bullet (1.0)} = 3.93 \approx 3.9\ \text{kg}$$

Envelope F - Equivalence relations were not needed for this case. The only isotopes present in significant quantities are ^{235}U, ^{236}U, and ^{238}U. ^{236}U and ^{238}U are both fissionable isotopes, thus their addition to a thermal system reduces the value of k-eff. In fast systems, ANS 8.1 states that ^{235}U limits apply to mixtures with ^{234}U, ^{236}U or ^{238}U provided ^{234}U is considered to be ^{235}U in the mass limit computation. Thus, the mass limit for envelope F is simply the limit for ^{235}U. Since envelope F is only carried in the 9972 (9965), the limit for envelope F is 13.5 kg, with or without the paragraph c exemption.

The results calculated in this section are summarized in Table 8. The values in parenthesis are the limits if the paragraph c exemption is denied.

TABLE 8

Envelope Mass Limits for Each Cask

Cask	Enevelope Mass Limit (kg)					
	A	B	C	D	E	F
9972	-	-	-	-	4.4 (3.9)	13.5 (13.5)
9973	-	-	4.4 (4.3)	-	-	-
9974	-	-	4.4 (4.3)	-	-	-
9975	4.4 (3.4)	4.4 (3.4)	4.4 (3.4)	4.4 (3.4)	-	-

5.0 DISCUSSION OF CONTINGENCIES

The contingencies that must be considered in shipping cask criticality analyses are specified in 10 CFR 71. These contingencies depend on the Fissile Class for the shipping package. The 9972-9975 casks are to be certified as Fissile Class I packages, which means they can be transported in unlimited numbers, in any arrangement, and require no nuclear criticality safety controls during transport. All fissile material packages must meet the requirements of 10 CFR 71.55 "General Requirements for All Fissile Materials Packages." The requirements of this subpart that relate to nuclear criticality safety are summarized below:

1. (Paragraph d) The package must be subcritical under Normal Conditions of Transport (NCT, *i.e.*, the cask loaded as expected).

2. (Paragraph b) The shipping cask must remain subcritical if water leaks into the containment system. In the analysis, the most reactive credible configuration of fissionable material chemical and physical form must be used, moderation by water must be considered to the most credible extent, and full water reflection must be assumed.

In paragraph (c), the Commission states that an exception to the above requirement may be granted if no single packaging error would permit leakage.

3. (Paragraph e) The package must be subcritical under Hypothetical Accident Conditions. The fissionable material must be

assumed to be in its most reactive credible physical and chemical form, with moderation by water to the most credible extent, and full water reflection. Hypothetical Accident Conditions (HAC) that must be considered are detailed in 10 CFR 71.73. They include various free drops that may deform the shipping package, a fire test in which parts of the cask may char or burn, and a water immersion test.

Note that while it is not specifically stated, it is implied that the requirements of 71.55 apply to a single package. Subpart 71.57, "Specific Standards for a Fissile Class I Package," specifically relates requirements for arrays of the shipping package. The requirements that relate to nuclear criticality safety are listed below:

1. (Paragraph a) Any number of undamaged packages must be subcritical in any arrangement. Optimum interspersed hydrogenous moderation must be assumed unless the amount of interspersed moderation actually present in the package is greater than the optimum amount. This is an NCT requirement.

2. (Paragraph b) 250 damaged packages, stacked together in any arrangement, must be subcritical. Optimum interspersed hydrogenous moderation and close water reflection on all sides, must be considered. This is an HAC requirement.

In this work, the analysis to support the requirements of 71.55 is referred to as single unit analysis, while array analysis supports 71.57 requirements.

According to SARP reviewers from Lawrence Livermore National Laboratory, current NRC (and therefore DOE) interpretation of 10 CFR 71.55 assumes that the requirement of the package to be subcritical when flooded by water (paragraph b), applies to arrays of the package as well. For the 9972 and 9975 casks, this requirement can only be met by reducing the mass limit below the operational requirements. Therefore, two results are reported in this NCSE for the 9972 and 9975 packages. One set assumes the exception in paragraph c will be granted, so that the operational requirements on mass limits can be met. The other set assumes the exception is not granted, and provides the necessary mass limits for that scenario. The Packaging and Transportation Group of SRTC will make the decision of whether or not to apply for the paragraph c exception for the 9972 and 9975 packages. Note that the operational mass requirements are met for the 9973 and 9974 packages without invoking the paragraph c exception.

The requirements of 10 CFR 71 are thorough and ensure the maximum credible value of k-eff is found in the analysis. The HAC requirements go far beyond double contingency requirements. The cask must remain subcritical even when damage from all accident conditions are included in the model (deformation from various free drops, fire test, water immersion).

From an operational standpoint, double contingency relies on human intervention. There is the possibility of putting too much fissionable material in the cask, or of improperly sealing the O-rings. The first of these issues will be addressed by administrative procedure, which will require someone to independently verify that the amount of fissionable material loaded into the cask does not exceed the limit. The O-ring issue is dealt with in the following manner. 10 CFR 71 requires the containment vessel to be leak tested following loading of the fissionable material. If the leak test is successful, then at least one of the O-rings is properly seated. If in fact only one O-ring is properly seated, the failure to properly seat the other O-ring constitutes the first failure. A second failure (failure of the second O-ring) would still be required for water leakage into the containment vessel.

6.0 EVALUATION AND RESULTS

The calculations performed to demonstrate that the 9972-9975 shipping casks meet the requirements of 10 CFR 71 are described in this section.

6.1 Calculational Models

The models used in the criticality analyses were derived from the data presented in Section 2. The following general comments apply to the models for all packages:

1. The rounded bottoms of the containment vessels were flattened such that the vessels are represented by simple cylinders. This was

done in a manner that increased the internal volume of the cylinder and maintained the maximum internal height.

2. The aluminum honeycomb spacer in the PCV was ignored, although the ones in the SCV were included in the model. The PCV volume is small compared to the volume needed for optimum moderation of the amount of fissionable material to be loaded into the casks. By leaving out the spacer, more volume is available for a fissile solution. This results in a fissile solution with an H/X closer to the optimum.

3. In the single unit analysis, the drum walls are ignored, since they would only introduce a negligible amount of added neutron absorption. (The drum walls are modeled in the array analysis.)

4. The pre-packing is ignored. The fissionable material is assumed to be loaded directly into the containment vessel. (Plastics in the containment vessel were initially ignored, but were addressed later in the analysis, as is discussed later in section 6.5.) Without the prepackaging to constrain its shape, the fissionable material is allowed to take on the most reactive geometry (sphere or cylinder with H/D as close to 1.0 as possible within the confines of the PCV).

5. With one exception, the nominal inner and outer diameters and wall thicknesses were assumed for the containment vessels and shields. The exception is for the PCV, where the maximum OD and minimum thickness was chosen. This maximizes the volume of the PCV, which maximizes the reactivity of fissile solutions. The other concern with wall thicknesses and vessel diameters is their effect on neutron absorption. This issue was addressed and is discussed in Section 6.6.

Figures 8-11 show the base models used for the 9972-9975 casks. These diagrams represent the model used for the NCT conditions for the single unit analysis. For HAC conditions in the single unit analysis, the Celotex insulation was assumed to absorb enough water to have the same moderating properties of water, and was thus modeled as water. For NCT array analyses, the model was similar to that shown in Figures 8-11 except that the drum wall was included.

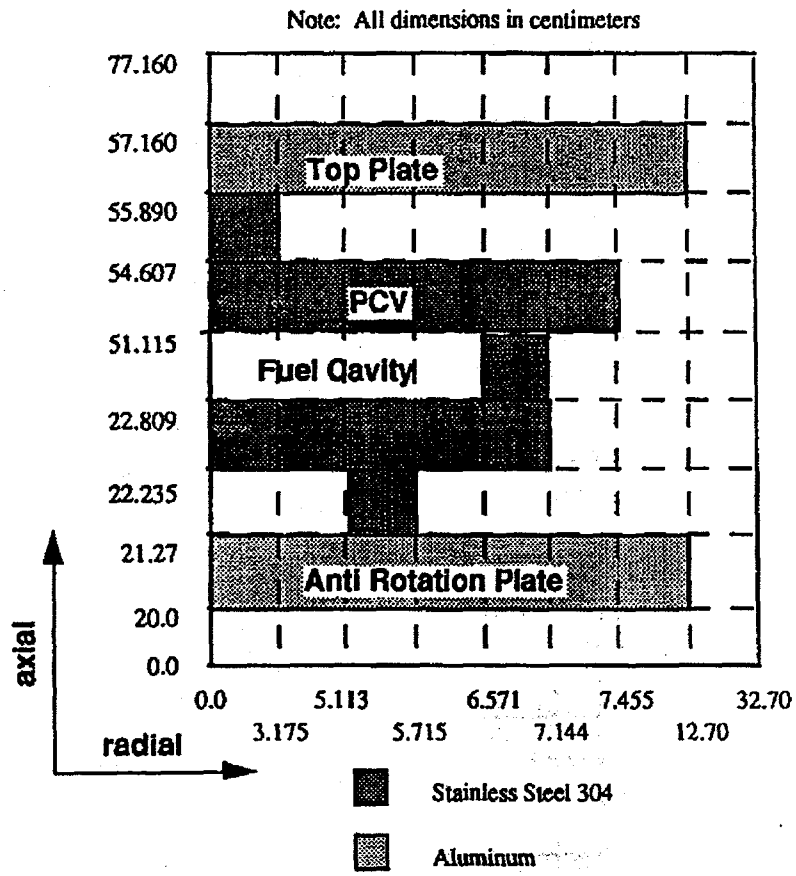


Figure 8. Computational model used for the 9972 cask.

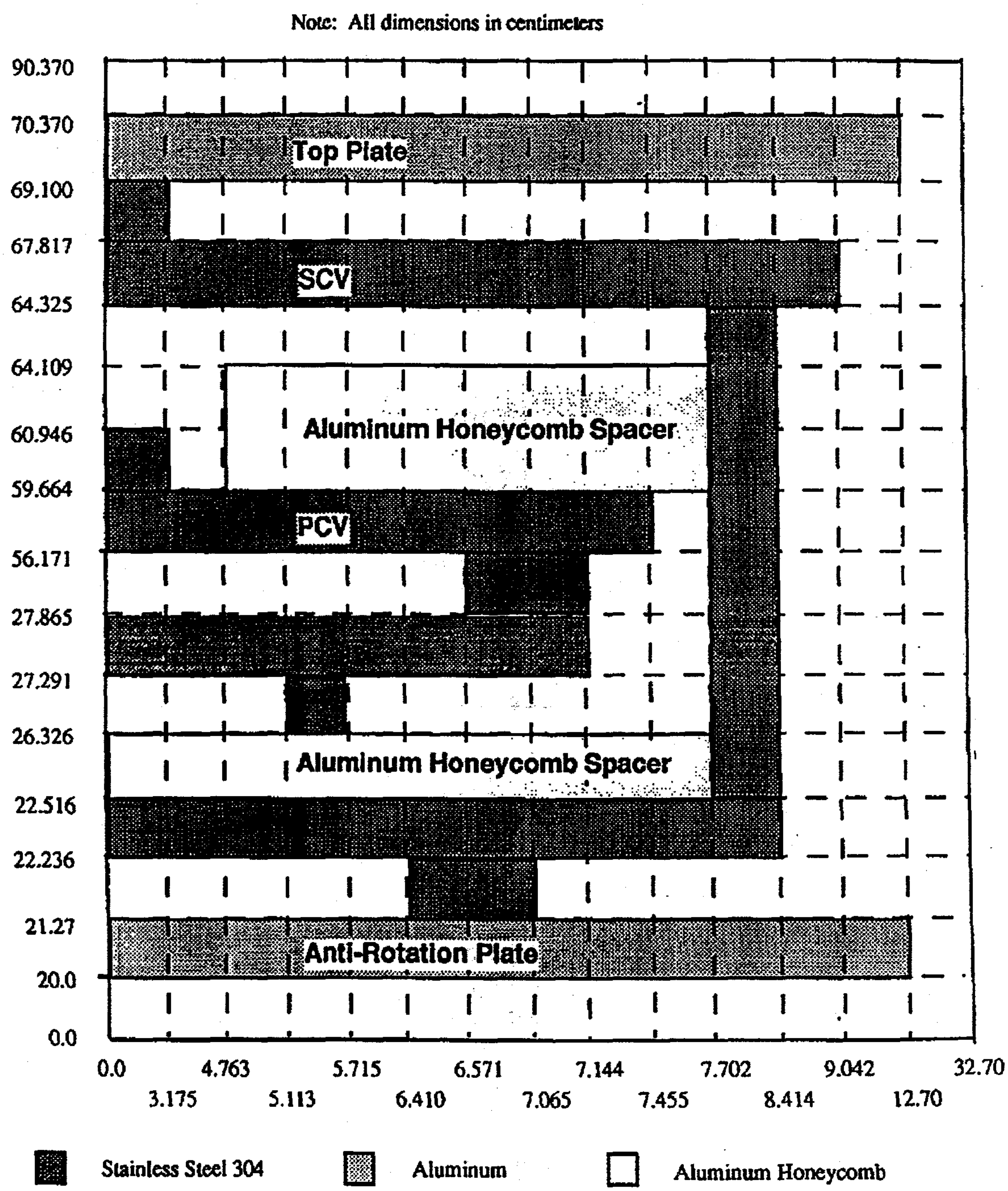


Figure 9. Computational model used for the 9973 cask.

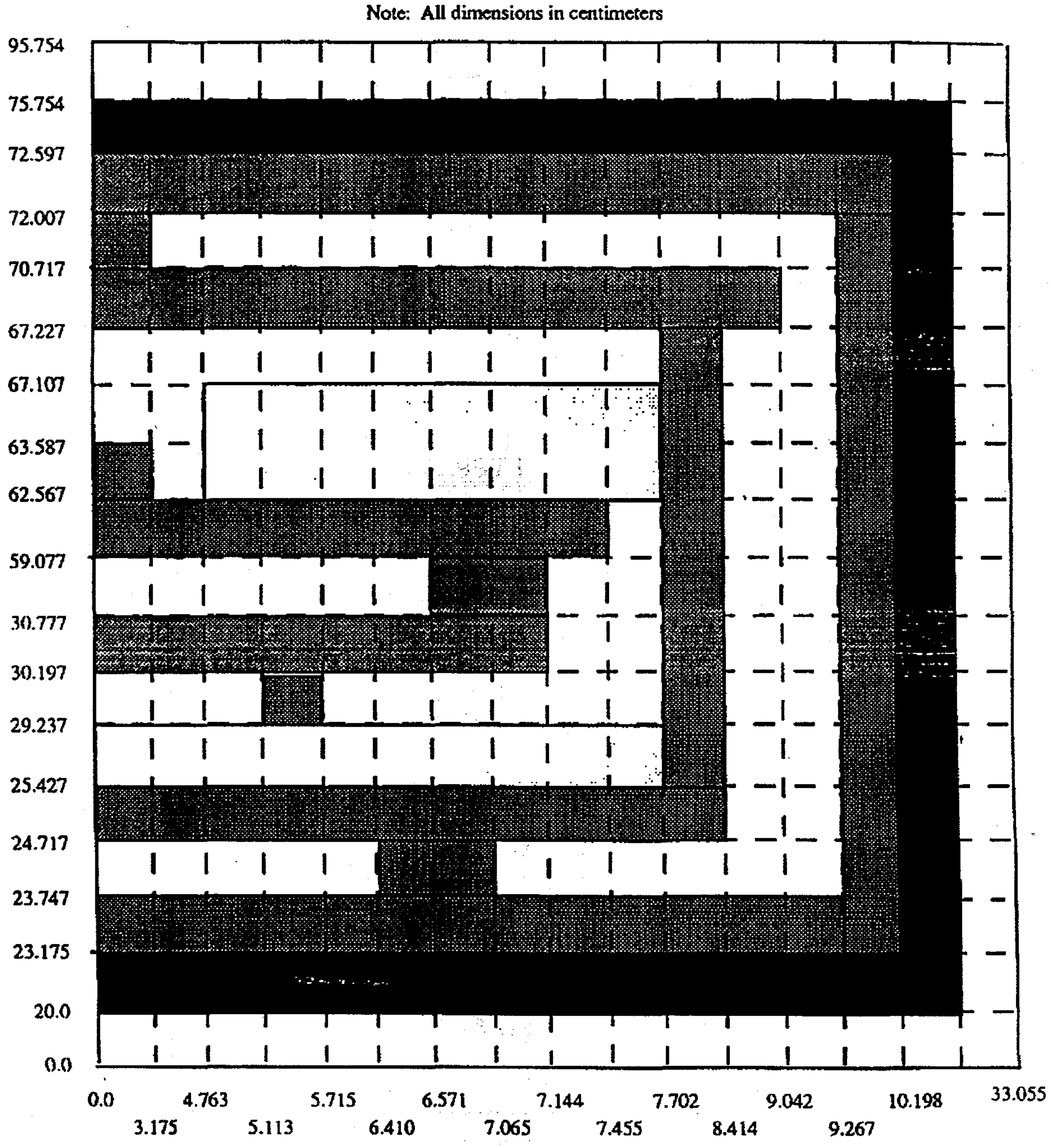


Figure 10. Computational model used for the 9974 cask.

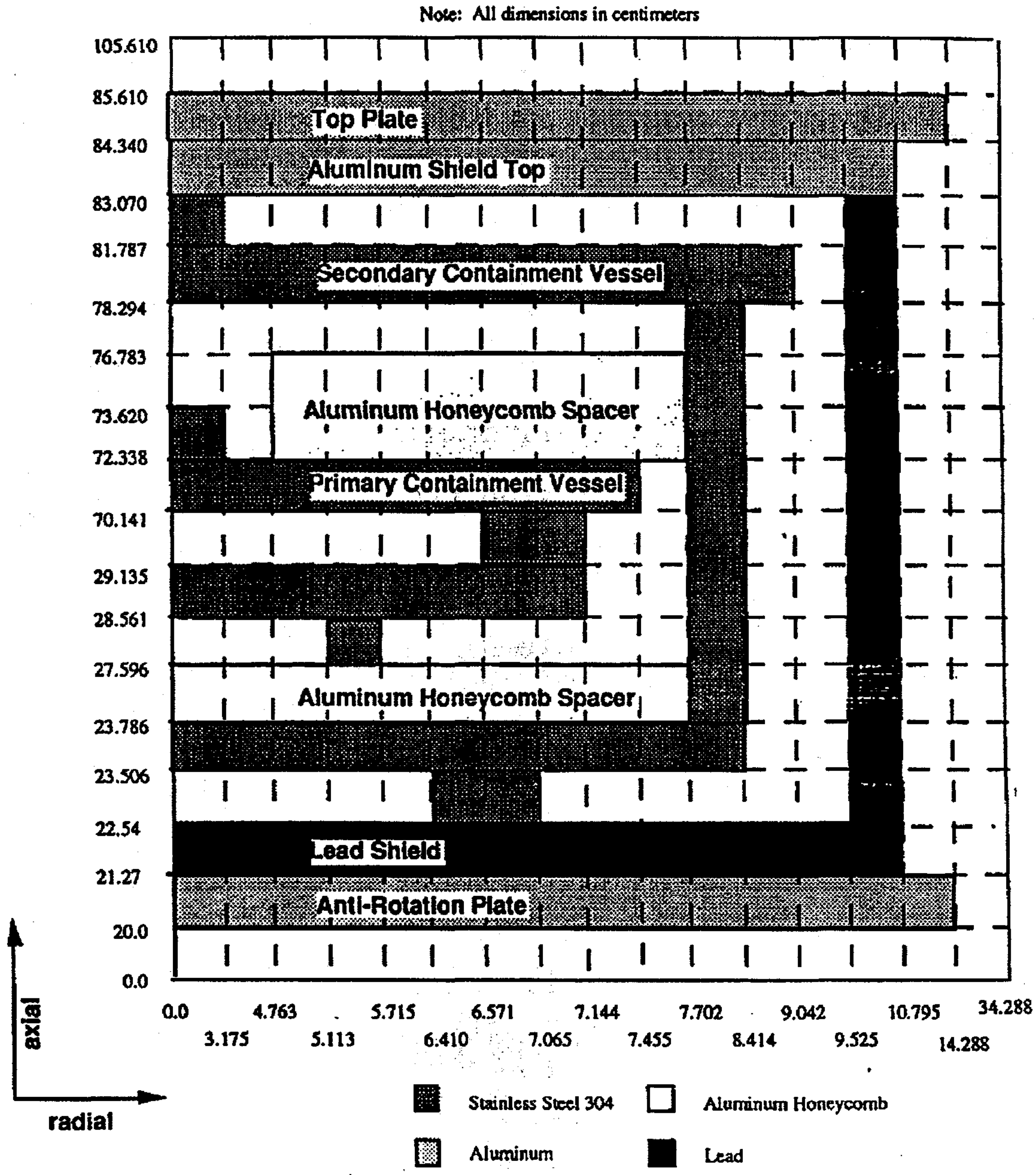


Figure 11. Computational model used for the 9975 cask.

For HAC array analyses, major changes to the models were required. The models for the containment structures did not change, but the placement of the containment structures within the drums, and the modeling of the Celotex insulation, did. To account for the possible changes that could occur to the casks as a result of the hypothetical accident scenarios, data from actual HAC tests (as specified in 10 CFR 71) were utilized. The most conservative results obtained from all tests were augmented by a 50% safety factor, combined, and used to create the HAC model. The test results used are documented in Ref. 24. The following results from a worst case hypothetical accident were included in the HAC model:

1. Movement of the containment structure within the drum due to crushing of the Celotex in a free drop. Movements of 2.5 inches axially and 1 inch radially were used.

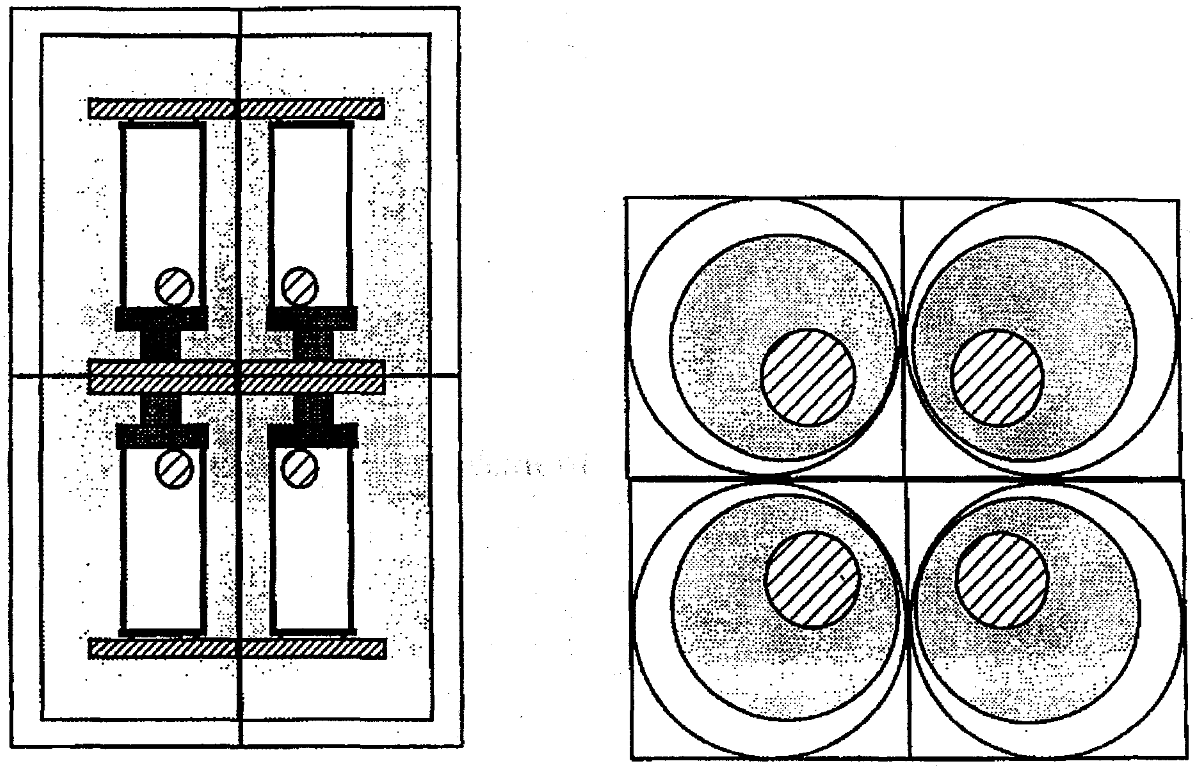
2. Destruction of the outer layers of Celotex due to charring and thermal degradation during the hypothetical fire. Reduction of 1.5 inches in the Celotex radius and 2 inches in Celotex height were used (the destroyed Celotex was assumed to vaporize, i.e., it is replaced with void).

3. Water flooding of the drum and/or the containment structure.

The total axial and radial reductions in Celotex thickness, after applying a 50% safety factor, are 6 and 4.5 inches, respectively. These reductions in thickness were used to move the containment structure within the drum, in a manner that would maximize the local fissionable material packing density. The result is a scheme that assumes the drums are stacked head to head, with the containment structures of four adjacent casks moved in radially toward the center of the four drums. This is illustrated in Figure 12. This is a highly conservative model.

6.1.1 Fissionable material models

Several different physical and chemical forms of fissionable materials were modeled. In all of the analyses, the fissionable material was assumed to be either ^{235}U or ^{239}Pu. The other isotopes that can be present in each content envelope are accounted for using equivalence relations, as discussed in Section 4.3. The fissionable



(a) (b)

Figure 12. These figures show the damaged array (HAC) configuration. The small spheres represent the fissionable material inside the PCV. In figure (b), the intermediate circle represents the Celotex. An infinite array was built by reflecting an array of 8 units configured as shown in (a) and (b).

material to be shipped is in either oxide or metal form. Therefore, the NCT analyses consider a sphere of fissionable oxide or metal (note that in reality, the pre-packaging would preclude the possibility of a spherical shape). For the HAC analyses, flooding has to be accounted for. Two different types of models arise depending on whether or not the paragraph c exception in 10 CFR 71.55 is assumed. If it is not, then water floods the PCV. If the fissionable material is in metallic form, the fissionable material model is simply the fissionable metal surrounded by water inside the PCV. If the fissionable material is in oxide form, a dispersion is formed in the water. Two different dispersions were considered. The more conservative model assumed a dispersion of the fissionable metal in water, while the more realistic model assumed a dispersion of the oxide powder in water.

If the paragraph c exception in 10 CFR 71.55 is assumed, water entry into the PCV does not have to be considered. The fissionable material model then is the same as for NCT conditions (although it is still placed in an HAC array).

6.2 Atom Densities

Densities and compositions for the structural materials were presented in Section 2. A density of 0.99823 g/cc was assumed for water. The composition of stainless steel used in the analysis was chosen to match that used in the previous SARP criticality work. These specifications agree with those in Table 4 with some minor exceptions: 0.75 wt. % Si is specified in Table 4, while 1.0 wt. % was used in the previous SARP work, and the P (.04 wt. %) and S (.03 wt. %) listed in Table 4 were not included. These exceptions have a negligible effect on the criticality analysis. The impurity atoms in the lead and aluminum were ignored, since they are limited to such small quantities by the specs. A density of 11.29 g/cc was used for lead, in order to be consistent with the previous SARP. This value is slightly less than the value of 11.34 g/cc found in the current literature. However, it is expected to have a negligible influence on the calculations. Table 9 lists the atom densities for the water, aluminum, lead and stainless steel (note that because the drum steel and the containment vessel steel were so similar, the same material

TABLE 9

Atom Densities for Non-Fissile Materials Except Celotex

Material	Density (g/cc)	Element	Atomic Mass	Atom Density (atms/b-cm)
Aluminum	2.7	Al	26.9815	6.0262e-02
Lead	11.29	Pb	207.2	3.2813e-02
Water	0.99823			
		H	1.0079	6.6737e-02
		O	15.9994	3.3369e-02
ss304	7.895			
(70.90 wt %)		Fe	55.847	6.0360e-02
(2.00 wt %)		Mn	54.938	1.7321e-03
(18.01 wt %)		Cr	51.996	1.6471e-02
(1.00 wt %)		Si	28.0855	1.6940e-03
(0.08 wt %)		C	12.011	3.1691e-04
(8.00 wt %)		Ni	58.69	6.4834e-03

was used for both). Appendix B gives the equations used in the atom density calculations.

As stated in Section 2, specifications require the Celotex insulation to have a minimum density of 0.22 g/cc. A density of 0.20 g/cc was used in the calculations to account for the possibility of void spaces between layers and to ensure conservatism. The Celotex was assumed to have the elemental composition of cellulose ($C_6H_{10}O_5$). The Celotex was assumed to absorb water when the drum was flooded. The atom densities for the Celotex as a function of weight percent water absorbed are given in Table 10.

TABLE 10

Celotex Atom Densities

Wt. % Water in Celotex	Effective Density (g/cc)	Atom Densities (atms/b-cm)		
		C	H	O
0	0.20	4.4569e-03	7.4282e-03	3.7141e-03
20	0.25	4.4569e-03	1.0772e-02	5.3861e-03
40	0.33	4.4569e-03	1.6342e-02	8.1709e-03
60	0.50	4.4569e-03	2.7485e-02	1.3743e-02
80	1.00	4.4569e-03	6.0914e-02	3.0457e-02

Densities of uranium and plutonium metal used in the analyses were 19.05 g/cc and 19.84 g/cc respectively. The 19.05 value for uranium is the theoretical value for the alpha-phase (Ref. 4), and is conservative compared to the normally-used value of 18.9 g/cc. It was used to be consistent with the previous SARP. 19.84 g/cc is the accepted density for ^{242}Pu metal in the alpha phase (Ref. 4). As an added conservatism, neither of these densities were corrected for isotopic composition, which would have reduced the densities in both cases. Uranium and plutonium dioxides were also considered as fissionable material. Dry densities of 10.96 g/cc for UO_2 and 11.46 g/cc for PuO_2 were used (Ref. 4). A maximum moisture content of 30 mg/g was included, as discussed in Section 2. Atom densities for the fissile material are included in Table 11.

The flooded oxides were modeled both as a dispersion of the metal in water and as a dispersion of the oxide in water. A series of computations described in Section 6.3 showed that for ^{235}U/water or ^{239}Pu/water dispersions, the value of k-eff is maximum when the fissile density in the mixture is equal to the fissile mass limit divided by the PCV volume. The atom densities of the corresponding fissile/water and oxide/water dispersions are presented in Table 11.

TABLE 11

Atom Densities for Fissile Materials

Material	Isotope	Atom Density (atms/b-cm)
U-235 Metal	U-235	4.8808e-02
Pu-239 Metal	Pu-239	4.9980e-02
Uranium Dioxide (3 wt. % water)	U-235	1.8440e-02
	O	4.5334e-02
	H	1.6908e-02
Plutonium Dioxide (3 wt. % water)	Pu-239	2.5460e-02
	O	5.2926e-02
	H	1.0028e-03
U-235 metal/water dispersion for the 9972 and 9974	U-235	9.0084e-03
	H	5.4409e-02
	O	2.7204e-02
U-235 metal/water dispersion for the 9973	U-235	9.6746e-03
	H	5.3509e-02
	O	2.6755e-02
U-235 metal/water dispersion for the 9975	U-235	5.2975e-03
	H	5.9495e-02
	O	2.9747e-02
Pu-239 metal/water dispersion for the 9972-9974	Pu-239	2.8870e-03
	H	6.2885e-02
	O	3.1442e-02
Pu-239 metal/water dispersion for the 9975	Pu-239	1.9927e-03
	H	6.4077e-02
	O	3.2039e-02
U-235 dioxide/water dispersion for the 9972 and 9974	U-235	9.0084e-03
	H	4.2414e-02
	O	3.9223e-02
U-235 dioxide/water dispersion for the 9973	U-235	9.6746e-03
	H	4.0613e-02
	O	3.9657e-02

(Continued on next page)

TABLE 11 (Continued)

Material	Isotope	Atom Density (atms/b-cm)
U-235 dioxide/water dispersion for the 9975	U-235	5.2975e-03
	H	5.2435e-02
	O	3.6811e-02
Pu-239 dioxide/water dispersion for the 9972-9974	Pu-239	2.8870e-03
	H	5.8917e-02
	O	3.5362e-02
Pu-239 dioxide/water dispersion for the 9975	Pu-239	1.9927e-03
	H	6.1514e-02
	O	3.4743e-02

6.3 Single Unit Analysis

The single unit analysis for normal conditions of transport was straight forward. Each cask was modeled with fissile (^{235}U or ^{239}Pu) metal and with fissile oxide (UO_2 or PuO_2). The oxide powder was modeled in two different ways: as a low density powder that completely filled the PCV, and as a packed powder at the theoretical density. The latter was found to be much more reactive. Comparing the metal and the packed powder, the metal was more reactive and thus limiting. For both metal and powder, k-eff was found to decrease if the Celotex insulation was replaced with a void in the model. The Celotex apparently acts as a reflector under these conditions, so its removal reduces k-eff. The Celotex was included in the model for the limiting cases.

For the hypothetical accident case, the Celotex insulation was replaced with water, and the containment structure was completely flooded. Oxide powder flooded with water was modeled as a ^{235}U or ^{239}Pu metal dispersion in water. A series of calculations was run to determine the optimum concentration of fissile material in the mixture. The results of these calculations are shown in Figures 13-16. All of the figures follow the same trend. The first maxima at the low density end of the graphs corresponds to a fissile density such that when the PCV is filled with this mixture, the mass of fissile

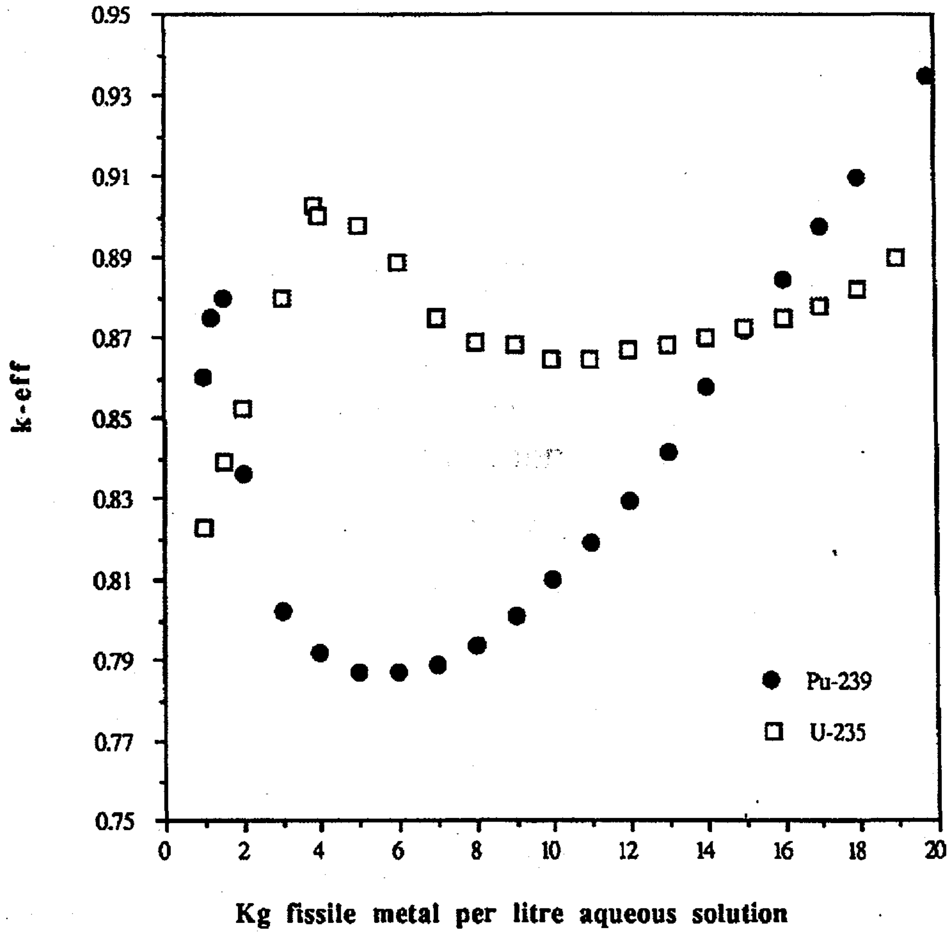


Figure 13. Variation of k-eff as a function of ^{239}Pu and ^{235}U density in a homogenous metal-water mixture for a single, water reflected 9972 cask.

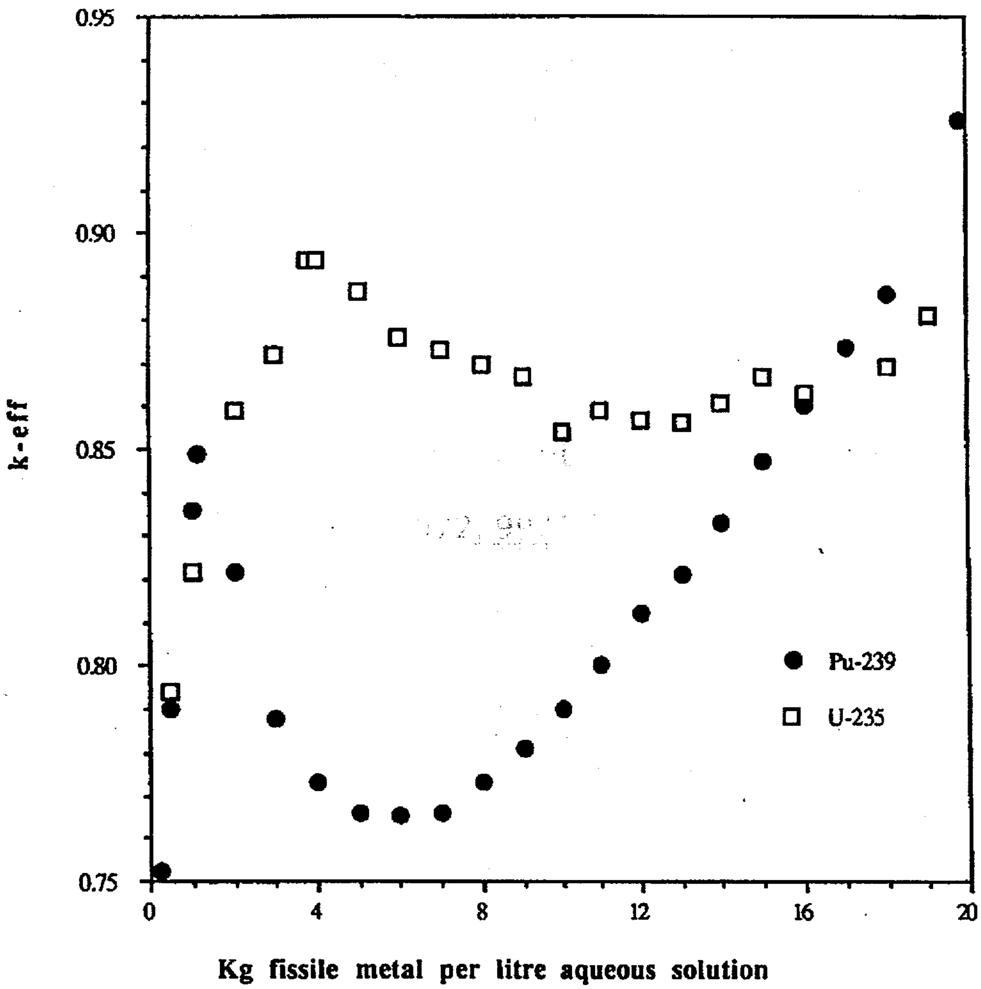


Figure 14. Variation of k-eff as a function of ^{239}Pu and ^{235}U density in a homogenous metal-water mixture for a single, water-reflected 9973 cask.

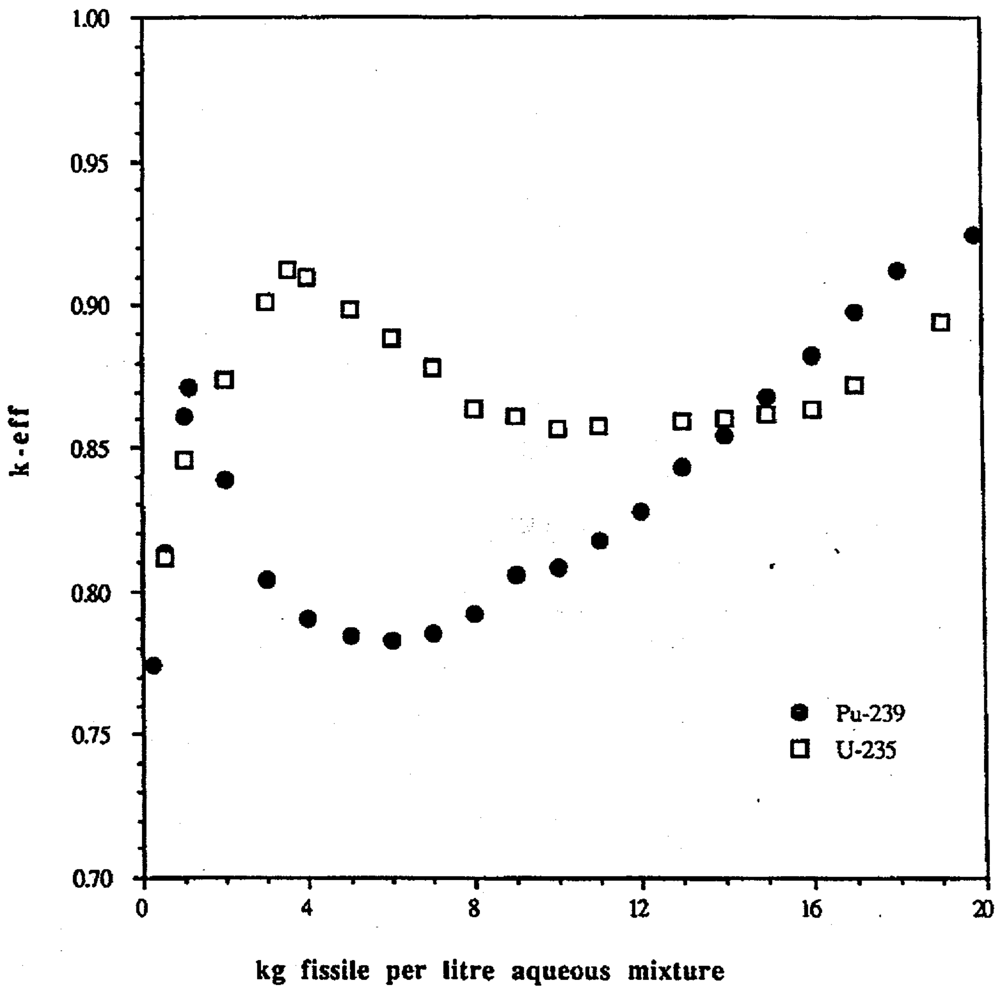


Figure 15. Variation of k-eff as a function of ^{239}Pu and ^{235}U density in a homogenous metal-water mixture for a single, water-reflected 9974 cask.

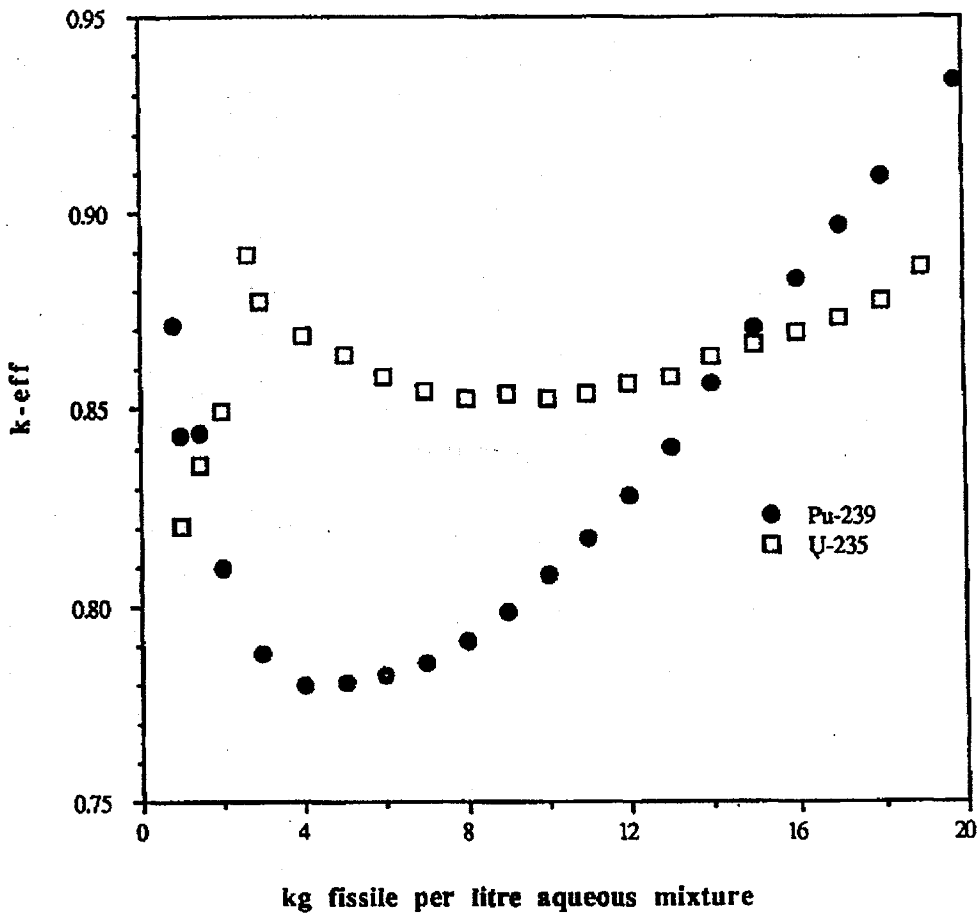


Figure 16. Variation of k-eff as a function of ^{239}Pu and ^{235}U density in a homogenous metal-water mixture for a single, water-reflected 9975 cask.

equals the fissile mass limit. To the left of this maxima, the fissile density is reduced. Under these conditions, the fissile mass that can be loaded into the PCV is less than the mass limit amount. The amount of fissile material that can be loaded into the PCV for all densities to the right of the first maxima is equal to the mass limit. As the density increases from the first maxima, k-eff first decreases as the system is under-moderated, and then increases as the neutron spectrum becomes hard and the system approaches a metal. The final point on the right hand side of the graph corresponds to the fissile metal at its maximum density, and is a second maxima. For all of the casks, the first maxima is larger than the second for ^{235}U systems, and the opposite is true for ^{239}Pu systems. This indicates that the single unit mass limit for uranium materials will be restrained by the fissile metal/water dispersion, whereas the plutonium mass limit will be restricted by the fissile metal.

The location of the first maxima is a function of the fissile mass limit and the PCV volume. Since the ^{239}Pu mass limit is much smaller than the ^{235}U mass limit for all of the casks, the ^{239}Pu maxima occurs at a lower fissile density than does the ^{235}U maxima. The location of this maxima for either isotope also varies among the four packages due to slightly different mass limits for the packages and, in the case of the 9975, different PCV volume.

The strategy for determining the maximum safe mass based on the single unit analysis was as follows. For ^{235}U payloads, the flooded $^{235}UO_2$ powder, modeled as a ^{235}U metal/water dispersion at the optimum concentration as discussed above, was used. The mass of ^{235}U was increased until a value of k-eff close to but less than k-safe was found. The other (less limiting) HAC and NCT cases were then run using this limiting mass, and the resulting k-eff was recorded. The same strategy was followed for ^{239}Pu payloads, except that the mass limit was set using a plutonium metal sphere flooded with water inside the PCV.

Table 12 reports the results of the single unit analysis for all of the casks. Plastics that may be used in the pre-pack were not included in the models. However, the single unit analysis considered complete water flooding of the PCV. Any reflection/moderation that may be provided by the small amount of plastic in the pre-pack is more than

TABLE 12

Single Unit Analysis Results
(For Masses in Table 13)

	k-effective				
	9972	9973	9974	9975	k-safe
Normal Conditions of Transport					
U-235 Metal	0.695	0.737	0.737	0.682	0.957
UO2 at full density	0.550	0.576	0.586	0.530	0.900
Pu-239 Metal	0.782	0.788	0.795	0.789	0.947
PuO2 at Full density	-	0.550	0.562	0.531	0.900
Hypothetical Accident Conditions					
U-235 Metal	0.880	0.898	0.892	0.852	0.957
U-235 metal/water dispersion	0.926	0.911	0.925	0.923	0.962
Pu-239 Metal	0.931	0.934	0.935	0.935	0.947
Pu-239 metal /water dispersion	-	0.865	0.883	0.887	0.962

TABLE 13

Single Unit Mass Limits

	9972	9973	9974	9975
U-235	13.5	14.5	13.5	11.5
Pu-239	4.4	4.4	4.4	4.4

compensated for by flooding the PCV with water. Therefore, plastics are not an issue in the single unit analysis.

6.4 Array Analysis

When analyzing arrays of fissile packages, finding the optimal interstitial hydrogenous moderation is a key concern. Water leakage into the drum (and consequent absorption of that water by the Celotex insulation) and the presence of water to varying degrees in the interstitial space between drums must be considered. The most common approach to solving this problem, which is the approach used in the previous SARP work for the 9972-9975 packages, is to perform a parametric study of k-eff as a function of weight percent water in the space between packages, and as a function of the amount of water absorbed in the Celotex. The optimal hydrogenous moderation is a strong function of the spacing between fissile units. For very close spacing, 100% water density is optimal, while for large spacings, no moderation is optimal. This can be explained as follows. The interstitial hydrogen can either moderate or absorb a neutron. For each individual interaction, scattering (moderation) is the most likely result. However, if the neutron undergoes a large number of interactions, the probability of absorption occurring in one of those interactions becomes high. For small fissile unit spacings, the number of interactions the neutron makes in the water before encountering another unit is small. Therefore, the likelihood of the neutron being absorbed before reaching another fissile unit is small, and the water acts as a moderator. For large fissile unit spacings, the likelihood of a neutron being absorbed before reaching another fissile unit is quite large, due to the large number of interactions the neutron makes with hydrogen molecules in the water. In this case, the water acts to isolate fissile units. Of course, there is a subset of fissile unit spacings for which the optimum hydrogenous moderation is provided by water at less than 100% of its normal density but greater than 0%. Parametric studies like the one mentioned above are designed to find the optimum water density that results in the maximum value of k-eff. For the 9972-9975 casks, the separation between fissile units is great enough that the optimal hydrogenous moderation condition is no moderation. To demonstrate this, a series of calculations was performed in which the density of the Celotex insulation was varied from full density down to zero density (no Celotex). The results of these studies are shown in Figures 17-20. This analysis demonstrates that as the Celotex density is decreased, k-eff increases rapidly. Obviously the Celotex alone is absorbing neutrons and isolating units; addition of water to the Celotex or to the spaces between drums will act only to further isolate the drums and reduce k-eff. The optimal hydrogenous moderation conditions for the 9972-9975 then are those corresponding to a dry cask: no water in the Celotex, and no water in the space between drums.

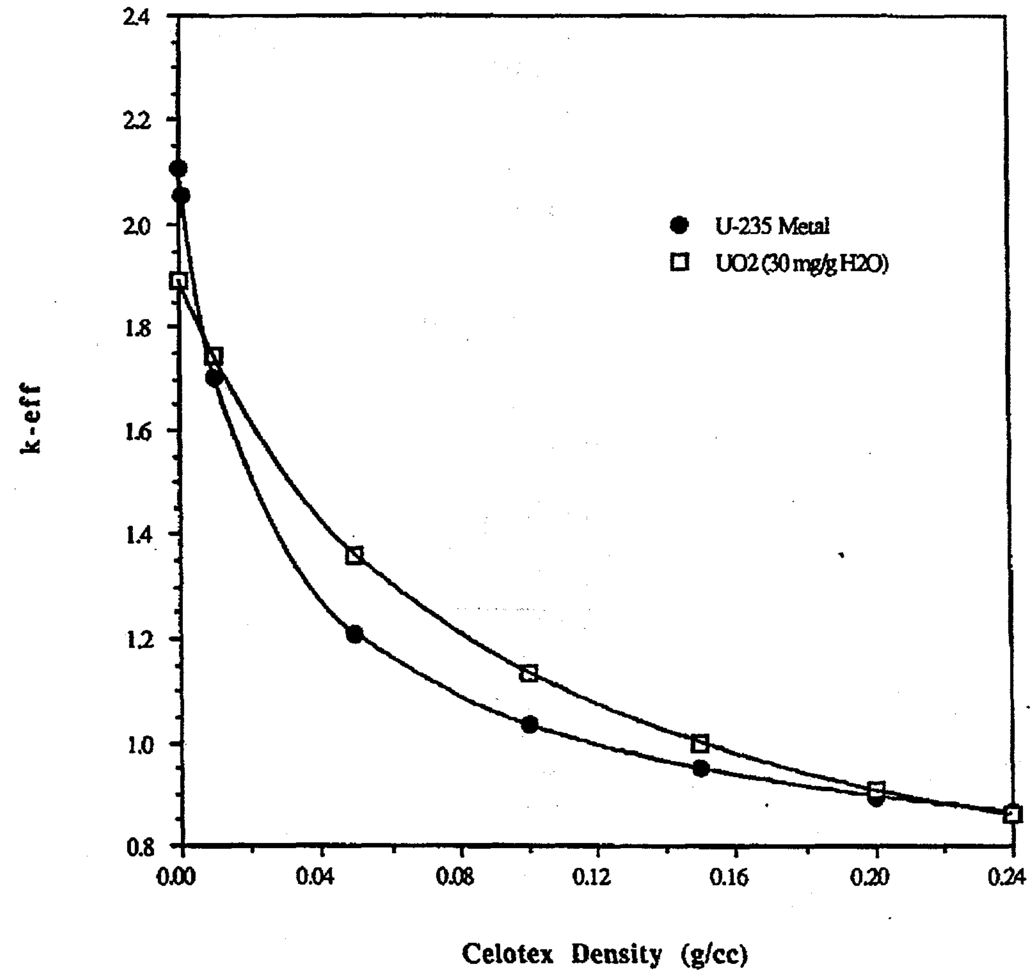


Figure 17. Variation of k-eff with Celotex density in an infinite array of 9972 casks.

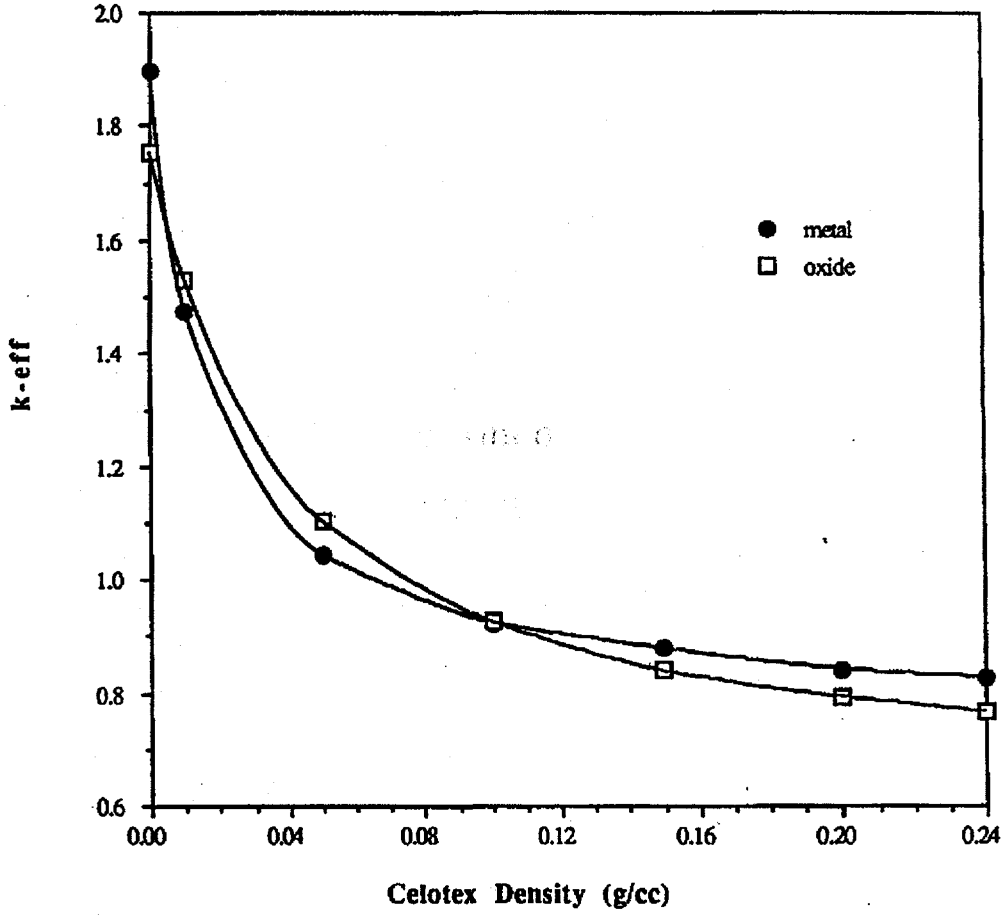


Figure 18. Variation of k-eff with Celotex density in an infinite array of 9973 casks.

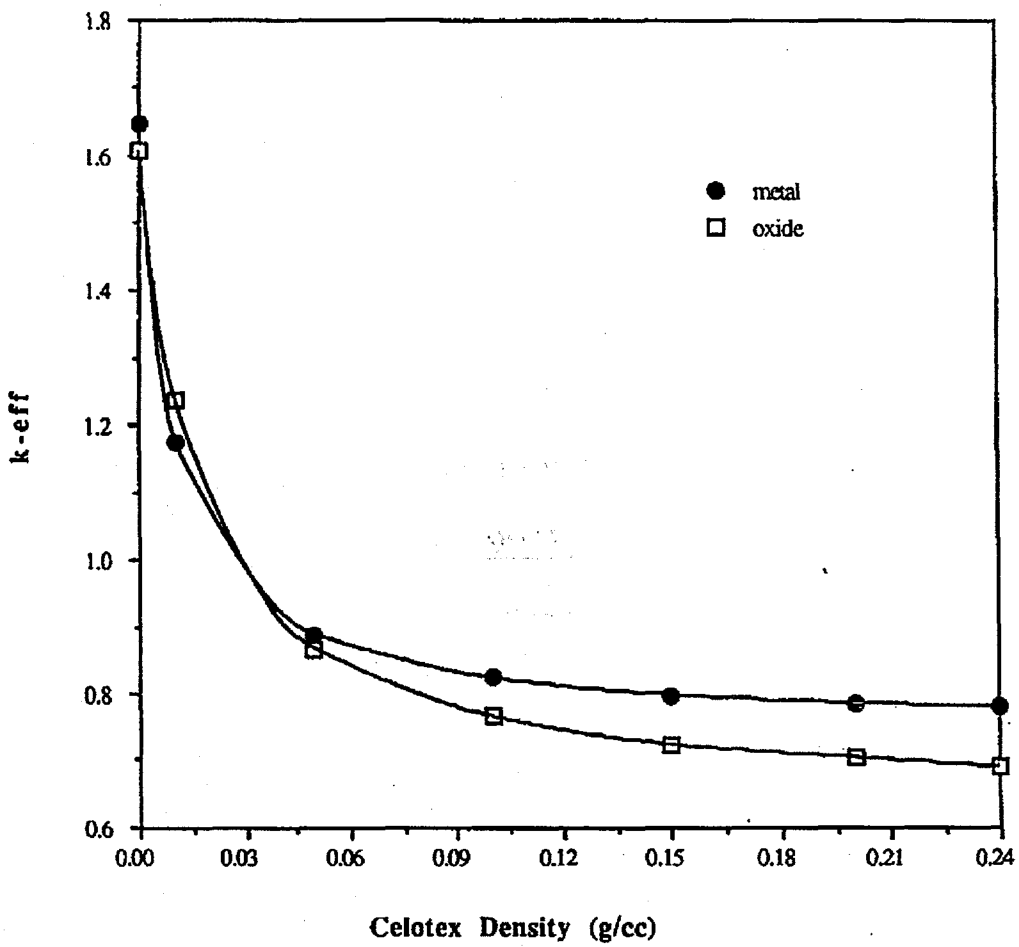


Figure 19. Variation of k-eff with Celotex density in an infinite array of 9974 casks.

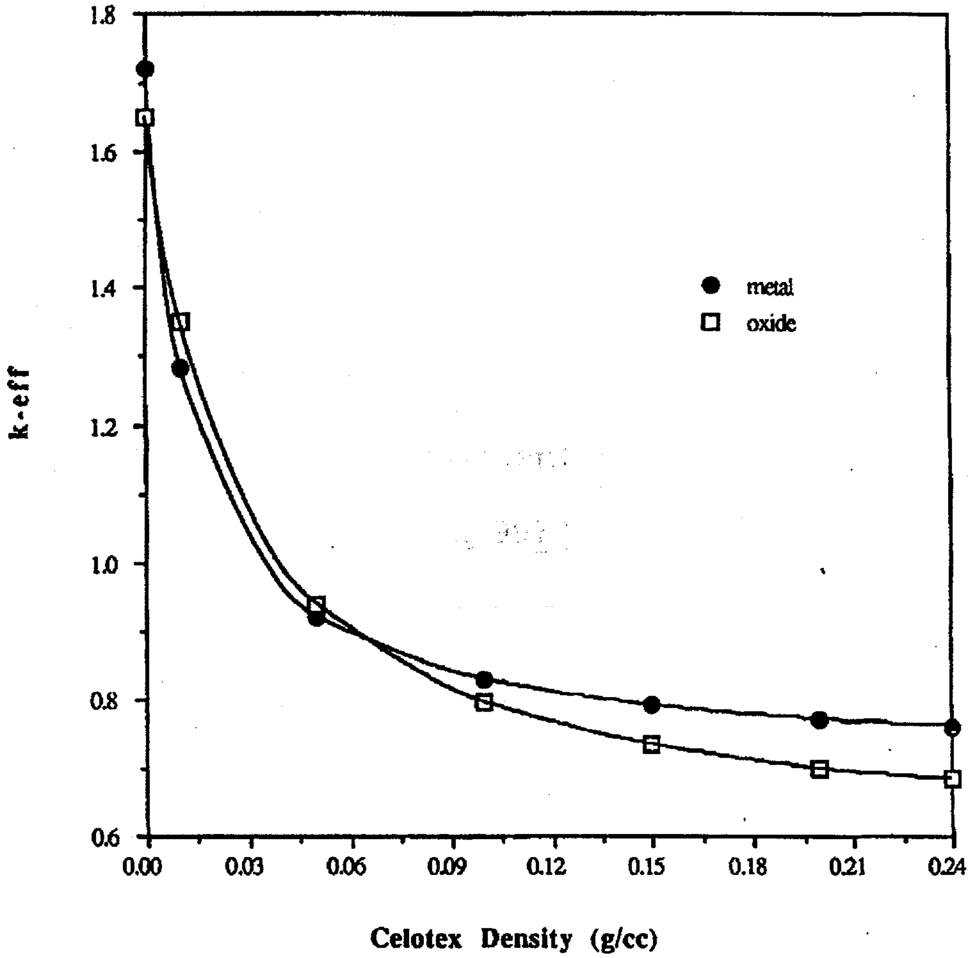


Figure 20. Variation of k-eff with Celotex density in an infinite array of 9975 casks.

The strategy for the criticality evaluation of arrays of casks was to start the analysis for each cask using the previously determined single unit mass limit (see Table 13). There are two possible results: the most limiting value of k-eff is less than k-safe, or the most limiting value of k-eff exceeds k-safe. The former result validates the use of the single unit mass limits as the safe mass limits for the casks, whereas the latter result indicates that the mass limits must be reduced from the single unit values to some lower value.

The following array scenarios were evaluated:

Normal Conditions of Transport:

1. ^{235}U or ^{239}Pu metal sphere
2. $^{235}UO_2$ or $^{239}PuO_2$, with 3 wt. % water

Hypothetical Accident Conditions:

1. ^{235}U or ^{239}Pu metal sphere flooded with water and in an array of damaged casks (HAC array)
2. Flooded $^{235}UO_2$ or $^{239}PuO_2$ in an array of damaged casks (HAC array)

The most limiting fuel loading for the HAC is $^{235}UO_2$ or $^{239}PuO_2$ flooded with water. In order for water to leak into the PCV, it must first leak into the drum. If a drum were submersed, water would first enter the drum and be absorbed by the Celotex insulation. Assuming a leakage path existed, it could then enter the PCV (after first passing through the shielding subassembly in the 9974 and 9975 and the SCV in the 9973-9975). The specifications state that the Celotex can absorb 7 volume percent water, or approximately 31 weight percent. An infinite array of any of the 9972-9975 casks with ^{235}U metal/water dispersion or ^{239}Pu metal/water dispersion is safely subcritical with this amount of water in the Celotex. However, if the Celotex dries out while the water in the PCV remains, k-eff for the infinite array is above 1.0. The results of a parametric analysis of k-eff as a function of percent water absorbed in the Celotex and percent water inside the PCV are shown in Figure 21. In the analysis, up to 80 weight percent water absorption by the Celotex was considered, far beyond the Standards value of approximately 31 weight percent. The results shown in Figure 21 are for an infinited

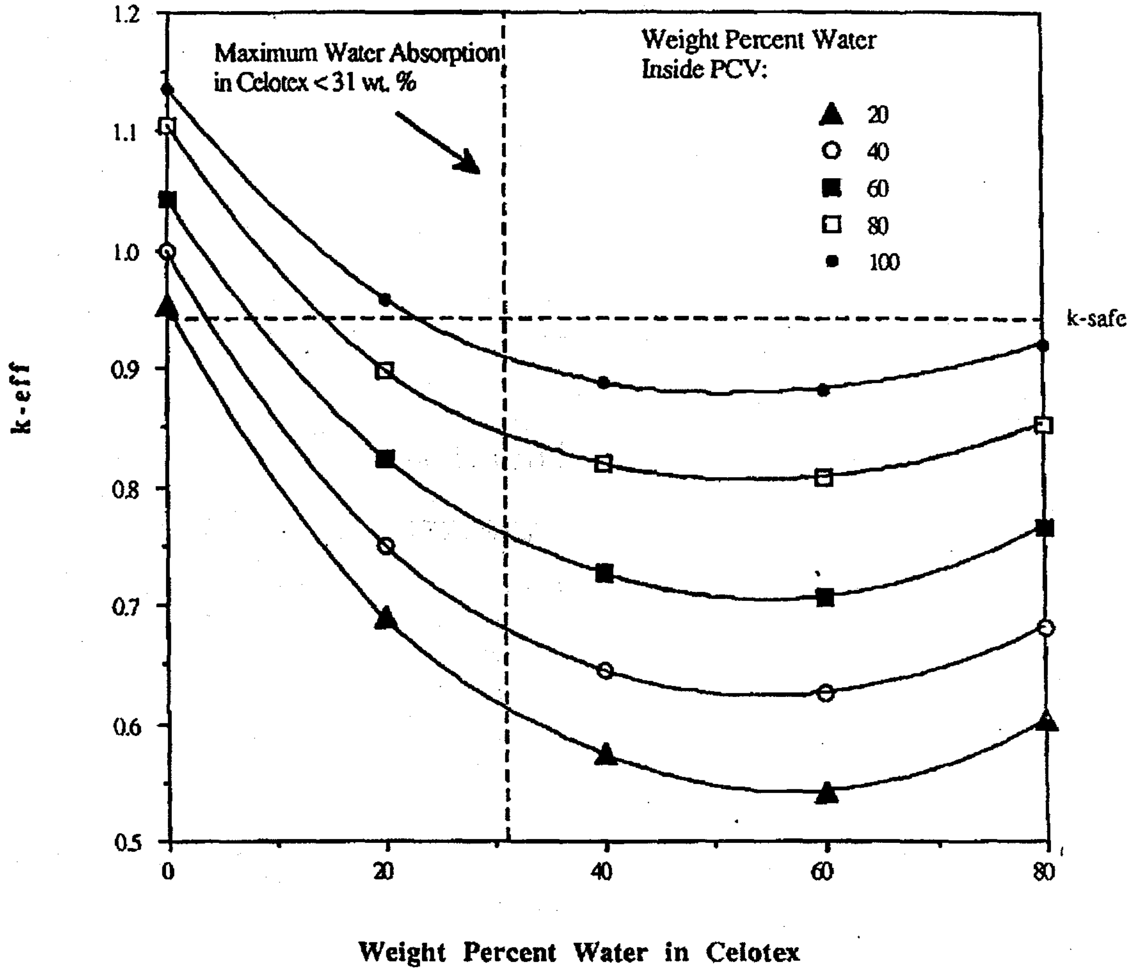


Figure 21. Results of parametric study of effect of water in the Celotex and in the PCV on the calculated value of k-eff for an infinite array of 9972 casks with flooded $^{235}UO_2$ (modeled as ^{235}U metal/water dispersion).

array of 9972 casks. The results for the other casks were similar, although the magnitude of k-eff was less. Figure 21 indicates that if the PCV is filled with water, an infinite array of casks is subcritical only if the Celotex has absorbed close to 30 weight percent water, *i.e.*, almost fully saturated. For lesser amounts of water in the PCV, less water absorbed in the Celotex is required to produce the needed amount of neutronic isolation of the casks. However, even with only 20 weight percent water in the PCV, k-eff exceeds k-safe if there is no water absorbed in the Celotex. Therefore, if flooding is considered credible, the most conservative model assumes complete flooding of the PCV, but dry Celotex.

Using single-unit mass limits, the infinite array k-eff for all four of the packages (9972, 9973, 9974, and 9975) exceeds k-safe with a ^{235}U metal/water dispersion and dry Celotex, as shown in Table 14. Fortunately, two conservatisms in the model can be removed to lower k-eff. 10 CFR 71.57 requires only that 250 packages be considered in the HAC analysis. The first step to reduce k-eff then is to model a finite array of 250 packages instead of an infinite array. Before this can be done, the optimal array shape must be determined. In the X,Y plane, a square shape will be optimal, since it minimizes surface area. Scoping studies were performed in which the number of casks in the axial direction was varied from 1 to 7, while the X and Y dimensions were chosen to approximate a square as closely as possible. Excess units were removed from the edges of the array so that each array had exactly 250 units. The results of the analysis are shown in Table 15. The array with 8 units in the x and y directions and 4 in the z direction is optimal. The second row in Table 14 shows the k-eff calculated for the ^{235}U metal/water dispersion with an 8 x 8 x 4 array. The value for the 9974 cask is now below k-safe, but the others are not. A second conservatism in the model is now removed. The flooded oxide is modeled as an oxide/water dispersion rather than a metal/water dispersion. This causes a reduction of approximately 20% in the hydrogen atom density. The k-eff's corresponding to an 8 x 8 x 4 array with an $^{235}UO_2$/water dispersion are shown in row 3 of Table 14. The k-eff's for the 9972-9974 are all below k-safe, but that for the 9975 still exceeds k-safe. The ^{235}U mass for the 9975 cask has to be reduced to 3.5 kg (from a single unit value of 11.5 kg) to get k-eff below k-safe. The final row in Table 14 shows the k-eff's that result if the 10 CFR 71.55 paragraph c exemption is assumed. These k-eff's

TABLE 14

HAC Results with $^{235}UO_2$ Using Single Unit Mass Limits (Celotex Dry)

	k-eff			
	9972	9973	9974	9975
Infinite array, metal/water dispersion	1.157	1.085	0.961	1.124
8 x 8 x 4 array, metal/water dispersion	0.994	0.974	0.923	1.011
8 x 8 x 4 array, oxide/water dispersion	0.941	0.899	0.853	0.983
infinite array, dry* oxide, no water flooding	0.917	0.908	0.750	0.727

* 3 wt. % H_2O

TABLE 15

Optimum Array Shape

Array (X x Y x Z)	k-eff
infinite	1.154
16 x 16 x 1	0.852
11 x 12 x 2	0.931
9 x 10 x 3	0.972
8 x 8 x 4	0.991
7 x 8 x 5	0.989
6 x 7 x 6	0.984
6 x 6 x 7	0.981

TABLE 16

HAC Results with $^{239}PuO_2$ Using Single Unit Mass Limits (Celotex Dry)

	k-eff			
	9972	9973	9974	9975
Infinite array, metal/water dispersion	-	1.016	0.918	1.071
8 x 8 x 4 array, metal/water dispersion	-	0.908	0.879	0.968
8 x 8 x 4 array, oxide/water dispersion	-	0.890	0.857	0.957
infinite array, dry* oxide, no water flooding	-	0.654	0.589	0.616

* 3 wt. % H_2O

correspond to the dry oxide powder in the HAC array, with no water flooding (flooding of the SCV and/or shielding sub-assembly reduces k-eff since it isolates the units). All cases in Table 14 were calculated using the single unit mass limits of Table 13.

Similar results were found for flooded $^{239}PuO_2$, as can be seen from Table 16. The 9973 and 9974 casks were safe using the single unit mass limit of 4.4 kg in an 8 x 8 x 4 array with a metal/water dispersion. The ^{239}Pu mass limit for the 9975 cask had to be reduced to 3.5 kg (from a single unit limit of 4.4 kg) in order to get k-eff less than k-safe, even with an oxide/water dispersion in an 8 X 8 X 4 array. All of the casks are safe with the single unit masses if the paragraph c exception is taken such that no water enters the PCV.

Flooding of the PCV was also considered for a metallic fissionable material form. A parametric analysis was performed to determine the most reactive combination of flooding of the PCV, SCV and shield sub-assembly. The results for single unit mass limits are shown in Table 17. The most reactive condition for all four casks occurs when only the PCV is flooded, with no flooding of the SCV or shield sub-assembly. With a ^{235}U payload, the 9973-9975 casks are safely subcritical with an infinite lattice using the single unit mass limits. A finite 8 x 8 x 4 array of the 9972 cask is safely subcritical with the single unit mass limit. For ^{239}Pu metal, an 8 x 8 x 4 array of the 9973-9975 casks is safely subcritical with the single unit mass limit, but the same array for the 9972 has k-eff > k-safe. If the ^{239}Pu mass limit in the 9972 cask is reduced to 4.0 kg, the 8 x 8 x 4 array is safely subcritical. If the exception in paragraph c is taken instead, the HAC metal model corresponds to the metal sphere in a HAC array with no water flooding. This results in a k-eff of 0.922 < k-safe for a 4.4 kg mass limit.

The final results of the array analysis are given in Tables 18 and 19. Two sets of results are given: the first set in Table 19 assumes the exception in 10 CFR 71.55 paragraph c will not be applied for, while the second set of results assumes it will be applied for. The mass limits resulting from both assumptions are given in Table 18. In Table 19, the values in square brackets [] under the "With Paragraph c Exemption" section are the same values reported under the "Without Paragraph c Exemption." These values are already below

TABLE 17

HAC Results for ^{235}U and ^{239}Pu Metals Using Single Unit Mass Limits

cask	Flood Shield Assembly?	Flood SCV?	Flood PCV?	U-235 Infinite Lattice	U-235 8 x 8 x 4 Array	Pu-239 Infinite Lattice	Pu-239 8 x 8 x 4 Array
9972	-	-	yes	0.943	0.916	0.973	0.965
9973	-	no	yes	0.933	-	0.947	0.938
	-	yes	no	0.884	-	0.879	-
	-	yes	yes	0.927	-	0.946	-
9974	no	no	yes	0.901	-	0.944	0.941
	no	yes	no	0.832	-	0.963	-
	no	yes	yes	0.898	-	0.941	-
	yes	no	no	0.826	-	0.858	-
	yes	yes	no	0.826	-	0.856	-
	yes	yes	yes	0.895	-	0.939	-
	yes	no	yes	0.894	-	0.939	-
9975	no	no	yes	0.885	-	0.956	0.944
	no	yes	no	0.821	-	0.884	-
	no	yes	yes	0.877	-	0.951	-
	yes	no	no	0.807	-	0.873	-
	yes	yes	no	0.81	-	0.869	-
	yes	yes	yes	0.869	-	0.945	-
	yes	no	yes	0.867	-	0.944	-

TABLE 18

Mass Limits From Array Analysis

	Mass Limit (kg)			
	9972	9973	9974	9975
No Paragraph c Exemption:				
U-235	13.5	14.5	13.5	3.5
Pu-239	4.0	4.4	4.4	3.5
With Paragraph c Exemption				
U-235	13.5	14.5	13.5	11.5
Pu-239	4.4	4.4	4.4	4.4

TABLE 19

Results of the Array Analysis

	k-eff				
	9972	9973	9974	9975	k-safe
Normal Conditions of Transport:					
U-235 metal (dry)	0.903	0.876	0.802	0.789	0.957
U-235 dioxide powder (3 wt. % Water)	0.820	0.798	0.704	0.708	0.900
Pu-239 metal (dry)	0.890	0.870	0.834	0.862	0.947
Pu-239 dioxide powder (3 wt. % Water)	-	0.590	0.548	0.585	0.900
Hypothetical Accident Conditions:					
Without Paragraph c Exemption:					
(Flooding considered)					
U-235 metal (water in PCV)	0.916	0.907	0.901	0.885	0.957
U-235 oxide/water dispersion	0.941	0.899	0.853	0.942	0.962
Pu-239 metal (water in PCV)	0.940	0.938	0.941	0.944	0.947
Pu-239 oxide/water dispersion	-	0.890	0.857	0.943	0.962
With Paragraph c Exemption:					
(Flooding not considered)					
U-235 metal	[0.916]	-	-	[.885]	0.957
U-235 oxide in HAC array	[.941]	-	-	0.727	0.962
Pu-239 metal	0.922	-	-	[.945]	0.947
Pu-239 oxide in HAC array	-	-	-	0.616	0.900

Note: With the exemption of the three shaded cells, all k-eff values reported in this table were calculated using single unit mass limits of Table 13, which are identical to the array mass limits with paragraph c exemption reported in Table 18. The shaded k-eff values were calculated using the reduced mass limits of Table 18 for no paragraph c exemption, *i.e.*, 3.5 kg ^{235}U in the 9975 and 4.0 kg ^{239}Pu in the 9972.

k-safe without taking the exemption (*i.e.*, with flooding of the PCV). The values with the exemption (no flooding of the PCV) would be lower, but there was no need to calculate them.

6.5 Analysis of Plastics in the Pre-Pack

As was discussed in Section 2.1, the pre-packing will most likely contain an as-of-yet undetermined amount of plastic. If the exemption in 10 CFR 71.55 paragraph c is not taken, the presence of plastic in the pre-pack will have an insignificant impact on the computed k-eff's, because it would simply be replacing water inside the PCV in the HAC analysis. However, if the paragraph c exemption is taken for the 9972 and 9975 casks, the presence of plastic inside the PCV will influence k-eff. For the 9975, Table 17 shows that even with water flooding of the PCV k-eff is less than or equal to k-safe for ^{235}U and ^{239}Pu metals. K-eff is .727 and .616 respectively for the ^{235}U and ^{239}Pu oxides in the dry HAC array. Addition of plastic to these cases will not be enough to raise the calculated k-eff's above k-safe. The 9972 cask with ^{235}U metal or oxide in the flooded condition is safe, so plastics will not increase the calculated k-eff's. However, the 9972 with ^{239}Pu metal needs to be investigated, since k-eff in the dry HAC array is 0.922.

Plastic was assumed to have the chemical composition $(CH_2)_n$. A parametric study was done by surrounding the ^{239}Pu metal sphere with plastic of 0.8, 1.0, and 1.2 g/cc, using a total mass of 30, 50, and 100 grams. The results are shown in Figure 22. The effect the plastic has on k-eff is a strong function of both the plastic density and the total plastic mass. Higher densities have a much stronger effect on k-eff. K-eff increases by less than .010 for a plastic mass of 100 grams and a plastic density of 1.2 g/cc. This small increase in k-eff can be absorbed without exceeding the k-safe value. Thus less than 100 grams of plastics in the pre-pack are not a criticality concern, provided the plastic density is less than 1.2 g/cc.

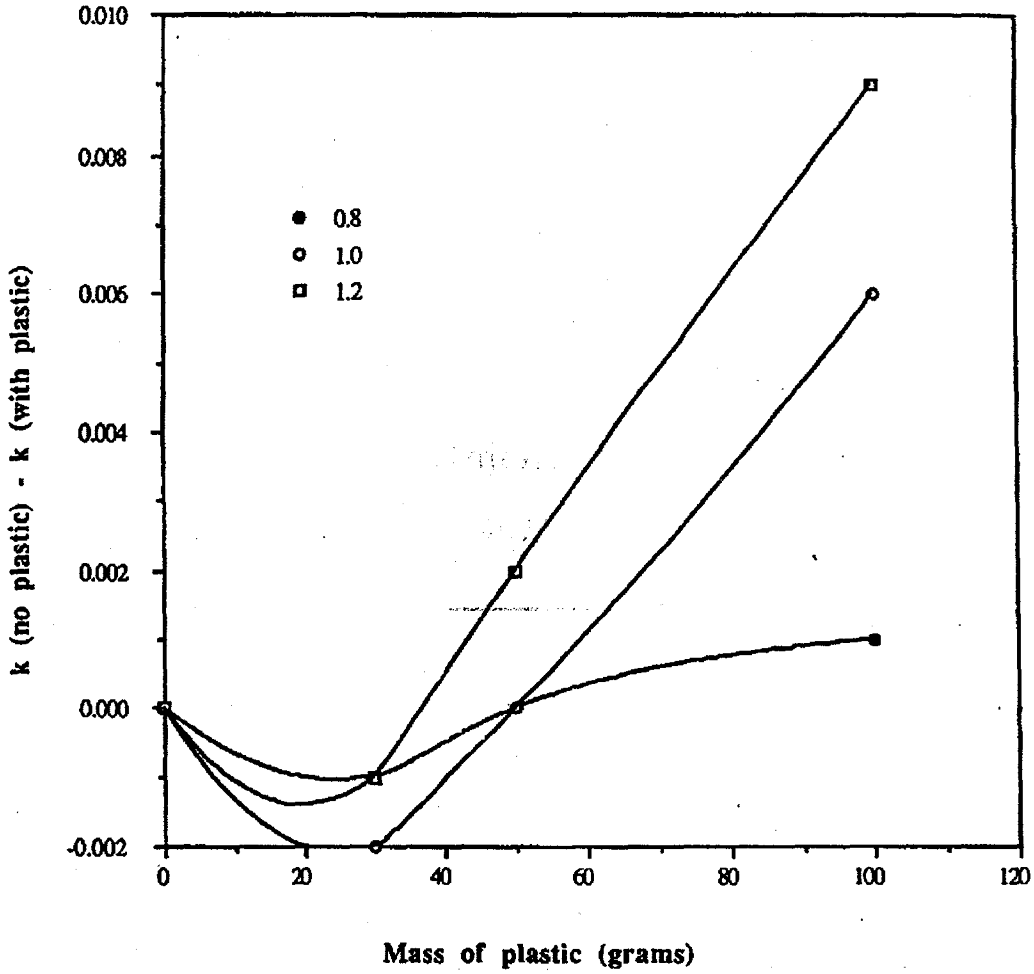


Figure 22. Effect of plastic inside the PCV on k-eff for the 9972 cask with ^{239}Pu metal.

6.6 Uncertainty in Wall Thicknesses

The effect of uncertainties in the thickness of the PCV, SCV, shield, and drum walls on the calculated k-eff was also considered in the analysis. It was found that there is no statistical significance between the values of k-eff calculated with nominal, minimum, and maximum wall thicknesses. The uncertainties used in the calculations are those discussed in Section 2.1.1.

7.0 Design Features (Active and Passive) and Administratively Controlled Limits and Requirements

The criticality analysis assumes the design of the 9972-9975 shipping casks is consistent with the drawings referenced in Section 2 (Refs. 2, 3, 4, 5, and 7). Any deviations in the design from these specifications must be cleared with the criticality engineer. The mass limits for each of the casks carrying fuel from any of the applicable content envelopes are as listed in Table 20. Under no circumstances may more than the listed amount of material be placed in a single cask. The shipping organization must develop procedures to ensure the loaded mass is independently verified as meeting the mass limit requirements. This is the only administratively controlled limit.

8.0 Summary and Conclusions

The amount of material from each envelope that can be placed in the 9972-9975 shipping casks is listed in Table 20. The calculated safe limits for the 9973 and 9974 match the desired operational requirements with no exemptions from the regulations. In order to meet the desired operational mass limits for the 9972 and 9975 casks, the exemption in paragraph c of 10 CFR 71.55 will have to be applied for and granted. If the exemption is not applied for or received, the mass limits for these two casks will be those given in parentheses in Table 20, which are less than the desired limits.

TABLE 20

Envelope Mass Limits for Each Cask

	Envelope Mass Limit (kg)					
Cask	A	B	C	D	E	F
9972	-	-	-	-	4.4 (4.0)	13.5
9973	-	-	4.4	-	-	-
9974	-	-	4.4	-	-	-
9975	4.4 (3.5)	4.4 (3.5)	4.4 (3.5)	4.3 (3.4)	-	-

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APPENDIX A

INPUT FILES FOR MOST LIMITING HAC CASES

File Organization:

KENO V.a Files for Array Analysis
U-235 metal files
U-235 oxide files
Pu-239 metal files
Pu-239 oxide files

TWODANT Files for Single Unit Analysis
U-235 metal files
Pu-239 metal files

1. 9972 with U-235 metal, flooded PCV, 8 x 8 x 4 array.

```
=ajax
1$$ 1 e t
2$$ 71 10 e t
3$$ 92235 1001 8016 24304 26304 28304 25055 14000 6012 13027 e t
end
=bonami
0$$ 1 e
1$$ 2 4 12 0 0 5 e t
3$$ 1 2r2 6r3 3r4 e
4$$ 92235 8016 1001 24304 26304 28304 25055 14000 6012 6012 1001 8016 e
5** 4.8808e-2 3.3369e-2 6.6737e-2 1.6471e-2 6.036e-2 6.4834e-3
    1.7321e-3 1.694e-3 3.1691e-4  4.4569e-3 7.4282e-3 3.7141e-3 e
6$$ 1 2 3 4 e
7** 5.5307 6.4891 7.144 27.144 e
8** 4r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 13 a8 5 e
t
2$$ 9223501 801604 100104 2430403 2630403 2830403 2505503 1400003
    601203 13027 601204 100102 801602 e
3** 9223501 300 2 3s 4.8808e-2 1 7s
    2430403 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630403 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
    2830403 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505503 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    t
end
=keno5
9972 shipping cask with u-235 metal sphere (5.5307 cm)
read param
tme=10000
lib=4
run=yes
plt=yes
gen=1200
npg=330
end param
read mixt
sct=3
mix=1 9223501 4.8808e-2
mix=2 601204 4.4569e-3 100104 7.4282e-3 801604 3.7141e-3
mix=3 601203 3.1691e-4 2430403 1.6471e-2 2505503 1.7321e-3 2630403
      6.036e-2 2830403 6.4834e-3 1400003 1.694e-3
mix=4 13027 6.0262e-2
mix=5 100102 6.6737e-2 801602 3.3369e-2
end mixt
read geom
unit 1
com='metal sphere and primary containment'
sphere   1 1.0 5.5307 origin 8.75 -8.75 8.62
cylinder 5 1.0 6.4891 2p14.153 origin 8.08 -8.08
```

```
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 -8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin 2.687 -2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   0 1 4p23.30 14.153 -14.727
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   0 1.0 4p23.30 3.492 0.0
unit 3
com='primary containment nut'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.455 1.283 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 1.283 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 1.283 0.0
cylinder 3 1.0 23.30 1.283 0.0
cuboid   0 1.0 4p23.30 1.283 0.0
unit 4
com='aluminum top plate'
cylinder 4 1 11.70 1.27 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 1.27 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   0 1.0 4p23.30 1.27 0.0
unit 5
com='pcv locking unit'
cylinder 0 1.0 5.113 0.966 0.0 origin 8.08 -8.08
cylinder 3 1.0 5.715 0.966 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.144 0.966 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 0.966 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 0.966 0.0
cylinder 3 1.0 23.30 0.966 0.0
cuboid   0 1.0 4p23.30 0.966 0.0
unit 6
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 1.27 -27.820 origin 2.687 -2.687
cylinder 0 1.0 23.18 1.27 -30.677
cylinder 3 1.0 23.30 1.27 -30.798
cuboid   0 1.0 4p23.30 1.27 -30.798
unit 8
com='metal sphere and primary containment'
sphere   1 1.0 5.5307 origin 8.75 -8.75 -8.62
cylinder 5 1.0 6.4891 2p14.153 origin 8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 -8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin 2.687 -2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   0 1.0 4p23.30 14.727 -14.153
unit 9
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 29.090 0.0 origin 2.687 -2.687
```

```
cylinder 0 1.0 23.18 31.947 0.0
cylinder 3 1.0 23.30 32.068 0.0
cuboid   0 1.0 4p23.30 32.068 0.0
unit 10
com='metal sphere and primary containment'
sphere   1 1.0 5.5307 origin -8.75 -8.75 8.62
cylinder 5 1.0 6.4891 2p14.153 origin -8.08 -8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 -8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin -2.687 -2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   0 1 4p23.30 14.153 -14.727
unit 11
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   0 1.0 4p23.30 3.492 0.0
unit 12
com='primary containment nut'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.455 1.283 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 1.283 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 1.283 0.0
cylinder 3 1.0 23.30 1.283 0.0
cuboid   0 1.0 4p23.30 1.283 0.0
unit 13
com='aluminum top plate'
cylinder 4 1 11.70 1.27 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 1.27 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   0 1.0 4p23.30 1.27 0.0
unit 14
com='pcv locking unit'
cylinder 0 1.0 5.113 0.966 0.0 origin -8.08 -8.08
cylinder 3 1.0 5.715 0.966 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.144 0.966 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 0.966 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 0.966 0.0
cylinder 3 1.0 23.30 0.966 0.0
cuboid   0 1.0 4p23.30 0.966 0.0
unit 15
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 1.27 -27.820 origin -2.687 -2.687
cylinder 0 1.0 23.18 1.27 -30.677
cylinder 3 1.0 23.30 1.27 -30.798
cuboid   0 1.0 4p23.30 1.27 -30.798
unit 16
com='metal sphere and primary containment'
sphere   1 1.0 5.5307 origin -8.75 -8.75 -8.62
cylinder 5 1.0 6.4891 2p14.153 origin -8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 -8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin -2.687 -2.687
```

```
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   0 1.0 4p23.30 14.727 -14.153
unit 17
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 29.090 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 31.947 0.0
cylinder 3 1.0 23.30 32.068 0.0
cuboid   0 1.0 4p23.30 32.068 0.0
unit 19
com='metal sphere and primary containment'
sphere   1 1.0 5.5307 origin 8.75 8.75 8.62
cylinder 5 1.0 6.4891 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin 2.687 2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   0 1 4p23.30 14.153 -14.727
unit 20
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   0 1.0 4p23.30 3.492 0.0
unit 21
com='primary containment nut'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 8.08
cylinder 0 1.0 7.455 1.283 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 1.283 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 1.283 0.0
cylinder 3 1.0 23.30 1.283 0.0
cuboid   0 1.0 4p23.30 1.283 0.0
unit 22
com='aluminum top plate'
cylinder 4 1 11.70 1.27 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 1.27 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   0 1.0 4p23.30 1.27 0.0
unit 23
com='pcv locking unit'
cylinder 0 1.0 5.113 0.966 0.0 origin 8.08 8.08
cylinder 3 1.0 5.715 0.966 0.0 origin 8.08 8.08
cylinder 0 1.0 7.144 0.966 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 0.966 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 0.966 0.0
cylinder 3 1.0 23.30 0.966 0.0
cuboid   0 1.0 4p23.30 0.966 0.0
unit 24
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 1.27 -27.820 origin 2.687 2.687
cylinder 0 1.0 23.18 1.27 -30.677
cylinder 3 1.0 23.30 1.27 -30.798
```

```
cuboid   0 1.0 4p23.30 1.27 -30.798
unit 25
com='metal sphere and primary containment'
sphere   1 1.0 5.5307 origin 8.75 8.75 -8.62
cylinder 5 1.0 6.4891 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin 2.687 2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   0 1.0 4p23.30 14.727 -14.153
unit 26
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 29.090 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 31.947 0.0
cylinder 3 1.0 23.30 32.068 0.0
cuboid   0 1.0 4p23.30 32.068 0.0
unit 28
com='metal sphere and primary containment'
sphere   1 1.0 5.5307 origin -8.75 8.75 8.62
cylinder 5 1.0 6.4891 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin -2.687 2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   0 1 4p23.30 14.153 -14.727
unit 29
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   0 1.0 4p23.30 3.492 0.0
unit 30
com='primary containment nut'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 8.08
cylinder 0 1.0 7.455 1.283 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 1.283 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 1.283 0.0
cylinder 3 1.0 23.30 1.283 0.0
cuboid   0 1.0 4p23.30 1.283 0.0
unit 31
com='aluminum top plate'
cylinder 4 1 11.70 1.27 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 1.27 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   0 1.0 4p23.30 1.27 0.0
unit 32
com='pcv locking unit'
cylinder 0 1.0 5.113 0.966 0.0 origin -8.08 8.08
cylinder 3 1.0 5.715 0.966 0.0 origin -8.08 8.08
cylinder 0 1.0 7.144 0.966 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 0.966 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 0.966 0.0
cylinder 3 1.0 23.30 0.966 0.0
```

```
cuboid   0 1.0 4p23.30 0.966 0.0
unit 33
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 1.27 -27.820 origin -2.687 2.687
cylinder 0 1.0 23.18 1.27 -30.677
cylinder 3 1.0 23.30 1.27 -30.798
cuboid   0 1.0 4p23.30 1.27 -30.798
unit 34
com='metal sphere and primary containment'
sphere   1 1.0 5.5307 origin -8.75 8.75 -8.62
cylinder 5 1.0 6.4891 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin -2.687 2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   0 1.0 4p23.30 14.727 -14.153
unit 35
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 29.090 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 31.947 0.0
cylinder 3 1.0 23.30 32.068 0.0
cuboid   0 1.0 4p23.30 32.068 0.0
unit 7
com='complete cask'
array 1 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 136.038 0.0
unit 18
com='complete cask'
array 2 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 136.038 0.0
unit 27
com='complete cask'
array 3 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 136.038 0.0
unit 36
com='complete cask'
array 4 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 136.038 0.0
unit 38
com='finite array 4 x 8 x 8'
array 5 3*0.0
cuboid 0 1.0 93.2  0. 93.2 0. 136.038  0.
end geom
read array
ara=1 nux=1 nuy=1 nuz=12 fill 6 5 1 2 3 4 4 3 2 8 5 9 end fill
ara=2 nux=1 nuy=1 nuz=12 fill 15 14 10 11 12 13 13 12 11 16 14 17 end
fill
ara=3 nux=1 nuy=1 nuz=12 fill 24 23 19 20 21 22 22 21 20 25 23 26 end
fill
ara=4 nux=1 nuy=1 nuz=12 fill 33 32 28 29 30 31 31 30 29 34 32 35 end
fill
ara=5 nux=2 nuy=2 nuz=1 fill 27 36 7 18 end fill
ara=6 nux=4 nuy=4 nuz=2 fill 32r38 end fill
end array
```

```
read plot
xul=0.
yul=94.
zul=56.381
xlr=94.
ylr=0.0
zlr=56.381
ttl='u-235 sphere in 9972 damaged type 2'
uax=1.0
vdn=-1.0
nax=131
end plot
end data
end
```

2. 9973 with U-235 metal, flooded PCV, infinite array.

```
=ajax
1$$ 1 e t
2$$ 71 10 e t
3$$ 92235 1001 8016 24304 26304 28304 25055 14000 6012 13027 e t
end
=bonami
0$$ 1 e
1$$ 2 6 12 0 0 5 e t
3$$ 1 2r2 6r3 3r4 e
4$$ 92235 8016 1001 24304 26304 28304 25055 14000 6012 8016 1001 6012 e
5** 4.8808e-2 3.3369e-2 6.6737e-2 1.6471e-2
    6.036e-2 6.4834e-3 1.7321e-3 1.694e-3 3.1691e-4
    3.7141e-3 7.4282e-3 4.4569e-3 e
6$$ 1 2 3 2 3 4 e
7** 5.6641 6.571 7.144 7.702 8.414 19.37 e
8** 5r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 13 a8 5 e
t
2$$ 9223501 801602 100102 2430403 2630403 2830403
    2505503 1400003 601203 13027 801606 100106 601206 e
3** 9223501 300 2 3s 4.8808e-2 1 7s
    2430403 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630403 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
    2830403 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505503 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    t
end
=keno5
9973 shipping cask with u-235 soln sphere (3.75 cm)
read param
tme=1000
lib=4
run=yes
plt=yes
gen=1200
```

```
npg=333
end param
read mixt
mix=1 9223501 4.8808e-2
mix=2 801606 3.7141e-3 100106 7.4282e-3 601206 4.4569e-3
mix=3 601203 3.1691e-4 2430403 1.6471e-2 2505503 1.7321e-3 2630403
      6.036e-2 2830403 6.4834e-3 1400003 1.694e-3
mix=4 13027 6.0262e-2
mix=5 13027 6.2e-3 100102 6.0e-2 801602 3.0e-2
mix=6 100102 6.6737e-2 801602 3.3369e-2
mix=7 6 1.e-10
mix=8 13027 6.2e-3
end mixt
read geom
unit 1
com='5.6641 cm sphere and primary containment'
sphere   1 1.0 5.6641 origin 8.71 -8.71 8.48
cylinder 6 1.0 6.571 2p14.153 origin 8.08 -8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 -8.08
cylinder 0 1.0 7.702 14.153 -14.727 origin 8.08 -8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin 8.08 -8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin 2.687 -2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   7 1 4p23.30 14.153 -14.727
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.702 3.492 0.0 origin 8.08 -8.08
cylinder 3 1.0 8.414 3.492 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 3
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 -8.08
cylinder 0 1.0 4.763 4.445 0.0 origin 8.08 -8.08
cylinder 5 1.0 7.702 4.445 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.702 4.661 0.0 origin 8.08 -8.08
cylinder 3 1.0 8.414 4.661 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 4.661 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 4
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 5
com='scv nut and al top plate'
cylinder 3 1.0 3.175 1.282 0.0 origin 8.08 -8.08
cylinder 0 1.0 8.414 1.282 0.0 origin 8.08 -8.08
```

```
cylinder 2 1.0 11.70 1.282 0.0 origin 8.08 -8.08
cylinder 4 1.0 11.70 2.552 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 6
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965 origin 8.08 -8.08
cylinder 3 1.0 5.715 0.0 -0.965 origin 8.08 -8.08
cylinder 0 1.0 7.702 0.0 -0.965 origin 8.08 -8.08
cylinder 8 1.0 7.702 0.0 -4.775 origin 8.08 -8.08
cylinder 3 1.0 8.414 0.0 -5.055 origin 8.08 -8.08
cylinder 2 1.0 19.37 0.0 -5.055 origin 2.687 -2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   7 1.0 4p23.30 0.0 -5.055
unit 7
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.965 origin 8.08 -8.08
cylinder 3 1.0 7.065 0.0 -0.965 origin 8.08 -8.08
cylinder 0 1.0 8.414 0.0 -0.965 origin 8.08 -8.08
cylinder 2 1.0 11.70 0.0 -0.965 origin 8.08 -8.08
cylinder 4 1.0 11.70 0.0 -2.235 origin 8.08 -8.08
cylinder 2 1.0 19.37 0.0 -16.498 origin 2.687 -2.687
cylinder 0 1.0 23.18 0.0 -19.355
cylinder 3 1.0 23.30 0.0 -19.355
cuboid   7 1.0 4p23.30 0.0 -19.355
unit 9
com='scv nut and al top plate'
cylinder 3 1.0 3.175 2.552 1.27 origin 8.08 -8.08
cylinder 0 1.0 8.414 2.552 1.27 origin 8.08 -8.08
cylinder 2 1.0 11.70 2.552 1.27 origin 8.08 -8.08
cylinder 4 1.0 11.70 2.552 0.   origin 8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0  origin 2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 10
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.661 3.378 origin 8.08 -8.08
cylinder 0 1.0 4.763 4.661 0.216 origin 8.08 -8.08
cylinder 5 1.0 7.702 4.661 0.216 origin 8.08 -8.08
cylinder 0 1.0 7.702 4.661 0.0   origin 8.08 -8.08
cylinder 3 1.0 8.414 4.661 0.0   origin 8.08 -8.08
cylinder 2 1.0 19.37 4.661 0.0   origin 2.687 -2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 11
com='5.6641 cm sphere and primary containment'
sphere   1 1.0 5.6641 origin 8.71 -8.71 -8.48
cylinder 6 1.0 6.571 2p14.153 origin 8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 -8.08
cylinder 0 1.0 7.702 14.727 -14.153 origin 8.08 -8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin 8.08 -8.08
```

```
cylinder 2 1.0 19.37 14.727 -14.153 origin 2.687 -2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   7 1 4p23.30 14.727 -14.153
unit 12
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.0 origin 8.08 -8.08
cylinder 3 1.0 5.715 0.965 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.702 0.965 0.0 origin 8.08 -8.08
cylinder 8 1.0 7.702 4.775 0.0 origin 8.08 -8.08
cylinder 3 1.0 8.414 5.055 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 5.055 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 5.055 0.0
cylinder 3 1.0 23.30 5.055 0.0
cuboid   7 1.0 4p23.30 5.055 0.0
unit 13
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.965 0.0 origin 8.08 -8.08
cylinder 3 1.0 7.065 0.965 0.0 origin 8.08 -8.08
cylinder 0 1.0 8.414 0.965 0.0 origin 8.08 -8.08
cylinder 2 1.0 11.70 0.965 0.0 origin 8.08 -8.08
cylinder 4 1.0 11.70 2.235 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 16.498 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 19.355 0.0
cylinder 3 1.0 23.30 19.355 0.0
cuboid   7 1.0 4p23.30 19.355 0.0
unit 14
com='5.6641 cm sphere and primary containment'
sphere   1 1.0 5.6641 origin -8.71 -8.71 8.48
cylinder 6 1.0 6.571 2p14.153 origin -8.08 -8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 -8.08
cylinder 0 1.0 7.702 14.153 -14.727 origin -8.08 -8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin -8.08 -8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin -2.687 -2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   7 1 4p23.30 14.153 -14.727
unit 15
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.702 3.492 0.0 origin -8.08 -8.08
cylinder 3 1.0 8.414 3.492 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 16
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 -8.08
cylinder 0 1.0 4.763 4.445 0.0 origin -8.08 -8.08
cylinder 5 1.0 7.702 4.445 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.702 4.661 0.0 origin -8.08 -8.08
cylinder 3 1.0 8.414 4.661 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 4.661 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
```

```
cuboid   7 1.0 4p23.30 4.661 0.0
unit 17
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 18
com='scv nut and al top plate'
cylinder 3 1.0 3.175 1.282 0.0 origin -8.08 -8.08
cylinder 0 1.0 8.414 1.282 0.0 origin -8.08 -8.08
cylinder 2 1.0 11.70 1.282 0.0 origin -8.08 -8.08
cylinder 4 1.0 11.70 2.552 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 19
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965 origin -8.08 -8.08
cylinder 3 1.0 5.715 0.0 -0.965 origin -8.08 -8.08
cylinder 0 1.0 7.702 0.0 -0.965 origin -8.08 -8.08
cylinder 8 1.0 7.702 0.0 -4.775 origin -8.08 -8.08
cylinder 3 1.0 8.414 0.0 -5.055 origin -8.08 -8.08
cylinder 2 1.0 19.37 0.0 -5.055 origin -2.687 -2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   7 1.0 4p23.30 0.0 -5.055
unit 20
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.965 origin -8.08 -8.08
cylinder 3 1.0 7.065 0.0 -0.965 origin -8.08 -8.08
cylinder 0 1.0 8.414 0.0 -0.965 origin -8.08 -8.08
cylinder 2 1.0 11.70 0.0 -0.965 origin -8.08 -8.08
cylinder 4 1.0 11.70 0.0 -2.235 origin -8.08 -8.08
cylinder 2 1.0 19.37 0.0 -16.498 origin -2.687 -2.687
cylinder 0 1.0 23.18 0.0 -19.355
cylinder 3 1.0 23.30 0.0 -19.355
cuboid   7 1.0 4p23.30 0.0 -19.355
unit 21
com='scv nut and al top plate'
cylinder 3 1.0 3.175 2.552 1.27 origin -8.08 -8.08
cylinder 0 1.0 8.414 2.552 1.27 origin -8.08 -8.08
cylinder 2 1.0 11.70 2.552 1.27 origin -8.08 -8.08
cylinder 4 1.0 11.70 2.552 0.  origin -8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0  origin -2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 22
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.661 3.378 origin -8.08 -8.08
cylinder 0 1.0 4.763 4.661 0.216 origin -8.08 -8.08
cylinder 5 1.0 7.702 4.661 0.216 origin -8.08 -8.08
cylinder 0 1.0 7.702 4.661 0.0  origin -8.08 -8.08
```

```
cylinder 3 1.0 8.414 4.661 0.0   origin -8.08 -8.08
cylinder 2 1.0 19.37 4.661 0.0   origin -2.687 -2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 23
com='5.6641 cm sphere and primary containment'
sphere   1 1.0 5.6641 origin -8.71 -8.71 -8.48
cylinder 6 1.0 6.571 2p14.153 origin -8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 -8.08
cylinder 0 1.0 7.702 14.727 -14.153 origin -8.08 -8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin -8.08 -8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin -2.687 -2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   7 1 4p23.30 14.727 -14.153
unit 24
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.0 origin -8.08 -8.08
cylinder 3 1.0 5.715 0.965 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.702 0.965 0.0 origin -8.08 -8.08
cylinder 8 1.0 7.702 4.775 0.0 origin -8.08 -8.08
cylinder 3 1.0 8.414 5.055 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 5.055 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 5.055 0.0
cylinder 3 1.0 23.30 5.055 0.0
cuboid   7 1.0 4p23.30 5.055 0.0
unit 25
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.965 0.0 origin -8.08 -8.08
cylinder 3 1.0 7.065 0.965 0.0 origin -8.08 -8.08
cylinder 0 1.0 8.414 0.965 0.0 origin -8.08 -8.08
cylinder 2 1.0 11.70 0.965 0.0 origin -8.08 -8.08
cylinder 4 1.0 11.70 2.235 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 16.498 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 19.355 0.0
cylinder 3 1.0 23.30 19.355 0.0
cuboid   7 1.0 4p23.30 19.355 0.0
unit 27
com='5.6641 cm sphere and primary containment'
sphere   1 1.0 5.6641 origin 8.71 8.71 8.48
cylinder 6 1.0 6.571 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 8.08
cylinder 0 1.0 7.702 14.153 -14.727 origin 8.08 8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin 8.08 8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin 2.687 2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   7 1 4p23.30 14.153 -14.727
unit 28
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin 8.08 8.08
cylinder 0 1.0 7.702 3.492 0.0 origin 8.08 8.08
cylinder 3 1.0 8.414 3.492 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
```

```
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 29
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 8.08
cylinder 0 1.0 4.763 4.445 0.0 origin 8.08 8.08
cylinder 5 1.0 7.702 4.445 0.0 origin 8.08 8.08
cylinder 0 1.0 7.702 4.661 0.0 origin 8.08 8.08
cylinder 3 1.0 8.414 4.661 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 4.661 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 30
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 31
com='scv nut and al top plate'
cylinder 3 1.0 3.175 1.282 0.0 origin 8.08 8.08
cylinder 0 1.0 8.414 1.282 0.0 origin 8.08 8.08
cylinder 2 1.0 11.70 1.282 0.0 origin 8.08 8.08
cylinder 4 1.0 11.70 2.552 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 32
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965 origin 8.08 8.08
cylinder 3 1.0 5.715 0.0 -0.965 origin 8.08 8.08
cylinder 0 1.0 7.702 0.0 -0.965 origin 8.08 8.08
cylinder 8 1.0 7.702 0.0 -4.775 origin 8.08 8.08
cylinder 3 1.0 8.414 0.0 -5.055 origin 8.08 8.08
cylinder 2 1.0 19.37 0.0 -5.055 origin 2.687 2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   7 1.0 4p23.30 0.0 -5.055
unit 33
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.965 origin 8.08 8.08
cylinder 3 1.0 7.065 0.0 -0.965 origin 8.08 8.08
cylinder 0 1.0 8.414 0.0 -0.965 origin 8.08 8.08
cylinder 2 1.0 11.70 0.0 -0.965 origin 8.08 8.08
cylinder 4 1.0 11.70 0.0 -2.235 origin 8.08 8.08
cylinder 2 1.0 19.37 0.0 -16.498 origin 2.687 2.687
cylinder 0 1.0 23.18 0.0 -19.355
cylinder 3 1.0 23.30 0.0 -19.355
cuboid   7 1.0 4p23.30 0.0 -19.355
unit 34
com='scv nut and al top plate'
cylinder 3 1.0 3.175 2.552 1.27 origin 8.08 8.08
cylinder 0 1.0 8.414 2.552 1.27 origin 8.08 8.08
```

```
cylinder 2 1.0 11.70 2.552 1.27 origin 8.08 8.08
cylinder 4 1.0 11.70 2.552 0.   origin 8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0  origin 2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 35
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.661 3.378 origin 8.08 8.08
cylinder 0 1.0 4.763 4.661 0.216 origin 8.08 8.08
cylinder 5 1.0 7.702 4.661 0.216 origin 8.08 8.08
cylinder 0 1.0 7.702 4.661 0.0   origin 8.08 8.08
cylinder 3 1.0 8.414 4.661 0.0   origin 8.08 8.08
cylinder 2 1.0 19.37 4.661 0.0   origin 2.687 2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 36
com='5.6641 cm sphere and primary containment'
sphere   1 1.0 5.6641 origin 8.71 8.71 -8.48
cylinder 6 1.0 6.571 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 8.08
cylinder 0 1.0 7.702 14.727 -14.153 origin 8.08 8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin 8.08 8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin 2.687 2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   7 1 4p23.30 14.727 -14.153
unit 37
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.0 origin 8.08 8.08
cylinder 3 1.0 5.715 0.965 0.0 origin 8.08 8.08
cylinder 0 1.0 7.702 0.965 0.0 origin 8.08 8.08
cylinder 8 1.0 7.702 4.775 0.0 origin 8.08 8.08
cylinder 3 1.0 8.414 5.055 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 5.055 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 5.055 0.0
cylinder 3 1.0 23.30 5.055 0.0
cuboid   7 1.0 4p23.30 5.055 0.0
unit 38
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.965 0.0 origin 8.08 8.08
cylinder 3 1.0 7.065 0.965 0.0 origin 8.08 8.08
cylinder 0 1.0 8.414 0.965 0.0 origin 8.08 8.08
cylinder 2 1.0 11.70 0.965 0.0 origin 8.08 8.08
cylinder 4 1.0 11.70 2.235 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 16.498 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 19.355 0.0
cylinder 3 1.0 23.30 19.355 0.0
cuboid   7 1.0 4p23.30 19.355 0.0
unit 40
com='5.6641 cm sphere and primary containment'
sphere   1 1.0 5.6641 origin -8.71 8.71 8.48
cylinder 6 1.0 6.571 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 8.08
cylinder 0 1.0 7.702 14.153 -14.727 origin -8.08 8.08
```

```
cylinder 3 1.0 8.414 14.153 -14.727 origin -8.08 8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin -2.687 2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   7 1 4p23.30 14.153 -14.727
unit 41
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin -8.08 8.08
cylinder 0 1.0 7.702 3.492 0.0 origin -8.08 8.08
cylinder 3 1.0 8.414 3.492 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 42
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 8.08
cylinder 0 1.0 4.763 4.445 0.0 origin -8.08 8.08
cylinder 5 1.0 7.702 4.445 0.0 origin -8.08 8.08
cylinder 0 1.0 7.702 4.661 0.0 origin -8.08 8.08
cylinder 3 1.0 8.414 4.661 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 4.661 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 43
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 44
com='scv nut and al top plate'
cylinder 3 1.0 3.175 1.282 0.0 origin -8.08 8.08
cylinder 0 1.0 8.414 1.282 0.0 origin -8.08 8.08
cylinder 2 1.0 11.70 1.282 0.0 origin -8.08 8.08
cylinder 4 1.0 11.70 2.552 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 45
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965 origin -8.08 8.08
cylinder 3 1.0 5.715 0.0 -0.965 origin -8.08 8.08
cylinder 0 1.0 7.702 0.0 -0.965 origin -8.08 8.08
cylinder 8 1.0 7.702 0.0 -4.775 origin -8.08 8.08
cylinder 3 1.0 8.414 0.0 -5.055 origin -8.08 8.08
cylinder 2 1.0 19.37 0.0 -5.055 origin -2.687 2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   7 1.0 4p23.30 0.0 -5.055
unit 46
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.965 origin -8.08 8.08
```

```
cylinder 3 1.0 7.065 0.0 -0.965 origin -8.08 8.08
cylinder 0 1.0 8.414 0.0 -0.965 origin -8.08 8.08
cylinder 2 1.0 11.70 0.0 -0.965 origin -8.08 8.08
cylinder 4 1.0 11.70 0.0 -2.235 origin -8.08 8.08
cylinder 2 1.0 19.37 0.0 -16.498 origin -2.687 2.687
cylinder 0 1.0 23.18 0.0 -19.355
cylinder 3 1.0 23.30 0.0 -19.355
cuboid   7 1.0 4p23.30 0.0 -19.355
unit 47
com='scv nut and al top plate'
cylinder 3 1.0 3.175 2.552 1.27 origin -8.08 8.08
cylinder 0 1.0 8.414 2.552 1.27 origin -8.08 8.08
cylinder 2 1.0 11.70 2.552 1.27 origin -8.08 8.08
cylinder 4 1.0 11.70 2.552 0.   origin -8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0  origin -2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 48
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.661 3.378 origin -8.08 8.08
cylinder 0 1.0 4.763 4.661 0.216 origin -8.08 8.08
cylinder 5 1.0 7.702 4.661 0.216 origin -8.08 8.08
cylinder 0 1.0 7.702 4.661 0.0   origin -8.08 8.08
cylinder 3 1.0 8.414 4.661 0.0   origin -8.08 8.08
cylinder 2 1.0 19.37 4.661 0.0   origin -2.687 2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 49
com='5.6641 cm sphere and primary containment'
sphere   1 1.0 5.6641 origin -8.71 8.71 -8.48
cylinder 6 1.0 6.571 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 8.08
cylinder 0 1.0 7.702 14.727 -14.153 origin -8.08 8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin -8.08 8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin -2.687 2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   7 1 4p23.30 14.727 -14.153
unit 50
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.0 origin -8.08 8.08
cylinder 3 1.0 5.715 0.965 0.0 origin -8.08 8.08
cylinder 0 1.0 7.702 0.965 0.0 origin -8.08 8.08
cylinder 8 1.0 7.702 4.775 0.0 origin -8.08 8.08
cylinder 3 1.0 8.414 5.055 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 5.055 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 5.055 0.0
cylinder 3 1.0 23.30 5.055 0.0
cuboid   7 1.0 4p23.30 5.055 0.0
unit 51
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.965 0.0 origin -8.08 8.08
cylinder 3 1.0 7.065 0.965 0.0 origin -8.08 8.08
cylinder 0 1.0 8.414 0.965 0.0 origin -8.08 8.08
```

```
cylinder 2 1.0 11.70 0.965 0.0 origin -8.08 8.08
cylinder 4 1.0 11.70 2.235 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 16.498 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 19.355 0.0
cylinder 3 1.0 23.30 19.355 0.0
cuboid   7 1.0 4p23.30 19.355 0.0
unit 8
com='containment vessels - top to top'
array 1 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 134.974 0.0
unit 26
com='containment vessels - top to top'
array 2 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 134.974 0.0
unit 39
com='containment vessels - top to top'
array 3 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 134.974 0.0
unit 52
com='containment vessels - top to top'
array 4 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 134.974 0.0
end geom
read array
ara=1 nux=1 nuy=1 nuz=14 fill 7 6 1 2 3 4 5 9 4 10 2 11 12 13 end fill
ara=2 nux=1 nuy=1 nuz=14 fill 20 19 14 15 16 17 18 21 17 22 15 23 24 25
end fill
ara=3 nux=1 nuy=1 nuz=14 fill 33 32 27 28 29 30 31 34 30 35 28 36 37 38
end fill
ara=4 nux=1 nuy=1 nuz=14 fill 46 45 40 41 42 43 44 47 43 48 41 49 50 51
end fill
ara=5 nux=2 nuy=2 nuz=1 fill 39 52 8 26 end fill
end array
read bounds all=mirror end bounds
read start
nst=0
xsm=25.
xsp=60.
ysm=25.
ysp=60.
zsm=40.
zsp=95.
end start
read plot
xul=0.
yul=94.
zul=47.617.
xlr=94.
ylr=0.
zlr=47.617
ttl='5.6641 cm u-235 sphere in 9973 damaged type 2'
uax=1.0
vdn=-1.0
nax=131
end plt1
xul=11.0
```

```
yul=19.37
zul=136.
xlr=82.
ylr=19.37
zlr=0.0
ttl='3.75 cm u-235 sphere in 9973 damaged type 2'
uax=1.0
wdn=-1.0
nax=131
end plt2
end plot
end data
end
```

3. 9974 with U-235 metal, flooded PCV, infinite array.

```
=ajax
1$$ 1 e t
2$$ 71 11 e t
3$$ 92235 1001 8016 24304 26304 28304 25055 14000 6012 13027
    82000 e t
end
=bonami
0$$ 1 e
1$$ 2 9 13 0 0 5 e t
3$$ 1 2r2 6r3 4 3r5 e
4$$ 92235 8016 1001 24304 26304 28304 25055 14000 6012
    82000 8016 1001 6012 e
5** 4.8808e-2 3.3369e-2 6.6737e-2 1.6471e-2
    6.036e-2 6.4834e-3 1.7321e-3 1.694e-3 3.1691e-4 3.2813e-2
    3.7141e-3 7.4282e-3 4.4569e-3 e
6$$ 1 2 3 2 3 2 3 4 5 e
7** 5.5307 6.4891 7.144 7.703 8.414 9.627 10.198 13.0556 24.765 e
8** 9r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 14 a8 6 e
t
2$$ 9223501 801609 100109 601209 2430403 2630403 2830403
    2505503 1400003 601203 13027 8200008 100102 801602 e
3** 9223501 300 2 3s 4.8808e-2 1 7s
    2430403 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630403 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
    2830403 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505503 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    8200008 300 2 3s 3.2813e-2 1 7s
    t
end
=keno5
9974 shipping cask with u-235 sphere (5.5307 cm)
read param
tme=1000
lib=4
run=yes
```

```
plt=yes
gen=1200
npg=333
end param
read mixt
mix=1 9223501 4.8808e-2
mix=2 801609 3.7141e-3 100109 7.4282e-3 601209 4.4569e-3
mix=3 601203 3.1691e-4 2430403 1.6471e-2 2505503 1.7321e-3 2630403
      6.036e-2 2830403 6.4834e-3 1400003 1.694e-3
mix=4 8200008 3.2813e-2
mix=5 13027 6.2e-3 100102 6.0e-2 801602 3.0e-2
mix=6 801602 3.3369e-2 100102 6.6737e-2
mix=7 6 1.e-15
mix=8 13027 6.2e-3
end mixt
read geom
unit 1
com='5.5307 cm sphere and primary containment'
sphere   1 1.0 5.5307 origin 8.75 -8.75 8.62
cylinder 6 1.0 6.4891 2p14.153 origin 8.08 -8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 -8.08
cylinder 0 1.0 7.703 14.153 -14.727 origin 8.08 -8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin 8.08 -8.08
cylinder 0 1.0 9.627 14.153 -14.727 origin 8.08 -8.08
cylinder 3 1.0 10.198 14.153 -14.727 origin 8.08 -8.08
cylinder 4 1.0 13.0556 14.153 -14.727 origin 8.08 -8.08
cylinder 2 1.0 24.765 14.153 -14.727  origin 2.687 -2.687
cylinder 0 1.0 28.575 14.153 -14.727
cylinder 3 1.0 28.727 14.153 -14.727
cuboid   7 1 4p28.727 14.153 -14.727
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.49 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.703 3.49 0.0 origin 8.08 -8.08
cylinder 3 1.0 8.414 3.49 0.0 origin 8.08 -8.08
cylinder 0 1.0 9.627 3.49 0.0 origin 8.08 -8.08
cylinder 3 1.0 10.198 3.49 0.0 origin 8.08 -8.08
cylinder 4 1.0 13.0556 3.49 0.0 origin 8.08 -8.08
cylinder 2 1.0 24.765 3.49 0.0 origin 2.687 -2.687
cylinder 0 1.0 28.575 3.49 0.0
cylinder 3 1.0 28.727 3.49 0.0
cuboid   7 1.0 4p28.727 3.49 0.0
unit 3
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 -8.08
cylinder 0 1.0 4.763 4.445 0.0 origin 8.08 -8.08
cylinder 8 1.0 7.703 4.445 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.703 4.66 0.0  origin 8.08 -8.08
cylinder 3 1.0 8.414 4.66 0.0  origin 8.08 -8.08
cylinder 0 1.0 9.627 4.66 0.0  origin 8.08 -8.08
cylinder 3 1.0 10.198 4.66 0.0 origin 8.08 -8.08
cylinder 4 1.0 13.0556 4.66 0.0 origin 8.08 -8.08
cylinder 2 1.0 24.765 4.66 0.0  origin 2.687 -2.687
cylinder 0 1.0 28.575 4.66 0.0
cylinder 3 1.0 28.727 4.66 0.0
cuboid   7 1.0 4p28.727 4.66 0.0
```

```
unit 4
com='secondary containment top'
cylinder 3 1.0 9.042 3.49 0.0 origin 8.08 -8.08
cylinder 0 1.0 9.627 3.49 0.0 origin 8.08 -8.08
cylinder 3 1.0 10.198 3.49 0.0 origin 8.08 -8.08
cylinder 4 1.0 13.0556 3.49 0.0 origin 8.08 -8.08
cylinder 2 1.0 24.765 3.49 0.0  origin 2.687 -2.687
cylinder 0 1.0 28.575 3.49 0.0
cylinder 3 1.0 28.727 3.49 0.0
cuboid   7 1.0 4p28.727 3.49 0.0
unit 5
com='scv nut and lead top plate'
cylinder 3 1.0 3.175 1.29 0.0 origin 8.08 -8.08
cylinder 0 1.0 9.627 1.29 0.0 origin 8.08 -8.08
cylinder 3 1.0 10.198 1.88 0.0 origin 8.08 -8.08
cylinder 4 1.0 13.0556 5.037 0.0 origin 8.08 -8.08
cylinder 2 1.0 24.765 5.037 0.0  origin 2.687 -2.687
cylinder 0 1.0 28.575 5.037 0.0
cylinder 3 1.0 28.727 5.037 0.0
cuboid   7 1.0 4p28.727 5.037 0.0
unit 6
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.96 origin 8.08 -8.08
cylinder 3 1.0 5.715 0.0 -0.96 origin 8.08 -8.08
cylinder 0 1.0 7.703 0.0 -0.96 origin 8.08 -8.08
cylinder 8 1.0 7.703 0.0 -4.77 origin 8.08 -8.08
cylinder 3 1.0 8.414 0.0 -5.48 origin 8.08 -8.08
cylinder 0 1.0 9.627 0.0 -5.48 origin 8.08 -8.08
cylinder 3 1.0 10.198 0.0 -5.48 origin 8.08 -8.08
cylinder 4 1.0 13.0556 0.0 -5.48 origin 8.08 -8.08
cylinder 2 1.0 24.765 0.0 -5.48  origin 2.687 -2.687
cylinder 0 1.0 28.575 0.0 -5.48
cylinder 3 1.0 28.727 0.0 -5.48
cuboid   7 1.0 4p28.727 0.0 -5.48
unit 7
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.97 origin 8.08 -8.08
cylinder 3 1.0 7.065 0.0 -0.97 origin 8.08 -8.08
cylinder 0 1.0 9.627 0.0 -0.97 origin 8.08 -8.08
cylinder 3 1.0 10.198 0.0 -1.542 origin 8.08 -8.08
cylinder 4 1.0 13.0556 0.0 -4.717 origin 8.08 -8.08
cylinder 2 1.0 24.765 0.0 -26.307 origin 2.687 -2.687
cylinder 0 1.0 28.575 0.0 -29.165
cylinder 3 1.0 28.727 0.0 -29.317
cuboid   7 1.0 4p28.727 0.0 -29.317
unit 9
com='scv nut and lead top plate'
cylinder 3 1.0 3.175 5.037 3.747 origin 8.08 -8.08
cylinder 0 1.0 9.627 5.037 3.747 origin 8.08 -8.08
cylinder 3 1.0 10.198 5.037 3.157 origin 8.08 -8.08
cylinder 4 1.0 13.0556 5.037 0.0 origin 8.08 -8.08
cylinder 2 1.0 24.765 5.037 0.0  origin 2.687 -2.687
cylinder 0 1.0 28.575 5.037 0.0
cylinder 3 1.0 28.727 5.037 0.0
cuboid   7 1.0 4p28.727 5.037 0.0
unit 10
```

```
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.66 3.377 origin 8.08 -8.08
cylinder 0 1.0 4.763 4.66 .215  origin 8.08 -8.08
cylinder 8 1.0 7.703 4.66 .215  origin 8.08 -8.08
cylinder 0 1.0 7.703 4.66 0.0   origin 8.08 -8.08
cylinder 3 1.0 8.414 4.66 0.0   origin 8.08 -8.08
cylinder 0 1.0 9.627 4.66 0.0   origin 8.08 -8.08
cylinder 3 1.0 10.198 4.66 0.0  origin 8.08 -8.08
cylinder 4 1.0 13.0556 4.66 0.0 origin 8.08 -8.08
cylinder 2 1.0 24.765 4.66 0.0  origin 2.687 -2.687
cylinder 0 1.0 28.575 4.66 0.0
cylinder 3 1.0 28.727 4.66 0.0
cuboid   7 1.0 4p28.727 4.66 0.0
unit 11
com='5.5307 cm sphere and primary containment'
sphere   1 1.0 5.5307 origin 8.75 -8.75 -8.62
cylinder 6 1.0 6.4891 2p14.153 origin 8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 -8.08
cylinder 0 1.0 7.703 14.727 -14.153 origin 8.08 -8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin 8.08 -8.08
cylinder 0 1.0 9.627 14.727 -14.153 origin 8.08 -8.08
cylinder 3 1.0 10.198 14.727 -14.153 origin 8.08 -8.08
cylinder 4 1.0 13.0556 14.727 -14.153 origin 8.08 -8.08
cylinder 2 1.0 24.765 14.727 -14.153  origin 2.687 -2.687
cylinder 0 1.0 28.575 14.727 -14.153
cylinder 3 1.0 28.727 14.727 -14.153
cuboid   7 1 4p28.727 14.727 -14.153
unit 12
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.96 0. origin 8.08 -8.08
cylinder 3 1.0 5.715 0.96 0. origin 8.08 -8.08
cylinder 0 1.0 7.703 0.96 0. origin 8.08 -8.08
cylinder 8 1.0 7.703 4.77 0. origin 8.08 -8.08
cylinder 3 1.0 8.414 5.48 0. origin 8.08 -8.08
cylinder 0 1.0 9.627 5.48 0. origin 8.08 -8.08
cylinder 3 1.0 10.198 5.48 0. origin 8.08 -8.08
cylinder 4 1.0 13.0556 5.48 0. origin 8.08 -8.08
cylinder 2 1.0 24.765 5.48 0.  origin 2.687 -2.687
cylinder 0 1.0 28.575 5.48 0.0
cylinder 3 1.0 28.727 5.48 0.0
cuboid   7 1.0 4p28.727 5.48 0.
unit 13
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.97 0.  origin 8.08 -8.08
cylinder 3 1.0 7.065 0.97 0.  origin 8.08 -8.08
cylinder 0 1.0 9.627 0.97 0.  origin 8.08 -8.08
cylinder 3 1.0 10.198 1.542 0. origin 8.08 -8.08
cylinder 4 1.0 13.0556 4.717 0. origin 8.08 -8.08
cylinder 2 1.0 24.765 26.307 0. origin 2.687 -2.687
cylinder 0 1.0 28.575 29.165 0.0
cylinder 3 1.0 28.727 29.317 0.0
cuboid   7 1.0 4p28.727 29.317 0.
unit 14
com='5.5307 cm sphere and primary containment'
sphere   1 1.0 5.5307 origin -8.75 -8.75 8.62
cylinder 6 1.0 6.4891 2p14.153 origin -8.08 -8.08
```

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cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 -8.08
cylinder 0 1.0 7.703 14.153 -14.727 origin -8.08 -8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin -8.08 -8.08
cylinder 0 1.0 9.627 14.153 -14.727 origin -8.08 -8.08
cylinder 3 1.0 10.198 14.153 -14.727 origin -8.08 -8.08
cylinder 4 1.0 13.0556 14.153 -14.727 origin -8.08 -8.08
cylinder 2 1.0 24.765 14.153 -14.727  origin -2.687 -2.687
cylinder 0 1.0 28.575 14.153 -14.727
cylinder 3 1.0 28.727 14.153 -14.727
cuboid   7 1 4p28.727 14.153 -14.727
unit 15
com='top of primary containment'
cylinder 3 1.0 7.455 3.49 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.703 3.49 0.0 origin -8.08 -8.08
cylinder 3 1.0 8.414 3.49 0.0 origin -8.08 -8.08
cylinder 0 1.0 9.627 3.49 0.0 origin -8.08 -8.08
cylinder 3 1.0 10.198 3.49 0.0 origin -8.08 -8.08
cylinder 4 1.0 13.0556 3.49 0.0 origin -8.08 -8.08
cylinder 2 1.0 24.765 3.49 0.0  origin -2.687 -2.687
cylinder 0 1.0 28.575 3.49 0.0
cylinder 3 1.0 28.727 3.49 0.0
cuboid   7 1.0 4p28.727 3.49 0.0
unit 16
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 -8.08
cylinder 0 1.0 4.763 4.445 0.0 origin -8.08 -8.08
cylinder 8 1.0 7.703 4.445 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.703 4.66 0.0  origin -8.08 -8.08
cylinder 3 1.0 8.414 4.66 0.0  origin -8.08 -8.08
cylinder 0 1.0 9.627 4.66 0.0  origin -8.08 -8.08
cylinder 3 1.0 10.198 4.66 0.0 origin -8.08 -8.08
cylinder 4 1.0 13.0556 4.66 0.0 origin -8.08 -8.08
cylinder 2 1.0 24.765 4.66 0.0  origin -2.687 -2.687
cylinder 0 1.0 28.575 4.66 0.0
cylinder 3 1.0 28.727 4.66 0.0
cuboid   7 1.0 4p28.727 4.66 0.0
unit 17
com='secondary containment top'
cylinder 3 1.0 9.042 3.49 0.0 origin -8.08 -8.08
cylinder 0 1.0 9.627 3.49 0.0 origin -8.08 -8.08
cylinder 3 1.0 10.198 3.49 0.0 origin -8.08 -8.08
cylinder 4 1.0 13.0556 3.49 0.0 origin -8.08 -8.08
cylinder 2 1.0 24.765 3.49 0.0  origin -2.687 -2.687
cylinder 0 1.0 28.575 3.49 0.0
cylinder 3 1.0 28.727 3.49 0.0
cuboid   7 1.0 4p28.727 3.49 0.0
unit 18
com='scv nut and lead top plate'
cylinder 3 1.0 3.175 1.29 0.0 origin -8.08 -8.08
cylinder 0 1.0 9.627 1.29 0.0 origin -8.08 -8.08
cylinder 3 1.0 10.198 1.88 0.0 origin -8.08 -8.08
cylinder 4 1.0 13.0556 5.037 0.0 origin -8.08 -8.08
cylinder 2 1.0 24.765 5.037 0.0  origin -2.687 -2.687
cylinder 0 1.0 28.575 5.037 0.0
cylinder 3 1.0 28.727 5.037 0.0
cuboid   7 1.0 4p28.727 5.037 0.0
```

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unit 19
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.96 origin -8.08 -8.08
cylinder 3 1.0 5.715 0.0 -0.96 origin -8.08 -8.08
cylinder 0 1.0 7.703 0.0 -0.96 origin -8.08 -8.08
cylinder 8 1.0 7.703 0.0 -4.77 origin -8.08 -8.08
cylinder 3 1.0 8.414 0.0 -5.48 origin -8.08 -8.08
cylinder 0 1.0 9.627 0.0 -5.48 origin -8.08 -8.08
cylinder 3 1.0 10.198 0.0 -5.48 origin -8.08 -8.08
cylinder 4 1.0 13.0556 0.0 -5.48 origin -8.08 -8.08
cylinder 2 1.0 24.765 0.0 -5.48  origin -2.687 -2.687
cylinder 0 1.0 28.575 0.0 -5.48
cylinder 3 1.0 28.727 0.0 -5.48
cuboid   7 1.0 4p28.727 0.0 -5.48
unit 20
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.97 origin -8.08 -8.08
cylinder 3 1.0 7.065 0.0 -0.97 origin -8.08 -8.08
cylinder 0 1.0 9.627 0.0 -0.97 origin -8.08 -8.08
cylinder 3 1.0 10.198 0.0 -1.542 origin -8.08 -8.08
cylinder 4 1.0 13.0556 0.0 -4.717 origin -8.08 -8.08
cylinder 2 1.0 24.765 0.0 -26.307 origin -2.687 -2.687
cylinder 0 1.0 28.575 0.0 -29.165
cylinder 3 1.0 28.727 0.0 -29.317
cuboid   7 1.0 4p28.727 0.0 -29.317
unit 21
com='scv nut and lead top plate'
cylinder 3 1.0 3.175 5.037 3.747 origin -8.08 -8.08
cylinder 0 1.0 9.627 5.037 3.747 origin -8.08 -8.08
cylinder 3 1.0 10.198 5.037 3.157 origin -8.08 -8.08
cylinder 4 1.0 13.0556 5.037 0.0 origin -8.08 -8.08
cylinder 2 1.0 24.765 5.037 0.0  origin -2.687 -2.687
cylinder 0 1.0 28.575 5.037 0.0
cylinder 3 1.0 28.727 5.037 0.0
cuboid   7 1.0 4p28.727 5.037 0.0
unit 22
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.66 3.377 origin -8.08 -8.08
cylinder 0 1.0 4.763 4.66 .215  origin -8.08 -8.08
cylinder 8 1.0 7.703 4.66 .215  origin -8.08 -8.08
cylinder 0 1.0 7.703 4.66 0.0   origin -8.08 -8.08
cylinder 3 1.0 8.414 4.66 0.0   origin -8.08 -8.08
cylinder 0 1.0 9.627 4.66 0.0   origin -8.08 -8.08
cylinder 3 1.0 10.198 4.66 0.0  origin -8.08 -8.08
cylinder 4 1.0 13.0556 4.66 0.0 origin -8.08 -8.08
cylinder 2 1.0 24.765 4.66 0.0  origin -2.687 -2.687
cylinder 0 1.0 28.575 4.66 0.0
cylinder 3 1.0 28.727 4.66 0.0
cuboid   7 1.0 4p28.727 4.66 0.0
unit 23
com='5.5307 cm sphere and primary containment'
sphere   1 1.0 5.5307 origin -8.75 -8.75 -8.62
cylinder 6 1.0 6.4891 2p14.153 origin -8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 -8.08
cylinder 0 1.0 7.703 14.727 -14.153 origin -8.08 -8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin -8.08 -8.08
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cylinder 0 1.0 9.627 14.727 -14.153 origin -8.08 -8.08
cylinder 3 1.0 10.198 14.727 -14.153 origin -8.08 -8.08
cylinder 4 1.0 13.0556 14.727 -14.153 origin -8.08 -8.08
cylinder 2 1.0 24.765 14.727 -14.153  origin -2.687 -2.687
cylinder 0 1.0 28.575 14.727 -14.153
cylinder 3 1.0 28.727 14.727 -14.153
cuboid   7 1 4p28.727 14.727 -14.153
unit 24
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.96 0. origin -8.08 -8.08
cylinder 3 1.0 5.715 0.96 0. origin -8.08 -8.08
cylinder 0 1.0 7.703 0.96 0. origin -8.08 -8.08
cylinder 8 1.0 7.703 4.77 0. origin -8.08 -8.08
cylinder 3 1.0 8.414 5.48 0. origin -8.08 -8.08
cylinder 0 1.0 9.627 5.48 0. origin -8.08 -8.08
cylinder 3 1.0 10.198 5.48 0. origin -8.08 -8.08
cylinder 4 1.0 13.0556 5.48 0. origin -8.08 -8.08
cylinder 2 1.0 24.765 5.48 0.  origin -2.687 -2.687
cylinder 0 1.0 28.575 5.48 0.
cylinder 3 1.0 28.727 5.48 0.0
cuboid   7 1.0 4p28.727 5.48 0.
unit 25
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.97 0.  origin -8.08 -8.08
cylinder 3 1.0 7.065 0.97 0.  origin -8.08 -8.08
cylinder 0 1.0 9.627 0.97 0.  origin -8.08 -8.08
cylinder 3 1.0 10.198 1.542 0. origin -8.08 -8.08
cylinder 4 1.0 13.0556 4.717 0. origin -8.08 -8.08
cylinder 2 1.0 24.765 26.307 0. origin -2.687 -2.687
cylinder 0 1.0 28.575 29.165 0.
cylinder 3 1.0 28.727 29.317 0.0
cuboid   7 1.0 4p28.727 29.317 0.
unit 27
com='5.5307 cm sphere and primary containment'
sphere   1 1.0 5.5307 origin 8.75 8.75 8.62
cylinder 6 1.0 6.4891 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 8.08
cylinder 0 1.0 7.703 14.153 -14.727 origin 8.08 8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin 8.08 8.08
cylinder 0 1.0 9.627 14.153 -14.727 origin 8.08 8.08
cylinder 3 1.0 10.198 14.153 -14.727 origin 8.08 8.08
cylinder 4 1.0 13.0556 14.153 -14.727 origin 8.08 8.08
cylinder 2 1.0 24.765 14.153 -14.727  origin 2.687 2.687
cylinder 0 1.0 28.575 14.153 -14.727
cylinder 3 1.0 28.727 14.153 -14.727
cuboid   7 1 4p28.727 14.153 -14.727
unit 28
com='top of primary containment'
cylinder 3 1.0 7.455 3.49 0.0 origin 8.08 8.08
cylinder 0 1.0 7.703 3.49 0.0 origin 8.08 8.08
cylinder 3 1.0 8.414 3.49 0.0 origin 8.08 8.08
cylinder 0 1.0 9.627 3.49 0.0 origin 8.08 8.08
cylinder 3 1.0 10.198 3.49 0.0 origin 8.08 8.08
cylinder 4 1.0 13.0556 3.49 0.0 origin 8.08 8.08
cylinder 2 1.0 24.765 3.49 0.0  origin 2.687 2.687
cylinder 0 1.0 28.575 3.49 0.0
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cylinder 3 1.0 28.727 3.49 0.0
cuboid   7 1.0 4p28.727 3.49 0.0
unit 29
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 8.08
cylinder 0 1.0 4.763 4.445 0.0 origin 8.08 8.08
cylinder 8 1.0 7.703 4.445 0.0 origin 8.08 8.08
cylinder 0 1.0 7.703 4.66 0.0  origin 8.08 8.08
cylinder 3 1.0 8.414 4.66 0.0  origin 8.08 8.08
cylinder 0 1.0 9.627 4.66 0.0  origin 8.08 8.08
cylinder 3 1.0 10.198 4.66 0.0 origin 8.08 8.08
cylinder 4 1.0 13.0556 4.66 0.0 origin 8.08 8.08
cylinder 2 1.0 24.765 4.66 0.0  origin 2.687 2.687
cylinder 0 1.0 28.575 4.66 0.0
cylinder 3 1.0 28.727 4.66 0.0
cuboid   7 1.0 4p28.727 4.66 0.0
unit 30
com='secondary containment top'
cylinder 3 1.0 9.042 3.49 0.0 origin 8.08 8.08
cylinder 0 1.0 9.627 3.49 0.0 origin 8.08 8.08
cylinder 3 1.0 10.198 3.49 0.0 origin 8.08 8.08
cylinder 4 1.0 13.0556 3.49 0.0 origin 8.08 8.08
cylinder 2 1.0 24.765 3.49 0.0  origin 2.687 2.687
cylinder 0 1.0 28.575 3.49 0.0
cylinder 3 1.0 28.727 3.49 0.0
cuboid   7 1.0 4p28.727 3.49 0.0
unit 31
com='scv nut and lead top plate'
cylinder 3 1.0 3.175 1.29 0.0 origin 8.08 8.08
cylinder 0 1.0 9.627 1.29 0.0 origin 8.08 8.08
cylinder 3 1.0 10.198 1.88 0.0 origin 8.08 8.08
cylinder 4 1.0 13.0556 5.037 0.0 origin 8.08 8.08
cylinder 2 1.0 24.765 5.037 0.0  origin 2.687 2.687
cylinder 0 1.0 28.575 5.037 0.0
cylinder 3 1.0 28.727 5.037 0.0
cuboid   7 1.0 4p28.727 5.037 0.0
unit 32
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.96 origin 8.08 8.08
cylinder 3 1.0 5.715 0.0 -0.96 origin 8.08 8.08
cylinder 0 1.0 7.703 0.0 -0.96 origin 8.08 8.08
cylinder 8 1.0 7.703 0.0 -4.77 origin 8.08 8.08
cylinder 3 1.0 8.414 0.0 -5.48 origin 8.08 8.08
cylinder 0 1.0 9.627 0.0 -5.48 origin 8.08 8.08
cylinder 3 1.0 10.198 0.0 -5.48 origin 8.08 8.08
cylinder 4 1.0 13.0556 0.0 -5.48 origin 8.08 8.08
cylinder 2 1.0 24.765 0.0 -5.48  origin 2.687 2.687
cylinder 0 1.0 28.575 0.0 -5.48
cylinder 3 1.0 28.727 0.0 -5.48
cuboid   7 1.0 4p28.727 0.0 -5.48
unit 33
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.97 origin 8.08 8.08
cylinder 3 1.0 7.065 0.0 -0.97 origin 8.08 8.08
cylinder 0 1.0 9.627 0.0 -0.97 origin 8.08 8.08
cylinder 3 1.0 10.198 0.0 -1.542 origin 8.08 8.08
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cylinder 4 1.0 13.0556 0.0 -4.717 origin 8.08 8.08
cylinder 2 1.0 24.765 0.0 -26.307 origin 2.687 2.687
cylinder 0 1.0 28.575 0.0 -29.165
cylinder 3 1.0 28.727 0.0 -29.317
cuboid   7 1.0 4p28.727 0.0 -29.317
unit 34
com='scv nut and lead top plate'
cylinder 3 1.0 3.175 5.037 3.747 origin 8.08 8.08
cylinder 0 1.0 9.627 5.037 3.747 origin 8.08 8.08
cylinder 3 1.0 10.198 5.037 3.157 origin 8.08 8.08
cylinder 4 1.0 13.0556 5.037 0.0 origin 8.08 8.08
cylinder 2 1.0 24.765 5.037 0.0  origin 2.687 2.687
cylinder 0 1.0 28.575 5.037 0.0
cylinder 3 1.0 28.727 5.037 0.0
cuboid   7 1.0 4p28.727 5.037 0.0
unit 35
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.66 3.377 origin 8.08 8.08
cylinder 0 1.0 4.763 4.66 .215  origin 8.08 8.08
cylinder 8 1.0 7.703 4.66 .215  origin 8.08 8.08
cylinder 0 1.0 7.703 4.66 0.0   origin 8.08 8.08
cylinder 3 1.0 8.414 4.66 0.0   origin 8.08 8.08
cylinder 0 1.0 9.627 4.66 0.0   origin 8.08 8.08
cylinder 3 1.0 10.198 4.66 0.0  origin 8.08 8.08
cylinder 4 1.0 13.0556 4.66 0.0 origin 8.08 8.08
cylinder 2 1.0 24.765 4.66 0.0  origin 2.687 2.687
cylinder 0 1.0 28.575 4.66 0.0
cylinder 3 1.0 28.727 4.66 0.0
cuboid   7 1.0 4p28.727 4.66 0.0
unit 36
com='5.5307 cm sphere and primary containment'
sphere   1 1.0 5.5307 origin 8.75 8.75 -8.62
cylinder 6 1.0 6.4891 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 8.08
cylinder 0 1.0 7.703 14.727 -14.153 origin 8.08 8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin 8.08 8.08
cylinder 0 1.0 9.627 14.727 -14.153 origin 8.08 8.08
cylinder 3 1.0 10.198 14.727 -14.153 origin 8.08 8.08
cylinder 4 1.0 13.0556 14.727 -14.153 origin 8.08 8.08
cylinder 2 1.0 24.765 14.727 -14.153  origin 2.687 2.687
cylinder 0 1.0 28.575 14.727 -14.153
cylinder 3 1.0 28.727 14.727 -14.153
cuboid   7 1 4p28.727 14.727 -14.153
unit 37
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.96 0. origin 8.08 8.08
cylinder 3 1.0 5.715 0.96 0. origin 8.08 8.08
cylinder 0 1.0 7.703 0.96 0. origin 8.08 8.08
cylinder 8 1.0 7.703 4.77 0. origin 8.08 8.08
cylinder 3 1.0 8.414 5.48 0. origin 8.08 8.08
cylinder 0 1.0 9.627 5.48 0. origin 8.08 8.08
cylinder 3 1.0 10.198 5.48 0. origin 8.08 8.08
cylinder 4 1.0 13.0556 5.48 0. origin 8.08 8.08
cylinder 2 1.0 24.765 5.48 0.  origin 2.687 2.687
cylinder 0 1.0 28.575 5.48 0.
cylinder 3 1.0 28.727 5.48 0.0
```

```
cuboid  7 1.0 4p28.727 5.48 0.
unit 38
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.97 0.  origin 8.08 8.08
cylinder 3 1.0 7.065 0.97 0.  origin 8.08 8.08
cylinder 0 1.0 9.627 0.97 0.  origin 8.08 8.08
cylinder 3 1.0 10.198 1.542 0. origin 8.08 8.08
cylinder 4 1.0 13.0556 4.717 0. origin 8.08 8.08
cylinder 2 1.0 24.765 26.307 0. origin 2.687 2.687
cylinder 0 1.0 28.575 29.165 0.
cylinder 3 1.0 28.727 29.317 0.0
cuboid   7 1.0 4p28.727 29.317 0.
unit 40
com='5.5307 cm sphere and primary containment'
sphere   1 1.0 5.5307 origin -8.75 8.75 8.62
cylinder 6 1.0 6.4891 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 8.08
cylinder 0 1.0 7.703 14.153 -14.727 origin -8.08 8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin -8.08 8.08
cylinder 0 1.0 9.627 14.153 -14.727 origin -8.08 8.08
cylinder 3 1.0 10.198 14.153 -14.727 origin -8.08 8.08
cylinder 4 1.0 13.0556 14.153 -14.727 origin -8.08 8.08
cylinder 2 1.0 24.765 14.153 -14.727  origin -2.687 2.687
cylinder 0 1.0 28.575 14.153 -14.727
cylinder 3 1.0 28.727 14.153 -14.727
cuboid   7 1 4p28.727 14.153 -14.727
unit 41
com='top of primary containment'
cylinder 3 1.0 7.455 3.49 0.0 origin -8.08 8.08
cylinder 0 1.0 7.703 3.49 0.0 origin -8.08 8.08
cylinder 3 1.0 8.414 3.49 0.0 origin -8.08 8.08
cylinder 0 1.0 9.627 3.49 0.0 origin -8.08 8.08
cylinder 3 1.0 10.198 3.49 0.0 origin -8.08 8.08
cylinder 4 1.0 13.0556 3.49 0.0 origin -8.08 8.08
cylinder 2 1.0 24.765 3.49 0.0  origin -2.687 2.687
cylinder 0 1.0 28.575 3.49 0.0
cylinder 3 1.0 28.727 3.49 0.0
cuboid   7 1.0 4p28.727 3.49 0.0
unit 42
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 8.08
cylinder 0 1.0 4.763 4.445 0.0 origin -8.08 8.08
cylinder 8 1.0 7.703 4.445 0.0 origin -8.08 8.08
cylinder 0 1.0 7.703 4.66 0.0  origin -8.08 8.08
cylinder 3 1.0 8.414 4.66 0.0  origin -8.08 8.08
cylinder 0 1.0 9.627 4.66 0.0  origin -8.08 8.08
cylinder 3 1.0 10.198 4.66 0.0 origin -8.08 8.08
cylinder 4 1.0 13.0556 4.66 0.0 origin -8.08 8.08
cylinder 2 1.0 24.765 4.66 0.0  origin -2.687 2.687
cylinder 0 1.0 28.575 4.66 0.0
cylinder 3 1.0 28.727 4.66 0.0
cuboid   7 1.0 4p28.727 4.66 0.0
unit 43
com='secondary containment top'
cylinder 3 1.0 9.042 3.49 0.0 origin -8.08 8.08
cylinder 0 1.0 9.627 3.49 0.0 origin -8.08 8.08
```

```
cylinder 3 1.0 10.198 3.49 0.0 origin -8.08 8.08
cylinder 4 1.0 13.0556 3.49 0.0 origin -8.08 8.08
cylinder 2 1.0 24.765 3.49 0.0  origin -2.687 2.687
cylinder 0 1.0 28.575 3.49 0.0
cylinder 3 1.0 28.727 3.49 0.0
cuboid   7 1.0 4p28.727 3.49 0.0
unit 44
com='scv nut and lead top plate'
cylinder 3 1.0 3.175 1.29 0.0 origin -8.08 8.08
cylinder 0 1.0 9.627 1.29 0.0 origin -8.08 8.08
cylinder 3 1.0 10.198 1.88 0.0 origin -8.08 8.08
cylinder 4 1.0 13.0556 5.037 0.0 origin -8.08 8.08
cylinder 2 1.0 24.765 5.037 0.0  origin -2.687 2.687
cylinder 0 1.0 28.575 5.037 0.0
cylinder 3 1.0 28.727 5.037 0.0
cuboid   7 1.0 4p28.727 5.037 0.0
unit 45
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.96 origin -8.08 8.08
cylinder 3 1.0 5.715 0.0 -0.96 origin -8.08 8.08
cylinder 0 1.0 7.703 0.0 -0.96 origin -8.08 8.08
cylinder 8 1.0 7.703 0.0 -4.77 origin -8.08 8.08
cylinder 3 1.0 8.414 0.0 -5.48 origin -8.08 8.08
cylinder 0 1.0 9.627 0.0 -5.48 origin -8.08 8.08
cylinder 3 1.0 10.198 0.0 -5.48 origin -8.08 8.08
cylinder 4 1.0 13.0556 0.0 -5.48 origin -8.08 8.08
cylinder 2 1.0 24.765 0.0 -5.48  origin -2.687 2.687
cylinder 0 1.0 28.575 0.0 -5.48
cylinder 3 1.0 28.727 0.0 -5.48
cuboid   7 1.0 4p28.727 0.0 -5.48
unit 46
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.97 origin -8.08 8.08
cylinder 3 1.0 7.065 0.0 -0.97 origin -8.08 8.08
cylinder 0 1.0 9.627 0.0 -0.97 origin -8.08 8.08
cylinder 3 1.0 10.198 0.0 -1.542 origin -8.08 8.08
cylinder 4 1.0 13.0556 0.0 -4.717 origin -8.08 8.08
cylinder 2 1.0 24.765 0.0 -26.307 origin -2.687 2.687
cylinder 0 1.0 28.575 0.0 -29.165
cylinder 3 1.0 28.727 0.0 -29.317
cuboid   7 1.0 4p28.727 0.0 -29.317
unit 47
com='scv nut and lead top plate'
cylinder 3 1.0 3.175 5.037 3.747 origin -8.08 8.08
cylinder 0 1.0 9.627 5.037 3.747 origin -8.08 8.08
cylinder 3 1.0 10.198 5.037 3.157 origin -8.08 8.08
cylinder 4 1.0 13.0556 5.037 0.0 origin -8.08 8.08
cylinder 2 1.0 24.765 5.037 0.0  origin -2.687 2.687
cylinder 0 1.0 28.575 5.037 0.0
cylinder 3 1.0 28.727 5.037 0.0
cuboid   7 1.0 4p28.727 5.037 0.0
unit 48
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.66 3.377 origin -8.08 8.08
cylinder 0 1.0 4.763 4.66 .215  origin -8.08 8.08
cylinder 8 1.0 7.703 4.66 .215  origin -8.08 8.08
```

```
cylinder 0 1.0 7.703 4.66 0.0   origin -8.08 8.08
cylinder 3 1.0 8.414 4.66 0.0   origin -8.08 8.08
cylinder 0 1.0 9.627 4.66 0.0   origin -8.08 8.08
cylinder 3 1.0 10.198 4.66 0.0  origin -8.08 8.08
cylinder 4 1.0 13.0556 4.66 0.0 origin -8.08 8.08
cylinder 2 1.0 24.765 4.66 0.0  origin -2.687 2.687
cylinder 0 1.0 28.575 4.66 0.0
cylinder 3 1.0 28.727 4.66 0.0
cuboid   7 1.0 4p28.727 4.66 0.0
unit 49
com='5.5307 cm sphere and primary containment'
sphere   1 1.0 5.5307 origin -8.75 8.75 -8.62
cylinder 6 1.0 6.4891 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 8.08
cylinder 0 1.0 7.703 14.727 -14.153 origin -8.08 8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin -8.08 8.08
cylinder 0 1.0 9.627 14.727 -14.153 origin -8.08 8.08
cylinder 3 1.0 10.198 14.727 -14.153 origin -8.08 8.08
cylinder 4 1.0 13.0556 14.727 -14.153 origin -8.08 8.08
cylinder 2 1.0 24.765 14.727 -14.153  origin -2.687 2.687
cylinder 0 1.0 28.575 14.727 -14.153
cylinder 3 1.0 28.727 14.727 -14.153
cuboid   7 1 4p28.727 14.727 -14.153
unit 50
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.96 0. origin -8.08 8.08
cylinder 3 1.0 5.715 0.96 0. origin -8.08 8.08
cylinder 0 1.0 7.703 0.96 0. origin -8.08 8.08
cylinder 8 1.0 7.703 4.77 0. origin -8.08 8.08
cylinder 3 1.0 8.414 5.48 0. origin -8.08 8.08
cylinder 0 1.0 9.627 5.48 0. origin -8.08 8.08
cylinder 3 1.0 10.198 5.48 0. origin -8.08 8.08
cylinder 4 1.0 13.0556 5.48 0. origin -8.08 8.08
cylinder 2 1.0 24.765 5.48 0.  origin -2.687 2.687
cylinder 0 1.0 28.575 5.48 0.0
cylinder 3 1.0 28.727 5.48 0.0
cuboid   7 1.0 4p28.727 5.48 0.
unit 51
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.97 0.  origin -8.08 8.08
cylinder 3 1.0 7.065 0.97 0.  origin -8.08 8.08
cylinder 0 1.0 9.627 0.97 0.  origin -8.08 8.08
cylinder 3 1.0 10.198 1.542 0. origin -8.08 8.08
cylinder 4 1.0 13.0556 4.717 0. origin -8.08 8.08
cylinder 2 1.0 24.765 26.307 0. origin -2.687 2.687
cylinder 0 1.0 28.575 29.165 0.
cylinder 3 1.0 28.727 29.317 0.0
cuboid   7 1.0 4p28.727 29.317 0.
unit 8
array 1 3*0.0
cuboid 0 1.0 57.454 0. 57.454 0. 160.708 0.
unit 26
array 2 3*0.0
cuboid 0 1.0 57.454 0. 57.454 0. 160.708 0.
unit 39
array 3 3*0.0
```

```
cuboid 0 1.0 57.454 0. 57.454 0. 160.708 0.
unit 52
array 4 3*0.0
cuboid 0 1.0 57.454 0. 57.454 0. 160.708 0.
end geom
read array
ara=1 nux=1 nuy=1 nuz=14 fill 7 6 1 2 3 4 5 9 4 10 2 11 12 13 end fill
ara=2 nux=1 nuy=1 nuz=14 fill 20 19 14 15 16 17 18 21 17 22 15 23 24 25
end fill
ara=3 nux=1 nuy=1 nuz=14 fill 33 32 27 28 29 30 31 34 30 35 28 36 37 38
end fill
ara=4 nux=1 nuy=1 nuz=14 fill 46 45 40 41 42 43 44 47 43 48 41 49 50 51
end fill
ara=5 nux=2 nuy=2 nuz=1 fill 39 52 8 26 end fill
end array
read bound all=mirror end bound
read start
nst=0
xsm=28.
xsp=85.
ysm=28.
ysp=85.
zsp=50.
zsm=100.
end start
read plot
xul=0.
yul=114.3
zul=58.14
xlr=114.3
ylr=0.
zlr=58.14
ttl='5.5307 cm u-235 sphere in 9974 damaged type 2'
uax=1.0
vdn=-1.0
nax=131
end plot
end data
end
```

4. 9975 with U-235 metal, flooded PCV, infinite array.

```
=ajax
1$$ 1 e t
2$$ 71 11 e t
3$$ 92235 1001 8016 24304 26304 28304 25055 14000 6012 13027
    82000 e t
end
=bonami
0$$ 1 e
1$$ 2 8 13 0 0 5 e t
3$$ 1 2r2 6r3 4 3r5 e
4$$ 92235 8016 1001 24304 26304 28304 25055 14000 6012
    82000 8016 1001 6012 e
5** 4.8808e-2 3.3369e-2 6.6737e-2 1.6471e-2
```

```
    6.036e-2 6.4834e-3 1.7321e-3 1.694e-3 3.1691e-4 3.2813e-2
    3.7141e-3 7.4282e-3 4.4569e-3 e
6$$ 1 2 3 2 3 2 4 5 e
7** 5.2429 6.4891 7.144 7.703 8.414 9.525 10.795 30.795 e
8** 8r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 14 a8 6 e
t
2$$ 9223501 801608 100108 601208 2430403 2630403 2830403
    2505503 1400003 601203 13027 8200007 100102 801602 e
3** 9223501 300 2 3s 4.8808e-2 1 7s
    2430403 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630403 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
    2830403 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505503 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    8200007 300 2 3s 3.2813e-2 1 7s
    t
end
=keno5
9975 shipping cask with u-235 metal sphere (5.2429 cm)
read param
tme=1000
lib=4
run=yes
plt=yes
gen=1200
npg=333
end param
read mixt
mix=1 9223501 4.8808e-2
mix=2 801608 3.7141e-3 100108 7.4282e-3 601208 4.4569e-3
mix=3 601203 3.1691e-4 2430403 1.6471e-2 2505503 1.7321e-3 2630403
      6.036e-2 2830403 6.4834e-3 1400003 1.694e-3
mix=4 8200007 3.2813e-2
mix=5 13027 6.2e-3 100102 6.0e-2 801602 3.0e-2
mix=6 13027 6.026e-2
mix=7 100102 6.6737e-2 801602 3.3369e-2
mix=8 7 1.e-15
mix=9 13027 6.2e-3
end mixt
read geom
unit 1
com='5.2429 cm sphere and stretched primary containment'
sphere   1 1.0 5.2429 origin 8.95 -8.95 15.26
cylinder 7 1.0 6.4891 2p20.503       origin 8.08 -8.08
cylinder 3 1.0 7.144 20.503 -21.077  origin 8.08 -8.08
cylinder 0 1.0 7.703 20.503 -21.077  origin 8.08 -8.08
cylinder 3 1.0 8.414 20.503 -21.077  origin 8.08 -8.08
cylinder 0 1.0 9.525 20.503 -21.077  origin 8.08 -8.08
cylinder 4 1.0 10.795 20.503 -21.077 origin 8.08 -8.08
cylinder 2 1.0 19.37 20.503 -21.077  origin 2.687 -2.687
cylinder 0 1.0 23.18 20.503 -21.077
cylinder 3 1.0 23.30 20.503 -21.077
cuboid   8 1 4p23.30 20.503 -21.077
```

```
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.493 0.0   origin 8.08 -8.08
cylinder 0 1.0 7.703 3.493 0.0   origin 8.08 -8.08
cylinder 3 1.0 8.414 3.493 0.0   origin 8.08 -8.08
cylinder 0 1.0 9.525 3.493 0.0   origin 8.08 -8.08
cylinder 4 1.0 10.795 3.493 0.0  origin 8.08 -8.08
cylinder 2 1.0 19.37 3.493 0.0   origin 2.687 -2.687
cylinder 0 1.0 23.18 3.493 0.0
cylinder 3 1.0 23.30 3.493 0.0
cuboid   8 1.0 4p23.30 3.493 0.0
unit 3
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0   origin 8.08 -8.08
cylinder 0 1.0 4.763 4.445 0.0   origin 8.08 -8.08
cylinder 9 1.0 7.703 4.445 0.0   origin 8.08 -8.08
cylinder 0 1.0 7.703 4.662 0.0   origin 8.08 -8.08
cylinder 3 1.0 8.414 4.662 0.0   origin 8.08 -8.08
cylinder 0 1.0 9.525 4.662 0.0   origin 8.08 -8.08
cylinder 4 1.0 10.795 4.662 0.0  origin 8.08 -8.08
cylinder 2 1.0 19.37 4.662 0.0   origin 2.687 -2.687
cylinder 0 1.0 23.18 4.662 0.0
cylinder 3 1.0 23.30 4.662 0.0
cuboid   8 1.0 4p23.30 4.662 0.0
unit 4
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0    origin 8.08 -8.08
cylinder 0 1.0 9.525 3.492 0.0    origin 8.08 -8.08
cylinder 4 1.0 10.795 3.492 0.0   origin 8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0    origin 2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   8 1.0 4p23.30 3.492 0.0
unit 5
com='scv nut and al shield top'
cylinder 3 1.0 3.175 1.282 0.0    origin 8.08 -8.08
cylinder 0 1.0 9.525 1.282 0.0    origin 8.08 -8.08
cylinder 4 1.0 10.795 1.282 0.0   origin 8.08 -8.08
cylinder 6 1.0 10.795 2.552 0.0   origin 8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0    origin 2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   8 1.0 4p23.30 2.552 0.0
unit 6
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965  origin 8.08 -8.08
cylinder 3 1.0 5.715 0.0 -0.965  origin 8.08 -8.08
cylinder 0 1.0 7.703 0.0 -0.965  origin 8.08 -8.08
cylinder 9 1.0 7.703 0.0 -4.775  origin 8.08 -8.08
cylinder 3 1.0 8.414 0.0 -5.055  origin 8.08 -8.08
cylinder 0 1.0 9.525 0.0 -5.055  origin 8.08 -8.08
cylinder 4 1.0 10.795 0.0 -5.055 origin 8.08 -8.08
cylinder 2 1.0 19.37 0.0 -5.055  origin 2.687 -2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   8 1.0 4p23.30 0.0 -5.055
```

```
unit 7
com='scv legs and bottom of lead shield'
cylinder 0 1.0 6.410 0.0 -0.965  origin 8.08 -8.08
cylinder 3 1.0 7.065 0.0 -0.965  origin 8.08 -8.08
cylinder 0 1.0 9.525 0.0 -0.965  origin 8.08 -8.08
cylinder 4 1.0 10.795 0.0 -2.235 origin 8.08 -8.08
cylinder 2 1.0 19.37 0.0 -2.235  origin 2.687 -2.687
cylinder 0 1.0 23.18 0.0 -2.235
cylinder 3 1.0 23.30 0.0 -2.235
cuboid   8 1.0 4p23.30 0.0 -2.235
unit 8
com='al top plate and water above'
cylinder 6 1.0 11.7 1.27 0.0  origin 8.08 -8.08
cylinder 2 1.0 19.37 1.27 0.0  origin 2.687 -2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   8 1.0 4p23.30 1.27 0.0
unit 9
com='al bottom plate and water under'
cylinder 6 1.0 11.7 0.0 -1.27   origin 8.08 -8.08
cylinder 2 1.0 19.37 0.0 -16.072 origin 2.687 -2.687
cylinder 0 1.0 23.18 0.0 -18.929
cylinder 3 1.0 23.30 0.0 -19.05
cuboid   8 1.0 4p23.30 0.0 -19.05
unit 11
com='scv nut and al shield top'
cylinder 3 1.0 3.175 2.552 1.27  origin 8.08 -8.08
cylinder 0 1.0 9.525 2.552 1.27  origin 8.08 -8.08
cylinder 4 1.0 10.795 2.552 1.27 origin 8.08 -8.08
cylinder 6 1.0 10.795 2.552 0.0  origin 8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0   origin 2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   8 1.0 4p23.30 2.552 0.0
unit 12
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.662 3.379  origin 8.08 -8.08
cylinder 0 1.0 4.763 4.662 0.217  origin 8.08 -8.08
cylinder 9 1.0 7.703 4.662 0.217  origin 8.08 -8.08
cylinder 0 1.0 7.703 4.662 0.0    origin 8.08 -8.08
cylinder 3 1.0 8.414 4.662 0.0    origin 8.08 -8.08
cylinder 0 1.0 9.525 4.662 0.0    origin 8.08 -8.08
cylinder 4 1.0 10.795 4.662 0.0   origin 8.08 -8.08
cylinder 2 1.0 19.37 4.662 0.0    origin 2.687 -2.687
cylinder 0 1.0 23.18 4.662 0.0
cylinder 3 1.0 23.30 4.662 0.0
cuboid   8 1.0 4p23.30 4.662 0.0
unit 13
com='5.2429 cm sphere and stretched primary containment'
sphere   1 1.0 5.2429 origin 8.95 -8.95 -15.26
cylinder 7 1.0 6.4891 2p20.503        origin 8.08 -8.08
cylinder 3 1.0 7.144 21.077 -20.503  origin 8.08 -8.08
cylinder 0 1.0 7.703 21.077 -20.503  origin 8.08 -8.08
cylinder 3 1.0 8.414 21.077 -20.503  origin 8.08 -8.08
cylinder 0 1.0 9.525 21.077 -20.503  origin 8.08 -8.08
cylinder 4 1.0 10.795 21.077 -20.503 origin 8.08 -8.08
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cylinder 2 1.0 19.37 21.077 -20.503  origin 2.687 -2.687
cylinder 0 1.0 23.18 21.077 -20.503
cylinder 3 1.0 23.30 21.077 -20.503
cuboid   8 1 4p23.30 21.077 -20.503
unit 14
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.   origin 8.08 -8.08
cylinder 3 1.0 5.715 0.965 0.   origin 8.08 -8.08
cylinder 0 1.0 7.703 0.965 0.   origin 8.08 -8.08
cylinder 9 1.0 7.703 4.7775 0.  origin 8.08 -8.08
cylinder 3 1.0 8.414 5.055 0.   origin 8.08 -8.08
cylinder 0 1.0 9.525 5.055 0.   origin 8.08 -8.08
cylinder 4 1.0 10.795 5.055 0.  origin 8.08 -8.08
cylinder 2 1.0 19.37 5.055 0.   origin 2.687 -2.687
cylinder 0 1.0 23.18 5.055 0.
cylinder 3 1.0 23.30 5.055 0.0
cuboid   8 1.0 4p23.30 5.055 0.
unit 15
com='scv legs and bottom of lead shield'
cylinder 0 1.0 6.410 0.965 0.   origin 8.08 -8.08
cylinder 3 1.0 7.065 0.965 0.   origin 8.08 -8.08
cylinder 0 1.0 9.525 0.965 0.   origin 8.08 -8.08
cylinder 4 1.0 10.795 2.235 0.  origin 8.08 -8.08
cylinder 2 1.0 19.37 2.235 0.   origin 2.687 -2.687
cylinder 0 1.0 23.18 2.235 0.
cylinder 3 1.0 23.30 2.235 0.
cuboid   8 1.0 4p23.30 2.235 0.
unit 16
com='al bottom plate and water under'
cylinder 6 1.0 11.7 1.27 0.   origin 8.08 -8.08
cylinder 2 1.0 19.37 16.072 0. origin 2.687 -2.687
cylinder 0 1.0 23.18 18.929 0.
cylinder 3 1.0 23.30 19.05 0.
cuboid   8 1.0 4p23.30 19.05 0.
unit 17
com='5.2429 cm sphere and stretched primary containment'
sphere   1 1.0 5.2429 origin -8.95 -8.95 15.26
cylinder 7 1.0 6.4891 2p20.503       origin -8.08 -8.08
cylinder 3 1.0 7.144 20.503 -21.077  origin -8.08 -8.08
cylinder 0 1.0 7.703 20.503 -21.077  origin -8.08 -8.08
cylinder 3 1.0 8.414 20.503 -21.077  origin -8.08 -8.08
cylinder 0 1.0 9.525 20.503 -21.077  origin -8.08 -8.08
cylinder 4 1.0 10.795 20.503 -21.077 origin -8.08 -8.08
cylinder 2 1.0 19.37 20.503 -21.077  origin -2.687 -2.687
cylinder 0 1.0 23.18 20.503 -21.077
cylinder 3 1.0 23.30 20.503 -21.077
cuboid   8 1 4p23.30 20.503 -21.077
unit 18
com='top of primary containment'
cylinder 3 1.0 7.455 3.493 0.0   origin -8.08 -8.08
cylinder 0 1.0 7.703 3.493 0.0   origin -8.08 -8.08
cylinder 3 1.0 8.414 3.493 0.0   origin -8.08 -8.08
cylinder 0 1.0 9.525 3.493 0.0   origin -8.08 -8.08
cylinder 4 1.0 10.795 3.493 0.0  origin -8.08 -8.08
cylinder 2 1.0 19.37 3.493 0.0   origin -2.687 -2.687
cylinder 0 1.0 23.18 3.493 0.0
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cylinder 3 1.0 23.30 3.493 0.0
cuboid   8 1.0 4p23.30 3.493 0.0
unit 19
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0   origin -8.08 -8.08
cylinder 0 1.0 4.763 4.445 0.0   origin -8.08 -8.08
cylinder 9 1.0 7.703 4.445 0.0   origin -8.08 -8.08
cylinder 0 1.0 7.703 4.662 0.0   origin -8.08 -8.08
cylinder 3 1.0 8.414 4.662 0.0   origin -8.08 -8.08
cylinder 0 1.0 9.525 4.662 0.0   origin -8.08 -8.08
cylinder 4 1.0 10.795 4.662 0.0  origin -8.08 -8.08
cylinder 2 1.0 19.37 4.662 0.0   origin -2.687 -2.687
cylinder 0 1.0 23.18 4.662 0.0
cylinder 3 1.0 23.30 4.662 0.0
cuboid   8 1.0 4p23.30 4.662 0.0
unit 20
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0    origin -8.08 -8.08
cylinder 0 1.0 9.525 3.492 0.0    origin -8.08 -8.08
cylinder 4 1.0 10.795 3.492 0.0   origin -8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0    origin -2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   8 1.0 4p23.30 3.492 0.0
unit 21
com='scv nut and al shield top'
cylinder 3 1.0 3.175 1.282 0.0    origin -8.08 -8.08
cylinder 0 1.0 9.525 1.282 0.0    origin -8.08 -8.08
cylinder 4 1.0 10.795 1.282 0.0   origin -8.08 -8.08
cylinder 6 1.0 10.795 2.552 0.0   origin -8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0    origin -2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   8 1.0 4p23.30 2.552 0.0
unit 22
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965  origin -8.08 -8.08
cylinder 3 1.0 5.715 0.0 -0.965  origin -8.08 -8.08
cylinder 0 1.0 7.703 0.0 -0.965  origin -8.08 -8.08
cylinder 9 1.0 7.703 0.0 -4.775  origin -8.08 -8.08
cylinder 3 1.0 8.414 0.0 -5.055  origin -8.08 -8.08
cylinder 0 1.0 9.525 0.0 -5.055  origin -8.08 -8.08
cylinder 4 1.0 10.795 0.0 -5.055 origin -8.08 -8.08
cylinder 2 1.0 19.37 0.0 -5.055  origin -2.687 -2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   8 1.0 4p23.30 0.0 -5.055
unit 23
com='scv legs and bottom of lead shield'
cylinder 0 1.0 6.410 0.0 -0.965  origin -8.08 -8.08
cylinder 3 1.0 7.065 0.0 -0.965  origin -8.08 -8.08
cylinder 0 1.0 9.525 0.0 -0.965  origin -8.08 -8.08
cylinder 4 1.0 10.795 0.0 -2.235 origin -8.08 -8.08
cylinder 2 1.0 19.37 0.0 -2.235  origin -2.687 -2.687
cylinder 0 1.0 23.18 0.0 -2.235
cylinder 3 1.0 23.30 0.0 -2.235
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cuboid   8 1.0 4p23.30 0.0 -2.235
unit 24
com='al top plate and water above'
cylinder 6 1.0 11.7 1.27 0.0  origin -8.08 -8.08
cylinder 2 1.0 19.37 1.27 0.0  origin -2.687 -2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   8 1.0 4p23.30 1.27 0.0
unit 25
com='al bottom plate and water under'
cylinder 6 1.0 11.7 0.0 -1.27   origin -8.08 -8.08
cylinder 2 1.0 19.37 0.0 -16.072 origin -2.687 -2.687
cylinder 0 1.0 23.18 0.0 -18.929
cylinder 3 1.0 23.30 0.0 -19.05
cuboid   8 1.0 4p23.30 0.0 -19.05
unit 26
com='scv nut and al shield top'
cylinder 3 1.0 3.175 2.552 1.27  origin -8.08 -8.08
cylinder 0 1.0 9.525 2.552 1.27  origin -8.08 -8.08
cylinder 4 1.0 10.795 2.552 1.27 origin -8.08 -8.08
cylinder 6 1.0 10.795 2.552 0.0  origin -8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0   origin -2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   8 1.0 4p23.30 2.552 0.0
unit 27
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.662 3.379  origin -8.08 -8.08
cylinder 0 1.0 4.763 4.662 0.217  origin -8.08 -8.08
cylinder 9 1.0 7.703 4.662 0.217  origin -8.08 -8.08
cylinder 0 1.0 7.703 4.662 0.0    origin -8.08 -8.08
cylinder 3 1.0 8.414 4.662 0.0    origin -8.08 -8.08
cylinder 0 1.0 9.525 4.662 0.0    origin -8.08 -8.08
cylinder 4 1.0 10.795 4.662 0.0   origin -8.08 -8.08
cylinder 2 1.0 19.37 4.662 0.0    origin -2.687 -2.687
cylinder 0 1.0 23.18 4.662 0.0
cylinder 3 1.0 23.30 4.662 0.0
cuboid   8 1.0 4p23.30 4.662 0.0
unit 28
com='5.2429 cm sphere and stretched primary containment'
sphere   1 1.0 5.2429 origin -8.95 -8.95 -15.26
cylinder 7 1.0 6.4891 2p20.503       origin -8.08 -8.08
cylinder 3 1.0 7.144 21.077 -20.503  origin -8.08 -8.08
cylinder 0 1.0 7.703 21.077 -20.503  origin -8.08 -8.08
cylinder 3 1.0 8.414 21.077 -20.503  origin -8.08 -8.08
cylinder 0 1.0 9.525 21.077 -20.503  origin -8.08 -8.08
cylinder 4 1.0 10.795 21.077 -20.503 origin -8.08 -8.08
cylinder 2 1.0 19.37 21.077 -20.503  origin -2.687 -2.687
cylinder 0 1.0 23.18 21.077 -20.503
cylinder 3 1.0 23.30 21.077 -20.503
cuboid   8 1 4p23.30 21.077 -20.503
unit 29
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.   origin -8.08 -8.08
cylinder 3 1.0 5.715 0.965 0.   origin -8.08 -8.08
cylinder 0 1.0 7.703 0.965 0.   origin -8.08 -8.08
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cylinder 9 1.0 7.703 4.7775 0.  origin -8.08 -8.08
cylinder 3 1.0 8.414 5.055 0.   origin -8.08 -8.08
cylinder 0 1.0 9.525 5.055 0.   origin -8.08 -8.08
cylinder 4 1.0 10.795 5.055 0.  origin -8.08 -8.08
cylinder 2 1.0 19.37 5.055 0.   origin -2.687 -2.687
cylinder 0 1.0 23.18 5.055 0.
cylinder 3 1.0 23.30 5.055 0.0
cuboid   8 1.0 4p23.30 5.055 0.
unit 30
com='scv legs and bottom of lead shield'
cylinder 0 1.0 6.410 0.965 0.   origin -8.08 -8.08
cylinder 3 1.0 7.065 0.965 0.   origin -8.08 -8.08
cylinder 0 1.0 9.525 0.965 0.   origin -8.08 -8.08
cylinder 4 1.0 10.795 2.235 0.  origin -8.08 -8.08
cylinder 2 1.0 19.37 2.235 0.   origin -2.687 -2.687
cylinder 0 1.0 23.18 2.235 0.
cylinder 3 1.0 23.30 2.235 0.
cuboid   8 1.0 4p23.30 2.235 0.
unit 31
com='al bottom plate and water under'
cylinder 6 1.0 11.7 1.27 0.   origin -8.08 -8.08
cylinder 2 1.0 19.37 16.072 0. origin -2.687 -2.687
cylinder 0 1.0 23.18 18.929 0.
cylinder 3 1.0 23.30 19.05 0.
cuboid   8 1.0 4p23.30 19.05 0.
unit 33
com='5.2429 cm sphere and stretched primary containment'
sphere   1 1.0 5.2429 origin 8.95 8.95 15.26
cylinder 7 1.0 6.4891 2p20.503        origin 8.08 8.08
cylinder 3 1.0 7.144 20.503 -21.077  origin 8.08 8.08
cylinder 0 1.0 7.703 20.503 -21.077  origin 8.08 8.08
cylinder 3 1.0 8.414 20.503 -21.077  origin 8.08 8.08
cylinder 0 1.0 9.525 20.503 -21.077  origin 8.08 8.08
cylinder 4 1.0 10.795 20.503 -21.077 origin 8.08 8.08
cylinder 2 1.0 19.37 20.503 -21.077  origin 2.687 2.687
cylinder 0 1.0 23.18 20.503 -21.077
cylinder 3 1.0 23.30 20.503 -21.077
cuboid   8 1 4p23.30 20.503 -21.077
unit 34
com='top of primary containment'
cylinder 3 1.0 7.455 3.493 0.0   origin 8.08 8.08
cylinder 0 1.0 7.703 3.493 0.0   origin 8.08 8.08
cylinder 3 1.0 8.414 3.493 0.0   origin 8.08 8.08
cylinder 0 1.0 9.525 3.493 0.0   origin 8.08 8.08
cylinder 4 1.0 10.795 3.493 0.0  origin 8.08 8.08
cylinder 2 1.0 19.37 3.493 0.0   origin 2.687 2.687
cylinder 0 1.0 23.18 3.493 0.0
cylinder 3 1.0 23.30 3.493 0.0
cuboid   8 1.0 4p23.30 3.493 0.0
unit 35
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0   origin 8.08 8.08
cylinder 0 1.0 4.763 4.445 0.0   origin 8.08 8.08
cylinder 9 1.0 7.703 4.445 0.0   origin 8.08 8.08
cylinder 0 1.0 7.703 4.662 0.0   origin 8.08 8.08
cylinder 3 1.0 8.414 4.662 0.0   origin 8.08 8.08
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cylinder 0 1.0 9.525 4.662 0.0  origin 8.08 8.08
cylinder 4 1.0 10.795 4.662 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 4.662 0.0  origin 2.687 2.687
cylinder 0 1.0 23.18 4.662 0.0
cylinder 3 1.0 23.30 4.662 0.0
cuboid   8 1.0 4p23.30 4.662 0.0
unit 36
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0   origin 8.08 8.08
cylinder 0 1.0 9.525 3.492 0.0   origin 8.08 8.08
cylinder 4 1.0 10.795 3.492 0.0  origin 8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0   origin 2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   8 1.0 4p23.30 3.492 0.0
unit 37
com='scv nut and al shield top'
cylinder 3 1.0 3.175 1.282 0.0   origin 8.08 8.08
cylinder 0 1.0 9.525 1.282 0.0   origin 8.08 8.08
cylinder 4 1.0 10.795 1.282 0.0  origin 8.08 8.08
cylinder 6 1.0 10.795 2.552 0.0  origin 8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0   origin 2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   8 1.0 4p23.30 2.552 0.0
unit 38
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965  origin 8.08 8.08
cylinder 3 1.0 5.715 0.0 -0.965  origin 8.08 8.08
cylinder 0 1.0 7.703 0.0 -0.965  origin 8.08 8.08
cylinder 9 1.0 7.703 0.0 -4.775  origin 8.08 8.08
cylinder 3 1.0 8.414 0.0 -5.055  origin 8.08 8.08
cylinder 0 1.0 9.525 0.0 -5.055  origin 8.08 8.08
cylinder 4 1.0 10.795 0.0 -5.055 origin 8.08 8.08
cylinder 2 1.0 19.37 0.0 -5.055  origin 2.687 2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   8 1.0 4p23.30 0.0 -5.055
unit 39
com='scv legs and bottom of lead shield'
cylinder 0 1.0 6.410 0.0 -0.965  origin 8.08 8.08
cylinder 3 1.0 7.065 0.0 -0.965  origin 8.08 8.08
cylinder 0 1.0 9.525 0.0 -0.965  origin 8.08 8.08
cylinder 4 1.0 10.795 0.0 -2.235 origin 8.08 8.08
cylinder 2 1.0 19.37 0.0 -2.235  origin 2.687 2.687
cylinder 0 1.0 23.18 0.0 -2.235
cylinder 3 1.0 23.30 0.0 -2.235
cuboid   8 1.0 4p23.30 0.0 -2.235
unit 40
com='al top plate and water above'
cylinder 6 1.0 11.7 1.27 0.0   origin 8.08 8.08
cylinder 2 1.0 19.37 1.27 0.0  origin 2.687 2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   8 1.0 4p23.30 1.27 0.0
unit 41
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com='al bottom plate and water under'
cylinder 6 1.0 11.7 0.0 -1.27   origin 8.08 8.08
cylinder 2 1.0 19.37 0.0 -16.072 origin 2.687 2.687
cylinder 0 1.0 23.18 0.0 -18.929
cylinder 3 1.0 23.30 0.0 -19.05
cuboid   8 1.0 4p23.30 0.0 -19.05
unit 42
com='scv nut and al shield top'
cylinder 3 1.0 3.175 2.552 1.27  origin 8.08 8.08
cylinder 0 1.0 9.525 2.552 1.27  origin 8.08 8.08
cylinder 4 1.0 10.795 2.552 1.27 origin 8.08 8.08
cylinder 6 1.0 10.795 2.552 0.0  origin 8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0   origin 2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   8 1.0 4p23.30 2.552 0.0
unit 43
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.662 3.379  origin 8.08 8.08
cylinder 0 1.0 4.763 4.662 0.217  origin 8.08 8.08
cylinder 9 1.0 7.703 4.662 0.217  origin 8.08 8.08
cylinder 0 1.0 7.703 4.662 0.0    origin 8.08 8.08
cylinder 3 1.0 8.414 4.662 0.0    origin 8.08 8.08
cylinder 0 1.0 9.525 4.662 0.0    origin 8.08 8.08
cylinder 4 1.0 10.795 4.662 0.0   origin 8.08 8.08
cylinder 2 1.0 19.37 4.662 0.0    origin 2.687 2.687
cylinder 0 1.0 23.18 4.662 0.0
cylinder 3 1.0 23.30 4.662 0.0
cuboid   8 1.0 4p23.30 4.662 0.0
unit 44
com='5.2429 cm sphere and stretched primary containment'
sphere   1 1.0 5.2429 origin 8.95 8.95 -15.26
cylinder 7 1.0 6.4891 2p20.503       origin 8.08 8.08
cylinder 3 1.0 7.144 21.077 -20.503  origin 8.08 8.08
cylinder 0 1.0 7.703 21.077 -20.503  origin 8.08 8.08
cylinder 3 1.0 8.414 21.077 -20.503  origin 8.08 8.08
cylinder 0 1.0 9.525 21.077 -20.503  origin 8.08 8.08
cylinder 4 1.0 10.795 21.077 -20.503 origin 8.08 8.08
cylinder 2 1.0 19.37 21.077 -20.503  origin 2.687 2.687
cylinder 0 1.0 23.18 21.077 -20.503
cylinder 3 1.0 23.30 21.077 -20.503
cuboid   8 1 4p23.30 21.077 -20.503
unit 45
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.   origin 8.08 8.08
cylinder 3 1.0 5.715 0.965 0.   origin 8.08 8.08
cylinder 0 1.0 7.703 0.965 0.   origin 8.08 8.08
cylinder 9 1.0 7.703 4.7775 0.  origin 8.08 8.08
cylinder 3 1.0 8.414 5.055 0.   origin 8.08 8.08
cylinder 0 1.0 9.525 5.055 0.   origin 8.08 8.08
cylinder 4 1.0 10.795 5.055 0.  origin 8.08 8.08
cylinder 2 1.0 19.37 5.055 0.   origin 2.687 2.687
cylinder 0 1.0 23.18 5.055 0.
cylinder 3 1.0 23.30 5.055 0.0
cuboid   8 1.0 4p23.30 5.055 0.
unit 46
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com='scv legs and bottom of lead shield'
cylinder 0 1.0 6.410 0.965 0.   origin 8.08 8.08
cylinder 3 1.0 7.065 0.965 0.   origin 8.08 8.08
cylinder 0 1.0 9.525 0.965 0.   origin 8.08 8.08
cylinder 4 1.0 10.795 2.235 0.  origin 8.08 8.08
cylinder 2 1.0 19.37 2.235 0.   origin 2.687 2.687
cylinder 0 1.0 23.18 2.235 0.
cylinder 3 1.0 23.30 2.235 0.
cuboid   8 1.0 4p23.30 2.235 0.
unit 47
com='al bottom plate and water under'
cylinder 6 1.0 11.7 1.27 0.   origin 8.08 8.08
cylinder 2 1.0 19.37 16.072 0. origin 2.687 2.687
cylinder 0 1.0 23.18 18.929 0.
cylinder 3 1.0 23.30 19.05 0.
cuboid   8 1.0 4p23.30 19.05 0.
unit 49
com='5.2429 cm sphere and stretched primary containment'
sphere   1 1.0 5.2429 origin -8.95 8.95 15.26
cylinder 7 1.0 6.4891 2p20.503        origin -8.08 8.08
cylinder 3 1.0 7.144 20.503 -21.077  origin -8.08 8.08
cylinder 0 1.0 7.703 20.503 -21.077  origin -8.08 8.08
cylinder 3 1.0 8.414 20.503 -21.077  origin -8.08 8.08
cylinder 0 1.0 9.525 20.503 -21.077  origin -8.08 8.08
cylinder 4 1.0 10.795 20.503 -21.077 origin -8.08 8.08
cylinder 2 1.0 19.37 20.503 -21.077  origin -2.687 2.687
cylinder 0 1.0 23.18 20.503 -21.077
cylinder 3 1.0 23.30 20.503 -21.077
cuboid   8 1 4p23.30 20.503 -21.077
unit 50
com='top of primary containment'
cylinder 3 1.0 7.455 3.493 0.0   origin -8.08 8.08
cylinder 0 1.0 7.703 3.493 0.0   origin -8.08 8.08
cylinder 3 1.0 8.414 3.493 0.0   origin -8.08 8.08
cylinder 0 1.0 9.525 3.493 0.0   origin -8.08 8.08
cylinder 4 1.0 10.795 3.493 0.0  origin -8.08 8.08
cylinder 2 1.0 19.37 3.493 0.0   origin -2.687 2.687
cylinder 0 1.0 23.18 3.493 0.0
cylinder 3 1.0 23.30 3.493 0.0
cuboid   8 1.0 4p23.30 3.493 0.0
unit 51
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0   origin -8.08 8.08
cylinder 0 1.0 4.763 4.445 0.0   origin -8.08 8.08
cylinder 9 1.0 7.703 4.445 0.0   origin -8.08 8.08
cylinder 0 1.0 7.703 4.662 0.0   origin -8.08 8.08
cylinder 3 1.0 8.414 4.662 0.0   origin -8.08 8.08
cylinder 0 1.0 9.525 4.662 0.0   origin -8.08 8.08
cylinder 4 1.0 10.795 4.662 0.0  origin -8.08 8.08
cylinder 2 1.0 19.37 4.662 0.0   origin -2.687 2.687
cylinder 0 1.0 23.18 4.662 0.0
cylinder 3 1.0 23.30 4.662 0.0
cuboid   8 1.0 4p23.30 4.662 0.0
unit 52
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0    origin -8.08 8.08
```

```
cylinder 0 1.0 9.525 3.492 0.0    origin -8.08 8.08
cylinder 4 1.0 10.795 3.492 0.0   origin -8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0    origin -2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   8 1.0 4p23.30 3.492 0.0
unit 53
com='scv nut and al shield top'
cylinder 3 1.0 3.175 1.282 0.0    origin -8.08 8.08
cylinder 0 1.0 9.525 1.282 0.0    origin -8.08 8.08
cylinder 4 1.0 10.795 1.282 0.0   origin -8.08 8.08
cylinder 6 1.0 10.795 2.552 0.0   origin -8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0    origin -2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   8 1.0 4p23.30 2.552 0.0
unit 54
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965  origin -8.08 8.08
cylinder 3 1.0 5.715 0.0 -0.965  origin -8.08 8.08
cylinder 0 1.0 7.703 0.0 -0.965  origin -8.08 8.08
cylinder 9 1.0 7.703 0.0 -4.775  origin -8.08 8.08
cylinder 3 1.0 8.414 0.0 -5.055  origin -8.08 8.08
cylinder 0 1.0 9.525 0.0 -5.055  origin -8.08 8.08
cylinder 4 1.0 10.795 0.0 -5.055 origin -8.08 8.08
cylinder 2 1.0 19.37 0.0 -5.055  origin -2.687 2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   8 1.0 4p23.30 0.0 -5.055
unit 55
com='scv legs and bottom of lead shield'
cylinder 0 1.0 6.410 0.0 -0.965  origin -8.08 8.08
cylinder 3 1.0 7.065 0.0 -0.965  origin -8.08 8.08
cylinder 0 1.0 9.525 0.0 -0.965  origin -8.08 8.08
cylinder 4 1.0 10.795 0.0 -2.235 origin -8.08 8.08
cylinder 2 1.0 19.37 0.0 -2.235  origin -2.687 2.687
cylinder 0 1.0 23.18 0.0 -2.235
cylinder 3 1.0 23.30 0.0 -2.235
cuboid   8 1.0 4p23.30 0.0 -2.235
unit 56
com='al top plate and water above'
cylinder 6 1.0 11.7 1.27 0.0   origin -8.08 8.08
cylinder 2 1.0 19.37 1.27 0.0  origin -2.687 2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   8 1.0 4p23.30 1.27 0.0
unit 57
com='al bottom plate and water under'
cylinder 6 1.0 11.7 0.0 -1.27    origin -8.08 8.08
cylinder 2 1.0 19.37 0.0 -16.072 origin -2.687 2.687
cylinder 0 1.0 23.18 0.0 -18.929
cylinder 3 1.0 23.30 0.0 -19.05
cuboid   8 1.0 4p23.30 0.0 -19.05
unit 58
com='scv nut and al shield top'
cylinder 3 1.0 3.175 2.552 1.27  origin -8.08 8.08
```

```
cylinder 0 1.0 9.525 2.552 1.27  origin -8.08 8.08
cylinder 4 1.0 10.795 2.552 1.27 origin -8.08 8.08
cylinder 6 1.0 10.795 2.552 0.0  origin -8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0   origin -2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   8 1.0 4p23.30 2.552 0.0
unit 59
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.662 3.379  origin -8.08 8.08
cylinder 0 1.0 4.763 4.662 0.217  origin -8.08 8.08
cylinder 9 1.0 7.703 4.662 0.217  origin -8.08 8.08
cylinder 0 1.0 7.703 4.662 0.0    origin -8.08 8.08
cylinder 3 1.0 8.414 4.662 0.0    origin -8.08 8.08
cylinder 0 1.0 9.525 4.662 0.0    origin -8.08 8.08
cylinder 4 1.0 10.795 4.662 0.0   origin -8.08 8.08
cylinder 2 1.0 19.37 4.662 0.0    origin -2.687 2.687
cylinder 0 1.0 23.18 4.662 0.0
cylinder 3 1.0 23.30 4.662 0.0
cuboid   8 1.0 4p23.30 4.662 0.0
unit 60
com='5.2429 cm sphere and stretched primary containment'
sphere   1 1.0 5.2429 origin -8.95 8.95 -15.26
cylinder 7 1.0 6.4891 2p20.503       origin -8.08 8.08
cylinder 3 1.0 7.144 21.077 -20.503  origin -8.08 8.08
cylinder 0 1.0 7.703 21.077 -20.503  origin -8.08 8.08
cylinder 3 1.0 8.414 21.077 -20.503  origin -8.08 8.08
cylinder 0 1.0 9.525 21.077 -20.503  origin -8.08 8.08
cylinder 4 1.0 10.795 21.077 -20.503 origin -8.08 8.08
cylinder 2 1.0 19.37 21.077 -20.503  origin -2.687 2.687
cylinder 0 1.0 23.18 21.077 -20.503
cylinder 3 1.0 23.30 21.077 -20.503
cuboid   8 1 4p23.30 21.077 -20.503
unit 61
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.   origin -8.08 8.08
cylinder 3 1.0 5.715 0.965 0.   origin -8.08 8.08
cylinder 0 1.0 7.703 0.965 0.   origin -8.08 8.08
cylinder 9 1.0 7.703 4.7775 0.  origin -8.08 8.08
cylinder 3 1.0 8.414 5.055 0.   origin -8.08 8.08
cylinder 0 1.0 9.525 5.055 0.   origin -8.08 8.08
cylinder 4 1.0 10.795 5.055 0.  origin -8.08 8.08
cylinder 2 1.0 19.37 5.055 0.   origin -2.687 2.687
cylinder 0 1.0 23.18 5.055 0.
cylinder 3 1.0 23.30 5.055 0.0
cuboid   8 1.0 4p23.30 5.055 0.
unit 62
com='scv legs and bottom of lead shield'
cylinder 0 1.0 6.410 0.965 0.   origin -8.08 8.08
cylinder 3 1.0 7.065 0.965 0.   origin -8.08 8.08
cylinder 0 1.0 9.525 0.965 0.   origin -8.08 8.08
cylinder 4 1.0 10.795 2.235 0.  origin -8.08 8.08
cylinder 2 1.0 19.37 2.235 0.   origin -2.687 2.687
cylinder 0 1.0 23.18 2.235 0.
cylinder 3 1.0 23.30 2.235 0.
cuboid   8 1.0 4p23.30 2.235 0.
```

```
unit 63
com='al bottom plate and water under'
cylinder 6 1.0 11.7 1.27 0.   origin -8.08 8.08
cylinder 2 1.0 19.37 16.072 0. origin -2.687 2.687
cylinder 0 1.0 23.18 18.929 0.
cylinder 3 1.0 23.30 19.05 0.
cuboid   8 1.0 4p23.30 19.05 0.
unit 10
array 1 3*0.0
cuboid 0 1.0 46.60 0. 46.60 0. 166.778 0.
unit 32
array 2 3*0.0
cuboid 0 1.0 46.60 0. 46.60 0. 166.778 0.
unit 48
array 3 3*0.0
cuboid 0 1.0 46.60 0. 46.60 0. 166.778 0.
unit 64
array 4 3*0.0
cuboid 0 1.0 46.60 0. 46.60 0. 166.778 0.
end geom
read array
ara=1 nux=1 nuy=1 nuz=18 fill 9 7 6 1 2 3 4 5 8 8 11 4 12 2 13 14 15 16
end fill
ara=2 nux=1 nuy=1 nuz=18 fill 25 23 22 17 18 19 20 21 24 24 26 20 27 18
28 29
                                  30 31 end fill
ara=3 nux=1 nuy=1 nuz=18 fill 41 39 38 33 34 35 36 37 40 40 42 36 43 34
44 45
                                  46 47 end fill
ara=4 nux=1 nuy=1 nuz=18 fill 57 55 54 49 50 51 52 53 56 56 58 52 59 50
60 61
                                  62 63 end fill
ara=5 nux=2 nuy=2 nuz=1 fill 48 64 10 32 end fill
end array
read bound all=mirror end bound
read start
nst=0
xsm=25.
xsp=68.
ysm=25.
ysp=68.
zsp=110.
zsm=55.
end start
read plot
xul=0.
yul=94.
zul=62.677
xlr=94.
ylr=0.
zlr=62.677
ttl='5.2429 cm u-235 sphere in 9975 in damaged type 2'
uax=1.0
vdn=-1.0
nax=131
end plot
```

```
end data
end
```

5. 9972 with $^{235}UO_2$/water dispersion, 8 x 8 x 4 array.

```
=ajax
1$$ 1 e t
2$$ 71 10 e t
3$$ 92235 1001 8016 24304 26304 28304 25055 14000 6012 13027 e t
end
=bonami
0$$ 1 e
1$$ 2 3 12 0 0 5 e t
3$$ 3r1 6r2 3r3 e
4$$ 92235 8016 1001 24304 26304 28304 25055 14000 6012 6012 1001 8016 e
5** 9.0084e-3 3.9223e-2 4.2414e-2 1.6471e-2 6.036e-2 6.4834e-3
    1.7321e-3 1.694e-3 3.1691e-4  4.4569e-3 7.4282e-3 3.7141e-3 e
6$$ 1 2 3 e
7**   6.571 7.144 27.144 e
8** 3r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 13 a8 5 e
t
2$$ 9223501 801603 100103 2430402 2630402 2830402 2505502 1400002
    601202 13027 601203 100101 801601 e
3** 9223501 300 2 3s 9.0084e-3 1 1. 139. 1 16. 11. 1 1.0
    2430402 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630402 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
    2830402 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505502 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    t
end
=keno5
9972 shipping cask with u-235 solution cylinder (7X8X5 array)
read param
tme=10000
lib=4
run=yes
plt=yes
gen=1200
npg=330
end param
read mixt
sct=3
mix=1 9223501 9.0084e-3
100101 4.2414e-2 801601 3.9223e-2
mix=2 601203 4.4569e-3 100103 7.4282e-3 801603 3.7141e-3
mix=3 601202 3.1691e-4 2430402 1.6471e-2 2505502 1.7321e-3 2630402
      6.036e-2 2830402 6.4834e-3 1400002 1.694e-3
mix=4 13027 6.0262e-2
mix=5 100103 6.6737e-2 801603 3.3369e-2
end mixt
read geom
```

```
unit 1
com='solution cylinder and primary containment'
cylinder 1 1.0 6.571 2p14.153
cylinder 3 1.0 7.144 14.153 -14.727
cylinder 2 1.0 23.18 14.153 -14.727
cuboid   0 1 4p23.18 14.153 -14.727
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0
cylinder 2 1.0 23.18 3.492 0.0
cuboid   0 1.0 4p23.18 3.492 0.0
unit 3
com='primary containment nut'
cylinder 3 1.0 3.175 1.283 0.0
cylinder 0 1.0 7.455 1.283 0.0
cylinder 2 1.0 23.18 1.283 0.0
cuboid   0 1.0 4p23.18 1.283 0.0
unit 4
com='aluminum top plate'
cylinder 4 1 12.70 1.27 0.0
cylinder 2 1.0 23.18 18.574 0.0
cuboid   0 1.0 4p23.18 18.574 0.0
unit 5
com='pcv locking unit'
cylinder 0 1.0 5.113 0.966 0.0
cylinder 3 1.0 5.715 0.966 0.0
cylinder 0 1.0 7.144 0.966 0.0
cylinder 2 1.0 23.18 0.966 0.0
cuboid   0 1.0 4p23.18 0.966 0.0
unit 6
com='anti-rotation plate'
cylinder 4 1.0 12.70 1.27 0.0
cylinder 2 1.0 23.18 1.27 -16.034
cuboid   0 1.0 4p23.18 1.27 -16.034
unit 7
com='complete cask'
array 1 3*0.0
unit 8
com='empty space'
cuboid 0 1.0 4p23.18 70.499 0.
unit 9
com='add water reflector'
array 2 3*0.0
cuboid 5 1.0 410.88 -40. 410.88 -40. 321.996 -40.
end geom
read array
ara=1 nux=1 nuy=1 nuz=6 fill 6 5 1 2 3 4 end fill
ara=2 nux=8 nuy=8 nuz=4 fill 6r8 250r7 end fill
end array
read plot
xul=0.
yul=375.
zul=35.
xlr=330.
ylr=0.
zlr=35.0
```

```
ttl='5X7X8 array'
uax=1.0
vdn=-1.0
nax=131
end plot
end data
end
```

6. 9973 with $^{235}UO_2$/water dispersion, 8 x 8 x 4 array.

```
=ajax
1$$ 1 e t
2$$ 71 10 e t
3$$ 92235 1001 8016 24304 26304 28304 25055 14000 6012 13027 e t
end
=bonami
0$$ 1 e
1$$ 2 5 12 0 0 5 e t
3$$ 3r1 6r2 3r3 e
4$$ 92235 8016 1001 24304 26304 28304 25055 14000 6012 8016 1001 6012 e
5** 9.6753e-3 2.6755e-2 5.3509e-2 1.6471e-2
    6.036e-2 6.4834e-3 1.7321e-3 1.694e-3 3.1691e-4
    3.7141e-3 7.4282e-3 4.4569e-3 e
6$$ 1 2 3 2 3 e
7**   6.571 7.144 7.702 8.414 23.18 e
8** 5r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 13 a8 5 e
t
2$$ 9223501 801601 100101 2430402 2630402 2830402
    2505502 1400002 601202 13027 801603 100103 601203 e
3** 9223501 300 2 3s 9.6753e-3 1 1. 25. 1 16. 2. 1 1.0
    2430402 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630402 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
    2830402 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505502 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    t
end
=keno5
9973 shipping cask with u-235 soln cylinder
read param
tme=1000
lib=4
run=yes
plt=yes
gen=300
npg=333
end param
read mixt
mix=1 9223501 9.6753e-3
100101 4.0613e-2 801601 3.9657e-2
mix=2 801603 3.7141e-3 100103 7.4282e-3 601203 4.4569e-3
mix=3 601202 3.1691e-4 2430402 1.6471e-2 2505502 1.7321e-3 2630402
```

```
     6.036e-2 2830402 6.4834e-3 1400002 1.694e-3
mix=4 13027 6.0262e-2
mix=5 13027 6.2e-3
mix=6 100103 6.6737e-2 801603 3.3369e-2
mix=7 6 1.e-10
end mixt
read geom
unit 1
com='5.6641 cm sphere and primary containment'
cylinder 1 1.0 6.571 2p14.153
cylinder 3 1.0 7.144 14.153 -14.727
cylinder 0 1.0 7.702 14.153 -14.727
cylinder 3 1.0 8.414 14.153 -14.727
cylinder 2 1.0 23.18 14.153 -14.727
cuboid   7 1 4p23.18 14.153 -14.727
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0
cylinder 0 1.0 7.702 3.492 0.0
cylinder 3 1.0 8.414 3.492 0.0
cylinder 2 1.0 23.18 3.492 0.0
cuboid   7 1.0 4p23.18 3.492 0.0
unit 3
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0
cylinder 0 1.0 4.763 4.445 0.0
cylinder 5 1.0 7.702 4.445 0.0
cylinder 0 1.0 7.702 4.661 0.0
cylinder 3 1.0 8.414 4.661 0.0
cylinder 2 1.0 23.18 4.661 0.0
cuboid   7 1.0 4p23.18 4.661 0.0
unit 4
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0
cylinder 2 1.0 23.18 3.492 0.0
cuboid   7 1.0 4p23.18 3.492 0.0
unit 5
com='scv nut and al top plate'
cylinder 3 1.0 3.175 1.282 0.0
cylinder 0 1.0 8.414 1.282 0.0
cylinder 2 1.0 12.70 1.282 0.0
cylinder 4 1.0 12.70 2.552 0.0
cylinder 2 1.0 23.18 12.712 0.0
cuboid   7 1.0 4p23.18 12.712 0.0
unit 6
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965
cylinder 3 1.0 5.715 0.0 -0.965
cylinder 0 1.0 7.702 0.0 -0.965
cylinder 5 1.0 7.702 0.0 -4.775
cylinder 3 1.0 8.414 0.0 -5.055
cylinder 2 1.0 23.18 0.0 -5.055
cuboid   7 1.0 4p23.18 0.0 -5.055
unit 7
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.965
```

```
cylinder 3 1.0 7.065 0.0 -0.965
cylinder 0 1.0 8.414 0.0 -0.965
cylinder 2 1.0 12.70 0.0 -0.965
cylinder 4 1.0 12.70 0.0 -2.235
cylinder 2 1.0 23.18 0.0 -11.735
cuboid   7 1.0 4p23.18 0.0 -11.735
unit 8
com='complete cask'
array 1 3*0.0
cuboid 0 1.0 46.36 0. 46.36 0.  70.027 0.
unit 9
com='empty cell'
cuboid 0 1.0 4p23.18 70.027 0.
unit 10
com='add water reflector'
array 2 3*0.0
cuboid 6 1.0 410.88 -40. 410.88 -40. 321.996 -40.
end geom
read array
ara=1 nux=1 nuy=1 nuz=7 fill 7 6 1 2 3 4 5 end fill
ara=2 nux=8 nuy=8 nuz=4 fill 6r9 250r8 end fill
end array
end data
end
```

7. 9974 with $^{235}UO_2$/water dispersion, 8 x 8 x 4 array.

```
=ajax
1$$ 1 e t
2$$ 71 11 e t
3$$ 92235 1001 8016 24304 26304 28304 25055 14000 6012 13027
    82000 e t
end
=bonami
0$$ 1 e
1$$ 2 8 13 0 0 5 e t
3$$ 3r1 6r2 3 3r4 e
4$$ 92235 8016 1001 24304 26304 28304 25055 14000 6012
    82000 8016 1001 6012 e
5** 9.0084e-3 3.9223e-2 4.2414e-2 1.6471e-2
    6.036e-2 6.4834e-3 1.7321e-3 1.694e-3 3.1691e-4 3.2813e-2
    3.7141e-3 7.4282e-3 4.4569e-3 e
6$$ 1 2 4 2 4 2 3 4 e
7**   6.571 7.144 7.702 8.414 9.627 10.198 13.018 28.26 e
8** 8r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 14 a8 6 e
t
2$$ 9223501 801603 100103 601203 2430402 2630402 2830402
    2505502 1400002 601202 13027 8200007 100101 801601 e
3** 9223501 300 2 3s 9.0084e-3 1 1. 28. 1 16. 2. 1 1.0
    2430402 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630402 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
```

```
    2830402 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505502 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    8200007 300 2 3s 3.2813e-2 1 7s
    t
end
=keno5
9974 shipping cask with u-235 sphere (5.5307 cm)
read param
tme=1000
lib=4
run=yes
plt=yes
gen=300
npg=333
end param
read mixt
mix=1 9223501 9.0084e-3
100101 4.2414e-2 801601 3.9223e-2
mix=2 801603 3.7141e-3 100103 7.4282e-3 601203 4.4569e-3
mix=3 601202 3.1691e-4 2430402 1.6471e-2 2505502 1.7321e-3 2630402
      6.036e-2 2830402 6.4834e-3 1400002 1.694e-3
mix=4 8200007 3.2813e-2
mix=5 13027 6.2e-3
mix=6 801603 3.3369e-2 100103 6.6737e-2
mix=7 6 1.e-15
end mixt
read geom
unit 1
com='5.5307 cm sphere and primary containment'
cylinder 1 1.0 6.571 2p14.153
cylinder 3 1.0 7.144 14.153 -14.727
cylinder 0 1.0 7.702 14.153 -14.727
cylinder 3 1.0 8.414 14.153 -14.727
cylinder 0 1.0 9.627 14.153 -14.727
cylinder 3 1.0 10.198 14.153 -14.727
cylinder 4 1.0 13.018 14.153 -14.727
cylinder 2 1.0 28.26 14.153 -14.727
cuboid   7 1 4p28.26 14.153 -14.727
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.49 0.0
cylinder 0 1.0 7.702 3.49 0.0
cylinder 3 1.0 8.414 3.49 0.0
cylinder 0 1.0 9.627 3.49 0.0
cylinder 3 1.0 10.198 3.49 0.0
cylinder 4 1.0 13.018 3.49 0.0
cylinder 2 1.0 28.26 3.49 0.0
cuboid   7 1.0 4p28.26 3.49 0.0
unit 3
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0
cylinder 0 1.0 4.763 4.445 0.0
cylinder 5 1.0 7.702 4.445 0.0
cylinder 0 1.0 7.702 4.66 0.0
cylinder 3 1.0 8.414 4.66 0.0
cylinder 0 1.0 9.627 4.66 0.0
```

```
cylinder 3 1.0 10.198 4.66 0.0
cylinder 4 1.0 13.018 4.66 0.0
cylinder 2 1.0 28.26 4.66 0.0
cuboid   7 1.0 4p28.26 4.66 0.0
unit 4
com='secondary containment top'
cylinder 3 1.0 9.042 3.49 0.0
cylinder 0 1.0 9.627 3.49 0.0
cylinder 3 1.0 10.198 3.49 0.0
cylinder 4 1.0 13.018 3.49 0.0
cylinder 2 1.0 28.26 3.49 0.0
cuboid   7 1.0 4p28.26 3.49 0.0
unit 5
com='scv nut and lead top plate'
cylinder 3 1.0 3.175 1.29 0.0
cylinder 0 1.0 9.627 1.29 0.0
cylinder 3 1.0 10.198 1.88 0.0
cylinder 4 1.0 13.018 5.037 0.0
cylinder 2 1.0 28.26 18.527 0.0
cuboid   7 1.0 4p28.26 18.527 0.0
unit 6
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.96
cylinder 3 1.0 5.715 0.0 -0.96
cylinder 0 1.0 7.702 0.0 -0.96
cylinder 5 1.0 7.702 0.0 -4.77
cylinder 3 1.0 8.414 0.0 -5.48
cylinder 0 1.0 9.627 0.0 -5.48
cylinder 3 1.0 10.198 0.0 -5.48
cylinder 4 1.0 13.018 0.0 -5.48
cylinder 2 1.0 28.26 0.0 -5.48
cuboid   7 1.0 4p28.26 0.0 -5.48
unit 7
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.97
cylinder 3 1.0 7.065 0.0 -0.97
cylinder 0 1.0 9.627 0.0 -0.97
cylinder 3 1.0 10.198 0.0 -1.542
cylinder 4 1.0 13.018 0.0 -4.717
cylinder 2 1.0 28.26 0.0 -18.367
cuboid   7 1.0 4p28.26 0.0 -18.367
unit 8
com='complete cask'
array 1 3*0.0
cuboid 0 1.0 56.52 0. 56.52 0. 82.894 0.
unit 9
com='empty cell'
cuboid 0 1.0 4p28.26 82.894 0.
unit 10
com='add water reflector'
array 2 3*0.0
cuboid 6 1.0 492.16 -40. 492.16 -40. 371.576 -40.
end geom
read array
ara=1 nux=1 nuy=1 nuz=7 fill 7 6 1 2 3 4 5 end fill
ara=2 nux=8 nuy=8 nuz=4 fill 6r9 250r8 end fill
```

```
end array
end data
end
```

8. 9975 with $^{235}UO_2$/water dispersion, 8 x 8 x 4 array.

```
=ajax
1$$ 1 e t
2$$ 71 11 e t
3$$ 92235 1001 8016 24304 26304 28304 25055 14000 6012 13027
    82000 e t
end
=bonami
0$$ 1 e
1$$ 2 7 13 0 0 5 e t
3$$ 3r1 6r2 3 3r4 e
4$$ 92235 8016 1001 24304 26304 28304 25055 14000 6012
    82000 8016 1001 6012 e
5** 2.3354e-3 3.4887e-2 6.0432e-2 1.6471e-2
    6.036e-2 6.4834e-3 1.7321e-3 1.694e-3 3.1691e-4 3.2813e-2
    3.7141e-3 7.4282e-3 4.4569e-3 e
6$$ 1 2 4 2 4 3 4 e
7**   6.571 7.144 7.702 8.414 9.525 10.795 30.795 e
8** 7r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 14 a8 6 e
t
2$$ 9223501 801603 100103 601203 2430402 2630402 2830402
    2505502 1400002 601202 13027 8200006 100101 801601 e
3** 9223501 300 2 3s 2.3354e-3 1 1. 468. 1 16. 49. 1 1.0
    2430402 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630402 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
    2830402 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505502 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    8200006 300 2 3s 3.2813e-2 1 7s
    t
end
=keno5
9975 shipping cask with u-235 soln
read param
tme=1000
lib=4
run=yes
plt=yes
gen=1200
npg=333
end param
read mixt
mix=1 9223501 2.3354e-3
100101 6.0432e-2 801601 3.4887e-2
mix=2 801603 3.7141e-3 100103 7.4282e-3 601203 4.4569e-3
mix=3 601202 3.1691e-4 2430402 1.6471e-2 2505502 1.7321e-3 2630402
      6.036e-2 2830402 6.4834e-3 1400002 1.694e-3
```

```
mix=4 8200006 3.2813e-2
mix=5 13027 6.2e-3
mix=6 13027 6.026e-2
mix=7 100103 6.6737e-2 801603 3.3369e-2
mix=8 7 1.e-15
end mixt
read geom
unit 1
com='5.2429 cm sphere and stretched primary containment'
cylinder 1 1.0 6.571 2p20.503
cylinder 3 1.0 7.144 20.503 -21.077
cylinder 0 1.0 7.702 20.503 -21.077
cylinder 3 1.0 8.414 20.503 -21.077
cylinder 0 1.0 9.525 20.503 -21.077
cylinder 4 1.0 10.795 20.503 -21.077
cylinder 2 1.0 23.18 20.503 -21.077
cuboid   8 1 4p23.18 20.503 -21.077
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.493 0.0
cylinder 0 1.0 7.702 3.493 0.0
cylinder 3 1.0 8.414 3.493 0.0
cylinder 0 1.0 9.525 3.493 0.0
cylinder 4 1.0 10.795 3.493 0.0
cylinder 2 1.0 23.18 3.493 0.0
cuboid   8 1.0 4p23.18 3.493 0.0
unit 3
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0
cylinder 0 1.0 4.763 4.445 0.0
cylinder 5 1.0 7.702 4.445 0.0
cylinder 0 1.0 7.702 4.662 0.0
cylinder 3 1.0 8.414 4.662 0.0
cylinder 0 1.0 9.525 4.662 0.0
cylinder 4 1.0 10.795 4.662 0.0
cylinder 2 1.0 23.18 4.662 0.0
cuboid   8 1.0 4p23.18 4.662 0.0
unit 4
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0
cylinder 0 1.0 9.525 3.492 0.0
cylinder 4 1.0 10.795 3.492 0.0
cylinder 2 1.0 23.18 3.492 0.0
cuboid   8 1.0 4p23.18 3.492 0.0
unit 5
com='scv nut and al shield top'
cylinder 3 1.0 3.175 1.282 0.0
cylinder 0 1.0 9.525 1.282 0.0
cylinder 4 1.0 10.795 1.282 0.0
cylinder 6 1.0 10.795 2.552 0.0
cylinder 2 1.0 23.18 2.552 0.0
cuboid   8 1.0 4p23.18 2.552 0.0
unit 6
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965
cylinder 3 1.0 5.715 0.0 -0.965
```

```
cylinder 0 1.0 7.702 0.0 -0.965
cylinder 5 1.0 7.702 0.0 -4.775
cylinder 3 1.0 8.414 0.0 -5.055
cylinder 0 1.0 9.525 0.0 -5.055
cylinder 4 1.0 10.795 0.0 -5.055
cylinder 2 1.0 23.18 0.0 -5.055
cuboid   8 1.0 4p23.18 0.0 -5.055
unit 7
com='scv legs and bottom of lead shield'
cylinder 0 1.0 6.410 0.0 -0.965
cylinder 3 1.0 7.065 0.0 -0.965
cylinder 0 1.0 9.525 0.0 -0.965
cylinder 4 1.0 10.795 0.0 -2.235
cylinder 2 1.0 23.18 0.0 -2.235
cuboid   8 1.0 4p23.18 0.0 -2.235
unit 8
com='al top plate and water above'
cylinder 6 1.0 14.288 1.27 0.0
cylinder 2 1.0 23.18 13.97 0.0
cuboid   8 1.0 4p23.18 13.97 0.0
unit 9
com='al bottom plate and water under'
cylinder 6 1.0 14.288 0.0 -1.27
cylinder 2 1.0 23.18 0.0 -8.89
cuboid   8 1.0 4p23.18 0.0 -8.89
unit 10
com='complete cask'
array 1 3*0.0
cuboid 0 1.0 46.36 0. 46.36 0. 85.929 0.
unit 11
com='empty unit'
cuboid 0 1.0 4p23.18 85.929 0.
unit 12
com='add water reflector'
array 2 3*0.0
cuboid 7 1.0
end geom
read array
ara=1 nux=1 nuy=1 nuz=9 fill 9 7 6 1 2 3 4 5 8 end fill
ara=2 nux=8 nuy=8 nuz=4 fill 6r11 250r10 end fill
end array
end data
end
```

9. 9972 with Pu-239 metal, flooded PCV, 8 x 8 x 4 array.

```
=ajax
1$$ 1 e t
2$$ 71 10 e t
3$$ 94239 1001 8016 24304 26304 28304 25055 14000 6012 13027 e t
end
=bonami
0$$ 1 e
1$$ 2 4 12 0 0 5 e t
3$$ 1 2r2 6r3 3r4 e
4$$ 94239 8016 1001 24304 26304 28304 25055 14000 6012 6012 1001 8016 e
5** 4.9980e-2 3.3369e-2 6.6737e-2 1.6471e-2 6.036e-2 6.4834e-3
    1.7321e-3 1.694e-3 3.1691e-4  4.4569e-3 7.4282e-3 3.7141e-3 e
6$$ 1 2 3 4 e
7** 3.6376 6.4891 7.144 27.144 e
8** 4r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 13 a8 5 e
t
2$$ 9423901 801604 100104 2430403 2630403 2830403 2505503 1400003
    601203 13027 601204 100102 801602 e
3** 9423901 300 2 3s 4.9980e-2 1 7s
    2430403 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630403 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
    2830403 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505503 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    t
end
=keno5
9972 shipping cask with pu-239 metal sphere (3.6376 cm)
read param
tme=10000
lib=4
run=yes
plt=yes
gen=1200
npg=330
end param
read mixt
sct=3
mix=1 9423901 4.9980e-2
mix=2 601204 4.4569e-3 100104 7.4282e-3 801604 3.7141e-3
mix=3 601203 3.1691e-4 2430403 1.6471e-2 2505503 1.7321e-3 2630403
      6.036e-2 2830403 6.4834e-3 1400003 1.694e-3
mix=4 13027 6.0262e-2
mix=5 100102 6.6737e-2 801602 3.3369e-2
end mixt
read geom
unit 1
com='metal sphere and primary containment'
sphere   1 1.0 3.6376 origin 8.75 -8.75 10.398
cylinder 5 1.0 6.4891 2p14.153 origin 8.08 -8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 -8.08
```

```
cylinder 2 1.0 19.37 14.153 -14.727 origin 2.687 -2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   0 1 4p23.30 14.153 -14.727
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   0 1.0 4p23.30 3.492 0.0
unit 3
com='primary containment nut'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.455 1.283 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 1.283 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 1.283 0.0
cylinder 3 1.0 23.30 1.283 0.0
cuboid   0 1.0 4p23.30 1.283 0.0
unit 4
com='aluminum top plate'
cylinder 4 1 11.70 1.27 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 1.27 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   0 1.0 4p23.30 1.27 0.0
unit 5
com='pcv locking unit'
cylinder 0 1.0 5.113 0.966 0.0 origin 8.08 -8.08
cylinder 3 1.0 5.715 0.966 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.144 0.966 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 0.966 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 0.966 0.0
cylinder 3 1.0 23.30 0.966 0.0
cuboid   0 1.0 4p23.30 0.966 0.0
unit 6
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 1.27 -27.820 origin 2.687 -2.687
cylinder 0 1.0 23.18 1.27 -30.677
cylinder 3 1.0 23.30 1.27 -30.798
cuboid   0 1.0 4p23.30 1.27 -30.798
unit 8
com='metal sphere and primary containment'
sphere   1 1.0 3.6376 origin 8.75 -8.75 -10.398
cylinder 5 1.0 6.4891 2p14.153 origin 8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 -8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin 2.687 -2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   0 1.0 4p23.30 14.727 -14.153
unit 9
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 29.090 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 31.947 0.0
```

```
cylinder 3 1.0 23.30 32.068 0.0
cuboid   0 1.0 4p23.30 32.068 0.0
unit 10
com='metal sphere and primary containment'
sphere   1 1.0 3.6376 origin -8.75 -8.75 10.398
cylinder 5 1.0 6.4891 2p14.153 origin -8.08 -8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 -8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin -2.687 -2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   0 1 4p23.30 14.153 -14.727
unit 11
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   0 1.0 4p23.30 3.492 0.0
unit 12
com='primary containment nut'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.455 1.283 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 1.283 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 1.283 0.0
cylinder 3 1.0 23.30 1.283 0.0
cuboid   0 1.0 4p23.30 1.283 0.0
unit 13
com='aluminum top plate'
cylinder 4 1 11.70 1.27 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 1.27 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   0 1.0 4p23.30 1.27 0.0
unit 14
com='pcv locking unit'
cylinder 0 1.0 5.113 0.966 0.0 origin -8.08 -8.08
cylinder 3 1.0 5.715 0.966 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.144 0.966 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 0.966 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 0.966 0.0
cylinder 3 1.0 23.30 0.966 0.0
cuboid   0 1.0 4p23.30 0.966 0.0
unit 15
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 1.27 -27.820 origin -2.687 -2.687
cylinder 0 1.0 23.18 1.27 -30.677
cylinder 3 1.0 23.30 1.27 -30.798
cuboid   0 1.0 4p23.30 1.27 -30.798
unit 16
com='metal sphere and primary containment'
sphere   1 1.0 3.6376 origin -8.75 -8.75 -10.398
cylinder 5 1.0 6.4891 2p14.153 origin -8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 -8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin -2.687 -2.687
cylinder 0 1.0 23.18 14.727 -14.153
```

```
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   0 1.0 4p23.30 14.727 -14.153
unit 17
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 29.090 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 31.947 0.0
cylinder 3 1.0 23.30 32.068 0.0
cuboid   0 1.0 4p23.30 32.068 0.0
unit 19
com='metal sphere and primary containment'
sphere   1 1.0 3.6376 origin 8.75 8.75 10.398
cylinder 5 1.0 6.4891 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin 2.687 2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   0 1 4p23.30 14.153 -14.727
unit 20
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   0 1.0 4p23.30 3.492 0.0
unit 21
com='primary containment nut'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 8.08
cylinder 0 1.0 7.455 1.283 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 1.283 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 1.283 0.0
cylinder 3 1.0 23.30 1.283 0.0
cuboid   0 1.0 4p23.30 1.283 0.0
unit 22
com='aluminum top plate'
cylinder 4 1 11.70 1.27 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 1.27 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   0 1.0 4p23.30 1.27 0.0
unit 23
com='pcv locking unit'
cylinder 0 1.0 5.113 0.966 0.0 origin 8.08 8.08
cylinder 3 1.0 5.715 0.966 0.0 origin 8.08 8.08
cylinder 0 1.0 7.144 0.966 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 0.966 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 0.966 0.0
cylinder 3 1.0 23.30 0.966 0.0
cuboid   0 1.0 4p23.30 0.966 0.0
unit 24
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 1.27 -27.820 origin 2.687 2.687
cylinder 0 1.0 23.18 1.27 -30.677
cylinder 3 1.0 23.30 1.27 -30.798
cuboid   0 1.0 4p23.30 1.27 -30.798
```

```
unit 25
com='metal sphere and primary containment'
sphere   1 1.0 3.6376 origin 8.75 8.75 -10.398
cylinder 5 1.0 6.4891 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin 2.687 2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   0 1.0 4p23.30 14.727 -14.153
unit 26
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 29.090 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 31.947 0.0
cylinder 3 1.0 23.30 32.068 0.0
cuboid   0 1.0 4p23.30 32.068 0.0
unit 28
com='metal sphere and primary containment'
sphere   1 1.0 3.6376 origin -8.75 8.75 10.398
cylinder 5 1.0 6.4891 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin -2.687 2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   0 1 4p23.30 14.153 -14.727
unit 29
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   0 1.0 4p23.30 3.492 0.0
unit 30
com='primary containment nut'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 8.08
cylinder 0 1.0 7.455 1.283 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 1.283 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 1.283 0.0
cylinder 3 1.0 23.30 1.283 0.0
cuboid   0 1.0 4p23.30 1.283 0.0
unit 31
com='aluminum top plate'
cylinder 4 1 11.70 1.27 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 1.27 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 1.27 0.0
cylinder 3 1.0 23.30 1.27 0.0
cuboid   0 1.0 4p23.30 1.27 0.0
unit 32
com='pcv locking unit'
cylinder 0 1.0 5.113 0.966 0.0 origin -8.08 8.08
cylinder 3 1.0 5.715 0.966 0.0 origin -8.08 8.08
cylinder 0 1.0 7.144 0.966 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 0.966 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 0.966 0.0
cylinder 3 1.0 23.30 0.966 0.0
cuboid   0 1.0 4p23.30 0.966 0.0
```

```
unit 33
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 1.27 -27.820 origin -2.687 2.687
cylinder 0 1.0 23.18 1.27 -30.677
cylinder 3 1.0 23.30 1.27 -30.798
cuboid   0 1.0 4p23.30 1.27 -30.798
unit 34
com='metal sphere and primary containment'
sphere   1 1.0 3.6376 origin -8.75 8.75 -10.398
cylinder 5 1.0 6.4891 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin -2.687 2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   0 1.0 4p23.30 14.727 -14.153
unit 35
com='anti-rotation plate'
cylinder 4 1.0 11.70 1.27 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 29.090 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 31.947 0.0
cylinder 3 1.0 23.30 32.068 0.0
cuboid   0 1.0 4p23.30 32.068 0.0
unit 7
com='complete cask'
array 1 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 136.038 0.0
unit 18
com='complete cask'
array 2 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 136.038 0.0
unit 27
com='complete cask'
array 3 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 136.038 0.0
unit 36
com='complete cask'
array 4 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 136.038 0.0
unit 38
com='finite array 4 x 8 x 8'
array 5 3*0.0
cuboid 0 1.0 93.2 0. 93.2 0. 136.038 0.
end geom
read array
ara=1 nux=1 nuy=1 nuz=12 fill 6 5 1 2 3 4 4 3 2 8 5 9 end fill
ara=2 nux=1 nuy=1 nuz=12 fill 15 14 10 11 12 13 13 12 11 16 14 17 end
fill
ara=3 nux=1 nuy=1 nuz=12 fill 24 23 19 20 21 22 22 21 20 25 23 26 end
fill
ara=4 nux=1 nuy=1 nuz=12 fill 33 32 28 29 30 31 31 30 29 34 32 35 end
fill
ara=5 nux=2 nuy=2 nuz=1 fill 27 36 7 18 end fill
ara=6 nux=4 nuy=4 nuz=2 fill 32r38 end fill
end array
read plot
```

```
xul=0.
yul=94.
zul=56.381
xlr=94.
ylr=0.0
zlr=56.381
ttl='pu-239 sphere in 9972 damaged type 2'
uax=1.0
vdn=-1.0
nax=131
end plot
end data
end
```

10. 9972 with Pu-239 metal, flooded PCV, 8 x 8 x 4 array.

```
=ajax
1$$ 1 e t
2$$ 71 10 e t
3$$ 94239 1001 8016 24304 26304 28304 25055 14000 6012 13027 e t
end
=bonami
0$$ 1 e
1$$ 2 6 12 0 0 5 e t
3$$ 1 2r2 6r3 3r4 e
4$$ 94239 8016 1001 24304 26304 28304 25055 14000 6012 8016 1001 6012 e
5** 4.9980e-2 3.3369e-2 6.6737e-2 1.6471e-2
    6.036e-2 6.4834e-3 1.7321e-3 1.694e-3 3.1691e-4
    3.7141e-3 7.4282e-3 4.4569e-3 e
6$$ 1 2 3 2 3 4 e
7** 3.7550 6.571 7.144 7.702 8.414 19.37 e
8** 5r300. e t
end
=nitawl
0$$ 22 e
1$$ 0 13 a8 5 e
t
2$$ 9423901 801602 100102 2430403 2630403 2830403
    2505503 1400003 601203 13027 801606 100106 601206 e
3** 9423901 300 2 3s 4.9980e-2 1 7s
    2430403 300 2 3s 1.6471e-2 1 58. 6.9 1 56. 41.8 1 1.0
    2630403 300 2 3s 6.036e-2  1 58. 1.9 1 52. 1.2 1 1.0
    2830403 300 2 3s 6.4834e-3 1 56. 106.1 1 52. 10.9 1 1.0
    2505503 300 2 3s 1.7321e-3 1 58. 65.5 1 56. 397.3 1 1.0
    t
end
=keno5
9973 shipping cask with pu-239 soln sphere (3.75 cm)
read param
tme=1000
lib=4
run=yes
plt=yes
gen=1200
npg=333
```

```
end param
read mixt
mix=1 9423901 4.9980e-2
mix=2 801606 3.7141e-3 100106 7.4282e-3 601206 4.4569e-3
mix=3 601203 3.1691e-4 2430403 1.6471e-2 2505503 1.7321e-3 2630403
      6.036e-2 2830403 6.4834e-3 1400003 1.694e-3
mix=4 13027 6.0262e-2
mix=5 13027 6.2e-3 100102 6.0e-2 801602 3.0e-2
mix=6 100102 6.6737e-2 801602 3.3369e-2
mix=7 6 1.e-10
mix=8 13027 6.2e-3
end mixt
read geom
unit 1
com='3.7550 cm sphere and primary containment'
sphere   1 1.0 3.7550 origin 8.71 -8.71 10.398
cylinder 6 1.0 6.571 2p14.153 origin 8.08 -8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 -8.08
cylinder 0 1.0 7.702 14.153 -14.727 origin 8.08 -8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin 8.08 -8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin 2.687 -2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   7 1 4p23.30 14.153 -14.727
unit 2
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.702 3.492 0.0 origin 8.08 -8.08
cylinder 3 1.0 8.414 3.492 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 3
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 -8.08
cylinder 0 1.0 4.763 4.445 0.0 origin 8.08 -8.08
cylinder 5 1.0 7.702 4.445 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.702 4.661 0.0 origin 8.08 -8.08
cylinder 3 1.0 8.414 4.661 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 4.661 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 4
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 5
com='scv nut and al top plate'
cylinder 3 1.0 3.175 1.282 0.0 origin 8.08 -8.08
cylinder 0 1.0 8.414 1.282 0.0 origin 8.08 -8.08
cylinder 2 1.0 11.70 1.282 0.0 origin 8.08 -8.08
```

```
cylinder 4 1.0 11.70 2.552 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 6
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965 origin 8.08 -8.08
cylinder 3 1.0 5.715 0.0 -0.965 origin 8.08 -8.08
cylinder 0 1.0 7.702 0.0 -0.965 origin 8.08 -8.08
cylinder 8 1.0 7.702 0.0 -4.775 origin 8.08 -8.08
cylinder 3 1.0 8.414 0.0 -5.055 origin 8.08 -8.08
cylinder 2 1.0 19.37 0.0 -5.055 origin 2.687 -2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   7 1.0 4p23.30 0.0 -5.055
unit 7
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.965 origin 8.08 -8.08
cylinder 3 1.0 7.065 0.0 -0.965 origin 8.08 -8.08
cylinder 0 1.0 8.414 0.0 -0.965 origin 8.08 -8.08
cylinder 2 1.0 11.70 0.0 -0.965 origin 8.08 -8.08
cylinder 4 1.0 11.70 0.0 -2.235 origin 8.08 -8.08
cylinder 2 1.0 19.37 0.0 -16.498 origin 2.687 -2.687
cylinder 0 1.0 23.18 0.0 -19.355
cylinder 3 1.0 23.30 0.0 -19.355
cuboid   7 1.0 4p23.30 0.0 -19.355
unit 9
com='scv nut and al top plate'
cylinder 3 1.0 3.175 2.552 1.27 origin 8.08 -8.08
cylinder 0 1.0 8.414 2.552 1.27 origin 8.08 -8.08
cylinder 2 1.0 11.70 2.552 1.27 origin 8.08 -8.08
cylinder 4 1.0 11.70 2.552 0.   origin 8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0  origin 2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 10
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.661 3.378 origin 8.08 -8.08
cylinder 0 1.0 4.763 4.661 0.216 origin 8.08 -8.08
cylinder 5 1.0 7.702 4.661 0.216 origin 8.08 -8.08
cylinder 0 1.0 7.702 4.661 0.0   origin 8.08 -8.08
cylinder 3 1.0 8.414 4.661 0.0   origin 8.08 -8.08
cylinder 2 1.0 19.37 4.661 0.0   origin 2.687 -2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 11
com='3.7550 cm sphere and primary containment'
sphere   1 1.0 3.7550 origin 8.71 -8.71 -10.398
cylinder 6 1.0 6.571 2p14.153 origin 8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 -8.08
cylinder 0 1.0 7.702 14.727 -14.153 origin 8.08 -8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin 8.08 -8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin 2.687 -2.687
```

```
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   7 1 4p23.30 14.727 -14.153
unit 12
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.0 origin 8.08 -8.08
cylinder 3 1.0 5.715 0.965 0.0 origin 8.08 -8.08
cylinder 0 1.0 7.702 0.965 0.0 origin 8.08 -8.08
cylinder 8 1.0 7.702 4.775 0.0 origin 8.08 -8.08
cylinder 3 1.0 8.414 5.055 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 5.055 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 5.055 0.0
cylinder 3 1.0 23.30 5.055 0.0
cuboid   7 1.0 4p23.30 5.055 0.0
unit 13
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.965 0.0 origin 8.08 -8.08
cylinder 3 1.0 7.065 0.965 0.0 origin 8.08 -8.08
cylinder 0 1.0 8.414 0.965 0.0 origin 8.08 -8.08
cylinder 2 1.0 11.70 0.965 0.0 origin 8.08 -8.08
cylinder 4 1.0 11.70 2.235 0.0 origin 8.08 -8.08
cylinder 2 1.0 19.37 16.498 0.0 origin 2.687 -2.687
cylinder 0 1.0 23.18 19.355 0.0
cylinder 3 1.0 23.30 19.355 0.0
cuboid   7 1.0 4p23.30 19.355 0.0
unit 14
com='3.7550 cm sphere and primary containment'
sphere   1 1.0 3.7550 origin -8.71 -8.71 10.398
cylinder 6 1.0 6.571 2p14.153 origin -8.08 -8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 -8.08
cylinder 0 1.0 7.702 14.153 -14.727 origin -8.08 -8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin -8.08 -8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin -2.687 -2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   7 1 4p23.30 14.153 -14.727
unit 15
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.702 3.492 0.0 origin -8.08 -8.08
cylinder 3 1.0 8.414 3.492 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 16
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 -8.08
cylinder 0 1.0 4.763 4.445 0.0 origin -8.08 -8.08
cylinder 5 1.0 7.702 4.445 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.702 4.661 0.0 origin -8.08 -8.08
cylinder 3 1.0 8.414 4.661 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 4.661 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
```

```
unit 17
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 18
com='scv nut and al top plate'
cylinder 3 1.0 3.175 1.282 0.0 origin -8.08 -8.08
cylinder 0 1.0 8.414 1.282 0.0 origin -8.08 -8.08
cylinder 2 1.0 11.70 1.282 0.0 origin -8.08 -8.08
cylinder 4 1.0 11.70 2.552 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 19
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965 origin -8.08 -8.08
cylinder 3 1.0 5.715 0.0 -0.965 origin -8.08 -8.08
cylinder 0 1.0 7.702 0.0 -0.965 origin -8.08 -8.08
cylinder 8 1.0 7.702 0.0 -4.775 origin -8.08 -8.08
cylinder 3 1.0 8.414 0.0 -5.055 origin -8.08 -8.08
cylinder 2 1.0 19.37 0.0 -5.055 origin -2.687 -2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   7 1.0 4p23.30 0.0 -5.055
unit 20
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.965 origin -8.08 -8.08
cylinder 3 1.0 7.065 0.0 -0.965 origin -8.08 -8.08
cylinder 0 1.0 8.414 0.0 -0.965 origin -8.08 -8.08
cylinder 2 1.0 11.70 0.0 -0.965 origin -8.08 -8.08
cylinder 4 1.0 11.70 0.0 -2.235 origin -8.08 -8.08
cylinder 2 1.0 19.37 0.0 -16.498 origin -2.687 -2.687
cylinder 0 1.0 23.18 0.0 -19.355
cylinder 3 1.0 23.30 0.0 -19.355
cuboid   7 1.0 4p23.30 0.0 -19.355
unit 21
com='scv nut and al top plate'
cylinder 3 1.0 3.175 2.552 1.27 origin -8.08 -8.08
cylinder 0 1.0 8.414 2.552 1.27 origin -8.08 -8.08
cylinder 2 1.0 11.70 2.552 1.27 origin -8.08 -8.08
cylinder 4 1.0 11.70 2.552 0.   origin -8.08 -8.08
cylinder 2 1.0 19.37 2.552 0.0  origin -2.687 -2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 22
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.661 3.378 origin -8.08 -8.08
cylinder 0 1.0 4.763 4.661 0.216 origin -8.08 -8.08
cylinder 5 1.0 7.702 4.661 0.216 origin -8.08 -8.08
cylinder 0 1.0 7.702 4.661 0.0   origin -8.08 -8.08
cylinder 3 1.0 8.414 4.661 0.0   origin -8.08 -8.08
```

```
cylinder 2 1.0 19.37 4.661 0.0   origin -2.687 -2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 23
com='3.7550 cm sphere and primary containment'
sphere   1 1.0 3.7550 origin -8.71 -8.71 -10.398
cylinder 6 1.0 6.571 2p14.153 origin -8.08 -8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 -8.08
cylinder 0 1.0 7.702 14.727 -14.153 origin -8.08 -8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin -8.08 -8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin -2.687 -2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   7 1 4p23.30 14.727 -14.153
unit 24
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.0 origin -8.08 -8.08
cylinder 3 1.0 5.715 0.965 0.0 origin -8.08 -8.08
cylinder 0 1.0 7.702 0.965 0.0 origin -8.08 -8.08
cylinder 8 1.0 7.702 4.775 0.0 origin -8.08 -8.08
cylinder 3 1.0 8.414 5.055 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 5.055 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 5.055 0.0
cylinder 3 1.0 23.30 5.055 0.0
cuboid   7 1.0 4p23.30 5.055 0.0
unit 25
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.965 0.0 origin -8.08 -8.08
cylinder 3 1.0 7.065 0.965 0.0 origin -8.08 -8.08
cylinder 0 1.0 8.414 0.965 0.0 origin -8.08 -8.08
cylinder 2 1.0 11.70 0.965 0.0 origin -8.08 -8.08
cylinder 4 1.0 11.70 2.235 0.0 origin -8.08 -8.08
cylinder 2 1.0 19.37 16.498 0.0 origin -2.687 -2.687
cylinder 0 1.0 23.18 19.355 0.0
cylinder 3 1.0 23.30 19.355 0.0
cuboid   7 1.0 4p23.30 19.355 0.0
unit 27
com='3.7550 cm sphere and primary containment'
sphere   1 1.0 3.7550 origin 8.71 8.71 10.398
cylinder 6 1.0 6.571 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin 8.08 8.08
cylinder 0 1.0 7.702 14.153 -14.727 origin 8.08 8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin 8.08 8.08
cylinder 2 1.0 19.37 14.153 -14.727 origin 2.687 2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   7 1 4p23.30 14.153 -14.727
unit 28
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin 8.08 8.08
cylinder 0 1.0 7.702 3.492 0.0 origin 8.08 8.08
cylinder 3 1.0 8.414 3.492 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
```

```
cuboid   7 1.0 4p23.30 3.492 0.0
unit 29
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin 8.08 8.08
cylinder 0 1.0 4.763 4.445 0.0 origin 8.08 8.08
cylinder 5 1.0 7.702 4.445 0.0 origin 8.08 8.08
cylinder 0 1.0 7.702 4.661 0.0 origin 8.08 8.08
cylinder 3 1.0 8.414 4.661 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 4.661 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 30
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 31
com='scv nut and al top plate'
cylinder 3 1.0 3.175 1.282 0.0 origin 8.08 8.08
cylinder 0 1.0 8.414 1.282 0.0 origin 8.08 8.08
cylinder 2 1.0 11.70 1.282 0.0 origin 8.08 8.08
cylinder 4 1.0 11.70 2.552 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 32
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965 origin 8.08 8.08
cylinder 3 1.0 5.715 0.0 -0.965 origin 8.08 8.08
cylinder 0 1.0 7.702 0.0 -0.965 origin 8.08 8.08
cylinder 8 1.0 7.702 0.0 -4.775 origin 8.08 8.08
cylinder 3 1.0 8.414 0.0 -5.055 origin 8.08 8.08
cylinder 2 1.0 19.37 0.0 -5.055 origin 2.687 2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   7 1.0 4p23.30 0.0 -5.055
unit 33
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.965 origin 8.08 8.08
cylinder 3 1.0 7.065 0.0 -0.965 origin 8.08 8.08
cylinder 0 1.0 8.414 0.0 -0.965 origin 8.08 8.08
cylinder 2 1.0 11.70 0.0 -0.965 origin 8.08 8.08
cylinder 4 1.0 11.70 0.0 -2.235 origin 8.08 8.08
cylinder 2 1.0 19.37 0.0 -16.498 origin 2.687 2.687
cylinder 0 1.0 23.18 0.0 -19.355
cylinder 3 1.0 23.30 0.0 -19.355
cuboid   7 1.0 4p23.30 0.0 -19.355
unit 34
com='scv nut and al top plate'
cylinder 3 1.0 3.175 2.552 1.27 origin 8.08 8.08
cylinder 0 1.0 8.414 2.552 1.27 origin 8.08 8.08
cylinder 2 1.0 11.70 2.552 1.27 origin 8.08 8.08
```

```
cylinder 4 1.0 11.70 2.552 0.   origin 8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0  origin 2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 35
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.661 3.378 origin 8.08 8.08
cylinder 0 1.0 4.763 4.661 0.216 origin 8.08 8.08
cylinder 5 1.0 7.702 4.661 0.216 origin 8.08 8.08
cylinder 0 1.0 7.702 4.661 0.0   origin 8.08 8.08
cylinder 3 1.0 8.414 4.661 0.0   origin 8.08 8.08
cylinder 2 1.0 19.37 4.661 0.0   origin 2.687 2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 36
com='3.7550 cm sphere and primary containment'
sphere   1 1.0 3.7550 origin 8.71 8.71 -10.398
cylinder 6 1.0 6.571 2p14.153 origin 8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin 8.08 8.08
cylinder 0 1.0 7.702 14.727 -14.153 origin 8.08 8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin 8.08 8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin 2.687 2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   7 1 4p23.30 14.727 -14.153
unit 37
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.0 origin 8.08 8.08
cylinder 3 1.0 5.715 0.965 0.0 origin 8.08 8.08
cylinder 0 1.0 7.702 0.965 0.0 origin 8.08 8.08
cylinder 8 1.0 7.702 4.775 0.0 origin 8.08 8.08
cylinder 3 1.0 8.414 5.055 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 5.055 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 5.055 0.0
cylinder 3 1.0 23.30 5.055 0.0
cuboid   7 1.0 4p23.30 5.055 0.0
unit 38
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.965 0.0 origin 8.08 8.08
cylinder 3 1.0 7.065 0.965 0.0 origin 8.08 8.08
cylinder 0 1.0 8.414 0.965 0.0 origin 8.08 8.08
cylinder 2 1.0 11.70 0.965 0.0 origin 8.08 8.08
cylinder 4 1.0 11.70 2.235 0.0 origin 8.08 8.08
cylinder 2 1.0 19.37 16.498 0.0 origin 2.687 2.687
cylinder 0 1.0 23.18 19.355 0.0
cylinder 3 1.0 23.30 19.355 0.0
cuboid   7 1.0 4p23.30 19.355 0.0
unit 40
com='3.7550 cm sphere and primary containment'
sphere   1 1.0 3.7550 origin -8.71 8.71 10.398
cylinder 6 1.0 6.571 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.153 -14.727 origin -8.08 8.08
cylinder 0 1.0 7.702 14.153 -14.727 origin -8.08 8.08
cylinder 3 1.0 8.414 14.153 -14.727 origin -8.08 8.08
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```
cylinder 2 1.0 19.37 14.153 -14.727 origin -2.687 2.687
cylinder 0 1.0 23.18 14.153 -14.727
cylinder 3 1.0 23.30 14.153 -14.727
cuboid   7 1 4p23.30 14.153 -14.727
unit 41
com='top of primary containment'
cylinder 3 1.0 7.455 3.492 0.0 origin -8.08 8.08
cylinder 0 1.0 7.702 3.492 0.0 origin -8.08 8.08
cylinder 3 1.0 8.414 3.492 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 42
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 1.283 0.0 origin -8.08 8.08
cylinder 0 1.0 4.763 4.445 0.0 origin -8.08 8.08
cylinder 5 1.0 7.702 4.445 0.0 origin -8.08 8.08
cylinder 0 1.0 7.702 4.661 0.0 origin -8.08 8.08
cylinder 3 1.0 8.414 4.661 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 4.661 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 43
com='secondary containment top'
cylinder 3 1.0 9.042 3.492 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 3.492 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 3.492 0.0
cylinder 3 1.0 23.30 3.492 0.0
cuboid   7 1.0 4p23.30 3.492 0.0
unit 44
com='scv nut and al top plate'
cylinder 3 1.0 3.175 1.282 0.0 origin -8.08 8.08
cylinder 0 1.0 8.414 1.282 0.0 origin -8.08 8.08
cylinder 2 1.0 11.70 1.282 0.0 origin -8.08 8.08
cylinder 4 1.0 11.70 2.552 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 45
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.0 -0.965 origin -8.08 8.08
cylinder 3 1.0 5.715 0.0 -0.965 origin -8.08 8.08
cylinder 0 1.0 7.702 0.0 -0.965 origin -8.08 8.08
cylinder 8 1.0 7.702 0.0 -4.775 origin -8.08 8.08
cylinder 3 1.0 8.414 0.0 -5.055 origin -8.08 8.08
cylinder 2 1.0 19.37 0.0 -5.055 origin -2.687 2.687
cylinder 0 1.0 23.18 0.0 -5.055
cylinder 3 1.0 23.30 0.0 -5.055
cuboid   7 1.0 4p23.30 0.0 -5.055
unit 46
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.0 -0.965 origin -8.08 8.08
cylinder 3 1.0 7.065 0.0 -0.965 origin -8.08 8.08
```

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cylinder 0 1.0 8.414 0.0 -0.965 origin -8.08 8.08
cylinder 2 1.0 11.70 0.0 -0.965 origin -8.08 8.08
cylinder 4 1.0 11.70 0.0 -2.235 origin -8.08 8.08
cylinder 2 1.0 19.37 0.0 -16.498 origin -2.687 2.687
cylinder 0 1.0 23.18 0.0 -19.355
cylinder 3 1.0 23.30 0.0 -19.355
cuboid   7 1.0 4p23.30 0.0 -19.355
unit 47
com='scv nut and al top plate'
cylinder 3 1.0 3.175 2.552 1.27 origin -8.08 8.08
cylinder 0 1.0 8.414 2.552 1.27 origin -8.08 8.08
cylinder 2 1.0 11.70 2.552 1.27 origin -8.08 8.08
cylinder 4 1.0 11.70 2.552 0.   origin -8.08 8.08
cylinder 2 1.0 19.37 2.552 0.0  origin -2.687 2.687
cylinder 0 1.0 23.18 2.552 0.0
cylinder 3 1.0 23.30 2.552 0.0
cuboid   7 1.0 4p23.30 2.552 0.0
unit 48
com='primary containment nut and al honeycomb'
cylinder 3 1.0 3.175 4.661 3.378 origin -8.08 8.08
cylinder 0 1.0 4.763 4.661 0.216 origin -8.08 8.08
cylinder 5 1.0 7.702 4.661 0.216 origin -8.08 8.08
cylinder 0 1.0 7.702 4.661 0.0   origin -8.08 8.08
cylinder 3 1.0 8.414 4.661 0.0   origin -8.08 8.08
cylinder 2 1.0 19.37 4.661 0.0   origin -2.687 2.687
cylinder 0 1.0 23.18 4.661 0.0
cylinder 3 1.0 23.30 4.661 0.0
cuboid   7 1.0 4p23.30 4.661 0.0
unit 49
com='3.7550 cm sphere and primary containment'
sphere   1 1.0 3.7550 origin -8.71 8.71 -10.398
cylinder 6 1.0 6.571 2p14.153 origin -8.08 8.08
cylinder 3 1.0 7.144 14.727 -14.153 origin -8.08 8.08
cylinder 0 1.0 7.702 14.727 -14.153 origin -8.08 8.08
cylinder 3 1.0 8.414 14.727 -14.153 origin -8.08 8.08
cylinder 2 1.0 19.37 14.727 -14.153 origin -2.687 2.687
cylinder 0 1.0 23.18 14.727 -14.153
cylinder 3 1.0 23.30 14.727 -14.153
cuboid   7 1 4p23.30 14.727 -14.153
unit 50
com='pcv legs, al honeycomb and scv bottom'
cylinder 0 1.0 5.113 0.965 0.0 origin -8.08 8.08
cylinder 3 1.0 5.715 0.965 0.0 origin -8.08 8.08
cylinder 0 1.0 7.702 0.965 0.0 origin -8.08 8.08
cylinder 8 1.0 7.702 4.775 0.0 origin -8.08 8.08
cylinder 3 1.0 8.414 5.055 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 5.055 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 5.055 0.0
cylinder 3 1.0 23.30 5.055 0.0
cuboid   7 1.0 4p23.30 5.055 0.0
unit 51
com='scv legs and anti-rotation plate'
cylinder 0 1.0 6.410 0.965 0.0 origin -8.08 8.08
cylinder 3 1.0 7.065 0.965 0.0 origin -8.08 8.08
cylinder 0 1.0 8.414 0.965 0.0 origin -8.08 8.08
cylinder 2 1.0 11.70 0.965 0.0 origin -8.08 8.08
```

```
cylinder 4 1.0 11.70 2.235 0.0 origin -8.08 8.08
cylinder 2 1.0 19.37 16.498 0.0 origin -2.687 2.687
cylinder 0 1.0 23.18 19.355 0.0
cylinder 3 1.0 23.30 19.355 0.0
cuboid   7 1.0 4p23.30 19.355 0.0
unit 8
com='containment vessels - top to top'
array 1 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 134.974 0.0
unit 26
com='containment vessels - top to top'
array 2 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 134.974 0.0
unit 39
com='containment vessels - top to top'
array 3 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 134.974 0.0
unit 52
com='containment vessels - top to top'
array 4 3*0.0
cuboid 0 1.0 46.60 0.0 46.60 0.0 134.974 0.0
unit 53
com='finite array 4 x 8 x 8'
array 5 3*0.0
cuboid 0 1.0 93.2  0. 93.2 0. 134.974 0.
end geom
read array
ara=1 nux=1 nuy=1 nuz=14 fill 7 6 1 2 3 4 5 9 4 10 2 11 12 13 end fill
ara=2 nux=1 nuy=1 nuz=14 fill 20 19 14 15 16 17 18 21 17 22 15 23 24 25
end fill
ara=3 nux=1 nuy=1 nuz=14 fill 33 32 27 28 29 30 31 34 30 35 28 36 37 38
end fill
ara=4 nux=1 nuy=1 nuz=14 fill 46 45 40 41 42 43 44 47 43 48 41 49 50 51
end fill
ara=5 nux=2 nuy=2 nuz=1 fill 39 52 8 26 end fill
ara=6 nux=4 nuy=4 nuz=2 fill 32r53 end fill
end array
read plot
xul=0.
yul=94.
zul=47.617.
xlr=94.
ylr=0.
zlr=47.617
ttl='3.7550 cm pu-239 sphere in 9973 damaged type 2'
uax=1.0
vdn=-1.0
nax=131
end plt1
xul=11.0
yul=19.37
zul=136.
xlr=82.
ylr=19.37
zlr=0.0
ttl='3.75 cm pu-239 sphere in 9973 damaged type 2'
```

APPENDIX B

ATOM DENSITY CALCULATIONS

Terms

ρ_m is the fissile metal density (19.05 g/cc for U-235, 19.84 g/cc for Pu-239)

ρ_{ox} is the fissile oxide density (10.96 g/cc for UO_2, 11.46 g/cc for PuO_2)

C is the concentration of fissile in a dispersion, g/cc

X is the concentration of water in a dispersion, g/cc

MW is the appropriate molecular weight

wtf is the weight fraction fissile in an oxide (.8802 for U-235, .8819 for Pu-239)

F, H, O, and Al are the fissile species, hydrogen, oxygen and aluminum atom densities, respectively

Molecular Weights:

U-235:	235.0439
Pu-239:	239.0522
O:	15.9994
H:	1.0079
235UO2:	267.0427
239PuO2:	271.0510
Al:	26.9815

Fissile Metal

$$F = \rho_m\,(g/cm^3)\left(\frac{mole}{MW_{fissile}(g)}\right)\left(\frac{0.60221\,atoms-cm^3}{mole-barn\cdot cm}\right)$$

Fissile Oxide

$$F = \frac{\rho_{ox}\,(g/cm^3)}{}\left(\frac{mole}{MW_{oxide}(g)}\right)\left(\frac{1\ mole\ fissile}{mole\ oxide}\right)\left(\frac{0.60221\,atoms-cm^3}{mole-barn\cdot cm}\right)$$

O=2*F

Fissile Metal/water dispersion

$$C = \frac{Fissile\ mass\ limit}{PCV\ volume}$$

$$F = \frac{C\,(g/cm^3)}{}\left(\frac{mole}{MW_{fissile}(g)}\right)\left(\frac{0.60221\,atoms-cm^3}{mole-barn\cdot cm}\right)$$

$$X = .99823\left(1-\frac{C}{\rho_m}\right)$$

$$H = \frac{X\,(g/cm^3)}{}\left(\frac{mole}{MW_{H_2O}(g)}\right)\left(\frac{2\ moles\ H}{mole\ H_2O}\right)\left(\frac{0.60221\,atoms-cm^3}{mole-barn\cdot cm}\right)$$

O=0.5*H

Fissile Oxide/water dispersion

$$C = \frac{Fissile\ mass\ limit/wtf}{PCV\ volume}$$

$$F = \frac{C\,(g/cm^3)}{}\left(\frac{mole}{MW_{oxide}(g)}\right)\left(\frac{mole\ fissile}{mole\ oxide}\right)\left(\frac{0.60221\,atoms-cm^3}{mole-barn\cdot cm}\right)$$

$$X = .99823\left(1-\frac{C}{\rho_{ox}}\right)$$

$$H = \frac{X\,(g/cm^3)}{}\left(\frac{mole}{MW_{H_2O}(g)}\right)\left(\frac{2\ moles\ H}{mole\ H_2O}\right)\left(\frac{0.60221\,atoms-cm^3}{mole-barn\cdot cm}\right)$$

O=0.5*H+2*F