CHAPTER 6
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FIGURES

TABLES

6. CRITICALITY EVALUATION

The GA-4 cask design provides criticality control to meet the Fissile Class I criticality performance requirements specified in Sections 71.55 and 71.57 of 10 CFR Part 71. The criticality control design ensures that the effective multiplication factor (k_{eff}) of the contained fuel is no greater than 0.95 for the most reactive configuration, including 2σ uncertainties and analytical bias. The design meets the Fissile Class I requirements for the following two conditions pertaining to criticality:

1. For normal conditions, an unlimited number of packages are to remain subcritical with optimum interspersed hydrogenous moderation. No water reflection necessary.

2. For hypothetical accident conditions, 250 packages are to remain subcritical in any arrangement, with optimum interspersed hydrogenous moderation and close reflection by water on all sides of the array.

6.1 Discussion and Results

Figure 6.1-1 shows the cross section of the GA-4 cask. The cask uses fixed B_4C pellets for criticality control. The cask fuel cavity structure consists of a steel cavity liner with a fuel support structure (FSS) in the center to provide the fixed poison absorber (B_4C) and to provide separation between the fuel assemblies loaded into the cask. As demonstrated by analysis in Chapter 2, the fuel support structure provides structural integrity to maintain the geometry for criticality control under hypothetical accident conditions.

The interactions between fuel assemblies are partially decoupled by the fuel support structure, which consists of solid boron carbide (B_4C) pellets enclosed in a stainless steel cruciform structure as shown in Figs. 6.1-1 and 6.1-2. Encasing the B_4C rods in the stainless steel structure prevents the B_4C from coming into contact with water. The steel structure also serves as a mild neutron absorber and physically separates the fuel assemblies, providing further reduction in reactivity.

The steel fuel cavity liner is a structural component and partially decouples the fuel assemblies neutronically from the depleted uranium (DU) shielding material and the other cask materials. The cavity liner partially decouples the interactions by reducing the number of thermal neutrons entering the DU shield and returning from the cask body due to reflection.

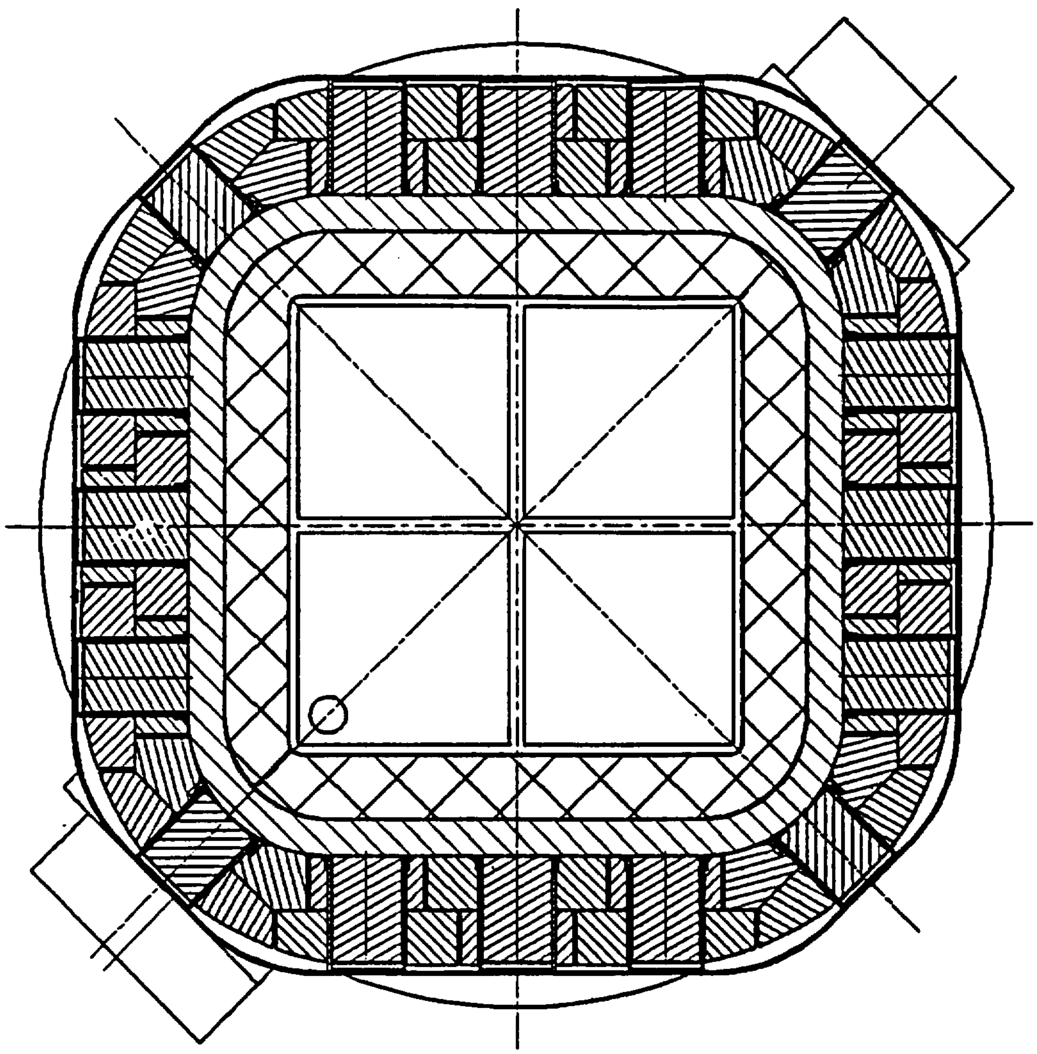

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Fig. 6.1-1. GA-4 legal weight truck cask cross section

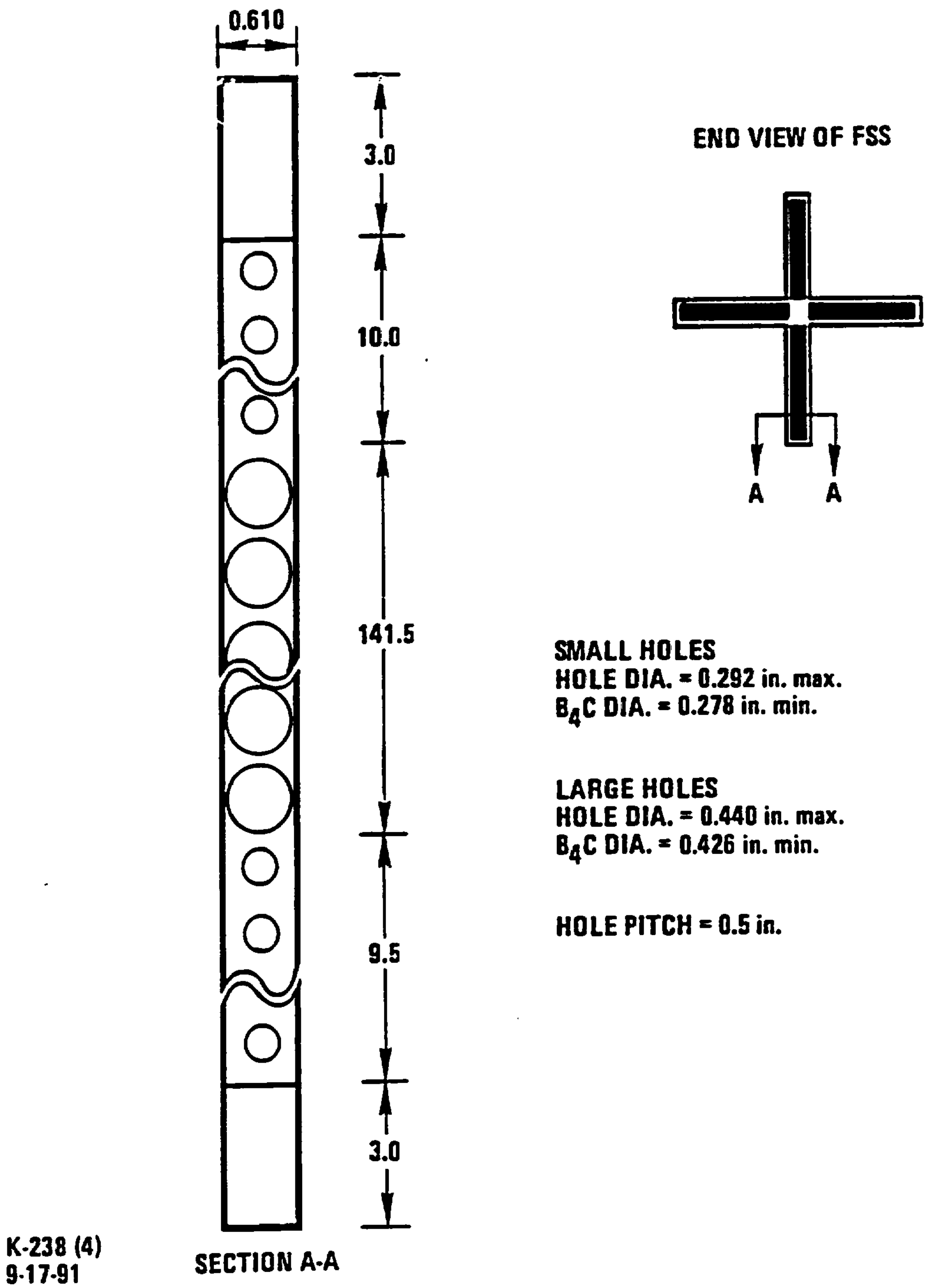

Fig. 6.1-2. GA-4 fuel support structure

Table 6.1-1 summarizes the criticality evaluation for normal and hypothetical accident conditions for the cask, showing that it meets the Fissile Class I criticality safety requirements. The containment criterion for both normal transport and hypothetical accident conditions as described in Chapter 4, "Containment" — is that the cask must be leaktight. The structural analysis in Chapter 2 shows that all structural criteria are met and there are no deformations that would affect the leaktightness of the seals. Therefore, the criticality analysis is based on the cask being watertight, allowing no water inleakage for either normal transport or hypothetical accident conditions. It is necessary to consider water inleakage only for a single undamaged package, in accordance with 10 CFR Part 71.55(b). The reactivity for the hypothetical accident conditions and the infinite array of casks under normal conditions of transport is much lower than for a single package with water in the cavity for normal transport. For this reason, the criticality analysis was performed for a single flooded package with close water reflection.

The criticality calculations assume the Westinghouse (W) 17 x 17 OFA fuel assembly because it is the most reactive fuel assembly allowed by the authorized contents. The calculations determine k_{eff} with the CSAS25 control module of SCALE-4.1 (Ref. 6.1-1) for various configurations and initial enrichments, including all uncertainties to assure criticality safety under all credible conditions.

The results of the evaluation demonstrate that the maximum k_{eff} — including statistical uncertainty and analytical bias — is 0.95 for the single undamaged package with water ingress.

TABLE 6.1-1 SUMMARY OF GA-4 CRITICALITY EVALUATION FISSILE CLASS I	
<u>Normal Conditions</u>	
Number of undamaged packages calculated to be subcritical	Infinite[a]
Optimum interspersed hydrogenous moderation[b]	Water
Closely reflected by water	Yes
Package size, cm^3	2.80×10^6
<u>Accident Conditions</u>	
Number of damaged packages calculated to be subcritical	250
Optimum interspersed hydrogenous moderation, full water reflection [a]	Water
Package size, cm^3	2.18×10^6
Transport index	N/A
[a]or single flooded package (most reactive configuration for GA-4 cask). [b]No water ingress assumed because cask is designed to be watertight.	

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6.2 Package Fuel Loading

The GA-4 cask is capable of transporting standard PWR fuel assemblies as intact assemblies. The fuel assemblies considered as design basis include the following:

GA-4 Cask (PWR Spent Fuels)

Westinghouse Electric, Standard	17 x 17
Westinghouse Electric, OFA	17 x 17
Westinghouse Electric, Vantage 5, H	17 x 17
Westinghouse Electric, Standard ZC	15 x 15
Westinghouse Electric, OFA	15 x 15
Westinghouse Electric, Standard ZCA	14 x 14
Westinghouse Electric, Standard ZCB	14 x 14
Westinghouse Electric, Mod	14 x 14
Westinghouse Electric, OFA	14 x 14
Babcock & Wilcox, Mark C	17 x 17
Babcock & Wilcox, Mark B, BZ, BGD	15 x 15
Combustion Engineering, St. Lucie	16 x 16
Combustion Engineering, Palisades	15 x 15
Combustion Engineering, Standard	14 x 14
Combustion Engineering, Fort Calhoun	14 x 14
Exxon Nuclear/ANF	17 x 17
Exxon Nuclear/ANF	15 x 15
Exxon Nuclear/ANF, CE	14 x 14
Exxon Nuclear/ANF, W	14 x 14

Table 6.2-1 lists the fuel parameters for the standard PWR fuel assemblies. The reference fuel chosen for the GA-4 cask criticality analysis is the W 17 x 17 OFA fuel assembly. The W 17 x 17 OFA assembly is used because, as demonstrated in Section 6.4, it is the most reactive assembly of those authorized to be shipped in the GA-4 cask.

TABLE 6.2-1
PARAMETERS FOR PWR ASSEMBLIES FOR SHIPMENT IN GA-4 CASK

Mfr.	Array	Version	Fuel Content (MTU)	Fuel Rods per Assembly	Pitch (cm)	Fuel o.d. (cm)	Clad o.d. (cm)
W	17x17	Std	0.464	264	1.25984	0.81915	0.94996
W	17x17	OFA	0.426	264	1.25984	0.784352	0.9144
W	17x17	Vant. 5, H	0.423	264	1.25984	0.784352	0.9144
W	15x15	Std/ZC	0.469	204	1.43002	0.929386	1.07188
W	15x15	OFA	0.463	204	1.43002	0.929386	1.07188
W	14x14	Std/ZCA	0.407	179	1.41224	0.933196	1.07188
W	14x14	Std/ZCB	0.407	179	1.41224	0.933196	1.07188
W	14x14	Model C	0.397	176	1.4732	0.96647	1.1176
W	14x14	OFA	0.358	179	1.41224	0.874776	1.016
B & W	17x17	Mark C	0.456	264	1.27508	0.820928	0.96266
B & W	15x15	Mark B, BZ, BGD	0.464	208	1.44272	0.936244	1.0922
CE	16x16	St. Lucie	0.39	224	1.28524	0.8255	0.97028
CE	15x15	Palisades	0.413	204	1.397	0.90932	1.06172
CE	14x14	Std/Gen.	0.386	176	1.4732	0.95631	1.1176
CE	14x14	Ft. Calhoun	0.376	176	1.4732	0.95631	1.1176
Exx/A	17x17	WE	0.401	264	1.25984	0.76962	0.9144
Exx/A	15x15	WE	0.432	204	1.43002	0.90551	1.07696
Exx/A	14x14	CE	0.381	176	1.4732	0.9398	1.1176
Exx/A	14x14	WE	0.379	179	1.41224	0.89027	1.07696

6.3 Model Specification

The following subsections describe the physical models and materials of the GA-4 cask used for input to the CSAS25 module of SCALE-4.1 (Ref. 6.1-1) to perform the criticality evaluation.

6.3.1 Description of Calculational Model

We modeled the cask with a square cross section because geometry limitations in KENO V.a of the CSAS25 module in SCALE-4.1 prevented modeling the exact cross section. This assumption is conservative because the slight increase of DU in the corners introduces additional fission reactions in the DU and also reflects more neutrons back into the system.

Two cask models were developed. The first cask model is a full-height and full-radial cross section of the cask. The second is a 1/4-radial and full-height cask model. Figure 6.3-1 illustrates the 1/4-radial cask model analysis. The W 17 x 17 OFA fuel assembly is modeled as a 17 x 17 array comprising (1) 264 fuel rods, including fuel, gap and cladding, and (2) 25 water holes. Figure 6.3-2 is a cross-sectional map of the fuel assembly as modeled. The assembly-to-assembly pitch is minimized (i.e., the assemblies are pushed to the center of the cask), to represent the most reactive configuration in the cask. Inclusion of the water holes is conservative as compared to modeling the entire 17 x 17 array filled with fuel. The B_4C is modeled with minimum pellet stack length and diameter in the center of the maximum diameter holes.

6.3.2 Package Regional Densities

The Oak Ridge National Laboratory (ORNL) SCALE code package (Ref. 6.1-1) contains a standard material data library for common elements, compounds, and mixtures. All the materials used for the cask analysis are available in this data library except for the neutron shield material. The polypropylene neutron shield material was created by combining its constituent elements in proportion to their number densities. The material data for the fuel assemblies were obtained from the DOE computerized database (Ref. 6.3-1).

Table 6.3-1 provides a complete list of all the relevant materials used for the criticality evaluation. The neutron shield material contains 1% by weight natural boron. To be conservative, however, we removed the boron from the neutron shield for the analysis. Also note that the neutron shield hydrogen atom density is higher than that of water; therefore, replacing the neutron shield with water would be slightly nonconservative.

FIGURE WITHHELD UNDER 10 CFR 2.390

Fig. 6.3-1. KENO Va. model of GA-4 cask

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1 = Fuel Rod
2 = Water Hole

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Fig. 6.3-2. Cross-section map of Westinghouse 17 x 17 OFA fuel assembly as modeled with KENO Va.

TABLE 6.3-1
MATERIAL PROPERTY DATA

Material	Density g/cm^3 (lb/in.^{3})	Element	Physical wt %	Modeled Atom Density (atoms/b-cm)
B_4C	2.346 (0.0847)	B-10 B-11 C	14.3 64.0 21.7	2.022E–2 8.207E–2 2.557E–2
XM-19 (SS-304)	7.92 0.286	Cr Mn Fe Ni	19.0 2.0 69.5 9.5	1.743E–2 1.736E–3 5.936E–2 7.721E–3
Water	1.0 (0.0361)	H O	11.1 88.9	6.675E–2 3.338E–2
Depleted uranium	19.05 (0.688)	U-235 U-238	0.3 99.7	1.464E–4 4.805E–2
Borated polypropylene	0.90 (0.0325)	O H B-10 B-11 C	4.44 13.83 0.185 0.815 80.72	1.504E–3 7.493E–2 0.0 0.0 3.645E–2
Fuel W 17 x 17 UO_2 2.9% enriched	10.36 (0.3741)	U-234 U-235 U-236 U-238 O	0.023 2.556 0.012 85.548 11.861	6.066E–6 6.786E–4 3.109E–6 2.243E–2 4.623E–2
Fuel W 17 x 17 UO_2 3.5% enriched	10.36 (0.3741)	U-234 U-235 U-236 U-238 O	0.027 3.085 0.014 85.019 11.854	7.321E–6 8.191E–4 3.752E–6 2.229E–2 4.623E–2
Fuel W 17 x 17 UO_2 4.5% enriched	10.358 (0.3741)	U-234 U-235 U-236 U-238 O	0.035 3.967 0.018 84.121 11.859	9.412E–6 1.053E–3 4.824E–6 2.205E–2 4.624E–2
Zircaloy	6.44 (0.2326)	Zr	100.0	4.252E–2

6.4 Criticality Calculations

This section describes the models used for the criticality analysis. The analyses were performed with the CSAS25 module of the SCALE system. A series of calculations were performed to determine the most reactive fuel and configuration. The most reactive fuel, as demonstrated by the analyses, is the Westinghouse 17 x 17 OFA assembly. The most reactive credible configuration is a single flooded undamaged cask with minimum assembly-to-assembly pitch.

6.4.1 Calculational Method

6.4.1.1 Computer Codes. The CSAS25 control module of SCALE-4.1 (Ref. 6.1-1) was used to calculate the effective multiplication factor (k_{eff}) of the fuel in the cask. The CSAS25 control module allows simplified data input to the functional modules BONAMI-S, NITAWL-S, and KENO V.a. These modules process the required cross sections and calculate the k_{eff} of the system. BONAMI-S performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL-S applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the k_{eff} of a three-dimensional system.

6.4.1.2 Physical and Nuclear Data. The physical and nuclear data required for the criticality analysis include the fuel assembly data and cross-section data as described below.

The physical data for the fuel assemblies are available in Report DOE/RW-0184 (Ref. 6.3-1). Table 6.4-1 reproduces the pertinent data for criticality analysis with the W 17 x 17 OFA fuel assembly.

The criticality analysis used the 27-group cross-section library (27BURNUPLIB) built into the SCALE system. ORNL used ENDF/B-IV data to develop this broad-group library specifically for criticality analysis of a wide variety of thermal systems.

6.4.1.3 Bases and Assumptions. The analytical results reported in Section 2.7 demonstrate that the cask containment boundary, fuel support structure, and cavity liner do not experience any distortion under hypothetical accident conditions. Therefore, for both normal and hypothetical accident conditions the cask geometries are identical except for the neutron shield and skin.

We modeled the cask with KENO V.a using the available geometry input. This option allows a model to be constructed that uses regular geometric shapes to define the material boundaries. The following conservative assumptions were also incorporated into the criticality calculations:

1. Omission of grid plates, spacers, and hardware in the fuel assembly.

TABLE 6.4-1
KEY PARAMETERS FOR CRITICALITY ANALYSIS

Description	Parameter
Fuel support structure poison material	B_4C rod
Minimum B_4C pellet diameter (in.) small pellets large pellets	 0.278 0.426
B_4C hole pitch (in.)	0.5
Maximum fuel cavity width (in.)	8.796
Fuel type	W 17 x 17 OFA
Fuel assembly-to-assembly pitch	Minimum
Number of fuel rods Number of water holes	264 25
Fuel rod pitch (in.)	0.496
Fuel o.d. (in.)	0.3088
Cladding thickness (in.)	0.0225
UO_2 smear density (% td)	94.5
Fuel enrichment (wt % U-235) 4 elements 3 elements 2 elements or less	 2.9 3.5 4.5

2. No burnable poisons accounted for in the fuel.

3. Water density at 1.0 g/cm^3.

4. Temperature at 20°C (293 K).

5. B_4C density assumed to be 93.1 percent theoretical density, accounting for 2 percent manufacturing uncertainty and 5 percent margin.

6. No boron modeled in the neutron shield.

6.4.1.4 Determination of k_{eff}. The criticality calculations were performed with the CSAS25 control module in SCALE-4.1.

The Monte Carlo calculations performed with CSAS25 (KENO V.a) used a flat neutron starting distribution. The total number of histories traced for each calculation was approximately 100,000. This number of histories was sufficient to converge the source and produce standard deviations of less than 0.3 percent in k_{eff}. The maximum k_{eff} for the calculation was determined with the following formula:

$$k_{eff} = k_{KENO} + BIAS + 2(\sigma_{BIAS}^2 + \sigma_{KENO}^2)^{1/2} \quad .$$

6.4.2 Fuel Loading Optimization

The fuel loading configuration of the cask affects the reactivity of the package. A series of analyses was first carried out to determine the most reactive credible cask configuration. The first series of runs determined the most reactive fuel assembly type. The model used for this analysis was a full-height, quarter-radial model. Each fuel assembly was modeled as an array of clad fuel pins with gap and water holes and an initial enrichment of 3.0 wt%.

The results of the most reactive fuel evaluation are given in Table 6.4-2 for each assembly type. The W 17 x 17 OFA assembly is the most reactive fuel assembly and is used in the remainder of the analysis.

The next series of analyses determined the most reactive configuration for the cask. For accident conditions, an infinite array of casks without inleakage of water, neutron shield, or outer skin was modeled to determine k_{eff} as a function of water gap between the casks. The results are given in Table 6.4-3. The most reactive accident configuration occurs when the array of casks is at minimum cask-to-cask pitch. This configuration however, is very subcritical as compared to a single flooded, undamaged cask.

TABLE 6.4-2
MOST REACTIVE FUEL ANALYSIS
(3.0 WT% INITIAL ENRICHMENT)

Mfr.	Array	Version	k_{KENO}	$\pm 1\ \sigma_{KENO}$	k_{eff} [a]
W	17x17	Std	0.9322	0.0021	0.9449
W	17x17	OFA	0.9433	0.0021	0.9560
W	17x17	Vant. 5, H	0.9431	0.0020	0.9557
W	15x15	Std/ZC	0.9397	0.0023	0.9528
W	15x15	OFA	0.9414	0.0020	0.9540
W	14x14	Std/ZCA Std/ZCB	0.9072	0.0020	0.9198
W	14x14	Model C	0.9202	0.0019	0.9326
W	14x14	OFA	0.9113	0.0021	0.9240
B & W	17x17	Mark C	0.9339	0.0017	0.9460
B & W	15x15	Mark B, BZ, BGD	0.9344	0.0021	0.9471
CE	16x16	St. Lucie	0.9171	0.0020	0.9297
CE	15x15	Palisades	0.9307	0.0020	0.9433
CE	14x14	Std/Gen.	0.9118	0.0020	0.9244
CE	14x14	Ft. Calhoun	0.9094	0.0018	0.9217
Exx/A	17x17	WE	0.9380	0.0021	0.9507
Exx/A	15x15	WE	0.9279	0.0022	0.9408
Exx/A	14x14	CE	0.9097	0.0023	0.9228
Exx/A	14x14	WE	0.8989	0.0021	0.9116

[a] $k_{eff} = k_{KENO} + BIAS + 2(\sigma_{BIAS}^2 + \sigma_{KENO}^2)^{1/2}$
as determined in Section 6.5.3

TABLE 6.4-3
MOST REACTIVE CONFIGURATION CALCULATIONS
(3.0 WT% INITIAL ENRICHMENT)

Hypothetical Accident Conditions Infinite Array with Water between Casks			
Water-filled space between casks (cm)	k_{KENO}	$\pm 1\ \sigma_{KENO}$	k_{eff}[a]
0	0.3483	0.0017	0.3604
5	0.3054	0.0013	0.3169
10	0.2975	0.0013	0.3090
15	0.2963	0.0014	0.3080
Undamaged Package Moderator Density Variations			
Water density (g/cm^3)	k_{KENO}	$\pm 1\ \sigma_{KENO}$	k_{eff}[a]
0.95	0.9198	0.0022	0.9327
0.9	0.9004	0.0021	0.9131
0.8	0.8603	0.0022	0.8732
0.7	0.8151	0.0023	0.8282
0.6	0.7614	0.0021	0.7741
0.5	0.6936	0.0021	0.7063
0.4	0.6174	0.0017	0.6295
0.3	0.5316	0.0018	0.5439
Undamaged Package Assembly-to-Assembly Pitch			
Assembly position	k_{KENO}	$\pm 1\ \sigma_{KENO}$	k_{eff}[a]
Maximum pitch	0.9229	0.0021	0.9356
Centered in cavity	0.9293	0.0020	0.9419
Minimum pitch	0.9362	0.0022	0.9491

[a] $k_{eff} = k_{KENO} + BIAS + 2(\sigma_{BIAS}^2 + \sigma_{KENO}^2)^{1/2}$, as determined in Section 6.5.3.

Given that the single flooded, undamaged package is more reactive than the package under hypothetical accident conditions, two additional series of runs were performed to determine what moderator density is most reactive and what assembly-to-assembly pitch produces the most reactive condition. Table 6.4-3 gives the results of the analysis, which show that a single flooded, undamaged package with minimum assembly-to-assembly pitch and a water density of 1 g/cm^3 gives the most reactive credible configuration for the GA-4 cask.

6.4.3 Criticality Results

Table 6.4-4 lists the results of the three final criticality calculations performed with CSAS25 of SCALE-4.1. For each case, the result includes (1) the KENO-calculated k_{eff}; (2) the one sigma uncertainty; and (3) the final k_{eff}, which accounts for the calculational bias and the two-sigma uncertainty. The results for all cases are given in Table 6.4-4. As stated before, the GA-4 cask can transport four PWR fuel assemblies with a maximum initial enrichment of 2.9 wt% U-235, or three PWR fuel assemblies with a maximum initial enrichment of 3.5 wt % U-235, one or two fuel PWR assemblies with a maximum initial enrichment of 4.5 wt% U-235 as a Fissile Class I package. For the two-element case, the fuel assemblies must be loaded in the fuel cavities which form the vertical diagonal in the cask. The input data for these three final cases are included in Appendix 6.6.

TABLE 6.4-4
FINAL CRITICALITY RESULTS

Number of Fuel Assemblies	Initial Enrichment (wt % U-235)	k_{KENO}	$\pm 1\ \sigma_{KENO}$	k_{eff}[(a)]
4	2.9	0.9362	0.0022	0.9491
3	3.5	0.9343	0.0023	0.9474
2[(b)]	4.5	0.8843	0.0022	0.8972

(a) $k_{eff} = k_{KENO} + BIAS + 2(\sigma_{BIAS}^2 + \sigma_{KENO}^2)^{1/2}$, as determined in Section 6.5.3.

(b) Fuel assemblies must be loaded in two cavities on the vertical diagonal.

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6.5 Critical Benchmark Experiments

The criticality safety analysis of the GA-4 shipping cask used the CSAS25 module of the SCALE system of codes. The CSAS25 control module allows simplified data input to the functional modules BONAMI-S, NITAWL-S, and KENO V.a. These modules process the required cross-section data and calculate the k_{eff} of the system. BONAMI-S performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL-S applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the effective neutron multiplication (k_{eff}) of a 3-D system.

The GA-4 cask uses the fresh fuel assumption for criticality analysis. The analysis employed the 27-group ENDF/B-IV (27BURNUPLIB) cross-section library because it has a small bias, as determined by the 15 benchmark calculations described in Section 6.5.1. The bias for the fresh fuel assumption was determined, using 15 fresh fuel criticals, as discussed in Sections 6.5.1 to 6.5.3.

6.5.1 Benchmark Experiments and Applicability

To verify the calculational techniques for fresh fuel used in the criticality safety analysis in Section 6.4.1, several critical benchmark experiments (Refs. 6.5-1 to 6.5-4) were selected and analyzed with the CSAS25 module of SCALE-4.1, using the 27BURNUPLIB cross-section library.

The selected fresh fuel critical experiments relate to the GA-4 cask conditions closely, with certain exceptions as noted in Table 6.5-1. The difference in the fuel cladding material has little effect on reactivity, since both Zircaloy and aluminum are weak neutron absorbers.

The fresh fuel benchmarks chosen were sufficiently diverse to cover the various neutron absorbers (B_4C, steel, water) between the fuel assemblies as well as close reflection from water, steel, or DU around the fuel assemblies. The experiments consisted of three enrichments: 2.35, 2.46, and 4.29 wt % U-235. These are representative of the range of fuel enrichments to be carried in the GA-4 cask. Table 6.5-2 lists, by case number, the critical experiment selected to represent the cask conditions listed. Table 6.5-3 provides a brief description of each critical experiment.

6.5.2 Details of Benchmark Calculations

Figure 6.5-1 illustrates the fuel rods and dimensions. Figure 6.5-2 shows the experimental geometry for Cases 1 through 12. The poison curtains (separating material in Table 6.5-2), when present, are positioned between the center cluster of fuel rods and the two outer clusters on either side, as shown in Fig. 6.5-2. Table 6.5-3 gives a brief description and dimensions for each critical benchmark experiment.

TABLE 6.5-1
COMPARISON OF SELECTED CRITICAL EXPERIMENTS
WITH GA-4 CASK CONDITIONS

Condition	GA-4 Cask	Critical Experiments
Fuel type	Low-enriched UO_2	Same
Enrichment (%)	2.9 to 4.5	2.35, 2.46, 4.31
Fuel pitch/rod diameter ratio	1.54	1.59 to 2.0
Moderator	Water	Same
Fixed absorber	B_4C/steel	B_4C, Boral, borated steel
Reflector	DU	DU/water
Fuel cladding material	Zircaloy	Al

TABLE 6.5-2
CASK CONDITIONS MODELED IN BENCHMARK CALCULATIONS

Case	Enrichment U-235 wt %	Separating Material	Surrounding Material	Pitch/Rod Ratio
1	4.31	Water	Water	2.008
2	4.31	Boral (B_4C)	Water	2.008
3	4.31	Steel w/boron	Water	2.008
4	4.31	Steel w/boron	Water	2.008
5	4.31	Steel w/boron	Water	2.008
6	4.31	Steel w/boron	Water	2.008
7	4.31	Water	Water/DU	2.008
8	4.31	Water	Water/DU	2.008
9	2.35	Boral (B_4C)	Water	1.818
10	2.35	Boral (B_4C)	Water	1.818
11	2.35	Water	Water/DU	1.818
12	2.35	Water	Water/DU	1.818
13	2.46	Water	Water	1.588
14	2.46	B_4C	Water	1.588
15	2.46	B_4C	Water	1.588

TABLE 6.5-3
CSAS25-CALCULATED k_{eff} FOR EXPERIMENTALLY CRITICAL LOW-ENRICHED UO_2 SYSTEMS

Case	Experiment Description[(a)]	Reference	27-Group $k_{eff} \pm 1\ \sigma$
1	Experiment 004. UO_2 rods, 4.31 wt % U-235, 1.2649 cm diameter. Al cladding, 1.3487 cm o.d., 0.066 cm thick. Fuel length 91.44 cm. Square pitch = 2.54 cm. 3 x 1 array of 15 x 8 rod bundles, 11.72 cm separation between bundles. Water-moderated and -reflected.	6.5-1	0.9926 ± 0.0022
2	Experiment 031. UO_2 rods, 4.31 wt % U-235, 1.2649 cm diameter. Al cladding, 1.3487 cm o.d., 0.066 cm thick. Fuel length 91.44 cm. Square pitch = 2.54 cm. 3 x 1 array of 15 x 8 rod bundles, 6.72 cm separation between bundles. Boral curtains, 0.713 cm thick, between bundles; 3.277 cm from edge of center bundle. Water-moderated and -reflected.	6.5-1	0.9949 ± 0.0023
3	Experiment 010. UO_2 rods, 4.31 wt % U-235, 1.2649 cm diameter. Al cladding, 1.3487 cm o.d., 0.066 cm thick. Fuel length 91.44 cm. Square pitch = 2.54 cm. 3 x 1 array of 15 x 8 rod bundles, 6.10 cm separation between bundles. SS304L 1.05 wt % boron curtains, 0.298 cm thick, between bundles; 0.432 cm from edge of center bundle. Water-moderated and -reflected.	6.5-1	0.9962 ± 0.0024
4	Experiment 009. UO_2 rods, 4.31 wt % U-235, 1.2649 cm diameter. Al cladding, 1.3487 cm o.d., 0.066 cm thick. Fuel length 91.44 cm. Square pitch = 2.54 cm. 3 x 1 array of 15 x 8 rod bundles, 8.08 cm separation between bundles. SS304L 1.05 wt % boron curtains, 0.298 cm thick, between bundles; 3.277 cm from edge of center bundle. Water-moderated and -reflected.	6.5-1	0.9945 ± 0.0025

TABLE 6.5-3
CSAS25-CALCULATED k_{eff} FOR EXPERIMENTALLY CRITICAL LOW-ENRICHED UO_2 SYSTEMS

Case	Experiment Description[a]	Reference	27-Group $k_{eff} \pm 1\ \sigma$
5	Experiment 012. UO_2 rods, 4.31 wt % U-235, 1.2649 cm diameter. Al cladding, 1.3487 cm o.d., 0.066 cm thick. Fuel length 91.44 cm. Square pitch = 2.54 cm. 3 x 1 array of 15 x 8 rod bundles, 5.76 cm separation between bundles. SS304L 1.62 wt % boron curtains, 0.298 cm thick, between bundles; 0.432 cm from edge of center bundle. Water-moderated and -reflected.	6.5-1	0.9914 ± 0.0022
6	Experiment 011. UO_2 rods, 4.31 wt % U-235, 1.2649 cm diameter. Al cladding, 1.3487 cm o.d., 0.I066 cm thick. Fuel length 91.44 cm. Square pitch = 2.54 cm. 3 x 1 array of 15 x 8 rod bundles, 7.90 cm separation between bundles. SS304L 1.62 wt % boron curtains, 0.298 cm thick, between bundles; 3.277 cm from edge of center bundle. Water-moderated and -reflected.	6.5-1	0.9998 ±0.0026
7	UO_2 rods, 4.31 wt % U-235, 1.2649 cm diameter. Al cladding, 1.3487 cm o.d., 0.066 cm thick. Fuel length 91.44 cm. Square pitch = 2.54 cm. 3 x 1 array of 13 x 8 rod bundles, 15.38 cm separation between bundles. Depleted uranium reflecting walls, 7.65 cm thick, 0.0 cm from left and right edges of bundles. Water-moderated and uranium-reflected.	6.5-4	0.9939 ± 0.0021
8	UO_2 rods, 4.31 wt % U-235, 1.2649 cm diameter. Al cladding, 1.3487 cm o.d., 0.066 cm thick. Fuel length 91.44 cm. Square pitch = 2.54 cm. 3 x 1 array of 13 x 8 rod bundles, 15.32 cm separation between bundles. Depleted uranium reflecting walls, 7.65 cm thick, 1.956 cm from left and right edges of bundles. Water-moderated and uranium-reflected.	6.5-4	0.9931 ±0.0022

TABLE 6.5-3
CSAS25-CALCULATED k_{eff} FOR EXPERIMENTALLY CRITICAL LOW-ENRICHED UO_2 SYSTEMS

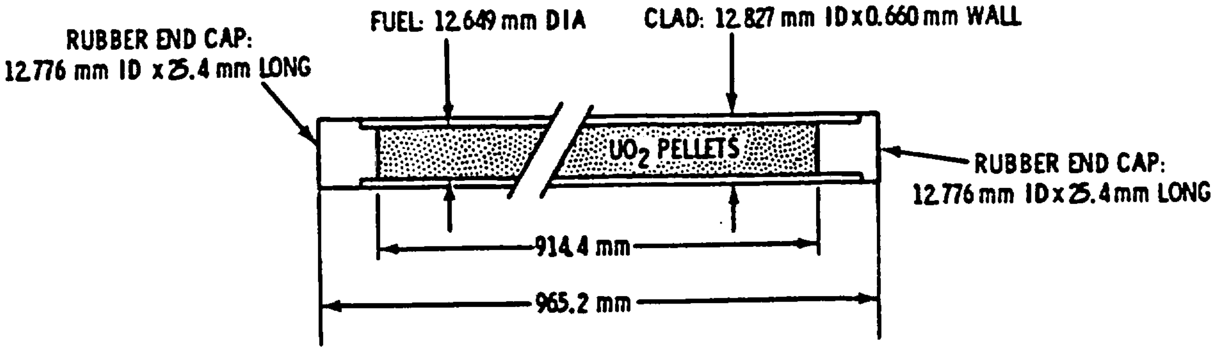
Case	Experiment Description[a]	Reference	27-Group $k_{eff} \pm 1\ \sigma$
9	UO_2 rods, 2.35 wt % U-235, 1.1176 cm diameter Al cladding, 1.270 cm o.d., 0.0762 cm thick. Fuel length = 91.44 cm. Square pitch = 2.032 cm. 3 x 1 array of 20 x 17 rod bundles, 6.34 cm separation between bundles. Boral curtains, 0.713 cm thick, between bundles; 0.645 cm from edge of center bundle. Water-moderated and -reflected.	6.5-2	0.9923 ± 0.0022
10	UO_2 rods, 2.35 wt % U-235, 1.1176 cm diameter. Al cladding, 1.270 cm o.d., 0.0762 cm thick. Fuel length = 91.44 cm. Square pitch = 2.032 cm. 3 x 1 array of 20 x 17 rod bundles, 6.34 cm separation between bundles. Boral curtains, 0.713 cm thick, between bundles; 09.645 cm from edge of center bundle. Water-moderated and -reflected.	6.5-2	0.9918 ± 0.0019
11	UO_2 rods, 2.35 wt % U-235, 1.1176 cm diameter. Al cladding, 1.2170 cm o.d., 90.0762 cm thick. Fuel length 91.44 cm. Square pitch = 2.032 cm. 3 x 1 array of 19 x 18 rod bundles, 11.83 cm separation between bundles. Depleted uranium reflecting walls, 10.2 cm thick, 0.l0 cm from left and right edges of bundles. Water-moderated and uranium-reflected.	6.5-4	0.9902 ± 0.0021
12	UO_2 rods, 2.35 wt % U-235, 1.1176 cm diameter. Al cladding, 1.270 cm o.d., 0.0762 cm thick. Fuel length 91.44 cm. Square pitch = 2.l032 cm. 3 x 1 array of 19 x 18 rod bundles, 14.11 cm separation between bundles. Depleted uranium reflecting walls, 10.2 cm thick, 1.956 cm from left and right edges of bundles. Water-moderated and uranium-reflected.	6.5-4	0.9983 ±0.0021

TABLE 6.5-3
CSAS25-CALCULATED k_{eff} FOR EXPERIMENTALLY CRITICAL LOW-ENRICHED UO_2 SYSTEMS

Case	Experiment Description[a]	Reference	27-Group $k_{eff} \pm 1\ \sigma$
13	Core I UO_2 rods, 2.46 wt % U-235, 1.03 cm diameter. Al cladding, 1.206 cm o.d., 0.081 cm thick. Fuel length = 153.34 cm. Square pitch = 1.636 cm. 438 rods in cylindrical arrangement. Water-moderated and -reflected.	6.5-3	0.9795 ± 0.0019
14	Core IV UO_2 Rods, 2.46 wt % U-235, 1.03 cm diameter. Al cladding, 1.206 cm o.d., 0.081 cm thick. Fuel length = 153.34 cm. Square pitch = 1.636 cm. 3 x 3 array of 14 x 14 rod bundles, 1-pitch separation with 84 B_4C pins between clusters. Water-moderated and -reflected.	6.5-3	0.9838 ± 0.0017
15	Core V UO_2 rods, 2.46 wt % U-235, 1.03 cm diameter. Al cladding, 1.206 cm o.d., 0.081 cm thick. Fuel length = 153.34 cm. Square pitch = 1.636 cm. 3 x 3 array of 14 x 14 rod bundles, 2-pitch separation with 64 B_4C pins between clusters. Water-moderated and -reflected.	6.5-3	0.9854 ± 0.0018

[a]See Fig. 6.5-2 for a graphical layout for cases 1 to 12.

4.31 wt% ^{235}U-ENRICHED UO_2 RODS



CLADDING: 6061 ALUMINUM TUBING

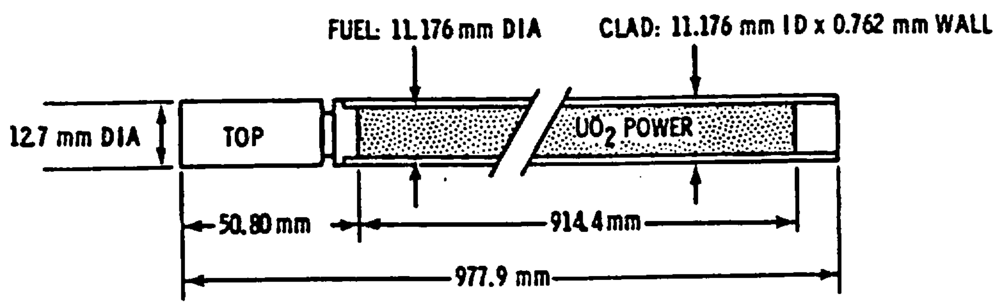
LOADING:

ENRICHMENT - 4.31 ± 0.01 wt% ^{235}U
FUEL DENSITY - 94.9 ± 0.55% OF THEORETICAL DENSITY
URANIUM ASSAY - 88.055 ± 0.261 wt% OF TOTAL FUEL COMPOSITION
UO_2 - 1203.38 ± 4.12 g/ROD

END CAP:

DENSITY - 1.321 g/cm^3
COMPOSITION - C - 58 ± 1 wt% S - 1.7 ± 0.2 wt%
H - 6.5 ± 0.3 wt% O - 22.1 wt% (BALANCE)
Ca - 11.4 ± 1.8 wt% Si - 0.3 ± 0.1 wt%

2.35 wt% ^{235}U-ENRICHED UO_2 RODS



CLADDING: 6061 ALUMINUM TUBING SEAL WELDED WITH A LOWER END PLUG OF 5052-H32 ALUMINUM AND A TOP PLUG OF 1100 ALUMINUM

LOADING:

ENRICHMENT - 2.35 ± 0.05 wt% ^{235}U
FUEL DENSITY - 9.20 mg/mm^3 (84% THEORETICAL DENSITY)
URANIUM ASSAY - 88.0 wt%
UO_2 - 825 g/ROD (AVERAGED)

Fig. 6.5-1. The 4.31 wt% U-235–enriched UO_2 rods and 2.35 wt% U-235–enriched UO_2 rods

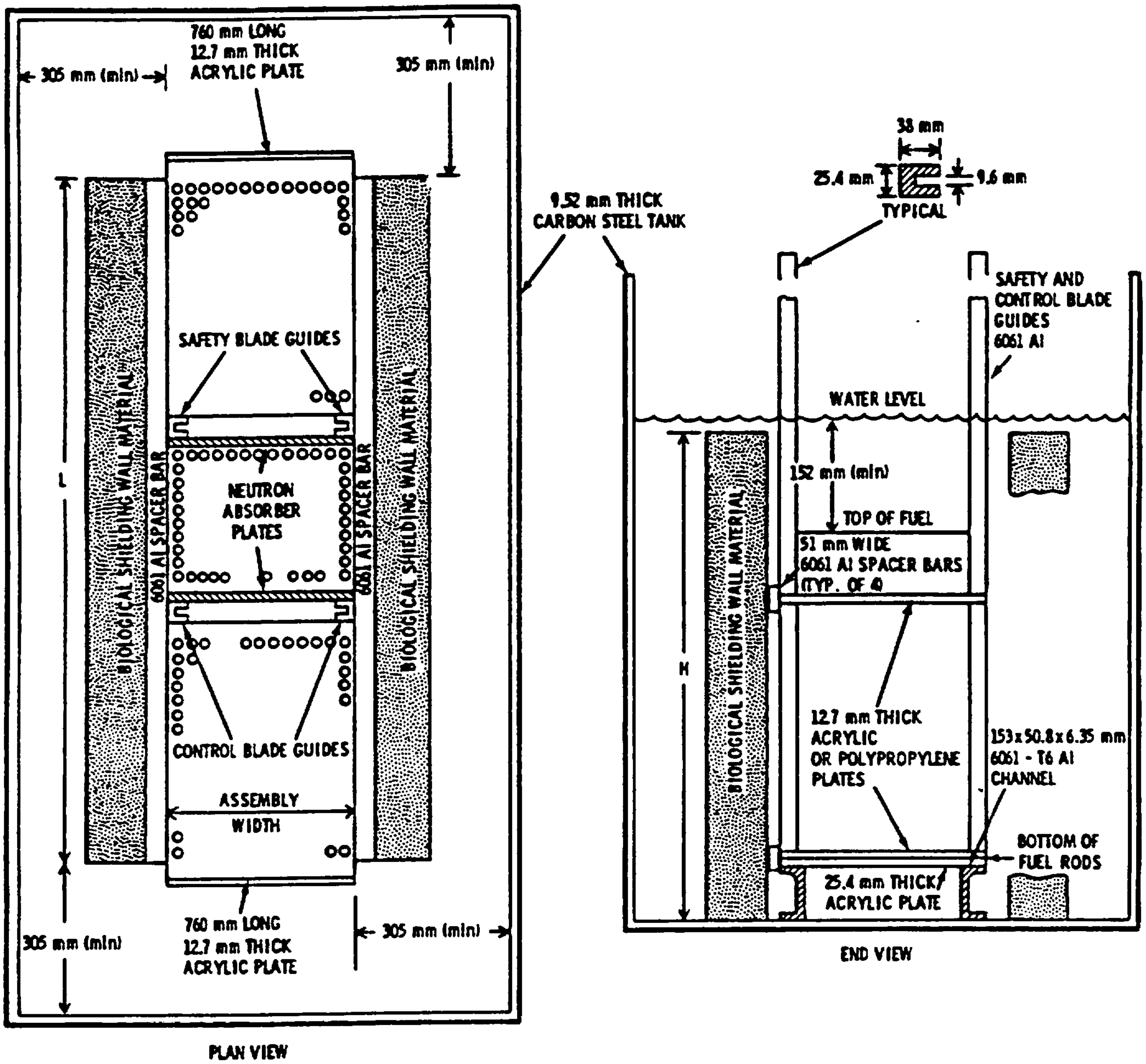


Fig. 6.5-2. Graphical arrangement of Cases 1 to 12

The KENO-Va. calculations modeled the fuel pins explicitly and the rest of the experiment as closely as possible. The models used the exact geometry and materials, with the following three exceptions:

1. The rubber end caps on the fuel rods were modeled as water.
2. The aluminum support structure was ignored.
3. The acrylic plates were treated as water.

The three assumptions are discussed in Ref. 6.5-1, p. 22, and Ref. 6.5-5, p. 238. The references conclude that the effect of the rubber end caps and aluminum support structure is negligible. The acrylic plates used in the experiments were modeled as water because the acrylic material (Plexiglas) has about the same density as water and the neutron-moderating characteristics are almost identical to those of water. These properties, combined with the small volume of acrylic used, have a negligible effect on the results, as discussed in the references cited above.

The complete list of the inputs to CSAS25 for all 15 experiments is given in Section 6.6.

6.5.3 Results of Benchmark Calculations

Table 6.5-3 shows the results for each calculation. The calculations performed by means of the 27-group ENDF/B-IV cross-section library (27BURNUPLIB) show an average calculational bias (BIAS) of ±0.0077 in k_{eff} (under prediction). The one-sigma uncertainty associated with the bias (σ_{BIAS}) is 0.0014. The BIAS and one-sigma uncertainty were determined by using the following equations:

$$BIAS = 1 - \frac{1}{15}\sum_{i=1}^{15} k_{eff_i}$$

$$\sigma_{BIAS} = \frac{1}{\sqrt{15}} \sqrt{\frac{\sum_{i=1}^{15}\left(k_{eff_i} - BIAS\right)^2}{15 - 1}}$$

6.6 Appendix

6.6.1 CSAS25 Input Data for Design Calculations

```
=csas25
4 pwr assem. w(17x17) ofa, e=2.90, bu=00,
27burnuplib  latticecell
u-234    1 0 6.066-6 end
u-235    1 0 6.786-4 end
u-236    1 0 3.109-6 end
u-238    1 0 2.243-2 end
o        1 0 4.623-2 end
zircalloy  2 1.0 end
h2o  3 1.0 end
b4c  4 0.931 end
ss304  5 1.0 end
uranium  6 1.0 293.0 92235 0.3 92238 99.7 end
o  7 0 1.5035-3 end
h  7 0 7.4931-2 end
c  7 0 3.6450-2 end
end comp
squarepitch 1.25984 0.784352 1 3 0.9144 2 0.8001 0 end
flat full height ga-4, 6/93, 95% for nrc with b4c
read param  tme=25.0 gen=100 npg=1000 flx=no fdn=no
end param
read array
ara=1 nux=37 nuy=37 nuz=1
fill
     18 17r16 15 17r16 18
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
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     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
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     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     14 17r37  3 17r37 14
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
      17 17r39 38 17r39 17
     18 17r16 15 17r16 18
     end fill
```

```
ara=2 nux=37 nuy=37 nuz=1
fill
     18 17r16 15 17r16 18
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     17 5r1 2 2r1 2 2r1 2 5r1 38 5r1 2 2r1 2 2r1 2 5r1 17
     17 3r1 2 9r1 2 3r1 38 3r1 2 9r1 2 3r1 17
     17 17r1  38 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  38 17r1  17
     17 3r1 2 9r1 2 3r1 38 3r1 2 9r1 2 3r1 17
     17 5r1 2 2r1 2 2r1 2 5r1 38 5r1 2 2r1 2 2r1 2 5r1 17
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     14 17r37  3 17r37 14
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     17 5r1 2 2r1 2 2r1 2 5r1 38 5r1 2 2r1 2 2r1 2 5r1 17
     17 3r1 2 9r1 2 3r1 38 3r1 2 9r1 2 3r1 17
     17 17r1  38 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
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     17 17r1  38 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  38 17r1  17
     17 3r1 2 9r1 2 3r1 38 3r1 2 9r1 2 3r1 17
     17 5r1 2 2r1 2 2r1 2 5r1 38 5r1 2 2r1 2 2r1 2 5r1 17
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     18 17r16 15 17r16 18
     end fill
ara=3 nux=37 nuy=37 nuz=1
fill
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     17 17r1  36 17r1  17
     17 17r1  32 17r1  17
     17 5r1 2 2r1 2 2r1 2 5r1 32 5r1 2 2r1 2 2r1 2 5r1 17
     17 3r1 2 9r1 2 3r1 32 3r1 2 9r1 2 3r1 17
     17 17r1  32 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r1  32 17r1  17
     17 17r1  32 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
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     17 17r1  32 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
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     17 17r1  26 17r1  17
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 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
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      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32
 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
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      17 17r1  34 17r1  17
      18 17r16 15 17r16 18
      end fill
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fill
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      17 3r1 2 9r1 2 3r1 9 3r1 2 9r1 2 3r1 17
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      17 17r1  9 17r1  17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
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      17 17r1  9 17r1  17
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      17 17r39  9 17r39 17
```

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      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
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      18 17r16 15 17r16 18
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      17 17r39 32 17r39 17
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      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
```

```
     17 17r39 32 17r39 17
     17 17r39 32 17r39 17
     17 17r39 34 17r39 17
     18 17r16 15 17r16 18
     end fill
ara=7 nux=1 nuy=1 nuz=332
fill
     4r40
     1r41
     19r42
     268r43
     15r44
     20r45
     5r40
     end fill
end array
read bnds all=vacuum   end bnds
read geom
unit 1
cylinder   1 1 0.392176 2p0.635
 cylinder   0 1 0.40005 2p0.635
cylinder   2 1 0.4572 2p0.635
cuboid     3 1 4p0.62992 2p0.635
unit 2
cylinder   3 1 0.56900 2p0.635
cylinder   2 1 0.61470 2p0.635
cuboid     3 1 4p0.62992 2p0.635
unit 3
cuboid     5 1 4p0.762 2p0.635
unit 4
xcylinder  4 1 0.5410 1.25984 0.60198
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 5
ycylinder  4 1 0.5410 0.65786 0.0
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 6
xcylinder  4 1 0.5410 0.65786 0.0
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 7
ycylinder  4 1 0.5410 1.25984 0.60198
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 8
xcylinder  4 1 0.5410 1.25984 0.0
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 9
ycylinder  4 1 0.5410 1.25984 0.0
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 10
xcylinder  4 1 0.5410 0.78994 0.0
xcylinder  0 1 0.5588 0.78994 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 11
ycylinder  4 1 0.5410 1.25984 0.4699
ycylinder  0 1 0.5588 1.25984 0.4699
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 12
xcylinder  4 1 0.5410 1.25984 0.4699
xcylinder  0 1 0.5588 1.25984 0.4699
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 13
ycylinder  4 1 0.5410 0.78994 0.0
ycylinder  0 1 0.5588 0.78994 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
```

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unit 14
cuboid      5 1 0.92456 0.0 2p0.762 2p0.635
unit 15
cuboid      5 1 2p0.762 0.92456 0.0 2p0.635
unit 16
cuboid      3 1 2p0.62992 0.92456 0.0 2p0.635
unit 17
cuboid      3 1 0.92456 0.0 2p0.62992 2p0.635
unit 18
cuboid      3 1 4p0.46228 2p0.635
 unit 19
xcylinder   4 1 0.5410 1.25984 0.0
xcylinder   0 1 0.5588 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 20
ycylinder   4 1 0.5410 1.25984 0.0
ycylinder   0 1 0.5588 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 21
xcylinder   4 1 0.5410 1.25984 0.0
xcylinder   0 1 0.5588 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 22
ycylinder   4 1 0.5410 1.25984 0.0
ycylinder   0 1 0.5588 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 23
xcylinder   4 1 0.35306 1.25984 0.49022
xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 24
ycylinder   4 1 0.35306 0.76962 0.0
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 25
xcylinder   4 1 0.35306 0.76962 0.0
xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 26
ycylinder   4 1 0.35306 1.25984 0.49022
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 27
xcylinder   4 1 0.35306 1.25984 0.0
xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 28
ycylinder   4 1 0.35306 1.25984 0.0
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 29
xcylinder   4 1 0.35306 1.25984 0.0
xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 30
ycylinder   4 1 0.35306 1.25984 0.0
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 31
xcylinder   4 1 0.35306 1.25984 0.0
xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 32
ycylinder   4 1 0.35306 1.25984 0.0
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 33
xcylinder   4 1 0.35306 0.78994 0.0
xcylinder   0 1 0.37084 0.78994 0.0
```

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 cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 34
ycylinder  4 1 0.35306 1.25984 0.4699
ycylinder  0 1 0.37084 1.25984 0.4699
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 35
xcylinder  4 1 0.35306 1.25984 0.4699
xcylinder  0 1 0.37084 1.25984 0.4699
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 36
ycylinder  4 1 0.35306 0.78994 0.0
ycylinder  0 1 0.37084 0.78994 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 37
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 38
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 39
cuboid     3 1 4p0.62992 2p0.635
unit 40
array 1 0.0 0.0 -0.635
unit 41
array 2 0.0 0.0 -0.635
unit 42
array 3 0.0 0.0 -0.635
unit 43
array 4 0.0 0.0 -0.635
unit 44
array 5 0.0 0.0 -0.635
unit 45
array 6 0.0 0.0 -0.635
core 7 1 -23.10384 -23.10384 1.27
cuboid 3 1 2p23.1040 2p23.1040 424.815 0.0
cuboid 5 1 2p24.0564 2p24.0564 424.815 0.0
cuboid 6 1 2p30.7874 2p30.7874 424.815 0.0
cuboid 5 1 2p34.5974 2p34.5974 452.755 -24.13
cuboid 7 1 2p46.0274 2p46.0274 452.755 -24.13
cuboid 5 1 2p46.2941 2p46.2941 452.755 -24.13
cuboid 3 1 2p100.0 2p100.0 510.0 -75.0
end geom
end data
end
```

```
=csas25
3 pwr assem. w(17x17) ofa, e=3.50, bu=00,
27burnuplib  latticecell
u-234   1 0 7.321-6 end
u-235   1 0 8.191-4 end
u-236   1 0 3.752-6 end
u-238   1 0 2.229-2 end
o       1 0 4.623-2 end
zircalloy  2 1.0 end
h2o  3 1.0 end
b4c  4 0.931 end
ss304  5 1.0 end
uranium  6 1.0 293.0 92235 0.3 92238 99.7 end
o  7 0 1.5035-3 end
h  7 0 7.4931-2 end
c  7 0 3.6450-2 end
end comp
squarepitch 1.25984 0.784352 1 3 0.9144 2 0.8001 0 end
flat full height ga-4, 6/93, 95% for nrc with b4c
read param  tme=25.0 gen=100 npg=1000 flx=no fdn=no
end param
read array
ara=1 nux=37 nuy=37 nuz=1
fill
     18 17r16 15 17r16 18
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     14 17r37  3 17r37 14
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
      17 17r39 38 17r39 17
     18 17r16 15 17r16 18
     end fill
ara=2 nux=37 nuy=37 nuz=1
fill
     18 17r16 15 17r16 18
     17 17r1  38 17r39 17
     17 17r1  38 17r39 17
     17 5r1 2 2r1 2 2r1 2 5r1 38 17r39 17
     17 3r1 2 9r1 2 3r1 38 17r39 17
```

```
     17 17r1  38 17r39 17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38 17r39 17
     17 17r1  38 17r39 17
     17 17r1  38 17r39 17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38 17r39 17
     17 17r1  38 17r39 17
     17 17r1  38 17r39 17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38 17r39 17
     17 17r1  38 17r39 17
     17 3r1 2 9r1 2 3r1 38 17r39 17
     17 5r1 2 2r1 2 2r1 2 5r1 38 17r39 17
     17 17r1  38 17r39 17
     17 17r1  38 17r39 17
     14 17r37  3 17r37 14
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     17 5r1 2 2r1 2 2r1 2 5r1 38 5r1 2 2r1 2 2r1 2 5r1 17
     17 3r1 2 9r1 2 3r1 38 3r1 2 9r1 2 3r1 17
     17 17r1  38 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  38 17r1  17
     17 3r1 2 9r1 2 3r1 38 3r1 2 9r1 2 3r1 17
     17 5r1 2 2r1 2 2r1 2 5r1 38 5r1 2 2r1 2 2r1 2 5r1 17
     17 17r1  38 17r1  17
     17 17r1  38 17r1  17
     18 17r16 15 17r16 18
     end fill
ara=3 nux=37 nuy=37 nuz=1
fill
     18 17r16 15 17r16 18
     17 17r1  36 17r39 17
     17 17r1  32 17r39 17
     17 5r1 2 2r1 2 2r1 2 5r1 32 17r39 17
     17 3r1 2 9r1 2 3r1 32 17r39 17
     17 17r1  32 17r39 17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32 17r39 17
     17 17r1  32 17r39 17
     17 17r1  32 17r39 17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32 17r39 17
     17 17r1  32 17r39 17
      17 17r1  32 17r39 17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32 17r39 17
     17 17r1  32 17r39 17
     17 3r1 2 9r1 2 3r1 32 17r39 17
     17 5r1 2 2r1 2 2r1 2 5r1 32 17r39 17
     17 17r1  30 17r39 17
     17 17r1  26 17r39 17
     14 35 14r31 29 25 3 23 27 14r31 33 14
     17 17r1  24 17r1  17
     17 17r1  28 17r1  17
     17 5r1 2 2r1 2 2r1 2 5r1 32 5r1 2 2r1 2 2r1 2 5r1 17
     17 3r1 2 9r1 2 3r1 32 3r1 2 9r1 2 3r1 17
     17 17r1  32 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  32 17r1  17
     17 17r1  32 17r1  17
     17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
     17 17r1  32 17r1  17
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```
      17 17r1  32 17r1  17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32
2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r1  32 17r1  17
      17 3r1 2 9r1 2 3r1 32 3r1 2 9r1 2 3r1 17
      17 5r1 2 2r1 2 2r1 2 5r1 32 5r1 2 2r1 2 2r1 2 5r1 17
      17 17r1  32 17r1  17
      17 17r1  34 17r1  17
      18 17r16 15 17r16 18
      end fill
ara=4 nux=37 nuy=37 nuz=1
fill
      18 17r16 15 17r16 18
      17 17r1  13 17r39 17
      17 17r1   9 17r39 17
      17 5r1 2 2r1 2 2r1 2 5r1 9 17r39 17
      17 3r1 2 9r1 2 3r1 9 17r39 17
      17 17r1  9 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 17r39 17
      17 17r1  9 17r39 17
      17 17r1  9 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 17r39 17
      17 17r1  9 17r39 17
      17 17r1  9 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 17r39 17
      17 17r1  9 17r39 17
      17 3r1 2 9r1 2 3r1 9 17r39 17
      17 5r1 2 2r1 2 2r1 2 5r1 9 17r39 17
      17 17r1  22 17r39 17
      17 17r1  7 17r39 17
      14 12 14r8 21 6 3 4 19 14r8 10 14
      17 17r1  5 17r1  17
      17 17r1  20 17r1  17
      17 5r1 2 2r1 2 2r1 2 5r1 9 5r1 2 2r1 2 2r1 2 5r1 17
      17 3r1 2 9r1 2 3r1 9 3r1 2 9r1 2 3r1 17
      17 17r1  9 17r1  17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r1  9 17r1  17
       17 17r1  9 17r1  17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r1  9 17r1  17
      17 17r1  9 17r1  17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r1  9 17r1  17
      17 3r1 2 9r1 2 3r1 9 3r1 2 9r1 2 3r1 17
      17 5r1 2 2r1 2 2r1 2 5r1 9 5r1 2 2r1 2 2r1 2 5r1 17
      17 17r1  9 17r1  17
      17 17r1  11 17r1  17
      18 17r16 15 17r16 18
      end fill
ara=5 nux=37 nuy=37 nuz=1
fill
      18 17r16 15 17r16 18
      17 17r39 13 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39 22 17r39 17
```

```
      17 17r39  7 17r39 17
      14 12 14r8 21 6 3 4 19 14r8 10 14
      17 17r39  5 17r39 17
      17 17r39 20 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39 11 17r39 17
      18 17r16 15 17r16 18
      end fill
 ara=6 nux=37 nuy=37 nuz=1
 fill
      18 17r16 15 17r16 18
      17 17r39 36 17r39 17
      17 17r39 32 17r39 17
       17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 30 17r39 17
      17 17r39 26 17r39 17
      14 35 14r31 29 25 3 23 27 14r31 33 14
      17 17r39 24 17r39 17
      17 17r39 28 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 34 17r39 17
      18 17r16 15 17r16 18
      end fill
ara=7 nux=1 nuy=1 nuz=332
fill
      4r40
      1r41
      19r42
      268r43
      15r44
      20r45
```

```
     5r40
     end fill
end array
read bnds all=vacuum   end bnds
read geom
unit 1
cylinder   1 1 0.392176 2p0.635
cylinder   0 1 0.40005 2p0.635
cylinder   2 1 0.4572 2p0.635
cuboid     3 1 4p0.62992 2p0.635
unit 2
cylinder   3 1 0.56900 2p0.635
cylinder   2 1 0.61470 2p0.635
cuboid     3 1 4p0.62992 2p0.635
unit 3
cuboid     5 1 4p0.762 2p0.635
 unit 4
xcylinder  4 1 0.5410 1.25984 0.60198
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 5
ycylinder  4 1 0.5410 0.65786 0.0
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 6
xcylinder  4 1 0.5410 0.65786 0.0
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 7
ycylinder  4 1 0.5410 1.25984 0.60198
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 8
xcylinder  4 1 0.5410 1.25984 0.0
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 9
ycylinder  4 1 0.5410 1.25984 0.0
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 10
xcylinder  4 1 0.5410 0.78994 0.0
xcylinder  0 1 0.5588 0.78994 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 11
ycylinder  4 1 0.5410 1.25984 0.4699
ycylinder  0 1 0.5588 1.25984 0.4699
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 12
xcylinder  4 1 0.5410 1.25984 0.4699
xcylinder  0 1 0.5588 1.25984 0.4699
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 13
ycylinder  4 1 0.5410 0.78994 0.0
ycylinder  0 1 0.5588 0.78994 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 14
cuboid     5 1 0.92456 0.0 2p0.762 2p0.635
unit 15
cuboid     5 1 2p0.762 0.92456 0.0 2p0.635
unit 16
cuboid     3 1 2p0.62992 0.92456 0.0 2p0.635
unit 17
cuboid     3 1 0.92456 0.0 2p0.62992 2p0.635
unit 18
cuboid     3 1 4p0.46228 2p0.635
unit 19
xcylinder  4 1 0.5410 1.25984 0.0
xcylinder  0 1 0.5588 1.25984 0.0
```

```
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 20
ycylinder  4 1 0.5410 1.25984 0.0
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 21
 xcylinder  4 1 0.5410 1.25984 0.0
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 22
ycylinder  4 1 0.5410 1.25984 0.0
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 23
xcylinder  4 1 0.35306 1.25984 0.49022
xcylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 24
ycylinder  4 1 0.35306 0.76962 0.0
ycylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 25
xcylinder  4 1 0.35306 0.76962 0.0
xcylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 26
ycylinder  4 1 0.35306 1.25984 0.49022
ycylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 27
xcylinder  4 1 0.35306 1.25984 0.0
xcylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 28
ycylinder  4 1 0.35306 1.25984 0.0
ycylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 29
xcylinder  4 1 0.35306 1.25984 0.0
xcylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 30
ycylinder  4 1 0.35306 1.25984 0.0
ycylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 31
xcylinder  4 1 0.35306 1.25984 0.0
xcylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 32
ycylinder  4 1 0.35306 1.25984 0.0
ycylinder  0 1 0.37084 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 33
xcylinder  4 1 0.35306 0.78994 0.0
xcylinder  0 1 0.37084 0.78994 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 34
ycylinder  4 1 0.35306 1.25984 0.4699
ycylinder  0 1 0.37084 1.25984 0.4699
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 35
xcylinder  4 1 0.35306 1.25984 0.4699
xcylinder  0 1 0.37084 1.25984 0.4699
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
 unit 36
ycylinder  4 1 0.35306 0.78994 0.0
ycylinder  0 1 0.37084 0.78994 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
```

```
unit 37
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 38
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 39
cuboid     3 1 4p0.62992 2p0.635
unit 40
array 1 0.0 0.0 -0.635
unit 41
array 2 0.0 0.0 -0.635
unit 42
array 3 0.0 0.0 -0.635
unit 43
array 4 0.0 0.0 -0.635
unit 44
array 5 0.0 0.0 -0.635
unit 45
array 6 0.0 0.0 -0.635
core 7 1 -23.10384 -23.10384 1.27
cuboid 3 1 2p23.1040 2p23.1040 424.815 0.0
cuboid 5 1 2p24.0564 2p24.0564 424.815 0.0
cuboid 6 1 2p30.7874 2p30.7874 424.815 0.0
cuboid 5 1 2p34.5974 2p34.5974 452.755 -24.13
cuboid 7 1 2p46.0274 2p46.0274 452.755 -24.13
cuboid 5 1 2p46.2941 2p46.2941 452.755 -24.13
cuboid 3 1 2p100.0 2p100.0 510.0 -75.0
end geom
end data
end
```

```
=csas25
2 pwr assem. w(17x17) ofa, e=4.50, bu=00,
27burnuplib  latticecell
u-234    1 0 9.412-6 end
u-235    1 0 1.053-3 end
u-236    1 0 4.824-6 end
u-238    1 0 2.205-2 end
o        1 0 4.624-2 end
zircalloy  2 1.0 end
h2o  3 1.0 end
b4c  4 0.931 end
ss304  5 1.0 end
uranium  6 1.0 293.0 92235 0.3 92238 99.7 end
o  7 0 1.5035-3 end
h  7 0 7.4931-2 end
c  7 0 3.6450-2 end
end comp
squarepitch 1.25984 0.784352 1 3 0.9144 2 0.8001 0 end
flat full height ga-4, 6/93, 95% for nrc with b4c
read param  tme=25.0 gen=100 npg=1000 flx=no fdn=no
end param
read array
ara=1 nux=37 nuy=37 nuz=1
fill
     18 17r16 15 17r16 18
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     14 17r37  3 17r37 14
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
     17 17r39 38 17r39 17
      17 17r39 38 17r39 17
     18 17r16 15 17r16 18
     end fill
ara=2 nux=37 nuy=37 nuz=1
fill
     18 17r16 15 17r16 18
     17 17r39 38 17r1  17
     17 17r39 38 17r1  17
     17 17r39 38 5r1 2 2r1 2 2r1 2 5r1 17
     17 17r39 38 3r1 2 9r1 2 3r1 17
```

```
      17 17r39 38 17r1  17
      17 17r39 38 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r39 38 17r1  17
      17 17r39 38 17r1  17
      17 17r39 38 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r39 38 17r1  17
      17 17r39 38 17r1  17
      17 17r39 38 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r39 38 17r1  17
      17 17r39 38 3r1 2 9r1 2 3r1 17
      17 17r39 38 5r1 2 2r1 2 2r1 2 5r1 17
      17 17r39 38 17r1  17
      17 17r39 38 17r1  17
      14 17r37  3 17r37 14
      17 17r1  38 17r39 17
      17 17r1  38 17r39 17
      17 5r1 2 2r1 2 2r1 2 5r1 38 17r39 17
      17 3r1 2 9r1 2 3r1 38 17r39 17
      17 17r1  38 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38 17r39 17
      17 17r1  38 17r39 17
      17 17r1  38 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38 17r39 17
      17 17r1  38 17r39 17
      17 17r1  38 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 38 17r39 17
      17 17r1  38 17r39 17
      17 3r1 2 9r1 2 3r1 38 17r39 17
      17 5r1 2 2r1 2 2r1 2 5r1 38 17r39 17
      17 17r1  38 17r39 17
      17 17r1  38 17r39 17
      18 17r16 15 17r16 18
      end fill
ara=3 nux=37 nuy=37 nuz=1
fill
      18 17r16 15 17r16 18
      17 17r39 36 17r1  17
      17 17r39 32 17r1  17
      17 17r39 32 5r1 2 2r1 2 2r1 2 5r1 17
      17 17r39 32 3r1 2 9r1 2 3r1 17
      17 17r39 32 17r1  17
      17 17r39 32 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r39 32 17r1  17
      17 17r39 32 17r1  17
      17 17r39 32 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r39 32 17r1  17
      17 17r39 32 17r1  17
      17 17r39 32 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r39 32 17r1  17
       17 17r39 32 3r1 2 9r1 2 3r1 17
      17 17r39 32 5r1 2 2r1 2 2r1 2 5r1 17
      17 17r39 30 17r1  17
      17  17r39 26 17r1  17
      14 35 14r31 29 25 3 23 27 14r31 33 14
      17 17r1  24 17r39 17
      17 17r1  28 17r39 17
      17 5r1 2 2r1 2 2r1 2 5r1 32 17r39 17
      17 3r1 2 9r1 2 3r1 32 17r39 17
      17 17r1  32 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32 17r39 17
      17 17r1  32 17r39 17
      17 17r1  32 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32 17r39 17
      17 17r1  32 17r39 17
      17 17r1  32 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 32 17r39 17
      17 17r1  32 17r39 17
      17 3r1 2 9r1 2 3r1 32 17r39 17
      17 5r1 2 2r1 2 2r1 2 5r1 32 17r39 17
```

```
      17 17r1  32 17r39 17
      17 17r1  34 17r39 17
      18 17r16 15 17r16 18
      end fill
ara=4 nux=37 nuy=37 nuz=1
fill
      18 17r16 15 17r16 18
      17 17r39 13 17r1  17
      17 17r39  9 17r1  17
      17 17r39  9 5r1 2 2r1 2 2r1 2 5r1 17
      17 17r39  9 3r1 2 9r1 2 3r1 17
      17 17r39  9 17r1  17
      17 17r39  9 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r39  9 17r1  17
      17 17r39  9 17r1  17
      17 17r39  9 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r39  9 17r1  17
      17 17r39  9 17r1  17
      17 17r39  9 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 17
      17 17r39  9 17r1  17
      17 17r39  9 3r1 2 9r1 2 3r1 17
      17 17r39  9 5r1 2 2r1 2 2r1 2 5r1 17
      17 17r39 22 17r1  17
      17 17r39  7 17r1  17
      14 12 14r8 21 6 3 4 19 14r8 10 14
      17 17r1  5 17r39 17
      17 17r1  20 17r39 17
      17 5r1 2 2r1 2 2r1 2 5r1 9 17r39 17
      17 3r1 2 9r1 2 3r1 9 17r39 17
      17 17r1  9 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 17r39 17
      17 17r1  9 17r39 17
      17 17r1  9 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 17r39 17
      17 17r1  9 17r39 17
      17 17r1  9 17r39 17
      17 2r1 2 2r1 2 2r1 2 2r1 2 2r1 2 2r1 9 17r39 17
      17 17r1  9 17r39 17
      17 3r1 2 9r1 2 3r1 9 17r39 17
       17 5r1 2 2r1 2 2r1 2 5r1 9 17r39 17
      17 17r1  9 17r39 17
      17 17r1  11 17r39 17
      18 17r16 15 17r16 18
      end fill
ara=5 nux=37 nuy=37 nuz=1
fill
      18 17r16 15 17r16 18
      17 17r39 13 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39 22 17r39 17
      17 17r39  7 17r39 17
      14 12 14r8 21 6 3 4 19 14r8 10 14
      17 17r39  5 17r39 17
      17 17r39 20 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
```

```
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39  9 17r39 17
      17 17r39 11 17r39 17
      18 17r16 15 17r16 18
      end fill
ara=6 nux=37 nuy=37 nuz=1
fill
      18 17r16 15 17r16 18
      17 17r39 36 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
       17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 30 17r39 17
      17 17r39 26 17r39 17
      14 35 14r31 29 25 3 23 27 14r31 33 14
      17 17r39 24 17r39 17
      17 17r39 28 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 32 17r39 17
      17 17r39 34 17r39 17
      18 17r16 15 17r16 18
      end fill
ara=7 nux=1 nuy=1 nuz=332
fill
      4r40
      1r41
      19r42
      268r43
      15r44
      20r45
      5r40
      end fill
end array
read bnds all=vacuum   end bnds
read geom
unit 1
```

```
cylinder   1 1 0.392176 2p0.635
cylinder   0 1 0.40005 2p0.635
cylinder   2 1 0.4572 2p0.635
cuboid     3 1 4p0.62992 2p0.635
unit 2
cylinder   3 1 0.56900 2p0.635
cylinder   2 1 0.61470 2p0.635
cuboid     3 1 4p0.62992 2p0.635
unit 3
cuboid     5 1 4p0.762 2p0.635
unit 4
xcylinder  4 1 0.5410 1.25984 0.60198
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 5
ycylinder  4 1 0.5410 0.65786 0.0
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 6
 xcylinder  4 1 0.5410 0.65786 0.0
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 7
ycylinder  4 1 0.5410 1.25984 0.60198
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 8
xcylinder  4 1 0.5410 1.25984 0.0
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 9
ycylinder  4 1 0.5410 1.25984 0.0
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 10
xcylinder  4 1 0.5410 0.78994 0.0
xcylinder  0 1 0.5588 0.78994 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 11
ycylinder  4 1 0.5410 1.25984 0.4699
ycylinder  0 1 0.5588 1.25984 0.4699
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 12
xcylinder  4 1 0.5410 1.25984 0.4699
xcylinder  0 1 0.5588 1.25984 0.4699
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 13
ycylinder  4 1 0.5410 0.78994 0.0
ycylinder  0 1 0.5588 0.78994 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 14
cuboid     5 1 0.92456 0.0 2p0.762 2p0.635
unit 15
cuboid     5 1 2p0.762 0.92456 0.0 2p0.635
unit 16
cuboid     3 1 2p0.62992 0.92456 0.0 2p0.635
unit 17
cuboid     3 1 0.92456 0.0 2p0.62992 2p0.635
unit 18
cuboid     3 1 4p0.46228 2p0.635
unit 19
xcylinder  4 1 0.5410 1.25984 0.0
xcylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 1.25984 0.0 2p0.762 2p0.635
unit 20
ycylinder  4 1 0.5410 1.25984 0.0
ycylinder  0 1 0.5588 1.25984 0.0
cuboid     5 1 2p0.762 1.25984 0.0 2p0.635
unit 21
```

```
xcylinder   4 1 0.5410 1.25984 0.0
xcylinder   0 1 0.5588 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 22
ycylinder   4 1 0.5410 1.25984 0.0
ycylinder   0 1 0.5588 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 23
xcylinder   4 1 0.35306 1.25984 0.49022
 xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 24
ycylinder   4 1 0.35306 0.76962 0.0
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 25
xcylinder   4 1 0.35306 0.76962 0.0
xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 26
ycylinder   4 1 0.35306 1.25984 0.49022
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 27
xcylinder   4 1 0.35306 1.25984 0.0
xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 28
ycylinder   4 1 0.35306 1.25984 0.0
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 29
xcylinder   4 1 0.35306 1.25984 0.0
xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 30
ycylinder   4 1 0.35306 1.25984 0.0
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 31
xcylinder   4 1 0.35306 1.25984 0.0
xcylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 32
ycylinder   4 1 0.35306 1.25984 0.0
ycylinder   0 1 0.37084 1.25984 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 33
xcylinder   4 1 0.35306 0.78994 0.0
xcylinder   0 1 0.37084 0.78994 0.0
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 34
ycylinder   4 1 0.35306 1.25984 0.4699
ycylinder   0 1 0.37084 1.25984 0.4699
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 35
xcylinder   4 1 0.35306 1.25984 0.4699
xcylinder   0 1 0.37084 1.25984 0.4699
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 36
ycylinder   4 1 0.35306 0.78994 0.0
ycylinder   0 1 0.37084 0.78994 0.0
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 37
cuboid      5 1 1.25984 0.0 2p0.762 2p0.635
unit 38
cuboid      5 1 2p0.762 1.25984 0.0 2p0.635
unit 39
 cuboid      3 1 4p0.62992 2p0.635
```

```
unit 40
array 1 0.0 0.0 -0.635
unit 41
array 2 0.0 0.0 -0.635
unit 42
array 3 0.0 0.0 -0.635
unit 43
array 4 0.0 0.0 -0.635
unit 44
array 5 0.0 0.0 -0.635
unit 45
array 6 0.0 0.0 -0.635
core 7 1 -23.10384 -23.10384 1.27
cuboid 3 1 2p23.1040 2p23.1040 424.815 0.0
cuboid 5 1 2p24.0564 2p24.0564 424.815 0.0
cuboid 6 1 2p30.7874 2p30.7874 424.815 0.0
cuboid 5 1 2p34.5974 2p34.5974 452.755 -24.13
cuboid 7 1 2p46.0274 2p46.0274 452.755 -24.13
cuboid 5 1 2p46.2941 2p46.2941 452.755 -24.13
cuboid 3 1 2p100.0 2p100.0 510.0 -75.0
end geom
end data
end
```

6.6.2 CSAS25 Input Data for Benchmark Calculations

CASE 1

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0073
27BURNUPLIB  LATTICECELL
UO2  1 0.949 293.0 92235 4.31 92238 95.69 END
AL  2 1.0 END
H2O  3 1.0 END
CARBONSTEEL  4 1.0 END
END COMP
SQUAREPITCH 2.54 1.2649 1 3 1.4147 2 1.2827 0 END
EXPLICIT FULL GEOMETRY OF EXPERIMENT 004
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=8 NUY=47 NUZ=1
LOOP
1 1 8 1 1 15 1 1 1 1
2 1 8 1 16 16 1 1 1 1
1 1 8 1 17 31 1 1 1 1
2 1 8 1 32 32 1 1 1 1
1 1 8 1 33 47 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.63245 91.44 0
CYLINDER 0 1 0.64135 91.44 0
CYLINDER 2 1 0.70735 91.44 0
CUBOID 3 1 4P1.270 91.44 0
UNIT 2
CUBOID 3 1 2P1.27 2P5.85 91.44 0.0
CORE 1 1 79.84 81.15 21.332
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 4 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
END DATA
END
```

CASE 2

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0073
27BURNUPLIB  LATTICECELL
UO2  1 0.949 293.0 92235 4.31 92238 95.69 END
AL  2 1.0 END
H2O  3 1.0 END
AL  4 0 3.4638-2 END
B-10  4 0 7.9196-3 END
B-11  4 0 3.1878-2 END
C  4 0 9.9557-3 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.54 1.2649 1 3 1.4147 2 1.2827 0 END
EXPLICIT FULL GEOMETRY OF BORAL EXPERIMENT 4.29% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=10 NUY=47 NUZ=1
LOOP
6 1 10 9 1 15 1 1 1 1
1 2 9 1 1 15 1 1 1 1
5 1 10 9 16 16 1 1 1 1
3 2 9 1 16 16 1 1 1 1
6 1 10 9 17 31 1 1 1 1
1 2 9 1 17 31 1 1 1 1
4 1 10 9 32 32 1 1 1 1
2 2 9 1 32 32 1 1 1 1
6 1 10 9 33 47 1 1 1 1
1 2 9 1 33 47 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.63245 91.44 0
CYLINDER 0 1 0.64135 91.44 0
CYLINDER 2 1 0.70735 91.44 0
CUBOID 3 1 4P1.270 91.50 0
UNIT 2
CUBOID 4 1 2.54 0.0 3.99 3.277 91.50 0.0
CUBOID 3 1 2.54 0.0 6.72 0.0 91.50 0.0
UNIT 3
CUBOID 4 1 2.54 0.0 3.443 2.730 91.50 0.0
CUBOID 3 1 2.54 0.0 6.72 0.0 91.50 0.0
UNIT 4
CUBOID 4 1 8.09 0.0 3.99 3.277 91.50 0.0
CUBOID 3 1 8.09 0.0 6.72 0.0 91.50 0.0
UNIT 5
CUBOID 4 1 8.09 0.0 3.443 2.730 91.50 0.0
CUBOID 3 1 8.09 0.0 6.72 0.0 91.50 0.0
UNIT 6
CUBOID 3 1 8.09 0.0 2P1.27 91.50 0.0
CORE 1 1 79.84 86.13 21.332
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
END DATA
END
```

CASE 3

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0073
27BURNUPLIB  LATTICECELL
UO2  1 0.949 293.0 92235 4.31 92238 95.69 END
AL  2 1.0 END
H2O  3 1.0 END
B-10  4 0 9.2388-4 END
B-11  4 0 3.6955-3 END
CR  4 0 1.7406-2 END
CU  4 0 2.0955-4 END
FE  4 0 5.7941-2 END
MN  4 0 1.3678-3 END
MO  4 0 2.4290-4 END
NI  4 0 7.7211-3 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.54 1.2649 1 3 1.4147 2 1.2827 0 END
EXPLICIT FULL GEOM. MIN SS304L 1.05% BORON 4.29% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=10 NUY=47 NUZ=1
LOOP
6 1 10 9 1 15 1 1 1 1
1 2 9 1 1 15 1 1 1 1
5 1 10 9 16 16 1 1 1 1
3 2 9 1 16 16 1 1 1 1
6 1 10 9 17 31 1 1 1 1
1 2 9 1 17 31 1 1 1 1
4 1 10 9 32 32 1 1 1 1
2 2 9 1 32 32 1 1 1 1
6 1 10 9 33 47 1 1 1 1
1 2 9 1 33 47 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.63245 91.44 0
CYLINDER 0 1 0.64135 91.44 0
CYLINDER 2 1 0.70735 91.44 0
CUBOID 3 1 4P1.270 91.50 0
UNIT 2
CUBOID 4 1 2.54 0.0 0.73 0.432 91.50 0.0
CUBOID 3 1 2.54 0.0 6.10 0.0 91.50 0.0
UNIT 3
CUBOID 4 1 2.54 0.0 5.668 5.370 91.50 0.0
CUBOID 3 1 2.54 0.0 6.10 0.0 91.50 0.0
UNIT 4
CUBOID 4 1 7.64 0.0 0.73 0.432 91.50 0.0
CUBOID 3 1 7.64 0.0 6.10 0.0 91.50 0.0
UNIT 5
CUBOID 4 1 7.64 0.0 5.668 5.370 91.50 0.0
CUBOID 3 1 7.64 0.0 6.10 0.0 91.50 0.0
UNIT 6
CUBOID 3 1 7.64 0.0 2P1.27 91.50 0.0
CORE 1 1 72.20 86.75 21.332
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
 END DATA
END
```

CASE 4

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0073
27BURNUPLIB  LATTICECELL
UO2  1 0.949 293.0 92235 4.31 92238 95.69 END
AL  2 1.0 END
H2O  3 1.0 END
B-10  4 0 9.2388-4 END
B-11  4 0 3.6955-3 END
CR  4 0 1.7406-2 END
CU  4 0 2.0955-4 END
FE  4 0 5.7941-2 END
MN  4 0 1.3678-3 END
MO  4 0 2.4290-4 END
NI  4 0 7.7211-3 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.54 1.2649 1 3 1.4147 2 1.2827 0 END
EXPLICIT FULL GEOM. MAX SS304L 1.05% BORON 4.29% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=10 NUY=47 NUZ=1
LOOP
6 1 10 9 1 15 1 1 1 1
1 2 9 1 1 15 1 1 1 1
5 1 10 9 16 16 1 1 1 1
3 2 9 1 16 16 1 1 1 1
6 1 10 9 17 31 1 1 1 1
1 2 9 1 17 31 1 1 1 1
4 1 10 9 32 32 1 1 1 1
2 2 9 1 32 32 1 1 1 1
6 1 10 9 33 47 1 1 1 1
1 2 9 1 33 47 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.63245 91.44 0
CYLINDER 0 1 0.64135 91.44 0
CYLINDER 2 1 0.70735 91.44 0
CUBOID 3 1 4P1.270 91.50 0
UNIT 2
CUBOID 4 1 2.54 0.0 3.575 3.277 91.50 0.0
CUBOID 3 1 2.54 0.0 8.08 0.0 91.50 0.0
UNIT 3
CUBOID 4 1 2.54 0.0 4.803 4.505 91.50 0.0
CUBOID 3 1 2.54 0.0 8.08 0.0 91.50 0.0
UNIT 4
CUBOID 4 1 7.64 0.0 3.575 3.277 91.50 0.0
CUBOID 3 1 7.64 0.0 8.08 0.0 91.50 0.0
UNIT 5
CUBOID 4 1 7.64 0.0 4.803 4.505 91.50 0.0
CUBOID 3 1 7.64 0.0 8.08 0.0 91.50 0.0
UNIT 6
CUBOID 3 1 7.64 0.0 2P1.27 91.50 0.0
CORE 1 1 72.20 84.77 21.332
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
 END DATA
END
```

CASE 5

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0073
27BURNUPLIB  LATTICECELL
UO2  1 0.949 293.0 92235 4.31 92238 95.69 END
AL  2 1.0 END
H2O  3 1.0 END
B-10  4 0 1.4020-3 END
B-11  4 0 5.6079-3 END
CR  4 0 1.7632-2 END
CU  4 0 1.9138-4 END
FE  4 0 5.5614-2 END
MN  4 0 1.4389-3 END
MO  4 0 1.5114-4 END
NI  4 0 8.0642-3 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.54 1.2649 1 3 1.4147 2 1.2827 0 END
EXPLICIT FULL GEOM. MIN SS304L 1.62% BORON 4.29% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=10 NUY=47 NUZ=1
LOOP
6 1 10 9 1 15 1 1 1 1
1 2 9 1 1 15 1 1 1 1
5 1 10 9 16 16 1 1 1 1
3 2 9 1 16 16 1 1 1 1
6 1 10 9 17 31 1 1 1 1
1 2 9 1 17 31 1 1 1 1
4 1 10 9 32 32 1 1 1 1
2 2 9 1 32 32 1 1 1 1
6 1 10 9 33 47 1 1 1 1
1 2 9 1 33 47 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.63245 91.44 0
CYLINDER 0 1 0.64135 91.44 0
CYLINDER 2 1 0.70735 91.44 0
CUBOID 3 1 4P1.270 91.50 0
UNIT 2
CUBOID 4 1 2.54 0.0 0.73 0.432 91.50 0.0
CUBOID 3 1 2.54 0.0 5.76 0.0 91.50 0.0
UNIT 3
CUBOID 4 1 2.54 0.0 5.328 5.030 91.50 0.0
CUBOID 3 1 2.54 0.0 5.76 0.0 91.50 0.0
UNIT 4
CUBOID 4 1 7.64 0.0 0.73 0.432 91.50 0.0
CUBOID 3 1 7.64 0.0 5.76 0.0 91.50 0.0
UNIT 5
CUBOID 4 1 7.64 0.0 5.328 5.030 91.50 0.0
CUBOID 3 1 7.64 0.0 5.76 0.0 91.50 0.0
UNIT 6
CUBOID 3 1 7.64 0.0 2P1.27 91.50 0.0
CORE 1 1 72.20 87.09 21.332
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
 END DATA
END
```

CASE 6

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0073
27BURNUPLIB  LATTICECELL
UO2  1 0.949 293.0 92235 4.31 92238 95.69 END
AL  2 1.0 END
H2O  3 1.0 END
B-10   4 0 1.4020-3 END
B-11   4 0 5.6079-3 END
CR  4 0 1.7632-2 END
CU  4 0 1.9138-4 END
FE  4 0 5.5614-2 END
MN  4 0 1.4389-3 END
MO  4 0 1.5114-4 END
NI  4 0 8.0642-3 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.54 1.2649 1 3 1.4147 2 1.2827 0 END
EXPLICIT FULL GEOM. MAX SS304L 1.62% BORON 4.29% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=10 NUY=47 NUZ=1
LOOP
6 1 10 9 1 15 1 1 1 1
1 2 9 1 1 15 1 1 1 1
5 1 10 9 16 16 1 1 1 1
3 2 9 1 16 16 1 1 1 1
6 1 10 9 17 31 1 1 1 1
1 2 9 1 17 31 1 1 1 1
4 1 10 9 32 32 1 1 1 1
2 2 9 1 32 32 1 1 1 1
6 1 10 9 33 47 1 1 1 1
1 2 9 1 33 47 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.63245 91.44 0
CYLINDER 0 1 0.64135 91.44 0
CYLINDER 2 1 0.70735 91.44 0
CUBOID 3 1 4P1.270 91.50 0
UNIT 2
CUBOID 4 1 2.54 0.0 3.575 3.277 91.50 0.0
CUBOID 3 1 2.54 0.0 7.90 0.0 91.50 0.0
UNIT 3
CUBOID 4 1 2.54 0.0 4.623 4.325 91.50 0.0
CUBOID 3 1 2.54 0.0 7.90 0.0 91.50 0.0
UNIT 4
CUBOID 4 1 7.64 0.0 3.575 3.277 91.50 0.0
CUBOID 3 1 7.64 0.0 7.90 0.0 91.50 0.0
UNIT 5
CUBOID 4 1 7.64 0.0 4.623 4.325 91.50 0.0
CUBOID 3 1 7.64 0.0 7.90 0.0 91.50 0.0
UNIT 6
CUBOID 3 1 7.64 0.0 2P1.27 91.50 0.0
CORE 1 1 72.20 84.95 21.332
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
 END DATA
END
```

CASE 7

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0796
27BURNUPLIB  LATTICECELL
UO2  1 0.949 293.0 92235 4.31 92238 95.69 END
AL  2 1.0 END
H2O  3 1.0 END
URANIUM  4 0.982 293.0 92235 0.199 92238 99.801 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.54 1.2649 1 3 1.4147 2 1.2827 0 END
EXPLICIT FULL GEOM. DU REFLECTED 0.0CM FROM 4.31% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=8 NUY=41 NUZ=1
LOOP
1 1 8 1 1 13 1 1 1 1
2 1 8 1 14 28 14 1 1 1
1 1 8 1 15 27 1 1 1 1
1 1 8 1 29 41 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.63245 91.44 0.0
CYLINDER 0 1 0.64135 91.44 0.0
CYLINDER 2 1 0.70735 91.44 0.0
CUBOID 3 1 4P1.27 91.44 0.0
UNIT 2
CUBOID 3 1 2P1.27 15.38 0.0 91.44 0.0
CORE 1 1 79.84 85.09 21.332
CUBOID 3 1 100.16 79.84 226.15 73.85 122.852 0.952
CUBOID 4 1 107.81 72.19 226.15 73.85 122.852 0.952
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
END DATA
END
```

CASE 8

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0796
27BURNUPLIB  LATTICECELL
UO2  1 0.949 293.0 92235 4.31 92238 95.69 END
AL  2 1.0 END
H2O  3 1.0 END
URANIUM  4 0.982 293.0 92235 0.199 92238 99.801 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.54 1.2649 1 3 1.4147 2 1.2827 0 END
EXPLICIT FULL GEOM. DU REFLECTED 1.956CM FROM 4.31% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=8 NUY=38 NUZ=1
LOOP
1 1 8 1 1 12 1 1 1 1
2 1 8 1 13 26 13 1 1 1
1 1 8 1 14 25 1 1 1 1
1 1 8 1 27 38 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.63245 91.44 0.0
CYLINDER 0 1 0.64135 91.44 0.0
CYLINDER 2 1 0.70735 91.44 0.0
CUBOID 3 1 4P1.27 91.44 0.0
UNIT 2
CUBOID 3 1 2P1.27 15.38 0.0 91.44 0.0
CORE 1 1 79.84 88.96 21.332
CUBOID 3 1 101.116 77.884 226.15 73.85 122.852 0.952
CUBOID 4 1 109.766 70.234 226.15 73.85 122.852 0.952
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
END DATA
END
```

CASE 9

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0073
27BURNUPLIB  LATTICECELL
UO2  1 0.8394 293.0 92235 2.35 92238 97.65 END
AL  2 1.0 END
H2O  3 1.0 END
AL  4 0 3.4638-2 END
B-10  4 0 7.9196-3 END
B-11  4 0 3.1878-2 END
C  4 0 9.9557-3 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.032 1.1176 1 3 1.270 2 END
EXPLICIT FULL GEOMETRY OF BORAL EXPERIMENT 2.35% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=19 NUY=62 NUZ=1
LOOP
6 1 19 18 1 20 1 1 1 1
1 2 18 1 1 20 1 1 1 1
5 1 19 18 21 21 1 1 1 1
4 2 18 1 21 21 1 1 1 1
6 1 19 18 22 41 1 1 1 1
1 2 18 1 22 41 1 1 1 1
3 1 19 18 42 42 1 1 1 1
2 2 18 1 42 42 1 1 1 1
6 1 19 18 43 62 1 1 1 1
1 2 18 1 43 62 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.5588 92.71 1.27
CYLINDER 2 1 0.63500 97.79 0.0
CUBOID 3 1 4P1.016 97.79 0.0
UNIT 2
CUBOID 4 1 2.032 0.0 1.358 0.645 92.77 1.27
CUBOID 3 1 2.032 0.0 6.34 0.0 97.79 0.0
UNIT 3
CUBOID 4 1 0.978 0.0 5.695 4.982 92.77 1.27
CUBOID 3 1 0.978 0.0 6.34 0.0 97.79 0.0
UNIT 4
CUBOID 4 1 2.032 0.0 1.358 0.645 92.77 1.27
CUBOID 3 1 2.032 0.0 6.34 0.0 97.79 0.0
UNIT 5
CUBOID 4 1 0.978 0.0 5.695 4.982 92.77 1.27
CUBOID 3 1 0.978 0.0 6.34 0.0 97.79 0.0
UNIT 6
CUBOID 3 1 0.978 0.0 2P1.016 97.79 0.0
CORE 1 1 71.75 82.70 21.332
CUBOID 3 1 179.048 0.952 299.048 0.952 135.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 135.512 0.0
END GEOM
END DATA
END
```

CASE 10

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0073
27BURNUPLIB  LATTICECELL
UO2  1 0.8394 293.0 92235 2.35 92238 97.65 END
AL  2 1.0 END
H2O  3 1.0 END
AL  4 0 3.4638-2 END
B-10  4 0 7.9196-3 END
B-11  4 0 3.1878-2 END
C  4 0 9.9557-3 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.032 1.1176 1 3 1.270 2 END
EXPLICIT FULL GEOMETRY OF BORAL EXPERIMENT 2.35% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=19 NUY=62 NUZ=1
LOOP
6 1 19 18 1 20 1 1 1 1
1 2 18 1 1 20 1 1 1 1
5 1 19 18 21 21 1 1 1 1
4 2 18 1 21 21 1 1 1 1
6 1 19 18 22 41 1 1 1 1
1 2 18 1 22 41 1 1 1 1
3 1 19 18 42 42 1 1 1 1
2 2 18 1 42 42 1 1 1 1
6 1 19 18 43 62 1 1 1 1
1 2 18 1 43 62 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.5588 92.71 1.27
CYLINDER 2 1 0.63500 97.79 0.0
CUBOID 3 1 4P1.016 97.79 0.0
UNIT 2
CUBOID 4 1 2.032 0.0 5.155 4.442 92.77 1.27
CUBOID 3 1 2.032 0.0 9.03 0.0 97.79 0.0
UNIT 3
CUBOID 4 1 0.978 0.0 4.588 3.875 92.77 1.27
CUBOID 3 1 0.978 0.0 9.03 0.0 97.79 0.0
UNIT 4
CUBOID 4 1 2.032 0.0 5.155 4.442 92.77 1.27
CUBOID 3 1 2.032 0.0 9.03 0.0 97.79 0.0
UNIT 5
CUBOID 4 1 0.978 0.0 4.588 3.875 92.77 1.27
CUBOID 3 1 0.978 0.0 9.03 0.0 97.79 0.0
UNIT 6
CUBOID 3 1 0.978 0.0 2P1.016 97.79 0.0
CORE 1 1 71.75 80.01 21.332
CUBOID 3 1 179.048 0.952 299.048 0.952 135.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 135.512 0.0
END GEOM
END DATA
END
```

CASE 11

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0796
27BURNUPLIB  LATTICECELL
UO2  1 0.8394 293.0 92235 2.35 92238 97.65 END
AL  2 1.0 END
H2O  3 1.0 END
URANIUM  4 0.982 293.0 92235 0.199 92238 99.801 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.032 1.1176 1 3 1.270 2 END
EXPLICIT FULL GEOM. DU REFLECTED 0.0CM FROM 2.35% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=16 NUY=59 NUZ=1
LOOP
1 1 16 1 1 19 1 1 1 1
2 1 16 1 20 40 20 1 1 1
1 1 16 1 21 39 1 1 1 1
1 1 16 1 41 59 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.5588 92.71 1.27
CYLINDER 2 1 0.635 97.79 0.0
CUBOID 3 1 4P1.016 97.79 0.0
UNIT 2
CUBOID 3 1 2P1.016 11.83 0.0 97.79 0.0
CORE 1 1 73.744 80.258 21.332
CUBOID 3 1 106.256 73.744 226.15 73.85 122.852 0.952
CUBOID 4 1 113.906 66.094 226.15 73.85 122.852 0.952
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
END DATA
END
```

CASE 12

```
=CSAS25
SCALE BENCHMARK FOR CRITICALITY ANALYSIS NUREG/CR-0796
27BURNUPLIB  LATTICECELL
UO2  1 0.8394 293.0 92235 2.35 92238 97.65 END
AL  2 1.0 END
H2O  3 1.0 END
URANIUM  4 0.982 293.0 92235 0.199 92238 99.801 END
CARBONSTEEL  5 1.0 END
END COMP
SQUAREPITCH 2.032 1.1176 1 3 1.27 2 END
EXPLICIT FULL GEOM. DU REFLECTED 1.956CM FROM 2.35% ENRICHED FUEL
READ PARAM  TME=15.0 GEN=103 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=16 NUY=59 NUZ=1
LOOP
1 1 16 1 1 19 1 1 1 1
2 1 16 1 20 40 20 1 1 1
1 1 16 1 21 39 1 1 1 1
1 1 16 1 41 59 1 1 1 1
END ARRAY
READ BNDS ALL=VAC END BNDS
READ GEOM
UNIT 1
CYLINDER 1 1 0.5588 92.71 1.27
CYLINDER 2 1 0.635 97.79 0.0
CUBOID 3 1 4P1.016 97.79 0.0
UNIT 2
CUBOID 3 1 2P1.016 11.83 0.0 97.79 0.0
CORE 1 1 73.744 77.978 21.332
CUBOID 3 1 108.212 71.788 226.15 73.85 122.852 0.952
CUBOID 4 1 115.862 64.138 226.15 73.85 122.852 0.952
CUBOID 3 1 179.048 0.952 299.048 0.952 130.512 0.952
CUBOID 5 1 180.0 0.0 300.0 0.0 130.512 0.0
END GEOM
END DATA
END
```

CASE 13

```
=CSAS25
CRIT. EXP/NO POISON 438 RODS IN CYLINDRICAL PATERN/CORE 1
27BURNUPLIB  LATTICECELL
U-235   1 0 5.67505-4 END
U-238   1 0 2.22265-2 END
O       1 0 4.55881-2 END
CU      2 0 1.02328-4 END
FE      2 0 2.03741-4 END
SI      2 0 4.63000-4 END
MN      2 0 4.43813-5 END
MG      2 0 5.34873-4 END
CR      2 0 1.09416-4 END
AL      2 0 5.80754-2 END
H       3 0 6.67755-2 END
O       3 0 3.33877-2 END
END COMP
SQUAREPITCH 1.636 1.03 1 3 1.206 2 1.044 0 END
EXPLICIT GEOMETRY FOR COREI IN CRITICAL EXPERIMENT FROM BAW-1487-7 (7/79)
READ PARAM  TME=20.0 GEN=153 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=19 NUY=38 NUZ=3
LOOP
4 1 19 1 1 38 1 1 1 1
5 1 19 1 1 38 1 2 2 1
6 1 19 1 1 38 1 3 3 1
1 1 3 1 8 31 1 1 1 1
2 1 3 1 8 31 1 2 2 1
3 1 3 2 8 31 1 3 3 1
1 4 5 1 9 30 1 1 1 1
2 4 5 1 9 30 1 2 2 1
3 4 5 1 9 30 1 3 3 1
1 6 7 1 10 29 1 1 1 1
2 6 7 1 10 29 1 2 2 1
3 6 7 1 10 29 1 3 3 1
1 8 8 1 11 28 1 1 1 1
2 8 8 1 11 28 1 2 2 1
3 8 8 1 11 28 1 3 3 1
1 9 9 1 12 27 1 1 1 1
2 9 9 1 12 27 1 2 2 1
3 9 9 1 12 27 1 3 3 1
1 10 10 1 13 26 1 1 1 1
2 10 10 1 13 26 1 2 2 1
3 10 10 1 13 26 1 3 3 1
1 11 11 1 15 24 1 1 1 1
2 11 11 1 15 24 1 2 2 1
3 11 11 1 15 24 1 3 3 1
1 12 12 1 18 22 1 1 1 1
2 12 12 1 18 22 1 2 2 1
3 12 12 1 18 22 1 3 3 1
END ARRAY
READ BNDS +XB=VAC -XB=MIR YFC=VAC ZFC=VAC END BNDS
READ GEOM
BOX TYPE 1
CYLINDER 2 1 0.602996 0.3175 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 0.3175 0.0
BOX TYPE 2
CYLINDER 1 1 0.514858 2.54 0.0
 CYLINDER 0 1 0.521716 2.54 0.0
CYLINDER 2 1 0.602996 2.54 0.0
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
```

```
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 3
CYLINDER 1 1 0.514858 142.1425 0.0
CYLINDER 0 1 0.521716 142.1425 0.0
CYLINDER 2 1 0.602996 142.1425 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
BOX TYPE 4
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 0.3175 0.0
BOX TYPE 5
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 6
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
CORE     0 1 0.0 0.0 0.0
ZHEMICYL+X  3 1 73.66 145.0 0.0
ZHEMICYL+X  2 1 73.66 145.0 -5.08
ZHEMICYL+X  3 1 76.20 145.0 -7.62
ZHEMICYL+X  0 1 76.20 190.38 -7.62
ZHEMICYL+X  2 1 77.47 190.38 -8.89
CUBOID   0 1 77.47 0.0 77.47 -77.47 190.38 -8.89
END GEOM
END DATA
END
```

CASE 14

```
=CSAS25
CRIT. EXP/84 B4C PINS/1 PTH SEP/0 PPM/17C/CORE IV/
27BURNUPLIB  LATTICECELL
U-235   1 0 5.67505-4 END
U-238   1 0 2.22265-2 END
O       1 0 4.55881-2 END
CU      2 0 1.02328-4 END
FE      2 0 2.03741-4 END
SI      2 0 4.63000-4 END
MN      2 0 4.43813-5 END
MG      2 0 5.34873-4 END
CR      2 0 1.09416-4 END
AL      2 0 5.80754-2 END
H       3 0 6.67755-2 END
O       3 0 3.33877-2 END
B-10    4 0 1.104414-2 END
B-11    4 0 4.445405-2 END
C       4 0 1.334967-2 END
O       4 0 3.32183-5 END
H       5 0 6.67755-2 END
O       5 0 3.33877-2 END
END COMP
SQUAREPITCH 1.636 1.03 1 3 1.206 2 1.044 0 END
EXPLICIT GEOMETRY FOR COREIV IN CRITICAL EXPERIMENT FROM BAW-1487-7 (7/79)
READ PARAM  TME=20.0 GEN=153 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=22 NUY=44 NUZ=3
LOOP
1 1 22 1 1 44 1 1 1 1
2 1 22 1 1 44 1 2 2 1
3 1 22 1 1 44 1 3 3 1
10 1 22 1 1 31 15 2 2 1
11 1 22 1 1 31 15 3 3 1
10 1 22 1 14 44 15 2 2 1
11 1 22 1 14 44 15 3 3 1
10 7 9 2 1 44 1 2 2 1
11 7 9 2 1 44 1 3 3 1
10 22 22 1 1 44 1 2 2 1
11 22 22 1 1 44 1 3 3 1
12 7 9 2 1 31 15 2 2 1
13 7 9 2 1 31 15 3 3 1
12 7 9 2 14 44 15 2 2 1
13 7 9 2 14 44 15 3 3 1
12 22 22 1 1 31 15 2 2 1
13 22 22 1 1 31 15 3 3 1
12 22 22 1 14 44 15 2 2 1
13 22 22 1 14 44 15 3 3 1
4 8 8 1 1 44 1 1 1 1
5 8 8 1 1 44 1 2 2 1
6 8 8 1 1 44 1 3 3 1
4 1 22 1 15 30 15 1 1 1
5 1 22 1 15 30 15 2 2 1
6 1 22 1 15 30 15 3 3 1
7 2 22 2 15 30 15 1 1 1
8 2 22 2 15 30 15 2 2 1
9 2 22 2 15 30 15 3 3 1
7 8 8 1 2 42 2 1 1 1
 8 8 8 1 2 42 2 2 2 1
9 8 8 1 2 42 2 3 3 1
END ARRAY
```

```
READ BNDS +XB=VAC -XB=MIR YFC=VAC ZFC=VAC END BNDS
READ GEOM
BOX TYPE 1
CYLINDER 2 1 0.602996 0.3175 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 0.3175 0.0
BOX TYPE 2
CYLINDER 1 1 0.514858 2.54 0.0
CYLINDER 0 1 0.521716 2.54 0.0
CYLINDER 2 1 0.602996 2.54 0.0
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 3
CYLINDER 1 1 0.514858 142.1425 0.0
CYLINDER 0 1 0.521716 142.1425 0.0
CYLINDER 2 1 0.602996 142.1425 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
BOX TYPE 4
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 0.3175 0.0
BOX TYPE 5
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 6
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
BOX TYPE 7
CYLINDER 2 1 0.5565 0.3175 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 0.3175 0.0
BOX TYPE 8
CYLINDER 4 1 0.4675 2.54 0.6349
CYLINDER 2 1 0.5565 2.54 0.0
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 9
CYLINDER 4 1 0.4675 142.1425 0.0
CYLINDER 2 1 0.5565 142.1425 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
BOX TYPE 10
CYLINDER 1 1 0.514858 2.54 0.0
CYLINDER 0 1 0.521716 2.54 0.0
CYLINDER 2 1 0.602996 2.54 0.0
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 11
CYLINDER 1 1 0.514858 142.1425 0.0
CYLINDER 0 1 0.521716 142.1425 0.0
CYLINDER 2 1 0.602996 142.1425 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
BOX TYPE 12
CYLINDER 1 1 0.514858 2.54 0.0
CYLINDER 0 1 0.521716 2.54 0.0
CYLINDER 2 1 0.602996 2.54 0.0
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 13
CYLINDER 1 1 0.514858 142.1425 0.0
CYLINDER 0 1 0.521716 142.1425 0.0
CYLINDER 2 1 0.602996 142.1425 0.0
 CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
CORE        0 1 0.0 -35.98672  0.0
ZHEMICYL+X  5 1 73.66 145.0 0.0
ZHEMICYL+X  2 1 73.66 145.0 -5.08
ZHEMICYL+X  5 1 76.20 145.0 -7.62
ZHEMICYL+X  0 1 76.20 190.38 -7.62
```

```
ZHEMICYL+X  2 1 77.47 190.38 -8.89
CUBOID    0 1 77.47 0.0 77.47 -77.47 190.38 -8.89
END GEOM
END DATA
END
```

CASE 15

```
=CSAS25
CRIT. EXP/64 B4C PINS/2 PTH SEP/0 PPM/17.5C/CORE V/
27BURNUPLIB  LATTICECELL
U-235   1 0 5.67505-4 END
U-238   1 0 2.22265-2 END
O       1 0 4.55881-2 END
CU      2 0 1.02328-4 END
FE      2 0 2.03741-4 END
SI      2 0 4.63000-4 END
MN      2 0 4.43813-5 END
MG      2 0 5.34873-4 END
CR      2 0 1.09416-4 END
AL      2 0 5.80754-2 END
H       3 0 6.67755-2 END
O       3 0 3.33877-2 END
B-10    4 0 1.104414-2 END
B-11    4 0 4.445405-2 END
C       4 0 1.334967-2 END
O       4 0 3.32183-5 END
H       5 0 6.67755-2 END
O       5 0 3.33877-2 END
END COMP
SQUAREPITCH 1.636 1.03 1 3 1.206 2 1.044 0 END
EXPLICIT GEOMETRY FOR CORE V IN CRITICAL EXPERIMENT FROM BAW-1487-7 (7/79)
READ PARAM  TME=20.0 GEN=153 NPG=1000 FLX=YES FDN=YES FAR=YES
END PARAM
READ ARRAY NUX=23 NUY=46 NUZ=3
LOOP
1 1 23 1 1 46 1 1 1 1
2 1 23 1 1 46 1 2 2 1
3 1 23 1 1 46 1 3 3 1
10 1 23 1 1 33 16 2 2 1
11 1 23 1 1 33 16 3 3 1
10 1 23 1 14 46 16 2 2 1
11 1 23 1 14 46 16 3 3 1
10 7 10 3 1 46 1 2 2 1
11 7 10 3 1 46 1 3 3 1
10 23 23 1 1 46 1 2 2 1
11 23 23 1 1 46 1 3 3 1
12 7 10 3 1 33 16 2 2 1
13 7 10 3 1 33 16 3 3 1
12 7 10 3 14 46 16 2 2 1
13 7 10 3 14 46 16 3 3 1
12 23 23 1 1 33 16 2 2 1
13 23 23 1 1 33 16 3 3 1
12 23 23 1 14 46 16 2 2 1
13 23 23 1 14 46 16 3 3 1
4 8 9 1 1 46 1 1 1 1
5 8 9 1 1 46 1 2 2 1
6 8 9 1 1 46 1 3 3 1
4 1 23 1 15 16 1 1 1 1
5 1 23 1 15 16 1 2 2 1
6 1 23 1 15 16 1 3 3 1
4 1 23 1 31 32 1 1 1 1
5 1 23 1 31 32 1 2 2 1
6 1 23 1 31 32 1 3 3 1
7 2 8 3 16 31 15 1 1 1
 8 2 8 3 16 31 15 2 2 1
9 2 8 3 16 31 15 3 3 1
7 10 22 3 16 31 15 1 1 1
8 10 22 3 16 31 15 2 2 1
```

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9 10 22 3 16 31 15 3 3 1
7 8 8 1 2 12 5 1 1 1
8 8 8 1 2 12 5 2 2 1
9 8 8 1 2 12 5 3 3 1
7 8 8 1 4 19 5 1 1 1
8 8 8 1 4 19 5 2 2 1
9 8 8 1 4 19 5 3 3 1
7 8 8 1 22 28 3 1 1 1
8 8 8 1 22 28 3 2 2 1
9 8 8 1 22 28 3 3 3 1
7 8 8 1 33 43 5 1 1 1
8 8 8 1 33 43 5 2 2 1
9 8 8 1 33 43 5 3 3 1
7 8 8 1 35 45 5 1 1 1
8 8 8 1 35 45 5 2 2 1
9 8 8 1 35 45 5 3 3 1
END ARRAY
READ BNDS +XB=VAC -XB=MIR YFC=VAC ZFC=VAC END BNDS
READ GEOM
BOX TYPE 1
CYLINDER 2 1 0.602996 0.3175 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 0.3175 0.0
BOX TYPE 2
CYLINDER 1 1 0.514858 2.54 0.0
CYLINDER 0 1 0.521716 2.54 0.0
CYLINDER 2 1 0.602996 2.54 0.0
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 3
CYLINDER 1 1 0.514858 142.1425 0.0
CYLINDER 0 1 0.521716 142.1425 0.0
CYLINDER 2 1 0.602996 142.1425 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
BOX TYPE 4
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 0.3175 0.0
BOX TYPE 5
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 6
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
BOX TYPE 7
CYLINDER 2 1 0.5565 0.3175 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 0.3175 0.0
BOX TYPE 8
CYLINDER 4 1 0.4675 2.54 0.6349
CYLINDER 2 1 0.5565 2.54 0.0
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 9
CYLINDER 4 1 0.4675 142.1425 0.0
CYLINDER 2 1 0.5565 142.1425 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
BOX TYPE 10
CYLINDER 1 1 0.514858 2.54 0.0
CYLINDER 0 1 0.521716 2.54 0.0
 CYLINDER 2 1 0.602996 2.54 0.0
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 11
CYLINDER 1 1 0.514858 142.1425 0.0
CYLINDER 0 1 0.521716 142.1425 0.0
CYLINDER 2 1 0.602996 142.1425 0.0
```

```
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
BOX TYPE 12
CYLINDER 1 1 0.514858 2.54 0.0
CYLINDER 0 1 0.521716 2.54 0.0
CYLINDER 2 1 0.602996 2.54 0.0
CUBOID   3 1 0.615 -0.615 0.615 -0.615 2.54 0.0
CUBOID   2 1 0.81788 -0.81788 0.81788 -0.81788 2.54 0.0
BOX TYPE 13
CYLINDER 1 1 0.514858 142.1425 0.0
CYLINDER 0 1 0.521716 142.1425 0.0
CYLINDER 2 1 0.602996 142.1425 0.0
CUBOID   3 1 0.81788 -0.81788 0.81788 -0.81788 142.1425 0.0
CORE     0 1 0.0 -37.62248  0.0
ZHEMICYL+X  5 1 73.66 145.0 0.0
ZHEMICYL+X  2 1 73.66 145.0 -5.08
ZHEMICYL+X  5 1 76.20 145.0 -7.62
ZHEMICYL+X  0 1 76.20 190.38 -7.62
ZHEMICYL+X  2 1 77.47 190.38 -8.89
CUBOID   0 1 77.47 0.0 77.47 -77.47 190.38 -8.89
END GEOM
END DATA
END
```

6.6.3 References for Sections 6.1 through 6.5

6.1-1 Computer Code Collection "SCALE-4.1, a Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation," Vol. 1-3, CCC-545, Oak Ridge National Laboratory, February 1990.

6.3-1 "Characteristics of Spent Fuel, High-Level Waste and Other Radioactive Wastes Which May Require Long-Term Isolation," DOE/RW-0184, December 1987.

6.5-1 Bierman, S. R., B. M. Durst, and E. D. Clayton, "Critical Separation between Subcritical Clusters of 4.29 wt% ^{235}U-Enriched UO_2 Rods in Water with Fixed Neutron Poisons," NUREG/CR-0073, U.S. Nuclear Regulatory Commission, May 1978.

6.5-2 Bierman, S. R., B. M. Durst, and E. D. Clayton, "Critical Separation Between Subcritical Clusters of 2.35 wt% ^{235}U-enriched UO_2 Rods in Water with Fixed Neutron Poisons," PNL-2438, Battelle Pacific Northwest Laboratories, 1977.

6.5-3 Baldwin, N. M., et al., "Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel," BAW-1487-7, July 1979.

6.5-4 Bierman, S. R., B. M. Durst, and E. D. Clayton, "Criticality Experiments with Subcritical Clusters of 2.35 wt% ^{235}U-UO_2 Rods in Water with Uranium or Lead Reflecting Walls," NUREG/CR-0796, U.S. Nuclear Regulatory Commission, March 1979.

6.5-5 Bierman, S. R., B. M. Durst, and E. D. Clayton, "Critical Separation between Subcritical Clusters of Low-Enriched UO_2 Rods in Water with Fixed Neutron Poisons," *Nuclear Technology*, Vol. 42, March 1979.

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CHAPTER 7
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7. OPERATING PROCEDURES

7.1 Procedure for Loading the Packaging

This section describes the general procedure for loading spent fuel into the casks. Any non-compliances as defined in 10 CFR Part 71.95 shall be reported within 30 days to the Director, Office of Nuclear Material Safety and Safeguards, US NRC, Washington, DC 20555.

7.1.1 Wet Loading at the Reactor Site

Each reactor site will normally use wet loading. Each site has different facilities, pool size, handling procedures, and administrative requirements.

7.1.1.1 Receipt Inspection

1. Document the receipt of the empty cask.
2. Conduct a radiation dose survey to verify compliance with 10 CFR Part 71.47. Conduct a contamination survey of the trailer and personnel barrier to verify compliance with 10 CFR Part 71.87(i).
3. Retract the personnel barrier; it remains on the trailer.
4. Perform contamination survey of accessible cask surfaces; complete the survey as the remaining areas become accessible to verify compliance with 10 CFR Part 71.87(i).
5. Inspect cask and trailer for damage.

7.1.1.2 Remove Cask from Trailer

1. Drive trailer into facility. Set brakes and block wheels during uprighting of the cask if the facility crane can be moved toward the rear tiedowns. If the crane cannot move all the way above the rear tiedowns, the trailer will have to move during uprighting.
2. Install a lifting sling on the impact limiters. Loosen the impact limiter attachment bolts and remove bottom and top impact limiters, using a crane, and store them on the trailer. Each impact limiter weighs 2000 lb. Use a load cell to ensure that only the weight of the impact limiter is being raised.
3. Remove the front and rear tiedowns by loosening the tiedown bolts and rotating the tiedown clamp out of the way.
4. Engage the cask lifting yoke and the cask lifting trunnion sockets near the top of the cask.

5. Raise the cask to a vertical position on the rear trailer supports. Keep the crane cables vertical over the lifting trunnions while hoisting. The trailer may have to be moved during hoisting to keep the crane cables vertical.

6. Transfer the cask from the trailer to the decontamination and service pad. For utilities that require redundant lifting when transferring the cask to the refueling floor, use the redundant lifting fixture which connects the sister hook to the cask trunnions. Disengage the lifting yoke.

7.1.1.3 Preparation for Transferring Cask to Pool

1. Clean the cask of road dirt in preparation for loading into pool.

2. Remove the gas sample port and drain valve covers. Remove the drain port plug and install a drain port valve in the closed position. Open the drain valve. Back out the gas sample port until it hits the stop and install a vent with a drain line.

3. Loosen and remove the closure bolts; inspect bolts and replace if damaged. Insert the two yoke guide pins into the appropriate bolt holes.

4.[a] Using a lifting sling, remove closure and set it down. Sometime before or during cask loading, inspect the seals and seal surface on the cask closure flange for damage. The seals shall be replaced if they have nicks, cuts, scratches, or other damage that would adversely affect seal performance.

5. Sometime before cask loading, inspect the interior of the cask for debris and damage. Also ensure that the correct fuel support structure is in place, that the correct fuel spacers at the bottom of the cask cavity are in place (if needed), and that the shielding inserts are installed in the correct location (if required).

7.1.1.4 Cask Loading

1. Engage the lifting yoke to the in-pool lifting sockets. For utilities that require redundant lifting, attach the redundant lifting fixture to the yoke and the sister hook. Engage the redundant lifting fixture and the upper trunnions. Lift cask and slowly lower it to the bottom of the pool, filling it with water as it is lowered.

(a) Alternatively, the cask may be filled with water before the closure is removed on the refueling floor, or the closure may be removed after the cask is lowered into the pool.

2. Disengage and remove the lifting yoke and redundant lifting fixture, if applicable, and remove yoke from the pool.

3.[(b)] Load fuel elements into the cask. Carefully lower the fuel elements into the cask to avoid damaging the sealing surface or the FSS.

4. Attach the closure to the lifting yoke and engage the lifting yoke in the in-pool lifting sockets (and the redundant lifting fixture in the upper trunnions, if applicable). The yoke pins guide both the yoke and the closure onto the cask. Verify full yoke engagement by observation of the black indicator rod on each arm of the yoke. Visually confirm that the closure is seated in the cask body with the top of the closure approximately 1/8 in. above the top of the cask.

5. Raise the cask so that the closure is just above the pool surface. Verify that the closure is properly seated with the top surface of the closure just above the top of the cask.

6. Lubricate the threads, install and hand-tighten at least two of the closure bolts.

7. Raise the cask out of the pool, rinsing the yoke and the outside of the cask with clean water as it is being raised.

8. Set the cask down on the decontamination and service pad.

9. Disengage lifting yoke and closure lifting sling (and redundant lifting fixture, if applicable).

10. Remove the yoke guide pins. Lubricate the threads and install the remainder of closure bolts. Tighten all bolts in three passes to a torque of 235 ± 15 ft-lb as specified in the O.M. Manual. Verify that each bolt head is 1/4 in. below the closure surface to ensure proper bolt engagement.

11. Perform contamination survey and decontaminate cask to acceptable shipping levels, following 10 CFR Part 71.87(i).

12.[(c)] Remove the vent and connect an air supply (not to exceed 10 psig) to the gas sample port. Connect a drain line to the drain port valve. Drain the cask into the pool, using the air supply to assist in draining the cask and to

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(b) Identify the fuel to be loaded and verify that it has been established that the fuel meets the requirements of the Certificate of Compliance.

(c) Alternatively, the cask may be drained as it is being removed from the pool.

ensure that all the water has drained. Remove the air supply connection from the gas sample port. Close the drain valve. Remove the drain line and drain port valve and install the drain port plug.

13. Connect a vacuum system to the gas sample port. Vacuum dry the cask cavity to desired level by reducing the cavity pressure to below the vapor pressure, as defined in the O.M. Manual.

14. Use the vacuum pump to pull a vacuum. Attach a helium supply to the gas sample port. Fill the cask with helium to atmospheric pressure. Disengage the helium supply. Fully engage the gas sample port plug handtight.

15. Perform a leakage test on the gas sample port and drain valve. Connect a vacuum and leakage testing system to the quick-disconnects on the gas sample port and drain valve. Pull a vacuum on the void between the primary and secondary seals of the gas sample port, closure, and drain valve. Measure the pressure rise and show that there is no leakage, measured to a sensitivity of 1×10^{-3} std-cm^3/s. Reinstall the port covers.

7.1.1.5 Cask Shipment

1. Engage the lifting yoke to the lifting trunnion sockets. (If redundant lifting is required, attach the yoke to the in-pool lifting sockets and the redundant lifting fixture to the lifting trunnion sockets.)

2. Verify that the trailer has "GA-4 Trailer" stenciled on the main beam. Lift the cask and move it to the trailer loading area. (Remove the redundant lifting fixture, if applicable, and engage the yoke to the lifting trunnion sockets.) Set the cask down on the rear tiedowns of the trailer as indicated by the "bottom of cask" stenciled on the vertical support tube. Verify that "bottom of cask" is stenciled on the side of the cask that will rest on the trailer.

3. Lower the cask to a horizontal position on the trailer. Keep the crane cables vertical over the lifting trunnions while setting the cask down on the front tiedowns. The trailer may have to be moved during lowering to keep the crane cables vertical. Disengage the lifting yoke.

4. Engage the front and rear tiedowns.

5. Using a crane and lifting slings, install each impact limiter on the cask. Use the alignment marks on the cask and impact limiter to assist installation.

6. Tighten the impact limiter attachment bolts to a torque of 230 ± 15 ft-lb. Install tamper-indicating seals between tabs both on the impact limiters and on the cask body; apply appropriate labels.

7. Install personnel barrier over the cask and tie it down to the trailer.

8. Conduct a radiation dose survey to ensure compliance with 10 CFR Part 71.47. Conduct a contamination survey of the trailer (before the personnel barrier is closed) and personnel barrier to ensure compliance with 10 CFR Part 71.87(i).

9. Complete shipping documents and apply the required placards.

7.1.2 Dry Cask Loading

These procedures are for a facility where a hot cell is available for dry loading. For dry loading at a reactor, a transfer cask would be used to remove the spent fuel from the pool or dry storage cask and transfer it to the GA-4 cask for loading. The transfer cask would be designed to interface with the cask.

7.1.2.1 Receipt Inspection

1. Document the receipt of the empty cask.

2. Conduct a radiation dose survey to ensure compliance with 10 CFR Part 71.47. Conduct a contamination survey of the trailer and personnel barrier to ensure compliance with 10 CFR Part 71.87(i).

3. Retract the personnel barrier; it remains on the trailer.

4. Perform contamination survey of accessible cask surfaces, complete the survey as the remaining areas become accessible to ensure compliance with 10 CFR Part 71.87(i).

5. Inspect the cask and trailer for damage.

7.1.2.2 Remove Cask from Trailer

1. Drive trailer into facility. Set brakes, and block wheels during uprighting of the cask if the facility crane can be moved toward the rear tiedowns. If the crane cannot move all the way above the rear tiedowns, the trailer will have to move during uprighting.

2. Install a lifting sling on the impact limiters. Loosen the impact limiter attachment bolts and remove bottom and top impact limiters; store them on the trailer. Each impact limiter weighs 2000 lb. Use a load cell to ensure that only the weight of the impact limiter is being raised.

3. Remove the front and rear tiedowns by loosening the tiedown bolts and rotating the tiedown clamp out of the way.

4. Engage the cask lifting yoke and the cask lifting trunnion sockets near the top of the cask.

5. Raise the cask to a vertical position on the rear trailer supports. Keep the crane cables vertical over the lifting trunnions while hoisting. The trailer may have to be moved during hoisting to keep the crane cables vertical.

6. Remove the cask from the trailer and set it down on the facility transfer cart. Disengage the lifting yoke.

7.1.2.3 Preparation for Loading the Cask

1. Move the cask and transfer cart to the cask preparation area.

2. Clean the cask of road dirt in preparation for unloading.

3. Remove the cover of the gas sample port. Back out the gas sample port until it hits the stop.

4. Loosen and remove the closure bolts; inspect bolts and replace if damaged.

5. Install a closure lifting sling or lifting fixture, remove closure, and set it down. Sometime before or during cask loading, inspect the seals and seal surface on the cask closure flange for damage. The seals shall be replaced if they have nicks, cuts, scratches, or other damage that would adversely affect seal performance.

6. Sometime before cask loading, inspect the interior of the cask for debris and damage. Also ensure that the fuel support structure is in place, that the correct fuel spacers at the bottom of the cask cavity are in place (if needed), and that the shielding inserts are installed in the correct location (if required).

7. Re-install closure on the cask.

8. Move cask to the loading area under the hot cell.

7.1.2.4 Cask Loading

1. Position the cask under the hot cell loading port.

2. Mate the hot cell port collar to the cask.

3. Open the loading port after the seal between the port collar and the cask surface seal is confirmed.

4. Remove the closure with the facility grapple.

5.[d] Load the fuel elements into the cask cavity. Carefully lower the fuel elements into the cask to avoid damaging the sealing surface and FSS.

6. Install the closure on the cask, taking care not to damage the cask sealing surface.

7. Close the loading port.

8. Disengage the hot cell port collar.

9. Perform a radiation dose survey.

10. Move the cask to the preparation area.

11. Remove the closure lifting sling and/or lifting fixture.

12. Lubricate the closure bolt threads. Install and tighten the closure bolts in three passes to a torque of 235 ± 15 ft-lb as specified in the O.M. Manual. Verify that the bolt heads are 1/4 in. below the closure surface to ensure proper bolt engagement.

13. Attach a vacuum pump to the gas sample port and pull a vacuum. Attach a helium supply to the gas sample port. Fill the cask with helium to atmospheric pressure. Disengage the helium supply. Fully engage the gas sample port plug handtight.

14. Perform a leakage test on the gas sample and drain valve. Connect a vacuum and leakage testing system to the quick-disconnects on the gas sample and drain valve. Pull a vacuum on the void between the primary and secondary seals of the gas sample port, closure, and drain valve. Measure the pressure rise and show that there is no leakage, measured to a sensitivity of 1×10^{-3} std-cm^3/s. Replace the port covers.

15. Perform contamination survey and decontaminate cask to acceptable shipping levels, following 10 CFR Part 71.87(i).

16. Move the cask and transfer cart to the shipping area.

7.1.2.5 <u>Cask Shipment</u>

1. Engage the lifting yoke and the lifting trunnion sockets.

(d) Identify the fuel to be loaded and verify that it has been established that the fuel meets the requirements of the Certificate of Compliance.

2. Verify that the trailer has "GA-4 Trailer" stenciled on the main beam. Lift the cask and move it to the trailer loading area. Set the cask down on the rear tiedowns of the trailer as indicated by the "bottom of cask" stenciled on the vertical support tube. Verify that "bottom of cask" is stenciled on the side of the cask that will rest on the trailer.

3. Lower the cask to a horizontal position on trailer. Keep the crane cables vertical over the lifting trunnions while setting the cask down on the front tiedowns. The trailer may have to be moved during lowering to keep the crane cable vertical. Disengage the lifting yoke.

4. Engage front and rear tiedowns.

5. Using a crane and lifting sling, install each impact limiter on the cask. Use the alignment marks on the cask and impact limiters to assist installation.

6. Tighten the impact limiter attachment bolts to a torque of 230 ± 15 ft-lb. Install tamper-indicating seals between tabs both on the impact limiters and on the cask body; apply appropriate labels.

7. Install personnel barrier over cask and tie down to trailer.

8. Conduct a radiation dose survey to ensure compliance with 10 CFR Part 71.47. Conduct a contamination survey of the trailer (before the personnel barrier is closed) and then of the personnel barrier to ensure compliance with 10 CFR Part 71.87(i).

9. Complete shipping documents and apply the required placards.

7.2 Procedure for Unloading the Packaging

This section describes the general procedure for unloading spent fuel from the casks. Any non-compliances as defined in 10 CFR Part 71.95 shall be reported within 30 days to the Director, Office of Nuclear Material Safety and Safeguards, US NRC, Washington, DC 20555.

7.2.1 Dry Cask Unloading

7.2.1.1 Receipt Inspection

1. Document the receipt of the cask.

2. Conduct a radiation dose survey to ensure compliance with 10 CFR Part 71.47. Conduct a contamination survey of the trailer and personnel barrier to ensure compliance with 10 CFR Part 71.87(i).

3. Retract the personnel barrier; it remains on the trailer.

4. Perform contamination survey of accessible cask surfaces; complete the survey as the remaining areas become accessible to ensure compliance with 10 CFR Part 71.87(i).

5. Inspect cask and trailer for damage and anti-tamper seals for tampering.

7.2.1.2 Remove Cask from Trailer

1. Drive trailer into facility. Set brakes and block wheels during uprighting of the cask if the facility crane can be moved toward the rear tiedowns. If the crane cannot move all the way above the rear tiedowns, the trailer will have to move during uprighting.

2. Install a lifting sling on the impact limiters. Loosen the impact limiter attachment bolts and remove bottom and top impact limiters; store them on the trailer. Use a load cell to ensure that only the weight of the impact limiter is being raised. Each impact limiter weighs 2000 lb.

3. Remove the front and rear tiedowns by loosening the tiedown bolts and rotating the tiedown clamp out of the way.

4. Engage the cask lifting yoke and the cask lifting trunnion sockets near the top of the cask.

5. Raise the cask to a vertical position on the rear trailer supports. Keep the crane cables vertical over the lifting trunnions while hoisting. The trailer may have to be moved during hoisting to keep the crane cables vertical.

6. Remove the cask from the trailer and set it down on the facility transfer cart. Disengage the lifting yoke.

7.2.1.3 Preparation for Unloading the Cask

1. Move the cask and transfer cart to the cask preparation area.

2. Clean the cask of road dirt in preparation for unloading.

3. Remove the cover of the gas sample port. Back out the gas sample port until it hits the stop.

4. Connect to the gas sample port plug quick-disconnect a pressure gauge, a vacuum system and the facility off-gas process system. Check the cavity pressure. Depressurize the cavity, if required.

5. Untorque and remove the closure bolts.

6. Install a lifting sling and/or lifting fixture on the closure.

7. Move the cask to the unloading area under the hot cell.

7.2.1.4 Cask Unloading

1. Position the cask under the hot cell unloading port.

2. Mate the hot cell port collar to the cask.

3. Open the unloading port after the seal between the port collar and the cask surface is confirmed.

4. Remove the closure with the hot cell grapple.

5. Unload the fuel elements from the cask.

6. Install the closure on the cask, taking care not to damage the sealing surface.

7. Close the unloading port.

8. Disengage the hot cell port collar.

9. Perform a radiation dose survey to verify that all fuel elements have been removed.

10. Move the cask to the preparation area.

11. Remove the closure lifting sling or lifting fixture.

12. Lubricate the closure bolt threads. Install and tighten the closure bolts to a torque of 235 ± 15 ft-lb as specified in the O.M. Manual. Verify that the bolt heads are 1/4 in. below the closure surface to ensure proper bolt engagement.

13. Perform contamination survey and decontaminate cask to acceptable levels, following 10 CFR Part 71.87(i).

14. Move the cask and transfer cart to the shipping area.

7.2.1.5 Cask Shipment

1. Engage the lifting yoke in the lifting trunnion sockets.

2. Verify that the trailer has "GA-4 Trailer" stenciled on the main beam. Lift the cask and move it to the trailer loading area. Set the cask down on the rear tiedowns of the trailer, as indicated by the "bottom of cask" stenciled on the vertical support tube. Verify that "bottom of cask" is stenciled on the side of the cask that will rest on the trailer.

3. Lower the cask to a horizontal position on trailer. Keep the crane cables vertical over the lifting trunnions while setting the cask down on the front tiedowns. The trailer may have to be moved during lowering to keep the crane cables vertical. Disengage the lifting yoke.

4. Engage front and rear tiedowns.

5. Using a crane and lifting sling, install each impact limiters on the cask. Use the alignment marks on the cask and impact limiter to assist installation.

6. Tighten the impact limiter attachment bolts to a torque of 230 ± 15 ft-lb. Apply appropriate labels.

7. Install personnel barrier over cask and tie it down to trailer.

8. Conduct a radiation dose survey to ensure compliance with 10 CFR Part 71.47. Conduct a contamination survey of the trailer (before the personnel barrier is closed) and personnel barrier to ensure compliance with 10 CFR Part 71.87(i).

9. Complete shipping documents and apply the required placards.

7.2.2 Wet Cask Unloading

7.2.2.1 Receipt Inspection

1. Document the receipt of the cask.

2. Conduct a radiation dose survey to ensure compliance with 10 CFR Part 71.47. Conduct a contamination survey of the trailer and personnel barrier to ensure compliance with 10 CFR Part 71.87(i).

3. Retract the personnel barrier; it remains on the trailer.

4. Perform contamination survey of accessible cask surfaces and complete survey as the remaining areas become accessible to ensure compliance with 10 CFR Part 71.87(i).

5. Inspect cask and trailer for damage and anti-tamper seals for tampering.

7.2.2.2 Remove Cask from Trailer

1. Drive trailer into facility. Set brakes and block wheels during uprighting of the cask if the facility crane can be moved toward the rear tiedowns. If the crane cannot move all the way above the rear tiedowns, the trailer will have to move during uprighting.

2. Install a lifting sling on the impact limiters. Loosen the impact limiter attachment bolts and remove bottom and top impact limiters, store on the trailer. Use a load cell to ensure that only the weight of the impact limiter is being raised. Each impact limiter weighs 2000 lb.

3. Remove the front and rear tiedowns by loosening the tiedown bolts and rotating the tiedown clamp out of the way.

4. Engage the cask lifting yoke and the cask lifting trunnion sockets near the top of the cask.

5. Raise the cask to a vertical position on the rear trailer supports. Keep the crane cables vertical over the lifting trunnions while hoisting. The trailer may have to be moved during hoisting to keep the crane cables vertical.

6. Remove the cask from the trailer and set it down on the decon/service pad. For facilities that require redundant lifting when moving the cask, use the redundant lifting fixture which connects the sister hook to the cask trunnions. Disengage the lifting yoke.

7.2.2.3 Preparation for Transferring Cask to Pool

1. Clean the cask of road dirt in preparation for loading into the pool.

2. Remove the covers of the gas sample port and drain valve. Back out the gas sample port until it hits the stop. Remove the drain port plug and install a drain port valve in the closed position. Open the drain valve.

3. Connect a pressure gauge and the facility off-gas process system to the gas sample port plug quick-disconnect. Check the cavity pressure. Depressurize the cavity to atmospheric pressure, if required.

4.[e] Connect a water supply with a pressure gauge and relief valve to the drain port valve. Slowly fill the cask cavity with water, ensuring that the cavity pressure does not exceed MNOP, and vent the cavity gas to the facility off-gas process system.

5. Untorque the closure bolts and remove all but at least two.

7.2.2.4 Cask Unloading

1. Engage lifting yoke and cask lifting trunnion sockets. Attach the lifting yoke to the closure. For facilities that require redundant lifting when moving the cask, attach the redundant lifting fixture to the cask and the sister hook before engaging the lifting yoke.

2. Lift cask and slowly lower it into the pool until closure bolts are just above the water surface; remove the remaining two bolts.

3. Lower the cask to the bottom of the pool.

4. Disengage and remove the lifting yoke and closure from the pool.

5. Inspect the closure seals and replace any of them that has nicks, cuts, scratches, or other deformations that will adversely affect seal performance.

6. Remove the fuel.

7. Attach the closure to the lifting yoke and engage the lifting yoke and the lifting trunnions. The yoke pins guide both the yoke and the closure onto the cask. Verify full yoke engagement by observation of the black indicator rod on each arm of the yoke. Visually confirm that the closure is seated in the

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(e) Alternatively, the cask cavity could be filled with water through the drain port valve as the cask is being lowered into the pool.

cask body with the top of the closure approximately 1/8 in. above the top of the cask.

8. Raise the cask so that the closure is just above the pool surface. Verify that the closure is properly seated with the top surface of the closure just above the top of the cask.

9. Lubricate the threads, install and hand-tighten at least two of the closure bolts, on opposite sides of the cask.

10. Connect an air supply (not to exceed 10 psig) to the gas sample port.

11. Raise the cask out of the pool. Rinse the yoke and the outside of the cask as it is being raised with clean water.

12.[f] Connect a drain line to the drain port valve. Drain the cask, using the air supply to ensure that all the water has drained.

13. Set down cask on the decontamination and service pad after the cask is drained. Remove the air supply connection from the gas sample port.

14. Disengage lifting yoke and closure lifting sling.

15. Remove the yoke guide pins. Lubricate the threads and install the remainder of the closure bolts. Tighten all bolts in three passes to a torque of 235 ± 15 ft-lb as specified in the O.M. Manual. Verify that the bolt head is 1/4 in. below the cask surface to ensure proper bolt engagement.

16. Close the drain valve handtight. Remove the drain port valve and install the drain port plug. Fully engage the gas sample port plug handtight. Install port covers.

17. Perform contamination survey and decontaminate cask to acceptable shipping levels, following 10 CFR Part 71.87(i).

7.2.2.5 <u>Cask Shipment</u>

1. Engage the lifting yoke in the lifting trunnion sockets. (If redundant lifting is required, attach the yoke to the in-pool lifting sockets and the redundant lifting fixture to the lifting trunnion sockets.)

2. Verify that the trailer has "GA-4 Trailer" stenciled on the main beam. Lift the cask and move it to the trailer loading area. (Remove the redundant lifting

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(f) Alternatively, the cask could be drained after the cask is set down on the decon/service pad.

fixture, if applicable, and engage the yoke to the lifting trunnion sockets.) Set the cask down on the rear tiedowns of the trailer, as indicated by the "bottom of cask" stenciled on the vertical support tube. Verify that "bottom of cask" is stenciled on the side of the cask that will rest on the trailer.

3. Lower the cask to a horizontal position on trailer. Keep the crane cables vertical over the lifting trunnions while setting the cask down on the front tiedowns. The trailer may have to be moved during lowering to keep the crane cables vertical. Disengage the lifting yoke.

4. Engage front and rear tiedowns.

5. Using a crane and lifting sling, install each impact limiter on the cask. Use the alignment marks on the cask and impact limiters to assist installation.

6. Tighten the impact limiter attachment bolts to a torque of 230 ± 15 ft-lb as specified in the O.M. Manual. Apply appropriate labels.

7. Install personnel barrier over cask and tie down to trailer.

8. Conduct a radiation dose survey to ensure compliance with 10 CFR Part 71.47. Conduct a contamination survey of the trailer (before the personnel barrier is closed) and then of the personnel barrier to ensure compliance with 10 CFR Part 71.87(i).

9. Complete shipping documents and apply the required placards.

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7.3 Preparation of an Empty Package for Transport

The procedures for the shipment of an empty cask shall be in accordance with the following:

1. Verify that the cask cavity has been drained of water as directed in Section 7.2.2, Wet Cask Unloading.

2. Verify that the closure bolts are tightened to a torque of 235 ± 15 ft-lb. Ensure that port plugs are fully engaged and covers are installed.

3. Conduct a contamination and radiation dose survey. External radiation and removable contamination shall not exceed the limits of 49 CFR Part 173.427 (Ref. 7.3-1) or 10 CFR Part 71.87(i) and Part 71.47, as appropriate. Decontaminate if necessary.

4. Engage the lifting yoke and the lifting trunnion sockets. (If redundant lifting is required, attach the yoke to the in-pool lifting sockets and the redundant lifting fixture to the lifting trunnion sockets.)

5. Verify that the trailer has "GA-4 Trailer" stenciled on the main beam. Lift the cask and move it to the trailer loading area. (Remove the redundant lifting fixture, if applicable, and engage the yoke to the lifting trunnion sockets.) Set it down on the rear tiedowns of the trailer, as indicated by the "bottom of cask" stenciled on the vertical support tube.

6. Lower the cask to a horizontal position on trailer. Keep the crane cables vertical over the lifting trunnions while setting the cask down on the front tiedowns. The trailer may have to be moved during lowering to keep the crane cables vertical. Disengage the lifting yoke.

7. Engage front and rear tiedowns.

8. Using a crane and lifting sling, install each impact limiter on the cask.

9. Tighten the impact limiter attachment bolts to a torque of 230 ± 15 ft-lb as specified in the O.M. Manual.

10. Affix a label to the cask based on radiation readings and estimated residual contents according to 49 CFR Part 172.403.

11. Install personnel barrier over cask and tie down to trailer.

12. Conduct a radiation dose survey to ensure compliance with 10 CFR Part 71.47. Conduct a contamination survey of the trailer and personnel barrier to ensure compliance with 10 CFR Part 71.87(i).

13. Prepare all necessary shipping papers.

7.4 Appendix

7.4.1 References for Section 7.3

7.3-1 49 CFR Part 173, "Shippers — General Requirements for Shipments and Packagings," 1983.

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CHAPTER 8
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TABLES

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

This section describes all of the testing required on the GA-4 cask prior to its first use and is summarized in Table 8.1-1.

8.1.1 Visual Inspection

Both the inside and the outside of the cask shall be visually inspected before its first use. The purpose of this inspection is to check for obvious damage — such as deep dents or gouges, damaged lifting or tiedown trunnions, missing or loose bolts, and missing or damaged seals — and to ensure that the cask is properly cleaned and that it satisfies all requirements on the licensing drawings, including all non-destructive examinations.

The acceptance criteria are that (1) there are no deep dents or gouges; (2) there are no scratches on the sealing surface that could affect seal performance; (3) there is no dirt, grease, or debris in or on the cask; and (4) the cask is assembled according to the licensing drawings.

8.1.2 Structural and Pressure Tests

8.1.2.1 Trunnion and In-pool Lifting Socket Proof Loading. The purpose of this test is to show that the trunnions are adequately designed to lift the cask safely. Three tests will be performed: one to simulate lifting the cask by the upper trunnions when its axis is vertical, one to simulate lifting the cask by the in-pool lifting sockets in a direction parallel to the cask axis, and one to simulate lifting the cask by all four trunnions when its axis is horizontal. For the first two tests, a load of 79,500 lb is applied to each of the two upper trunnions and in-pool lifting sockets in a direction parallel to the cask axis. The load is equal to 300 percent of one-half of the combined weight of the cask (without impact limiters), contents, and water in the cavity (53,000 lb). This proof load is double the normal 150 percent since the lifting system is designed to double the normal factors of safety of a redundant lifting design. The lower two trunnions do not need to be proof-loaded in a direction parallel to the cask axis because they are not used for lifting in that direction. The load will be applied for a minimum of 10 minutes.

For the third test, a load of 20,625 lb is applied to each trunnion in a direction perpendicular to the cask axis and trunnion axis. This load is equal to 150 percent of one-quarter of the cask's design weight (55,000 lb). The load will be applied for a minimum of 10 minutes.

TABLE 8.1-1
ACCEPTANCE TESTS PRIOR TO FIRST USE

Test	Inspection and Test Criteria
Visual inspection	Inspect inside and outside of cask and components for damage
Trunnion and in-pool lifting socket proof loading	Proof-load 2 upper trunnions and separately 2 in-pool lifting sockets to 3 times (loaded cask weight + water in cavity – impact limiters) in cask axial direction
	Proof-load four trunnions to 1.5 times loaded cask weight in cask transverse direction
Pressure test	Pressure test at 1.5 times MNOP
Containment system fabrication verification leakage tests	1×10^{-7} std-cm^3/s air maximum allowable rate of leakage
Shielding integrity	Gamma scan of DU shield liner
Component tests	Ensure functional acceptability of all cask components

Following the tests, all trunnions and in-pool lifting sockets will be visually examined for any signs of cracking, yielding, or other damage, and all welds will be liquid-penetrant-examined, following ASME Code, Subsection NG 5233. The examination technique specified in ASME Code Section V, Article 6, and the acceptance criteria specified in NG 5350 shall be used.

8.1.2.2 Pressure Test. The purpose of the pressure test is to show that the cask containment boundary is capable of sustaining a maximum normal operating pressure of 45 psig without mechanical damage. As required by 10 CFR Part 71 paragraph 71.85(b), the pressure test is performed at 1.5 times MNOP (45 psig), i.e., 67.5 psig. The test shall be conducted and accepted according to ASME Code Section III, Div. 1, Subsection NB-6000.

First, the closure plate will be placed in position and the 12 closure bolts torqued in the sequence described in the Operations and Maintenance (O.M.) Manual. The cask will then be pressurized to 67.5 psig. A pressure gauge installed in the pressurizing line will be used to observe the charge pressure and any subsequent pressure decay. The pressurizing line valve shall be monitored to ensure that there is no leakage through the valve. The cask will be maintained at the test pressure for a minimum of 10 min prior to the leakage and pressure decay examination. The pressure will then be held for sufficient time to permit all joints, connections, and regions of high stress, such as thickness transition sections, to be examined for leakage. A pressure reading will be made and recorded to note any pressure decay.

8.1.3 Containment System Fabrication Verification Leakage Test

The purpose of the leakage test is to verify that the containment boundary leakage rate does not exceed the maximum allowable design leakage rate. The containment boundary includes the cask body (cask body wall, flange, and bottom plate), closure, closure bolts, gas sample port, drain valve, and primary O-rings. Leakage tests are required to show that all components of the containment boundary are leaktight. All cask body containment boundary welds will be leak tested during fabrication. The containment boundary seals — consisting of the inner of the two concentric closure O-ring seals and the inner of the two gas sample port and drain valve O-ring seals — will both be tested, using the gas sample port plug and drain valve.

8.1.3.1 Cask Body. A leakage test, following the procedures given in ASME Code Section V, Article 10 (using the hood method helium mass spectrometer technique), will be used to verify that the cask body containment boundary is leaktight. The test will be performed before the final weld on the cavity liner is made. Either the closure or a temporary substitute can be installed on the cask body. The test equipment shall be operated to verify that there are no defects in the cask body that allow helium to reach the detector. The maximum allowable leakage is 1×10^{-7} std-cm^3/s, and test procedure sensitivity must be equal to or greater than 5×10^{-8} std-cm^3/s.

8.1.3.2 O-ring Seals. The O-ring seals at the interface between (1) the closure and the seal flange, (2) the gas sample port and closure, and (3) the drain valve and lower plate shall be tested for leakage through the gas sample port plug and drain valve. A helium mass spectrometer test shall be performed. The test procedure must have a minimum sensitivity of 5×10^{-8} std-cm^3/s (air), and the maximum measured leakage shall not exceed 1×10^{-7} std-cm^3/s (air). The following test procedures shall be used:

Primary closure and gas sample port seals

1. With the gas sample port fully engaged, connect the helium mass spectrometer leak detector line to the gas sample port quick-disconnect. Evacuate the seal interspace and measure the background helium until it falls below 1×10^{-7} std-cm^3/s.

2. With the drain valve open, evacuate the cask cavity through an installed drain port valve.

3. Connect a helium source to the drain port valve and backfill the cask cavity to 1 atm.

4. Perform the leakage test immediately after backfilling the cask cavity with helium.

Drain valve seals

1. Remove helium from cask cavity through the drain port valve. Remove the drain valve and replace the seals. Reinsert and close the drain valve.

2. Connect the helium mass spectrometer leak detector to the drain valve quick-disconnect. Evacuate the seal interspace and measure the background helium until it falls below 1×10^{-7} std-cm^3/s.

3. With the gas sample port disengaged, evacuate the cask cavity through the gas sample quick-disconnect.

4. Connect a helium source to the gas sample quick-disconnect and backfill the cask cavity to 1 atm.

5. Perform the leakage test immediately after backfilling the cask cavity with helium.

8.1.4 Component Tests

All components that require testing will be tested to show that they operate according to their design requirements. Any component that does not perform according to its design requirements will be rejected and replaced.

8.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices. This cask does not require rupture discs. The gas sample port and drain valve perform a safety function when they are fully engaged in that they form a part of the containment boundary. However, a test is not required since the thermal and structural loading on them is insignificant and their design adequacy can be shown by analysis. The quick-disconnects attached to the gas sample port plug and drain valve are not part of the containment boundary and are used only for seal leakage testing, venting, vacuum drying, or inerting. The drain plug is not part of the containment boundary and is used only for shielding; therefore, it also does not need to be tested.

8.1.4.2 Gaskets. An acceptance test of the seals is not required other than the Containment System Fabrication Verification Leakage Test. Section 4.1.3 describes the successful design verification test that was performed on the ethylene propylene O-ring seals specified in the drawings in Section 1.3. The seals were tested in a test article (Section 4.5.1) with the same configuration as shown in the drawings in Section 1.3 and under conditions simulating the most severe service conditions under which the O-rings are to perform.

8.1.4.3 Miscellaneous. The impact limiters contain aluminum honeycomb with nominal crush strengths of 220 psi, 725 psi, and 1400 psi. Tests are required to verify that the nominal crush strength is within a range of plus or minus 12½% of the nominal value over a temperature range of –20°F to 200°F. The tests required are as follows:

- Qualification tests for each honeycomb type shall be performed at –20°F, room temperature (70°F), and 200°F, to establish the temperature effect on the crush strength of each honeycomb type.

- Verification tests of each production lot of honeycomb used shall be performed at room temperature (70°F). These tests together with the temperature effects established previously shall be used to verify the crush strength requirements.

The B_4C criticality poison that is inserted into drilled holes in the fuel support structure (FSS) is tested during fabrication to verify that its minimum density is equal to 98% of its theoretical density, or .0892 lb/in^3. In addition, during fabrication of the FSS, the minimum length of B_4C pellets (defined on the drawings in Section 1.3 for each hole in the FSS) is verified.

8.1.5 Tests for Shielding Integrity

The integrity of the cask's shielding will be determined during cask fabrication. The depleted uranium (DU) shield procurement specification requires that the fabricator perform a gamma scan to ensure that there are no shielding discontinuities. A continuous gamma scan will be performed at a scanning rate and grid spacing that will provide 100 percent inspection coverage. The source will be selected so that count rates are high enough to minimize statistical errors in counting and so that they significantly exceed the background count. The shielding effectiveness will be shown to be equivalent to 100 percent of the minimum DU wall thickness.

The shielding effectiveness of the steel portion of the cask wall is verified by requiring that the shell thicknesses meet the drawing dimensions.

The weight and dimensions of each neutron shield block will be checked during fabrication to ensure that they meet minimum requirements for shielding effectiveness. The hydrogen and boron content of each production lot will be determined to verify that it meets the minimum specification requirements.

8.1.6 Thermal Acceptance Tests

The thermal stress analysis discussed in Section 2.6 indicates that, because of the relatively low thermal gradients, the maximum thermal stresses are small. The material selected for the elastomer cask seals has an operating range of from −70° to 250°F, 300°F for 1000 hours, and 400°F for five hours. The worst-case normal condition temperatures are well within this range.

There is a temperature margin of 89°F between the neutron shield's softening point and the neutron shield's maximum operating temperature. The thermal analysis is sufficient to verify the cask's thermal performance.

The hypothetical thermal accident condition discussed in Chapter 3 shows that the seals will attain a maximum temperature of 365°F and will be above 250°F for only 5½ hours, both of which are also within the operating range of the elastomer. Accordingly, no thermal acceptance tests are required.

8.2 Maintenance Program

This section describes the scheduled maintenance operations required for the safe and efficient use of the GA-4 cask; detailed descriptions of the maintenance procedures will be provided in the O.M. Manual. The annual program, summarized in Table 8.2-1, shall have been performed within the preceding 12-month period before the cask is used. When the cask is not used for more than a year, the annual maintenance is not required until its next use.

8.2.1 Structural and Pressure Tests

Neither structural nor pressure tests are required as part of the normal maintenance program.

8.2.2 Leakage Tests

8.2.2.1 Containment System Periodic Verification Leakage Test. The two O-ring seals at the closure/seal/flange interface, the two O-ring seals on the gas sample port, and all primary and secondary drain valve and drain plug O-rings shall be replaced after the third use of the cask and before the containment system's periodic verification leakage test which is performed annually. To meet the containment criteria defined in Chapter 4, the cask shall have been tested within the preceding 12-month period before the cask is used. The test procedure must have a minimum sensitivity of 5×10^{-8} std-cm^3/s (air), and the maximum measured leakage of any primary seal shall not exceed 1.0×10^{-7} std-cm^3/s (air).

8.2.2.2 Containment System Assembly Verification Leakage Test. Before each shipment, a leakage test is required of the primary O-ring seals at the closure/seal/flange interface, the drain valve, and the gas sample port. This test is performed after final installation of the cask lid and final closure of the gas sample port and drain valve. A gas pressure rise test that shows there is no leakage, measured to a sensitivity of 1×10^{-3} std-cm^3/s (air), shall be performed.

8.2.3 Subsystem Maintenance

This section describes the inspection and replacement of package components. All replaced or repaired parts shall meet the same requirements as the original part, as specified in the fabrication drawing.

8.2.3.1 Fasteners. All fasteners shall be given a careful visual examination before each shipment. During the annual maintenance fasteners and threaded inserts shall be given a careful examination. Any fasteners with damaged heads or threads which affect the fastener performance such as broken threads or the torque wrench slips off the head, shall be replaced.

TABLE 8.2-1 ANNUAL MAINTENANCE PROGRAM	
Requirement	Inspection and Test
Visual inspection	Inspect cask and components to ensure that they are in unimpaired physical condition.
Subsystem maintenance	Inspect fasteners; impact limiters; neutron shield outer skin; gas sample port plug and drain valve and their quick-disconnects; and lifting and tiedown trunnions for damage. Replace wear surfaces if function is impaired.
Containment system periodic verification leakage test	Closure, drain valve, and gas sample port primary O-ring seals: 1.00×10^{-7} std-cm^3/s (air) allowable leakage rate; replace O-rings before test.

8.2.3.2 Impact Limiters. The exterior of the impact limiters shall be visually inspected before each shipment and during the annual inspection to ensure that they are in unimpaired physical condition, with the exception of superficial defects such as marks or dents.

8.2.3.3 Lifting and Tiedown Trunnions. The lifting and tiedown trunnions will be visually examined for damage upon the arrival of the cask at each destination. If a trunnion wear surface is found to have significant damage or excessive wear, the wear surfaces shall be replaced.

8.2.4 Valves and O-ring Seals on the Containment Vessel

8.2.4.1 Gas Sample Port. The gas sample port assembly and the associated plug shall be disassembled and given a careful visual examination as part of the annual inspection and maintenance program.

O-ring seals shall be replaced and any damaged parts shall be repaired or replaced if their performance has been affected. Repaired or replaced parts shall meet the same requirements as the original part, as specified in the fabrication drawing.

8.2.4.2 Drain Valve and Drain Plug. The drain valve and drain plug shall be disassembled and given a careful visual examination as part of the annual inspection and maintenance program. O-rings shall be replaced, and damaged parts shall be repaired or replaced if their performance has been affected. Repaired or replaced parts shall meet the same requirements as the original part, as specified in the fabrication drawing.

8.2.4.3 Closure O-ring Seals. The closure O-ring seals shall be replaced before the containment system periodic verification leakage test. Replacement of O-ring seals shall be in accordance with the specifications in the fabrication drawing.

8.2.5 Shielding

The depleted-uranium gamma shield does not require any planned maintenance.

The neutron shield cavity shall be checked annually for leaks and presence of moisture. One of the fuse plugs is removed and used for the check. If a leak is detected, the leak location shall be found and repaired. If there is moisture in the cavity, the cavity shall be vacuum-dried and resealed.

8.2.6 Thermal

Due to the very low thermal gradient and the passive cooling of the cask, no thermal tests are required as part of the planned maintenance.

8.2.7 Miscellaneous

The exterior of the package shall be inspected before each shipment and during the annual inspection to ensure that the package is in an unimpaired physical condition, with the exception of superficial defects such as marks or dents. More specific criteria will be included in the O.M. Manual.

No other planned inspection or maintenance is required.

CHAPTER 9
TABLE OF CONTENTS

TABLES

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9. QUALITY ASSURANCE

9.1 Introduction

This chapter identifies the overall quality assurance program requirements for the design, procurement, fabrication, testing, operation, repair, and maintenance of the GA-4 legal weight truck (LWT) cask development program. The preceding chapters of this report provide full information regarding environmental testing and design. The requirements of 10 CFR Part 71, Subpart H (Ref. 9.1-1); NRC Regulatory Guide 7.10 (Ref. 9.1-2); ASME NQA-1 (Ref. 9.1-3); and 10 CFR Part 21 (Ref. 9.1-4); are implemented through this program, as are the requirements of pertinent sub-tier documents identified in Section 9.2.

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9.2 Quality Assurance Program

An effective integrated quality assurance (QA) program has been established and documented and is being maintained and executed for the project. This program applies to design, procurement, fabrication, handling, shipping, storage, cleaning, assembly, inspection, testing, operation, repair, and maintenance. This section defines the elements of the GA quality assurance program.

GA has the ultimate responsibility for ensuring that satisfactory in-service performance is achieved. Documented provisions exist for extending the quality assurance requirements (including quality control aspects) to sub-tier suppliers at all levels for the establishment and implementation of quality assurance programs equivalent to those described in this report.

The users have full responsibility for the operation, repair, and maintenance, which includes ensuring that the required QA program, as identified in Section 9.1, is established, implemented, and maintained.

Sub-tier suppliers' quality performance shall be monitored and evaluated. These measures include

1. Development and submission of quality plans specifically tailored to the contracted activities for review and approval by the buyer's quality organization.

2. Post-award and progress meetings with suppliers' management personnel to establish mutual understanding of the procurement quality requirements and to discuss past and future performance and plans.

3. Review of supplier-generated documentation to ensure that requirements are properly translated from design documents.

4. Verification of activities such as surveillance and inspections at suppliers' facilities, on both a random and a hold-point basis.

5. Assignment of resident quality assurance representatives to perform surveillance during critical periods of fabrication.

6. Review of supplier-generated records, as well as their collection, storage, and maintenance.

7. Participation in the disposition of nonconforming items and formulation of corrective actions to prevent recurrence.

8. Quality audits to formally verify compliance with procurement quality requirements.

9. Verification at sub-tier suppliers' facilities that the suppliers are adequately monitoring and evaluating their quality performance in a like manner.

In addition, the manufacturing, inspection, and testing program shall include the following types of information as appropriate:

1. A listing of inspections that the inspector or representative is required to perform, and a listing of the tests to be witnessed.

2. The inspection method to be used in determining compliance where the method is special or nonstandard.

3. Qualitative and quantitative acceptance criteria.

4. Verification of conformance of the Certified Material Test Report and related documents with the material specification and additional code requirements.

5. Verification of heat numbers, manufacturing serial numbers, document numbers, and other identification systems used when product traceability is a requirement.

6. Verification that operations of the manufacturing, inspection, and test plans have been completed, that data have been properly recorded, and that necessary documentation has been submitted and is acceptable.

7. Verification of packaging, preservation, handling, and shipping methods in accordance with the approved requirements.

8. Verification that special processes — including welding, cleaning, and nondestructive examination — are controlled and accomplished by qualified personnel, using qualified procedures and equipment.

The GA quality assurance program, as described in Ref. 9.2-1 and Table 9.2-1, has been accepted by the NRC for gas-cooled reactor and radioactive material transportation package programs (Ref. 9.2-2). Table 9.2-2 outlines the elements of this generic program corresponding to the criteria in 10 CFR Part 71, Subpart H, and ASME NQA-1.

NRC FORM 311
(2-83)

U. S. NUCLEAR REGULATORY COMMISSION

QUALITY ASSURANCE PROGRAM APPROVAL
FOR RADIOACTIVE MATERIAL PACKAGES

1. APPROVAL NUMBER: 0030
REVISION NUMBER: 5

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974, as amended, and Title 10, Code of Federal Regulations, Chapter 1, Part 71, and in reliance on statements and representations heretofore made in Item 5 by the person named in Item 2, the Quality Assurance Program identified in Item 5 is hereby approved. This approval is issued to satisfy the requirements of Section 71.101 of 10 CFR Part 71. This approval is subject to all applicable rules, regulations, and orders of the Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified below.

2. NAME: General Atomics

STREET ADDRESS: P.O. Box 85608

CITY	STATE	ZIP CODE
San Diego	CA	92186

3. EXPIRATION DATE: April 30, 1999

4. DOCKET NUMBER: 71-0030

5. QUALITY ASSURANCE PROGRAM APPLICATION DATE(S): November 3, 1993

6. CONDITIONS

Transportation and packaging activities conducted under applicable criteria of Appendix B of 10 CFR Part 50 to be executed in accordance with the latest revision of your NRC-approved Licensing Topical Report GA-LTR-11, Amendment 12 "General Atomics QA Program".

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

Dennis L. Reid for
John P. Jankovich
~~CHIEF~~ TRANSPORTATION BRANCH
DIVISION OF INDUSTRIAL AND MEDICAL NUCLEAR SAFETY
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

APR 14 1994
DATE

TABLE 9.2-1
GA QUALITY ASSURANCE PROGRAM

GA QUALITY ASSURANCE PROGRAM
REPORT: GA-A13010A

- APPROVED:

  10 CFR PART 50 APPENDIX B, AND
  10 CFR PART 71, SUBPART H, ACTIVITIES

GA QUALITY ASSURANCE MANUAL

- STATES POLICIES, RESPONSIBILITIES, AND PROCEDURES FOR PRODUCT QUALITY
- IMPLEMENTS THE REQUIREMENTS OF 10 CFR PART 71, SUBPART H; ASME N45.2; ASME CODE, SECTION III; AND ASME NQA-1
- SPECIFIC REQUIREMENTS DESCRIBED IN THE QUALITY PROCEDURES

QUALITY ASSURANCE PROGRAM DOCUMENT

- IMPLEMENTS THE SPECIFIC QA REQUIREMENTS FOR EACH PROJECT
- IDENTIFIES SPECIFIC PROCEDURES FROM THE QAM
- IDENTIFIES SPECIFIC PROCEDURES FROM THE PROGRAM/RESOURCES PROCEDURES MANUAL (PRPM)

GA-4 LWT CASK DEVELOPMENT PROGRAM

TABLE 9.2-2
GA IMPLEMENTING DOCUMENTS

Document[a]	Title	ASME NQA-1 10 CFR Part 71 Subpart H, Criterion	Remarks
QAM, QP1	Organization	I	Identifies organizations and their relationships in performance of activities affecting quality.
QAM, QP2	QA Program	II	Describes basic methods for establishing a documented quality assurance program that implements requirements of 10 CFR Part 71, Subpart H, and ASME NQA-1; and of contracts with customers.
QAM, QP3	Design Control	III	Describes design control measures established for structures, systems, and components to be delivered.
QAM, QP4	Procurement Document Control	IV	Describes procedures for ensuring that applicable regulatory requirements, design bases, and other requirements necessary to ensure adequate quality are suitably included or referenced in documents for procurement of material, equipment, and services.
QAM, QP5	Instructions, Procedures, and Drawings	V	Establishes measures for the preparation and implementation of detailed procedures for all organizational activities at GA that affect the requirements prescribed in the QAM.
QAM, QP6	Document Control	VI	Establishes measures to control the issuance of documents, and changes thereto, that prescribe requirements that establish or evaluate product quality; such documents are directly used as a basis for achieving or determining compliance of deliverable items with requirements.
QAM, QP7	Control of Purchased Items and Services	VII	Defines measures established to ensure that purchased material, equipment, and services conform to procurement documents.
QAM, QP8	Identification and Control of Items	VIII	Establishes measures used to identify and control materials, manufacturing parts, components, and assemblies within GA's scope of supply.
QAM, QP9	Control of Processes	IX	Describes measures used to control special processes such as welding, heat treatment, cleaning, and nondestructive examination.
QAM, QP10	Inspection	X	Establishes requirement that activities affecting the quality of deliverable items be inspected to verify their conformance with documented instructions, procedures, and drawings.

TABLE 9.2-2
GA IMPLEMENTING DOCUMENTS

Document[a]	Title	ASME NQA-1 10 CFR Part 71 Subpart H, Criterion	Remarks
QAM, QP11	Test Control	XI	Defines measures for control of tests performed prior to shipment to ensure that equipment will perform satisfactorily in service. (Does not apply to nonoperational tests such as hydrostatic, helium leak, radiographic, or other nondestructive tests. Such tests are controlled by the requirements of QP9.)
QAM, QP12	Control of Measuring and Test Equipment	XII	Describes requirements and procedures for calibrating, measuring, and testing equipment.
QAM, QP13	Handling, Storage, and Shipping	XIII	Establishes procedures and responsibilities for ensuring that proper methods, materials, and equipment are used in handling, preservation, storage, and shipping of products in compliance with applicable specifications and contractual requirements.
QAM, QP14	Inspection, Test, and Operating Status	XIV	Defines procedures and responsibilities for indicating inspection status of parts and materials throughout GA processing for contract end-item application.
QAM, QP15	Control of Non-conforming Items	XV	Establishes procedures and responsibilities for identification, segregation, review, and disposition of nonconforming parts and materials throughout GA processing for contract end-item application.
QAM, QP16	Corrective Action	XVI	Establishes requirements and procedures for corrective action within the GA quality assurance program.
QAM, QP17	Quality Assurance Records	XVII	Establishes measures for retention and retrieval of quality assurance records, defined as documents that furnish evidence of compliance of safety-related deliverable hardware and of activities affecting quality.
QAM, QP18	Audits	XVIII	Establishes requirements and procedures for audits to verify effectiveness of GA quality assurance.

[a]QAM = GA Quality Assurance Manual
QP = Quality Procedure

The following documents are pertinent to the GA-4 LWT cask development quality assurance requirements:

TABLE 9.2-3
PERTINENT QA DOCUMENTS

1. 10 CFR Part 71, Subpart H
2. NRC Regulatory Guide 7.10
3. 10 CFR Part 21
4. ASME NQA-1
5. ASME *Boiler and Pressure Vessel Code*, Sections II, III, V, IX, and XI
6. American Society for Nondestructive Testing Recommended Practice, SNT-TC-1A

Compliance with the quality assurance requirements has been verified by internal General Atomics audits and by DOE audits. There are no outstanding quality assurance issues.

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9.3 References for Sections 9.1 through 9.2

9.1-1 Code of Federal Regulations, Title 10, Part 71 (10 CFR Part 71), "Packaging and Transportation of Radioactive Material," Subpart H — "Quality Assurance," current edition.

9.1-2 NRC Regulatory Guide 7.10, "Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material," June 1986.

9.1-3 ASME NQA-1, "Quality Assurance Program Requirements for Nuclear Facilities," 1989 edition, including all supplements.

9.1-4 Code of Federal Regulations, Title 10, Part 21 (10 CFR Part 21), "Reporting of Defects and Noncompliance," current edition.

9.2-1 "GA Quality Assurance Program," GA Report GA-A13010A, GA-LTR-11, Amendment 12, November 1993.

9.2-2 NRC Quality Assurance Program Approval for Radioactive Material Packages, Approval Number 0030, Rev. 5, expiration date April 30, 1999, Docket Number 71-0030.

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