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5.0 SHIELDING EVALUATION

Specific dose rate limits for individual casks in a storage array are not established by 10 CFR 72 [1]. Annual dose limit criteria for the independent spent fuel storage installation (ISFSI) controlled area boundary are established by 10 CFR 72.104 and 10 CFR 72.106 for normal conditions and for design basis accidents. These regulations require that, for an array of casks in an ISFSI, the annual dose to an individual outside the controlled area boundary must not exceed 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ during normal operations. For a design basis accident, the dose to an individual outside the controlled area boundary must not exceed 5 rem to the whole body. The ISFSI must be at least 100 meters from the owner controlled area boundary. In addition, the occupational dose limits and radiation dose limits established in 10 CFR Part 20 (Subparts C and D) [2] for individual members of the public must be met.

This chapter describes the shielding design and the analysis used to establish bounding radiological dose rates for the storage of various types of PWR and BWR fuel assemblies. The analysis shows that the Universal Storage System meets the requirements of 10 CFR 72.104 and 10 CFR 72.106 when the system is configured and used in accordance with the design basis established by this Safety Analysis Report.

The Universal Storage System compliance with the requirements of 10 CFR 72 with regard to annual and occupational doses at the owner controlled area boundary is demonstrated in Section 10.3 and 10.4.

5.1 Discussion and Results

The transfer cask is provided in either the Standard or Advanced configuration. Canister handling, fuel loading and canister closing are operationally identical for either transfer cask configuration.

The Standard and Advanced transfer casks have a radial shield comprised of 0.75 inch of low alloy steel, 4.00 inches of lead, 2.75 inches of solid borated polymer (NS-4-FR), and 1.25 inches of low alloy steel. An additional 0.625 inch of stainless steel shielding is provided, radially, by the canister shell. Gamma shielding is provided primarily by the steel and lead layers, and neutron shielding is provided primarily by the NS-4-FR. The transfer cask bottom shield design is a solid section of 7.5 inches of low alloy steel and 1.5 inches of NS-4-FR. The top shielding of the transfer cask is provided by the stainless steel canister shield and structural lids, which are 7 inches and 3 inches thick, respectively. In addition, 5 inches of steel is used as temporary shielding during welding, draining, drying, helium backfill, and other operations related to closing the canister. This temporary shielding is removed prior to storage.

The Advanced transfer cask incorporates a trunnion support plate that allows it to lift a heavier canister. The support plate has no significant shielding impact due to its location above the trunnion. The evaluations and results provided for the Standard transfer cask are, therefore, applicable to the Advanced transfer cask.

The vertical concrete cask radial shield design is comprised of a 2.5-inch thick carbon steel inner liner surrounded by 28.25 inches of concrete. Gamma shielding is provided by both the carbon steel and concrete, and neutron shielding is provided primarily by the concrete. As in the transfer cask, an additional 0.625 inch thickness of stainless steel radial gamma shielding is provided by the canister shell. The concrete cask top shielding design is comprised of 10 inches of stainless steel from the canister lids, a shield plug containing a 1-inch thickness of NS-4-FR or 1.5 inches of NS-3 and 4.1 inches of carbon steel, and a 1.5-inch thick carbon steel lid. Since the bottom of the concrete cask rests on a concrete pad, the cask bottom shielding is comprised of 1.75 inch of stainless steel from the canister bottom plate, 2 inches of carbon steel (pedestal plate) and 1 inch of carbon steel cask base plate. The base plate and pedestal base are structural components that position the canister above the air inlets. The cask base supports the concrete cask during lifting, and forms the cooling air inlet channels at the cask bottom. An optional carbon steel supplemental shielding fixture, shown in Drawing 790-613, may be installed to reduce the radiation dose rates at the air inlets.

The spent fuel that may be stored in the Universal Storage System is divided into 5 classes, three PWR and two BWR, depending on the length of the fuel assembly. The transportable storage canister, transfer cask, and vertical concrete cask are provided in 5 lengths, corresponding to the lengths of the fuel assemblies.

The designs for PWR and BWR fuel are similar, but differ slightly in the design of the basket structure. The shielding analysis is based on the use of bounding dose rates for the design basis PWR and BWR fuel assembly, and its associated canister, transfer cask, and concrete cask.

The design basis PWR fuel for the shielding evaluation of the standard transfer cask and vertical concrete cask is the Westinghouse 17×17 standard assembly with an average burnup of 40,000 MWD/MTU, an initial enrichment of 3.7 wt % ^{235}U, and a 5-year cooling time. The shielding design basis BWR fuel is a GE 9×9 assembly with a burnup of 40,000 MWD/MTU, an initial enrichment of 3.25 wt % ^{235}U, and a 5-year cooling time. The source term specification is provided in Section 5.2. The shielding evaluation for fuel having different burnups and initial enrichments is provided in Sections 5.4 and 5.5.

The design basis PWR and BWR fuel assemblies are determined by considering all assembly types intended for storage in the Universal Storage System, and identifying those assemblies expected to have the highest source terms based on initial loading of fuel and other operating factors. Then, detailed source descriptions of these selected assemblies are developed by using the SCALE SAS2H code [5]. The resulting source descriptions for each assembly type are employed in one-dimensional shielding calculations in order to identify bounding design basis assembly descriptions for both PWR and BWR assemblies on the basis of computed dose rates. Three-dimensional analyses of these design basis assemblies are then conducted to establish licensing basis dose rates.

The determination of design basis fuel descriptions on the basis of one-dimensional shielding analyses is a unique approach which captures the combined effects of fuel self-shielding, spectral differences between assembly source terms, the relative contributions from gamma and neutron sources, and the influence of cask shielding materials and geometry. The design basis is selected as the result of computed dose rates rather than from a single gross assembly characteristic such as source rate or initial heavy metal loading.

Shielding evaluations are performed for the transfer cask with both wet and dry canister cavities. The wet canister cavity condition occurs during the welding of the shield lid. During the welding of the structural lid, the canister cavity is assumed to be completely dry. Note that in the wet canister condition, the modeled water level is the base of the upper end fitting. Shielding evaluations for the concrete cask assume a dry cavity.

Dose rate profiles for the transfer cask and the vertical concrete cask are presented in Section 5.4.

Site-specific fuels, which may have configurations or parameters that are not considered in the design basis fuels, are described in Section 5.6. As described in Section 5.6, the site-specific fuels must either be shown to be bounded by the evaluation of the design basis fuel, or be separately evaluated to establish limits which are maintained by administrative controls.

5.1.1 Fuel Assembly Classification

5.1.1.1 PWR Fuel Assembly Classes

As discussed in Chapters 1.0 and 6.0 of this report, the PWR fuel assemblies to be stored in the vertical concrete cask are divided into three classes on the basis of similarity of their lengths. Of the PWR assemblies to be stored, the following four are selected for further analysis on the basis of their computed radiation source terms:

PWR Assembly Type	Class
Westinghouse 15×15 Std	Class 1
Westinghouse 17×17 Std	Class 1
Babcock & Wilcox 15×15 Mark B	Class 2
Combustion Engineering 16×16 System 80	Class 3

These assembly types represent candidate design basis assemblies. The design basis assembly is chosen by performing one-dimensional shielding calculations for each assembly type. The results of the one-dimensional analysis are used to identify the single limiting assembly type which is then used in subsequent detailed three-dimensional shielding calculations in order to determine bounding dose rates for the PWR case. Using this approach, the limiting assembly type is determined on the basis of actual computed dose rates, including factors such as fuel self-shielding and spectral effects, which would otherwise be ignored if the design basis were selected on the basis of source rates alone.

The candidate PWR fuel assemblies are analyzed on the basis of an assumed initial enrichment of 3.7 wt % ^{235}U, a burnup of 40,000 MWD/MTU, and a cooling time of 5 years. The initial enrichment assumed in the shielding analysis is significantly less than the criticality analysis design basis value of 4.2 wt % ^{235}U, so that the calculated neutron source rate bounds that of higher enrichment fuel, which may reach the design basis burnup of 40,000 MWD/MTU. This assumption produces a neutron source that is 30% higher than that calculated assuming a 4.2 wt % ^{235}U initial enrichment.

In addition, the source terms for each assembly type include bounding fuel and non-fuel hardware source terms associated with certain control components, including burnable poison clusters and power shaping elements specific to each fuel type. The source specifications for the design basis fuel are discussed in Section 5.2.

5.1.1.2 BWR Fuel Assembly Classes

On the basis of similarity of length, the BWR fuel assemblies to be stored in the vertical concrete cask are divided into two classes (Class 4 corresponds to BWR/2–3 assemblies and Class 5 corresponds to BWR/4–6 assemblies). In a manner similar to that employed in the PWR case, the following BWR assemblies are chosen as candidate design basis assemblies for the shielding analysis on the basis of their computed radiation source terms:

BWR Assembly Type	Class
GE 7×7 BWR/2–3 version GE-2b	Class 4
GE 8×8-2 BWR/2–3 version GE-5	Class 4
GE 8×8-4 BWR/2–3 version GE-8	Class 4
GE 7×7 BWR/4–6 version GE-2	Class 5
GE 8×8-2 BWR/4–6 version GE-5	Class 5
GE 8×8-4 BWR/4–6 version GE-10	Class 5
GE 9×9-2 BWR/4–6 version GE-11	Class 5

One-dimensional shielding calculations are performed for each assembly in order to identify a single assembly type as the design basis assembly for subsequent detailed three-dimensional shielding analysis. The candidate BWR fuel assemblies are analyzed on the basis of an initial enrichment of 3.25 wt % ^{235}U, a burnup of 40,000 MWD/MTU, and a cooling time of 5 years. The initial enrichment assumed in the shielding analysis is significantly less than the criticality analysis design basis value of 4.0 wt % ^{235}U, so that the calculated neutron source rate bounds that of higher enrichment fuel, which may reach the design basis burnup of 40,000 MWD/MTU. This assumption produces a neutron source that is 20% higher than that calculated assuming a 4.0 wt % ^{235}U initial enrichment.

5.1.2 Codes Employed

The SCALE 4.3PC [4] code system is used in the analysis of the vertical concrete cask and the transfer cask, with the MCBEND [23] code used to calculate dose rates at the concrete cask air inlets and outlets. Source terms are generated by using the SAS2H [5] sequence as described in

Section 5.2. One-dimensional radial and axial SAS1 [6] analyses are performed in order to identify design basis PWR and BWR fuel types. With these design basis source descriptions, detailed three-dimensional analyses are performed by using the SAS4 [3] Monte Carlo shielding analysis sequence and the MCBEND Monte Carlo code. Modifications to SAS4 permit computation of dose rate profiles along surface detectors. These changes are further described in Section 5.4.1.

The 27-group neutron, 18 group gamma, coupled cross-section library (27N-18COUPLE) [7] derived from ENDF/B-IV data is used in the concrete cask and standard transfer cask shielding evaluations. The MCBEND shielding evaluations use the 28-group and 22-group gamma energy structures embedded in the code. Source terms include fuel neutron, fuel gamma, and gamma contributions from activated hardware. The effects of subcritical neutron multiplication and secondary gamma production due to neutron capture are included in the analysis. Dose rate evaluations include the effect of axial fuel burnup variation on fuel neutron and gamma source terms as described in Section 5.2.6.

5.1.3 Results of Analysis

This section summarizes the results of the three-dimensional shielding analysis. Reported values are rounded up to the indicated level of precision. Due to the statistical nature of Monte Carlo analysis, all dose rate results are shown with the relative standard deviation in the result, expressed as a percentage.

5.1.3.1 Dose Rates for Vertical Concrete Cask

Cask Containing PWR Fuel

A summary of the maximum calculated dose rates for the concrete cask under normal and accident conditions is shown in Table 5.1-1 for the design basis PWR fuel. These dose rates are based on three-dimensional Monte Carlo analysis. Uncertainty in Monte Carlo results is indicated in parentheses. Under normal conditions with design basis fuel and the Transportable Storage Cask centered in the Vertical Concrete Cask, the concrete cask maximum side wall surface dose rate is 49 (<1%) mrem/hr at the fuel midplane and 56 (6%) mrem/hr on the top surface at locations on the cask top directly above the outlet vents. Since the concrete cask is vertical during normal storage operation, the cask bottom is inaccessible. The maximum surface dose rate at the lower air inlet openings is 136 (1%) mrem/hr with supplemental shielding and

694 (<1%) mrem/hr without supplemental shielding. The maximum surface dose rate at the air outlet openings is 63 (1%) mrem/hr. The average maximum inlet plus outlet dose rate is 99.5 mrem/hr with supplemental shielding.

The overall cask side average surface dose rate is 38 (<1%) mrem/hr for the PWR design basis fuel. On the cask top, the PWR average surface dose rate is 27 (2%) mrem/hr.

The postulated accident condition involves a projectile impact resulting in localized loss of 6 inches of concrete. The accident is analyzed assuming that the outermost 3 inches of concrete is lost from the entire outer surface of the cask. In this case, the surface average dose rate increases to 89 (<1%) mrem/hr with design basis PWR fuel. The maximum dose rate, assuming a 3-inch concrete loss over the entire radial surface of the cask, is 143 (3%) mrem/hr. At the postulated missile impact area, the estimated localized dose rate is less than 250 mrem/hr. There are no design basis accidents that result in a tip-over of the concrete cask.

Cask Containing BWR Fuel

Table 5.1-2 provides the maximum calculated dose rates for the concrete cask under normal and accident conditions for the design basis BWR fuel. As in the PWR case, these dose rates are based on three-dimensional Monte Carlo analysis. Uncertainty in Monte Carlo results is indicated in parentheses. Under normal conditions with design basis BWR fuel, the concrete cask maximum side surface dose rate is 31 (1%) mrem/hr at the fuel midplane and 43 (5%) mrem/hr on the top surface at locations directly above the air outlet structures. The dose rate at the air inlet opening is 129 (1%) mrem/hr with supplemental shielding and 645 (<1%) mrem/hr without supplemental shielding. The maximum surface dose rate at the air outlet openings is 55 (1%) mrem/hr.

Under accident conditions involving a projectile impact and an assumed 3 inches of concrete removed from the entire radial surface of the cask, the surface dose rate maximum increases to 85 (4%) mrem/hr with design basis BWR fuel. The radial surface average dose rate increases to 54 (<1%) mrem/hr and the cask surface dose rate for the localized loss of 6 inches of concrete is estimated to be less than 250 mrem/hr.

The overall cask side average surface dose rates are 23 (<1%) mrem/hr for the BWR design basis fuel. On the cask top, the BWR average surface dose rate is 20 (1%) mrem/hr.

5.1.3.2 Dose Rates for Transfer Cask

Transfer Cask Containing PWR Fuel

Maximum dose rates for the standard or advanced transfer cask with a wet and dry canister cavity are shown in Table 5.1-3 for design basis PWR fuel. Under wet canister conditions, the maximum surface dose rates with design basis PWR fuel are 259 (<1%) mrem/hr on the cask side and 579 (<1%) mrem/hr on the cask bottom. The cask side average surface dose rate under wet conditions is 137 (<1%) mrem/hr, and the bottom average surface dose rate is 258 (<1%) mrem/hr. Under dry conditions, the maximum surface dose rates are 410 (<1%) mrem/hr on the cask side and 819 (<1%) mrem/hr on the cask bottom. Cask average surface dose rates are 306 (<1%) mrem/hr on the side and 374 (<1%) mrem/hr on the bottom. In normal operation, the bottom of the transfer cask is inaccessible during welding of the canister lids.

During the lid welding operation, localized maximum surface dose rates occur at the canister periphery. Under wet canister conditions with a 5-inch temporary shield in place atop the shield lid, the maximum contact dose rate is 2,092 (4%) mrem/hr. This dose rate is highly localized to the narrow gap between the temporary shielding and the cask inner wall. At 1 meter above the top of the cask, the maximum dose rate is 320 (6%) mrem/hr. The surface average dose rate at the cask top surface is 579 (3%) mrem/hr under these conditions.

Under dry conditions with the shield lid and structural lid in place, and with no additional temporary shielding, the maximum surface dose rate is 715 (<1%) mrem/hr. The cask top average surface dose rate is 369 (2%) mrem/hr under these conditions.

Transfer Cask Containing BWR Fuel

Maximum dose rates for the standard or advanced transfer cask with a wet and dry canister cavity are shown in Table 5.1-4 for design basis BWR fuel. Under wet canister conditions, the maximum surface dose rates with design basis BWR fuel are 189 (<1%) mrem/hr on the cask side and 539 (<1%) mrem/hr on the cask bottom. The cask side average surface dose rate under wet conditions is 79 (<1%) mrem/hr, and the bottom average surface dose rate is 254 (<1%) mrem/hr. Under dry conditions, the maximum surface dose rates are 325 (<1%) mrem/hr on the cask side and 786 (<1%) mrem/hr on the cask bottom. Cask average surface dose rates are 228 (<1%) mrem/hr on the side and 379 (<1%) mrem/hr on the bottom. In normal operation, the bottom of the transfer cask is inaccessible during welding of the canister lids.

During the lid welding operation, localized maximum dose rates occur at the canister periphery. Under wet canister conditions with a 5 inch temporary shield in place atop the shield lid, the maximum surface dose rate is 1803 (4%) mrem/hr. This dose rate is highly localized to the narrow gap between the temporary shielding and the cask inner wall. At 1 meter above the top of the cask, the maximum dose rate is 314 (7%) mrem/hr. The surface average dose rate at the cask top surface is 466 (3%) mrem/hr under these conditions.

Under dry conditions with the shield lid and structural lid in place, and no additional temporary shielding, the maximum surface dose rate is 396 (<1%) mrem/hr. The cask top average surface dose rate is 222 (3%) mrem/hr under these conditions.

Table 5.1-1 Summary of Maximum Dose Rates: Vertical Concrete Cask with PWR Fuel

Condition	Source	Cask Surface (mrem/hr with relative uncertainty)				1 Meter From Surface (mrem/hr with relative uncertainty)			
		Side		Top		Side		Top	
Normal	Neutron	0.1	1%	0.3	14%	<0.1	<1%	5.3	1%
	Gamma	48.6	<1%	55.1	6%	25.2	<1%	8.0	7%
	Total	49.[2]	<1%	56.	6%	26.	<1%	14.	5%
Design Basis Accident	Neutron	0.3	10%	N/A[1]		0.1	2%	N/A[1]	
	Gamma	141.9	3%	N/A[1]		62.5	<1%	N/A[1]	
	Total	143.[3]	3%	N/A[1]		63.	<1%	N/A[1]	

1. No design basis accident impacts top dose rates.
2. At the fuel midplane. Without supplemental shielding, the air inlet dose rate is 694 (<1%) mrem/hr.
3. At the missile impact area.

Table 5.1-2 Summary of Maximum Dose Rates: Vertical Concrete Cask with BWR Fuel

Condition	Source	Cask Surface (mrem/hr with relative uncertainty)				1 Meter From Surface (mrem/hr with relative uncertainty)			
		Side		Top		Side		Top	
Normal	Neutron	0.2	<1%	0.2	19%	<0.1	<1%	3.2	2%
	Gamma	30.6	1%	42.2	5%	15.3	<1%	5.3	4%
	Total	31.[2]	1%	43.	5%	16.	<1%	9.	2%
Design Basis Accident	Neutron	0.5	8%	N/A[1]		0.2	1%	N/A[1]	
	Gamma	83.8	4%	N/A[1]		38.3	1%	N/A[1]	
	Total	85.[3]	4%	N/A[1]		39.	1%	N/A[1]	

1. No design basis accident impacts top dose rates.
2. At the fuel midplane. Without supplemental shielding, the air inlet dose rate is 645 (<1%) mrem/hr.
3. At the missile impact area.

Table 5.1-3 Summary of Maximum Dose Rates: Standard or Advanced Transfer Cask with PWR Fuel

		Cask Surface (mrem/hr with relative uncertainty)						1 Meter From Surface (mrem/hr with relative uncertainty)					
Condition	Source	Side		Top		Bottom		Side		Top		Bottom	
Normal Wet[1]	Neutron	0.1	8%	0.2	3%	0.3	2%	1.3	<1%	<0.1	2%	0.1	2%
	Gamma	258.7	<1%	2091.	4%	578.2	<1%	65.3	<1%	319.8	6%	266.4	<1%
	Total	259.	<1%	2092.	4%	579.	<1%	67.	<1%	320.	6%	267.	<1%
Normal Dry[2]	Neutron	12.6	2%	111.5	<1%	37.8	<1%	29.5	<1%	28.7	1%	10.0	<1%
	Gamma	397.2	<1%	603.4	<1%	781.1	<1%	126.5	<1%	278.3	<1%	365.5	<1%
	Total	410.	<1%	715.	<1%	819.	<1%	156.	<1%	307.	<1%	376.	<1%

[1] 5 inches of carbon steel temporary shielding, shield lid in position.
[2] Shield lid and structural lid in position, no additional temporary shielding.

Table 5.1-4 Summary of Maximum Dose Rates: Standard or Advanced Transfer Cask with BWR Fuel

		Cask Surface (mrem/hr with relative uncertainty)						1 Meter From Surface (mrem/hr with relative uncertainty)					
Condition	Source	Side		Top		Bottom		Side		Top		Bottom	
Normal Wet[1]	Neutron	<0.1	31%	<0.1	17%	<0.1	7%	2.3	<1%	<0.1	12%	<0.1	6%
	Gamma	188.2	<1%	1803.	4%	538.1	<1%	34.8	<1%	313.2	7%	258.5	<1%
	Total	189.	<1%	1803.	4%	539.	<1%	38.	<1%	314.	7%	259.	<1%
Normal Dry[2]	Neutron	152.3	<1%	62.1	1%	34.7	1%	53.5	<1%	16.3	2%	9.3	1%
	Gamma	171.8	1%	333.6	<1%	750.7	<1%	67.3	<1%	156.4	1%	360.3	<1%
	Total	325.	<1%	396.	<1%	786.	<1%	121.	<1%	173.	1%	370.	<1%

[1] 5 inches of carbon steel temporary shielding, shield lid in position.
[2] Shield lid and structural lid in position, no additional temporary shielding.

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5.2 Source Specification

The procedure used to identify a design basis fuel assembly for PWR and BWR fuel types is described in this section. Each of the candidate fuel assemblies described in Section 5.1.1 is represented in one-dimensional radial and axial models of the fully loaded cask. The results of this one-dimensional shielding analysis are then used to identify a limiting fuel design for PWR and BWR fuel types. The limiting fuel design is then used in the shielding evaluation of the standard transfer cask and vertical concrete cask.

The SAS2H code sequence [5] is used to generate source terms for the shielding analysis. This code sequence is part of the SCALE 4.3 code package [4] for the personal computer (PC). SAS2H includes an XSDRNPM [8] neutronics model of the fuel assembly and ORIGEN-S [9] fuel depletion and source term calculations. Source terms are generated for both UO_2 fuel and fuel assembly hardware. The hardware activation is calculated by light element transmutation using the incore neutron flux spectrum produced by the SAS2H neutronics model. The hardware is assumed to be Type 304 stainless steel with 1.2 g/kg ^{59}Co impurity. The effects of axial flux spectrum and magnitude variation on hardware activation are estimated by flux ratios determined from empirical data [15].

5.2.1 Design Basis Gamma Source

The fuel gamma source contains contributions from both fission products and actinides. The spectra are presented in the 18-group structure consistent with the SCALE 4.3 27N-18COUPLE cross-section library. The hardware gamma spectra contain contributions primarily from ^{60}Co due to the activation of Type 304 stainless steel with 1.2 g/kg ^{59}Co impurity and with minor contributions from ^{59}Ni and ^{58}Fe. The hardware gamma spectral distribution is determined by the irradiation of 1 kg of stainless steel in the incore flux spectrum produced by the SAS2H neutronics calculation.

The activated fuel assembly hardware source term magnitudes are found by multiplying the source strength from 1 kg by the total mass of steel and inconel in the plenum, upper end fitting, or lower end fitting regions, and by then multiplying this result by a regional flux activation ratio. This regional flux ratio accounts for the effects of both magnitude and spectrum variation on hardware activation. These ratios are determined from empirical data [15]. A flux ratio of 0.2 is applied to hardware regions directly adjacent to the active core region, i.e., upper plenum and lower end fitting (or lower plenum, if present), and a flux ratio of 0.1 is applied to hardware regions once removed from the active core region, i.e., upper end fitting region.

In evaluations using the SCALE package, spectra are presented in the 18-group structure consistent with the SCALE 4.3 27N-18COUPLE cross-section library. MCBEND evaluations employ the same spectra rebinned onto the 22-group structure inherent to the code, shown in Table 5.2-29.

5.2.2 Design Basis Neutron Source

Light water reactor spent fuel neutron sources result from actinide spontaneous fission and from (α,n) reactions. The isotopes ^{242}Cm and ^{244}Cm characteristically produce all but a few percent of the spontaneous fission neutrons and (α,n) source in PWR and BWR fuel. The next largest contribution is from (α,n) reactions in ^{238}Pu. The neutron spectra for each emission type are included in the ORIGEN-S nuclear data libraries of the SCALE 4.3 code package. The spectra are collapsed from the energy group structure of the data library into that of the SCALE 27-group neutron cross-section library [7].

In evaluations using the SCALE package, the spectra are collapsed from the energy group structure of the data library into that of the SCALE 27-group neutron cross-section library [7]. MCBEND evaluations employ the same spectra rebinned onto the 28-group structure inherent to the code, shown in Table 5.2-28.

Neutron shielding evaluations for fissile material must account for subcritical multiplication (neutron production) inside the system being evaluated. This subcritical multiplication may be taken into account either by directly calculating the additional neutron source during the Monte Carlo simulation, as done in MORSE, or by adjusting the input neutron source term or output dose result by a scale factor. The code module in MCBEND responsible for accelerating result convergence by importance biasing does not efficiently account for subcritical multiplication. Code biasing is set to optimize the speed at which cask surface dose rates are obtained. Thermal energy neutrons within the fuel region are not likely to escape the shielded storage system and tend to be biased out of the evaluation. However, the thermal neutrons account for a significant portion of the subcritical multiplication. Removing the thermal neutrons from the system by biasing for cask surface dose, therefore, undersamples the subcritical multiplication. To account for undersampling, neutron source rates are scaled by a subcritical multiplication factor based on the system multiplication factor, k_{eff}:

$$\text{Scale Factor} = \frac{1}{1-k_{eff}}$$

For dry cask conditions, the system k_{eff} is taken as 0.4, with a resulting scale factor of 1.67. The scale factor is applied in MCBEND input as a component to the source strength in Unit 15 (source strength).

5.2.3 PWR Fuel Assembly Descriptions

The radiation source in the Universal Storage System consists of 24 design basis PWR spent fuel assemblies. The design basis PWR fuel has an average burnup of 40,000 MWd/MTU, an initial enrichment of 4.2 wt % ^{235}U, and a post-irradiation cooling time of 5 years and includes source contributions from an activated burnable absorber assembly. However, to bound the neutron source produced by lower enrichment fuel which may achieve this burnup, the design basis PWR source terms are calculated with an initial enrichment of 3.7 wt % ^{235}U. This assumption produces a neutron source 30% higher than that obtained by assuming 4.2 wt % ^{235}U initial enrichment. Assembly power density and cycle parameters are selected such that the assembly is activated at a power level 5% greater than a typical PWR assembly to allow for assembly power peaking during core residence. This treatment results in conservatively higher source rates due to enhanced actinide production and a shorter activation period.

Source spectra and source region elevations are determined for the four major PWR fuel assembly types (see Table 5.2-1):

PWR Assembly Type	Class
Westinghouse 15×15 Std	Class 1
Westinghouse 17×17 Std	Class 1
Babcock & Wilcox 15×15 Mark B	Class 2
Combustion Engineering 16×16 System 80	Class 3

These assembly types are referred to by the abbreviated names given in Table 5.2-1. Based on their initial heavy metal loading, these assemblies produce the limiting source terms for the specified design basis burnup of 40,000 MWd/MTU. Fuel assembly physical characteristics are given in Table 5.2-2, and hardware masses are given in Table 5.2-3. The results of the source term analysis for the fuel types given here are summarized in Table 5.2-4. Fuel assembly activated hardware source terms are shown in Table 5.2-5. These non-fuel source terms are determined on the basis of the hardware source per kilogram given in Table 5.2-4 and the hardware masses given in Table 5.2-3. The hardware activation is based on a stainless steel Type 304 composition with an assumed ^{59}Co impurity level of 1.2 g/kg. A sketch of the WE 17×17 fuel assembly source region elevations is shown in Figure 5.2-5. Additional assembly detail is employed in the MCBEND assembly models. Three-dimensional parameters for the MCBEND fuel assembly model are shown in Table 5.2-27.

In order to account for spectral differences in the activating neutron flux, a flux ratio of 0.2 is applied to hardware regions directly adjacent to the active core region, i.e., the lower end-fitting and upper plenum. A flux ratio of 0.1 is applied to the upper end-fitting region, except for the CE 16×16 upper end-fitting for which a 0.05 flux ratio is used. The lower end fitting region in the BW 15×15 fuel assembly model uses a 0.1 flux ratio since the model explicitly includes a lower plenum region adjacent to the fuel region. This lower plenum region in the BW 15×15 assembly is activated with a 0.20 flux ratio. The ORIGEN-S code is used directly to calculate hardware activation spectra by activating the fuel assembly components in the SAS2H-calculated flux spectrum for each assembly type.

5.2.4 BWR Fuel Assembly Descriptions

The Universal Storage System can store up to 56 intact BWR fuel assemblies. BWR fuel is analyzed on the basis of 3.25 wt % ^{235}U initial enrichment, 40,000 MWd/MTU average burnup, and a post irradiation cooling time of 5 years. Assembly power density and cycle parameters are selected such that the assembly is activated at a power level 10% greater than a typical BWR assembly to allow for assembly power peaking during core residence. This treatment results in conservatively higher source rates due to enhanced actinide production and a shorter activation period.

Source term spectra and source region elevations are determined for the major BWR fuel assembly types (see Table 5.2-1):

BWR Assembly Type	Class
GE 7×7 BWR/2-3 version GE-2b	Class 4
GE 8×8 BWR/2-3 version GE-5, 2 water holes	Class 4
GE 8×8 BWR/2-3 version GE-10, 1 large water hole	Class 4
GE 7×7 BWR/4-6 version GE-2	Class 5
GE 8×8 BWR/4-6 version GE-5, 2 water holes	Class 5
GE 8×8 BWR/4-6 version GE-10, 1 large water hole	Class 5
GE 9×9 BWR/4-6 version GE-11, 2 water holes, 79 fuel rods	Class 5

These assembly types are referred to by the abbreviated names given in Table 5.2-1. The abbreviated name of each BWR class assembly includes a suffix designation indicating the reactor type. The "S" designation corresponds to BWR/2-3 class reactors, and the "L" designation corresponds to BWR/4-6 class reactors. The physical characteristics of the two classes of BWR fuel are given in Table 5.2-6 and Table 5.2-7. For fuel assemblies with an average burnup of 40,000 MWD/MTU, the fuel requires a minimum of 5 years of cooling after discharge to meet the radiation source rate values specified in Table 5.2-8 and Table 5.2-9. The GE BWR/2-3 8x8 fuel assembly designs are analyzed on the basis of a 144-inch active fuel length in order to provide a consistent basis for comparison with the other BWR/2-3 fuel assembly designs. The GE-2b version of the GE BWR/2-3 7x7 fuel assembly is selected over the older GE-2a design since it has been discharged more recently, although the GE-2a assembly has a marginally higher (0.4%) initial heavy metal loading. A sketch of the GE 9×9-2L fuel assembly source region elevations is shown in Figure 5.2-6. Additional assembly detail is employed in the MCBEND assembly models. Three-dimensional parameters for the MCBEND fuel assembly model are shown in Table 5.2-27.

5.2.5 Design Basis Fuel Assemblies

For the shielding analysis, the WE 17×17 and GE 9×9-2L fuel assembly types are selected as the design basis PWR and BWR fuel assemblies, respectively. These assembly designs are selected on the basis of the one-dimensional shielding analysis results for both the storage and standard transfer casks. Standard transfer cask results are presented in Table 5.2-10 through Table 5.2-15. Similar results are obtained for the storage cask one-dimensional analysis. To facilitate comparison, the results for each fuel assembly type are shown on a normalized basis relative to the design basis fuel assembly dose rates. With the exceptions discussed below, the computed dose rates vary over a narrow range.

In the PWR case, the inclusion of source terms from fuel assembly control components (i.e., burnable poison clusters) causes the WE 15×15 assembly to give slightly higher dose rates than the WE 17×17 assembly. However, the WE 17×17 is limiting with respect to dose rate delivered by fuel neutron and fuel gamma sources alone. Hence, in order to develop a single limiting fuel description, the WE 17×17 upper end-fitting and fuel hardware source rates are scaled to match the WE 15×15 values. This scaling results in a 35% increase in the WE 17×17 end-fitting source rate and a 17% increase in the fuel hardware source rate. Both of these source rate increases are considered in the SCALE and MCBEND evaluations. In the SCALE analysis, no corresponding adjustment is made to material smear densities; the MCBEND analysis takes credit for the additional self-shielding as shown by the activated hardware inventory in Table 5.2-30.

Five-year cooled source spectra for the PWR design basis WE 17×17 fuel assembly are shown in Table 5.2-16 through Table 5.2-18.

In the BWR case, the GE 7x7 BWR/2–3 and GE 7x7 BWR/4–6 fuel assembly types show the highest radial model dose rates. However, these assemblies are not considered as design basis assemblies because they are no longer in common use, and the U.S. spent fuel inventory does not contain a significant number of these assemblies with burnup, initial enrichment, and decay time combinations leading to source rates as high as those of the GE 9x9-2L [10].

In a manner similar to the PWR case, the GE 9x9-2L assembly represents the bounding case with respect to dose rate delivered by fuel neutron and fuel gamma sources, but the inclusion of additional non-fuel hardware sources leads to higher overall dose rates from the GE 8x8-4L assembly. Again, a bounding characterization is achieved by scaling the GE 9x9-2L upper end fitting, lower end fitting, and fuel hardware source terms to match the GE 8x8-4L values. As for the PWR models, both the SCALE and MCBEND analyses have scaled source terms, while the MCBEND analysis takes credit for the self-shielding of the additional mass as shown in Table 5.2-30. A summary of non-fuel hardware scale factors is provided in Table 5.2-24. These scale factors are included in the MCBEND analysis by increasing the activated mass as shown in Table 5.2-30.

Five-year cooled source spectra for the BWR design basis GE 9x9-2L fuel assembly are shown in Table 5.2-19 through Table 5.2-21.

5.2.6 Axial Profiles

5.2.6.1 Axial Burnup Profile

For PWR fuel with burnup exceeding 30 GWD/MTU, an enveloping axial burnup profile with a 1.08 uniform peaking factor can be justified on the basis of calculated PWR data from Seabrook Station and Maine Yankee and from measured Turkey Point gamma data [16,17,18,19,20]. This normalized enveloping shape is shown in Figure 5.2-1. A uniform burnup peaking factor of 1.08 is applied between 15% and 85% of core height. Above and below these elevations, the relative burnup/decay heat decreases linearly to 0.547 at the top and bottom of the active fuel region.

For BWR fuel with burnup exceeding 30 GWD/MTU, an enveloping burnup profile with a 1.22 maximum peaking factor can be justified on the basis of calculated BWR data from Washington Public Power BWR/4-6 data [21]. This normalized enveloping shape is shown in Figure 5.2-2. Uniform peaking factors of 1.22 and 1.18 are applied from 15% to 55% and from 55% to 80% of core height, respectively. Above and below these elevations, the burnup profile decreases linearly to 0.043 at the top and bottom of the active fuel region.

5.2.6.2 Axial Source Profile

In the three-dimensional analyses, axial radiation source rate profiles are related to the axial burnup profile described in the previous section. Source rates are assumed to vary with burnup according to:

$$S = aB^{b}$$

where "S" is the source rate for a particular radiation type, "B" is the burnup at a given axial elevation, "a" is a normalization factor, and "b" is the exponent given in Table 5.2-22 for each radiation type. The exponent "b" is determined from fits to SAS2H-computed source rates at various burnups for both PWR and BWR fuels. The numeric value of "a" is not computed explicitly.

Neutron source is not proportional to burnup. Therefore, the axially integrated source is not equal to the source at the average burnup. MCBEND directly applies the source profile as axial source scaling factors. By default, SAS4 normalizes the source profile, and the scaling factor is applied to the source magnitude. This scaling factor "r" relates the total source rate (SAS4 input parameter) to the source rate at the average burnup (as computed from SAS2H analyses).

$$r = \frac{\overline{S}}{S(\overline{B})} = \frac{\frac{a}{H}\int B^b dz}{a\overline{B}^b}$$

where "H" is the height of the fuel region. With the burnup profile normalized to unity, this becomes:

$$r = \frac{1}{H}\int B^b dz .$$

The integral is evaluated numerically by using the trapezoid rule, and the resulting scale factors are shown in Table 5.2-23 for PWR and BWR neutron source rates. The scale factor for gamma sources is 1.0 because the computed relation between gamma source rate and burnup is linear.

The fuel neutron and fuel gamma source rate profile for the design basis PWR fuel assembly is tabulated in Table 5.2-25 and shown graphically in Figure 5.2-3. Corresponding BWR profiles are given in Table 5.2-26 and Figure 5.2-4.

In the BWR case, the axial source profiles are asymmetric with respect to the fuel axial midplane. To ensure that the correct total source is modeled in each SAS4 half model, a scale factor is computed which relates the actual source rate in each half model to the total assembly source rate. These values are shown in Table 5.2-24. This scaling is necessary in order that cask features located near the top or bottom of the cask are modeled correctly.

The results of the one-dimensional dose rate calculations indicate that bounding, conservative PWR and BWR source descriptions are achieved by scaling the design basis WE 17×17 and GE 9x9-2L non-fuel hardware gamma source rates to match the corresponding WE 15×15 and GE 8x8-4L values, respectively. The SCALE evaluations perform a source rate scaling without the corresponding increase in mass; the MCBEND evaluations both increase the source and the associated mass. This scaling is only performed in the analysis of the standard transfer cask and the storage cask.

As a final remark, the scale factors given in Table 5.2-24 are actually applied in a post-processing step to the computed dose rate associated with each source region, rather than to the source rate itself. In this manner, all SAS1 and SAS4 input files are developed using consistent source rates.

Figure 5.2-1 Enveloping Axial Burnup Profile for PWR Design Basis Fuel

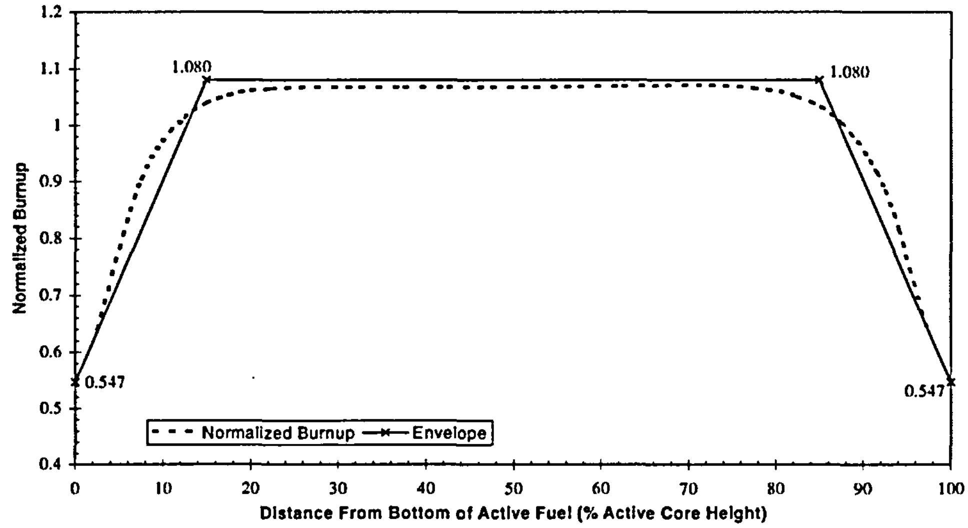


Figure 5.2-2 Enveloping Axial Burnup Profile for BWR Design Basis Fuel

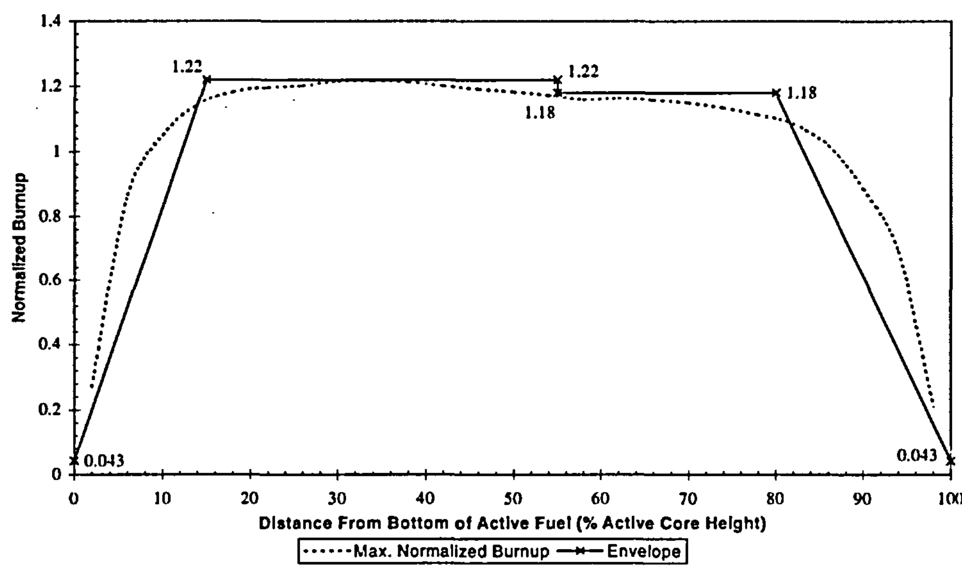


Figure 5.2-3 PWR Photon and Neutron Axial Source Profiles

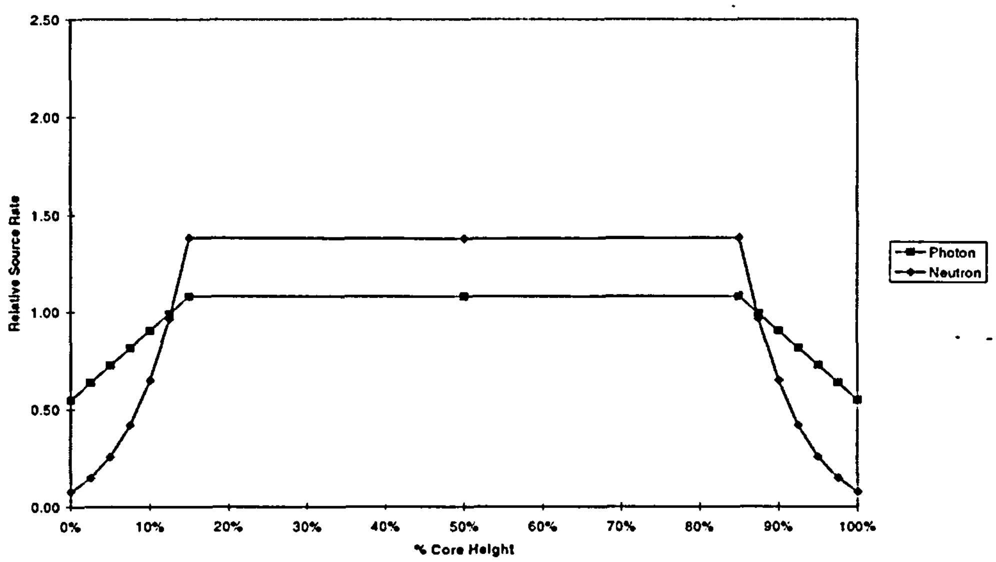


Figure 5.2-4 BWR Photon and Neutron Axial Source Profiles

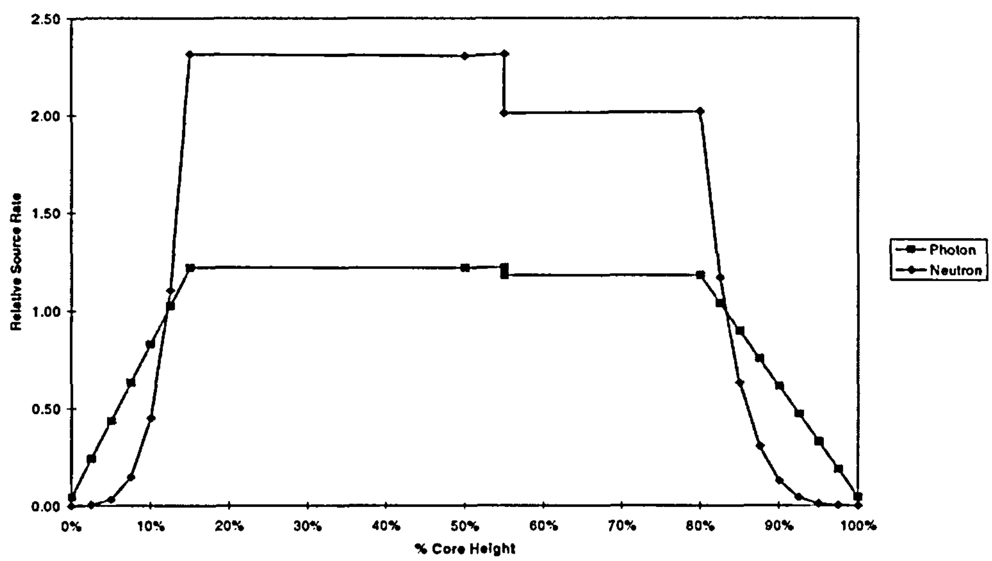
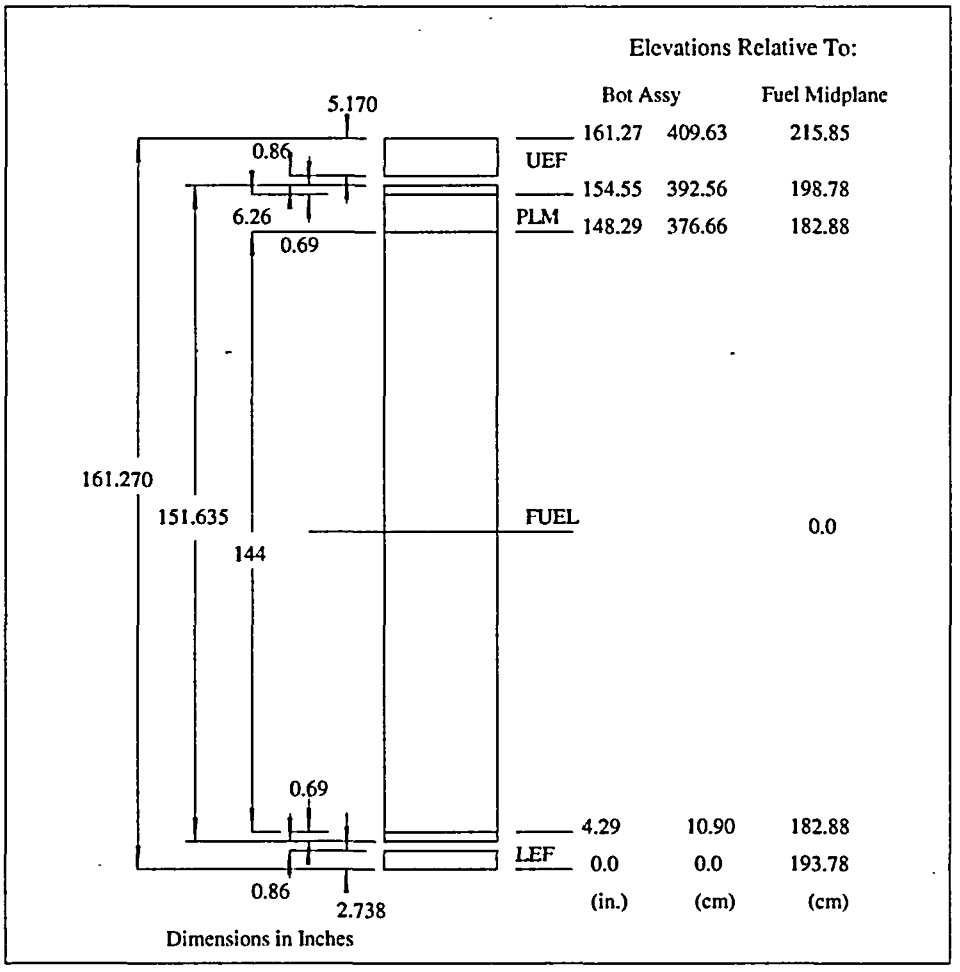


Figure 5.2-5 WE 17×17 Assembly Geometrical Parameters



UEF = Upper End Fitting Region
LEF = Lower End Fitting Region
PLM = Plenum Region

Figure 5.2-6 GE 9×9-2L Assembly Geometrical Parameters

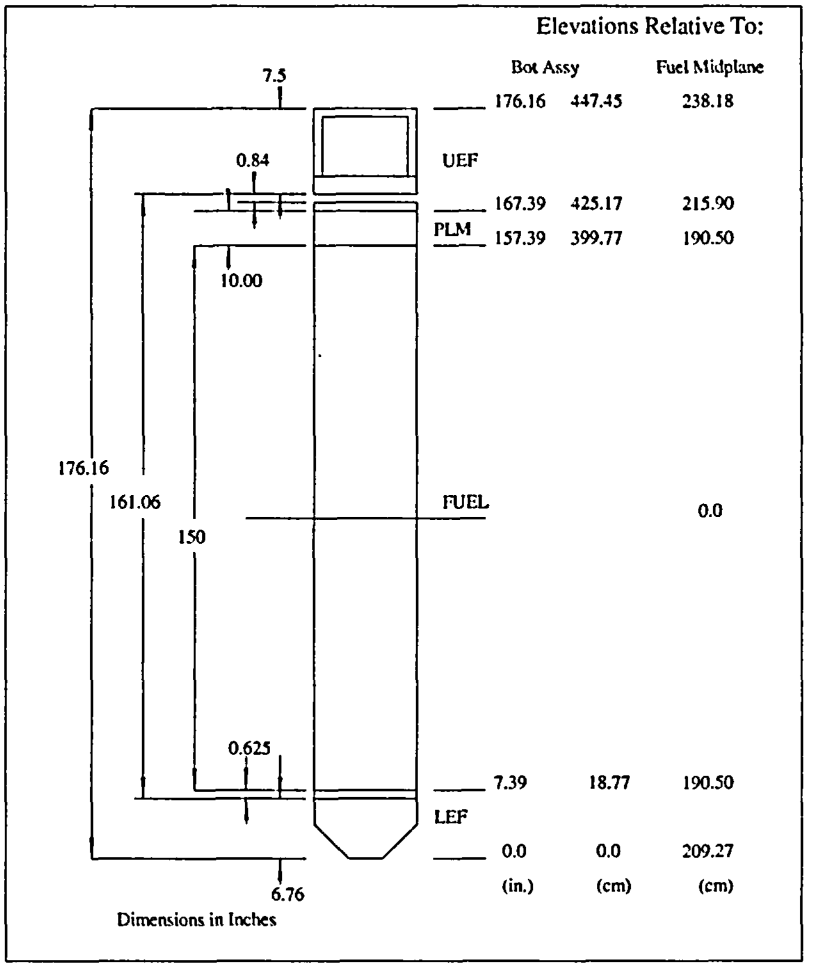


Table 5.2-1 Description of Design Basis Fuel Assembly Types

Fuel Type	Class	Description
WE 15×15	1	Westinghouse 15×15
WE 17×17	1	Westinghouse 17×17
BW 15×15	2	Babcock & Wilcox 15×15
CE 16×16	3	Combustion Engineering 16×16
GE 7×7S	4	General Electric 7×7 BWR/2-3 Reactor Type
GE 8×8-2S	4	General Electric 8×8 BWR/2-3 Reactor Type, 2 water holes
GE 8×8-4S	4	General Electric 8×8 BWR/2-3 Reactor Type, 1 water hole
GE 7×7L	5	General Electric 7×7 BWR/4-6 Reactor Type
GE 8×8-2L	5	General Electric 8×8 BWR/4-6 Reactor Type, 2 water holes
GE 8×8-4L	5	General Electric 8×8 BWR/4-6 Reactor Type, 1 water hole
GE 9×9-2L	5	General Electric 9×9 BWR/4-6 Reactor Type, 2 water holes, 79 fuel rods

Table 5.2-2 Representative Design Basis PWR Fuel Assembly Physical Characteristics

Fuel Parameter	WE 15×15 Std (Class 1)	WE 17×17 Std (Class 1)	BW 15×15 Mark B (Class 2)	CE 16×16 System 80 (Class 3)
Assembly Data				
Rod array	15×15	17×17	15×15	16×16
Assembly length, in[1]	161.27	161.27	170.75	178.25
Assembly width, in.	8.43	8.43	8.54	8.10
Active fuel length, in	144	144	144	150
Max U loading, kg	464.6	467.1	480.7	441.7
Assy power level, MW	16.28	18.48	16.49	16.59
Fuel temperature, K	900	900	900	900
Clad temperature, K	620	620	620	620
Moderator temperature, K	580	580	580	580
Fuel Rod Data				
No. of fuel rods	204	264	208	236
Rod pitch, in	0.563	0.496	0.568	0.506
Rod diameter, in	0.422	0.374	0.430	0.382
Cladding material	Zirc–4	Zirc–4	Zirc–4	Zirc–4
Cladding thickness, in	0.0242	0.0225	0.0265	0.0250
Pellet diameter, in	0.3659	0.3225	0.3686	0.3250
Init. Enrich, wt %	3.7	3.7	3.7	3.7
Guide Tube Data				
No. tubes	16	24	16	5
Tube diameter, in.	0.545	0.482	0.530	0.98
Tube thickness, in.	0.015	0.016	0.016	0.035
Tube material	Zirc	Zirc	Zirc	Zirc
Instrument Tube Data				
No. tubes	1	1	1	0
Tube diameter, in.	0.545	0.482	0.493	–
Tube thickness, in.	0.015	0.016	0.026	–
Tube material	Zirc	Zirc	Zirc	–

1. Fuel assembly length including burnable absorber rods or thimble plugs.

Table 5.2-3 Representative Design Basis PWR Fuel Assembly Hardware Data Per Assembly

Assembly Region	WE 15×15 Std (Class 1)	WE 17×17 Std (Class 1)	BW 15×15 Mark B (Class 2)	CE 16×16 System 80 (Class 3)
	Material Mass [kg/assembly]			
Upper End Fitting	Inconel/SS 11.80	Inconel/SS 7.85	Inconel/SS 10.76	Inconel/SS 15.90
Lower End Fitting	Inconel/SS 5.44	Inconel/SS 5.90	Inconel/SS 8.31	Inconel/SS 7.30
Upper End Fitting BP / Thimble Plug	SS 2.47	SS 2.95	SS 3.64	–
Upper Plenum Springs	Inconel 4.07	Inconel 4.43	Inconel 1.98	Inconel 10.70
Upper Plenum Grid	Inconel 1.07	Inconel/SS 0.88	Zirc 1.04	Zirc 0.82
Upper Plenum BP / Thimble Plug	SS 3.16	SS 3.16	SS 3.41	–
Lower Plenum Springs	–	–	Inconel 1.98	–
Lower Plenum Grid	–	–	Zirc 1.3	–
Incore Grid	Inconel/SS 8.06	Inconel/SS 5.44	Inconel 4.9	Zirc 7.35
Guide Tubes	Zirc 9.39	Zirc 9.53	Zirc 8.64	Zirc 11.3
Incore Burnable Poison (BP)	SS 11.39	SS 11.00	–	–

Table 5.2-4 Nuclear Parameters of Design Basis PWR Fuel Assemblies with 3.7 wt % ^{235}U Enrichment, 40,000 MWD/MTU Burnup, 5-Year Cooling Time

Assembly	Neutron Source [n/s]	Gamma Source [γ/s]	Hardware Source [γ/kg/s]
WE 15×15	1.985E+08	5.870E+15	6.919E+12
WE 17×17	1.984E+08	5.946E+15	7.005E+12
BW 15×15	1.961E+08	5.825E+15	6.925E+12
CE 16×16	1.872E+08	5.603E+15	6.951E+12

Table 5.2-5 Design Basis PWR Fuel Assembly Activated Hardware Comparison [γ/s], 5-Year Cooling Time

Fuel Type	Lower End-Fitting	Lower Plenum	Fuel Hardware	Upper Plenum	Upper End-Fitting
WE 15×15	7.528E+12	–	1.346E+14	1.149E+13	9.874E+12
WE 17×17	8.266E+12	–	1.151E+14	1.187E+13	7.565E+12
BW 15×15	5.755E+12	2.742E+12	3.393E+13	7.785E+12	9.813E+12
CE 16×16	1.015E+13	–	0.000E+00	1.488E+13	5.839E+12

Table 5.2-6 Representative Design Basis BWR Fuel Physical Characteristics

Assembly	GE 7×7		GE 8×8-2		GE 8×8-4		GE 9×9-2
BWR Reactor	2–3	4–6	2–3	4–6	2–3	4–6	4–6
Canister Class	4	5	4	5	4	5	5
Assembly Version	GE-2b	GE-2	GE-5	GE-5	GE-10	GE-10	GE-11
Assembly Data							
Assembly length, in.[2]	171.3	176.2	171.3	176.2	171.3	176.2	176.2
Assembly width, in.	5.44	5.44	5.44	5.44	5.44	5.44	5.44
Active fuel length, in.	144	144	144[1]	150	144[1]	150	150
Max U loading, kg	197.7	197.7	177.3[1]	184.7	171.7[1]	178.7	197.9
Assembly power, MW	3.85	4.95	3.85	4.95	3.85	4.95	4.95
Fuel temperature, K	840	840	840	840	840	840	840
Clad temperature, K	620	620	620	620	620	620	620
Moderator void frac	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Fuel Rod Data							
No. fuel rods	49	49	62	62	60	60	79
Rod pitch, in.	0.738	0.738	0.640	0.640	0.640	0.640	0.567
Rod diameter, in.	0.563	0.563	0.483	0.483	0.484	0.484	0.441
Cladding material	Zirc–2	Zirc–2	Zirc–2	Zirc–2	Zirc–4	Zirc–4	Zirc–4
Cladding thick, in.	0.032	0.032	0.032	0.032	0.032	0.032	0.028
Pellet diameter, in.	0.487	0.487	0.410	0.410	0.410	0.410	0.376

(1) Active fuel length normalized to 144 inches.

(2) Modeled assembly length standardized to 171.3 inches for BWR/2-3 fuel and 176.2 inches for BWR/4-6 fuel.

Table 5.2-7 Representative Design Basis BWR Fuel Assembly Hardware Data

Array	Reactor Type	Upper End Mass [kg]	Lower End Mass [kg]	Plenum Spring Mass [kg]	Incore Grid Mass [kg]	
					Zirc	Inconel
GE 7×7S	BWR/2–3	2.05	4.36	1.85	1.70	0.32
GE 7×7L	BWR/4–6	2.05	4.36	1.85	1.70	0.32
GE 8×8-2S	BWR/2–3	2.1	4.83	2.0	2.20	0.29
GE 8×8-2L	BWR/4–6	2.1	4.83	2.0	2.20	0.29
GE 8×8-4S	BWR/2–3	2.56	4.75	1.3	2.20	0.29
GE 8×8-4L	BWR/4–6	2.56	4.75	1.3	2.20	0.29
GE 9×9-2L	BWR/4–6	2.08	4.74	1.68	2.50	0.12

Table 5.2-8 Nuclear and Thermal Parameters of Design Basis BWR Fuel with 3.25 wt % ^{235}U Enrichment, 40,000 MWD/MTU Burnup, and 5-Year Cooling Time

Assembly	Reactor	Neutron Source [n/s]	Gamma Source [γ/s]	Hardware Source [γ/kg/s]
GE 7×7S	BWR/2–3	1.045E+08	2.227E+15	7.011E+12
GE 7×7L	BWR/4–6	1.055E+08	2.354E+15	7.518E+12
GE 8×8-2S	BWR/2–3	8.595E+07	2.029E+15	7.298E+12
GE 8×8-2L	BWR/4–6	9.016E+07	2.209E+15	7.698E+12
GE 8×8-4S	BWR/2–3	8.115E+07	1.974E+15	7.440E+12
GE 8×8-4L	BWR/4–6	8.474E+07	2.146E+15	7.824E+12
GE 9×9-2L	BWR/4–6	1.028E+08	2.347E+15	7.450E+12

Table 5.2-9 Design Basis BWR Fuel Assembly Activated Hardware Comparison [γ/s] at 40,000 MWD/MTU Burnup, 5-Year Cooling Time

Fuel Type	Reactor	Lower End-Fitting	Fuel Hardware	Upper Plenum	Upper End-Fitting
GE 7×7S	BWR/2–3	4.585E+12	2.243E+12	2.594E+12	1.437E+12
GE 7×7L	BWR/4–6	4.917E+12	2.406E+12	2.782E+12	1.541E+12
GE 8×8-2S	BWR/2–3	5.288E+12	2.117E+12	2.919E+12	1.533E+12
GE 8×8-2L	BWR/4–6	5.577E+12	2.232E+12	3.079E+12	1.616E+12
GE 8×8-4S	BWR/2–3	5.301E+12	2.158E+12	1.934E+12	1.905E+12
GE 8×8-4L	BWR/4–6	5.575E+12	2.269E+12	2.034E+12	2.003E+12
GE 9×9-2L	BWR/4–6	5.297E+12	8.940E+11	2.503E+12	1.550E+12

Table 5.2-10 Standard Transfer Cask One-Dimensional Top Axial Dose Rate Results Relative to PWR Design Basis

Fuel	Shield Lid Wet	Structural Lid Dry	Weld Shield Wet
WE 17×17	1.00	1.00	1.00
WE 15×15	0.85	0.89	0.85
CE 16×16	0.46	0.57	0.45
BW 15×15	0.74	0.78	0.78

Table 5.2-11 Standard Transfer Cask One-Dimensional Radial Dose Rate Results Relative to PWR Design Basis

Fuel	Dry Condition	Wet Condition
WE 17×17	1.00	1.00
WE 15×15	0.99	0.98
CE 16×16	0.69	0.59
BW 15×15	0.73	0.68

Table 5.2-12 Standard Transfer Cask One-Dimensional Bottom Axial Dose Rate Results Relative to PWR Design Basis

Fuel	Dry Condition	Wet Condition
WE 17×17	1.00	1.00
WE 15×15	0.96	0.95
CE 16×16	1.00	1.00
BW 15×15	0.63	0.59

Table 5.2-13 Standard Transfer Cask One-Dimensional Top Axial Dose Rate Results Relative to BWR Design Basis

Fuel	Shield Lid Wet	Structural Lid Dry	Weld Shield Wet
GE 9x9-2L	1.00	1.00	1.00
GE 8x8-4L	0.91	0.85	0.90
GE 8x8-4S	0.84	0.80	0.83
GE 8x8-2L	0.91	0.90	0.91
GE 8x8-2S	0.83	0.85	0.82
GE 7x7L	0.76	0.85	0.74
GE 7x7S	0.79	0.94	0.78

Table 5.2-14 Standard Transfer Cask One-Dimensional Radial Dose Rate Results Relative to BWR Design Basis

Fuel	Dry Condition	Wet Condition
GE 9x9-2L	1.00	1.00
GE 8x8-4L	0.90	0.94
GE 8x8-4S	0.85	0.86
GE 8x8-2L	0.95	0.97
GE 8x8-2S	0.90	0.89
GE 7x7L	1.04	1.03
GE 7x7S	0.98	0.94

Table 5.2-15 Standard Transfer Cask One-Dimensional Bottom Axial Dose Rate Results Relative to BWR Design Basis

Fuel	Dry Condition	Wet Condition
GE 9×9-2L	1.00	1.00
GE 8×8-4L	0.97	1.00
GE 8×8-4S	0.93	0.95
GE 8×8-2L	0.98	0.99
GE 8×8-2S	0.93	0.94
GE 7×7L	0.95	0.91
GE 7×7S	0.89	0.85

Table 5.2-16 Design Basis PWR 5-Year Fuel Neutron Source Spectrum

Group	E_{low} [MeV]	E_{high} [MeV]	Spectrum [n/sec/assy]
1	6.43E+00	2.00E+01	3.661E+06
2	3.00E+00	6.43E+00	4.163E+07
3	1.85E+00	3.00E+00	4.615E+07
4	1.40E+00	1.85E+00	2.598E+07
5	9.00E-01	1.40E+00	3.514E+07
6	4.00E-01	9.00E-01	3.832E+07
7	1.00E-01	4.00E-01	7.500E+06
8	1.70E-02	1.00E-01	0.000E+00
9	3.00E-03	1.70E-02	0.000E+00
10	5.50E-04	3.00E-03	0.000E+00
11	1.00E-04	5.50E-04	0.000E+00
12	3.00E-05	1.00E-04	0.000E+00
13	1.00E-05	3.00E-05	0.000E+00
14	3.05E-06	1.00E-05	0.000E+00
15	1.77E-06	3.05E-06	0.000E+00
16	1.30E-06	1.77E-06	0.000E+00
17	1.13E-06	1.30E-06	0.000E+00
18	1.00E-06	1.13E-06	0.000E+00
19	8.00E-07	1.00E-06	0.000E+00
20	4.00E-07	8.00E-07	0.000E+00
21	3.25E-07	4.00E-07	0.000E+00
22	2.25E-07	3.25E-07	0.000E+00
23	1.00E-07	2.25E-07	0.000E+00
24	5.00E-08	1.00E-07	0.000E+00
25	3.00E-08	5.00E-08	0.000E+00
26	1.00E-08	3.00E-08	0.000E+00
27	1.00E-11	1.00E-08	0.000E+00
Total			**1.984E+08**

Table 5.2-17 Design Basis PWR 5-Year Fuel Photon Spectrum

Group	E_{low} [MeV]	E_{high} [MeV]	Spectrum [γ/sec/assy]	Spectrum [MeV/sec/assy]
1	8.00E+00	1.00E+01	1.1222E+05	1.0100E+06
2	6.50E+00	8.00E+00	5.2856E+05	3.8321E+06
3	5.00E+00	6.50E+00	2.6947E+06	1.5495E+07
4	4.00E+00	5.00E+00	6.7148E+06	3.0217E+07
5	3.00E+00	4.00E+00	1.0245E+10	3.5858E+10
6	2.50E+00	3.00E+00	8.2534E+10	2.2697E+11
7	2.00E+00	2.50E+00	2.6257E+12	5.9078E+12
8	1.66E+00	2.00E+00	1.1070E+12	2.0258E+12
9	1.33E+00	1.66E+00	2.5755E+13	3.8504E+13
10	1.00E+00	1.33E+00	1.1513E+14	1.3413E+14
11	8.00E-01	1.00E+00	3.2879E+14	2.9591E+14
12	6.00E-01	8.00E-01	2.3388E+15	1.6372E+15
13	4.00E-01	6.00E-01	7.2421E+14	3.6211E+14
14	3.00E-01	4.00E-01	6.6148E+13	2.3152E+13
15	2.00E-01	3.00E-01	9.8414E+13	2.4604E+13
16	1.00E-01	2.00E-01	3.6058E+14	5.4087E+13
17	5.00E-02	1.00E-01	4.2971E+14	3.2228E+13
18	1.00E-02	5.00E-02	1.4544E+15	4.3632E+13
Total			**5.9458E+15**	**2.6537E+15**

Table 5.2-18 Design Basis PWR 5-Year Hardware Photon Spectrum

Group	E_{low} [MeV]	E_{high} [MeV]	Spectrum [γ/sec/kg]	Spectrum [MeV/sec/kg]
1	8.00E+00	1.00E+01	0.0000E+00	0.0000E+00
2	6.50E+00	8.00E+00	0.0000E+00	0.0000E+00
3	5.00E+00	6.50E+00	0.0000E+00	0.0000E+00
4	4.00E+00	5.00E+00	0.0000E+00	0.0000E+00
5	3.00E+00	4.00E+00	1.4997E-15	5.2490E-15
6	2.50E+00	3.00E+00	5.5445E+04	1.5247E+05
7	2.00E+00	2.50E+00	3.5757E+07	8.0453E+07
8	1.66E+00	2.00E+00	4.1887E+02	7.6653E+02
9	1.33E+00	1.66E+00	1.5067E+12	2.2525E+12
10	1.00E+00	1.33E+00	5.3355E+12	6.2159E+12
11	8.00E-01	1.00E+00	4.7463E+10	4.2717E+10
12	6.00E-01	8.00E-01	6.3039E+06	4.4127E+06
13	4.00E-01	6.00E-01	1.8179E+07	9.0895E+06
14	3.00E-01	4.00E-01	2.8721E+08	1.0052E+08
15	2.00E-01	3.00E-01	2.1890E+08	5.4725E+07
16	1.00E-01	2.00E-01	4.4085E+09	6.6128E+08
17	5.00E-02	1.00E-01	1.8273E+10	1.3705E+09
18	1.00E-02	5.00E-02	9.1992E+10	2.7598E+09
Total			**7.0049E+12**	**8.5161E+12**

Table 5.2-19 Design Basis BWR 5-Year Fuel Neutron Source Spectrum

Group	E_{low} [MeV]	E_{high} [MeV]	Spectrum [n/sec/assy]
1	6.43E+00	2.00E+01	1.902E+06
2	3.00E+00	6.43E+00	2.158E+07
3	1.85E+00	3.00E+00	2.384E+07
4	1.40E+00	1.85E+00	1.346E+07
5	9.00E-01	1.40E+00	1.823E+07
6	4.00E-01	9.00E-01	1.990E+07
7	1.00E-01	4.00E-01	3.895E+06
8	1.70E-02	1.00E-01	0.000E+00
9	3.00E-03	1.70E-02	0.000E+00
10	5.50E-04	3.00E-03	0.000E+00
11	1.00E-04	5.50E-04	0.000E+00
12	3.00E-05	1.00E-04	0.000E+00
13	1.00E-05	3.00E-05	0.000E+00
14	3.05E-06	1.00E-05	0.000E+00
15	1.77E-06	3.05E-06	0.000E+00
16	1.30E-06	1.77E-06	0.000E+00
17	1.13E-06	1.30E-06	0.000E+00
18	1.00E-06	1.13E-06	0.000E+00
19	8.00E-07	1.00E-06	0.000E+00
20	4.00E-07	8.00E-07	0.000E+00
21	3.25E-07	4.00E-07	0.000E+00
22	2.25E-07	3.25E-07	0.000E+00
23	1.00E-07	2.25E-07	0.000E+00
24	5.00E-08	1.00E-07	0.000E+00
25	3.00E-08	5.00E-08	0.000E+00
26	1.00E-08	3.00E-08	0.000E+00
27	1.00E-11	1.00E-08	0.000E+00
Total			**1.028E+08**

Table 5.2-20 Design Basis BWR 5-Year Fuel Photon Spectrum

Group	E_{low} [MeV]	E_{high} [MeV]	Spectrum [γ/sec/assy]	Spectrum [MeV/sec/assy]
1	8.00E+00	1.00E+01	5.8267E+04	5.2440E+05
2	6.50E+00	8.00E+00	2.7444E+05	1.9897E+06
3	5.00E+00	6.50E+00	1.3991E+06	8.0448E+06
4	4.00E+00	5.00E+00	3.4861E+06	1.5687E+07
5	3.00E+00	4.00E+00	3.5189E+09	1.2316E+10
6	2.50E+00	3.00E+00	2.8233E+10	7.7641E+10
7	2.00E+00	2.50E+00	7.8700E+11	1.7708E+12
8	1.66E+00	2.00E+00	3.7821E+11	6.9212E+11
9	1.33E+00	1.66E+00	9.9908E+12	1.4936E+13
10	1.00E+00	1.33E+00	4.8604E+13	5.6624E+13
11	8.00E-01	1.00E+00	1.2924E+14	1.1632E+14
12	6.00E-01	8.00E-01	9.5614E+14	6.6930E+14
13	4.00E-01	6.00E-01	2.7603E+14	1.3802E+14
14	3.00E-01	4.00E-01	2.4650E+13	8.6275E+12
15	2.00E-01	3.00E-01	3.7603E+13	9.4008E+12
16	1.00E-01	2.00E-01	1.3759E+14	2.0639E+13
17	5.00E-02	1.00E-01	1.6347E+14	1.2260E+13
18	1.00E-02	5.00E-02	5.6276E+14	1.6883E+13
Total			**2.3473E+15**	**1.0656E+15**

Table 5.2-21 Design Basis BWR 5-Year Hardware Photon Spectrum

Group	E_{low} [MeV]	E_{high} [MeV]	Spectrum [γ/sec/kg]	Spectrum [MeV/sec/kg]
1	8.00E+00	1.00E+01	0.0000E+00	0.0000E+00
2	6.50E+00	8.00E+00	0.0000E+00	0.0000E+00
3	5.00E+00	6.50E+00	0.0000E+00	0.0000E+00
4	4.00E+00	5.00E+00	0.0000E+00	0.0000E+00
5	3.00E+00	4.00E+00	1.2594E-15	4.4079E-15
6	2.50E+00	3.00E+00	5.9094E+04	1.6251E+05
7	2.00E+00	2.50E+00	3.8110E+07	8.5748E+07
8	1.66E+00	2.00E+00	3.2071E+02	5.8690E+02
9	1.33E+00	1.66E+00	1.6059E+12	2.4008E+12
10	1.00E+00	1.33E+00	5.6866E+12	6.6249E+12
11	8.00E-01	1.00E+00	3.4375E+10	3.0938E+10
12	6.00E-01	8.00E-01	6.7188E+06	4.7032E+06
13	4.00E-01	6.00E-01	1.9368E+07	9.6840E+06
14	3.00E-01	4.00E-01	3.0611E+08	1.0714E+08
15	2.00E-01	3.00E-01	2.3331E+08	5.8328E+07
16	1.00E-01	2.00E-01	4.6987E+09	7.0481E+08
17	5.00E-02	1.00E-01	1.9476E+10	1.4607E+09
18	1.00E-02	5.00E-02	9.8098E+10	2.9429E+09
Total			**7.4498E+12**	**9.0620E+12**

Table 5.2-22 Source Rate Versus Burnup Fit Parameters

Radiation Type	Exponent, *b*
Neutron	4.22
Photon	1.00

Table 5.2-23 SAS4 SCALE Factors Applied to Neutron Source Rate at Average Burnup

Fuel Type	Scale Factor
PWR	1.125
BWR	1.582

Table 5.2-24 Additional SCALE Factors Applied to Region Source Rates for SAS4 Analysis

Source Region	WE 17×17	GE 9×9-2L
Upper End Fitting	1.345	1.293
Upper Plenum	1.000	1.000
Top Fuel Neutron	1.000	0.887
Bot Fuel Neutron	1.000	1.113
Top Fuel Gamma	1.000	0.957
Bot Fuel Gamma	1.000	1.043
Fuel Hardware	1.169	2.538
Lower End Fitting	1.000	1.052

Table 5.2-25 PWR Axial Source Profile

% Core Height	Burnup Profile	Photon Source	Neutron Source
0.00%	0.5470	0.5470	7.840E-02
2.50%	0.6358	0.6358	1.479E-01
5.00%	0.7247	0.7247	2.569E-01
7.50%	0.8135	0.8135	4.185E-01
10.00%	0.9023	0.9023	6.481E-01
12.50%	0.9912	0.9912	9.633E-01
15.00%	1.0800	1.0800	1.384E+00
50.00%	1.0790	1.0790	1.378E+00
85.00%	1.0800	1.0800	1.384E+00
87.50%	0.9912	0.9912	9.633E-01
90.00%	0.9023	0.9023	6.481E-01
92.50%	0.8135	0.8135	4.185E-01
95.00%	0.7247	0.7247	2.569E-01
97.50%	0.6358	0.6358	1.479E-01
100.00%	0.5470	0.5470	7.840E-02

Table 5.2-26 BWR Axial Source Rate Profile

% Core Height	Burnup Profile	Photon Source	Neutron Source
0.00%	0.0430	0.0430	1.711E-06
2.50%	0.2392	0.2392	2.388E-03
5.00%	0.4353	0.4353	2.991E-02
7.50%	0.6315	0.6315	1.437E-01
10.00%	0.8277	0.8277	4.501E-01
12.50%	1.0238	1.0238	1.105E+00
15.00%	1.2200	1.2200	2.314E+00
50.00%	1.2190	1.2190	2.306E+00
55.00%	1.2200	1.2200	2.314E+00
55.01%	1.1800	1.1800	2.011E+00
80.00%	1.1810	1.1810	2.018E+00
82.50%	1.0379	1.0379	1.170E+00
85.00%	0.8958	0.8958	6.284E-01
87.50%	0.7536	0.7536	3.031E-01
90.00%	0.6115	0.6115	1.255E-01
92.50%	0.4694	0.4694	4.110E-02
95.00%	0.3272	0.3272	8.970E-03
97.50%	0.1851	0.1851	8.104E-04
100.00%	0.0430	0.0430	1.711E-06

Table 5.2-27 MCBEND Three-Dimensional Design Basis Fuel Assembly Descriptions

Parameter	WE17×17	GE9×9-2L
Fuel Rod Height [cm]	385.14	407.80
Top End-Cap Height [cm]	1.74	0.88
Bottom End-Cap Height [cm]	1.74	1.59
Active Fuel Region Height [cm]	365.76	381.00
Fuel Rod Diameter [cm]	0.95	1.12
Fuel Clad Thickness [cm]	0.06	0.07
Fuel Pellet Diameter [cm]	0.82	0.96
Fuel Rod Pitch [cm]	1.26	1.44
Number of Water Rods	----	2
Water Rod OD [cm]	----	1.12
Water Rod Thickness [cm]	----	0.07
Channel Inner Dimension [cm]	----	13.41
Channel Thickness [cm]	----	0.20
Number of Guide Tubes	24	----
Guide Tube OD [cm]	1.22	----
Guide Tube Thickness [cm]	0.04	----
Number of Instrument Tubes	1	----
Instrument Tube OD [cm]	1.22	----
Instrument Tube Thickness [cm]	0.04	----
Fuel Assembly Height [cm]	405.89	447.45
Fuel Assembly Width [cm]	21.40	14.02
Lower Nozzle Height [cm]	6.86	17.17
Upper Nozzle Height [cm]	9.32	19.05
Gap Fuel Rod to Top Nozzle [cm]	4.57	3.43
Upper Plenum Region Height [cm]	15.90	24.33
Number of Fuel Rods	264	79
Calculated MTU [MTU]	0.4671	0.1979

Table 5.2-28 MCBEND Standard 28 Group Neutron Boundaries

Group	E Lower [MeV]	E Upper [MeV]	E Average [MeV]
1	1.360E+01	1.460E+01	1.410E+01
2	1.250E+01	1.360E+01	1.305E+01
3	1.125E+01	1.250E+01	1.188E+01
4	1.000E+01	1.125E+01	1.063E+01
5	8.250E+00	1.000E+01	9.125E+00
6	7.000E+00	8.250E+00	7.625E+00
7	6.070E+00	7.000E+00	6.535E+00
8	4.720E+00	6.070E+00	5.395E+00
9	3.680E+00	4.720E+00	4.200E+00
10	2.870E+00	3.680E+00	3.275E+00
11	1.740E+00	2.870E+00	2.305E+00
12	6.400E-01	1.740E+00	1.190E+00
13	3.900E-01	6.400E-01	5.150E-01
14	1.100E-01	3.900E-01	2.500E-01
15	6.740E-02	1.100E-01	8.870E-02
16	2.480E-02	6.740E-02	4.610E-02
17	9.120E-03	2.480E-02	1.696E-02
18	2.950E-03	9.120E-03	6.035E-03
19	9.610E-04	2.950E-03	1.956E-03
20	3.540E-04	9.610E-04	6.575E-04
21	1.660E-04	3.540E-04	2.600E-04
22	4.810E-05	1.660E-04	1.071E-04
23	1.600E-05	4.810E-05	3.205E-05
24	4.000E-06	1.600E-05	1.000E-05
25	1.500E-06	4.000E-06	2.750E-06
26	5.500E-07	1.500E-06	1.025E-06
27	7.090E-08	5.500E-07	3.105E-07
28	1.000E-11	7.090E-08	3.546E-08

Table 5.2-29 MCBEND Standard 22 Group Gamma Boundaries

Group	E Lower [MeV]	E Upper [MeV]	E Average [MeV]
1	1.200E+01	1.400E+01	1.300E+01
2	1.000E+01	1.200E+01	1.100E+01
3	8.000E+00	1.000E+01	9.000E+00
4	6.500E+00	8.000E+00	7.250E+00
5	5.000E+00	6.500E+00	5.750E+00
6	4.000E+00	5.000E+00	4.500E+00
7	3.000E+00	4.000E+00	3.500E+00
8	2.500E+00	3.000E+00	2.750E+00
9	2.000E+00	2.500E+00	2.250E+00
10	1.660E+00	2.000E+00	1.830E+00
11	1.440E+00	1.660E+00	1.550E+00
12	1.220E+00	1.440E+00	1.330E+00
13	1.000E+00	1.220E+00	1.110E+00
14	8.000E-01	1.000E+00	9.000E-01
15	6.000E-01	8.000E-01	7.000E-01
16	4.000E-01	6.000E-01	5.000E-01
17	3.000E-01	4.000E-01	3.500E-01
18	2.000E-01	3.000E-01	2.500E-01
19	1.000E-01	2.000E-01	1.500E-01
20	5.000E-02	1.000E-01	7.500E-02
21	2.000E-02	5.000E-02	3.500E-02
22	1.000E-02	2.000E-02	1.500E-02

Table 5.2-30 MCBEND Fuel Assembly Hardware Mass and Flux Factors by Source Region

WE17×17		
Region	**Act. Mass [kg/assy]**	**Flux Factor**
Lower Nozzle	5.90	0.20
Fuel	19.21	1.00
Upper Plenum	8.47	0.20
Upper Nozzle	14.53	0.10
GE9×9-2L		
Region	**Act. Mass [kg/assy]**	**Flux Factor**
Lower Nozzle	4.99	0.15
Fuel	0.30	1.00
Upper Plenum	1.68	0.20
Upper Nozzle	2.69	0.10

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5.3 Model Specification

The transfer cask and storage cask are evaluated using one-dimensional SAS1 and three-dimensional SAS4 models. The storage cask air inlets and outlets are evaluated using the three-dimensional MCBEND Monte Carlo transport code.

SCALE Package Model Specification

Both one-dimensional SAS1 and three-dimensional SAS4 models are used in the shielding evaluations of the Universal Storage System. The SAS1 radial and axial model results are used to determine the bounding design basis fuel assembly descriptions for subsequent use in detailed three-dimensional analyses. The one-dimensional models represent the casks as either semi-infinite cylinders or slabs. The method of solution uses the XSDRNPM [8] discrete ordinates code and the XSDOSE [14] flux-at-a-point estimation code. Bucklings are applied to the SAS1 models to account for transverse leakage. The one-dimensional analysis also serves as a cross-check to the more complex three-dimensional model results.

The SAS4 three-dimensional shielding models are used to estimate the dose profiles at the surfaces of the cask and at potential streaming paths such as the canister vent and drain ports. The method of solution is Monte Carlo [3] with an adjoint discrete ordinates biasing technique using the XSDRNPM and MORSE codes. The adjoint biasing performed by XSDRNPM is a one-dimensional solution, which may not generate optimal importance maps for geometries which differ from the user-supplied bias map. For example, an importance map optimized for particle acceleration at the fuel midplane elevation yields an unoptimized radial importance map at the concrete cask air inlets. This phenomenon has yielded non-converging dose rate results at the inlets, due to high weight, low probability particles passing the detector surface. In order to more effectively estimate air inlet dose rates, the MCBEND code is employed, which has as one of its features the option of a user-supplied three-dimensional importance map. In order to present a consistent set of results, the air outlets are also analyzed using MCBEND.

Since SAS4 requires model symmetry at the fuel midplane, two models are created for each cask, a top and a bottom model. Radial biasing is performed to estimate dose rates on the sides of the cask, and axial biasing is performed to estimate dose rates on the top and bottom surfaces of the cask. Modifications are made to SAS4 to tally dose rates along the radial, top, and bottom surfaces of the cask as well as any cylindrical surface surrounding the cask. Thus, detailed dose rate profiles are determined that explicitly show peaks due to the fuel burnup profile, activated hardware gamma emission, and streaming paths.

In both SAS1 and SAS4 models, the fuel and hardware source regions are homogenized within the volumes defined by the periphery of the basket tubes and the respective elevations of the active fuel region, the plenum, and the end fittings. Within these volumes, the material masses of the fuel assembly and basket are homogenized. The resulting material and nuclide densities for both the PWR and the BWR cases are shown in Table 5.3-1 through Table 5.3-5. In all models, the cask and canister shield thicknesses and axial extents are explicitly represented.

Furthermore, in the three-dimensional models, the homogenized fuel region is represented geometrically by a shape approximating the periphery of the fuel assembly bundle within the basket.

Both the SAS1 and SAS4 models utilize fuel midplane symmetry. Thus, all shielding models are developed with respect to the fuel midplane as the origin. This symmetry is required in the SAS4 models due to the automated biasing techniques employed.

The axial source profile is considered in establishing total fuel region source rates for the top and bottom models. In the BWR case, due to the asymmetry in source profile about the fuel midplane, a greater fraction of the total fuel neutron and gamma source is emitted in the bottom half of the fuel. The three-dimensional shielding model therefore represents a higher total source rate in the bottom model. The relative fractions of source in each model region are given in Table 5.2-24. Since the PWR source profile is symmetric about the fuel axial midplane, the corresponding relative source fractions are 1.0.

MCBEND Model Description

Three-dimensional MCBEND models are constructed to analyze the concrete cask air inlets and outlets. Detailed models are constructed of the fuel assemblies, basket, and cask shield configurations, including streaming paths.

The MCBEND three-dimensional shielding models are used to estimate the dose profiles at the concrete cask inlets and outlets. MCBEND employs an automated biasing technique for the Monte Carlo calculation based on a three-dimensional adjoint diffusion calculation. Mesh cells for the adjoint solution are selected based on half value thicknesses for each material. Radial biasing is performed to estimate dose rates at the storage cask inlets and outlets, with an additional angular biasing component used to capture the azimuthal variation in bulk shielding properties.

In the MCBEND fuel assembly model, the fuel and hardware source regions are homogenized within a volume defined by the fuel assembly width and height. This volume is subdivided axially into lower end fitting, active fuel, upper plenum, and upper end fitting source regions. Within these axial volumes, the material masses of the fuel assembly are homogenized. In all models, the cask and canister shield thicknesses and axial extents are explicitly represented.

The gamma and neutron axial source profiles from Section 5.2 are input directly into MCBEND and require none of the source scaling factors required by SAS4.

5.3.1 Description of Radial and Axial Shielding Configurations

The vertical concrete cask has an interior cavity with a radius of 37.25 inches. Radial shielding consists of a 2.5-inch carbon steel shell surrounded by 28.25 inches of concrete. Gamma shielding is provided by both the carbon steel and concrete, and neutron shielding is provided primarily by the concrete. An additional 0.625 inch of stainless steel is provided by the canister shell for radial gamma shielding. The concrete cask top shielding is comprised of 10 inches of stainless steel from the canister lids, 4.1 inches of carbon steel from the shield plug which encloses 1 inch of NS-4-FR or 1.5 inches of NS-3, and 1.5 inches of carbon steel from the concrete cask lid. The bottom of the cask rests on the concrete pad and is inaccessible. In the case of the concrete cask inlets, some shielding is provided by the cask structural components. These components include 2 inches of carbon steel from the pedestal plate and 1 inch of carbon steel from the cask base plate. There is also 1.75 inches of stainless steel from the canister bottom plate.

The Standard or Advanced transfer cask has an inside radius of 33.875 inches and has a multi-wall radial shield design consisting of 0.75 inch of low alloy steel, 4.00 inches of lead, 2.75 inches of a solid borated polymer (NS-4-FR), and 1.25 inches of low alloy steel in an outer shell. Gamma shielding is provided by the steel and lead layers, and neutron shielding is provided primarily by the NS-4-FR. An additional 0.625 inch of stainless steel gamma shielding is provided by the canister shell. The transfer cask bottom shield design is comprised of carbon steel doors 9 inches thick. The top shielding of the transfer cask is provided by the 7-inch stainless steel shield lid and the 3-inch stainless steel structural lid. In addition, a 5-inch carbon steel temporary shield is used during welding, draining, and drying operations. This temporary shielding is assumed to be removed prior to moving the cask.

5.3.2 SCALE One-Dimensional Radial and Axial Shielding Models

Since the fuel assembly and basket features are not explicitly modeled in one-dimensional analysis, the fuel/basket interior is modeled as a set of homogenized material volumes based on an equivalent cylindrical volume. This volume is defined by the cross-sectional area created by the periphery of the basket tubes and the respective elevations of the fuel, end-fitting, and plenum regions.

5.3.2.1 SCALE One-Dimensional Radial Model

In the one-dimensional model, the canister interior is divided into two homogenized radial regions: a fuel/basket region and a basket/disk region. The fuel region smear has an equivalent radius of 71.695 cm in the PWR model and 73.235 cm in the BWR model. Support disk and heat transfer disk materials which fall within this region are homogenized in the fuel region smear. Basket and support disk materials outside this equivalent radius are homogenized in the annular region outside the fuel. Note that this annular smear is employed in the one-dimensional analysis only. In the three-dimensional analysis, basket support and heat transfer disks in the annular region are modeled explicitly.

The fuel region smear consists of the relevant fuel assembly material and any basket material present within the axial extent of the active fuel region. Basket materials include the steel support disks, aluminum heat transfer disks, top and bottom weldments, fuel tubes, neutron absorber sheets, and neutron absorber cover sheets. Fuel assembly materials include: UO_2, cladding, and spacer grids. The resulting material and nuclide densities are described in Section 5.3.5.

Similarly, homogenized material descriptions of the end-fitting and plenum source regions are determined by considering the mass and composition of fuel assembly and basket materials, which lie within the axial extents of the source region.

The one-dimensional radial models of the concrete cask and transfer cask are based on the cylindrical representation of the fuel/basket source regions (previously described) surrounded by the explicit canister and cask radial shield dimensions. An axial buckling equal to the active fuel height is employed for all radial models.

5.3.2.2 SCALE One-Dimensional Axial Model

The one-dimensional top and bottom axial models of the storage cask and transfer casks are based on a buckled slab representation of the fuel/basket, canister, and concrete cask axial shield regions. As previously stated, the one-dimensional axial model elevations are specified with respect to the active fuel midplane, which is modeled as a reflecting boundary in SAS1. Two axial models are utilized for each cask: one from the active fuel midplane to the top of the cask; and one from the active fuel midplane to the bottom of the cask. For gamma calculations, the transverse buckling parameter is set equal to the fuel region equivalent diameter. For neutron calculations, the buckling parameter is set to the diameter of the cask.

5.3.3 SCALE Three-Dimensional Top and Bottom Shielding Models

SAS4 three-dimensional shielding analysis allows detailed modeling of the fuel assemblies, basket, and cask shield configuration including streaming paths. Some fuel assembly and basket detail is homogenized to simplify model input and improve computational efficiency. Thus, the three-dimensional models maintain the equivalent fuel/basket source volumes developed for the one-dimensional models, but explicitly model the axial extent of the source regions, the basket spacer plates outside the homogenized source region, and the cask body details. In addition, the source region axial cross-section is represented in a volume-conserving rectilinear shape, which approximates the periphery of the fuel assemblies in the basket.

As in the SAS1 models, the fuel and hardware source regions are homogenized within the volumes defined by the periphery of the basket tubes and the various source region elevations. Cask body details include the true axial extent of the cask shield as described by the license drawings in Chapter 1, as well as radiation streaming paths such as the storage cask inlets and outlets and the canister vent and drain ports.

SAS4 requires cask model symmetry at the fuel midplane due to the nature of the automated biasing techniques employed and because dose rate tallies from the symmetric halves of the model are averaged together for computational efficiency. Thus, two SAS4 models are created for each cask, a top and a bottom model. As in the SAS1 models, all three-dimensional shielding models are developed with respect to the fuel axial midplane.

The geometric description of a SAS4 model is based on the MARS combinatorial geometry system embedded in the MORSE code [12]. In this system, bodies such as cylinders and rectangular parallelepipeds, and their logical intersections and unions, are used to describe the extent of material zones.

SAS4 employs an automated biasing technique for the MORSE Monte Carlo calculations based on either a radial or an axial XSDRNPM adjoint calculation. In the case of radial biasing, the adjoint calculation is performed based on a one-dimensional description of the radial shields and corresponding fuel/basket regions. In the case of axial biasing, the adjoint calculation is performed for the top or bottom shields and corresponding axial fuel/basket regions. Radial biasing is employed to improve the Monte Carlo computational efficiency and dose rate statistics on the sides of the cask. .Axial biasing is employed to improve Monte Carlo computational efficiency and dose rate statistics on the top or bottom surfaces of the cask. The dose rate profiles resulting from both radial and axial biasing calculations yield a complete dose profile of the entire cask.

MORSE Monte Carlo calculations are performed for each source type present in each source region. This approach entails six separate analyses for the top model, encompassing fuel neutron, fuel gamma, fuel n-gamma (secondary gammas arising from neutron interaction in the shield), fuel hardware, upper plenum, and upper end-fitting gamma sources. The bottom model requires a similar level of detail, although only five source cases are considered since no plenum is included in the lower fuel assembly region. Typically, a total of some 20 to 30 million histories are tracked to yield dose rate profiles for each model. These cases are analyzed for both radial and axial geometries, and for both PWR and BWR design basis fuel descriptions. Furthermore, the standard transfer cask top axial model is analyzed for a number of operational configurations of the top lids and temporary shielding, and for both wet and dry canisters. All told, the storage and transfer cask results presented here are based on a total of 220 distinct SAS4 analyses.

5.3.3.1 SCALE Canister and Basket Model

For a given fuel type, the SAS4 description of the canister and basket elements forms a common submodel employed in all storage cask and standard transfer cask analyses. The key features of the model are the accurate positioning of basket support and heat transfer disks and the inclusion of the vent and drain ports located in the canister shield lid.

The axial elevations of basket support and heat transfer disks are determined by placing the elements accurately with respect to the axial elevation of either the top or bottom end of the canister depending on which SAS4 half model is under consideration. In this way, basket disks are accurately located with respect to important cask features, such as trunnions and shield wall axial extents.

The vent ports in the canister shield lid are modeled as a series of three overlapping concentric cylinders, as shown in Figure 5.3-1 with port cover in place. The vent port cover is also modeled, but may or may not be in place depending on the particular operational condition specified. In the top axial analysis of the transfer cask, the vent port covers are assumed to be installed when the canister is in a dry condition, and removed when the canister is modeled in a wet condition. Port covers are in place in all storage cask top model analyses. The vent port cover is modeled as a solid piece of stainless steel of the dimensions indicated in Figure 5.3-1.

5.3.3.2 SCALE Vertical Concrete Cask Three-Dimensional Models

Three-Dimensional Top Model

The three-dimensional top model of the vertical concrete cask containing design basis fuel assemblies is based on the homogenized representation of the basket, and the following features of the storage cask upper region:

- Heat transfer annulus
- Carbon steel weldment with four cutouts for outlet vents
- Concrete shield with four cutouts for outlet vents
- Four outlet vents including carbon steel lining
- Carbon steel shield plug
- Shield plug neutron shield
- Carbon steel top lid

Detailed model parameters used in creating the three-dimensional top model are taken directly from the license drawings in Chapter 1. Elevations associated with the concrete cask three-dimensional features are established with respect to the active fuel midplane of the fuel assembly for the combinatorial model. The three-dimensional concrete cask top models for the design basis PWR are shown in Figure 5.3-2. The cask dimensions in the BWR model are identical, although the cask model is elongated slightly to allow for the longer active fuel region in the BWR design basis assembly.

A detailed sketch of a cross-section of the air outlet model is shown in Figure 5.3-3. The outlet channel walls are modeled as carbon steel.

Three-Dimensional Bottom Model

The three-dimensional bottom model of the concrete cask containing design basis fuel assemblies is based on the homogenized representation of the fuel/basket and the following bottom features of the concrete cask:

- Heat transfer annulus
- Carbon steel weldment with four cutouts for the air inlets
- Concrete shield with four cutouts for the air inlets
- Four inlets with carbon steel linings
- Carbon steel bottom base plate
- Carbon steel support stand with four cutouts for air flow
- Carbon steel shield ring
- Carbon steel storage cask bottom
- Concrete pad below base plate

The three-dimensional concrete cask bottom model is shown in Figure 5.3-4 for the design basis PWR fuel. An identical cask model is employed in the BWR analysis, except that it is elongated slightly to allow for the longer active fuel region in the design basis BWR assembly.

5.3.3.3 SCALE Transfer Cask Three-Dimensional Models

Three-Dimensional Top Model

In order to estimate occupational dose rates associated with the canister sealing operation, a number of operational configurations of the standard transfer cask are considered for the three-dimensional model of the upper cask region. These include wet and dry canister conditions and various shield lid, structural lid, and temporary shielding configurations. The temporary shield is modeled as a 5-inch thick cylindrical carbon steel plate with a radius two inches shorter than the canister inner radius. The temporary shield is assumed to have oversized cutouts to permit access to the canister vent ports and a 45 degree taper around the circumference to permit the automated welding machine access to the canister shield lid/canister wall interface. This configuration amounts to an assumed temporary shielding configuration. In reality, the temporary shield may be supplemented with additional shielding materials on site, although no credit for such material is taken here.

The top configuration of the transfer cask is evaluated in detail for the welding, draining, and drying operations. As with the concrete cask models, top models of the transfer cask containing design basis fuel assemblies are based on a homogenized representation of the basket. Model features include:

- Vent and drain port openings in the canister shield lid.
- Edge tapering and port cutouts in the temporary shielding.
- Upper trunnions cut through the radial shield and extending from the inner shell to the outer shell. No credit for the radial extent of the trunnions outside the cask outer shell is taken.
- Equivalent-volume model of the heat transfer fins embedded in the neutron shield.
- Lead and neutron shielding overlap at the top as per the transfer cask drawings.

Details of the elevations and radii used in creating the three-dimensional top model are taken directly from the license drawings in Chapter 1. As with the other three-dimensional models, elevations associated with the transfer cask three-dimensional features are established with respect to the active fuel midplane of the fuel assembly for the combinatorial geometry model.

The three-dimensional transfer cask top model including shield and structural lid installation is shown in Figure 5.3-5 for the cask containing design basis PWR fuel. The BWR model is identical, except the BWR fuel and basket homogenizations and elevations are employed and the model is reflected about the axial midplane of the design basis BWR fuel assembly.

Initial designs of the standard transfer cask called for the insertion of carbon steel heat transfer fins embedded in the radial neutron shield region and a lead thickness of 3.75 inches. In the SCALE model of the standard transfer cask, the fins are treated as a thin shell of carbon steel placed between the lead and NS-4-FR walls and modeled on an equivalent-volume basis. The resulting modeled thickness of the heat fin shell is 0.304 inch. The neutron shield material thickness is then modeled as 2.696 inches, so the combined thickness of both regions is 3.00 inches. The modeled radial configuration of the transfer cask shields is, thus, 0.75 inch of low alloy steel, 3.75 inches of lead, 0.304 inch of low alloy steel (heat fins), 2.696 inches of NS-4-FR, and 1.25 inches of low alloy steel. The model conservatively underestimates the amount of both neutron shielding, due to less NS-4-FR, and gamma shielding, due to the attenuation difference between the 4 inches of lead in the design and the 3.75 inches of lead and 0.304 inch of steel modeled.

Three-Dimensional Bottom Model

The three-dimensional bottom model of the transfer cask is based on the same homogenized representation of the fuel/basket as the top model. As with the top model of the transfer cask, evaluations of both a wet and dry canister are performed. The following bottom features of the transfer cask are considered:

- Termination of the radial shields at the bottom plate.
- An explicit model of the bottom door assembly including door rails and axial neutron shield configuration.

The transfer cask bottom model is shown in Figure 5.3-6 for the cask containing PWR design basis fuel. The BWR model is identical, except the BWR fuel and basket homogenizations and elevations are employed and the model is reflected about the axial midplane of the design basis BWR fuel assembly.

5.3.4 MCBEND Three-Dimensional Concrete Cask Models

MCBEND three-dimensional shielding analysis allows detailed modeling of fuel assemblies, basket, and cask shield configuration, including streaming paths. For fuel assembly sources, some fuel assembly detail is homogenized in the model to simplify model input and improve computational efficiency. Thus, the three-dimensional models represent the various fuel assembly source regions as homogenized zones within the basket, but explicitly model the axial extent of the source regions. The fuel and hardware source regions of each assembly are therefore homogenized within the volumes defined by the periphery of the fuel assembly and the source region axial extents. The basket plate details are explicitly modeled. Cask details include the axial extent of the cask shield as described by the License Drawings.

The geometric description of a MCBEND model is based on the combinatorial geometry system embedded in the code. In this system, bodies such as cylinders and rectangular parallelpipeds, and their logical intersections and unions, are used to describe the extent of material zones.

MCBEND employs an automated biasing technique for the Monte Carlo calculation based on a three-dimensional adjoint diffusion calculation. Mesh cells for the adjoint solution are selected based on half value thicknesses for each material.

MCBEND Monte Carlo calculations are performed for each source type present in each source region. This approach entails seven separate analyses, encompassing fuel neutron, fuel gamma, fuel n-gamma (secondary gammas arising from neutron interaction in the shield), fuel region hardware, upper plenum, and upper and lower end-fitting gamma sources. Typically, a total of 5 to 20 million histories are tracked to yield dose rate profiles for each model. These cases are analyzed for azimuthally divided radial detectors at the concrete cask air inlets and outlets.

5.3.4.1 MCBEND Fuel Assembly Model

Based on the fuel assembly physical parameters provided in Table 5.2-27 and the hardware masses in Table 5.2-30, homogenized treatments of fuel assembly source regions are developed. The homogenized fuel assembly is represented in the model as a stack of boxes with width equal to the fuel assembly width. The height of each box corresponds to the modeled height of the corresponding assembly region.

The active fuel region homogenizations for the two design basis assemblies are shown in Table 5.3-6. The non-fuel assembly material is void for dry storage conditions. The clad region is Zircaloy (density 6.55 g/cm^3). The resulting fuel compositions on an atom/barn-cm basis are shown in Table 5.3-8.

Fuel assembly non-fuel regions are homogenized as shown in Table 5.3-7. Volume fractions of material are based on the modeled regional volume and the volume of stainless steel present. The stainless steel volume is computed from the modeled mass and density (7.92 g/cm^3).

5.3.4.2 MCBEND Basket Model

For a given fuel type, the MCBEND description of the basket elements forms a common sub-model employed in the PWR and BWR concrete cask analyses. The key feature of the model is the detailed representation of the geometry of the basket support and heat transfer disks.

5.3.4.3 MCBEND Concrete Cask Model

The three-dimensional model of the vertical concrete cask containing design basis fuel is based on the explicit modeling of the basket, and the following features of the storage cask:

- Heat transfer annulus.
- Carbon steel weldment with cutouts for inlets and outlets.
- Concrete shield with cutouts for inlets and outlets.

- Air outlet model including carbon steel channel walls.
- Air inlet model including baffle pipes and carbon steel channel walls.
- Carbon steel shield plug with 1.0-inch NS-4-FR and 68-inch outer diameter steel cap.
- Carbon steel top lid.
- Carbon steel bottom base plate.
- Carbon steel support stand with four cutouts for air flow.
- Carbon steel shield ring.
- Carbon steel storage cask bottom.
- Concrete pad below base plate.

Detailed model parameters used in creating the three-dimensional model are taken directly from the License drawings. Elevations associated with the concrete cask three-dimensional features are established with respect to the bottom plate of the canister for the global model. The three-dimensional concrete cask model is shown in Figures 5.3-7 and 5.3-8.

5.3.5 Shield Regional Densities

Shield regional densities for the SAS1 and SAS4 analysis of the transfer and concrete casks are discussed in Section 5.3.5.1. Shield regional densities for the MCBEND analysis of the storage cask air inlets and outlets are discussed in Section 5.3.5.2.

5.3.5.1 SCALE Shield Regional Densities

The SCALE 4.3 standard composition library [11] default compositions and isotopic distributions are used unless otherwise indicated. The composition densities before homogenization are:

Material	Density (g/cm^3)
UO_2	10.412
Zircaloy	6.56
H_2O	0.9982
Type 304 Stainless Steel	7.92
Lead	11.344
Aluminum	2.702
Neutron Absorber (core)	2.623
NS-4-FR	1.68
Concrete	2.243
Carbon Steel	7.821

The regional homogenized densities and shield densities for the PWR and BWR fuel are provided in Table 5.3-1 through Table 5.3-5.

5.3.5.2 MCBEND Shield Regional Densities

Based on the homogenization described in Section 5.3.4.1, the resulting active fuel regional densities are shown in Table 5.3-8. Material compositions for remaining structural and shield materials are shown in Table 5.3-9. Compositions for fuel assembly non-fuel regions are equivalent to the stainless steel composition in Table 5.3-9 scaled by the material volume fractions shown in Table 5.3-7.

Figure 5.3-1 SCALE Vent Port Model with Port Cover in Place (Dimensions in cm)

Figure Withheld Under 10 CFR 2.390

Figure 5.3-2 SCALE Vertical Concrete Cask Three-Dimensional Top Model PWR Design Basis

Figure Withheld Under 10 CFR 2.390

Figure 5.3-3 Schematic of SCALE Upper Vent Model Showing Key Points

Figure Withheld Under 10 CFR 2.390

Figure 5.3-4 SCALE Vertical Concrete Cask Three-Dimensional Bottom Model – PWR Design Basis

Figure Withheld Under 10 CFR 2.390

Figure 5.3-5 SCALE Standard Transfer Cask Three-Dimensional Top Model Including Shield and Structural Lid – PWR Design Basis

Figure Withheld Under 10 CFR 2.390

Figure 5.3-6 SCALE Standard Transfer Cask Three-Dimensional Bottom Model – PWR Design Basis

Figure Withheld Under 10 CFR 2.390

Figure 5.3-7 MCBEND Three-Dimensional Vertical Concrete Cask Model – Axial Dimensions

Figure Withheld Under 10 CFR 2.390

Figure 5.3-8 MCBEND Three-Dimensional Vertical Concrete Cask Model – Radial Dimensions

Figure Withheld Under 10 CFR 2.390

Table 5.3-1 SCALE PWR Dry Canister Material Densities

Material	Mixture ID	SCL Name	Density [g/cm^3]	27N-18G Library Nuclide	Density [a/barn-cm]
Fuel Region	1	UO2	2.1530	BORON-10	1.9090E-04
		ZIRCALOY	0.4494	BORON-11	7.6839E-04
		SS304	0.3807	CARBON-12	2.3982E-04
		AL	0.0894	OXYGEN-16	9.6038E-03
		B4C	0.0220	ALUMINUM	1.9953E-03
				CHROMIUM(SS304)	8.3776E-04
				MANGANESE	8.3462E-05
				IRON(SS304)	2.8532E-03
				NICKEL(SS304)	3.7112E-04
				ZIRCALOY	2.9669E-03
				URANIUM-234	2.6411E-07
				URANIUM-235	3.4574E-05
				URANIUM-238	4.7671E-03
Fuel Region Annulus (One-D only)	2	SS304	0.7691	ALUMINUM	5.6780E-03
		AL	0.2544	CHROMIUM(SS304)	1.6925E-03
				MANGANESE	1.6861E-04
				IRON(SS304)	5.7642E-03
				NICKEL(SS304)	7.4975E-04
Upper Plenum	3	ZIRCALOY	0.4494	CHROMIUM(SS304)	2.2706E-03
		SS304	1.0318	MANGANESE	2.2621E-04
				IRON(SS304)	7.7330E-03
				NICKEL(SS304)	1.0058E-03
				ZIRCALLOY	2.9669E-03
Upper Plenum Annulus (One-D only)	4	SS304	0.6101	CHROMIUM(SS304)	1.3426E-03
				MANGANESE	1.3375E-04
				IRON(SS304)	4.5725E-03
				NICKEL(SS304)	5.9475E-04
Upper End Fitting	5	SS304	1.2537	CHROMIUM(SS304)	2.7589E-03
				MANGANESE	2.7485E-04
				IRON(SS304)	9.3961E-03
				NICKEL(SS304)	1.2222E-03
Upper End Fitting Annulus (One-D only)	6	SS304	1.1366	CHROMIUM(SS304)	2.5012E-03
				MANGANESE	2.4918E-04
				IRON(SS304)	8.5185E-03
				NICKEL(SS304)	1.1080E-03
Lower End Fitting	9	SS304	1.4554	CHROMIUM(SS304)	3.2027E-03
				MANGANESE	3.1907E-04
				IRON(SS304)	1.0908E-02
				NICKEL(SS304)	1.4188E-03
Lower End Fitting Annulus (One-D only)	10	SS304	1.7805	CHROMIUM(SS304)	3.9181E-03
				MANGANESE	3.9035E-04
				IRON(SS304)	1.3344E-02
				NICKEL(SS304)	1.7357E-03

Table 5.3-2 SCALE PWR Wet Canister Material Densities

Material	Mixture ID	SCL Name	Density [g/cm³]	27N-18G Library Nuclide	Density [a/barn-cm]
Fuel	1	UO2	2.1530	HYDROGEN	4.1824E-02
		ZIRCALOY	0.4494	BORON-10	1.9090E-04
		SS304	0.3807	BORON-11	7.6839E-04
		AL	0.0894	CARBON-12	2.3982E-04
		B4C	0.0220	OXYGEN-16	3.0516E-02
		H2O	VF=0.6264	ALUMINUM	1.9953E-03
				CHROMIUM(SS304)	8.3776E-04
				MANGANESE	8.3462E-05
				IRON(SS304)	2.8532E-03
				NICKEL(SS304)	3.7112E-04
				ZIRCALOY	2.9669E-03
				URANIUM-234	2.6411E-07
				URANIUM-235	3.4574E-05
				URANIUM-238	4.7671E-03
Fuel Region Annulus (One-D only)	2	SS304	0.7691	HYDROGEN	5.3996E-02
		AL	0.2544	OXYGEN-16	2.6998E-02
		H2O	VF=0.8087	ALUMINUM	5.6780E-03
				CHROMIUM(SS304)	1.6925E-03
				MANGANESE	1.6861E-04
				IRON(SS304)	5.7642E-03
				NICKEL(SS304)	7.4975E-04
Upper Plenum	3	ZIRCALOY	0.4494	HYDROGEN	3.9127E-02
		SS304	1.0318	OXYGEN-16	1.9563E-02
		H2O	VF=0.5860	CHROMIUM(SS304)	2.2706E-03
				MANGANESE	2.2621E-04
				IRON(SS304)	7.7330E-03
				NICKEL(SS304)	1.0058E-03
				ZIRCALOY	2.9669E-03
Upper Plenum Annulus (One-D only)	4	SS304	0.6101	HYDROGEN	6.1628E-02
		H2O	VF=0.9230	OXYGEN-16	3.0814E-02
				CHROMIUM(SS304)	1.3426E-03
				MANGANESE	1.3375E-04
				IRON(SS304)	4.5725E-03
				NICKEL(SS304)	5.9475E-04
Upper End Fitting	5	SS304	1.2537	CHROMIUM(SS304)	2.7589E-03
				MANGANESE	2.7485E-04
				IRON(SS304)	9.3961E-03
				NICKEL(SS304)	1.2222E-03
Upper End Fitting Annulus (One-D only)	6	SS304	1.1366	CHROMIUM(SS304)	2.5012E-03
				MANGANESE	2.4918E-04
				IRON(SS304)	8.5185E-03
				NICKEL(SS304)	1.1080E-03

Table 5.3-2 SCALE PWR Wet Canister Material Densities (continued)

Material	Mixture ID	SCL Name	Density [g/cm^3]	27N-18G Library Nuclide	Density [a/barn-cm]
Lower End Fitting	9	SS304 H2O	1.4554 VF=0.8162	HYDROGEN OXYGEN-16 CHROMIUM(SS304) MANGANESE IRON(SS304) NICKEL(SS304)	5.4497E-02 2.7249E-02 3.2027E-03 3.1907E-04 1.0908E-02 1.4188E-03
Lower End Fitting Annulus (One-D only)	10	SS304 H2O	1.7805 VF=0.7752	HYDROGEN OXYGEN-16 CHROMIUM(SS304) MANGANESE IRON(SS304) NICKEL(SS304)	5.1760E-02 2.5880E-02 3.9181E-03 3.9035E-04 1.3344E-02 1.7357E-03

Table 5.3-3 SCALE BWR Dry Canister Material Densities

Material	Mixture ID	SCL Name	Density [g/cm^3]	27N-18G Library Nuclide	Density [a/barn-cm]
Fuel	1	UO2	1.9583	BORON-10	5.1195E-05
		ZIRCALOY	0.6769	BORON-11	2.0607E-04
		SS304	0.2228	CARBON-12	1.6127E-04
		CARBONSTEEL	0.1932	OXYGEN-16	8.7353E-03
		AL	0.0874	ALUMINUM	1.9507E-03
		B4C	0.0059	CHROMIUM(SS304)	4.9029E-04
				MANGANESE	4.8845E-05
				IRON	2.0626E-03
				IRON(SS304)	1.6698E-03
				NICKEL(SS304)	2.1719E-04
				ZIRCALOY	4.4688E-03
				URANIUM-234	2.4022E-07
				URANIUM-235	3.1447E-05
				URANIUM-238	4.3360E-03
Fuel Region Annulus	2	CARBONSTEEL	1.2195	CARBON-12	6.1200E-04
		AL	0.1404	ALUMINUM	3.1336E-03
				IRON	1.3019E-02
Upper Plenum	3	ZIRCALOY	0.6551	CARBON-12	7.4574E-05
		SS304	0.2198	CHROMIUM(SS304)	4.8369E-04
		CARBONSTEEL	0.1486	MANGANESE	4.8188E-05
				IRON	1.5864E-03
				IRON(SS304)	1.6473E-03
				NICKEL(SS304)	2.1427E-04
				ZIRCALOY	4.3248E-03
Upper Plenum Annulus	4	CARBONSTEEL	0.9381	CARBON-12	4.7078E-04
				IRON	1.0015E-02
Upper End Fitting	5	SS304	0.5708	CHROMIUM(SS304)	1.2561E-03
				MANGANESE	1.2514E-04
				IRON(SS304)	4.2780E-03
				NICKEL(SS304)	5.5644E-04
Upper End Fitting Annulus	6	SS304	0.8665	CHROMIUM(SS304)	1.9068E-03
				MANGANESE	1.8997E-04
				IRON(SS304)	6.4942E-03
				NICKEL(SS304)	8.4470E-04
Lower End Fitting	9	SS304	1.4132	CHROMIUM(SS304)	3.1099E-03
				MANGANESE	3.0982E-04
				IRON(SS304)	1.0592E-02
				NICKEL(SS304)	1.3776E-03
Lower End Fitting Annulus	10	SS304	1.0283	CHROMIUM(SS304)	2.2629E-03
				MANGANESE	2.2544E-04
				IRON(SS304)	7.7068E-03
				NICKEL(SS304)	1.0024E-03

Table 5.3-4 SCALE BWR Wet Canister Material Densities

Material	Mixture ID	SCL Name	Density [g/cm³]	27N-18G Library Nuclide	Density [a/barn-cm]
Fuel	1	UO2	1.9583	HYDROGEN	4.0869E-02
		ZIRCALOY	0.6769	BORON-10	5.1195E-05
		SS304	0.2228	BORON-11	2.0607E-04
		CARBONSTEEL	0.1932	CARBON-12	1.6127E-04
		AL	0.0874	OXYGEN-16	2.9170E-02
		B4C	0.0059	ALUMINUM	1.9507E-03
		H2O	0.6121	CHROMIUM(SS304)	4.9029E-04
				MANGANESE	4.8845E-05
				IRON	2.0626E-03
				IRON(SS304)	1.6698E-03
				NICKEL(SS304)	2.1719E-04
				ZIRCALOY	4.4688E-03
				URANIUM-234	2.4022E-07
				URANIUM-235	3.1447E-05
				URANIUM-238	4.3360E-03
Fuel Region Annulus	2	CARBONSTEEL	1.2195	HYDROGEN	5.2888E-02
		AL	0.1404	CARBON-12	6.1200E-04
		H2O	0.7921	OXYGEN-16	2.6444E-02
				ALUMINUM	3.1336E-03
				IRON	1.3019E-02
Upper Plenum	3	ZIRCALOY	0.6551	HYDROGEN	4.3814E-02
		SS304	0.2198	CARBON-12	7.4574E-05
		CARBONSTEEL	0.1486	OXYGEN-16	2.1907E-02
		H2O	0.6562	CHROMIUM(SS304)	4.8369E-04
				MANGANESE	4.8188E-05
				IRON	1.5864E-03
				IRON(SS304)	1.6473E-03
				NICKEL(SS304)	2.1427E-04
				ZIRCALOY	4.3248E-03
Upper Plenum Annulus	4	CARBONSTEEL	0.9381	HYDROGEN	5.8764E-02
		H2O	0.8801	CARBON-12	4.7078E-04
				OXYGEN-16	2.9382E-02
				IRON	1.0015E-02
Upper End Fitting	5	SS304	0.5708	CHROMIUM(SS304)	1.2561E-03
				MANGANESE	1.2514E-04
				IRON(SS304)	4.2780E-03
				NICKEL(SS304)	5.5644E-04
Upper End Fitting Annulus	6	SS304	0.8665	CHROMIUM(SS304)	1.9068E-03
				MANGANESE	1.8997E-04
				IRON(SS304)	6.4942E-03
				NICKEL(SS304)	8.4470E-04

Table 5.3-4 SCALE BWR Wet Canister Material Densities (continued)

Material	Mixture ID	SCL Name	Density [g/cm³]	27N-18G Library Nuclide	Density [a/barn-cm]
Lower End Fitting	9	SS304	1.4132	HYDROGEN	5.4858E-02
		H2O	0.8216	OXYGEN-16	2.7429E-02
				CHROMIUM(SS304)	3.1099E-03
				MANGANESE	3.0982E-04
				IRON(SS304)	1.0592E-02
				NICKEL(SS304)	1.3776E-03
Lower End Fitting Annulus	10	SS304	1.0283	HYDROGEN	5.8103E-02
		H2O	0.8702	OXYGEN-16	2.9051E-02
				CHROMIUM(SS304)	2.2629E-03
				MANGANESE	2.2544E-04
				IRON(SS304)	7.7068E-03
				NICKEL(SS304)	1.0024E-03

Table 5.3-5 SCALE Standard Transfer Cask Material Densities

Material	Mixture ID	SCL Name	Density [g/cm³]	27N-18G Library Nuclide	Density [a/barn-cm]
Carbon and Low-Alloy Steel	11	CARBONSTEEL	7.8212	CARBON-12 IRON	3.9250E-03 8.3498E-02
Stainless Steel	12	SS304	7.9200	CHROMIUM(SS304) MANGANESE IRON(SS304) NICKEL(SS304)	1.7429E-02 1.7363E-03 5.9358E-02 7.7207E-03
Lead	13	PB	11.3440	LEAD	3.2969E-02
NS-4-FR	14	H B-10 B-11 C N O AL	1.63	HYDROGEN BORON-10 BORON-11 CARBON-12 NITROGEN-14 OXYGEN-16 ALUMINUM	5.8540E-02 8.5530E-05 3.4220E-04 2.2640E-02 1.3940E-03 2.6090E-02 7.7630E-03
Aluminum	17	AL	2.7020	ALUMINUM	6.0307E-02
Concrete	18	REG-CONCRETE	2.2426	HYDROGEN OXYGEN-16 SODIUM-23 ALUMINUM SILICON CALCIUM IRON	1.3401E-02 4.4931E-02 1.7036E-03 1.7018E-03 1.6205E-02 1.4826E-03 3.3857E-04
Canister Void (Dry Conditions)	19	N	VF=1.0E-6	NITROGEN-14	4.3006E-08
Canister Water (Wet Conditions)	19	H2O	0.9982	HYDROGEN OXYGEN-16	6.6769E-02 3.3385E-02

Table 5.3-6 MCBEND Fuel Region Homogenization

WE 17×17						
Component	**Area [cm²]**	**Area Fraction**	**Volume Fraction of Components**			
			UO_2	**Void**	**Clad**	**Interstitial**
Fuel	1.3913E+02	3.0375E-01	3.0375E-01			
Gap	5.6649E+00	1.2367E-02		1.2367E-02		
Clad	4.2318E+01	9.2389E-02			9.2389E-02	
Guide Tube	3.4075E+00	7.4392E-03			7.4392E-03	
Instrument Tube	1.4198E-01	3.0997E-04			3.0997E-04	
Inside Tubes	2.5881E+01	5.6502E-02				5.6502E-02
Interstitial	2.4150E+02	5.2725E-01				5.2725E-01
Total	4.5805E+02		3.0375E-01	1.2367E-02	1.0014E-01	5.8375E-01
GE 9×9-2L						
Component	**Area [cm²]**	**Area Fraction**	**Volume Fraction of Components**			
			UO_2	**Void**	**Clad**	**Interstitial**
Fuel	5.6593E+01	2.8809E-01	2.8809E-01			
Gap	2.8033E+00	1.4271E-02		1.4271E-02		
Clad	1.8455E+01	9.3945E-02			9.3945E-02	
Water Rod	4.6792E-01	2.3820E-03			2.3820E-03	
Inside Tubes	1.5024E+00	7.6484E-03				7.6484E-03
Interstitial	1.1662E+02	5.9366E-01				5.9366E-01
Total	1.9644E+02		2.8809E-01	1.4271E-02	9.6327E-02	6.0131E-01

Table 5.3-7 MCBEND Fuel Assembly Hardware Region Homogenization

WE 17×17					
Region	**Mass SS [kg/assy]**	**SS Volume [cm^3/assy]**	**Height [cm]**	**Volume [cm^3/assy]**	**Volume Fraction**
Lower Nozzle	5.90	7.4495E+02	8.5979	3.9382E+03	1.8916E-01
Upper Plenum	8.47	1.0694E+03	22.2123	1.0174E+04	1.0511E-01
Upper Nozzle	14.53	1.8341E+03	9.3218	4.2698E+03	4.2955E-01
GE 9×9-2L					
Region	**Mass SS [kg/assy]**	**SS Volume [cm^3/assy]**	**Height [cm]**	**Volume [cm^3/assy]**	**Volume Fraction**
Lower Nozzle	4.99	6.2961E+02	18.7579	3.6848E+03	1.7087E-01
Upper Plenum	1.68	2.1212E+02	28.6421	5.6265E+03	3.7701E-02
Upper Nozzle	2.69	3.3958E+02	19.0500	3.7422E+03	9.0743E-02

Table 5.3-8 MCBEND Homogenized Fuel Regional Densities

Element	Density [atom/b-cm]	
	WE 17x17	GE 9×9-2L
CR	7.5967E-06	7.3075E-06
FE	1.4146E-05	1.3607E-05
HF	2.2130E-07	2.1288E-07
NI	6.7299E-07	6.4737E-07
O	1.4131E-02	1.3403E-02
SN	4.9912E-05	4.8011E-05
U	7.0560E-03	6.6919E-03
ZR	4.2469E-03	4.0852E-03

Table 5.3-9 MCBEND Regional Densities for Concrete Cask Structural and Shield Materials

Material	Element	Density [atom/b-cm]
Stainless Steel	CR	1.6511E-02
	FE	6.3199E-02
	NI	6.5009E-03
Carbon Steel	C	3.9250E-03
	FE	8.3498E-02
Aluminum	AL	6.0263E-02
NS-4-FR	AL	7.8000E-03
	B	4.2750E-04
	C	2.2600E-02
	H	5.8500E-02
	N	1.3900E-03
	O	2.6100E-02
Concrete	AL	1.7018E-03
	CA	1.4826E-03
	FE	3.3857E-04
	H	1.3401E-02
	NA	1.7036E-03
	O	4.4931E-02
	SI	1.6205E-02

5.4 Shielding Evaluation

This section evaluates the shielding design of the vertical concrete cask and the standard transfer cask. The calculational methods and the computer codes used in the evaluation are described. Shielding calculations are performed with design basis PWR and BWR fuel source terms at 40,000 MWD/MTU and 5-year cooling time. Dose rate profiles are reported as a function of distance from the sides and top of the concrete cask and from the sides, top, and bottom of the transfer cask containing PWR or BWR fuel. Top axial dose rates for operational configurations of the transfer cask during the canister sealing operation are also provided.

5.4.1 Calculational Methods

5.4.1.1 SCALE Package Calculational Methods

The shielding evaluations of the concrete cask and standard transfer cask are performed with SCALE 4.3 for the PC [4]. In particular, SCALE shielding analysis sequence SAS2H [5] is used to generate source terms for the design basis fuel. SAS1 [6] is used to perform one-dimensional radial and axial shielding analyses in order to identify bounding PWR and BWR fuel descriptions. A modified version of SAS4 [3] is used to perform three-dimensional shielding analysis. The coupled 27 group neutron, 18 group gamma ENDF/B-IV (27N-18COUPLE) cross-section library is used in all shielding evaluations. Source terms include fuel neutron, fuel gamma, and gamma contributions from activated hardware. Dose rate evaluations include the effect of fuel burnup peaking on fuel neutron and gamma source terms. The SCALE shielding analysis sequences and cross-section libraries have recently been benchmarked to measurements of light water reactor fuel source terms, shielding material dose rate attenuation, and spent fuel storage and transport cask dose rates [13].

As discussed in Section 5.2, the SAS2H code sequence [5] is used to generate source terms for the PWR and BWR design basis fuel. SAS2H includes an XSDRNPM [8] neutronics model of the fuel assembly and ORIGEN-S [9] fuel depletion/source terms calculations. Source terms are generated for both UO_2 fuel and fuel assembly hardware. The hardware activation is calculated by ORIGEN-S using the incore neutron flux spectrum produced by the SAS2H neutronics model. The hardware is assumed to be Type 304 stainless steel with 1.2 g/kg ^{59}Co impurity. The effects of axial flux spectrum and magnitude variation on hardware activation are estimated by flux ratios based on empirical data [15].

The SAS4 shielding models are used to estimate the dose profiles along the surfaces of the transfer and concrete casks and to estimate doses in and around streaming paths such as the canister vent and drain ports. The SAS4 models represent the cask body and any streaming paths with combinatorial logic. The method of solution is adjoint discrete ordinates and Monte Carlo [3] using the XSDRNPM and MORSE codes, respectively. Since SAS4 requires model symmetry at the fuel midplane, two models are created for each cask, a top and a bottom model. Radial biasing is performed to estimate dose rates on the sides of the cask, and axial biasing is performed to estimate dose rates on the top and bottom surfaces of the cask. Modifications are made to SAS4 to determine dose rates all along the radial, top, and bottom surfaces of the cask as well as any cylindrical surface surrounding the cask. Thus, detailed dose profiles are determined that explicitly show peaks due to the fuel burnup profile, activated hardware gamma emission, and potential streaming paths.

In both the SAS1 and SAS4 models, the fuel and hardware source regions are homogenized within the volumes described by the periphery of the basket tubes, and defined by fuel assembly active fuel, plenum, and end fitting elevations. Within these volumes, the material masses of the fuel assembly and basket are preserved.

5.4.1.2 MCBEND Calculational Methods

The shielding evaluations of the storage cask air inlets and outlets are performed with MCBEND version 9E. Source terms include fuel neutron, fuel gamma, and gamma contributions from activated hardware. As described in Section 5.2, these evaluations include the effect of fuel burnup peaking on fuel neutron and gamma source terms.

The MCBEND shielding models described in Section 5.3 are utilized with the source terms described in Section 5.2 to estimate the azimuthal dose rate profiles at the surface of the concrete cask inlets and outlets. The method of solution is continuous energy Monte Carlo with an adjoint diffusion solution for generating importance meshes. Radial biasing is performed within the MCBEND code, with an additional azimuthal component added to the splitting mesh to account for the angular variations in the bulk shielding properties of the concrete cask at the inlets and outlets.

The MCBEND code has been validated against various classical shielding problems, including fast and thermal neutron sources penetrating through single material slab geometries of iron, graphite and water. The validation suite also includes fast neutron transmission through alternating slabs of iron and water. Of particular interest is a benchmark of MCBEND to gamma and neutron dose rates outside a metal transport cask, where agreement between measurement and calculation is within 20% for the majority of dose locations.

MCBEND results are calculated using the JEF2.2 neutron cross-section library and the ANSWERS gamma library.

5.4.2 Flux-to-Dose Rate Conversion Factors

The ANSI/ANS 6.1.1-1977 flux-to-dose rate conversion factors [22] are used in all Universal Storage System shielding evaluations. These factors are the defaults for SCALE 4.3 analyses. Tables 5.4-1 and 5.4-2 show the group flux-to-dose rate factors associated with the coupled 27 group neutron and 18 group gamma cross-section library used in the SCALE shielding evaluations. Tables 5.4-3 and 5.4-4 show the group flux-to-dose rate factors in the 28-group neutron and 22-group gamma energy structure employed in the MCBEND evaluations.

5.4.3 Dose Rate Results

This section provides detailed dose rate profiles for the vertical concrete cask and the standard transfer cask based on the source terms presented in Section 5.2. Design basis fuel source terms include contributions from fuel neutron, fuel gamma, and activated hardware gamma. The fuel assembly activated hardware gamma source terms include: steel and inconel in the upper and lower fuel assembly end fittings, upper fuel rod plenum hardware, and activated non-fuel material in the active fuel region. The three-dimensional model dose rates include the effects of axial profiles for neutron and gamma source distributions shown in Figure 5.2-3 and Figure 5.2-4 for PWR and BWR fuel assemblies, respectively.

Three-dimensional dose rates for the concrete cask side and top are calculated using SAS4, with detailed air inlet and outlet results calculated using MCBEND. Three-dimensional dose rates for the transfer cask are calculated using SAS4 exclusively.

5.4.3.1 Vertical Concrete Cask Dose Rates

One-Dimensional Dose Rates

One-dimensional radial dose rates with design basis PWR or BWR fuel are found to be in good agreement with the corresponding three-dimensional models at the radial midplane. Generally, the homogenization of canister annulus basket material employed in the one-dimensional analysis leads to a slight under-prediction of radial gamma dose rates. The three-dimensional models more accurately characterize the shielding effectiveness of the basket support disks. One-dimensional analysis is found to support the results of the more sophisticated three-dimensional models.

Three-Dimensional Dose Rates for Concrete Cask Containing PWR Fuel

The three-dimensional model dose rates for the concrete cask containing PWR fuel are presented in Figures 5.4-1 through 5.4-5. Figure 5.4-1 shows the axial dose rate profile along the cask surface broken down by contributing radiation type. Dose rates along the cask axial surface are dominated by gamma contributions due to the relatively high neutron shielding effectiveness of the concrete. Figure 5.4-2 shows the total dose rate profile at various radial distances from the cask surface.

In the axial profile plots, each datum represents the circumferentially averaged dose rate at the corresponding elevation. Negative elevations indicate axial locations below the fuel axial midplane, and correspond to results obtained from the three-dimensional bottom half model. In the vertical dose profile, peaking is observed at the upper and lower end fitting locations as well as at the locations of the lower intake and upper outlet vents.

At locations away from the air inlets and outlets, the maximum axial dose rates occur at the fuel midplane, where a peak dose rate of 49 (<1%) mrem/hr is computed. At the air outlets, an azimuthal maximum of 63 mrem/hr (1%) is computed. Figure 5.4-3 illustrates the azimuthal variation of total dose rate at the air outlet elevation. Dose rates at the inlets are considerably higher than at the outlets. The dose rate at the air inlet openings is 136 (1%) mrem/hr with supplemental shielding and 694 (<1%) mrem/hr without supplemental shielding. The azimuthal variation of dose rate at the air inlets is shown in Figure 5.4-4 with supplemental shielding in the inlets.

In Figure 5.4-5, the radial dose rate profile at the top surface of the cask is shown. Two peaks occur in the radial profile. Above the canister/weldment annulus, a peak is formed from approximately equal contributions of end-fitting and plenum gamma and fuel neutron. At radial locations above the upper vents, another peak is observed due primarily to end-fitting gammas.

Three-Dimensional Dose Rates for Concrete Cask Containing BWR Fuel

Figures 5.4-6 through 5.4-10 present the three-dimensional model dose rates for the concrete cask containing BWR fuel. Figure 5.4-6 shows the axial dose rate profile along the cask surface broken down by contributing radiation type. Dose rates along the cask axial surface are dominated by gamma contributions due to the relatively high neutron shielding effectiveness of the concrete. Figure 5.4-7 shows the total dose rate profile at various radial distances from the cask surface.

In the axial profile plots, each datum represents the circumferentially averaged dose rate at the corresponding elevation. Negative elevations indicate axial locations below the fuel axial midplane, and correspond to results obtained from the three-dimensional bottom half model. In the vertical dose profile, peaking is observed at the upper and lower end fitting locations as well as at the locations of the lower intake and upper outlet vents.

At locations away from the air inlets and outlets, the maximum axial dose rates occurs at the fuel midplane, where a peak dose rate of 351 (13%) mrem/hr is computed. At the air outlets, an azimuthal maximum of 55 mrem/hr (1%) is computed. Figure 5.4-8 illustrates the azimuthal variation of total dose rate at the air outlet elevation. Dose rates at the air inlets are considerably lower higher than at the air outlets. This is a result of the thick 2.5-inch plate, which forms the roof of the inlet channel roof. The dose rate at the air inlet opening is 129 (1%) mrem/hr with supplemental shielding and 645 (<1%) mrem/hr without supplemental shielding,. The azimuthal variation of dose rate at the air inlet is shown in Figure 5.4-9.

In Figure 5.4-10, the radial dose rate profile at the top surface of the cask is shown. Two peaks occur in the radial profile. Above the canister/weldment annulus, a peak is formed from approximately equal contributions of end-fitting and plenum gamma and fuel neutron. At radial locations above the upper vents, another peak is observed due primarily to end-fitting gammas.

5.4.3.2 Standard Transfer Cask Dose Rates

One-Dimensional Dose Rates

One-dimensional radial dose rates for the standard transfer cask with design basis PWR or BWR fuel are in good agreement with the corresponding three-dimensional models at the radial midplane. As with the concrete cask one-dimensional radial model, the peaks in the radial dose rates due to activated end fittings cannot be captured by one-dimensional analysis. One-dimensional analysis supports the results of the more sophisticated three-dimensional models.

Three-Dimensional Dose Rates for the Standard Transfer Cask Containing PWR Fuel

The three-dimensional model dose rates for the standard transfer cask containing PWR fuel are presented in Figures 5.4-11 through 5.4-19. For the top and bottom axial cases, the SAS4 surface detectors are subdivided in a manner which gives the centermost subdetector a relatively large radius. This detector partitioning more closely balances subdetector areas and avoids poor Monte Carlo statistics on the central subdetector.

The transfer cask side dose rate profiles with a dry cavity are shown in Figure 5.4-11 for the constituent source components and in Figure 5.4-13 at various distances from the cask surface. In this condition, the majority of the dose rate is from fuel neutron and gamma source, but significant peaks are shown from the activated end fittings. In this condition, the peak dose rate on the side of the transfer cask is 410 (<1%) mrem/hr.

The transfer cask side dose rate profiles with a wet canister are shown in Figure 5.4-12 for the constituent source components and in Figure 5.4-14 at various distances from the cask surface. In the wet case, the majority of the dose rate is from fuel gamma sources and activated non-fuel hardware gamma. Note that in the wet condition, it is assumed in the model that the water level in the canister is lowered to the base of the upper end-fitting in order to facilitate the lid welding operations. Thus, the top end fitting is uncovered and causes a peak in dose rate at the top of the transfer cask due to the gamma source from the activated top end fitting. In this condition, the peak dose rate on the side of the transfer cask is 259 (<1%) mrem/hr.

When configured for the shield lid welding operation, the standard transfer cask, with wet canister and temporary shielding in place, has a peak surface dose rate of 2,092 (4%) in the narrow gap between the temporary shield and the cask inner shell. This dose rate is highly localized; the average dose rate on the top of the cask under these conditions is 579 (3%) mrem/hr. Refer to Figure 5.4-15 for a plot of the radial dose profile.

After draining the canister cavity and in preparation for the vent port cover welding operation, the shield lid, temporary shield, and vent port covers are in place. Under these conditions, the surface dose rate radial profile is shown in Figure 5.4-16. The peak surface dose rate is 1147 (2%) mrem/hr, and the surface average value is 382 (2%) mrem/hr.

After completion of the lid welding operation, the transfer cask will have a dry canister cavity, and both shield lid and structural lids in place with no temporary shielding. In this condition, the transfer cask top dose rate profile is shown in Figure 5.4-17 for each source component. In this condition, the majority of the dose rate is from end fitting gamma. The peak and average dose rates on the top of the transfer cask containing PWR fuel are 715 (<1%) mrem/hr and 369 (2%) mrem/hr, respectively.

The standard transfer cask bottom dose rate radial profiles with dry and wet canisters are shown in Figures 5.4-18 and 5.4-19, respectively. In the dry canister condition, the peak and average dose rates on the bottom of the transfer cask are 819 (<1%) mrem/hr and 374 (<1%) mrem/hr, respectively. In the wet condition, the peak and average dose rates on the bottom of the transfer cask are 579 (<1%) mrem/hr and 258 (<1%) mrem/hr, respectively.

<u>Three-Dimensional Dose Rates for Standard Transfer Cask Containing BWR Fuel</u>

The three-dimensional model dose rates for the standard transfer cask containing BWR fuel are presented in Figures 5.4-20 through 5.4-28.

The transfer cask side dose rate profiles with a dry cavity are shown in Figure 5.4-20 for the constituent source components and in Figure 5.4-22 at various distances from the cask surface. In this condition, the majority of the dose rate is from fuel neutron and gamma source, but significant peaks are shown from the activated end fittings. In this condition, the peak dose rate on the side of the transfer cask is 325 (<1%) mrem/hr.

The transfer cask side dose rate profiles with a wet canister are shown in Figure 5.4-21 for the constituent source components and in Figure 5.4-23 at various distances from the cask surface.

In the wet case, the majority of the dose rate is from fuel gamma sources and activated non-fuel hardware gamma. Note that in the wet condition, it is assumed in the model that the water level in the canister is lowered to the base of the upper end-fitting in order to facilitate the lid welding operations. Thus, the top end fitting is uncovered and causes a peak in dose rate at the top of the transfer cask due to the gamma source from the activated top end fitting. In this condition, the peak dose rates on the side of the transfer cask is 189 (<1%) mrem/hr.

When configured for the shield lid welding operation, the standard transfer cask, with wet canister and temporary shielding in place, has a peak surface dose rate of 1803 (4%) in the narrow gap between the temporary shield and the cask inner shell.. This dose rate is highly localized; the average dose rate on the top of the cask under these conditions is 466 (3%) mrem/hr. Refer to Figure 5.4-24 for a plot of the radial dose profile.

After draining the canister cavity and in preparation for the vent port cover welding operation, the shield lid, temporary shield, and vent port covers are in place. Under these conditions, the radial surface dose rate profile is shown in Figure 5.4-25. The localized peak surface dose rate is 846 (3%) mrem/hr, and the surface average value is 264 (2%) mrem/hr.

After completion of the lid welding operation, the transfer cask will have a dry canister cavity, and both shield lid and structural lids in place with no temporary shielding. In this condition, the transfer cask top dose rate profile is shown in Figure 5.4-26 for each source component. In this condition, the majority of the dose rate is from end fitting gamma. The peak and average dose rates on the top of the transfer cask containing BWR fuel are 396 (<1%) mrem/hr and 222 (2%) mrem/hr, respectively.

The standard transfer cask bottom dose rate radial profiles with dry and wet canisters are shown in Figures 5.4-27 and 5.4-28, respectively. In the dry canister condition, the peak and average dose rates on the bottom of the transfer cask are 786 (<1%) mrem/hr and 379 (<1%) mrem/hr, respectively. In the wet condition, the peak and average dose rates on the bottom of the transfer cask are 539 (<1%) mrem/hr and 254 (<1%) mrem/hr, respectively.

<u>Transfer Cask Extension</u>

The transfer cask may be lengthened using a steel transfer cask extension. The extension is used when loading canisters containing fuel assemblies with control element assemblies inserted, which generally requires a longer canister than the canister used if fuel does not contain control elements. The transfer cask extension does not require neutron shielding since it is located axially above the active fuel region. As shown in the axial dose rate plots of Figure 5.4-11 and 5.4-12, the neutron dose decreases rapidly above the active fuel region. Since the top of the control element is located well outside the active core during reactor operations, activation of the top of the control element is minimal. Therefore, the solid steel extension is sufficient to attenuate the gamma sources in this region of the transfer cask.

To accommodate the use of the transfer cask extension, the transfer cask design is modified to replace the axial three inches of neutron shielding (NS-4-FR) by an annular steel ring equal in radii to the lead shield. The removed NS-4-FR is an annular ring modeled between the lead shield and the transfer cask top plate. Replacing the NS-4-FR with steel minimizes the gamma dose rate peaking at the radial cask surface below the interface between the cask extension and the transfer cask top plate, when a longer canister is used.

The annular steel ring serves to decrease cask surface dose rates at the ring elevation to a value lower than the calculated maximum radial dose rate for the cask without extension. Without the steel replacement, the longer canister, in the otherwise shorter transfer cask body, results in the canister lids shifting axially above the elevation of the lead shield, thereby providing a gamma ray streaming path.

Figure 5.4-1 Vertical Concrete Cask Axial Surface Dose Rate Profile by Source Component – Azimuthal Average – PWR Fuel

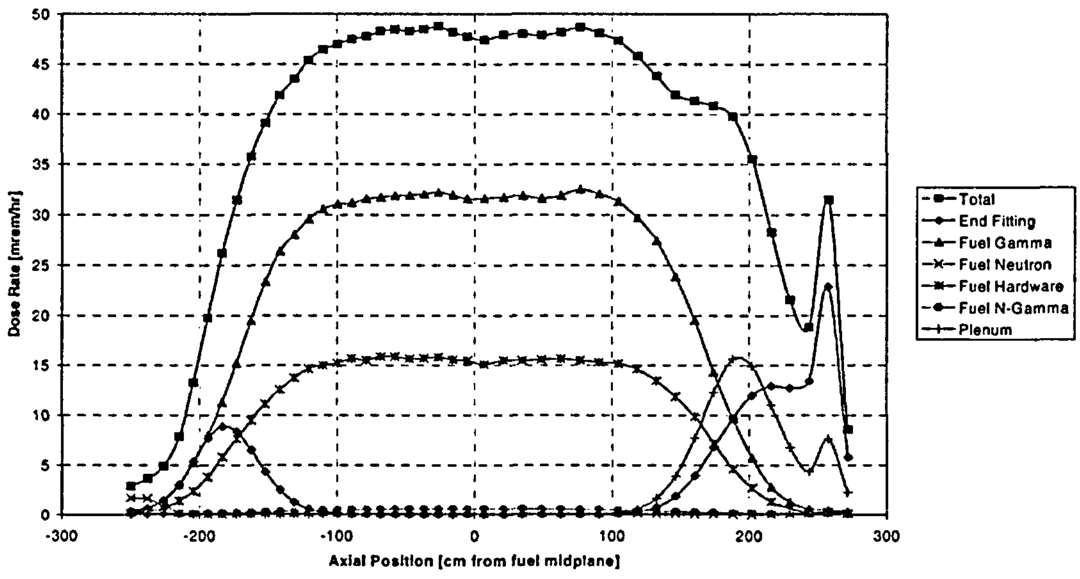

Figure 5.4-2 Vertical Concrete Cask Axial Surface Dose Rate Profile at Various Distances from Cask – Azimuthal Average – PWR Fuel

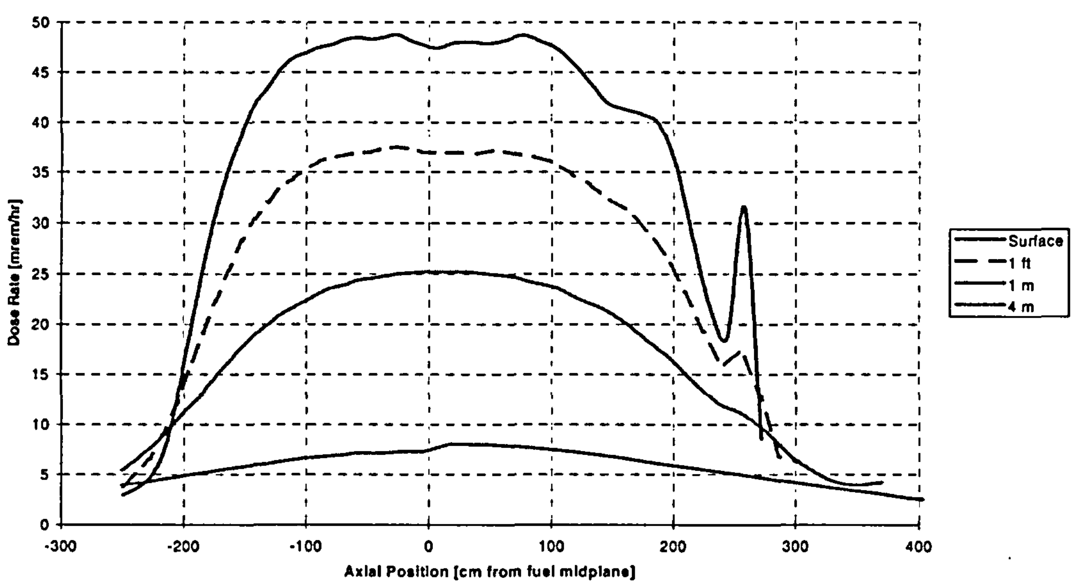

Figure 5.4-3 Vertical Concrete Cask Top Air Outlet Elevation Azimuthal Surface Dose Rate Profile – PWR Fuel

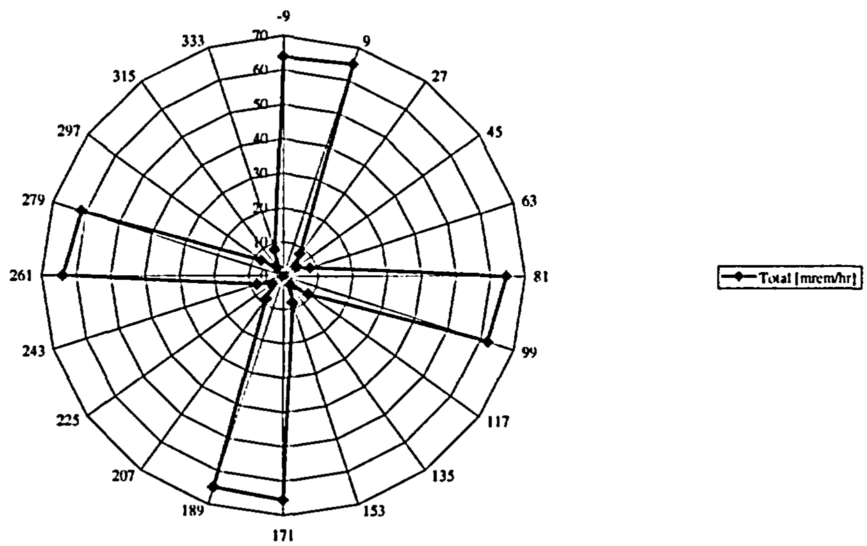

Figure 5.4-4 Vertical Concrete Cask Bottom Air Inlet Elevation Azimuthal Dose Rate Profile – PWR Fuel

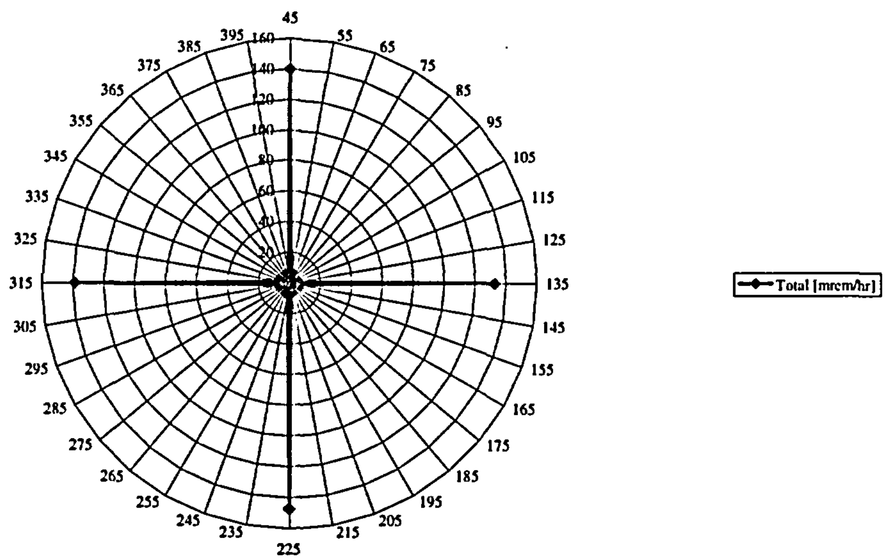

Figure 5.4-5 Vertical Concrete Cask Top Radial Surface Dose Rate Profile – Azimuthal Maximum – PWR Fuel

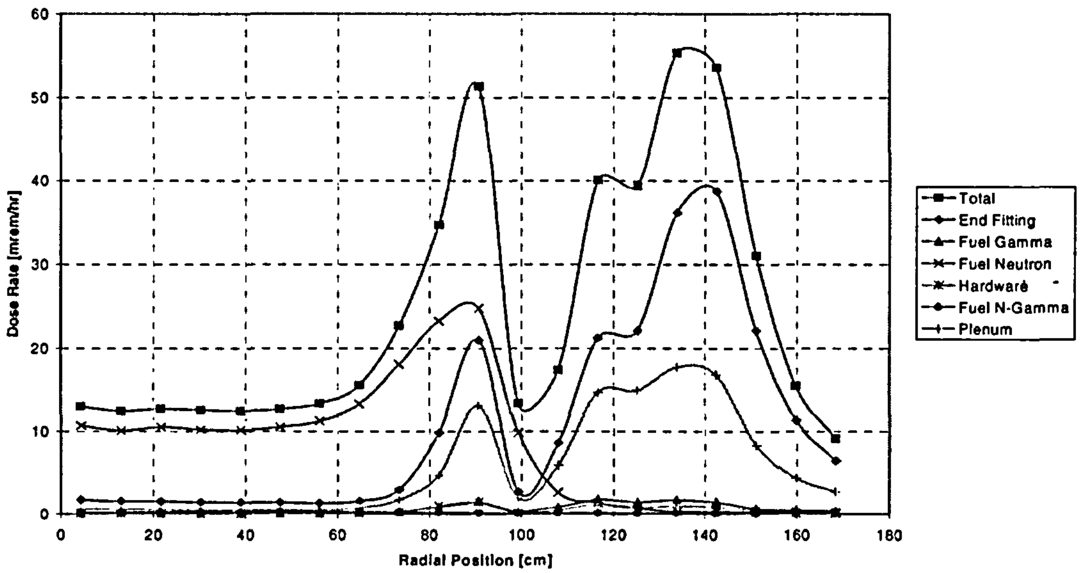

Figure 5.4-6 Vertical Concrete Cask Surface Dose Rate Profile by Source Component – Azimuthal Average – BWR Fuel

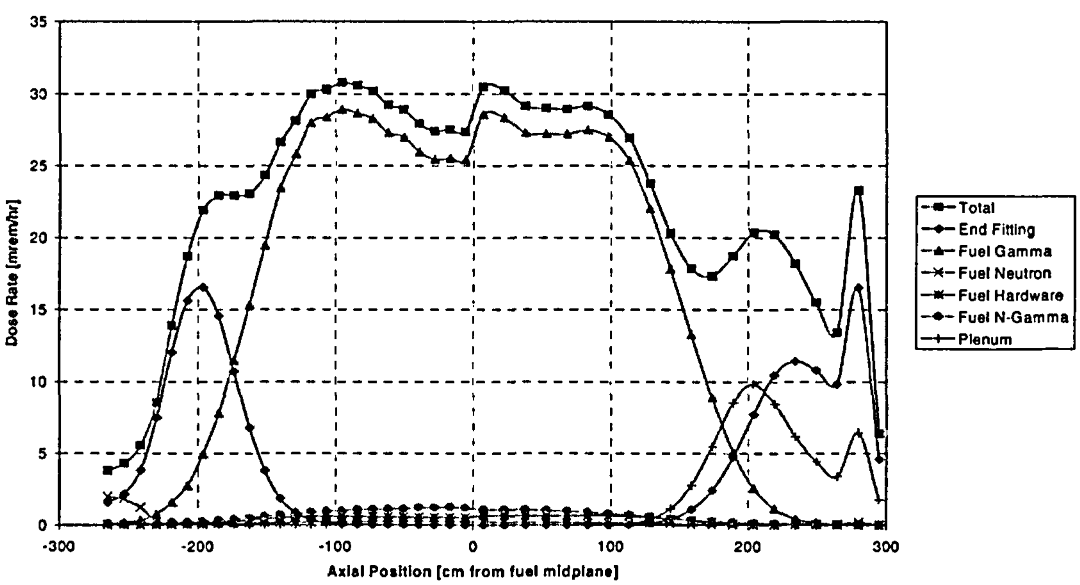

Figure 5.4-7 Vertical Concrete Cask Surface Dose Rate Profile at Various Distances from Cask – Azimuthal Average – BWR Fuel

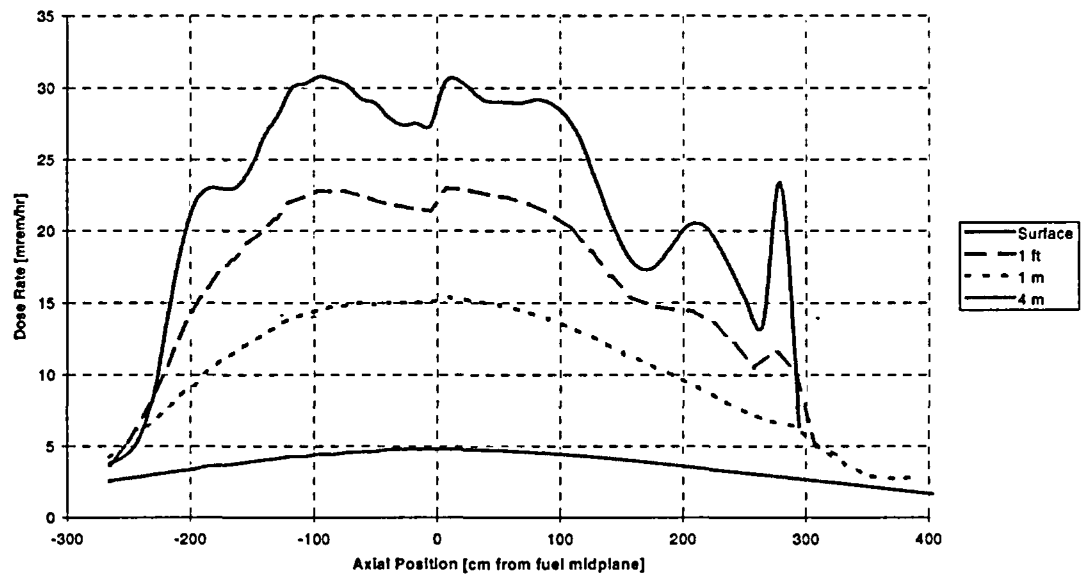

Figure 5.4-8 Vertical Concrete Cask Top Air Outlet Elevation Azimuthal Surface Dose Rate Profile – BWR Fuel

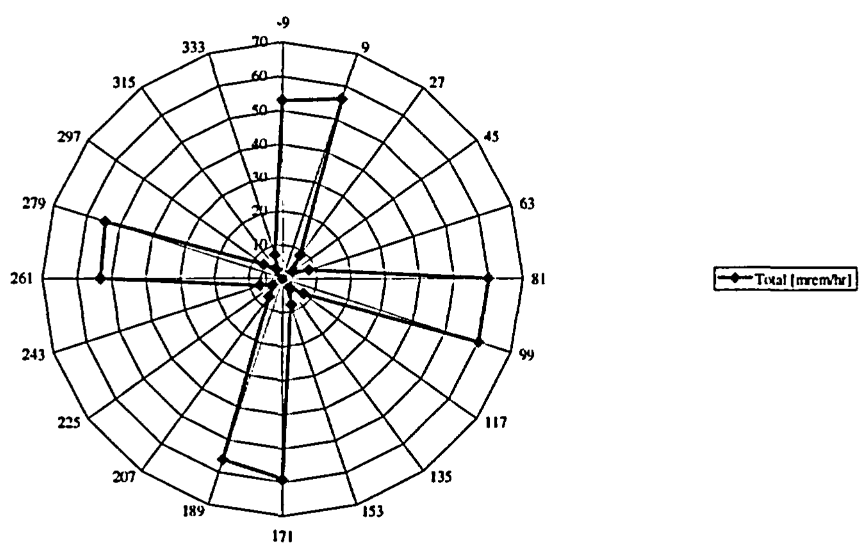

Figure 5.4-9 Vertical Concrete Cask Bottom Air Inlet Elevation Azimuthal Dose Rate Profile – BWR Fuel

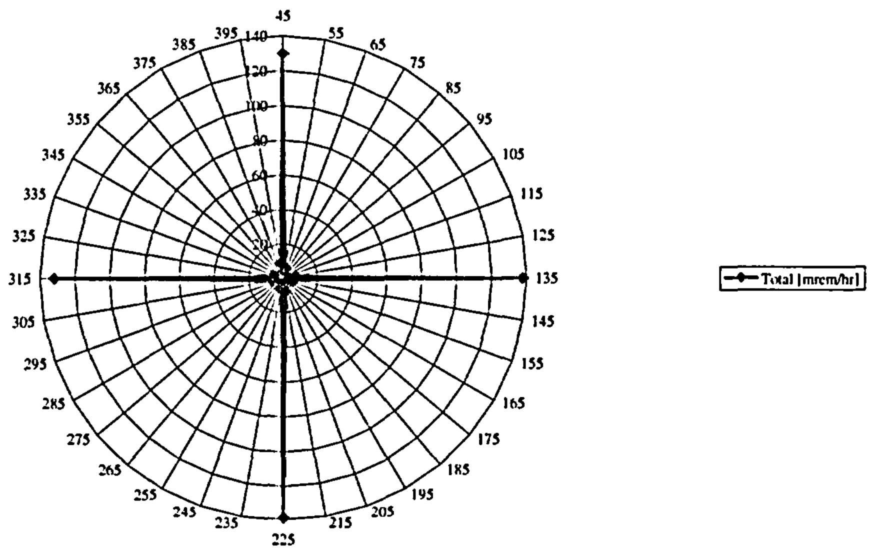

Figure 5.4-10 Vertical Concrete Cask Top Radial Surface Dose Rate Profile – Azimuthal Maximum – BWR Fuel

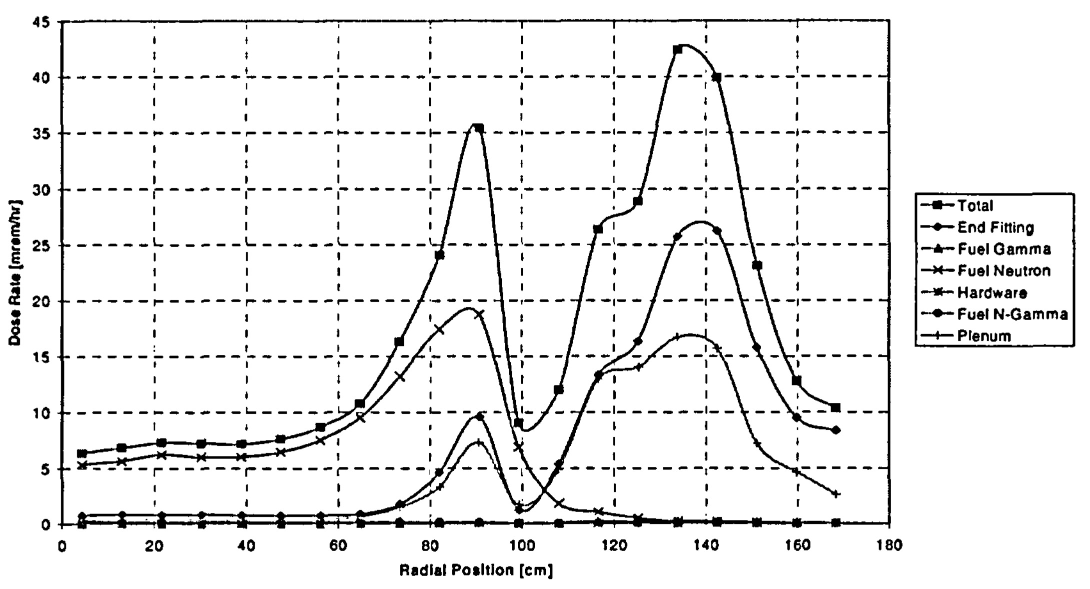

Figure 5.4-11 Standard Transfer Cask Axial Surface Dose Rate Profile – Dry Canister – PWR Fuel

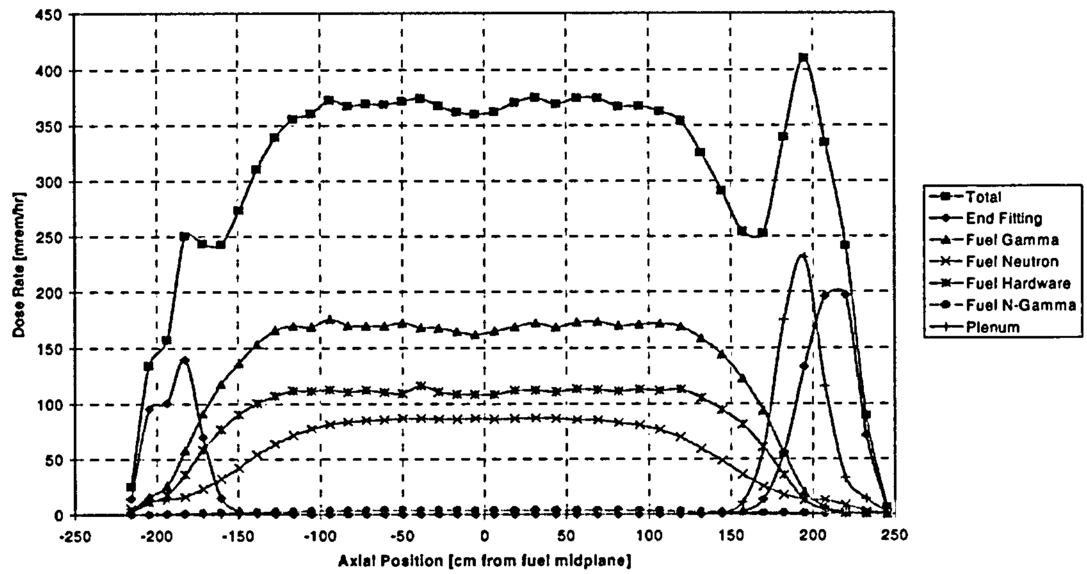

Figure 5.4-12 Standard Transfer Cask Axial Surface Dose Rate Profile – Wet Canister – PWR Fuel

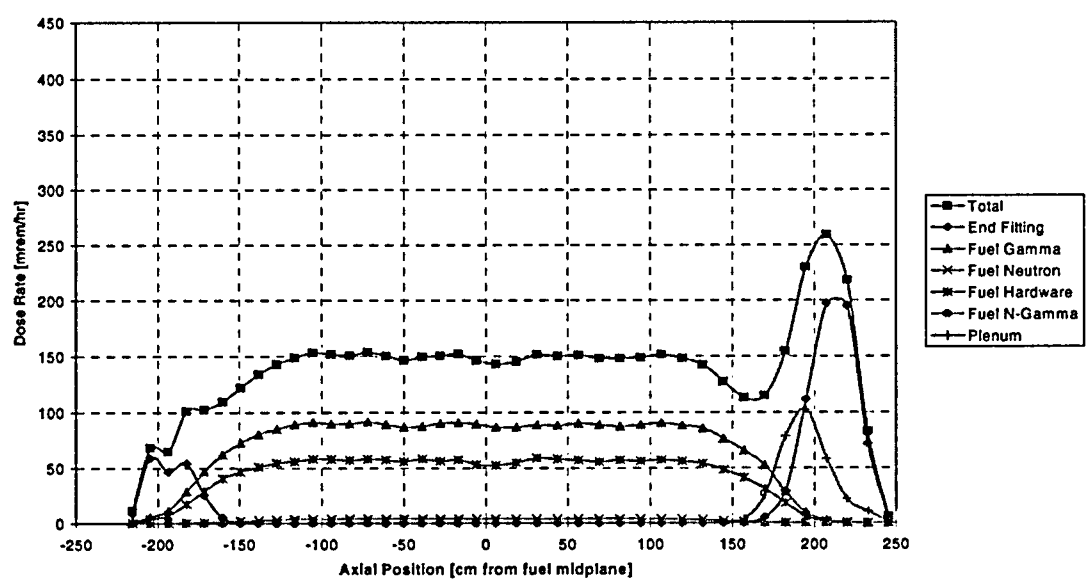

Figure 5.4-13 Standard Transfer Cask Axial Dose Rate Profile at Various Distances from Cask – Dry Canister – PWR Fuel

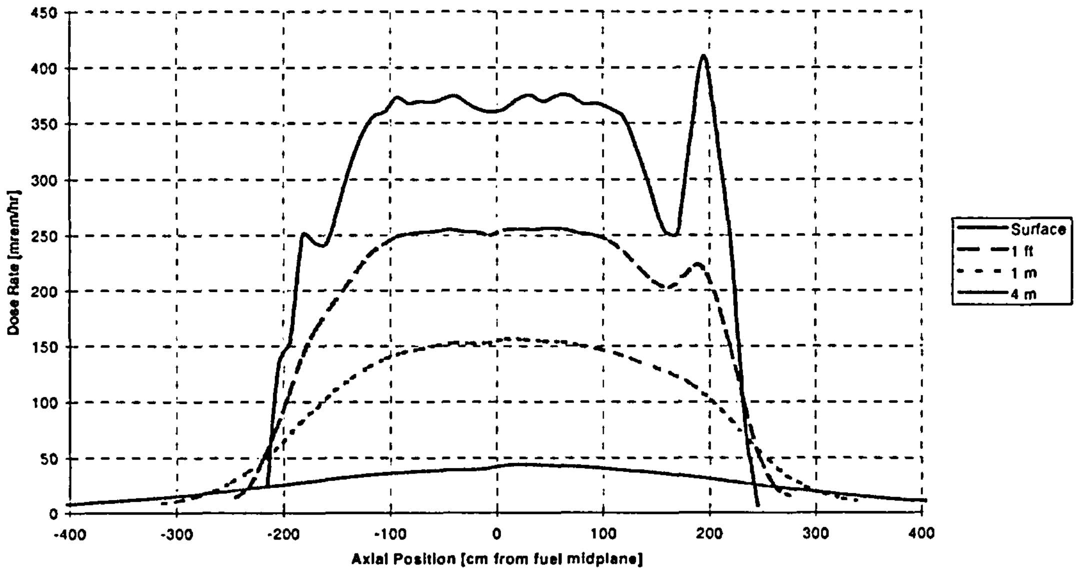

Figure 5.4-14 Standard Transfer Cask Axial Dose Rate Profile at Various Distances from Cask – Wet Canister – PWR Fuel

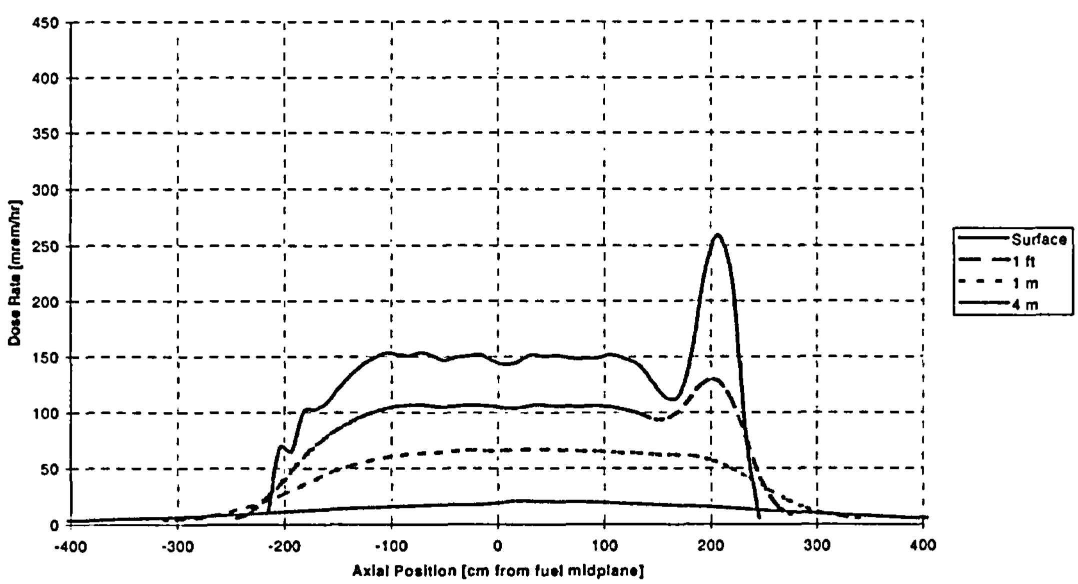

Figure 5.4-15 Standard Transfer Cask Top Radial Surface Dose Rate Profile – Shield Lid and Temporary Shield – Vent Port Covers Off – Wet Canister – PWR Fuel

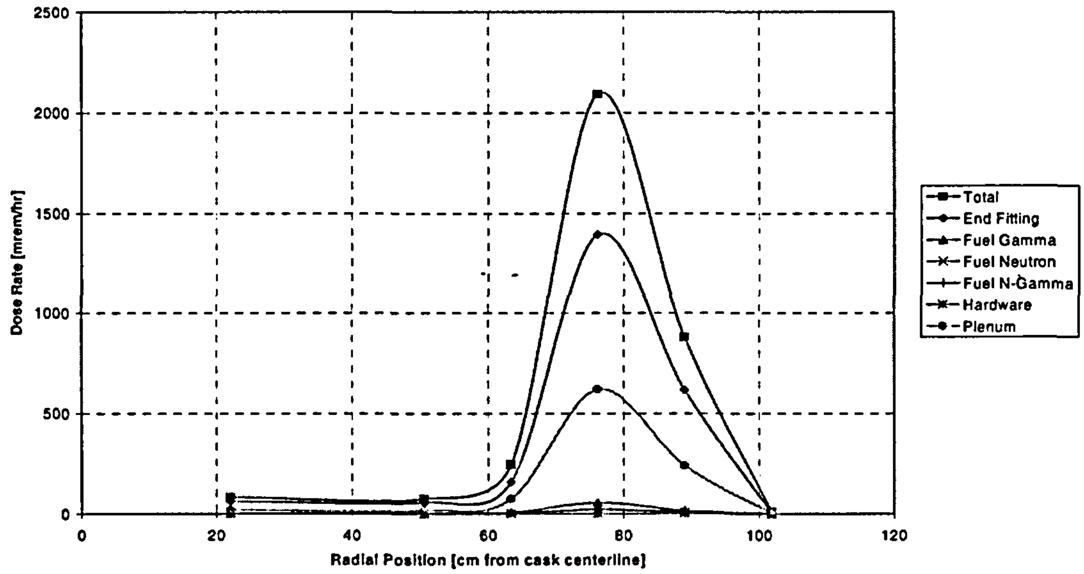

Figure 5.4-16 Standard Transfer Cask Top Radial Surface Dose Rate Profile – Shield Lid and Temporary Shield – Vent Port Covers On – Dry Canister – PWR Fuel

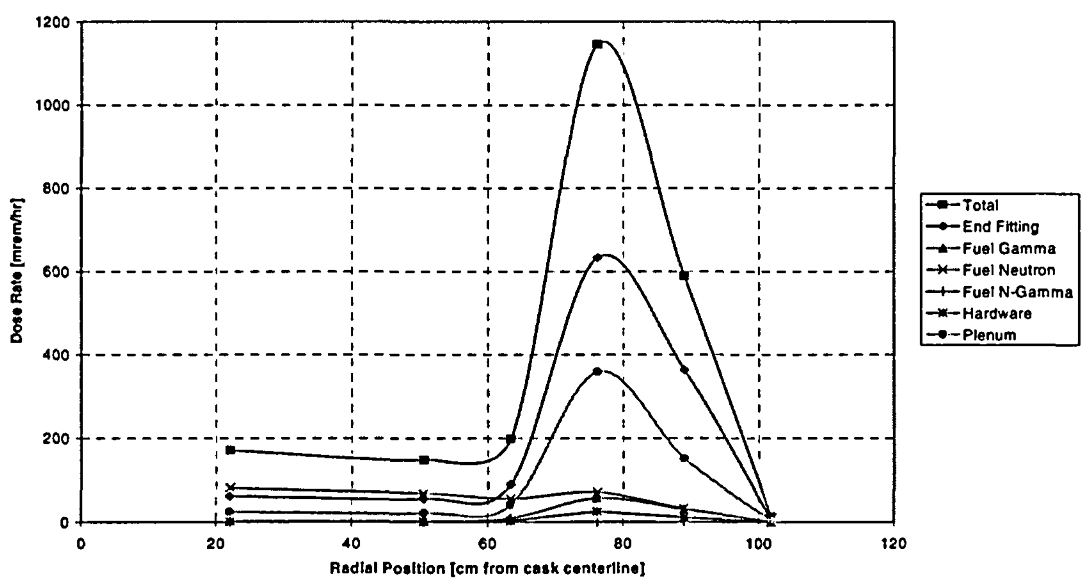

Figure 5.4-17 Standard Transfer Cask Top Radial Surface Dose Rate Profile – Shield Lid and Structural Lid – Dry Canister – PWR Fuel

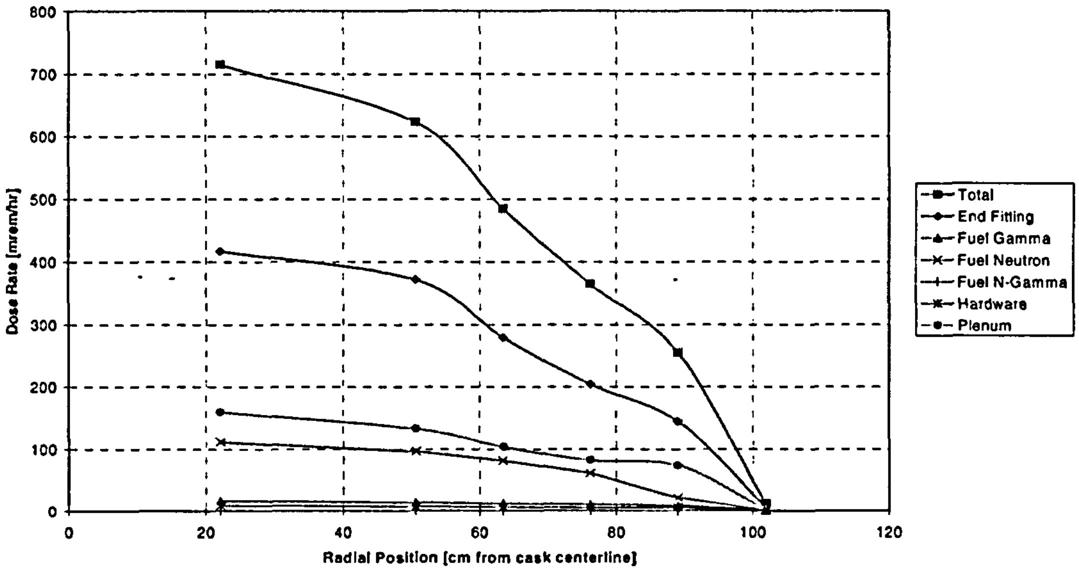

Figure 5.4-18 Standard Transfer Cask Bottom Radial Surface Dose Rate Profile – Dry Canister – PWR Fuel

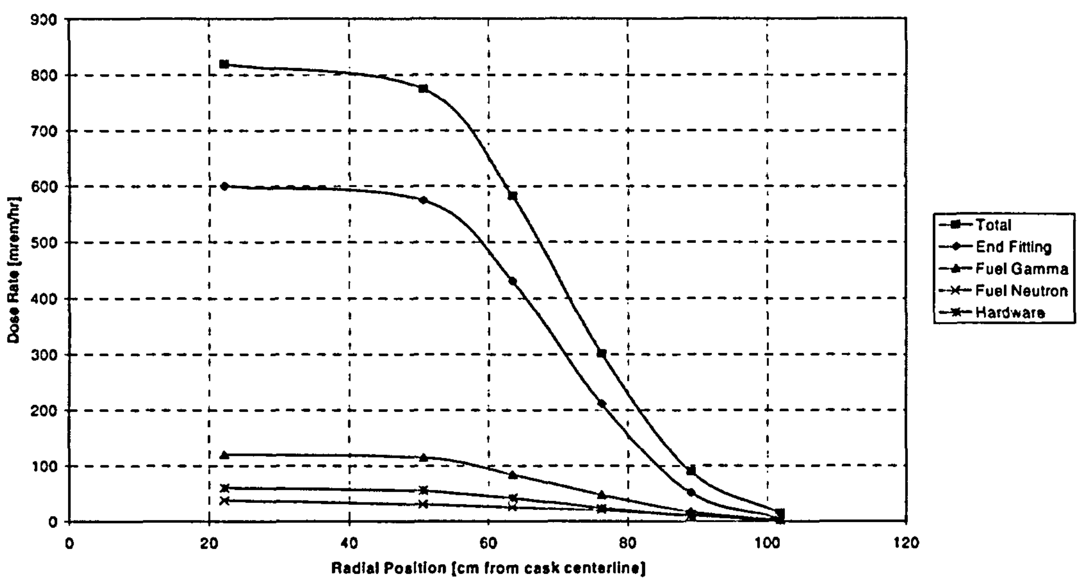

Figure 5.4-19 Standard Transfer Cask Bottom Radial Surface Dose Rate Profile – Wet Canister – PWR Fuel

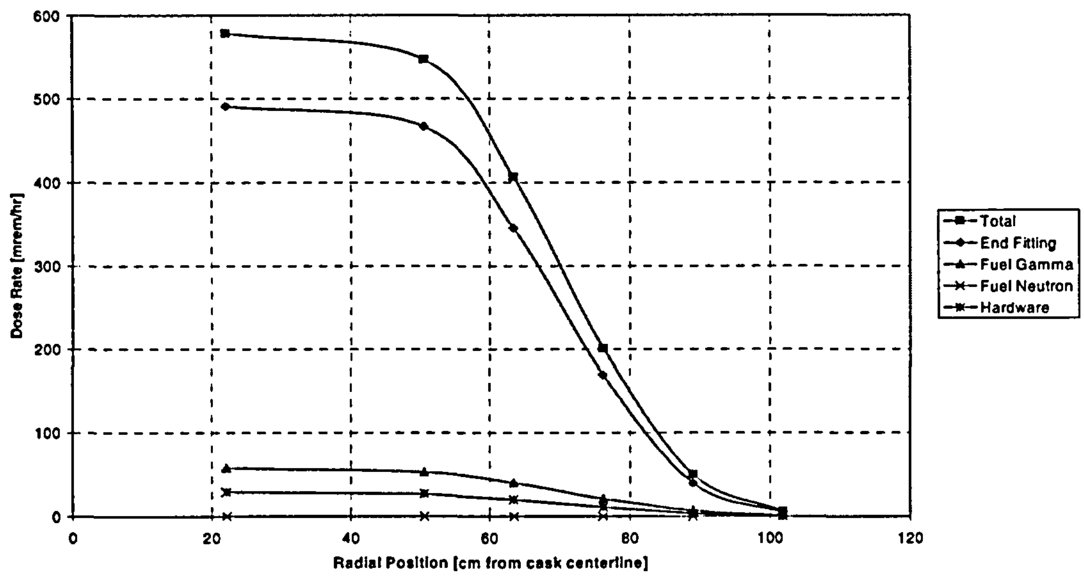

Figure 5.4-20 Standard Transfer Cask Axial Surface Dose Rate Profile – Dry Canister – BWR Fuel

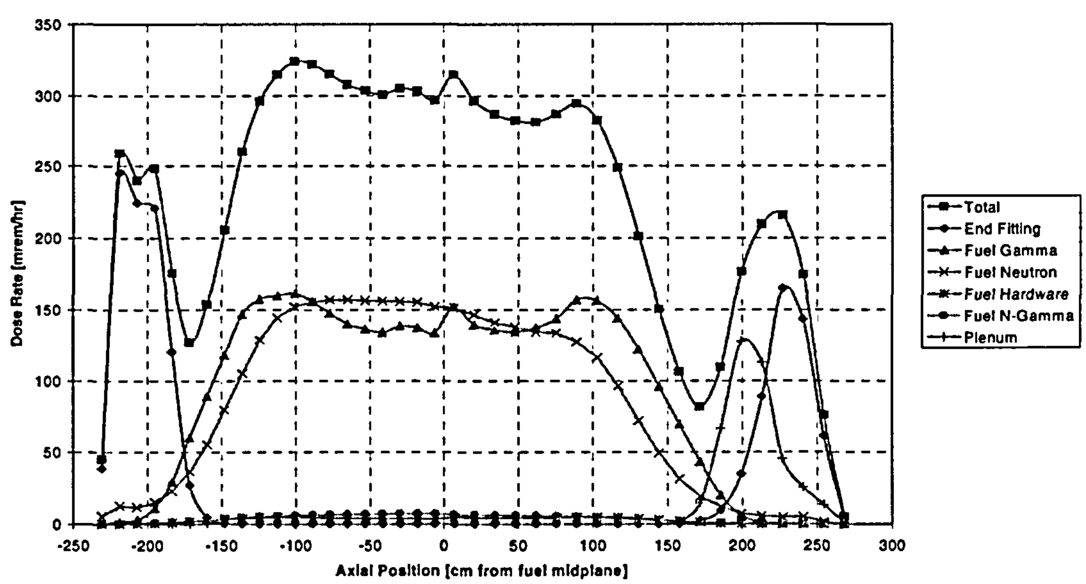

Figure 5.4-21 Standard Transfer Cask Axial Surface Dose Rate Profile – Wet Canister – BWR Fuel

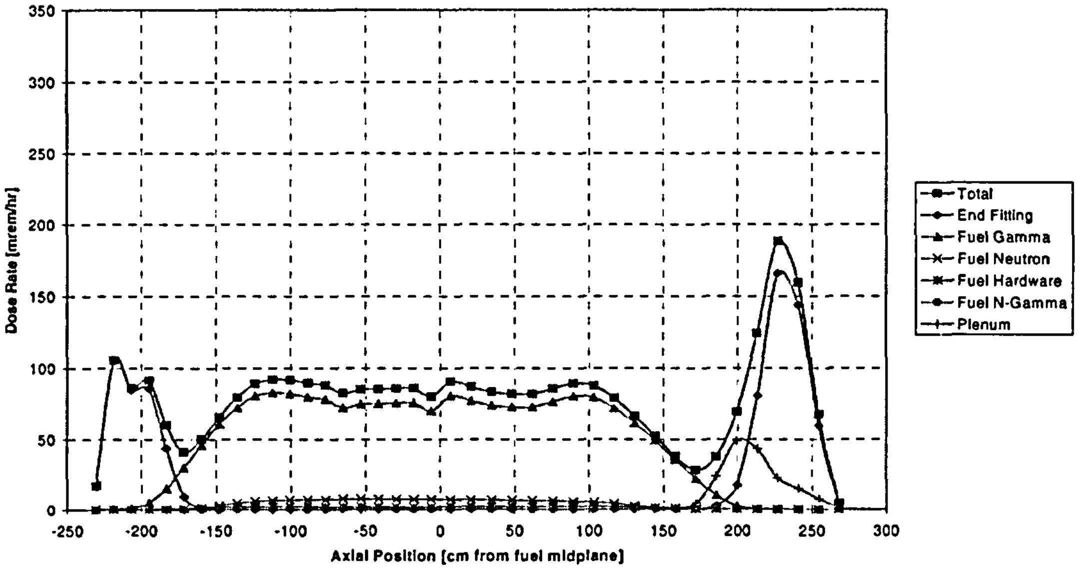

Figure 5.4-22 Standard Transfer Cask Axial Surface Dose Rate Profile at Various Distances From Cask – Dry Canister – BWR Fuel

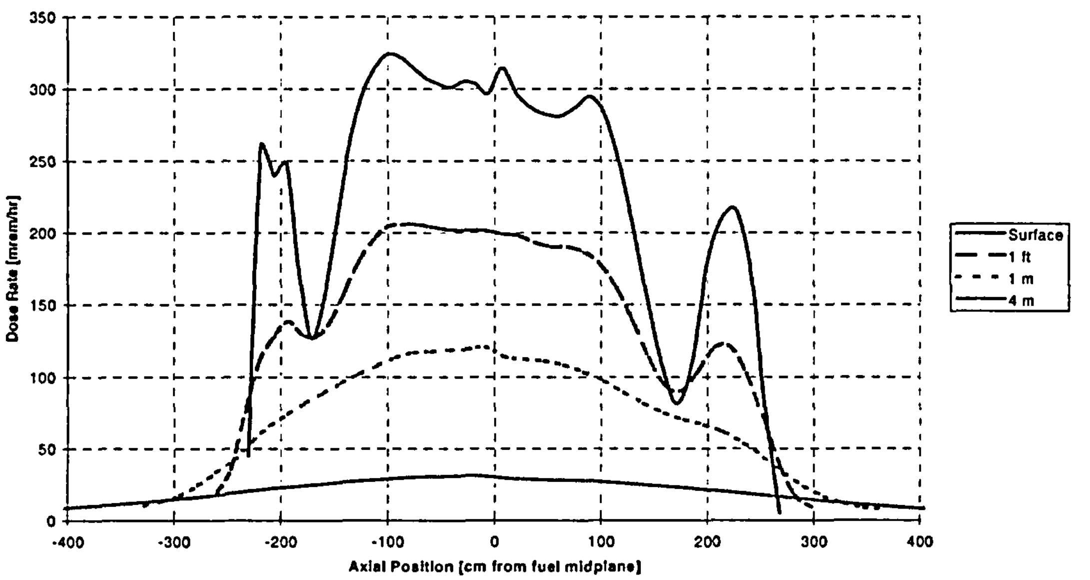

Figure 5.4-23 Standard Transfer Cask Axial Surface Dose Rate Profile at Various Distances From Cask – Wet Canister – BWR Fuel

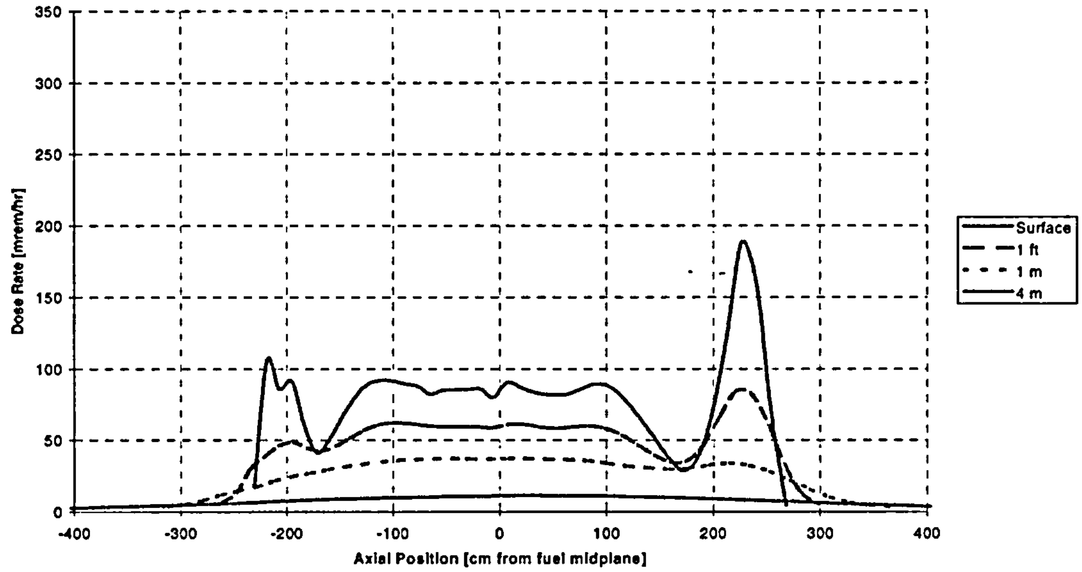

Figure 5.4-24 Standard Transfer Cask Top Radial Surface Dose Rate Profile – Shield Lid and Temporary Shield – Vent Port Covers Off – Wet Canister – BWR Fuel

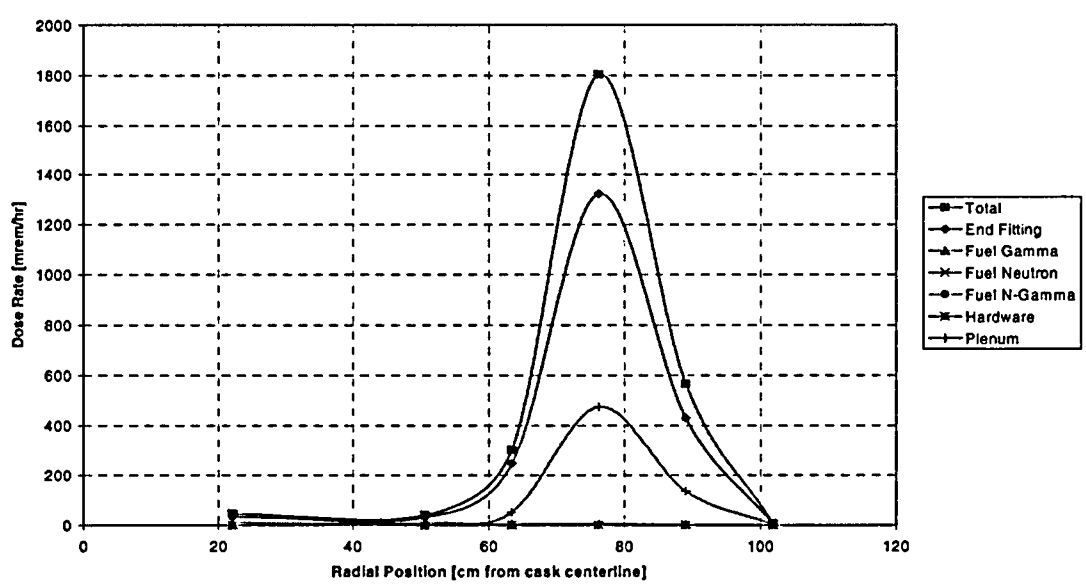

Figure 5.4-25 Standard Transfer Cask Top Radial Surface Dose Rate Profile – Shield Lid and Temporary Shield – Vent Port Covers On – Dry Canister – BWR Fuel

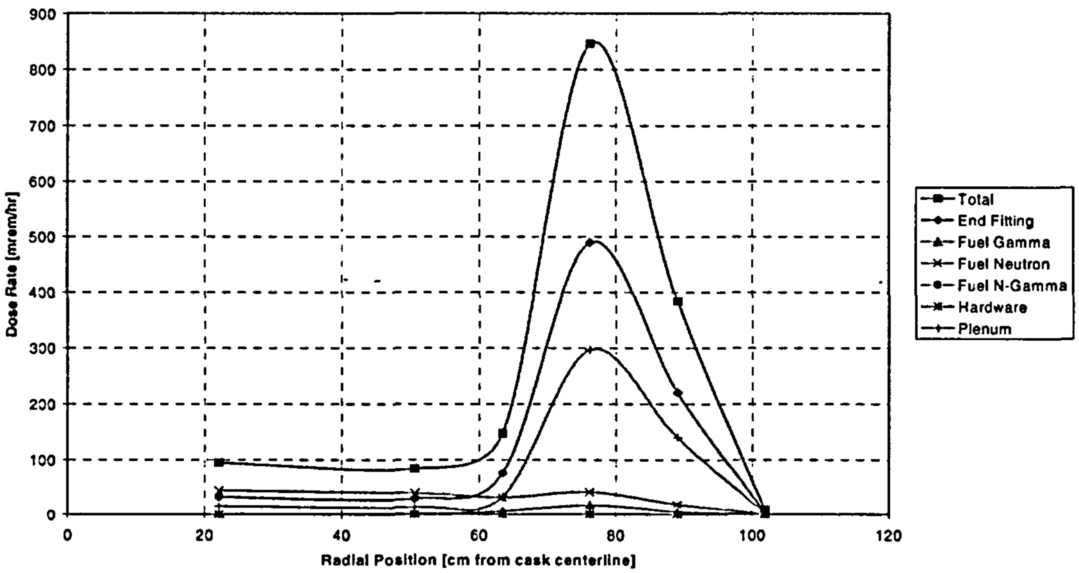

Figure 5.4-26 Standard Transfer Cask Top Radial Surface Dose Rate Profile – Shield Lid and Structural Lid – Dry Canister – BWR Fuel

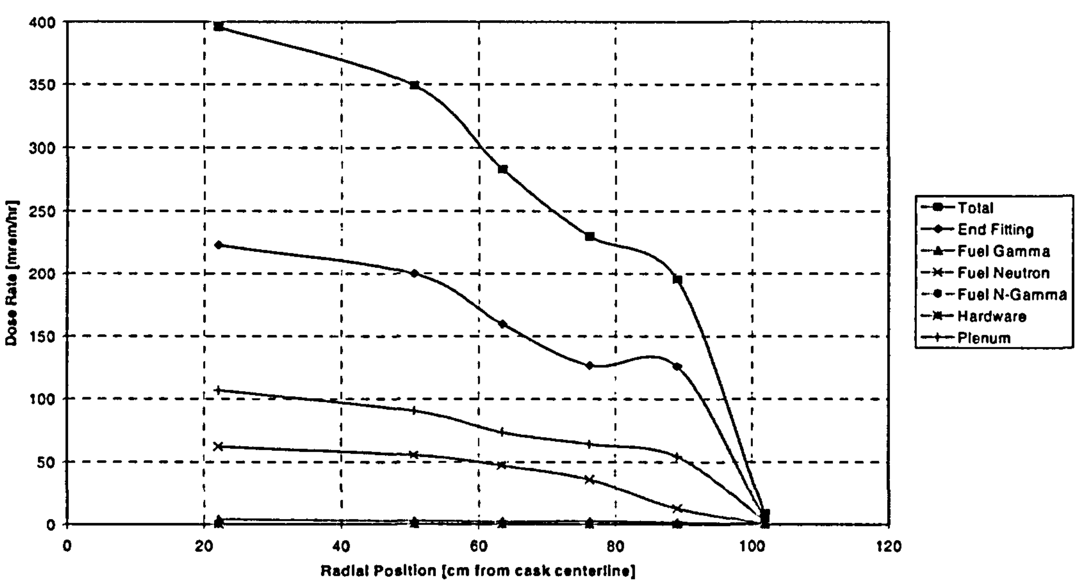

Figure 5.4-27 Standard Transfer Cask Bottom Radial Surface Dose Rate Profile – Dry Canister – BWR Fuel

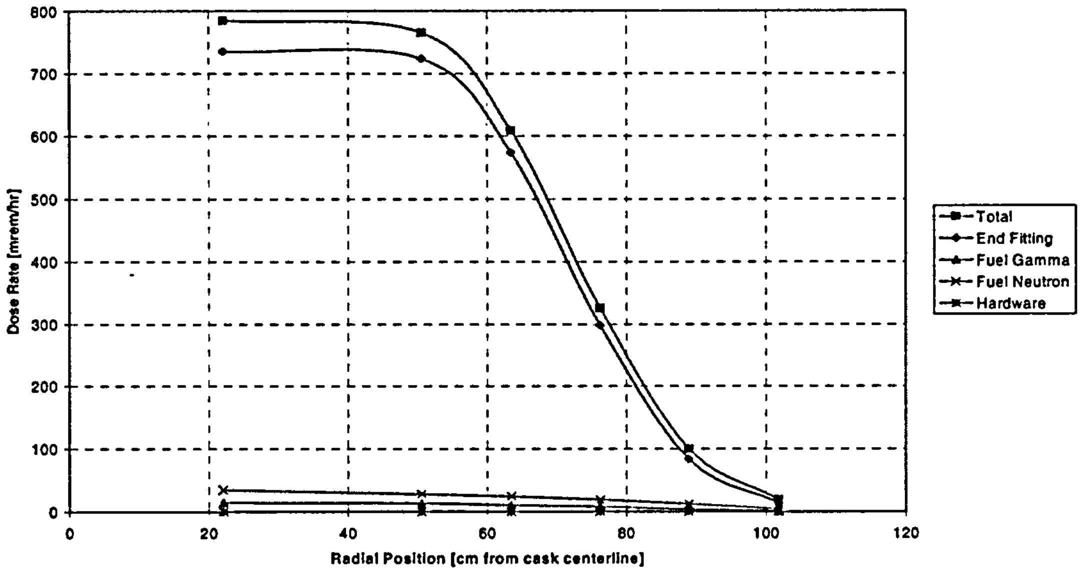

Figure 5.4-28 Standard Transfer Cask Bottom Radial Surface Dose Rate Profile – Wet Canister – BWR Fuel

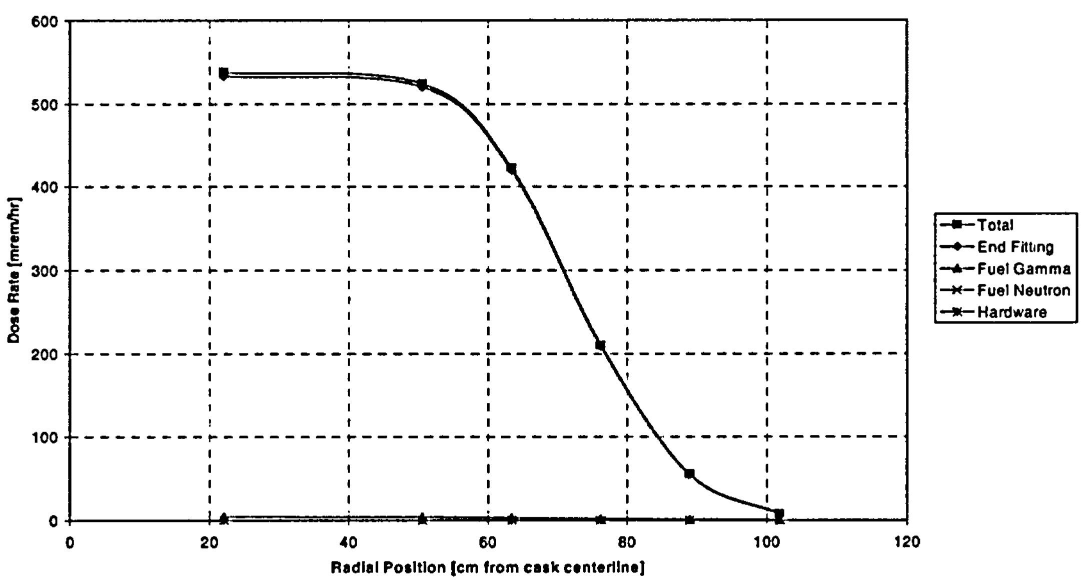

Table 5.4-1 ANSI Standard Neutron Flux-To-Dose Rate Factors

Group	(rem/hr)/(n/cm^2/sec)
1	1.49160E-04
2	1.44640E-04
3	1.27010E-04
4	1.28110E-04
5	1.29770E-04
6	1.02810E-04
7	5.11830E-05
8	1.23189E-05
9	3.83650E-06
10	3.72469E-06
11	4.01500E-06
12	4.29259E-06
13	4.47439E-06
14	4.56760E-06
15	4.55809E-06
16	4.51850E-06
17	4.48790E-06
18	4.46649E-06
19	4.43450E-06
20	4.32709E-06
21	4.19750E-06
22	4.09759E-06
23	3.83900E-06
24	3.67480E-06
25	3.67480E-06
26	3.67480E-06
27	3.67480E-06

Table 5.4-2 ANSI Standard Gamma Flux-To-Dose Rate Factors

Group	(rem/hr)/(γ/cm^2/sec)
1	8.77160E-06
2	7.47849E-06
3	6.37479E-06
4	5.41360E-06
5	4.62209E-06
6	3.95960E-06
7	3.46860E-06
8	3.01920E-06
9	2.62759E-06
10	2.20510E-06
11	1.83260E-06
12	1.52280E-06
13	1.17250E-06
14	8.75940E-07
15	6.30610E-07
16	3.83380E-07
17	2.66930E-07
18	9.34720E-07

Table 5.4-3 ANSI Standard Neutron Flux-To-Dose Rate Factors in MCBEND Group Structure

Group	Upper E [MeV]	Lower E [MeV]	Response [(mrem/hr)/(n/cm²/sec)]
1	1.46E+01	1.36E+01	2.0533E-01
2	1.36E+01	1.25E+01	1.8999E-01
3	1.25E+01	1.13E+01	1.7250E-01
4	1.13E+01	1.00E+01	1.5399E-01
5	1.00E+01	8.25E+00	1.4700E-01
6	8.25E+00	7.00E+00	1.4700E-01
7	7.00E+00	6.07E+00	1.4929E-01
8	6.07E+00	4.72E+00	1.5348E-01
9	4.72E+00	3.68E+00	1.4580E-01
10	3.68E+00	2.87E+00	1.3478E-01
11	2.87E+00	1.74E+00	1.2657E-01
12	1.74E+00	6.40E-01	1.2570E-01
13	6.40E-01	3.90E-01	8.8205E-02
14	3.90E-01	1.10E-01	4.6004E-02
15	1.10E-01	6.74E-02	1.8108E-02
16	6.74E-02	2.48E-02	1.0774E-02
17	2.48E-02	9.12E-03	4.9057E-03
18	9.12E-03	2.95E-03	3.6168E-03
19	2.95E-03	9.61E-04	3.7152E-03
20	9.61E-04	3.54E-04	3.8611E-03
21	3.54E-04	1.66E-04	4.0252E-03
22	1.66E-04	4.81E-05	4.1919E-03
23	4.81E-05	1.60E-05	4.3795E-03
24	1.60E-05	4.00E-06	4.5200E-03
25	4.00E-06	1.50E-06	4.4895E-03
26	1.50E-06	5.50E-07	4.3924E-03
27	5.50E-07	7.09E-08	3.9685E-03
28	7.09E-08	0.00E+00	2.3759E-03

Table 5.4-4 ANSI Standard Gamma Flux-To-Dose Rate Factors in MCBEND Group Structure

Group	Upper E [MeV]	Lower E [MeV]	Response [(mrem/hr)/(γ/cm²/sec)]
1	1.40E+01	1.20E+01	1.1728E-02
2	1.20E+01	1.00E+01	1.0225E-02
3	1.00E+01	8.00E+00	8.7164E-03
4	8.00E+00	6.50E+00	7.4457E-03
5	6.50E+00	5.00E+00	6.3551E-03
6	5.00E+00	4.00E+00	5.3991E-03
7	4.00E+00	3.00E+00	4.5984E-03
8	3.00E+00	2.50E+00	3.9449E-03
9	2.50E+00	2.00E+00	3.4485E-03
10	2.00E+00	1.66E+00	2.9982E-03
11	1.66E+00	1.44E+00	2.6706E-03
12	1.44E+00	1.22E+00	2.3929E-03
13	1.22E+00	1.00E+00	2.1055E-03
14	1.00E+00	8.00E-01	1.8164E-03
15	8.00E-01	6.00E-01	1.5143E-03
16	6.00E-01	4.00E-01	1.1686E-03
17	4.00E-01	3.00E-01	8.6947E-04
18	3.00E-01	2.00E-01	6.2398E-04
19	2.00E-01	1.00E-01	3.8050E-04
20	1.00E-01	5.00E-02	2.7163E-04
21	5.00E-02	2.00E-02	5.8620E-04
22	2.00E-02	1.00E-02	2.3540E-03

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5.5 Minimum Allowable Cooling Time Evaluation for PWR and BWR Fuel

Sections 5.1 through 5.4 include the source term and shielding analyses for the design basis UMS® PWR and BWR assemblies with a burnup of 40 GWD/MTU and a 5-year cool time. The shielding evaluation design basis fuel assemblies source term are based on an initial minimum enrichment of 3.7 wt % ^{235}U for PWR and 3.25 wt % ^{235}U for BWR fuel assemblies. The source terms for the design basis assemblies represent a maximum heat load of 25.2 kW for the PWR cask and 24 kW for the BWR cask. The maximum allowable heat load for the UMS® storage system is 23 kW.

This section determines minimum cooling times for PWR and BWR assemblies at burnups ranging from 30 to 45 GWD/MTU with corresponding minimum initial enrichments from 1.9 wt % ^{235}U to 5.0 wt % ^{235}U. For each combination of initial enrichment and burnup, the minimum cooling times necessary to meet the maximum allowable decay heat, maximum transfer cask dose rate and maximum storage cask dose rate are determined. The listed minimum cooling times are the most limiting time required to meet either the canister maximum allowable heat load, the transfer cask design basis radial dose rates or storage cask design basis radial dose rates.

To address differences in the fissile material loading between assemblies, the assemblies are grouped by fuel pin array size. The BWR fuel types evaluated are 7×7, 8×8 and 9×9 assemblies and the PWR fuel types evaluated are 14×14, 15×15, 16×16 and 17×17 fuel assemblies.

5.5.1 Selection of Limiting PWR and BWR Fuel Types for Minimum Cooling Time Determination

The bounding PWR and BWR fuel assemblies are listed in Table 5.5-1. The selection of the limiting PWR and BWR assemblies is made based upon bounding maximum initial uranium loadings at 95% theoretical fuel density. Detailed PWR and BWR fuel characteristics, including the maximum MTU loadings, are documented in Table 6.2-1 and Table 6.2-2 for a wide range of PWR and BWR fuel assemblies.

Bounding uranium loadings produce the maximum heat loads and fuel radiation source terms. To ensure that fuel hardware such as grid spacers and burnable poison rods are fully considered in selecting the shielding limited fuel types the Westinghouse 15×15, GE 8×8-62 fuel rod and GE 8×8 60 fuel rod fuel assembly types are also evaluated.

5.5.2 Decay Heat Limit

The maximum allowable heat load, or decay heat limit as used in the context of this chapter, is based on the overall maximum decay heat limit of 23 kW. The maximum allowable heat load on a per assembly basis is 0.958 kW.

As documented in Section 5.4.1, the SAS2H sequence of SCALE 4.3 is used to determine source term magnitudes for each fuel assembly type, initial enrichment and burnup combination. Source term in this context implies both heat load and radiation sources for both fuel and activated hardware.

5.5.3 Storage Cask and Standard Transfer Cask Dose Rate Limits and Dose Calculation Method

Storage cask and standard transfer cask radial surface dose rates for the design basis assemblies are presented in Tables 5.1-1 through 5.1-4. The design basis radial storage and transfer cask (dry cavity) dose rates are used as an upper bound dose rate limit for any other fuel assembly type, burnup, and enrichment combination.

To avoid the significant effort required to prepare and execute hundreds of one-dimensional cases for all fuel configurations and burnups under consideration, a unique device is employed which permits the ready calculation of dose rates at a given location using a dose rate response function. The dose rate response function for a given source type at a given detector location is a collection of values, one for each energy group, each of which gives the contribution to the dose rate at the detector location from a unit source strength in that energy group. With this response function, the dose rate, d, at the corresponding detector location is determined for any given fuel type by vector multiplying the unnormalized source spectrum, f, by the response function, r:

$$d = r \cdot f$$

The dose rate response function is computed by solving a series of one-dimensional cases, one for each energy group, with a unit source strength in each energy group. In practice, the source strength is normalized to some large value (here, 10^{10}) in order to avoid numeric underflow in the calculation.

Sample response functions for the PWR and BWR storage casks and the standard transfer cask are listed in Table 5.5-3 and Table 5.5-4 for neutron and gamma sources, respectively. Only seven energy groups are presented for the fuel neutron source since the complete SAS2H neutron source is located in these energy groups.

With the dose rate response method a convenient and simple method for determining storage and transfer cask surface dose rates is available.

5.5.4 Minimum Allowable Cooling Time Determination

The following strategy is used to determine limiting cooling times for each combination of fuel type, initial enrichment, and burnup:

a) Determine decay heat and dose rate values at each cooling time step.
b) Interpolate in the resulting collection of data to find minimum cooling time required to meet each limiting value, decay heat and transfer and storage cask dose rate, individually.
c) Select the maximum of this collection of minimum required cooling times, rounded up to the next whole year, as the minimum required cooling time for this combination of burnup, enrichment and cooling time.

5.5.4.1 PWR and BWR Assembly Minimum Cooling Times

Minimum allowable cooling times are established for each of the fuel type, burnup, and enrichment combinations based on the cask decay heat limit of 23 kW and the one-dimensional dose rate limits in Table 5.5-2. A sample of the calculated cooling times required to reach each of the limits for Westinghouse 17×17 and GE 9×9 fuel assemblies at 40 GWD/MTU are shown in Tables 5.5-5 and 5.5-6, respectively. The identical calculation sequence is repeated for all the assembly types and burnups indicated in Section 5.5-1. The limiting cooling times are then collapsed to array size specific limiting values as listed in Table 5.5-7 and Table 5.5-8.

Table 5.5-1 Limiting PWR and BWR Fuel Types Based on Uranium Loading

Reactor	Array	Fuel Assembly
PWR	17×17	WE 17×17 Standard
PWR	16×16	CE 16×16 System 80
PWR	15×15	BW 15×15
PWR	14×14	WE 14×14
BWR	9×9	GE 9×9-79 Fuel Rods (GE 9×9-2L)
BWR	8×8	GE 8×8-63 Fuel Rods
BWR	7×7	GE 7×7

Table 5.5-2 Design Basis Assembly Dose Rate Limit (mrem/hr)

Configuration	Neutron	Gamma	Hardware Gamma	Total[1]
PWR Storage	0.6	22.5	11.1	34.2
BWR Storage	0.9	16.5	0.1	17.6
PWR Transfer	68.1	127.4	82.4	277.8
BWR Transfer	108.0	92.6	1.1	201.6

1. Measurements in mrem/hr.

Table 5.5-3 Radial Surface Response to Neutrons

Group	E_{avg} (MeV)	Storage Cask[1]		Standard Transfer Cask[1]	
		WE17×17	GE9×9-2L	WE17×17	GE9×9-2L
1	1.32E+01	1.4090E+07	1.4092E+07	1.6120E+09	1.5776E+09
2	4.72E+00	8.0067E+06	8.3652E+06	1.0621E+09	1.0579E+09
3	2.43E+00	6.9413E+06	7.4255E+06	9.9278E+08	1.0147E+09
4	1.63E+00	5.4135E+06	5.9542E+06	6.9518E+08	7.2993E+08
5	1.15E+00	4.7208E+06	5.2315E+06	5.1436E+08	5.4559E+08
6	6.50E-01	4.4771E+06	5.0154E+06	3.6579E+08	4.0159E+08
7	2.50E-01	3.3522E+06	3.8567E+06	1.0275E+08	1.1960E+08

1. mrem/hr per 10^{10} neutrons/second.

Table 5.5-4 Radial Surface Response to Gammas

Group	E_{avg} (MeV)	Storage Cask[1]		Standard Transfer Cask[1]	
		WE17×17	GE9×9-2L	WE17×17	GE9×9-2L
1	9.00E+00	2.1642E+05	2.0388E+05	8.8476E+04	8.4060E+04
2	7.25E+00	1.6963E+05	1.6008E+05	1.0748E+05	1.0204E+05
3	5.75E+00	1.1013E+05	1.0387E+05	1.1130E+05	1.0542E+05
4	4.50E+00	6.0237E+04	5.6658E+04	1.0110E+05	9.5390E+04
5	3.50E+00	2.8958E+04	2.7132E+04	8.0031E+04	7.5091E+04
6	2.75E+00	1.1556E+04	1.0761E+04	5.2075E+04	4.8507E+04
7	2.25E+00	4.8220E+03	4.4662E+03	2.9488E+04	2.7289E+04
8	1.83E+00	1.6449E+03	1.5139E+03	1.2645E+04	1.1617E+04
9	1.50E+00	5.2977E+02	4.8508E+02	4.3386E+03	3.9611E+03
10	1.17E+00	1.1402E+02	1.0395E+02	7.2955E+02	6.6298E+02
11	9.00E-01	1.6902E+01	1.5317E+01	4.6940E+01	4.2324E+01
12	7.00E-01	2.8772E+00	2.6068E+00	1.5996E+00	1.4442E+00
13	5.00E-01	2.5056E-01	2.2771E-01	8.5258E-04	7.7577E-04
14	3.50E-01	6.0028E-03	5.3421E-03	1.8977E-11	1.6941E-11
15	2.50E-01	2.1429E-04	1.8519E-04	1.1956E-32	1.0398E-32
16	1.50E-01	4.3116E-08	2.8984E-08	0.0000E+00	0.0000E+00
17	7.50E-02	2.5041E-35	2.2809E-36	0.0000E+00	0.0000E+00
18	3.00E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

1. mrem/hr per 10^{10} γ/second.

Table 5.5-5 Westinghouse 17×17 Minimum Cooling Time Evaluation

Enrichment (wt % ^{235}U)	Minimum Cooling Time (Years)[1]				Active Constraint
	Decay Heat	Storage Dose	Transfer Dose	Limiting	
1.9	6.3	6.0	9.5	10	Transfer Dose
2.1	6.2	5.8	8.5	9	Transfer Dose
2.3	6.1	5.7	7.7	8	Transfer Dose
2.5	6	5.6	7	7	Transfer Dose
2.7	5.9	5.5	6.5	7	Transfer Dose
2.9	5.9	5.4	6.1	7	Transfer Dose
3.1	5.8	5.3	5.8	6	Decay Heat
3.3	5.8	5.2	5.5	6	Decay Heat
3.5	5.7	5.1	5.2	6	Decay Heat
3.7	5.7	5	5	6	Decay Heat
3.9	5.6	5	5	6	Decay Heat
4.1	5.6	5	5	6	Decay Heat
4.3	5.5	5	5	6	Decay Heat
4.5	5.5	5	5	6	Decay Heat
4.7	5.4	5	5	6	Decay Heat
4.9	5.4	5	5	6	Decay Heat

1. 40,000 MWD/MTU burnup.

Table 5.5-6 GE 9×9-2L Minimum Cooling Time Evaluation

Enrichment	Minimum Cooling Time (Years)[1]				Active
(wt % ^{235}U)	Decay Heat	Storage Dose	Transfer Dose	Limiting	Constraint
1.9	5.8	5.6	14.3	15	Transfer Dose
2.1	5.7	5.5	11.7	12	Transfer Dose
2.3	5.6	5.4	9.5	10	Transfer Dose
2.5	5.5	5.3	7.9	8	Transfer Dose
2.7	5.4	5.2	6.7	7	Transfer Dose
2.9	5.3	5.2	5.9	6	Transfer Dose
3.1	5.2	5.1	5.4	6	Transfer Dose
3.3	5.2	5	5	6	Decay Heat
3.5	5.1	5	5	6	Decay Heat
3.7	5	5	5	5	Decay Heat
3.9	5	5	5	5	Decay Heat
4.1	5	5	5	5	Decay Heat
4.3	5	5	5	5	Decay Heat
4.5	5	5	5	5	Decay Heat
4.7	5	5	5	5	Decay Heat
4.9	5	5	5	5	Decay Heat

1. 40,000 MWD/MTU burnup.

Table 5.5-7 Loading Table for PWR Fuel

Minimum Initial Enrichment wt % ^{235}U (E)	Burnup ≤30 GWD/MTU Minimum Cooling Time [years]				30< Burnup ≤35 GWD/MTU Minimum Cooling Time [years]			
	14×14	15×15	16×16	17×17	14×14	15×15	16×16	17×17
1.9 ≤ E < 2.1	5	5	5	5	7	7	5	7
2.1 ≤ E < 2.3	5	5	5	5	7	6	5	6
2.3 ≤ E < 2.5	5	5	5	5	6	6	5	6
2.5 ≤ E < 2.7	5	5	5	5	6	6	5	6
2.7 ≤ E < 2.9	5	5	5	5	6	5	5	5
2.9 ≤ E < 3.1	5	5	5	5	5	5	5	5
3.1 ≤ E < 3.3	5	5	5	5	5	5	5	5
3.3 ≤ E < 3.5	5	5	5	5	5	5	5	5
3.5 ≤ E < 3.7	5	5	5	5	5	5	5	5
3.7 ≤ E < 3.9	5	5	5	5	5	5	5	5
3.9 ≤ E < 4.1	5	5	5	5	5	5	5	5
4.1 ≤ E < 4.3	5	5	5	5	5	5	5	5
4.3 ≤ E < 4.5	5	5	5	5	5	5	5	5
4.5 ≤ E < 4.7	5	5	5	5	5	5	5	5
4.7 ≤ E < 4.9	5	5	5	5	5	5	5	5
E ≥ 4.9	5	5	5	5	5	5	5	5
Minimum Initial Enrichment wt % ^{235}U (E)	**35< Burnup ≤40 GWD/MTU Minimum Cooling Time [years]**				**40< Burnup ≤45 GWD/MTU Minimum Cooling Time [years]**			
	14×14	15×15	16×16	17×17	14×14	15×15	16×16	17×17
1.9 ≤ E < 2.1	10	10	7	10	15	15	11	15
2.1 ≤ E < 2.3	9	9	6	9	14	13	9	13
2.3 ≤ E < 2.5	8	8	6	8	12	12	8	12
2.5 ≤ E < 2.7	8	7	6	7	11	11	7	11
2.7 ≤ E < 2.9	7	7	6	7	10	10	7	10
2.9 ≤ E < 3.1	7	6	6	7	9	9	7	9
3.1 ≤ E < 3.3	6	6	6	6	9	8	7	8
3.3 ≤ E < 3.5	6	6	6	6	8	8	7	8
3.5 ≤ E < 3.7	6	6	6	6	7	8	7	7
3.7 ≤ E < 3.9	6	6	6	6	7	8	7	7
3.9 ≤ E < 4.1	6	6	6	6	7	7	7	7
4.1 ≤ E < 4.3	5	6	6	6	6	7	7	7
4.3 ≤ E < 4.5	5	6	6	6	6	7	7	7
4.5 ≤ E < 4.7	5	6	5	6	6	7	6	7
4.7 ≤ E < 4.9	5	6	5	6	6	7	6	7
E ≥ 4.9	5	6	5	6	6	7	6	7

Table 5.5-8 Loading Table for BWR Fuel

Minimum Initial Enrichment	Burnup ≤30 GWD/MTU Minimum Cooling Time [years]			30< Burnup ≤35 GWD/MTU Minimum Cooling Time [years]		
wt % ^{235}U (E)	7×7	8×8	9×9	7×7	8×8	9×9
1.9 ≤ E < 2.1	5	5	5	8	7	7
2.1 ≤ E < 2.3	5	5	5	6	6	6
2.3 ≤ E < 2.5	5	5	5	6	5	6
2.5 ≤ E < 2.7	5	5	5	5	5	5
2.7 ≤ E < 2.9	5	5	5	5	5	5
2.9 ≤ E < 3.1	5	5	5	5	5	5
3.1 ≤ E < 3.3	5	5	5	5	5	5
3.3 ≤ E < 3.5	5	5	5	5	5	5
3.5 ≤ E < 3.7	5	5	5	5	5	5
3.7 ≤ E < 3.9	5	5	5	5	5	5
3.9 ≤ E < 4.1	5	5	5	5	5	5
4.1 ≤ E < 4.3	5	5	5	5	5	5
4.3 ≤ E < 4.5	5	5	5	5	5	5
4.5 ≤ E < 4.7	5	5	5	5	5	5
4.7 ≤ E < 4.9	5	5	5	5	5	5
E ≥ 4.9	5	5	5	5	5	5

Minimum Initial Enrichment	35< Burnup ≤40 GWD/MTU Minimum Cooling Time [years]			40< Burnup ≤45 GWD/MTU Minimum Cooling Time [years]		
wt % ^{235}U (E)	7×7	8×8	9×9	7×7	8×8	9×9
1.9 ≤ E < 2.1	16	14	15	26	24	25
2.1 ≤ E < 2.3	13	12	12	23	21	22
2.3 ≤ E < 2.5	11	9	10	20	18	19
2.5 ≤ E < 2.7	9	8	8	18	16	17
2.7 ≤ E < 2.9	8	7	7	15	13	14
2.9 ≤ E < 3.1	7	6	6	13	11	12
3.1 ≤ E < 3.3	6	6	6	11	10	10
3.3 ≤ E < 3.5	6	5	6	9	8	9
3.5 ≤ E < 3.7	6	5	6	8	7	7
3.7 ≤ E < 3.9	6	5	5	7	6	7
3.9 ≤ E < 4.1	5	5	5	7	6	7
4.1 ≤ E < 4.3	5	5	5	7	6	6
4.3 ≤ E < 4.5	5	5	5	6	6	6
4.5 ≤ E < 4.7	5	5	5	6	6	6
4.7 ≤ E < 4.9	5	5	5	6	6	6
E ≥ 4.9	5	5	5	6	6	6

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5.6 Shielding Evaluation for Site Specific Spent Fuel

This section presents the shielding evaluation for spent fuel configurations that are unique to specific reactor sites. These site specific fuel configurations result from conditions that occurred during reactor operations, participation in research and development programs, and testing programs intended to improve reactor operations. Site specific fuel configurations include standard fuel with inserted non fuel-bearing components, fuel assemblies with missing or replaced fuel rods or poison rods, fuel assemblies unique to the reactor design, fuel with a parameter that exceeds the design basis parameter, such as enrichment or burnup, consolidated fuel and fuel that is classified as damaged.

Site specific fuel assembly configurations are either shown to be bounded by the analysis of the standard design basis fuel assembly configuration of the same type (PWR or BWR), or are shown to be acceptable contents by specific evaluation of the configuration.

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5.6.1 Shielding Evaluation for Maine Yankee Site Specific Spent Fuel

This analysis considers both assembly fuel sources and sources from activated non-fuel material such as control element assemblies (CEA), in-core instrument (ICI) segments, and fuel assemblies containing activated stainless steel replacement (SSR) rods and other non-fuel material, including neutron sources. It considers the consolidated fuel, damaged fuel, and fuel debris present in the Maine Yankee spent fuel inventory, in addition to those fuel assemblies having a burnup between 45,000 and 50,000 MWD/MTU.

The Maine Yankee spent fuel inventory also contains fuel assemblies with hollow zirconium rods, removed fuel rods, axial blankets, poison rods, variable radial enrichment, and low enriched substitute rods. These components do not result in additional sources to be considered in shielding evaluations and are, therefore, enveloped by the standard fuel assembly evaluation. For shielding considerations of the variable radial enrichment assemblies, the planar-average enrichment is employed in determining minimum cool times. As described in Section 6.6.1.2.2, fuel assemblies with variable radial enrichment incorporate fuel rods that are enriched to one of two levels of enrichment. Fuel assemblies that also incorporate axial blankets are described in Section 6.6.1.2.3. Axial blankets consist of annular fuel pellets enriched to 2.6 wt % ^{235}U, used in the top and bottom 5% (≈ 7 inches) of the active fuel length. The remaining active fuel length of the fuel rod is enriched to one of two levels of enrichment incorporated in the fuel design.

5.6.1.1 Fuel Source Term Description

Maine Yankee utilized 14×14 array size fuel based on designs provided by Combustion Engineering, Westinghouse, and Exxon Nuclear. The previously analyzed Combustion Engineering CE 14×14 standard fuel design is selected as the design basis for this analysis because its uranium loading is the highest of the three vendor fuel types, based on a 0.3765-inch nominal fuel pellet diameter, a 137-inch active fuel length, and a 95% theoretical fuel density. This results in a fuel mass of 0.4037 MTU. This exceeds the maximum reported Maine Yankee fuel mass of 0.397 MTU and, therefore, produces bounding source terms. The SAS2H model of the CE 14×14 assembly (shown in Figure 5.6.1-1) at a nominal burnup of 40,000 MWD/MTU and initial enrichment of 3.7 wt % ^{235}U, is based on data provided in Table 2.1.1-1.

Source terms for various combinations of burnup and initial enrichment are computed by adjusting the SAS2H BURN parameter to model the desired burnup and specifying the initial enrichment in the Material Information Processor input for UO_2.

5.6.1.1.1 Control Element Assemblies (CEA)

For the CEA evaluation, the assumptions are:

1. The irradiated portion of the CEA assembly is limited to the CEA tips since during normal operation the elements are retracted from the core and only the tips are subject to significant neutron flux.
2. The CEA tips are defined as that portion present in the "Gas Plenum" neutron source region in the Characteristics Database (CDB) [10].
3. Material subject to activation in the CEA tips is limited to stainless steel, Inconel and Ag-In-Cd in the tip of the CEA absorber rods. Stainless steel and Inconel is assumed to have a concentration of 1.2 g/kg ^{59}Co. The CDB indicates that a total of 2.495 kg/CEA of this material is present in the Gas Plenum region of the core during operation. The Ag-In-Cd alloy present in the gas plenum region during core operation is approximately 80% silver and weighs 2.767 kg/CEA.
4. The irradiated CEA material is assumed to be present in the lower 8 inches of the active fuel region when inserted in the assembly. The location of the CEA source is based on the relative length of the fuel assembly and CEA rods and the insertion depth of the CEA spider into the top end-fitting.
5. The decay heat generated in the most limiting CEA at 5 years cool time is 2.16 W/kg of activated steel and inconel, and 3.11 W/kg of activated Ag-In-Cd. Although longer cool times are considered in this analysis for the fuel source term, this decay heat generation rate is conservatively used for all longer CEA cool times. For a cask fully loaded with fuel assemblies containing design basis CEAs, the additional heat generation due to the CEAs amounts to (2.16 W/kg × 2.495 kg/CEA + 3.11 × 2.767 kg/CEA)(24 CEA/cask) = 336 W/cask, which is conservatively rounded to 350 W/cask.

Since the activated portion of the CEA is present only in the lower 8 inches of the active fuel, an adjustment to the one-dimensional dose rate limit is derived based on detailed three-dimensional results obtained for the CE 14×14 fuel with and without a CEA present.

Table 5.6.1-1 shows the activation history for CEAs employed at Maine Yankee. Based on this data, individual source term calculations are performed for each CEA group, and a single bounding CEA description is determined based on the maximum computed source rate as of January 1, 2001. The bounding CEA description is based on CEA group "A1-A8," and the resulting CEA spectra at 5, 10 15, and 20 years cool time are shown in Table 5.6.1-2.

5.6.1.1.2 In-Core Instrument (ICI) Thimbles

Activation of ICI thimble material is determined by accumulating the hardware activation incurred during each cycle the ICI thimble is present in the reactor core. The ICI thimbles are first grouped according to exposure history as shown in Table 5.6.1-3. The cycle exposure data for each Maine Yankee cycle is shown in Table 5.6.1-4. With these data, the accumulated hardware source is obtained by summing the contributions made from each cycle of exposure. It is assumed that:

1. The average cycle exposure is sufficient to represent the ICI thimble exposure during each cycle.
2. Spectral differences between hardware source terms are insignificant.
3. The ICI thimble activated hardware source rate does not decrease after January 1, 2001.
4. The ICI thimble activated hardware spectrum is assumed to be identical to the fuel activated hardware spectrum in distribution, but not total source strength, i.e., the majority of the source is the result of ^{60}Co at a fixed spectrum.

The portion of the ICI thimble present in the active fuel region during reactor operation is composed entirely of Zircaloy and receives no significant activation. The activated components of the ICI thimble are present in the upper end fitting region of the core, and the material is assumed to be irradiated at a flux factor of 0.1 consistent with the activation ratio used for upper end fitting hardware. A total mass of 0.664 kg/ICI thimble of activated material (assumed to be stainless steel with an initial ^{59}Co concentration of 1.2 g/kg) is modeled in the upper end fitting region.

The resulting total source rate as of January 1, 2001, for the activated components of each ICI thimble group are shown in Table 5.6.1-3. ICI Thimble Group J has the highest source rate (1.4940E+13 γ/sec), and this value is selected as the design basis for the loading table analysis. Note that for the purposes of determining the required cool time for a fuel assembly containing a ICI thimble, no further decay of the ICI thimble is considered after January 1, 2001.

5.6.1.1.3 Stainless Steel Replacement Rods

Maine Yankee fuel assemblies containing stainless steel replacement (SSR) rods are listed in Table 5.6.1-5. Note that for "N" and "R" numbered fuel assemblies, the SSR rods are only subject to exposure after the first fuel assembly cycle of irradiation. For "U" numbered assemblies, the assemblies saw no additional exposure after the rods were inserted. Hence, these "U" numbered assemblies are not further considered since their SSR rods received no activation.

The SSR rod is assumed to be solid stainless steel with the same dimensions as a fuel rod and with an initial ^{59}Co concentration of 1.2 g/kg. The SSR rod mass is 2.91 kg/SSR. Hardware gamma source terms are generated for each of the SSR rods in Table 5.6.1-5 based on the one or two cycle exposure seen by the stainless steel rods in question. This additional hardware source is then used to increase the existing hardware source of the assembly.

5.6.1.1.4 Consolidated Fuel

There are two consolidated fuel lattices. The lattices house fuel rods taken from assemblies as shown in Table 5.6.1-6. Each lattice presents a 17×17 array, with top and bottom end fittings connected by solid steel connector rods. No explicit source term analysis is conducted for the consolidated fuel lattices themselves, instead, an analysis is presented based on the source term computed for the fuel assemblies from which the contents are derived.

5.6.1.2 Model Specification

The one- and three-dimensional models described in Section 5.3 are employed in this analysis. No modifications are required to the models except for the substitution of CE 14×14 homogenized source descriptions. These homogenizations are shown in Tables 5.6.1-7 through 5.6.1-9.

5.6.1.3 Shielding Evaluation

The shielding evaluation consists of a loading table analysis of the CE 14×14 fuel following the methodology developed in Section 5.5 (Minimum Allowable Cooling Time Evaluation for PWR and BWR fuel). Fuel assemblies which include non-fuel hardware are addressed explicitly. The results of the analysis are loading tables which give the required cool time for a particular fuel configuration.

No restrictions are placed on the loading locations for any of the non-fuel assembly hardware components.. This implies that a canister may contain up to 24 CEAs, 24 ICI thimbles, or 24 steel substitute rod assemblies or any combination thereof as long as the most limiting cool time is selected for any of the components in the canister. Neither CEAs or ICI thimbles may be placed into an assembly containing steel substitute rods that have received core exposure. ICI thimbles and CEAs may be inserted in fuel assemblies that also have hollow Zircaloy rods replacing burnable poison rods, solid steel rods replacing fuel rods provided there has been no reactor core exposure of the steel rods, fuel assemblies with fuel rods removed from the lattice, fuel assemblies with variable enrichment or low enrichment replacement fuel rods, or axial blanket fuel assemblies. Due to physical constraints, ICI thimbles and CEAs cannot be located in the same assembly.

5.6.1.4 Standard Fuel Source Term

Results are obtained, for CE 14×14 fuel with no additional non-fuel material included, by following the minimum allowable cooling time evaluation (loading table analysis) methodology developed in Section 5.5. CE 14×14 source terms at various combinations of initial enrichment and burnup are computed using the CE 14×14 SAS2H model described in Section 5.6.1.1.

Following the methodology developed in Section 5.5, one-dimensional shielding calculations are performed for CE 14×14 fuel region sources at various combinations of initial enrichment, burnup, and cool time. The resulting dose rate and source term data is interpolated to determine the cool time required for each combination of enrichment and burnup to decay below the design basis limiting values of dose and heat generation rate.

The resulting loading table for CE 14×14 fuel with no additional non-fuel material is shown in Table 5.6.1-10.

In addition to the standard fuel evaluation, a preferential loading strategy is analyzed. The preferential loading configuration relies on placing higher heat load fuel assemblies on the periphery of the basket than would be allowed with a uniform loading strategy. Peripheral loadings are evaluated with decay heats of up to 1.05 kW per peripheral assembly. To maintain the maximum allowable heat load per basket of 23 kW, the maximum allowable per assembly heat load in the interior location of the basket is reduced to compensate for the higher heat load peripheral elements. Burnup and cool time combinations for peripheral and interior assemblies are listed in Table 5.6.1-10 as a function of initial enrichment. The cool time column for peripheral element and interior assembly loading is indicated by the "P" and "I" indicators in the column headings.

5.6.1.4.1 Control Element Assemblies (CEA)

The result of the analysis is a set of loading tables for Maine Yankee fuel giving the cool time required for a fuel assembly with a specified burnup and enrichment combination to contain a design basis CEA with a cool time of 5, 10, 15, or 20 years. Fuel assemblies containing CEAs will be loaded into Class 2 canisters, which are slightly longer than the Class 1 canisters used for bare fuel assemblies. The additional length is required to accommodate the CEA, which is inserted in the top of the fuel assembly.

The approach taken is to compute downward adjustments to the design basis one-dimensional dose rate limiting value for the storage cask (as specified in Table 5.5-3) which ensures that the fuel sources have decayed adequately to cover the effect of the additional source added as a result of CEA containment. The adjustment is determined on the basis of a conservative comparison of three-dimensional shielding analysis results for the original Class 1 canister containing CE 14×14 fuel assemblies and the Class 2 canister containing either no CEA or CEAs cooled to 5, 10, 15, or 20 years. Results for CEA cool times longer than 20 years are bounded by the 20 year results.

Assuming design basis CE 14×14 fuel with a burnup of 40,000 MWD/MTU, 3.7 wt % ^{235}U enrichment and a 5-year cool time, the additional CEA source results in a localized peak near the bottom of the transfer cask that results in a surface dose rate that is less than 500 mrem/hr. Since this is comparable to the no-CEA case, it is not necessary to extend cool time of fuel assemblies with CEAs inserted to account for an increased transfer cask surface dose.

5.6.1.4.1.1 Establishment of Limiting Values

Since the additional activated material in the CEA analysis is assumed present in the lower 8 inches of the active fuel source region, the one-dimensional dose methodology is not appropriate to address the additional source term due to its small axial extent. The one-dimensional analysis is based on the response from the full-length fuel region source. To account for the additional source, the one-dimensional normal conditions dose rate limit is adjusted by an amount that ensures that the contribution from the additional activated material is bounded.

By adjusting the one-dimensional dose rate limit, we require the fuel to cool to a point where the decrease in fuel region dose rate matches the increased dose rate due to the additional CEA material. Hence, it is necessary to determine the amount by which the dose rate increases as a result of the added material. A one-dimensional calculation of this additional dose rate is not reasonable due to the small axial extent of the CEA source. One-dimensional buckling corrections are inaccurate for a cylindrical source where the ratio of height to diameter of the source is less than unity, as is the case here.

Instead, the additional contribution to dose rate due to the activated material is computed by a detailed three-dimensional shielding model. The model is based on the three-dimensional models described in Section 5.3. However, the fuel is modeled in a Class 2 canister since that canister will be used to store/transfer CEA-bearing assemblies.

The three-dimensional shielding evaluation is conducted for the CE 14×14 fuel at a burnup of 40,000 MWD/MTU and initial enrichment of 3.7 wt % ^{235}U. According to the cool time analysis conducted for PWR fuels in Table 5.6.1-10, this fuel will require a 5-year cool time before it is acceptable for transfer or storage in the UMS® vertical concrete cask. Hence, the 5-year cooled CE 14×14 at 40,000 MWD/MTU and 3.7 wt % ^{235}U initial enrichment provides the base case for the dose rate limit adjustment calculation.

Additional three-dimensional models are defined based on the base case fuel configuration in a Class 2 canister and either containing a design basis CEA assumed to be cooled for 5, 10, 15, or 20 years or containing no CEA at all (no CEA case below).

5.6.1.4.1.2 Three-Dimensional Model Results

Table 5.6.1-11 gives the three-dimensional UMS® Vertical Concrete Cask and transfer cask bottom model results for each case. Only the bottom model is considered because the top model is not sensitive to changes in the CEA description. The parameter Delta shown in the table is the difference between the base case maximum (from Table 5.5-2 for the storage cask) dose rate and the value computed for each remaining case. This quantity is directly applied to the one-dimensional design basis normal conditions dose rate limit, as specified in Table 5.6.1-11 for the storage cask to determine a modified limiting value applicable to each CEA decay case. The resulting dose rate limits are shown in the "Limit" column of the table.

Note that direct application of the "Delta" to the one-dimensional dose rate limit is somewhat conservative. The three-dimensional maximum dose rate results are significantly higher than the one-dimensional results, hence a given difference between three-dimensional results represents a larger percentage of the corresponding one-dimensional results.

Also note that the dose rate delta for the "No-CEA" case in Table 5.6.1-11 is zero. Unlike the UMS® transport cask, where a spacer positions the canister in the cask, the UMS® standard transfer and storage casks are extended to accommodate the longer Class 2 canister. These cask extensions maintain the spacing of the fuel assembly with respect to the points of minimum shielding in the bottom cask model, and thereby result in identical cask bottom half dose rates for fuel assemblies in Class 1 and Class 2 canisters.

5.6.1.4.1.3 Decay Heat Limits

As discussed in Section 5.6.1.1.1, the additional decay heat associated with a full cask of CEAs is conservatively taken as 0.35 kW/cask. This additional heat load is accounted for by reducing the fuel assembly decay heat limit to 22.65 kW/cask.

5.6.1.4.1.4 Loading Table Analysis

With the adjusted one-dimensional dose and heat generation rate limits established above, the loading table analysis proceeds following the methodology developed in Section 5.5. Each combination of initial enrichment and burnup is analyzed to determine the minimum required cool time in order for an assembly to either 1) contain a design basis CEA cooled 5, 10, 15, or 20 years or 2) to be present in a Class 2 canister with no CEA inserted. The resulting cool times are shown in Table 5.6.1-12.

5.6.1.4.2 In-Core Instrument (ICI) Thimbles

The loading table analysis of the in-core instrument thimble follows the same methodology as that developed above for activated CEA hardware. The activated portion of the ICI thimbles is present in the upper end fitting region when loaded into a host fuel assembly. Since the source region is outside the fuel region, direct application of the one-dimensional loading table analysis is not possible. Instead, as in the CEA case, the approach is to identify a conservative adjustment to the one-dimensional dose rate limit, thereby forcing the fuel to cool a longer time in order to offset the additional dose from the ICI thimble.

5.6.1.4.2.1 Establishment of Limiting Values

Decay heat from the activated ICI thimble is insignificant (< 0.05 kW/cask), so no adjustment to the decay heat limit is employed. The one-dimensional normal conditions dose rate limit is adjusted in a manner identical to that employed in the CEA analysis. Two configurations of the CE 14×14 Class 1 canister are analyzed in full three-dimensional detail. The first configuration is the base case CE 14×14 fuel at 40,000 MWD/MTU, 3.7 wt % enrichment, and 5-year cool time. The second configuration is identical to the base case with the addition of the source term for 24 ICI thimbles to the upper end fitting source region. No credit is taken for the self-shielding effectiveness of the added material. The base case upper end fitting total source strength is 2.031E+14 γ/sec. The design basis ICI thimble source strength is determined in Section 5.6.1.1.2 to be 2.988E+13 γ/sec. The ICI thimble activated hardware spectrum is assumed to be identical to the fuel activated hardware spectrum.

The results of the two three-dimensional cases for the storage cask are shown in Table 5.6.1-13. The addition of ICI thimble sources to the top end-fitting source region has no discernable impact on the storage cask or transfer cask surface average dose rate. A 2 mrem/hr increase in the storage cask air outlet dose was calculated due to the additional source (against a 70 mrem/hr dose rate for the CE 14×14 40,000 MWD/MTU burned, 5-year cooled base case). Due to the location and size of the air outlets in relation to the storage cask total surface the small increase in dose will have no impact on the on-site and off-site exposures. The presence of the ICI thimble source in the transfer cask also has no discernable effect on the computed cask maximum surface dose rate. A slight increase in surface dose rate is observed in the vicinity of the added source, but the computed dose rate at this location is less than the maximum surface dose rate.

5.6.1.4.2.2 Loading Table Analysis

Since no significant dose rate changes occurred due to the addition of the ICI thimble source no revised loading tables are provided. The standard and preferential assembly loading table (Table 5.6.1-10) may be used for determining minimum assembly cool time for loading with or without an ICI thimble assembly.

5.6.1.4.3 Stainless Steel Replacement Rods

Maine Yankee fuel assemblies containing stainless steel replacement (SSR) rods are listed in Table 5.6.1-5. Note that for "N" and "R" numbered fuel assemblies, the SSR rods are only subject to exposure after the first cycle of irradiation of the fuel assembly. For "U" numbered assemblies, the assemblies saw no additional exposure after the rods were inserted. Hence, these "U" numbered assemblies are not further considered since the SSR rods received no activation.

The SSR rod is assumed to be solid stainless steel with the same dimensions as a fuel rod and a mass of 2.91 kg/SSR.

Based on the exposure data provided, SAS2H source calculations are performed explicitly for each SSR-bearing fuel assembly, which received additional exposure. Each fuel assembly is modeled at its initial enrichment (rounded down to the nearest enrichment level equal to a modeled enrichment value) and cycle length parameters are computed to achieve the required burnups as indicated in Table 5.6.1-5. The resulting SSR source strengths as of January 1, 2001, are shown in Table 5.6.1-14.

A cool time analysis is conducted for each assembly containing irradiated SSR rods. The activated SSR material is treated explicitly by adding the source directly to the fuel hardware source term. Hence, no adjustment to the one-dimensional dose rate limits is required as in previous analyses involving added non-fuel sources. The results of the cool time analysis for each assembly are shown in Table 5.6.1-14.

The desired final fuel loading time for the Maine Yankee spent fuel inventory is August 2002. As such two assemblies fall outside the standard loading curve. Employing the preferential loading pattern, permitting 1.05 kW per peripheral assembly, reduces the minimum cool time based on thermal constraints to 6 years. The storage cask dose rate constraint is satisfied for the preferentially loaded assembles after 5 years cooling. Recognizing that only two of the assemblies in the Maine Yankee spent fuel inventory, R439 and R444, require peripheral loading, the transfer cask dose rate limit is not applied for these two assemblies. Since the dose rate comparisons are made on the basis of an assumed fuel cask of assemblies, the transfer cask dose rate limit is unnecessarily restrictive.

5.6.1.4.4 Consolidated Fuel

There are two consolidated fuel lattices intended for storage (and transfer) in the Universal Storage Cask. The lattices house fuel rods taken from assemblies as shown in Table 5.6.1-6. This fuel has decayed for over twenty years and does not represent a significant shielding issue.

A limiting cool time analysis is conducted by identifying a fuel assembly description analyzed in the loading table analysis that bounds the parameters of the fuel rods in the consolidated fuel lattices. The parameters of those fuel rods are shown in Table 5.6.1-15. The CE 14×14 fuel at 30,000 MWD/MTU and 1.9 wt % ^{235}U enrichment represents a bounding assembly type, since it has a significantly higher burnup and a lower enrichment than the original assemblies. This fuel requires 6-year cool time before it can be loaded in the storage or transfer cask as shown in Table 5.6.1-10. The consolidated fuel has been cooled for at least 24 years. For container CN-1 lattice, one can immediately conclude that dose rates are bounded by the limiting fuel.

However, the CN-10 lattice contains significantly more fuel rods than an intact assembly. Neglecting the mitigating effects of additional self-shielding, this situation is addressed by comparing the radiation source strength of the limiting fuel at six- and 24-year cool time. Conservatively assuming that all fuel rods present in CN-10 are at the limiting conditions of 30,000 MWD/MTU and 1.9 wt % ^{235}U, the ratio of the source rate in the CN-10 to the source rate in the limiting fuel assembly is shown to be less than one for each source type in Table 5.6.1-16. For each source type, the ratio is computed as:

Ratio = (Num Rods in CN-10)(Source Rate at 24 Yr) / (Num Rods in F/A)(Source Rate at 6 Yr)

Hence, CN-10 is also bounded by the limiting case as of January 1, 2001.

5.6.1.4.5 Damaged Fuel and Fuel Debris

The Maine Yankee spent fuel inventory includes fuel assemblies containing damaged fuel rods and fuel debris. Damaged fuel rods and fuel debris will be placed into one of the two configurations of the screened Maine Yankee Fuel Can prior to loading in the UMS® basket. Maine Yankee fuel cans are restricted to loading into one of the four corner basket locations. The damaged fuel mass cannot exceed the fuel mass of 100% of an intact fuel assembly. Damaged fuel rods may be loaded in the can with intact rods.

To approximate the effect of collapsed fuel inside the Maine Yankee fuel can, a three-dimensional shielding analysis was performed doubling the source magnitude and material density in the four corner basket locations. Conservatively, the screened can itself is not included in the shielding model. As expected, the increased self-shielding of the collapsed fuel material minimizes the dose rate increase resulting from the source term density doubling. Based on a cask average surface dose rate of less than 40 mrem/hr under normal operating conditions, no significant increases in personnel exposures are expected as a result of the collapsed fuel material.

Where no collapse of the fuel rods occurs, the analysis presented for the intact fuel assemblies bounds that of the damaged fuel rods. Since the additional shielding provided by the screened canister is not being credited by this approach, the actual expected dose rates will be lower for the transportable storage canisters loaded with damaged fuel. For cases in which the Maine Yankee fuel can holds fuel rods from multiple assemblies, the minimum cool time for the rods containing the most restrictive enrichment and burnup combination is applied to the contents of the entire can.

Fuel debris must be placed into a rod structure prior to loading into the screened canister. Once the fuel debris is configured in a rod structure it can be treated from a shielding perspective identical to the damaged fuel rods.

5.6.1.4.6 Additional Non-fuel and Neutron Source Material

The additional non-fuel material consists of:

1. Three plutonium-beryllium (Pu-Be) neutron sources, two irradiated and one unirradiated.
2. Two antimony-beryllium (Sb-Be) neutron sources, both irradiated.

3. Control element assembly (CEA) fingertips.
4. ICI string segment.

The five neutron sources will be inserted into the center guide tubes of five different assemblies and loaded into Class 1 canisters. These five assemblies will be loaded in five different canisters. This requirement is conservative since the shielding evaluation shows that only the irradiated Pu-Be sources must be placed in different canisters and that the remaining sources may be loaded in any remaining corner positions of the canister. The CEA fingertips and ICI string segment may be inserted into one or more assemblies and loaded into a Class 2 canister to accommodate a CEA flow plug to close the guide tubes with the added hardware. These fuel assemblies must be loaded in corner positions in the fuel basket.

The characterization of the additional non-fuel hardware is provided in Tables 5.6.1-17 and 5.6.1-18. The data is divided into two separate categories:

1. Non-neutron producing radiation sources – this category includes the CEA fingertips, ICI string, and the Sb-Be neutron sources (the neutron production rate of these is negligible).
2. Neutron producing radiation sources – this category includes the two irradiated and one unirradiated Pu-Be neutron sources.

The masses of ^{238}Pu and ^{239}Pu given for the unirradiated Pu-Be source are used in conjunction with the delivery date of May 1972 to generate source terms.

The neutron sources have an additional source component due to the irradiation of the stainless steel rod encasing the source. The quantity of irradiated steel is taken as 10 lbs. (4.54 kg) for this evaluation.

From the waste characterization, it is apparent that the Sb-Be sources already include the contribution of irradiated stainless steel. Therefore, only the Pu-Be irradiated stainless steel requires activation. The hardware source spectra for the irradiated Pu-Be sources are based on the Maine Yankee exposure history shown in Table 5.6.1-4. The combined Pu-Be assembly hardware irradiation for Cycles 1-13 is shown in Table 5.6.1-19 at a cool time of five years from 1/1/1997.

The waste characterization sources given in Tables 5.6.1-17 and 5.6.1-18 are used to generate source terms using ORIGEN-S [9]. For the non-neutron producing sources, the total curie content is assigned to ^{60}Co to provide bounding source terms. Also, only one Sb-Be spectrum is produced, based on the higher curie content source. For the neutron producing sources, the given curie contents are used for irradiated sources, whereas the plutonium masses are used for the unirradiated Pu-Be source.

Based on the loading plan, there are two areas of application of both spectra and dose rates. The CEA fingertips and the ICI string segment will be loaded into one assembly. Therefore, the gamma spectra of these items are summed and only one gamma spectrum is used to calculate the dose rates due to this loaded assembly. If these items are loaded into separate fuel assemblies, the source term is lower. Each of the five neutron sources will be loaded into a separate assembly, and the spectra are presented accordingly. The single assembly spectra for the inserted hardware items are presented in Table 5.6.1-20. The startup source spectra are presented in Table 5.6.1-21.

Dose rates are calculated by simply groupwise multiplying the spectra and CE 14×14 dose rate response functions and adjusting by a factor of 24/(10E+10 × 5.6193E+06) to remove the volume component and the calculation scaling factor. Dose rates are presented in Tables 5.6.1-22 through 5.6.1-24 and show the minimal dose rate contribution due to the inclusion of the additional non-fuel material.

Figure 5.6.1-1 SAS2H Model Input File – CE 14 x 14

```
=SAS2H       PARM=(HALT03,SKIPSHIPDATA)
CE 14 x 14 3.7 W/O U235, 45000 MWD/MTU 12.0-22.0 YEAR COOLING
27GROUPNDF4 LATTICECELL
UO2          1 0.950 900 92235 3.7 92238 96.3 END
ZIRCALLOY  2 1.0 620 END
H2O          3 DEN=0.725 1.0 580 END
ARBM-BORMOD 0.725 1 1 0 0 5000 100 3 550.0E-6 580 END
END COMP
SQUAREPITCH 1.4732 0.9563 1 3 1.1176 2 0.9754 0 END
NPIN=176 FUEL=347.98 NCYC=3 NLIB=1 PRIN=6 LIGH=5
INPL=1 NUMH=20 NUMI=0 ORTU=0.5588 SRTU=0.49285 END
POWER=13.065 BURN=463.5350 DOWN=60.0 END
POWER=13.065 BURN=463.5350 DOWN=60.0 END
POWER=13.065 BURN=463.5350 DOWN=1461.00 END
```

Table 5.6.1-1 Maine Yankee CEA Exposure History by Group

CEA Group	First Cycle	Last Cycle	Maximum Exposure (MWD/MTU)	Number of Cycles	Exposure Per Cycle (MWD/MTU)	Cool Time as of 1/1/2001 (y)
A1-A8	7	15	60239	9	6693	4
B1-B5	9	15	48909	7	6987	4
C1-C11, C13-C15	10	15	44315	6	7386	4
D1-D15	11	15	35283	5	7057	4
E1-E17, GN, *78, 101, 102, 138-153	12	15	29367	4	7342	4
F1,F2	13	15	18663	3	6221	4
4A	12	12	9786	1	9786	8
C12	10	12	24309	3	8103	8
NA	1	11	75444	11	6859	10
1-69	1	8	53258	8	6657	15

Note: The asterisk is added to CEA 78* to distinguish it from the original CEA 78.

Table 5.6.1-2 Maine Yankee CEA Hardware Spectra - 5, 10, 15 and 20 Years Cool Time

Energy Group	5 yr (γ / sec)	10 yr (γ / sec)	15 yr (γ / sec)	20 yr (γ / sec)
1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	1.3479E-04	4.4697E-06	1.4822E-07	4.9154E-09
6	7.1467E+06	2.6384E+06	1.3598E+06	7.0431E+05
7	4.0337E+09	1.6979E+09	8.7691E+08	4.5422E+08
8	3.7246E+10	2.3434E+08	1.4804E+06	1.5188E+04
9	1.8642E+14	7.1649E+13	3.6955E+13	1.9142E+13
10	4.8840E+14	2.5265E+14	1.3086E+14	6.7790E+13
11	1.3804E+14	9.4554E+11	4.7779E+10	3.7897E+10
12	1.1469E+15	9.3808E+14	9.1172E+14	8.8714E+14
13	4.3885E+14	4.2316E+14	4.1174E+14	4.0065E+14
14	9.1526E+11	5.5505E+11	5.2913E+11	5.0949E+11
15	1.2039E+12	8.4093E+11	8.0140E+11	7.6939E+11
16	3.8479E+12	2.9855E+12	2.7489E+12	2.5803E+12
17	5.1828E+13	4.4134E+13	4.2118E+13	4.0659E+13
18	3.4899E+14	2.7741E+14	2.6393E+14	2.5520E+14
Steel/Inc Source Rate	6.3886E+14	3.2951E+14	1.7066E+14	8.8413E+13
Ag-In-Cd Source Rate	2.1666E+15	1.6829E+15	1.6308E+15	1.5861E+15
Total Source Rate	2.8055E+15	2.0124E+15	1.8014E+15	1.6745E+15
SFA	5.6110E+15	4.0249E+15	3.6029E+15	3.3490E+15

Table 5.6.1-3 Maine Yankee ICI Thimble Exposure History and Source Rate by Group

Group	Quantity	Cycles Exposed	Number of Cycles	Total Source [γ/sec]
A	41	1, 1A, 2	3	9.1881E+11
B	1	1	1	2.3775E+11
C	2	1, 1A	2	3.6244E+11
D	1	1A, 2	2	6.8106E+11
E	3	2	1	5.5637E+11
F	15	3 thru 11, 13	10	1.1695E+13
G	12	3 thru 11, 14	10	1.2126E+13
H	12	3 thru 11, 15	10	1.1454E+13
I	3	3 thru 9,14,15	9	1.1309E+13
J	2	10 thru 15	6	1.4940E+13
K	1	10 thru 12	3	6.1296E+12
L	25	12 thru 15	4	1.1491E+13
M	17	12	1	2.6801E+12
N	3	13 thru 15	3	8.8105E+12

Table 5.6.1-4 Maine Yankee Core Exposure History by Cycle of Operation

Cycle	Discharge Date	Cycle Burnup [MWD/MTU]	Core Average Enrichment [wt %]
1	6/29/74	10367	2.44
1A	5/2/75	4492	2.30
2	4/9/77	17365	2.45
3	7/14/78	11105	2.59
4	1/11/80	10500	2.84
5	5/8/81	10799	2.98
6	9/24/82	11585	3.01
7	3/31/84	12483	3.10
8	8/17/85	12504	3.20
9	3/28/87	14424	3.29
10	10/15/88	12675	3.36
11	4/7/90	13786	3.50
12	2/14/92	15364	3.62
13	7/30/93	13668	3.68
14	1/14/95	13075	3.75
15	12/6/96	7859	3.76

Table 5.6.1-5 Burnup of Maine Yankee Fuel Assemblies with Stainless Steel Replacement Rods

Assembly Number	1st Cycle	2nd Cycle	3rd Cycle	1st Cycle Burnup[1]	2nd Cycle Burnup[1]	3rd Cycle Burnup[1]	Number of SSR Rods
N420	9	10	11	16,428	13,467	11,893	3
N842	9	10	-	18,420	13,885	0	1
N868	9	10	11	18,622	13,386	4,919	1
R032	12	13	14	16,464	15,386	12,168	1
R439	12	13	14	20,371	14,779	11,685	1
R444	12	13	14	20,371	14,779	11,685	4
U01	15	-	-	7,339	0	0	1
U05	15	-	-	7,339	0	0	1
U16	15	-	-	10,598	0	0	1
U37	15	-	-	9,005	0	0	1
U51	15	-	-	8,288	0	0	1
U60	15	-	-	8,288	0	0	6

1. MWD/MTU.

Table 5.6.1-6 Contents of Maine Yankee Consolidated Fuel Lattices CN-1 and CN-10

Consolidated Fuel Lattice	Original Fuel Assembly	Number of Rods	Actual Burnup [MWD/MTU]	Initial Enrichment [wt %]
CN-1	EF0039	172	5150	1.929
CN-10	EF0045	176	17150	1.953
	EF0046	107	17150	1.953

Table 5.6.1-7 Maine Yankee CE 14 × 14 Homogenized Fuel Region Isotopic Composition

Isotope	CE 14 × 14 [atom/b-cm]
ALUMINUM	2.05114E-03
BORON-10	1.90898E-04
BORON-11	7.68387E-04
CARBON-12	2.39821E-04
CHROMIUM(SS304)	7.19369E-04
IRON(SS304)	2.4501E-03
MANGANESE	7.16674E-05
NICKEL(SS304)	3.18674E-04
OXYGEN-16	8.72597E-03
URANIUM-234	2.39964E-07
URANIUM-235	3.14135E-05
URANIUM-238	4.33133E-03
ZIRCALLOY	3.06324E-03

Table 5.6.1-8 Isotopic Compositions of Maine Yankee CE 14 × 14 Fuel Assembly Non-Fuel Source Regions

Isotope	Upper Plenum [atom/b-cm]	Upper End Fit [atom/b-cm]	Lower End Fit [atom/b-cm]
CHROMIUM(SS304)	1.59190E-03	1.89910E-03	3.08125E-03
MANGANESE	1.58594E-04	1.89199E-04	3.06971E-04
IRON(SS304)	5.42166E-03	6.46791E-03	1.04941E-02
NICKEL(SS304)	7.05196E-04	8.41284E-04	1.36497E-03
ZIRCALLOY	3.22036E-03	–	–

Table 5.6.1-9 Isotopic Compositions of Maine Yankee CE 14 × 14 Canister Annular Region Materials (One-Dimensional Analysis Only)

Isotope	Fuel Annulus [atom/b-cm]	Upper Plenum Annulus [atom/b-cm]	Upper End Fit Annulus [atom/b-cm]	Lower End Fit Annulus [atom/b-cm]
ALUMINUM	5.96817E-03	–	–	–
CHROMIUM(SS304)	1.77895E-03	9.31065E-04	2.53529E-03	4.13797E-03
MANGANESE	1.77228E-04	9.27577E-05	2.52579E-04	4.12247E-04
IRON(SS304)	6.05870E-03	3.1710E-03	8.63463E-03	1.40930E-02
NICKEL(SS304)	7.88057E-04	4.12453E-04	1.12311E-03	1.83308E-03

Table 5.6.1-10 Loading Table for Maine Yankee CE 14 × 14 Fuel with No Non-Fuel Material – Required Cool Time in Years Before Assembly is Acceptable

	Burnup ≤ 30 GWD/MTU - Minimum Cool Time [years] for		
Enrichment	**Standard[1]**	**Preferential (I)[2]**	**Preferential (P)[3]**
1.9 ≤ E < 2.1	5	5	5
2.1 ≤ E < 2.3	5	5	5
2.3 ≤ E < 2.5	5	5	5
2.5 ≤ E < 2.7	5	5	5
2.7 ≤ E < 2.9	5	5	5
2.9 ≤ E < 3.1	5	5	5
3.1 ≤ E < 3.3	5	5	5
3.3 ≤ E < 3.5	5	5	5
3.5 ≤ E < 3.7	5	5	5
3.7 ≤ E ≤ 4.2	5	5	5
	30 < Burnup ≤ 35 GWD/MTU – Minimum Cool Time [years] for		
Enrichment	**Standard[1]**	**Preferential (I)[2]**	**Preferential (P)[3]**
1.9 ≤ E < 2.1	5	5	5
2.1 ≤ E < 2.3	5	5	5
2.3 ≤ E < 2.5	5	5	5
2.5 ≤ E < 2.7	5	5	5
2.7 ≤ E < 2.9	5	5	5
2.9 ≤ E < 3.1	5	5	5
3.1 ≤ E < 3.3	5	5	5
3.3 ≤ E < 3.5	5	5	5
3.5 ≤ E < 3.7	5	5	5
3.7 ≤ E ≤ 4.2	5	5	5
	35 < Burnup ≤ 40 GWD/MTU - Minimum Cool Time [years] for		
Enrichment	**Standard[1]**	**Preferential (I)[2]**	**Preferential (P)[3]**
1.9 ≤ E < 2.1	7	7	5
2.1 ≤ E < 2.3	6	6	5
2.3 ≤ E < 2.5	6	6	5
2.5 ≤ E < 2.7	5	6	5
2.7 ≤ E < 2.9	5	6	5
2.9 ≤ E < 3.1	5	6	5
3.1 ≤ E < 3.3	5	6	5
3.3 ≤ E < 3.5	5	6	5
3.5 ≤ E < 3.7	5	6	5
3.7 ≤ E ≤ 4.2	5	6	5

1. "Standard" loading pattern: allowable decay heat = 0.958 kW per assembly
2. "Preferential" loading pattern, interior basket locations: allowable heat decay = 0.867 kW per assembly
3. "Preferential" loading pattern, periphery basket locations: allowable heat decay = 1.05 kW per assembly

Table 5.6.1-10 Loading Table for Maine Yankee CE 14 × 14 Fuel with No Non-Fuel Material – Required Cool Time in Years Before Assembly is Acceptable (Continued)

	40 < Burnup ≤ 45 GWD/MTU - Minimum Cool Time [years] for		
Enrichment	**Standard**[1]	**Preferential (I)**[2]	**Preferential (P)**[3]
1.9 ≤ E < 2.1	11	11	6
2.1 ≤ E < 2.3	9	9	6
2.3 ≤ E < 2.5	8	8	6
2.5 ≤ E < 2.7	7	7	6
2.7 ≤ E < 2.9	7	7	6
2.9 ≤ E < 3.1	6	7	6
3.1 ≤ E < 3.3	6	7	5
3.3 ≤ E < 3.5	6	7	5
3.5 ≤ E < 3.7	6	7	5
3.7 ≤ E ≤ 4.2	6	7	5
	45 < Burnup ≤ 50 GWD/MTU - Minimum Cool Time [years] for		
Enrichment	**Standard**[1]	**Preferential (I)**[2]	**Preferential (P)**[3]
1.9 ≤ E < 2.1	Not allowed	Not allowed	7
2.1 ≤ E < 2.3	Not allowed	Not allowed	7
2.3 ≤ E < 2.5	Not allowed	Not allowed	7
2.5 ≤ E < 2.7	Not allowed	Not allowed	7
2.7 ≤ E < 2.9	Not allowed	Not allowed	7
2.9 ≤ E < 3.1	Not allowed	Not allowed	7
3.1 ≤ E < 3.3	Not allowed	Not allowed	7
3.3 ≤ E < 3.5	Not allowed	Not allowed	6
3.5 ≤ E < 3.7	Not allowed	Not allowed	6
3.7 ≤ E ≤ 4.2	Not allowed	Not allowed	6

1. "Standard" loading pattern: allowable decay heat = 0.958 kW per assembly
2. "Preferential" loading pattern, interior basket locations: allowable heat decay = .0.867 kW per assembly
3. "Preferential" loading pattern, periphery basket locations: allowable heat decay = 1.05 kW per assembly

Table 5.6.1-11 Three-Dimensional Shielding Analysis Results for Various Maine Yankee CEA Configurations Establishing One-Dimensional Dose Rate Limits for Loading Table Analysis

CEA Cool Time [years]	Dose Rate [mrem/hr]	FSD	Delta [mrem/hr]	Limit [mrem/hr]
Class 1 Result	32.0	0.85%	-	34.2
No CEA	32.0	0.85%	-0.0	34.2
05y	43.8	0.59%	-11.8	22.4
10y	33.1	0.69%	-1.1	33.1
15y	32.0	0.85%	-0.0	34.2
20y	32.0	0.85%	-0.0	34.2

Table 5.6.1-12 Loading Table for Maine Yankee CE 14 × 14 Fuel Containing CEA Cooled to Indicated Time

	≤ 30 GWD/MTU Burnup - Minimum Cool Time in Years for				
Enrichment	No CEA (Class 2)	5 Year CEA	10 Year CEA	15 Year CEA	20 Year CEA
1.9 ≤ E < 2.1	5	5	5	5	5
2.1 ≤ E < 2.3	5	5	5	5	5
2.3 ≤ E < 2.5	5	5	5	5	5
2.5 ≤ E < 2.7	5	5	5	5	5
2.7 ≤ E < 2.9	5	5	5	5	5
2.9 ≤ E < 3.1	5	5	5	5	5
3.1 ≤ E < 3.3	5	5	5	5	5
3.3 ≤ E < 3.5	5	5	5	5	5
3.5 ≤ E < 3.7	5	5	5	5	5
3.7 ≤ E ≤ 4.2	5	5	5	5	5
	30 < Burnup ≤ 35 GWD/MTU - Minimum Cool Time in Years for				
Enrichment	No CEA (Class 2)	5 Year CEA	10 Year CEA	15 Year CEA	20 Year CEA
1.9 ≤ E < 2.1	5	5	5	5	5
2.1 ≤ E < 2.3	5	5	5	5	5
2.3 ≤ E < 2.5	5	5	5	5	5
2.5 ≤ E < 2.7	5	5	5	5	5
2.7 ≤ E < 2.9	5	5	5	5	5
2.9 ≤ E < 3.1	5	5	5	5	5
3.1 ≤ E < 3.3	5	5	5	5	5
3.3 ≤ E < 3.5	5	5	5	5	5
3.5 ≤ E < 3.7	5	5	5	5	5
3.7 ≤ E ≤ 4.2	5	5	5	5	5
	35 < Burnup ≤ 40 GWD/MTU - Minimum Cool Time in Years for				
Enrichment	No CEA (Class 2)	5 Year CEA	10 Year CEA	15 Year CEA	20 Year CEA
1.9 ≤ E < 2.1	7	7	7	7	7
2.1 ≤ E < 2.3	6	6	6	6	6
2.3 ≤ E < 2.5	6	6	6	6	6
2.5 ≤ E < 2.7	5	6	5	5	5
2.7 ≤ E < 2.9	5	6	5	5	5
2.9 ≤ E < 3.1	5	6	5	5	5
3.1 ≤ E < 3.3	5	5	5	5	5
3.3 ≤ E < 3.5	5	5	5	5	5
3.5 ≤ E < 3.7	5	5	5	5	5
3.7 ≤ E ≤ 4.2	5	5	5	5	5
	40 < Burnup ≤ 45 GWD/MTU - Minimum Cool Time in Years for				
Enrichment	No CEA (Class 2)	5 Year CEA	10 Year CEA	15 Year CEA	20 Year CEA
1.9 ≤ E < 2.1	11	11	11	11	11
2.1 ≤ E < 2.3	9	9	9	9	9
2.3 ≤ E < 2.5	8	8	8	8	8
2.5 ≤ E < 2.7	7	7	7	7	7
2.7 ≤ E < 2.9	7	7	7	7	7
2.9 ≤ E < 3.1	6	6	6	6	6
3.1 ≤ E < 3.3	6	6	6	6	6
3.3 ≤ E < 3.5	6	6	6	6	6
3.5 ≤ E < 3.7	6	6	6	6	6
3.7 ≤ E ≤ 4.2	6	6	6	6	6

Note: The NoCEA (Class 2) column is provided for comparison. Fuel assemblies without a CEA insert may not be loaded in a Class 2 canister.

Table 5.6.1-13 Establishment of Dose Rate Limit for Maine Yankee ICI Thimble Analysis

Case	Top Model	
	Rate (mrem/hr)	FSD
No ICI Thimble	33.3	1.4%
4 Year Cooled ICI Thimble	33.3	1.4%
Delta	0.0	

Table 5.6.1-14 Required Cool Time for Maine Yankee Fuel Assemblies with Activated Stainless Steel Replacement Rods

Assembly Number	Burnup [MWD/MTU]	Enrichment [wt %]	SSR Source [g/s/assy]	Cool Time [years]	Earliest Loadable	Loading Configuration
N420	45,000	3.3	2.1602E+13	6	Jan 2001	Standard
N842	35,000	3.3	3.1396E+12	5	Jan 2001	Standard
N868	40,000	3.3	5.2444E+12	5	Jan 2001	Standard
R032	45,000	3.5	1.4550E+13	6	Jan 2002	Standard
R439	50,000	3.5	1.3998E+13	7	Jan 2003	Standard
R444	50,000	3.5	5.5993E+13	8	Jan 2004	Standard
R439	50,000	3.5	1.3998E+13	6	Jan 2002	Pref(1.050)
R444	50,000	3.5	5.5993E+13	6	Jan 2002	Pref(1.050)

Table 5.6.1-15 Maine Yankee Consolidated Fuel Model Parameters

Lattice	Assy	Num Rods	Actual Burnup [MWD/MTU]	Actual Enrichment [wt %]	Modeled Burnup [MWD/MTU]	Modeled Enrichment [wt %]	Required Cool Time [y]	Cool Time 1/1/01 [y]
CN-1	EF0039	172	5150	1.929	30000	1.9	6	26
CN-10	EF0045	176	17150	1.953	30000	1.9	6	24
	EF0046	107	17150	1.953	30000	1.9	6	24

Table 5.6.1-16 Maine Yankee Source Rate Analysis for CN-10 Consolidated Fuel Lattice

Cool Time [years]	Num Rods Present	Decay Heat [kW/cask]	Fuel Neutron [n/s/assy]	Fuel Gamma [g/sec/assy]	Fuel Hardware [g/sec/assy]
6	176	13.9	1.63E+08	3.16E+15	9.28E+12
24	283	7.42	8.41E+07	1.28E+15	8.67E+11
Src Ratio 24/6		0.86	0.83	0.65	0.15

Table 5.6.1-17 Additional Maine Yankee Non-Fuel Hardware Characterization – Non-Neutron Sources

Non Fuel Material	Waste Volume [ft^3]	Total Curies	Co-60 Curies
Sb-Be Source 1H1	0.020	4.15E+02	2.22E+02
Sb-Be Source 6H4	0.020	4.32E+02	2.31E+02
CEA Tips	0.100	1.06E+02	8.90E+01
ICI	0.007	2.82E+01	1.76E+01

Table 5.6.1-18 Additional Maine Yankee Non-Fuel Hardware Characterization – Neutron Sources

Non Fuel Material	Pu-238 grams	Pu-238 Curies	Pu-239 grams	Pu-239 Curies
Pu-Be Unirradiated Source	1.16	-	0.24	-
Pu-Be Irradiated Sources	1.16	5.10E-02	0.24	5.88E-05

Table 5.6.1-19 Pu-Be Assembly Hardware Spectra (Cycles 1-13) – 5 Year Cool Time from 1/1/1997

Group	Pu-Be SS Hardware [g/sec]
1	0.0000E+00
2	0.0000E+00
3	0.0000E+00
4	0.0000E+00
5	1.8059E-15
6	3.5714E+05
7	2.3032E+08
8	8.9078E-03
9	9.7053E+12
10	3.4367E+13
11	1.2604E+10
12	4.0605E+07
13	1.1692E+08
14	1.8500E+09
15	1.4100E+09
16	2.8397E+10
17	1.1771E+11
18	5.9808E+11
TOTAL	4.4833E+13

Table 5.6.1-20 Additional Maine Yankee Non-Fuel Hardware – HW Assembly Spectra (Class 2 Canister) – 5 Year Cool Time from 1/1/1997

Group	ICI Segment [g/sec]	CEA Tips [g/sec]	Total Gamma [g/sec]
1	0.0000E+00	0.0000E+00	0.00E+00
2	0.0000E+00	0.0000E+00	0.00E+00
3	0.0000E+00	0.0000E+00	0.00E+00
4	0.0000E+00	0.0000E+00	0.00E+00
5	0.0000E+00	0.0000E+00	0.00E+00
6	5.6364E+04	1.4995E+04	7.14E+04
7	3.6350E+07	9.6704E+06	4.60E+07
8	0.0000E+00	0.0000E+00	0.00E+00
9	1.5317E+12	4.0749E+11	1.94E+12
10	5.4239E+12	1.4430E+12	6.87E+12
11	2.4164E+08	6.4285E+07	3.06E+08
12	6.4084E+06	1.7049E+06	8.11E+06
13	1.8453E+07	4.9092E+06	2.34E+07
14	2.9197E+08	7.7675E+07	3.70E+08
15	2.2253E+08	5.9201E+07	2.82E+08
16	4.4816E+09	1.1923E+09	5.67E+09
17	1.8576E+10	4.9418E+09	2.35E+10
18	9.3171E+10	2.4787E+10	1.18E+11
Total	7.0726E+12	1.8816E+12	8.95E+12

Table 5.6.1-21 Additional Maine Yankee Non-Fuel Hardware – Source Assembly Spectra – 5 Year Cool Time from 1/1/1997

Group	Sb-Be Source	Pu-Be Unirradiated Source		Pu-Be Irradiated Source			
	Gamma [g/sec]	Gamma [g/sec]	Neutron [n/sec]	Gamma [g/sec]	Hw Gamma [g/sec]	Total Gamma [g/sec]	Neutron [n/sec]
1	0.0000E+00	1.8438E+00	4.7620E+01	5.9037E-03	0.0000E+00	5.9037E-03	1.5250E-01
2	0.0000E+00	9.0379E+00	3.1850E+03	2.8938E-02	0.0000E+00	2.8938E-02	1.0200E+01
3	0.0000E+00	4.8704E+01	8.0950E+03	1.5595E-01	0.0000E+00	1.5595E-01	2.5920E+01
4	0.0000E+00	1.2868E+02	2.3510E+03	4.1204E-01	0.0000E+00	4.1204E-01	7.5290E+00
5	0.0000E+00	4.0697E+02	1.5900E+03	1.3030E+00	1.8059E-15	1.3030E+00	5.0900E+00
6	2.2971E+05	4.7836E+02	8.2740E+02	1.5315E+00	3.5714E+05	3.5714E+05	2.6490E+00
7	1.4814E+08	8.6530E+02	1.4900E+02	2.7621E+00	2.3032E+08	2.3032E+08	4.7700E-01
8	0.0000E+00	1.5016E+03	-	4.7854E+00	8.9078E-03	4.7943E+00	-
9	6.2425E+12	4.2159E+00	-	4.6985E-07	9.7053E+12	9.7053E+12	-
10	2.2105E+13	8.9859E+03	-	2.8745E+01	3.4367E+13	3.4367E+13	-
11	9.8479E+08	3.9420E+04	-	1.2621E+02	1.2604E+10	1.2604E+10	-
12	2.6117E+07	3.0176E+05	-	9.6649E+02	4.0605E+07	4.0606E+07	-
13	7.5204E+07	8.7531E+03	-	3.4464E+01	1.1692E+08	1.1692E+08	-
14	1.1899E+09	2.6915E+04	-	1.0614E+02	1.8500E+09	1.8500E+09	-
15	9.0690E+08	2.5370E+04	-	8.3993E+01	1.4100E+09	1.4100E+09	-
16	1.8265E+10	2.0487E+07	-	6.5574E+04	2.8397E+10	2.8397E+10	-
17	7.5705E+10	2.8935E+07	-	9.2577E+04	1.1771E+11	1.1771E+11	-
18	3.7972E+11	3.1017E+10	-	9.9310E+07	5.9808E+11	5.9818E+11	-
Total	2.8825E+13	3.1067E+10	1.625E+04	9.9470E+07	4.4833E+13	4.4833E+13	5.202E+01

Table 5.6.1-22 Additional Maine Yankee Non-Fuel Hardware – Hardware Assembly Dose Rates (Class 2) – 5 Years Cooled from 1/1/1997

Group	Storage - Surface Gamma Dose [mrem/hr]	Transfer - Surface Gamma Dose [mrem/hr]
1	3.66E-10	1.51E-10
2	1.41E-09	8.97E-10
3	4.92E-09	5.00E-09
4	7.10E-09	1.20E-08
5	1.08E-08	2.99E-08
6	4.21E-08	1.91E-07
7	9.96E-06	6.12E-05
8	2.24E-09	1.72E-08
9	4.59E-02	3.77E-01
10	3.49E-02	2.24E-01
11	2.31E-07	6.42E-07
12	1.82E-09	1.02E-09
13	2.68E-10	9.13E-13
14	9.84E-11	3.12E-19
15	2.65E-12	1.49E-40
16	1.11E-14	0.00E+00
17	1.91E-41	0.00E+00
18	0.00E+00	0.00E+00
Total	8.09E-02	6.01E-01

Table 5.6.1-23 Additional Maine Yankee Non-Fuel Hardware – Storage Cask Source Assembly Surface Dose Rates – 5 Years Cooled from 1/1/1997

	Sb-Be Source Dose	Pu-Be Unirradiated Source Dose		Pu-Be Irradiated Source Dose	
Group	Gamma [mrem/hr]	Gamma [mrem/hr]	Neutron [mrem/hr]	Gamma [mrem/hr]	Neutron [mrem/hr]
1	0.00E+00	1.81E-11	2.94E-08	5.78E-14	9.41E-11
2	0.00E+00	6.93E-11	1.11E-06	2.22E-13	3.57E-09
3	0.00E+00	2.42E-10	2.45E-06	7.76E-13	7.85E-09
4	0.00E+00	3.50E-10	5.57E-07	1.12E-12	1.78E-09
5	0.00E+00	5.31E-10	3.29E-07	1.70E-12	1.05E-09
6	1.19E-07	2.49E-10	1.62E-07	1.86E-07	5.19E-10
7	3.21E-05	1.87E-10	2.19E-08	4.99E-05	7.02E-11
8	0.00E+00	1.11E-10	-	3.53E-13	-
9	1.48E-01	9.99E-14	-	2.30E-01	-
10	1.12E-01	4.57E-11	-	1.75E-01	-
11	7.41E-07	2.97E-11	-	9.48E-06	-
12	3.34E-09	3.86E-11	-	5.19E-09	-
13	8.37E-10	9.74E-14	-	1.30E-09	-
14	3.15E-10	7.13E-15	-	4.90E-10	-
15	8.52E-12	2.38E-16	-	1.32E-11	-
16	3.34E-14	3.74E-17	-	5.19E-14	-
17	5.99E-41	2.29E-44	-	9.31E-41	-
18	0.00E+00	0.00E+00	-	0.00E+00	-
Total	2.60E-01	1.87E-09	4.67E-06	4.05E-01	1.49E-08

Table 5.6.1-24 Additional Maine Yankee Non-Fuel Hardware – Transfer Cask Source Assembly Surface Dose Rates – 5 Years Cooled from 1/1/1997

Group	Sb-Be Source Dose	Pu-Be Unirradiated Source Dose		Pu-Be Irradiated Source Dose	
	Gamma [mrem/hr]	Gamma [mrem/hr]	Neutron [mrem/hr]	Gamma [mrem/hr]	Neutron [mrem/hr]
1	0.00E+00	7.43E-12	3.40E-06	2.38E-14	1.09E-08
2	0.00E+00	4.42E-11	1.50E-04	1.42E-13	4.81E-07
3	0.00E+00	2.46E-10	3.57E-04	7.89E-13	1.14E-06
4	0.00E+00	5.90E-10	7.29E-05	1.89E-12	2.33E-07
5	0.00E+00	1.47E-09	3.65E-05	4.72E-12	1.17E-07
6	5.40E-07	1.12E-09	1.34E-05	8.40E-07	4.30E-08
7	1.97E-04	1.15E-09	6.69E-07	3.06E-04	2.14E-09
8	0.00E+00	8.53E-10	-	2.72E-12	-
9	1.21E+00	8.20E-13	-	1.89E+00	-
10	7.21E-01	2.93E-10	-	1.12E+00	-
11	2.06E-06	8.25E-11	-	2.64E-05	-
12	1.86E-09	2.15E-11	-	2.89E-09	-
13	2.85E-12	3.32E-16	-	4.44E-12	-
14	9.99E-19	2.26E-23	-	1.55E-18	-
15	4.77E-40	1.33E-44	-	7.42E-40	-
16	0.00E+00	0.00E+00	-	0.00E+00	-
17	0.00E+00	0.00E+00	-	0.00E+00	-
18	0.00E+00	0.00E+00	-	0.00E+00	-
Total	1.94E+00	5.89E-09	6.34E-04	3.01E+00	2.03E-06

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6.0 CRITICALITY EVALUATION

This chapter documents the criticality evaluation of the Universal Storage System with either PWR or BWR contents. The results demonstrate that the effective neutron multiplication factor, k_{eff}, of the Universal Storage System under normal, off-normal, and accident conditions, is less than 0.95 including biases and uncertainties. The system design therefore meets the criticality requirements of 10 CFR 72.124(a) [1], 10 CFR 72.236(c), and Chapter 6 of NUREG-1536 [2].

6.1 Discussion and Results

The Universal Storage System consists of a Transportable Storage Canister, a transfer cask and a Vertical Concrete Cask. The system is designed to safely store up to 24 intact PWR fuel assemblies or 56 intact BWR fuel assemblies. Maximum initial enrichment for each PWR and BWR fuel assembly grouping, as a function of the assemblies' key parameters, is shown in Tables 6.1-1 and 6.1-2. PWR maximum initial enrichments are provided for loading with and without soluble boron credit. For PWR fuel assemblies, the maximum enrichment allowed ranges from 4.3 wt. % to 5.0 wt. % without any soluble boron, and a maximum of 5.0 wt. % for all PWR fuel with at least 1000 ppm of soluble boron. Maximum initial enrichment is defined as peak rod enrichment for PWR assemblies and the maximum initial peak planar-average enrichment for BWR assemblies. The maximum initial peak planar-average enrichment is the maximum planar-average enrichment at any height along the axis of the fuel assembly. For BWR fuel assemblies, the maximum enrichment allowed ranges from 4.4 wt. % to 4.8 wt. %.

Primarily on the basis of their lengths and cross-sections, the fuel assemblies are categorized into classes. Three classes of PWR fuel assemblies and two classes of BWR fuel assemblies are evaluated for storage. Five Transportable Storage Canister assemblies of different lengths and configuration are designed to store the three classes of PWR fuel assemblies and the two classes of BWR fuel assemblies. The canister is comprised of a stainless steel canister and a fuel basket within which fuel is loaded. The canister is loaded into the Vertical Concrete Cask for storage. The length of the Vertical Concrete Cask also varies depending upon the type of the canister it is designed to store.

A transfer cask is used for handling the canister during loading of spent fuel. Fuel is loaded into the canister contained within the transfer cask underwater in the spent fuel pool. Once loaded with fuel, the canister is drained, dried, inerted, and welded shut. The transfer cask is then used to transfer the canister into and out of the concrete cask or shipping cask. The transfer cask provides shielding during the canister loading and transfer operations.

The PWR transfer cask is designed in two configurations, standard and advanced. The advanced design is identical to the standard design with the exception of a trunnion support plate. This plate has no impact on system reactivity. Therefore, all analysis of the standard transfer cask applies to the advanced transfer cask.

Under normal conditions, such as loading in a spent fuel pool, moderator (water) is present in the canister while it is in the transfer cask. Also, during draining and drying operations, moderator with varying density is present. Thus, the criticality evaluation of the transfer cask includes a variation in moderator density and a determination of optimum moderator density. Off-normal and accident conditions are bounded by assuming the most reactive mechanical basket configuration as well as moderator intrusion into the fuel cladding (i.e., 100% fuel failure).

Under normal and accident conditions, moderator is not present in the canister while it is in the concrete cask. However, access to the environment is possible via the air inlets in the concrete cask and the convective heat transfer annulus between the canister and the cask steel liner. This access provides paths for moderator intrusion during a flood. Under off-normal conditions, moderator intrusion into the convective heat transfer annulus is evaluated. For the initial evaluation without soluble boron credit, under hypothetical accident conditions, it is assumed that the canister confinement fails, and moderator intrusion into the canister and into the fuel cladding (100% fuel failure) is evaluated. This is a conservative assumption, since normal, off-normal and design basis accident analysis shows that the confinement boundary remains intact. Therefore, there are no circumstances under which there would be water in the canister. In the PWR soluble boron evaluation, credit is taken for the dry canister. For this configuration, a wet transfer cask containing a canister filled with a water/soluble boron mixture and a dry canister in a concrete cask are assumed.

Criticality control in the PWR basket is achieved by using a flux trap, or a combination flux trap and soluble neutron absorber (boron). Individual fuel assemblies are held in place by fuel tubes surrounded by four neutron absorber sheets. The neutron absorber modeled is a borated aluminum neutron absorber. Any similar material meeting the ^{10}B areal density and physical dimension requirement will produce similar reactivity results. A stainless steel cover holds the neutron absorber sheets in place. The fuel tubes are separated by a gap that is filled with water when the canister is flooded. Fast neutrons escaping one fuel assembly are moderated in the water gap and are absorbed by the neutron absorber between the assemblies before they can cause a fission in the adjacent assembly. The flux trap gap spacing is maintained by the basket's stainless steel support disks, which separate individual fuel assembly tubes. Alternating stainless steel disks and aluminum heat transfer disks are placed axially at intervals determined by thermal and structural constraints. The PWR basket design includes 30, 32, or 34 support disks and 29, 31, or 33 heat transfer disks, respectively. The minimum loading of the neutron absorber sheets in the PWR fuel tubes is 0.025 g $^{10}B/cm^2$. To reach higher initial enrichments than those allowed by using only the flux trap for criticality control, a separate evaluation, including soluble boron at 1000 ppm in the moderator, is performed. The soluble boron absorbs thermal neutrons inside the assembly, as well as in the flux traps. In combination with the flux traps and fixed neutron poison, the soluble boron allows loading of PWR fuel assemblies with an initial enrichment up to 5.0 wt. % ^{235}U.

Criticality control in the BWR basket is achieved by a single neutron absorber sheet between each fuel assembly. The neutron absorber modeled is a borated aluminum neutron absorber. Any similar material meeting the ^{10}B areal density and physical dimension requirement will produce similar reactivity results. Individual fuel assemblies in the BWR basket are held in place by fuel tubes. The fuel tubes are of three types: tubes with neutron absorber on two sides; tubes with neutron absorber on one side; and tubes with no neutron absorber. The fuel tube types are arranged such that there is at least one sheet of neutron absorber between adjacent assemblies. As in the PWR basket, a stainless steel cover holds the neutron absorber sheets in place, and the fuel tubes are separated by a gap that is filled with water when the canister is flooded. In the case of BWR fuel, this arrangement is sufficient to moderate and absorb thermal neutrons before they can cause a fission in the adjacent assembly. The use of flux traps between BWR assemblies is not necessary because of the smaller size and amount of fissile material in BWR assemblies compared with PWR assemblies. Of the total 56 fuel tubes in each BWR basket, 42 tubes contain neutron absorber sheets on two sides of the tubes; 11 tubes contain neutron absorber sheets on one side; and the remaining 3 tubes contain no neutron absorber sheets. The engineered placement of the neutron absorber sheets assures sufficient absorption of thermal neutrons to achieve a neutron multiplication factor (k_s) below 0.95. The minimum loading of the neutron absorber sheets in the BWR tubes is 0.011 g $^{10}B/cm^2$. The BWR Class 4 and 5 basket designs include 40 and 41 carbon steel support disks, respectively. The BWR basket design also includes 17 aluminum heat transfer disks.

The SCALE 4.3 Criticality Safety Analysis Sequence (CSAS) [3, 4] and ANSWERS MONK module [20] are used to perform the Universal Storage System criticality analysis. This sequence includes KENO-Va [5] Monte Carlo analysis to determine k_{eff} under normal and accident conditions. The 27-group ENDF/B-IV neutron cross-section library [6] is used in all calculations. CSAS with the 27-group library is benchmarked by comparison to 63 critical experiments relevant to light water reactor fuel in storage and transport casks. The MONK8A Monte Carlo Program for Nuclear Criticality Safety Analysis (SERCO Assurance [20]) employs the Monte Carlo technique in combination with JEF 2.2-based point energy neutron libraries to determine the effective neutron multiplication factor (k_{eff}). The specific libraries are dice96j2v5 for general neutron cross-section information and therm96j2v2 for thermal scatter data in the water moderator. MONK8a, with the JEF 2.2 neutron cross-section libraries, is benchmarked by comparison to critical experiments relevant to light-water reactor fuel in storage and transport casks shown in Section 6.5.

The most reactive PWR assembly is the Westinghouse 17×17 OFA and the most reactive BWR fuel assembly is the Exxon/ANF/Siemens Power Corp. (Ex/ANF) 9×9 with 79 fuel rods (see Section 6.4.1.2 for detailed discussion). These assemblies, respectively, bound all PWR (Classes 1-3) and BWR (Classes 4-5) fuel assemblies to be stored (see Tables 6.2-1 and 6.2-2), as demonstrated in Section 6.4.1.2. The most reactive PWR and BWR fuel assemblies, evaluated as fresh fuel in their respective basket configuration, are used in the criticality calculations for the transfer cask and the concrete cask.

The maximum multiplication factors with uncertainties and code bias are calculated, using conservative assumptions, for the transfer cask and the Vertical Concrete Cask containing PWR (4.2 wt. % ^{235}U) or BWR (4.0 wt. % ^{235}U) fuel. The calculations for the transfer cask are performed for normal and accident conditions, and those for the concrete cask are performed for normal, accident, and off-normal conditions. The results of the analyses are presented in detail in Section 6.4.3 and are summarized as:

Condition	Maximum Multiplication Factors with Uncertainties (k_s)			
	PWR Fuel		BWR Fuel	
	Transfer Cask	Concrete Cask	Transfer Cask	Concrete Cask
Normal	0.93921	0.38329	0.91919	0.38168
Accident	0.94749	0.94704	0.92235	0.92332
Off-Normal	--	0.37420	--	0.38586

Analysis of simultaneous moderator density variation inside and outside either the transfer or concrete casks shows a monotonic decrease in reactivity with decreasing moderator density. Thus, the full moderator density condition bounds any off-normal or accident condition. Analysis of moderator intrusion into the concrete cask heat transfer annulus with the dry canister shows a slight decrease in reactivity from the completely dry condition.

The fixed maximum enrichment evaluation is augmented by assembly-specific analyses. Fuel types identified in Section 6.2 are grouped based on key fuel lattice characteristics. Each of the groups is then evaluated to determine the maximum enrichment for which cask reactivity (k_{eff}) plus two sigma (2σ) remains below the upper safety limit (USL) of 0.9426. The maximum allowed enrichment with the key lattice parameters is shown in Tables 6.1-1 and 6.1-2 for PWR and BWR fuel assemblies, respectively. Table 6.1-2 enrichments do not take credit for any soluble boron. At 1000 ppm soluble boron, the maximum allowed initial enrichment for all PWR fuel assembly types is 5.0 wt. % ^{235}U.

Table 6.1-1 PWR Fuel Assembly Maximum Allowed Enrichment

ID	No. of Fuel Rods	Max MTU	Max Pitch (in)	Min Rod Dia (in)	Min Clad Thick (in)	Max Pellet Dia (in)	Max Active Length (in)	No. Guide/ Instr. Tubes	Min Tube Thick (in)	Max Enrich. (wt.% ^{235}U)
ce14a	176	0.404	0.580	0.440	0.0280	0.3765	137.0	5	N/A	5.0
we14d	176	0.411	0.580	0.440	0.0260	0.3805	136.7	5	N/A	5.0
ce14my	176	0.411	0.590	0.4375	0.0240	0.3800	137.0	5	N/A	4.7
ex14a	179	0.369	0.556	0.424	0.0300	0.3505	142.0	17	0.034	5.0
we14a	179	0.414	0.556	0.422	0.0225	0.3674	145.2	17	0.034	5.0
we14b	179	0.361	0.556	0.400	0.0243	0.3444	144.0	17	0.034	5.0
ex15a	204	0.441	0.563	0.424	0.0300	0.3565	144.0	21	0.017	4.6
we15a	204	0.465	0.563	0.422	0.0242	0.3659	144.0	21	0.015	4.3
bw15a	208	0.481	0.568	0.430	0.0265	0.3686	144.0	17	0.016	4.4
ce16e	236	0.443	0.506	0.382	0.0230	0.3255	150.0	5	N/A	4.8
ex17a	264	0.412	0.496	0.360	0.0250	0.3030	144.0	25	0.016	4.4
we17a	264	0.467	0.496	0.374	0.0225	0.3225	144.0	25	0.015	4.5
we17b	264	0.428	0.496	0.360	0.0225	0.3088	144.0	25	0.015	4.3
bw17a	264	0.466	0.502	0.379	0.0240	0.3232	143.0	25	0.0175	4.4
Palisades[1]	216	0.432	0.550	0.418	0.0260	0.3580	132.0	N/A	N/A	4.2[1]
Palisades[1]	179	0.374	0.556	0.417	0.0300	0.3505	144.0	5	N/A	4.2[1]
Palisades[1]	216	0.431	0.550	0.417	0.0300	0.3580	131.8	N/A	N/A	4.2[1]

Note: Site specific.

1. Palisades 15×15 fuel assemblies and Prairie Island 14×14 assemblies are not re-evaluated and remain at the 4.2 wt% original design basis enrichment.

Table 6.1-2 BWR Fuel Assembly Maximum Allowed Enrichment – No Soluble Boron

ID	No. of Fuel Rods	Max MTU	Max Pitch (in)	Min Rod Dia (in)	Min Clad Thick (in)	Max Pellet Dia (in)	Max Active Length (in)	No. Water Rods	Min Rod Thick (in)	Max Enrich. (wt.% ^{235}U)
ex07a	48	0.196	0.738	0.570	0.036	0.4900	144.0	0	N/A	4.5
ge07a	49	0.198	0.738	0.570	0.036	0.4880	144.0	0	N/A	4.5
ge07f	49	0.198	0.738	0.563	0.032	0.4870	144.0	0	N/A	4.5
ge07h	49	0.192	0.738	0.563	0.037	0.4770	146.0	0	N/A	4.7
ge08i	60	0.179	0.640	0.484	0.032	0.4100	150.0	1	N/A	4.5
ge08k	62	0.185	0.640	0.483	0.032	0.4100	150.0	2	0.0300	4.5
ex08b	62	0.180	0.641	0.484	0.036	0.4045	150.0	2	0.0360	4.7
ge08n	63	0.188	0.640	0.493	0.034	0.4160	146.0	1	0.0340	4.8
ex08a	63	0.177	0.641	0.484	0.036	0.4045	145.2	0	N/A	4.7
ex09b	74	0.167	0.572	0.424	0.030	0.3565	150.0	2	N/A	4.4
ge09a	74	0.185	0.566	0.441	0.028	0.3760	150.0	2	N/A	4.5
ex09c	79	0.178	0.572	0.424	0.030	0.3565	150.0	2	0.0300	4.4
ge09b	79	0.198	0.566	0.441	0.028	0.3760	150.0	2	0.0280	4.6

6.2 Spent Fuel Loading

The Universal Storage System is designed to store Transportable Storage Canisters containing spent nuclear fuel. Canisters of five different lengths are designed, each to accommodate one of three classes of PWR fuel assemblies or one of two classes of BWR fuel assemblies. The classification of the fuel assemblies is based primarily on fuel assembly length and cross-section. The classes of major fuel assemblies to be stored in the Universal Storage System and their characteristics are shown in Tables 6.2-1 (PWR) and 6.2-2 (BWR). Sections 6.4.5 and 6.4.6 extend the evaluation of the single PWR (4.2 wt. % ^{235}U) and BWR (4.0 wt. % ^{235}U) maximum initial enrichments to an assembly-specific maximum initial enrichment. The enrichments represent maximum planar average enrichment for BWR assemblies and peak fuel rod enrichments for PWR assemblies. Tables 6.2-1 and 6.2-2 include a column containing an identifier linking each of the listed assembly types to the allowable maximum initial enrichment searches in Sections 6.4.5 and 6.4.6.

Class 1 Westinghouse fuel assemblies and Class 2 B&W fuel assemblies include inserts. Fuel assembly inserts are nonfuel bearing components, such as flow mixers, in-core instrument thimbles and burnable poison rod inserts. These components are inserted into the fuel assembly guide tubes. The criticality analyses do not take credit for displacement of moderator by the inserts. For the unborated moderator analyses, insertion of an in-core instrument thimble or a burnable poison rod assembly reduces reactivity by further decreasing the (unborated) moderator to fuel ratio in the fuel assembly lattice. For the analyses that take credit for soluble boron in the moderator, insertion of an in-core instrument thimble or burnable poison rod assembly would displace boron for which credit is taken. Therefore, a burnable poison rod assembly or an in-core instrument thimble shall only be loaded into an assembly that does not require credit to be taken for soluble boron in the moderator in order to meet the assembly enrichment limit. Insertion of a flow mixer is not restricted, as this component does not displace moderator in the active fuel region.

To preclude a potential increase in reactivity as a result of empty fuel rod positions in the assembly, any empty fuel rod position is to be filled with a solid filler rod. Filler rods may be fabricated from either solid Zircaloy or solid Type 304 stainless steel, or may be solid neutron absorber rods inserted for in-core reactivity control prior to reactor operations.

Table 6.2-1 PWR Fuel Assembly Characteristics (Zirc-4 Clad)

Fuel Class	Vendor	Array	Version	Max MTU	No of Fuel Rods	Pitch (in)	Rod Dia. (in)	Clad Thick (in)	Pellet Dia (in)	Active Length (in)	ID
1	CE	14 × 14	Std.	0.4037	176	0.5800	0.440	0.0280	0.3765	137.0	ce14a
1	CE	14 × 14	Ft Cal.	0.3772	176	0.5800	0.440	0.0280	0.3765	128.0	ce14a
1	CE	15 × 15	Palis.	0.4317	216	0.5500	0.418	0.0260	0.3580	132.0	—[1]
1	CE	16 × 16	Lucie 2	0.4025	236	0.5060	0.382	0.0250	0.3250	136.7	ce16d
1	Ex/ANF	14 × 14	WE	0.3689	179	0.5560	0.424	0.0300	0.3505	142.0	ex14a
1	Ex/ANF	14 × 14	CE	0.3814	176	0.5800	0.440	0.0310	0.3700	134.0	ce14a
1	Ex/ANF	14 × 14	Praire Isl.	0.3741	179	0.5560	0.417	0.0300	0.3505	144.0	—[1]
1	Ex/ANF	15 × 15	WE	0.4410	204	0.5630	0.424	0.0300	0.3565	144.0	ex15a
1	Ex/ANF	15 × 15	Palis	0.4310	216	0.5500	0.417	0.0300	0.3580	131.8	—[1]
1	Ex/ANF	17 × 17	WE	0.4123	264	0.4960	0.360	0.0250	0.3030	144.0	ex17a
1	WE	14 × 14	Std/ZCA	0.4144	179	0.5560	0.422	0.0225	0.3674	145.2	we14a
1	WE	14 × 14	OFA	0.3612	179	0.5560	0.400	0.0243	0.3444	144.0	we14b
1	WE	14 × 14	Std/ZCB	0.4144	179	0.5560	0.422	0.0225	0.3674	145.2	we14a
1	WE	14 × 14	CE Model	0.4115	176	0.5800	0.440	0.0260	0.3805	136.7	we14d
1	WE	15 × 15	Std	0.4646	204	0.5630	0.422	0.0242	0.3659	144.0	we15a
1	WE	15 × 15	Std/ZC	0.4646	204	0.5630	0.422	0.0242	0.3659	144.0	we15a
1	WE	15 × 15	OFA	0.4646	204	0.5630	0.422	0.0242	0.3659	144.0	we15a
1	WE	17 × 17	Std	0.4671	264	0.4960	0.374	0.0225	0.3225	144.0	we17a
1	WE	17 × 17	OFA	0.4282	264	0.4960	0.360	0.0225	0.3088	144.0	we17b
1	WE	17 × 17	Vant 5	0.4282	264	0.4960	0.360	0.0225	0.3088	144.0	we17b
2	B&W	15 × 15	Mark B	0.4807	208	0.5680	0.430	0.0265	0.3686	144.0	bw15a
2	B&W	15 × 15	Mark BZ	0.4807	208	0.5680	0.430	0.0265	0.3686	144.0	bw15a
2	B&W	17 × 17	Mark C	0.4658	264	0.5020	0.379	0.0240	0.3232	143.0	bw17a
3	CE	16 × 16	Sono 2&3	0.4417	236	0.5060	0.382	0.0230	0.3255	150.0	ce16e
3	CE	16 × 16	ANO2	0.4417	236	0.5060	0.382	0.0230	0.3255	150.0	ce16e
3	CE	16 × 16	SYS80	0.4417	236	0.5060	0.382	0.0230	0.3255	150.0	ce16e

1. These site specific fuels were not re-evaluated and remain at a maximum initial enrichment of 4.2 wt% ^{235}U.

Table 6.2-2 BWR Fuel Assembly Characteristics (Zirc-2 Clad)

Fuel Class	Vendor	Array	Version	Max MTU	No of Fuel Rods	Pitch (in)	Rod Dia (in)	Clad Thick (in)	Pellet Dia (in)	Active Length (in)	ID
4(5)	Ex/ANF	7 × 7	GE	0.1960	48	0.738	0.570	0.036	0.490	144	ex07a
4	Ex/ANF	8 × 8	JP-3	0.1764	63	0.641	0.484	0.036	0.4045	145.2	ex08a
4	Ex/ANF	9 × 9	JP-3	0.1722	79	0.572	0.424	0.03	0.3565	145.2	ex09c
4	GE	7 × 7	GE-2a	0.1985	49	0.738	0.570	0.036	0.488	144	ge07a
4	GE	7 × 7	GE-2b	0.1977	49	0.738	0.563	0.032	0.487	144	ge07f
4	GE	7 × 7	GE-3	0.1896	49	0.738	0.563	0.037	0.477	144	ge08h
4	GE	8 × 8	GE-4	0.1855	63	0.640	0.493	0.034	0.416	144	ge08n
4	GE	8 × 8	GE-5	0.1788	62	0.640	0.483	0.032	0.410	145.2	ge08k
4	GE	8 × 8	GE-6 (prep)	0.1788	62	0.640	0.483	0.032	0.410	145.2	ge08k
4	GE	8 × 8	GE-7 (barr)	0.1788	62	0.640	0.483	0.032	0.410	145.2	ge08k
4	GE	8 × 8	GE-8	0.1730	60	0.640	0.484	0.032	0.410	145.2(1)	ge08i
4	GE	8 × 8	GE-10	0.1730	60	0.640	0.484	0.032	0.410	145.2(1,2)	ge08i
5(6)	Ex/ANF	8 × 8	JP-4,5	0.1793	62	0.641	0.484	0.036	0.4045	150	ex08b
5	Ex/ANF	9 × 9	JP-4,5	0.1779	79	0.572	0.424	0.03	0.3565	150	ex09c
5	Ex/ANF	9 × 9	JP-4,5	0.1666	74	0.572	0.424	0.03	0.3565	150	ex09b
5	GE	7 × 7	GE-2	0.1977	49	0.738	0.563	0.032	0.487	144	ge07f
5	GE	7 × 7	GE-3a	0.1896	49	0.738	0.563	0.037	0.477	144	ge07h
5	GE	7 × 7	GE-3b	0.1923	49	0.738	0.563	0.037	0.477	146	ge07h
5	GE	8 × 8	GE-4a	0.1855	63	0.640	0.493	0.034	0.416	144	ge08n
5	GE	8 × 8	GE-4b	0.1880	63	0.640	0.493	0.034	0.416	146	ge08n
5	GE	8 × 8	GE-5	0.1847	62	0.640	0.483	0.032	0.410	150(1)	ge08k
5	GE	8 × 8	GE-6 (prep)	0.1847	62	0.640	0.483	0.032	0.410	150(1)	ge08k
5	GE	8 × 8	GE-7 (barr)	0.1847	62	0.640	0.483	0.032	0.410	150(1)	ge08k
5	GE	8 × 8	GE-10	0.1787	60	0.640	0.484	0.032	0.410	150(1,2)	ge08i
5	GE	9 × 9	GE-11	0.1854	74	0.566	0.441	0.028	0.376	150(1,3,4)	ge09a
5	GE	9 × 9	GE-11	0.1979	79	0.566	0.441	0.028	0.376	150(1,3,4)	ge09b

Notes
1. 6-in, natural uranium blankets on top and bottom.
2. 1 large water hole - 3.2 cm ID, 0.1 cm thickness.
3. 2 large water holes occupying 7 fuel rod locations - 2.5 cm ID, 0.07 cm thickness.
4. Shortened active fuel length in some rods.
5. Class of fuel for BWR/2-3.
6. Class of fuel for BWR/4-6.

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6.3 Criticality Model Specification

6.3.1 Calculational Methodology

Evaluations determining the maximum reactivity configuration of the Universal Storage System for PWR and BWR fuel at design basis enrichment levels are performed with the SCALE 4.3 PC CSAS sequence [3, 4]. Assembly specific maximum enrichment level determinations, with and without soluble boron, are performed with the ANSWERS MONK8A code [20].

The SCALE 4.3 PC CSAS25 [3, 4] sequence and the SCALE 27-group neutron library are used to perform the criticality analysis of the Universal Storage System. This sequence includes the SCALE Material Information Processor [7], BONAMI-S [8], NITAWL-S [9], and KENO-Va [5]. The Material Information Processor generates number densities for standard compositions, prepares geometry data for resonance self-shielding, and creates data input files for the cross-section processing codes. The BONAMI-S and NITAWL-S codes are used to prepare a resonance-corrected cross-section library in AMPX working format. The KENO-Va code uses Monte Carlo techniques to calculate k_{eff}. The 27-group ENDF/B-IV group neutron library is used in all cask criticality calculations.

The CSAS criticality analysis sequence is validated through a series of calculations based on critical experiments performed by Babcock and Wilcox [13], Pacific Northwest Laboratory [14, 15, 16, and 17], and Valduc Critical Mass Laboratory [18]. The 27-group ENDF/B-IV neutron cross-section library is used in the validation, which includes statistical analysis of results. Validation of the CSAS and the method statistics are addressed in Section 6.5.

The MONK8A (AEA Technology) Monte Carlo Program for Nuclear Criticality Safety Analysis employs the Monte Carlo technique in combination with JEF 2.2-based point energy neutron libraries to determine the effective neutron multiplication factor (k_{eff}). The specific libraries are dice96j2v5 for general neutron cross-section information and therm96j2v2 for thermal scatter data in the water moderator. MONK8A, with the JEF 2.2 neutron cross-section libraries, is benchmarked by comparison to critical experiments relevant to light water reactor fuel in storage and transport casks as shown in Section 6.5.

The criticality analysis of the Universal Storage System is performed in several steps.

- The PWR and BWR fuel assembly designs described in Tables 6.2-1 and 6.2-2 are screened to identify sets of standard PWR and BWR arrays.

- The identified sets of arrays are analyzed to determine the most reactive PWR and BWR fuel assemblies for the initial design basis limiting condition.

- The criticality impact of mechanical perturbations and geometric tolerances is evaluated using a fuel tube-in-basket model (PWR) and a basket in-cask-model (BWR) based on the most reactive assembly of each type. These models are described in Section 6.4.1.3.

- A canister-in-cask model is prepared to evaluate the reactivity variation between normal and worst-case configurations of the cask contents under normal and hypothetical accident conditions.

- Key fuel parameters are evaluated to determine a bounding description set. This set of parameters maximizes system reactivity based on the number of fuel rods, a minimum rod outer diameter, maximum pellet diameter, minimum clad thickness, maximum active fuel length, and minimum guide/instrument tube or water rod thickness.

- The fuel data set is, again, reviewed based on the maximum/minimum criteria and a set of bounding fuel assemblies is determined. This set is evaluated at various enrichment levels to set the maximum initial enrichment levels producing a reactivity lower than the upper safety limit (USL).

- For the PWR fuel assemblies, the maximum allowed initial enrichment search is repeated based on a 1000 ppm soluble boron level.

The results of criticality calculations for PWR and BWR assembly loaded casks are provided in Sections 6.4.3.2 and 6.4.3.3, respectively.

6.3.2 Model Assumptions

Assumptions for the basket model are as follows.

- The fuel assembly is modeled at a fuel density of 95% theoretical (0.95×10.96 gm/cm^2 = 10.412 g/cm^2).

- Baseline enrichment for the PWR fuel assembly is 4.2 wt % ^{235}U. The PWR fuel assembly included in this model is the Westinghouse 17×17 OFA fuel assembly which is determined to be the most reactive assembly in the PWR basket (see Section 6.4.1.2.1). The most reactive BWR fuel assembly included in this model is the Ex/ANF 9×9 fuel assembly with an enrichment of 4.00 wt % ^{235}U (see Section 6.4.1.2.2). BWR analysis of heterogeneous versus homogeneous pin enrichment shows that assuming a homogeneous enrichment produces conservative k_{eff} values in the BWR canister (see section 6.4.1.3.2). Homogeneous enrichment is defined to be a planar-average enrichment.

- With the exception of the fuel assembly channels in the BWR case, no fuel assembly structural materials (e.g., spacer grids, thimble plugs, or burnable poisons as applicable to PWR/BWR fuel types) are included in the active fuel region. Eliminating the structural materials simplifies model construction significantly. Removing parasitic absorbers and increasing the effective H/U ratio in the normally under-moderated assembly increases reactivity. Evaluation of the reactivity impact for a variety of channel dimensions in the BWR most reactive assembly analysis demonstrates that the impact of the channel material on cask criticality is not statistically significant. Removal of the channel on the most reactive assembly (Ex/ANF 9×9) results in k_{eff} decrease of 0.001 from 0.872 to 0.871 with a Monte Carlo uncertainty of 0.001.

- Fuel assembly neutron poisons, e.g., gadolinium rods (BWR), are excluded from the analysis, thereby substantially increasing assembly reactivity of the unburned assembly.

- Fuel assembly cladding is intact. For normal operating conditions, no water is present in the gap between fuel pellet and clad. For hypothetical accident conditions, water is assumed to be present in the pellet-to-clad gap. Because the canister is shown not to fail structurally under normal or accident conditions and the presence of water in the pellet-to-clad gap requires failure of the sealed canister and the fuel, the assumption of water in the pellet-to-clad gap for accident analysis is extremely conservative.

- The moderator is assumed to be pure water (no soluble boron) at standard temperature and pressure (293K and 0.9982 gm/cm^3) or water containing soluble boron at 1000 ppm. The density of 0.9982 gm/cm^3 corresponds to a relative density in SCALE's Material Information Processor of 1.0. The fuel, cladding and other structural materials are assumed to be at 293K.

- The models for all analyses are axially infinite, i.e., no axial leakage. The BWR basket design contains fuel elevations with and without heat transfer disks. The axially infinite length basket model relies on the basket elevation containing the aluminum heat transfer disk. Criticality control in both PWR and BWR baskets is by neutron absorber plate. The neutron absorber plates contain ^{10}B as a neutron absorber, which requires thermalization of the neutrons prior to capture. Modeling the basket elevation containing the heat transfer disk displaces water required for neutrons to be thermalized prior to reaching the neutron absorber plate and, therefore, increases the reactivity of the system.

- ^{10}B density is reduced to 75% in accordance with 10 CFR 71 [10] licensing guidance and requirements provided in the "Standard Review Plan for Dry Cask Storage Systems" (NUREG-1536) [2].

- Geometric tolerances and mechanical perturbations (fuel movement in tube, tube movement in the disk opening, and combined fuel and tube movement) are analyzed to arrive at the highest reactivity basket configuration. PWR system geometric tolerances and mechanical perturbations are initially evaluated by using an "infinite array" of tubes in the basket model. An "infinite array" of tubes is produced by modeling mirrored boundary conditions in the x-y plane and a single fuel tube surrounded by the basket structure out to one half the web width. A basket-in-canister model taking into account any positive biases determined from the single-tube-in-basket model is the "worst case," highest reactivity, concrete cask configuration. BWR geometric tolerances and mechanical perturbations are directly evaluated by a basket-in-cask model.

- Fuel assembly and basket will retain their structure and will not show any significant permanent deformation during normal or accident conditions.

- The canister support disks are modeled as stainless steel 304 instead of stainless steel 17-4PH. The SCALE Material Composition Library and ANSWERS standard mixture library stainless steel definitions are used for all types of stainless steel in the criticality analysis.

- The A-588 Low Alloy Steel used in the transfer cask shell is modeled using the carbon steel properties resident in the SCALE4.3 Standard Composition Library.

- All carbon steel rebar in the concrete is ignored in the concrete cask model.

- The concrete cask center-to-center spacing in the SCALE 4.3 models is 15 feet. The ANSWERS models are directly reflected on the cask surface. The concrete shield reduces the neutron flux to negligible levels. No significant neutron interaction occurs between the storage casks.

- No fuel assembly inserts (in particular poison rods) are modeled.

6.3.3 Description of Calculational Models

The PWR and BWR KENO-Va basket cell models are shown in Figure 6.3-1 and Figure 6.3-2, respectively. The PWR KENO-Va models for the transfer cask and the concrete cask are shown in Figure 6.3-3 and Figure 6.3-4, respectively. Figures 6.3-5 and 6.3-6 show the BWR KENO-Va models for the standard transfer cask and concrete cask. Criticality control provisions in the PWR and BWR basket designs are illustrated in Figures 6.3-7 and 6.3-8, respectively. Sketches of the three-dimensional ANSWERS transfer cask PWR and vertical concrete cask BWR models are shown in Figures 6.3-9 and 6.3-10, respectively. Cross-sections of the ANSWERS model are similar to those of the SCALE models, with the difference being a discrete modeling of the BWR basket with aluminum heat transfer disks restricted to the central fuel area.

The PWR KENO-Va models are derived from a cylindrical segment of either the transfer or storage cask at the active fuel region. Each model is a stack of four slices: one at the steel disk elevation and thickness, one at the aluminum disk elevation and thickness, and two composed of the water space between disks. The basket is modeled in each slice and contains 24 design basis PWR fuel assemblies at 4.2 wt % ^{235}U enrichment and a fuel density corresponding to UO_2 at 95% of theoretical. Each fuel assembly array is explicitly modeled in each of the 24 basket locations. Each basket slice is surrounded by the cask body shielding regions of either the transfer or the storage cask. Each cask slice is surrounded by a KENO-Va cuboid. The four slices are stacked into the KENO global unit.

The BWR KENO-Va models are also derived from a cylindrical segment of either the transfer or storage cask at the center of the active fuel region. As with the PWR models, the BWR models are a stack of four slices, one at the carbon steel disk elevation and thickness, one at the aluminum disk elevation and thickness, and two composed of the water space between disks. The basket is modeled in each slice and contains 56 design basis BWR fuel assemblies at 4.0 wt % ^{235}U enrichment and fuel density corresponding to a 95% theoretical fuel density. Each fuel assembly array is explicitly modeled in each of the 56 basket locations. Each basket slice is surrounded by the cask body shielding regions of either the transfer or storage cask. Each cask slice is surrounded by a KENO-Va cuboid. The four slices are stacked into the KENO global unit.

In both the PWR and BWR KENO-Va models, periodic boundary conditions are imposed on the top and bottom of the global KENO-Va unit to simulate an infinite cylinder, and reflecting boundary conditions are imposed on the sides, thereby simulating an infinite number of casks in the x-y plane. The reflecting boundary condition on the exterior cuboid's x-y faces forms a square pitch array. As shown in Section 6.4, due to the size of the transfer and storage casks, the baskets are neutronically isolated from one another. Moderator density is varied both in the cask cavity and in the exterior cuboid.

Similar to the SCALE 4.3 models, the ANSWERS code is used to model a UMS® storage and transfer cask containing a PWR or BWR canister and basket, with either 24 PWR assemblies or 56 BWR fuel assemblies. The ANSWERS geometry package uses fractal geometry, which allows the model to be divided into self-contained parts. The self-contained parts can be used to separate canister, cask, and fuel into individual components that can be easily modified and checked. Fractal geometry is the result of combining structured geometry and combinatorial geometry (CG). The basic component of the fractal geometry package is a set of simple bodies, such as spheres, boxes, and rods (cylinders). Models are constructed by combining geometry components (bodies) into PARTS. PARTS may be included within other PARTS to any depth of nesting, and a given PART may be included in different positions within the geometry. An additional feature referred to as a HOLE can be used as special contents in different material zones. The advantage to using HOLES is converting a complex geometric description into a simple one. Finite cask/canister/basket/fuel models (termed cask model henceforth) are constructed for the UMS® storage and transfer system containing PWR and BWR canisters. The cask models are constructed in a set of distinct phases. The first four phases are repeated for the

PWR and BWR canisters. The fifth phase represents the UMS® storage and transfer cask model, which is the same for both canisters. In the first phase, a fuel assembly is constructed from the basic components of the fuel assembly, i.e., fuel rod, guide tube, instrument tube (water rods for the BWR assemblies) and nozzles. An array feature is used to form the rod arrangements. To minimize the complexity of these arrays, a check is made on all water rod or guide/instrument tubes to verify that they only occupy one lattice location. If the rod or tube exceeds one lattice location (such as the CE guide tubes), the tube or rod material is neglected from the model. Next the fuel assembly is placed into a fuel tube and surrounded by neutron absorber sheets. These fuel assemblies, with the fuel tube and attached neutron absorber, are then placed in a planar (x-y) configuration. The tubes are placed in the basket stack composed of bottom weldment, stainless steel or carbon steel support disks, aluminum heat transfer disks, and the top weldment. After completing the canister cavity model, a canister shell is placed around the basket with a structural and shield lid stacked on top of the basket. The appropriate cask shields then surround the canister.

6.3.4 Cask Regional Densities

The densities used in the criticality analyses are listed in the following table. Slight differences in the default densities employed by the SCALE and ANSWERS codes exist. These differences do not significantly impact the results of the criticality analysis. For the neutron absorber, densities for the BORAL core material and the METAMIC sheet are provided.

Material	ANSWERS Model Density (g/cc)	SCALE Model Density (g/cc)
UO_2	10.412 (95% theoretical)	10.412 (95% theoretical)
Zircaloy	6.55	6.56
H_2O	0.9982	0.9982
Stainless steel	7.93	7.92
Carbon steel	7.82	7.82
Lead	11.04	11.35
Aluminum	2.70	2.70
BORAL (core) PWR	2.60	2.60
BORAL (core) BWR	2.68	2.68
METAMIC (40% B_4C)	2.62	2.62
NS-4-FR	1.63	1.63
NS-3	1.65	1.65
Concrete	2.24	2.24
H_2O + H_3BO_3 (borated water) – Full Density – 1000 ppm Boron	1.0015	---

6.3.4.1 Active Fuel Region

Fuel rod densities for normal operations conditions are shown below.

Material	Element	Density (atoms/barn-cm)
UO_2 (4.2 wt % ^{235}U)	^{235}U	9.877×10^{-4}
	^{238}U	2.224×10^{-2}
	O	4.646×10^{-2}
UO_2 (4.0 wt % ^{235}U)	^{235}U	9.406×10^{-4}
	^{238}U	2.229×10^{-2}
	O	4.646×10^{-2}
Zircaloy	Zr	4.331×10^{-2}
H_2O	H	6.677×10^{-2}
	O	3.338×10^{-2}
$H_2O + H_3BO_3$	H	6.675×10^{-2}
	O	3.346×10^{-2}
	B	5.581×10^{-5}
	O	3.338×10^{-2}

6.3.4.2 Cask Material

SCALE 4.3 model cask material densities used in the criticality evaluation are listed in the following table. With the exception of the slightly higher stainless steel and lower lead, default densities employed by the ANSWERS code, the material composition is identical between SCALE and ANSWERS models.

Material	Element	Density (atoms/barn-cm)
Neutron Absorber core	^{10}B	8.880×10^{-3} (75% of Nominal)
(0.025 g $^{10}B/cm^2$)	^{11}B	4.906×10^{-2}
	C	1.522×10^{-3}
	Al	2.694×10^{-2}
Neutron Absorber core	^{10}B	2.212×10^{-3} (75% of Nominal)
(0.011 g $^{10}B/cm^2$)	^{11}B	1.219×10^{-2}
	C	3.786×10^{-3}
	Al	5.217×10^{-2}

Aluminum	Al	6.031×10^{-2}
Steel 304	Cr	1.743×10^{-2}
	Fe	5.936×10^{-2}
	Ni	7.721×10^{-3}
	Mn	1.736×10^{-3}
Carbon steel	C	3.925×10^{-3}
	Fe	8.350×10^{-2}
Lead	Pb	3.297×10^{-2}
NS-4-FR	H	5.854×10^{-2}
	O	2.609×10^{-2}
	C	2.264×10^{-2}
	N	1.394×10^{-3}
	Al	7.763×10^{-3}
	^{11}B	3.422×10^{-4}
	^{10}B	8.553×10^{-5}
Concrete		
	O	4.494×10^{-2}
	Si	1.621×10^{-2}
	H	1.340×10^{-2}
	Na	1.704×10^{-3}
	Ca	1.483×10^{-3}
	Fe	3.386×10^{-4}
	Al	1.702×10^{-3}

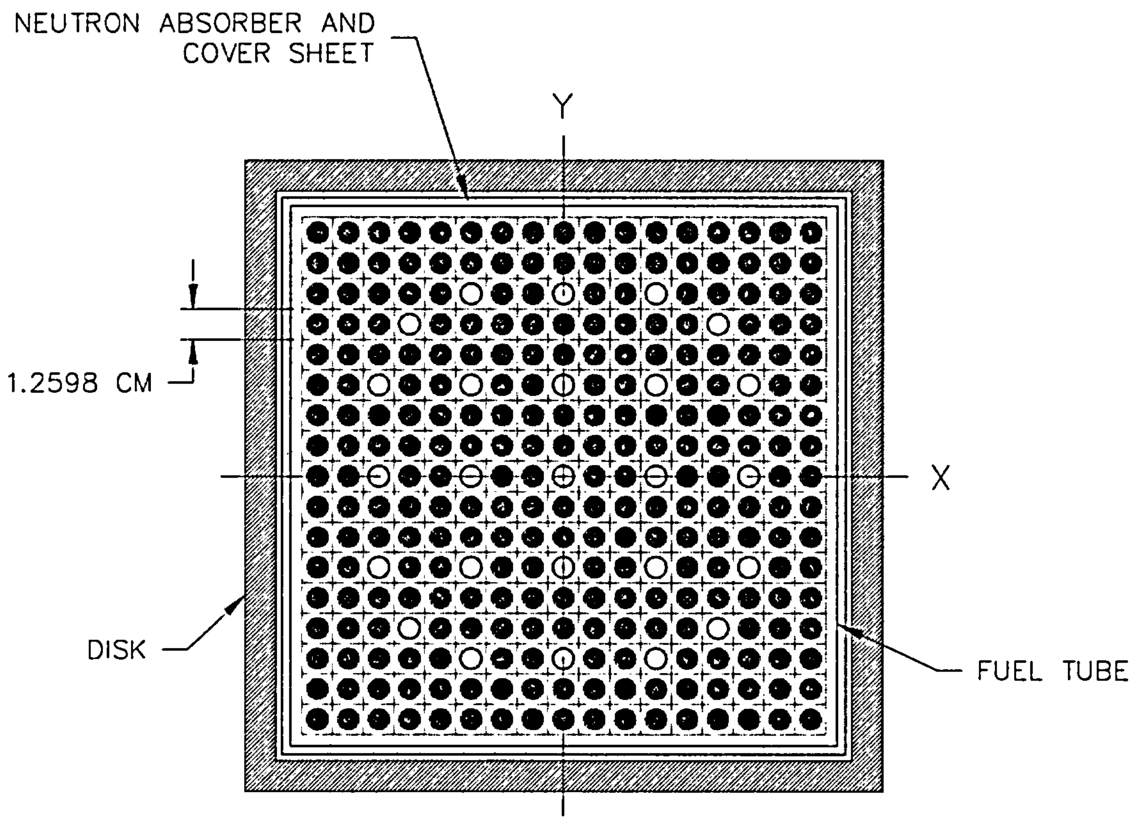
6.3.4.3 Water Reflector Densities

The material densities for the water reflector outside the cask are:

Material	Element	Density (atoms/barn-cm)
H_2O	H	6.677×10^{-2}
	O	3.338×10^{-2}

Water density is varied using the VF (volume fraction) parameter on the SCALE 4.3 material information processor card. This acts as a simple multiplier on the previously listed densities. ANSWERS models are directly reflected on the cask surface and, therefore, do not employ an exterior material.

Figure 6.3-1 KENO-Va PWR Basket Cell Model



Neutron Absorber on Four Sides

Figure 6.3-2 KENO-Va BWR Basket Cell Model

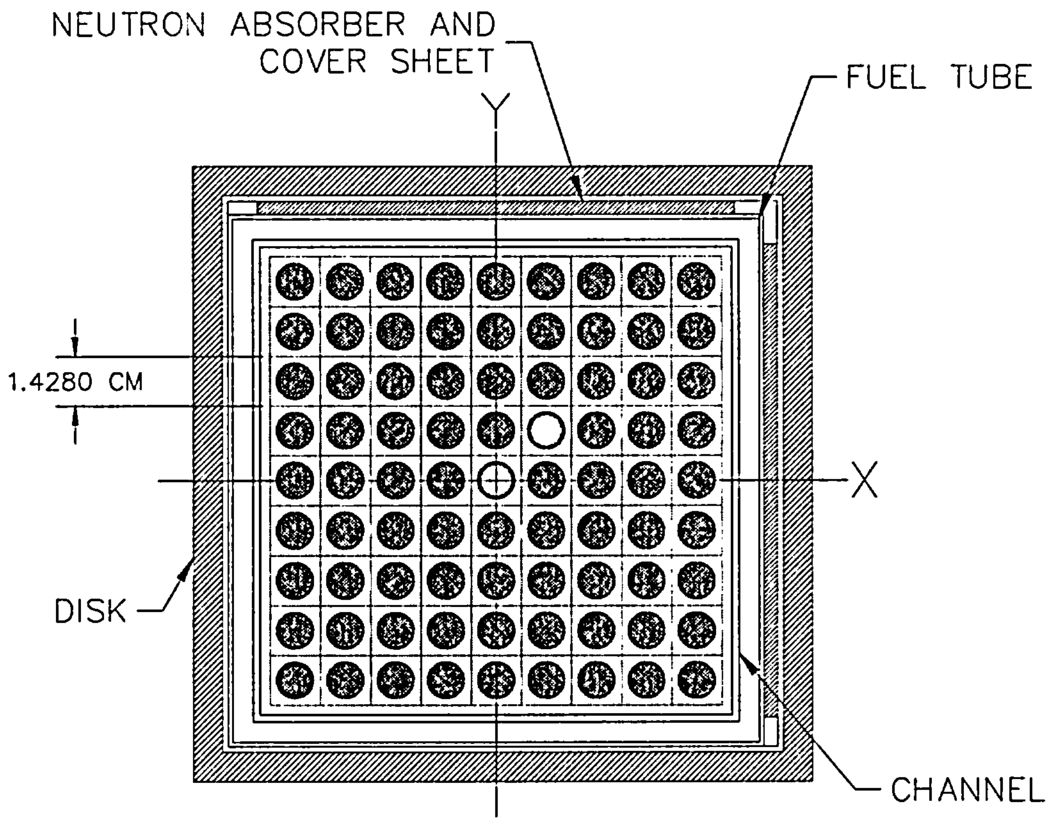


Figure 6.3-3 PWR KENO-Va Transfer Cask Model

Figure Withheld Under 10 CFR 2.390

Figure 6.3-4 PWR KENO-Va Vertical Concrete Cask Model

Figure Withheld Under 10 CFR 2.390

Figure 6.3-5 BWR KENO-Va Transfer Cask Model

Figure Withheld Under 10 CFR 2.390

Figure 6.3-6 BWR KENO-Va Vertical Concrete Cask Model

Figure Withheld Under 10 CFR 2.390

Figure 6.3-7 PWR Basket Criticality Control Design

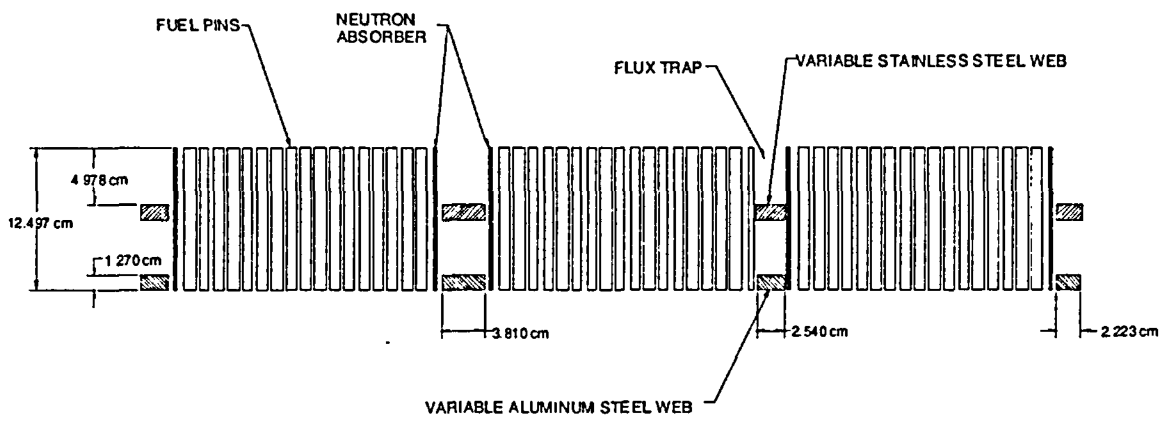


Figure 6.3-8 BWR Basket Criticality Control Design

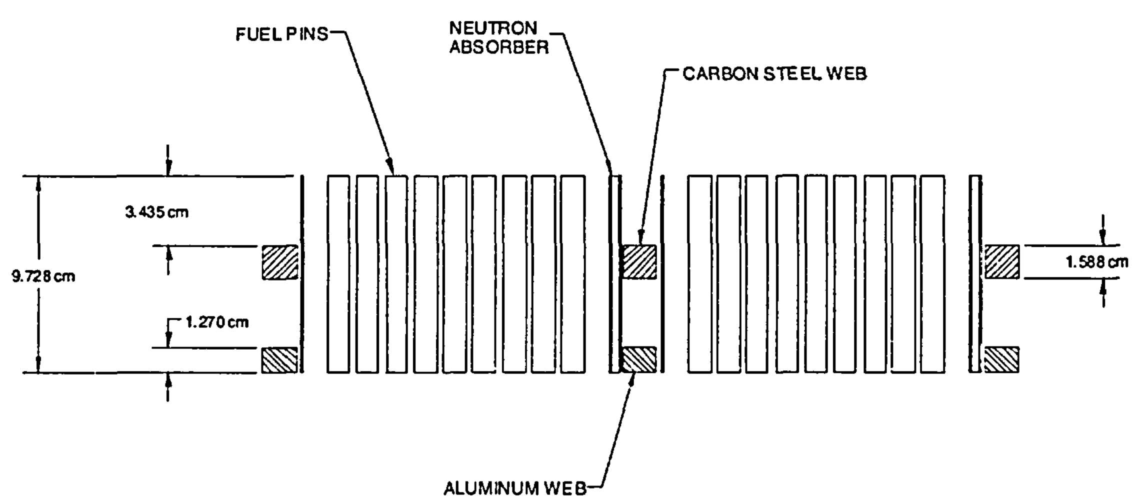


Figure 6.3-9 Standard Transfer Cask Containing a PWR Basket and Canister

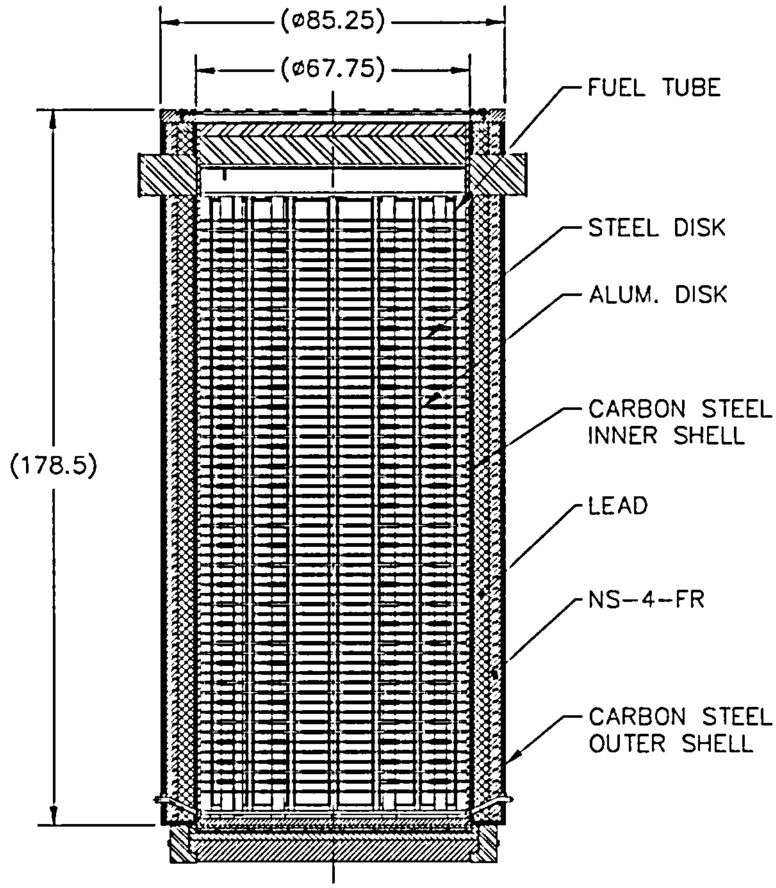
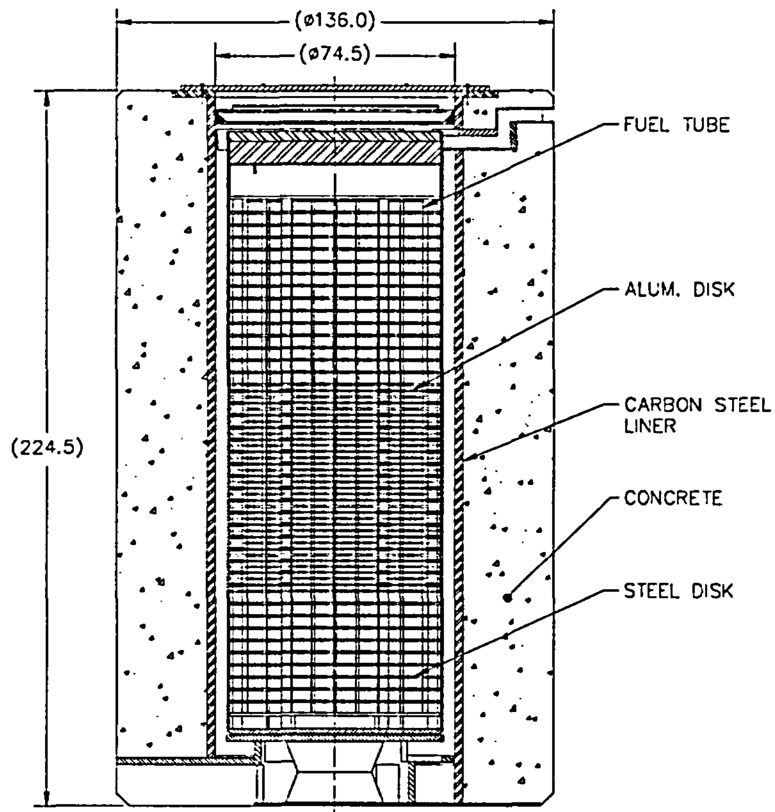


Figure 6.3-10 Vertical Concrete Cask Containing a BWR Basket and Canister



6.4 Criticality Calculation

6.4.1 Calculational or Experimental Method

As discussed earlier, criticality analysis of the Universal Storage System involves identification of fuel arrays for analysis, determination of most reactive PWR and BWR assemblies, and cask criticality analysis. Section 6.4.5 augments the evaluation of the most reactive PWR and BWR assemblies by determining assembly specific maximum initial enrichments.

6.4.1.1 Determination of Fuel Arrays for Criticality Analysis

As shown previously, the maximum values for physical dimensions, cross-sections, and weights vary among the fuel assemblies. Therefore, qualitatively determining one enveloping assembly for the criticality analysis is difficult. Thus, a set of standard fuel arrays in the basket configuration are selected and modeled with KENO-Va. Since the assembly is considered to be axially infinite in length, the selected standard PWR and BWR arrays that bound other assemblies in their sub classes and are as follows.

PWR Fuel Assemblies

- B&W 15×15 Mark B
- B&W 17×17 Mark C
- CE 14×14
- CE 16×16 System 80
- Westinghouse 14×14
- Westinghouse 14×14 OFA
- Westinghouse 15×15
- Westinghouse 17×17
- Westinghouse 17×17 OFA
- Ex/ANF 14×14 (CE)
- Ex/ANF 14×14 (WE)
- Ex/ANF 15×15 (WE)
- Ex/ANF 17×17 (WE)

BWR Fuel Assemblies

- Ex/ANF 7×7
- Ex/ANF 8×8 (63)*
- Ex/ANF 8×8 (62)*
- Ex/ANF 9×9 (79)*
- Ex/ANF 9×9 (74)*
- GE 7×7
- GE 8×8 (63)*
- GE 8×8 (62)*
- GE 8×8 (60)*
- GE 9×9 (79)*
- GE 9×9 (74)*

*Number of Fuel Rods Shown in Parentheses

For the BWR arrays, variation in Zircaloy channel thickness is also evaluated. Section 6.4.4 augments the assembly characteristics definition by evaluating the reactivity impact of variations in fuel rod pitch, pellet diameter, clad thickness and guide tube thickness.

6.4.1.2 Most Reactive Fuel Assembly Determination

To determine the most reactive assembly within each type of fuel, a KENO-Va calculation is performed for the PWR and BWR fuel assemblies identified in Section 6.4.1.1. The calculated k_{eff} values for the various classes of fuel are given in Tables 6.4-1 through 6.4-4. The model for the PWR and the BWR fuel assembly types is discussed in the following paragraphs. On the basis of this analysis, the Westinghouse 17×17 OFA fuel assembly is determined to be the most reactive PWR fuel assembly. The Ex/ANF 9 x 9 fuel assembly with 79 fuel rods is determined to be the most reactive BWR fuel assembly.

6.4.1.2.1 Most Reactive PWR Assembly Analysis

The most reactive assembly analysis is based on an infinite array of basket cells, Figure 6.3-1. The assembly is in the PWR basket surrounded by the steel tube, four neutron absorber sheets, neutron absorber cover sheets, water to disk gap and steel, aluminum or water disk material. For the most reactive assembly analysis, the assembly is centered in the tube and the tube centered in the disk opening. Web thickness of 1.5, 1.0 and 0.875 in. is present in the PWR basket. Web thickness is assumed to have minimal impact on the most reactive assembly analysis. Therefore, the analysis is performed for a web thickness of 1.0 inch.

The basket cell model requires four basket slices at the active fuel elevation: one at the stainless steel disk elevation and thickness, one at the aluminum disk elevations and thickness, and two of the water space between disks. By stacking four of the slices (water, steel, water, and aluminum) on top of one another and periodically reflecting the disk stack, an axially infinite fuel-assembly-in-basket model is created. By imposing reflective boundary conditions on the sides of the basket cell model an infinite x-y array is also created.

With the exception of the axial (z) length, identical KENO-Va units are constructed for fuel pins, guide/instrument tubes, and neutron absorber sheets in the water and disk slice. Neutron absorber sheet KENO-Va units are required, one sheet running parallel to the x-plane, and one for the y plane for disk and water elevations. Axial dimensions for these units are made equal to either the water gap between disks or the disk heights (stainless steel disk and aluminum disk). In this analysis, all unit cells, except for the global unit, are centered on themselves, which implies symmetric upper and lower z elevation bounds.

After establishing fuel pin, guide tube, instrument tubes and neutron absorber sheet KENO-Va units, the fuel assembly arrays are constructed. The fuel assembly array, composed of fuel pins and guide/instrument tubes, is surrounded by a water gap, the fuel tube, and a water gap equal in x, y dimensions to the exterior of the neutron absorber sheet. The neutron absorber sheets are placed as holes into the water cuboid surrounding the tube. The cuboid containing the neutron absorber sheets is then surrounded by a thin encapsulating shell and a water cuboid out to the disk opening. Surrounding the disk opening cuboid is either water or disk material out to one half the web thickness (in this case 0.5 in. of material). The fuel tube is centered in the disk opening and the assembly is centered in the tube.

Calculated values of k_{eff} for the PWR assemblies selected for most reactive assembly analysis are listed in Table 6.4-1. The table includes data for assemblies with water in the fuel-pellet-to-cladding gap and for assemblies with no water in the gap. Also included is a Δk between the dry and wet cases. Note, the k_{eff} values in Table 6.4-1 are for a representative 1.0 inch flux trap, a ^{10}B areal density of 0.02 g/cm^2 and represent an infinite array basket cells. Therefore, k_{eff} exceeds 0.95 for a number of the assemblies analyzed. The purpose of this table is to justify the most reactive assembly. The k_{eff} values of the transfer and storage casks with the most reactive assembly are below 0.95 with bias and uncertainty included.

Table 6.4-1 results are based on a web width of 1.0 inch. The basket centerline web thickness is 1.5 inch. To assure that the most reactive assembly calculation applies to the whole basket and to verify that web spacing does not impact results, Table 6.4-2 is generated to include reactivity data for the highest reactivity assemblies in a 1.5-inch web.

From the 1.0-inch web, dry gap analysis, the Westinghouse 15×15 fuel assembly has a 0.0005 higher k_{eff} than the Westinghouse 17×17 OFA assembly. However, given the 0.001 Monte Carlo uncertainty associated with the k_{eff} values calculated, no statistically significant difference exists between the k_{eff} values. The 1.5-inch web analysis results in a statistically significantly higher k_{eff} for the Westinghouse 17×17 OFA assembly than for the Westinghouse 15×15 assembly, a Δk_{eff} of +0.005. Therefore, the Westinghouse 17 × 17 OFA fuel assembly is selected as the most reactive design basis PWR fuel for criticality analysis.

6.4.1.2.2 Most Reactive BWR Assembly Analysis

The most reactive assembly analysis is based on the full cask (transfer or concrete cask) model. Assemblies in the BWR basket are surrounded by the assembly channel, channel-to-tube gap, steel fuel tube, neutron absorber sheet and neutron absorber cover sheet on applicable sides of the tube, water-to-disk gap, and steel and aluminum disk material. For the most reactive assembly analysis, the assembly is centered in the tube and the tube centered in the disk opening.

The full cask model requires four basket slices to be made at the active fuel elevation: one at the carbon steel disk elevation and thickness, one at the aluminum disk elevation and thickness, and two at the water space between disk elevation and thickness. Each of the disks containing the fuel tubes is surrounded by the canister shell and the cask radial shields. By stacking the three cask slices on top of one another and periodically reflecting the stack, an axially infinite cask model is built. Building an axially infinite model eliminates axial leakage. Into each of the basket slices, the 56 disk openings are inserted as KENO-Va HOLE's. Each of the disk openings contains a KENO-Va HOLE representing the fuel tube, which in turn has the fuel assembly, including channel, inserted as a HOLE. This modeling approach facilitates component movement, fuel tube or fuel assembly, by simply modifying the HOLE origin coordinate.

Calculated values of k_{eff} for the BWR assemblies selected for analysis of the most reactive assembly are provided in Tables 6.4-3 and 6.4-4. The table includes data for no water in the pellet-to-clad gap. As can be seen from the table, the most reactive is the Ex/ANF 9x9 fuel assembly with 79 fuel pins and 2 water rods. It is statistically significantly more reactive than any of the other BWR assemblies analyzed; therefore, no "wet" gap cases were analyzed. In addition, the BWR fuel assembly is analyzed with and without the channel. The channel is shown to have little effect on the criticality results.

6.4.1.3 Transfer Cask and Vertical Concrete Cask Criticality Analysis

The KENO-Va models employed in the criticality analysis of the transfer cask and the Vertical Concrete Cask are built on those developed in the most reactive assembly calculations (See Section 6.4.1.2). The criticality analysis for the transfer and concrete casks is performed in three steps.

1. Resolution of the criticality impact of mechanical perturbations and geometric tolerances on the basis of a fuel tube-in-basket model (PWR) and basket-in-cask-model (BWR) using the most reactive assembly.
2. Preparation of a basket-in-cask model (PWR) to evaluate the reactivity variation between normal and worst-case configuration (a BWR basket-in-cask model having been constructed in step 1 for the most reactive assembly analysis).

3. Evaluation of k_{eff} and k_s for a single transfer cask, a single concrete cask, and for an array of casks on the basis of the worst-case configured cask basket under normal and accident conditions.

Construction of the cask criticality models for normal and accident conditions involves modifications to moderator compositions, cask spacing, material in the gap between fuel pellet and clad, and cask neutron shield material description.

This section presents the evaluation of the standard transfer cask configuration in significant detail. The evaluation identifies the most reactive standard transfer cask conditions.

6.4.1.3.1 Standard Transfer Cask and Vertical Concrete Cask Containing PWR Fuel

Mechanical Perturbations and Geometric Tolerance: Fuel Tube in PWR Basket Unit Cell Model

Because of the gaps between the fuel assembly and the fuel tube, and between the fuel tube and disk opening, a certain amount of mechanical perturbation in the configuration is possible. In addition, manufacturing tolerances in the basket may cause variation in the gaps and basket disk fuel tube hole positions. The criticality impact of such mechanical variations is evaluated with a KENO-Va model of the PWR basket unit cell. The following mechanical and geometric perturbations are evaluated:

a. Fuel assembly movement in the fuel tube,
b. Fuel tube movement in the disk opening,
c. Variation in the basket fuel tube opening,
d. Variation in the disk opening, and
e. Variation in positioning of the disk opening,

Fuel assembly movement in the tube is based on the physical limits of the inside envelope of the tube and the width of the fuel assembly array. For the design basis fuel, the maximum movement within the tube is ± 0.184 in. (0.468 cm). As a result of PWR basket tube symmetry, only one movement direction requires analysis. Fuel assembly movement is bounded by shifting the fuel assembly to the upper right-hand corner of the basket tube. This corner movement maximizes the reactivity impact of movement in one direction.

Similarly, movement of the fuel tube is maximized by shifting to the upper right hand corner of the basket disk opening. The maximum tube movement in the basket disk opening is ± 0.095 in. (0.242 cm). The tube outer neutron absorber sheet, and neutron absorber cover sheet dimensions are moved based on the inner tube dimension plus the relevant material thickness.

Both the fuel assembly movement and the fuel tube movement are analyzed with periodic and mirrored boundary conditions. The periodic boundary condition approximates a shift of all assemblies/fuel tubes in the basket to one side (i.e., the upper right hand corner). The mirrored boundary approximates clusters of four assemblies or fuel tubes moved towards a central location.

Variation in the fuel tube opening is evaluated by adding or subtracting a tolerance of ± 0.030 in. (0.076 cm) to the nominal dimensions and adjusting the neutron absorber sheet and cover sheet positions accordingly. Variation in basket disk opening is modeled by adding or subtracting a tolerance of ± 0.015 in. (0.038 cm) to the nominal dimension of the opening. The tolerance on the opening size modifies the web thickness but does not impact tube positioning.

Variation in basket disk opening position is limited by the positional tolerance, within the diameter, of 0.015 in. (0.038 cm). As with the fuel assembly and tube movements, the reactivity effect of the opening position is maximized by shifting the opening to the upper right hand corner by 0.0053 in. $(0.0075^2/2)^{1/2}$ in both +x and +y directions. This minimizes the webbing and corresponding flux trap gap effectiveness.

The results of the PWR basket unit cell perturbation evaluations are shown in Table 6.4-5.

Mechanical Perturbations and Geometric Tolerance: PWR Basket in Cask

To establish the maximum credible k_{eff} for the PWR basket with design basis fuel, the mechanical perturbations and basket geometric tolerances, shown in previous sections to produce positive reactivity relative to the nominal configuration, are included in the full transfer cask model and the full concrete cask model. The mechanical variations which produce positive reactivity effects are as follows.

a. Maximum tube size,
b. Fuel assembly centered in tube,
c. Fuel tube with assembly centered moved towards the basket center, and
d. Disk opening coordinates moved toward the basket center.

The above conditions define the worst-case PWR basket configuration. The results are shown in Tables 6.4-6 and 6.4-7 for the transfer cask and the concrete cask, respectively. Side and corner shifts are included in the tables to provide a k_{eff} comparison to different orientation of the components in the casks.

An additional evaluation is made addressing tolerances associated with the neutron absorber sheet. The minimum neutron absorber sheet widths are included in the most reactive cask configuration in order to evaluate the potential reactivity effects from both manufacturing tolerances and shifting of the neutron absorber sheets beneath the cover plates. For this model, neutron absorber sheet widths are reduced by a total of 0.10 inches to 8.10 inches and all assemblies are shifted radially in towards the center of the cask. This results in a combined Δk_{eff} of +0.00246. However, incorporating this increase in reactivity, as derived from the worst case accident scenario, results in a k_s = 0.94749 which is below the NRC criticality safety limit of 0.95. This Δk_{eff} of +0.00246 is, therefore, added to the results of all bounding PWR fuel conditions of the storage cask array and the transfer cask array reported in Section 6.4.3.1.

PWR Criticality Calculations for Single Standard Transfer Cask and Array of Concrete Casks

Values of k_{eff} and k_s (the bias adjusted k_{eff}) are evaluated for a single transfer cask, a single concrete cask, and for an array of casks containing PWR fuel. The evaluation is based on the worst-case configured cask basket under normal operating (dry interior) and accident (wet interior, no neutron shield) conditions of storage. The k_{eff} produced by KENO-Va is adjusted according to the following equations to account for code bias and Monte Carlo uncertainty. KENO-Va bias is calculated to be 0.0052 with a one-sided 95/95 uncertainty factor of 0.0087 (See Section 6.5). Base model for the KENO-Va interior and exterior moderator variation is the "worst configuration, highest reactivity" basket inputs.

$$k_s = k_{eff} + \Delta k_{Bias} + \sqrt{\sigma_{Bias}^{2} + (2 * \sigma_{mc})^2} \leq 0.95$$

$$k_s = k_{eff} + 0.0052 + \sqrt{0.0087^2 + (2\sigma_{mc})^2} \leq 0.95$$

where:

k_s = the calculated allowable maximum multiplication factor, k_{eff}, of system being evaluated for all normal or credible abnormal conditions or events.

k_{eff} = the KENO - Va calculated k_{eff}

σ_{mc} = KENO - Va calculated Monte Carlo error.

Results of the criticality calculations are provided in Section 6.4.3.2.

6.4.1.3.2 Standard Transfer Cask and Vertical Concrete Cask Containing BWR Fuel

Mechanical Perturbations and Geometric Tolerance: BWR Basket in Cask

The BWR basket is subject to the same types of mechanical perturbations and geometric tolerances, which have an impact on the criticality evaluation, as is considered for the PWR basket. However, due to the asymmetry of the BWR basket and the engineered placement of neutron absorber among the fuel tubes, a full basket surrounded by the cask shield regions is used in the evaluation of mechanical and geometric tolerances. As with the PWR basket, the following mechanical and geometric tolerances are evaluated:

a. Fuel assembly (with channel) movement in the tube,
b. Fuel tube movement in the disk opening,
c. Variation in the basket tube opening,
d. Variation in disk opening, and
e. Variation in positioning of the disk opening,

For the design basis fuel, the maximum fuel movement within the tube is ± 0.231 in. (0.587 cm). The maximum movement of the tube in the disk opening is ± 0.064 in. (0.165 cm). For the movement analysis, the components, fuel tube or assembly, are shifted radially inward, radially outward, left, right, top, bottom and to the four basket corner locations. Due to the asymmetric neutron absorber sheet pattern of the BWR basket, all ten movement directions are evaluated.

Variations in the tube opening are evaluated by adding or subtracting a tolerance of ± 0.02 in. (0.051 cm) to the nominal tube inner width. Tube outer, neutron absorber sheet, and neutron absorber cover sheet dimensions are adjusted accordingly. Variations in disk opening are also evaluated by adding or subtracting a tolerance of ± 0.015 in. to the nominal disk opening.

Variation in basket disk opening position is limited by the positional tolerance within a diameter of 0.015 in. As with the fuel assembly and tube movements, the reactivity effect of the opening position is maximized by shifting the opening to the upper right hand corner by 0.0053 in. $(0.0075^2/2)^{1/2}$ in both +x and +y directions. This minimizes the webbing and neutron absorber effectiveness.

The results are shown in Tables 6.4-8 and 6.4-9 for the transfer cask and the concrete cask, respectively. The mechanical perturbations that produce a significant positive reactivity are included in a full cask model to establish the maximum credible k_{eff} for the transfer cask and the Vertical Concrete Cask loaded with 4.00 wt % ^{235}U Ex/ANF 9×9 fuel assembly. The combination of the radial movement of the fuel assembly and the fuel tube towards the basket center results in the maximum positive reactivity. This configuration is defined to be the worst-case for the BWR basket.

An additional evaluation is made addressing tolerances associated with the neutron absorber sheet. The minimum neutron absorber sheet widths are included in an analysis of the most reactive cask configuration in order to evaluate the potential reactivity effects from both manufacturing tolerances and shifting of the neutron absorber sheets beneath the cover plates.

For this model, neutron absorber sheet widths are reduced by a total of 0.08 inches to 6.22 inches. The resulting change in reactivity is within the statistics of the Monte Carlo code. Therefore, it is appropriate to neglect these tolerances in the maximum reactivity BWR model.

In addition to the neutron absorber sheet width evaluation, an analysis modeling the four oversized fuel tubes is included. The oversized fuel tubes are 0.15 inch larger to allow space for assemblies with channels that are bowed or twisted. However, the spacer grids of the fuel assembly maintain the pitch of the fuel rod array. Therefore, the fuel rod lattice and rod dimensions are not changed by the minor distortions that occur in the channel. An additional BWR criticality analysis is added which conservatively models the four 'oversized' fuel tubes (with nominal (straight) fuel assemblies) shifted further in towards the center of the cask as far as physically possible. This geometry minimizes the distance between the absorber sheets of the neighboring fuel tubes. This results in a k_{eff} of 0.91032. The change in reactivity, a Δk_{eff} of +0.00105, is within 2σ of the base case. Therefore, no statistically significant conclusion can be made as to the actual impact of the model change, and the existing most reactive configuration is left unchanged.

BWR Criticality Calculations for Single Standard Transfer Cask and Array of Concrete Casks

Values of k_{eff} and k_s (the bias adjusted k_{eff}) are evaluated for a single transfer cask, a single Vertical Concrete Cask, and for arrays of casks containing BWR fuel. The evaluation is based on the worst-case configured cask basket under normal operating (dry interior) and accident (wet interior, no neutron shield) conditions. The k_{eff} produced by KENO-Va is adjusted according to the following equation (the same equation used for the PWR fuel criticality calculations - see Section 6.4.1.3.1). A KENO-Va bias of 0.0052 and a one-sided 95/95 uncertainty factor of 0.0087 are used in the BWR fuel criticality calculations.

$$k_s = k_{eff} + \Delta k_{Bias} + \sqrt{\sigma_{Bias}^{\ 2} + (2 * \sigma_{mc})^2} \le 0.95$$

$$k_s = k_{eff} + 0.0052 + \sqrt{0.0087^2 + (2\sigma_{mc})^2} \le 0.95$$

where:

k_s = calculated allowable maximum multiplication factor, k_{eff}, of the system being evaluated for all normal or credible abnormal conditions or events

k_{eff} = KENO - Va calculated k_{eff}

σ_{mc} = KENO - Va calculated Monte Carlo error.

The results of the criticality analysis for a single cask (transfer cask and concrete cask) and for arrays of casks under normal, off-normal (concrete cask only), and accident conditions are provided in Section 6.4.3.3.

Homogeneous versus Heterogeneous Assembly Enrichment Evaluation

BWR fuel assemblies are typically loaded with a heterogeneous enrichment scheme of multiple fuel pin enrichments in one assembly. For the criticality analysis presented previously, a initial peak planar-average enrichment is used. The initial peak planar-average enrichment is the maximum planar-average enrichment at any height along the axis of the fuel assembly. This section demonstrates that the use of a planar-average enrichment provides a conservative eigenvalue compared to the heterogeneous fuel assembly. Three fuel assembly loading patterns are evaluated using both homogeneous and heterogeneous enrichment schemes and the resulting eigenvalues are compared. No gadolinium poisons are included in any of the models.

Fuel assembly types studied are the GE 8 × 8 60 and 62 fuel rod assembly types, the GE 9 × 9 74 fuel rod and the Ex/ANF 74 fuel rod assembly type. Each of the fuel assemblies is evaluated at a planar-average homogeneous enrichment and the actual documented enrichment pattern. In addition to actual documented enrichment patterns, BWR assemblies are analyzed at a planar-average enrichment of 3.75 and 4.0 wt % ^{235}U (4.0 wt % being the UMS® BWR design basis enrichment). Also evaluated is the impact of rotating water holes inside the assembly and the generation of a hypothetical enrichment pattern with 5.0 wt % enriched fuel surrounding the central water holes. Results of the heterogeneous versus homogeneous analyses, listed in Table 6.4-10, shows that for all cases, the heterogeneous enrichment produces a lower k_{eff} than the homogeneous bundle average enrichment case. This demonstrates that applying the bundle average enrichment provides a conservative estimate of the cask k_s. The maximum and minimum pin enrichments in each of the assemblies evaluated are listed in Table 6.4-10.

In addition to the homogeneous versus heterogeneous eigenvalue comparison, an in-core k_∞ for the GE 8×8-62 fuel rod assembly is calculated. The in-core k_∞ of the design basis BWR fuel assembly is 1.41. This fuel assembly design basis reactivity is much higher than is typically allowed for BWR fuel in the core.

6.4.2 Fuel Loading Optimization

The fuel loading is optimized in the Universal Storage System criticality models by using: 1) fresh fuel; 2) the most reactive PWR or BWR fuel assembly type; 3) the highest possible fuel stack density (95% of theoretical); and 4) the most reactive basket configuration. The cask models represent fully loaded baskets with 24 PWR or 56 BWR design basis fuel assemblies. The models use reflective boundary conditions on the sides and periodic boundary conditions on the top and bottom. These boundary conditions simulate an infinite array of casks of infinite axial extent.

6.4.3 Criticality Results

6.4.3.1 Summary of Maximum Criticality Values

The effective neutron multiplication factor, k_s, for the standard transfer cask and the Vertical Concrete Cask containing the most reactive PWR or BWR fuel assemblies in the most reactive configuration is below the 0.95 NRC criticality safety limit, including all biases and uncertainties, under normal, off normal and accident conditions.

Criticality Values for the Standard Transfer Cask

The maximum neutron multiplication factor with uncertainties for the standard transfer cask containing PWR fuel assemblies is 0.93921 under normal transfer conditions and 0.94749 under accident conditions. For the standard transfer cask containing BWR fuel, the multiplication factor is 0.91919 under normal transfer conditions and 0.92235 under accident conditions. These values reflect the following conditions:

- A method bias and uncertainty associated with KENO-Va and the 27 group ENDF/B-IV library
- An infinite cask array (even though there will only be one built)
- Full interior, exterior and fuel clad gap moderator (water) density
- 24 Westinghouse 17×17 OFA fuel assemblies at 4.2 wt % ^{235}U (most reactive PWR fuel assembly type) or 56 Ex/ANF 9×9-79 rod fuel assemblies at 4.00 wt % ^{235}U (most reactive BWR fuel assembly type)
- No fuel burnup
- 75% of nominal ^{10}B loading in the neutron absorber
- Most reactive mechanical configuration for PWR: (Assemblies and fuel tubes moved toward the center of the basket; maximum fuel tube openings; minimum neutron absorber sheet widths and closely packed disk openings)
- Most reactive mechanical configuration for BWR (Assemblies and fuel tubes moved toward the center of the basket)

Analysis of moderator density variation inside the transfer cask basket shows a monotonic decrease in reactivity with decreasing moderator density. Thus, the full moderator density situation bounds draining and drying operations in the transfer cask. As shown in Sections 6.4.3.2 and 6.4.3.3, the change in reactivity between the two transfer cask configurations is within the statistics of the Monte Carlo code (2σ) for the most reactive conditions.

Criticality Values for the Vertical Concrete Storage Cask

The maximum multiplication factor with uncertainties for the Vertical Concrete Cask containing PWR fuel assemblies is 0.38329 under normal storage conditions, 0.37420 under off-normal conditions and 0.94704 under accident conditions involving full moderator intrusion.

Corresponding values for the cask containing BWR fuel assemblies are 0.38168 under normal storage conditions, 0.38586 under off-normal conditions and 0.92332 under accident conditions involving full moderator intrusion. These values reflect the following conditions:

- A method bias and uncertainty associated with KENO-Va and the 27 group ENDF/B-IV library
- An infinite cask array
- Normal condition is defined to be a dry basket, dry heat transfer annulus and dry exterior
- Accident condition is defined to be full interior, exterior and fuel clad gap moderator (water) intrusion
- Westinghouse 17×17 OFA fuel assemblies at 4.2 wt % ^{235}U (most reactive PWR fuel assembly type) or 56 Ex/ANF 9×9-79 rod fuel assemblies at 4.0 wt % ^{235}U (most reactive BWR fuel assembly type)
- No fuel burnup
- 75% of nominal ^{10}B loading in the neutron absorber
- Most reactive mechanical configuration for PWR (assemblies and fuel tubes moved toward the center of the basket; maximum fuel tube openings; minimum neutron absorber sheet widths and closely packed disk openings)
- Most reactive mechanical configuration for BWR (assemblies and fuel tubes moved toward the center of the basket)

Analysis of simultaneous moderator density variation inside and outside the concrete cask shows a monotonic decrease in reactivity with decreasing moderator density. Thus, the full moderator density situation bounds any off normal or accident condition. Analysis of moderator intrusion into the cask heat transfer annulus with a dry canister shows a slight decrease in reactivity from the completely dry situation. This is due to better neutron reflection from the concrete cask steel shell and concrete shielding with no moderator present.

Analysis of the BWR cask reactivity of the fuel assemblies in the axial region above the top of partial length rods shows this region to be less reactive than the region with all of the fuel rods present. Therefore, it is appropriate to represent partial length rods as full length rods in the BWR fuel models.

6.4.3.2 Criticality Results for PWR Fuel

Transfer Cask

Results of the calculations for the standard transfer cask containing PWR fuel are provided in Tables 6.4-11 through 6.4-13. The tables list k_s without the Δk penalty associated with neutron absorber plates. A Δk of 0.00246 is added in the k_s listed below. CSAS input for the normal conditions analysis for the standard transfer cask is provided in Figure 6.8-1. Figure 6.8-2 provides CSAS input for the standard transfer cask analysis under hypothetical accident conditions.

Under normal conditions involving loading, draining and drying, the maximum k_{eff} including bias and uncertainties (k_s) is 0.93921 for the standard transfer cask. In the accident situation involving fuel failure and moderator intrusion, the maximum k_{eff} including biases and uncertainties (k_s) is 0.94749. Thus, the multiplication factor for the standard transfer cask containing 24 design basis PWR fuel assemblies of the most reactive type in the most reactive configuration is below the NRC criticality safety limit of 0.95 including all biases and uncertainties under normal, and accident conditions.

Vertical Concrete Cask

Results of the calculations for the Vertical Concrete Cask containing PWR fuel are provided in Tables 6.4-14 through 6.4-16. Figure 6.8-3 provides CSAS input for the analysis of the cask under normal conditions. Figure 6.8-4 provides CSAS input for the concrete cask analysis for hypothetical accident conditions.

Under normal dry conditions, maximum k_{eff} including biases and uncertainty (k_s) is 0.38329 for the concrete cask. Under off-normal conditions involving flooding of the heat transfer annulus, the k_s of the cask is even less (0.37420). Under accident conditions involving full moderator intrusion into the canister and fuel clad gap, the maximum k_s of the concrete cask is 0.94704. Thus, the multiplication factor for the concrete cask containing 24 design basis PWR fuel assemblies of the most reactive type in the most reactive configuration is below the NRC criticality safety limit of 0.95 including all biases and uncertainties under normal, off-normal, and accident conditions.

6.4.3.3 Criticality Results for BWR Fuel

Transfer Cask

Results of the criticality calculations for the standard transfer cask containing BWR fuel are provided in Tables 6.4-17 through 6.4-19. CSAS input for the normal conditions analysis for the standard transfer cask are provided in Figure 6.8-5. Figure 6.8-6 provides CSAS input for the analysis for the standard transfer cask hypothetical accident conditions.

As the tables show, under normal conditions involving loading, draining and drying, the maximum k_{eff} including bias and uncertainties is 0.91919 for the standard transfer cask. In the accident condition involving fuel failure and moderator intrusion, the maximum k_{eff} including biases and uncertainties is 0.92235. Thus, the multiplication factor for the transfer cask containing 56 design basis BWR fuel assemblies of the most reactive type in the most reactive configuration is below the NRC criticality safety limit of 0.95 including all biases and uncertainties under normal, and accident conditions.

Vertical Concrete Cask

Tables 6.4-20 through 6.4-22 provide results of the criticality calculations for the Vertical Concrete Cask containing BWR fuel assemblies. CSAS input for the normal condition analysis for the concrete cask are provided in Figure 6.8-7. Figure 6.8-8 provides CSAS input under hypothetical accident conditions.

For the concrete cask containing BWR fuel, under normal dry conditions, maximum k_{eff} including biases and uncertainty is calculated to be 0.38168. Under off-normal conditions involving flooding of the heat transfer annulus, the k_{eff} of the cask is 0.38586. Under accident conditions involving full moderator intrusion into the canister and fuel clad gap, the maximum k_{eff} of the concrete cask is 0.92332. Thus, the multiplication factor for the concrete cask containing 56 design basis BWR fuel assemblies of the most reactive type in the most reactive configuration is below the NRC criticality safety limit of 0.95 including all biases and uncertainties under normal, off-normal, and accident conditions.

6.4.4 Fuel Assembly Lattice Dimension Variations

The nominal lattice dimensions for the most reactive PWR and BWR fuel under the most reactive accident conditions are varied to determine if dimensional perturbations significantly affect the reactivity of the system. Accident conditions are defined to be full interior, exterior and fuel-clad gap moderator (water) intrusion at a density of 1 g/cc and a temperature of 70 °F. Flooding the fuel-clad gap magnifies the effect on reactivity from lattice dimensional variations by adding or removing moderator from the undermoderated fuel lattice. The conclusions drawn are then used to establish fuel dimension limits for the PWR and BWR fuel assemblies previously evaluated as UMS® contents nominal fuel assembly dimensions.

The PWR analysis is performed modeling a Westinghouse 17×17 OFA fuel assembly in an infinite array of infinitely tall fuel tube cells. This prevents any leakage of neutrons from the system. The BWR analysis is performed modeling an infinite array of infinitely tall Vertical Concrete Casks filled with Exxon/ANF 9x9 fuel assemblies. The following fuel assembly nominal lattice dimensions are modified to determine if these perturbations significantly affect the reactivity of the system:

a) Pellet Radius
b) Clad Inner Radius
c) Clad Outer Radius
d) Water Rod Inner Radius
e) Water Rod Outer Radius

As shown in Tables 6.4-23 and 6.4-24, the following dimensional perturbations were determined to significantly decrease the reactivity of both the PWR and the BWR systems: decreasing the clad inner radius and increasing the clad outer radius. Decreasing the pellet radius of the BWR fuel assembly was also determined to significantly decrease the reactivity. The results are as expected as these perturbations decrease the H/U ratio in the undermoderated fuel lattice. Additionally, varying the BWR water rod dimensions was determined to have an insignificant effect on the reactivity of the system. Therefore, these nominal dimension variations are of no concern with regards to the criticality safety of the system.

The following perturbations were determined to significantly increase the reactivity of both the PWR and BWR systems: increasing the clad inner radius and decreasing the clad outer radius, increasing the guide tube inner radius, decreasing the guide tube outer radius. The increase in reactivity is due to the fact that these perturbations increase the H/U ratio in the undermoderated fuel lattice.

An increase in reactivity was also seen in the PWR system when decreasing the pellet diameter. This slight increase in reactivity, 0.004 Δk, is due to flooding of the pellet-to-clad gap in the accident model, which provides additional moderator to the lattice. Since 100% of clad failure is not expected during normal or accident operating conditions, no lower bound limit is placed on the fuel pellet diameter.

The effect on reactivity from perturbations in the nominal fuel dimensions requires the following limits on the fuel assembly lattice parameters in order to retain the maximum reactivity of the UMS system below existing design basis results:

PWR

a) Fuel Rod Diameter ≥ Nominal Dimension
b) Clad Thickness ≥ Nominal Dimension
c) Fuel Rod Pitch ≤ Nominal Dimension
d) Guide Tube (Instrument Tube) Thickness ≥ Nominal Dimension
e) Pellet Diameter ≤ Nominal Dimension

BWR

a) Fuel Rod Diameter ≥ Nominal Dimension
b) Clad Thickness ≥ Nominal Dimension
c) Fuel Rod Pitch ≤ Nominal Dimension
d) Pellet Diameter ≤ Nominal Dimension

6.4.5 PWR and BWR Fuel Assembly Specific Maximum Initial Enrichments

After grouping the assemblies listed in Tables 6.2-1 and 6.2-2, according to the criteria presented in Section 6.4.4, each assembly group is evaluated at enrichments ranging up to 5.0 wt. % ^{235}U. Maximum initial enrichments are set by comparing the resulting reactivity from each of the runs to the upper safety limit (USL) of 0.9426.

6.4.5.1 PWR Maximum Initial Enrichment – No Soluble Boron

The various UMS® design basis fuel assembly groups are evaluated at enrichments ranging from 4.2 to 5.0 wt. % ^{235}U. For each of the cases, the most reactive configuration determined in Section 6.4.1 is employed. Rather than adding reactivity offsets for the shifted neutron absorber sheet, each of these cases contains a shifted, minimum width, neutron absorber sheet. The resulting $k_{eff} + 2\sigma$ is compared to the USL of 0.9426. The reactivity of each of the bounding fuel groupings is listed in Table 6.4-25. A summary maximum enrichment table for all standard PWR fuel types, including the critical fuel dimensions, is shown in Table 6.1-1. To simplify model construction, guide tubes larger than one lattice location are conservatively neglected from the model. This results in N/A (not applicable) entries in Table 6.1-1.

The maximum enrichment for the Maine Yankee fuel data set was determined to be 4.7 wt. % ^{235}U at a $k_{eff} + 2\sigma$ of 0.9404.

6.4.5.2 PWR Storage Cask Result Verification

To verify that the reactivity of the canister evaluated in the transfer configuration is not significantly different in reactivity to that of the storage configuration, a simple comparison for the Westinghouse 17×17 OFA (See we17b in Table 6.1-1) assembly is made at an enrichment of 4.2 wt. % ^{235}U inside the storage cask. Cases are executed with and without soluble boron in the moderator.

Executing the cases results in a k_{eff} of 0.9346 for the unborated water case and 0.8175 for the borated water case. The storage case is 0.0001 Δk higher than that of the transfer cask, while the difference in the borated case is 0.0016 Δk. Both runs validate the use of the transfer cask results for both transfer and storage operations.

6.4.5.3 BWR Maximum Initial Enrichment – No Soluble Boron

Each of the BWR fuel assembly groups is evaluated at enrichments ranging from 4.0 wt. % ^{235}U (UMS® design basis) to 5.0 wt. % ^{235}U. The resulting $k_{eff} + 2\sigma$ is compared to the USL of 0.9426. The reactivity of each of the bounding fuel groupings is listed in Table 6.4-26. A summary maximum enrichment table for all standard BWR fuel types, including the critical fuel dimensions, is shown in Table 6.1-2. Similar to the PWR cask evaluations, a comparison analysis to the storage cask is made, demonstrating a slightly lower reactivity for the canister inside the concrete cask body.

6.4.6 PWR Soluble Boron Credit Evaluation

The maximum reactivity configuration employed in the previously described analysis results from the particular basket geometry that separates the fuel assemblies by borated aluminum sheets and water "flux traps." Filling the space with a water/soluble boron solution may result in a modified most reactive basket/fuel configuration. For the soluble boron analysis, the maximum reactivity configuration study is, therefore, repeated prior to the enrichment study. Also verified is the assumption that the maximum reactivity is achieved at full density water plus soluble boron. All analyses are based on 1000 ppm by weight of boron being present in the water spaces of the canister cavity. Water spaces include the flux traps, tube to assembly gap, lattice space between the rods and the pellet to clad gaps.

6.4.6.1 Maximum Reactivity Geometry

A limited evaluation of component tolerances and shifting is performed to verify the most reactive configuration for the PWR basket containing borated water. The assembly chosen for this evaluation is the Westinghouse 17×17 OFA (we17b) fuel assembly at 4.2 wt. % ^{235}U.

The key fabrication tolerance impacted variables evaluated are the size of the tube and disk opening and the location of the disk opening within the disk. Similar to the unborated evaluation, the maximum fuel tube opening increases reactivity in the shifted radial in configuration. While the maximum disk opening did not statistically impact the results of the evaluation, it is modeled at its maximum size for the enrichment search. These configuration changes make the soluble boron model consistent with that of the unborated cases.

Component movements evaluated are the fuel tube shifting within the disk opening and the assembly shifting within the tube. As shown in Table 6.4-27, the most reactive configuration is a shifted radial in fuel tube and assembly.

Also included in the evaluations is the shifted minimum neutron absorber width, since it will increase neutron interaction between assemblies. The result of the evaluation containing the maximum reactivity combination of parameters is included in Table 6.4-27.

6.4.6.2 Soluble Boron and Moderator Density Study

A moderator density study is performed to confirm that maximum reactivity occurs at full water density. Reducing water density in the borated cases not only reduces the moderating medium but also removes poison. As seen in Table 6.4-28, the maximum reactivity occurs at full density water.

6.4.6.3 Maximum Allowed Initial Enrichment Search

Similar to the unborated water configuration, the various UMS® design basis fuel assembly groups are evaluated at enrichments ranging from 4.2 to 5.0 wt. % ^{235}U. For each of the cases, the most reactive configuration determined in Section 6.4.6.1 is employed. The resulting $k_{eff} + 2\sigma$ is compared to the USL of 0.9426. The reactivity of each of the bounding fuel groupings is listed in Table 6.4-29. A summary maximum enrichment table for all standard PWR fuel types, including the critical fuel dimensions, is shown in Table 6.1-1.

To verify that a dry gap would not result in a more reactive configuration, the enrichment study is repeated with a dry gap. A dry gap has the potential for increasing reactivity due to the removal of the soluble boron. For all cases evaluated, reactivity decreased when the gap material was changed to "dry."

Table 6.4-1 k_{eff} for Most Reactive PWR Fuel Assembly Determination

Assembly Type	Dry Pellet Clad Gap		Wet Pellet Clad Gap		Δk_{eff}[1]
	k_{eff}	σ	k_{eff}	σ	Wet - Dry
B&W 15×15 Mark B	0.9613	0.0011	0.9692	0.0012	0.0079
B&W 17×17 Mark C	0.9621	0.0012	0.9705	0.0011	0.0084
CE 14×14	0.9295	0.0013	0.9381	0.0011	0.0085
CE 16×16 SYS 80	0.9348	0.0012	0.9442	0.0012	0.0095
West 14×14	0.9177	0.0013	0.9264	0.0012	0.0086
West 14×14 OFA	0.9238	0.0012	0.9326	0.0012	0.0088
West 15×15	0.9662	0.0011	0.9712	0.0012	0.0050
West 17×17	0.9596	0.0012	0.9673	0.0012	0.0077
West 17×17 OFA	0.9656	0.0013	0.9727	0.0012	0.0070
Ex/ANF 14×14 CE	0.9309	0.0012	0.9362	0.0011	0.0053
Ex/ANF 14×14 WE	0.9065	0.0012	0.9176	0.0011	0.0111
Ex/ANF 15×15 WE	0.9559	0.0012	0.9634	0.0013	0.0074
Ex/ANF 17×17 WE	0.9631	0.0012	0.9704	0.0012	0.0073

1. Infinite Array of Basket Cells with a 1.0-inch Web.

Table 6.4-2 k_{eff} for Highest Reactivity PWR Fuel Assemblies

Assembly Type	k_{eff}[1]	σ
B&W 15×15 Mark B4	0.9119	0.0011
B&W 17×17 Mark C	0.9141	0.0011
West 15×15	0.9147	0.0013
West 17×17	0.9116	0.0012
West 17×17 OFA	0.9196	0.0012
Ex/ANF 17×17 WE	0.9172	0.0011

1. Infinite Array of Basket Cells with a 1.5-inch Web.

Table 6.4-3 k_{eff} for Most Reactive BWR Fuel Assembly Determination (Standard Transfer Cask)

Assembly Type	Number of Rods		Channel Thickness	Dry Gap	
	Fuel	Water		k_{eff}	σ
GE 7×7	49	0	80Mils	0.88240	0.00113
GE 8×8	63	1	80Mils	0.87868	0.00114
GE 8×8	63	1	100 Mils	0.87803	0.00116
GE 8×8	63	1	120 Mils	0.87709	0.00108
GE 8×8	62	2	80Mils	0.88130	0.00118
GE 8×8	62	2	100 Mils	0.88388	0.00110
GE 8×8	60	4	2mm	0.87917	0.00122
GE 9×9	79	2	2mm	0.87746	0.00115
GE 9×9	74	2(1)	2mm	0.87874	0.00114
GE 9×9	74	2(1)	80 Mils	0.88232	0.00114
Ex 7×7	49	0	80Mils	0.88070	0.00117
Ex 8×8-1	63	1	80Mils	0.87477	0.00111
Ex 8×8-2	62	2	80Mils	0.87778	0.00119
Ex 9×9	79	2	2mm	0.88498	0.00082
Ex 9×9	79	2	80Mils	0.88669	0.00081
Ex 9×9	74	2(1)	2mm	0.88594	0.00108

Note: (1) Two large water rods occupying the space of seven fuel rods.

Table 6.4-4 k_{eff} for Most Reactive BWR Fuel Assembly Determination (Vertical Concrete Cask)

Assembly Type	Number of Rods		Channel Thickness	Dry Gap	
	Fuel	Water		k_{eff}	σ
GE 7×7	49	0	80Mils	0.87876	0.00120
GE 8×8	63	1	80Mils	0.87850	0.00118
GE 8×8	63	1	100 Mils	0.87586	0.00111
GE 8×8	63	1	120 Mils	0.87612	0.00114
GE 8×8	62	2	80Mils	0.87917	0.00120
GE 8×8	62	2	100 Mils	0.88278	0.00119
GE 8×8	60	4	2mm	0.88093	0.00112
GE 9×9	79	2	2mm	0.87682	0.00115
GE 9×9	74	2	2mm	0.87645	0.00121
GE 9×9	74	2	80 Mils	0.88104	0.00113
Ex 7×7	49	0	80Mils	0.87910	0.00120
Ex 8×8-1	63	1	80Mils	0.87823	0.00111
Ex 8×8-2	62	2	80Mils	0.87640	0.00126
Ex 9×9	79	2	2mm	0.88794	0.00087
Ex 9×9	79	2	80Mils	0.88560	0.00077
Ex 9×9	74	2[(2)]	2mm	0.88571	0.00120

Table 6.4-5 PWR Fuel Tube in Basket Model KENO-Va Results for Geometric Tolerances and Mechanical Perturbations

	k_{eff}	σ	Δk_{eff}	$\Delta k_{eff}/\sigma$
Reference case	0.9582	0.0006		
Dimensions Tolerance on Disk Opening Center Location				
Minimum web	0.9598	0.0006	0.0015	2.6
Maximum web	0.9575	0.0006	-0.0008	-1.3
Dimensions tolerance on tube opening				
Minimum tube	0.9546	0.0006	-0.0036	-6.2
Maximum tube	0.9627	0.0006	0.0045	7.6
Dimension tolerance on disk opening				
Minimum opening	0.9594	0.0006	0.0012	2.0
Maximum opening	0.9591	0.0006	0.0008	1.4
Fuel movement in tube - tube centered in disk opening				
Mirrored boundary	0.9572	0.0006	-0.0011	-1.8
Periodic boundary	0.9566	0.0006	-0.0016	-2.8
Tube movement in disk opening - fuel assembly centered in tube				
Mirrored boundary	0.9606	0.0006	0.0024	4.0
Periodic boundary	0.9591	0.0006	0.0009	1.5
Move fuel tube in opening and assembly in tube				
Mirrored boundary	0.9595	0.0006	0.0012	2.1
Periodic boundary	0.9567	0.0006	-0.0015	-2.5

Table 6.4-6 PWR Basket in Transfer Cask KENO-Va Results for Geometric Tolerances and Tube Movement

Analysis	k_{eff}	σ	Δk_{eff}	$\Delta k_{eff}/\sigma$
Nominal	0.91306	0.00088	N/A	N/A
Nominal Wet Gap	0.92212	0.00085	0.00906	10.7
Geometric Tolerance	0.92278	0.00088	0.00972	11.0
Geo. Tol.+Tube In	0.93096	0.00084	0.01790	21.3
Geo. Tol.+Tube Out	0.91716	0.00086	0.00410	4.8
Geo. Tol.+Tube Side	0.92506	0.00083	0.01200	14.5
Geo. Tol.+Tube Corner	0.92275	0.00084	0.00969	11.5

Table 6.4-7 PWR Basket in Vertical Concrete Cask KENO-Va Results for Geometric Tolerances and Tube Movement

Analysis	k_{eff}	σ	Δk_{eff}	$\Delta k_{eff}/\sigma$
Nominal	0.91486	0.00087	N/A	N/A
Nominal Wet Gap	0.92266	0.00082	0.00780	9.5
Geometric Tolerance	0.92545	0.00086	0.01059	12.3
Geo. Tol.+Tube In	0.93052	0.00084	0.01566	18.6
Geo. Tol.+Tube Out	0.91659	0.00085	0.00173	2.0
Geo. Tol.+Tube Side	0.92415	0.00088	0.00929	10.6
Geo. Tol.+Tube Corner	0.92477	0.00082	0.00991	12.1

Table 6.4-8 BWR Basket in Transfer Cask KENO-Va Results for Geometric Tolerances and Mechanical Perturbations

Analysis	k_{eff}	σ	Δk_{eff}	$\Delta k_{eff}/\sigma$
Nominal Basket	0.88696	0.00082	N/A	N/A
Geometric Tolerances				
Min Tube	0.88401	0.00081	-0.00295	-3.642
Max Tube	0.88913	0.00084	0.00217	2.583
Min Disk Opening	0.88549	0.00083	-0.00147	-1.771
Max Disk Opening	0.88663	0.00081	-0.00033	-0.407
Shift Openings In	0.88659	0.00084	-0.00037	-0.440
Shift Openings Out	0.88434	0.00084	-0.00262	-3.119
Mechanical Perturbations				
Assembly Shift Top Right	0.86659	0.00086	-0.02037	-23.686
Assembly Shift Top	0.87661	0.00082	-0.01035	-12.622
Assembly Shift Top Left	0.88278	0.00087	-0.00418	-4.805
Assembly Shift Left	0.89037	0.00082	0.00341	4.159
Assembly Shift Bottom Left	0.89539	0.00081	0.00843	10.407
Assembly Shift Bottom	0.89270	0.00080	0.00574	7.175
Assembly Shift Bottom Right	0.88264	0.00083	-0.00432	-5.205
Assembly Shift Right	0.87691	0.00082	-0.01005	-12.256
Assembly Shift Radial In	0.89991	0.00080	0.01295	16.188
Assembly Shift Radial Out	0.87083	0.00082	-0.01613	-19.671
Fuel Tube Shift Top Right	0.88792	0.00084	0.00096	1.143
Fuel Tube Shift Top	0.88668	0.00085	-0.00028	-0.329
Fuel Tube Shift Top Left	0.88682	0.00086	-0.00014	-0.163
Fuel Tube Shift Left	0.88707	0.00083	0.00011	0.133
Fuel Tube Shift Bottom Left	0.88601	0.00081	-0.00095	-1.173
Fuel Tube Shift Bottom	0.88553	0.00086	-0.00143	-1.663
Fuel Tube Shift Bottom Right	0.88561	0.00082	-0.00135	-1.646
Fuel Tube Shift Right	0.88589	0.00083	-0.00107	-1.289
Fuel Tube Shift Radial In	0.89236	0.00081	0.00540	6.667
Fuel Tube Shift Radial Out	0.88287	0.00083	-0.00409	-4.928
Combined Analysis				
Tube + Assembly Radial In	0.90434	0.00082	0.01738	21.195

Table 6.4-9 BWR Basket in Vertical Concrete Cask KENO-Va Results for Geometric Tolerances and Mechanical Perturbations

Analysis	k_{eff}	σ	Δk_{eff}	$\Delta k_{eff}/\sigma$
Nominal Basket	0.88524	0.00078	N/A	N/A
Geometric Tolerances				
Min Tube	0.88476	0.00083	-0.00048	-0.578
Max Tube	0.88835	0.00082	0.00311	3.793
Min Disk Opening	0.88685	0.00081	0.00161	1.988
Max Disk Opening	0.88734	0.00082	0.00210	2.561
Shift Openings In	0.88740	0.00084	0.00216	2.571
Shift Openings Out	0.88627	0.00082	0.00103	1.256
Mechanical Perturbations				
Assembly Shift Top Right	0.86663	0.00087	-0.01861	-21.391
Assembly Shift Top	0.87675	0.00081	-0.00849	-10.481
Assembly Shift Top Left	0.88012	0.00084	-0.00512	-6.095
Assembly Shift Left	0.89115	0.00083	0.00591	7.120
Assembly Shift Bottom Left	0.89484	0.00083	0.00960	11.566
Assembly Shift Bottom	0.89129	0.00080	0.00605	7.563
Assembly Shift Bottom Right	0.88037	0.00081	-0.00487	-6.012
Assembly Shift Right	0.87643	0.00080	-0.00881	-11.013
Assembly Shift Radial In	0.89903	0.00081	0.01379	17.025
Assembly Shift Radial Out	0.86978	0.00086	-0.01546	-17.977
Fuel Tube Shift Top Right	0.88733	0.00084	0.00209	2.488
Fuel Tube Shift Top	0.88752	0.00084	0.00228	2.714
Fuel Tube Shift Top Left	0.88611	0.00086	0.00087	1.012
Fuel Tube Shift Left	0.88649	0.00084	0.00125	1.488
Fuel Tube Shift Bottom Left	0.88560	0.00083	0.00036	0.434
Fuel Tube Shift Bottom	0.88406	0.00082	-0.00118	-1.439
Fuel Tube Shift Bottom Right	0.88633	0.00084	0.00109	1.298
Fuel Tube Shift Right	0.88571	0.00084	0.00047	0.560
Fuel Tube Shift Radial In	0.89183	0.00083	0.00659	7.940
Fuel Tube Shift Radial Out	0.88298	0.00079	-0.00226	-2.861
Combined Analysis				
Tube + Assembly Radial In	0.90454	0.00083	0.01930	23.253

Table 6.4-10 Heterogeneous vs. Homogeneous Enrichment Analysis Results

Case		Enrichment (% ^{235}U)			Loading Pattern				
Array	Fuel Rods	Average	Min	Max	Heterog.	Homog.	k_{eff}	σ	$\Delta k/\sigma$
8×8	62	2.824	N/A	N/A		X	0.8024	0.0011	---
8×8	62	2.824	1.30	3.80	X		0.7894	0.0011	-12.28
8×8	62	3.750	N/A	N/A		X	0.8683	0.0011	---
8×8	62	3.750	1.73	3.98	X		0.8501	0.0011	-15.93
8×8	60	3.404	N/A	N/A		X	0.8418	0.0012	---
8×8	60	3.404	1.60	3.90	X		0.8364	0.0011	-4.53
8×8	60	3.750	N/A	N/A		X	0.8648	0.0012	---
8×8	60	3.750	1.76	4.35	X		0.8547	0.0011	-8.22
9×9	74	4.085	N/A	N/A		X	0.8884	0.0012	---
9×9	74	4.085	2.00	4.90	X		0.8785	0.0012	-8.37
9×9(1)	74	4.085	2.00	4.90	X		0.8809	0.0012	-6.31
9×9	74	3.750	N/A	N/A		X	0.8707	0.0011	---
9×9	74	3.750	1.84	4.50	X		0.8608	0.0011	-8.84
9×9(1)	74	3.750	1.84	4.50	X		0.8672	0.0011	-7.13
9×9	74	4.000	N/A	N/A		X	0.8839	0.0011	N/A
9×9	74	4.000	1.96	4.80	X		0.8759	0.0012	-7.06
9×9(2)	74	4.000	N/A	N/A		X	0.8890	0.0012	N/A
9×9(2)	74	4.000	1.96	4.80	X		0.8805	0.0012	-7.08
9×9(3)	74	4.000	3.68	5.00	X		0.8821	0.0012	-5.77

Notes:

(1) Rotated water holes.

(2) Exxon Assembly.

(3) Eighteen 5 wt% ^{235}U enriched rods near center of assembly.

Table 6.4-11 PWR Single Standard Transfer Cask Analysis Criticality Results

Water Density (g/cm^3)						
Inside Canister	**Outside Canister**	**Water in Gap**	^{10}B	k_{eff}	σ	k_s [1]
1.0	1.0	No	100%	0.91385	0.00088	0.92793
1.0	1.0	No	75%	0.92319	0.00086	0.93726
0.0001	1.0	No	75%	0.33461	0.00061	0.34860
1.0	1.0	Yes	100%	0.92116	0.00091	0.93525
1.0	1.0	Yes	75%	0.93052	0.00084	0.94458
0.0001	1.0	Yes	75%	0.33471	0.00064	0.34870

1. Does not include Δk of 0.00246 from neutron absorber plate evaluation.

Table 6.4-12 PWR Standard Transfer Cask Array Analysis Criticality Results - Normal Conditions

Water Density (g/cm^3)						
Inside Canister	Outside Canister	Water in Gap	^{10}B	k_{eff}	σ	k_s[1]
1.0	1.0	No	75%	0.92225	0.00164	0.93675
0.9	0.9	No	75%	0.89374	0.00189	0.90843
0.8	0.8	No	75%	0.85650	0.00172	0.87106
0.6	0.6	No	75%	0.77522	0.00148	0.78961
0.4	0.4	No	75%	0.67495	0.00151	0.68936
0.2	0.2	No	75%	0.54140	0.00117	0.55561
0.1	0.1	No	75%	0.46986	0.00091	0.48395
1.0	0.0001	No	75%	0.91984	0.00171	0.93439
0.9	0.0001	No	75%	0.89131	0.00184	0.90596
0.8	0.0001	No	75%	0.85741	0.00171	0.87196
0.6	0.0001	No	75%	0.77648	0.00160	0.79095
0.4	0.0001	No	75%	0.67475	0.00153	0.68917
0.2	0.0001	No	75%	0.54275	0.00128	0.55702
0.1	0.0001	No	75%	0.47271	0.00088	0.48679

[1] Does not include Δk of 0.00246 from the neutron absorber plate evaluation.

Table 6.4-13 PWR Standard Transfer Cask Array Analysis Criticality Results - Accident Conditions

Water Density (g/cm^3)						
Inside Canister	Outside Canister	Water in Gap	^{10}B	k_{eff}	σ	k_s[1]
1.0	1.0	Yes	75%	0.93096	0.00084	0.94502
0.9	0.9	Yes	75%	0.89908	0.00084	0.91314
0.8	0.8	Yes	75%	0.86363	0.00084	0.87769
0.6	0.6	Yes	75%	0.78291	0.00108	0.79707
0.4	0.4	Yes	75%	0.68031	0.00105	0.69446
0.2	0.2	Yes	75%	0.54830	0.00114	0.56249
0.1	0.1	Yes	75%	0.47334	0.00094	0.48744

[1] Does not include Δk of 0.00246 from the neutron absorber plate evaluation.

Table 6.4-14 PWR Single Vertical Concrete Cask Analysis Criticality Results

Water Density (g/cm^3)		Water in				
Inside	Outside	Gap	^{10}B	k_{eff}	σ	k_s[1]
1.0	1.0	No	100%	0.91385	0.00088	0.92793
1.0	1.0	No	75%	0.92319	0.00086	0.93726
0.0001	1.0	No	75%	0.33461	0.00061	0.34860
1.0	1.0	Yes	100%	0.92116	0.00091	0.93525
1.0	1.0	Yes	75%	0.93052	0.00084	0.94458
0.0001	1.0	Yes	75%	0.33471	0.00064	0.34870

[1] Does not include Δk of 0.00246 from the neutron absorber plate evaluation.

Table 6.4-15 PWR Vertical Concrete Cask Array Analysis Criticality Results - Normal and Off-Normal Conditions

Water Density (g/cm^3)						
Inside Canister	Outside Canister	Water in Gap	^{10}B	k_{eff}	σ	k_s[1]
0.0001	1.0	No	75%	0.33461	0.00061	0.34860
0.0001	0.9	No	75%	0.33453	0.00065	0.34853
0.0001	0.8	No	75%	0.33383	0.00061	0.34782
0.0001	0.6	No	75%	0.33542	0.00062	0.34941
0.0001	0.4	No	75%	0.33844	0.00064	0.35243
0.0001	0.2	No	75%	0.34600	0.00065	0.36000
0.0001	0.1	No	75%	0.35777	0.00057	0.37174
0.0001	0.0001	No	75%	0.36684	0.00064	0.38083

[1] Does not include Δk of 0.00246 from the neutron absorber plate evaluation.

Table 6.4-16 PWR Vertical Concrete Cask Array Analysis Criticality Results - Accident Conditions

Water Density (g/cm^3)						
Inside Canister	Outside Canister	Water in Gap	^{10}B	k_{eff}	σ	k_s[1]
1.0	1.0	Yes	75%	0.93052	0.00084	0.94458
0.9	0.9	Yes	75%	0.89707	0.00084	0.91113
0.8	0.8	Yes	75%	0.86351	0.00087	0.87758
0.6	0.6	Yes	75%	0.78276	0.00117	0.79697
0.4	0.4	Yes	75%	0.67967	0.00101	0.69380
0.2	0.2	Yes	75%	0.54104	0.00118	0.55525
0.1	0.1	Yes	75%	0.46245	0.00078	0.47649

[1] Does not include Δk of 0.00246 from the neutron absorber plate evaluation.

Table 6.4-17 BWR Single Standard Transfer Cask Analysis Criticality Results

Water Density (g/cm^3)						
Inside Canister	Outside Canister	Water in Gap	^{10}B	k_{eff}	σ	k_s
1.0	1.0	No	100%	0.88987	0.00083	0.90393
1.0	1.0	No	75%	0.90369	0.00082	0.91774
0.0001	1.0	No	75%	0.38112	0.00065	0.39512
1.0	1.0	Yes	100%	0.89298	0.00084	0.90704
1.0	1.0	Yes	75%	0.90710	0.00080	0.92115
0.0001	1.0	Yes	75%	0.38145	0.00067	0.39545

Table 6.4-18 BWR Standard Transfer Cask Array Analysis Criticality Results - Normal Conditions

Water Density (g/cm^3)						
Inside Canister	Outside Canister	Water in Gap	^{10}B	k_{eff}	σ	k_s
1.0	1.0	No	75%	0.90446	0.00081	0.91851
0.9	0.9	No	75%	0.88965	0.00081	0.90370
0.8	0.8	No	75%	0.87509	0.00081	0.88914
0.6	0.6	No	75%	0.83357	0.00079	0.84761
0.4	0.4	No	75%	0.76643	0.00075	0.78046
0.2	0.2	No	75%	0.64878	0.00115	0.66298
0.1	0.1	No	75%	0.55967	0.00105	0.57382
1.0	0.0001	No	75%	0.90513	0.00083	0.91919
0.9	0.0001	No	75%	0.88954	0.00080	0.90359
0.8	0.0001	No	75%	0.87540	0.00078	0.88944
0.6	0.0001	No	75%	0.83281	0.00111	0.84699
0.4	0.0001	No	75%	0.76682	0.00149	0.78122
0.2	0.0001	No	75%	0.65055	0.00122	0.66479
0.1	0.0001	No	75%	0.56286	0.00106	0.57701

Table 6.4-19 BWR Standard Transfer Cask Array Analysis Criticality Results - Accident Conditions

Water Density (gm/cm^3)						
Inside Canister	Outside Canister	Water in Gap	^{10}B	k_{eff}	σ	k_s
1.0	1.0	Yes	75%	0.90831	0.00079	0.92235
0.9	0.9	Yes	75%	0.89634	0.00086	0.91041
0.8	0.8	Yes	75%	0.87974	0.00080	0.89379
0.6	0.6	Yes	75%	0.83966	0.00082	0.85371
0.4	0.4	Yes	75%	0.76946	0.00071	0.78348
0.2	0.2	Yes	75%	0.65287	0.00062	0.66686
0.1	0.1	Yes	75%	0.55975	0.00101	0.57388

Table 6.4-20 BWR Single Vertical Concrete Cask Analysis Criticality Results

Water Density (g/cm³)		Water in				
Inside	Outside	Gap	^{10}B	k_{eff}	σ	k_s
1.0	1.0	No	100%	0.88991	0.00077	0.90395
1.0	1.0	No	75%	0.90327	0.00078	0.91731
0.0001	1.0	No	75%	0.35531	0.00062	0.36930
1.0	1.0	Yes	100%	0.89567	0.00081	0.90972
1.0	1.0	Yes	75%	0.90842	0.00085	0.92248
0.0001	1.0	Yes	75%	0.35418	0.00070	0.36819

Table 6.4-21 BWR Vertical Concrete Cask Array Analysis Criticality Results - Normal and Off-Normal Conditions

Water Density (gm/cm³)						
Inside Canister	Outside Canister	Water in Gap	^{10}B	k_{eff}	σ	k_s
0.0001	1.0	No	75%	0.35565	0.00069	0.36966
0.0001	0.9	No	75%	0.35586	0.00077	0.36990
0.0001	0.8	No	75%	0.35506	0.00074	0.36908
0.0001	0.6	No	75%	0.35674	0.00071	0.37076
0.0001	0.4	No	75%	0.35783	0.00072	0.37185
0.0001	0.2	No	75%	0.36488	0.00072	0.37890
0.0001	0.1	No	75%	0.37186	0.00065	0.38586
0.0001	0.0001	No	75%	0.36769	0.00061	0.38168

Table 6.4-22 BWR Vertical Concrete Cask Array Analysis Criticality Results - Accident Conditions

Water Density (gm/cm^3)						
Inside Canister	Outside Canister	Water in Gap	^{10}B	k_{eff}	σ	k_s
1.0	1.0	Yes	75%	0.90927	0.00081	0.92332
0.9	0.9	Yes	75%	0.89683	0.00083	0.91089
0.8	0.8	Yes	75%	0.87840	0.00077	0.89244
0.6	0.6	Yes	75%	0.83670	0.00078	0.85074
0.4	0.4	Yes	75%	0.76572	0.00069	0.77973
0.2	0.2	Yes	75%	0.64324	0.00062	0.65723
0.1	0.1	Yes	75%	0.54855	0.00049	0.56251

Table 6.4-23 PWR Lattice Parameter Study Criticality Analysis Results

Description	k_{eff}	σ	Δk	2σ	Δk/2σ
base case	**0.9732**	**0.0008**	**----**	**0.0016**	**----**
decreases clad inner radius by 0.005 cm	0.9697	0.0008	-0.0035	----	-2.1875
increases clad inner radius by 0.005 cm	0.9784	0.0008	0.0052	----	3.2500
decreases clad outer radius by 0.005 cm	0.9782	0.0009	0.0050	----	3.1250
increases clad outer radius by 0.005 cm	0.9702	0.0009	-0.0030	----	-1.8750
decreases pellet radius by 0.005 cm	0.9744	0.0008	0.0012	----	0.7500
decreases pellet radius by 0.010 cm	0.9742	0.0008	0.0010	----	0.6250
decreases pellet radius by 0.015 cm	0.9773	0.0008	0.0041	----	2.5625
decreases pellet radius by 0.020 cm	0.9758	0.0008	0.0026	----	1.6250
decreases pellet radius by 0.025 cm	0.9761	0.0008	0.0029	----	1.8125
decreases pellet radius by 0.030 cm	0.9754	0.0008	0.0022	----	1.3750
decreases pellet radius by 0.035 cm	0.9750	0.0008	0.0018	----	1.1250
decreases pellet radius by 0.040 cm	0.9750	0.0008	0.0018	----	1.1250
increases pellet radius by 0.005 cm	0.9714	0.0009	-0.0018	----	-1.1250
decreases pellet & clad inner radii by 0.015 cm	0.9637	0.0008	-0.0095	----	-5.9375
decreases guide tube inner radius by 0.010 cm	0.9710	0.0008	-0.0022	----	-1.3750
increases guide tube inner radius by 0.015 cm	0.9753	0.0008	0.0021	----	1.3125
increases guide tube inner radius by 0.010 cm	0.9740	0.0009	0.0008	----	0.5000
decreases guide tube outer radius by 0.010 cm	0.9755	0.0008	0.0023	----	1.4375
increases guide tube outer radius by 0.015 cm	0.9712	0.0008	-0.0020	----	-1.2500
increases guide tube outer radius by 0.010 cm	0.9720	0.0008	-0.0012	----	-0.7500

Table 6.4-24 BWR Lattice Parameter Study Criticality Analysis Results

Description	k_{eff}	σ	Δ k	2 σ	Δ k / 2 σ
base case	**0.8904**	**0.0008**	----	**0.0016**	----
decreases clad inner radius by 0.005 cm	0.8889	0.0008	-0.0015	----	-0.9375
decreases clad inner radius by 0.008 cm	0.8874	0.0008	-0.0030	----	-1.8750
increases clad inner radius by 0.005 cm	0.8930	0.0008	0.0026	----	1.6250
decreases clad outer radius by 0.005 cm	0.8919	0.0008	0.0015	----	0.9375
decreases clad outer radius by 0.010 cm	0.8957	0.0008	0.0053	----	3.3125
increases clad outer radius by 0.005 cm	0.8885	0.0009	-0.0019	----	-1.1875
increases clad outer radius by 0.010 cm	0.8830	0.0009	-0.0074	----	-4.6250
decreases pellet radius by 0.005 cm	0.8896	0.0008	-0.0008	----	-0.5000
decreases pellet radius by 0.010 cm	0.8909	0.0008	0.0005	----	0.3125
decreases pellet radius by 0.015 cm	0.8881	0.0008	-0.0023	----	-1.4375
decreases pellet radius by 0.020 cm	0.8832	0.0008	-0.0072	----	-4.5000
decreases pellet radius by 0.025 cm	0.8867	0.0008	-0.0037	----	-2.3125
decreases pellet radius by 0.030 cm	0.8835	0.0008	-0.0069	----	-4.3125
decreases pellet radius by 0.035 cm	0.8837	0.0008	-0.0067	----	-4.1875
decreases pellet radius by 0.040 cm	0.8807	0.0008	-0.0097	----	-6.0625
increases pellet radius by 0.005 cm	0.8908	0.0008	0.0004	----	0.2500
increases pellet radius by 0.008 cm	0.8907	0.0009	0.0003	----	0.1875
decreases water rod inner radius by 0.010 cm	0.8908	0.0008	0.0004	----	0.2500
decreases water rod inner radius by 0.015 cm	0.8916	0.0008	0.0012	----	0.7500
increases water rod inner radius by 0.010 cm	0.8919	0.0008	0.0015	----	0.9375
increases water rod inner radius by 0.015 cm	0.8911	0.0008	0.0007	----	0.4375
decreases water rod outer radius by 0.010 cm	0.8901	0.0008	-0.0003	----	-0.1875
decreases water rod outer radius by 0.015 cm	0.8913	0.0008	0.0009	----	0.5625
increases water rod outer radius by 0.010 cm	0.8916	0.0008	0.0012	----	0.7500
increases water rod outer radius by 0.015 cm	0.8892	0.0009	-0.0012	----	-0.7500
replaces water rod with water	0.8926	0.0008	0.0022	----	1.3750

Table 6.4-25 PWR Maximum Allowable Enrichment – No Soluble Boron

Fuel Type	Enrichment (^{235}U wt%)	k_{eff}	σ	$k_{eff} + 2\sigma$
ce14a	5.0	0.9369	0.0008	0.9385
we14d	5.0	0.9359	0.0008	0.9375
ex14a	5.0	0.9184	0.0008	0.9200
we14a	5.0	0.9258	0.0008	0.9274
we14b	5.0	0.9340	0.0008	0.9356
ex15a	4.5	0.9363	0.0008	0.9379
we15a	4.4	0.9397	0.0008	0.9413
bw15a	4.4	0.9379	0.0008	0.9395
ce16e	4.8	0.9374	0.0008	0.9390
ex17a	4.4	0.9399	0.0008	0.9415
we17a	4.5	0.9385	0.0008	0.9401
we17b	4.3	0.9388	0.0008	0.9404
bw17a	4.4	0.9383	0.0008	0.9399
ce14MY	4.7	0.9404	0.0008	0.9420

Table 6.4-26 BWR Maximum Allowable Enrichment – No Soluble Boron

Fuel Type	Enrichment (^{235}U wt%)	k_{eff}	σ	$k_{eff} + 2\sigma$
ex07a	4.5	0.9403	0.0008	0.9419
ge07a	4.5	0.9375	0.0008	0.9391
ge07f	4.5	0.9381	0.0008	0.9397
ge07h	4.7	0.9402	0.0008	0.9418
ge08a	4.6	0.9379	0.0008	0.9395
ge08b	4.5	0.9322	0.0008	0.9338
ge08i	4.5	0.9391	0.0008	0.9407
ge08k	4.5	0.9369	0.0008	0.9385
ge08n	4.7	0.9368	0.0008	0.9384
ex08a	4.7	0.9394	0.0008	0.9410
ex08b	4.6	0.9355	0.0008	0.9371
ex09b	4.4	0.9361	0.0008	0.9377
ge09a	4.5	0.9391	0.0008	0.9407
ex09c	4.5	0.9404	0.0008	0.9420
ge09b	4.6	0.9390	0.0008	0.9406

Table 6.4-27 Most Reactive Geometry for a Borated Water PWR Canister

Tube Outer Width	Tube Thick.	Neutron Absorber Width	Disk Op. Width	Disk Op. Location	Rad Fuel Shift	Rad Tube Shift	Neutron Absorber Shift	$k_{eff} + 2\sigma$	Δk
Nom	Nom	Nom	Nom	Nom	Center	Center	No	0.8045	0.0000
Nom	Nom	Nom	Nom	Nom	In	In	No	0.8119	0.0074
Nom	Nom	Nom	Nom	Nom	In	In	Yes	0.8152	0.0107
Nom	Nom	Nom	Min	Nom	In	In	Yes	0.8142	-0.0010
Nom	Nom	Nom	Max	Nom	In	In	Yes	0.8151	-0.0001
Nom	Nom	Nom	Nom	Min	In	In	Yes	0.8158	0.0006
Nom	Nom	Nom	Nom	Max	In	In	Yes	0.8145	-0.0007
Min	Nom	Nom	Nom	Nom	In	In	Yes	0.8125	-0.0027
Max	Nom	Nom	Nom	Nom	In	In	Yes	0.8166	0.0014
Nom	Min	Nom	Nom	Nom	In	In	Yes	0.8140	-0.0012
Nom	Max	Nom	Nom	Nom	In	In	Yes	0.8149	-0.0003
Max	Nom	Min	Max	Nom	In	In	Yes	0.8175	0.0023

Table 6.4-28 Moderator Density versus Reactivity for the Borated Water Cases

Water Density[1] (g/cc)	k_{eff}	σ	$k_{eff} + 2\sigma$	Δk
0.9998	0.8159	0.0008	0.8175	0.0000
0.95	0.8065	0.0008	0.8081	-0.0094
0.9	0.7985	0.0008	0.8001	-0.0174
0.85	0.7900	0.0008	0.7916	-0.0259
0.8	0.7789	0.0008	0.7805	-0.0370
0.75	0.7689	0.0008	0.7705	-0.0470
0.7	0.7565	0.0008	0.7581	-0.0594
0.65	0.7437	0.0008	0.7453	-0.0722
0.6	0.7280	0.0008	0.7296	-0.0879
0.55	0.7125	0.0008	0.7141	-0.1034
0.5	0.6941	0.0008	0.6957	-0.1218
0.45	0.6732	0.0008	0.6748	-0.1427
0.4	0.6518	0.0008	0.6534	-0.1641
0.35	0.6257	0.0008	0.6273	-0.1902
0.3	0.5963	0.0008	0.5979	-0.2196
0.25	0.5658	0.0008	0.5674	-0.2501
0.2	0.5345	0.0008	0.5361	-0.2814
0.15	0.4985	0.0008	0.5001	-0.3174
0.1	0.4648	0.0008	0.4664	-0.3511
0.05	0.4332	0.0008	0.4348	-0.3827
0.0001	0.3605	0.0008	0.3621	-0.4554

Notes:

[1] Indicates water density prior to insertion of 1000 ppm boron.

Table 6.4-29 PWR Maximum Allowable Enrichment – Soluble Boron

Fuel Type	Enrichment (^{235}U wt%)	k_{eff}	σ	$k_{eff} + 2\sigma$
ce14a	5.0	0.8237	0.0008	0.8253
we14d	5.0	0.8231	0.0008	0.8247
ex14a	5.0	0.8034	0.0008	0.8050
we14a	5.0	0.8187	0.0008	0.8203
we14b	5.0	0.8097	0.0008	0.8113
ex15a	5.0	0.8460	0.0008	0.8476
we15a	5.0	0.8613	0.0008	0.8629
bw15a	5.0	0.8604	0.0008	0.8620
ce16e	5.0	0.8344	0.0008	0.8360
ex17a	5.0	0.8486	0.0008	0.8502
we17a	5.0	0.8606	0.0008	0.8622
we17b	5.0	0.8556	0.0008	0.8572
bw17a	5.0	0.8594	0.0008	0.8610

6.5 Critical Benchmark Experiments

Criticality code validation is performed for the CSAS analysis sequence in the SCALE 4.3 package in Section 6.5.1 and for the MONK8A code of the ANSWERS software package in Section 6.5.2.

6.5.1 SCALE 4.3 Benchmark Experiments and Applicability

This section provides the validation of the CSAS25 criticality analysis sequence contained in Version 4.3 of the SCALE package. CSAS includes the SCALE Material Information Processor, BONAMI-S, NITAWL-S, and KENO-Va. The Material Information Processor generates number densities for standard compositions, prepares geometry data for resonance self-shielding, and creates data input files for the cross-section processing codes. The BONAMI-S and NITAWL- S codes are used to prepare a resonance-corrected cross-section library in AMPX working format. The KENO-Va code uses Monte Carlo techniques to calculate the model k_{eff}. The 27-group ENDF/B-IV neutron cross-section library is used in this validation. The CSAS validation is required by the criticality safety standards ANSI/ANS-8.1 [11]. The section describes the method, computer program and cross-section libraries used, experimental data, areas of applicability, and bias and margins of safety.

ANSI/ANS-8.17 [12] prescribes the criterion to establish subcriticality safety margins. This criterion is as follows:

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m \qquad (1)$$

where:

k_s = calculated allowable maximum multiplication factor, k_{eff}, of system being evaluated for all normal or credible abnormal conditions or events.

k_c = mean k_{eff} that results from calculation of benchmark criticality experiments using particular calculational method. If calculated k_{eff} values for criticality experiments exhibit trend with parameter, then k_c shall be determined by extrapolation based on best fit to calculated values. Criticality experiments used as benchmarks in computing k_c should have physical compositions, configurations, and nuclear characteristics (including reflectors) similar to those of system being evaluated.

Δk_s = allowance for

a. statistical or convergence uncertainties, or both, in computation of k_s,
b. material and fabrication tolerances, and
c. geometric or material representations used in computational method.

Δk_c = margin for uncertainty in k_c which includes allowance for

a. uncertainties in critical experiments,
b. statistical or convergence uncertainties, or both, in computation of k_c,
c. uncertainties resulting from extrapolation of k_c outside range of experimental data, and
d. uncertainties resulting from limitations in geometrical or material representations used in computational method.

Δk_m = arbitrary margin to ensure subcriticality of k_s.

The various uncertainties are combined statistically if they are independent. Correlated uncertainties are combined by addition.

Equation 1 can be rewritten as:

$$k_s \leq 1 - \Delta k_m - \Delta k_s - (1\text{-}k_c) - \Delta k_c \qquad (2)$$

Noting that the NRC requires a 5% subcriticality margin ($\Delta k_m = 0.05$) and the definition of the bias ($\beta = 1\text{-}k_c$), the equation 2 can then be written as:

$$k_s \leq 0.95 - \Delta k_s - \beta - \Delta\beta \qquad (3)$$

where $\Delta\beta = \Delta k_c$. Thus, the k_s (the maximum allowable value for k_{eff}) must be below 0.95 minus the bias, uncertainties in the bias, and uncertainties in the system being analyzed (i.e., Monte Carlo, mechanical, and modeling). This is an upper safety limit criteria often used in the DOE criticality safety community.

Alternatively, equation 3 can be rewritten applying the bias and uncertainties to the k_{eff} of the system being analyzed as:

$$k_s \equiv k_{eff} + \Delta k_s + \beta + \Delta\beta \leq 0.95 \qquad (4)$$

In Equation 4, k_{eff} replaces k_s, and k_s has been redefined as the effective multiplication factor of the system being analyzed, including the method bias and all uncertainties. This is a maximum calculated k_{eff} criteria often used in light water reactor spent fuel storage and transport analyses.

Both β and $\Delta\beta$ are evaluated below for KENO-Va with the 27-group ENDF/B-IV library for use in criticality evaluations of light water reactor fuel in storage and transport casks.

6.5.1.1 Description of Experiments

The 63 critical experiments selected are as follows: nine B&W 2.46 wt % ^{235}U fuel storage [13], ten PNL 4.31 wt % ^{235}U lattice [14], twenty-one PNL 2.35 and 4.31 wt % ^{235}U with metal reflectors (Bierman, April 1979 and August 1981) [15, 16], twelve PNL flux trap [14, 17] and eleven VCML 4.74 wt % ^{235}U experiments, some involving moderator density variations [18]. These experiments span a range of fuel enrichments, fuel rod pitches, neutron absorber sheet characteristics, shielding materials and geometries that are typical of light water reactor fuel in a cask.

To achieve accurate results, three-dimensional models, as close to the actual experiment as possible, are used to evaluate the experiments. Stochastic Monte Carlo error is kept within ±0.1% by executing at least 1,000 neutrons/generation for more than 400 generations.

6.5.1.2 Applicability of Experiments

All of the experiments chosen in this validation are applicable to either PWR or BWR fuel. Fuel enrichments have covered a range from 2.35 up to 4.74 wt % ^{235}U, typical of light water reactor fuel presently used. The experiment fuel rod and pitch characteristics are within the range of standard PWR or BWR fuel rods (i.e., pellet OD from 0.78 to 1.2 cm, rod OD from 0.95 to 1.88 cm, and pitch from 1.26 to 1.87 cm). This is particularly true of the VCML (PWR rod type) and B&W experiments (BWR rod type). The H/U volume ratios of the experimental fuel arrays are within the range of PWR fuel assemblies (1.6 to 2.32) and BWR fuel assemblies (1.6 to 1.9). Experiments covered the geometry and neutron absorber sheet arrangements typical of NAC basket designs. Flux trap gap spacings of 3.81 cm such as those in the NAC-STC and UMS® PWR baskets and gap spacings as low 1.91 cm as in the NAC-MPC were included. ^{10}B neutron absorber loadings, also typical of NAC basket designs (0.005 to 0.025 $^{10}B/cm^2$), were included as well. The experiments addressed the influence of water and metal reflector regions, including steel and lead, that would be present in storage and transport cask shielding.

Confidence in predicting criticality, including bias and uncertainty, has been demonstrated for light water reactor fuel with enrichments up to 4.74 wt % ^{235}U and results indicate confidence well above 5 wt % ^{235}U. Confidence in predicting criticality has been demonstrated for storage and transport arrays in which critical controls consist of flux trap or single neutron absorber sheets or simple spacing. Confidence in predicting criticality has been demonstrated for light water reactor fuel storage and transport arrays next to water and metal reflector regions.

6.5.1.3 Results of Benchmark Calculations

The k-effective results for the experiments are shown in Table 6.5.1-1 and a frequency plot is provided in Figure 6.5.1-1. Five sets of cases are presented: Set 1, B&W; Set 2, PNL lattice; Set 3, PNL reflector; Set 4, PNL flux trap, and Set 5,VCML critical experiments. Sixty-three results are reported.

The overall average and standard deviation of the 63 cases is 0.9948±0.0044. The average Monte Carlo error (statistical convergence) is ±0.0012 for the 63 cases. This uncertainty component is statistically subtracted from the uncertainties, because it is previously included in the standard deviation. The KENO-Va models are three-dimensional, fully explicit representations (no homogenization) of the experimental geometry. Therefore, the uncertainty resulting from limitations of geometrical modeling is taken to be 0.0. The experiments modeled cover the range of fuel types, enrichments, neutron absorber configurations, neutron absorber B^{10} loading, and metal reflector effects so that no extrapolations are necessary outside the range of data, and the uncertainty resulting from extrapolation is also taken to be 0.0.

On the basis of the reported experimental error for the B&W cases, the reported error of the critical size number of rods for the PNL cases and the reported error for the critical height in the VCML cases, the experimental error is conservatively taken to be ±0.001. Criticality can then be represented as 1.000±0.001. This uncertainty component is statistically added to the sum of the other uncertainties, because the bias is the difference between two random variates (i.e., criticality and code prediction, and the uncertainty in the difference between two random variables is the statistical sum [(rms)] of their individual uncertainties).

Thus, the bias or average difference between code calculated and the critical condition is β=1-0.9948 = 0.0052. The uncertainty in the bias, accounting for the statistical convergence (Monte Carlo error) and the uncertainty in criticality is $(0.0044^2 - 0.0012^2 + 0.0010^2)^{1/2} = 0.0043$. For 63 samples of criticality, the 95/95 one-side tolerance factor is 2.012 [19]. The result is a 95/95 one-sided uncertainty in the bias of $\Delta\beta$=2.012×0.0043=0.0087. Equation 3 now becomes:

$$k_{eff} + \Delta k_s + 0.0052 + 0.0087 \leq 0.95 \qquad (5)$$

where Δk_s becomes the uncertainty in k_s resulting from Monte Carlo error, mechanical and material tolerances, and geometric or material representations. If the nominal representation of the system is evaluated for k_s, then the mechanical and material perturbations can be evaluated independently and can be combined statistically as the root sum of squares. If the worst-case mechanical and material tolerances are used to calculate k_s (e. g., 75% of boron loading and most reactive positioning of fuel or basket components), then Δk_s becomes 0.0 and the Monte Carlo error, σ_{mc}, can be combined statistically, because it is independent, with the uncertainty in the bias as:

$$k_{eff} + 0.0052 + \sqrt{0.0087^2 + (2\sigma)^2} \leq 0.95 \qquad (6)$$

6.5.1.4 Trends

Scatter plots of k_{eff} versus wt % ^{235}U, rod pitch, H/U volume ratio, average neutron group causing fission, ^{10}B loading for flux trap cases, and flux trap gap thickness are shown in Figures 6.5.1-2 through 6.5.1-7. Included in these scatter plots are linear regression lines with a corresponding correlation coefficient (r) to statistically indicate any trend or lack thereof. In particular, the correlation coefficient is a measure of the linear relationship between k_{eff} and a critical experiment parameter. If r is +1, a perfect linear relationship with a positive slope is indicated, and if r is -1, a perfect linear relationship with a negative slope is indicated. When r is 0, no linear relationship is indicated.

The largest correlation coefficient indicated in the plots is 0.3608 (k_{eff} versus enrichment) and the lowest is 0.0693 (k_{eff} versus ^{10}B loading in flux trap experiments). On the basis of the correlation coefficients, no statistically significant trends exist over the range of variables studied. Most importantly, no trend is shown with flux trap gap spacing and/or ^{10}B loading. This is the major criticality control feature of the UMS® Storage System basket.

6.5.1.5 Comparison of NAC Method to NUREG/CR-6361 – SCALE 4.3

NUREG/CR-6361, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages" (NUREG), provides a guide to LWR criticality benchmark calculations and the determination of bias and subcritical limits in critical safety evaluations. In Section 2 of the NUREG, a series of LWR critical experiments are described in sufficient detail for independent modeling. In Section 3, the critical experiments are modeled, and the results (k_{eff} values) are presented. The method utilized in the NUREG is KENO-Va with the 44 group ENDF/B-V cross-section library embedded in SCALE 4.3. Inputs are provided in Appendix A of the NUREG. In Section 4, a guide for the determination of bias and subcritical safety limits is provided based on ANSI/ANS-8.17 and statistical analysis of the trending in the bias. Finally, guidelines for experiment selection and applicability are presented in Section 5. The approach outlined in Section 4 of the NUREG is described in detail below and is compared to the NAC approach presented in Sections 6.5.1, 6.5.1.1 and 6.5.1.2.

NAC has performed an extensive LWR critical benchmarking as documented in Sections 6.5.1.1 and 6.5.1.2. The method used in NAC benchmarking/validation included the CSAS25 (KENO-Va) criticality analysis sequence, with the 27 group ENDF/B-IV library, contained in SCALE 4.3. Trending in k_{eff} was evaluated for the following independent variables: wt % ^{235}U, rod pitch, H/U volume ratio, average neutron group causing fission, ^{10}B loading for flux trap cases, and flux trap gap thickness. No statistically significant trends were found, and a constant bias with associated uncertainty was determined for criticality evaluation.

Both the NUREG/CR-6361 and the NAC approach to criticality evaluation start with ANSI/ANS-8.17 criticality safety criterion. This criterion is as follows:

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m \qquad (1)$$

where:

k_s = calculated allowable maximum multiplication factor, k_{eff}, of the system being evaluated for all normal or credible abnormal conditions or events.

k_c = mean k_{eff} that results from a calculation of benchmark criticality experiments using a particular calculation method. If the calculated k_{eff} values for the criticality experiments exhibit a trend with an independent parameter, then k_c shall be determined by extrapolation based on best fit to calculated values. Criticality experiments used as benchmarks in computing k_c should have physical compositions, configurations, and nuclear characteristics (including reflectors) similar to those of the system being evaluated.

Δk_s = allowance for:

a) statistical or convergence uncertainties, or both, in computation of k_s,
b) material and fabrication tolerances, and
c) geometric or material representations used in computational method.

Δk_c = margin for uncertainty in k_c which includes allowance for:

a) uncertainties in critical experiments,
b) statistical or convergence uncertainties, or both, in computation of k_c,
c) uncertainties resulting from extrapolation of k_c outside range of experimental data, and
d) uncertainties resulting from limitations in geometrical or material representations used in the computational method.

Δk_m= arbitrary administrative margin to ensure subcriticality of k_s

The various uncertainties are combined statistically if they are independent. Correlated uncertainties are combined by addition.

Equation 1 can be rewritten as:

$$k_s \leq 1 - \Delta k_m - \Delta k_s - (1 - k_c) - \Delta k_c \qquad (2)$$

Noting that the definition of the bias is $\beta = 1 - k_c$, Equation 2 can be written as:

$$k_s + \Delta k_s \leq 1 - \Delta k_m - \beta - \Delta\beta \qquad (3)$$

where $\Delta\beta = \Delta k_c$. Thus, the maximum allowable value for k_{eff} plus uncertainties in the system being analyzed must be below 1 minus an administrative margin (typically 0.05), which includes the bias and the uncertainty in the bias. This can also be written as:

$$k_s + \Delta k_s \leq \text{Upper Subcritical Limit (USL)} \qquad (4)$$

where:

$$USL \equiv 1 - \Delta k_m - \beta - \Delta\beta \qquad (5)$$

This is the Upper Subcritical Limit criterion as described in Section 4 of NUREG/CR-6361. Two methods are prescribed for the statistical determination of the USL: Confidence Band with

Administrative Margin (USL-1) and Single Sided Uniform with Close Approach (USL-2). In the first method, $\Delta k_m = 0.05$ and a lower confidence band (usually 95%) is specified based on a linear regression of k_{eff} as a function of some system parameter. In the second method, the arbitrary administrative margin is set to zero and a uniform lower tolerance band is determined based on a linear regression. The second method provides a criticality safety margin that is generally less than 0.05. In cases where there are a limited number of data points, this method may indicate the need for a larger administrative margin. In both cases, all of the significant system parameters need to be studied to determine the strongest correlation.

In the analyses presented in Section 6.5.1.2, the bias and uncertainties are applied directly to the estimate of the system k_{eff}. Noting that the NRC requires a 5% subcriticality margin ($\Delta k_m = 0.05$), Equation 3 can be rewritten applying the bias and uncertainty in the bias to the k_{eff} of the system being analyzed as:

$$k_s + \Delta k_s + \beta + \Delta\beta \leq 0.95 \qquad (6)$$

In Equation 6, the method bias and all uncertainties are added to k_s. This is the maximum k_{eff} criterion defined in Section 6.5.1.2.

To this point, both the USL criterion and maximum k_{eff} criterion are equivalent. The effects of trending in the bias or the uncertainty in the bias can be directly incorporated into either Equation 5 or Equation 6. Trending is established by performing a regression analysis of k_{eff} as a function of the principle system variables such as: enrichment, rod pitch, H to U ratio, average group of fission, ^{10}B absorber loading and flux trap gap spacing. Usually, simple linear regression is performed, and the line with the greatest correlation is used to functionalize β. This approach is recommended in NUREG/CR-6361. However, if no strong correlation can be determined, then a constant bias adjustment can be made. This is typically done with a one-side tolerance factor that guarantees 95% confidence in the uncertainty in the bias. This is the approach taken in the UMS® criticality analysis.

Both NUREG/CR-6361 and the NAC evaluation perform regression analysis on key system parameters. For all of the major system parameters, the evaluation found no strong correlation. This is based on the observation that the correlation coefficients are all much less than ± 1. Thus a constant bias with a 95/95 confidence factor is applied to the system k_{eff}. NAC's statistical analysis of the k_{eff} results produced a bias of 0.0052 and a 95/95 uncertainty of 0.0087. Adding the two together and subtracting from 0.95 yields an effective constant USL of 0.9361.

To assure compliance with NUREG/CR-6361, an upper safety limit is generated using USLSTATS and is compared to the constant NAC bias and bias uncertainty used in Section 6.5.1.2.

To evaluate the relative importance of the trend analysis to the upper subcritical limits, correlation coefficients are required for all independent parameters. Table 6.5.1-2 contains the correlation coefficient, R, for each linear fit of k_{eff} versus experimental parameter (data is extracted from Figures 6.5.1-2 through 6.5.1-7 by taking the square root of the R^2 value). Based on the highest correlation coefficient and the method presented in NUREG/CR-6361, a USL is established based on the variation of k_{eff} with enrichment. Note that even the enrichment function shows a low statistical correlation coefficient (an |R| equal or near 1 would indicate a good fit). The output generated by USLSTATS is shown in Figure 6.5.1-8.

The NAC applied USL of 0.9361 bounds the calculated upper subcritical limits for all enrichment values above 3.0 wt % ^{235}U. Since the maximum reactivities in the UMS® are calculated at enrichments well above this level, the existing bias bounds the NUREG calculated USL. The parameters of the most reactive cask configuration are presented in Table 6.5.1-3. The most reactive UMS® configuration is the PWR basket configuration with Westinghouse 17×17 OFA fuel assemblies.

Figure 6.5.1-1 KENO-Va Validation—27-Group Library Results: Frequency Distribution of k_{eff} Values

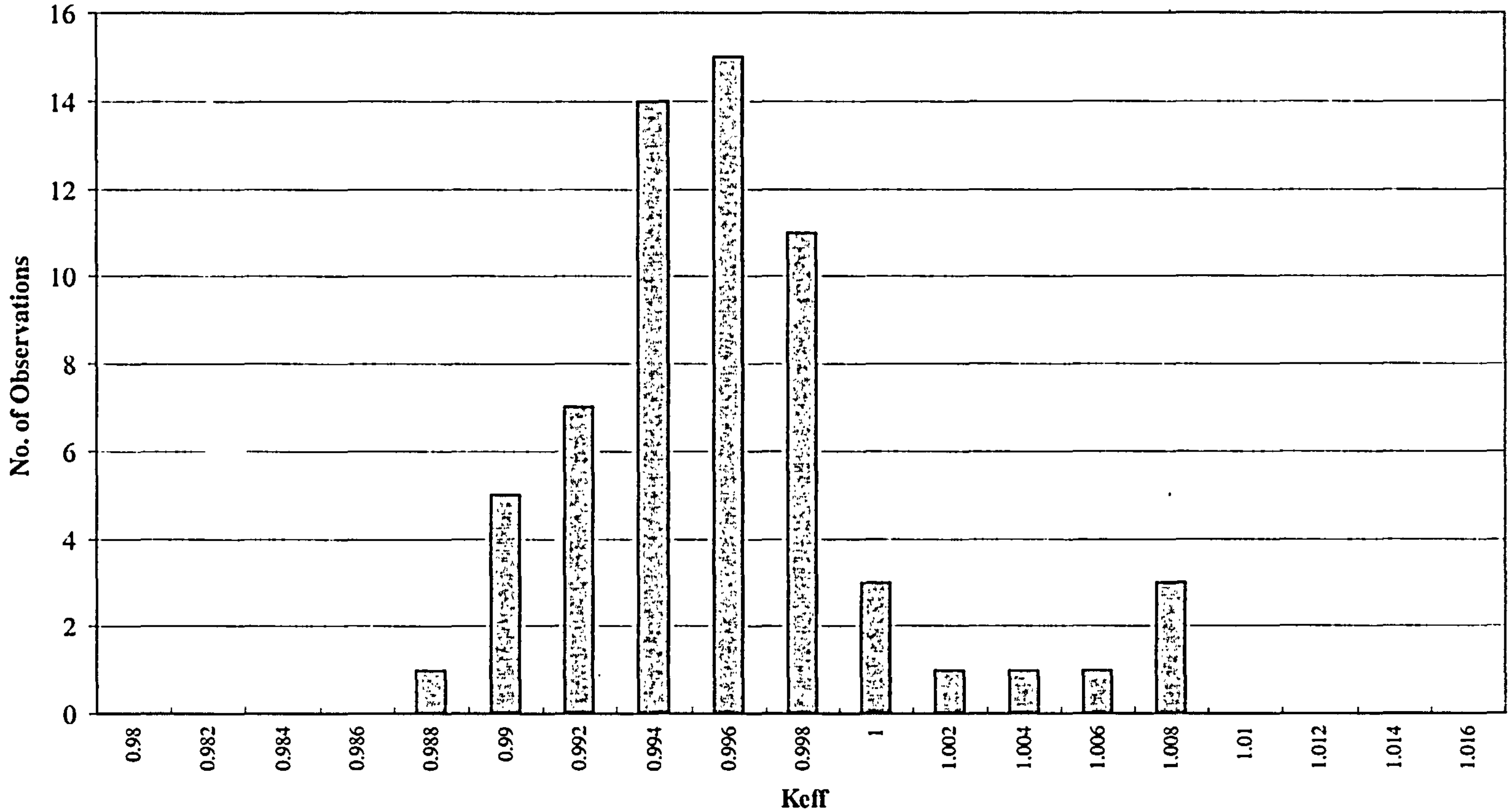


Figure 6.5.1-2 KENO-Va Validation—27-Group Library Results: k_{eff} versus Enrichment

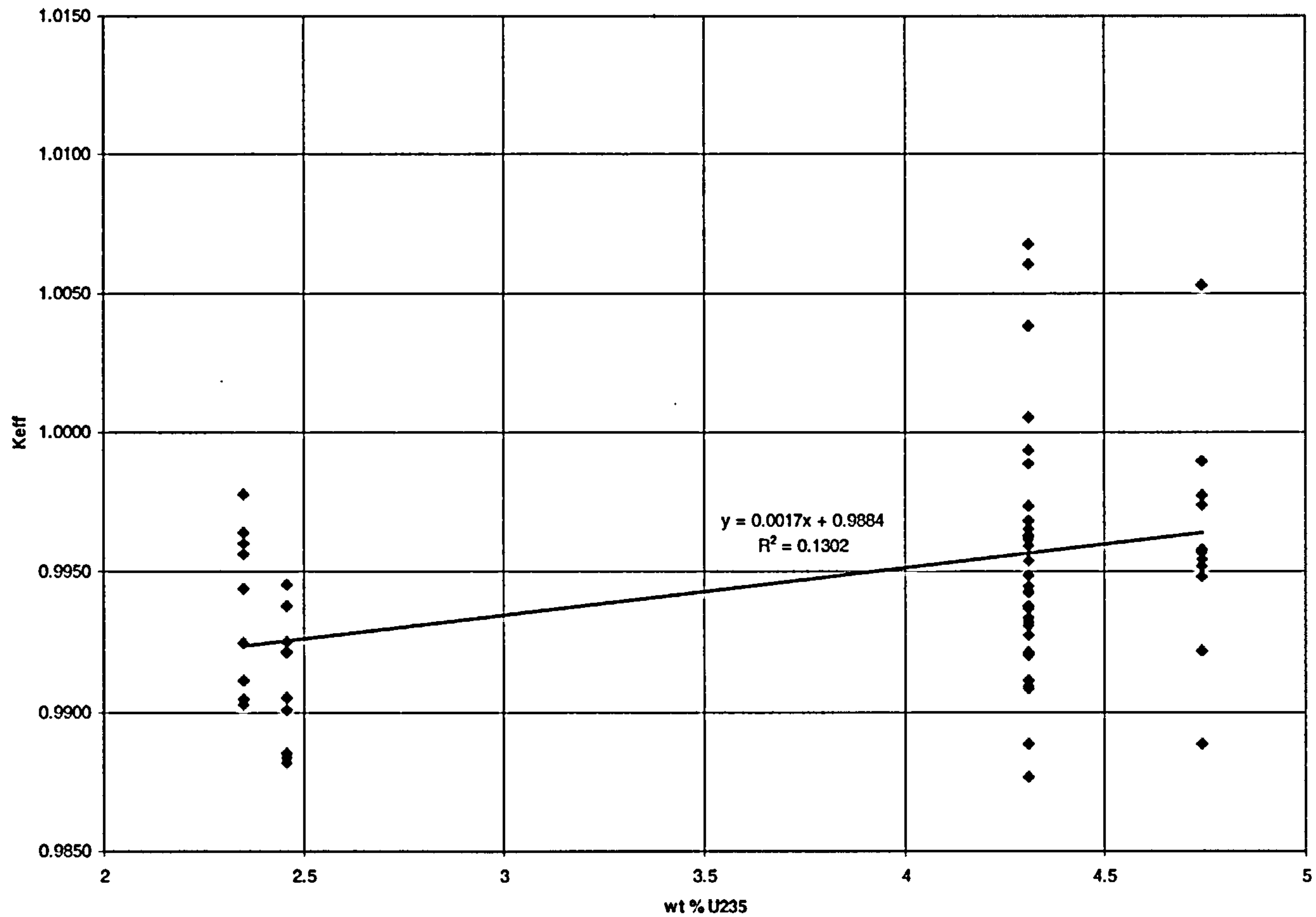


Figure 6.5.1-3 KENO-Va Validation—27-Group Library Results: k_{eff} versus Rod Pitch

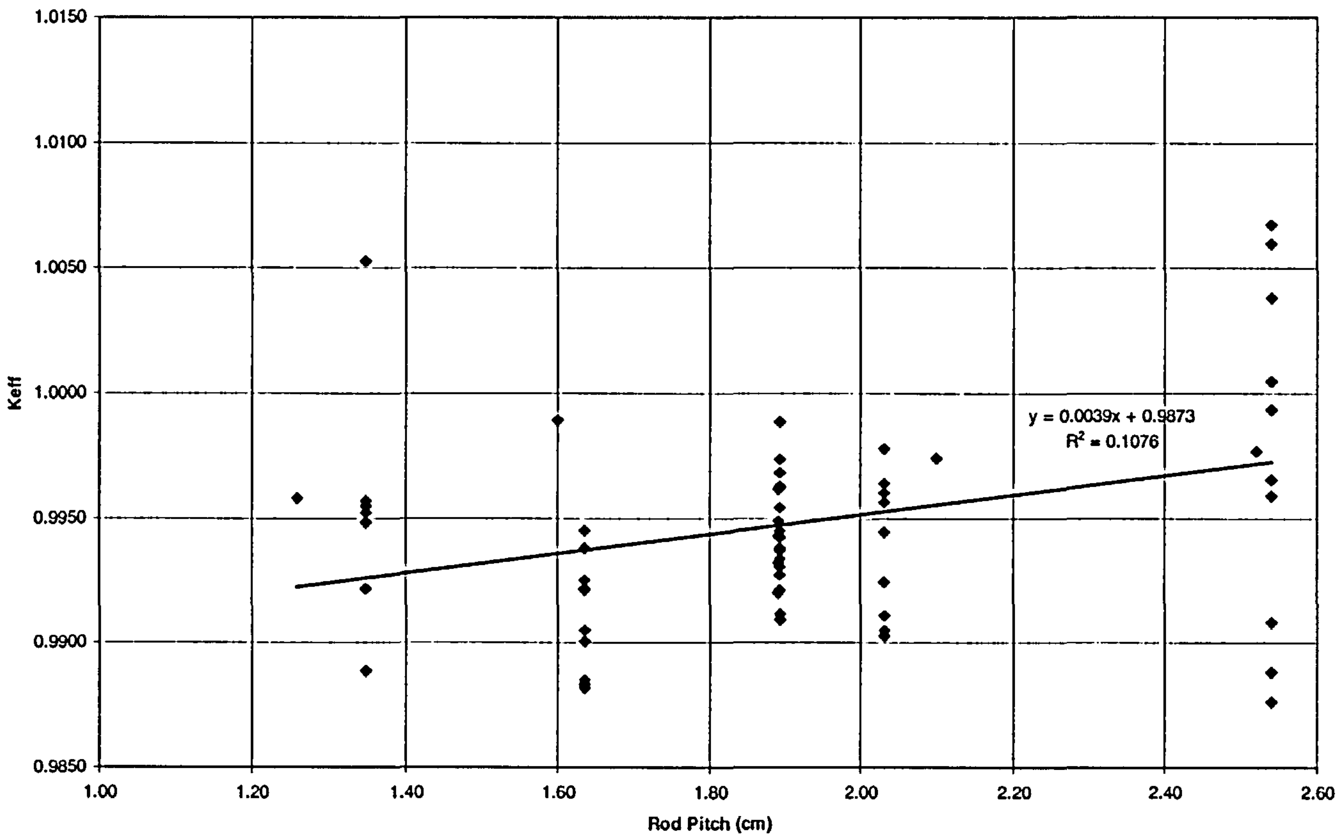


Figure 6.5.1-4 KENO-Va Validation—27-Group Library Results: k_{eff} versus H/U Volume Ratio

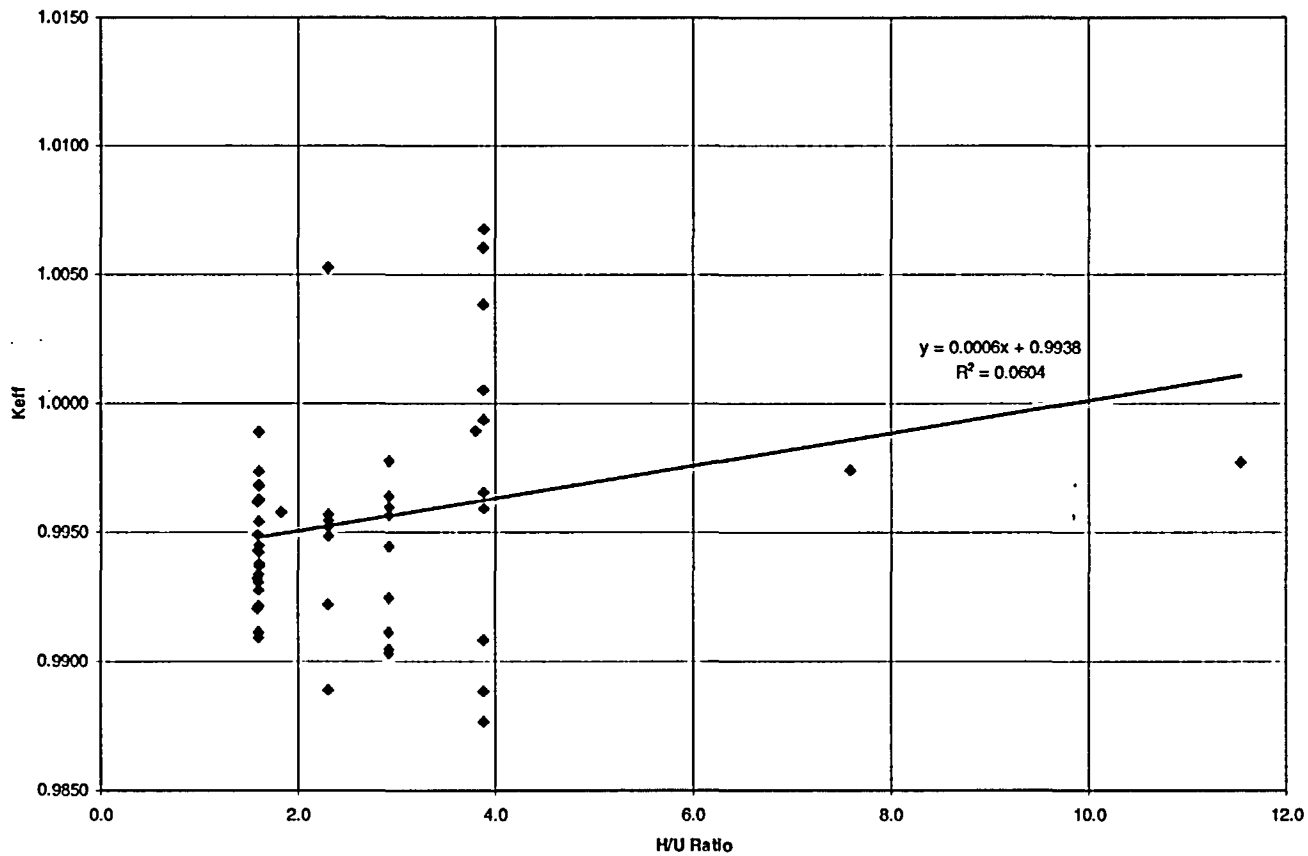


Figure 6.5.1-5 KENO-Va Validation—27-Group Library Results: k_{eff} versus Average Group of Fission

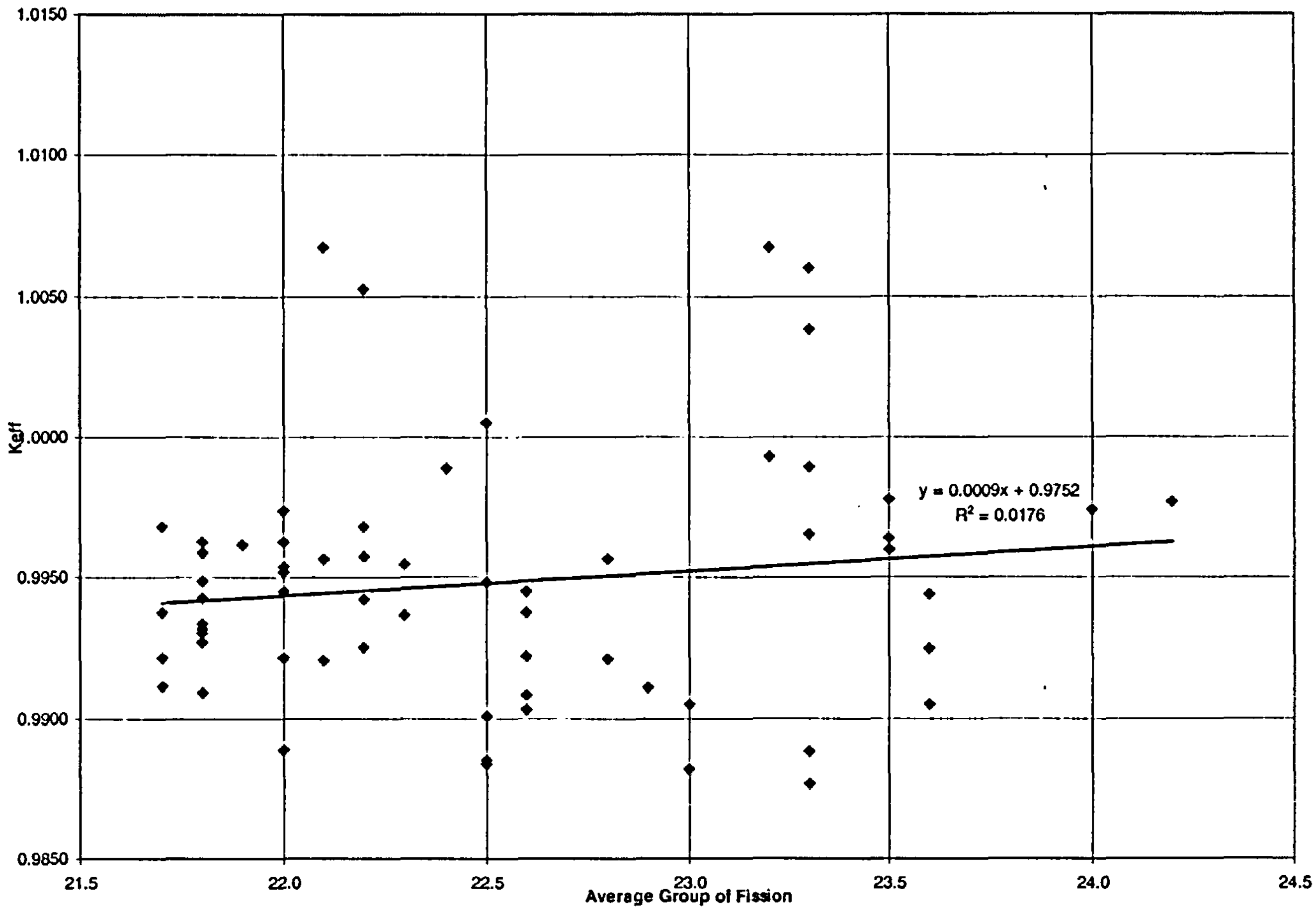


Figure 6.5.1-6 KENO-Va Validation—27-Group Library Results: k_{eff} versus ^{10}B Loading for Flux Trap Criticals

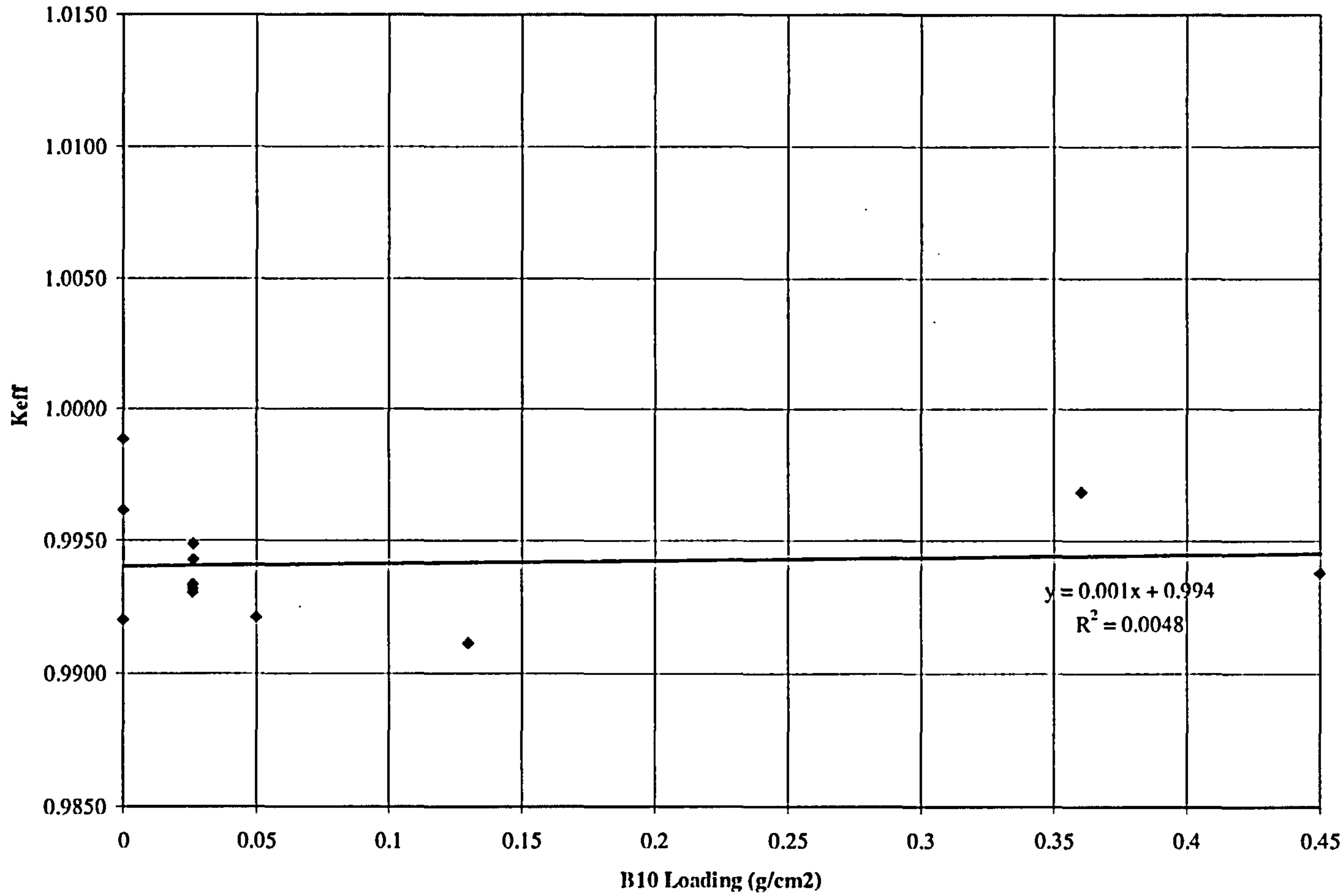


Figure 6.5.1-7 KENO-Va Validation—27-Group Library Results: k_{eff} versus Flux Trap Critical Gap Thickness

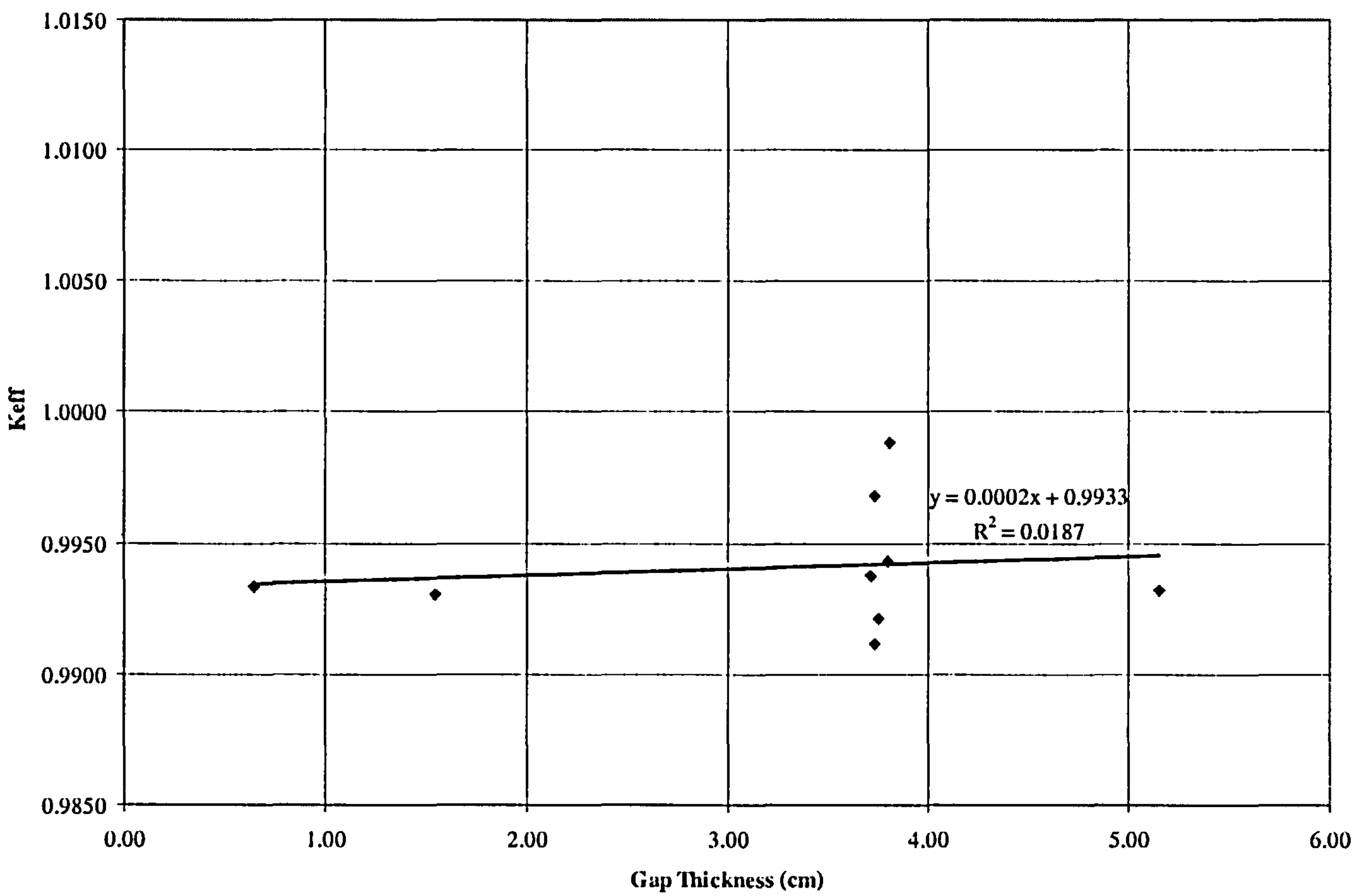


Figure 6.5.1-8 USLSTATS Output for Fuel Enrichment Study

```
uslstats: a utility to calculate upper subcritical
limits for criticality safety applications

****************************************************************************
Version 1.3.4, February 12, 1998
Oak Ridge National Laboratory
****************************************************************************

Input to statistical treatment from file:EN_KEFF.TXT

Title: 63 LWR CRITICAL EXPERIMENT KEFF VS ENRICHMENT

Proportion of the population = .995
Confidence of fit            = .950
Confidence on proportion     = .950
Number of observations       =  63
Minimum value of closed band =   0.00
Maximum value of closed band =   0.00
Administrative margin        =   0.05
```

independent variable - x	dependent variable - y	deviation in y	independent variable - x	dependent variable - y	deviation in y
2.35000E+00	9.96400E-01	1.00000E-03	4.31000E+00	9.96500E-01	1.10000E-03
2.35000E+00	9.94400E-01	1.00000E-03	4.31000E+00	1.00680E+00	2.10000E-03
2.35000E+00	9.90500E-01	1.00000E-03	4.31000E+00	1.00380E+00	1.20000E-03
2.35000E+00	9.96000E-01	1.10000E-03	4.31000E+00	9.88900E-01	1.10000E-03
2.35000E+00	9.97800E-01	1.00000E-03	4.31000E+00	9.95900E-01	1.10000E-03
2.35000E+00	9.92500E-01	1.00000E-03	4.31000E+00	1.00670E+00	1.00000E-03
2.35000E+00	9.90300E-01	9.00000E-04	4.31000E+00	1.00050E+00	1.10000E-03
2.35000E+00	9.95700E-01	1.00000E-03	4.31000E+00	9.90800E-01	1.10000E-03
2.35000E+00	9.91100E-01	1.00000E-03	4.31000E+00	9.98900E-01	1.20000E-03
2.46000E+00	9.92100E-01	1.10000E-03	4.31000E+00	9.92100E-01	1.20000E-03
2.46000E+00	9.92500E-01	9.00000E-04	4.31000E+00	9.91100E-01	1.20000E-03
2.46000E+00	9.93800E-01	9.00000E-04	4.31000E+00	9.96800E-01	1.30000E-03
2.46000E+00	9.90500E-01	1.00000E-03	4.31000E+00	9.93800E-01	1.20000E-03
2.46000E+00	9.88200E-01	1.00000E-03	4.31000E+00	9.93400E-01	1.00000E-03
2.46000E+00	9.94500E-01	1.00000E-03	4.31000E+00	9.93100E-01	1.00000E-03
2.46000E+00	9.92200E-01	1.00000E-03	4.31000E+00	9.94300E-01	1.00000E-03
2.46000E+00	9.88500E-01	1.00000E-03	4.31000E+00	9.93200E-01	1.00000E-03
2.46000E+00	9.88400E-01	1.00000E-03	4.31000E+00	9.94900E-01	1.00000E-03
2.46000E+00	9.90100E-01	9.00000E-04	4.31000E+00	9.92000E-01	1.00000E-03
4.31000E+00	9.95400E-01	1.40000E-03	4.31000E+00	9.96200E-01	1.00000E-03
4.31000E+00	9.94500E-01	1.30000E-03	4.74000E+00	9.92200E-01	1.30000E-03
4.31000E+00	9.97400E-01	1.30000E-03	4.74000E+00	9.88900E-01	1.30000E-03
4.31000E+00	9.96300E-01	1.30000E-03	4.74000E+00	9.95700E-01	1.30000E-03
4.31000E+00	9.92700E-01	1.20000E-03	4.74000E+00	1.00530E+00	1.10000E-03
4.31000E+00	9.90900E-01	1.20000E-03	4.74000E+00	9.95500E-01	1.20000E-03
4.31000E+00	9.96200E-01	1.20000E-03	4.74000E+00	9.94800E-01	1.30000E-03
4.31000E+00	9.93700E-01	1.30000E-03	4.74000E+00	9.95800E-01	1.20000E-03
4.31000E+00	9.94200E-01	1.20000E-03	4.74000E+00	9.95200E-01	1.20000E-03
4.31000E+00	9.96800E-01	1.20000E-03	4.74000E+00	9.98900E-01	1.30000E-03
4.31000E+00	9.87700E-01	2.30000E-03	4.74000E+00	9.97400E-01	1.20000E-03
4.31000E+00	9.99300E-01	1.20000E-03	4.74000E+00	9.97700E-01	1.10000E-03
4.31000E+00	1.00600E+00	2.20000E-03			

```
chi =  2.1587 (upper bound = 9.49). The data tests normal.

Output from statistical treatment

63 LWR CRITICAL EXPERIMENT KEFF VS ENRICHMENT

Number of data points (n)                       63
Linear regression, k(X)                       0.9884 + ( 1.6748E-03)*X
Confidence on fit (1-gamma) [input]             95.0%
Confidence on proportion (alpha) [input]        95.0%
Proportion of population falling above
lower tolerance interval (rho) [input]          99.5%
Minimum value of X                                2.3500
Maximum value of X                                4.7400
Average value of X                                3.81143
```

Figure 6.5.1-8 USLSTATS Output for Fuel Enrichment Study (Continued)

```
Average value of k                                 0.99482
Minimum value of k                                 0.98770
Variance of fit, s(k,X)^2                         1.6973E-05
Within variance, s(w)^2                           1.4306E-06
Pooled variance, s(p)^2                           1.8404E-05
Pooled std. deviation, s(p)                       4.2900E-03
C(alpha,rho)*s(p)                                 1.5488E-02
student-t @ (n-2,1-gamma)                         1.67078E+00
Confidence band width, W                          7.3606E-03
Minimum margin of subcriticality, C*s(p)-W        8.1273E-03

Upper subcritical limits: (  2.35000 <= X <=   4.74000)
***** *********** *******

USL Method 1 (Confidence Band with
Administrative Margin)             USL1 = 0.9311 + ( 1.6748E-03)*X

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)    USL2 = 0.9729 + ( 1.6748E-03)*X


USLs Evaluated Over Range of Parameter X:
**** ********* **** ***** ** ********* **

X:    2.35   2.69   3.03   3.37   3.72   4.06   4.40   4.74
---------------------------------------------------------
USL-1:  0.9350 0.9356 0.9362 0.9367 0.9373 0.9379 0.9384 0.9390
USL-2:  0.9769 0.9775 0.9780 0.9786 0.9792 0.9797 0.9803 0.9809
---------------------------------------------------------

**************************************************************************
Thus spake USLSTATS
Finis.
```

Table 6.5.1-1 KENO-Va and 27-Group Library Validation Statistics

Criticals	Configuration	wt % ^{235}U	Pitch (cm)	Pellet OD (cm)	Clad OD (cm)	H/U	Sol. Boron (ppm)	Poison	B^{10}/cm^2 (gm)	Gap (cm)	Gap Density (gm/cm^3)	Ave. Group Fission	k_{eff}	σ
Set 1										Gap				
B&W-I	Cylindrical	2.46	1.636	1.03	1.206	1.6	0	na	na	0	na	22.8	0.9921	0.0011
B&W-II	3x3-14x14	2.46	1.636	1.03	1.206	1.6	1037	na	na	0	na	22.2	0.9925	0.0009
B&W-III	3x3-14x14	2.46	1.636	1.03	1.206	1.6	764	na	na	1.636	0.9982	22.6	0.9938	0.0009
B&W-IX	3x3-14x14	2.46	1.636	1.03	1.206	1.6	0	na	na	6.543	0.9982	23	0.9905	0.0010
B&W-X	3x3-14x14	2.46	1.636	1.03	1.206	1.6	143	na	na	4.907	0.9982	23	0.9882	0.0010
B&W-XI	3x3-14x14	2.46	1.636	1.03	1.206	1.6	514	Steel	0	1.636	0.9982	22.6	0.9945	0.0010
B&W-XIII	3x3-14x14	2.46	1.636	1.03	1.206	1.6	15	B-Al	0.0052	1.636	0.9982	22.6	0.9922	0.0010
B&W-XIV	3x3-14x14	2.46	1.636	1.03	1.206	1.6	92	B-Al	0.0040	1.636	0.9982	22.5	0.9885	0.0010
B&W-XVII	3x3-14x14	2.46	1.636	1.03	1.206	1.6	487	B-Al	0.0008	1.636	0.9982	22.5	0.9884	0.0010
B&W-XIX	3x3-14x14	2.46	1.636	1.03	1.206	1.6	634	B-Al	0.0003	1.636	0.9982	22.5	0.9901	0.0009
												Average	0.9911	0.0023

Table 6.5.1-1 KENO-Va and 27-Group Library Validation Statistics (Continued)

Criticals Set 2	Configuration	wt % ^{235}U	Pitch (cm)	Pellet OD (cm)	Clad OD (cm)	H/U	Sol. Boron (ppm)	Poison	B^{10}/cm^2 (gm)	Gap (cm)	Gap Density (gm/cm^3)	Ave. Group Fission	k_{eff}	σ
PNL-043	17×13 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9954	0.0014
PNL-044	16×14 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9945	0.0013
PNL-045	14×16 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9974	0.0013
PNL-046	12×19 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9963	0.0013
PNL-087	4 11×14 Arrays	4.31	1.892	1.415	1.265	1.6	0	BORAL	0.066	2.83	0.9982	21.8	0.9927	0.0012
PNL-079	4 11×14 Arrays	4.31	1.892	1.415	1.265	1.6	0	BORAL	0.030	2.83	0.9982	21.8	0.9909	0.0012
PNL-093	4 11×14 Arrays	4.31	1.892	1.415	1.265	1.6	0	BORAL	0.026	2.83	0.9982	21.8	0.9962	0.0012
PNL-115	4 9×12 Arrays	4.31	1.892	1.415	1.265	1.6	0	Aluminum	0	2.83	0.9982	22.3	0.9937	0.0013
PNL-064	4 9×12 Arrays	4.31	1.892	1.415	1.265	1.6	0	Steel (.302)	0	2.83	0.9982	22.2	0.9942	0.0012
PNL-071	4 9×12 Arrays	4.31	1.892	1.415	1.265	1.6	0	Steel (.485)	0	2.83	0.9982	22.2	0.9968	0.0012
												Average	0.9948	0.0020

Table 6.5.1-1 KENO-Va and 27-Group Library Validation Statistics (Continued)

Criticals Set 3	Configura-tion	wt % ^{235}U	Pitch (cm)	Pellet OD (cm)	Clad OD (cm)	H/U	Sol. Boron (ppm)	Poison	B^{10}/cm^2 (gm)	Gap Cluster (cm)	Gap Wall/ Cluster (cm)	Ave. Group Fission	k_{eff}	σ
PNL-STA	3×1 St Refl.	2.35	2.032	1.1176	1.27	2.9	0	na	na	10.65	0.00	23.5	0.9964	0.0010
PNL-STB	3×1 St Refl.	2.35	2.032	1.1176	1.27	2.9	0	na	na	11.20	1.32	23.6	0.9944	0.0010
PNL-STC	3×1 St Refl.	2.35	2.032	1.1176	1.27	2.9	0	na	na	10.36	2.62	23.6	0.9905	0.0010
PNL-PBA	3×1 Pb Refl.	2.35	2.032	1.1176	1.27	2.9	0	na	na	13.84	0.00	23.5	0.9960	0.0011
PNL-PBB	3×1 Pb Refl.	2.35	2.032	1.1176	1.27	2.9	0	na	na	13.72	0.66	23.5	0.9978	0.0010
PNL_PBC	3×1 Pb Refl.	2.35	2.032	1.1176	1.27	2.9	0	na	na	11.25	2.62	23.6	0.9925	0.0010
PNL-DUA	3×1 DU Refl.	2.35	2.032	1.1176	1.27	2.9	0	na	na	11.83	0.00	22.6	0.9903	0.0009
PNL-DUB	3×1 DU Refl.	2.35	2.032	1.1176	1.27	2.9	0	na	na	14.11	1.96	22.8	0.9957	0.0010
PNL-DUC	3×1 DU Refl.	2.35	2.032	1.1176	1.27	2.9	0	na	na	13.70	2.62	22.9	0.9911	0.0010

Table 6.5.1-1 KENO-Va and 27-Group Library Validation Statistics (Continued)

Criticals	Configura-tion	wt % ^{235}U	itch (cm)	Pellet OD (cm)	Clad OD (cm)	H/U	Sol. Boron (ppm)	Poison	B^{10}/cm^2 (gm)	Gap (cm)	Gap (cm)	Ave. Group Fission	k_{eff}	σ
Set 3 (Contd.)										Cluster	Wall/ Cluster			
PNL-H20	3x1 H2O Refl	4.31	2.54	1.265	1.415	3.9	0	na	na	8.24	inf	23.3	0.9877	0.0023
PNL-ST0	3x1 St Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	12.89	0	23.2	0.9993	0.0012
PNL-ST1	3x1 St Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	14.12	1.32	23.3	1.0060	0.0022
PNL-ST26	3x1 St Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	12.44	2.62	23.3	0.9965	0.0011
PNL-PB0	3x1 Pb Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	20.62	0	23.2	1.0068	0.0021
PNL-PB13	3x1 Pb Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	19.04	1.32	23.3	1.0038	0.0012
PNL-PB5	3x1 Pb Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	10.3	5.41	23.3	0.9889	0.0011
PNL-DU0	3x1 DU Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	15.38	0	21.8	0.9959	0.0011
PNL-DU13	3x1 DU Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	19.04	1.32	22.1	1.0067	0.0010
PNL-DU39	3x1 DU Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	18.05	3.91	22.5	1.0005	0.0011
PNL-DU54	3x1 DU Refl.	4.31	2.54	1.265	1.415	3.9	0	na	na	13.49	5.41	22.6	0.9908	0.0011
												Average	0.9964	0.0060

Table 6.5.1-1 KENO-Va and 27-Group Library Validation Statistics (Continued)

Criticals	Configuration	wt % U^{235}	Pitch (cm)	Pellet OD (cm)	Clad OD (cm)	H/U	Sol. Boron (ppm)	Poison	B^{10}/cm^2 (gm)	Gap (cm)	Gap Density (gm/cm^3)	Ave. Group Fission	k_{eff}	σ
Set 4														
PNL-229	2x2 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Aluminum	0	3.81	0.9982	22.4	0.9989	0.0012
PNL-230	2x2 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Neutron Absorber	0.05	3.75	0.9982	21.7	0.9921	0.0012
PNL-228	2x2 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Neutron Absorber	0.13	3.73	0.9982	21.7	0.9911	0.0012
PNL-214	2x2 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Neutron Absorber	0.36	3.73	0.9982	21.7	0.9968	0.0013
PNL-231	2x2 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Neutron Absorber	0.45	3.71	0.9982	21.7	0.9938	0.0012
PNL-127	2x1 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Neutron Absorber	0.026	0.64	0.9982	21.8	0.9934	0.0010
PNL-126	2x1 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Neutron Absorber	0.026	1.54	0.9982	21.8	0.9931	0.0010
PNL-123	2x1 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Neutron Absorber	0.026	3.80	0.9982	21.8	0.9943	0.0010
PNL-125	2x1 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Neutron Absorber	0.026	5.16	0.9982	21.8	0.9932	0.0010
PNL-124	2x1 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Neutron Absorber	0.026	INF	0.9982	21.8	0.9949	0.0010
PNL-123-S	2x1 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Steel	0	3.80	0.9982	22.1	0.9920	0.0010
PNL-124-S	2x1 Flux Trap	4.31	1.89	1.265	1.415	1.6	0	Steel	0	INF	0.9982	21.9	0.9962	0.0010
												Average	0.9941	0.0022

Table 6.5.1-1 KENO-Va and 27-Group Library Validation Statistics (Continued)

Criticals	Configuration	wt % U^{235}	Pitch (cm)	Pellet OD (cm)	Clad OD (cm)	H/U	Sol. Boron (ppm)	Poison	B^{10}/cm^2 (gm)	Gap (cm)	Gap Density (gm/cm^3)	Ave. Group Fission	k_{eff}	σ
Set 5														
VCML	2x2 Water Gap	4.74	1.35	0.79	0.94	2.3	0	na	na	1.90	0	22.0	0.9922	0.0013
VCML	2x2 Water Gap	4.74	1.35	0.79	0.94	2.3	0	na	na	1.90	0.0323	22.0	0.9889	0.0013
VCML	2x2 Water Gap	4.74	1.35	0.79	0.94	2.3	0	na	na	1.90	0.2879	22.1	0.9957	0.0013
VCML	2x2 Water Gap	4.74	1.35	0.79	0.94	2.3	0	na	na	1.90	0.5540	22.2	1.0053	0.0011
VCML	2x2 Water Gap	4.74	1.35	0.79	0.94	2.3	0	na	na	2.50	0.9982	22.3	0.9955	0.0012
VCML	2x2 Water Gap	4.74	1.35	0.79	0.94	2.3	0	na	na	5.00	0.9982	22.5	0.9948	0.0013
VCML	Square Lattice	4.74	1.26	0.79	0.94	1.8	0	na	na	na	na	22.2	0.9958	0.0012
VCML	Square Lattice	4.74	1.35	0.79	0.94	2.3	0	na	na	na	na	22.0	0.9952	0.0012
VCML	Square Lattice	4.74	1.60	0.79	0.94	3.8	0	na	na	na	na	23.3	0.9989	0.0013
VCML	Square Lattice	4.74	2.10	0.79	0.94	7.6	0	na	na	na	na	24.0	0.9974	0.0012
VCML	Square Lattice	4.74	2.52	0.79	0.94	11.5	0	na	na	na	na	24.2	0.9977	0.0011
												Average	0.9961	0.0041

Table 6.5.1-2 SCALE 4.3 Correlation Coefficient for Linear Curve-Fit of Critical Benchmarks

Correlation Studied	Correlation Coefficient (R)
k_{eff} versus enrichment	0.361
k_{eff} versus rod pitch	0.328
k_{eff} versus H/U volume ratio	0.246
k_{eff} versus ^{10}B loading	0.069
k_{eff} versus average group causing fission	0.133
k_{eff} versus flux gap thickness	0.137

Table 6.5.1-3 SCALE 4.3 Range of Correlated Parameters of Most Reactive Configurations

Parameter	Benchmark Minimum Value	Benchmark Maximum Value	UMS® Design Basis PWR Fuel Most Reactive Configuration	Maine Yankee Fuel Most Reactive Configuration
Enrichment (wt. % ^{235}U)	2.35	4.74	4.2	4.2
Rod pitch (cm)	1.26	2.54	1.26	1.50
H/U volume ratio	1.6	11.5	1.9	2.6
^{10}B areal density (g/cm^2)	0.00	0.45	0.025	0.025
Average energy group causing fission	21.7	24.2	22.3	22.5
Flux gap thickness (cm)	0.64	5.16	2.2 to 3.8	2.22 to 3.8

6.5.2 MONK Validation in Accordance with NUREG/CR-6361

NUREG/CR-6361, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages" (NUREG), provides a guide to LWR criticality benchmark calculations and the determination of bias and subcritical limits in critical safety evaluations. Section 6.5.1.5 presents the implementation of the NUREG in subcritical limit evaluations for the UMS® storage and transfer casks. This section implements the USLSTATS method of the NUREG for MONK8A application with JEF 2.2 point energy libraries in LWR transport and storage applications.

SERCO Assurance has performed an extensive benchmarking of MONK8A. The cross-section set and key geometry features employed in the critical benchmark models are reflected in the UMS® cask evaluation models. Consequently, the SERCO produced critical benchmark models are applicable to the evaluation of the UMS® system. The critical benchmarks relevant to LWR fuel evaluations were extracted from the total benchmark set and listed in Table 6.5.2-3. The range of the parameters to be benchmarked is summarized in Table 6.5.2-1. Trending in k_{eff} was evaluated for the following independent variables: enrichment, rod pitch, fuel pellet diameter, fuel rod diameter, H/U ratio, average neutron group causing fission, ^{10}B plate loading for flux trap cases, flux trap gap thickness, and soluble boron concentration in the moderator. The data is plotted in Figures 6.5.2-1 through 6.5.2-9.

To evaluate the relative importance of the trend analysis to the upper safety limits, correlation coefficients are required for all independent parameters. Table 6.5.2-2 contains the correlation coefficient, R, for each linear fit of k_{eff} versus experimental parameter (data is extracted from Figure 6.5.2-1 through Figure 6.5.2-9 by taking the square root of the R^2 value). The k_{eff} versus soluble boron concentration in the moderator displays the most statistically significant correlation to system reactivity. The k_{eff} versus cluster (assembly) gap thickness displays the second most statistically significant correlation to system reactivity. Not all NAC criticality safety evaluations take credit for the soluble boron within the spent fuel pool water at PWR reactors. Based on NUREG/CR-6361 guidance, k_{eff} versus soluble boron concentration in the moderator and k_{eff} versus cluster gap thickness are, therefore, chosen to calculate the USL (Upper Safety Limit). Note that even the flux trap function shows a low statistical correlation coefficient (an $|R|$ equal or near 1 would indicate a good fit). The output generated by USLSTATS is shown in Figure 6.5.2-10. If no credit is taken for boron in the moderator and the maximum gap thickness is 3.5 inches, then the appropriate USL to use is 0.9426. However, if credit is taken for a boron concentration in the moderator of more than 298.2 ppm (by mass), then it is acceptable to apply a USL of 0.9441.

The NAC-applied USL is 0.9426, and bounds the calculated upper safety limits for the typical flux trap spacing found in multi-purpose casks and typical soluble boron concentrations within the spent fuel pool water at PWR reactors. The range of the correlated parameters of the most reactive design basis fuel is included in Table 6.5.2-1 to show that the most reactive configuration is within the range of applicability of the validation.

Figure 6.5.2-1 MONK8A – JEF 2.2 Library Validation Statistics – k_{eff} versus Fuel Enrichment

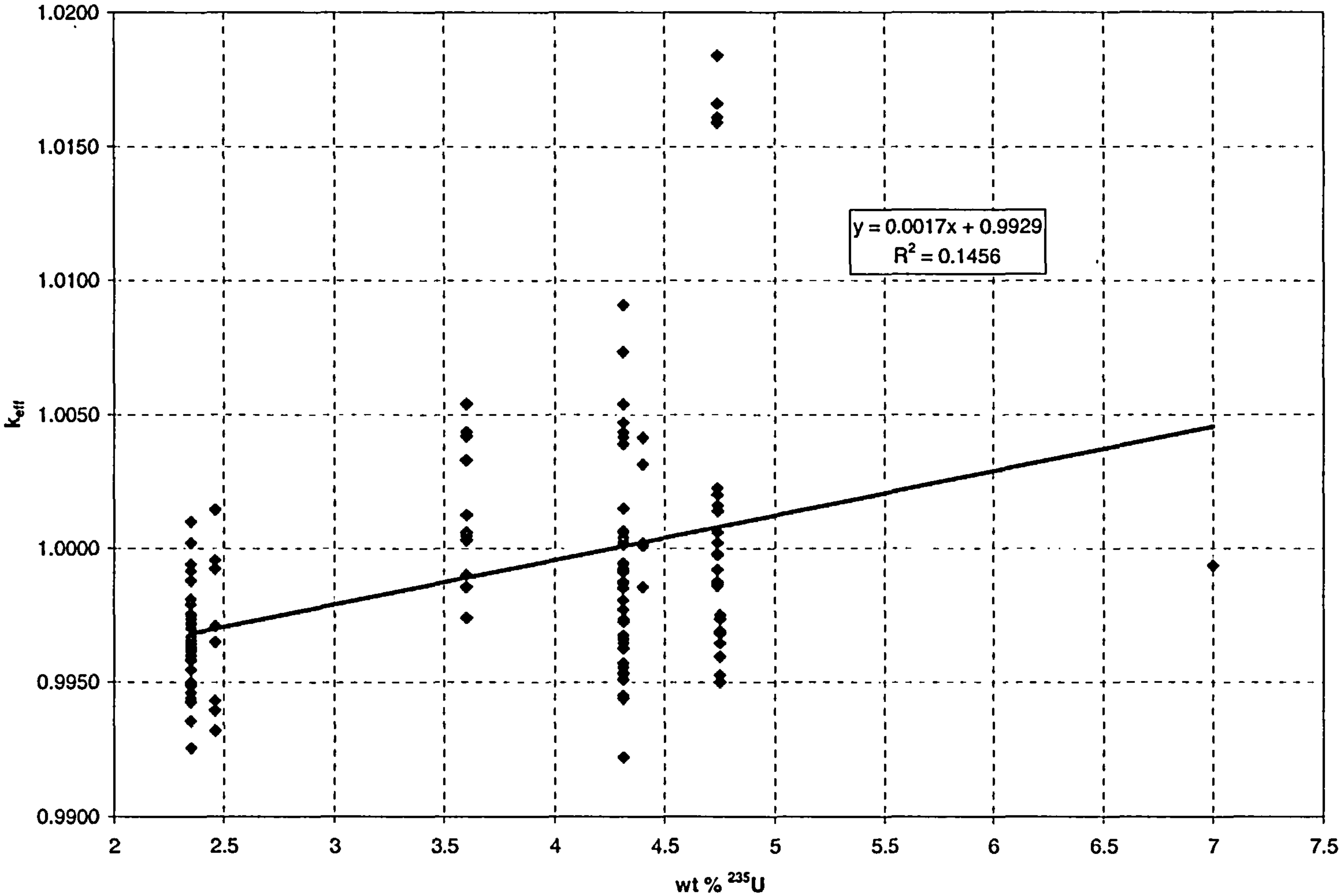


Figure 6.5.2-2 MONK8A – JEF 2.2 Library – k_{eff} versus Rod Pitch

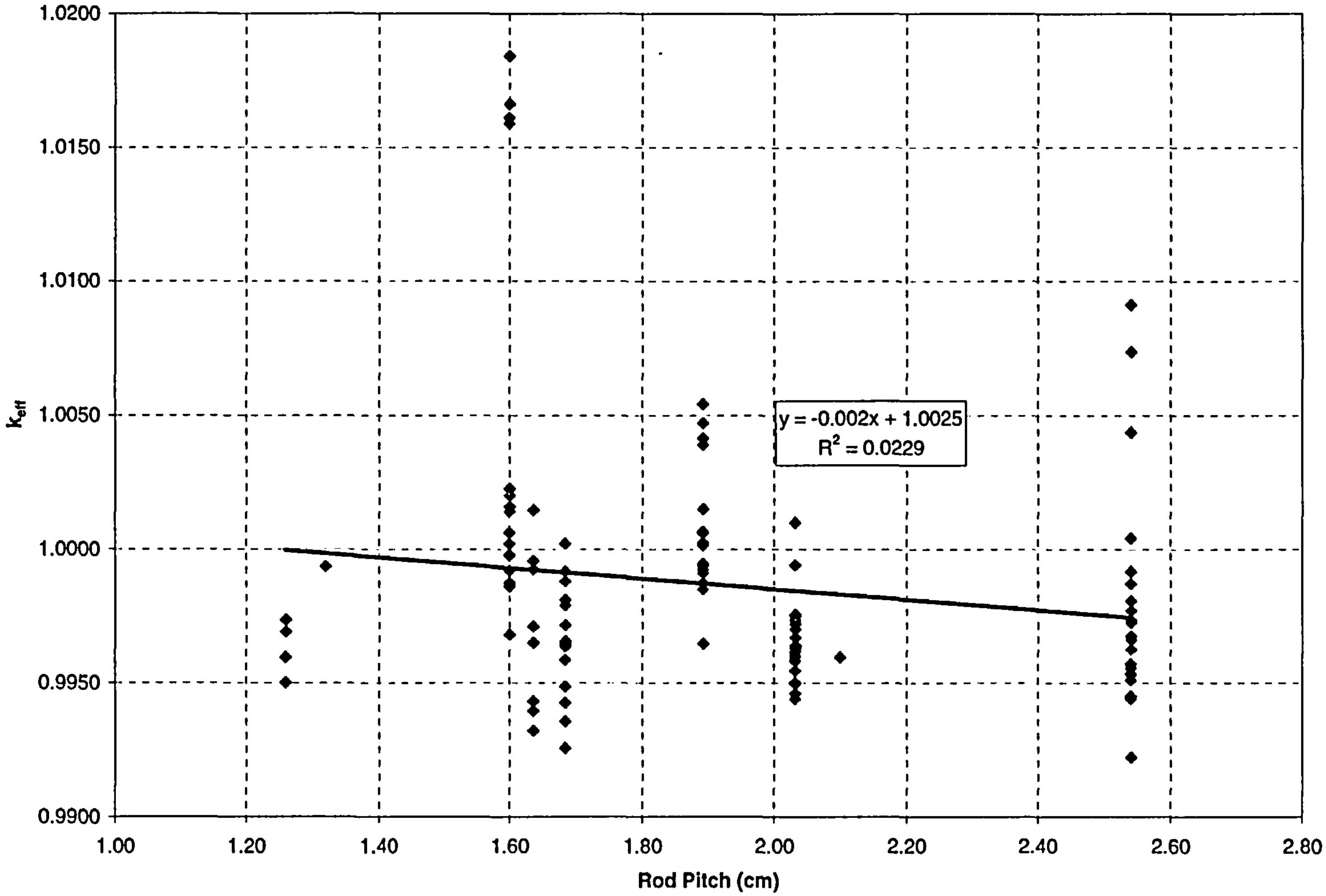


Figure 6.5.2-3 MONK8A – JEF 2.2 Library – k_{eff} versus H/U (fissile) Atom Ratio

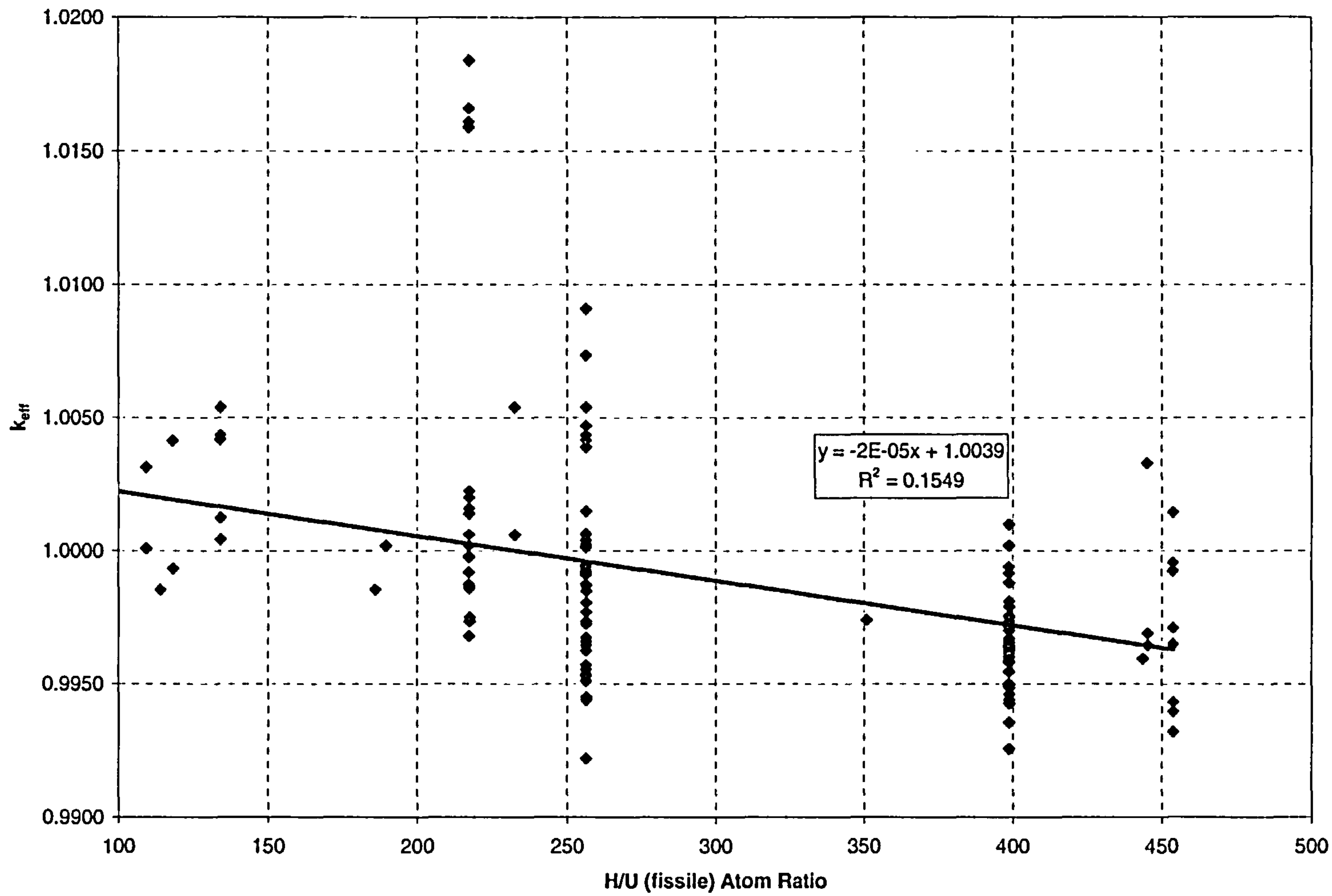


Figure 6.5.2-4 MONK8A – JEF 2.2 Library – k_{eff} versus ^{10}B Plate Loading

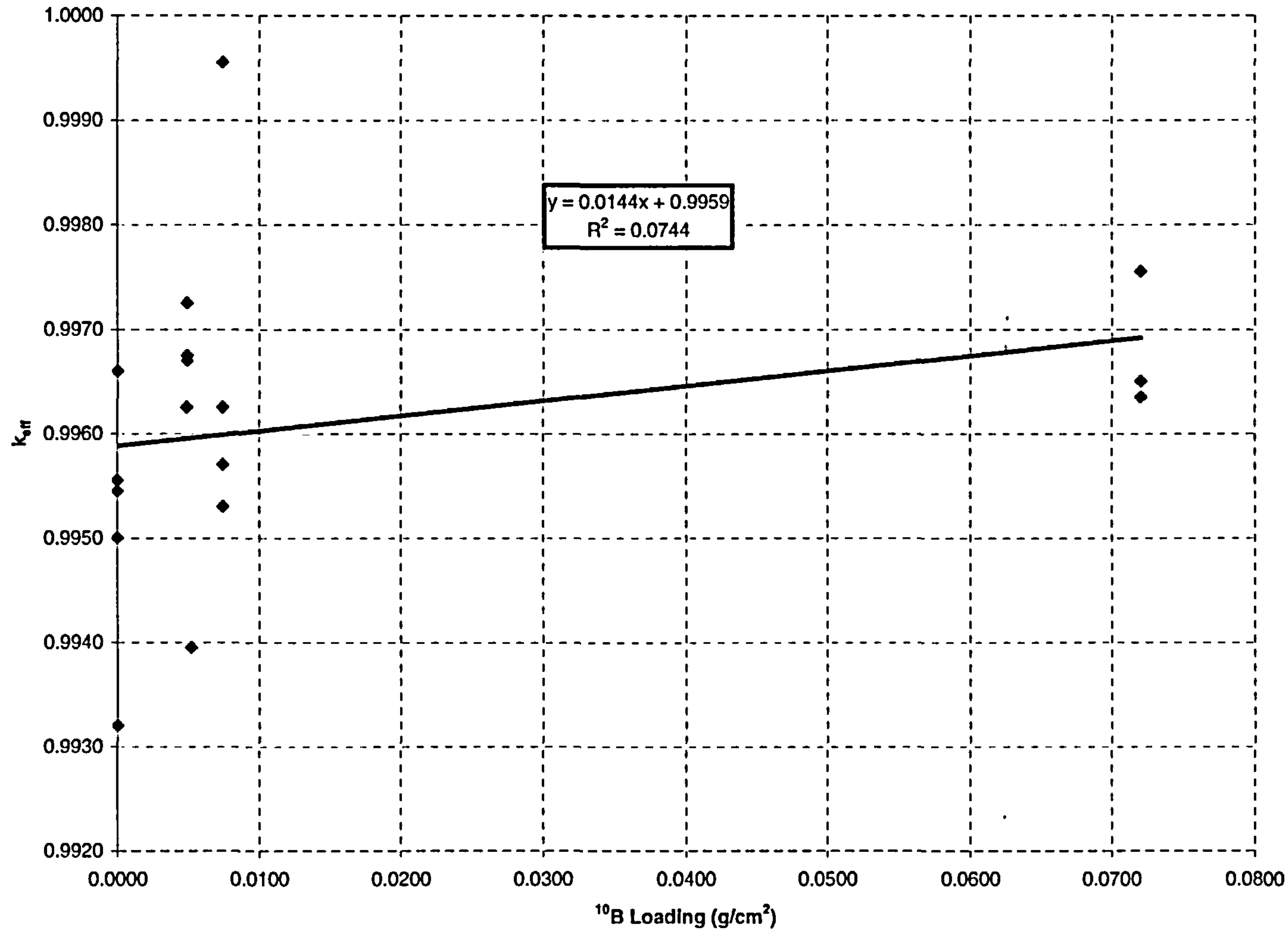


Figure 6.5.2-5 MONK8A – JEF 2.2 Library – k_{eff} versus Mean Neutron Log(E) Causing Fission

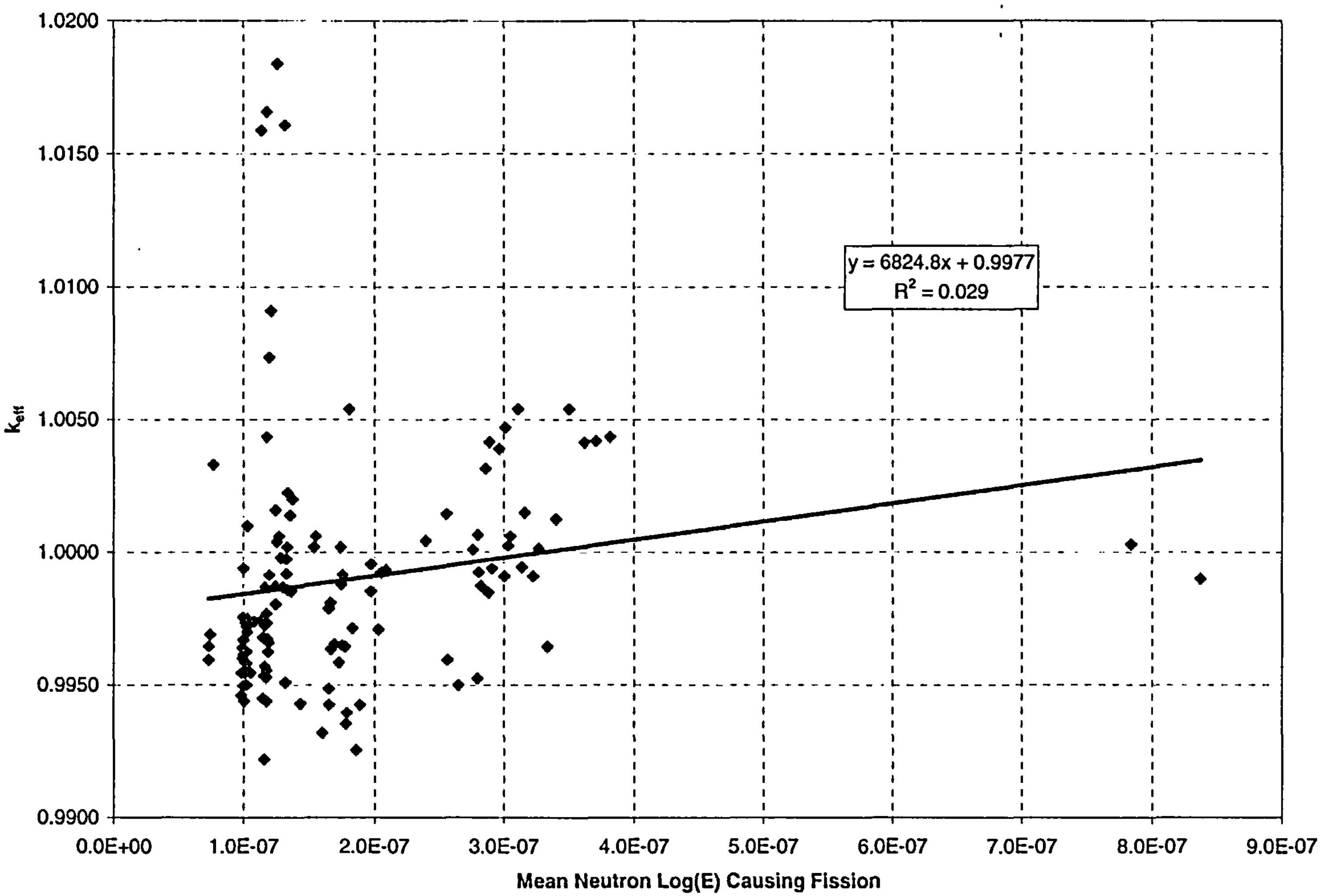


Figure 6.5.2-6 MONK8A – JEF 2.2 Library – k_{eff} versus Cluster Gap Thickness

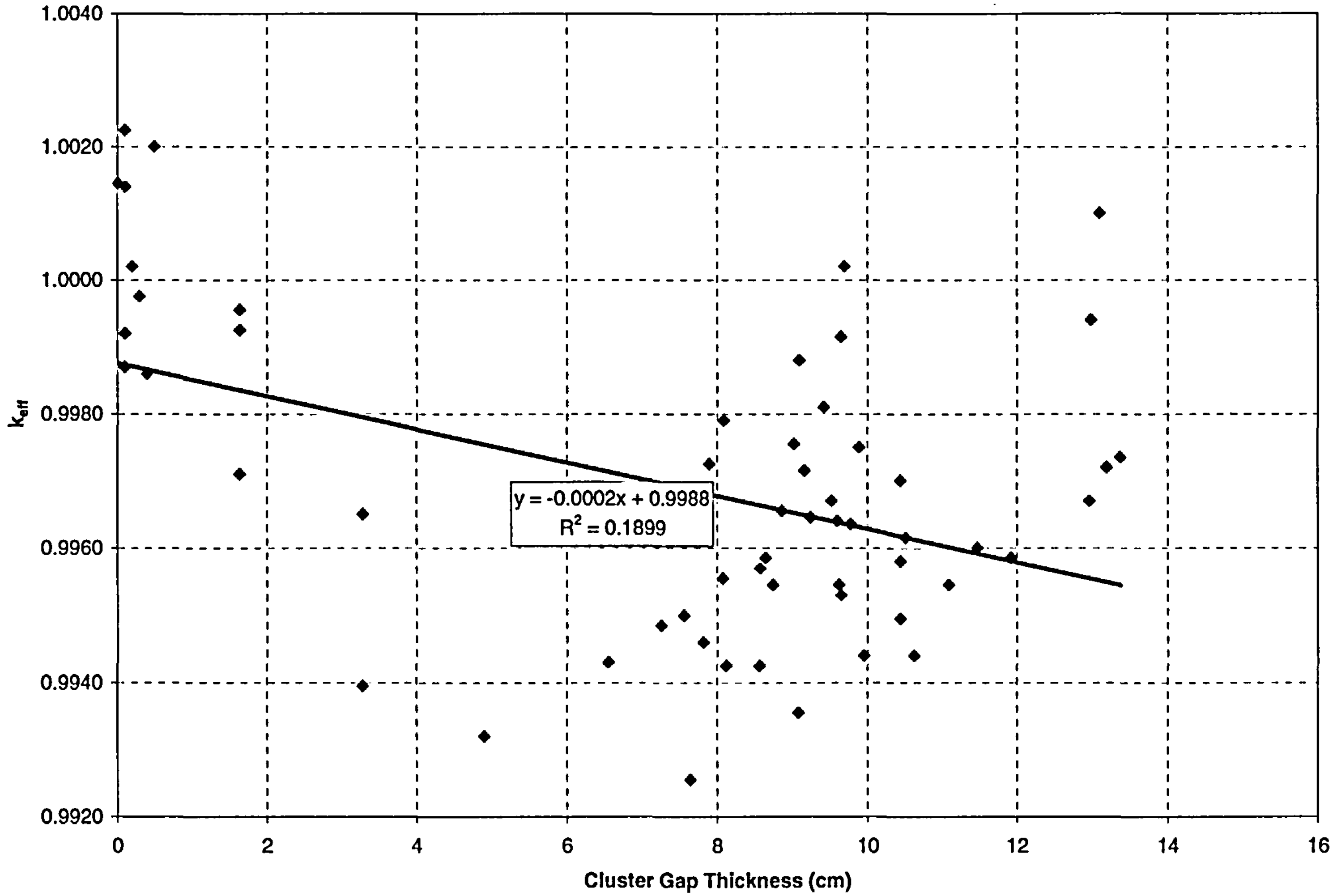


Figure 6.5.2-7 MONK8A – JEF 2.2 Library – k_{eff} versus Fuel Pellet Outside Diameter

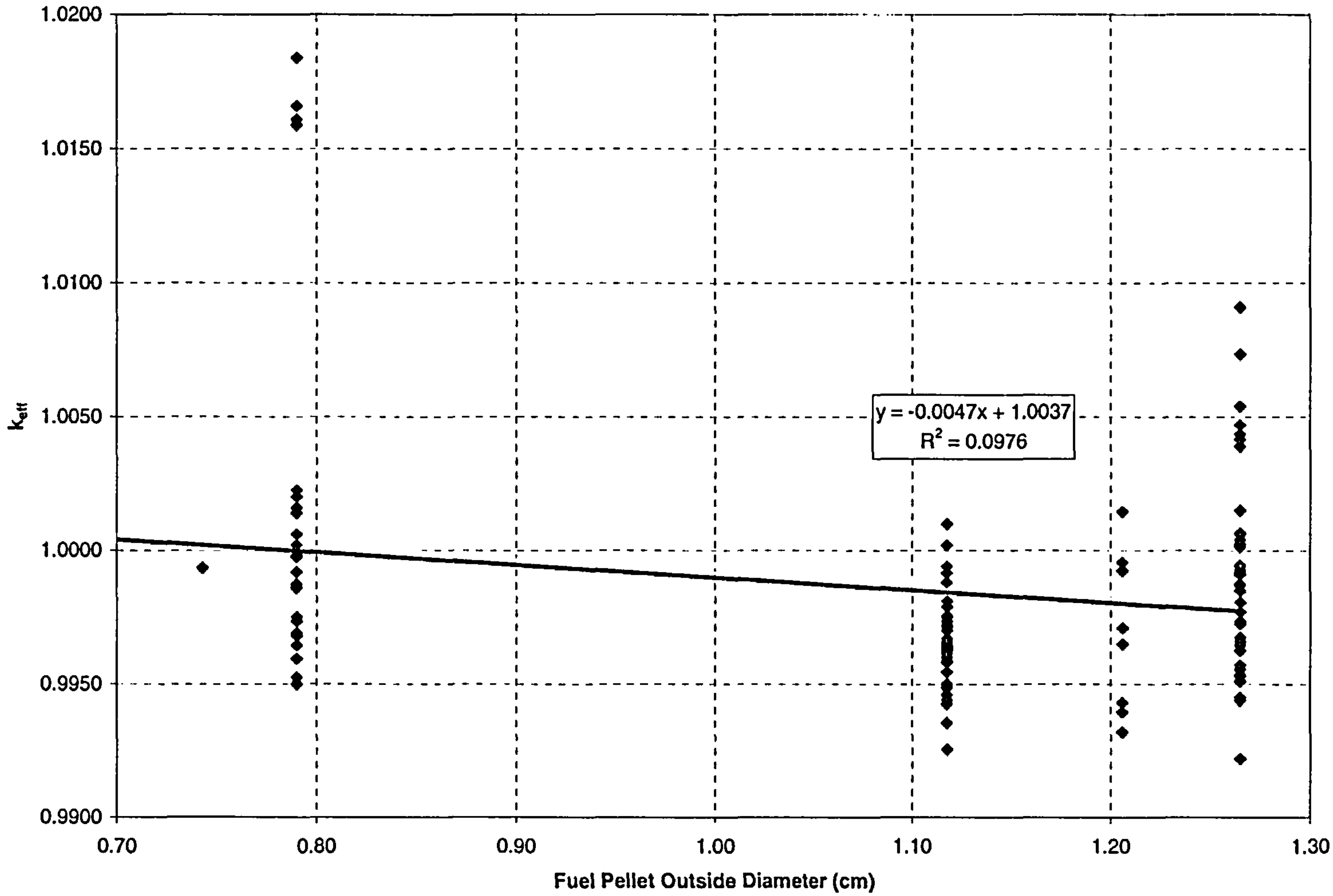


Figure 6.5.2-8 MONK8A – JEF 2.2 Library – k_{eff} versus Fuel Rod Outside Diameter

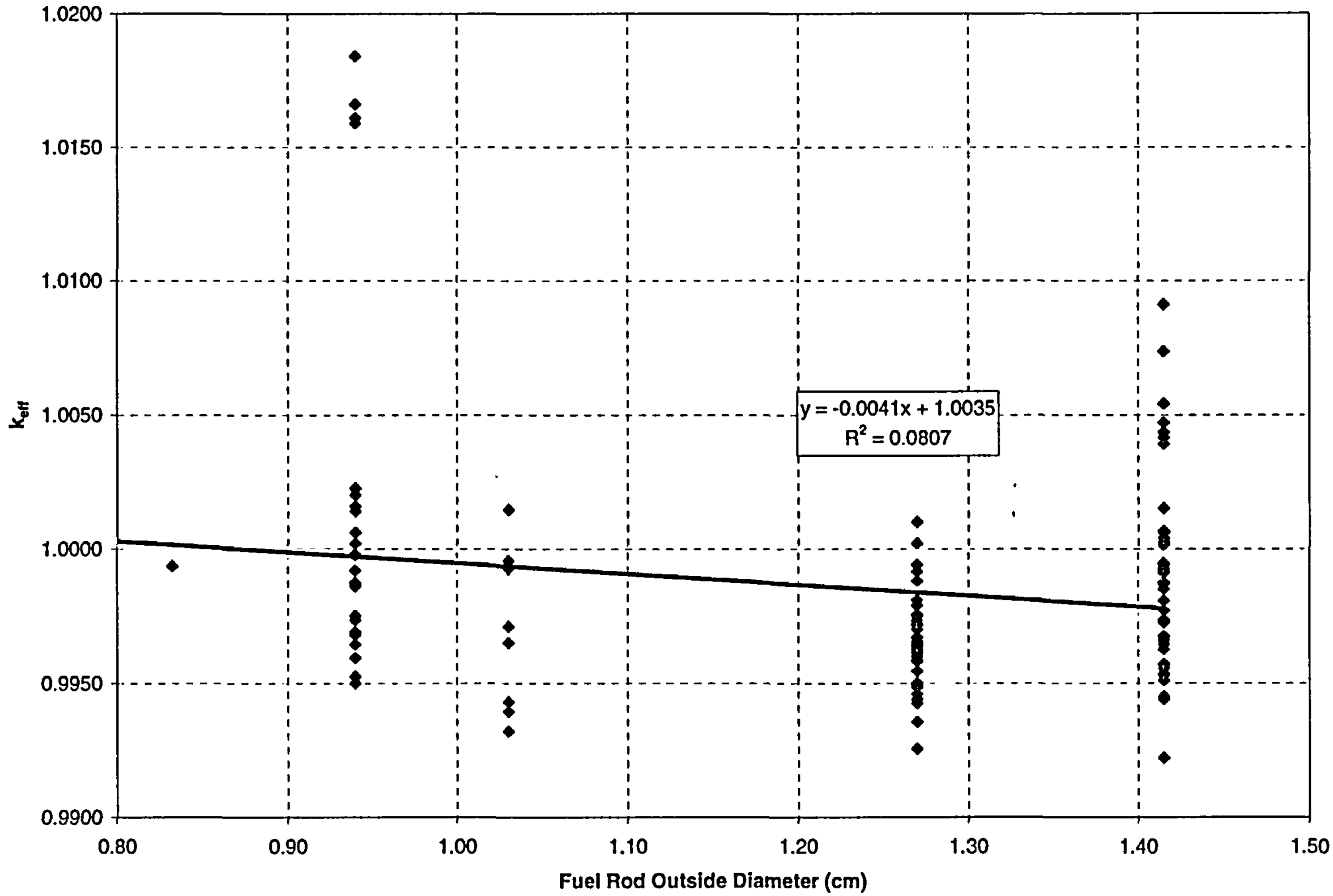


Figure 6.5.2-9 MONK8A – JEF 2.2 Library – k_{eff} versus Soluble Boron PPM in Moderator

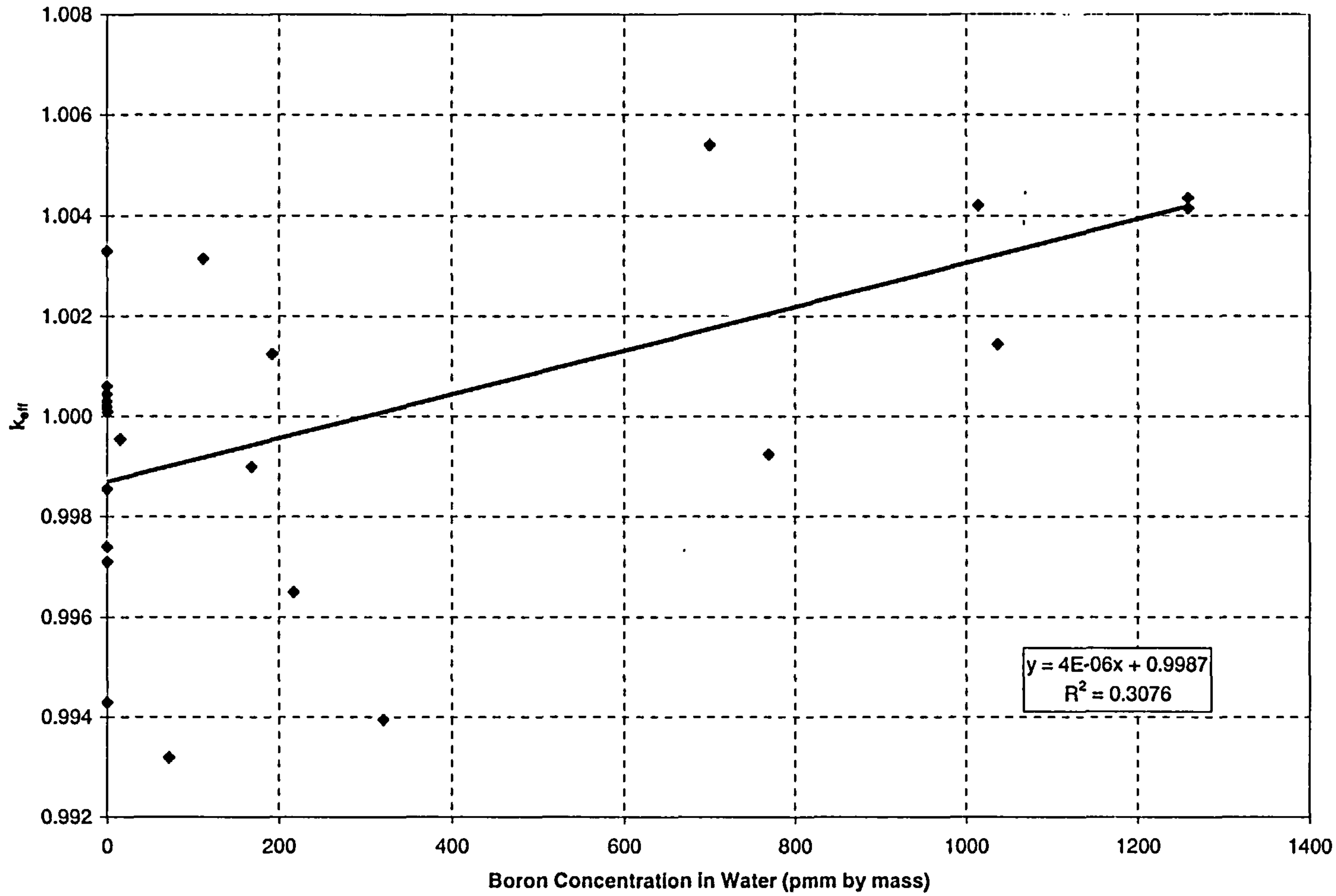


Figure 6.5.2-10 USLSTATS Output – k_{eff} versus Gap Thickness

```
uslstats: a utility to calculate upper subcritical
                   limits for criticality safety applications

  ******************************************************************
                     Version 1.3.4, February 12, 1998
                    Oak Ridge National Laboratory
  ******************************************************************

   Input to statistical treatment from file:Gap_keff.txt

Title: 62 Critical Experiment KEFFs VS Gap Thickness - Experiments 1, 3, 7, 17, & 40

   Proportion of the population = .995
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  62
   Minimum value of closed band =   0.00
   Maximum value of closed band =   0.00
   Administrative margin        =   0.05
```

independent variable - x	dependent variable - y	deviation in y	independent variable - x	dependent variable - y	deviation in y
6.33000E+00	9.96350E-01	1.00000E-03	1.29600E+01	9.96700E-01	1.00000E-03
9.03000E+00	9.97550E-01	1.00000E-03	9.95000E+00	9.94400E-01	1.00000E-03
1.04400E+01	9.94950E-01	1.00000E-03	7.82000E+00	9.94600E-01	1.00000E-03
1.14700E+01	9.96000E-01	1.00000E-03	9.89000E+00	9.97500E-01	1.00000E-03
7.56000E+00	9.95000E-01	1.00000E-03	1.04400E+01	9.97000E-01	1.00000E-03
9.62000E+00	9.95450E-01	1.00000E-03	1.04400E+01	9.95800E-01	1.00000E-03
7.36000E+00	9.96250E-01	1.00000E-03	9.60000E+00	9.96400E-01	1.00000E-03
9.52000E+00	9.96700E-01	1.00000E-03	8.75000E+00	9.95450E-01	1.00000E-03
1.19200E+01	9.95850E-01	1.00000E-03	8.57000E+00	9.94250E-01	1.00000E-03
1.06200E+01	9.94400E-01	1.00000E-03	9.17000E+00	9.97150E-01	1.00000E-03
8.58000E+00	9.95700E-01	1.00000E-03	9.10000E+00	9.98800E-01	1.00000E-03
9.65000E+00	9.95300E-01	1.00000E-03	9.25000E+00	9.96450E-01	1.00000E-03
6.10000E+00	9.96600E-01	1.00000E-03	8.87000E+00	9.96550E-01	1.00000E-03
8.08000E+00	9.95550E-01	1.00000E-03	8.65000E+00	9.95850E-01	1.00000E-03
5.76000E+00	9.96750E-01	1.00000E-03	8.13000E+00	9.94250E-01	1.00000E-03
7.90000E+00	9.97250E-01	1.00000E-03	7.26000E+00	9.94850E-01	1.00000E-03
6.72000E+00	9.96250E-01	1.00000E-03	9.65000E+00	9.99150E-01	1.00000E-03
0.00000E+00	1.00145E+00	1.00000E-03	9.70000E+00	1.00020E+00	1.00000E-03
1.64000E+00	9.99250E-01	1.00000E-03	8.09000E+00	9.97900E-01	1.00000E-03
1.64000E+00	9.97100E-01	1.00000E-03	7.65000E+00	9.92550E-01	1.00000E-03
1.64000E+00	9.99550E-01	1.00000E-03	9.09000E+00	9.93550E-01	1.00000E-03
3.27000E+00	9.96500E-01	1.00000E-03	9.42000E+00	9.98100E-01	1.00000E-03
3.27000E+00	9.93950E-01	1.00000E-03	9.78000E+00	9.96350E-01	1.00000E-03
4.91000E+00	9.93200E-01	1.00000E-03	1.00000E-01	9.99200E-01	1.00000E-03
6.54000E+00	9.94300E-01	1.00000E-03	2.00000E-01	1.00020E+00	1.00000E-03
1.31000E+01	1.00100E+00	1.00000E-03	2.90000E-01	9.99750E-01	1.00000E-03
1.29800E+01	9.99400E-01	1.00000E-03	3.90000E-01	9.98600E-01	1.00000E-03
1.05100E+01	9.96150E-01	1.00000E-03	4.90000E-01	1.00200E+00	1.00000E-03
1.10900E+01	9.95450E-01	1.00000E-03	1.00000E-01	1.00140E+00	1.00000E-03
1.31900E+01	9.97200E-01	1.00000E-03	1.00000E-01	1.00225E+00	1.00000E-03
1.33700E+01	9.97350E-01	1.00000E-03	1.00000E-01	9.98700E-01	1.00000E-03

```
   chi =  3.1613 (upper bound = 9.49). The data tests normal.
```

Figure 6.5.2-10 USLSTATS Output - k_{eff} versus Gap Thickness (continued)

```
        Output from statistical treatment

   62 Critical Experiment KEFFs VS Gap Thickness - Experiments 1, 3, 7, 17, & 40

    Number of data points (n)                         62
    Linear regression, k(X)                          0.9988 + (-2.4725E-04)*X
    Confidence on fit (1-gamma) [input]               95.0%
    Confidence on proportion (alpha) [input]          95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]            99.5%
    Minimum value of X                                   0.0000
    Maximum value of X                                  13.3700
    Average value of X                                   7.38403
    Average value of k                                 0.99693
    Minimum value of k                                 0.99255
    Variance of fit, s(k,X)^2                         4.1441E-06
    Within variance, s(w)^2                           1.0000E-06
    Pooled variance, s(p)^2                           5.1441E-06
    Pooled std. deviation, s(p)                       2.2681E-03
    C(alpha,rho)*s(p)                                 8.4077E-03
    student-t @ (n-2,1-gamma)                         1.67100E+00
    Confidence band width, W                          3.9264E-03
    Minimum margin of subcriticality, C*s(p)-W        4.4812E-03

    Upper subcritical limits: (  0.00000 <= X <=  13.37000)
    ***** *********** *******

    USL Method 1 (Confidence Band with
    Administrative Margin)           USL1 = 0.9448 + (-2.4725E-04)*X

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)   USL2 = 0.9903 + (-2.4725E-04)*X



    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:   0.00   1.91   3.82   5.73   7.64   9.55  11.46  13.37
       ---------------------------------------------------------
USL-1:  0.9448 0.9444 0.9439 0.9434 0.9429 0.9425 0.9420 0.9415
USL-2:  0.9903 0.9899 0.9894 0.9889 0.9885 0.9880 0.9875 0.9870
       ---------------------------------------------------------

  ****************************************************************************
                              Thus spake USLSTATS
                                     Finis.
```

Table 6.5.2-1 MONK8A Range of Correlated Parameters for Design Basis Fuel

Parameter	Benchmark Minimum Value	Benchmark Maximum Value	Design Basis (WE 17×17 OFA)
Enrichment (wt % ^{235}U)	2.35	7.00	5.00
Rod pitch (cm)	1.26	2.54	1.26
H/U (fissile) atomic ratio	72.1	453.84	111.31
^{10}B plate loading (g/cm^2)	0.000	0.072	0.025
Log energy causing fission	7.31E-08	3.33E-07	2.39E-07
Cluster gap thickness (cm)	0.0	13.37	2.22-3.81
Fuel diameter (cm)	0.743	1.265	0.7844
Clad diameter (cm)	0.8324	1.4150	0.9144
Soluble boron ppm	0	1258	1000

Table 6.5.2-2 MONK8A – Correlation Coefficient for Linear Curve-Fit of Critical Benchmarks

Correlation Studied	Correlation Coefficient (R)
k_{eff} versus enrichment	0.382
k_{eff} versus rod pitch	0.151
k_{eff} versus H/U (fissile) atomic ratio	0.394
k_{eff} versus ^{10}B plate loading	0.273
k_{eff} versus log energy causing fission	0.170
k_{eff} versus cluster gap thickness	0.436
k_{eff} versus fuel diameter	0.312
k_{eff} versus clad diameter	0.284
k_{eff} versus soluble boron ppm	0.555

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G $^{10}B/cm^2$	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
1.01	3 clusters; 20×17 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Neutron Absorber	0.0720	6.33	Inf	Water	1.00E-07	0.9964	0.0010
1.02	3 clusters; 20×17 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Neutron Absorber	0.0720	9.03	Inf	Water	9.95E-08	0.9976	0.0010
1.03	3 clusters; 20×17 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	304L Steel (no boron)	0	10.44	Inf	Water	9.97E-08	0.9950	0.0010
1.04	3 clusters; 20×17 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	304L Steel (no boron)	0	11.47	Inf	Water	9.95E-08	0.9960	0.0010
1.05	3 clusters; 20×17 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	304L Steel (1.05% boron)	0.0049	7.56	Inf	Water	1.02E-07	0.9950	0.0010
1.06	3 clusters; 20×17 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	304L Steel (1.05% boron)	0.0049	9.62	Inf	Water	1.01E-07	0.9955	0.0010
1.07	3 clusters; 20×17 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	304L Steel (1.62% boron)	0.0074	7.36	Inf	Water	1.02E-07	0.9963	0.0010
1.08	3 clusters; 20×17 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	304L Steel (1.62% boron)	0.0074	9.52	Inf	Water	9.99E-08	0.9967	0.0010
1.09	3 clusters; 20×17 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	None	Na	11.92	Inf	Water	1.01E-07	0.9959	0.0010
2.01	1.26 (square)	4.75	1.26	0.79	0.94	Al	98.21	0	Na	Na	Na	Na	Water	2.57E-07	0.9960	0.0010
2.02	1.60 (square)	4.75	1.60	0.79	0.94	Al	217.26	0	Na	Na	Na	Na	Water	1.15E-07	0.9968	0.0010
2.03	2.10 (square)	4.75	2.10	0.79	0.94	Al	443.75	0	Na	Na	Na	Na	Water	7.31E-08	0.9960	0.0010

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics (continued)

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G $^{10}B/cm^2$	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
2.04	1.35 (triangular)	4.75	1.35	0.79	0.94	Al	97.08	0	Na	Na	Na	Na	Water	2.80E-07	0.9953	0.0010
2.05	1.72 (triangular)	4.75	1.72	0.79	0.94	Al	217.51	0	Na	Na	Na	Na	Water	1.15E-07	0.9975	0.0010
2.06	2.26 (triangular)	4.75	2.26	0.79	0.94	Al	445.38	0	Na	Na	Na	Na	Water	7.34E-08	0.9965	0.0010
2.07	1.26 (square-1 in 5 missing)	4.75	1.26	0.79	0.94	Al	97.08	0	Na	Na	Na	Na	Water	2.65E-07	0.9950	0.0010
2.08	1.26 (square-1 in 2 missing)	4.75	1.26	0.79	0.94	Al	217.51	0	Na	Na	Na	Na	Water	1.16E-07	0.9974	0.0010
2.09	1.26 (square-1 in 3 missing)	4.75	1.26	0.79	0.94	Al	445.38	0	Na	Na	Na	Na	Water	7.42E-08	0.9969	0.0010
3.01	3 clusters; 8×15 pins	4.31	2.54	1.265	1.415	Al	256.38	0	None	Na	10.62	Inf	Water	1.18E-07	0.9944	0.0010
3.02	3 clusters; 8×15 pins	4.31	2.54	1.265	1.415	Al	256.38	0	304L Steel (no boron)	0	8.58	Inf	Water	1.17E-07	0.9957	0.0010
3.03	3 clusters; 8×15 pins	4.31	2.54	1.265	1.415	Al	256.38	0	304L Steel (no boron)	0	9.65	Inf	Water	1.18E-07	0.9953	0.0010
3.04	3 clusters; 8×15 pins	4.31	2.54	1.265	1.415	Al	256.38	0	304L Steel (1.05% boron)	0.0049	6.10	Inf	Water	1.19E-07	0.9966	0.0010
3.05	3 clusters; 8×15 pins	4.31	2.54	1.265	1.415	Al	256.38	0	304L Steel (1.05% boron)	0.0049	8.08	Inf	Water	1.18E-07	0.9956	0.0010
3.06	3 clusters; 8×15 pins	4.31	2.54	1.265	1.415	Al	256.38	0	304L Steel (1.62% boron)	0.0074	5.76	Inf	Water	1.18E-07	0.9968	0.0010
3.07	3 clusters; 8×15 pins	4.31	2.54	1.265	1.415	Al	256.38	0	304L Steel (1.62% boron)	0.0074	7.90	Inf	Water	1.16E-07	0.9973	0.0010

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics (continued)

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G $^{10}B/cm^2$	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
3.08	3 clusters; 8×15 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Neutron Absorber	0.0720	6.72	Inf	Water	1.19E-07	0.9963	0.0010
7.01	3x3 clusters; 14×14 pins	2.46	1.6358	1.206	1.03	Al	453.84	1037	None	Na	0	Inf	Water	2.56E-07	1.0015	0.0010
7.02	3x3 clusters; 14×14 pins	2.46	1.6358	1.206	1.03	Al	453.84	769	None	Na	1.64	Inf	Water	2.05E-07	0.9993	0.0010
7.03	3x3 clusters; 14×14 pins	2.46	1.6358	1.206	1.03	Al	453.84	0	B_4C Pins	Na	1.64	Inf	Water	2.03E-07	0.9971	0.0010
7.04	3x3 clusters; 14×14 pins	2.46	1.6358	1.206	1.03	Al	453.84	15	B/Al (1.61wt% B)	0.0052	1.64	Inf	Water	1.98E-07	0.9996	0.0010
7.05	3x3 clusters; 14×14 pins	2.46	1.6358	1.206	1.03	Al	453.84	217	Stainless Steel	0	3.27	Inf	Water	1.75E-07	0.9965	0.0010
7.06	3x3 clusters; 14×14 pins	2.46	1.6358	1.206	1.03	Al	453.84	320	B/Al (0.1wt% B)	0.0003	3.27	Inf	Water	1.79E-07	0.9940	0.0010
7.07	3x3 clusters; 14×14 pins	2.46	1.6358	1.206	1.03	Al	453.84	72	B/Al (0.1wt% B)	0.0003	4.91	Inf	Water	1.61E-07	0.9932	0.0010
7.08	3x3 clusters; 14×14 pins	2.46	1.6358	1.206	1.03	Al	453.84	0	None	Na	6.54	Inf	Water	1.44E-07	0.9943	0.0010
27.01	Cylindrical	7.00	1.32	0.743	0.8324	SS	118.39	0	Na	Na	Na	Na	Water	2.09E-07	0.9994	0.0010
32.01	14×14 array	4.74	1.60	0.79	0.94	Al	217.31	0	Na	Na	Na	0.0	Lead and light water	1.32E-07	1.0161	0.0010

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics (continued)

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G $^{10}B/cm^2$	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
32.02	14×14 array	4.74	1.60	0.79	0.94	Al	217.31	0	Na	Na	Na	0.5	Lead and light water	1.26E-07	1.0184	0.0010
32.03	14×14 array	4.74	1.60	0.79	0.94	Al	217.31	0	Na	Na	Na	1.0	Lead and light water	1.18E-07	1.0166	0.0010
32.04	14×14 array	4.74	1.60	0.79	0.94	Al	217.31	0	Na	Na	Na	1.5	Lead and light water	1.14E-07	1.0159	0.0010
40.01	22×22	4.74	1.60	0.79	0.94	Al	217.31	0	Hafnium plate	Na	0.0978	Na	Water	1.33E-07	0.9992	0.0010
40.02	22×22	4.74	1.60	0.79	0.94	Al	217.31	0	Hafnium plate	Na	0.1956	Na	Water	1.34E-07	1.0002	0.0010
40.03	22×22	4.74	1.60	0.79	0.94	Al	217.31	0	Hafnium plate	Na	0.2934	Na	Water	1.33E-07	0.9998	0.0010
40.04	22×22	4.74	1.60	0.79	0.94	Al	217.31	0	Hafnium plate	Na	0.3912	Na	Water	1.34E-07	0.9986	0.0010
40.05	22×22	4.74	1.60	0.79	0.94	Al	217.31	0	Hafnium plate	Na	0.489	Na	Water	1.37E-07	1.0020	0.0010
40.06	21×21	4.74	1.60	0.79	0.94	Al	217.31	0	Hafnium plate	Na	0.0978	Na	Water	1.36E-07	1.0014	0.0010
40.07	20×21	4.74	1.60	0.79	0.94	Al	217.31	0	Hafnium plate	Na	0.0978	Na	Water	1.34E-07	1.0023	0.0010
40.08	20×20	4.74	1.60	0.79	0.94	Al	217.31	0	Hafnium plate	Na	0.0978	Na	Water	1.30E-07	0.9987	0.0010
40.09	22×22	4.74	1.60	0.79	0.94	Al	217.31	0	None	Na	-	Na	Water	1.29E-07	0.9998	0.0010
40.10	21×21	4.74	1.60	0.79	0.94	Al	217.31	0	None	Na	-	Na	Water	1.27E-07	1.0006	0.0010
40.11	21×20	4.74	1.60	0.79	0.94	Al	217.31	0	None	Na	-	Na	Water	1.25E-07	1.0016	0.0010
40.12	20×20	4.74	1.60	0.79	0.94	Al	217.31	0	None	Na	-	Na	Water	1.25E-07	0.9988	0.0010

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics (continued)

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G $^{10}B/cm^2$	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
17.01	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	13.100	0.000	Lead	1.03E-07	1.0010	0.0010
17.02	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	12.980	0.660	Lead	1.00E-07	0.9994	0.0010
17.03	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	10.510	2.616	Lead	1.00E-07	0.9962	0.0010
17.04	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	11.090	0.000	Uranium	1.05E-07	0.9955	0.0010
17.05	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	13.190	1.321	Uranium	1.02E-07	0.9972	0.0010
17.06	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	13.370	1.956	Uranium	1.02E-07	0.9974	0.0010
17.07	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	12.960	2.616	Uranium	1.00E-07	0.9967	0.0010
17.08	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	9.950	5.405	Uranium	1.01E-07	0.9944	0.0010
17.09	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	7.820	10.676	Uranium	9.86E-08	0.9946	0.0010
17.10	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	9.888	0.000	Steel	1.03E-07	0.9975	0.0010
17.11	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	10.438	0.660	Steel	1.03E-07	0.9970	0.0010
17.12	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	10.438	1.321	Steel	1.02E-07	0.9958	0.0010

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics (continued)

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G ^{10}B/cm^2	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
17.13	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	9.598	2.616	Steel	9.91E-08	0.9964	0.0010
17.14	3 clusters; 16×19 pins	2.35	2.032	1.1176	1.27	Al	398.80	0	Na	Na	8.748	3.912	Steel	9.88E-08	0.9955	0.0010
17.15	18×25(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	8.566	0.000	Steel	1.89E-07	0.9943	0.0010
17.16	18×25(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	9.166	0.660	Steel	1.83E-07	0.9972	0.0010
17.17	18×25(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	9.096	1.321	Steel	1.75E-07	0.9988	0.0010
17.18	18×25(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	9.246	1.684	Steel	1.77E-07	0.9965	0.0010
17.19	18×25(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	8.866	2.344	Steel	1.69E-07	0.9966	0.0010
17.20	18×25(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	8.646	3.005	Steel	1.73E-07	0.9959	0.0010
17.21	18×25(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	8.126	3.912	Steel	1.66E-07	0.9943	0.0010
17.22	18×25(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	7.256	6.726	Steel	1.65E-07	0.9949	0.0010
17.23	18×23(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	9.646	0.000	Lead	1.76E-07	0.9992	0.0010
17.24	18×23(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	9.696	0.660	Lead	1.74E-07	1.0002	0.0010

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics (continued)

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G ^{10}B/cm^2	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
17.25	18×23(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	8.086	3.276	Lead	1.65E-07	0.9979	0.0010
17.26	18×23(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	7.646	0.000	Uranium	1.86E-07	0.9926	0.0010
17.27	18×23(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	9.086	1.321	Uranium	1.78E-07	0.9936	0.0010
17.28	18×23(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	9.416	2.616	Uranium	1.66E-07	0.9981	0.0010
17.29	18×23(center), 18×20(two outer)	2.35	1.684	1.1176	1.27	Al	398.80	0	Na	Na	9.776	3.912	Uranium	1.67E-07	0.9964	0.0010
10.01	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	19.495	0.000	Lead	1.22E-07	1.0091	0.0010
10.02	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	19.655	0.660	Lead	1.20E-07	1.0074	0.0010
10.03	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	17.915	1.321	Lead	1.18E-07	1.0044	0.0010
10.04	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	9.175	5.405	Lead	1.15E-07	0.9945	0.0010
10.05	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	14.255	0.000	Uranium	1.32E-07	0.9951	0.0010
10.06	3 clusters; 8×12 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	14.195	1.956	Uranium	1.18E-07	0.9974	0.0010
10.07	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	16.925	3.912	Uranium	1.18E-07	0.9977	0.0010

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics (continued)

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G $^{10}B/cm^2$	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
10.08	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	12.365	5.405	Uranium	1.16E-07	0.9922	0.0010
10.09	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	11.765	0.000	Steel	1.26E-07	1.0004	0.0010
10.10	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	13.125	0.660	Steel	1.25E-07	0.9981	0.0010
10.11	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	12.995	1.321	Steel	1.20E-07	0.9992	0.0010
10.12	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	11.315	2.616	Steel	1.17E-07	0.9987	0.0010
10.13	3 clusters; 8×13 pins	4.31	2.54	1.265	1.415	Al	256.38	0	Na	Na	8.675	5.405	Steel	1.16E-07	0.9954	0.0010
10.14	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	14.393	0.000	Steel	3.27E-07	1.0002	0.0010
10.15	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	15.263	0.660	Steel	3.16E-07	1.0015	0.0010
10.16	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	15.393	1.321	Steel	3.04E-07	1.0003	0.0010
10.17	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	15.363	1.956	Steel	2.97E-07	1.0039	0.0010
10.18	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	14.973	2.616	Steel	2.91E-07	0.9994	0.0010
10.19	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	13.343	5.405	Steel	2.80E-07	1.0007	0.0010

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics (continued)

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G $^{10}B/cm^2$	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
10.20	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	17.263	0.000	Lead	3.11E-07	1.0054	0.0010
10.21	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	17.703	0.660	Lead	3.01E-07	1.0047	0.0010
10.22	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	16.953	1.956	Lead	2.89E-07	1.0042	0.0010
10.23	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	13.873	5.001	Lead	2.81E-07	0.9993	0.0010
10.24	3 clusters; 12x16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	14.853	0.000	Uranium	3.33E-07	0.9965	0.0010
10.25	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	16.233	0.660	Uranium	3.23E-07	0.9991	0.0010
10.26	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	17.793	1.321	Uranium	3.14E-07	0.9995	0.0010
10.27	3 clusters; 12×16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	18.763	1.956	Uranium	3.05E-07	1.0006	0.0010
10.28	3 clusters; 12x16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	18.893	2.616	Uranium	3.01E-07	0.9991	0.0010
10.29	3 clusters; 12x16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	18.303	3.276	Uranium	2.88E-07	0.9985	0.0010
10.30	3 clusters; 12x16 pins	4.31	1.892	1.265	1.415	Al	256.38	0	Na	Na	15.923	5.405	Uranium	2.83E-07	0.9988	0.0010

Table 6.5.2-3 MONK8A – JEF 2.2 Library Validation Statistics (continued)

Case	Configuration	wt % ^{235}U	Pitch (cm)	Fuel OD (cm)	Clad OD (cm)	Clad Mat'l.	H/U (fissile)	Sol. B (ppm)	Poison Type/Absorber	G $^{10}B/cm^2$	Cluster Gap (cm)	Wall/ Cluster (cm)	Reflector	Mean Log(E) Neutrons Causing Fission	k_{eff} (JEF2.2)	σ
50.01	triangular pitch	3.6	1.27	0.76	0.905	Zr	134.24	0	None	na	na	na	Water	2.40E-07	1.0005	0.0010
50.02	triangular pitch	3.6	1.27	0.76	0.905	Zr	134.23	193	None	na	na	na	Water	3.40E-07	1.0013	0.0010
50.03	triangular pitch	3.6	1.27	0.76	0.905	Zr	134.20	700	None	na	na	na	Water	3.50E-07	1.0054	0.0010
50.04	triangular pitch	3.6	1.27	0.76	0.905	Zr	134.18	1014	None	na	na	na	Water	3.71E-07	1.0042	0.0010
50.05	triangular pitch	3.6	1.27	0.76	0.905	Zr	134.16	1258	None	na	na	na	Water	3.82E-07	1.0044	0.0010
50.06	triangular pitch	3.6	1.1	0.76	0.905	Zr	72.08	0	None	na	na		Water	7.84E-07	1.0003	0.0010
50.07	triangular pitch	3.6	1.1	0.76	0.905	Zr	72.08	168	None	na	na		Water	8.38E-07	0.9990	0.0010
50.08	triangular pitch	3.6	1.5	0.76	0.905	Zr	232.53	0	None	na	na		Water	1.55E-07	1.0006	0.0010
50.09	triangular pitch	3.6	1.5	0.76	0.905	Zr	232.45	700	None	na	na		Water	1.81E-07	1.0054	0.0010
50.10	triangular pitch	4.4	1.5	0.76	0.905	Zr	189.50	0	None	na	na		Water	1.54E-07	1.0002	0.0010
50.11	triangular pitch	3.6	1.905	0.76	0.905	Zr	445.28	0	None	na	na		Water	7.67E-08	1.0033	0.0010
50.12	triangular pitch	3.6	1.27	0.76	0.905	Zr	185.93	0	None	na	na		Water	1.97E-07	0.9986	0.0010
50.13	triangular pitch	4.4	1.27	0.76	0.905	Zr	109.40	0	None	na	na		Water	2.76E-07	1.0001	0.0010
50.14	triangular pitch	4.4	1.27	0.76	0.905	Zr	109.39	112	None	na	na		Water	2.86E-07	1.0032	0.0010
50.15	triangular pitch	4.4	1.27	0.76	0.905	Zr	114.01	0	None	na	na		Water	1.37E-07	0.9986	0.0010
50.16	triangular pitch	4.4	1.27	0.76	0.905	Zr	118.14	1258	None	na	na		Water	3.62E-07	1.0042	0.0010
50.17	triangular pitch	3.6	1.5	0.76	0.905	Zr	350.93	0	None	na	na		Water	1.09E-07	0.9974	0.0010

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6.6 Criticality Evaluation for Site Specific Spent Fuel

This section presents the criticality evaluation for fuel assembly types or configurations, which are unique to specific reactor sites. Site specific spent fuel configurations result from conditions that occurred during reactor operations, participation in research and development programs, testing programs intended to improve reactor operations and from decommissioning activities. Site specific fuel includes fuel assemblies that are uniquely designed to accommodate reactor physics, such as axial fuel blanket and variable enrichment assemblies.

Site specific fuel assembly configurations are either shown to be bounded by the analysis of the standard design basis fuel assembly configuration of the same type (PWR or BWR), or are shown to be acceptable by specific evaluation of the configuration.

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6.6.1 Criticality Evaluation for Maine Yankee Site Specific Spent Fuel

In Section 6.4, loading the storage cask with the standard CE 14 × 14 fuel assembly is shown to be less reactive than loading the cask with the most reactive Westinghouse 17 × 17 OFA design basis spent fuel. This analysis addresses variations in fuel assembly dimensions, variable enrichment axial zoning patterns, annular axial fuel blankets, removed fuel rods or empty rod positions, fuel rods placed in guide tubes, fuel assemblies with a start-up source or other components in a guide tube, consolidated fuel assemblies, and damaged fuel and fuel debris. These configurations are not included in the standard fuel analysis, but are present in the site fuel inventory that must be stored.

6.6.1.1 Maine Yankee Fuel Criticality Model

The criticality evaluations of the Maine Yankee fuel inventory require the basket cell and basket in cask models described in Section 6.3 and 6.4. The basket cell model is principally employed in the most reactive dimension evaluation for the Maine Yankee intact fuel types. The basket cell model represents an infinite array of fuel tubes separated by one-inch flux traps and neglects the radial neutron leakage of the basket. This will result in k_{eff} values greater than 0.95. The basket cell model is, therefore, only used to determine relative reactivities of the various physical dimensions of the Maine Yankee fuel inventory, not to establish maximum k_s values for the basket loaded with Maine Yankee fuel assemblies. The basket-in-cask model is used for the evaluation of the remaining fuel configurations. The basket criticality model uses the nominal basket configuration with full moderation under accident conditions, where accident conditions implying the loss of fuel cladding integrity and flooding of the pellet to cladding gap in all fuel rods. The analyses presented are performed using the UMS® transport cask shield geometry. Based on the evaluation presented in Section 6.4 and the licensing analysis of the transport overpack, the most reactive transportable storage canister configuration is independent of the canister outer shell geometry (i.e., different casks – transport, transfer, or storage). Since the criticality evaluation is not sensitive to the shielding geometry outside of the canister, this result is applicable to the concrete storage cask and the transfer cask. The transport cask criticality model is identical to the transfer cask and storage cask models with the exception that the radial shielding outside of the canister is comprised of a total of 4.75 inches of steel, 2.75 inches of NS-4-FR neutron shielding and 2.75 inches of lead. The $k_{eff} + 2\sigma$ of this configuration is 0.9210, which is slightly lower than the wet gap $k_{eff} + 2\sigma$ values of 0.9238 and 0.9234 reported in Tables 6.4-6 and 6.4-7 for the transfer cask and storage cask, respectively.

6.6.1.2 Maine Yankee Intact Spent Fuel

The evaluation of the intact Maine Yankee spent fuel inventory demonstrates that, under all conditions, the maximum reactivity of the UMS® basket loaded with Maine Yankee fuel assemblies is bounded by the Westinghouse 17 × 17 OFA evaluation presented in Section 6.4. The intact fuel assembly evaluation includes the determination of maximum reactivity dimensions of the Maine Yankee fuel assemblies, and the reactivity effects of variably enriched assemblies, annular axial end blankets, removed rods, fuel in guide tubes, and consolidated fuel assemblies. Where necessary, loading restrictions are applied to limit the number and location of the basket payload evaluated.

6.6.1.2.1 Fuel Assembly Lattice Dimensional Variations

Maine Yankee 14 × 14 PWR fuel has been provided by Combustion Engineering, Exxon/ANF, and Westinghouse. The range of fuel assembly dimensions evaluated for Maine Yankee is shown in Table 6.6.1-1. Bounding fuel assembly dimensions are determined using the guidelines presented in Section 6.4.4 and are reported in Table 6.6.1-2. The dimensional perturbations that can increase the reactivity of an undermoderated array of fuel assemblies in a flooded system (including flooding the fuel-cladding gap) are:

- Decreasing the cladding outside diameter (OD)
- Increasing the cladding inside diameter (ID) (i.e., increasing the gap)
- Decreasing the pellet diameter
- Decreasing the guide tube thickness

To conservatively model the cladding thickness of the Maine Yankee standard fuel, the outside diameter of the cladding is decreased until the cladding thickness reaches the minimum. The pellet diameter is studied separately to determine which diameter maximizes the reactivity of the assembly. This study is performed using an infinite array of hybrid 14 × 14 fuel assemblies. These hybrid assemblies have the combination of the most reactive dimensions listed in Table 6.6.1-2 and are used in the evaluation of site specific fuel configurations as described in the following sections. The pellet diameter is modeled first at the maximum diameter; then it is iteratively decreased until a peak reactivity (H/U ratio) is reached. The results of this study are reported in Table 6.6.1-3. The maximum reactivity occurs at a pellet diameter of 0.3527 inches. This pellet diameter is conservatively used in the analyses of an assembly with 176 fuel rods.

The reactivity of an infinite array of basket unit cells containing infinitely tall, hybrid 14 × 14 fuel assemblies and a flooded fuel-cladding gap is $k_{eff} + 2\sigma = 0.96268$. This is less reactive than the same array of Westinghouse 17 × 17 OFA assemblies ($k_{eff} + 2\sigma = 0.9751$ from Table 6.4-1). Therefore, the design basis Westinghouse 17 × 17 OFA fuel criticality evaluation is bounding. The conservatism obtained by decreasing the pellet diameter below that of the reported Maine Yankee fuel pellet diameter is equivalent to a Δk_{eff} of 0.00247.

The most reactive lattice dimensions determined by the basket cell model are incorporated into the basket in cask model. Evaluating 24 hybrid 14 × 14 fuel assemblies with the most reactive pellet diameter for the accident condition produces a $k_{eff} + 2\sigma$ of 0.91014. This is less reactive than the accident condition for the transport cask loaded with the Westinghouse 17 × 17 OFA assemblies ($k_{eff} + 2\sigma$ of 0.9210). Therefore, the Westinghouse 17 × 17 OFA fuel criticality evaluation is bounding.

6.6.1.2.2 Variably Enriched Fuel Assemblies

Two batches of fuel used at Maine Yankee contain variably enriched fuel rods. Fuel rod enrichments of one batch are 4.21 wt % ^{235}U and 3.5 wt % ^{235}U. The maximum planar average enrichment of this batch is 3.99 wt %. In the other batch, the fuel rod enrichments are 4.0 wt % and 3.4 wt % ^{235}U. The maximum planar average enrichment of this batch is 3.92 wt %. Loading 24 variably enriched fuel assemblies having both a maximum fuel rod enrichment of 4.21 wt % and a maximum planar average enrichment of 3.99 wt % results in a $k_{eff} + 2\sigma$ of 0.89940. Using a planar fuel rod enrichment of 4.2 wt % results in a $k_{eff} + 2\sigma$ of 0.91014. Therefore, all of the fuel rods are conservatively modeled as if enriched to 4.2 wt % ^{235}U for the remaining Maine Yankee analyses.

6.6.1.2.3 Assemblies with Annular Axial End Blankets

One batch of variably enriched fuel also incorporates 2.6 wt % ^{235}U axial end blankets with annular fuel pellets. The top and bottom 5% of the active fuel length of each fuel rod in this batch contains annular fuel pellets having an inner diameter of 0.183 inches.

This geometry is discretely modeled as approximately 5% annular fuel, 90% solid fuel and then 5% annular fuel, with all fuel materials enriched to 4.2 wt % ^{235}U. The diameter of all pellets is initially modeled as the most reactive pellet diameter. The accident case model, which includes flooding of the fuel cladding annulus, is used in this evaluation. Axial periodic boundary conditions are placed on the model, retaining the conservatism of the infinite fuel length. Use of a smaller pellet diameter is not considered to be conservative when evaluating the annular fuel pellets. The smaller pellet diameter is the most reactive diameter under the assumption that it is solid and not an annulus. Flooding the axial end blanket annulus provides additional moderator to the fuel lattice. Therefore, the diameter of the annular pellets is also modeled as the maximum pellet diameter of 0.380 inch. The 0.380-inch diameter is applied to the annular pellets, while the smaller diameter is applied to the solid pellets. The results of both evaluations are reported in Table 6.6.1-4.

The most reactive annular fuel model for the annular axial end blankets results in a slightly more reactive system than the hybrid fuel accident evaluation, the annular condition is less reactive than the evaluation including Westinghouse 17 × 17 OFA assemblies. Therefore, the Westinghouse 17 × 17 OFA fuel criticality evaluation is bounding.

6.6.1.2.4 Assemblies with Removed Fuel Rods

Some of the Maine Yankee fuel assemblies have had fuel rods removed from the 14 × 14 lattice or have had poison rods replaced by hollow Zircaloy rods. The exact number and location of removed rods and hollow rods differs from one assembly to another. To determine a bounding reactivity for these assemblies, an analysis changing the location and the number of removed rods is performed. The removed rod analysis bounds that of the hollow rod analysis, since the Zircaloy tubes displace moderator in the under moderated assembly lattice. For each case, all 24 assemblies are centered in the fuel tubes and have the same number and location of removed fuel rods. Various patterns of removed fuel rod locations are analyzed when the number of removed fuel rods is small enough to allow a different and possibly more reactive geometry. As the number of removed fuel rods increases, the number of possible highly reactive locations for these removed rods decreases. The fuel pellet diameter is modeled first at the most reactive diameter (0.3527 inches as determined in Section 6.6.1.2.1), and then at the maximum diameter of 0.380 inches.

The results of these analyses, which determine the most reactive number and geometry of removed rods for any Maine Yankee assembly, are presented in Tables 6.6.1-5 and 6.6.1-6. Table 6.6.1-5 contains the results based on a 0.3527-inch fuel pellet. All of the removed fuel rod cases using the smaller pellet diameter show cask reactivity levels lower than those of Westinghouse 17 × 17 OFA fuel. Table 6.6.1-6 contains the results of the evaluation using the maximum pellet diameter of 0.380 inch. Using the maximum pellet diameter provides for a more reactive system, since moderator is added (at the removed rod locations), to an assembly that contains more fuel. The most reactive removed fuel rod case occurs when 24 fuel rods are removed in the diamond shaped geometry shown in Figure 6.6.1-1, from the model containing the largest allowed pellet diameter.

This case represents the bounding number and geometry of removed fuel rods for the Maine Yankee fuel assemblies. It results in a more reactive system than either the Maine Yankee hybrid 14 × 14 fuel accident case or the Westinghouse 17 × 17 OFA accident case assuming unrestricted loading. However, as shown in Table 6.6.1-6, when the loading of any assembly with less than 176 fuel rods or filler rods is restricted to the four corner fuel tubes, the reactivity of the worse case drops well below that of the Westinghouse 17 × 17 OFA fuel assemblies. Therefore, loading of Maine Yankee fuel assemblies with removed fuel rods, or with hollow Zircaloy rods, is restricted to the four corner fuel tube positions of the basket. With this loading restriction, the Westinghouse 17 × 17 OFA criticality evaluation remains bounding.

6.6.1.2.5 Assemblies with Fuel Rods in the Guide Tubes

A few of the Maine Yankee intact assemblies may contain up to two intact fuel rods in some of the guide tubes (i.e., allowing for the potential storage of individual intact fuel rods in an intact fuel assembly). To evaluate loading of these assemblies into the canister, an analysis adding 1 and then 2 intact fuel rods into 1, 2, 3 and then 5 guide tubes is made. This approach considers a fuel assembly with up to 186 fuel rods. The results of the evaluation of these configurations are shown in Table 6.6.1-7. While higher in reactivity than the Maine Yankee hybrid base case, any fuel configuration with up to 2 fuel rods per guide tube is less reactive than the accident case for the Westinghouse 17 × 17 OFA fuel assemblies. Therefore, the Westinghouse 17 × 17 OFA fuel criticality evaluation is bounding.

Fuel rods may also be inserted in the guide tubes of fuel assemblies from which the fuel rods were removed (i.e., fuel rods removed from a fuel assembly and re-installed in the guide tubes of the same fuel assembly). These fuel rods may be intact or damaged. The maximum number of fuel rods in these assemblies, including fuel rods in the guide tubes remains 176. These configurations are restricted to loading in one of the two configurations of the Maine Yankee Fuel Can in a corner fuel position in the basket. As shown in Section 6.6.1.2.4 for the removed fuel rods, and Section 6.6.1.3 for the damaged fuel, the maximum reactivity of Maine Yankee assemblies containing 176 fuel rods in various configurations is bounded by the Westinghouse 17 × 17 OFA evaluation. These non-standard Maine Yankee assemblies are restricted to the corner fuel positions.

In addition to the fuel rods, some Maine Yankee assemblies may contain poison shim rods in guide tubes. These solid fill rods will serve as parasitic absorber and displace moderator and are, therefore, not included in the criticality model but are bounded by the evaluation performed.

6.6.1.2.6 Consolidated Fuel

The consolidated fuel is a 17 × 17 array of intact fuel rods with a pitch of 0.492 inches. Some of the locations in the array contain solid fill rods and some are empty. To determine the reactivity of the consolidated fuel lattice with empty fuel rod positions, an analysis changing the location and the number of empty positions is performed. This analysis considers 24 consolidated fuel lattices in the basket. All 24 consolidated fuel lattices are centered in the fuel tubes and have the same number and location of empty fuel rod positions.

As shown in Section 6.6.1.2.4, the removed fuel rod configuration with a 0.380-inch pellet diameter provides a more reactive system than a system using the optimum pellet diameter from Section 6.6.1.2.1. The larger pellet cases are more reactive, since moderator is added at the empty fuel rod positions to an assembly that contains more fuel. Therefore, the consolidated assembly empty rod position evaluation is performed with the 0.380-inch pellet diameter.

The results of this evaluation are shown in Table 6.6.1-8. Configurations having more than 73 empty positions result in a more reactive system than the Westinghouse 17 × 17 OFA model. The most reactive consolidated assembly case occurs with 113 empty rod positions in the geometry shown in Figure 6.6.1-2. However, when the loading of the consolidated fuel is restricted to the four corner fuel tubes, the reactivity of the system is lower than the accident condition of the basket loaded with Westinghouse 17 × 17 OFA assemblies. Therefore, loading of the consolidated fuel is restricted to the four corner fuel tube positions of the basket. With this loading restriction, the Westinghouse 17 × 17 OFA fuel criticality evaluation is bounding.

6.6.1.2.7 Conclusions

The criticality analyses for the Maine Yankee site specific fuel demonstrate that the UMS® basket loaded with these fuel assemblies results in a system that is less reactive than loading the basket with the Westinghouse 17 × 17 OFA fuel assemblies, provided that loading is restricted to the four corner fuel tube positions in the basket for:

- All 14 × 14 fuel assemblies with less than 176 fuel rods or solid filler rods
- All 14 × 14 fuel assemblies with hollow rods
- All 17 × 17 consolidated fuel lattices
- All 14 × 14 fuel assemblies with fuel rods in the guide tubes and a maximum of 176 fuel rods or solid rods and fuel rods.

The following Maine Yankee fuels are not restricted as to loading position within the basket:

- All 14 × 14 fuel assemblies with 176 fuel rods or solid filler rods at a maximum enrichment of 4.2 wt % ^{235}U.
- Variably enriched fuel with a maximum fuel rod enrichment of 4.21 wt % ^{235}U with a maximum planar average enrichment of 3.99 wt % ^{235}U.
- Fuel with solid stainless steel filler rods, solid Zircaloy filler rods or solid poison shim rods in any location.
- Fuel with annular axial end blankets of up to 4.2 wt % ^{235}U.
- Fuel with a maximum of 2 intact fuel rods in each guide tube for a total of 186 fuel rods.

Assemblies defined as unrestricted may be loaded into the basket in any basket location and may be mixed in the same basket. While not analyzed in detail, CEAs and ICI thimble assemblies may be loaded into any intact assemblies. These components displace a significant amount of water in the fuel lattice while adding parasitic absorber, thereby reducing system reactivity.

Since the storage cask and the transfer cask loaded with the Westinghouse 17 × 17 OFA fuel assemblies is criticality safe, it is inherent that the same cask loaded with the less reactive fuel assemblies employed at Maine Yankee, using the fuel assembly loading restrictions presented above, is also criticality safe.

6.6.1.3 Maine Yankee Damaged Spent Fuel and Fuel Debris

Damaged fuel assemblies are placed in one of the two configurations of the Maine Yankee Fuel Can prior to loading in the basket (see Drawings 412-501 and 412-502). The Maine Yankee Fuel Can has screened openings in the baseplate and the lid to permit drainage, vacuum drying, and inerting of the can. This evaluation conservatively considers 100% of the fuel rods in the fuel can as damaged.

Fuel debris can be loaded in a rod or tube structure that is subsequently loaded into a Maine Yankee fuel can. The mass of fuel debris placed in the rod or tube is restricted to the mass equivalent of a fuel rod of an intact fuel assembly.

The Maine Yankee spent fuel inventory includes fuel assemblies with fuel rods inserted in the guide tubes of the assembly. If the integrity of the cladding of the fuel rods in the guide tubes cannot be ascertained, then those fuel rods are assumed to be damaged.

6.6.1.3.1 Damaged Fuel Rods

All of the spent fuel classified as damaged, and all of the spent fuel not in its original lattice, are stored in a Maine Yankee fuel can. This fuel is analyzed using a 100% fuel rod failure assumption. The screened fuel can is designed to preclude the release of pellets and gross particulate to the canister cavity. Evaluation of the canister with four (4) Maine Yankee fuel cans containing CE 14 × 14 fuel assemblies that have up to 176 damaged fuel rods, or consolidated fuel consisting of up to 289 fuel rods, considers 100% dispersal of the fuel from these rods within the fuel can. The Maine Yankee fuel can is restricted to loading in the four corner positions of the basket.

All loose fuel in each analysis is modeled as a homogeneous mixture of fuel and water of which the volume fractions of the fuel versus the water are varied from 0 - 100. By varying the fuel fraction up to 100%, this evaluation addresses fuel masses significantly larger than those available in a standard or consolidated fuel assembly. First, loose fuel from damaged fuel rods within a fuel assembly is evaluated between the remaining rods of the most reactive missing rod array. The results of this analysis, provided in Table 6.6.1-9, show a slight decrease in the reactivity of the system. This results from adding fuel to the already optimized H/U ratio of the bounding missing rod array. This effectively returns the system to an undermoderated state. Second, loose fuel is considered above and below the active fuel region of this most reactive missing rod array. This analysis is performed within a finite cask model. The results of this study, provided in Table 6.6.1-10, show that any possible mixture combination of fuel and water above and below the active fuel region, and hence, above and below the neutron absorber sheet coverage, will not significantly increase the reactivity of the system beyond that of the missing rod array. Loose fuel is also considered to replace all contents of the Maine Yankee fuel can in each four corner fuel tube location. The results of this study, provided in Table 6.6.1-11, show that any mixture of fuel and water within this cavity will not significantly increase the reactivity of the system beyond that of the missing rod array.

Damaged fuel within the fuel can may also result from a loss of integrity of a consolidated fuel assembly. As described in Section 6.6.1.2.6, the consolidated assembly missing rod study shows that a potentially higher reactivity heterogeneous configuration does not increase the overall reactivity of the system beyond that of loading 24 Westinghouse 17 × 17 OFA assemblies when this configuration is restricted to the four corner locations. The homogeneous mixture study of loose fuel and water replacing the contents of the Maine Yankee fuel can (in each of the four corner fuel tube locations) considers more fuel than is present in the 289 fuel rod consolidated assembly. This study shows that a homogeneous mixture at an optimal H/U ratio within the fuel can also does not affect the reactivity of the system.

The transfer and the storage casks loaded with the Westinghouse 17 × 17 OFA fuel assemblies remain subcritical. Therefore, it is inherent that a statistically equivalent, or less reactive, canister loading of 4 Maine Yankee fuel cans containing assemblies with up to 176 damaged rods, or consolidated assemblies with up to 289 rods and 20 of the most reactive Maine Yankee fuel assemblies, will remain subcritical. Consequently, assemblies with up to 176 damaged rods and consolidated assemblies with up to 289 rods are allowed contents as long as they are loaded into Maine Yankee fuel cans.

6.6.1.3.2 Fuel Debris

Prior to loading fuel debris into the screened Maine Yankee fuel can, fuel debris must be placed into a rod type structure. Placing the debris into rods confines the spent nuclear material to a known volume and allows the fuel debris to be treated identically to the damaged fuel for criticality analysis.

Based on the arguments presented in Section 6.6.1.3.1, the maximum k_s of the UMS® canister with fuel debris will be less than 0.95, including associated uncertainty and bias.

6.6.1.4 Fuel Assemblies with a Source or Other Component in Guide Tubes

The effect on reactivity from loading Maine Yankee fuel assemblies with components inserted in the center or corner guide tube positions is also evaluated. These components include start-up sources, Control Element Assembly (CEA) fingertips, and a 24-inch ICI segment. Start-up sources must be inserted in the center guide tube. The CEA fingertips and ICI segment must be inserted in a corner guide tube that is closed at the bottom end of the assembly and closed at the top using a CEA flow plug.

6.6.1.4.1 Assemblies with Start-up Sources

Maine Yankee has three Pu-Be sources and two Sb-Be sources that will be installed in the center guide tubes of 14 × 14 assemblies that subsequently must be loaded in one of the four corner fuel positions of the basket. Each source is designed to fit in the center guide tube of an assembly. All five of these start-up sources contain Sb-Be pellets, which are 50% beryllium (Be) by volume. The moderation potential of the Be is evaluated to ensure that this material will not increase the reactivity of the system beyond that reported for the accident condition. The antimony (Sb) content is ignored. The start-up source is assumed to remain within the center guide tube for all conditions. The base case infinite height model used for comparison is the bounding Maine Yankee geometry with fuel assemblies that have 24 empty rod positions in the most reactive geometry, in the four corner locations of the basket, i.e., Case "24 (Four Corners)" reported in Table 6.6.1-6. The center guide tube of this model is filled with 50% water and 50% Be. The analysis assumes that assemblies with start-up sources are loaded in all four of the basket corner fuel positions. This configuration, resulting in a system reactivity of $k_{eff} \pm \sigma$, or 0.91085 ± 0.00087, shows that loading Sb-Be sources or the used Pu-Be sources into the center guide tubes of the assemblies in the four corner locations of the basket does not significantly impact the reactivity of the system.

One of the three Pu-Be sources was never irradiated. Analysis of this source is equivalent to assuming that the spent Pu-Be sources are fresh. The unused source has 1.4 grams of plutonium in two capsules. All of this material is conservatively assumed to be in one capsule and is modeled as ^{239}Pu. The diameter of the capsule cavity is 0.270 inch and its length is 9.75 inches. This corresponds to a capsule volume of approximately 9.148 cubic centimeters. Thus, the 1.4 grams of ^{239}Pu occupies ~0.77% of the volume at a density of 19.84 g/cc. This material composition is then conservatively assumed to fill the entire center guide tube, which models considerably more ^{239}Pu than is actually present within the Pu-Be source. The remaining volume of the guide tube is analyzed at various fractions of Be, water and/or void to ensure that any combination of these materials is considered. The results of these analyses, provided in Table 6.6.1-12, show that loading a fresh Pu-Be start-up source into the center guide tube of each of the four corner assemblies does not significantly impact the reactivity of the system. Both heterogeneous and homogeneous analyses are performed.

6.6.1.4.2 Fuel Assemblies with Inserted CEA Fingertips or ICI String Segment

Maine Yankee fuel assemblies may have CEA finger ends (fingertips) or an ICI segment inserted in one of the four corner guide tubes of the same 14 × 14 assembly. The ICI segment is approximately 24 inches long. These components do not contain fissile or moderating material. Therefore, it is conservative to ignore these components, as they displace moderator when the basket is flooded, thereby reducing reactivity.

6.6.1.4.3 Maine Yankee Miscellaneous Component Loading Restrictions

Based on the evaluation of Maine Yankee fuel assemblies with start-up sources, CEA fingertips, or an ICI segment inserted in guide tubes, the following loading restrictions apply:

1) Any Maine Yankee fuel assembly having a component evaluated in this section inserted in a corner or center guide tube must be loaded in one of the four corner fuel loading positions of the UMS® basket. Basket corner positions are also peripheral positions and are marked "P/C" in Figure 2.1.3.1-1.
2) Start-up sources shall be restricted to loading in the center guide tubes of fuel assemblies classified as intact and must be loaded in a Class 1 canister.
3) Only one start-up source may be loaded into any intact fuel assembly.
4) The CEA finger tips and ICI segment must be loaded in a guide tube location that is closed at the bottom end (corner guide tubes) of an intact fuel assembly. The guide tube must be closed at the top end using a CEA flow plug.
5) Fuel assemblies having a CEA flow plug installed must be loaded in a Class 2 canister.
6) Up to four intact fuel assemblies with inserted start-up sources may be loaded in any canister (using the four corner positions of the basket).

When loaded in accordance with these restrictions, the evaluated components do not significantly impact the reactivity of the system.

6.6.1.5 Maine Yankee Fuel Comparison to Criticality Benchmarks

The most reactive system configuration parameters for Maine Yankee fuel have been compared to the range of applicability of the critical benchmarks evaluated using the KENO-Va code of the SCALE 4.3 CSAS sequence. As shown in the following table, all of the Maine Yankee fuel parameters fall within the benchmark range.

Parameter	Benchmark Minimum Value	Benchmark Maximum Value	Maine Yankee Fuel Most Reactive Configuration
Enrichment (wt. % ^{235}U)	2.35	4.74	4.2
Rod pitch (cm)	1.26	2.54	1.50
H/U volume ratio	1.6	11.5	2.6
^{10}B areal density (g/cm^2)	0.00	0.45	0.025
Average energy group causing fission	21.7	24.2	22.5
Flux gap thickness (cm)	0.64	5.16	2.22 to 3.81
Fuel diameter (cm)	0.790	1.265	0.896
Clad diameter (cm)	0.940	1.415	1.111

The H/U volume ratio for the assembly is shown. The lattice H/U volume ratio is 2.2 for the clad gap flooded scenario.

The results of the NAC-UMS® Storage System benchmark calculations are provided in Section 6.5.1.

Figure 6.6.1-1 24 Removed Fuel Rods - Diamond Shaped Geometry, Maine Yankee Site Specific Fuel

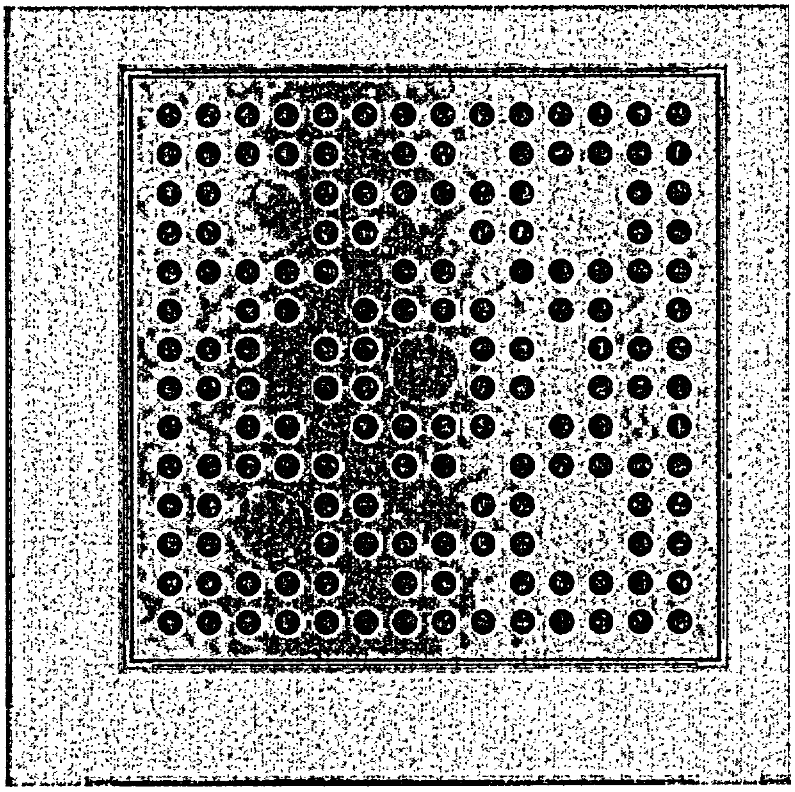

Figure 6.6.1-2 Consolidated Fuel Geometry, 113 Empty Fuel Rod Positions, Maine Yankee Site Specific Fuel

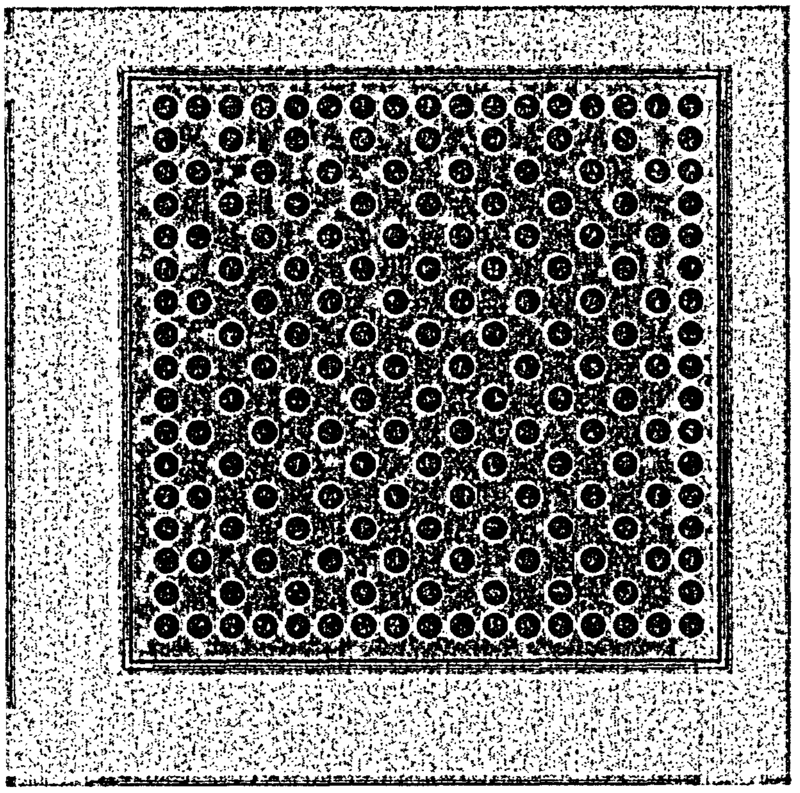

Table 6.6.1-1 Maine Yankee Standard Fuel Characteristics

Fuel Class[1]	Vendor	Array	Version	Number of Fuel Rods	Pitch (in.)	Rod Diameter (in.)	Clad ID (in.)	Clad Thickness (in.)	Pellet Diameter (in.)	GT[2] Thickness (in.)
1	CE	14×14	Std.	160[3]-176	0.570-0.590	0.438-0.442	0.3825-0.3895	0.024-0.028	0.376-0.380	0.036-0.040
1	Ex/ANF	14×14	CE	164[4]-176	0.580	0.438-0.442	0.3715-0.3795	0.0294-0.031	0.3695-0.3705	0.036-0.040
1	WE	14×14	CE	176	0.575-0.585	0.438-0.442	0.3825-0.3855	0.0262-0.028	0.376-0.377	0.034-0.038

1. All fuel rods are Zircaloy clad.
2. Guide Tube thickness.
3. Up to 16 fuel rod positions may have solid filler rods or burnable poison rods.
4. Up to 12 fuel rod positions may have solid filler rods or burnable poison rods.

Table 6.6.1-2 Maine Yankee Most Reactive Fuel Dimensions

Parameter	Bounding Dimensional Value
Maximum Rod Enrichment[1]	4.2 wt % ^{235}U
Maximum Number of Fuel Rods[2]	176
Maximum Pitch (in.)	0.590
Maximum Active Length (in.)	N/A – Infinite Model
Minimum Clad OD (in.)	0.4375
Maximum Clad ID (in.)	0.3895
Minimum Clad Thickness (in.)	0.024
Maximum Pellet Diameter (in.)	0.3800 - Study
Minimum Guide Tube OD (in.)	1.108
Maximum Guide Tube ID (in.)	1.040
Minimum Guide Tube Thickness (in.)	0.034

1. Variably enriched fuel assemblies may have a maximum fuel rod enrichment of 4.21 wt % ^{235}U with a maximum planar average enrichment of 3.99 wt % ^{235}U.
2. Assemblies with less than 176 fuel rods or solid dummy rods are addressed after the determination of the most reactive dimensions.

Table 6.6.1-3 Maine Yankee Pellet Diameter Study

Diameter (inches)	k_{eff}	σ	$k_{eff}+2\sigma$
0.3800	0.95585	0.00085	0.95755
0.3779	0.95784	0.00080	0.95944
0.3758	0.95714	0.00085	0.95884
0.3737	0.95863	0.00082	0.96027
0.3716	0.95862	0.00084	0.96030
0.3695	0.95855	0.00083	0.96021
0.3674	0.95863	0.00085	0.96033
0.3653	0.95982	0.00084	0.96150
0.3632	0.95854	0.00088	0.96030
0.3611	0.95966	0.00083	0.96132
0.3590	0.95990	0.00084	0.96158
0.3569	0.96082	0.00082	0.96246
0.3548	0.96053	0.00083	0.96219
0.3527	0.96104	0.00082	0.96268
0.3506	0.95964	0.00087	0.96138
0.3485	0.95993	0.00086	0.96165
0.3464	0.95916	0.00084	0.96084
0.3443	0.95847	0.00083	0.96013
0.3422	0.95876	0.00083	0.96042
0.3401	0.95865	0.00081	0.96027
0.3380	0.95734	0.00084	0.95902

Table 6.6.1-4 Maine Yankee Annular Fuel Results

Case Description	k_{eff}	σ	$k_{eff}+2\sigma$
All pellets with a diameter of 0.3527 inches	0.90896	0.00083	0.91061
Annular pellet diameter changed to 0.3800 inches	0.91013	0.00087	0.91187

Table 6.6.1-5 Maine Yankee Removed Rod Results with Small Pellet Diameter

Number of Removed Rods	Number of Fuel Rods	k_{eff}	σ	$k_{eff} + 2\sigma$
4	172	0.91171	0.00088	0.91347
4	172	0.91292	0.00086	0.91464
4	172	0.91479	0.00081	0.91640
4	172	0.91125	0.00087	0.91299
6	170	0.91418	0.00087	0.91592
6	170	0.91264	0.00085	0.91435
6	170	0.91314	0.00086	0.91487
6	170	0.90322	0.00086	0.90493
8	168	0.91555	0.00087	0.91729
8	168	0.91490	0.00093	0.91676
8	168	0.91457	0.00088	0.91633
8	168	0.91590	0.00087	0.91764
8	168	0.89729	0.00088	0.89905
12	164	0.91654	0.00086	0.91827
12	164	0.91469	0.00085	0.91639
12	164	0.91149	0.00083	0.91315
16	160	0.91725	0.00084	0.91893
16	160	0.91567	0.00084	0.91735
16	160	0.90986	0.00088	0.91162
16	160	0.90849	0.00083	0.91015
16	160	0.90704	0.00086	0.90876
24	152	0.91572	0.00083	0.91739
32	144	0.91037	0.00088	0.91213
48	128	0.89385	0.00085	0.89554
48	128	0.84727	0.00079	0.84886
64	112	0.79602	0.00083	0.79768
96	80	0.69249	0.00077	0.69402
Westinghouse 17 × 17 OFA		0.9192	0.0009	0.9210

Table 6.6.1-6 Maine Yankee Removed Fuel Rod Results with Maximum Pellet Diameter

Number of Removed Rods	Number of Fuel Rods	k_{eff}	σ	$k_{eff} + 2\sigma$
4	172	0.91078	0.00086	0.91250
4	172	0.90916	0.00085	0.91085
4	172	0.91164	0.00087	0.91338
4	172	0.90809	0.00085	0.90979
6	170	0.91223	0.00085	0.91393
6	170	0.91223	0.00080	0.91384
6	170	0.91270	0.00086	0.91442
6	170	0.90245	0.00086	0.90416
6	170	0.89801	0.00086	0.89972
8	168	0.91567	0.00085	0.91736
8	168	0.91448	0.00085	0.91618
8	168	0.91355	0.00086	0.91526
8	168	0.91293	0.00085	0.91463
12	164	0.91639	0.00090	0.91818
12	164	0.91803	0.00086	0.91974
12	164	0.91235	0.00083	0.91401
16	160	0.91665	0.00091	0.91847
16	160	0.92136	0.00087	0.92310
16	160	0.91231	0.00084	0.91400
16	160	0.90883	0.00087	0.91057
24	152	0.92227	0.00087	0.92400
32	144	0.92164	0.00088	0.92340
48	128	0.91212	0.00081	0.91373
48	128	0.86308	0.00082	0.86472
64	112	0.81978	0.00080	0.82138
88	88	0.72087	0.00083	0.72247
24 (Four Corners)	152	0.91153	0.00085	0.91323
Westinghouse 17 × 17 OFA		0.9192	0.0009	0.9210

Table 6.6.1-7 Maine Yankee Fuel Rods in Guide Tube Results

Number of Guide Tubes with Rods	Number of Rods in Each	k_{eff}	σ	$k_{eff} + 2\sigma$
1	1	0.91102	0.00089	0.91280
2	1	0.91059	0.00088	0.91234
3	1	0.91172	0.00087	0.91346
5	1	0.91411	0.00086	0.91583
1	2	0.91169	0.00090	0.91349
2	2	0.91201	0.00087	0.91375
3	2	0.91173	0.00086	0.91344
5	2	0.91357	0.00086	0.91529
Design Basis Westinghouse 17 × 17 OFA		0.9192	0.0009	0.9210

Table 6.6.1-8 Maine Yankee Consolidated Fuel Empty Fuel Rod Position Results

Number of Empty Positions	Number of Fuel Rods	k_{eff}	σ	$k_{eff} + 2\sigma$
4	285	0.79684	0.00082	0.79848
9	280	0.80455	0.00081	0.80616
9	280	0.80812	0.00079	0.80970
13	276	0.81573	0.00083	0.81739
24	265	0.84187	0.00080	0.84347
25	264	0.84017	0.00083	0.84182
25	264	0.84634	0.00081	0.84795
25	264	0.84583	0.00083	0.84750
25	264	0.85524	0.00083	0.85690
25	264	0.83396	0.00081	0.83558
25	264	0.84625	0.00083	0.84790
27	262	0.85438	0.00083	0.85604
29	260	0.85179	0.00081	0.85340
31	258	0.85930	0.00084	0.86098
33	256	0.86407	0.00082	0.86571
35	254	0.86740	0.00082	0.86904
37	252	0.87372	0.00084	0.87541
45	244	0.88630	0.00081	0.88793
45	244	0.87687	0.00079	0.87844
52	237	0.90062	0.00083	0.90228
57	232	0.87975	0.00087	0.88149
61	258	0.89055	0.00083	0.89221
73	216	0.90967	0.00082	0.91131
84	205	0.93261	0.00091	0.93443
85	204	0.94326	0.00086	0.94499
113	176	0.95626	0.00084	0.95794
117	172	0.95373	0.00088	0.95549
119	170	0.95315	0.00085	0.95485
125	164	0.95020	0.00086	0.95192
141	148	0.94348	0.00086	0.94521
145	144	0.93868	0.00089	0.94047
113 (Four Corners)	176	0.91292	0.00087	0.91466
Design Basis Westinghouse 17 × 17 OFA		0.9192	0.0009	0.9210

Table 6.6.1-9 Fuel Can Infinite Height Model Results of Fuel-Water Mixture Between Rods

Volume Fraction of UO_2 in Water	k_{eff}	Δk_{eff} to 24 (Four Corners)[1]
0.000	0.91090	-0.00063
0.001	0.91138	-0.00015
0.002	0.91120	-0.00033
0.003	0.91177	0.00024
0.004	0.91285	0.00132
0.005	0.90908	-0.00245
0.006	0.91001	-0.00152
0.007	0.90895	-0.00258
0.008	0.91005	-0.00148
0.009	0.90986	-0.00167
0.010	0.90864	-0.00289
0.020	0.91003	-0.00150
0.030	0.90963	-0.00190
0.040	0.91063	-0.00090
0.050	0.90931	-0.00222
0.060	0.90765	-0.00388
0.070	0.90753	-0.00400
0.080	0.91088	-0.00065
0.090	0.91122	-0.00031
0.100	0.90879	-0.00274
0.150	0.90968	-0.00185
0.200	0.90952	-0.00201
0.250	0.90815	-0.00338
0.300	0.90748	-0.00405
0.350	0.90581	-0.00572
0.400	0.90963	-0.00190
0.450	0.90547	-0.00606
0.500	0.90603	-0.00550
0.550	0.90753	-0.00400
0.600	0.90674	-0.00479
0.650	0.90589	-0.00564
0.700	0.90594	-0.00559
0.750	0.90568	-0.00585
0.800	0.90532	-0.00621
0.850	0.90693	-0.00460
0.900	0.90639	-0.00514
0.950	0.90684	-0.00469
1.000	0.90677	-0.00476

Table 6.6.1-10 Fuel Can Finite Model Results of Fuel-Water Mixture Outside Neutron Absorber Coverage

Volume Fraction of UO_2 in Water	k_{eff}	Δk_{eff} to 0.00 UO_2 in Water	Δk_{eff} to 24 (Four Corners)[1]
0.00	0.91045[2]	NA	-0.00108
0.05	0.90781	-0.00264	-0.00372
0.10	0.90978	-0.00067	-0.00175
0.15	0.91048	0.00003	-0.00105
0.20	0.90916	-0.00129	-0.00237
0.25	0.90834	-0.00211	-0.00319
0.30	0.90935	-0.00110	-0.00218
0.35	0.90786	-0.00259	-0.00367
0.40	0.90892	-0.00153	-0.00261
0.45	0.91015	-0.00030	-0.00138
0.50	0.91011	-0.00034	-0.00142
0.55	0.91003	-0.00042	-0.00150
0.60	0.90874	-0.00171	-0.00279
0.65	0.91165	0.00120	0.00012
0.70	0.90977	-0.00068	-0.00176
0.75	0.90813	-0.00232	-0.00340
0.80	0.90909	-0.00136	-0.00244
0.85	0.91028	-0.00017	-0.00125
0.90	0.91061	0.00016	-0.00092
0.95	0.91129	0.00084	-0.00024
1.00	0.91076	0.00031	-0.00077

1. See Table 6.6.1-6.
2. $\sigma = 0.00084$.

Table 6.6.1-11 Fuel Can Finite Model Results of Replacing All Rods with Fuel-Water Mixture

Volume Fraction of UO_2 in Water	k_{eff}	Δk_{eff} to 24 (Four Corners) Finite Height Model[1]	Δk_{eff} to 24 (Four Corners) Infinite Height Model[2]
0	0.90071	-0.00974	-0.01082
5	0.90194	-0.00851	-0.00959
10	0.90584	-0.00461	-0.00569
15	0.90837	-0.00208	-0.00316
20	0.91008	-0.00037	-0.00145
25	0.91086	0.00041	-0.00067
30	0.90964	-0.00081	-0.00189
35	0.90828	-0.00217	-0.00325
40	0.90805	-0.00240	-0.00348
45	0.90730	-0.00315	-0.00423
50	0.90637	-0.00408	-0.00516
55	0.90672	-0.00373	-0.00481
60	0.90649	-0.00396	-0.00504
65	0.90632	-0.00413	-0.00521
70	0.90435	-0.00610	-0.00718
75	0.90792	-0.00253	-0.00361
80	0.90376	-0.00669	-0.00777
85	0.90528	-0.00517	-0.00625
90	0.90454	-0.00591	-0.00699
95	0.90360	-0.00685	-0.00793
100	0.90416	-0.00629	-0.00737

1. The k_{eff} comparison basis for this column is the finite height model with the four corner locations of the basket loaded with Maine Yankee assemblies in the most reactive missing rod geometry. This case is the first case presented in Table 6.6.1-10 with 0% UO_2 in the water above and below the active fuel of the missing rod array.
2. The k_{eff} comparison basis for this column is the infinite height model with the four corner locations of the basket loaded with Maine Yankee assemblies in the most reactive missing rod geometry, the case presented in Table 6.6.1-6 labeled "24 (Four Corners)", k_{eff} = 0.91153.

Table 6.6.1-12 Infinite Height Analysis of Maine Yankee Start-up Sources

Pu Vf	Be Vf	H_2O Vf	Void Vf	k_{eff}	sd	k_{eff}+2sd	Delta K*
0	0.5	0.5	0	0.91085	0.00087	0.91259	-0.00068
0.008	0.992	0	0	0.91034	0.00089	0.91212	-0.00119
0.008	0.9	0.092	0	0.91151	0.00087	0.91325	-0.00002
0.008	0.8	0.192	0	0.91138	0.00087	0.91312	-0.00015
0.008	0.7	0.292	0	0.91042	0.00085	0.91212	-0.00111
0.008	0.6	0.392	0	0.91231	0.00086	0.91403	0.00078
0.008	0.5	0.492	0	0.90922	0.00083	0.91088	-0.00231
0.008	0.4	0.592	0	0.91197	0.00087	0.91371	0.00044
0.008	0.3	0.692	0	0.91203	0.00086	0.91375	0.00050
0.008	0.2	0.792	0	0.90922	0.00084	0.91090	-0.00231
0.008	0.1	0.892	0	0.91140	0.00085	0.91310	-0.00013
0.008	0	0.992	0	0.91149	0.00086	0.91321	-0.00004
0.008	0.9	0	0.092	0.91075	0.00087	0.91249	-0.00078
0.008	0.8	0	0.192	0.91143	0.00091	0.91325	-0.00010
0.008	0.7	0	0.292	0.91182	0.00086	0.91354	0.00029
0.008	0.6	0	0.392	0.91072	0.00082	0.91236	-0.00081
0.008	0.5	0	0.492	0.90984	0.00085	0.91154	-0.00169
0.008	0.4	0	0.592	0.90982	0.00091	0.91164	-0.00171
0.008	0.3	0	0.692	0.91055	0.00087	0.91229	-0.00098
0.008	0.2	0	0.792	0.91054	0.00085	0.91224	-0.00099
0.008	0.1	0	0.892	0.91006	0.00088	0.91182	-0.00147
0.008	0	0	0.992	0.90957	0.00086	0.91129	-0.00196

*Change in reactivity from case "24 (Four Corners)" in Table 6.6.1-6.

6.7 References

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2. Nuclear Regulatory Commission, "Standard Review Plan for Dry Cask Storage Systems," NUREG-1536, January 1997.

3. ORNL CCC-545, "SCALE 4.3: Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers," September 1995.

4. ORNL/NUREG/CSD-2/V1/R5, Section C4, "CSAS: Control Module for Enhanced Criticality Safety Analysis Sequences," Landers, N.F., and Petrie L.M., September 1995.

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6. ORNL/NUREG/CSD-2/V3/R5, Section M4, "SCALE Cross-Section Libraries," Jordan, W.C., September 1995.

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14. NUREG/CR-1547, "Criticality Experiments with Subcritical Clusters of 2.35 Wt % and 4.31 Wt % ^{235}U Enriched UO_2 Rods in Water at a Water-to-Fuel Volume Ratio of 1.6," Bierman, S.R., Clayton, E.D., July 1980.

15. Bierman, S.R., and E. D. Clayton, "Criticality Experiments with Subcritical Clusters of 2.35 Wt % and 4.31 Wt % ^{235}U Enriched UO_2 Rods in Water with Steel Reflecting Walls," Nuclear Technology, Volume 54, pp 131-144, August 1981.

16. NUREG/CR-0796, "Criticality Experiments with Subcritical Clusters of 2.35 Wt % and 4.31 Wt % ^{235}U Enriched UO_2 Rods in Water with Uranium or Lead Reflecting Walls," Bierman, S.R., Durst, B.M., and Clayton, E.D., April 1979.

17. Bierman, B.M., "Criticality Experiments to Provide Benchmark Data on Neutron Flux Traps," PNL-6205/UC-714, June 1988.

18. Manaranche, J.C. et al, "Dissolution and Storage Experiment with 4.75 Wt % U^{235} Enriched UO2 Rods," Nuclear Technology, Volume 50, September 1980.

19. Owen, D. B., "Factors for One-Sided Tolerance Limits and for Variables Sampling Plans," SCR-607, 1963.

20. SERCO Assurance, "MCBEND, A Monte Carlo Program for General Radiation Transport Solutions, User Guide for Version 9," ANSWERS/MCBEND (94) 15, June 2000.

6.8 CSAS Inputs

The CSAS25 input files for the criticality analyses of the Universal Storage System standard transfer and concrete casks containing PWR or BWR fuel, under normal and accident conditions, are provided in Figures 6.8-1 through 6.8-8. A standard transfer cask PWR Westinghouse 17×17 OFA (we17b) input file containing soluble boron at 1000 ppm, with a fuel initial enrichment of 5.0 wt. % ^{235}U, is shown in Figure 6.8-9. A BWR standard transfer cask model input containing 56 Exxon/ANF 9×9 79-fuel rod assemblies (ex09c) at 4.4 wt. % ^{235}U is shown in Figure 6.8-10.

The CSAS25 input files refer to BORAL as the neutron absorber material. BORAL is a trade name for one of the neutron absorber materials used in the fuel tube design. As described in the license drawings in Chapter 1, either BORAL or METAMIC neutron absorber sheet may be used as a neutron absorber material. These materials are specified with the ^{10}B areal density appropriate to the PWR or BWR fuel tube design.

Figure 6.8-1 CSAS Input for Normal Conditions - Transfer Cask Containing PWR Fuel

```
=CSAS25
UMS PWR TFR; NORMAL OP; ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 250 CM PITCH
27GROUPNDF4 LATTICECELL
UO2  1  0.95 293.0 92235 4.20 92238 95.80 END
ZIRCALLOY   2  1.0  293.0  END
H2O  3  1.0  293.0  END
AL   4  1.0  293.0  END
SS304 5 1.0  293.0  END
AL     6 DEN=2.6000 0.4627 293.0 END
B-10   6 DEN=2.6000 0.0568 293.0 END
B-11   6 DEN=2.6000 0.3449 293.0 END
C      6 DEN=2.6000 0.1167 293.0 END
PB     7 1.0 293.0  END
B-10   8 0.0 8.553-5 293.0 END
B-11   8 0.0 3.422-4 293.0 END
AL     8 0.0 7.763-3 293.0 END
H      8 0.0 5.854-2 293.0 END
O      8 0.0 2.609-2 293.0 END
C      8 0.0 2.264-2 293.0 END
N      8 0.0 1.394-3 293.0 END
H2O   9 1.0 293.0 END
H2O  10 1.0 293.0 END
CARBONSTEEL 11 1.0 293.0 END
END COMP
SQUAREPITCH  1.2598 0.7844 1 3 0.9144 2 0.8001 0 END
UMS PWR TFR; NORMAL OP; ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 250 CM PITCH
READ PARAM RUN=YES PLT=NO TME=5000 GEN=203 NPG=1000 END PARAM
READ GEOM
UNIT  1
COM='FUEL PIN CELL - BETWEEN DISKS'
CYLINDER   1 1  0.3922   2P2.4892
CYLINDER   0 1  0.4001   2P2.4892
CYLINDER   2 1  0.4572   2P2.4892
CUBOID     3 1  4P0.6299 2P2.4892
UNIT  2
COM='WATER ROD CELL - BETWEEN DISKS'
CYLINDER  3 1  0.5715   2P2.4892
CYLINDER  2 1  0.6121   2P2.4892
CUBOID    3 1  4P0.6299 2P2.4892
UNIT  3
COM='FUEL PIN CELL - FOR DISK SLICE OF CASK'
CYLINDER   1 1  0.3922   2P0.6350
CYLINDER   0 1  0.4001   2P0.6350
CYLINDER   2 1  0.4572   2P0.6350
CUBOID     3 1  4P0.6299 2P0.6350
UNIT  4
COM='WATER ROD CELL - FOR DISK SLICE OF CASK'
CYLINDER  3 1  0.5715   2P0.6350
CYLINDER  2 1  0.6121   2P0.6350
CUBOID    3 1  4P0.6299 2P0.6350
UNIT 5
COM='X-X BORAL SHEET BETWEEN DISKS'
CUBOID 6 1 2P10.4140 2P0.0635 2P2.4892
CUBOID 4 1 2P10.4140 2P0.0951 2P2.4892
UNIT 6
COM='Y-Y BORAL SHEET BETWEEN DISKS'
CUBOID 6 1 2P0.0635 2P10.4140 2P2.4892
CUBOID 4 1 2P0.0951 2P10.4140 2P2.4892
UNIT 7
COM='X-X BORAL SHEET WITH DISKS'
CUBOID 6 1 2P10.4140 2P0.0635 2P0.6350
CUBOID 4 1 2P10.4140 2P0.0951 2P0.6350
UNIT 8
COM='Y-Y BORAL SHEET WITH DISKS'
CUBOID 6 1 2P0.0635 2P10.4140 2P0.6350
CUBOID 4 1 2P0.0951 2P10.4140 2P0.6350
UNIT 10
COM='TUBE CELL IN H2O BETWEEN DISKS (A)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P2.4892
UNIT 11
COM='TUBE CELL IN H2O BETWEEN DISKS (B)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
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Figure 6.8-1 (continued)

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CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P2.4892
UNIT 12
COM='TUBE CELL IN H2O BETWEEN DISKS (C)'
ARRAY 1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P2.4892
UNIT 13
COM='TUBE CELL IN H2O BETWEEN DISKS (D)'
ARRAY 1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P2.4892
UNIT 14
COM='WEB UNIT (1.5" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.8725 2P2.4892
UNIT 15
COM='WEB UNIT (1.0" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.2510 2P2.4892
UNIT 16
COM='WEB UNIT (0.875" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.0923 2P2.4892
UNIT 17
COM='6X1 FUEL TUBE STACK BETWEEN DISKS (-X)'
ARRAY 10 -11.7946 -77.3262 -2.4892
UNIT 18
COM='6X1 FUEL TUBE STACK BETWEEN DISKS (+X)'
ARRAY 11 -11.7946 -77.3262 -2.4892
UNIT 19
COM='2X1 FUEL TUBE STACK OF TUBES BETWEEN DISKS (-X)'
ARRAY 12 -11.7946 -25.4616 -2.4892
UNIT 20
COM='2X1 FUEL TUBE STACK OF TUBES BETWEEN DISKS (+X)'
ARRAY 13 -11.7946 -25.4616 -2.4892
UNIT 30
COM='TUBE CELL IN ST DISK (A)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P0.6350
UNIT 31
COM='TUBE CELL IN ST DISK (B)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P0.6350
UNIT 32
COM='TUBE CELL IN ST DISK (C)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P0.6350
UNIT 33
COM='TUBE CELL IN ST DISK (D)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P0.6350
UNIT 34
COM='WEB UNIT (1.5" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.8725 2P0.6350
```

Figure 6.8-1 (continued)

```
UNIT 35
COM='WEB UNIT (1.0" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.2510 2P0.6350
UNIT 36
COM='WEB UNIT (0.875" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.0923 2P0.6350
UNIT 37
COM='6x1 FUEL TUBE STACK ST DISK (-X)'
ARRAY 20 -11.7946 -77.3262 -0.6350
UNIT 38
COM='6x1 FUEL TUBE STACK ST DISK (+X)'
ARRAY 21 -11.7946 -77.3262 -0.6350
UNIT 39
COM='2X1 FUEL TUB STACK OF TUBES ST DISK (-X)'
ARRAY 22 -11.7946 -25.4616 -0.6350
UNIT 40
COM='2X1 FUEL TUB STACK OF TUBES ST DISK (+X)'
ARRAY 23 -11.7946 -25.4616 -0.6350
UNIT 50
COM='TUBE CELL IN AL DISK (A)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P0.6350
UNIT 51
COM='TUBE CELL IN AL DISK (B)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P0.6350
UNIT 52
COM='TUBE CELL IN AL DISK (C)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P0.6350
UNIT 53
COM='TUBE CELL IN AL DISK (D)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P0.6350
UNIT 54
COM='WEB UNIT (1.5" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.8725 2P0.6350
UNIT 55
COM='WEB UNIT (1.0" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.2510 2P0.6350
UNIT 56
COM='WEB UNIT (0.875" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.0923 2P0.6350
UNIT 57
COM='6X1 FUEL TUBE STACK AL DISK'
ARRAY 30 -11.7946 -77.3262 -0.6350
UNIT 58
COM='6X1 FUEL TUBE STACK AL DISK'
ARRAY 31 -11.7946 -77.3262 -0.6350
UNIT 59
COM='2X1 FUEL TUBE STACK OF TUBES AL DISK'
ARRAY 32 -11.7946 -25.4616 -0.6350
UNIT 60
COM='2X1 FUEL TUBE STACK OF TUBES AL DISK'
ARRAY 33 -11.7946 -25.4616 -0.6350
UNIT 70
COM='BASKET STRUCTURE IN TRANSFER CASK - WATER DISK'
CYLINDER 3 1 +83.5787 2P2.4892
HOLE 17  -13.6669 0.0 0.0
HOLE 18  +13.6669 0.0 0.0
HOLE 19  -39.7578 0.0 0.0
HOLE 20  +39.7578 0.0 0.0
HOLE 19  -65.5312 0.0 0.0
HOLE 20  +65.5312 0.0 0.0
HOLE 10  +40.8048 +40.8048 0.0
HOLE 11  -40.8048 +40.8048 0.0
```

Figure 6.8-1 (continued)

```
HOLE 12  -40.8048 -40.8048 0.0
HOLE 13  +40.8048 -40.8048 0.0
CYLINDER  5 1  +85.1662 2P2.4892
CYLINDER   9 1  +86.0425 2P2.4892
CYLINDER  11 1  +87.9475 2P2.4892
CYLINDER   7 1  +97.4725 2P2.4892
CYLINDER   8 1 +102.5525 2P2.4892
CYLINDER  11 1 +105.7275 2P2.4892
CUBOID     9 1 4P125.0   2P2.4892
UNIT 71
COM='BASKET STRUCTURE IN TRANSFER CASK - ST DISK'
CYLINDER  5 1 +83.1850 2P0.6350
HOLE 37  -13.6669 0.0 0.0
HOLE 38  +13.6669 0.0 0.0
HOLE 39  -39.7578 0.0 0.0
HOLE 40  +39.7578 0.0 0.0
HOLE 39  -65.5312 0.0 0.0
HOLE 40  +65.5312 0.0 0.0
HOLE 30  +40.8048 +40.8048 0.0
HOLE 31  -40.8048 +40.8048 0.0
HOLE 32  -40.8048 -40.8048 0.0
HOLE 33  +40.8048 -40.8048 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER   9 1  +86.0425 2P0.6350
CYLINDER  11 1  +87.9475 2P0.6350
CYLINDER   7 1  +97.4725 2P0.6350
CYLINDER   8 1 +102.5525 2P0.6350
CYLINDER  11 1 +105.7275 2P0.6350
CUBOID     9 1 4P125.0   2P0.6350
UNIT 72
COM='BASKET STRUCTURE IN TRANSFER CASK - AL DISK'
CYLINDER  4 1 +82.8675 2P0.6350
HOLE 57  -13.6669 0.0 0.0
HOLE 58  +13.6669 0.0 0.0
HOLE 59  -39.7578 0.0 0.0
HOLE 60  +39.7578 0.0 0.0
HOLE 59  -65.5312 0.0 0.0
HOLE 60  +65.5312 0.0 0.0
HOLE 50  +40.8048 +40.8048 0.0
HOLE 51  -40.8048 +40.8048 0.0
HOLE 52  -40.8048 -40.8048 0.0
HOLE 53  +40.8048 -40.8048 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER   9 1  +86.0425 2P0.6350
CYLINDER  11 1  +87.9475 2P0.6350
CYLINDER   7 1  +97.4725 2P0.6350
CYLINDER   8 1 +102.5525 2P0.6350
CYLINDER  11 1 +105.7275 2P0.6350
CUBOID     9 1 4P125.0   2P0.6350
GLOBAL UNIT 73
COM='DISK SLICE STACK'
ARRAY  40 -125.0 -125.0 0.0
END GEOM
READ ARRAY
ARA=1    NUX=17 NUY=17 NUZ=1  FILL
                         34R1
          5R1   2   2R1   2   2R1   2   5R1
               3R1   2   9R1   2   3R1
                         17R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                         34R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                         34R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                         17R1
               3R1   2   9R1   2   3R1
          5R1   2   2R1   2   2R1   2   5R1
                         34R1
END FILL
ARA=2  NUX=17 NUY=17 NUZ=1  FILL
                         34R3
          5R3   4   2R3   4   2R3   4   5R3
               3R3   4   9R3   4   3R3
                         17R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                         34R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                         34R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                         17R3
               3R3   4   9R3   4   3R3
          5R3   4   2R3   4   2R3   4   5R3
                         34R3
END FILL
ARA=10 NUX=1 NUY=11 NUZ=1 FILL 12 16 12 15 12 14 11 15 11 16 11 END FILL
ARA=11 NUX=1 NUY=11 NUZ=1 FILL 13 16 13 15 13 14 10 15 10 16 10 END FILL
ARA=12 NUX=1 NUY=3  NUZ=1 FILL 12 14 11 END FILL
ARA=13 NUX=1 NUY=3  NUZ=1 FILL 13 14 10 END FILL
ARA=20 NUX=1 NUY=11 NUZ=1 FILL 32 36 32 35 32 34 31 35 31 36 31 END FILL
ARA=21 NUX=1 NUY=11 NUZ=1 FILL 33 36 33 35 33 34 30 35 30 36 30 END FILL
ARA=22 NUX=1 NUY=3  NUZ=1 FILL 32 34 31 END FILL
ARA=23 NUX=1 NUY=3  NUZ=1 FILL 33 34 30 END FILL
ARA=30 NUX=1 NUY=11 NUZ=1 FILL 52 56 52 55 52 54 51 55 51 56 51 END FILL
ARA=31 NUX=1 NUY=11 NUZ=1 FILL 53 56 53 55 53 54 50 55 50 56 50 END FILL
ARA=32 NUX=1 NUY=3  NUZ=1 FILL 52 54 51 END FILL
ARA=33 NUX=1 NUY=3  NUZ=1 FILL 53 54 50 END FILL
```

Figure 6.8-1 (continued)

```
ARA=40 NUX=1 NUY=1 NUZ=4 FILL 70 71 70 72 END FILL
END ARRAY
READ BOUNDS ZFC=PER YXF=MIRROR END BOUNDS
END DATA
END

SECONDARY MODULE 000008    HAS BEEN CALLED.
```

Figure 6.8-2 CSAS Input for Accident Conditions– Transfer Cask Containing PWR Fuel

```
=CSAS25
UMS PWR TFR; ACCIDENT; ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 250 CM PITCH
27GROUPNDF4 LATTICECELL
UO2  1  0.95 293.0 92235 4.20 92238 95.80 END
ZIRCALLOY   2  1.0   293.0   END
H2O  3  1.0   293.0   END
AL   4  1.0   293.0   END
SS304 5 1.0   293.0   END
AL     6 DEN=2.6000 0.4627 293.0 END
B-10   6 DEN=2.6000 0.0568 293.0 END
B-11   6 DEN=2.6000 0.3449 293.0 END
C      6 DEN=2.6000 0.1167 293.0 END
PB     7 1.0 293.0  END
B-10   8 0.0 8.553-5 293.0 END
B-11   8 0.0 3.422-4 293.0 END
AL     8 0.0 7.763-3 293.0 END
H      8 0.0 5.854-2 293.0 END
O      8 0.0 2.609-2 293.0 END
C      8 0.0 2.264-2 293.0 END
N      8 0.0 1.394-3 293.0 END
H2O    9 1.0 293.0 END
H2O   10 1.0 293.0 END
CARBONSTEEL 11 1.0 293.0 END
END COMP
SQUAREPITCH  1.2598 0.7844 1 3 0.9144 2 0.8001 10 END
UMS PWR TFR; ACCIDENT; ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 250 CM PITCH
READ PARAM RUN=YES PLT=NO TME=5000 GEN=803 NPG=1000 END PARAM
READ GEOM
UNIT  1
COM='FUEL PIN CELL - BETWEEN DISKS'
CYLINDER    1 1  0.3922    2P2.4892
CYLINDER   10 1  0.4001    2P2.4892
CYLINDER    2 1  0.4572    2P2.4892
CUBOID      3 1  4P0.6299 2P2.4892
UNIT  2
COM='WATER ROD CELL - BETWEEN DISKS'
CYLINDER  3 1  0.5715    2P2.4892
CYLINDER  2 1  0.6121    2P2.4892
CUBOID    3 1  4P0.6299 2P2.4892
UNIT  3
COM='FUEL PIN CELL - FOR DISK SLICE OF CASK'
CYLINDER    1 1  0.3922    2P0.6350
CYLINDER   10 1  0.4001    2P0.6350
CYLINDER    2 1  0.4572    2P0.6350
CUBOID      3 1  4P0.6299 2P0.6350
UNIT  4
COM='WATER ROD CELL - FOR DISK SLICE OF CASK'
CYLINDER  3 1  0.5715    2P0.6350
CYLINDER  2 1  0.6121    2P0.6350
CUBOID    3 1  4P0.6299 2P0.6350
UNIT 5
COM='X-X BORAL SHEET BETWEEN DISKS'
CUBOID 6 1 2P10.4140 2P0.0635 2P2.4892
CUBOID 4 1 2P10.4140 2P0.0951 2P2.4892
UNIT 6
COM='Y-Y BORAL SHEET BETWEEN DISKS'
CUBOID 6 1 2P0.0635 2P10.4140 2P2.4892
CUBOID 4 1 2P0.0951 2P10.4140 2P2.4892
UNIT 7
COM='X-X BORAL SHEET WITH DISKS'
CUBOID 6 1 2P10.4140 2P0.0635 2P0.6350
CUBOID 4 1 2P10.4140 2P0.0951 2P0.6350
UNIT 8
COM='Y-Y BORAL SHEET WITH DISKS'
CUBOID 6 1 2P0.0635 2P10.4140 2P0.6350
CUBOID 4 1 2P0.0951 2P10.4140 2P0.6350
UNIT 10
COM='TUBE CELL IN H2O BETWEEN DISKS (A)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P2.4892
UNIT 11
COM='TUBE CELL IN H2O BETWEEN DISKS (B)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
```

Figure 6.8-2 (continued)

```
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P2.4892
UNIT 12
COM='TUBE CELL IN H2O BETWEEN DISKS (C)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P2.4892
UNIT 13
COM='TUBE CELL IN H2O BETWEEN DISKS (D)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P2.4892
UNIT 14
COM='WEB UNIT (1.5" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.8725 2P2.4892
UNIT 15
COM='WEB UNIT (1.0" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.2510 2P2.4892
UNIT 16
COM='WEB UNIT (0.875" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.0923 2P2.4892
UNIT 17
COM='6X1 FUEL TUBE STACK BETWEEN DISKS (-X)'
ARRAY 10 -11.7946 -77.3262 -2.4892
UNIT 18
COM='6X1 FUEL TUBE STACK BETWEEN DISKS (+X)'
ARRAY 11 -11.7946 -77.3262 -2.4892
UNIT 19
COM='2X1 FUEL TUBE STACK OF TUBES BETWEEN DISKS (-X)'
ARRAY 12 -11.7946 -25.4616 -2.4892
UNIT 20
COM='2X1 FUEL TUBE STACK OF TUBES BETWEEN DISKS (+X)'
ARRAY 13 -11.7946 -25.4616 -2.4892
UNIT 30
COM='TUBE CELL IN ST DISK (A)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P0.6350
UNIT 31
COM='TUBE CELL IN ST DISK (B)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P0.6350
UNIT 32
COM='TUBE CELL IN ST DISK (C)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P0.6350
UNIT 33
COM='TUBE CELL IN ST DISK (D)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P0.6350
UNIT 34
COM='WEB UNIT (1.5" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.8725 2P0.6350
UNIT 35
```

Figure 6.8-2 (continued)

```
COM='WEB UNIT (1.0" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.2510 2P0.6350
UNIT 36
COM='WEB UNIT (0.875" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.0923 2P0.6350
UNIT 37
COM='6x1 FUEL TUBE STACK ST DISK (-X)'
ARRAY 20 -11.7946 -77.3262 -0.6350
UNIT 38
COM='6x1 FUEL TUBE STACK ST DISK (+X)'
ARRAY 21 -11.7946 -77.3262 -0.6350
UNIT 39
COM='2X1 FUEL TUB STACK OF TUBES ST DISK (-X)'
ARRAY 22 -11.7946 -25.4616 -0.6350
UNIT 40
COM='2X1 FUEL TUB STACK OF TUBES ST DISK (+X)'
ARRAY 23 -11.7946 -25.4616 -0.6350
UNIT 50
COM='TUBE CELL IN AL DISK (A)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P0.6350
UNIT 51
COM='TUBE CELL IN AL DISK (B)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P0.6350
UNIT 52
COM='TUBE CELL IN AL DISK (C)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P0.6350
UNIT 53
COM='TUBE CELL IN AL DISK (D)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P0.6350
UNIT 54
COM='WEB UNIT (1.5" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.8725 2P0.6350
UNIT 55
COM='WEB UNIT (1.0" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.2510 2P0.6350
UNIT 56
COM='WEB UNIT (0.875" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.0923 2P0.6350
UNIT 57
COM='6X1 FUEL TUBE STACK AL DISK'
ARRAY 30 -11.7946 -77.3262 -0.6350
UNIT 58
COM='6X1 FUEL TUBE STACK AL DISK'
ARRAY 31 -11.7946 -77.3262 -0.6350
UNIT 59
COM='2X1 FUEL TUBE STACK OF TUBES AL DISK'
ARRAY 32 -11.7946 -25.4616 -0.6350
UNIT 60
COM='2X1 FUEL TUBE STACK OF TUBES AL DISK'
ARRAY 33 -11.7946 -25.4616 -0.6350
UNIT 70
COM='BASKET STRUCTURE IN TRANSFER CASK - WATER DISK'
CYLINDER 3 1 +83.5787 2P2.4892
HOLE 17  -13.6669 0.0 0.0
HOLE 18  +13.6669 0.0 0.0
HOLE 19  -39.7578 0.0 0.0
HOLE 20  +39.7578 0.0 0.0
HOLE 19  -65.5312 0.0 0.0
HOLE 20  +65.5312 0.0 0.0
HOLE 10  +40.8048 +40.8048 0.0
HOLE 11  -40.8048 +40.8048 0.0
HOLE 12  -40.8048 -40.8048 0.0
```

Figure 6.8-2 (continued)

```
HOLE 13  +40.8048 -40.8048 0.0
CYLINDER  5 1  +85.1662 2P2.4892
CYLINDER   9 1  +86.0425 2P2.4892
CYLINDER  11 1  +87.9475 2P2.4892
CYLINDER   7 1  +97.4725 2P2.4892
CYLINDER   8 1 +102.5525 2P2.4892
CYLINDER  11 1 +105.7275 2P2.4892
CUBOID     9 1 4P125.0   2P2.4892
UNIT 71
COM='BASKET STRUCTURE IN TRANSFER CASK - ST DISK'
CYLINDER  5 1 +83.1850 2P0.6350
HOLE 37  -13.6669 0.0 0.0
HOLE 38  +13.6669 0.0 0.0
HOLE 39  -39.7578 0.0 0.0
HOLE 40  +39.7578 0.0 0.0
HOLE 39  -65.5312 0.0 0.0
HOLE 40  +65.5312 0.0 0.0
HOLE 30  +40.8048 +40.8048 0.0
HOLE 31  -40.8048 +40.8048 0.0
HOLE 32  -40.8048 -40.8048 0.0
HOLE 33  +40.8048 -40.8048 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER   9 1  +86.0425 2P0.6350
CYLINDER  11 1  +87.9475 2P0.6350
CYLINDER   7 1  +97.4725 2P0.6350
CYLINDER   8 1 +102.5525 2P0.6350
CYLINDER  11 1 +105.7275 2P0.6350
CUBOID     9 1 4P125.0   2P0.6350
UNIT 72
COM='BASKET STRUCTURE IN TRANSFER CASK - AL DISK'
CYLINDER  4 1 +82.8675 2P0.6350
HOLE 57  -13.6669 0.0 0.0
HOLE 58  +13.6669 0.0 0.0
HOLE 59  -39.7578 0.0 0.0
HOLE 60  +39.7578 0.0 0.0
HOLE 59  -65.5312 0.0 0.0
HOLE 60  +65.5312 0.0 0.0
HOLE 50  +40.8048 +40.8048 0.0
HOLE 51  -40.8048 +40.8048 0.0
HOLE 52  -40.8048 -40.8048 0.0
HOLE 53  +40.8048 -40.8048 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER   9 1  +86.0425 2P0.6350
CYLINDER  11 1  +87.9475 2P0.6350
CYLINDER   7 1  +97.4725 2P0.6350
CYLINDER   8 1 +102.5525 2P0.6350
CYLINDER  11 1 +105.7275 2P0.6350
CUBOID     9 1 4P125.0   2P0.6350
GLOBAL UNIT 73
COM='DISK SLICE STACK'
ARRAY  40 -125.0 -125.0 0.0
END GEOM
READ ARRAY
ARA=1    NUX=17 NUY=17 NUZ=1  FILL
                        34R1
          5R1   2   2R1   2   2R1   2   5R1
               3R1   2   9R1   2   3R1
                        17R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                        34R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                        34R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                        17R1
               3R1   2   9R1   2   3R1
          5R1   2   2R1   2   2R1   2   5R1
                        34R1
END FILL
ARA=2  NUX=17 NUY=17 NUZ=1  FILL
                        34R3
          5R3   4   2R3   4   2R3   4   5R3
               3R3   4   9R3   4   3R3
                        17R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                        34R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                        34R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                        17R3
               3R3   4   9R3   4   3R3
          5R3   4   2R3   4   2R3   4   5R3
                        34R3
END FILL
ARA=10 NUX=1 NUY=11 NUZ=1 FILL 12 16 12 15 12 14 11 15 11 16 11 END FILL
ARA=11 NUX=1 NUY=11 NUZ=1 FILL 13 16 13 15 13 14 10 15 10 16 10 END FILL
ARA=12 NUX=1 NUY=3  NUZ=1 FILL 12 14 11 END FILL
ARA=13 NUX=1 NUY=3  NUZ=1 FILL 13 14 10 END FILL
ARA=20 NUX=1 NUY=11 NUZ=1 FILL 32 36 32 35 32 34 31 35 31 36 31 END FILL
ARA=21 NUX=1 NUY=11 NUZ=1 FILL 33 36 33 35 33 34 30 35 30 36 30 END FILL
ARA=22 NUX=1 NUY=3  NUZ=1 FILL 32 34 31 END FILL
ARA=23 NUX=1 NUY=3  NUZ=1 FILL 33 34 30 END FILL
ARA=30 NUX=1 NUY=11 NUZ=1 FILL 52 56 52 55 52 54 51 55 51 56 51 END FILL
ARA=31 NUX=1 NUY=11 NUZ=1 FILL 53 56 53 55 53 54 50 55 50 56 50 END FILL
ARA=32 NUX=1 NUY=3  NUZ=1 FILL 52 54 51 END FILL
ARA=33 NUX=1 NUY=3  NUZ=1 FILL 53 54 50 END FILL
ARA=40 NUX=1 NUY=1 NUZ=4 FILL 70 71 70 72 END FILL
```

Figure 6.8-2 (continued)

```
END ARRAY
READ BOUNDS ZFC=PER YXF=MIRROR END BOUNDS
END DATA
END
```

Figure 6.8-3 CSAS Input for Normal Conditions–Vertical Concrete Cask Containing PWR Fuel

```
=CSAS25
UMS PWR SC; NORMAL OP; ARRAY; 0.0001 GM/CC IN - 0.0001 GM/CC EX; 460 CM PITCH
27GROUPNDF4 LATTICECELL
UO2  1  0.95 293.0 92235 4.20 92238 95.80 END
ZIRCALLOY   2  1.0  293.0  END
H2O  3  0.0001  293.0  END
AL   4  1.0  293.0  END
SS304 5 1.0  293.0  END
AL     6 DEN=2.6000 0.4627 293.0 END
B-10  6 DEN=2.6000 0.0568 293.0 END
B-11  6 DEN=2.6000 0.3449 293.0 END
C     6 DEN=2.6000 0.1167 293.0 END
CARBONSTEEL  7 1.0    293.0  END
REG-CONCRETE 8 0.9750 293.0 END
H2O   9 0.0001 293.0 END
H2O  10 0.0001 293.0 END
END COMP
SQUAREPITCH  1.2598 0.7844 1 3 0.9144 2 0.8001 0 END
UMS PWR SC; NORMAL OP; ARRAY; 0.0001 GM/CC IN - 0.0001 GM/CC EX; 460 CM PITCH
READ PARAM RUN=YES PLT=NO TME=5000 GEN=203 NPG=1000 END PARAM
READ GEOM
UNIT  1
COM='FUEL PIN CELL - BETWEEN DISKS'
CYLINDER   1 1  0.3922   2P2.4892
CYLINDER   0 1  0.4001   2P2.4892
CYLINDER   2 1  0.4572   2P2.4892
CUBOID     3 1  4P0.6299 2P2.4892
UNIT  2
COM='WATER ROD CELL - BETWEEN DISKS'
CYLINDER  3 1  0.5715   2P2.4892
CYLINDER  2 1  0.6121   2P2.4892
CUBOID    3 1  4P0.6299 2P2.4892
UNIT  3
COM='FUEL PIN CELL - FOR DISK SLICE OF CASK'
CYLINDER   1 1  0.3922   2P0.6350
CYLINDER   0 1  0.4001   2P0.6350
CYLINDER   2 1  0.4572   2P0.6350
CUBOID     3 1  4P0.6299 2P0.6350
UNIT  4
COM='WATER ROD CELL - FOR DISK SLICE OF CASK'
CYLINDER  3 1  0.5715   2P0.6350
CYLINDER  2 1  0.6121   2P0.6350
CUBOID    3 1  4P0.6299 2P0.6350
UNIT 5
COM='X-X BORAL SHEET BETWEEN DISKS'
CUBOID 6 1 2P10.4140 2P0.0635 2P2.4892
CUBOID 4 1 2P10.4140 2P0.0951 2P2.4892
UNIT 6
COM='Y-Y BORAL SHEET BETWEEN DISKS'
CUBOID 6 1 2P0.0635 2P10.4140 2P2.4892
CUBOID 4 1 2P0.0951 2P10.4140 2P2.4892
UNIT 7
COM='X-X BORAL SHEET WITH DISKS'
CUBOID 6 1 2P10.4140 2P0.0635 2P0.6350
CUBOID 4 1 2P10.4140 2P0.0951 2P0.6350
UNIT 8
COM='Y-Y BORAL SHEET WITH DISKS'
CUBOID 6 1 2P0.0635 2P10.4140 2P0.6350
CUBOID 4 1 2P0.0951 2P10.4140 2P0.6350
UNIT 10
COM='TUBE CELL IN H2O BETWEEN DISKS (A)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P2.4892
UNIT 11
COM='TUBE CELL IN H2O BETWEEN DISKS (B)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P2.4892
UNIT 12
COM='TUBE CELL IN H2O BETWEEN DISKS (C)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P2.4892
```

Figure 6.8-3 (continued)

```
UNIT 13
COM='TUBE CELL IN H2O BETWEEN DISKS (D)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P2.4892
UNIT 14
COM='WEB UNIT (1.5" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.8725 2P2.4892
UNIT 15
COM='WEB UNIT (1.0" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.2510 2P2.4892
UNIT 16
COM='WEB UNIT (0.875" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.0923 2P2.4892
UNIT 17
COM='6X1 FUEL TUBE STACK BETWEEN DISKS (-X)'
ARRAY 10 -11.7946.-77.3262 -2.4892
UNIT 18
COM='6X1 FUEL TUBE STACK BETWEEN DISKS (+X)'
ARRAY 11 -11.7946 -77.3262 -2.4892
UNIT 19
COM='2X1 FUEL TUBE STACK OF TUBES BETWEEN DISKS (-X)'
ARRAY 12 -11.7946 -25.4616 -2.4892
UNIT 20
COM='2X1 FUEL TUBE STACK OF TUBES BETWEEN DISKS (+X)'
ARRAY 13 -11.7946 -25.4616 -2.4892
UNIT 30
COM='TUBE CELL IN ST DISK (A)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P0.6350
UNIT 31
COM='TUBE CELL IN ST DISK (B)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P0.6350
UNIT 32
COM='TUBE CELL IN ST DISK (C)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P0.6350
UNIT 33
COM='TUBE CELL IN ST DISK (D)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P0.6350
UNIT 34
COM='WEB UNIT (1.5" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.8725 2P0.6350
UNIT 35
COM='WEB UNIT (1.0" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.2510 2P0.6350
UNIT 36
COM='WEB UNIT (0.875" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.0923 2P0.6350
UNIT 37
COM='6x1 FUEL TUBE STACK ST DISK (-X)'
ARRAY 20 -11.7946 -77.3262 -0.6350
UNIT 38
COM='6x1 FUEL TUBE STACK ST DISK (+X)'
ARRAY 21 -11.7946 -77.3262 -0.6350
UNIT 39
```

Figure 6.8-3 (continued)

```
COM='2X1 FUEL TUB STACK OF TUBES ST DISK (-X)'
ARRAY 22 -11.7946 -25.4616 -0.6350
UNIT 40
COM='2X1 FUEL TUB STACK OF TUBES ST DISK (+X)'
ARRAY 23 -11.7946 -25.4616 -0.6350
UNIT 50
COM='TUBE CELL IN AL DISK (A)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P0.6350
UNIT 51
COM='TUBE CELL IN AL DISK (B)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P0.6350
UNIT 52
COM='TUBE CELL IN AL DISK (C)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P0.6350
UNIT 53
COM='TUBE CELL IN AL DISK (D)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P0.6350
UNIT 54
COM='WEB UNIT (1.5" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.8725 2P0.6350
UNIT 55
COM='WEB UNIT (1.0" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.2510 2P0.6350
UNIT 56
COM='WEB UNIT (0.875" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.0923 2P0.6350
UNIT 57
COM='6X1 FUEL TUBE STACK AL DISK'
ARRAY 30 -11.7946 -77.3262 -0.6350
UNIT 58
COM='6X1 FUEL TUBE STACK AL DISK'
ARRAY 31 -11.7946 -77.3262 -0.6350
UNIT 59
COM='2X1 FUEL TUBE STACK OF TUBES AL DISK'
ARRAY 32 -11.7946 -25.4616 -0.6350
UNIT 60
COM='2X1 FUEL TUBE STACK OF TUBES AL DISK'
ARRAY 33 -11.7946 -25.4616 -0.6350
UNIT 70
COM='BASKET STRUCTURE IN STORAGE CASK - WATER DISK'
CYLINDER 3 1 +83.5787 2P2.4892
HOLE 17  -13.6669 0.0 0.0
HOLE 18  +13.6669 0.0 0.0
HOLE 19  -39.7578 0.0 0.0
HOLE 20  +39.7578 0.0 0.0
HOLE 19  -65.5312 0.0 0.0
HOLE 20  +65.5312 0.0 0.0
HOLE 10  +40.8048 +40.8048 0.0
HOLE 11  -40.8048 +40.8048 0.0
HOLE 12  -40.8048 -40.8048 0.0
HOLE 13  +40.8048 -40.8048 0.0
CYLINDER  5 1  +85.1662 2P2.4892
CYLINDER  9 1  +94.615 2P2.4892
CYLINDER  7 1 +100.965 2P2.4892
CYLINDER  8 1 +172.72 2P2.4892
CUBOID    9 1 4P230.0 2P2.4892
UNIT 71
COM='BASKET STRUCTURE IN STORAGE CASK - ST DISK'
CYLINDER  5 1 +83.1850 2P0.6350
HOLE 37  -13.6669 0.0 0.0
HOLE 38  +13.6669 0.0 0.0
HOLE 39  -39.7578 0.0 0.0
```

Figure 6.8-3 (continued)

```
HOLE 40  +39.7578 0.0 0.0
HOLE 39  -65.5312 0.0 0.0
HOLE 40  +65.5312 0.0 0.0
HOLE 30  +40.8048 +40.8048 0.0
HOLE 31  -40.8048 +40.8048 0.0
HOLE 32  -40.8048 -40.8048 0.0
HOLE 33  +40.8048 -40.8048 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER  9 1  +94.615 2P0.6350
CYLINDER  7 1 +100.965 2P0.6350
CYLINDER  8 1 +172.72 2P0.6350
CUBOID    9 1 4P230.0 2P0.6350
UNIT 72
COM='BASKET STRUCTURE IN STORAGE CASK - AL DISK'
CYLINDER  4 1 +82.8675 2P0.6350
HOLE 57  -13.6669 0.0 0.0
HOLE 58  +13.6669 0.0 0.0
HOLE 59  -39.7578 0.0 0.0
HOLE 60  +39.7578 0.0 0.0
HOLE 59  -65.5312 0.0 0.0
HOLE 60  +65.5312 0.0 0.0
HOLE 50  +40.8048 +40.8048 0.0
HOLE 51  -40.8048 +40.8048 0.0
HOLE 52  -40.8048 -40.8048 0.0
HOLE 53  +40.8048 -40.8048 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER  9 1  +94.615 2P0.6350
CYLINDER  7 1 +100.965 2P0.6350
CYLINDER  8 1 +172.72 2P0.6350
CUBOID    9 1 4P230.0 2P0.6350
GLOBAL UNIT 73
COM='DISK SLICE STACK'
ARRAY  40 -230.0 -230.0 0.0
END GEOM
READ ARRAY
ARA=1   NUX=17 NUY=17 NUZ=1  FILL
                             34R1
          5R1   2   2R1   2   2R1   2   5R1
               3R1   2   9R1   2   3R1
                             17R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                             34R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                             34R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                             17R1
               3R1   2   9R1   2   3R1
          5R1   2   2R1   2   2R1   2   5R1
                             34R1
END FILL
ARA=2  NUX=17 NUY=17 NUZ=1  FILL
                             34R3
          5R3   4   2R3   4   2R3   4   5R3
               3R3   4   9R3   4   3R3
                             17R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                             34R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                             34R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                             17R3
               3R3   4   9R3   4   3R3
          5R3   4   2R3   4   2R3   4   5R3
                             34R3
END FILL
ARA=10 NUX=1 NUY=11 NUZ=1 FILL 12 16 12 15 12 14 11 15 11 16 11 END FILL
ARA=11 NUX=1 NUY=11 NUZ=1 FILL 13 16 13 15 13 14 10 15 10 16 10 END FILL
ARA=12 NUX=1 NUY=3  NUZ=1 FILL 12 14 11 END FILL
ARA=13 NUX=1 NUY=3  NUZ=1 FILL 13 14 10 END FILL
ARA=20 NUX=1 NUY=11 NUZ=1 FILL 32 36 32 35 32 34 31 35 31 36 31 END FILL
ARA=21 NUX=1 NUY=11 NUZ=1 FILL 33 36 33 35 33 34 30 35 30 36 30 END FILL
ARA=22 NUX=1 NUY=3  NUZ=1 FILL 32 34 31 END FILL
ARA=23 NUX=1 NUY=3  NUZ=1 FILL 33 34 30 END FILL
ARA=30 NUX=1 NUY=11 NUZ=1 FILL 52 56 52 55 52 54 51 55 51 56 51 END FILL
ARA=31 NUX=1 NUY=11 NUZ=1 FILL 53 56 53 55 53 54 50 55 50 56 50 END FILL
ARA=32 NUX=1 NUY=3  NUZ=1 FILL 52 54 51 END FILL
ARA=33 NUX=1 NUY=3  NUZ=1 FILL 53 54 50 END FILL
ARA=40 NUX=1 NUY=1 NUZ=4 FILL 70 71 70 72 END FILL
END ARRAY
READ BOUNDS ZFC=PER YXF=MIRROR END BOUNDS
END DATA
END
```

Figure 6.8-4 CSAS Input for Accident Conditions– Vertical Concrete Cask Containing PWR Fuel

```
=CSAS25
UMS PWR SC; ACCIDENT; ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 460 CM PITCH
27GROUPNDF4 LATTICECELL
UO2  1  0.95 293.0 92235 4.20 92238 95.80 END
ZIRCALLOY   2  1.0   293.0  END
H2O  3  1.0  293.0  END
AL   4  1.0  293.0  END
SS304 5 1.0  293.0  END
AL     6 DEN=2.6000 0.4627 293.0 END
B-10   6 DEN=2.6000 0.0568 293.0 END
B-11   6 DEN=2.6000 0.3449 293.0 END
C      6 DEN=2.6000 0.1167 293.0 END
CARBONSTEEL  7 1.0     293.0  END
REG-CONCRETE 8 0.9750 293.0 END
H2O   9 1.0 293.0 END
H2O  10 1.0 293.0 END
END COMP
SQUAREPITCH  1.2598 0.7844 1 3 0.9144 2 0.8001 10 END
UMS PWR SC; ACCIDENT; ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 460 CM PITCH
READ PARAM RUN=YES PLT=NO TME=5000 GEN=803 NPG=1000 END PARAM
READ GEOM
UNIT  1
COM='FUEL PIN CELL - BETWEEN DISKS'
CYLINDER   1 1  0.3922   2P2.4892
CYLINDER  10 1  0.4001   2P2.4892
CYLINDER   2 1  0.4572   2P2.4892
CUBOID     3 1  4P0.6299 2P2.4892
UNIT  2
COM='WATER ROD CELL - BETWEEN DISKS'
CYLINDER  3 1  0.5715   2P2.4892
CYLINDER  2 1  0.6121   2P2.4892
CUBOID    3 1  4P0.6299 2P2.4892
UNIT  3
COM='FUEL PIN CELL - FOR DISK SLICE OF CASK'
CYLINDER   1 1  0.3922   2P0.6350
CYLINDER  10 1  0.4001   2P0.6350
CYLINDER   2 1  0.4572   2P0.6350
CUBOID     3 1  4P0.6299 2P0.6350
UNIT  4
COM='WATER ROD CELL - FOR DISK SLICE OF CASK'
CYLINDER  3 1  0.5715   2P0.6350
CYLINDER  2 1  0.6121   2P0.6350
CUBOID    3 1  4P0.6299 2P0.6350
UNIT 5
COM='X-X BORAL SHEET BETWEEN DISKS'
CUBOID 6 1 2P10.4140 2P0.0635 2P2.4892
CUBOID 4 1 2P10.4140 2P0.0951 2P2.4892
UNIT 6
COM='Y-Y BORAL SHEET BETWEEN DISKS'
CUBOID 6 1 2P0.0635 2P10.4140 2P2.4892
CUBOID 4 1 2P0.0951 2P10.4140 2P2.4892
UNIT 7
COM='X-X BORAL SHEET WITH DISKS'
CUBOID 6 1 2P10.4140 2P0.0635 2P0.6350
CUBOID 4 1 2P10.4140 2P0.0951 2P0.6350
UNIT 8
COM='Y-Y BORAL SHEET WITH DISKS'
CUBOID 6 1 2P0.0635 2P10.4140 2P0.6350
CUBOID 4 1 2P0.0951 2P10.4140 2P0.6350
UNIT 10
COM='TUBE CELL IN H2O BETWEEN DISKS (A)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P2.4892
UNIT 11
COM='TUBE CELL IN H2O BETWEEN DISKS (B)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P2.4892
UNIT 12
COM='TUBE CELL IN H2O BETWEEN DISKS (C)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
```

Figure 6.8-4 (continued)

```
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P2.4892
UNIT 13
COM='TUBE CELL IN H2O BETWEEN DISKS (D)'
ARRAY  1  -10.7083 -10.7083 -2.4892
CUBOID 3 1 4P11.2141 2P2.4892
CUBOID 5 1 4P11.3355 2P2.4892
CUBOID 3 1 4P11.5260 2P2.4892
HOLE  5 0.0 +11.4308 0.0
HOLE  5 0.0 -11.4308 0.0
HOLE  6 +11.4308 0.0 0.0
HOLE  6 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P2.4892
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P2.4892
UNIT 14
COM='WEB UNIT (1.5" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.8725 2P2.4892
UNIT 15
COM='WEB UNIT (1.0" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.2510 2P2.4892
UNIT 16
COM='WEB UNIT (0.875" WEB) - BETWEEN DISKS'
CUBOID 3 1  2P11.7946 2P1.0923 2P2.4892
UNIT 17
COM='6X1 FUEL TUBE STACK BETWEEN DISKS (-X)'
ARRAY 10 -11.7946 -77.3262 -2.4892
UNIT 18
COM='6X1 FUEL TUBE STACK BETWEEN DISKS (+X)'
ARRAY 11 -11.7946 -77.3262 -2.4892
UNIT 19
COM='2X1 FUEL TUBE STACK OF TUBES BETWEEN DISKS (-X)'
ARRAY 12 -11.7946 -25.4616 -2.4892
UNIT 20
COM='2X1 FUEL TUBE STACK OF TUBES BETWEEN DISKS (+X)'
ARRAY 13 -11.7946 -25.4616 -2.4892
UNIT 30
COM='TUBE CELL IN ST DISK (A)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P0.6350
UNIT 31
COM='TUBE CELL IN ST DISK (B)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P0.6350
UNIT 32
COM='TUBE CELL IN ST DISK (C)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P0.6350
UNIT 33
COM='TUBE CELL IN ST DISK (D)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P0.6350
UNIT 34
COM='WEB UNIT (1.5" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.8725 2P0.6350
UNIT 35
COM='WEB UNIT (1.0" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.2510 2P0.6350
UNIT 36
COM='WEB UNIT (0.875" WEB) - ST DISKS'
CUBOID 5 1  2P11.7946 2P1.0923 2P0.6350
UNIT 37
COM='6x1 FUEL TUBE STACK ST DISK (-X)'
ARRAY 20 -11.7946 -77.3262 -0.6350
```

Figure 6.8-4 (continued)

```
UNIT 38
COM='6x1 FUEL TUBE STACK ST DISK (+X)'
ARRAY 21 -11.7946 -77.3262 -0.6350
UNIT 39
COM='2X1 FUEL TUB STACK OF TUBES ST DISK (-X)'
ARRAY 22 -11.7946 -25.4616 -0.6350
UNIT 40
COM='2X1 FUEL TUB STACK OF TUBES ST DISK (+X)'
ARRAY 23 -11.7946 -25.4616 -0.6350
UNIT 50
COM='TUBE CELL IN AL DISK (A)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +12.0176 -11.5715 2P0.6350
UNIT 51
COM='TUBE CELL IN AL DISK (B)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +12.0176 -11.5715 2P0.6350
UNIT 52
COM='TUBE CELL IN AL DISK (C)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +11.5715 -12.0176 +11.5715 -12.0176 2P0.6350
UNIT 53
COM='TUBE CELL IN AL DISK (D)'
ARRAY  2 -10.7083 -10.7083 -0.6350
CUBOID 3 1 4P11.2141 2P0.6350
CUBOID 5 1 4P11.3355 2P0.6350
CUBOID 3 1 4P11.5260 2P0.6350
HOLE  7 0.0 +11.4308 0.0
HOLE  7 0.0 -11.4308 0.0
HOLE  8 +11.4308 0.0 0.0
HOLE  8 -11.4308 0.0 0.0
CUBOID 5 1 4P11.5715 2P0.6350
CUBOID 3 1 +12.0176 -11.5715 +11.5715 -12.0176 2P0.6350
UNIT 54
COM='WEB UNIT (1.5" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.8725 2P0.6350
UNIT 55
COM='WEB UNIT (1.0" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.2510 2P0.6350
UNIT 56
COM='WEB UNIT (0.875" WEB) - AL DISKS'
CUBOID 4 1  2P11.7946 2P1.0923 2P0.6350
UNIT 57
COM='6X1 FUEL TUBE STACK AL DISK'
ARRAY 30 -11.7946 -77.3262 -0.6350
UNIT 58
COM='6X1 FUEL TUBE STACK AL DISK'
ARRAY 31 -11.7946 -77.3262 -0.6350
UNIT 59
COM='2X1 FUEL TUBE STACK OF TUBES AL DISK'
ARRAY 32 -11.7946 -25.4616 -0.6350
UNIT 60
COM='2X1 FUEL TUBE STACK OF TUBES AL DISK'
ARRAY 33 -11.7946 -25.4616 -0.6350
UNIT 70
COM='BASKET STRUCTURE IN STORAGE CASK - WATER DISK'
CYLINDER 3 1 +83.5787 2P2.4892
HOLE 17  -13.6669 0.0 0.0
HOLE 18  +13.6669 0.0 0.0
HOLE 19  -39.7578 0.0 0.0
HOLE 20  +39.7578 0.0 0.0
HOLE 19  -65.5312 0.0 0.0
HOLE 20  +65.5312 0.0 0.0
HOLE 10  +40.8048 +40.8048 0.0
HOLE 11  -40.8048 +40.8048 0.0
HOLE 12  -40.8048 -40.8048 0.0
HOLE 13  +40.8048 -40.8048 0.0
CYLINDER  5 1  +85.1662 2P2.4892
CYLINDER  9 1  +94.615 2P2.4892
CYLINDER  7 1 +100.965 2P2.4892
CYLINDER  8 1 +172.72 2P2.4892
CUBOID    9 1 4P230.0 2P2.4892
UNIT 71
COM='BASKET STRUCTURE IN STORAGE CASK - ST DISK'
CYLINDER  5 1 +83.1850 2P0.6350
```

Figure 6.8-4 (continued)

```
HOLE 37  -13.6669 0.0 0.0
HOLE 38  +13.6669 0.0 0.0
HOLE 39  -39.7578 0.0 0.0
HOLE 40  +39.7578 0.0 0.0
HOLE 39  -65.5312 0.0 0.0
HOLE 40  +65.5312 0.0 0.0
HOLE 30  +40.8048 +40.8048 0.0
HOLE 31  -40.8048 +40.8048 0.0
HOLE 32  -40.8048 -40.8048 0.0
HOLE 33  +40.8048 -40.8048 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER  9 1  +94.615 2P0.6350
CYLINDER  7 1 +100.965 2P0.6350
CYLINDER  8 1 +172.72 2P0.6350
CUBOID    9 1 4P230.0 2P0.6350
UNIT 72
COM='BASKET STRUCTURE IN STORAGE CASK - AL DISK'
CYLINDER  4 1 +82.8675 2P0.6350
HOLE 57  -13.6669 0.0 0.0
HOLE 58  +13.6669 0.0 0.0
HOLE 59  -39.7578 0.0 0.0
HOLE 60  +39.7578 0.0 0.0
HOLE 59  -65.5312 0.0 0.0
HOLE 60  +65.5312 0.0 0.0
HOLE 50  +40.8048 +40.8048 0.0
HOLE 51  -40.8048 +40.8048 0.0
HOLE 52  -40.8048 -40.8048 0.0
HOLE 53  +40.8048 -40.8048 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER  9 1  +94.615 2P0.6350
CYLINDER  7 1 +100.965 2P0.6350
CYLINDER  8 1 +172.72 2P0.6350
CUBOID    9 1 4P230.0 2P0.6350
GLOBAL UNIT 73
COM='DISK SLICE STACK'
ARRAY  40 -230.0 -230.0 0.0
END GEOM
READ ARRAY
ARA=1   NUX=17 NUY=17 NUZ=1  FILL
                         34R1
          5R1   2   2R1   2   2R1   2   5R1
               3R1   2   9R1   2   3R1
                         17R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                         34R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                         34R1
2R1   2   2R1   2   2R1   2   2R1   2   2R1   2   2R1
                         17R1
               3R1   2   9R1   2   3R1
          5R1   2   2R1   2   2R1   2   5R1
                         34R1
END FILL
ARA=2  NUX=17 NUY=17 NUZ=1  FILL
                         34R3
          5R3   4   2R3   4   2R3   4   5R3
               3R3   4   9R3   4   3R3
                         17R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                         34R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                         34R3
2R3   4   2R3   4   2R3   4   2R3   4   2R3   4   2R3
                         17R3
               3R3   4   9R3   4   3R3
          5R3   4   2R3   4   2R3   4   5R3
                         34R3
END FILL
ARA=10 NUX=1 NUY=11 NUZ=1 FILL 12 16 12 15 12 14 11 15 11 16 11 END FILL
ARA=11 NUX=1 NUY=11 NUZ=1 FILL 13 16 13 15 13 14 10 15 10 16 10 END FILL
ARA=12 NUX=1 NUY=3  NUZ=1 FILL 12 14 11 END FILL
ARA=13 NUX=1 NUY=3  NUZ=1 FILL 13 14 10 END FILL
ARA=20 NUX=1 NUY=11 NUZ=1 FILL 32 36 32 35 32 34 31 35 31 36 31 END FILL
ARA=21 NUX=1 NUY=11 NUZ=1 FILL 33 36 33 35 33 34 30 35 30 36 30 END FILL
ARA=22 NUX=1 NUY=3  NUZ=1 FILL 32 34 31 END FILL
ARA=23 NUX=1 NUY=3  NUZ=1 FILL 33 34 30 END FILL
ARA=30 NUX=1 NUY=11 NUZ=1 FILL 52 56 52 55 52 54 51 55 51 56 51 END FILL
ARA=31 NUX=1 NUY=11 NUZ=1 FILL 53 56 53 55 53 54 50 55 50 56 50 END FILL
ARA=32 NUX=1 NUY=3  NUZ=1 FILL 52 54 51 END FILL
ARA=33 NUX=1 NUY=3  NUZ=1 FILL 53 54 50 END FILL
ARA=40 NUX=1 NUY=1 NUZ=4 FILL 70 71 70 72 END FILL
END ARRAY
READ BOUNDS ZFC=PER YXP=MIRROR END BOUNDS
END DATA
END
```

Figure 6.8-5 CSAS Input for Normal Conditions – Transfer Cask Containing BWR Fuel

```
=CSAS25
UMS BWR TFR; NORMAL OP; CASK ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 75%B10
27GROUPNDF4 LATTICECELL
UO2   1 0.95 293.0 92235 4.00 92238 96.00 END
ZIRCALLOY  2 1.0  293.0  END
H2O   3 1.0  293.0  END
AL    4 1.0  293.0  END
SS304 5 1.0  293.0  END
AL    6 DEN=2.6849 0.8706 293.0 END
B-10  6 DEN=2.6849 0.0137 293.0 END
B-11  6 DEN=2.6849 0.0830 293.0 END
C     6 DEN=2.6849 0.0281 293.0 END
CARBONSTEEL 7 1.0 293.0 END
PB    8 1.0 293.0  END
B-10  9 0.0 8.553-5 END
B-11  9 0.0 3.422-4 END
AL    9 0.0 7.763-3 END
H     9 0.0 5.854-2 END
O     9 0.0 2.609-2 END
C     9 0.0 2.264-2 END
N     9 0.0 1.394-3 END
H2O  10 1.0 293.0 END
END COMP
SQUAREPITCH  1.4529 0.9055 1 3 1.0770 2 0.9246 0 END
UMS BWR TFR; NORMAL OP; CASK ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 75%B10
READ PARAM RUN=YES PLT=NO TME=5000 GEN=803 NPG=1000 END PARAM
READ GEOM
UNIT  1
COM='FUEL PIN CELL - WITH H2O'
CYLINDER  1 1  0.4528   2P1.7145
CYLINDER  0 1  0.4623   2P1.7145
CYLINDER  2 1  0.5385   2P1.7145
CUBOID    3 1  4P0.7264 2P1.7145
UNIT  2
COM='WATER ROD CELL - WITH H2O'
CYLINDER  3 1  0.4623   2P1.7145
CYLINDER  2 1  0.5385   2P1.7145
CUBOID    3 1  4P0.7264 2P1.7145
UNIT  3
COM='FUEL PIN CELL - WITH ST DISK'
CYLINDER  1 1  0.4528   2P0.7938
CYLINDER  0 1  0.4623   2P0.7938
CYLINDER  2 1  0.5385   2P0.7938
CUBOID    3 1  4P0.7264 2P0.7938
UNIT  4
COM='WATER ROD CELL - WITH ST DISK'
CYLINDER  3 1  0.4623   2P0.7938
CYLINDER  2 1  0.5385   2P0.7938
CUBOID    3 1  4P0.7264 2P0.7938
UNIT  5
COM='FUEL PIN CELL - WITH AL DISK'
CYLINDER  1 1  0.4528   2P0.6350
CYLINDER  0 1  0.4623   2P0.6350
CYLINDER  2 1  0.5385   2P0.6350
CUBOID    3 1  4P0.7264 2P0.6350
UNIT  6
COM='WATER ROD CELL - WITH AL DISK'
CYLINDER  3 1  0.4623   2P0.6350
CYLINDER  2 1  0.5385   2P0.6350
CUBOID    3 1  4P0.7264 2P0.6350
UNIT  7
COM='FUEL PIN ARRAY + CHANNEL - BETWEEN DISKS'
ARRAY  1   -6.5376 -6.5376 -1.7145
CUBOID 3 1 4P6.7031 2P1.7145
CUBOID 2 1 4P6.9063 2P1.7145
UNIT  8
COM='FUEL PIN ARRAY + CHANNEL - ST DISKS'
ARRAY  2   -6.5376 -6.5376 -0.7938
CUBOID 3 1 4P6.7031 2P0.7938
CUBOID 2 1 4P6.9063 2P0.7938
UNIT  9
COM='FUEL PIN ARRAY + CHANNEL - AL DISKS'
ARRAY  3   -6.5376 -6.5376 -0.6350
CUBOID 3 1 4P6.7031 2P0.6350
CUBOID 2 1 4P6.9063 2P0.6350
UNIT 10
COM='X-X BORAL + COVER SHEET BETWEEN DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P1.7145
CUBOID 4 1 2P6.7310 2P0.1714 2P1.7145
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P1.7145
UNIT 11
COM='Y-Y BORAL + COVER SHEET BETWEEN DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P1.7145
CUBOID 4 1 2P0.1714 2P6.7310 2P1.7145
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P1.7145
UNIT 12
COM='X-X BORAL + COVER SHEET WITH ST DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P0.7938
CUBOID 4 1 2P6.7310 2P0.1714 2P0.7938
```

Figure 6.8-5 (continued)

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CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P0.7938
UNIT 13
COM='Y-Y BORAL + COVER SHEET WITH ST DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P0.7938
CUBOID 4 1 2P0.1714 2P6.7310 2P0.7938
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P0.7938
UNIT 14
COM='X-X BORAL + COVER SHEET WITH AL DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P0.6350
CUBOID 4 1 2P6.7310 2P0.1714 2P0.6350
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P0.6350
UNIT 15
COM='Y-Y BORAL + COVER SHEET WITH AL DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P0.6350
CUBOID 4 1 2P0.1714 2P6.7310 2P0.6350
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P0.6350
UNIT 20
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (TR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 21
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 22
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 23
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 24
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (T)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 25
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 26
COM='FUEL TUBE CELL TOP BORAL SHEETS - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
UNIT 27
COM='FUEL TUBE CELL TOP BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
UNIT 28
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 29
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 30
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
```

Figure 6.8-5 (continued)

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UNIT 31
COM='FUEL TUBE CELL NO BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
UNIT 40
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (TR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 41
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 42
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 43
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 44
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (T)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 45
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 46
COM='FUEL TUBE CELL TOP BORAL SHEETS - STEEL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
UNIT 47
COM='FUEL TUBE CELL TOP BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
UNIT 48
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE   13 +7.7859 0.0 0.0
UNIT 49
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE   13 +7.7859 0.0 0.0
UNIT 50
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE   13 +7.7859 0.0 0.0
UNIT 51
COM='FUEL TUBE CELL NO BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
UNIT 60
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (TR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
```

Figure 6.8-5 (continued)

```
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 61
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 62
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 63
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 64
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (T)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 65
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 66
COM='FUEL TUBE CELL TOP BORAL SHEETS - AL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
UNIT 67
COM='FUEL TUBE CELL TOP BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
UNIT 68
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 69
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 70
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 71
COM='FUEL TUBE CELL NO BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
UNIT 80
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (TR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   20  -0.0297 -0.0297 0.0
UNIT 81
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   21  -0.3586 -0.0297 0.0
UNIT 82
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   22  -0.3586 -0.3586 0.0
UNIT 83
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   23  -0.0297 -0.3586 0.0
UNIT 84
```

Figure 6.8-5 (continued)

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COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (T)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   24  -0.1942 -0.0297 0.0
UNIT 85
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   25  -0.1942 -0.3586 0.0
UNIT 86
COM='DISK OPENING TOP BORAL SHEET TUBE - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   26  -0.3586 -0.0297 0.0
UNIT 87
COM='DISK OPENING TOP BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   27  -0.3586 -0.3586 0.0
UNIT 88
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   28  -0.3586 -0.3586 0.0
UNIT 89
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   29  -0.1942 -0.3586 0.0
UNIT 90
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   30  -0.0297 -0.3586 0.0
UNIT 91
COM='DISK OPENING NO BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   31  -0.3586 -0.3586 0.0
UNIT 100
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (TR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   40  -0.0297 -0.0297 0.0
UNIT 101
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   41  -0.3586 -0.0297 0.0
UNIT 102
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   42  -0.3586 -0.3586 0.0
UNIT 103
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   43  -0.0297 -0.3586 0.0
UNIT 104
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (T)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   44  -0.1942 -0.0297 0.0
UNIT 105
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   45  -0.1942 -0.3586 0.0
UNIT 106
COM='DISK OPENING TOP BORAL SHEET TUBE - STEEL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   46  -0.3586 -0.0297 0.0
UNIT 107
COM='DISK OPENING TOP BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   47  -0.3586 -0.3586 0.0
UNIT 108
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   48  -0.3586 -0.3586 0.0
UNIT 109
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   49  -0.1942 -0.3586 0.0
UNIT 110
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   50  -0.0297 -0.3586 0.0
UNIT 111
COM='DISK OPENING NO BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   51  -0.3586 -0.3586 0.0
UNIT 120
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (TR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   60  -0.0297 -0.0297 0.0
UNIT 121
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   61  -0.3586 -0.0297 0.0
UNIT 122
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   62  -0.3586 -0.3586 0.0
UNIT 123
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   63  -0.0297 -0.3586 0.0
UNIT 124
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (T)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   64  -0.1942 -0.0297 0.0
```

Figure 6.8-5 (continued)

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UNIT 125
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   65  -0.1942 -0.3586 0.0
UNIT 126
COM='DISK OPENING TOP BORAL SHEET TUBE - AL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   66  -0.3586 -0.0297 0.0
UNIT 127
COM='DISK OPENING TOP BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   67  -0.3586 -0.3586 0.0
UNIT 128
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   68  -0.3586 -0.3586 0.0
UNIT 129
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   69  -0.1942 -0.3586 0.0
UNIT 130
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   70  -0.0297 -0.3586 0.0
UNIT 131
COM='DISK OPENING NO BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   71  -0.3586 -0.3586 0.0
UNIT 140
COM='BASKET STRUCTURE IN TRANPORT CASK - WATER DISK'
CYLINDER 3 1 +83.5787 2P1.7145
HOLE 90  -70.3885  +8.7986 0.0
HOLE 83  -52.7914  +8.7986 0.0
HOLE 83  -52.7914 +26.3957 0.0
HOLE 90  -52.7914 +43.9928 0.0
HOLE 83  -35.1942  +8.7986 0.0
HOLE 83  -35.1942 +26.3957 0.0
HOLE 83  -35.1942 +43.9928 0.0
HOLE 90  -35.1942 +61.5899 0.0
HOLE 83  -17.5971  +8.7986 0.0
HOLE 83  -17.5971 +26.3957 0.0
HOLE 83  -17.5971 +43.9928 0.0
HOLE 90  -17.5971 +61.5899 0.0
HOLE 85   0.0      +8.7986 0.0
HOLE 85   0.0     +26.3957 0.0
HOLE 85   0.0     +43.9928 0.0
HOLE 89   0.0     +61.5899 0.0
HOLE 82  +17.5971  +8.7986 0.0
HOLE 82  +17.5971 +26.3957 0.0
HOLE 82  +17.5971 +43.9928 0.0
HOLE 88  +17.5971 +61.5899 0.0
HOLE 82  +35.1942  +8.7986 0.0
HOLE 82  +35.1942 +26.3957 0.0
HOLE 82  +35.1942 +43.9928 0.0
HOLE 91  +35.1942 +61.5899 0.0
HOLE 82  +52.7914  +8.7986 0.0
HOLE 87  +52.7914 +26.3957 0.0
HOLE 91  +52.7914 +43.9928 0.0
HOLE 91  +70.3885  +8.7986 0.0
HOLE 80  -70.3885  -8.7986 0.0
HOLE 80  -52.7914  -8.7986 0.0
HOLE 80  -52.7914 -26.3957 0.0
HOLE 80  -52.7914 -43.9928 0.0
HOLE 80  -35.1942  -8.7986 0.0
HOLE 80  -35.1942 -26.3957 0.0
HOLE 80  -35.1942 -43.9928 0.0
HOLE 80  -35.1942 -61.5899 0.0
HOLE 80  -17.5971  -8.7986 0.0
HOLE 80  -17.5971 -26.3957 0.0
HOLE 80  -17.5971 -43.9928 0.0
HOLE 80  -17.5971 -61.5899 0.0
HOLE 84   0.0      -8.7986 0.0
HOLE 84   0.0     -26.3957 0.0
HOLE 84   0.0     -43.9928 0.0
HOLE 84   0.0     -61.5899 0.0
HOLE 81  +17.5971  -8.7986 0.0
HOLE 81  +17.5971 -26.3957 0.0
HOLE 81  +17.5971 -43.9928 0.0
HOLE 81  +17.5971 -61.5899 0.0
HOLE 81  +35.1942  -8.7986 0.0
HOLE 81  +35.1942 -26.3957 0.0
HOLE 81  +35.1942 -43.9928 0.0
HOLE 86  +35.1942 -61.5899 0.0
HOLE 81  +52.7914  -8.7986 0.0
HOLE 86  +52.7914 -26.3957 0.0
HOLE 86  +52.7914 -43.9928 0.0
HOLE 86  +70.3885  -8.7986 0.0
CYLINDER   5 1  +85.1662 2P1.7145
CYLINDER  10 1  +86.0425 2P1.7145
CYLINDER   7 1  +87.9475 2P1.7145
CYLINDER   8 1  +97.4725 2P1.7145
CYLINDER   9 1 +102.5525 2P1.7145
CYLINDER   7 1 +105.7275 2P1.7145
CUBOID    10 1 4P125.0   2P1.7145
UNIT 141
COM='BASKET STRUCTURE IN TRANPORT CASK - SS DISK'
CYLINDER 7 1  +83.1850 2P0.7938
HOLE 110  -70.3885  +8.7986 0.0
HOLE 103  -52.7914  +8.7986 0.0
```

Figure 6.8-5 (continued)

```
HOLE 103  -52.7914 +26.3957 0.0
HOLE 110  -52.7914 +43.9928 0.0
HOLE 103  -35.1942  +8.7986 0.0
HOLE 103  -35.1942 +26.3957 0.0
HOLE 103  -35.1942 +43.9928 0.0
HOLE 110  -35.1942 +61.5899 0.0
HOLE 103  -17.5971  +8.7986 0.0
HOLE 103  -17.5971 +26.3957 0.0
HOLE 103  -17.5971 +43.9928 0.0
HOLE 110  -17.5971 +61.5899 0.0
HOLE 105   0.0      +8.7986 0.0
HOLE 105   0.0     +26.3957 0.0
HOLE 105   0.0     +43.9928 0.0
HOLE 109   0.0     +61.5899 0.0
HOLE 102  +17.5971  +8.7986 0.0
HOLE 102  +17.5971 +26.3957 0.0
HOLE 102  +17.5971 +43.9928 0.0
HOLE 108  +17.5971 +61.5899 0.0
HOLE 102  +35.1942  +8.7986 0.0
HOLE 102  +35.1942 +26.3957 0.0
HOLE 102  +35.1942 +43.9928 0.0
HOLE 111  +35.1942 +61.5899 0.0
HOLE 102  +52.7914  +8.7986 0.0
HOLE 107  +52.7914 +26.3957 0.0
HOLE 111  +52.7914 +43.9928 0.0
HOLE 111  +70.3885  +8.7986 0.0
HOLE 100  -70.3865  -8.7986 0.0
HOLE 100  -52.7914  -8.7986 0.0
HOLE 100  -52.7914 -26.3957 0.0
HOLE 100  -52.7914 -43.9928 0.0
HOLE 100  -35.1942  -8.7986 0.0
HOLE 100  -35.1942 -26.3957 0.0
HOLE 100  -35.1942 -43.9928 0.0
HOLE 100  -35.1942 -61.5899 0.0
HOLE 100  -17.5971  -8.7986 0.0
HOLE 100  -17.5971 -26.3957 0.0
HOLE 100  -17.5971 -43.9928 0.0
HOLE 100  -17.5971 -61.5899 0.0
HOLE 104   0.0      -8.7986 0.0
HOLE 104   0.0     -26.3957 0.0
HOLE 104   0.0     -43.9928 0.0
HOLE 104   0.0     -61.5899 0.0
HOLE 101  +17.5971  -8.7986 0.0
HOLE 101  +17.5971 -26.3957 0.0
HOLE 101  +17.5971 -43.9928 0.0
HOLE 101  +17.5971 -61.5899 0.0
HOLE 101  +35.1942  -8.7986 0.0
HOLE 101  +35.1942 -26.3957 0.0
HOLE 101  +35.1942 -43.9928 0.0
HOLE 106  +35.1942 -61.5899 0.0
HOLE 101  +52.7914  -8.7986 0.0
HOLE 106  +52.7914 -26.3957 0.0
HOLE 106  +52.7914 -43.9928 0.0
HOLE 106  +70.3885  -8.7986 0.0
CYLINDER   3 1  +83.5787 2P0.7938
CYLINDER   5 1  +85.1662 2P0.7938
CYLINDER  10 1  +86.0425 2P0.7938
CYLINDER   7 1  +87.9475 2P0.7938
CYLINDER   8 1  +97.4725 2P0.7938
CYLINDER   9 1 +102.5525 2P0.7938
CYLINDER   7 1 +105.7275 2P0.7938
CUBOID    10 1 4P125.0   2P0.7938
UNIT 142
COM='BASKET STRUCTURE IN TRANPORT CASK - AL DISK'
CYLINDER 4 1  +82.8675 2P0.6350
HOLE 130  -70.3885  +8.7986 0.0
HOLE 123  -52.7914  +8.7986 0.0
HOLE 123  -52.7914 +26.3957 0.0
HOLE 130  -52.7914 +43.9928 0.0
HOLE 123  -35.1942  +8.7986 0.0
HOLE 123  -35.1942 +26.3957 0.0
HOLE 123  -35.1942 +43.9928 0.0
HOLE 130  -35.1942 +61.5899 0.0
HOLE 123  -17.5971  +8.7986 0.0
HOLE 123  -17.5971 +26.3957 0.0
HOLE 123  -17.5971 +43.9928 0.0
HOLE 130  -17.5971 +61.5899 0.0
HOLE 125   0.0      +8.7986 0.0
HOLE 125   0.0     +26.3957 0.0
HOLE 125   0.0     +43.9928 0.0
HOLE 129   0.0     +61.5899 0.0
HOLE 122  +17.5971  +8.7986 0.0
HOLE 122  +17.5971 +26.3957 0.0
HOLE 122  +17.5971 +43.9928 0.0
HOLE 128  +17.5971 +61.5899 0.0
HOLE 122  +35.1942  +8.7986 0.0
HOLE 122  +35.1942 +26.3957 0.0
HOLE 122  +35.1942 +43.9928 0.0
HOLE 131  +35.1942 +61.5899 0.0
HOLE 122  +52.7914  +8.7986 0.0
HOLE 127  +52.7914 +26.3957 0.0
HOLE 131  +52.7914 +43.9928 0.0
HOLE 131  +70.3885  +8.7986 0.0
HOLE 120  -70.3885  -8.7986 0.0
HOLE 120  -52.7914  -8.7986 0.0
HOLE 120  -52.7914 -26.3957 0.0
HOLE 120  -52.7914 -43.9928 0.0
HOLE 120  -35.1942  -8.7986 0.0
HOLE 120  -35.1942 -26.3957 0.0
```

Figure 6.8-5 (continued)

```
HOLE 120  -35.1942 -43.9928 0.0
HOLE 120  -35.1942 -61.5899 0.0
HOLE 120  -17.5971  -8.7986 0.0
HOLE 120  -17.5971 -26.3957 0.0
HOLE 120  -17.5971 -43.9928 0.0
HOLE 120  -17.5971 -61.5899 0.0
HOLE 124   0.0      -8.7986 0.0
HOLE 124   0.0     -26.3957 0.0
HOLE 124   0.0     -43.9928 0.0
HOLE 124   0.0     -61.5899 0.0
HOLE 121  +17.5971  -8.7986 0.0
HOLE 121  +17.5971 -26.3957 0.0
HOLE 121  +17.5971 -43.9928 0.0
HOLE 121  +17.5971 -61.5899 0.0
HOLE 121  +35.1942  -8.7986 0.0
HOLE 121  +35.1942 -26.3957 0.0
HOLE 121  +35.1942 -43.9928 0.0
HOLE 126  +35.1942 -61.5899 0.0
HOLE 121  +52.7914  -8.7986 0.0
HOLE 126  +52.7914 -26.3957 0.0
HOLE 126  +52.7914 -43.9928 0.0
HOLE 126  +70.3885  -8.7986 0.0
CYLINDER   3 1  +83.5787 2P0.6350
CYLINDER   5 1  +85.1662 2P0.6350
CYLINDER  10 1  +86.0425 2P0.6350
CYLINDER   7 1  +87.9475 2P0.6350
CYLINDER   8 1  +97.4725 2P0.6350
CYLINDER   9 1 +102.5525 2P0.6350
CYLINDER   7 1 +105.7275 2P0.6350
CUBOID    10 1 4P125.0   2P0.6350
GLOBAL UNIT 143
COM='CASK SLICES TOGETHER'
ARRAY  4 -125.00 -125.00 0.0
END GEOM
READ ARRAY
ARA=1   NUX=9 NUY=9 NUZ=1  FILL
    36R1
 4R1  2   4R1
 5R1  2   3R1
    27R1
END FILL
ARA=2   NUX=9 NUY=9 NUZ=1  FILL
    36R3
 4R3  4   4R3
 5R3  4   3R3
    27R3
END FILL
ARA=3   NUX=9 NUY=9 NUZ=1  FILL
    36R5
 4R5  6   4R5
 5R5  6   3R5
    27R5
END FILL
ARA=4 NUX=1 NUY=1 NUZ=4 FILL 140 141 140 142 END FILL
END ARRAY
READ BOUNDS ZFC=PER YXF=PER END BOUNDS
END DATA
END
```

Figure 6.8-6 CSAS Input for Accident Conditions - Transfer Cask Containing BWR Fuel

```
=CSAS25
UMS BWR TFR; ACCIDENT OP; CASK ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 75%B10
27GROUPNDF4 LATTICECELL
UO2   1 0.95 293.0 92235 4.00 92238 96.00 END
ZIRCALLOY  2 1.0  293.0  END
H2O   3 1.0  293.0  END
AL    4 1.0  293.0  END
SS304 5 1.0  293.0  END
AL    6 DEN=2.6849 0.8706 293.0 END
B-10  6 DEN=2.6849 0.0137 293.0 END
B-11  6 DEN=2.6849 0.0830 293.0 END
C     6 DEN=2.6849 0.0281 293.0 END
CARBONSTEEL 7 1.0 293.0 END
PB    8 1.0 293.0  END
B-10  9 0.0 8.553-5 END
B-11  9 0.0 3.422-4 END
AL    9 0.0 7.763-3 END
H     9 0.0 5.854-2 END
O     9 0.0 2.609-2 END
C     9 0.0 2.264-2 END
N     9 0.0 1.394-3 END
H2O  10 1.0 293.0 END
H2O  11 1.0 293.0 END
END COMP
SQUAREPITCH  1.4529 0.9055 1 3 1.0770 2 0.9246 11 END
UMS BWR TFR; ACCIDENT OP; CASK ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 75%B10
READ PARAM RUN=YES PLT=NO TME=5000 GEN=803 NPG=1000 END PARAM
READ GEOM
UNIT  1
COM='FUEL PIN CELL - WITH H2O'
CYLINDER  1 1  0.4528   2P1.7145
CYLINDER 11 1  0.4623   2P1.7145
CYLINDER  2 1  0.5385   2P1.7145
CUBOID    3 1  4P0.7264 2P1.7145
UNIT  2
COM='WATER ROD CELL - WITH H2O'
CYLINDER  3 1  0.4623   2P1.7145
CYLINDER  2 1  0.5385   2P1.7145
CUBOID    3 1  4P0.7264 2P1.7145
UNIT  3
COM='FUEL PIN CELL - WITH ST DISK'
CYLINDER  1 1  0.4528   2P0.7938
CYLINDER 11 1  0.4623   2P0.7938
CYLINDER  2 1  0.5385   2P0.7938
CUBOID    3 1  4P0.7264 2P0.7938
UNIT  4
COM='WATER ROD CELL - WITH ST DISK'
CYLINDER  3 1  0.4623   2P0.7938
CYLINDER  2 1  0.5385   2P0.7938
CUBOID    3 1  4P0.7264 2P0.7938
UNIT  5
COM='FUEL PIN CELL - WITH AL DISK'
CYLINDER  1 1  0.4528   2P0.6350
CYLINDER 11 1  0.4623   2P0.6350
CYLINDER  2 1  0.5385   2P0.6350
CUBOID    3 1  4P0.7264 2P0.6350
UNIT  6
COM='WATER ROD CELL - WITH AL DISK'
CYLINDER  3 1  0.4623   2P0.6350
CYLINDER  2 1  0.5385   2P0.6350
CUBOID    3 1  4P0.7264 2P0.6350
UNIT  7
COM='FUEL PIN ARRAY + CHANNEL - BETWEEN DISKS'
ARRAY  1   -6.5376 -6.5376 -1.7145
CUBOID 3 1 4P6.7031 2P1.7145
CUBOID 2 1 4P6.9063 2P1.7145
UNIT  8
COM='FUEL PIN ARRAY + CHANNEL - ST DISKS'
ARRAY  2   -6.5376 -6.5376 -0.7938
CUBOID 3 1 4P6.7031 2P0.7938
CUBOID 2 1 4P6.9063 2P0.7938
UNIT  9
COM='FUEL PIN ARRAY + CHANNEL - AL DISKS'
ARRAY  3   -6.5376 -6.5376 -0.6350
CUBOID 3 1 4P6.7031 2P0.6350
CUBOID 2 1 4P6.9063 2P0.6350
UNIT 10
COM='X-X BORAL + COVER SHEET BETWEEN DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P1.7145
CUBOID 4 1 2P6.7310 2P0.1714 2P1.7145
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P1.7145
UNIT 11
COM='Y-Y BORAL + COVER SHEET BETWEEN DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P1.7145
CUBOID 4 1 2P0.1714 2P6.7310 2P1.7145
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P1.7145
UNIT 12
COM='X-X BORAL + COVER SHEET WITH ST DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P0.7938
CUBOID 4 1 2P6.7310 2P0.1714 2P0.7938
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P0.7938
UNIT 13
COM='Y-Y BORAL + COVER SHEET WITH ST DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P0.7938
CUBOID 4 1 2P0.1714 2P6.7310 2P0.7938
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P0.7938
```

Figure 6.8-6 (continued)

```
UNIT 14
COM='X-X BORAL + COVER SHEET WITH AL DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P0.6350
CUBOID 4 1 2P6.7310 2P0.1714 2P0.6350
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P0.6350
UNIT 15
COM='Y-Y BORAL + COVER SHEET WITH AL DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P0.6350
CUBOID 4 1 2P0.1714 2P6.7310 2P0.6350
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P0.6350
UNIT 20
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (TR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 21
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 22
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 23
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 24
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (T)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 25
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 26
COM='FUEL TUBE CELL TOP BORAL SHEETS - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
UNIT 27
COM='FUEL TUBE CELL TOP BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
UNIT 28
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 29
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 30
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 31
COM='FUEL TUBE CELL NO BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
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Figure 6.8-6 (continued)

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HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
UNIT 40
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (TR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 41
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 42
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 43
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 44
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (T)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 45
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 46
COM='FUEL TUBE CELL TOP BORAL SHEETS - STEEL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
UNIT 47
COM='FUEL TUBE CELL TOP BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
UNIT 48
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE   13 +7.7859 0.0 0.0
UNIT 49
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE   13 +7.7859 0.0 0.0
UNIT 50
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE   13 +7.7859 0.0 0.0
UNIT 51
COM='FUEL TUBE CELL NO BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
UNIT 60
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (TR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
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Figure 6.8-6 (continued)

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HOLE   15 +7.7859 0.0 0.0
UNIT 61
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 62
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 63
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 64
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (T)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 65
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 66
COM='FUEL TUBE CELL TOP BORAL SHEETS - AL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
UNIT 67
COM='FUEL TUBE CELL TOP BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
UNIT 68
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 69
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 70
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 71
COM='FUEL TUBE CELL NO BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
UNIT 80
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (TR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   20  -0.0297 -0.0297 0.0
UNIT 81
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   21  -0.3586 -0.0297 0.0
UNIT 82
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   22  -0.3586 -0.3586 0.0
UNIT 83
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   23  -0.0297 -0.3586 0.0
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Figure 6.8-6 (continued)

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UNIT 84
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (T)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   24  -0.1942 -0.0297 0.0
UNIT 85
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   25  -0.1942 -0.3586 0.0
UNIT 86
COM='DISK OPENING TOP BORAL SHEET TUBE - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   26  -0.3586 -0.0297 0.0
UNIT 87
COM='DISK OPENING TOP BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   27  -0.3586 -0.3586 0.0
UNIT 88
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   28  -0.3586 -0.3586 0.0
UNIT 89
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   29  -0.1942 -0.3586 0.0
UNIT 90
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   30  -0.0297 -0.3586 0.0
UNIT 91
COM='DISK OPENING NO BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   31  -0.3586 -0.3586 0.0
UNIT 100
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (TR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   40  -0.0297 -0.0297 0.0
UNIT 101
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   41  -0.3586 -0.0297 0.0
UNIT 102
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   42  -0.3586 -0.3586 0.0
UNIT 103
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   43  -0.0297 -0.3586 0.0
UNIT 104
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (T)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   44  -0.1942 -0.0297 0.0
UNIT 105
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   45  -0.1942 -0.3586 0.0
UNIT 106
COM='DISK OPENING TOP BORAL SHEET TUBE - STEEL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   46  -0.3586 -0.0297 0.0
UNIT 107
COM='DISK OPENING TOP BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   47  -0.3586 -0.3586 0.0
UNIT 108
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   48  -0.3586 -0.3586 0.0
UNIT 109
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   49  -0.1942 -0.3586 0.0
UNIT 110
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   50  -0.0297 -0.3586 0.0
UNIT 111
COM='DISK OPENING NO BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   51  -0.3586 -0.3586 0.0
UNIT 120
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (TR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   60  -0.0297 -0.0297 0.0
UNIT 121
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   61  -0.3586 -0.0297 0.0
UNIT 122
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   62  -0.3586 -0.3586 0.0
UNIT 123
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   63  -0.0297 -0.3586 0.0
UNIT 124
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Figure 6.8-6 (continued)

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COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (T)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   64  -0.1942 -0.0297 0.0
UNIT 125
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   65  -0.1942 -0.3586 0.0
UNIT 126
COM='DISK OPENING TOP BORAL SHEET TUBE - AL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   66  -0.3586 -0.0297 0.0
UNIT 127
COM='DISK OPENING TOP BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   67  -0.3586 -0.3586 0.0
UNIT 128
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   68  -0.3586 -0.3586 0.0
UNIT 129
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   69  -0.1942 -0.3586 0.0
UNIT 130
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   70  -0.0297 -0.3586 0.0
UNIT 131
COM='DISK OPENING NO BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   71  -0.3586 -0.3586 0.0
UNIT 140
COM='BASKET STRUCTURE IN TRANPORT CASK - WATER DISK'
CYLINDER 3 1 +83.5787 2P1.7145
HOLE 90  -70.3885  +8.7986 0.0
HOLE 83  -52.7914  +8.7986 0.0
HOLE 83  -52.7914 +26.3957 0.0
HOLE 90  -52.7914 +43.9928 0.0
HOLE 83  -35.1942  +8.7986 0.0
HOLE 83  -35.1942 +26.3957 0.0
HOLE 83  -35.1942 +43.9928 0.0
HOLE 90  -35.1942 +61.5899 0.0
HOLE 83  -17.5971  +8.7986 0.0
HOLE 83  -17.5971 +26.3957 0.0
HOLE 83  -17.5971 +43.9928 0.0
HOLE 90  -17.5971 +61.5899 0.0
HOLE 85   0.0      +8.7986 0.0
HOLE 85   0.0     +26.3957 0.0
HOLE 85   0.0     +43.9928 0.0
HOLE 89   0.0     +61.5899 0.0
HOLE 82  +17.5971  +8.7986 0.0
HOLE 82  +17.5971 +26.3957 0.0
HOLE 82  +17.5971 +43.9928 0.0
HOLE 88  +17.5971 +61.5899 0.0
HOLE 82  +35.1942  +8.7986 0.0
HOLE 82  +35.1942 +26.3957 0.0
HOLE 82  +35.1942 +43.9928 0.0
HOLE 91  +35.1942 +61.5899 0.0
HOLE 82  +52.7914  +8.7986 0.0
HOLE 87  +52.7914 +26.3957 0.0
HOLE 91  +52.7914 +43.9928 0.0
HOLE 91  +70.3885  +8.7986 0.0
HOLE 80  -70.3885  -8.7986 0.0
HOLE 80  -52.7914  -8.7986 0.0
HOLE 80  -52.7914 -26.3957 0.0
HOLE 80  -52.7914 -43.9928 0.0
HOLE 80  -35.1942  -8.7986 0.0
HOLE 80  -35.1942 -26.3957 0.0
HOLE 80  -35.1942 -43.9928 0.0
HOLE 80  -35.1942 -61.5899 0.0
HOLE 80  -17.5971  -8.7986 0.0
HOLE 80  -17.5971 -26.3957 0.0
HOLE 80  -17.5971 -43.9928 0.0
HOLE 80  -17.5971 -61.5899 0.0
HOLE 84   0.0      -8.7986 0.0
HOLE 84   0.0     -26.3957 0.0
HOLE 84   0.0     -43.9928 0.0
HOLE 84   0.0     -61.5899 0.0
HOLE 81  +17.5971  -8.7986 0.0
HOLE 81  +17.5971 -26.3957 0.0
HOLE 81  +17.5971 -43.9928 0.0
HOLE 81  +17.5971 -61.5899 0.0
HOLE 81  +35.1942  -8.7986 0.0
HOLE 81  +35.1942 -26.3957 0.0
HOLE 81  +35.1942 -43.9928 0.0
HOLE 86  +35.1942 -61.5899 0.0
HOLE 81  +52.7914  -8.7986 0.0
HOLE 86  +52.7914 -26.3957 0.0
HOLE 86  +52.7914 -43.9928 0.0
HOLE 86  +70.3885  -8.7986 0.0
CYLINDER   5 1  +85.1662 2P1.7145
CYLINDER  10 1  +86.0425 2P1.7145
CYLINDER   7 1  +87.9475 2P1.7145
CYLINDER   8 1  +97.4725 2P1.7145
CYLINDER   9 1 +102.5525 2P1.7145
CYLINDER   7 1 +105.7275 2P1.7145
CUBOID    10 1 4P125.0   2P1.7145
```

Figure 6.8-6 (continued)

```
UNIT 141
COM='BASKET STRUCTURE IN TRANPORT CASK - SS DISK'
CYLINDER 7 1  +83.1850 2P0.7938
HOLE 110  -70.3885  +8.7986 0.0
HOLE 103  -52.7914  +8.7986 0.0
HOLE 103  -52.7914 +26.3957 0.0
HOLE 110  -52.7914 +43.9928 0.0
HOLE 103  -35.1942  +8.7986 0.0
HOLE 103  -35.1942 +26.3957 0.0
HOLE 103  -35.1942 +43.9928 0.0
HOLE 110  -35.1942 +61.5899 0.0
HOLE 103  -17.5971  +8.7986 0.0
HOLE 103  -17.5971 +26.3957 0.0
HOLE 103  -17.5971 +43.9928 0.0
HOLE 110  -17.5971 +61.5899 0.0
HOLE 105   0.0      +8.7986 0.0
HOLE 105   0.0     +26.3957 0.0
HOLE 105   0.0     +43.9928 0.0
HOLE 109   0.0     +61.5899 0.0
HOLE 102  +17.5971  +8.7986 0.0
HOLE 102  +17.5971 +26.3957 0.0
HOLE 102  +17.5971 +43.9928 0.0
HOLE 108  +17.5971 +61.5899 0.0
HOLE 102  +35.1942  +8.7986 0.0
HOLE 102  +35.1942 +26.3957 0.0
HOLE 102  +35.1942 +43.9928 0.0
HOLE 111  +35.1942 +61.5899 0.0
HOLE 102  +52.7914  +8.7986 0.0
HOLE 107  +52.7914 +26.3957 0.0
HOLE 111  +52.7914 +43.9928 0.0
HOLE 111  +70.3885  +8.7986 0.0
HOLE 100  -70.3885  -8.7986 0.0
HOLE 100  -52.7914  -8.7986 0.0
HOLE 100  -52.7914 -26.3957 0.0
HOLE 100  -52.7914 -43.9928 0.0
HOLE 100  -35.1942  -8.7986 0.0
HOLE 100  -35.1942 -26.3957 0.0
HOLE 100  -35.1942 -43.9928 0.0
HOLE 100  -35.1942 -61.5899 0.0
HOLE 100  -17.5971  -8.7986 0.0
HOLE 100  -17.5971 -26.3957 0.0
HOLE 100  -17.5971 -43.9928 0.0
HOLE 100  -17.5971 -61.5899 0.0
HOLE 104   0.0      -8.7986 0.0
HOLE 104   0.0     -26.3957 0.0
HOLE 104   0.0     -43.9928 0.0
HOLE 104   0.0     -61.5899 0.0
HOLE 101  +17.5971  -8.7986 0.0
HOLE 101  +17.5971 -26.3957 0.0
HOLE 101  +17.5971 -43.9928 0.0
HOLE 101  +17.5971 -61.5899 0.0
HOLE 101  +35.1942  -8.7986 0.0
HOLE 101  +35.1942 -26.3957 0.0
HOLE 101  +35.1942 -43.9928 0.0
HOLE 106  +35.1942 -61.5899 0.0
HOLE 101  +52.7914  -8.7986 0.0
HOLE 106  +52.7914 -26.3957 0.0
HOLE 106  +52.7914 -43.9928 0.0
HOLE 106  +70.3885  -8.7986 0.0
CYLINDER   3 1  +83.5787 2P0.7938
CYLINDER   5 1  +85.1662 2P0.7938
CYLINDER  10 1  +86.0425 2P0.7938
CYLINDER   7 1  +87.9475 2P0.7938
CYLINDER   8 1  +97.4725 2P0.7938
CYLINDER   9 1 +102.5525 2P0.7938
CYLINDER   7 1 +105.7275 2P0.7938
CUBOID    10 1 4P125.0   2P0.7938
UNIT 142
COM='BASKET STRUCTURE IN TRANPORT CASK - AL DISK'
CYLINDER 4 1  +82.8675 2P0.6350
HOLE 130  -70.3885  +8.7986 0.0
HOLE 123  -52.7914  +8.7986 0.0
HOLE 123  -52.7914 +26.3957 0.0
HOLE 130  -52.7914 +43.9928 0.0
HOLE 123  -35.1942  +8.7986 0.0
HOLE 123  -35.1942 +26.3957 0.0
HOLE 123  -35.1942 +43.9928 0.0
HOLE 130  -35.1942 +61.5899 0.0
HOLE 123  -17.5971  +8.7986 0.0
HOLE 123  -17.5971 +26.3957 0.0
HOLE 123  -17.5971 +43.9928 0.0
HOLE 130  -17.5971 +61.5899 0.0
HOLE 125   0.0      +8.7986 0.0
HOLE 125   0.0     +26.3957 0.0
HOLE 125   0.0     +43.9928 0.0
HOLE 129   0.0     +61.5899 0.0
HOLE 122  +17.5971  +8.7986 0.0
HOLE 122  +17.5971 +26.3957 0.0
HOLE 122  +17.5971 +43.9928 0.0
HOLE 128  +17.5971 +61.5899 0.0
HOLE 122  +35.1942  +8.7986 0.0
HOLE 122  +35.1942 +26.3957 0.0
HOLE 122  +35.1942 +43.9928 0.0
HOLE 131  +35.1942 +61.5899 0.0
HOLE 122  +52.7914  +8.7986 0.0
HOLE 127  +52.7914 +26.3957 0.0
HOLE 131  +52.7914 +43.9928 0.0
```

Figure 6.8-6 (continued)

```
HOLE 131  +70.3885  +8.7986 0.0
HOLE 120  -70.3885  -8.7986 0.0
HOLE 120  -52.7914  -8.7986 0.0
HOLE 120  -52.7914 -26.3957 0.0
HOLE 120  -52.7914 -43.9928 0.0
HOLE 120  -35.1942  -8.7986 0.0
HOLE 120  -35.1942 -26.3957 0.0
HOLE 120  -35.1942 -43.9928 0.0
HOLE 120  -35.1942 -61.5899 0.0
HOLE 120  -17.5971  -8.7986 0.0
HOLE 120  -17.5971 -26.3957 0.0
HOLE 120  -17.5971 -43.9928 0.0
HOLE 120  -17.5971 -61.5899 0.0
HOLE 124   0.0      -8.7986 0.0
HOLE 124   0.0     -26.3957 0.0
HOLE 124   0.0     -43.9928 0.0
HOLE 124   0.0     -61.5899 0.0
HOLE 121  +17.5971  -8.7986 0.0
HOLE 121  +17.5971 -26.3957 0.0
HOLE 121  +17.5971 -43.9928 0.0
HOLE 121  +17.5971 -61.5899 0.0
HOLE 121  +35.1942  -8.7986 0.0
HOLE 121  +35.1942 -26.3957 0.0
HOLE 121  +35.1942 -43.9928 0.0
HOLE 126  +35.1942 -61.5899 0.0
HOLE 121  +52.7914  -8.7986 0.0
HOLE 126  +52.7914 -26.3957 0.0
HOLE 126  +52.7914 -43.9928 0.0
HOLE 126  +70.3885  -8.7986 0.0
CYLINDER   3 1  +83.5787 2P0.6350
CYLINDER   5 1  +85.1662 2P0.6350
CYLINDER  10 1  +86.0425 2P0.6350
CYLINDER   7 1  +87.9475 2P0.6350
CYLINDER   8 1  +97.4725 2P0.6350
CYLINDER   9 1 +102.5525 2P0.6350
CYLINDER   7 1 +105.7275 2P0.6350
CUBOID    10 1 4P125.0   2P0.6350
GLOBAL UNIT 143
COM='CASK SLICES TOGETHER'
ARRAY  4 -125.00 -125.00 0.0
END GEOM
READ ARRAY
ARA=1   NUX=9 NUY=9 NUZ=1  FILL
    36R1
 4R1  2   4R1
 5R1  2   3R1
    27R1
END FILL
ARA=2   NUX=9 NUY=9 NUZ=1  FILL
    36R3
 4R3  4   4R3
 5R3  4   3R3
    27R3
END FILL
ARA=3   NUX=9 NUY=9 NUZ=1  FILL
    36R5
 4R5  6   4R5
 5R5  6   3R5
    27R5
END FILL
ARA=4 NUX=1 NUY=1 NUZ=4 FILL 140 141 140 142 END FILL
END ARRAY
READ BOUNDS ZFC=PER YXF=PER END BOUNDS
END DATA
END
```

Figure 6.8-7 CSAS Input for Normal Conditions–Vertical Concrete Cask Containing BWR Fuel

```
=CSAS25
UMS BWR VCC; NORMAL CP; CASK ARRAY; 0.0001 GM/CC IN - 0.0001 GM/CC EX; 75%B10
27GROUPNDF4 LATTICECELL
UO2   1 0.95 293.0 92235 4.00 92238 96.00 END
ZIRCALLOY  2 1.0  293.0  END
H2O   3 0.0001  293.0  END
AL    4 1.0  293.0  END
SS304 5 1.0  293.0  END
AL    6 DEN=2.6849 0.8706 293.0 END
B-10  6 DEN=2.6849 0.0137 293.0 END
B-11  6 DEN=2.6849 0.0830 293.0 END
C     6 DEN=2.6849 0.0281 293.0 END
CARBONSTEEL 7 1.0 293.0 END
REG-CONCRETE 8 0.9750 293.0 END
H2O   9 0.0001 293.0 END
END COMP
SQUAREPITCH  1.4529 0.9055 1 3 1.0770 2 0.9246 0 END
UMS BWR VCC; NORMAL OP; CASK ARRAY; 0.0001 GM/CC IN - 0.0001 GM/CC EX; 75%B10
READ PARAM RUN=YES PLT=NO TME=5000 GEN=203 NPG=1000 END PARAM
READ GEOM
UNIT  1
COM='FUEL PIN CELL - WITH H2O'
CYLINDER  1 1  0.4528   2P1.7145
CYLINDER  0 1  0.4623   2P1.7145
CYLINDER  2 1  0.5385   2P1.7145
CUBOID    3 1  4P0.7264 2P1.7145
UNIT  2
COM='WATER ROD CELL - WITH H2O'
CYLINDER  3 1  0.4623   2P1.7145
CYLINDER  2 1  0.5385   2P1.7145
CUBOID    3 1  4P0.7264 2P1.7145
UNIT  3
COM='FUEL PIN CELL - WITH ST DISK'
CYLINDER  1 1  0.4528   2P0.7938
CYLINDER  0 1  0.4623   2P0.7938
CYLINDER  2 1  0.5385   2P0.7938
CUBOID    3 1  4P0.7264 2P0.7938
UNIT  4
COM='WATER ROD CELL - WITH ST DISK'
CYLINDER  3 1  0.4623   2P0.7938
CYLINDER  2 1  0.5385   2P0.7938
CUBOID    3 1  4P0.7264 2P0.7938
UNIT  5
COM='FUEL PIN CELL - WITH AL DISK'
CYLINDER  1 1  0.4528   2P0.6350
CYLINDER  0 1  0.4623   2P0.6350
CYLINDER  2 1  0.5385   2P0.6350
CUBOID    3 1  4P0.7264 2P0.6350
UNIT  6
COM='WATER ROD CELL - WITH AL DISK'
CYLINDER  3 1  0.4623   2P0.6350
CYLINDER  2 1  0.5385   2P0.6350
CUBOID    3 1  4P0.7264 2P0.6350
UNIT  7
COM='FUEL PIN ARRAY + CHANNEL - BETWEEN DISKS'
ARRAY  1    -6.5376 -6.5376 -1.7145
CUBOID 3 1 4P6.7031 2P1.7145
CUBOID 2 1 4P6.9063 2P1.7145
UNIT  8
COM='FUEL PIN ARRAY + CHANNEL - ST DISKS'
ARRAY  2    -6.5376 -6.5376 -0.7938
CUBOID 3 1 4P6.7031 2P0.7938
CUBOID 2 1 4P6.9063 2P0.7938
UNIT  9
COM='FUEL PIN ARRAY + CHANNEL - AL DISKS'
ARRAY  3    -6.5376 -6.5376 -0.6350
CUBOID 3 1 4P6.7031 2P0.6350
CUBOID 2 1 4P6.9063 2P0.6350
UNIT 10
COM='X-X BORAL + COVER SHEET BETWEEN DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P1.7145
CUBOID 4 1 2P6.7310 2P0.1714 2P1.7145
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P1.7145
UNIT 11
COM='Y-Y BORAL + COVER SHEET BETWEEN DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P1.7145
CUBOID 4 1 2P0.1714 2P6.7310 2P1.7145
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P1.7145
UNIT 12
COM='X-X BORAL + COVER SHEET WITH ST DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P0.7938
CUBOID 4 1 2P6.7310 2P0.1714 2P0.7938
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P0.7938
UNIT 13
COM='Y-Y BORAL + COVER SHEET WITH ST DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P0.7938
CUBOID 4 1 2P0.1714 2P6.7310 2P0.7938
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P0.7938
```

Figure 6.8-7 (continued)

```
UNIT 14
COM='X-X BORAL + COVER SHEET WITH AL DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P0.6350
CUBOID 4 1 2P6.7310 2P0.1714 2P0.6350
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P0.6350
UNIT 15
COM='Y-Y BORAL + COVER SHEET WITH AL DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P0.6350
CUBOID 4 1 2P0.1714 2P6.7310 2P0.6350
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P0.6350
UNIT 20
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (TR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 21
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 22
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 23
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 24
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (T)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 25
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 26
COM='FUEL TUBE CELL TOP BORAL SHEETS - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
UNIT 27
COM='FUEL TUBE CELL TOP BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
UNIT 28
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 29
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 30
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 31
COM='FUEL TUBE CELL NO BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
```

Figure 6.8-7 (continued)

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UNIT 40
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (TR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE  12 0.0 +7.7859 0.0
HOLE  13 +7.7859 0.0 0.0
UNIT 41
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE  12 0.0 +7.7859 0.0
HOLE  13 +7.7859 0.0 0.0
UNIT 42
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE  12 0.0 +7.7859 0.0
HOLE  13 +7.7859 0.0 0.0
UNIT 43
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE  12 0.0 +7.7859 0.0
HOLE  13 +7.7859 0.0 0.0
UNIT 44
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (T)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE  12 0.0 +7.7859 0.0
HOLE  13 +7.7859 0.0 0.0
UNIT 45
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE  12 0.0 +7.7859 0.0
HOLE  13 +7.7859 0.0 0.0
UNIT 46
COM='FUEL TUBE CELL TOP BORAL SHEETS - STEEL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE  12 0.0 +7.7859 0.0
UNIT 47
COM='FUEL TUBE CELL TOP BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE  12 0.0 +7.7859 0.0
UNIT 48
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE  13 +7.7859 0.0 0.0
UNIT 49
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE  13 +7.7859 0.0 0.0
UNIT 50
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE  13 +7.7859 0.0 0.0
UNIT 51
COM='FUEL TUBE CELL NO BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE  8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
UNIT 60
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (TR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE  9 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE  14 0.0 +7.7859 0.0
HOLE  15 +7.7859 0.0 0.0
UNIT 61
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (TL)'
```

Figure 6.8-7 (continued)

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CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 62
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 63
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 64
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (T)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +6.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 65
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 66
COM='FUEL TUBE CELL TOP BORAL SHEETS - AL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
UNIT 67
COM='FUEL TUBE CELL TOP BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
UNIT 68
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 69
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 70
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 71
COM='FUEL TUBE CELL NO BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
UNIT 80
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (TR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   20  -0.0297 -0.0297 0.0
UNIT 81
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   21  -0.3586 -0.0297 0.0
UNIT 82
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   22  -0.3586 -0.3586 0.0
UNIT 83
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   23  -0.0297 -0.3586 0.0
UNIT 84
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (T)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   24  -0.1942 -0.0297 0.0
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Figure 6.8-7 (continued)

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UNIT 85
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE  25  -0.1942 -0.3586 0.0
UNIT 86
COM='DISK OPENING TOP BORAL SHEET TUBE - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE  26  -0.3586 -0.0297 0.0
UNIT 87
COM='DISK OPENING TOP BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE  27  -0.3586 -0.3586 0.0
UNIT 88
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE  28  -0.3586 -0.3586 0.0
UNIT 89
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE  29  -0.1942 -0.3586 0.0
UNIT 90
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE  30  -0.0297 -0.3586 0.0
UNIT 91
COM='DISK OPENING NO BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE  31  -0.3586 -0.3586 0.0
UNIT 100
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (TR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  40  -0.0297 -0.0297 0.0
UNIT 101
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  41  -0.3586 -0.0297 0.0
UNIT 102
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  42  -0.3586 -0.3586 0.0
UNIT 103
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  43  -0.0297 -0.3586 0.0
UNIT 104
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (T)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  44  -0.1942 -0.0297 0.0
UNIT 105
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  45  -0.1942 -0.3586 0.0
UNIT 106
COM='DISK OPENING TOP BORAL SHEET TUBE - STEEL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  46  -0.3586 -0.0297 0.0
UNIT 107
COM='DISK OPENING TOP BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  47  -0.3586 -0.3586 0.0
UNIT 108
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  48  -0.3586 -0.3586 0.0
UNIT 109
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  49  -0.1942 -0.3586 0.0
UNIT 110
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  50  -0.0297 -0.3586 0.0
UNIT 111
COM='DISK OPENING NO BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE  51  -0.3586 -0.3586 0.0
UNIT 120
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (TR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE  60  -0.0297 -0.0297 0.0
UNIT 121
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE  61  -0.3586 -0.0297 0.0
UNIT 122
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE  62  -0.3586 -0.3586 0.0
UNIT 123
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE  63  -0.0297 -0.3586 0.0
UNIT 124
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (T)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE  64  -0.1942 -0.0297 0.0
UNIT 125
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (B)'
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Figure 6.8-7 (continued)

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CUBOID 3 1 4P7.9731 2P0.6350
HOLE   65  -0.1942 -0.3586 0.0
UNIT 126
COM='DISK OPENING TOP BORAL SHEET TUBE - AL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   66  -0.3586 -0.0297 0.0
UNIT 127
COM='DISK OPENING TOP BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   67  -0.3586 -0.3586 0.0
UNIT 128
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   68  -0.3586 -0.3586 0.0
UNIT 129
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   69  -0.1942 -0.3586 0.0
UNIT 130
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   70  -0.0297 -0.3586 0.0
UNIT 131
COM='DISK OPENING NO BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   71  -0.3586 -0.3586 0.0
UNIT 140
COM='BASKET STRUCTURE IN TRANPORT CASK - WATER DISK'
CYLINDER 3 1 +83.5787 2P1.7145
HOLE 90  -70.3885  +8.7986 0.0
HOLE 83  -52.7914  +8.7986 0.0
HOLE 83  -52.7914 +26.3957 0.0
HOLE 90  -52.7914 +43.9928 0.0
HOLE 83  -35.1942  +8.7986 0.0
HOLE 83  -35.1942 +26.3957 0.0
HOLE 83  -35.1942 +43.9928 0.0
HOLE 90  -35.1942 +61.5899 0.0
HOLE 83  -17.5971  +8.7986 0.0
HOLE 83  -17.5971 +26.3957 0.0
HOLE 83  -17.5971 +43.9928 0.0
HOLE 90  -17.5971 +61.5899 0.0
HOLE 85   0.0      +8.7986 0.0
HOLE 85   0.0     +26.3957 0.0
HOLE 85   0.0     +43.9928 0.0
HOLE 89   0.0     +61.5899 0.0
HOLE 82  +17.5971  +8.7986 0.0
HOLE 82  +17.5971 +26.3957 0.0
HOLE 82  +17.5971 +43.9928 0.0
HOLE 88  +17.5971 +61.5899 0.0
HOLE 82  +35.1942  +8.7986 0.0
HOLE 82  +35.1942 +26.3957 0.0
HOLE 82  +35.1942 +43.9928 0.0
HOLE 91  +35.1942 +61.5899 0.0
HOLE 82  +52.7914  +8.7986 0.0
HOLE 87  +52.7914 +26.3957 0.0
HOLE 91  +52.7914 +43.9928 0.0
HOLE 91  +70.3885  +8.7986 0.0
HOLE 80  -70.3885  -8.7986 0.0
HOLE 80  -52.7914  -8.7986 0.0
HOLE 80  -52.7914 -26.3957 0.0
HOLE 80  -52.7914 -43.9928 0.0
HOLE 80  -35.1942  -8.7986 0.0
HOLE 80  -35.1942 -26.3957 0.0
HOLE 80  -35.1942 -43.9928 0.0
HOLE 80  -35.1942 -61.5899 0.0
HOLE 80  -17.5971  -8.7986 0.0
HOLE 80  -17.5971 -26.3957 0.0
HOLE 80  -17.5971 -43.9928 0.0
HOLE 80  -17.5971 -61.5899 0.0
HOLE 84   0.0      -8.7986 0.0
HOLE 84   0.0     -26.3957 0.0
HOLE 84   0.0     -43.9928 0.0
HOLE 84   0.0     -61.5899 0.0
HOLE 81  +17.5971  -8.7986 0.0
HOLE 81  +17.5971 -26.3957 0.0
HOLE 81  +17.5971 -43.9928 0.0
HOLE 81  +17.5971 -61.5899 0.0
HOLE 81  +35.1942  -8.7986 0.0
HOLE 81  +35.1942 -26.3957 0.0
HOLE 81  +35.1942 -43.9928 0.0
HOLE 86  +35.1942 -61.5899 0.0
HOLE 81  +52.7914  -8.7986 0.0
HOLE 86  +52.7914 -26.3957 0.0
HOLE 86  +52.7914 -43.9928 0.0
HOLE 86  +70.3885  -8.7986 0.0
CYLINDER  5 1  +85.1662 2P1.7145
CYLINDER  9 1  +94.615 2P1.7145
CYLINDER  7 1 +100.965 2P1.7145
CYLINDER  8 1 +172.72  2P1.7145
CUBOID    9 1 4P230.0  2P1.7145
UNIT 141
COM='BASKET STRUCTURE IN TRANPORT CASK - SS DISK'
CYLINDER 7 1  +83.1850 2P0.7938
HOLE 110  -70.3885  +8.7986 0.0
HOLE 103  -52.7914  +8.7986 0.0
HOLE 103  -52.7914 +26.3957 0.0
HOLE 110  -52.7914 +43.9928 0.0
HOLE 103  -35.1942  +8.7986 0.0
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Figure 6.8-7 (continued)

```
HOLE 103  -35.1942 +26.3957 0.0
HOLE 103  -35.1942 +43.9928 0.0
HOLE 110  -35.1942 +61.5899 0.0
HOLE 103  -17.5971  +8.7986 0.0
HOLE 103  -17.5971 +26.3957 0.0
HOLE 103  -17.5971 +43.9928 0.0
HOLE 110  -17.5971 +61.5899 0.0
HOLE 105   0.0      +8.7986 0.0
HOLE 105   0.0     +26.3957 0.0
HOLE 105   0.0     +43.9928 0.0
HOLE 109   0.0     +61.5899 0.0
HOLE 102  +17.5971  +8.7986 0.0
HOLE 102  +17.5971 +26.3957 0.0
HOLE 102  +17.5971 +43.9928 0.0
HOLE 108  +17.5971 +61.5899 0.0
HOLE 102  +35.1942  +8.7986 0.0
HOLE 102  +35.1942 +26.3957 0.0
HOLE 102  +35.1942 +43.9928 0.0
HOLE 111  +35.1942 +61.5899 0.0
HOLE 102  +52.7914  +8.7986 0.0
HOLE 107  +52.7914 +26.3957 0.0
HOLE 111  +52.7914 +43.9928 0.0
HOLE 111  +70.3885  +8.7986 0.0
HOLE 100  -70.3885  -8.7986 0.0
HOLE 100  -52.7914  -8.7986 0.0
HOLE 100  -52.7914 -26.3957 0.0
HOLE 100  -52.7914 -43.9928 0.0
HOLE 100  -35.1942  -8.7986 0.0
HOLE 100  -35.1942 -26.3957 0.0
HOLE 100  -35.1942 -43.9928 0.0
HOLE 100  -35.1942 -61.5899 0.0
HOLE 100  -17.5971  -8.7986 0.0
HOLE 100  -17.5971 -26.3957 0.0
HOLE 100  -17.5971 -43.9928 0.0
HOLE 100  -17.5971 -61.5899 0.0
HOLE 104   0.0      -8.7986 0.0
HOLE 104   0.0     -26.3957 0.0
HOLE 104   0.0     -43.9928 0.0
HOLE 104   0.0     -61.5899 0.0
HOLE 101  +17.5971  -8.7986 0.0
HOLE 101  +17.5971 -26.3957 0.0
HOLE 101  +17.5971 -43.9928 0.0
HOLE 101  +17.5971 -61.5899 0.0
HOLE 101  +35.1942  -8.7986 0.0
HOLE 101  +35.1942 -26.3957 0.0
HOLE 101  +35.1942 -43.9928 0.0
HOLE 106  +35.1942 -61.5899 0.0
HOLE 101  +52.7914  -8.7986 0.0
HOLE 106  +52.7914 -26.3957 0.0
HOLE 106  +52.7914 -43.9928 0.0
HOLE 106  +70.3885  -8.7986 0.0
CYLINDER  3 1  +83.5787 2P0.7938
CYLINDER  5 1  +85.1662 2P0.7938
CYLINDER  9 1  +94.615 2P0.7938
CYLINDER  7 1 +100.965 2P0.7938
CYLINDER  8 1 +172.72  2P0.7938
CUBOID    9 1 4P230.0  2P0.7938
UNIT 142
COM='BASKET STRUCTURE IN TRANPORT CASK - AL DISK'
CYLINDER 4 1  +82.8675 2P0.6350
HOLE 130  -70.3885  +8.7986 0.0
HOLE 123  -52.7914  +8.7986 0.0
HOLE 123  -52.7914 +26.3957 0.0
HOLE 130  -52.7914 +43.9928 0.0
HOLE 123  -35.1942  +8.7986 0.0
HOLE 123  -35.1942 +26.3957 0.0
HOLE 123  -35.1942 +43.9928 0.0
HOLE 130  -35.1942 +61.5899 0.0
HOLE 123  -17.5971  +8.7986 0.0
HOLE 123  -17.5971 +26.3957 0.0
HOLE 123  -17.5971 +43.9928 0.0
HOLE 130  -17.5971 +61.5899 0.0
HOLE 125   0.0      +8.7986 0.0
HOLE 125   0.0     +26.3957 0.0
HOLE 125   0.0     +43.9928 0.0
HOLE 129   0.0     +61.5899 0.0
HOLE 122  +17.5971  +8.7986 0.0
HOLE 122  +17.5971 +26.3957 0.0
HOLE 122  +17.5971 +43.9928 0.0
HOLE 128  +17.5971 +61.5899 0.0
HOLE 122  +35.1942  +8.7986 0.0
HOLE 122  +35.1942 +26.3957 0.0
HOLE 122  +35.1942 +43.9928 0.0
HOLE 131  +35.1942 +61.5899 0.0
HOLE 122  +52.7914  +8.7986 0.0
HOLE 127  +52.7914 +26.3957 0.0
HOLE 131  +52.7914 +43.9928 0.0
HOLE 131  +70.3885  +8.7986 0.0
HOLE 120  -70.3885  -8.7986 0.0
HOLE 120  -52.7914  -8.7986 0.0
HOLE 120  -52.7914 -26.3957 0.0
HOLE 120  -52.7914 -43.9928 0.0
HOLE 120  -35.1942  -8.7986 0.0
HOLE 120  -35.1942 -26.3957 0.0
HOLE 120  -35.1942 -43.9928 0.0
HOLE 120  -35.1942 -61.5899 0.0
HOLE 120  -17.5971  -8.7986 0.0
HOLE 120  -17.5971 -26.3957 0.0
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Figure 6.8-7 (continued)

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HOLE 120  -17.5971 -43.9928 0.0
HOLE 120  -17.5971 -61.5899 0.0
HOLE 124   0.0      -8.7986 0.0
HOLE 124   0.0     -26.3957 0.0
HOLE 124   0.0     -43.9928 0.0
HOLE 124   0.0     -61.5899 0.0
HOLE 121  +17.5971  -8.7986 0.0
HOLE 121  +17.5971 -26.3957 0.0
HOLE 121  +17.5971 -43.9928 0.0
HOLE 121  +17.5971 -61.5899 0.0
HOLE 121  +35.1942  -8.7986 0.0
HOLE 121  +35.1942 -26.3957 0.0
HOLE 121  +35.1942 -43.9928 0.0
HOLE 126  +35.1942 -61.5899 0.0
HOLE 121  +52.7914  -8.7986 0.0
HOLE 126  +52.7914 -26.3957 0.0
HOLE 126  +52.7914 -43.9928 0.0
HOLE 126  +70.3885  -8.7986 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER  9 1  +94.615 2P0.6350
CYLINDER  7 1 +100.965 2P0.6350
CYLINDER  8 1 +172.72  2P0.6350
CUBOID    9 1 4P230.0  2P0.6350
GLOBAL UNIT 143
COM='CASK SLICES TOGETHER'
ARRAY  4 -230.00 -230.00 0.0
END GEOM
READ ARRAY
ARA=1   NUX=9 NUY=9 NUZ=1  FILL
    36R1
 4R1  2   4R1
 5R1  2   3R1
    27R1
END FILL
ARA=2   NUX=9 NUY=9 NUZ=1  FILL
    36R3
 4R3  4   4R3
 5R3  4   3R3
    27R3
END FILL
ARA=3   NUX=9 NUY=9 NUZ=1  FILL
    36R5
 4R5  6   4R5
 5R5  6   3R5
    27R5
END FILL
ARA=4 NUX=1 NUY=1 NUZ=4 FILL 140 141 140 142 END FILL
END ARRAY
READ BOUNDS ZFC=PER YXF=PER END BOUNDS
END DATA
END
```

Figure 6.8-8 CSAS Input for Accident Conditions–Vertical Concrete Cask Containing BWR Fuel

```
=CSAS25
UMS BWR VCC; ACCIDENT; CASK ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 75%B10
27GROUPNDF4 LATTICECELL
UO2   1 0.95 293.0 92235 4.00 92238 96.00 END
ZIRCALLOY  2 1.0  293.0  END
H2O   3 1.0  293.0  END
AL    4 1.0  293.0  END
SS304 5 1.0  293.0  END
AL    6 DEN=2.6849 0.8706 293.0 END
B-10  6 DEN=2.6849 0.0137 293.0 END
B-11  6 DEN=2.6849 0.0830 293.0 END
C     6 DEN=2.6849 0.0281 293.0 END
CARBONSTEEL 7 1.0 293.0 END
REG-CONCRETE 8 0.9750 293.0 END
H2O   9 1.0 293.0 END
H2O  10 1.0 293.0 END
END COMP
SQUAREPITCH  1.4529 0.9055 1 3 1.0770 2 0.9246 10 END
UMS BWR VCC; ACCIDENT; CASK ARRAY; 1.0 GM/CC IN - 1.0 GM/CC EX; 75%B10
READ PARAM RUN=YES PLT=NO TME=5000 GEN=803 NPG=1000 END PARAM
READ GEOM
UNIT  1
COM='FUEL PIN CELL - WITH H2O'
CYLINDER  1 1  0.4528   2P1.7145
CYLINDER 10 1  0.4623   2P1.7145
CYLINDER  2 1  0.5385   2P1.7145
CUBOID    3 1  4P0.7264 2P1.7145
UNIT  2
COM='WATER ROD CELL - WITH H2O'
CYLINDER  3 1  0.4623   2P1.7145
CYLINDER  2 1  0.5385   2P1.7145
CUBOID    3 1  4P0.7264 2P1.7145
UNIT  3
COM='FUEL PIN CELL - WITH ST DISK'
CYLINDER  1 1  0.4528   2P0.7938
CYLINDER 10 1  0.4623   2P0.7938
CYLINDER  2 1  0.5385   2P0.7938
CUBOID    3 1  4P0.7264 2P0.7938
UNIT  4
COM='WATER ROD CELL - WITH ST DISK'
CYLINDER  3 1  0.4623   2P0.7938
CYLINDER  2 1  0.5385   2P0.7938
CUBOID    3 1  4P0.7264 2P0.7938
UNIT  5
COM='FUEL PIN CELL - WITH AL DISK'
CYLINDER  1 1  0.4528   2P0.6350
CYLINDER 10 1  0.4623   2P0.6350
CYLINDER  2 1  0.5385   2P0.6350
CUBOID    3 1  4P0.7264 2P0.6350
UNIT  6
COM='WATER ROD CELL - WITH AL DISK'
CYLINDER  3 1  0.4623   2P0.6350
CYLINDER  2 1  0.5385   2P0.6350
CUBOID    3 1  4P0.7264 2P0.6350
UNIT  7
COM='FUEL PIN ARRAY + CHANNEL - BETWEEN DISKS'
ARRAY  1    -6.5376 -6.5376 -1.7145
CUBOID 3 1 4P6.7031 2P1.7145
CUBOID 2 1 4P6.9063 2P1.7145
UNIT  8
COM='FUEL PIN ARRAY + CHANNEL - ST DISKS'
ARRAY  2    -6.5376 -6.5376 -0.7938
CUBOID 3 1 4P6.7031 2P0.7938
CUBOID 2 1 4P6.9063 2P0.7938
UNIT  9
COM='FUEL PIN ARRAY + CHANNEL - AL DISKS'
ARRAY  3    -6.5376 -6.5376 -0.6350
CUBOID 3 1 4P6.7031 2P0.6350
CUBOID 2 1 4P6.9063 2P0.6350
UNIT 10
COM='X-X BORAL + COVER SHEET BETWEEN DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P1.7145
CUBOID 4 1 2P6.7310 2P0.1714 2P1.7145
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P1.7145
UNIT 11
COM='Y-Y BORAL + COVER SHEET BETWEEN DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P1.7145
CUBOID 4 1 2P0.1714 2P6.7310 2P1.7145
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P1.7145
UNIT 12
COM='X-X BORAL + COVER SHEET WITH ST DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P0.7938
CUBOID 4 1 2P6.7310 2P0.1714 2P0.7938
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P0.7938
UNIT 13
COM='Y-Y BORAL + COVER SHEET WITH ST DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P0.7938
CUBOID 4 1 2P0.1714 2P6.7310 2P0.7938
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P0.7938
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Figure 6.8-8 (continued)

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UNIT 14
COM='X-X BORAL + COVER SHEET WITH AL DISKS'
CUBOID 6 1 2P6.7310 2P0.1124 2P0.6350
CUBOID 4 1 2P6.7310 2P0.1714 2P0.6350
CUBOID 5 1 2P6.7765 +0.2168 -0.1714 2P0.6350
UNIT 15
COM='Y-Y BORAL + COVER SHEET WITH AL DISKS'
CUBOID 6 1 2P0.1124 2P6.7310 2P0.6350
CUBOID 4 1 2P0.1714 2P6.7310 2P0.6350
CUBOID 5 1 +0.2168 -0.1714 2P6.7765 2P0.6350
UNIT 20
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (TR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 21
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 22
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 23
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 24
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (T)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 25
COM='FUEL TUBE CELL 2 BORAL SHEETS - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
HOLE   11 +7.7859 0.0 0.0
UNIT 26
COM='FUEL TUBE CELL TOP BORAL SHEETS - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
UNIT 27
COM='FUEL TUBE CELL TOP BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P1.7145
HOLE   10 0.0 +7.7859 0.0
UNIT 28
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 29
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 30
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P1.7145
HOLE   11 +7.7859 0.0 0.0
UNIT 31
COM='FUEL TUBE CELL NO BORAL SHEETS - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.4930 2P1.7145
HOLE   7 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P1.7145
UNIT 40
```

Figure 6.8-8 (continued)

```
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (TR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 41
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 42
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 43
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 44
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (T)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 45
COM='FUEL TUBE CELL 2 BORAL SHEETS - STEEL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
HOLE   13 +7.7859 0.0 0.0
UNIT 46
COM='FUEL TUBE CELL TOP BORAL SHEETS - STEEL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
UNIT 47
COM='FUEL TUBE CELL TOP BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.7938
HOLE   12 0.0 +7.7859 0.0
UNIT 48
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE   13 +7.7859 0.0 0.0
UNIT 49
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE   13 +7.7859 0.0 0.0
UNIT 50
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - STEEL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.7938
HOLE   13 +7.7859 0.0 0.0
UNIT 51
COM='FUEL TUBE CELL NO BORAL SHEETS - STEEL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.7938
HOLE   8 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.7938
UNIT 60
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (TR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 61
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 +0.5867 0.0
```

Figure 6.8-8 (continued)

```
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 62
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 63
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 64
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (T)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 65
COM='FUEL TUBE CELL 2 BORAL SHEETS - AL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
HOLE   15 +7.7859 0.0 0.0
UNIT 66
COM='FUEL TUBE CELL TOP BORAL SHEETS - AL DISKS (TL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 +0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
UNIT 67
COM='FUEL TUBE CELL TOP BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +7.6144 -7.6144 +8.0028 -7.6144 +2P0.6350
HOLE   14 0.0 +7.7859 0.0
UNIT 68
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 69
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (B)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 0.0 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 70
COM='FUEL TUBE CELL RIGHT BORAL SHEETS - AL DISKS (BR)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 +0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
CUBOID 3 1 +8.0028 -7.6144 +7.6144 -7.6144 +2P0.6350
HOLE   15 +7.7859 0.0 0.0
UNIT 71
COM='FUEL TUBE CELL NO BORAL SHEETS - AL DISKS (BL)'
CUBOID 3 1 4P7.4930 2P0.6350
HOLE   9 -0.5867 -0.5867 0.0
CUBOID 5 1 4P7.6144 2P0.6350
UNIT 80
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (TR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   20  -0.0297 -0.0297 0.0
UNIT 81
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   21  -0.3586 -0.0297 0.0
UNIT 82
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   22  -0.3586 -0.3586 0.0
UNIT 83
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   23  -0.0297 -0.3586 0.0
UNIT 84
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (T)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   24  -0.1942 -0.0297 0.0
UNIT 85
COM='DISK OPENING 2 BORAL SHEET TUBE - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.9731 2P1.7145
```

Figure 6.8-8 (continued)

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HOLE   25  -0.1942 -0.3586 0.0
UNIT 86
COM='DISK OPENING TOP BORAL SHEET TUBE - BETWEEN DISKS (TL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   26  -0.3586 -0.0297 0.0
UNIT 87
COM='DISK OPENING TOP BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   27  -0.3586 -0.3586 0.0
UNIT 88
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   28  -0.3586 -0.3586 0.0
UNIT 89
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (B)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   29  -0.1942 -0.3586 0.0
UNIT 90
COM='DISK OPENING RIGHT BORAL SHEET TUBE - BETWEEN DISKS (BR)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   30  -0.0297 -0.3586 0.0
UNIT 91
COM='DISK OPENING NO BORAL SHEET TUBE - BETWEEN DISKS (BL)'
CUBOID 3 1 4P7.9731 2P1.7145
HOLE   31  -0.3586 -0.3586 0.0
UNIT 100
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (TR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   40  -0.0297 -0.0297 0.0
UNIT 101
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   41  -0.3586 -0.0297 0.0
UNIT 102
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   42  -0.3586 -0.3586 0.0
UNIT 103
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   43  -0.0297 -0.3586 0.0
UNIT 104
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (T)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   44  -0.1942 -0.0297 0.0
UNIT 105
COM='DISK OPENING 2 BORAL SHEET TUBE - STEEL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   45  -0.1942 -0.3586 0.0
UNIT 106
COM='DISK OPENING TOP BORAL SHEET TUBE - STEEL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   46  -0.3586 -0.0297 0.0
UNIT 107
COM='DISK OPENING TOP BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   47  -0.3586 -0.3586 0.0
UNIT 108
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   48  -0.3586 -0.3586 0.0
UNIT 109
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   49  -0.1942 -0.3586 0.0
UNIT 110
COM='DISK OPENING RIGHT BORAL SHEET TUBE - STEEL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   50  -0.0297 -0.3586 0.0
UNIT 111
COM='DISK OPENING NO BORAL SHEET TUBE - STEEL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.7938
HOLE   51  -0.3586 -0.3586 0.0
UNIT 120
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (TR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   60  -0.0297 -0.0297 0.0
UNIT 121
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (TL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   61  -0.3586 -0.0297 0.0
UNIT 122
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   62  -0.3586 -0.3586 0.0
UNIT 123
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   63  -0.0297 -0.3586 0.0
UNIT 124
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (T)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   64  -0.1942 -0.0297 0.0
UNIT 125
COM='DISK OPENING 2 BORAL SHEET TUBE - AL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   65  -0.1942 -0.3586 0.0
UNIT 126
COM='DISK OPENING TOP BORAL SHEET TUBE - AL DISKS (TL)'
```

Figure 6.8-8 (continued)

```
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   66  -0.3586 -0.0297 0.0
UNIT 127
COM='DISK OPENING TOP BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   67  -0.3586 -0.3586 0.0
UNIT 128
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   68  -0.3586 -0.3586 0.0
UNIT 129
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (B)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   69  -0.1942 -0.3586 0.0
UNIT 130
COM='DISK OPENING RIGHT BORAL SHEET TUBE - AL DISKS (BR)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   70  -0.0297 -0.3586 0.0
UNIT 131
COM='DISK OPENING NO BORAL SHEET TUBE - AL DISKS (BL)'
CUBOID 3 1 4P7.9731 2P0.6350
HOLE   71  -0.3586 -0.3586 0.0
UNIT 140
COM='BASKET STRUCTURE IN TRANPORT CASK - WATER DISK'
CYLINDER 3 1 +83.5787 2P1.7145
HOLE 90  -70.3885  +8.7986 0.0
HOLE 83  -52.7914  +8.7986 0.0
HOLE 83  -52.7914 +26.3957 0.0
HOLE 90  -52.7914 +43.9928 0.0
HOLE 83  -35.1942  +8.7986 0.0
HOLE 83  -35.1942 +26.3957 0.0
HOLE 83  -35.1942 +43.9928 0.0
HOLE 90  -35.1942 +61.5899 0.0
HOLE 83  -17.5971  +8.7986 0.0
HOLE 83  -17.5971 +26.3957 0.0
HOLE 83  -17.5971 +43.9928 0.0
HOLE 90  -17.5971 +61.5899 0.0
HOLE 85   0.0      +8.7986 0.0
HOLE 85   0.0     +26.3957 0.0
HOLE 85   0.0     +43.9928 0.0
HOLE 89   0.0     +61.5899 0.0
HOLE 82  +17.5971  +8.7986 0.0
HOLE 82  +17.5971 +26.3957 0.0
HOLE 82  +17.5971 +43.9928 0.0
HOLE 88  +17.5971 +61.5899 0.0
HOLE 82  +35.1942  +8.7986 0.0
HOLE 82  +35.1942 +26.3957 0.0
HOLE 82  +35.1942 +43.9928 0.0
HOLE 91  +35.1942 +61.5899 0.0
HOLE 82  +52.7914  +8.7986 0.0
HOLE 87  +52.7914 +26.3957 0.0
HOLE 91  +52.7914 +43.9928 0.0
HOLE 91  +70.3885  +8.7986 0.0
HOLE 80  -70.3885  -8.7986 0.0
HOLE 80  -52.7914  -8.7986 0.0
HOLE 80  -52.7914 -26.3957 0.0
HOLE 80  -52.7914 -43.9928 0.0
HOLE 80  -35.1942  -8.7986 0.0
HOLE 80  -35.1942 -26.3957 0.0
HOLE 80  -35.1942 -43.9928 0.0
HOLE 80  -35.1942 -61.5899 0.0
HOLE 80  -17.5971  -8.7986 0.0
HOLE 80  -17.5971 -26.3957 0.0
HOLE 80  -17.5971 -43.9928 0.0
HOLE 80  -17.5971 -61.5899 0.0
HOLE 84   0.0      -8.7986 0.0
HOLE 84   0.0     -26.3957 0.0
HOLE 84   0.0     -43.9928 0.0
HOLE 84   0.0     -61.5899 0.0
HOLE 81  +17.5971  -8.7986 0.0
HOLE 81  +17.5971 -26.3957 0.0
HOLE 81  +17.5971 -43.9928 0.0
HOLE 81  +17.5971 -61.5899 0.0
HOLE 81  +35.1942  -8.7986 0.0
HOLE 81  +35.1942 -26.3957 0.0
HOLE 81  +35.1942 -43.9928 0.0
HOLE 86  +35.1942 -61.5899 0.0
HOLE 81  +52.7914  -8.7986 0.0
HOLE 86  +52.7914 -26.3957 0.0
HOLE 86  +52.7914 -43.9928 0.0
HOLE 86  +70.3885  -8.7986 0.0
CYLINDER  5 1  +85.1662 2P1.7145
CYLINDER  9 1  +94.615 2P1.7145
CYLINDER  7 1 +100.965 2P1.7145
CYLINDER  8 1 +172.72  2P1.7145
CUBOID    9 1 4P230.0  2P1.7145
UNIT 141
COM='BASKET STRUCTURE IN TRANPORT CASK - SS DISK'
CYLINDER 7 1  +83.1850 2P0.7938
HOLE 110  -70.3885  +8.7986 0.0
HOLE 103  -52.7914  +8.7986 0.0
HOLE 103  -52.7914 +26.3957 0.0
HOLE 110  -52.7914 +43.9928 0.0
HOLE 103  -35.1942  +8.7986 0.0
HOLE 103  -35.1942 +26.3957 0.0
HOLE 103  -35.1942 +43.9928 0.0
HOLE 110  -35.1942 +61.5899 0.0
HOLE 103  -17.5971  +8.7986 0.0
HOLE 103  -17.5971 +26.3957 0.0
```

Figure 6.8-8 (continued)

```
HOLE 103  -17.5971 +43.9928 0.0
HOLE 110  -17.5971 +61.5899 0.0
HOLE 105   0.0      +8.7986 0.0
HOLE 105   0.0     +26.3957 0.0
HOLE 105   0.0     +43.9928 0.0
HOLE 109   0.0     +61.5899 0.0
HOLE 102  +17.5971  +8.7986 0.0
HOLE 102  +17.5971 +26.3957 0.0
HOLE 102  +17.5971 +43.9928 0.0
HOLE 108  +17.5971 +61.5899 0.0
HOLE 102  +35.1942  +8.7986 0.0
HOLE 102  +35.1942 +26.3957 0.0
HOLE 102  +35.1942 +43.9928 0.0
HOLE 111  +35.1942 +61.5899 0.0
HOLE 102  +52.7914  +8.7986 0.0
HOLE 107  +52.7914 +26.3957 0.0
HOLE 111  +52.7914 +43.9928 0.0
HOLE 111  +70.3885  +8.7986 0.0
HOLE 100  -70.3885  -8.7986 0.0
HOLE 100  -52.7914  -8.7986 0.0
HOLE 100  -52.7914 -26.3957 0.0
HOLE 100  -52.7914 -43.9928 0.0
HOLE 100  -35.1942  -8.7986 0.0
HOLE 100  -35.1942 -26.3957 0.0
HOLE 100  -35.1942 -43.9928 0.0
HOLE 100  -35.1942 -61.5899 0.0
HOLE 100  -17.5971  -8.7986 0.0
HOLE 100  -17.5971 -26.3957 0.0
HOLE 100  -17.5971 -43.9928 0.0
HOLE 100  -17.5971 -61.5899 0.0
HOLE 104   0.0      -8.7986 0.0
HOLE 104   0.0     -26.3957 0.0
HOLE 104   0.0     -43.9928 0.0
HOLE 104   0.0     -61.5899 0.0
HOLE 101  +17.5971  -8.7986 0.0
HOLE 101  +17.5971 -26.3957 0.0
HOLE 101  +17.5971 -43.9928 0.0
HOLE 101  +17.5971 -61.5899 0.0
HOLE 101  +35.1942  -8.7986 0.0
HOLE 101  +35.1942 -26.3957 0.0
HOLE 101  +35.1942 -43.9928 0.0
HOLE 106  +35.1942 -61.5899 0.0
HOLE 101  +52.7914  -8.7986 0.0
HOLE 106  +52.7914 -26.3957 0.0
HOLE 106  +52.7914 -43.9928 0.0
HOLE 106  +70.3885  -8.7986 0.0
CYLINDER  3 1  +83.5787 2P0.7938
CYLINDER  5 1  +85.1662 2P0.7938
CYLINDER  9 1  +94.615 2P0.7938
CYLINDER  7 1 +100.965 2P0.7938
CYLINDER  8 1 +172.72  2P0.7938
CUBOID    9 1 4P230.0  2P0.7938
UNIT 142
COM='BASKET STRUCTURE IN TRANPORT CASK - AL DISK'
CYLINDER 4 1  +82.8675 2P0.6350
HOLE 130  -70.3885  +8.7986 0.0
HOLE 123  -52.7914  +8.7986 0.0
HOLE 123  -52.7914 +26.3957 0.0
HOLE 130  -52.7914 +43.9928 0.0
HOLE 123  -35.1942  +8.7986 0.0
HOLE 123  -35.1942 +26.3957 0.0
HOLE 123  -35.1942 +43.9928 0.0
HOLE 130  -35.1942 +61.5899 0.0
HOLE 123  -17.5971  +8.7986 0.0
HOLE 123  -17.5971 +26.3957 0.0
HOLE 123  -17.5971 +43.9928 0.0
HOLE 130  -17.5971 +61.5899 0.0
HOLE 125   0.0      +8.7986 0.0
HOLE 125   0.0     +26.3957 0.0
HOLE 125   0.0     +43.9928 0.0
HOLE 129   0.0     +61.5899 0.0
HOLE 122  +17.5971  +8.7986 0.0
HOLE 122  +17.5971 +26.3957 0.0
HOLE 122  +17.5971 +43.9928 0.0
HOLE 128  +17.5971 +61.5899 0.0
HOLE 122  +35.1942  +8.7986 0.0
HOLE 122  +35.1942 +26.3957 0.0
HOLE 122  +35.1942 +43.9928 0.0
HOLE 131  +35.1942 +61.5899 0.0
HOLE 122  +52.7914  +8.7986 0.0
HOLE 127  +52.7914 +26.3957 0.0
HOLE 131  +52.7914 +43.9928 0.0
HOLE 131  +70.3885  +8.7986 0.0
HOLE 120  -70.3885  -8.7986 0.0
HOLE 120  -52.7914  -8.7986 0.0
HOLE 120  -52.7914 -26.3957 0.0
HOLE 120  -52.7914 -43.9928 0.0
HOLE 120  -35.1942  -8.7986 0.0
HOLE 120  -35.1942 -26.3957 0.0
HOLE 120  -35.1942 -43.9928 0.0
HOLE 120  -35.1942 -61.5899 0.0
HOLE 120  -17.5971  -8.7986 0.0
HOLE 120  -17.5971 -26.3957 0.0
HOLE 120  -17.5971 -43.9928 0.0
HOLE 120  -17.5971 -61.5899 0.0
HOLE 124   0.0      -8.7986 0.0
HOLE 124   0.0     -26.3957 0.0
HOLE 124   0.0     -43.9928 0.0
HOLE 124   0.0     -61.5899 0.0
```

Figure 6.8-8 (continued)

```
HOLE 121  +17.5971  -8.7986 0.0
HOLE 121  +17.5971 -26.3957 0.0
HOLE 121  +17.5971 -43.9928 0.0
HOLE 121  +17.5971 -61.5899 0.0
HOLE 121  +35.1942  -8.7986 0.0
HOLE 121  +35.1942 -26.3957 0.0
HOLE 121  +35.1942 -43.9928 0.0
HOLE 126  +35.1942 -61.5899 0.0
HOLE 121  +52.7914  -8.7986 0.0
HOLE 126  +52.7914 -26.3957 0.0
HOLE 126  +52.7914 -43.9928 0.0
HOLE 126  +70.3885  -8.7986 0.0
CYLINDER  3 1  +83.5787 2P0.6350
CYLINDER  5 1  +85.1662 2P0.6350
CYLINDER  9 1  +94.615 2P0.6350
CYLINDER  7 1 +100.965 2P0.6350
CYLINDER  8 1 +172.72  2P0.6350
CUBOID    9 1 4P230.0  2P0.6350
GLOBAL UNIT 143
COM='CASK SLICES TOGETHER'
ARRAY  4 -230.00 -230.00 0.0
END GEOM
READ ARRAY
ARA=1   NUX=9 NUY=9 NUZ=1  FILL
    36R1
 4R1  2   4R1
 5R1  2   3R1
    27R1
END FILL
ARA=2   NUX=9 NUY=9 NUZ=1  FILL
    36R3
 4R3  4   4R3
 5R3  4   3R3
    27R3
END FILL
ARA=3   NUX=9 NUY=9 NUZ=1  FILL
    36R5
 4R5  6   4R5
 5R5  6   3R5
    27R5
END FILL
ARA=4 NUX=1 NUY=1 NUZ=4 FILL 140 141 140 142 END FILL
END ARRAY
READ BOUNDS ZFC=PER YXF=PER END BOUNDS
END DATA
END
```

Figure 6.8-9 MONK8A Input for PWR Transfer Cask with Soluble Boron

```
columns 1 200
*
*   UMS Transfer Cask - we17b Standard
*
*   Cask Lid Configurations
*           Shield Lid - No Ports
*           Structural Lid - No Weld Shield
*
*   Neutron Poison Loading -  75 %
*   Exterior Water Density 0.0001
*   Cavity Water Density 0.9998
*   Fuel to Clad Gap Water Density 0.9998
*
*   Boron Content in Water - 1000 ppm
*
*   Model Revision v3.0
*
* Parameters
*
@randseed =  12345
*
*
* Unit 1 Control Data
*
begin control data
*READ   ! read and check each independently
*SEEK MULTIPLE DEFINITIONS

SEEDS  @randseed  @randseed
STAGES -15 810 4000 STDV 0.0008

end
*
* Unit 9 Material Specification
*
begin material specification
normalise
nmixtures  7
weight  mixture  1
      u235  4.4072E-02
      u238  8.3737E-01
      o16  1.1856E-01
atoms  mixture  2
      h  6.6667E-01
      o16  3.3333E-01
atoms  mixture  3
      h  6.6667E-01
      o16  3.3333E-01
atoms  mixture  4
      h  4.2857E-01
      b  1.4286E-01
      o16  4.2857E-01
weight  mixture  5
      al  4.6148E-01
      b10  7.5880E-02
      b11  3.4567E-01
      c  1.1697E-01
atoms  mixture  6
      c  2.8571E-01
      h  4.7619E-01
      o16  2.3810E-01
weight  mixture  7
      h  4.2152E-02
      o16  5.4785E-01
      fe  4.7900E-02
      c  9.3500E-02
      si  3.3600E-02
      ca  5.6100E-02
      al  1.7890E-01
*
* Materials List - v1.2 - Class 1 - we17b - WE17 (OFA) Fuel
*
nmaterials  23
volume              ! UO2 at 5%
material  1
  mixture  1  density  10.4120  prop  1.00000
volume              ! Fuel pin cladding
material  2
  zircalloy    density  6.5500  prop  1.00000
volume              ! Water In Lattice and Tube
material  3
  mixture  4  density  1.0015  prop  0.00572  ! mixBoricAcid
  mixture  2  density  1.0015  prop  0.99428  ! mixH2O
volume              ! Water In Fuel Rod Clad Gap
material  4
  mixture  4  density  1.0015  prop  0.00572  ! mixBoricAcid
  mixture  2  density  1.0015  prop  0.99428  ! mixH2O
volume              ! Lower Nozzle Material
material  5
  stainless 304l steel    density  7.9200  prop  0.23669
  mixture  4  density  1.0015  prop  0.00437  ! mixBoricAcid
  mixture  2  density  1.0015  prop  0.75894  ! mixH2O
volume              ! Upper Nozzle Material
material  6
  stainless 304l steel    density  7.9200  prop  0.23180
  mixture  4  density  1.0015  prop  0.00439  ! mixBoricAcid
  mixture  2  density  1.0015  prop  0.76381  ! mixH2O
```

Figure 6.8-9 (continued)

```
*
* Materials List - Common Materials - v2.0
*
volume              ! Tube wall and cover sheet
material  7
  stainless 304l steel    density  7.9300  prop  1.0000
volume              ! BORAL core
material  8
  mixture  5  density  1.9457  prop  1.0000  ! mixBORAL
volume              ! BORAL alumnimum clad
material  9
  aluminium        prop  1.0000
volume              ! Structural Disk Material
material  10
  stainless 304l steel    density  7.9300  prop  1.0000
volume              ! Weldment Material
material  11
  stainless 304l steel    density  7.9300  prop  1.0000
volume              ! Heat Transfer Disk Material
material  12
  aluminium        prop  1.0000
volume              ! Canister Material
material  13
  stainless 304l steel    density  7.9300  prop  1.0000
atoms              ! Transfer steel
material  14    density  0      !  (SCALE carbon steel)
    fe      prop  8.3498E-02
    c      prop  3.9250E-03
volume              ! Lead
material  15
  pb    density  11.0400  prop  1.0000
atoms              ! NS-4-FR
material  16    density  0      ! 0 means atom/b-cm
    b10      prop  8.5500E-05
    b11      prop  3.4200E-04
    al      prop  7.8000E-03
    h      prop  5.8500E-02
    o16      prop  2.6100E-02
    c      prop  2.2600E-02
    n      prop  1.3900E-03
volume              ! Stainless Steel 304
material  17
  stainless 304l steel    density  7.9300  prop  1.0000
volume              ! Vent port middle cylinder
material  18
  stainless 304l steel    density  7.9300  prop  0.5000
  void        prop  0.5000
atoms              ! SCALE Concrete
material  19    density  0
    h      prop  1.3401E-02
    o16      prop  4.4931E-02
    na      prop  1.7036E-03
    al      prop  1.7018E-03
    si      prop  1.6205E-02
    ca      prop  1.4826E-03
    fe      prop  3.3857E-04
volume              ! Heat fins for transport cask
material  20
  cu    density  8.9200  prop  0.4286
  stainless 304l steel    density  7.9300  prop  0.5714
volume              ! Balsa
material  21
  mixture  6  density  0.1250  prop  1.0000
volume              ! Redwood
material  22
  mixture  6  density  0.3870  prop  1.0000
volume              ! NS3
material  23
  mixture  7  density  1.6507  prop  1.0000  ! Weight loss @ 200F of 2.90%
end

*
* Unit 2 Material Geometry
*
begin material geometry
* Fuel Rod - Class 1 - we17b - WE17 (OFA)
PART  1
ZROD  1    0.0000  0.0000  1.7399  0.3922  365.7600    ! Fuel pellet stack
ZROD  2    0.0000  0.0000  1.7399  0.4001  381.6604    ! Annulus + Plenum
ZROD  3    0.0000  0.0000  0.0000  0.4572  385.1402    ! Clad
ZROD  4    0.0000  0.0000  385.1402  0.0000  4.5720    ! Fuel rod to top nozzle
BOX  5    -0.6299  -0.6299  0.0000  1.2597  1.2597  389.7122  ! Pitch box
ZONES
/Fuel/    M1  +1
/Fuel to Clad Gap/    M4  +2  -1
/Clad & End Plugs/    M2  +3  -2
/Rod to Top Nozzle/    M2  +4
/Rod in Pitch/    M3  +5  -4  -3
* PWR Guide Tube - Class 1 - we17b - WE17 (OFA)
PART  2  NEST
ZROD  M3    0.0000  0.0000  0.0000  0.5740  365.7600    ! Guide tube interior
ZROD  M2    0.0000  0.0000  0.0000  0.6121  365.7600    ! Clad
BOX  M3    -0.6299  -0.6299  0.0000  1.2597  1.2597  389.7122  ! Pitch box
* PWR Instrument Tube - Class 1 - we17b - WE17 (OFA)
PART  3  NEST
ZROD  M3    0.0000  0.0000  0.0000  0.5740  365.7600    ! Inst. tube interior
ZROD  M2    0.0000  0.0000  0.0000  0.6121  365.7600    ! Clad
BOX  M3    -0.6299  -0.6299  0.0000  1.2597  1.2597  389.7122  ! Pitch box
* Array_17x17_264
```

Figure 6.8-9 (continued)

```
PART  4  ARRAY
17  17  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  2  1  1  2  1  1  2  1  1  1  1  1
1  1  1  2  1  1  1  1  1  1  1  1  1  2  1  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  2  1  1  2  1  1  2  1  1  2  1  1  2  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  2  1  1  2  1  1  3  1  1  2  1  1  2  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  2  1  1  2  1  1  2  1  1  2  1  1  2  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  1  2  1  1  1  1  1  1  1  1  1  2  1  1  1
1  1  1  1  1  2  1  1  2  1  1  2  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
* Fuel Assembly Array Inserted Into Assembly - Class 1 - we17b - WE17 (OFA)
PART  5  NEST
BOX  P4  -10.7075  -10.7075  6.8580  21.4149  21.4149  389.7122    ! Array
BOX  M3  -10.7086  -10.7086  6.8580  21.4173  21.4173  389.7122    ! Fuel Width Envelope
BOX  M5  -10.7086  -10.7086  0.0000  21.4173  21.4173  396.5702    ! Lower Nozzle
BOX  M6  -10.7086  -10.7086  0.0000  21.4173  21.4173  405.8920    ! Upper Nozzle - Envelope
* PWR Neutron Poison and Cover Sheet            Configuration  R
PART  6  ·
BOX  1  -9.9009  0.0318  0.0508  20.7467  0.1270  382.2700  ! BORAL Core
BOX  2  -9.9009  0.0000  0.0508  20.7467  0.1905  382.2700  ! BORAL Clad
BOX  3  -10.8458  0.0000  0.0508  21.6916  0.1905  384.2004  ! Space under Cover Sheet
BOX  4  -10.8915  0.0000  0.0051  21.7830  0.2362  384.2918  ! Cover Sheet (top/side)
BOX  5  -10.8966  0.0000  0.0000  21.7932  0.0457  384.3020  ! Remaining Cover Sheet
BOX  6  -10.8966  0.0000  0.0000  21.7932  0.2362  384.3020  ! Container
ZONES
/BORAL Core/    M8  +1
/BORAL Clad/    M9  +2  -1
/Space Under Cover/    H5  +3  -2
/Enclosing Cover/    M7  +4  -3
/Remaining Cover/    M7  +5  -4
/Container/    H5  +6  -5  -4
VOLUMES UNITY
* PWR Neutron Poison and Cover Sheet            Configuration  L
PART  7
BOX  1  -10.8458  0.0318  0.0508  20.7467  0.1270  382.2700  ! BORAL Core
BOX  2  -10.8458  0.0000  0.0508  20.7467  0.1905  382.2700  ! BORAL Clad
BOX  3  -10.8458  0.0000  0.0508  21.6916  0.1905  384.2004  ! Space under Cover Sheet
BOX  4  -10.8915  0.0000  0.0051  21.7830  0.2362  384.2918  ! Cover Sheet (top/side)
BOX  5  -10.8966  0.0000  0.0000  21.7932  0.0457  384.3020  ! Remaining Cover Sheet
BOX  6  -10.8966  0.0000  0.0000  21.7932  0.2362  384.3020  ! Container
ZONES
/BORAL Core/    M8  +1
/BORAL Clad/    M9  +2  -1
/Space Under Cover/    H5  +3  -2
/Enclosing Cover/    M7  +4  -3
/Remaining Cover/    M7  +5  -4
/Container/    H5  +6  -5  -4
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q1_4B
PART  8
BOX  1  -11.1684  -11.1684  0.0000  21.4173  21.4173  405.8920    ! Fuel assembly
BOX  2  -11.1684  -11.1684  0.0000  22.3368  22.3368  414.7820    ! Space inside tube from can lid to bottom
BOX  3  -11.2903  -11.2903  5.0800  22.5806  22.5806  388.1120    ! Fuel tube
BOX  4  -10.6807  11.2903  7.1120  21.7932  0.2362  384.3020    ! Boral plus cover sheet - Top (+Y)
BOX  5  11.1125  -11.2903  7.1120  21.7932  0.2362  384.3020  ZROT 180  ! Boral plus cover sheet - Bottom (-Y)
BOX  6  11.2903  11.1125  7.1120  21.7932  0.2362  384.3020  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  7  -11.2903  -10.6807  7.1120  21.7932  0.2362  384.3020  ZROT 270  ! Boral plus cover sheet - Left (-X)
BOX  8  -11.5265  -11.5265  0.0000  23.0530  23.0530  414.7820    ! Complete tube with poison
BOX  9  -11.5265  -11.5265  0.0000  23.5890  23.5890  414.7820    ! Disk Opening
ZONES
/Fuel Assembly/  P5  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P6  +4
/Boral plus Cover/  P7  +5
/Boral plus Cover/  P7  +6
/Boral plus Cover/  P6  +7
/Fuel Tube+Poison/  H5  +8  -3  -2  -4  -6  -5  -7
/Disk Opening/  H5  +9  -8
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q2_4B
PART  9
BOX  1  -10.2489  -11.1684  0.0000  21.4173  21.4173  405.8920    ! Fuel assembly
BOX  2  -11.1684  -11.1684  0.0000  22.3368  22.3368  414.7820    ! Space inside tube from can lid to bottom
BOX  3  -11.2903  -11.2903  5.0800  22.5806  22.5806  388.1120    ! Fuel tube
BOX  4  -11.1125  11.2903  7.1120  21.7932  0.2362  384.3020    ! Boral plus cover sheet - Top (+Y)
BOX  5  10.6807  -11.2903  7.1120  21.7932  0.2362  384.3020  ZROT 180  ! Boral plus cover sheet - Bottom (-Y)
BOX  6  11.2903  11.1125  7.1120  21.7932  0.2362  384.3020  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  7  -11.2903  -10.6807  7.1120  21.7932  0.2362  384.3020  ZROT 270  ! Boral plus cover sheet - Left (-X)
BOX  8  -11.5265  -11.5265  0.0000  23.0530  23.0530  414.7820    ! Complete tube with poison
BOX  9  -12.0625  -11.5265  0.0000  23.5890  23.5890  414.7820    ! Disk Opening
ZONES
/Fuel Assembly/  P5  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P7  +4
/Boral plus Cover/  P6  +5
/Boral plus Cover/  P7  +6
/Boral plus Cover/  P6  +7
/Fuel Tube+Poison/  H5  +8  -3  -2  -4  -6  -5  -7
```

Figure 6.8-9 (continued)

```
/Disk Opening/  H5  +9  -8
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q3_4B
PART  10
BOX  1  -10.2489  -10.2489  0.0000  21.4173  21.4173  405.8920     ! Fuel assembly
BOX  2  -11.1684  -11.1684  0.0000  22.3368  22.3368  414.7820     ! Space inside tube from can lid to bottom
BOX  3  -11.2903  -11.2903  5.0800  22.5806  22.5806  388.1120     ! Fuel tube
BOX  4  -11.1125  11.2903  7.1120  21.7932  0.2362  384.3020    ! Boral plus cover sheet - Top (+Y)
BOX  5  10.6807  -11.2903  7.1120  21.7932  0.2362  384.3020  ZROT 180  ! Boral plus cover sheet - Bottom (-Y)
BOX  6  11.2903  10.6807  7.1120  21.7932  0.2362  384.3020  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  7  -11.2903  -11.1125  7.1120  21.7932  0.2362  384.3020  ZROT 270  ! Boral plus cover sheet - Left (-X)
BOX  8  -11.5265  -11.5265  0.0000  23.0530  23.0530  414.7820     ! Complete tube with poison
BOX  9  -12.0625  -12.0625  0.0000  23.5890  23.5890  414.7820     ! Disk Opening
ZONES
/Fuel Assembly/  P5  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P7  +4
/Boral plus Cover/  P6  +5
/Boral plus Cover/  P6  +6
/Boral plus Cover/  P7  +7
/Fuel Tube+Poison/  H5  +8  -3  -2  -4  -6  -5  -7
/Disk Opening/  H5  +9  -8
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q4_4B
PART  11
BOX  1  -11.1684  -10.2489  0.0000  21.4173  21.4173  405.8920     ! Fuel assembly
BOX  2  -11.1684  -11.1684  0.0000  22.3368  22.3368  414.7820     ! Space inside tube from can lid to bottom
BOX  3  -11.2903  -11.2903  5.0800  22.5806  22.5806  388.1120     ! Fuel tube
BOX  4  -10.6807  11.2903  7.1120  21.7932  0.2362  384.3020    ! Boral plus cover sheet - Top (+Y)
BOX  5  11.1125  -11.2903  7.1120  21.7932  0.2362  384.3020  ZROT 180  ! Boral plus cover sheet - Bottom (-Y)
BOX  6  11.2903  10.6807  7.1120  21.7932  0.2362  384.3020  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  7  -11.2903  -11.1125  7.1120  21.7932  0.2362  384.3020  ZROT 270  ! Boral plus cover sheet - Left (-X)
BOX  8  -11.5265  -11.5265  0.0000  23.0530  23.0530  414.7820     ! Complete tube with poison
BOX  9  -11.5265  -12.0625  0.0000  23.5890  23.5890  414.7820     ! Disk Opening
ZONES
/Fuel Assembly/  P5  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P6  +4
/Boral plus Cover/  P7  +5
/Boral plus Cover/  P6  +6
/Boral plus Cover/  P7  +7
/Fuel Tube+Poison/  H5  +8  -3  -2  -4  -6  -5  -7
/Disk Opening/  H5  +9  -8
VOLUMES UNITY
* PWR Canister Cavity - Basket Radius v2.0
PART  12
BOX  1  -77.3392  -25.4749  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 1
BOX  2  -77.3392  1.8860  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 2
BOX  3  -52.8358  -52.8358  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 3
BOX  4  -51.5658  -25.4749  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 4
BOX  5  -51.5658  1.8860  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 5
BOX  6  -52.8358  29.2468  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 6
BOX  7  -25.4749  -77.3392  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 7
BOX  8  -25.4749  -51.5658  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 8
BOX  9  -25.4749  -25.4749  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 9
BOX  10  -25.4749  1.8860  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 10
BOX  11  -25.4749  27.9768  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 11
BOX  12  -25.4749  53.7502  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 12
BOX  13  1.8860  -77.3392  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 13
BOX  14  1.8860  -51.5658  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 14
BOX  15  1.8860  -25.4749  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 15
BOX  16  1.8860  1.8860  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 16
BOX  17  1.8860  27.9768  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 17
BOX  18  1.8860  53.7502  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 18
BOX  19  29.2468  -52.8358  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 19
BOX  20  27.9768  -25.4749  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 20
BOX  21  27.9768  1.8860  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 21
BOX  22  29.2468  29.2468  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 22
BOX  23  53.7502  -25.4749  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 23
BOX  24  53.7502  1.8860  0.0000  23.5890  23.5890  414.7820  ! Basket Opening 24
CONTAINER
ZROD  25  0.0000  0.0000  0.0000  82.9564  414.7820    ! Basket stack to cavity height
ZONES
/Opening01/  P10  +1
/Opening02/  P9  +2
/Opening03/  P10  +3          ! Corner position
/Opening04/  P10  +4
/Opening05/  P9  +5
/Opening06/  P9  +6          ! Corner position
/Opening07/  P10  +7
/Opening08/  P10  +8
/Opening09/  P10  +9
/Opening10/  P9  +10
/Opening11/  P9  +11
/Opening12/  P9  +12
/Opening13/  P11  +13
/Opening14/  P11  +14
/Opening15/  P11  +15
/Opening16/  P8  +16
/Opening17/  P8  +17
/Opening18/  P8  +18
/Opening19/  P11  +19          ! Corner position
/Opening20/  P11  +20
/Opening21/  P8  +21
/Opening22/  P8  +22          ! Corner position
/Opening23/  P11  +23
/Opening24/  P8  +24
```

Figure 6.8-9 (continued)

```
/Basket/  H1  +25  -1  -2  -3  -4  -5
    -6  -7  -8  -9  -10  -11
    -12  -13  -14  -15  -16  -17
    -18  -19  -20  -21  -22  -23
    -24

VOLUMES  UNITY
* Basket in Canister Cavity v2.0
PART  13  NEST
ZROD  P12  0.0000  0.0000  0.0000  82.9564  414.7820    ! Basket inserted - Includes gap to lid
ZROD  H5  0.0000  0.0000  0.0000  83.5787  414.7820    ! Inserts flood matl to canister shell
* Canister - Structural Lid - No Weld Shield v2.0
PART  14
ZROD  1  0.0000  0.0000  0.0000  83.5787  414.7820    ! Canister cavity contents
ZROD  2  0.0000  0.0000  -4.4450  85.1662  4.4450    ! Canister Bottom Plate
ZROD  3  0.0000  0.0000  414.7820  83.5787  17.7800    ! Shield Lid
ZROD  4  0.0000  0.0000  432.5620  83.5787  7.6200    ! Structural Lid
ZROD  5  0.0000  0.0000  0.0000  83.5787  440.1820    ! Canister Shell Inner
ZROD  6  0.0000  0.0000  0.0000  85.1662  440.1820    ! Canister Shell Outer
ZROD  7  0.0000  0.0000  -4.4450  85.1662  444.6270    ! Inner Detector Surface
ZONES
/Cavity/  P13  +1
/BottomPlate/  M13  +2
/ShieldLid/  P15  +3
/StructLid/  M13  +4
/Shell/  M13  +6  -5
/Canister/  M0  +7  -6  -4  -2
VOLUMES  UNITY
* Shield Lid - With Ports v2.0
PART  15  CLUSTER
ZROD  P16  -41.8271  59.7354  0.0000  7.6200  17.7800    ! Vent port
ZROD  P16  41.8271  -59.7354  0.0000  7.6200  17.7800    ! Drain port
ZROD  M13  0.0000  0.0000  0.0000  83.5787  17.7800    ! Shield Lid
* Vent Port Model - No Port v2.0
PART  16  CLUSTER
ZROD  M13  0.0000  0.0000  0.0000  1.3843  8.4328    ! Bottom Cylinder
ZROD  M13  0.0000  0.0000  8.4328  5.0800  7.9248    ! Middle Cyclinder
ZROD  M13  0.0000  0.0000  16.3576  7.6200  1.4224    ! Top Cylinder
ZROD  M13  0.0000  0.0000  0.0000  7.6200  17.7800    ! Shield lid material
* Transfer Cask Geometry - No Weld Shield - v2.0
PART  17
ZROD  1  0.0000  0.0000  0.0000  85.1662  444.6270    ! TSC
ZROD  2  0.0000  0.0000  0.0000  86.0425  450.3420    ! Cask cavity
ZROD  3  0.0000  0.0000  0.0000  108.2675  2.5400    ! Bottom plate
ZROD  4  0.0000  0.0000  2.5400  87.9475  442.7220    ! Inner shell
ZROD  5  0.0000  0.0000  2.5400  97.8535  436.6260    ! Lead shell
ZROD  6  0.0000  0.0000  2.5400  105.0925  442.7220    ! NS-4-FR shell
ZROD  7  0.0000  0.0000  2.5400  108.2675  442.7220    ! Outer shell
ZROD  8  0.0000  0.0000  445.2620  108.2675  5.0800    ! Top plate
ZROD  9  0.0000  0.0000  450.3420  82.2325  1.9050    ! Area inside retaining ring
ZROD  10  0.0000  0.0000  450.3420  97.8535  1.9050    ! Retaining ring
ZROD  11  0.0000  0.0000  -22.8600  108.2675  22.8600    ! Shield doors and rails
YP  12  102.5525              ! Y plane for shield door rail cutoff
YP  13  -102.5525              ! Y plane for shield door rail cutoff
XROD  14  -118.2675  0.0000  412.2420  12.7000  236.5350    ! Trunions (extended in x)
YROD  15  0.0000  -118.2675  412.2420  12.7000  236.5350    ! Trunions (extended in y)
ZROD  16  0.0000  0.0000  439.1660  97.8535  6.0960    ! Shielding ring
BOX  17  -2.5400  -86.8045  -5.0800  64.9732  173.6090  3.8100  ! Shield door B NS box
YXPRISM  18  62.4332  -86.8045  -5.0800        ! Shield door B NS trapezoid
    173.6090  39.4984  3.8100  36.9157  36.9157
BOX  19  -62.4332  -86.8045  -5.0800  54.8132  173.6090  3.8100  ! Shield door A NS box
YXPRISM  20  -101.9316  -34.2265  -5.0800        ! Shield door A NS trapezoid
    68.4530  39.4984  3.8100  143.0843  143.0843
YXPRISM  21  64.2620  -90.6780  -22.8600        ! Shield door B cut prism
    181.3560  41.4020  22.8600  36.9157  36.9157
XP  22  64.2620              ! Cut plane for NS boundary B
YXPRISM  23  -105.6640  -35.5600  -22.8600        ! Shield door A cut prism
    71.1200  41.4020  22.8600  143.0843  143.0843
XP  24  -64.2620              ! Cut plane for NS boundary A
ZROD  25  0.0000  0.0000  -22.8600  108.2675  475.1070    ! Container
ZONES
/TSC/  P14  +1            ! TSC
/CaskCavity/  M0  +2  -1          ! Cask cavity
/BottomPlate/  M14  +3  -2          ! Bottom plate
/InnerShell/  M14  +4  -2  -14  -15      ! Inner shell
/LeadShell/  M15  +5  -4  -14  -15      ! Lead shell
/NS-4-FRShell/  M16  +6  -5  -14  -15  -16    ! NS-4-FR shell
/ShieldRing/  M14  +16  -4  -14  -15      ! Shielding ring
/OuterShell/  M14  +7  -6  -14  -15      ! Outer shell
/TopPlate/  M14  +8  -2          ! Top plate
/RetRingInner/  M0  +9          ! Area inside retaining ring (null)
/RetRing/  M0  +10  -9          ! Retaining ring
/ShieldDoor1/  M14  +11  +13  -12  -17  -19    ! Shield doors and rails
    -18  -20  -22  +24
/ShieldDoor2/  M14  +11  +13  -12  -17  -19    ! Shield doors and rails
    -18  -20  +22  +21
/ShieldDoor3/  M14  +11  +13  -12  -17  -19    ! Shield doors and rails
    -18  -20  -24  +23
/ShieldDoorOuter1/  M0  +11  +12          ! Space outside of shield door
/ShieldDoorOuter2/  M0  +11  -13          ! Space outside of shield door
/ShieldDoorOuter3/  M0  +11  +22  -21        ! Space outside of shield door B
/ShieldDoorOuter4/  M0  +11  -24  -23        ! Space outside of shield door A
/XTrunions/  M14  +14  +7  -2        ! X Trunions
/YTrunions/  M14  +15  +7  -2        ! Y Trunions
/ShldDrBNSBox/  M16  +17          ! Shield door B NS box
/ShldDrANSBox/  M16  +19          ! Shield door A NS box
/ShldDrBNSTrap/  M16  +18          ! Shield door B NS trapezoid
/ShldDrANSTrap/  M16  +20          ! Shield door A NS trapezoid
/Container/  M0  +25  -11  -3  -7  -8  -10  ! Container
```

Figure 6.8-9 (continued)

```
VOLUMES UNITY
end

*
* Unit 5 - Source Geometry for
*
begin source geometry
ZONEMAT
ALL / MATERIAL    1
end

*
* Unit 3 Hole Data
*
begin hole data
* PWR Canister Hole Description v2.0
* Hole  1  General Basket Structure
PLATE
0  0  1
5
413.0040  0      ! Top of Basket
379.9840  -2      ! Top of Highest Support Disk
16.3068  -4      ! Bottom of Lowest Support Disk
0.0000  -3      ! Bottom of Basket
0.0000  3      ! Basket Offset
3

* Hole  2  Top Weldment Disk - no structure above the weldment disk
RZMESH
2         ! number of radial points
82.2198
83.1850
5         ! number of axial intervals
379.9840         ! Top of diskstack
394.4620         ! Bottom of weldment
397.6370         ! Top of weldment plate
406.1241         ! Ullage
411.7340         ! Flange
413.0040         ! Void to top of basket
3  3       ! Material below weldment
11  11       ! Plate Material
3  11       ! Ullage
3  11       ! Flange
3  3       ! Void to top of basket
3         ! Outside material

* Hole  3  Bottom Weldment Disk - no structure in the weldment disk support
RZMESH
1         ! number of radial points
83.1850
1         ! number of axial intervals
2.5400
5.0800         ! Coordinates inherited from PLATE Hole
11         ! Plate Material
3         ! Outside material

* Hole  4  Support disk and heat transfer disk stack
PLATE
origin  0  0  16.3068  ! Origin
0  0  1
4
cell  12.4968       ! Sets up a repeating lattice of cells
12.4968  3      ! flood matl
7.5184  3      ! water gap
6.2484  12      ! aluminium disk
1.2700  3      ! water gap
10         ! steel disk

* Hole  5  Flood material model
PLATE
0  0  1
1
406.1241  3      ! Above flooded region
3         ! Flooded region

end
```

Figure 6.8-10 MONK8A Input for BWR Transfer Cask

```
columns 1 200
*
*   UMS Transfer Cask - ex09c Standard
*
*   Cask Lid Configurations
*           Shield Lid - No Ports
*           Structural Lid - No Weld Shield
*
*   Neutron Poison Loading -  75 %
*   Exterior Water Density 0.0001
*   Cavity Water Density 0.9998
*   Fuel to Clad Gap Water Density 0.9998
*
*   Boron Content in Water - 0 ppm
*
*   Model Revision v3.0
*
* Parameters
*
@randseed =  12345
*
*
* Unit 1 Control Data
*
begin control data
*READ   ! read and check each independently
*SEEK MULTIPLE DEFINITIONS

SEEDS  @randseed  @randseed
STAGES -15 810 4000 STDV 0.0008

end
*
* Unit 9 Material Specification
*
begin material specification
normalise
nmixtures  7
weight  mixture  1
      u235  3.8784E-02
      u238  8.4267E-01
      o16  1.1855E-01
atoms  mixture  2
      h  6.6667E-01
      o16  3.3333E-01
atoms  mixture  3
      h  6.6667E-01
      o16  3.3333E-01
atoms  mixture  4
      h  4.2857E-01
      b  1.4286E-01
      o16  4.2857E-01
weight  mixture  5
      al  7.6834E-01
      b10  3.2642E-02
      b11  1.4870E-01
      c  5.0317E-02
atoms  mixture  6
      c  2.8571E-01
      h  4.7619E-01
      o16  2.3810E-01
weight  mixture  7
      h  4.2152E-02
      o16  5.4785E-01
      fe  4.7900E-02
      c  9.3500E-02
      si  3.3600E-02
      ca  5.6100E-02
      al  1.7890E-01
*
* Materials List - v1.2 - Class 5 - ex09c - Ex/ANF9 (JP-4,5) Fuel
*
nmaterials  23
volume              ! UO2 at 4.4%
material  1
  mixture  1  density  10.4120  prop  1.00000
volume              ! Fuel pin cladding
material  2
  zircalloy    density  6.5500  prop  1.00000
volume              ! Water In Lattice and Tube
material  3
  mixture  2  density  0.9998  prop  1.00000  ! mixH2O
volume              ! Water In Fuel Rod Clad Gap
material  4
  mixture  2  density  0.9998  prop  1.00000  ! mixH2O
volume              ! Lower Nozzle Material
material  5
  stainless 304l steel    density  7.9200  prop  0.17007
  mixture  2  density  0.9998  prop  0.82993  ! mixH2O
volume              ! Upper Nozzle Material
material  6
  stainless 304l steel    density  7.9200  prop  0.06774
  mixture  2  density  0.9998  prop  0.93226  ! mixH2O
```

Figure 6.8-10 (continued)

```
*
* Materials List - Common Materials - v2.0
*
volume              ! Tube wall and cover sheet
material  7
  stainless 304l steel    density  7.9300  prop  1.0000
volume              ! BORAL core
material  8
  mixture  5  density  1.9901  prop  1.0000  ! mixBORAL
volume              ! BORAL alumnimum clad
material  9
  aluminium         prop  1.0000
volume              ! Structural Disk Material
material  10
  stainless 304l steel    density  7.9300  prop  1.0000
volume              ! Weldment Material
material  11
  stainless 304l steel    density  7.9300  prop  1.0000
volume              ! Heat Transfer Disk Material
material  12
  aluminium         prop  1.0000
volume              ! Canister Material
material  13
  stainless 304l steel    density  7.9300  prop  1.0000
atoms              ! Transfer steel
material  14    density  0      !  (SCALE carbon steel)
    fe      prop  8.3498E-02
    c      prop  3.9250E-03
volume              ! Lead
material  15
  pb    density  11.0400  prop  1.0000
atoms               ! NS-4-FR
material  16    density  0      ! 0 means atom/b-cm
    b10      prop  8.5500E-05
    b11      prop  3.4200E-04
    al      prop  7.8000E-03
    h      prop  5.8500E-02
    o16      prop  2.6100E-02
    c      prop  2.2600E-02
    n      prop  1.3900E-03
volume              ! Stainless Steel 304
material  17
  stainless 304l steel    density  7.9300  prop  1.0000
volume              ! Vent port middle cylinder
material  18
  stainless 304l steel    density  7.9300  prop  0.5000
  void        prop  0.5000
atoms              ! SCALE Concrete
material  19    density  0
    h      prop  1.3401E-02
    o16      prop  4.4931E-02
    na      prop  1.7036E-03
    al      prop  1.7018E-03
    si      prop  1.6205E-02
    ca      prop  1.4826E-03
    fe      prop  3.3857E-04
volume              ! Heat fins for transport cask
material  20
  cu    density  8.9200  prop  0.4286
  stainless 304l steel    density  7.9300  prop  0.5714
volume              ! Balsa
material  21
  mixture  6  density  0.1250  prop  1.0000
volume              ! Redwood
material  22
  mixture  6  density  0.3870  prop  1.0000
volume              ! NS3
material  23
  mixture  7  density  1.6507  prop  1.0000  ! Weight loss @ 200F of 2.90%
end

*
* Unit 2 Material Geometry
*
begin material geometry
* Fuel Rod - Class 5 - ex09c - Ex/ANF9 (JP-4,5)
PART  1
ZROD  1     0.0000  0.0000  0.9017  0.4528  381.0000    ! Fuel pellet stack
ZROD  2     0.0000  0.0000  0.9017  0.4623  405.3281    ! Annulus + Plenum
ZROD  3     0.0000  0.0000  0.0000  0.5385  407.1315    ! Clad
ZROD  4     0.0000  0.0000  407.1315  0.2692  3.3782    ! Fuel rod to top nozzle
BOX  5    -0.7264  -0.7264  0.0000  1.4528  1.4528  410.5097  ! Pitch box
ZONES
/Fuel/    M1  +1
/Fuel to Clad Gap/    M4  +2  -1
/Clad & End Plugs/    M2  +3  -2
/Rod to Top Nozzle/    M2  +4
/Rod in Pitch/    M3  +5  -4  -3
* BWR Water Rod - Class 5 - ex09c - Ex/ANF9 (JP-4,5)
PART  2  NEST
ZROD  M3    0.0000  0.0000  0.0000  0.4623  381.0000    ! Water Rod Interior
ZROD  M2    0.0000  0.0000  0.0000  0.5385  381.0000    ! Clad
BOX  M3    -0.7264  -0.7264  0.0000  1.4528  1.4528  410.5097  ! Pitch box
* Array_9x9_79
PART  3  ARRAY
9  9  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
```

Figure 6.8-10 (continued)

```
1  1  1  1  1  1  1  1  1
1  1  1  1  2  1  1  1  1
1  1  1  1  1  2  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
* Fuel Assembly Array Inserted Into Assembly - Class 5 - ex09c - Ex/ANF9 (JP-4,5)
PART  4  NEST
BOX  P3  -6.5376  -6.5376  17.6276  13.0752  13.0752  410.5097    ! Array
BOX  M3  -6.7031  -6.7031  17.6276  13.4061  13.4061  410.5097    ! BWR Channel Interior
BOX  M2  -6.9063  -6.9063  17.6276  13.8125  13.8125  410.5097    ! BWR Channel
BOX  M3  -6.9063  -6.9063  17.6276  13.8125  13.8125  410.5097    ! Fuel Width Envelope
BOX  M5  -6.9063  -6.9063  0.0000  13.8125  13.8125  428.1373    ! Lower Nozzle
BOX  M6  -6.9063  -6.9063  0.0000  13.8125  13.8125  447.1873    ! Upper Nozzle - Envelope
* BWR Neutron Poison and Cover Sheet          Configuration  C
PART  5
BOX  1  -6.7031  0.1080  0.0508  13.4061  0.1270  396.4940  ! BORAL Core
BOX  2  -6.7031  0.0000  0.0508  13.4061  0.3429  396.4940  ! BORAL Clad
BOX  3  -7.1755  0.0000  0.0508  14.3510  0.3429  398.4244  ! Space under Cover Sheet
BOX  4  -7.2212  0.0000  0.0051  14.4424  0.3886  398.5158  ! Cover Sheet (top/side)
BOX  5  -7.2263  0.0000  0.0000  14.4526  0.0457  398.5260  ! Remaining Cover Sheet
BOX  6  -7.2263  0.0000  0.0000  14.4526  0.3886  398.5260  ! Container
ZONES
/BORAL Core/    M8  +1
/BORAL Clad/    M9  +2  -1
/Space Under Cover/    H5  +3  -2
/Enclosing Cover/    M7  +4  -3
/Remaining Cover/    M7  +5  -4
/Container/    H5  +6  -5  -4
VOLUMES UNITY
* BWR Neutron Poison and Cover Sheet          Configuration  R
PART  6
BOX  1  -6.2306  0.1080  0.0508  13.4061  0.1270  396.4940  ! BORAL Core
BOX  2  -6.2306  0.0000  0.0508  13.4061  0.3429  396.4940  ! BORAL Clad
BOX  3  -7.1755  0.0000  0.0508  14.3510  0.3429  398.4244  ! Space under Cover Sheet
BOX  4  -7.2212  0.0000  0.0051  14.4424  0.3886  398.5158  ! Cover Sheet (top/side)
BOX  5  -7.2263  0.0000  0.0000  14.4526  0.0457  398.5260  ! Remaining Cover Sheet
BOX  6  -7.2263  0.0000  0.0000  14.4526  0.3886  398.5260  ! Container
ZONES
/BORAL Core/    M8  +1
/BORAL Clad/    M9  +2  -1
/Space Under Cover/    H5  +3  -2
/Enclosing Cover/    M7  +4  -3
/Remaining Cover/    M7  +5  -4
/Container/    H5  +6  -5  -4
VOLUMES UNITY
* BWR Neutron Poison and Cover Sheet          Configuration  L
PART  7
BOX  1  -7.1755  0.1080  0.0508  13.4061  0.1270  396.4940  ! BORAL Core
BOX  2  -7.1755  0.0000  0.0508  13.4061  0.3429  396.4940  ! BORAL Clad
BOX  3  -7.1755  0.0000  0.0508  14.3510  0.3429  398.4244  ! Space under Cover Sheet
BOX  4  -7.2212  0.0000  0.0051  14.4424  0.3886  398.5158  ! Cover Sheet (top/side)
BOX  5  -7.2263  0.0000  0.0000  14.4526  0.0457  398.5260  ! Remaining Cover Sheet
BOX  6  -7.2263  0.0000  0.0000  14.4526  0.3886  398.5260  ! Container
ZONES
/BORAL Core/    M8  +1
/BORAL Clad/    M9  +2  -1
/Space Under Cover/    H5  +3  -2
/Enclosing Cover/    M7  +4  -3
/Remaining Cover/    M7  +5  -4
/Container/    H5  +6  -5  -4
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q1_2B
PART  8
BOX  1  -7.4981  -7.4981  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480    ! Fuel tube
BOX  4  -7.1120  7.6200  14.7320  14.4526  0.3886  398.5260    ! Boral plus cover sheet - Top (+Y)
BOX  5  7.6200  7.3406  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  6  -7.6200  -7.6200  0.0000  15.6286  15.6286  453.6440    ! Complete tube with poison
BOX  7  -7.6200  -7.6200  0.0000  15.9461  15.9461  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P6  +4
/Boral plus Cover/  P7  +5
/Fuel Tube+Poison/  H5  +6  -3  -2  -4  -5
/Disk Opening/  H5  +7  -6
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q2_2B
PART  9
BOX  1  -6.3144  -7.4981  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480    ! Fuel tube
BOX  4  -7.3406  7.6200  14.7320  14.4526  0.3886  398.5260    ! Boral plus cover sheet - Top (+Y)
BOX  5  7.6200  7.3406  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  6  -7.6200  -7.6200  0.0000  15.6286  15.6286  453.6440    ! Complete tube with poison
BOX  7  -7.9375  -7.6200  0.0000  15.9461  15.9461  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P7  +4
/Boral plus Cover/  P7  +5
/Fuel Tube+Poison/  H5  +6  -3  -2  -4  -5
/Disk Opening/  H5  +7  -6
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q3_2B
```

Figure 6.8-10 (continued)

```
PART  10
BOX  1  -6.3144  -6.3144  0.0000  13.8125  13.8125  447.1873     ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440     ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480     ! Fuel tube
BOX  4  -7.3406  7.6200  14.7320  14.4526  0.3886  398.5260     ! Boral plus cover sheet - Top (+Y)
BOX  5  7.6200  7.1120  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  6  -7.6200  -7.6200  0.0000  15.6286  15.6286  453.6440     ! Complete tube with poison
BOX  7  -7.9375  -7.9375  0.0000  15.9461  15.9461  453.6440     ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P7  +4
/Boral plus Cover/  P6  +5
/Fuel Tube+Poison/  H5  +6  -3  -2  -4  -5
/Disk Opening/  H5  +7  -6
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q4_2B
PART  11
BOX  1  -7.4981  -6.3144  0.0000  13.8125  13.8125  447.1873     ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440     ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480     ! Fuel tube
BOX  4  -7.1120  7.6200  14.7320  14.4526  0.3886  398.5260     ! Boral plus cover sheet - Top (+Y)
BOX  5  7.6200  7.1120  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  6  -7.6200  -7.6200  0.0000  15.6286  15.6286  453.6440     ! Complete tube with poison
BOX  7  -7.6200  -7.9375  0.0000  15.9461  15.9461  453.6440     ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P6  +4
/Boral plus Cover/  P6  +5
/Fuel Tube+Poison/  H5  +6  -3  -2  -4  -5
/Disk Opening/  H5  +7  -6
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  CT_2B
PART  12
BOX  1  -6.9063  -7.4981  0.0000  13.8125  13.8125  447.1873     ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440     ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480     ! Fuel tube
BOX  4  -7.2263  7.6200  14.7320  14.4526  0.3886  398.5260     ! Boral plus cover sheet - Top (+Y)
BOX  5  7.6200  7.3406  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  6  -7.6200  -7.6200  0.0000  15.6286  15.6286  453.6440     ! Complete tube with poison
BOX  7  -7.7788  -7.6200  0.0000  15.9461  15.9461  453.6440     ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P5  +4
/Boral plus Cover/  P7  +5
/Fuel Tube+Poison/  H5  +6  -3  -2  -4  -5
/Disk Opening/  H5  +7  -6
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  CB_2B
PART  13
BOX  1  -6.9063  -6.3144  0.0000  13.8125  13.8125  447.1873     ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440     ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480     ! Fuel tube
BOX  4  -7.2263  7.6200  14.7320  14.4526  0.3886  398.5260     ! Boral plus cover sheet - Top (+Y)
BOX  5  7.6200  7.1120  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  6  -7.6200  -7.6200  0.0000  15.6286  15.6286  453.6440     ! Complete tube with poison
BOX  7  -7.7788  -7.9375  0.0000  15.9461  15.9461  453.6440     ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P5  +4
/Boral plus Cover/  P6  +5
/Fuel Tube+Poison/  H5  +6  -3  -2  -4  -5
/Disk Opening/  H5  +7  -6
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q1_RB
PART  14
BOX  1  -7.4981  -7.4981  0.0000  13.8125  13.8125  447.1873     ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440     ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480     ! Fuel tube
BOX  4  7.6200  7.3406  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  5  -7.6200  -7.6200  0.0000  15.6286  15.2400  453.6440     ! Complete tube with poison
BOX  6  -7.6200  -7.6200  0.0000  15.9461  15.9461  453.6440     ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P7  +4
/Fuel Tube+Poison/  H5  +5  -3  -2    -4
/Disk Opening/  H5  +6  -5
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q2_RB
PART  15
BOX  1  -6.3144  -7.4981  0.0000  13.8125  13.8125  447.1873     ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440     ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480     ! Fuel tube
BOX  4  7.6200  7.3406  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  5  -7.6200  -7.6200  0.0000  15.6286  15.2400  453.6440     ! Complete tube with poison
BOX  6  -7.9375  -7.6200  0.0000  15.9461  15.9461  453.6440     ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
```

Figure 6.8-10 (continued)

```
/Boral plus Cover/  P7  +4
/Fuel Tube+Poison/  H5  +5  -3  -2    -4
/Disk Opening/  H5  +6  -5
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  CT_RB
PART  16
BOX  1  -6.9063  -7.4981  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480    ! Fuel tube
BOX  4  7.6200  7.3406  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  5  -7.6200  -7.6200  0.0000  15.6286  15.2400  453.6440    ! Complete tube with poison
BOX  6  -7.7788  -7.6200  0.0000  15.9461  15.9461  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P7  +4
/Fuel Tube+Poison/  H5  +5  -3  -2    -4
/Disk Opening/  H5  +6  -5
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q1_TB
PART  17
BOX  1  -7.4981  -7.4981  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480    ! Fuel tube
BOX  4  -7.1120  7.6200  14.7320  14.4526  0.3886  398.5260    ! Boral plus cover sheet - Top (+Y)
BOX  5  -7.6200  -7.6200  0.0000  15.2400  15.6286  453.6440    ! Complete tube with poison
BOX  6  -7.6200  -7.6200  0.0000  15.9461  15.9461  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P6  +4
/Fuel Tube+Poison/  H5  +5  -3  -2  -4
/Disk Opening/  H5  +6  -5
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q4_TB
PART  18
BOX  1  -7.4981  -6.3144  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480    ! Fuel tube
BOX  4  -7.1120  7.6200  14.7320  14.4526  0.3886  398.5260    ! Boral plus cover sheet - Top (+Y)
BOX  5  -7.6200  -7.6200  0.0000  15.2400  15.6286  453.6440    ! Complete tube with poison
BOX  6  -7.6200  -7.9375  0.0000  15.9461  15.9461  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P6  +4
/Fuel Tube+Poison/  H5  +5  -3  -2  -4
/Disk Opening/  H5  +6  -5
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q1_NB
PART  19
BOX  1  -7.4981  -7.4981  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
BOX  2  -7.4981  -7.4981  0.0000  14.9962  14.9962  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.6200  -7.6200  12.7000  15.2400  15.2400  409.4480    ! Fuel tube
BOX  4  -7.6200  -7.6200  0.0000  15.2400  15.2400  453.6440    ! Complete tube with poison
BOX  5  -7.6200  -7.6200  0.0000  15.9461  15.9461  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Fuel Tube+Poison/  H5  +4  -3  -2
/Disk Opening/  H5  +5  -4
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q10_NB
PART  20
BOX  1  -7.6759  -7.6759  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
BOX  2  -7.6759  -7.6759  0.0000  15.3518  15.3518  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.7978  -7.7978  12.7000  15.5956  15.5956  409.4480    ! Fuel tube
BOX  4  -7.7978  -7.7978  0.0000  15.5956  15.5956  453.6440    ! Complete tube with poison
BOX  5  -7.7978  -7.7978  0.0000  16.3271  16.3271  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Fuel Tube+Poison/  H5  +4  -3  -2
/Disk Opening/  H5  +5  -4
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q20_RB
PART  21
BOX  1  -6.1366  -7.6759  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
BOX  2  -7.6759  -7.6759  0.0000  15.3518  15.3518  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.7978  -7.7978  12.7000  15.5956  15.5956  409.4480    ! Fuel tube
BOX  4  7.7978  7.5184  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  5  -7.7978  -7.7978  0.0000  15.9842  15.5956  453.6440    ! Complete tube with poison
BOX  6  -8.1407  -7.7978  0.0000  16.3271  16.3271  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P7  +4
/Fuel Tube+Poison/  H5  +5  -3  -2    -4
/Disk Opening/  H5  +6  -5
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q30_2B
PART  22
BOX  1  -6.1366  -6.1366  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
```

Figure 6.8-10 (continued)

```
BOX  2  -7.6759  -7.6759  0.0000  15.3518  15.3518  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.7978  -7.7978  12.7000  15.5956  15.5956  409.4480    ! Fuel tube
BOX  4  -7.5184  7.7978  14.7320  14.4526  0.3886  398.5260    ! Boral plus cover sheet - Top (+Y)
BOX  5  7.7978  6.9342  14.7320  14.4526  0.3886  398.5260  ZROT 90  ! Boral plus cover sheet - Right (+X)
BOX  6  -7.7978  -7.7978  0.0000  15.9842  15.9842  453.6440    ! Complete tube with poison
BOX  7  -8.1407  -8.1407  0.0000  16.3271  16.3271  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P7  +4
/Boral plus Cover/  P6  +5
/Fuel Tube+Poison/  H5  +6  -3  -2  -4  -5
/Disk Opening/  H5  +7  -6
VOLUMES UNITY
* Fuel Assembly in Tube v2.0          Configuration  Q40_TB
PART  23
BOX  1  -7.6759  -6.1366  0.0000  13.8125  13.8125  447.1873    ! Fuel assembly
BOX  2  -7.6759  -7.6759  0.0000  15.3518  15.3518  453.6440    ! Space inside tube from can lid to bottom
BOX  3  -7.7978  -7.7978  12.7000  15.5956  15.5956  409.4480    ! Fuel tube
BOX  4  -6.9342  7.7978  14.7320  14.4526  0.3886  398.5260    ! Boral plus cover sheet - Top (+Y)
BOX  5  -7.7978  -7.7978  0.0000  15.5956  15.9842  453.6440    ! Complete tube with poison
BOX  6  -7.7978  -8.1407  0.0000  16.3271  16.3271  453.6440    ! Disk Opening
ZONES
/Fuel Assembly/  P4  +1
/Space in Tube/  H5  +2  -1
/Fuel Tube/  M7  +3  -2
/Boral plus Cover/  P6  +4
/Fuel Tube+Poison/  H5  +5  -3  -2  -4
/Disk Opening/  H5  +6  -5
VOLUMES UNITY
* BWR Canister Cavity - Basket Radius v2.0
PART  24
BOX  1  -78.3615  -16.7716  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 1
BOX  2  -78.3615  0.8255  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 2
BOX  3  -60.9549  -52.1564  0.0000  16.3271  16.3271  453.6440  ! Basket Opening 3 - Oversize
BOX  4  -60.7644  -34.3687  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 4
BOX  5  -60.7644  -16.7716  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 5
BOX  6  -60.7644  0.8255  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 6
BOX  7  -60.7644  18.4226  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 7
BOX  8  -60.9549  35.8292  0.0000  16.3271  16.3271  453.6440  ! Basket Opening 8 - Oversize
BOX  9  -43.1673  -69.5630  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 9
BOX  10  -43.1673  -51.9659  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 10
BOX  11  -43.1673  -34.3687  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 11
BOX  12  -43.1673  -16.7716  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 12
BOX  13  -43.1673  0.8255  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 13
BOX  14  -43.1673  18.4226  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 14
BOX  15  -43.1673  36.0197  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 15
BOX  16  -43.1673  53.6169  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 16
BOX  17  -25.5702  -69.5630  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 17
BOX  18  -25.5702  -51.9659  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 18
BOX  19  -25.5702  -34.3687  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 19
BOX  20  -25.5702  -16.7716  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 20
BOX  21  -25.5702  0.8255  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 21
BOX  22  -25.5702  18.4226  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 22
BOX  23  -25.5702  36.0197  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 23
BOX  24  -25.5702  53.6169  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 24
BOX  25  -7.9731  -69.5630  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 25
BOX  26  -7.9731  -51.9659  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 26
BOX  27  -7.9731  -34.3687  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 27
BOX  28  -7.9731  -16.7716  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 28
BOX  29  -7.9731  0.8255  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 29
BOX  30  -7.9731  18.4226  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 30
BOX  31  -7.9731  36.0197  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 31
BOX  32  -7.9731  53.6169  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 32
BOX  33  9.6241  -69.5630  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 33
BOX  34  9.6241  -51.9659  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 34
BOX  35  9.6241  -34.3687  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 35
BOX  36  9.6241  -16.7716  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 36
BOX  37  9.6241  0.8255  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 37
BOX  38  9.6241  18.4226  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 38
BOX  39  9.6241  36.0197  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 39
BOX  40  9.6241  53.6169  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 40
BOX  41  27.2212  -69.5630  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 41
BOX  42  27.2212  -51.9659  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 42
BOX  43  27.2212  -34.3687  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 43
BOX  44  27.2212  -16.7716  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 44
BOX  45  27.2212  0.8255  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 45
BOX  46  27.2212  18.4226  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 46
BOX  47  27.2212  36.0197  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 47
BOX  48  27.2212  53.6169  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 48
BOX  49  44.6278  -52.1564  0.0000  16.3271  16.3271  453.6440  ! Basket Opening 49 - Oversize
BOX  50  44.8183  -34.3687  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 50
BOX  51  44.8183  -16.7716  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 51
BOX  52  44.8183  0.8255  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 52
BOX  53  44.8183  18.4226  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 53
BOX  54  44.6278  35.8292  0.0000  16.3271  16.3271  453.6440  ! Basket Opening 54 - Oversize
BOX  55  62.4154  -16.7716  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 55
BOX  56  62.4154  0.8255  0.0000  15.9461  15.9461  453.6440  ! Basket Opening 56
CONTAINER
ZROD  57  0.0000  0.0000  0.0000  82.8675  453.6440    ! Basket stack to cavity height
ZONES
/Opening1/  P10  +1
/Opening2/  P15  +2
/Opening3/  P22  +3          ! Oversized opening
/Opening4/  P10  +4
/Opening5/  P10  +5
/Opening6/  P9  +6
/Opening7/  P9  +7
```

Figure 6.8-10 (continued)

```
/Opening8/  P21  +8          ! Oversized opening
/Opening9/  P10  +9
/Opening10/  P10  +10
/Opening11/  P10  +11
/Opening12/  P10  +12
/Opening13/  P9  +13
/Opening14/  P9  +14
/Opening15/  P9  +15
/Opening16/  P15  +16
/Opening17/  P10  +17
/Opening18/  P10  +18
/Opening19/  P10  +19
/Opening20/  P10  +20
/Opening21/  P9  +21
/Opening22/  P9  +22
/Opening23/  P9  +23
/Opening24/  P15  +24
/Opening25/  P13  +25
/Opening26/  P13  +26
/Opening27/  P13  +27
/Opening28/  P13  +28
/Opening29/  P12  +29
/Opening30/  P12  +30
/Opening31/  P12  +31
/Opening32/  P16  +32
/Opening33/  P11  +33
/Opening34/  P11  +34
/Opening35/  P11  +35
/Opening36/  P11  +36
/Opening37/  P8  +37
/Opening38/  P8  +38
/Opening39/  P8  +39
/Opening40/  P14  +40
/Opening41/  P18  +41
/Opening42/  P11  +42
/Opening43/  P11  +43
/Opening44/  P11  +44
/Opening45/  P8  +45
/Opening46/  P8  +46
/Opening47/  P8  +47
/Opening48/  P19  +48
/Opening49/  P23  +49          ! Oversized opening
/Opening50/  P18  +50
/Opening51/  P11  +51
/Opening52/  P8  +52
/Opening53/  P17  +53
/Opening54/  P20  +54          ! Oversized opening
/Opening55/  P18  +55
/Opening56/  P19  +56
/Basket/  H1  +57  -1  -2  -3  -4  -5
    -6  -7  -8  -9  -10  -11
    -12  -13  -14  -15  -16  -17
    -18  -19  -20  -21  -22  -23
    -24  -25  -26  -27  -28  -29
    -30  -31  -32  -33  -34  -35
    -36  -37  -38  -39  -40  -41
    -42  -43  -44  -45  -46  -47
    -48  -49  -50  -51  -52  -53
    -54  -55  -56

VOLUMES  UNITY
* Basket in Canister Cavity v2.0
PART  25  NEST
ZROD  P24  0.0000  0.0000  0.0000  82.8675  453.6440    ! Basket inserted - Includes gap to lid
ZROD  H5  0.0000  0.0000  0.0000  83.5787  453.6440    ! Inserts flood matl to canister shell
* Canister - Structural Lid - No Weld Shield v2.0
PART  26
ZROD  1  0.0000  0.0000  0.0000  83.5787  453.6440    ! Canister cavity contents
ZROD  2  0.0000  0.0000  -4.4450  85.1662  4.4450    ! Canister Bottom Plate
ZROD  3  0.0000  0.0000  453.6440  83.5787  17.7800    ! Shield Lid
ZROD  4  0.0000  0.0000  471.4240  83.5787  7.6200    ! Structural Lid
ZROD  5  0.0000  0.0000  0.0000  83.5787  479.0440    ! Canister Shell Inner
ZROD  6  0.0000  0.0000  0.0000  85.1662  479.0440    ! Canister Shell Outer
ZROD  7  0.0000  0.0000  -4.4450  85.1662  483.4890    ! Inner Detector Surface
ZONES
/Cavity/  P25  +1
/BottomPlate/  M13  +2
/ShieldLid/  P27  +3
/StructLid/  M13  +4
/Shell/  M13  +6  -5
/Canister/  M0  +7  -6  -4  -2
VOLUMES  UNITY
* Shield Lid - With Ports v2.0
PART  27  CLUSTER
ZROD  P28  -46.8743  55.8626  0.0000  7.6200  17.7800    ! Vent port
ZROD  P28  46.8743  -55.8626  0.0000  7.6200  17.7800    ! Drain port
ZROD  M13  0.0000  0.0000  0.0000  83.5787  17.7800    ! Shield Lid
* Vent Port Model - No Port v2.0
PART  28  CLUSTER
ZROD  M13  0.0000  0.0000  0.0000  1.3843  8.4328    ! Bottom Cylinder
ZROD  M13  0.0000  0.0000  8.4328  5.0800  7.9248    ! Middle Cyclinder
ZROD  M13  0.0000  0.0000  16.3576  7.6200  1.4224    ! Top Cylinder
ZROD  M13  0.0000  0.0000  0.0000  7.6200  17.7800    ! Shield lid material
* Transfer Cask Geometry - No Weld Shield - v2.0
PART  29
ZROD  1  0.0000  0.0000  0.0000  85.1662  483.4890    ! TSC
ZROD  2  0.0000  0.0000  0.0000  86.0425  489.2040    ! Cask cavity
ZROD  3  0.0000  0.0000  0.0000  108.2675  2.5400    ! Bottom plate
ZROD  4  0.0000  0.0000  2.5400  87.9475  481.5840    ! Inner shell
```

Figure 6.8-10 (continued)

```
ZROD  5  0.0000  0.0000  2.5400  97.8535  475.4880    ! Lead shell
ZROD  6  0.0000  0.0000  2.5400  105.0925  481.5840    ! NS-4-FR shell
ZROD  7  0.0000  0.0000  2.5400  108.2675  481.5840    ! Outer shell
ZROD  8  0.0000  0.0000  484.1240  108.2675  5.0800    ! Top plate
ZROD  9  0.0000  0.0000  489.2040  82.2325  1.9050    ! Area inside retaining ring
ZROD  10  0.0000  0.0000  489.2040  97.8535  1.9050    ! Retaining ring
ZROD  11  0.0000  0.0000  -22.8600  108.2675  22.8600    ! Shield doors and rails
YP  12  102.5525            ! Y plane for shield door rail cutoff
YP  13  -102.5525           ! Y plane for shield door rail cutoff
XROD  14  -118.2675  0.0000  451.1040  12.7000  236.5350    ! Trunions (extended in x)
YROD  15  0.0000  -118.2675  451.1040  12.7000  236.5350    ! Trunions (extended in y)
ZROD  16  0.0000  0.0000  478.0280  97.8535  6.0960    ! Shielding ring
BOX  17  -2.5400  -86.8045  -5.0800  64.9732  173.6090  3.8100  ! Shield door B NS box
YXPRISM  18  62.4332  -86.8045  -5.0800       ! Shield door B NS trapezoid
    173.6090  39.4984  3.8100  36.9157  36.9157
BOX  19  -62.4332  -86.8045  -5.0800  54.8132  173.6090  3.8100  ! Shield door A NS box
YXPRISM  20  -101.9316  -34.2265  -5.0800       ! Shield door A NS trapezoid
    68.4530  39.4984  3.8100  143.0843  143.0843
YXPRISM  21  64.2620  -90.6780  -22.8600       ! Shield door B cut prism
    181.3560  41.4020  22.8600  36.9157  36.9157
XP  22  64.2620            ! Cut plane for NS boundary B
YXPRISM  23  -105.6640  -35.5600  -22.8600       ! Shield door A cut prism
    71.1200  41.4020  22.8600  143.0843  143.0843
XP  24  -64.2620            ! Cut plane for NS boundary A
ZROD  25  0.0000  0.0000  -22.8600  108.2675  513.9690    ! Container
ZONES
/TSC/  P26  +1           ! TSC
/CaskCavity/  M0  +2  -1          ! Cask cavity
/BottomPlate/  M14  +3  -2          ! Bottom plate
/InnerShell/  M14  +4  -2  -14  -15      ! Inner shell
/LeadShell/  M15  +5  -4  -14  -15      ! Lead shell
/NS-4-FRShell/  M16  +6  -5  -14  -15  -16    ! NS-4-FR shell
/ShieldRing/  M14  +16  -4  -14  -15      ! Shielding ring
/OuterShell/  M14  +7  -6  -14  -15      ! Outer shell
/TopPlate/  M14  +8  -2          ! Top plate
/RetRingInner/  M0  +9           ! Area inside retaining ring (null)
/RetRing/  M0  +10  -9          ! Retaining ring
/ShieldDoor1/  M14  +11  +13  -12  -17  -19    ! Shield doors and rails
    -18  -20  -22  +24
/ShieldDoor2/  M14  +11  +13  -12  -17  -19    ! Shield doors and rails
    -18  -20  +22  +21
/ShieldDoor3/  M14  +11  +13  -12  -17  -19    ! Shield doors and rails
    -18  -20  -24  +23
/ShieldDoorOuter1/  M0  +11  +12         ! Space outside of shield door
/ShieldDoorOuter2/  M0  +11  -13         ! Space outside of shield door
/ShieldDoorOuter3/  M0  +11  +22  -21       ! Space outside of shield door B
/ShieldDoorOuter4/  M0  +11  -24  -23       ! Space outside of shield door A
/XTrunions/  M14  +14  +7  -2         ! X Trunions
/YTrunions/  M14  +15  +7  -2         ! Y Trunions
/ShldDrBNSBox/  M16  +17           ! Shield door B NS box
/ShldDrANSBox/  M16  +19           ! Shield door A NS box
/ShldDrBNSTrap/  M16  +18           ! Shield door B NS trapezoid
/ShldDrANSTrap/  M16  +20           ! Shield door A NS trapezoid
/Container/  M0  +25  -11  -3  -7  -8  -10  ! Container
VOLUMES UNITY
end

*
* Unit 5 - Source Geometry for
*
begin source geometry
ZONEMAT
ALL / MATERIAL    1
end

*
* Unit 3 Hole Data
*
begin hole data
* BWR Canister Hole Description v2.0
* Hole  1  General Basket Structure
PLATE
0  0  1
7
451.8660  0      ! Top of Basket
413.1056  -2      ! Top of Highest Support Disk
275.3233  -7      ! Resume support disk only
110.1598  -4      ! Start of support+heat disk region
22.6060  -6      ! Bottom of Lowest Support Disk
0.0000  -3      ! Bottom of Basket
0.0000  3      ! Basket Offset
3

* Hole  2  Top Weldment Disk - no structure above the weldment disk
RZMESH
2       ! number of radial points
82.2198
83.1850
5       ! number of axial intervals
413.1056       ! Top of diskstack
423.1640       ! Bottom of weldment
425.7040       ! Top of weldment plate
444.9861       ! Ullage
450.4690       ! Flange
451.8660       ! Void to top of basket
3  3      ! Material below weldment
11  11      ! Plate Material
3  11      ! Ullage
3  11      ! Flange
```

Figure 6.8-10 (continued)

```
3  3      ! Void to top of basket
3        ! Outside material

* Hole  3  Bottom Weldment Disk - no structure in the weldment disk support
RZMESH
1        ! number of radial points
83.1850
1        ! number of axial intervals
10.1600
12.7000        ! Coordinates inherited from PLATE Hole
11        ! Plate Material
3        ! Outside material

* Hole  4  Support disk and heat transfer disk stack
PLATE
origin  0  0  110.1598  ! Origin
0  0  1
4
cell  9.7155      ! Sets up a repeating lattice of cells
9.7155  3      ! flood matl
6.2865  3      ! water gap
5.0165  12      ! aluminium disk
1.5875  3      ! water gap
10        ! steel disk

* Hole  5  Flood material model
PLATE
0  0  1
1
444.9861  3      ! Above flooded region
3        ! Flooded region

* Hole  6  Support disk stack lower
PLATE
origin  0  0  22.6060  ! Origin
0  0  1
2
cell  9.7282      ! Sets up a repeating lattice of cells
9.7282  3      ! flood matl
1.5875  3      ! water gap
10        ! steel disk

* Hole  7  Support disk stack upper
PLATE
origin  0  0  275.3233  ! Origin
0  0  1
2
cell  9.7282      ! Sets up a repeating lattice of cells
9.7282  3      ! flood matl
1.5875  3      ! water gap
10        ! steel disk

end
```

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7.0 CONFINEMENT

The Universal Storage System Transportable Storage Canister provides confinement for its radioactive contents in long-term storage. The confinement boundary is closed by welding, creating a solid barrier to the release of contents in all of the design basis normal, off-normal and accident conditions. The welds are visually inspected and nondestructively examined to verify integrity. The containment boundary is leaktight as defined by ANSI N 14.5 [1].

The sealed canister contains an inert gas (helium). The confinement boundary retains the helium and also prevents the entry of outside air into the canister in long term storage. The exclusion of air precludes degradation of the fuel rod cladding, over time, due to cladding oxidation failures.

The Universal Storage System canister confinement system meets the requirements of 10 CFR 72.24 for protection of the public from release of radioactive material [2]. It also meets the requirements of 10 CFR 72.122 for protection of the spent fuel contents in long-term storage such that future handling of the contents would not pose an operational safety concern.

7.1 Confinement Boundary

The transportable storage canister provides confinement of the PWR or BWR contents in long-term storage. The welded canister forms the confinement vessel.

The primary confinement boundary of the canister consists of the canister shell, bottom plate, shield lid, the two port covers, and the welds that join these components. A secondary confinement boundary consists of the canister shell, the structural lid, and the welds that join the structural lid and canister shell. The confinement boundaries are shown in Figures 7.1-1 and 7.1-2. There are no bolted closures or mechanical seals in the primary or secondary confinement boundary. The confinement boundary welds are described in Table 7.1-1.

7.1.1 Confinement Vessel

The canister consists of three principal components: the canister shell, the shield lid, and the structural lid. The canister shell is a right circular cylinder constructed of 0.625-inch thick rolled Type 304L stainless steel plate. The edges of the rolled plate are joined using full penetration welds. It is closed at the bottom end by a 1.75-inch thick circular plate joined to the shell by a full penetration weld. The inside and outside diameters of the canister are 65.81 inches and 67.06 inches, respectively. The canister has a length that is variable, depending on the canister class.

The canister is fabricated in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, except for the field installed structural lid and shield lid closure welds [3]. These welds are not full penetration welds, but are inspected either ultrasonically or by using a progressive liquid penetrant examination.

After loading, the canister is closed at the top by a shield lid and a structural lid. The shield lid is a 7-inch-thick Type 304 stainless steel plate. It is joined to the canister shell using a field installed bevel weld. The shield lid contains the drain and vent penetrations and provides gamma radiation shielding for the operators during the welding, draining, drying and inerting operations. After the shield lid is welded in place, the canister is pressure tested and leak tested to ensure leak tightness. Following draining, drying and inerting operations, the vent and drain penetrations are closed with Type 304 stainless steel port covers that are welded in place with bevel welds. The operating procedures, describing the handling steps to close the canister, are presented in Section 8.1.1. The pressure and leak test procedures are described in Section 9.1.

A secondary, or redundant, confinement boundary is formed at the top of the canister by the structural lid, which is placed over the shield lid. The structural lid is a 3-inch thick Type 304L stainless steel plate. The structural lid provides the attachment points for lifting the loaded canister. The structural lid is welded to the shell using a field installed bevel weld.

The weld specifications and the weld examination and acceptance criteria for the shield lid and stuctural lid welds are presented in Sections 7.1.3.2 and 7.1.3.3, respectively.

The confinement boundaries are shown in Figures 7.1-1 and 7.1-2. As illustrated in Figure 7.1-2, the secondary confinement boundary includes the structural lid, the upper 3.2 inches of the canister shell and the joining weld. This boundary provides additional assurance of the leak tightness of the canister during its service life.

7.1.1.1 Design Documents, Codes and Standards

The canister is constructed in accordance with the license drawings presented in Section 1.8. The principal Codes and Standards that apply to the canister design, fabrication and assembly are described in Sections 7.1.1 and 7.1.3, and are shown on the licensing drawings.

7.1.1.2 Technical Requirements for the Canister

The canister confines up to 24 PWR, or 56 BWR, fuel assemblies. Over its 50-year design life, the canister precludes the release of radioactive contents and the entry of air that could potentially damage the cladding of the stored spent fuel. The design of the canister to the requirements of the ASME Code Section III, Subsection NB ensures that the canister maintains confinement in all of the evaluated normal, off-normal, and accident conditions.

The canister has no exposed penetrations, no mechanical closures, and does not employ seals to maintain confinement. There is no requirement for continuous monitoring of the welded closures. The design of the canister allows the recovery of stored spent fuel should it become necessary.

The minimum helium purity level of 99.9% specified in Section 8.1.1 of the Operating Procedures maintains the quantity of oxidizing contaminants to less than one mole per canister for all loading conditions. Based on the calculations presented in Section 4.4.5, the free gas volume of the empty canister yields an inventory of less than 300 moles. Conservatively assuming that all of the impurities in 99.9% pure helium are oxidents, a maximum of 0.3 moles of oxidants could exist in the largest NAC-UMS® canister during storage. By limiting the amount of oxidants to less than one mole, the recommended limits for preventing cladding degradation found in the Pacific Northwest Laboratory, "Evaluation of Cover Gas Impuritities and Their Effects on the Dry Storage of LWR Spent Fuel," PNL-6365 [7] are satisfied.

The design criteria that apply to the canister, as an element of the NAC-UMS® dry storage system, are presented in Table 1.2-1. The design basis parameters of the PWR and BWR spent fuel contents are presented in Section 1.3.

7.1.1.3 Release Rate

The primary confinement boundary is formed by joining the canister confinement boundary stainless steel components by welding. The canister shell longitudinal and girth welds are visually inspected, ultrasonically examined and pressure tested as described in Section 7.1.3.3 to confirm integrity. The shield lid welds are liquid penetrant examined following the root and the final weld passes. The shield lid to canister shell weld is pressure tested as described in Section 7.1.3.3. The structural lid to canister shell multi-pass weld is either: 1) progressively liquid penetrant examined; or 2) ultrasonically examined in conjunction with a liquid penetrant examination of the final weld surface.

To demonstrate leak tightness of the shield lid to canister shell weld, the leaktight criteria of 1×10^{-7} ref cm^3/sec, or 2×10^{-7} cm^3/sec (helium) at standard conditions, as defined in Section 2.1 of ANSI N14.5-1997, is applied. "Standard" conditions are defined as the leak rate at 298K (25°C) with a one atmosphere pressure differential in the test condition. Since helium at approximately 25°C (77°F) is injected into the canister, at the point of the procedure (Section 8.1.1) that the leak test is performed, the actual temperature of the helium is always equal to, or higher than, 25°C due to the decay heat of the contents. This results in a pressure within the canister that is higher than the 0 psig (helium) that is initially established. To ensure that the leak test is conservatively performed, the ANSI N14.5 defined leak rate of 2×10^{-7} cm^3/sec is used. The higher temperature and higher pressure differential that actually exist in the canister, are conservatively ignored. The sensitivity of the leak test is 1×10^{-7} cm^3/sec (helium). Using this criterion, there is no maximum allowable leak rate specified for the canister, and calculation of the radionuclide inventory is not required. The leak test is described in Section 7.1.3.3 and in Section 8.1.1.

These steps provide reasonable assurance that the confinement boundary is leak tight and does not provide a path for the release of any of the content particulates, fission gases, volatiles, corrosion products or fill gases.

7.1.2 Confinement Penetrations

Two penetrations (with quick disconnect fittings) are provided in the canister shield lid for operator use. One penetration is used for draining residual water from the canister. It connects to a drain tube that extends to the bottom of the canister. The other penetration extends only to the underside of the shield lid. It is used to introduce air, or inert gas, into the top of the canister.

Once draining is completed, either penetration may be used for vacuum drying and backfilling with helium. After backfilling, both penetrations are closed with port covers that are welded to the shield lid. When the port covers are in place, the penetrations are not accessible. These port covers are enclosed and covered by the structural lid, which is also welded in place to form the secondary confinement boundary. The structural lid and the remainder of the canister have no penetrations.

7.1.3 Seals and Welds

This section describes the process used to properly assemble the confinement vessel (canister). Weld processes and inspection and acceptance criteria are described in Sections 7.1.3.2 and 7.1.3.3.

No elastomer or metallic seals are used in the confinement boundary of the canister.

7.1.3.1 Fabrication

All cutting, machining, welding, and forming are performed in accordance with Section III, Article NB-4000 of the ASME Code, unless otherwise specified in the approved fabrication drawings and specifications. License drawings are provided in Section 1.8. Code exceptions are listed in Table B3-1 of Appendix B.

7.1.3.2 Welding Specifications

The canister body is assembled using longitudinal and circumferential welds in the shell and a circumferential weld at the bottom plate/ shell juncture.

Weld procedures and qualifications are in accordance with ASME Code Section IX. The welds joining the canister shell are radiographed in accordance with ASME Code Section V, Article 2. The weld joining the bottom plate to the canister shell is ultrasonically examined in accordance with ASME Code Section V, Article 5 [5]. The acceptance criteria for these welds is as specified in ASME Code Section III, NB-5320 (radiographic) and NB-5330 (ultrasonic). The finished surfaces of these welds are liquid penetrant examined in accordance with ASME Code, Section III, NB-5350.

After loading, the canister is closed by the shield lid and the structural lid using field installed groove welds.

After the shield lid is welded in place, the canister is pneumatically (air/nitrogen/helium over water) pressure tested. Following draining, drying and inerting operations, the vent and drain ports are closed with port covers that are welded in place. The root and final surfaces of the shield lid to port cover welds are liquid penetrant examined in accordance with ASME Code Section V, Article 6 for welds requiring multiple passes. For port cover welds completed in a single pass, the final surface is liquid penetrant examined in accordance with the Section V, Article 6 criteria. Acceptance is in accordance with ASME Code Section III, NB-5350. The shield lid to canister shell weld is liquid penetrant examined at the root and final surfaces in accordance with ASME Code Section V, Article 6, with acceptance in accordance with ASME Code Section III, NB-5350, and is pressure and leak tested to ensure leaktightness. The operating procedures, describing the handling steps to seal the canister are presented in Section 8.1.1. The pressure and leak test procedures are described in Sections 8.1.1 and 9.1.3.

A redundant confinement boundary is provided at the top of the canister by the structural lid, which is placed over the shield lid. The structural lid is welded to the canister shell using a field-installed groove weld. The structural lid to canister shell weld is either: 1) ultrasonically examined (UT) in accordance with ASME Code Section V, Article 5, with the final weld surface liquid penetrant (PT) examined in accordance with ASME Code Section V, Article 6; or, 2) progressive liquid penetrant examined in accordance with ASME Code Section V, Article 6. Acceptance criteria are specified in ASME Code Section III, NB-5330 (UT) and NB-5350 (PT).

All welding procedures are written and qualified in accordance with Section IX of the ASME Code. Each welder and welding operator must be qualified in accordance with Section IX of the ASME Code.

7.1.3.3 Testing, Inspection, and Examination

The following tests are performed to ensure satisfactory performance of the confinement vessel:

1. All components are visually examined for conformance with the fabrication drawings.

2. All welds that are directly visible are visually examined in accordance with the requirements of ASME Code Section V, Article 9.

3. The acceptance standards for visual examination of canister welded joints are as specified in ASME Code, Section III, Paragraphs NB-4424 and NB-4427. Unacceptable weld defects are repaired in accordance with ASME Code Section III, Subarticle NB-4450 and visually re-examined.

4. Canister welds designated to be examined by radiographic examination are examined in accordance with the requirements of Section V, Article 2 of the ASME Code. The minimum acceptance standards for radiographic examination are as specified in ASME Code Section III, NB-5320. Welds designated for ultrasonic examinations are examined in accordance with the requirements of Section V, Article 5 of the ASME Code. The minimum acceptance standards for ultrasonic examination are as specified in ASME Code Section III, NB-5330. Unacceptable defects in the welds are repaired in accordance with ASME Code Section III, NB-4450 and re-examined.

5. A written report of each weld examined is prepared. At a minimum, the written report will include: identification of part, material, name and level of examiner, NDE procedure used and the findings or dispositions, if any.

6. All personnel performing nondestructive examinations are qualified in accordance with American Society of Nondestructive Testing Recommended Practice No. SNT-TC-1A [6].

7. Field installed welds shall be inspected by either ultrasonic or liquid penetrant examination methods. For liquid penetrant examination of the shield lid to canister shell weld, the root layer and final surface shall be examined. For liquid penetrant examination of the structural lid to canister shell weld, examination of the root layer, the final weld surface, and each approximately 3/8 inch of intermediate weld depth shall be performed. For welds completed in a single layer (i.e., shield lid vent and drain port cover welds), only the final weld surface is liquid penetrant examined.

8. The results of the structural lid weld liquid penetrant examination final interpretation, as described by ASME Section V, Article 6, T-676, including all relevant indications, are recorded by video, photographic or other means to provide a retrievable record of weld integrity.

9. Individuals qualified for NDT Level I, NDT Level II, or NDT level III may perform nondestructive testing. Only Level II or Level III personnel may interpret the results of an examination or make a determination of the acceptability of examined parts.

10. The vendor completely assembles the canister prior to shipping. The purpose of assembling the canister is to ensure that all items specified have been supplied and to test the fit of the shield lid assembly including the shield lid, drain tube and the structural lid.

11. A pressure test to 35 psia is conducted after welding of the shield lid following loading of the fuel assemblies. The pressure test is performed in accordance with ASME Code, NB-6321.

12. A helium leak test is used to verify that the shield lid welds are leak tight. The canister is pressurized with helium to 0 psig when the canister is closed. A leak test fixture is used to create a volume above the shield lid, which is evacuated. This volume is then tested, using a mass spectrometer type helium leak detector, to verify that the shield lid welds meet the leak tight criteria to a leak test sensitivity of 1×10^{-7} cm^3/sec (helium). The leak test conforms to the evacuated envelope method of ANSI N14.5. As noted in the procedure presented in Section 8.1.1, a "sniffer detector" test method may be used as an optional informational leak test prior to the installation of the vent and drain port covers. This leak test is intended to ensure that there are no leaks in the shield lid welds at a leak rate of 1×10^{-5} cm^3/sec (helium) based on the detector leak rate sensitivity of 5×10^{-6} cm^3/sec (helium).

7.1.4 Closure

The primary closure of the transportable storage canister consists of the welded shield lid and the two welded port covers. There are no bolted closures or mechanical seals in the primary closure. A secondary closure is provided at the top end of the canister by the structural lid. The structural lid, when welded to the canister shell, fully encloses the shield lid and the port covers.

Figure 7.1-1 Transportable Storage Canister Primary and Secondary Confinement Boundaries

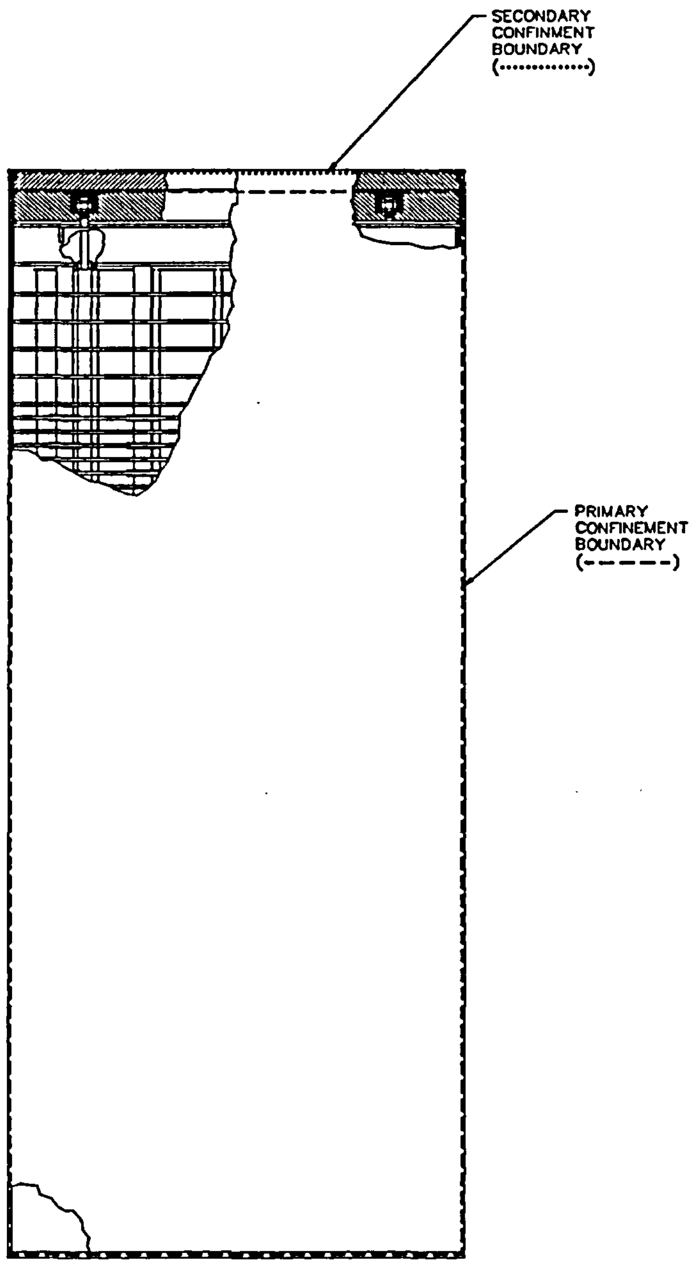

Figure 7.1-2 Confinement Boundary Detail at Shield Lid Penetration

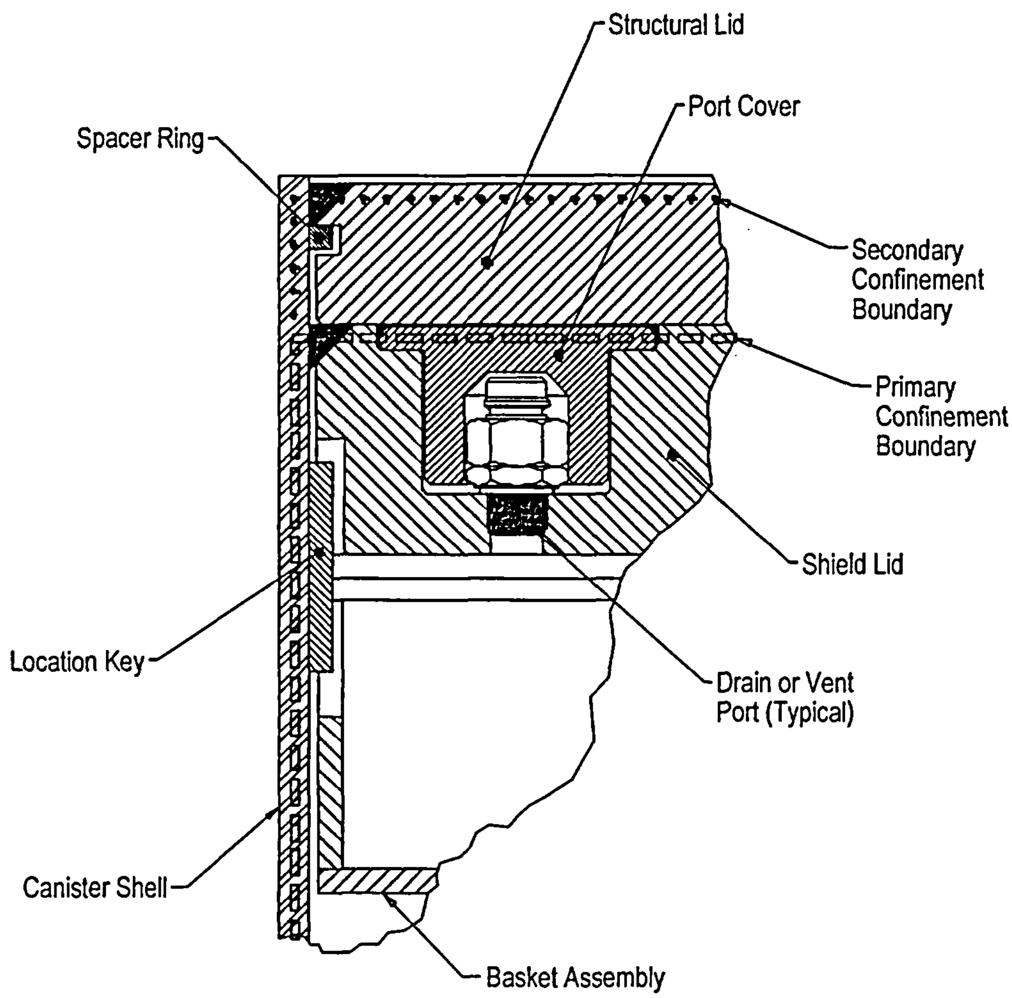

Table 7.1-1 Canister Confinement Boundary Welds

Confinement Boundary Welds		
Weld Location	**Weld Type**	**ASME Code Category (Section III, Subsection NB)**
Shell longitudinal	Full penetration groove (shop weld)	A
Shell circumferential (if used)	Full penetration groove (shop weld)	B
Bottom plate to shell	Full penetration groove (shop weld)	C
Shield lid to shell	Bevel (field weld)	C
Structural lid to shell	Bevel (field weld)	C
Vent and drain port covers to shield lid	Bevel (field weld)	C

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7.2 Requirements for Normal Conditions of Storage

The canister is transferred to a vertical concrete cask using a transfer cask. During this transfer, the canister is subject to handling loads. The evaluation of the canister for normal handling loads is provided in Section 3.4.4. The principal design criteria for the Universal Storage System are provided in Table 2-1.

Once the canister is placed inside of the vertical concrete storage cask, it is effectively protected from direct loading due to natural phenomena, such as wind, snow and ice loading. The principal direct loading for normal operating conditions arises from increased internal pressure caused by decay heat, solar insolation, and ambient temperature. The effect of the normal operating internal pressure is evaluated in Section 3.4.4.

7.2.1 Release of Radioactive Material

The structural analysis of the canister for normal conditions of storage presented in Section 3.4.4 shows that the canister is not breached in any of the normal operating events. Consequently, there is no release of radioactive material during normal conditions of storage.

7.2.2 Pressurization of the Confinement Vessel

The canister is vacuum dried and backfilled with helium at one atmosphere absolute prior to installing and welding the penetration port covers. In normal service, the internal pressure increases due to an increase in temperature of the helium and due to the postulated failure of fuel rod cladding of 3% of the fuel rods, which releases 30% of the available fission gases in those rods.

The canister, shield lid, fittings, and the canister basket are fabricated from materials that do not react with ordinary or borated spent fuel pool water to generate gases. The aluminum heat transfer disks are protected by an oxide film that forms shortly after fabrication. This oxide layer effectively precludes further oxidation of the aluminum components or other reaction with water in the canister at temperatures less than 200°F, which is higher than the typical spent fuel pool water temperature. The neutron absorber criticality control poison plates in the fuel baskets are enclosed by a welded stainless steel cover. No steels requiring protective coatings or paints are used in the PWR configuration canister, shield lid, fittings, or basket, or in the BWR configuration canister, shield lid, or fittings. Carbon steel support disks are used in the BWR configuration basket. These disks are completely coated to protect the disks in immersion in the spent fuel pool, as defined on Drawing 790-573. The consequence of the use of a coating in BWR spent fuel pools is evaluated in Sections 3.4.1.2.3 and 3.4.1.2.4. That evaluation shows that no adverse interactions result from the use of the coating. The coating does not contain Zinc, and no gases are formed as a result of the exposure of this coating to the neutrally buffered water used in BWR spent fuel pools.

Since the canister is vacuum dried and backfilled with helium prior to sealing, no significant moisture or gases, such as air, remain in the canister. Consequently, there is no potential that radiolytic decomposition could cause an increase in canister internal pressure or result in a build up of explosive gases in the canister.

The calculation of the canister pressure increase based on these conditions is less than the pressure evaluated in Section 3.4.4 for the maximum normal operating pressure. As shown in Section 3.4.4, there are no adverse consequences due to the internal pressure resulting from normal storage conditions.

Since the containment boundary is closed by welding and contains no seals or O-rings, and since the boundary is not ruptured or otherwise compromised in normal handling events, no leakage of contents occurs in normal conditions.

7.3 Confinement Requirements for Hypothetical Accident Conditions

The evaluation of the canister for off-normal and accident condition loading is provided in Sections 11.1 and 11.2, respectively.

Once the canister is placed inside the vertical concrete cask, it is effectively protected from direct loading due to natural phenomena, such as seismic events, flooding and tornado (wind driven) missiles. Accident conditions assume the cladding failure of all the fuel rods stored in the canister. Consequently, there is an increase in canister internal pressure due to the release of a fraction of the fission product and charge gases. The accident conditions internal pressure for the PWR and BWR configurations is calculated in Section 11.2.1.

For evaluation purposes, a class of events identified as off-normal is also considered in Section 11.1. The off-normal class of events is not considered here, since off-normal conditions are bounded by the hypothetical accident conditions.

The structural analysis of the canister for off-normal and accident conditions of storage, presented in Chapter 11, show that the canister is not breached in any of the evaluated events. Consequently, based on a leaktight configuration, there is no release of radioactive material during off-normal or accident conditions of storage.

The resulting site boundary dose due to a hypothetical accident is, therefore, less than the 5 rem whole body or organ (including skin) dose at 100 meter minimum boundary required by 10 CFR 72.106 (b) for accident exposures.

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7.4 Confinement Evaluation for Site Specific Spent Fuel

This section presents the confinement evaluation for fuel assembly types or configurations, which are unique to specific reactor sites. Site specific spent fuel configurations result from conditions that occurred during reactor operations, participation in research and development programs, and from testing programs intended to improve reactor operations. Site specific fuel includes fuel assemblies that are uniquely designed to accommodate reactor physics, such as axial fuel blanket and variable enrichment assemblies, and fuel rod or assemblies that are classified as damaged.

The design of the Transportable Storage Canister incorporates a leak tight configuration as described in Section 7.1 and as defined by ANSI N 14.5. Consequently, site specific fuel configurations need be evaluated only if the configuration results in a modification of the confinement boundary of the canister that is intended for use or when the configuration could result in a higher internal pressure or temperature than is used in the design basis analysis.

7.4.1 Confinement Evaluation for Maine Yankee Site Specific Spent Fuel

Maine Yankee site specific spent fuel is to be stored in either the Class 1 or Class 2 Transportable Storage Canister, depending on the overall length of the fuel assembly, including inserted non fuel-bearing components. These canisters are closed by welding and are inspected and tested to confirm the leak tight condition.

Site specific fuel includes fuel having variable enrichment radial zoning patterns and annular axial fuel blankets, removed fuel rods or empty rod positions, fuel rods placed in guide tubes, consolidated fuel, damaged fuel, and high burnup fuel (fuel with a burnup between 45,000 MWD/MTU and 50,000 MWD/MTU). These configurations are not included in the standard fuel analysis, but are present in the site fuel inventory that must be stored. As discussed in Section 4.5.1, the site specific fuel configurations do not result in a canister pressure or temperature that exceeds the canister design basis. Since the canisters are leak tight, there is no release from a canister containing Maine Yankee high burnup fuel rods site-specific spent fuel.

Intact site specific fuel is loaded directly into the fuel tubes in the PWR basket. Damaged fuel is inserted into one of the two configurations of the Maine Yankee Fuel Can, shown in Drawings 412-501 and 412-502, which precludes the release of gross particulate material from the fuel can. The fuel can is sized to allow its insertion into a fuel position in the PWR basket.

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7.5 References

1. ANSI N14.5-1997, "American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment," American National Standards Institute, 1997.

2. Title 10 of the Code of Federal Regulations, Part 72 (10 CFR 72), "Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation," April 1996 Edition.

3. ASME Boiler and Pressure Vessel Code, Section III, Division I, "Rules for Construction of Nuclear Power Plant Components," 1995 Edition with 1997 Addenda.

4. ASME Boiler and Pressure Vessel Code, Section IX, "Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators," 1995 Edition with 1997 Addenda.

5. ASME Boiler and Pressure Vessel Code, Section V, "Nondestructive Examination," 1995 Edition with 1997 Addenda.

6. Recommended Practice No. SNT-TC-1A, "Personnel Qualification and Certification in Nondestructive Testing," The American Society for Nondestructive Testing, Inc., edition as invoked by the applicable ASME Code.

7. PNL-6365, "Evaluation of Cover Gas Impuritities and Their Effects on the Dry Storage of LWR Spent Fuel," Pacific Northwest Laboratory, Richland, Washington, November, 1987.

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8.0 OPERATING PROCEDURES

This chapter provides general guidance for operating the Universal Storage System. Three operating conditions are addressed. The first is loading the transportable storage canister, installing it in the vertical concrete cask, and transferring it to the storage (Independent Spent Fuel Storage Installation (ISFSI)) pad. The second is the removal of the loaded canister from the concrete storage cask. The third is opening the canister to remove spent fuel in the unlikely event that this should be necessary.

The operating procedure for transferring a loaded canister from a storage cask to the Universal Transport Cask, is described in Section 7.2.2 of the UMS® Universal Transport Cask Safety Analysis Report. [1]

Users shall develop written and approved site-specific procedures that implement the operational sequences presented in the procedures in this chapter. These procedures present the general guidance for operations and the establishment of the process in which Technical Specification limits and requirements presented in Appendix A of Certificate of Compliance No. 72-1015 are met. The procedures provide the guidance and basis for the development and implementation of more detailed site-specific operating and test procedures required of the NAC-UMS® Storage System user. A departure from the specific way in which a given operational activity is performed may result from variations in specific site equipment or operational philosophy. Site-specific procedures shall also incorporate site-specific Technical Specifications, surveillance requirements, administrative controls, and other limits appropriate to the use of the NAC-UMS® Storage System to ensure that system/component design function is maintained. The user's site-specific procedures shall incorporate spent fuel assembly selection and verification requirements to ensure that the spent fuel assemblies loaded into the UMS® Storage System are as authorized by the Approved Contents and Design Features presented in Appendix B of the Amendment 3 Technical Specifications and the Certificate of Compliance.

Operation of the Universal Storage System requires the use of ancillary equipment items. The ancillary equipment supplied with the system is shown in Table 8.1.1-1. The system does not rely on the use of bolted closures, but bolts are used to secure retaining rings and lids. The hoist rings used for lifting the shield lid and canister have threaded fittings. Table 8.1.1-2 provides the torque values for installed bolts and hoist rings. Supplemental shielding may be employed to reduce radiation exposure for certain of the tasks specified by these procedures. Use of supplemental shielding is at the discretion of the User.

The design of the Universal Storage System is such that the potential for spread of contamination during handling and future transport of the canister is minimized. The transportable storage canister is loaded in the spent fuel pool but is protected from gross contact with pool water by a jacket of clean or filtered pool water while it is in the transfer cask. Clean water is processed or filtered pool water, or any water external to the spent fuel pool that has a water chemistry that is compatible with use in the pool. Only the top of the open canister is exposed to contaminated pool water. The top of the canister is closed by the structural lid, which is not contaminated when it is installed. Consequently, the canister external surface is expected to be essentially free of contamination. There are no radioactive effluents from the canister or the concrete cask in routine operations or in the design basis accident events.

When used in accordance with these procedures, the user dose is As Low As Reasonably Achievable (ALARA).

A training program is described in Section A 5.0 of Appendix A of the Amendment 3 Technical Specifications, that is intended to assist the User in complying with the training and dry run requirements of 10 CFR 72. This program addresses the controls and limits applicable to the UMS® Storage System. It also addresses the system operational features and requirements.

8.1 Procedures For Loading the Universal Storage System

The Universal Storage System consists of three principal components: the transportable storage canister (canister), the transfer cask, and the vertical concrete cask. The transfer cask is used to hold the canister during loading and while the canister is being closed and sealed. The transfer cask is also used to transfer the canister to the concrete cask and to load the canister into the transport cask. The principal handling operations involve closing and sealing the canister by welding, and placing the loaded canister in the vertical concrete cask. The typical vent and drain port locations are shown in Figure 8.1.1-1.

The transfer cask is provided in either the Standard or Advanced configuration that weigh approximately 121,500 pounds each, depending on Class. Canister handling, fuel loading and canister closing are operationally identical for either transfer cask configuration. Either transfer cask can accommodate an extension fixture to allow the use of the next longer length canister.

This procedure assumes that the canister with an empty basket is installed in the transfer cask, that the transfer cask is positioned in the decontamination area or other suitable work station, and that the vertical concrete cask is positioned in the plant cask receiving area or other suitable staging area. The transfer cask extension must be installed on the transfer cask if its use is required. To facilitate movement of the transfer cask to the concrete cask, the staging area should be within the operational "footprint" of the cask handling crane. The concrete cask may be positioned on a heavy-haul transporter, or on the floor of the work area.

The User must ensure that the fuel assemblies selected for loading conform to the Approved Contents provisions of Section B2.0 of Appendix B of the Amendment 3 Technical Specifications. Fuel assembly loading may also be administratively controlled to ensure that fuel assemblies with specific characteristics are preferentially loaded in specified positions in the canister. Preferential loading requirements are described in Section B2.1.2 of Appendix B of the Amendment 3 Technical Specifications.

Certain steps of the procedures in this section may be completed out of sequence to allow for operational efficiency. Changing the order of these steps, within the intent of the procedures, has no effect on the safety of the canister loading process and does not violate any requirements stated in the Technical Specifications. These steps include the placement and installation of air pads and the sequence and use of an annulus fill system, including optional seals and/or foreign material exclusion devices.

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8.1.1 Loading and Closing the Transportable Storage Canister

1. Visually inspect the basket fuel tubes to ensure that they are unobstructed and free of debris. Ensure that the welding zones on the canister, shield, and structural lids, and the port covers are prepared for welding. Ensure transfer cask door lock bolts/lock pins are installed and secure.
2. Fill the canister with clean water until the water is about 4 inches from the top of the canister.

   Note: Do not fill the canister completely in order to avoid spilling water during the transfer to the spent fuel pool.

   Note: If fuel loading requires boron credit, the minimum boron concentration of the water in the canister must be at least 1,000 ppm (boron), in accordance with LCO 3.3.1.
3. Install the annulus fill system to transfer cask, including the clean water lines.
4. If it is not already attached, attach the transfer cask lifting yoke to the cask handling crane, and engage the transfer cask lifting trunnions.

   Note: The minimum temperature of the transfer cask (i.e., surrounding air temperature) must be verified to be higher than 0°F prior to lifting, in accordance with Section B3.4.1 (8) of Appendix B of the Amendment 3 Technical Specifications.
5. Raise the transfer cask and move it over the pool, following the prescribed travel path.
6. Lower the transfer cask to the pool surface and turn on the clean water line to fill the canister and the annulus between the transfer cask and canister.
7. Lower the transfer cask as the annulus fills with clean water until the trunnions are at the surface, and hold that position until the clean water overflows through the upper fill lines or annulus of the transfer cask. Then lower the transfer cask to the bottom of the pool cask loading area.

   Note: If an intermediate shelf is used to avoid wetting the cask handling crane hook, follow the plant procedure for use of the crane lift extension piece.
8. Disengage the transfer cask lifting yoke to provide clear access to the canister.
9. Load the previously designated fuel assemblies into the canister.

   Note: Contents must be in accordance with the Approved Contents provisions of Section B2.0 of Appendix B of the Amendment 3 Technical Specifications.

   Note: Contents shall be administratively controlled to ensure that fuel assemblies with certain characteristics are preferentially loaded in specified positions in the basket. Preferential loading requirements are presented in Section B2.1.2 of Appendix B of the Amendment 3 Technical Specifications.

10. Attach a three-legged sling to the shield lid using the swivel hoist rings. Torque hoist rings in accordance with Table 8.1-2. Attach the suction pump fitting to the vent port.

    Caution: Verify that the hoist rings are fully seated against the shield lid.

    Note: Ensure that the shield lid key slot aligns with the key welded to the canister shell.

11. Using the cask handling crane, or auxiliary hook, lower the shield lid until it rests in the top of the canister.

12. Raise the transfer cask until its top just clears the pool surface. Hold at that position, and using a suction pump, drain the pool water from above the shield lid. After the water is removed, continue to raise the cask. Note the time that the transfer cask is removed from the pool. Operations through Step 28 must be completed in accordance with the time limits presented in Table 8.1.1-3.

    Note: Alternately, the temperature of the water in the canister may be used to establish the time for completion through Step 28. Those operations must be completed within 2 hours of the time that the canister water temperature is 200°F. For this alternative, the water temperature must be determined every 2 hours beginning 17 hours after the time the transfer cask is removed from the pool.

    Note: As an alternative, some sites may choose to perform welding operations for closure of the canister in a cask loading pit with water around the canister (below the trunnions) and in the annulus. This alternative provides additional shielding during the closure operation.

13. As the cask is raised, spray the transfer cask outer surface with clean water to wash off any gross contamination.

14. When the transfer cask is clear of the pool surface, but still over the pool, turn off the clean water flow to the annulus, remove hoses and allow the annulus water to drain to the pool. Move the transfer cask to the decontamination area or other suitable work station.

    Note: Access to the top of the transfer cask is required. A suitable work platform may need to be erected.

15. Verify that the shield lid is level and centered.

16. Attach the suction pump to the suction pump fitting on the vent port. Operate the suction pump to remove free water from the shield lid surface. Disconnect the suction pump and suction pump fitting. Remove any free standing water from the shield lid surface and from the vent and drain ports.

17. Decontaminate the top of the transfer cask and shield lid as required to allow welding and inspection activities.

    Note: Supplemental shielding may be used for activities around the shield lid.

18. Insert the drain tube assembly with a female quick-disconnect attached through the drain port of the shield lid into the basket drain tube sleeve. Remove the female quick-disconnect. Torque the drain tube assembly by hand until metal-to-metal contact is achieved; then torque to 135 ± 15 ft-lbs for Furon metal seals or 115 ± 5 ft-lbs for elastomer seals (EPDM or Viton). Install a quick-disconnect in the vent port.
19. Connect the suction pump to the drain port. Verify that the vent port is open. Remove approximately 70 gallons of water from the canister. Disconnect and remove the pump.
    Caution: Radiation level may increase as water is removed from the canister.
20. Install the automatic welding equipment, including the supplemental shield plate.
21. Attach the hydrogen gas detector to the vent port. Verify that the concentration of any detectable hydrogen gas is below 2.4%.
    Note: If the concentration exceeds 2.4%, connect and operate the vacuum system to remove gases from the underside of the shield lid and re-verify the hydrogen gas concentration. Disconnect and remove vacuum system.
22. Operate the welding equipment to complete the root weld joining the shield lid to the canister shell following approved procedures. Remove the hydrogen detector from the vent tube. Leave the connector and vent tube installed to vent the canister.
23. Examine the root weld using liquid penetrant and record the results.
24. Complete welding of the shield lid to the canister shell.
25. Liquid penetrant examine the final weld surface and record the results.
26. Attach a regulated air, nitrogen or helium supply line to the vent port. Install a fitting on the drain port. Pressurize the canister to 35 psia and hold the pressure. There must be no loss of pressure for a minimum of 10 minutes.
27. Release the pressure.
    Note: As an option, an informational helium leak test may be conducted at this point using the following steps (the record leak test is performed at Step 49).
    27a. Evacuate and backfill the canister with helium having a minimum purity of 99.9% to a pressure of 18.0 psia.
    27b. Using a helium leak detector ("sniffer" detector) with a test sensitivity of 5×10^{-5} cm^3/sec (helium), survey the weld joining the shield lid and canister shell.
    27c. At the completion of the survey, vent the canister helium pressure to one atmosphere (0 psig).
28. Drain the canister.
    Drain the remaining water from the canister cavity. Draining of the canister may be performed by suction, by a blow-down gas pressure of 15-18 psig, or by a combination of

suction and a blow-down gas pressure of 15-18 psig. After removal of the water from the canister, disconnect the equipment from the canister. Note the time that the last free water is removed from the canister cavity. If not already installed, install a quick-disconnect to the open vent port.

Caution: Radiation levels at the top and sides of the transfer cask will rise as water is removed.

Note: The time duration from completion of draining the canister through completion of vacuum dryness testing and the introduction of helium backfill (Step 34) shall be monitored in accordance with LCO 3.1.1.

29. Attach the vacuum equipment to the vent and drain ports. Dry any free standing water in the vent and drain port recesses.
30. Operate the vacuum equipment until a vacuum of ≤3 mm of mercury exists in the canister.
31. Verify that no water remains in the canister by holding the vacuum of ≤3 mm of mercury for a minimum of 30 minutes. If water is present in the cavity, the pressure will rise as the water vaporizes. Continue the vacuum/hold cycle until the conditions of LCO 3.1.2 are met.
32. Backfill the canister cavity with helium having a minimum purity of 99.9% to a pressure of one atmosphere (0 psig).
33. Restart the vacuum equipment and operate until a vacuum of 3 mm of mercury exists in the canister.
34. Backfill the canister with helium having a minimum purity of 99.9% to a pressure of one atmosphere (0 psig).

    Note: Canister helium backfill pressure must conform to the requirements of LCO 3.1.3.

    Note: Monitor the time from this step (completion of helium backfill) until completion of canister transfer to the concrete cask in accordance with LCO 3.1.4.
35. Disconnect the vacuum and helium supply lines from the vent and drain ports. Dry any residual water that may be present in the vent and drain port cavities.
36. Install the vent and drain port covers.
37. Complete the root pass weld of the drain port cover to the shield lid.

    Note: If the drain port cover weld is completed in a single pass, the weld final surface is liquid penetrant inspected in accordance with Step 40.
38. Prepare the weld and perform a liquid penetrant examination of the root pass. Record the results.
39. Complete welding of the drain port cover to the shield lid.
40. Prepare the weld and perform a liquid penetrant examination of the drain port cover weld final pass. Record the results.

41. Complete the root pass weld of the vent port cover to the shield lid.

    Note: If the drain port cover weld is completed in a single pass, the weld final surface is liquid penetrant inspected in accordance with Step 44.

42. Prepare the weld and perform a liquid penetrant examination of the root pass. Record the results.

43. Complete welding of the vent port cover to the shield lid.

44. Prepare the weld and perform a liquid penetrant examination of the weld final surface. Record the results.

45. Remove the welding machine and any supplemental shielding used during shield lid closure activities.

46. Install the helium leak test fixture.

47. Attach the vacuum line and leak detector to the leak test fixture fitting.

48. Operate the vacuum system to establish a vacuum in the leak test fixture.

49. Operate the helium leak detector to verify that there is no indication of a helium leak exceeding 2×10^{-7} cm^3/second, at a minimum test sensitivity of 1×10^{-7} cm^3/second helium, in accordance with the requirements of LCO 3.1.5.

50. Release the vacuum and disconnect the vacuum and leak detector lines from the fixture.

51. Remove the leak test fixture.

52. Attach a three-legged sling to the structural lid using the swivel hoist rings.

    Caution: Ensure that the hoist rings are fully seated against the structural lid. Torque the hoist rings in accordance with Table 8.1.1-2. Verify that the spacer ring is in place on the structural lid.

    Note: Verify that the structural lid is stamped or otherwise marked to provide traceability of the canister contents.

53. Using the cask handling crane or the auxiliary hook, install the structural lid in the top of the canister. Verify that the structural lid is flush with, or protrudes slightly above, the canister shell. Verify that the gap in the spacer ring is not aligned with the shield lid alignment key. Remove the hoist rings.

54. Install the automatic welding equipment on the structural lid including the supplemental shield plate.

55. Operate the welding equipment to complete the root weld joining the structural lid to the canister shell.

56. Prepare the weld and perform a liquid penetrant examination of the weld root pass. Record the results.

57. Continue with the welding procedure, examining the weld at 3/8-inch intervals using liquid penetrant. Record the results of each intermediate and the final examination.

Note: If ultrasonic testing of the weld is used, testing is performed after the weld is completed.

58. Remove the weld equipment and supplemental shielding.
59. Perform a smear survey of the accessible area at the top of the canister to ensure that the surface contamination is less than the limits established for the site. Smear survey results shall meet the requirements of Technical Specification LCO 3.2.1.
60. Install the transfer cask retaining ring. Torque bolts to 155 ± 10 ft-lbs. (Table 8.1.1-2).
61. Decontaminate the external surface of the transfer cask to the limits established for the site.

Figure 8.1.1-1 Typical Vent and Drain Port Locations

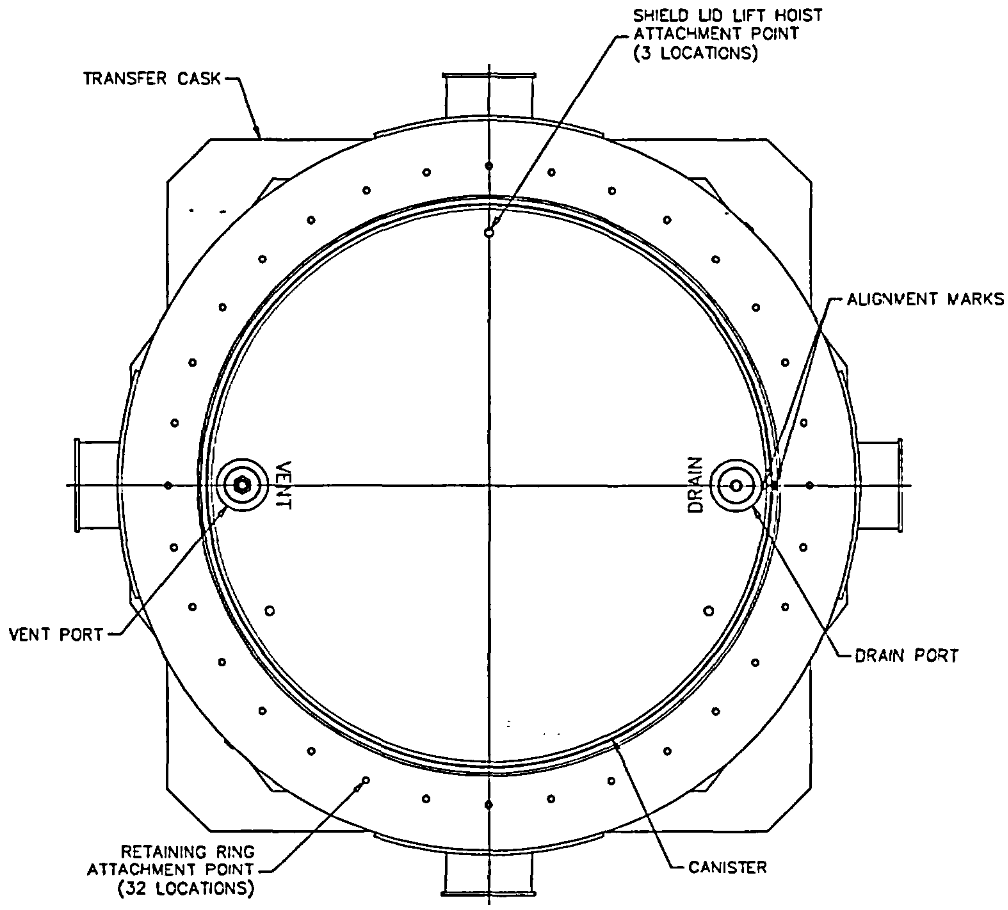


Table 8.1.1-1 List of Principal Ancillary Equipment

Item	Description
Transfer Cask Lifting Yoke	Required for lifting and moving the transfer cask.
Heavy-Haul Transporter (Optional)	Heavy-haul (double drop frame) trailer required for moving the loaded and empty vertical concrete cask to and from the ISFSI pad.
Mobile Lifting Frame (Optional)	A self-propelled or towed A-frame lifting device for the concrete cask. Mobile Lifting Frame is used to lift the cask and move it using two lifting lugs in the top of the concrete cask.
Helium Supply System	Supplies helium to the canister for helium backfill and purging operations.
Vacuum Drying System	Used for evacuating the canister. Used to remove residual water, air and initial helium backfill.
Automated Welding System	Used for welding the shield lid and structural lid to the canister shell.
Self-Priming Pump	Used to remove water from the canister.
Shield Lid Sling	A three-legged sling used for lifting the shield lid. It is also used to lift the concrete cask shield plug and lid.
Canister Sling	A set of 2 three-legged slings used for lifting the structural lid by itself, or for lifting the canister when the structural lid is welded to it. The slings are configured to provide for simultaneous loading during the canister lift.
Transfer Adapter	Used to align the transfer cask to the vertical concrete cask or the Universal Transport Cask. Provides the platform for the operation of the transfer cask shield doors.
Transfer Cask Extension	A carbon steel ring used to extend the height of the transfer cask when using the next longer size canister.
Hydraulic Unit	Operates the shield doors of the transfer cask.
Lift Pump Unit	Jacking system for raising and lowering the concrete cask.
Air Pad Rig Set	Air cushion system used for moving the concrete cask.
Supplemental Shielding Fixture	An optional carbon steel fixture inserted in the Vertical Concrete Cask air inlets to reduce radiation dose rates at the inlets.

Table 8.1.1-2 Torque Values

Fastener	Torque Value (ft-lbs)	Torque Pattern
Transfer Adapter Bolts (Optional)	40 ± 5	None
Transfer Cask Retaining Ring	155 ±10	0°, 180°, 270° and 90° in two passes
Transfer Cask Extension	155 ±10	None
Vertical Concrete Cask Lid	40 ± 5	None
Lifting Hoist Rings – Canister Structural Lid Lid Only Loaded Canister	 Hand Tight 800 +80, -0	None
Canister Lid Plug Bolts Shield Lid Plug Bolts	Hand Tight Hand Tight	None None
Transfer Cask Door Lock Bolts	Hand Tight	None
Canister Drain Tube	135 ± 15 (Furon metal seals) or 115 ± 5 (elastomer seals, EPDM or Viton)	None

Table 8.1.1-3 Handling Time Limits Based on Decay Heat Load with Canister Full of Water

Total Heat Load (L) (kW)	**PWR Time Limit (Hours)**	**BWR Time Limit (Hours)**
20.0 < L ≤ 23.0	17	17
17.6 < L ≤ 20.0	18	17
14.0 < L ≤ 17.6	20	17
11.0 < L ≤ 14.0	22	17
8.0 < L ≤ 11.0	24	17
L ≤ 8.0	26	17

8.1.2 Loading the Vertical Concrete Cask

This section of the loading procedure assumes that the vertical concrete cask is located on the bed of a heavy-haul transporter, or on the floor of the work area, under a crane suitable for lifting the loaded transfer cask. The vertical concrete cask shield plug and lid are not in place, and the bottom pedestal plate cover is installed.

1. Using a suitable crane, place the transfer adapter on the top of the concrete cask.
2. If using the transfer adapter bolt hole pattern for alignment, align the adapter to the concrete cask. Bolt the adapter to the cask using four (4) socket head cap screws. (Note: Bolting of the transfer adapter to the cask is optional.)
3. Verify that the shield door connectors on the adapter plate are in the fully extended position.
   Note: Steps 4 through 6 may be performed in any order, as long as all items are completed.
4. If not already done, attach the transfer cask lifting yoke to the cask handling crane. Verify that the transfer cask retaining ring is installed.
5. Install six (6) swivel hoist rings in the structural lid of the canister and torque to the value specified in Table 8.1.1-2. Attach two (2) three-legged slings to the hoist rings.
   Caution: Ensure that the hoist rings are fully seated against the structural lid.
6. Stack the slings on the top of the canister so they are available for use in lowering the canister into the storage cask.
7. Engage the transfer cask trunnions with the transfer cask lifting yoke. Ensure that all lines are disconnected from the transfer cask.
   Note: The minimum temperature of the transfer cask (i.e., temperature of the surrounding air) must be verified to be higher than 0°F prior to lifting, in accordance with Section B 3.4.1(8) of Appendix B of the Amendment 3 Technical Specifications.
   Note: Verify that the transfer cask extension is installed if required.
8. Raise the transfer cask and move it over the concrete cask. Lower the transfer cask, ensuring that the transfer cask shield door rails and connector tees align with the adapter plate rails and door connectors. Prior to final set down, remove transfer cask shield door lock bolts/lock pins (there is a minimum of one per door), or the door stop, as appropriate.
9. Ensure that the shield door connector tees are engaged with the adapter plate door connectors.
10 Disengage the transfer cask yoke from the transfer cask and from the cask handling crane hook.

11. Return the cask handling crane hook to the top of the transfer cask and engage the two (2) three-legged slings attached to the canister.
    Caution: The top connection of the three-legged slings must be at least 75 inches above the top of the canister.
12. Lift the canister slightly (about ½ inch) to take the canister weight off of the transfer cask shield doors.
    Note: A load cell may be used to determine when the canister is supported by the crane.
    Caution: Avoid raising the canister to the point that the canister top engages the transfer cask retaining ring, as this could result in lifting the transfer cask.
13. Using the hydraulic system, open the shield doors to access the concrete cask cavity.
14. Lower the canister into the concrete cask, using a slow crane speed as the canister nears the pedestal at the base of the concrete cask.
15. When the canister is properly seated, disconnect the slings from the canister at the crane hook, and close the transfer cask shield doors.
16. Retrieve the transfer cask lifting yoke and attach the yoke to the transfer cask.
17. Lift the transfer cask off of the vertical concrete cask and return it to the decontamination area or designated work station.
    Note: Ensure that the canister is located within the boundary of the support ring.
18. Using the auxiliary crane, remove the adapter plate from the top of the concrete cask.
19. Remove the swivel hoist rings from the structural lid and replace them with threaded plugs.
20. Install three swivel hoist rings in the shield plug and torque in accordance with Table 8.1.1-2.
21. Using the auxiliary crane, retrieve the shield plug and install the shield plug in the top of the concrete cask. Remove swivel hoist rings.
22. Install seal tape around the diameter of the lid bolting pattern on the concrete cask flange.
23. Using the auxiliary crane, retrieve the concrete cask lid and install the lid in the top of the concrete cask. Secure the lid using six stainless steel bolts. Torque bolts in accordance with Table 8.1.1-2.
24. Ensure that there is no foreign material left at the top of the concrete cask. Install the tamper-indicating seal.
25. If used, install a supplemental shielding fixture in each of the four inlets. Note: The supplemental shielding fixtures may also be shop installed.

8.1.3 Transport and Placement of the Vertical Concrete Cask

This procedure assumes that the loaded vertical concrete cask is positioned on a heavy-haul transporter and is to be positioned on the ISFSI pad using the air pad set. Alternately, the concrete cask may be lifted and moved using a mobile lifting frame. The mobile lifting frame lifts the cask using four lifting lugs at the top of the concrete cask. The lifting frame may be self-propelled or towed, and does not use the air pad set.

The vertical concrete cask lift height limit is 24 inches when the cask is moved using the air pad set or the mobile lifting frame in accordance with the requirements of Section A5.6(c) and Table A5-1 of Appendix A of the Amendment 3 Technical Specifications. Because of lift fixture configuration, the maximum lift height of the concrete cask using the jacking arrangement is approximately 4 inches.

The concrete cask surface dose rates must be verified in accordance with the requirements of LCO 3.2.2. These measurements may be made prior to movement of the cask, at a location along the transport path, or at the ISFSI. An optional supplemental shielding fixture, shown in Drawing 790-613, may be installed in the concrete cask air inlets to reduce the radiation dose rate at the inlets.

1. Using a suitable towing vehicle, tow the heavy-haul transporter to the dry storage pad (ISFSI). Verify that the bed of the transporter is approximately at the same height as the pad surface. Install four (4) hydraulic jacks at the four (4) designated jacking points at the air inlets in the bottom of the vertical concrete cask.
2. Raise the concrete cask approximately 4 inches using the hydraulic jacks.
   Caution: Do not exceed a maximum lift height of 24 inches, in accordance with the requirements of Administrative Control A5.6(c).
3. Move the air-bearing rig set under the cask.
4. Inflate the air-bearing rig set. Remove the four (4) hydraulic jacks.
5. Using a suitable towing vehicle, move the concrete cask from the bed of the transporter to the designated location on the storage pad.
   Note: Spacing between concrete casks must not be less than 15 feet (center-to-center).
6. Turn off the air-bearing rig set, allowing it to deflate.

7. Reinstall the four (4) hydraulic jacks and raise the concrete cask approximately 4 inches. Caution: Do not exceed a maximum lift height of 24 inches, in accordance with the requirements of Administrative Control A5.6(c).
8. Remove the air-bearing rig set pads. Ensure that the surface of the dry storage pad under the concrete cask is free of foreign objects.
9. Lower the concrete cask to the surface and remove the four (4) hydraulic jacks.
10. Install the screens in the inlets and outlets.
11. Install/connect temperature monitoring equipment and verify operation in accordance with LCO 3.1.6.
12. Scribe/stamp concrete cask name plate to indicate loading information.

8.2 Removal of the Loaded Transportable Storage Canister from the Vertical Concrete Cask

Removal of the loaded canister from the vertical concrete cask is expected to occur at the time of shipment of the canistered fuel off site. Alternately, removal could be required in the unlikely event of an accident condition that rendered the concrete cask or canister unsuitable for continued long-term storage or for transport. This procedure assumes that the concrete cask is being returned to the reactor cask receiving area. However, the cask may be moved to another facility or area using the same operations. It identifies the general steps to return the loaded canister to the transfer cask and return the transfer cask to the decontamination station, or other designated work. area or facility. Since these steps are the reverse of those undertaken to place the canister in the concrete cask, as described in Section 8.1.2, they are only summarized here.

The concrete cask may be moved using the air pad set or a mobile lifting frame. This procedure assumes the use of the air pad set. If a lifting frame is used, the concrete cask is lifted using four lifting lugs in the top of the cask, and the air pad set and heavy haul transporter are not required. The mobile lifting frame may be self-powered or towed.

At the option of the user, the canister may be removed from the concrete cask and transferred to another concrete cask or to the Universal Transport Cask at the ISFSI site. This transfer is done using the transfer cask, which provides shielding for the canister contents during the transfer.

Certain steps of the procedures in this section may be completed out of sequence to allow for operational efficiency. Changing the order of these steps, within the intent of the procedures, has no effect on the safety of the canister loading process and does not violate any requirements stated in the Technical Specifications or the NAC-UMS® FSAR. This includes the placement and installation of the air pads.

1. Remove the screens and instrumentation.
2. Using the hydraulic jacking system and the air pad set, move the concrete cask from the ISFSI pad to the heavy-haul transporter. The bed of the transporter must be approximately level with the surface of the pad and sheet metal plates are placed across the gap between the pad and the transporter bed.

   Caution: Do not exceed a maximum lift height of 24 inches when raising the concrete cask.
3. Tow the transporter to the cask receiving area or other designated work area or facility.

4. Remove the concrete cask shield plug and lid. Install the hoist rings in the canister structural lid and torque to the value specified in Table 8.1.1-2. Verify that the hoist rings are fully seated against the structural lid and attach the lift slings. Install the transfer adapter on the top of the concrete cask.
5. Retrieve the transfer cask with the retaining ring installed, and position it on the transfer adapter. Attach the shield door hydraulic cylinders.

   Note: The surrounding air temperature for cask unloading operations shall be ≥ 0°F.
6. Open the shield doors. Attach the canister lift slings to the cask handling crane hook.

   Caution: The attachment point of the two three-legged slings must be at least 75 inches above the top of the canister.
7. Raise the canister into the transfer cask.

   Caution: Avoid raising the canister to the point that the canister top engages the transfer cask retaining ring, as this could result in lifting the transfer cask.
8. Close the shield doors. Lower the canister to rest on the shield doors. Disconnect the canister slings from the crane hook. Install and secure door lock bolts/lock pins.
9. Retrieve the transfer cask lifting yoke. Engage the transfer cask trunnions and move the transfer cask to the decontamination area or designated work station.

After the transfer cask containing the canister is in the decontamination area or other suitable work station, additional operations may be performed on the canister. It may be opened, transferred to another storage cask, or placed in the Universal Transport Cask.

8.3 Unloading the Transportable Storage Canister

This section describes the basic operations required to open the sealed canister if circumstances arise that dictate the opening of a previously loaded canister and the removal of the stored spent fuel. It is assumed that the canister is positioned in the transfer cask and that the transfer cask is in the decontamination station or other suitable work station in the facility. The principal mechanical operations are the cutting of the closure welds, filling the canister with water, cooling the fuel contents, and removing the spent fuel. Supplemental shielding is used as required. The time duration for holding the canister in the transfer cask shall not exceed 4 hours without forced air cooling. Once forced air cooling is initiated, the amount of time that the canister may be in the transfer cask is not limited. The canister cooling water temperature, flow rate and pressure must be limited in accordance with this procedure.

Certain steps of the procedures in this section may be completed out of sequence to allow for operational efficiency. Changing the order of these steps, within the intent of the procedures, has no effect on the safety of the canister loading process and does not violate any requirements stated in the Technical Specifications of the NAC-UMS® Storage FSAR. This includes the sequence and use of an annulus fill system including optional seals and/or foreign material exclusion devices.

1. Remove the transfer cask retaining ring.
2. Survey the top of the canister to establish the radiation level and contamination level at the structural lid.
3. Set up the weld cutting equipment to cut the structural lid weld (Abrasive grinding, hydrolaser, or similar cutting equipment).
4. Enclose the top of the transfer cask in a radioactive material retention tent, as required.
   Caution: Monitor for any out-gassing. Wear respiratory protection as required.
5. Operate the cutting equipment to cut the structural lid weld.
6. After proper monitoring, remove the retention tent. Remove the cutting equipment and attach a three-legged sling to the structural lid.
7. Using the auxiliary crane, lift the structural lid from the canister and out of the transfer cask.
8. Survey the top of the shield lid to determine radiation and contamination levels. Use supplemental shielding as necessary. Decontaminate the top of the shield lid, if necessary.
9. Reinstall the retention tent. Using an abrasive grinder or hydrolaser, or other appropriate cutting equipment excluding open flame, and wearing suitable respiratory protection if required, cut the welds joining the vent and drain port covers to the shield lid.
   Caution: The canister could be pressurized.

10. Remove the port covers. Monitor for any out-gassing and survey the radiation level at the quick-disconnect fittings.
11. Attach a nitrogen gas line to the drain port quick-disconnect and a discharge line from the vent port quick-disconnect to an off-gas handling system in accordance with the schematic shown in Figure 8.3-1. Set up the vent line with appropriate instruments so that the pressure in the discharge line and the temperature of the discharge gas are indicated. Continuously monitor the radiation level of the discharge line.

    Caution: The discharge gas temperature could initially be above 400°F. The discharge line and fittings may be very hot.

    Note: Any significant radiation level in the discharge gas indicates the presence of fission gas products. The temperature of the gas indicates the thermal conditions in the canister.
12. Start the flow of nitrogen through the line until there is no evidence of fission gas activity in the discharge line. Continue to monitor the gas discharge temperature. When there is no additional evidence of fission gas, stop the nitrogen flow and disconnect the drain and vent port line connections. The nitrogen gas flush must be maintained for at least 10 minutes.

    Note: See Figure 8.3-1 for Canister Reflood Piping and Control Schematic.
13. Ensure the vent port quick-disconnect has new Viton seals by replacing the seals in the existing quick-disconnect or installing a new quick-disconnect. Ensure the drain port quick-disconnect has new Viton seals by replacing the seals in the existing quick-disconnect, installing a new quick-disconnect or installing a new drain tube assembly. Ensure the quick-disconnect assemblies are torqued to the value specified in Table 8.1.1-2.
14. Perform canister refill and fuel cooldown operations. Attach a source of clean water with a minimum temperature of 70°F and a maximum supply pressure of 25 (+10, -0) psig to the drain port quick-disconnect. Attach a steam rated discharge line to the vent port quick-disconnect and route it to the spent fuel pool, an in-pool cooler, or an in-pool steam condensing unit. Slowly start the flow of clean or filtered pool water to establish a flow rate at 5 (+3, -0) gpm. Monitor the discharge line pressure gauge during canister flooding. Stop filling the canister if the canister vent line pressure exceeds 45 psig. Re-establish water flow when the canister pressure is below 35 psig. The discharge line will initially discharge hot gas, but after the canister fills, it will discharge hot water.

    Caution: Relatively cool water may flash to steam as it encounters hot surfaces within the canister.

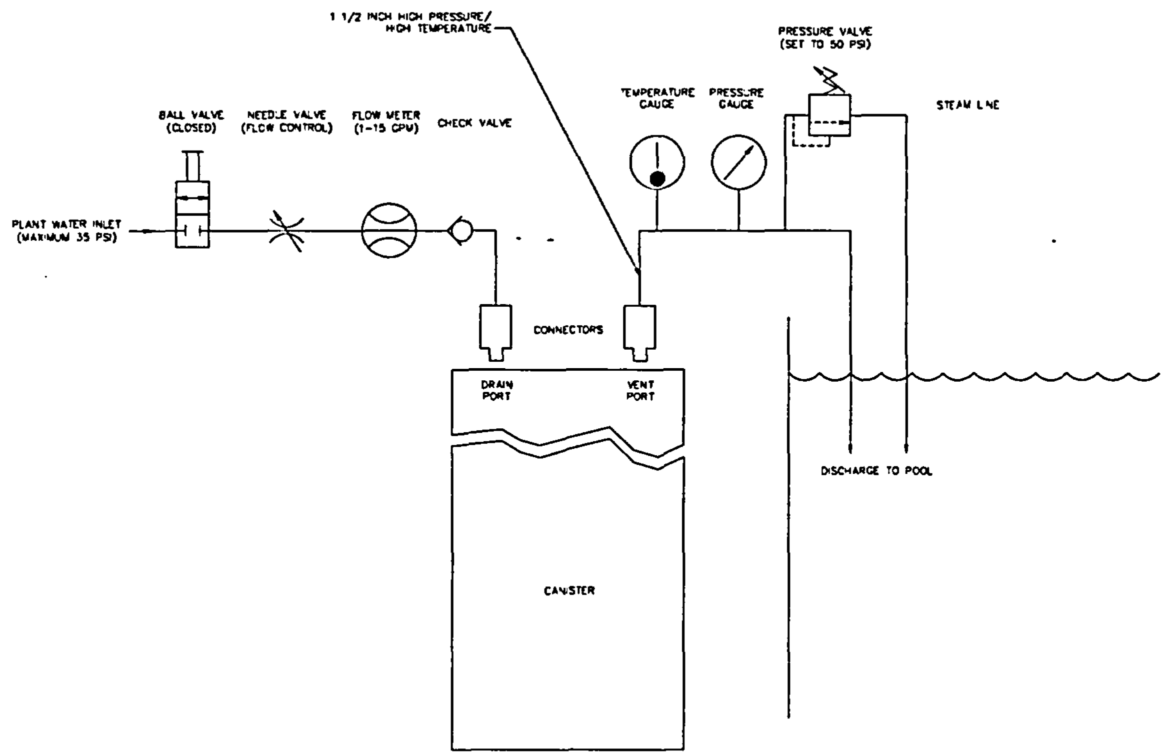
    Caution: If there are grossly failed or ruptured fuel rods within the canister, very high levels of radiation could rapidly appear at the discharge line. The radiation level of the discharge gas or water should be continuously monitored.

    Caution: Reflooding requires the use of borated water in accordance with LCO 3.3.1 if borated water was required for the initial fuel loading.

15. Monitor water flow through the canister until the water discharge temperature is below 200°F. Stop the flow of water and remove the connection to the drain line.
    Note: Monitor canister water temperature and reinitiate cooldown operations if temperature exceeds 200°F.
16. Connect a suction pump to the drain port and a vent line to the vent port. Operate the pump and remove approximately 70 gallons of water. Disconnect and remove the pump.
17. Set up the weld cutting equipment to cut the shield lid weld (Abrasive grinding, hydrolaser, or similar cutting equipment.). Route the vent line to avoid interference with the weld cutting operation.
18. Tent the top of the transfer cask and wear respiratory protection equipment as required. Attach a hydrogen gas detector to the vent port line. Verify that the concentration of hydrogen gas is less than 2.4%.
19. Operate the cutting equipment to cut the shield lid weld.
    Note: Stop the cutting operation if the hydrogen gas detector indicates a concentration of hydrogen gas above 2.4%. Connect the vacuum drying system and evacuate gas before proceeding with the cutting operation.
20. Remove the cutting equipment. Remove all loose shims. Remove supplemental shielding if used. Install the shield lid lifting hoist rings, verifying that the hoist rings are fully seated against the shield lid, and attach a three-legged sling. Attach a tag line to the sling set to aid in attaching the sling to the crane hook (at Step 25).
21. Install the annulus fill system to the transfer cask, including the clean water lines.
22. Retrieve the transfer cask lifting yoke and engage the transfer cask lifting trunnions.
23. Move the transfer cask over the pool and lower the bottom of the transfer cask to the surface. Start the flow of clean water to the transfer cask annulus. Continue to lower the transfer cask, as the annulus fills with water, until the top of the transfer cask is about 4 inches above the pool surface. Hold this position until clean water fills to the top of the transfer cask.
24. Lower the transfer cask to the bottom of the cask loading area and remove the lifting yoke.
25. Attach the shield lid lifting sling to the crane hook.
    Caution: The drain line tube is suspended from the under side of the shield lid. The lid should be raised as straight as possible until the drain tube clears the canister basket. The under side of the shield lid could be highly contaminated.
26. Slowly lift the shield lid. Move the shield lid to one side after it is raised clear of the transfer cask.
27. Visually inspect the fuel for damage.

At this point, the spent fuel could be transferred from the canister to the fuel racks. If the fuel is damaged, special handling equipment may be required to remove the fuel. In addition, the bottom of the canister could be highly contaminated. Care must be exercised in the handling of the transfer cask when it is removed from the pool.

Figure 8.3-1 Canister Reflood Piping and Controls Schematic



8.4 References

1. "Safety Analysis Report for the UMS® Universal Transport Cask," Docket Number 71-9270, NAC International, April 1997.

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