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11.0 ACCIDENT ANALYSES

The analyses of the off-normal and accident design events, including those identified by ANSI/ANS 57.9-1992 [1], are presented in this chapter. Section 11.1 describes the off-normal events that could occur during the use of the Universal Storage System, possibly as often as once per calendar year. Section 11.2 addresses very low probability events that might occur once during the lifetime of the ISFSI or hypothetical events that are postulated because their consequences may result in the maximum potential impact on the surrounding environment.

The Universal Storage System includes the Standard and Advanced configurations of the Transportable Storage Canisters, transfer casks (including the 100-ton transfer cask) and Vertical Concrete Casks. The Standard and Advanced configurations are provided in different lengths to accommodate the various PWR and BWR fuel designs. In the analyses of this chapter, the bounding concrete cask parameters (such as weight and center of gravity) are conservatively used, as appropriate, to determine the cask's capability to withstand the effects of the analyzed events for each configuration. In some cases, the configuration does not affect the results of the analysis of the event. Where configuration does affect results, the results are presented separately.

The load conditions imposed on the canisters and the baskets by the design basis normal, off-normal, and accident conditions of storage are less rigorous than those imposed by the transport conditions–including the 30-foot drop impacts and the fire accident (10 CFR 71) [2]. Consequently, the evaluation of the canisters and the baskets for transport conditions bounds those for storage conditions evaluated in this chapter. A complete evaluation of the normal and accident transport condition loading on the PWR and BWR canisters and the baskets is presented in the Safety Analysis Report for the Universal Transport Cask. [3]

This chapter demonstrates that the Universal Storage System satisfies the requirements of 10 CFR 72.24 and 10 CFR 72.122 [4] for off-normal and accident conditions. These analyses are based on conservative assumptions to ensure that the consequences of off-normal conditions and accident events are bounded by the reported results. If required for a site specific application, a more detailed evaluation could be used to extend the limits defined by the events evaluated in this chapter.

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11.1 Off-Normal Events

This section evaluates postulated events that might occur once during any calendar year of operations. The actual occurrence of any of these events is, therefore, infrequent.

11.1.1 Severe Ambient Temperature Conditions (106°F and -40°F)

This section evaluates the Universal Storage System for the steady state effects of severe ambient temperature conditions (106°F and -40°F), which are applied to both the Standard and the Advanced configurations of the Universal Storage System.

11.1.1.1 Cause of Severe Ambient Temperature Event

Large geographical areas of the United States are subjected to sustained summer temperatures in the 90°F to 100°F range and winter temperatures that are significantly below zero. To bound the expected steady state temperatures of the canister and storage cask during these severe ambient conditions, analyses are performed to calculate the steady state storage cask, canister, and fuel cladding temperatures for a 106°F ambient temperature and solar loads (see Table 4.1-1). Similarly, winter weather analyses are performed for a -40°F ambient temperature with no solar load. Neither ambient temperature condition is expected to last more than several days.

11.1.1.2 Detection of Severe Ambient Temperature Event

Detection of off-normal ambient temperatures would occur during the daily measurement of ambient temperature and storage cask outlet air temperature.

11.1.1.3 Analysis of Severe Ambient Temperature Event

Analysis of the severe ambient temperature event for the Standard configuration is provided in Section 11.1.1.3.1 and for the Advanced configuration in Section 11.1.1.3.2.

11.1.1.3.1 Analysis of Severe Ambient Temperature Event for the Standard Configuration

Off-normal temperature conditions for the Standard configuration are evaluated by using the thermal models described in Section 4.4.1.1. The design basis heat load of 23.0 kW is used in the evaluation of PWR and BWR fuels. The concrete temperatures are determined using the two-dimensional axisymmetric air flow and concrete cask models (Section 4.4.1.1.1) and the canister, basket and fuel cladding temperatures are determined using the three-dimensional canister models (Section 4.4.1.2). A steady state condition is considered in all analyses. The temperature profiles for the Standard concrete cask and for the air flow associated with a 106°F ambient condition are shown in Figure 11.1.1-1 and Figure 11.1.1-2, respectively. Temperature profiles for the -40°F ambient temperature condition for the Standard PWR cask are shown in Figure 11.1.1-3 and Figure 11.1.1-4. Temperature profiles for the Standard BWR cask are similar.

The principal component temperatures for each of the ambient temperature conditions discussed above are summarized in the following table along with the allowable temperatures. As the table shows, the component temperatures are within the allowable values for the off-normal ambient conditions.

Principal Component Temperatures - Standard

	106°F Ambient Max Temp. (°F)		**-40°F Ambient Max Temp. (°F)**		**Allowable Temp. (°F)**	
Component	**PWR**	**BWR**	**PWR**	**BWR**	**PWR**	**BWR**
Fuel Cladding	694	677	584	548	1058	1058
Support Disks	642	651	521	515	800	700
Heat Transfer Disks	638	648	516	513	700	700
Canister Shell	381	405	226	252	800	800
Concrete	228	231	17	20	350	350

The thermal stress evaluations for the Standard concrete cask for these off-normal conditions are bounded by those for the accident condition of "Maximum Anticipated Heat Load (133°F ambient temperature)" as presented in Section 11.2.7. Thermal stress analyses for the Standard canister and basket components are performed using the ANSYS finite element models as described in Section 3.4.4. Evaluations of the thermal stresses combined with the stresses due to other off-normal loads (e.g., canister internal pressure and handling) are shown in Section 11.1.3.

There are no adverse consequences for these off-normal conditions. The maximum component temperatures are within the allowable temperature values.

11.1.1.3.2 Analysis of Severe Ambient Temperature Event for the Advanced Configuration

Off-normal temperature conditions for the Advanced configuration are evaluated by using the thermal models described in Section 4.4.1.2. The design basis heat load of 29.2 kW is used in the evaluation of PWR fuel. The concrete temperatures are determined using the two-dimensional axisymmetric air flow and concrete cask models (Section 4.4.1.2.2) and the canister, basket and fuel cladding temperatures are determined using the three-dimensional canister models (Section

4.4.1.2.1). A steady state condition is considered in all analyses. Temperature profiles for the advanced concrete cask with a 106°F and -40°F ambient conditions are shown in Figure 11.1.1-5 and Figure 11.1.1-6, respectively.

The principal component temperatures for each of the ambient temperature conditions are summarized in the following table along with the allowable temperatures. As shown in the table, the component temperatures are within the allowable values for the off-normal ambient conditions.

Principal Component Temperatures - Advanced

Component	**106°F Ambient, Maximum Temperatures (°F)**	**-40°F Ambient, Maximum Temperatures (°F)**	**Allowable Temperature (°F)**
Fuel Cladding	733	605	1,058
Basket Plates	720	586	850
Canister Shell	399	248	800
Concrete	240	39	350

The thermal stress evaluations for the Advanced concrete cask for these off-normal conditions are bounded by those for the accident condition of "Maximum Anticipated Heat Load (133°F ambient temperature)" as presented in Section 11.2.7. Thermal stress analyses for the Advanced canister and basket components are performed using the ANSYS finite element models as described in Section 3.4.4. Evaluations of the thermal stresses combined with the stresses due to other off-normal loads (e.g., canister internal pressure and handling) are shown in Section 11.1.3.

There are no adverse consequences for these off-normal conditions. The maximum component temperatures are within the allowable temperature values.

11.1.1.4 Corrective Actions

No corrective actions are required for this off-normal condition.

11.1.1.5 Radiological Impact

There is no radiological impact due to this off-normal event.

Figure 11.1.1-1 Concrete Temperature (°F) for Off-Normal Storage Condition 106°F Ambient Temperature for the Standard Configuration with PWR Fuel

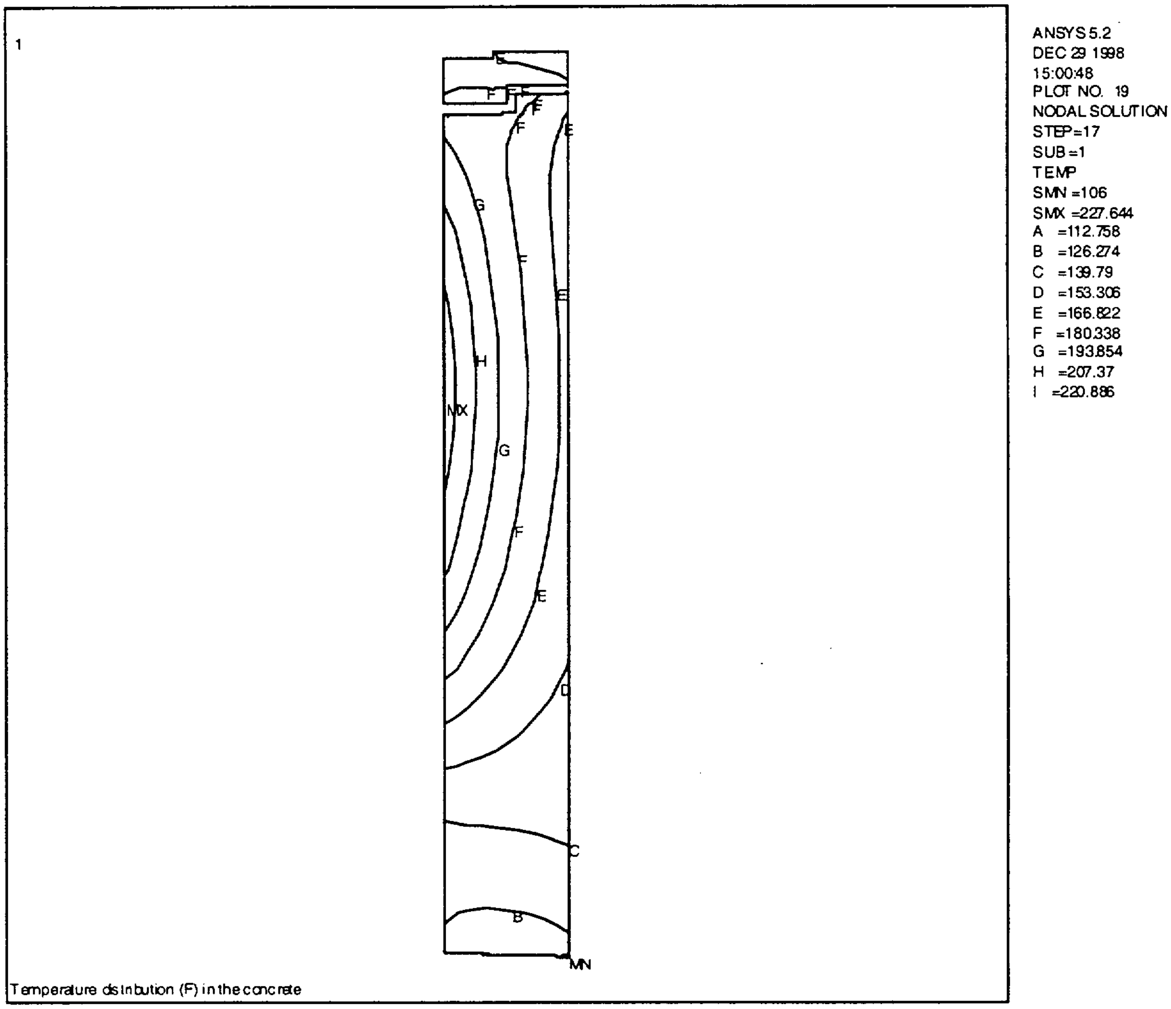


Figure 11.1.1-2 Standard Vertical Concrete Cask Air Temperature (°F) Profile for Off-Normal Storage Condition 106°F Ambient Temperature (PWR Fuel)

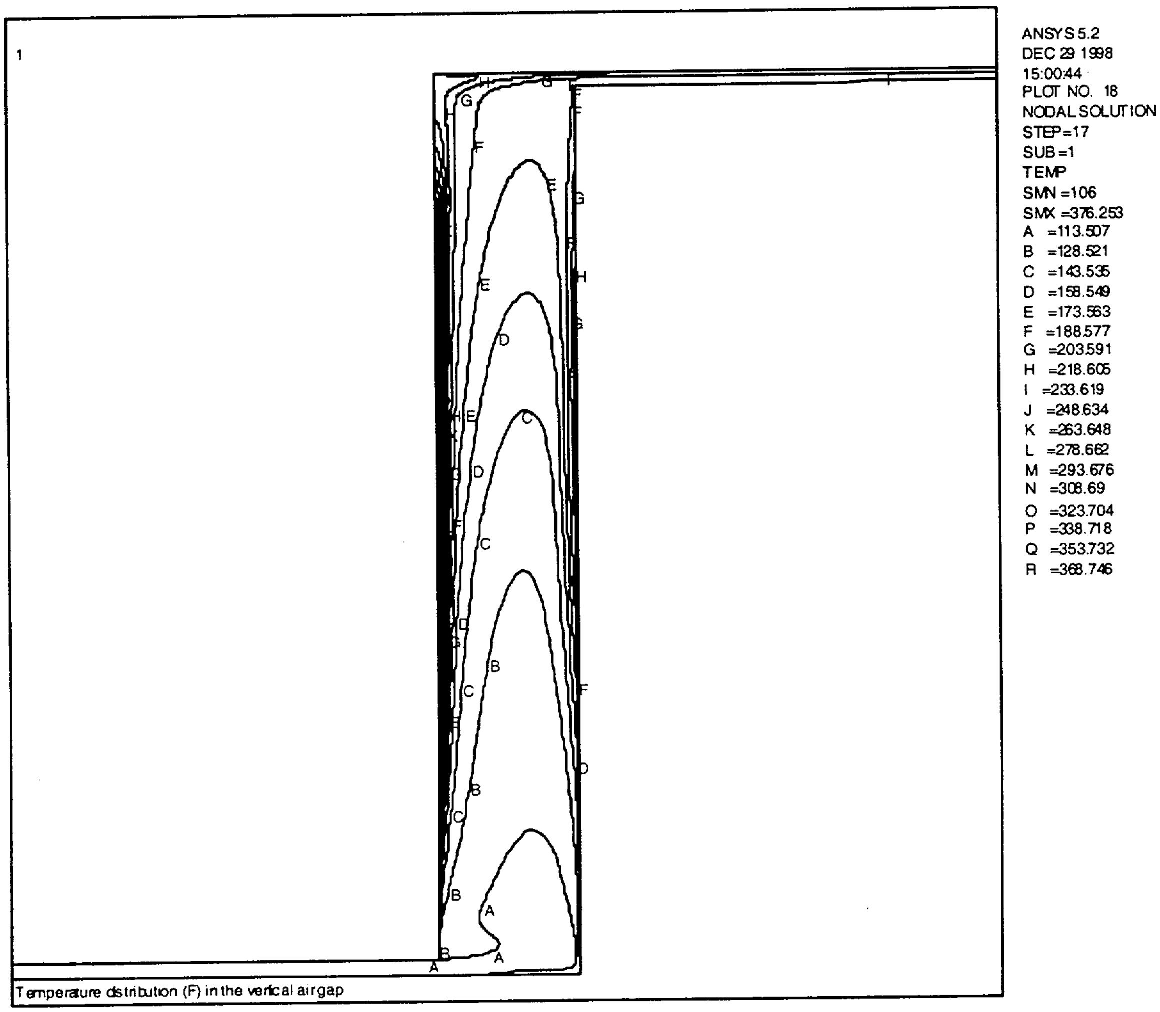


Figure 11.1.1-3 Concrete Temperature (ºF) for Off-Normal Storage Condition -40°F Ambient Temperature for the Standard Configuration with PWR Fuel

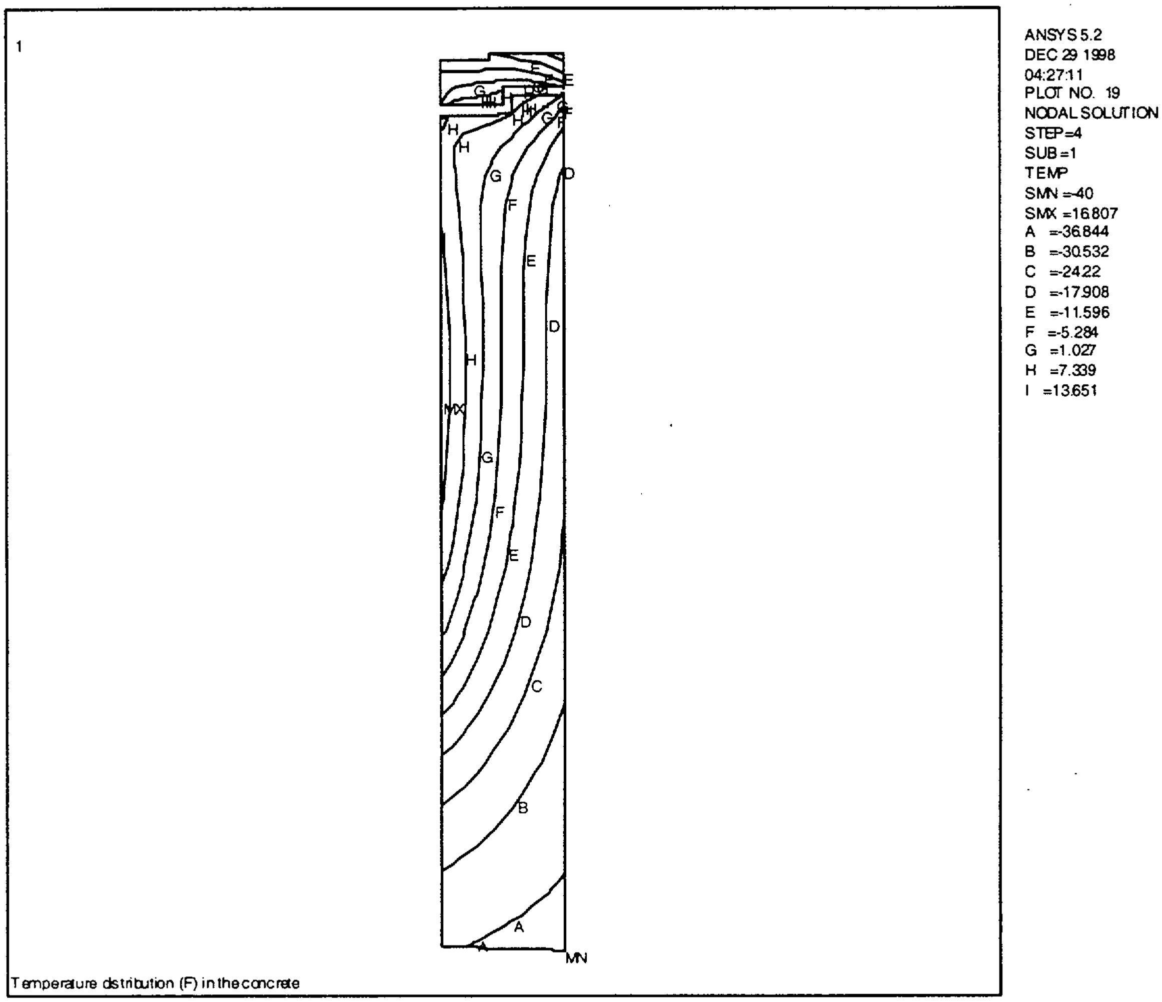


Figure 11.1.1-4 Standard Vertical Concrete Cask Air Temperature (°F) Profile for Off-Normal Storage Condition -40°F Ambient Temperature (PWR Fuel)

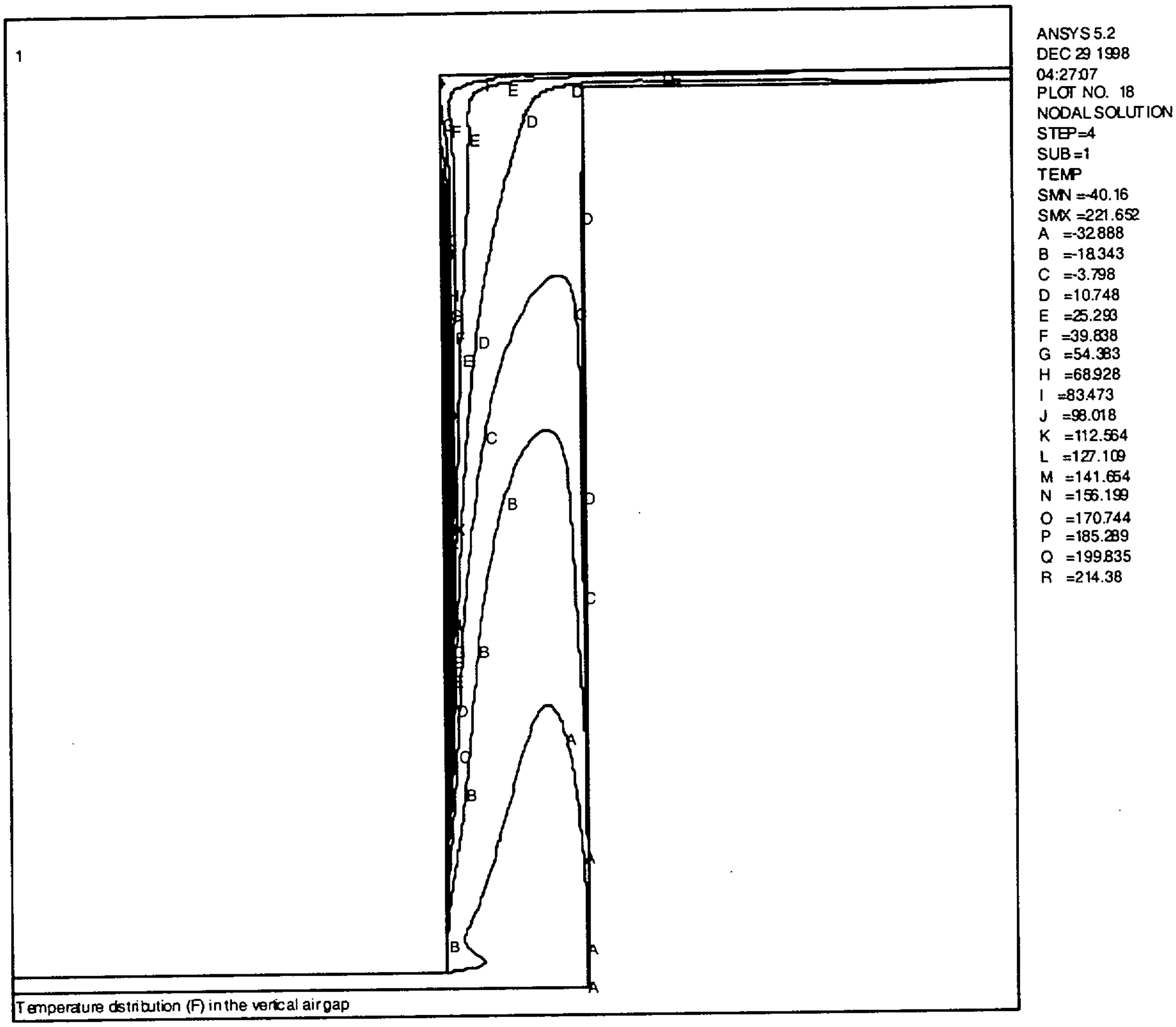
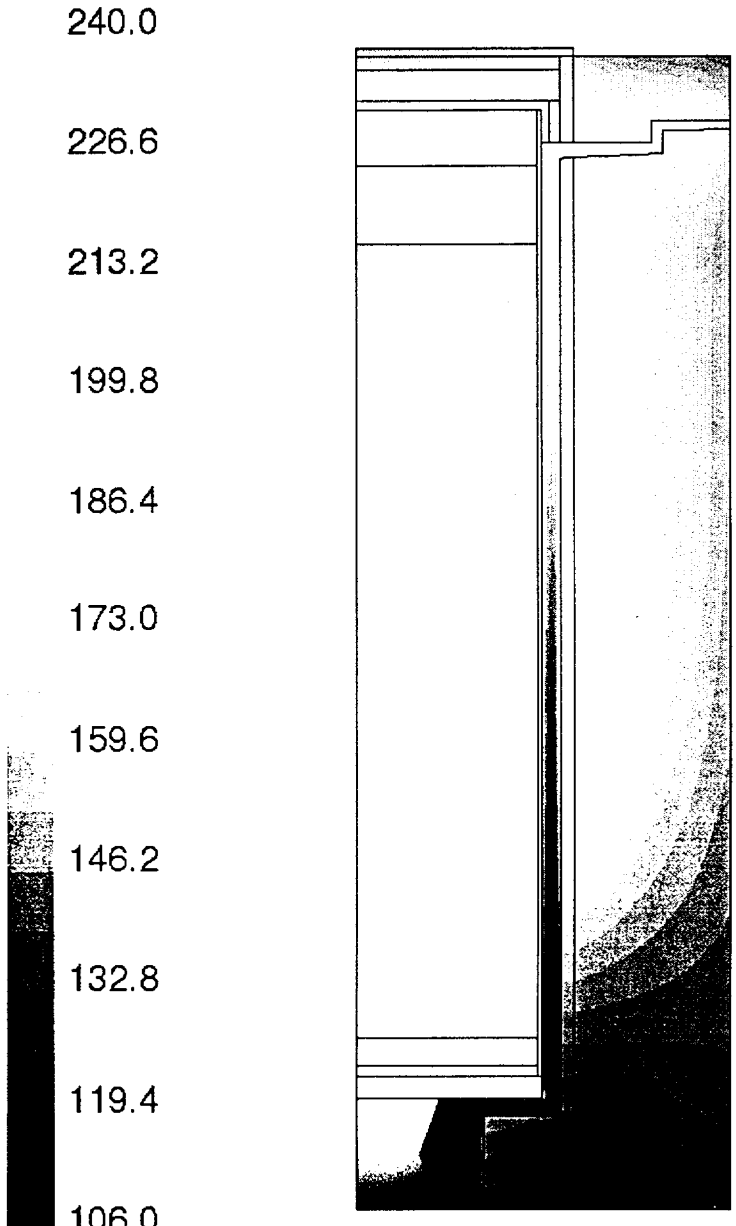
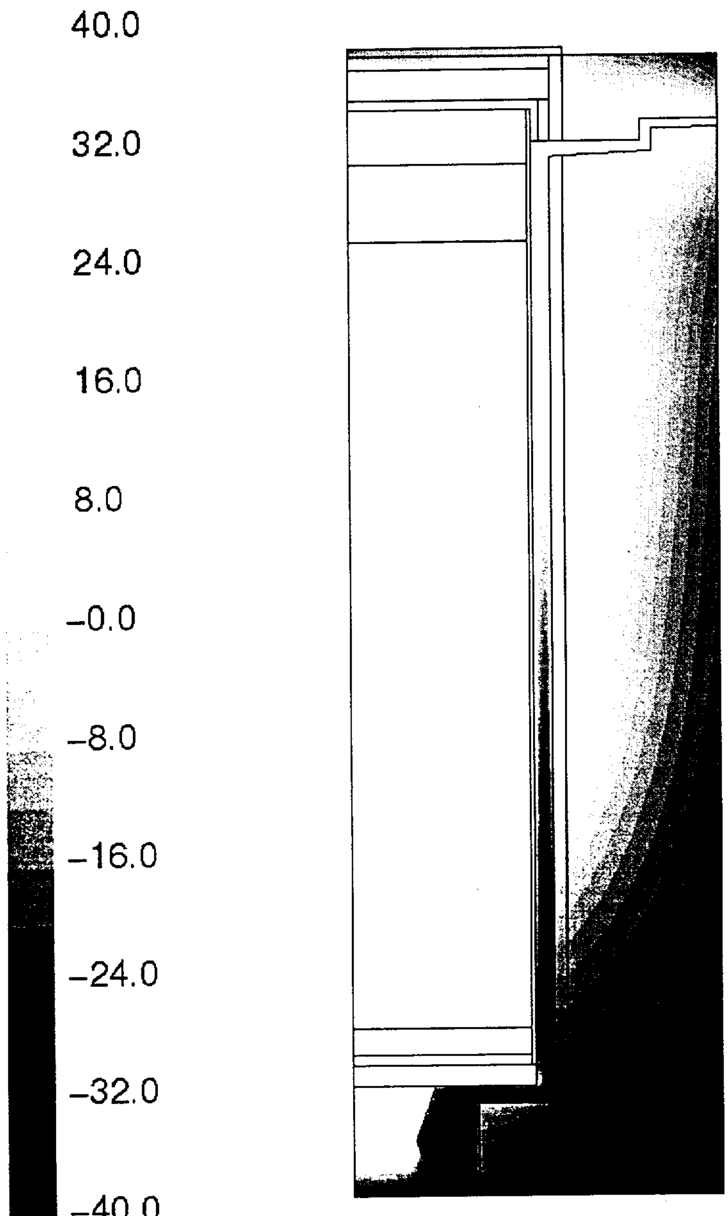


Figure 11.1.1-5 Temperature Distribution in the Advanced Concrete Cask for the 106°F Ambient Temperature Condition



Contours of Static Temperature (ºF)
In the Range from 76ºF to 240ºF

Figure 11.1.1-6 Temperature Distribution in the Advanced Concrete Cask for the -40°F Ambient Temperature Condition



Contours of Static Temperature (ºF)
In the Range of –40ºF to +40ºF

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11.1.2 Blockage of Half of the Air Inlets

This section evaluates the Standard and Advanced configurations of the Universal Storage System for the steady state effects of a blockage of one-half of the air inlets at the normal ambient temperature (76°F). The evaluation for the Standard configuration is presented in Section 11.1.2.3.1. The evaluation of the Advanced configuration is presented in Section 11.1.2.3.2.

11.1.2.1 Cause of the Blockage Event

Although unlikely, blockage of half of the air inlets may occur due to blowing debris, snow, intrusion of a burrowing animal, etc. The screens over the inlets are expected to minimize any blockage of the inlet channels.

11.1.2.2 Detection of the Blockage Event

This event would be detected visually by the persons inspecting the air inlets and gathering outlet air temperature data on a daily basis. It could also be detected by security forces, or other operations personnel, engaged in other routine activities such as fence inspection, or grounds maintenance.

11.1.2.3 Analysis of the Blockage Event

The evaluation of the half inlets blocked condition uses the same methods and the same thermal models described in Section 11.1.1 for the off-normal conditions of severe ambient temperatures for the Standard and Advanced configurations, respectively. The boundary conditions of the two-dimensional axisymmetric air flow and concrete cask models are modified to allow only half of the air flow into the air inlet to simulate the half inlets blocked condition.

11.1.2.3.1 Analysis of the Half Inlets Blocked Condition for the Standard Configuration

The calculated maximum component temperatures due to this off-normal condition are compared to the allowable component temperatures. Table 11.1.2-1 summarizes the component temperatures for off-normal conditions. As the table demonstrates, the calculated temperatures are shown to be below the component allowable temperatures.

The thermal stress evaluations for the concrete cask for this off-normal condition are bounded by those for the accident condition of "Maximum Anticipated Heat Load (133°F ambient temperature)" as presented in Section 11.2.7. Thermal stress analyses for the canister and basket components are performed using the ANSYS finite element models described in Section 3.4.4. Evaluations of the thermal stresses combined with stresses due to other off-normal loads (e.g., canister internal pressure and handling) are shown in Section 11.1.3.

11.1.2.3.2 Analysis of the Half Inlets Blocked Condition for the Advanced Configuration

The calculated maximum component temperatures due to this off-normal condition are compared to the allowable component temperatures. Table 11.1.2-2 summarizes the component temperatures for off-normal conditions. As shown in the table, the calculated temperatures are below the component allowable temperatures.

The thermal stress evaluations for the concrete cask for this off-normal condition are bounded by those for the accident condition of "Maximum Anticipated Heat Load (133°F ambient temperature)" as presented in Section 11.2.7. Thermal stress analyses for the canister and basket components are performed using the ANSYS finite element models described in Section 3.4.4. Evaluations of the thermal stresses combined with stresses due to other off-normal loads (e.g., canister internal pressure and handling) are shown in Section 11.1.3.

11.1.2.4 Corrective Actions

The debris blocking the affected air inlets must be manually removed. The nature of the debris may indicate that other actions are required to prevent recurrence of the blockage.

11.1.2.5 Radiological Impact

There are no significant radiological consequences for this event. Personnel will be subject to an estimated maximum contact dose rate of 66 mrem/hr when clearing the PWR cask inlets. If it is assumed that a worker kneeling with his hands on the inlets would require 15 minutes to clear the inlets, the estimated maximum extremity dose is 17 mrem. For clearing the BWR cask inlets, the maximum contact dose rate and the maximum extremity dose are estimated to be 51 mrem/hr and 13 mrem, respectively. The whole body dose in both PWR and BWR cases will be significantly less.

Table 11.1.2-1 Standard Configuration Component Temperatures for Half of Inlets Blocked Off-Normal Event

Component	Half of Inlets Blocked Max Temperature (°F)		Allowable Temperature (°F)	
	PWR	BWR	PWR	BWR
Fuel Cladding	671	652	1058	1058
Support Disks	617	625	800	700
Heat Transfer Disks	613	622	700	700
Canister Shell	350	374	800	800
Concrete	191	195	350	350

Table 11.1.2-2 Advanced Configuration Component Temperatures for Half of Inlets Blocked Off-Normal Event

Component	Half Inlets Blocked Maximum Temperatures (°F)	Allowable Temperature (°F)
Fuel Cladding	709	1,058
Basket Plates	694	850
Canister Shell	369	800
Concrete	202	350

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11.1.3 Off-Normal Canister Handling Load

This section evaluates the consequence of loads on the Transportable Storage Canister during the installation of the canister in the Vertical Concrete Cask, or removal of the canister from the concrete cask or from the transfer cask. The canister may be handled vertically in the Standard or Advanced transfer casks, or vertically and horizontally in the 100-ton transfer cask. The Standard and Advanced transfer casks are identical except that the Advanced transfer cask incorporates a reinforcing gusset at the lifting trunnions allowing the handling of either the Standard or Advanced canister.

11.1.3.1 Cause of Off-Normal Canister Handling Load Event

Unintended loads could be applied to the canister due to misalignment or faulty crane operation, or inattention of the operators.

11.1.3.2 Detection of Off-Normal Canister Handling Load Event

The event can be detected visually during the handling of the canister, or banging or scraping noise associated with the canister movement. The event is expected to be obvious to the operators at the time of occurrence.

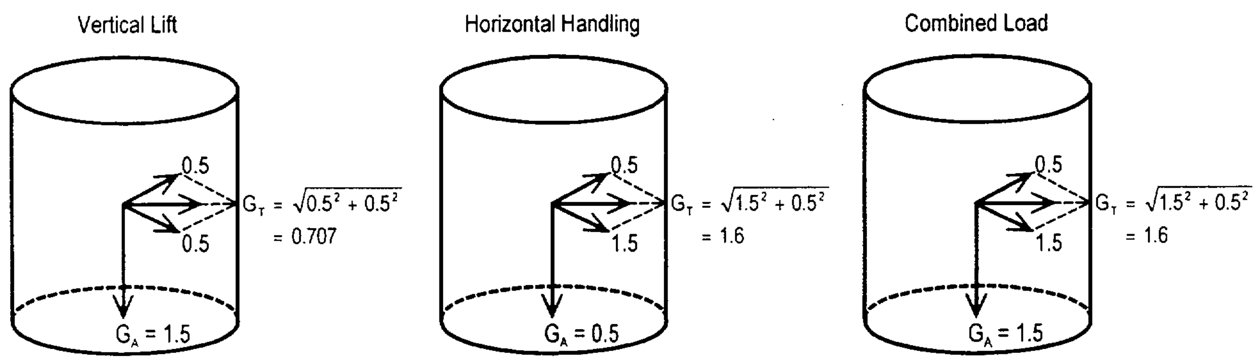
11.1.3.3 Analysis of the Off-Normal Canister Handling Load Event

The analysis of the Standard canister in the Standard transfer cask is provided in Section 11.1.3.3.1. Use of the Standard transfer cask is limited to vertical handling of the canister. The analysis of the Advanced canister in either the Advanced transfer cask or 100-ton transfer cask is provided in Section 11.1.3.3.2. Both the Standard and Advanced canisters may be handled vertically in the Advanced transfer cask, or vertically and horizontally in the 100-ton transfer cask.

11.1.3.3.1 Analysis of the Off-Normal Standard Canister Handling Load Event

The Standard canister off-normal handling analysis is performed using an ANSYS finite element model as shown in Figure 11.1.3-1. The model is based on the canister model presented in Section 3.4.4.1 with the elements fuel basket (support disks and top and bottom weldment disks) added. The disks are modeled with SHELL63 elements. These elements are included to transfer loads from the basket to the canister shell for loads in the canister transverse direction. The interface between the disks and the canister shell is simulated by CONTAC52 elements. For the transverse loads, uniform pressure loads representing the weight (including appropriate g-loading) of the fuel assemblies, fuel tubes, heat transfer disks, tie-rods, spacers, washers, and nuts are applied to the slots of the support/weldment disks. For loads in the canister axial direction, interaction between the fuel basket and the canister is modeled by applying a uniform pressure representing the weight of the fuel assemblies and basket (including appropriate g-loading) to the canister bottom plate. The model is used to evaluate the canisters for both PWR and BWR fuel types by modeling the shortest canister (Class 1 PWR) with the heaviest fuel/fuel basket weight (Class 5 BWR). The material stress allowables used in the analysis consider the higher component temperatures that occur during transfer operations.

The normal handling loads are defined as 1g of dead weight plus a 10% dynamic load factor (a total of 1.1g in the axial direction). The off-normal handling loads are defined as 0.5g in all directions plus 1g of dead weight. The canister may be handled in a standard transfer cask (always in vertical orientation) or a 100-ton transfer cask, which may be in a vertical orientation or rotated into a horizontal orientation. To bound the vertical lift and horizontal handling cases, the accelerations for these cases are applied to the ANSYS model as shown in the "combined load" figure.



The boundary conditions (restraints) for the canister model are the same as those described in Section 3.4.4.1.4 for the normal handling condition, using the Class 5 (BWR) canister weight.

The resulting maximum canister stresses for off-normal handling loads are summarized in Tables 11.1.3-1 and 11.1.3-2 for primary membrane and primary membrane plus bending stresses, respectively.

The resulting maximum canister stresses for combined off-normal handling, maximum off-normal internal pressure (15 psig), and thermal stress loads are summarized in Tables 11.1.3-3, 11.1.3-4, and 11.1.3-5 for primary membrane, primary membrane plus bending, and primary plus secondary stresses, respectively.

The sectional stresses shown in Tables 11.1.3-1 through 11.1.3-5 at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.1-4.

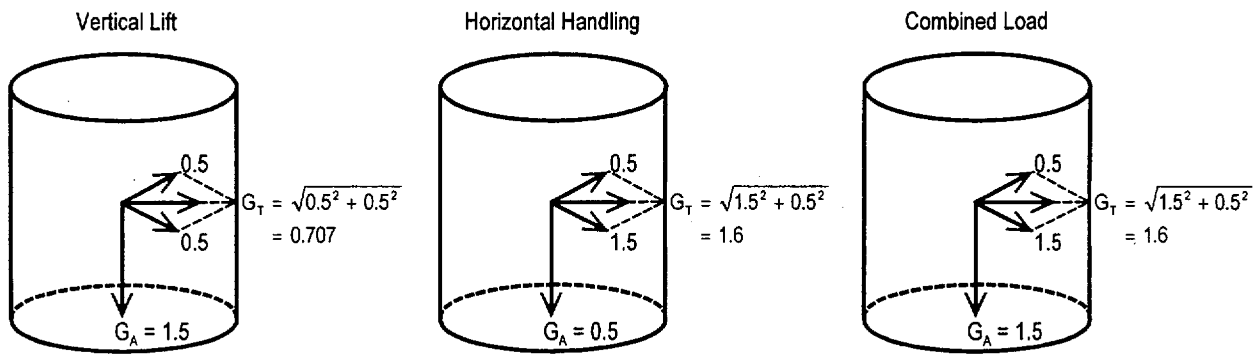
To determine the structural adequacy of the PWR and BWR fuel basket support disks and weldments for off-normal conditions, a structural analysis is performed by using ANSYS to evaluate off-normal handling loads. To simulate off-normal loading conditions, an inertial load of 1.5g is applied to the support disk and the weldments in the axial (canister axial) direction and 0.5g in two orthogonal disk in-plane directions (0.707g resultant), for the governing case (canister handled in the vertical orientation).

Stresses in the support disks and weldments are calculated by applying the off-normal loads to the ANSYS models described in Sections 3.4.4.1.8 and 3.4.4.1.9. An additional in-plane displacement constraint is applied to each model at one node (conservative) at the periphery of the disk or the weldment plate to simulate the side restraint of the canister shell for the lateral load (0.7071g). To evaluate the most critical regions of the support disks, a series of cross sections is considered. The locations of these sections on the PWR and BWR support disks are shown in Figures 3.4.4.1-7, 3.4.4.1-8, and Figures 3.4.4.1-13 through 3.4.4.1-16 (Note: stress allowables for support disks are taken at 800°F). The stress evaluation for the support disk and weldment is performed according to ASME Code, Section III, Subsection NG. For off-normal conditions, Level C allowable stresses are used: the allowable stress is 1.2 S_m or S_y, 1.8 S_m or 1.5S_y, and 3.0 S_m for the P_m, P_m+P_b, and P_m+P_b+Q stress categories, respectively. The stress evaluation results are presented in Tables 11.1.3-6 through 11.1.3-8 for the PWR support disks and in Tables 11.1.3-9 through 11.1.3-11 for the BWR support disks. The tables list the 40 sections with the highest P_m, P_m+P_b, and P_m+P_b+Q stress intensities. All of the support disk sections have large margins of safety. The stress results for the PWR and BWR weldments are shown in Table 11.1.3-12.

The canisters and fuel baskets maintain positive margins of safety for the off-normal handling condition. There is no deterioration of canister or fuel basket performance. The Universal Storage System is in compliance with all applicable regulatory criteria.

11.1.3.3.2 Analysis of the Off-Normal Advanced Canister Handling Load Event

The off-normal handling loads are defined as 0.5g in all directions plus 1g of dead weight. The canister may be handled in the vertical or horizontal orientations. To bound the vertical lift and horizontal handling cases, the accelerations for these cases are applied to the ANSYS canister model as shown in the “combined load” figure.



The boundary conditions (restraints) for the canister model are the same as those described in Section 3.4.4.1.2 for the normal handling condition. For the off-normal handling condition, gap elements (CONTAC52) representing the distance between the canister and concrete cask are added for the transverse loading.

The analysis for off-normal pressure with normal handling loads and normal pressure with off-normal handling loads.

The canister structural analysis, including lifting loads, is performed by using the same ANSYS finite element model presented in Section 3.4.4.3. For the transverse loads, uniform loads representing the weight (including appropriate g-loading) of the fuel assemblies and baskets are applied to the canister shell. For loads in the canister axial direction, interaction between the fuel basket and the canister is modeled by applying a uniform pressure representing the weight of the fuel assemblies and basket (including appropriate g-loading) to the canister bottom plate. The model evaluates canister loading by modeling the shortest canister (Class 1) with a bounding loaded basket weight of 84,800 lbs inside the shortest canister.

The resulting maximum canister stresses for off-normal handling loads are summarized in Tables 11.1.3-18 through 11.1.3-22 for primary membrane, primary membrane plus bending stresses, and primary plus secondary stresses. Tables 11.1.3-13 through 11.1.3-15 present results for normal handling and pressure only conditions. Cross-sections 2 and 3 (see Figure 3.4.4.3-4) correspond to the junction of a flat head and a cylindrical shell. Per ASME Code Section NB-3217, the primary membrane plus primary bending stress intensity may be classified as a secondary stress intensity provided the stress intensity at the center of the plate maintains positive stress margins under the pressure load applied to the plate. For this reason, the primary bending plus primary membrane in Table 11.1.3-14 are not reported. The stress intensity for sections 2 and 3 are reported in Table 11.1.3-15 for the primary plus secondary stresses. Table 11.1.3-23 contains the stress margins for the bottom canister plate subject to a pressure load in which the outer diameter of the plate is simply supported. The simply supported boundary condition represents the case that the cylindrical shell provides no stiffness to the bottom canister plates. Table 11.1.3-23 shows a positive margin at the center of the bottom canister plate, which satisfies the condition of NB-3217.

The sectional stresses shown in Tables 11.1.3-13 through 11.1.3-22 at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.3-4.

Stresses in the basket are calculated by applying the off-normal loads to the ANSYS model as shown in Figure 11.3.1-2. Contact between the basket outer shell and the canister shell (not modeled) is simulated using CONTAC52 gap elements. The model uses the same methodology as described in Section 3.4.4.3.9; however, the acceleration load applied in axial direction, 1.5g, is combined with an acceleration load of 1.6g in the transverse direction (-y). Pressure load representing the weight of fuel assemblies (× 1.6g) is also applied to basket.

The stress evaluation uses the peak nodal stresses in the basket and weldment. Nodal stresses at the middle, top, and bottom of the elements are examined. Middle plane stresses represent the membrane stresses. Stresses at the top or bottom element surface represent the membrane plus bending stress. Stresses in the basket and weldment are evaluated separately. The table below summarizes the basket stresses for off-normal condition.

Stress (psi)	P_m Stress	$P_m + P_b$ Stress	P_m Allowable	P_m MS	$P_m + P_b$ Allowable	$P_m + P_b$ MS
Basket	2,624	18,321	35,100	+ large	41,760	+1.28
Bottom Weldment*	11,187	15,994	35,100	+ 2.14	41,760	+1.61

* Stresses for the bottom weldment bound the stresses for the top weldment.

Stresses for the bottom weldment bound the stresses for the top weldment. Combining the maximum basket nodal stress (preceding table) and the maximum thermal stress (Section 3.4.4.3.9) conservatively evaluates the off-normal primary plus secondary stress. The bounding primary plus secondary stress is 51.8 ksi (P + Q, 18.3 ksi + 33.5 ksi). The allowable stress, $3S_m$, is 69.6 ksi. The margin of safety is 0.34 (69.6/51.8-1).

During off-normal conditions, the tabs can be subjected to bending loads from the fuel assemblies. Using a simply supported beam of length 8.8 inches and width of 15.68 inches (center to center distance of the tabs) the evaluation of the tab is performed. The bounding load is from the PWR Class 1 configuration and is:

P = [(1,567 lb x 32 + 950 lb)/ 32]/[153.3 in. x 8.8 in.] x 1.6g = 1.9 psi

where:

fuel weight	= 1,567 lb
neutron poison sheets	= 950 lb
basket length	= 153.3 in.
fuel cell width	= 8.8 in.

The load per inch is then 1.9 psi x 15.68 inches = 29.8 lb/in (use 30 lb/in). The reaction load for the beam is:

R = 30 lb/in x 8.8 / 2 = 132 lbs.

The shear stress is then 132 lbs / (3.28 in × 0.3125 inches) = 130 psi. Conservatively adding the shear stress from the axial load (798 lbs × 1.1/2.05 in^2 = 430 psi) ratioed to 1.5g off-normal axial acceleration, results in a shear stress of 130 psi + 430 psi (1.5/1.1) = 716 psi.

The margin of safety (MS) for the shear stress is:

MS = 15,540 / 716 −1 = + large.

The bending load at the tab/ligament plate interface is conservatively calculated as:

M = 132 lbs x (0.3125 + 0.06) = 49.2 in-lbs. (Use 50 in-lbs.)

The bending stress is:

$S_b = 6M / bt^2 = 6\ (50 \text{ in-lbs}) / (3.28 \text{ in} \times 0.3125^2 \text{ in}) = 938$ psi.

The margin of safety (MS) for bending during off-normal conditions is:

MS = 1.65 (25,900)/ 938 − 1 = + large.

The Advanced canisters and fuel baskets maintain positive margins of safety for the off-normal handling condition. There is no deterioration of canister or fuel basket performance. The Universal Storage System in the Advanced configuration is in compliance with applicable regulatory criteria.

11.1.3.4 Corrective Actions

Operations should be halted until the cause of the misalignment, interference or faulty operation is identified and corrected. Since the radiation level of the canister sides and bottom is high, extreme caution should be exercised if inspection of these surfaces is required.

11.1.3.5 Radiological Impact

There are no radiological consequences associated with this off-normal event.

Figure 11.1.3-1 Standard Canister Finite Element Model

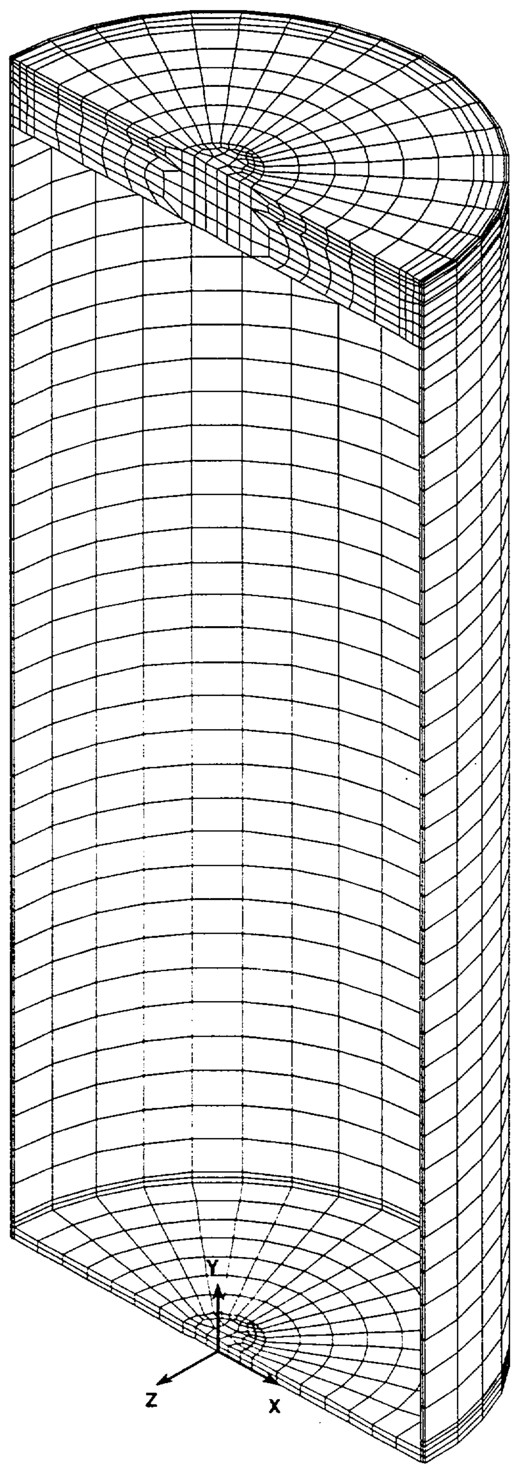


Figure 11.1.3-2 Advanced Fuel Basket Finite Element Model

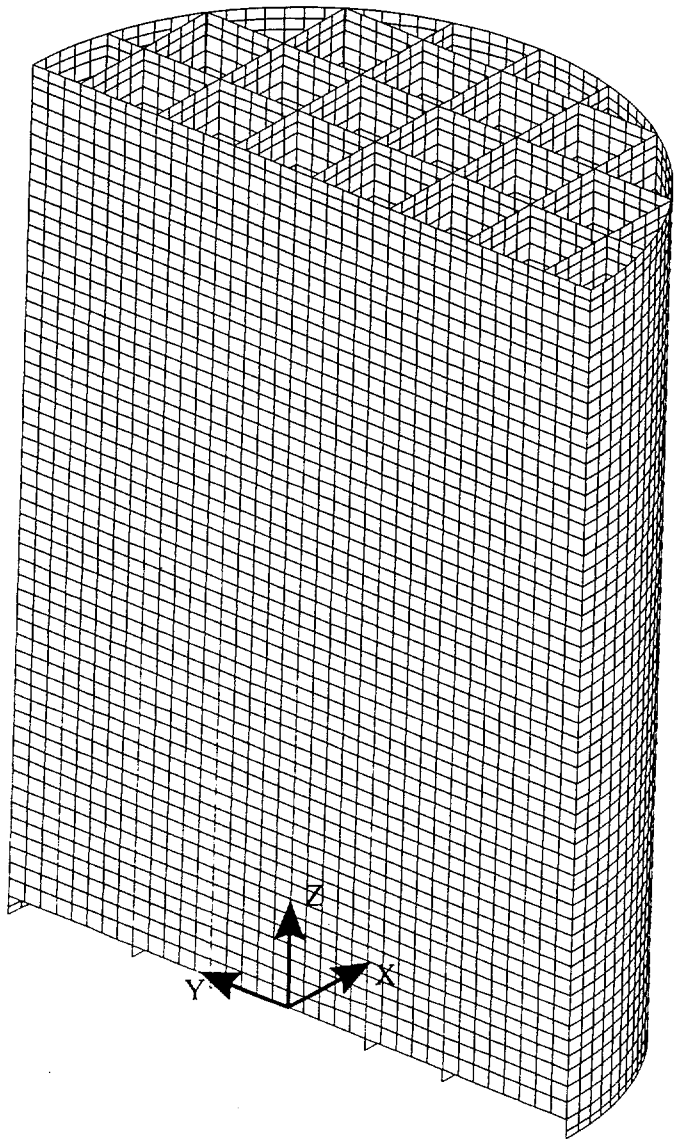


Table 11.1.3-1 Standard Canister Off-Normal Handling (No Internal Pressure) Primary Membrane (P_m) Stresses

Section No.[1]	Angle[1] (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	0	-1.47	2.90	0.41	0.30	-0.06	-0.20	4.43
2	0	2.40	-1.16	-2.40	-0.09	-0.17	-0.41	4.89
3	0	-0.14	0.82	0.00	-0.01	-0.01	0.02	0.97
4	0	-0.20	0.76	0.00	0.00	-0.01	0.01	0.96
5	0	-0.22	0.78	0.00	0.00	0.00	0.01	1.00
6	0	-0.25	0.83	-0.01	0.00	0.00	0.00	1.08
7	0	-0.27	0.99	-0.05	0.00	0.01	-0.01	1.26
8	0	-0.03	1.94	-0.09	-0.02	0.20	0.03	2.07
9	0	0.39	3.46	0.76	0.20	0.38	0.15	3.19
10	0	-0.32	4.34	0.62	-0.02	0.53	0.17	4.76
11	0	0.33	3.60	1.50	-1.32	0.55	-0.10	4.32
12	120	0.55	3.15	0.08	-0.17	-0.16	-0.35	3.29
13	0	-4.88	0.02	0.69	-2.06	0.14	-0.09	6.53
14	0	0.31	-0.02	0.42	-0.04	-0.17	0.00	0.56
15	170	-0.05	0.00	-0.04	0.00	0.00	0.00	0.04
16	0	-0.07	0.00	0.04	0.00	0.01	0.00	0.11

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.

Table 11.1.3-2 Standard Canister Off-Normal Handling (No Internal Pressure) Primary Membrane plus Bending ($P_m + P_b$) Stresses

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	0	-8.34	-2.16	-0.38	0.06	-0.14	-0.25	7.98
2	0	0.78	-12.39	-6.16	-0.82	-0.41	-0.67	13.36
3	0	-0.12	0.85	0.15	-0.02	0.00	0.03	0.98
4	0	-0.21	0.77	0.05	0.00	-0.01	0.01	0.98
5	0	-0.24	0.82	0.15	0.00	-0.01	0.02	1.06
6	0	-0.27	0.90	0.24	0.00	-0.01	0.03	1.17
7	0	-0.30	1.07	0.27	0.01	0.02	0.02	1.37
8	0	0.01	1.97	-0.15	-0.02	0.18	0.02	2.15
9	0	0.54	5.13	1.12	-0.03	0.46	0.16	4.69
10	0	-0.58	4.18	0.70	0.23	0.37	0.23	4.86
11	0	-0.85	2.51	1.29	-2.13	0.39	-0.17	5.51
12	120	0.68	4.30	-0.06	-0.22	-0.21	-0.56	4.70
13	0	-9.91	-1.78	-0.12	-1.63	-0.04	0.03	10.11
14	180	8.86	0.24	8.88	-0.04	-0.17	0.01	8.65
15	0	-0.25	-0.01	-0.23	0.00	0.00	0.00	0.25
16	0	-1.10	-0.03	-0.97	0.00	0.01	0.01	1.07

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.

Table 11.1.3-3 Standard Canister Off-Normal Handling plus Normal/Off-Normal Internal Pressure (15 psig) Primary Membrane (P_m) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[2]	Margin of Safety
1	0	-1.45	4.36	0.94	0.11	-0.04	-0.17	5.83	21.04	2.61
2	0	3.38	-2.09	-3.64	-0.30	-0.16	-0.57	7.14	21.03	1.94
3	0	-0.14	1.28	0.79	0.02	-0.02	0.08	1.43	19.61	12.75
4	0	-0.20	1.18	0.79	0.00	-0.01	0.08	1.38	18.40	12.29
5	0	-0.23	1.18	0.78	0.00	-0.01	0.08	1.42	17.41	11.29
6	0	-0.25	1.24	0.77	0.00	0.00	0.07	1.50	18.26	11.21
7	0	-0.29	1.39	0.73	0.00	0.01	0.06	1.68	19.38	10.54
8	0	-0.05	2.41	0.31	-0.02	0.24	0.08	2.51	20.60	7.22
9	0	0.09	3.69	0.89	0.24	0.38	0.13	3.70	20.94	4.66
10	0	-0.56	4.45	0.75	0.01	0.52	0.17	5.11	20.95	3.10
11	0	-0.24	3.29	1.33	-1.18	0.53	-0.08	4.36	21.06	3.83
12	0	-0.36	2.90	0.62	0.24	0.30	0.17	3.35	20.94	5.24
13	0	-4.45	0.09	0.89	-1.96	0.14	-0.05	6.19	21.07	2.40
14	0	0.55	-0.03	0.67	-0.07	-0.27	0.00	0.90	20.04	21.38
15	0	-0.07	-0.01	-0.06	0.00	0.00	0.00	0.06	20.96	348.83
16	0	-0.04	0.00	0.06	0.00	0.01	0.00	0.11	20.96	195.09

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.
2. ASME Service Level C is used for material allowable stress.

Table 11.1.3-4 Standard Canister Off-Normal Handling plus Normal/Off-Normal Internal Pressure (15 psig) Primary Membrane plus Bending ($P_m + P_b$) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[2]	Margin of Safety
1	0	6.65	11.53	1.34	0.53	0.04	-0.20	10.26	31.23	2.04
2	0	1.23	-19.14	-9.27	-1.30	-0.39	-0.96	20.64	31.21	0.51
3	0	-0.13	1.36	1.03	0.02	0.00	0.10	1.49	27.78	17.63
4	0	-0.21	1.18	0.81	0.00	-0.02	0.08	1.40	25.48	17.20
5	0	-0.25	1.23	0.95	0.00	-0.01	0.09	1.48	24.10	15.25
6	0	-0.28	1.32	1.07	0.00	-0.01	0.10	1.61	25.29	14.75
7	0	-0.32	1.50	1.14	0.01	0.01	0.09	1.82	27.24	13.93
8	0	-0.07	2.48	0.45	-0.02	0.29	0.09	2.61	30.15	10.57
9	0	0.03	5.40	1.22	0.14	0.48	0.14	5.44	30.97	4.69
10	0	-0.24	4.83	0.77	-0.15	0.69	0.13	5.21	31.02	4.95
11	0	-1.09	2.73	1.36	-2.08	0.40	-0.14	5.73	31.28	4.46
12	0	-0.95	3.75	0.64	0.16	0.34	0.22	4.77	30.99	5.49
13	0	-9.02	-1.74	0.16	-1.55	-0.04	0.09	9.51	31.29	2.29
14	130	13.93	0.38	13.96	-0.07	-0.27	0.01	13.60	28.81	1.12
15	0	-0.20	-0.01	-0.22	0.00	0.00	0.00	0.20	31.04	152.95
16	0	0.96	0.03	1.07	0.00	0.01	-0.01	1.05	31.04	28.67

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.
2. ASME Service Level C is used for material allowable stress.

Table 11.1.3-5 Standard Canister Off-Normal Handling plus Normal/Off-Normal Internal Pressure (15 psig) Primary plus Secondary (P + Q) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[2]	Margin of Safety
1	60	3.46	14.31	4.54	-0.08	-0.26	-0.65	11.17	50.10	3.49
2	50	-4.61	-23.19	-2.69	-1.05	1.10	-5.11	24.92	50.10	1.01
3	0	-0.47	1.15	3.82	0.02	-0.43	0.32	4.41	49.02	10.12
4	0	-1.15	0.70	8.50	-0.04	-0.55	0.78	9.81	46.00	3.69
5	0	-2.65	-9.75	-17.93	0.03	0.04	-3.38	16.71	43.52	1.60
6	0	-1.40	1.34	9.43	0.04	0.55	0.83	10.98	45.66	3.16
7	0	-0.97	2.75	5.42	0.04	0.48	0.38	6.52	48.45	6.43
8	0	0.41	6.76	1.16	0.18	1.13	0.34	6.72	50.10	6.45
9	0	1.97	8.26	2.92	1.51	0.46	-0.33	7.14	50.10	6.02
10	0	-8.12	3.90	-1.97	-0.90	0.00	0.26	12.16	50.10	3.12
11	0	2.08	-11.54	-2.14	0.57	-0.29	-0.28	13.70	50.10	2.66
12	0	-8.12	3.90	-1.97	-0.90	0.00	0.26	12.16	50.10	3.12
13	0	2.44	8.20	4.06	-1.97	0.26	0.25	7.03	50.10	6.13
14	0	-15.14	-0.25	-14.60	-0.09	0.02	-0.27	15.00	50.10	2.34
15	180	-8.63	-6.89	-7.75	0.01	-0.50	-0.19	2.02	50.10	23.80
16	50	0.22	-0.57	0.26	0.02	0.06	-0.03	0.85	50.10	57.91

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.
2. ASME Service Level C is used for material allowable stress.

Table 11.1.3-6 P_m Stresses for the Standard Configuration PWR Support Disk in Off-Normal Conditions (ksi)

Section[1]	S_x	S_y	S_{xy}	Stress Intensity	Allowable Stress[2]	Margin of Safety
120	0.8	-0.8	0.1	1.6	77.7	47.6
114	-0.5	1.0	-0.1	1.5	77.7	50.8
21	-0.3	-1.1	0.1	1.1	77.7	69.6
37	-1.1	-0.3	0.1	1.1	77.7	69.6
23	0.0	1.0	0.2	1.1	77.7	69.6
35	1.0	0.0	0.2	1.1	77.7	69.6
111	-0.3	0.5	0.2	0.9	77.7	85.3
112	0.5	-0.3	0.2	0.9	77.7	85.3
98	-0.5	-0.8	-0.2	0.9	77.7	85.3
40	0.1	-0.7	0.1	0.9	77.7	85.3
28	-0.8	0.1	0.1	0.9	77.7	85.3
51	0.8	0.1	0.1	0.8	77.7	96.1
7	0.1	0.8	0.1	0.8	77.7	96.1
110	-0.8	0.0	0.1	0.8	77.7	96.1
72	-0.8	-0.7	0.0	0.8	77.7	96.1
26	-0.8	-0.4	0.1	0.8	77.7	96.1
119	0.0	-0.8	0.1	0.8	77.7	96.1
42	-0.4	-0.8	0.1	0.8	77.7	96.1
95	0.0	-0.8	0.1	0.8	77.7	96.1
64	-0.8	0.0	0.1	0.8	77.7	96.1
49	-0.7	0.0	0.1	0.8	77.7	96.1
9	0.0	-0.7	0.1	0.8	77.7	96.1
94	-0.8	0.0	0.1	0.8	77.7	96.1
71	0.0	-0.7	0.1	0.8	77.7	96.1
46	-0.7	-0.2	0.1	0.7	77.7	110.0
123	-0.3	0.4	-0.1	0.7	77.7	110.0
124	0.4	-0.3	-0.1	0.7	77.7	110.0
96	-0.4	0.1	0.2	0.7	77.7	110.0
63	0.1	-0.4	0.2	0.7	77.7	110.0
92	0.2	-0.4	-0.2	0.7	77.7	110.0
91	-0.4	0.2	-0.2	0.7	77.7	110.0
99	-0.5	0.1	0.0	0.7	77.7	110.0
74	0.1	-0.5	0.0	0.7	77.7	110.0
104	-0.6	0.0	-0.2	0.6	77.7	128.5
106	0.1	-0.5	-0.1	0.6	77.7	128.5
117	-0.4	0.2	0.0	0.6	77.7	128.5
113	0.2	-0.3	0.0	0.6	77.7	128.5
67	-0.5	0.1	-0.1	0.6	77.7	128.5
88	0.5	0.2	-0.2	0.6	77.7	128.5
39	0.0	-0.5	0.1	0.6	77.7	128.5

1. Section locations are shown in Figures 3.4.4.1-7 and 3.4.4.1-8.
2. Stress allowables are taken at 800°F.

Table 11.1.3-7 $P_m + P_b$ Stresses for the Standard Configuration PWR Support Disk in Off-Normal Conditions (ksi)

Section[1]	S_x	S_y	S_{xy}	Stress Intensity	Allowable Stress[2]	Margin of Safety
37	-2.5	-5.1	0.6	5.3	63.2	10.9
21	-5.1	-2.5	0.6	5.3	63.2	10.9
120	-0.4	-5.1	0.4	5.1	63.2	11.4
23	4.5	2.5	0.6	4.6	63.2	12.7
35	2.4	4.5	0.6	4.6	63.2	12.7
4	3.0	4.3	0.4	4.5	63.2	13.0
1	4.3	3.0	0.4	4.4	63.2	13.4
112	-1.1	-4.7	0.0	4.7	63.2	12.4
111	-4.7	-1.1	0.0	4.7	63.2	12.4
51	2.0	4.3	0.5	4.4	63.2	13.4
7	4.3	2.0	0.5	4.4	63.2	13.4
9	-3.9	-1.9	0.5	4.0	63.2	14.8
49	-1.9	-3.9	0.5	4.0	63.2	14.8
66	4.1	1.0	0.4	4.1	63.2	14.4
3	-3.7	-2.8	0.5	3.9	63.2	15.2
2	-2.8	-3.6	0.5	3.8	63.2	15.6
20	-2.9	-3.7	0.4	3.9	63.2	15.2
34	-3.7	-2.9	0.4	3.9	63.2	15.2
42	-0.9	-4.0	0.2	4.0	63.2	14.8
26	-4.0	-0.9	0.2	4.0	63.2	14.8
96	0.9	3.9	0.0	3.9	63.2	15.2
63	3.9	0.9	0.0	3.9	63.2	15.2
28	-3.6	-0.4	0.1	3.6	63.2	16.6
40	-0.4	-3.6	0.1	3.6	63.2	16.6
95	-3.3	-2.1	0.5	3.5	63.2	17.1
64	-2.1	-3.3	0.5	3.4	63.2	17.6
48	3.1	2.4	0.3	3.2	63.2	18.8
6	2.4	3.1	0.3	3.2	63.2	18.8
14	3.1	0.7	0.2	3.1	63.2	19.4
54	0.7	3.1	0.2	3.1	63.2	19.4
56	0.4	3.1	0.0	3.1	63.2	19.4
12	3.1	0.4	0.0	3.1	63.2	19.4
79	2.9	1.6	0.3	3.0	63.2	20.1
80	1.6	2.9	0.3	3.0	63.2	20.1
122	-2.8	-0.4	0.4	2.9	63.2	20.8
115	-0.4	-2.8	0.4	2.9	63.2	20.8
72	-1.5	-2.6	0.3	2.7	63.2	22.4
82	-2.4	-0.4	0.3	2.4	63.2	25.3
123	-1.9	0.2	-0.6	2.3	63.2	26.5
124	0.2	-1.9	-0.6	2.3	63.2	26.5

1. Section locations are shown in Figures 3.4.4.1-7 and 3.4.4.1-8.
2. Stress allowables are taken at 800°F.

Table 11.1.3-8 $P_m + P_b + Q$ Stresses for the Standard Configuration PWR Support Disk in Off-Normal Conditions (ksi)

Section[1]	S_x	S_y	S_{xy}	Stress Intensity	Allowable Stress[2]	Margin of Safety
44	-9.2	-31.2	6.5	33.0	105.3	2.19
58	-9.0	-29.6	6.2	31.3	105.3	2.36
21	-25.3	-9.2	2.9	25.8	105.3	3.08
37	-9.1	-25.3	2.8	25.8	105.3	3.08
49	-8.5	-23.9	2.7	24.3	105.3	3.33
9	-23.8	-8.6	2.7	24.3	105.3	3.33
112	-8.8	-24.2	2.4	24.5	105.3	3.30
111	-24.1	-8.7	2.4	24.4	105.3	3.32
107	22.9	2.0	-4.2	23.7	105.3	3.44
123	21.9	2.6	5.8	23.5	105.3	3.48
124	2.5	21.9	5.7	23.4	105.3	3.50
76	1.9	22.7	-4.1	23.4	105.3	3.50
75	22.2	1.8	-4.1	22.9	105.3	3.60
80	-8.2	-22.1	2.3	22.5	105.3	3.68
79	-22.0	-8.1	2.3	22.4	105.3	3.70
92	2.1	21.3	5.4	22.7	105.3	3.64
91	21.2	2.3	5.6	22.7	105.3	3.64
108	1.6	21.9	-4.0	22.7	105.3	3.64
32	20.7	-0.4	-1.2	21.2	105.3	3.97
31	20.3	-0.5	1.6	21.1	105.3	3.99
45	-0.5	20.0	-1.5	20.7	105.3	4.09
17	19.9	-0.3	-1.2	20.4	105.3	4.16
18	19.5	-0.5	1.5	20.2	105.3	4.21
60	-0.4	19.2	-1.4	19.9	105.3	4.29
46	-2.3	17.2	0.3	19.5	105.3	4.40
20	-13.7	-13.8	4.9	18.6	105.3	4.66
34	-13.7	-13.7	4.9	18.5	105.3	4.69
59	-2.2	16.6	0.3	18.8	105.3	4.60
6	-13.0	-12.8	4.6	17.5	105.3	5.02
48	-12.7	-13.0	4.6	17.4	105.3	5.05
30	-11.4	-13.9	4.8	17.6	105.3	4.98
7	-16.2	-4.8	-1.9	16.5	105.3	5.38
120	-4.7	-17.0	1.4	17.2	105.3	5.12
42	-6.2	-16.7	1.5	16.9	105.3	5.23
95	-16.1	-7.2	-2.4	16.8	105.3	5.27
51	-4.7	-16.1	-1.9	16.4	105.3	5.42
26	-16.5	-6.1	1.4	16.7	105.3	5.31
64	-7.2	-16.0	-2.4	16.6	105.3	5.34
16	-10.8	-13.5	4.5	16.9	105.3	5.23
23	-16.0	-4.4	-1.8	16.3	105.3	5.46

1. Section locations are shown in Figures 3.4.4.1-7 and 3.4.4.1-8.
2. Stress allowables are taken at 800°F.

Table 11.1.3-9 P_m Stresses for the Standard Configuration BWR Support Disk in Off-Normal Conditions (ksi)

Section[1]	S_x	S_y	S_{xy}	Stress Intensity	Allowable Stress[2]	Margin of Safety
265	-0.9	0.9	0.1	1.9	58.3	29.7
10	0.7	-0.4	-0.7	1.8	58.3	31.4
277	0.9	-0.9	0.1	1.8	58.3	31.4
262	-0.8	0.7	0.1	1.5	58.3	37.9
259	-0.7	0.6	0.1	1.4	58.3	40.6
77	0.6	-0.8	0.0	1.3	58.3	43.8
194	-0.6	0.6	0.1	1.2	58.3	47.6
197	-0.5	0.5	0.1	1.1	58.3	52.0
263	-0.9	-0.9	0.1	1.0	58.3	57.3
12	-0.4	0.0	-0.4	1.0	58.3	57.3
229	-0.8	0.2	0.1	1.0	58.3	57.3
264	-0.9	0.0	0.1	1.0	58.3	57.3
276	0.5	-0.4	0.1	0.9	58.3	63.8
76	0.6	-0.3	0.1	0.9	58.3	63.8
16	-0.3	0.4	-0.3	0.9	58.3	63.8
260	-0.8	-0.8	0.1	0.9	58.3	63.8
286	0.4	-0.5	0.1	0.9	58.3	63.8
85	-0.9	-0.8	0.0	0.9	58.3	63.8
269	-0.8	-0.9	0.0	0.9	58.3	63.8
273	0.0	-0.9	0.0	0.9	58.3	63.8
211	-0.6	0.3	0.1	0.9	58.3	63.8
261	-0.8	0.0	0.1	0.9	58.3	63.8
193	-0.7	-0.8	0.1	0.8	58.3	71.9
289	-0.8	-0.5	0.1	0.8	58.3	71.9
88	0.6	-0.2	0.1	0.8	58.3	71.9
103	-0.8	-0.1	0.1	0.8	58.3	71.9
9	0.0	-0.1	-0.4	0.8	58.3	71.9
14	-0.3	0.0	-0.3	0.8	58.3	71.9
81	0.0	-0.8	0.0	0.8	58.3	71.9
258	-0.7	0.0	0.1	0.8	58.3	71.9
268	-0.7	-0.4	0.1	0.7	58.3	82.3
97	0.6	-0.1	0.1	0.7	58.3	82.3
11	0.0	-0.1	-0.4	0.7	58.3	82.3
294	-0.7	-0.1	0.2	0.7	58.3	82.3
196	-0.6	-0.7	0.1	0.7	58.3	82.3
166	0.7	0.1	0.1	0.7	58.3	82.3
280	-0.7	-0.5	0.1	0.7	58.3	82.3
84	-0.7	-0.3	0.1	0.7	58.3	82.3
246	-0.1	-0.7	0.1	0.7	58.3	82.3
199	-0.5	-0.7	0.1	0.7	58.3	82.3

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.
2. Stress allowables are taken at 800°F.

Table 11.1.3-10 $P_m + P_b$ Stresses for the Standard Configuration BWR Support Disk in Off-Normal Conditions (ksi)

Section[1]	S_x	S_y	S_{xy}	Stress Intensity	Allowable Stress[2]	Margin of Safety
265	-4.6	0.8	-0.2	5.3	48.6	8.2
295	-1.6	-5.0	0.5	5.1	48.6	8.5
294	-2.2	-4.9	0.5	5.0	48.6	8.7
254	-4.8	-2.2	0.5	4.9	48.6	8.9
257	-4.5	-1.6	0.6	4.6	48.6	9.6
293	-1.9	-4.4	0.4	4.5	48.6	9.8
289	-2.3	-4.3	0.6	4.5	48.6	9.8
243	-4.3	-1.5	0.2	4.3	48.6	10.3
24	-4.3	-1.4	0.1	4.3	48.6	10.3
263	-4.0	-2.4	0.7	4.3	48.6	10.3
275	1.7	4.3	0.3	4.3	48.6	10.3
252	4.2	1.7	0.3	4.3	48.6	10.3
246	-4.1	-1.7	0.5	4.2	48.6	10.6
274	1.7	4.1	0.3	4.2	48.6	10.6
10	-0.3	-2.2	-1.9	4.2	48.6	10.6
267	-1.6	-4.1	0.2	4.2	48.6	10.6
241	4.1	1.5	0.2	4.1	48.6	10.9
288	1.8	4.1	0.4	4.1	48.6	10.9
227	0.9	4.1	0.2	4.1	48.6	10.9
75	-1.7	-4.1	0.3	4.1	48.6	10.9
22	-4.1	-1.7	0.3	4.1	48.6	10.9
208	-1.6	-4.0	0.3	4.1	48.6	10.9
32	4.0	1.6	0.3	4.0	48.6	11.2
51	4.0	1.0	0.1	4.0	48.6	11.2
237	4.0	1.8	0.3	4.0	48.6	11.2
83	-1.6	-4.0	0.3	4.0	48.6	11.2
19	4.0	1.6	0.3	4.0	48.6	11.2
62	3.9	1.4	0.4	4.0	48.6	11.2
228	0.8	3.9	0.3	4.0	48.6	11.2
21	3.9	1.7	0.3	4.0	48.6	11.2
240	3.9	1.8	0.3	4.0	48.6	11.2
74	1.6	3.9	0.3	3.9	48.6	11.5
174	3.9	1.7	0.3	3.9	48.6	11.5
238	3.9	1.4	0.2	3.9	48.6	11.5
209	-1.4	-3.9	0.3	3.9	48.6	11.5
18	3.9	1.6	0.3	3.9	48.6	11.5
266	1.7	3.9	0.3	3.9	48.6	11.5
184	-3.8	-1.6	0.3	3.9	48.6	11.5
137	1.7	3.8	0.3	3.9	48.6	11.5
49	-3.8	-1.5	0.2	3.9	48.6	11.5

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.
2. Stress allowables are taken at 800°F.

Table 11.1.3-11 $P_m + P_b + Q$ Stresses for the Standard Configuration BWR Support Disk in Off-Normal Conditions (ksi)

Section[1]	S_x	S_y	S_{xy}	Stress Intensity	Allowable Stress[2]	Margin of Safety
295	-2.0	-20.5	1.3	20.6	81.0	2.93
268	-9.2	-18.9	2.2	19.4	81.0	3.18
289	-6.6	-18.8	1.6	19.0	81.0	3.26
16	16.0	5.1	5.4	18.3	81.0	3.43
139	-8.7	-17.8	2.1	18.2	81.0	3.45
30	-9.1	-17.2	2.7	18.0	81.0	3.50
14	15.7	4.6	5.2	17.8	81.0	3.55
265	-17.5	-6.3	1.6	17.7	81.0	3.58
276	-6.3	-17.5	1.3	17.7	81.0	3.58
166	-0.3	-17.4	0.9	17.5	81.0	3.63
43	-9.3	-16.5	2.7	17.4	81.0	3.66
266	-9.7	-16.4	2.2	17.0	81.0	3.76
137	-9.6	-16.2	2.1	16.8	81.0	3.82
24	-15.6	-10.2	2.9	16.8	81.0	3.82
18	-16.0	-8.6	2.6	16.8	81.0	3.82
15	13.6	4.8	-6.2	16.8	81.0	3.82
160	-5.5	-16.4	1.4	16.6	81.0	3.88
31	-15.8	-8.6	2.6	16.6	81.0	3.88
21	-16.0	-7.8	2.4	16.6	81.0	3.88
269	-7.8	-15.9	1.9	16.3	81.0	3.97
263	-16.1	-6.6	1.5	16.3	81.0	3.97
147	-6.1	-16.1	1.3	16.3	81.0	3.97
34	-15.6	-7.5	2.4	16.3	81.0	3.97
2	-1.8	14.2	-1.0	16.1	81.0	4.03
1	-1.8	14.2	-1.0	16.1	81.0	4.03
274	-7.8	-15.7	1.9	16.1	81.0	4.03
246	-15.9	-5.2	1.6	16.1	81.0	4.03
13	13.0	4.4	-6.0	16.1	81.0	4.03
37	-14.5	-9.6	2.7	15.7	81.0	4.16
238	-15.3	-8.4	1.8	15.7	81.0	4.16
241	-15.5	-6.8	1.4	15.7	81.0	4.16
145	-7.7	-15.2	1.8	15.6	81.0	4.19
243	-15.4	-6.8	1.3	15.6	81.0	4.19
4	-1.8	13.6	-0.9	15.5	81.0	4.23
3	-1.8	13.6	-0.9	15.5	81.0	4.23
111	-15.0	-8.2	1.8	15.4	81.0	4.26
267	-9.2	-14.8	1.9	15.3	81.0	4.29
277	-3.8	-14.8	1.4	15.0	81.0	4.40
140	-7.4	-14.4	1.7	14.8	81.0	4.47
27	-13.9	-8.4	2.5	14.8	81.0	4.47

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16.
2. Stress allowables are taken at 800°F.

Table 11.1.3-12 Summary of Maximum Stresses for PWR and BWR Fuel Basket Weldments in the Standard Configuration - Off-Normal Condition (ksi)

Component	Stress Category	Maximum Stress Intensity[1]	Node Temperature (°F)	Allowable Stress[2,3]	Margin of Safety
PWR Top Weldment	$P_m + P_b$	0.7	297	20.7	+Large
	$P_m + P_b + Q$	52.1	292	56.1	+0.08
PWR Bottom Weldment	$P_m + P_b$	0.8	179	22.5	+Large
	$P_m + P_b + Q$	20.9	175	60.0	+1.87
BWR Top Weldment	$P_m + P_b$	1.2	226	19.4	+Large
	$P_m + P_b + Q$	14.6	383	52.5	+2.60
BWR Bottom Weldment	$P_m + P_b$	1.5	265	22.5	+Large
	$P_m + P_b + Q$	36.6	203	60.0	+0.64

1. Nodal stresses are from the finite element analysis.
2. Conservatively, stress allowables are taken at 400°F for the PWR top weldment, 300°F for the PWR bottom weldment, 500°F for the BWR top weldment, and 300°F for the BWR bottom weldment.
3. P_m stress allowables are conservatively used for the P_m+P_b evaluation.

Table 11.1.3-13 Advanced Canister Normal Handling plus Off-Normal Internal Pressure (50 psig) Primary Membrane (P_m) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	180	0.25	5.28	2.03	0.63	0.00	-0.11	5.19	16.21	2.12
2	180	2.94	-3.18	-5.65	0.71	0.04	0.49	8.73	16.20	0.86
3	0	-0.76	2.01	-8.74	1.53	-0.10	-0.53	11.48	16.18	0.41
4	0	-0.02	1.92	2.65	0.00	0.00	0.17	2.69	15.36	4.71
5	0	-0.01	1.92	2.62	0.00	0.00	0.17	2.66	14.63	4.50
6	180	-0.01	1.95	2.62	0.00	0.00	-0.17	2.65	14.59	4.51
7	0	-0.01	2.03	2.61	0.00	0.01	0.17	2.65	15.40	4.81
8	180	-0.01	2.34	1.94	0.02	0.05	-0.13	2.36	16.33	5.92
9	0	0.14	2.38	0.95	0.19	0.10	0.05	2.28	16.57	6.27
10	180	-0.73	2.35	0.68	0.24	0.18	-0.10	3.14	16.58	4.28
11	45	0.62	-0.41	0.62	0.03	-0.03	-0.34	1.38	16.65	11.07
12	180	-0.35	0.78	0.39	0.12	0.07	-0.10	1.18	16.58	13.05
13	180	0.17	0.85	1.36	0.43	0.03	-0.15	1.43	16.65	10.64
14	180	0.81	-0.04	0.81	-0.20	-0.52	0.00	1.40	15.34	9.96
15	0	-0.12	-0.03	-0.12	0.00	0.01	0.00	0.09	16.27	179.78
16	180	0.12	0.00	0.12	0.01	0.02	0.00	0.12	16.48	136.33

Note: Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-14 Advanced Canister Normal Handling plus Off-Normal Internal Pressure (50 psig) Primary Membrane plus Bending ($P_m + P_b$) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	180	2.75	12.86	-1.07	0.09	0.02	0.16	13.95	24.31	0.74
4	180	-0.03	1.87	2.66	0.01	0.00	-0.18	2.71	23.05	7.51
5	180	-0.03	1.92	2.62	0.00	0.00	-0.17	2.67	21.94	7.22
6	180	0.00	1.96	2.67	0.00	0.00	-0.18	2.69	21.89	7.14
7	0	0.00	2.08	2.75	0.00	0.01	0.18	2.77	23.10	7.34
8	180	-0.02	2.72	2.15	0.02	0.05	-0.15	2.76	24.49	7.87
9	180	0.12	3.54	1.24	-0.28	0.14	-0.05	3.47	24.86	6.16
10	0	-0.42	3.43	1.03	-0.17	0.25	0.09	3.90	24.88	5.38
11	45	0.11	-2.88	0.11	0.06	-0.06	-0.63	3.63	24.97	5.88
12	180	-1.04	0.80	0.20	0.32	0.09	-0.13	1.97	24.86	11.62
13	0	0.35	1.88	1.18	-0.77	0.11	0.01	2.19	24.98	10.41
14	180	20.15	0.48	20.26	-0.20	-0.52	0.00	19.81	23.01	0.16
15	0	-1.09	-0.07	-1.09	0.00	0.01	0.00	1.03	24.40	22.69
16	0	0.99	0.02	0.99	0.01	0.02	0.00	0.97	24.73	24.49

Notes:
1. Bending stresses at the flat head junction to the shell (Section Numbers 2 and 3) can be classified as secondary in accordance with NB-3217.
2. Stress Allowable is ASME Service Level A.
3. Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-15 Advanced Canister Normal Handling plus Off-Normal Internal Pressure (50 psig) Primary plus Secondary (P + Q) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	0	4.40	18.09	2.24	0.20	0.01	-0.04	15.85	48.62	2.07
2	0	2.36	-29.76	-12.65	-1.71	0.12	-0.92	32.36	48.61	0.50
3	0	-2.83	37.16	1.13	1.93	-0.13	0.19	40.19	48.53	0.21
4	0	-0.04	1.85	2.65	-0.01	-0.01	0.18	2.71	46.09	16.01
5	0	-0.02	1.99	2.58	-0.01	-0.01	0.17	2.63	43.88	15.68
6	15	0.14	2.10	2.42	0.01	0.02	0.66	2.64	43.78	15.58
7	180	0.00	2.09	2.75	0.00	0.00	-0.18	2.77	46.20	15.68
8	0	-0.04	2.76	2.13	-0.02	0.04	0.15	2.82	48.98	16.37
9	0	1.04	3.96	1.64	1.35	0.05	0.03	3.98	49.72	11.49
10	45	-0.15	8.38	-0.15	0.21	-0.21	2.31	10.85	49.75	3.59
11	45	0.08	-11.42	0.08	0.29	-0.29	-2.45	13.98	49.95	2.57
12	0	-6.98	-1.31	-2.30	-1.33	0.15	0.31	6.28	49.73	6.92
13	135	-1.02	1.62	-1.02	-0.52	-0.52	-1.49	4.38	49.96	10.41
14	45	-20.19	-2.78	-19.78	-0.05	0.35	-0.07	17.43	46.13	1.65
15	180	-16.57	-13.09	-15.73	-0.03	-1.01	-0.25	3.92	48.80	11.45
16	180	-3.66	-3.53	-3.43	0.02	0.35	-0.08	0.73	49.45	66.74

Notes:
1. ASME Section III, Subsection NB does not specify allowable stresses for primary plus secondary for Service Level B; therefore, the allowables for Service Level A are used.
2. Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-16 Off-Normal Internal Pressure (50 psig) Only Primary Membrane (P_m) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	0	0.18	3.66	1.41	-0.45	0.01	0.08	3.60	17.83	3.95
2	0	2.06	-2.23	-3.75	-0.48	0.03	-0.33	5.91	17.82	2.02
3	0	-0.54	1.37	-5.72	1.08	-0.07	-0.35	7.61	17.79	1.34
4	180	-0.02	1.30	2.64	0.00	0.00	-0.17	2.68	16.90	5.31
5	0	-0.01	1.30	2.62	0.00	0.00	0.17	2.66	16.09	5.05
6	0	-0.01	1.30	2.62	0.00	0.00	0.17	2.66	16.05	5.03
7	0	-0.01	1.30	2.62	0.00	0.00	0.17	2.66	16.94	5.37
8	0	-0.02	1.30	1.98	-0.02	0.00	0.13	2.01	17.96	7.94
9	0	0.10	1.00	0.66	0.14	-0.01	0.04	0.94	18.23	18.39
10	0	-0.55	0.61	0.37	-0.20	0.01	0.05	1.23	18.24	13.83
11	90	0.27	-0.17	0.61	0.00	0.02	0.00	0.79	18.31	22.18
12	180	-0.24	-0.73	0.06	0.19	-0.01	-0.02	0.85	18.23	20.45
13	0	-0.02	0.66	0.38	0.05	-0.01	0.03	0.69	18.32	25.55
14	180	0.57	-0.02	0.57	-0.13	-0.35	0.00	0.96	16.88	16.58
15	180	-0.09	-0.04	-0.09	0.00	0.01	0.00	0.06	17.89	297.17
16	180	0.10	0.00	0.10	0.00	0.01	0.00	0.10	18.13	180.30

Note: Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-17 Advanced Canister Off-Normal Internal Pressure (50 psig) Only Primary Membrane plus Bending ($P_m + P_b$) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	180	1.95	8.90	-0.56	0.06	0.02	0.10	9.47	26.74	1.82
2	0	1.36	-17.08	-8.33	-1.07	0.06	-0.59	18.60	26.74	0.44
3	0	-1.73	22.32	0.11	1.26	-0.08	0.07	24.18	26.69	0.10
4	180	-0.03	1.27	2.66	0.00	0.00	-0.18	2.71	25.35	8.35
5	0	-0.03	1.31	2.65	0.00	0.00	0.18	2.70	24.14	7.94
6	180	-0.03	1.31	2.65	0.00	0.00	-0.18	2.70	24.08	7.92
7	180	-0.03	1.31	2.65	0.00	0.00	-0.18	2.70	25.41	8.41
8	180	-0.03	1.63	2.04	0.02	0.00	-0.13	2.09	26.94	11.89
9	0	0.14	1.90	0.93	0.28	-0.02	0.05	1.85	27.35	13.78
10	0	-0.34	2.68	1.05	-0.02	0.01	0.08	3.02	27.37	8.06
11	180	0.49	-1.67	-0.21	-0.02	0.00	0.03	2.15	27.47	11.78
12	0	-0.70	-1.36	-0.26	-0.38	-0.01	0.03	1.28	27.35	20.37
13	180	-0.58	0.24	0.14	-0.13	-0.02	-0.04	0.86	27.48	30.95
14	180	13.61	0.32	13.68	-0.13	-0.35	0.00	13.38	25.32	0.89
15	180	-1.10	-0.07	-1.10	0.00	0.01	0.00	1.03	26.84	25.06
16	0	0.58	0.01	0.59	0.00	0.01	0.00	0.58	27.20	45.90

Notes:
1. Stress allowables are for ASME Service Level B.
2. Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-18 Advanced Canister Off-Normal Handling (No Internal Pressure) Primary Membrane (P_m) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	180	0.74	2.07	1.05	-3.44	-1.44	0.23	7.57	19.45	1.57
2	180	1.57	5.60	0.22	-1.66	-1.69	-0.78	7.41	19.45	1.62
3	180	2.04	7.94	-0.06	-0.33	-1.47	-0.65	8.72	19.41	1.23
4	0	2.69	2.78	0.16	-0.01	0.00	-0.42	2.69	18.44	5.86
5	0	3.04	2.76	0.13	0.00	-0.01	-0.44	3.05	17.55	4.75
6	0	2.93	2.55	0.14	0.00	-0.02	-0.43	2.92	17.51	5.00
7	0	2.44	2.07	0.20	0.01	-0.04	-0.38	2.36	18.48	6.83
8	90	-0.04	1.82	0.01	-0.13	0.00	0.00	1.87	19.59	9.48
9	90	0.69	2.53	0.09	-0.16	-0.14	-0.02	2.47	19.89	7.05
10	180	1.86	5.11	1.24	-0.75	0.48	-0.23	4.19	19.90	3.75
11	180	1.59	3.85	1.33	1.44	0.63	0.03	3.89	19.98	4.14
12	180	1.06	3.21	0.78	-1.16	0.27	-0.32	3.32	19.89	4.99
13	180	0.54	0.38	1.11	2.19	0.45	0.29	4.54	19.98	3.40
14	180	0.01	-0.02	0.06	-0.33	0.38	-0.08	1.01	18.41	17.23
15	143	0.00	0.08	-0.02	0.13	-0.01	-0.03	0.28	19.53	68.75
16	180	-0.04	-0.05	0.04	-0.43	0.10	-0.03	0.89	19.78	21.22

Note: Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-19 Advanced Canister Off-Normal Handling (No Internal Pressure) Primary Membrane plus Bending ($P_m + P_b$) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	180	0.78	4.17	-0.56	-3.43	-1.49	-1.31	9.26	27.41	1.96
2	180	1.12	5.32	-0.22	-3.09	-1.41	-1.06	9.04	27.40	2.03
3	180	1.88	8.69	-0.59	-0.22	-1.34	-0.66	9.83	27.32	1.78
4	0	1.61	1.07	-4.47	-0.01	0.07	-0.60	6.20	25.53	3.12
5	0	1.75	0.71	-5.43	0.00	0.01	-0.66	7.31	24.31	2.33
6	0	1.68	0.54	-5.30	0.00	-0.04	-0.64	7.09	24.25	2.42
7	0	1.39	0.41	-4.30	0.01	-0.10	-0.55	5.80	25.59	3.41
8	0	0.69	0.51	-1.50	-0.03	-0.26	-0.31	2.32	27.74	10.96
9	90	0.94	3.65	-0.01	-0.22	-0.06	-0.01	3.69	28.45	6.71
10	180	1.64	4.79	1.14	-1.26	0.42	-0.34	4.35	28.47	5.54
11	180	1.03	2.50	1.03	2.39	0.57	0.02	5.12	28.66	4.60
12	180	1.47	4.34	1.05	-1.38	0.36	-0.40	4.24	28.45	5.71
13	180	0.63	1.19	0.65	2.37	0.59	-0.01	4.91	28.67	4.84
14	180	0.84	0.17	2.92	-0.33	0.38	-0.40	3.03	25.50	7.42
15	180	-0.15	0.12	-0.61	0.18	0.04	-0.21	0.92	27.57	28.97
16	180	0.18	-0.23	0.95	-0.42	0.25	0.40	1.73	28.19	15.29

Notes:
1. Stress allowables are for ASME Service Level C.
2. Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-20 Advanced Canister Off-Normal Handling plus Normal Internal Pressure (40 psig) Primary Membrane (P_m) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	180	1.43	4.12	1.97	-6.77	-2.83	0.50	14.88	19.45	0.31
2	180	3.16	11.12	0.48	-3.21	-3.33	-1.57	14.62	19.45	0.33
3	180	4.25	15.81	0.27	-0.74	-2.95	-1.31	17.05	19.41	0.14
4	15	0.68	3.38	2.04	-0.03	-0.13	0.36	2.80	18.44	5.59
5	15	0.68	3.11	2.06	-0.02	-0.06	0.34	2.52	17.55	5.96
6	15	0.66	2.87	2.08	-0.02	-0.08	0.35	2.30	17.51	6.61
7	75	1.96	1.63	0.14	-0.33	-0.09	0.53	2.28	18.48	7.11
8	90	1.54	2.89	0.00	-0.13	0.02	0.00	2.90	19.59	5.76
9	90	1.06	3.38	0.10	-0.16	-0.18	-0.02	3.32	19.89	4.99
10	90	0.82	3.59	-0.74	-0.18	0.24	0.02	4.36	19.90	3.56
11	180	1.73	4.05	1.52	1.55	0.82	0.03	4.23	19.98	3.72
12	180	1.27	3.05	0.86	-0.41	0.39	-0.16	2.44	19.89	7.15
13	180	0.60	0.41	1.39	2.38	0.59	0.39	5.05	19.98	2.96
14	180	0.05	-0.05	0.19	-0.38	0.76	-0.08	1.72	18.41	9.70
15	150	-0.03	-0.02	-0.07	0.06	0.00	-0.03	0.15	19.53	129.20
16	0	0.04	0.00	0.13	-0.01	-0.04	-0.03	0.16	19.78	122.63

Note: Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-21 Advanced Canister Off-Normal Handling plus Normal Internal Pressure (40 psig) Primary Membrane plus Bending ($P_m + P_b$) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	180	1.56	8.29	-1.01	-6.71	-2.96	-2.55	18.18	27.41	0.51
2	180	2.24	10.58	-0.31	-6.03	-2.82	-2.09	17.77	27.40	0.54
3	180	3.96	17.44	-0.57	-0.53	-2.84	-1.33	19.25	27.32	0.42
4	0	2.82	2.60	-3.02	-0.01	0.03	-0.59	5.97	25.53	3.28
5	0	2.88	2.06	-3.72	0.00	-0.01	-0.62	6.72	24.31	2.62
6	0	2.77	1.83	-3.50	0.00	-0.04	-0.59	6.37	24.25	2.81
7	0	2.48	1.69	-2.54	0.01	-0.09	-0.50	5.13	25.59	3.99
8	15	0.38	2.86	3.03	-0.11	-0.44	0.76	3.36	27.74	7.26
9	90	1.51	5.14	0.05	-0.22	-0.22	-0.01	5.12	28.45	4.56
10	180	2.37	6.51	1.74	-0.15	0.77	0.01	5.01	28.47	4.68
11	180	1.10	2.68	1.28	2.56	0.79	0.05	5.58	28.66	4.14
12	180	1.59	3.88	1.06	-0.76	0.47	-0.21	3.23	28.45	7.81
13	180	0.66	1.26	0.86	2.56	0.79	0.03	5.40	28.67	4.31
14	180	1.75	0.33	6.02	-0.38	0.76	-0.49	6.02	25.50	3.24
15	180	-0.25	-0.03	-0.74	0.07	0.00	-0.11	0.75	27.57	35.76
16	180	0.13	0.03	0.43	0.00	-0.04	-0.04	0.41	28.19	67.76

Notes:
1. Stress allowables are for ASME Service Level C.
2. Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-22 Advanced Canister Off-Normal Handling plus Normal Internal Pressure (40 psig) Primary plus Secondary (P + Q) Stresses (ksi)

Section Number	Angle (degree)	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity	Stress Allowable	Margin of Safety
1	180	2.40	11.82	1.44	-6.44	-2.94	-2.39	18.69	48.62	1.60
2	180	2.40	11.82	1.44	-6.44	-2.94	-2.39	18.69	48.61	1.60
3	180	3.70	22.15	0.84	-0.69	-2.83	-1.43	22.66	48.53	1.14
4	0	2.82	2.61	-3.00	-0.01	0.04	-0.59	5.94	46.09	6.76
5	0	2.88	2.00	-3.78	0.00	0.00	-0.62	6.77	43.88	5.48
6	0	2.78	1.68	-3.57	0.00	-0.05	-0.59	6.46	43.78	5.78
7	0	2.48	1.70	-2.52	0.01	-0.10	-0.50	5.11	46.20	8.04
8	15	0.37	2.90	3.01	-0.11	-0.44	0.76	3.37	48.98	13.53
9	90	1.92	5.61	0.99	-0.21	-1.30	-0.01	5.31	49.72	8.36
10	90	1.92	9.05	-2.50	-0.20	-0.14	0.01	11.56	49.75	3.30
11	75	-1.87	-10.88	2.10	0.12	-0.41	-1.28	13.38	49.95	2.73
12	90	-2.07	0.08	-6.98	-0.14	1.23	0.03	7.48	49.73	5.65
13	180	3.64	6.31	3.55	2.37	0.81	0.05	5.67	49.96	7.81
14	105	-33.42	-26.43	-36.89	-0.11	1.31	-0.42	10.83	46.06	3.25
15	180	-15.60	-13.04	-15.27	0.03	-1.02	-0.37	3.33	48.80	13.65
16	180	-4.69	-3.57	-4.58	0.02	0.30	-0.10	1.29	49.45	37.33

Notes:
1. ASME Section III, Subsection NB does not specify allowable stresses for primary plus secondary for Service Level C; therefore, the allowables for Service Level A are used.
2. Section locations are shown in Figure 3.4.4.3-4.

Table 11.1.3-23 Stresses at Center of Advanced PWR Canister Bottom Plate

Load Case	Pressure (psi)	Bending Stress (psi)	Allowable stress ($P_m + P_b$) (psi)	Margin of Safety
Level B				
Off-normal Pressure	50	16,749	1.65 S_m (26,575)	+ 0.53
Off-normal Pressure + Normal Handling	73.9	24,754	1.65 S_m (26,575)	+ 0.03
Level C				
Normal Pressure	40	13,400	Lesser of 1.8 S_m or 1.5 S_y (25,710)	+ 0.92
Normal Pressure + Off-Normal Handling	72.7	24,352	Lesser of 1.8 S_m or 1.5 S_y (25,710)	+ 0.08

Note: See Table 3.4.4.3-11 for additional details.

11.1.4 Failure of Instrumentation

The Universal Storage System uses an electronic temperature sensing system to read and record the outlet air temperature at each of the four air outlets on each Standard or Advanced Vertical Concrete Cask. The temperatures are read and recorded daily.

11.1.4.1 Cause of Instrumentation Failure Event

Failure of the temperature measuring instrumentation could occur as a result of component failure, or as a result of another accident condition that interrupted power or damaged the sensing or reader terminals.

11.1.4.2 Detection of Instrumentation Failure Event

The failure is identified by the lack of a reading at the temperature reader terminal. The failure could also be identified by disparities between outlet temperatures in a cask or between similar casks.

11.1.4.3 Analysis of Instrumentation Failure Event

Since the temperature of each outlet of each concrete cask is recorded daily, the maximum time period during which the instrumentation failure may go undetected is 24 hours. Therefore, the maximum time period, during which an increase in the outlet air temperatures may go undetected, is 24 hours. The principal condition that could cause an increase in temperature is the blockage of the cooling air inlets or outlets. Section 11.2.13 shows that even if all of the inlets and outlets of a single cask are blocked immediately after a temperature measurement, it would take longer than 24 hours before any component approaches its allowable temperature limit. Therefore, the opportunity exists to identify and correct a defect prior to reaching the temperature limits. During the period of loss of instrumentation, no significant change in canister temperature will occur under normal conditions.

The purpose of the daily temperature monitoring is to ensure that the passive cooling system is continuing to operate normally. Instrument failure would be of no consequence, if the affected storage cask continued to operate in normal storage conditions.

Because the canister and the concrete cask are a large heat sink, and because there are few conditions that could result in a cooling air temperature increase, the temporary loss of remote sensing and monitoring of the outlet air temperature is not a major concern. No applicable regulatory criteria are violated by the failure of the temperature instrumentation system.

11.1.4.4 Corrective Actions

This event requires that the temperature reporting equipment be either replaced or repaired and calibrated. Prior to repair or replacement, the temperature shall be recorded manually.

11.1.4.5 Radiological Impact

There are no radiological consequences for this event.

11.1.5 Small Release of Radioactive Particulate From the Canister Exterior

The procedures for loading the canister provide for steps to minimize exterior surface contact with contaminated spent fuel pool water, and the exterior surface of the canister is surveyed by smear at the top end to verify canister surface conditions. Design features are also employed to ensure that the canister surface is generally free of surface contamination prior to its installation in the concrete cask. The surface of the canister is free of traps that could hold contamination. The presence of contamination on the external surface of the canister is unlikely, and, therefore, no particulate release from the canister exterior surface is expected to occur in normal use. Since the Standard and Advanced canisters of the same class have the same surface area, the analysis is applicable to both configurations.

11.1.5.1 Cause of Radioactive Particulate Release Event

In spite of precautions taken to preclude contamination of the external surface of the canister, it is possible that a portion of the canister surface may become slightly contaminated during fuel loading by the spent fuel pool water and that the contamination may go undetected. Surface contamination could become airborne and be released as a result of the air flow over the canister surface.

11.1.5.2 Detection of Radioactive Particulate Release Event

The release of small amounts of radioactive particles over time is difficult to detect. Any release is likely to be too low to be detected by any of the normally employed long-term radiation dose monitoring methods (such as TLDs). It is possible that a suspected release could be verified by a smear survey of the air outlets.

11.1.5.3 Analysis of Radioactive Particulate Release Event

A calculation is made to determine the level of surface contamination that if released would result in a dose of one tenth of one (0.1) mrem at a minimum distance of 100 meters from a design basis storage cask. ISFSI-specific allowable dose rates and surface contamination limits will be calculated on a site specific basis to conform to 10 CFR 72. The method for determining the residual contamination limit is based on the plume dispersion calculations presented in U.S. NRC Regulatory Guides 1.109 [9] and 1.145 [13] and is highly conservative. The calculation shows that a residual contamination of approximately 1.57×10^5 dpm/100 cm^2 β-γ and 5.24×10^2 dpm/100 cm^2 α activity, on the surface of the design basis canister, is required to yield a dose of one tenth of one

(0.1) mrem at the minimum distance of 100 meters. The canister surface area is inversely proportional to the allowable surface contamination. The design basis cask is, therefore, the Class 3 PWR cask, which has the largest canister surface area at 3.06×10^5 cm^2.

The above analysis demonstrates that the off-site radiological consequences from the release of canister surface contamination is negligible, and all applicable regulatory criteria can be met for an ISFSI array.

11.1.5.4 Corrective Actions

No corrective action is required since the radiological consequence is negligible.

11.1.5.5 Radiological Impact

As shown above, the potential off-site radiological impact due to the release of canister surface contamination is negligible.

11.1.6 Off-Normal Events Evaluation for Site Specific Spent Fuel

This section presents the off-normal events evaluation of spent fuel assemblies or fuel configurations, which 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 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 blankets and variable enrichment assemblies, fuel with burnup that exceeds the design basis, 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 of the same type (PWR or BWR), or are shown to be acceptable contents, by specific evaluation of the configuration.

Specific reactor sites may use either the Standard or Advanced configurations of the Universal Storage System.

11.1.6.1 Off-Normal Events Evaluation for Maine Yankee Site Specific Spent Fuel

Maine Yankee site specific fuels are described in Section 1.3.2.1. A thermal evaluation has been performed for Maine Yankee site specific fuels that exceed the design basis burnup as shown in Section 4.5.1.2. As shown in that section, loading of fuel with a burnup between 45,000 and 50,000 MWD/MTU is subject to preferential loading in designated basket positions in the Standard Transportable Storage Canister.

With preferential loading, the design basis total heat load of the canister is not changed. Consequently, the thermal performance for the Maine Yankee site specific fuels is bounded by the design basis PWR fuels. Therefore, no further evaluation is required for the off-normal thermal events (severe ambient temperature conditions and blockage of half of the air inlets) as shown in Sections 11.1.1 and 11.1.2. In Section 3.6.1.1, the total weight of the canister contents for Maine Yankee site specific fuels is shown to be bounded by the PWR design basis fuels. Therefore, the evaluation for the off-normal canister handling load in Section 11.1.3 bounds the canister configuration loaded with Maine Yankee fuels.

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11.2 Accidents and Natural Phenomena

This section presents the results of analyses of the design basis and hypothetical accident conditions evaluated for the Universal Storage System. In addition to design basis accidents, this section addresses very low probability events, including natural phenomena, that might occur over the lifetime of the ISFSI, or hypothetical events that are postulated to occur because their consequences may result in the maximum potential impact on the immediate environment.

The Universal Storage System includes the Standard and Advanced configurations of the Transportable Storage Canisters and Vertical Concrete Casks. The Standard and Advanced configurations are provided in different lengths to accommodate the various PWR and BWR fuel designs. In the accident analyses of this section, the bounding cask parameters (such as weight and center of gravity) are conservatively used, as appropriate, to determine the cask's capability to withstand the effects of the accidents.

The results of analyses show that no credible potential accident exists that will result in a dose of ≥ 5 rem beyond the postulated controlled area. The Universal Storage System is demonstrated to have a substantial design margin of safety and to provide protection to the public and to occupational personnel during storage of spent nuclear fuel.

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11.2.1 Accident Pressurization

Accident pressurization is a hypothetical event that assumes the failure of all of the fuel rods contained within the Transportable Storage Canister (canister). No storage conditions are expected to lead to the rupture of all of the fuel rods.

Results of analysis of this event demonstrate that the canister is not significantly affected by the increase in internal pressure that results from the hypothetical rupture of all of the fuel rods contained within the canister. Positive margins of safety exist throughout the canister for any configuration.

11.2.1.1 Cause of Pressurization

The hypothetical failure of all of the fuel rods in a canister would release the fission and fill gases to the interior of the canister, resulting in the pressurization of the canister.

11.2.1.2 Detection of Accident Pressurization

The rupture of fuel rods within the canister is unlikely to be detected by any measurements or inspections that could be undertaken from the exterior of the canister or the concrete cask.

11.2.1.3 Analysis of Accident Pressurization

Analysis of this accident involves evaluation of the maximum canister internal pressure and the canister stress due to the maximum internal pressure. The canister is provided in the Standard and Advanced configurations. The accident pressurization analysis for the Standard canister configuration is provided in Section 11.2.1.3.1 and for the Advanced canister configuration in Section 11.2.1.3.2.

11.2.1.3.1 Analysis of Accident Pressurization for the Standard Canister Configuration

The analysis requires the calculation of the free volume of the Standard canister, calculation of the releasable quantity of fill and fission gas in the fuel assemblies, BPRA gases, and the subsequent calculation of the pressure in the canister if these gases are added to the helium pressure (initially at 1 atm) already present in the canister (Section 4.4.5). Canister pressures are determined for two accident scenarios, 100% fuel failure and a maximum temperature accident. The maximum temperature accident bounds the fire accident and full blockage of the air inlets and outlets. While no design basis event results in a 100% fuel failure condition, the pressures from this condition are presented to form a complete licensing basis. The method employed in either of the accident analyses is identical to that employed in the normal condition evaluation of Section 4.4.5.

Maximum Accident Condition Internal Pressure for Standard PWR Canister

For the maximum temperature accident condition, the gas quantities are combined with a conservative accident average gas temperature of 505°F to calculate a conservative maximum system pressure. The maximum Standard PWR canister pressure under the maximum temperature accident condition is 6.15 psig.

The maximum Standard PWR canister pressure under the 100% fuel failure assumption is 59.2 psig. The assembly producing the maximum pressure is identical to that of the normal condition evaluation, i.e., the B&W 17×17 Mark C in the Standard UMS® canister Class 2 for PWR assemblies. Similar pressures result from the Westinghouse 17×17 standard fuel assembly in the Standard UMS® canister Class 1.

Maximum Accident Condition Internal Pressure for Standard BWR Canister

For the maximum temperature accident condition, the gas quantities are combined with a conservative accident average gas temperature of 465°F to calculate a conservative maximum system pressure. The maximum Standard BWR canister pressure under the maximum temperature accident condition is 5.13 psig.

The maximum Standard BWR canister pressure under the 100% fuel failure assumption is 37.4 psig. The assembly producing the maximum pressure is identical to that of the normal condition evaluation, i.e., the GE 7×7 (49 fuel rod) assembly in the Standard UMS® canister Class 4 for BWR assemblies. Similar pressures result from the GE 9×9 (79 fuel rod) assembly in the Standard UMS® canister Class 5.

Maximum Standard Canister Stress Due to Internal Pressure

The stresses that result in the Standard canister due to the internal pressure are evaluated using the ANSYS finite element model that envelopes both PWR and BWR configurations as described in Section 3.4.4. The pressure used for the model is 65 psig, which bounds the maximum single accident condition pressures of 59.2 and 37.4 psig for the PWR and BWR, respectively.

The resulting maximum canister stresses for accident pressure loads are summarized in Tables 11.2.1-1 and 11.2.1-2 for primary membrane and primary membrane plus bending stresses, respectively.

The resulting maximum canister stresses and margins of safety for combined normal handling (Section 3.4.4.1.1) and maximum accident internal pressure (65 psig) are summarized in Tables 11.2.1-3 and 11.2.1-4 for primary membrane and primary membrane plus bending stresses, respectively.

The sectional stresses shown in Tables 11.2.1-1 through 11.2.1-4 at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.1-4.

All margins of safety are positive. Consequently, there is no adverse consequence to the canister as a result of the combined normal handling and maximum accident internal pressure (65 psig).

11.2.1.3.2 Analysis of Accident Pressurization for the Advanced Canister Configuration

The methodology used to determine maximum accident internal pressures and resulting stresses for the Standard UMS® was applied to the analysis of the Advanced UMS®.

Maximum Accident Condition Internal Pressure for Advanced PWR Canister

For the maximum temperature accident condition, the gas quantities are combined with a conservative accident average gas temperature of 630°F to calculate a conservative maximum system pressure. The maximum Advanced PWR canister pressure under the maximum temperature accident condition is 32.0 psig.

The maximum Advanced PWR canister pressure under the 100% fuel failure assumption is 124.9 psig. The assembly producing the maximum pressure is a hybrid 17×17 assembly in the Advanced UMS® canister Class 1 for PWR assemblies.

Maximum Advanced Canister Stress Due to Internal Pressure

The stresses in the Advanced canister due to the internal pressure are evaluated using the ANSYS finite element model and pressure that envelopes the PWR configurations as described in Section

3.4.4.3.1. The pressure used for the model is 130 psig, which bounds the 100% fuel rod failure event.

The resulting maximum canister stresses for accident pressure (130 psig) loads are summarized in Tables 11.2.1-5 and 11.2.1-6 for the primary membrane and primary membrane plus bending stresses, respectively.

The resulting maximum canister stresses and margins of safety for combined normal handling (Section 3.4.4.3.1) and maximum accident internal pressure are summarized in Tables 11.2.1-7 and 11.2.1-8 for primary membrane and primary membrane plus bending stresses, respectively.

The sectional stresses shown in Tables 11.2.1-5 through 11.2.1-8 at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.3-4.

All margins of safety are positive. Consequently, there is no adverse consequence to the canister as a result of the combined normal handling and maximum accident internal pressure.

The maximum pressure during a fire accident combined with a postulated 100% fuel rod failure is analyzed at 145 psig, which bounds the calculated pressure of 143 psig for this condition. The results of the 130 psig analysis are ratioed to obtain the results for the 145 psig case.

From Table 11.2.1-9, the maximum stress in the bottom plate of the canister is conservatively calculated as:

$$S = \frac{145\text{ psig}}{130\text{ psig}}(34{,}830) = 38.8\text{ ksi (Membrane + Bending)}$$

Using a bounding temperature of 500°F for the bottom of the canister, the allowable stress is 57.8 ksi for SA-240 Type 304L stainless steel. Therefore, conservatively, the margin of safety is:

$$MS = \frac{Su}{S} - 1 = \frac{57.8}{38.8} - 1 = 0.49 \text{ (Membrane + Bending)}$$

For the canister membrane stress, the maximum stress is conservatively calculated as:

$$S = \frac{145 \text{ psig}}{130 \text{ psig}}(23.64) = 26.4 \text{ ksi (Table 11.2.1-7)}$$

and the Margin of Safety is:

$$MS = \frac{35.52}{26.4} - 1 = 0.34$$

From Tables 11.2.1-7 and 11.2.1-8, the maximum membrane and membrane plus bending stress intensity is 6.98 ksi and 9.21 ksi, respectively, for section cuts 4 through 13. Section cuts 4 through 13 are for the canister shell and lid welds. For a pressure of 145 psig the membrane stress is:

$$S_m = \frac{145}{130} \text{ x } 6.98 = 7.8 \text{ ksi}$$

and the membrane plus bending stress is:

$$S_m + S_b = \frac{145}{130} \text{ x } 9.21 = 10.3 \text{ ksi}$$

Using a bounding temperature of 700°F the margin of safety for membrane stress is:

$$MS = \frac{2.4 S_m}{S} - 1 = \frac{2.4(13.6)}{7.8} - 1 = 3.18$$

For the membrane plus bending stress, the margin of safety is:

$$MS = \frac{S_u}{S} - 1 = \frac{56.28}{10.3} - 1 = 4.46$$

Therefore, for a bounding 145 psig pressure, the minimum Margin of Safety for the canister is 0.49 at the bottom of the canister.

11.2.1.4 Corrective Actions

No recovery or corrective actions are required for this hypothetical accident.

11.2.1.5 Radiological Impact

There are no dose consequences due to this accident.

Table 11.2.1-1 Standard Canister Accident Internal Pressure (65 psig) Only Primary Membrane (P_m) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	0	0.4	6.3	2.5	-0.9	0.1	0.2	6.18
2	0	4.2	-4.1	-5.3	-0.9	0.1	-0.7	9.69
3	0	-0.8	1.8	-8.1	1.8	-0.2	-0.7	10.89
4	0	0	1.7	3.4	0	0	0.3	3.49
5	0	0	1.7	3.4	0	0	0.3	3.45
6	0	0	1.7	3.4	0	0	0.3	3.45
7	0	0	1.7	3.4	0	0	0.3	3.46
8	0	0	1.7	1.7	-0.1	0	0.2	1.76
9	0	0.2	1.2	0.9	0.1	0	0.1	1.11
10	0	-0.6	0.8	0.6	-0.2	0	0.1	1.45
11	60	0.5	-0.2	0.6	0	0	-0.2	0.90
12	80	0.1	-0.8	-0.3	0	0.3	0.1	1.08
13	0	-0.1	0.8	0.5	0.1	0	0.1	0.93
14	80	0.8	-0.1	0.8	0.8	-0.6	0	2.16
15	70	-0.1	0	-0.1	0	0	0	0.05
16	70	0.1	0	0.1	0	0	0	0.12

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.

Table 11.2.1-2 Standard Canister Accident Internal Pressure (65 psig) Only Primary Membrane + Primary Bending ($P_m + P_b$) Stresses (ksi)

Section No. (1)	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity
1	0	4.8	15.3	0.5	-0.1	0.1	-0.2	14.76
2	0	2.0	-29.4	-13.3	-2.1	0.1	-1.3	31.86
3	0	-3.1	41.2	2.9	2.3	-0.2	0.4	44.49
4	0	0.0	1.6	3.4	0.0	0	0.3	3.52
5	0	0.0	1.7	3.4	0	0	0.3	3.51
6	0	0.0	1.7	3.4	0	0	0.3	3.51
7	0	0.0	1.7	3.4	0	0	0.3	3.51
8	0	0	1.9	1.8	-0.1	0.0	0.2	1.92
9	0	0.2	2.6	1.3	0.4	0.0	0.1	2.50
10	0	-0.4	3.2	1.3	0.1	0.0	0.1	3.66
11	80	-0.2	-2.0	0.6	0.0	-0.1	-0.1	2.58
12	80	-0.2	-1.5	-0.8	-0.1	0.4	0.1	1.55
13	0	-1.0	0.3	0.1	0.1	0	0.1	1.32
14	180	20.9	0.1	21.1	0.7	-0.7	0.1	21.01
15	0	-1.5	-0.1	-1.5	0	0	0	1.49
16	0	0.8	0	0.8	0	0	0	0.76

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.

Table 11.2.1-3 Standard Canister Normal Handling plus Accident Internal Pressure (65 psig) Primary Membrane (P_m) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[2]	Margin of Safety
1	0	0.6	8.1	3.2	-1.2	0.1	0.2	7.94	40.08	4.05
2	0	5.4	-5.3	-6.9	-1.2	0.1	-0.9	12.61	40.08	2.18
3	0	-1	2.4	-10.7	2.3	-0.2	-0.9	14.31	40.08	1.80
4	180	0	2.2	3.4	0	0	-0.3	3.50	39.76	10.36
5	180	0	2.2	3.4	0	0	-0.3	3.46	36.98	9.68
6	180	0	2.1	3.4	0	0	-0.3	3.46	36.52	9.54
7	180	0	2	3.4	0	0	-0.3	3.46	38.55	10.14
8	0	0	2.8	1.7	-0.1	0.1	0.2	2.83	40.08	13.16
9	0	0.2	2.7	1.2	0.2	0.1	0.1	2.54	40.08	14.80
10	0	-0.8	2.6	0.9	-0.1	0.2	0.1	3.46	40.08	10.58
11	150	0.9	-0.3	0.4	0	-0.2	0.2	1.30	40.08	29.76
12	90	0	-1.4	-0.3	-0.2	0.4	0.1	1.56	40.08	24.73
13	0	0.2	0.6	1.4	-0.5	0	0.2	1.66	40.08	23.19
14	80	1	-0.1	1	1	-0.8	0	2.81	40.08	13.28
15	170	-0.1	0	-0.1	0	0	0	0.08	40.08	471.31
16	70	0.1	0	0.1	0	0	0	0.14	40.08	292.20

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.
2. ASME Service Level D is used for material allowable stress.

Table 11.2.1-4 Standard Canister Normal Handling plus Accident Internal Pressure (65 psig) Primary Membrane + Primary Bending ($P_m + P_b$) Stresses (ksi)

Section No.(1)	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable(2)	Margin of Safety
1	0	6.2	19.7	0.5	-0.1	0.1	-0.3	19.19	60.12	2.13
2	0	2.6	-37.8	-17.3	-2.7	0.2	-1.7	40.91	60.12	0.47
3	0	-3.9	53.1	3.4	2.9	-0.2	0.5	57.32	60.12	0.05
4	180	0.0	2.1	3.5	0.0	0	-0.3	3.60	59.64	15.57
5	180	0.0	2.2	3.6	0	0	-0.3	3.65	55.47	14.19
6	180	0.0	2.2	3.6	0	0	-0.3	3.70	54.79	13.80
7	180	0.0	2.1	3.6	0	0	-0.3	3.67	57.83	14.75
8	0	0	3.0	1.7	-0.1	0.1	0.1	3.00	60.12	19.02
9	0	0.1	4.2	1.6	0.4	0.2	0.1	4.13	60.12	13.55
10	0	-0.6	4.2	1.4	0.1	0.3	0.1	4.85	60.12	11.39
11	150	0.5	-2.5	-0.2	0.0	-0.2	0.5	3.32	60.12	17.10
12	90	-0.3	-2.2	-0.7	-0.2	0.6	0.1	2.16	60.12	26.83
13	0	0.2	1.5	1.3	-0.9	0.1	0.1	2.26	60.12	25.59
14	180	27.3	0.2	27.4	1.0	-0.9	0.1	27.33	60.12	1.20
15	0	-1.7	0	-1.7	0	0	0	1.66	60.12	35.17
16	70	0.3	0	0.3	-0.1	0	0	0.31	60.12	194.89

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.
2. ASME Service Level D is used for material allowable stress.

Table 11.2.1-5 Advanced Canister Accident Internal Pressure (130 psig) Only Primary Membrane (P_m) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[2]	Margin of Safety
1	180	0.46	9.51	3.68	1.16	0.02	-0.20	9.35	38.90	3.16
2	180	5.37	-5.80	-9.75	1.26	0.08	0.85	15.36	38.89	1.53
3	0	-1.40	3.56	-14.87	2.82	-0.18	-0.90	19.78	38.82	0.96
4	180	-0.05	3.39	6.86	0.00	0.00	-0.45	6.97	36.88	4.29
5	0	-0.04	3.39	6.81	0.00	0.00	0.45	6.91	35.11	4.08
6	0	-0.03	3.39	6.82	0.00	0.00	0.45	6.91	35.03	4.07
7	180	-0.03	3.39	6.82	0.00	0.00	-0.45	6.91	36.96	4.35
8	0	-0.04	3.39	5.13	-0.05	0.00	0.34	5.22	39.18	6.51
9	180	0.27	2.59	1.70	-0.36	-0.03	-0.10	2.43	39.78	15.37
10	180	-1.42	1.59	0.97	0.52	0.02	-0.14	3.19	39.80	11.48
11	90	0.71	-0.45	1.59	0.00	0.05	0.00	2.04	39.96	18.59
12	180	-0.62	-1.89	0.15	0.50	-0.03	-0.06	2.22	39.78	16.92
13	180	-0.05	1.72	0.98	-0.12	-0.03	-0.07	1.79	39.97	21.33
14	180	1.48	-0.06	1.49	-0.35	-0.92	0.00	2.50	36.82	13.73
15	0	-0.24	-0.09	-0.24	0.01	0.03	0.00	0.16	39.04	243.00
16	180	0.25	-0.01	0.25	0.01	0.02	0.00	0.26	39.56	151.15

1. Section locations are shown in Figure 3.4.4.3-4.
2. Stress Allowable value is for ASME Service Level D.

Table 11.2.1-6 Advanced Canister Accident Internal Pressure (130 psig) Only Primary Membrane + Primary Bending ($P_m + P_b$) Stresses (ksi)

Section No.[1,2]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[3]	Margin of Safety
1	180	5.08	23.15	-1.47	0.15	0.05	0.26	24.63	58.35	1.37
4	180	-0.08	3.31	6.91	0.01	0.00	-0.46	7.05	55.31	6.85
5	180	-0.07	3.41	6.89	0.00	0.00	-0.46	7.02	52.66	6.50
6	180	-0.07	3.41	6.89	0.00	0.00	-0.46	7.02	52.54	6.48
7	180	-0.07	3.40	6.90	0.00	0.00	-0.46	7.02	55.44	6.90
8	0	-0.08	4.23	5.31	-0.05	0.00	0.35	5.44	58.78	9.81
9	0	0.36	4.94	2.42	0.72	-0.04	0.14	4.81	59.67	11.41
10	0	-0.87	6.95	2.72	-0.05	0.02	0.21	7.84	59.71	6.62
11	90	-0.54	-4.34	1.26	0.00	-0.05	0.00	5.60	59.94	9.70
12	0	-1.82	-3.54	-0.67	-0.98	-0.02	0.08	3.33	59.68	16.92
13	0	-1.51	0.62	0.35	0.33	-0.05	0.11	2.24	59.95	25.76
14	180	35.39	0.84	35.57	-0.35	-0.91	0.00	34.78	55.23	0.59
15	0	-2.86	-0.17	-2.85	0.01	0.02	0.00	2.69	58.56	20.77
16	0	1.52	0.03	1.52	0.01	0.02	0.00	1.50	59.34	38.56

1. Section locations are shown in Figure 3.4.4.3-4.
2. Sections 2 and 3 are not shown as the stress at these locations is classified as secondary in accordance with NB-3217 and need not to be considered.
3. Stress Allowable value is for ASME Service Level D.

Table 11.2.1-7 Advanced Canister Normal Handling plus Accident Internal Pressure (130 psig) Primary Membrane (P_m) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[2]	Margin of Safety
1	0	0.53	11.13	4.29	-1.35	0.01	0.23	10.95	38.90	2.55
2	0	6.25	-6.75	-11.65	-1.49	0.10	-1.01	18.18	38.89	1.14
3	0	-1.63	4.20	-17.89	3.27	-0.21	-1.08	23.65	38.82	0.64
4	0	-0.05	4.00	6.87	0.00	0.00	0.45	6.98	36.88	4.28
5	0	-0.04	4.01	6.81	0.00	0.00	0.45	6.91	35.11	4.08
6	180	-0.03	4.03	6.81	0.00	0.00	-0.45	6.90	35.03	4.08
7	0	-0.03	4.12	6.81	0.00	0.01	0.45	6.90	36.96	4.36
8	165	0.30	4.14	4.78	0.03	0.10	-1.29	5.18	39.18	6.56
9	0	0.30	3.88	2.02	0.40	0.09	0.11	3.68	39.78	9.81
10	0	-1.61	3.11	1.28	-0.53	0.20	0.19	4.87	39.80	7.17
11	135	1.23	-0.51	1.23	0.04	0.04	0.56	2.30	39.96	16.37
12	158	-0.50	-2.39	-0.09	0.54	0.38	-0.30	2.69	39.78	13.79
13	158	0.07	1.92	0.82	-0.16	-0.08	-0.35	2.02	39.97	18.79
14	180	1.73	-0.08	1.73	-0.41	-1.09	0.00	2.94	36.82	11.52
15	180	-0.26	-0.12	-0.26	0.01	0.02	0.00	0.14	39.04	277.86
16	180	0.27	-0.04	0.27	0.01	0.03	0.00	0.31	39.56	126.61

1. Section locations are shown in Figure 3.4.4.3-4.
2. Stress Allowable value is for ASME Service Level D.

Table 11.2.1-8 Advanced Canister Normal Handling plus Accident Internal Pressure (130 psig) Primary Membrane + Primary Bending ($P_m + P_b$) Stresses (ksi)

Section No.[1,2]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Stress Allowable[3]	Margin of Safety
1	0	5.87	27.11	-1.98	-0.18	0.06	-0.32	29.10	58.35	1.01
4	180	-0.08	3.90	6.91	0.01	0.00	-0.46	7.05	55.31	6.85
5	180	-0.07	4.02	6.87	0.00	0.00	-0.46	6.99	52.66	6.53
6	180	-0.06	4.02	6.81	0.00	0.00	-0.45	6.93	52.54	6.58
7	0	0.00	4.16	6.89	0.00	0.01	0.46	6.95	55.44	6.98
8	0	-0.07	5.31	5.40	-0.05	0.05	0.36	5.54	58.78	9.61
9	0	0.37	6.60	2.81	0.77	0.12	0.14	6.43	59.67	8.28
10	0	-0.99	8.19	2.92	-0.13	0.26	0.23	9.21	59.71	5.48
11	45	0.35	-4.83	0.35	0.03	-0.03	-1.07	6.25	59.94	8.59
12	23	-1.54	-4.22	-0.98	-0.98	0.61	0.41	3.92	59.68	14.22
13	23	-1.40	0.72	-0.19	0.34	-0.16	0.76	2.61	59.95	21.97
14	180	41.93	1.00	42.15	-0.41	-1.08	0.00	41.21	55.23	0.34
15	0	-2.96	-0.18	-2.95	0.01	0.02	0.00	2.78	58.56	20.06
16	0	1.51	0.01	1.51	0.01	0.03	0.00	1.50	59.34	38.56

1. Section locations are shown in Figure 3.4.4.3-4.
2. Sections 2 and 3 are not shown as the stress at these locations is classified as secondary in accordance with NB-3217 and need not to be considered.
3. Stress Allowable value is for ASME Service Level D.

Table 11.2.1-9 Stresses at the Center of the Advanced Canister Bottom Plate

Load Case Level D	Pressure (psi)	Bending Stress (psi)	$P_m + P_b$ Allowable stress (psi)		Margin of Safety
Accident Pressure	130	43,546	3.6 S_m or 1.0 S_u	55,800	+ 0.28
Accident Pressure + Normal Handling	153.9	51,552	3.6 S_m or 1.0 S_u	55,800	+ 0.08

1. See Section 3.4.4.3.3.

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11.2.2 Failure of All Fuel Rods With a Ground Level Breach of the Canister

Since no mechanistic failure of the Standard or Advanced canister occurs, and since the canister is leaktight, this potential accident condition is not evaluated.

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11.2.3 Fresh Fuel Loading in the Canister

This section evaluates the effects of an inadvertent loading of up to 24 fresh, unburned PWR fuel assemblies or up to 56 fresh, unburned BWR fuel assemblies in a Standard canister or up to 32 fresh, unburned PWR fuel assemblies in an Advanced canister. There are no adverse effects on either canister configuration due to this event since the criticality control features ensure that the k_{eff} of the fuel is less than 0.95 for all loading conditions of fresh fuel.

11.2.3.1 Cause of Fresh Fuel Loading

The cause of this event is operator and/or procedural error. In-plant operational procedures and engineering and quality control programs are expected to preclude occurrence of this event. Nonetheless, it is evaluated here to demonstrate the adequacy of the canister designs for accommodating fresh fuel without a resulting criticality event.

11.2.3.2 Detection of Fresh Fuel Loading

This accident is expected to be identified immediately by observation of the condition of the fuel installed in the canister or by a review of the fuel handling records.

11.2.3.3 Analysis of Fresh Fuel Loading

The criticality analysis presented in Chapter 6 assumes the loading of up to 24 design basis PWR or up to 56 design basis BWR fuel assemblies in the Standard canister configuration, or up to 32 PWR fuel assemblies in the Advanced canister configuration, having no burnup. This analysis shows that for the Standard PWR canister, the maximum k_s for the dry normal condition is 0.3833. The maximum k_{eff} for the accident conditions is calculated to be 0.9470. The accident condition assumes the most reactive configuration of the fuel and full moderator intrusion.

For the Standard BWR canister, the values of maximum k_s for the dry normal condition and the accident conditions are calculated to be 0.3817 and 0.9233, respectively.

Similarly, for the Advanced PWR canister, the values of maximum $k_s + 2\sigma$ for the dry normal storage condition and the wet accident transfer conditions are calculated to be 0.4739 and 0.9284, respectively.

The criticality control features of either canister and basket design ensure that the k_{eff} of the fuel is less than 0.95 for all loading conditions of fresh fuel. Therefore, there is no adverse impact on the Universal Storage System due to this event.

11.2.3.4 Corrective Actions

This event requires that the canister be unloaded when the incorrect fuel loading is identified. The cause for the error should be identified and procedural actions implemented to preclude recurrence.

11.2.3.5 Radiological Impact

There are no dose implications due to this event.

11.2.4 24-Inch Drop of the Vertical Concrete Cask

This analysis evaluates a loaded Vertical Concrete Cask for a 24-inch drop onto a concrete storage pad. The Universal Storage System includes the Standard and Advanced configurations of the Transportable Storage Canisters (canister) and Vertical Concrete Casks (concrete cask). The Standard and Advanced configurations are provided in different lengths to accommodate the various PWR and BWR fuel designs. The evaluation of the Standard configuration is based on the Standard canister loaded with Class 5 BWR fuel. This is the heaviest Standard configuration and it is conservatively used in the analysis as the bounding case. The analysis for the Standard configuration is presented in Section 11.2.4.3. For the Advanced configuration, a bounding weight is also used for the Advanced canister. The analysis for the Advanced configuration is presented in Section 11.2.4.4. The Advanced canister may not be loaded in the Standard concrete cask. The results of these evaluations show that neither the concrete cask nor the Transportable Storage Canister, in either configuration, experience significant adverse effects due to the 24-inch drop event.

11.2.4.1 Cause of the 24-Inch Concrete Cask Drop

The Vertical Concrete Cask may be lifted and moved using either an air pad system, which lifts the concrete cask from the bottom, or a mobile lifting frame, which lifts the concrete casks using lifting lugs in the top of the cask.

Using the air pad system, the concrete cask, containing a loaded canister, must be raised approximately 4 inches to enable installation of the inflatable air-pads beneath it. The air pads use pressurized air to allow the cask to be moved across the surfaces of the transporter and the ISFSI pad to the designated position. The cask is raised using hydraulic jacks installed at jack-points in the cask's air inlets. The failure of one or more of the jacks or of the air pad system could result in a drop of the cask.

The concrete cask may be lifted and moved by a mobile lifting frame, which may be self-propelled or towed. The lifting frame uses hydraulic power to raise the cask approximately 20 inches using a lifting attachment that connects to the four cask lifting lugs. The failure of one or more of the lifting lugs, or the failure of the hydraulic pistons, could result in a drop of the cask.

Although a lift of only about 4 inches is required to install and remove the air pads, the mobile lifting frame will lift the cask approximately 20 inches, so this analysis conservatively evaluates the consequences of a 24-inch drop.

11.2.4.2 Detection of the 24-Inch Concrete Cask Drop

This event will be detected by the operators as it occurs.

11.2.4.3 Analysis of the Standard Concrete Cask 24-Inch Drop

A bottom end impact is assumed to occur normal to the concrete cask bottom surface, transmitting the maximum load to the concrete cask and the canister. The energy absorption is computed as the product of the compressive force acting on the concrete cask and its displacement. Conservatively assuming that the storage surface impacted is an infinitely rigid surface, the concrete cask body will crush until the impact energy is absorbed.

A compressive strength of 4,000 psi is used for the cask concrete. The evaluation conservatively ignores any energy absorption by the internal friction of the aggregate as crushing occurs.

The canister rests upon a base weldment designed to allow cooling of the canister. Following the initial impact, the inlet system will partially collapse, providing an energy absorption mechanism that somewhat reduces the deceleration force on the canister.

Evaluation of the Standard Concrete Cask

In the 24-inch bottom drop of the Standard concrete cask, the cylindrical portion of the concrete is in contact with the steel bottom plate that is a part of the base weldment. The plate is assumed to be part of an infinitely rigid storage pad. No credit is taken for the crush properties of the storage pad or the underlying soil layer. Therefore, energy absorbed by the crushing of the cylindrical concrete region of the concrete cask equals the product of the compressive strength of the concrete, the crush depth of the concrete, and the projected area of the concrete cylinder. Crushing of the concrete continues until the energy absorbed equals the potential energy of the cask at the initial drop height. The canister is not rigidly attached to the concrete cask, so it is not considered to contribute to the concrete crushing. The energy balance equation is:

$$w(h+\delta) = P_o A\delta,$$

where:

h = 24 in., the drop height,

δ = the crush depth of the concrete cask,

P_o = 4000 psi, the compressive strength of the concrete,

A = $\pi(R_1^2 - R_2^2)$ = 7,904 in^2, the projected area of the concrete shield wall,

w = 176,010 lbs (concrete ≅ 170,000 lbs plus reinforcing steel ≅ 6,010 lbs)

It is assumed that the maximum force that can be exerted on the concrete cask is the compressive strength of the concrete multiplied by the area of the concrete being crushed. The concrete cask's steel shell will not experience any significant damage during a 24-inch drop. Therefore, its functionality will not be impaired due to the drop.

The crush distance computed from the energy balance equation is:

$$\delta = \frac{hw}{P_o A - w} = \frac{(24)(176{,}010)}{(4000)(7{,}904) - (176{,}010)} = 0.134 \text{ inch}$$

where,

w = 176,010 lbs (the highest weight is used to obtain the maximum deformation)

The resultant inlet deformation is 0.134 inch.

Evaluation of the Standard Canister for a 24-inch Bottom End Drop

Upon a bottom end impact of the concrete cask, the Standard canister produces a force on the base weldment located near the bottom of the cask (see Figure 11.2.4.3-1). The ring above the air inlets is expected to yield. To determine the resulting acceleration of the canister and deformation of the pedestal, an LS-DYNA analysis is used. The Advanced canister is not loaded in the Standard concrete cask.

A half-symmetry model of the base weldment is built using the ANSYS preprocessor (see Figure 11.2.4.3-2). The model is constructed of 8-node brick and 4-node shell elements. Symmetry conditions are applied along the plane of symmetry (X-Z plane). Lumped mass elements located in the canister bottom plate represent the loaded canister. The impact plane is represented as a rigid plane, which is considered conservative, since the energy absorption due to the impact plane is neglected (infinitely rigid). To determine the maximum acceleration and deformations, impact analyses are solved using LS-DYNA program.

The weldment ring, weldment plate, and the inner cone (see Figure 11.2.4.3-1) materials are modeled using LS-DYNA's piece wise linear plasticity model. This material model accepts stress–strain curves for different strain rates. These stress strain curves were obtained from the Atlas of Stress-Strain Curves [44] and are shown in Figure 11.2.4.3-3. To ensure that maximum deformations and accelerations are determined, two analyses are performed. One analysis, which uses the static stress strain curve, envelopes the maximum deformation of the pedestal. The second analysis employs the multiple stress-strain curves to account for different strain rates.

The maximum accelerations of the Standard canister during the 24-inch bottom end impact are 45.0g and 44.5g for the variable strain rate material model and the static stress-strain curve, respectively. The resulting acceleration time histories of the bottom canister plate, which correspond to a filter frequency of 200 Hz, are shown in Figure 11.2.4.3-4 for the analysis using the static stress-strain curve and Figure 11.2.4.3-5 for the analysis corresponding to the series of stress-strain curves at different strain rates. These time histories indicate that the maximum accelerations do not occur at the beginning where the strain rate is maximum, but rather, at a time where the strain rate has a marginal effect on the accelerations. Therefore, the use of the multiple strain rate material model is consider to bound the accelerations imposed on the canister, since it considers the effect of strain rate on the stress-strain curves.

The filter frequency used in the LS-DYNA evaluation is determined by performing two modal analyses of a quarter symmetry model of the base weldment. Symmetry boundary conditions are applied of the planes of symmetry of the model for both analyses. The second analysis considers a boundary condition that is the center node of the base weldment bottom plate, restrained in the vertical direction. These analyses result in a modal frequency of 173 Hz and 188 Hz, respectively. Therefore, a filter frequency of 200 Hz is selected.

Results of the LS-DYNA analysis show that the maximum deformation of the base weldment is about 1 inch. This deformation is small when compared to the 12-inch height of the air inlet. Therefore, a 24-inch drop of the concrete cask does not result in a blockage of the air inlets.

The dynamic response of the Standard canister and basket on impact is amplified by the most flexible components of the system. In the case of the canister and basket, the basket support disk bounds this response. To account for the transient response of the support disk, a dynamic load factor (DLF) for the support disk is computed for the inertia loading developed during the deceleration of the canister bottom plate. The DLF is determined using quarter symmetry models of the PWR and BWR disks as shown in Figures 11.2.4.3-6 and 11.2.4.3-7, respectively. These models are generated using ANSYS, Revision 5.5.

To support the disks in the models, restraints are applied at the basket tie-rod locations. For each tie-rod locations, a single node is restrained in the vertical direction allowing the support disks to vibrate freely when the accelerations are applied at the tie rod locations. A transient analysis using ANSYS, Revision 5.5 is performed which uses the acceleration time histories computed from the LS-DYNA analyses. The time history corresponding to the stress–strain curves at different strain rates is used. This case is considered bounding since the maximum acceleration occurs when the rate dependent stress-strain curves are used.

The DLF is determined to be the maximum deflection of the disk (which occurs at the center of the disk) divided by the static displacement (The static analysis used the maximum acceleration determined from the LS-DYNA analysis). The DLF for the PWR and the BWR are determined to be 1.01 and 1.29, respectively.

Therefore, multiplying the calculated accelerations by the DLF's results in effective accelerations of 45.5g and 58.1g for the PWR and BWR canisters, respectively. These values are enveloped by the 60g acceleration employed in the stress evaluation of the end impact of the canister and support disks. These accelerations are considered to be bounding since they incorporate the effect of the strain rate on the plastic behavior of the pedestal and ignore any energy absorption by the impact plane.

Standard Canister Stress Evaluation

The Standard canister stress evaluation for the Standard concrete cask 24-inch bottom end drop accident is performed using a load of 60g. This evaluation bounds the acceleration that is calculated for the 24-inch bottom end drop event determined above. This canister evaluation is performed using the ANSYS finite element program. The canister finite element model is shown in Figure 11.2.4.3-8. The construction and details of the finite element model are described in Section 3.4.4.1.1. Stress evaluations are performed with and without an internal pressure of 25 psig.

The principal components of the canister are the canister shell, including the bottom plate, the fuel basket, the shield lid, and the structural lid. The structural design criteria for the canister are contained in the ASME Code, Section III, Subsection NB. This analysis shows that the structural components of the canister (shell, bottom plate, and structural lid) satisfy the allowable stress intensity limits.

The results of the analysis of the PWR and BWR canisters for the 60g bottom end impact loading are presented in Tables 11.2.4.3-1 through 11.2.4.3-4. These results are for the load case that includes a canister internal pressure of 25 psig, since that case results in the minimum margin of safety.

The minimum margin of safety at each section of the canister is presented by denoting the circumferential angle at which the minimum margin of safety occurs. A cross-section of the canister showing the section locations is presented in Figure 11.2.4.3-9. Stresses are evaluated at 9° increments around the circumference of the canister for each of the locations shown. The minimum margin of safety is denoted by an angular location at each section.

For the canister to structural lid weld (Section 13, Figure 11.2.4.3-9), base metal properties are used to define the allowable stress limits since the tensile properties of the weld filler metal are greater than those of the base metal. The allowable stress at Section 13 is multiplied by a stress reduction factor of 0.8 in accordance with NRC Interim Staff Guidance (ISG) No. 4, Revision 1.

The allowable stresses presented in Tables 11.2.4.3-1 through 11.2.4.3-4, and in Tables 11.2.4.3-6 and 11.2.4.3-7, are for Type 304L stainless steel. Because the shield lid is constructed of Type 304 stainless steel, which possesses higher allowable stresses, a conservative evaluation results. The allowable stresses are evaluated at 380°F. A review of the thermal analyses shows that the maximum temperature of the canister is 351°F (Table 4.1-4) for PWR fuel and 376°F (Table 4.1-5) for BWR fuel, which occurs in the center portion of the canister wall (Sections 5 and 6).

Standard Canister Buckling Evaluation

Code Case N-284-1 of the ASME Boiler and Pressure Vessel Code is used to analyze the canister for the 60g bottom end impact. The evaluation requirements of Regulatory Guide 7.6, Paragraph C.5, are shown to be satisfied by the results of the buckling interaction equation calculations.

The internal stress field that controls the buckling of a cylindrical shell consists of the longitudinal (axial) membrane, circumferential (hoop) membrane, and in-plane shear stresses. These stresses may exist singly or in combination, depending on the applied loading. The buckling evaluation is performed without the internal 25 psig pressure, since this results in the minimum margin of safety.

The primary membrane stress results for the 60g bottom impact with no internal pressure are presented in Table 11.2.4.3-6 for the PWR canister, and in Table 11.2.4.3-7 for the BWR canister.

The stress results from the ANSYS analyses are screened for the maximum values of the longitudinal compression, circumferential compression, and in-plane shear stresses for the 60g bottom end impact. For each loading case, the largest of each of the three stress components, regardless of location within the canister shell are combined.

The maximum stress components used in the evaluation and the resulting buckling interaction equation ratios are provided in Table 11.2.4.3-8. The results show that all interaction equation ratios are less than 1.0. Therefore, the buckling criteria of Code Case N-284-1 are satisfied, demonstrating that buckling of the canister does not occur.

Standard Basket Stress Evaluation

Stresses in the support disks and weldments are calculated by applying the accident loads to the ANSYS models described in Sections 3.4.4.1.8 and 3.4.4.1.9. An inertial load of 60g is conservatively applied to the support disks and weldments in the axial (out of plane) direction. To evaluate the most critical regions of the support disks, a series of cross sections are considered. The locations of these sections on the PWR and BWR support disks are shown in Figures 3.4.4.1-7, 3.4.4.1-8 and Figures 3.4.4.1-13 through 3.4.4.1-16. The stress evaluations for the support disk and weldments are performed according to ASME Code, Section III, Subsection NG. For accident conditions, Level D allowable stresses are used: the allowable stress is $0.7S_u$ and S_u for P_m and P_m+P_b stress categories, respectively. The stress evaluation results are presented in Tables 11.2.4.3-9 and 11.2.4.3-10 for the PWR and BWR support disks, respectively. The tables list the 40 highest P_m+P_b stress intensities. The minimum margins of safety are +1.86 and +0.56 for PWR and BWR disks, respectively. The stress results for the PWR and BWR weldments are shown in Table 11.2.4.3-5. The minimum margin of safety is +1.31 and +0.26 for the PWR and BWR weldments, respectively. Note that the P_m stresses for the disks and weldments are essentially zero, since there are no loads in the plane of the support disk or weldment for a bottom end impact.

Standard Basket Tie Rod Evaluation

The tie rods serve basket assembly purposes and are not part of the load path for the conditions evaluated. The tie rods are loaded during basket assembly by a 50 ± 10 ft-lbs torque applied to the tie rod end nut. The tensile pre-load on the tie rod, P_B, is [41]:

$$T = P_B\,(0.159\,L + 1.156\,\mu\,d)$$

where:

T = 60 ft-lb

L= 1/8

$\mu = 0.15$

d = 1.625 in.

Solving for P_B:

P_B = 2,387 lbs. per rod

The maximum tensile stress in the tie rod occurs while the basket is being lifted for installation in the canister. The Standard BWR basket configuration is limiting because it has six tie rods, compared to eight tie rods in the PWR basket, and weighs more than the PWR basket. The load on each BWR basket tie rod is:

$$P = 2{,}387 + \frac{1.1 \times 18{,}199}{6} = 5{,}723 \text{ lbs.}$$

where the weight of the Standard BWR basket is 18,199 pounds.

The maximum tensile stress, S, at room temperature (70°F) is:

$$S = \frac{5{,}723}{\pi \times 0.25 \times 1.625^2} = 2{,}760 \text{ psi}$$

Therefore, the margin of safety is:

$$MS = \frac{20{,}000}{2{,}760} - 1 = +\text{Large}$$

This result bounds that for the Standard PWR basket configuration. The tie rod is not loaded in drop events; therefore, no additional analysis of the tie rod is required.

Standard PWR and BWR Basket Tie Rod Spacer Analysis

The Standard PWR and BWR basket support disks and heat transfer disks are connected by tie rods (8 for PWR and 6 for BWR) and located by spacers to maintain the disk spacing. The PWR and BWR spacers are constructed from ASME SA479 Type 304 stainless steel or ASME SA312

Type 304 stainless steel. The difference in using the two materials is the cross-sectional area of the spacers. The geometry of the spacers is:

For SA479 stainless steel:

Spacer:	Outside Diameter	= 3.00 in.
	Inside Diameter	= 1.75 in.
Split Spacer:	Outside Diameter	= 2.50 in. (Machined down section)
	Inside Diameter	= 1.75 in.
	Outside Diameter	= 3.00 in.

For the full spacer, the cross-section area is 4.66 inches^2, and for the split spacer, the cross-section area is 2.5 inches^2.

For SA312 stainless steel:

Spacer:	Outside Diameter	= 2.875 in.
	Inside Diameter	= 1.771 in.
Split Spacer:	Outside Diameter	= 2.50 in. (Machined down section)
	Inside Diameter	= 1.771 in.
	Outside Diameter	= 2.875 in.

For the full spacer, the cross-section area is 4.03 inches^2, and for the split spacer, the cross-section area is 2.45 inches^2.

During a 24-inch drop, the weight of the support disks, top weldment, heat transfer disks, spacers, and end nuts are supported by the spacers on the tie rods. A conservative deceleration of 60g is applied to the spacers. The bounding spacer load occurs at the bottom weldment of the BWR basket. The bounding split-spacer load occurs at the 10th support disk (from bottom of the basket) of the Standard BWR basket.

The applied load on the BWR bottom spacer is 131,507 lbs.

$$P = 60(P_S) + P_T = 131{,}507 \text{ lbs.}$$

where:

$P_T = 2387$ lbs	torque pre-load
$P_s = 2152$ lbs	load on the spacer due to basket structure above the spacer location

$$P_s = \frac{18{,}199 - 623 - 4665}{6} = 2{,}152 \text{ lbs}$$

where:

18,199 lb.	BWR basket weight
623 lb.	BWR bottom weldment weight
4,665 lb.	BWR fuel tube weight

The applied load on the BWR split spacer is 108,227 lbs.

$$P = 60(P_S) + P_T = 108{,}227 \text{ lbs}$$

where:

P_T = 2387 lbs torque pre-load

P_s = 1764 lbs load on the spacer due to basket structure above the spacer location

$$P_s = \frac{18199 - 623 - 4665 - 10 \times 203 - 60 \times 5}{6} = 1{,}764 \text{ lbs}$$

18,199 lbs	BWR basket weight
623 lbs	BWR bottom weldment weight
4,665 lbs	BWR fuel tube weight
203 lbs	BWR support disk weight (Qty = 10)
5 lbs	BWR full spacer weight (Qty = 60)

The margins of safety for the spacers are:

	Applied Load (lbs)	Cross-sectional area (in^2)	Stress (psi)	Temperature (°F)	Allowable Stress (psi)	Margin of Safety
Spacer						
SA479	131507	4.66	28,220	250	47,950	0.70
SA312	131507	4.03	32,632	250	47,950	0.46
Split Spacer						
SA479	108227	2.50	43,291	350	45,640	0.05
SA312	108227	2.45	44174	350	45,640	0.03

The temperatures used bound the analysis locations for all storage conditions. The actual temperatures at these locations for storage for the BWR spacer at the bottom weldment is 118°F (minimum bottom weldment temperature), and 329°F (minimum temperature of 10^{th} support disk) for the split spacer. The 10^{th} support disk is counted from bottom weldment.

Standard Configuration Fuel Tube Analysis

During the postulated 24-inch end drop of the Standard concrete cask, fuel assemblies are supported by the canister bottom plate. The fuel assembly weight is not carried by the fuel tubes in the end drop. Therefore, evaluation of the fuel tube is performed considering the weight of the fuel tube, the canister deceleration and the minimum fuel tube cross-section. The minimum cross-section is located at the contact point of the fuel tube with the basket bottom weldment. The PWR fuel tube analysis is bounding because its weight (153 pounds/tube) is approximately twice that of the BWR fuel tube (83 pounds/tube). The minimum cross-section area of the PWR fuel tube is:

$$A = \text{(thickness)(mean perimeter)}$$

$$A = (0.048 \text{ in.})(8.80 \text{ in.} + 0.048 \text{ in.})(4) = 1.69 \text{ in}^2$$

The maximum compressive and bearing stress in the fuel tube is:

$$S_b = \frac{(60g)(153 \text{ lbs})}{1.69 \text{ in}^2} = 5{,}432 \text{ psi}$$

The Type 304 stainless steel yield strength is 17,300 psi at a conservatively high temperature of 750°F. The margin of safety is:

$$MS = \frac{S_y}{S_b} - 1 = \frac{17{,}300 \text{ psi}}{5{,}432 \text{ psi}} - 1 = +2.18 \text{ at } 750°F$$

Summary of Results for 24-Inch Drop of the Standard Configuration

Evaluation of the Standard concrete cask and canister in the 24-inch drop event shows that the resulting maximum acceleration of the canister is 58.1g. The acceleration determined for the canister during the 24-inch drop is less than its design allowable g-load and, therefore, is considered bounded. This accident condition does not lead to a reduction in the cask's shielding effectiveness. The base weldment, which includes the air inlets, is crushed approximately 1-inch as the result of the 24-inch drop. The effect of the reduction of the inlet area by the drop is to reduce cooling airflow. This condition is bounded by the consequences of the loss of one-half of the air inlets evaluated in Section 11.1.2.

Figure 11.2.4.3-1 Standard Concrete Cask Base Weldment

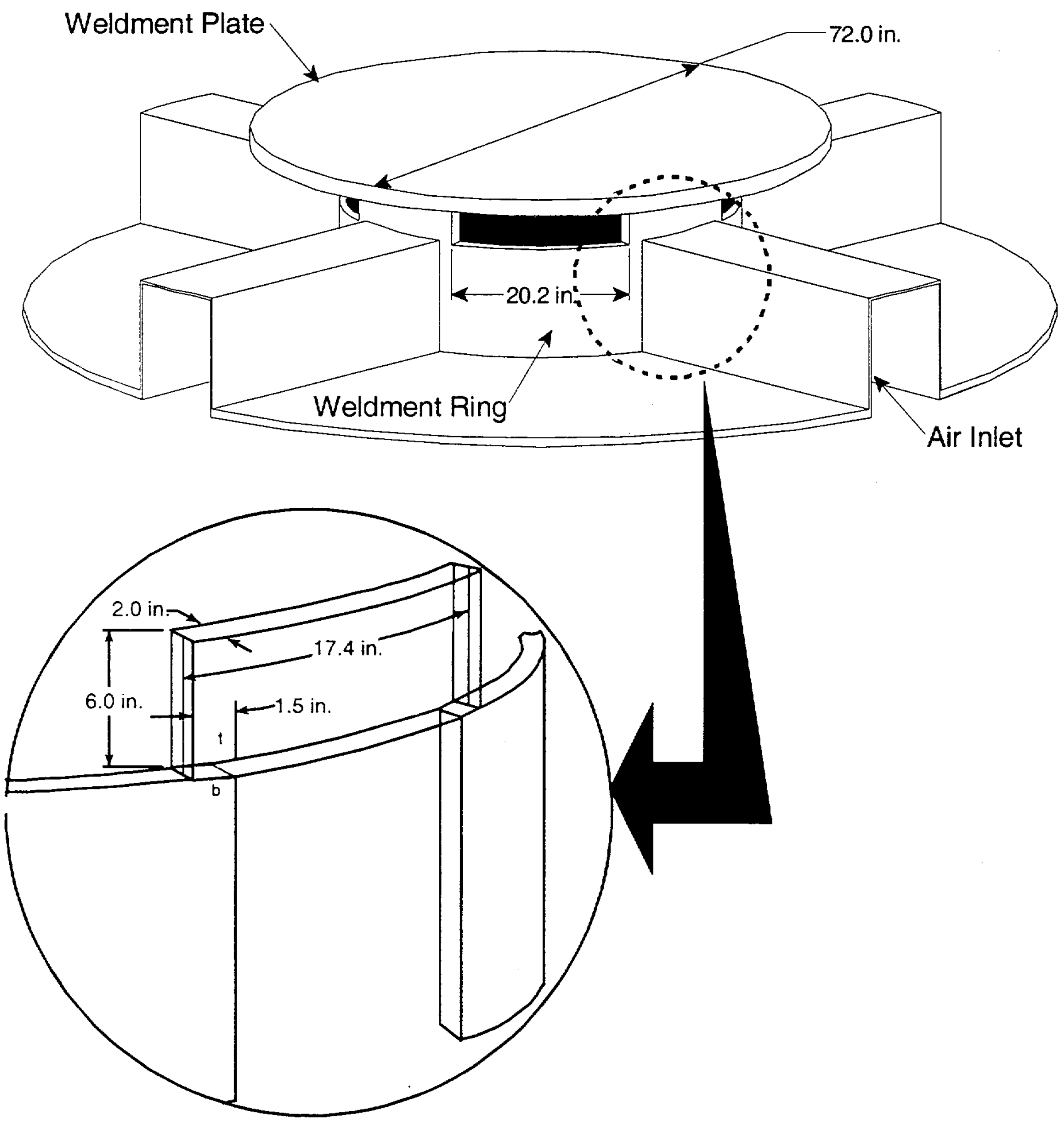


Figure 11.2.4.3-2 Standard Concrete Cask Base Weldment Finite Element Model

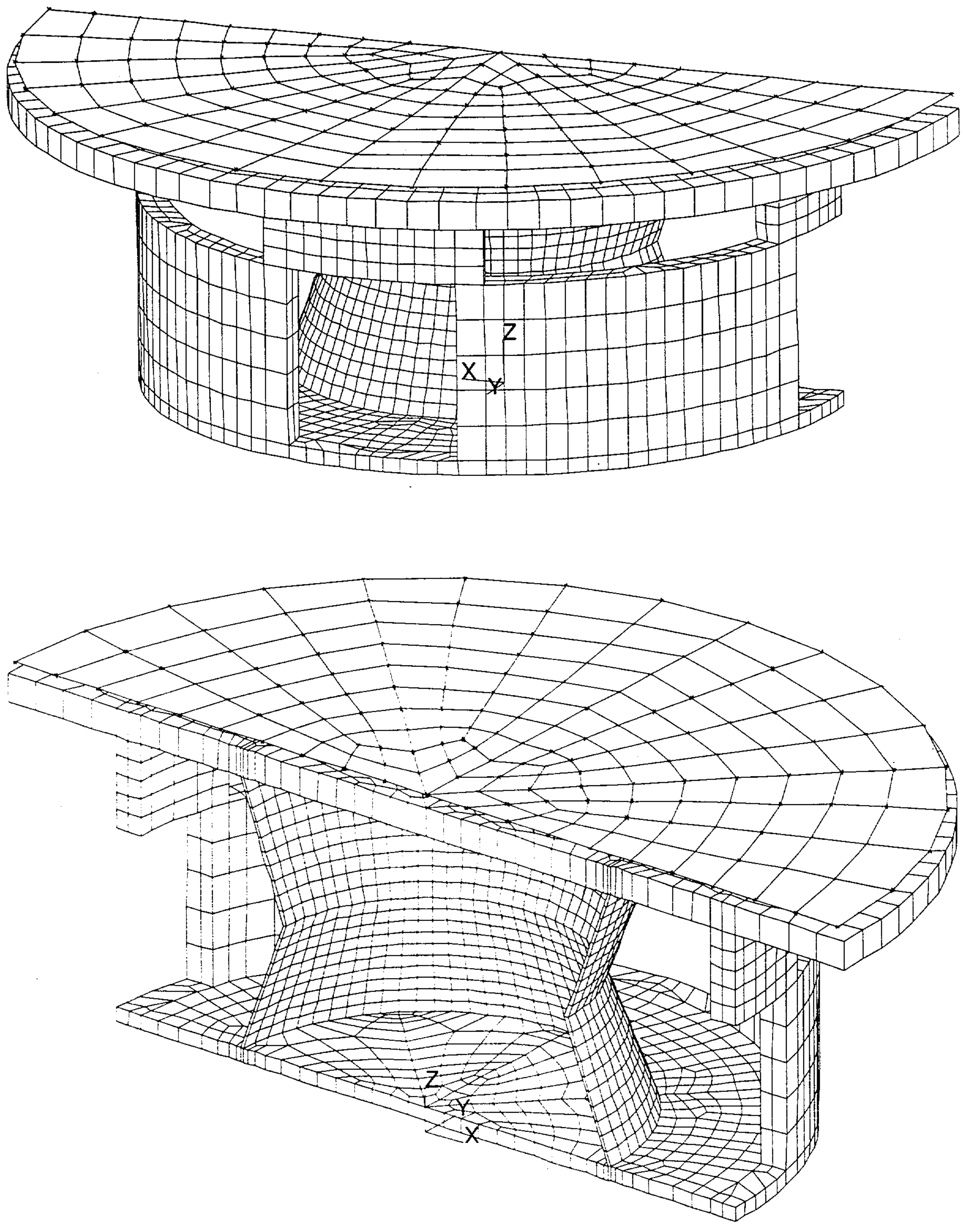


Figure 11.2.4.3-3 Strain Rate Dependent Stress-Strain Curves for Standard Concrete Cask Base Weldment Structural Steel

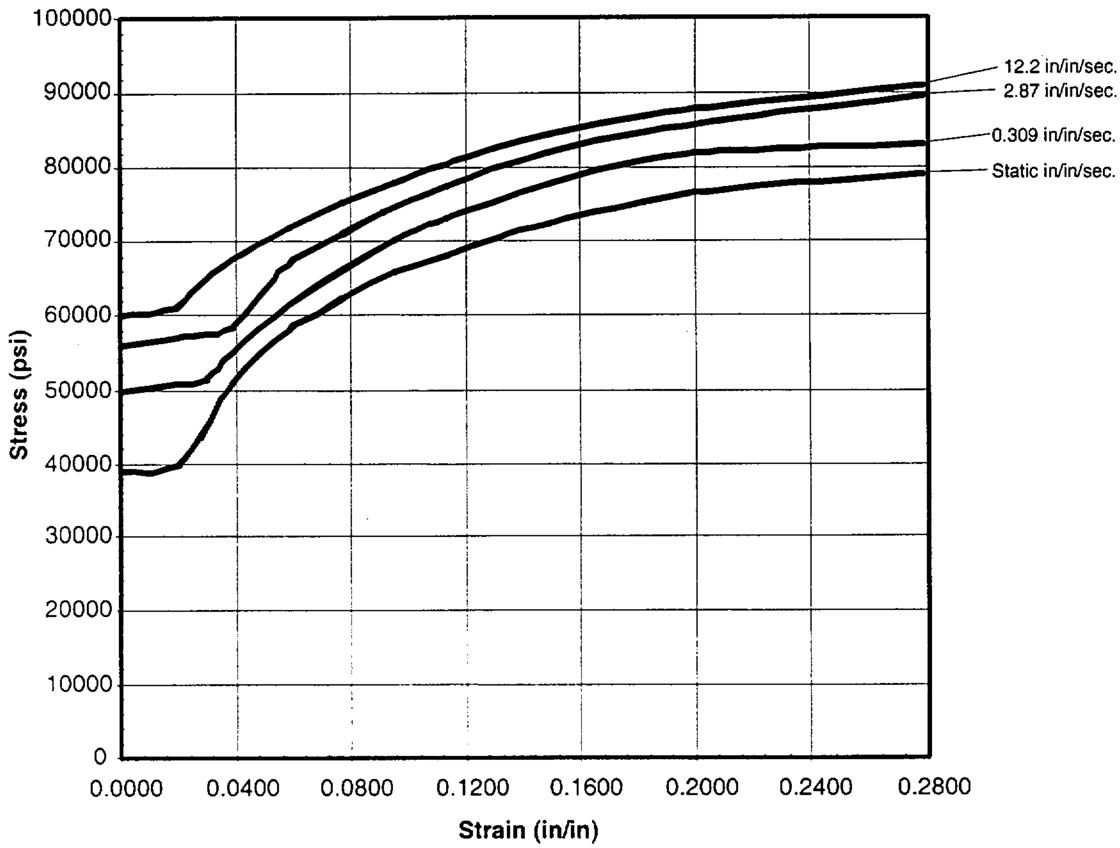


Figure 11.2.4.3-4 Acceleration Time-History of the Standard Canister Bottom During the Concrete Cask 24-Inch Drop Accident With Static Strain Properties

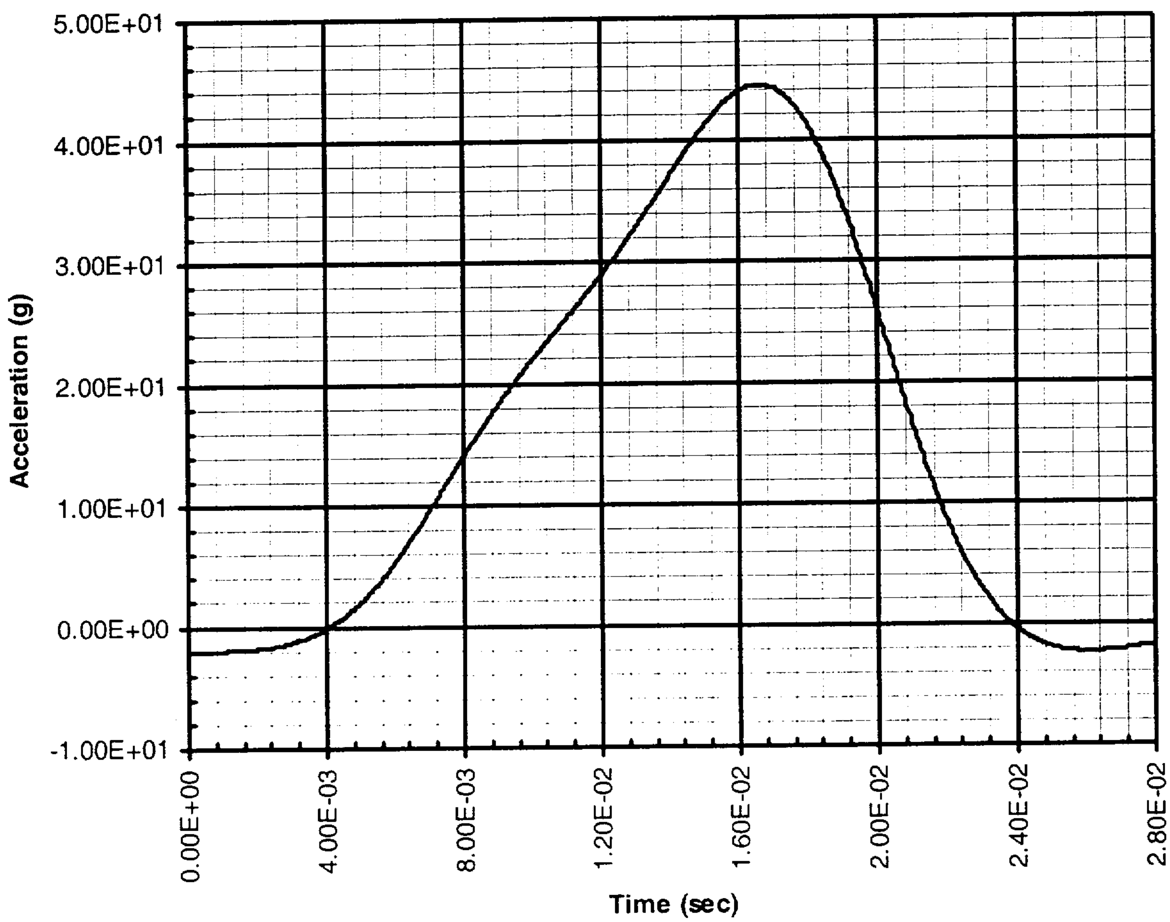


Figure 11.2.4.3-5 Acceleration Time-History of the Standard Canister Bottom During the Concrete Cask 24-Inch Drop Accident With Strain Rate Dependent Properties

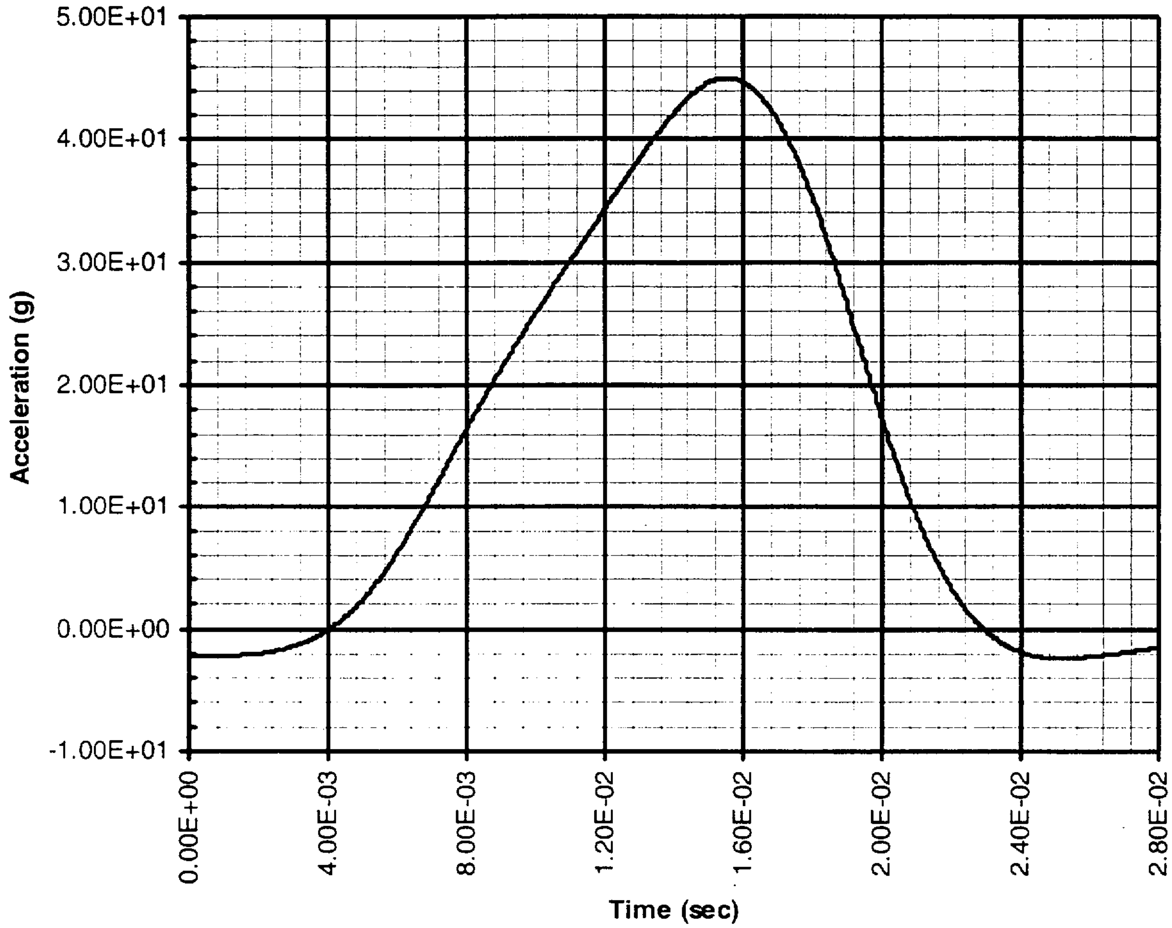


Figure 11.2.4.3-6 Quarter Model of the Standard PWR Basket Support Disk

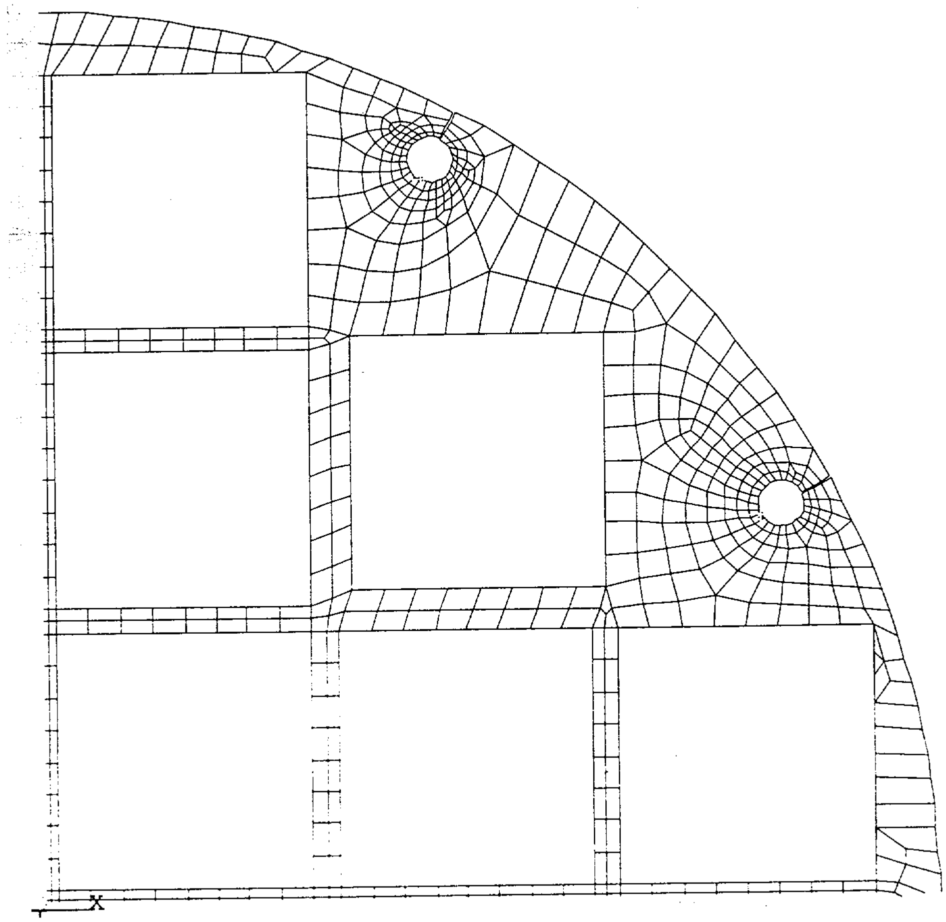


Figure 11.2.4.3-7 Quarter Model of the Standard BWR Basket Support Disk

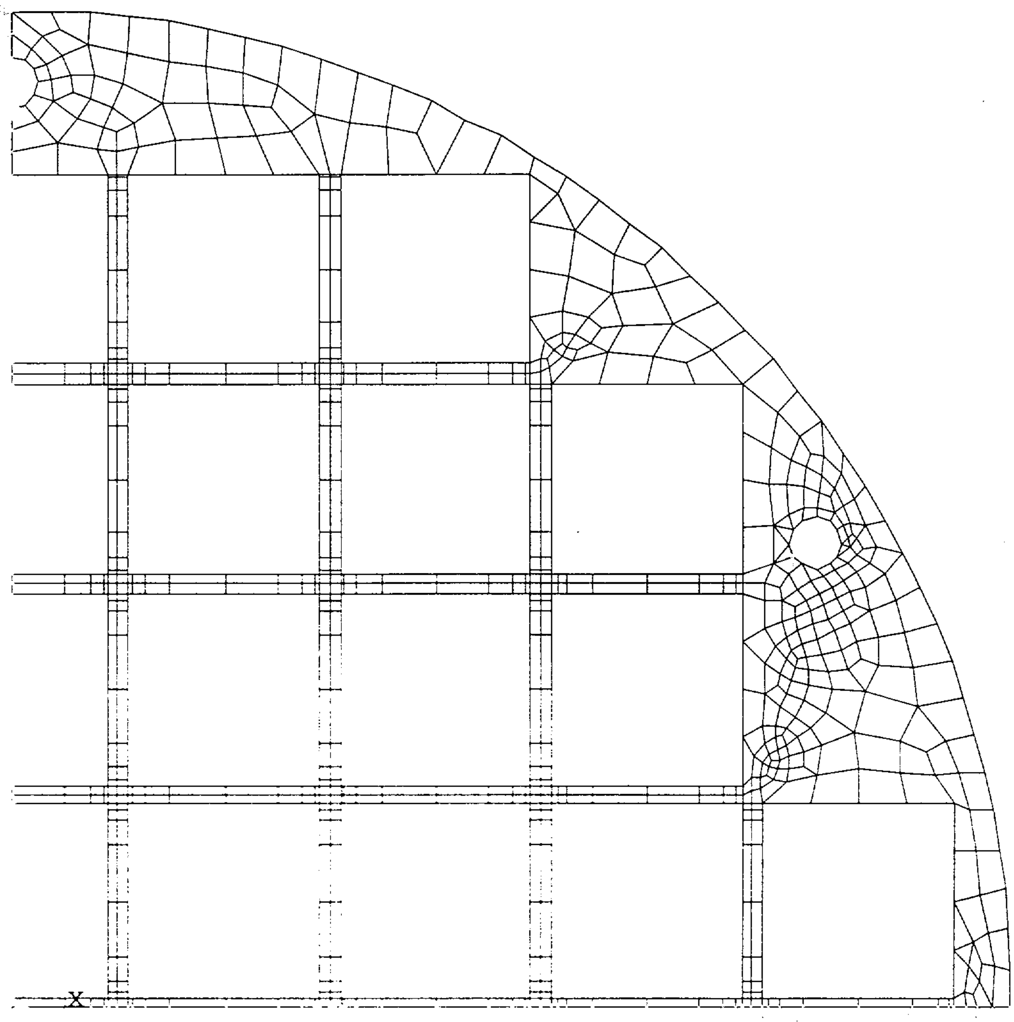
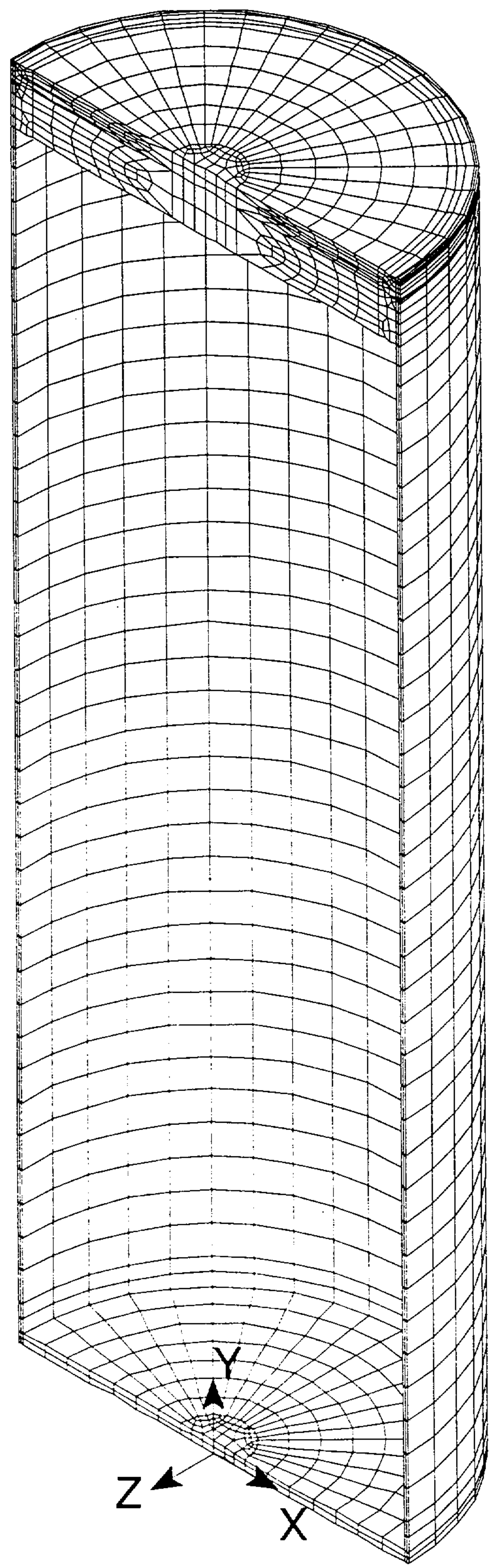
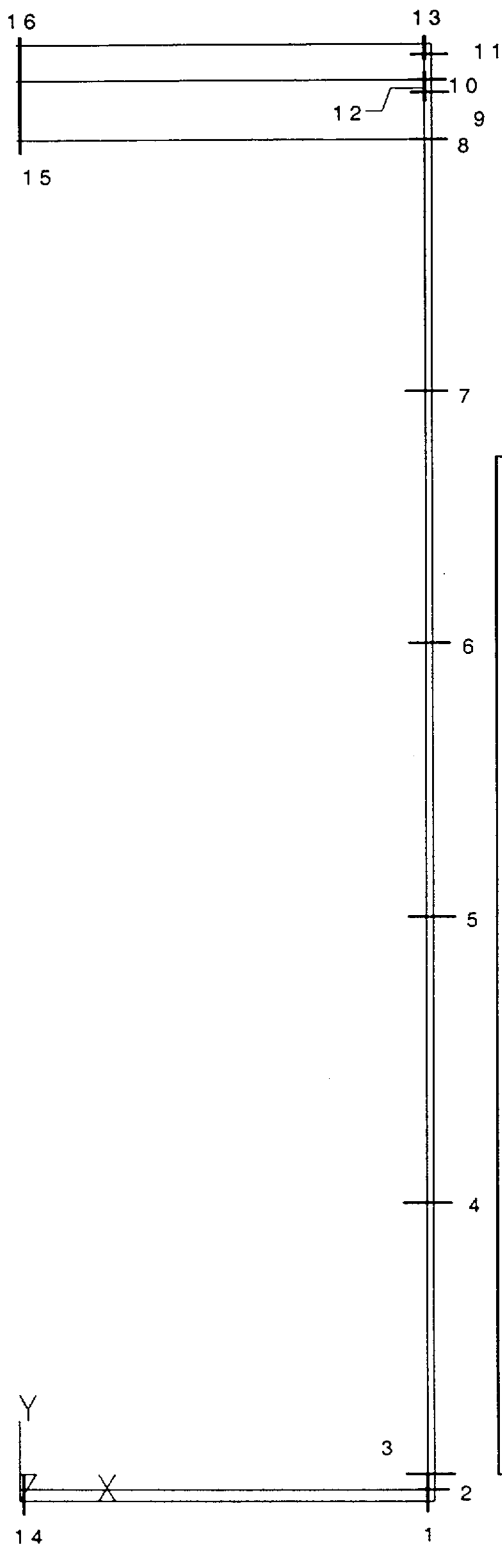


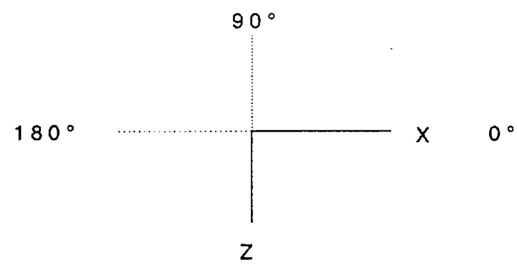
Figure 11.2.4.3-8 Canister Finite Element Model for 60g Bottom End Impact



Canister Model for Standard and Advanced Configurations

Figure 11.2.4.3-9 Identification of the Canister Sections for the Evaluation of Canister Stresses due to a 60g Bottom End Impact





Top View of Axis

PWR Section Coordinates at Z = 0

Axial Section	Node 1 x	Node 1 y	Node 2 x	Node 2 y
1	32.905	0.0	32.905	1.75
2	32.905	1.75	33.53	1.75
3	32.905	2.25	33.53	2.25
4	32.905	34.15	33.53	34.15
5	32.905	66.55	33.53	66.55
6	32.905	98.95	33.53	98.95
7	32.905	131.35	33.53	131.35
8	32.905	163.75	33.53	163.75
9	32.905	170.25	33.53	170.25
10	32.905	170.75	33.53	170.75
11	32.905	172.87	33.53	172.87
12	32.905	170.25	32.905	170.75
13	32.905	172.87	32.905	173.75
14	0.1	0.0	0.1	1.75
15	0.1	163.75	0.1	170.73
16	0.1	170.75	0.1	173.75

BWR Section Coordinates at Z = 0

Axial Section	Node 1 x	Node 1 y	Node 2 x	Node 2 y
1	32.905	0.0	32.905	1.75
2	32.905	1.75	33.53	1.75
3	32.905	2.25	33.53	2.25
4	32.905	37.79	33.53	37.79
5	32.905	73.83	33.53	73.83
6	32.905	109.87	33.53	109.87
7	32.905	145.91	33.53	145.91
8	32.905	181.95	33.53	181.95
9	32.905	188.45	33.53	188.45
10	32.905	188.95	33.53	188.95
11	32.905	191.07	33.53	191.07
12	32.905	188.45	32.905	188.95
13	32.905	191.07	32.905	191.95
14	0.1	0.0	0.1	1.75
15	0.1	181.95	0.1	188.73
16	0.1	188.97	0.1	191.95

Canister Sections for Standard and Advanced Configurations

Table 11.2.4.3-1 Standard PWR Canister P_m Stresses During a 60g Bottom Impact (25 psig Internal Pressure)

Section Location	P_m Stress (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
	Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-2.6	-0.4	0.2	0.1	0	2.6	38.4	13.85
2	0.7	-6.3	-1.1	0.3	0.1	0.1	7.1	38.4	4.43
3	0.1	-6.9	-1.2	0	0.1	0.1	7	38.4	4.49
4	0	-6.3	1.3	0	0	-0.1	7.7	38.4	4.01
5	0	-5.8	1.3	0	0	-0.1	7.1	38.4	4.41
6	0	-5.2	1.3	0	0	-0.1	6.5	38.4	4.88
7	0	-4.6	1.3	0	0	-0.1	6	38.4	5.44
8	0.7	-3.1	0.1	0	-0.1	0.1	3.8	38.4	9.03
9	-1.7	-1.9	-0.7	-0.1	0.4	-0.4	1.6	38.4	22.94
10	1.7	-1.3	-1	-0.3	0	0.2	3.1	38.4	11.5
11	-2	0.5	-0.9	0	0	0.1	2.5	38.4	14.17
12	0.7	1.8	-0.4	0.2	0.1	-0.1	2.2	38.4	16.18
13	0	-2	-1.2	0	0	0.1	2	30.72*	14.36
14	0.1	-1.1	0.1	0	0	0	1.2	38.4	30.57
15	0.2	-0.1	0.2	0	0	0	0.2	38.4	186.72
16	-0.2	0	-0.2	0	0	0	0.2	38.4	223.94

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Table 11.2.4.3-2 Standard PWR Canister $P_m + P_b$ Stresses During a 60g Bottom Impact (25 psig Internal Pressure)

Section Location	$P_m + P_b$ Stress (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
	Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0.4	-2.9	-0.2	0.3	0.1	0	3.4	57.5	16.11
2	0.4	-9.5	-2.1	0.1	0.1	0.2	9.9	57.5	4.84
3	0.1	-8.9	-1.8	-0.1	0.1	0.1	9	57.5	5.39
4	0	-6.3	1.3	0	0	-0.1	7.7	57.5	6.49
5	0	-5.8	1.3	0	0	0.1	7.1	57.5	7.1
6	0	-5.2	1.3	0	0	-0.1	6.5	57.5	7.8
7	0	-4.6	1.3	0	0	-0.1	6	57.5	8.64
8	0.6	-3.4	0.3	0	-0.2	0	4.1	57.5	13.03
9	-2.4	-3.9	-0.4	0	0.7	0	3.7	57.5	14.53
10	-2.9	-6.6	0.6	0	0.2	0	7.3	57.5	6.91
11	-1.1	5.6	0.9	-0.4	0	0.1	6.8	57.5	7.52
12	2.6	3.6	0.7	0.7	0	-0.1	3.3	57.5	16.27
13	2.3	0.1	0.1	0.4	0.1	0.2	2.4	46.0*	18.17
14	0.1	-1.2	0.1	0	0	0	1.3	57.5	43.49
15	3.6	0	3.6	0	0	0	3.6	57.5	14.82
16	-1.8	0	-1.8	0	0	0	1.8	57.5	31.14

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Table 11.2.4.3-3 Standard BWR Canister P_m Stresses During a 60g Bottom Impact (25 psig Internal Pressure)

Section Location	P_m Stress (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
	Sx	Sy	Sz	Sxy	Syz	Sxz			
1*	-0.1	-2.8	-0.4	0.2	0.1	0	2.8	38.4	12.57
2	0.6	-6.5	-1.2	0.3	0.1	0.1	7.1	38.4	4.39
3	0.4	-6.7	-1.1	0.2	0.1	0.1	7.1	38.4	4.37
4	0	-6.6	1.3	0	0	-0.1	7.9	38.4	3.85
5	0	-6	1.3	0	0	-0.1	7.3	38.4	4.27
6	0	-5.3	1.3	0	0	-0.1	6.6	38.4	4.77
7	0	-4.7	1.3	0	0	-0.1	6	38.4	5.37
8	0.5	-3.1	0.3	0	0	0.3	3.8	38.4	9.03
9	-1.7	-1.9	-0.7	-0.1	0.4	-0.4	1.6	38.4	22.94
10	1.7	-1.3	-1	-0.3	0	0.2	3.1	38.4	11.5
11	-2	0.5	-0.9	0	0	0.1	2.5	38.4	14.17
12	0.7	1.8	-0.4	0.2	0.1	-0.1	2.2	38.4	16.18
13	0	-2	-1.2	0	0	0.1	2	30.72**	14.36
14*	0.1	-1.1	0.1	0	0	0	1.3	38.4	29.44
15	0.2	-0.1	0.2	0	0	0	0.2	38.4	186.72
16	-0.2	0	-0.2	0	0	0	0.2	38.4	223.54

* Stresses at these locations are increased by 5% to account for the heavier BWR fuel basket/fuel assemblies.

** Allowable stress includes stress reduction factor for weld: 0.8 x stress allowable.

Table 11.2.4.3-4 Standard BWR Canister $P_m + P_b$ Stresses During a 60g Bottom Impact (25 psig Internal Pressure)

Section Location	$P_m + P_b$ Stress (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
	Sx	Sy	Sz	Sxy	Syz	Sxz			
1*	0.3	-3.2	-0.3	0.3	0.1	0	3.7	57.5	14.54
2	0.3	-9.4	-2.1	0.2	0.1	0.2	9.7	57.5	4.95
3	0.2	-9	-1.8	0.1	0.1	0.1	9.2	57.5	5.28
4	0	-6.6	1.3	0	0	-0.1	7.9	57.5	6.25
5	0	-6	1.3	0	0	0.1	7.3	57.5	6.89
6	0	-5.3	1.3	0	0	-0.1	6.7	57.5	7.64
7	0	-4.7	1.3	0	0	-0.1	6	57.5	8.54
8	0.5	-3.4	0.5	0.1	-0.1	0.2	4.1	57.5	13.03
9	-2.4	-3.9	-0.4	0	0.7	0	3.7	57.5	14.53
10	-2.9	-6.6	0.6	0	0.2	0	7.3	57.5	6.91
11	-1.1	5.6	0.9	-0.4	0	0.1	6.8	57.5	7.52
12	2.6	3.6	0.7	0.7	0	-0.1	3.3	57.5	16.27
13	2.3	0.1	0.1	0.4	0.1	0.2	2.4	46.0**	18.17
14*	0.1	-1.1	0.1	0	0	0	1.4	57.5	37.33
15	3.6	0	3.6	0	0	0	3.6	57.5	14.82
16	-1.8	0	-1.8	0	0	0	1.8	57.5	31.14

* Stresses at these locations are increased by 5% to account for the heavier BWR fuel basket/fuel assemblies.

** Allowable stress includes stress reduction factor for weld: 0.8 x stress allowable.

Table 11.2.4.3-5 Summary of Maximum Stresses for Standard PWR and BWR Basket Weldments During a 60g Bottom Impact

Case	Stress Category	Maximum Stress Intensity[1] (ksi)	Allowable Stress[2] (ksi)	Margin of Safety
PWR Top Weldment	$P_m + P_b$	27.5	63.5	1.31
PWR Bottom Weldment	$P_m + P_b$	12.0	68.5	+Large
BWR Top Weldment	$P_m + P_b$	34.1	64.0	0.88
BWR Bottom Weldment	$P_m + P_b$	51.9	65.2	0.26

1. Nodal stresses from the finite element analysis results are used.
2. Allowable stresses are conservatively determined at the maximum temperatures of the weldments.

Table 11.2.4.3-6 Standard PWR Canister P_m Stresses During a 60g Bottom Impact (No Internal Pressure)

Section Location	P_m Stress (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
	Sx	Sy	Sz	Sxy	Syz	Sxz			
1	-0.1	-3	-0.5	0.2	0.1	0	2.9	38.4	12.08
2	0.6	-6.7	-1.3	0.3	0.1	0.1	7.3	38.4	4.27
3	0.1	-7.4	-1.5	0	0.1	0.1	7.5	38.4	4.09
4	0	-7	0	0	0	0	7	38.4	4.48
5	0	-6.4	0	0	0	0	6.4	38.4	4.97
6	0	-5.9	0	0	0	0	5.9	38.4	5.55
7	0	-5.3	0	0	0	0	5.3	38.4	6.24
8	0.1	-3.6	0.1	0.1	-0.1	-0.1	3.7	38.4	9.28
9	-2	-2.1	-0.9	-0.2	0.5	-0.4	1.8	38.4	20.52
10	2	-1.4	-1.2	-0.3	0	0.2	3.5	38.4	9.85
11	-2.3	0.6	-1.1	0	0	0.1	3	38.4	11.97
12	0.8	2	-0.5	0.3	0.1	-0.1	2.5	38.4	14.15
13	0	-2.3	-1.3	0	0	0.1	2.3	30.72*	12.36
14	0.1	-1.1	0.1	0	0	0	1.2	38.4	32.35
15	0.2	0	0.2	0	0	0	0.2	38.4	174.28
16	-0.2	0	-0.2	0	0	0	0.2	38.4	191.24

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Table 11.2.4.3-7 Standard BWR Canister P_m Stresses During a 60g Bottom Impact (No Internal Pressure)

Section Location	P_m Stress (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
	Sx	Sy	Sz	Sxy	Syz	Sxz			
1*	-0.1	-3.1	-0.6	0.2	0.1	0	3.2	38.4	11.13
2	0.5	-6.9	-1.4	0.3	0.1	0.1	7.4	38.4	4.16
3	0.4	-7.1	-1.3	0.2	0.1	0.1	7.5	38.4	4.08
4	0	-7.2	0	0	0	0	7.2	38.4	4.29
5	0	-6.6	0	0	0	0	6.6	38.4	4.8
6	0	-6	0	0	0	0	6	38.4	5.41
7	0	-5.4	0	0	0	0	5.4	38.4	6.15
8	0.1	-3.6	0.1	0.1	-0.1	-0.1	3.7	38.4	9.28
9	-2	-2.1	-0.9	-0.2	0.5	-0.4	1.8	38.4	20.52
10	-0.9	-1.5	1.7	0.1	-0.3	-0.9	3.5	38.4	9.85
11	-2.3	0.6	-1.1	0	0	0.1	3	38.4	11.97
12	0.8	2	-0.5	0.3	0.1	-0.1	2.5	38.4	14.15
13	0	-2.3	-1.3	0	0	0.1	2.3	30.72**	12.36
14*	0.1	-1.1	0.1	0	0	0	1.2	38.4	31.18
15	0.2	0	0.2	0	0	0	0.2	38.4	174.36
16	-0.2	0	-0.2	0	0	0	0.2	38.4	190.95

*Stresses at these locations are increased by 5% to account for the heavier BWR fuel basket/fuel assemblies.

**Allowable stress includes stress reduction factor for weld: 0.8 x stress allowable.

Table 11.2.4.3-8 Standard Canister Buckling Evaluation Results for 60g Bottom End Impact

Standard Canister	**PWR**	**BWR**
Longitudinal (Axial) Stress* Sy (psi)	7,400	7,200
Circumferential (Hoop) Stress* Sz (psi)	1,500	1,300
In-Plane Shear Stress Syz (psi)	100	300
Elastic Buckling Interaction Equations		
Q1	0.142	0.122
Q2	0.159	0.152
Q3	0.219	0.188
Q4	0.142	0.122
Plastic Buckling Interaction Equations		
Q5	0.159	0.152
Q6	0.219	0.188
Q7	0.159	0.152
Q8	0.219	0.188

Component stresses include thermal stresses.

* Compressive stresses

Table 11.2.4.3-9 $P_m + P_b$ Stresses for Standard PWR Support Disk - 60g Concrete Cask Bottom End Impact (ksi)

Section[1]	S_x	S_y	S_{xy}	Stress Intensity	Allowable Stress	Margin of Safety
66	37.6	18.1	15.1	45.8	130.9	1.86
120	17.7	37.3	-15.2	45.6	130.9	1.87
82	37.5	18.1	-14.6	45.3	130.9	1.89
72	17.9	37.2	14.8	45.2	130.9	1.89
42	8.4	-24.2	-2.3	32.9	130.1	2.95
40	8.4	-24.2	2.3	32.9	130.1	2.95
56	8.4	-24.2	2.3	32.9	130.1	2.96
12	-24.2	8.4	2.3	32.9	130.1	2.96
28	-24.1	8.4	2.3	32.9	130.1	2.96
54	8.4	-24.2	-2.3	32.9	130.1	2.96
14	-24.2	8.4	-2.3	32.9	130.1	2.96
26	-24.1	8.4	-2.3	32.8	130.1	2.96
90	24.3	3.5	-10.3	29.3	130.9	3.46
122	24.4	3.8	-10.4	29.3	130.9	3.46
106	24.3	3.7	10.3	29.2	130.9	3.48
74	24.3	3.9	10.3	29.1	130.9	3.5
99	3	23.7	10.2	29	130.9	3.51
115	3.5	23.7	-10.1	28.6	130.9	3.58
114	9.1	11.2	-14.2	28.5	130.9	3.59
83	3.4	23.8	-10	28.5	130.9	3.59
67	3.4	23.6	10.1	28.5	130.9	3.59
88	11.1	9.5	-14.1	28.2	130.9	3.64
104	11.2	9.4	13.3	26.7	130.9	3.91
98	10.5	11	13.3	26.6	130.9	3.92
3	-19.8	-11.1	-7.7	24.4	124.3	4.1
4	-11.2	-19.8	-7.7	24.4	124.3	4.1
1	-19.8	-11.1	-7.7	24.4	124.3	4.1
2	-11.2	-19.8	-7.7	24.4	124.3	4.1
51	-5.5	-22.4	-4.2	23.4	128.1	4.47
49	-5.5	-22.4	4.3	23.4	128.1	4.47
9	-22.4	-5.5	4.2	23.4	128.1	4.47
23	-22.4	-5.5	-4.2	23.4	128.1	4.47
7	-22.4	-5.5	-4.2	23.4	128.1	4.48
21	-22.4	-5.5	4.2	23.4	128.1	4.48
35	-5.5	-22.4	-4.2	23.4	128.1	4.48
37	-5.4	-22.4	4.2	23.4	128.1	4.48
39	9.3	-12.4	4.3	23.3	130.1	4.58
11	-12.4	9.3	-4.3	23.3	130.1	4.59
53	9.3	-12.4	-4.3	23.3	130.1	4.59
25	-12.4	9.3	-4.3	23.3	130.1	4.59

1. Section locations are shown in Figures 3.4.4.1-7 and 3.4.4.1-8.

Table 11.2.4.3-10 $P_m + P_b$ Stresses for Standard BWR Support Disk - 60g Concrete Cask Bottom End Impact (ksi)

Section[1]	Sx	Sy	Sxy	Stress Intensity	Allowable Stress	Margin of Safety
257	54.5	19.9	11	57.7	90	0.56
171	10.3	52.8	8	54.3	90	0.66
108	9	52.9	-7.7	54.2	90	0.66
234	10.9	52.8	-6.9	53.9	90	0.67
129	50.5	16.5	10.9	53.7	90	0.68
65	49.8	15.7	-10.9	53	90	0.7
182	49.8	9.1	10.6	52.4	90	0.72
192	49.2	13.9	-10.3	52	90	0.73
300	7.7	50.4	7	51.6	90	0.75
119	48	8.4	-9.4	50.1	90	0.8
54	48	8.3	9.4	50.1	90	0.8
246	47.7	9.1	-9	49.7	90	0.81
103	14.1	16.5	11.4	26.8	90	2.36
235	-4.8	21.1	1.6	26	90	2.46
229	13.5	16.1	11.1	25.9	90	2.47
140	10.5	-14.2	-3.9	25.9	90	2.48
77	10.5	-14.2	3.9	25.9	90	2.48
269	10.5	-14.2	-3.8	25.9	90	2.48
203	10.5	-14.2	3.8	25.9	90	2.48
295	13.3	15.6	-11	25.6	90	2.52
301	-4.7	20.4	-2.5	25.5	90	2.52
134	1.6	11.8	-11.6	25.4	90	2.55
197	1.6	11.8	11.6	25.4	90	2.55
71	1.6	11.8	11.6	25.4	90	2.55
263	1.6	11.7	-11.6	25.3	90	2.56
172	-3.5	21.5	-1.6	25.1	90	2.58
166	13	15.4	-10.8	25	90	2.59
40	15.3	-9	2.9	25	90	2.6
27	15.3	-9	-2.9	25	90	2.6
228	-12.3	-4.5	11.8	24.9	90	2.61
165	-12.3	-4.6	-11.8	24.9	90	2.61
102	-12.3	-4.5	11.8	24.9	90	2.61
294	-12.3	-4.6	-11.8	24.9	90	2.61
252	-20.5	-6.5	-8.6	24.6	90	2.66
124	-20.6	-6.5	-8.6	24.6	90	2.66
60	-20.5	-6.5	8.6	24.6	90	2.66
187	-20.5	-6.5	8.6	24.6	90	2.66
109	-2.6	21.4	2.6	24.6	90	2.67
73	5	13.9	11.4	24.5	90	2.68
199	4.5	14.3	11.1	24.2	90	2.72

1. Section locations are shown in Figures 3.4.4.1-13 through 3.4.4.1-16

11.2.4.4 Analysis of Advanced Concrete Cask 24-Inch Cask Drop

A bottom end impact is assumed to occur normal to the Advanced concrete cask bottom surface, transmitting the maximum load to the concrete cask and the canister. The energy absorption is computed as the product of the compressive force acting on the concrete cask and its displacement. Conservatively assuming that the storage surface impacted is an infinitely rigid surface, the concrete cask body will crush until the impact energy is absorbed.

A compressive strength of 4,000 psi is used for the cask concrete. The evaluation conservatively ignores any energy absorption by the internal friction of the aggregate as crushing occurs.

The canister rests upon a base weldment designed to allow cooling of the canister. Following the initial impact, the inlet system will partially collapse, providing an energy absorption mechanism that somewhat reduces the deceleration force on the canister.

Evaluation of the Advanced Concrete Cask

In the 24-inch bottom drop of the Advanced concrete cask, the cylindrical portion of the concrete is in contact with the steel bottom plate that is a part of the base weldment. The plate is assumed to be part of an infinitely rigid storage pad. No credit is taken for the crush properties of the storage pad or the underlying soil layer. Therefore, energy absorbed by the crushing of the cylindrical concrete region of the concrete cask equals the product of the compressive strength of the concrete, the crush depth of the concrete, and the projected area of the concrete cylinder. Crushing of the concrete continues until the energy absorbed equals the potential energy of the cask at the initial drop height. The canister is not rigidly attached to the concrete cask, so it is not considered to contribute to the concrete crushing. The energy balance equation is:

$$w(h+\delta) = P_o A \delta,$$

where:

h = 24 in., the drop height,

δ = the crush depth of the concrete cask,

P_o = 4000 psi, the compressive strength of the concrete,

A = $\pi(R_1^2 - R_2^2)$ = 7,904 in^2, the projected area of the concrete shield wall,

w = 180,000 lbs (bounding weight for Advanced UMS® configurations)

It is assumed that the maximum force that can be exerted on the concrete cask is the compressive strength of the concrete multiplied by the area of the concrete being crushed. The concrete cask's steel shell will not experience any significant damage during a 24-inch drop. Therefore, its functionality will not be impaired due to the drop.

The crush distance computed from the energy balance equation is:

$$\delta = \frac{hw}{P_o A - w} = \frac{(24)(180{,}000)}{(4000)(7{,}904) - (180{,}000)} = 0.137 \; inch$$

where:

w = 180,000 lbs (the bounding weight is used to obtain the maximum deformation)

The resultant inlet deformation is 0.137 inch.

Evaluation of the Advanced Canister for a 24-inch Bottom End Drop

Upon a bottom end impact of the concrete cask, the canister produces a force on the base weldment located near the bottom of the cask (see Figure 11.2.4.4-1). The ring above the air inlets is expected to yield. To determine the resulting acceleration of the canister and deformation of the pedestal, an LS-DYNA analysis is used.

A half-symmetry model of the base weldment is built using the ANSYS preprocessor (see Figure 11.2.4.4-2). The model is constructed of 8-node brick and 4-node shell elements. Symmetry conditions are applied along the plane of symmetry (X-Z plane). The canister bottom plate is used to represent the weight of the loaded canister. The canister weight is simulated by increasing the density of the rigid plate material. The impact plane is represented as a rigid plane, which is considered conservative, since the energy absorption due to the impact plane is neglected (infinitely rigid). To determine the maximum acceleration and deformations, impact analyses are solved using the LS-DYNA program.

The weldment ring, weldment plate, and the inner cone (see Figure 11.2.4.4-1) materials are modeled using LS-DYNA's piece wise linear plasticity model. This material model accepts stress–strain curves for different strain rates. These stress strain curves were obtained from the Atlas of Stress-Strain Curves [44] and are shown in Figure 11.2.4.4-3. To ensure that maximum deformations and accelerations are determined, two analyses are performed. One analysis, which uses the static stress strain curve, envelopes the maximum deformation of the pedestal. The second analysis employs the multiple stress-strain curves to account for different strain rates.

The maximum accelerations of the Advanced canister during the 24-inch bottom end impact are 38.5g and 36.2g for the variable strain rate material model and the static stress-strain curve, respectively. The resulting acceleration time histories of the bottom canister plate, which correspond to a filter frequency of 225 Hz, are shown in 11.2.4.4-4 for the analysis using the static stress-strain curve and Figure 11.2.4.4-5 for the analysis corresponding to the series of stress-strain curves at different strain rates. These time histories indicate that the maximum accelerations do not occur at the beginning where the strain rate is maximum, but rather, at a time where the strain rate has a marginal effect on the accelerations. Therefore, the use of the multiple strain rate material model bounds the accelerations imposed on the canister, since it considers the effect of strain rate on the stress-strain curves.

The filter frequency used in the LS-DYNA evaluation is determined by performing modal analysis of a quarter-symmetry model of the base weldment in ANSYS. The model uses the lightest and most flexible system to determine the lowest frequency. Symmetry boundary conditions are applied at the planes of symmetry of the model. The analysis resulted in a fundamental natural frequency of 205.15 Hz. Therefore, a filter frequency of 225 Hz is selected.

Results of the LS-DYNA analysis show that the maximum deformation of the base weldment is about 0.81 inch. This deformation is small when compared to the 12-inch height of the air inlet. Therefore, a 24-inch drop of the concrete cask does not result in a blockage of the air inlets.

The dynamic response of the canister and basket on impact is amplified by the most flexible components of the system. In this case, the canister bounds the response. To account for the transient response of the canister, a dynamic load factor (DLF) for the canister is computed for the inertia loading developed during the deceleration of the canister bottom plate. The fundamental frequency of the canister is estimated by of a fixed-free (cantilever) bar in longitudinal vibration and is given as follows ("Formulas for Natural Frequency and Mode Shape" R. D. Blevins, Robert E. Krieger Publishing Company, Malabar, Florida, 1995 [19]):

$$f = \frac{1}{4}\sqrt{\frac{Eg}{\rho L^2}} = 167.0 \text{ Hz}$$

where:

E = modulus of elasticity = 29×10^6 psi
g = acceleration due to gravity = 386.4 in/sec^2
ρ = net density = 0.29 (steel) + 0.39 (lid) = 0.68 lb/in^3
L = length of canister = 192.0 in.

The total duration taken from the acceleration time histories from Figures 11.2.4.4-4 and 11.2.4.4-5 is approximately 0.02 seconds. Figure 11.2.4.4-6 shows the response spectrum for a half-sine load pulse ("Introduction to Structural Dynamics", J. M. Biggs, McGraw-Hill Inc., 1964 [43]). The maximum response ratio (DLF) for the impulse duration/period ratio of 3.34 (0.02×167.0) from Figure 11.2.4.4-6 is 1.17. Therefore, the DLF is 1.17.

Multiplying the calculated acceleration by the DLF results in an effective acceleration of 45g. This value is enveloped by the 60g acceleration employed in the stress evaluation of the end impact of the canister and basket. This acceleration is considered to be bounding since it incorporates the effect of the strain rate on the plastic behavior of the pedestal and ignores any energy absorption by the impact plane.

Canister Stress Evaluation

The Transportable Storage Canister stress evaluation for the concrete cask 24-inch bottom end drop accident is performed using a load of 60g, which bounds the 45g load calculated for the 24-inch bottom end drop event. This canister evaluation is performed using the ANSYS finite element program. The canister finite element model is shown in Figure 11.2.4.4-7. The construction and details of the finite element model are described in Section 3.4.4.3.1. Stress evaluations are performed with an internal pressure of 40 psig.

The principal components of the canister are the canister shell, including the bottom plate, the fuel basket, the shield lid, and the structural lid. The structural design criteria for the canister are contained in the ASME Code, Section III, and Subsection NB. This analysis shows that the structural components of the canister (shell, bottom plate, and structural lid) satisfy the allowable stress intensity limits.

The results of the analysis of the Advanced canister for the 60g bottom end impact loading are presented in Tables 11.2.4.4-1 and 11.2.4.4-2. The minimum margin of safety at each section of the canister is presented by denoting the circumferential angle at which the minimum margin of safety occurs. A cross-section of the canister showing the section locations is presented in Figure 11.2.4.4-8. Stresses are evaluated at 7.5° increments around the circumference of the canister for each of the locations shown. The minimum margin of safety is denoted by an angular location at each section.

For the canister to structural lid weld (Section 13, Figure 11.2.4.4-8), base metal properties are used to define the allowable stress limits since the tensile properties of the weld filler metal are greater than those of the base metal. The allowable stress at Section 13 is multiplied by a stress reduction factor of 0.8 in accordance with NRC Interim Staff Guidance (ISG) No. 4, Revision 1 [56].

The allowable stresses presented in Tables 11.2.4.4-1 and 11.2.4.4-2, are for Type 304L stainless steel. Because the shield lid is constructed of Type 304 stainless steel, which possesses higher allowable stresses, a conservative evaluation results. The allowable stresses are evaluated with a temperature distribution that envelops the canister normal conditions storage and handling temperature gradients.

Advanced Canister Buckling Evaluation

Code Case N-284-1 of the ASME Boiler and Pressure Vessel Code [58] is used to analyze the canister for the 60g bottom end impact. The evaluation requirements of Regulatory Guide 7.6, Paragraph C.5 [57], are satisfied by the results of the buckling interaction equation calculations. Since the Advanced canister is the same as the standard configuration canister and experiences the same end drop loads, the canister buckling analysis presented in Section 11.2.4.3 is bounding.

Advanced Basket Stress Evaluation

Stresses in the Advanced basket are calculated by applying the 60g accident acceleration in the axial direction to the ANSYS models described in Section 3.4.4.3.9. The stress evaluation uses the peak nodal stresses in the basket and weldment. Nodal stresses at the middle, top, and bottom of the elements are examined. Middle plane stresses represent the membrane stresses. Stresses at the top or bottom element surface represent the membrane plus bending stress. Stresses in the basket and weldment are evaluated separately. The basket stresses for accident conditions are summarized as:

P_m Stress	P_m Allowable	P_m MS	$P_m + P_b$ Stress	$P_m + P_b$ Allowable	$P_m + P_b$ MS
Basket Stresses (psi)					
22,901	54,460	+ 1.38	37,601	81,690	+ 1.17
Bottom Weldment Stresses (psi)					
52,171	54,460	+ 0.04	52,693	81,690	+ 0.55

An evaluation of the plate tabs is performed to ensure that the tabs can withstand the storage loadings. During normal and accident conditions, the tabs are subjected to an axial shear load. Assuming this load is reacted by two tabs (conservative since there are 22 tabs), the shear stress in the tab is calculated as follows:

condition. The body force is included as an acceleration in the vertical direction (386.4 inches/sec^2).

Filter Frequency

A modal analysis was performed using the ANSYS program on the 100-ton transfer cask model to determine the frequency to be used in filtering the acceleration time history data generated by the LS-DYNA program. The 100-ton transfer cask modal analysis finite element model is shown in Figure 11.2.16-5. The x-z plane is the plane of symmetry (at Y=0, Uy=0). The vibration modes of interest for the side-drop are primarily in the lateral direction to the cask body, i.e., the global z-direction. To find the primary vibration mode in the lateral direction, the nodes at the two extreme ends of the cask on the plane of symmetry are pinned in the z-direction (Uz=0 at X_{max}, Y_{min} and X_{min}, Y_{min}). The modal frequency and modal participation factor for the primary mode in the lateral direction is presented in the following table and Figure 11.2.16-6.

Description of Primary Mode of Excitation	Global Direction	Frequency, Hz	Effective Mass, slugs	Sum of Effective Mass, slugs	Percent Mass Participation Factor
Lateral	Z	38.3	82.2	90.7	90.6%

The vibration mode presented is based on the highest percent mass participation factor and is, therefore, called the primary mode of vibration since more than 50% of the mass participates in this mode. As the table shows, the cut-off frequency of the 100-ton transfer cask is 38 Hz. The predicted accelerations are, therefore, obtained by filtering the LS-DYNA acceleration outputs using a filter frequency of 50 Hz.

100-Ton Transfer Cask Side Drop Analysis Results for the Standard PWR Canister

The analysis results are obtained by using the LS-DYNA postprocessor, LS-POST, to display the nodal acceleration time-histories. From the modal analysis, a filter frequency of 50 Hz is used in conjunction with the LS-POST Butterworth filter. For the PWR basket/canister, the maximum filtered acceleration of 24.9g occurs near the bottom of fuel canister.

11.2.16.3.2 Analysis of the 100-Ton Transfer Cask Side Drop for the Standard BWR Canister

The side drop of the 100-ton transfer cask with the BWR fuel canister was evaluated using the finite model described above. The soil material properties and the concrete pad material properties in Section 11.2.12.3.2 were incorporated in the model for the side drop. To account for large deformation and buckling, the mechanical property of Type 304 stainless steel is represented by an elastic-plastic material formula with LS-DYNA material type 24 (Piecewise_Linear_Plasticity). The detailed stress-strain curve for Type 304 stainless steel at room temperature beyond yield is presented in Figure 11.2.16-4 ("Impact Dynamics" J.A. Zukas, T. Nicholas, H.F. Swift, L.B. Greszczuk, and D.R. Curran, John Wiley & Sons).

Boundary and Initial Condition

The assumed effective drop height of the 100-ton transfer cask is 53 inches. Since the 53-inch drop represents the dynamic force input, the initial velocity is 202.38 in/sec, i.e., the vertical velocity of a rigid body after a free fall of 53-in under 1-g gravitational force. The kinetic energy is checked to ensure that the total initial energy is correct.

The symmetry condition is at the XZ-plane (Y=0), at which all displacements in the Y-direction are constrained. The soil mat is constrained at the boundaries (X_{max}, X_{min}, Y_{max}, Z_{min}) with a roller condition. The body force is included as an acceleration in the vertical direction (386.4 inches/sec^2).

Filter Frequency

A modal analysis was performed using the ANSYS program on the 100-ton transfer cask to determine the frequency to be used in filtering the acceleration time history data generated by the LS-DYNA program. The 100-ton transfer cask modal analysis finite element model is shown in Figure 11.2.16-5. The x-z plane is the plane of symmetry (at Y=0, Uy=0). The vibration modes of interest for the side-drop are primarily in the lateral direction to the cask body, i.e., the global z-direction. To find the primary vibration mode in the lateral direction, the nodes at the two extreme ends of the cask on the plane of symmetry are pinned in the z-direction (Uz=0 at X_{max}, Y_{min} and X_{min}, Y_{min}). The modal frequency and modal participation factor for the primary mode in the lateral direction is presented in the following table and Figure 11.2.16-6.

Description of Primary Mode of Excitation	Global Direction	Frequency, Hz	Effective Mass, slugs	Sum of Effective Mass, slugs	Percent Mass Participation Factor
Lateral	Z	38.3	82.2	90.7	90.6%

The vibration mode presented is based on the highest percent mass participation factor and is, therefore, called the primary mode of vibration since more than 50% of the mass participates in this mode. As the table shows, the cut-off frequency of the 100-ton transfer cask is 38 Hz. The

Shear area = 2×3.28 in. $\times 0.3125$ in. = 2.05 in^2.

The axial shear force is taken as the weight of the largest center plate = 798 lb.

During accident conditions the shear stress is 798 lb × 60g / 2.05 in^2 = 23,360 psi. The allowable shear at 700°F is 0.42Su = 0.42(77,800) = 32,676 psi. The accident margin of safety is 32,676/23,360 – 1 = +0.40.

Neutron Absorber Sheets Analysis

For the worst case end drop, the neutron absorber sheets are designed so that entire weight of the sheet is taken by the two 1.00-inch tabs located near the bottom of the basket. During a 60g end drop, the applied load is

$$P = g \times \text{density} \times \text{thickness} \times (\text{sheet width} \times \text{sheet length} + \text{tab qty} \times \text{tab length} \times \text{tab width})$$
$$P = 60 \times 0.095 \times 0.050 \times (8.67 \times 173.5 + 44 \times 1.0 \times 0.30) = 432.5 \text{ lb}$$

The shear stress on one of the two tabs is

$$\tau = \frac{432.5/2}{0.050 \times 1.00} = 4{,}325 \text{ psi (use 4,500 psi)}$$

The allowable shear stress for accident conditions is defined as $0.42S_u$. At 500°F, the allowable stress is 7,940 psi. The margin of safety is

$$MS = \frac{7{,}940}{4{,}500} - 1 = 0.76$$

Summary of Results for the Advanced Concrete Cask

Evaluation of the Advanced concrete cask and canister during a 24-inch drop accident shows that the resulting maximum acceleration of the canister is 45g. The acceleration determined for the canister during the 24-inch drop is less than its design allowable g-load and, therefore, is considered bounded. This accident condition does not lead to a reduction in the cask's shielding effectiveness. The base weldment, which includes the air inlets, is crushed approximately 1-inch as the result of the 24-inch drop. The effect of the reduction of the inlet area by the drop is to reduce cooling airflow. This condition is bounded by the consequences of the loss of one-half of the air inlets evaluated in Section 11.1.2.

Figure 11.2.4.4-1 Advanced Concrete Cask Base Weldment

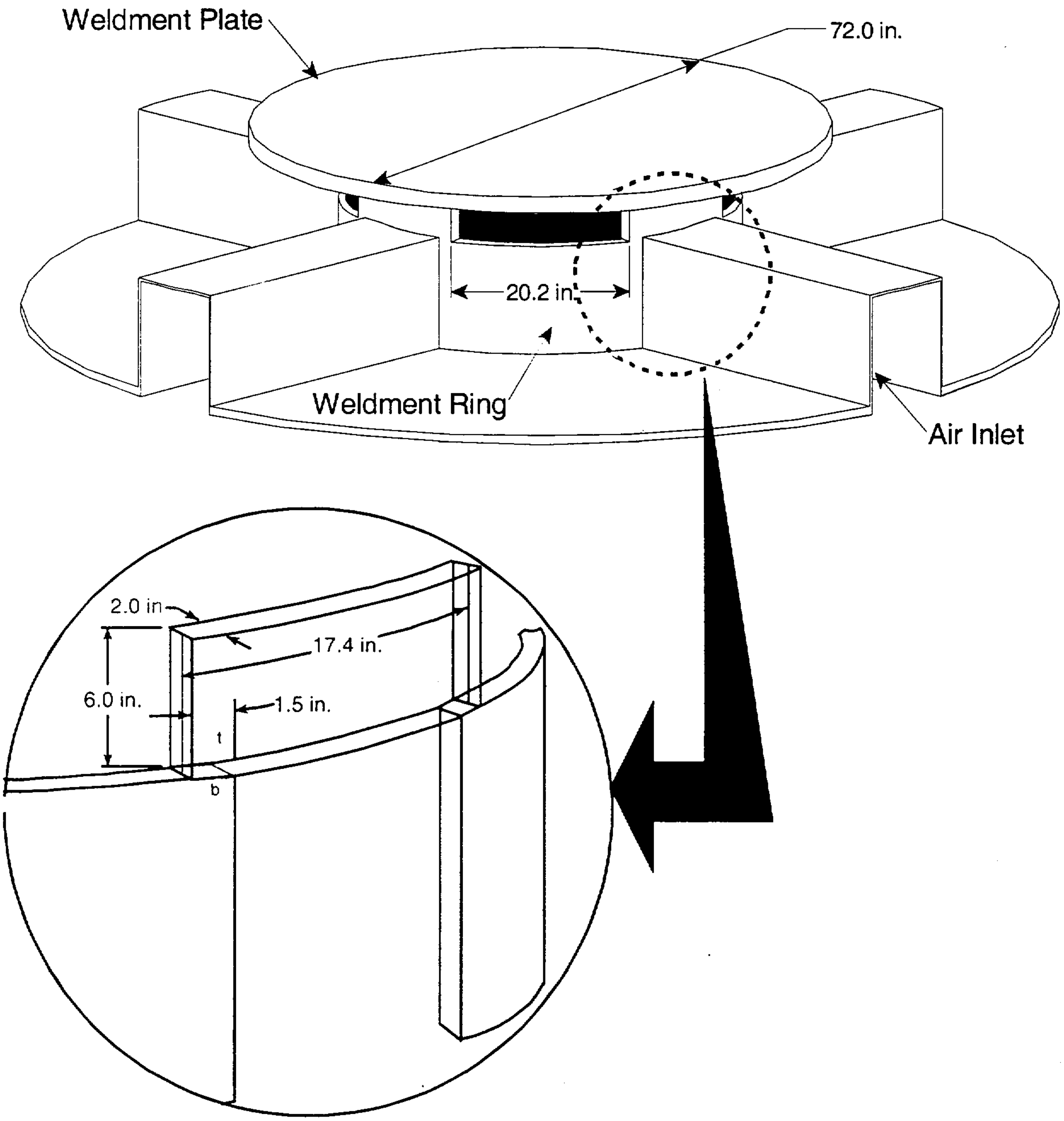


Figure 11.2.4.4-2 Advanced Concrete Cask Base Weldment Finite Element Model

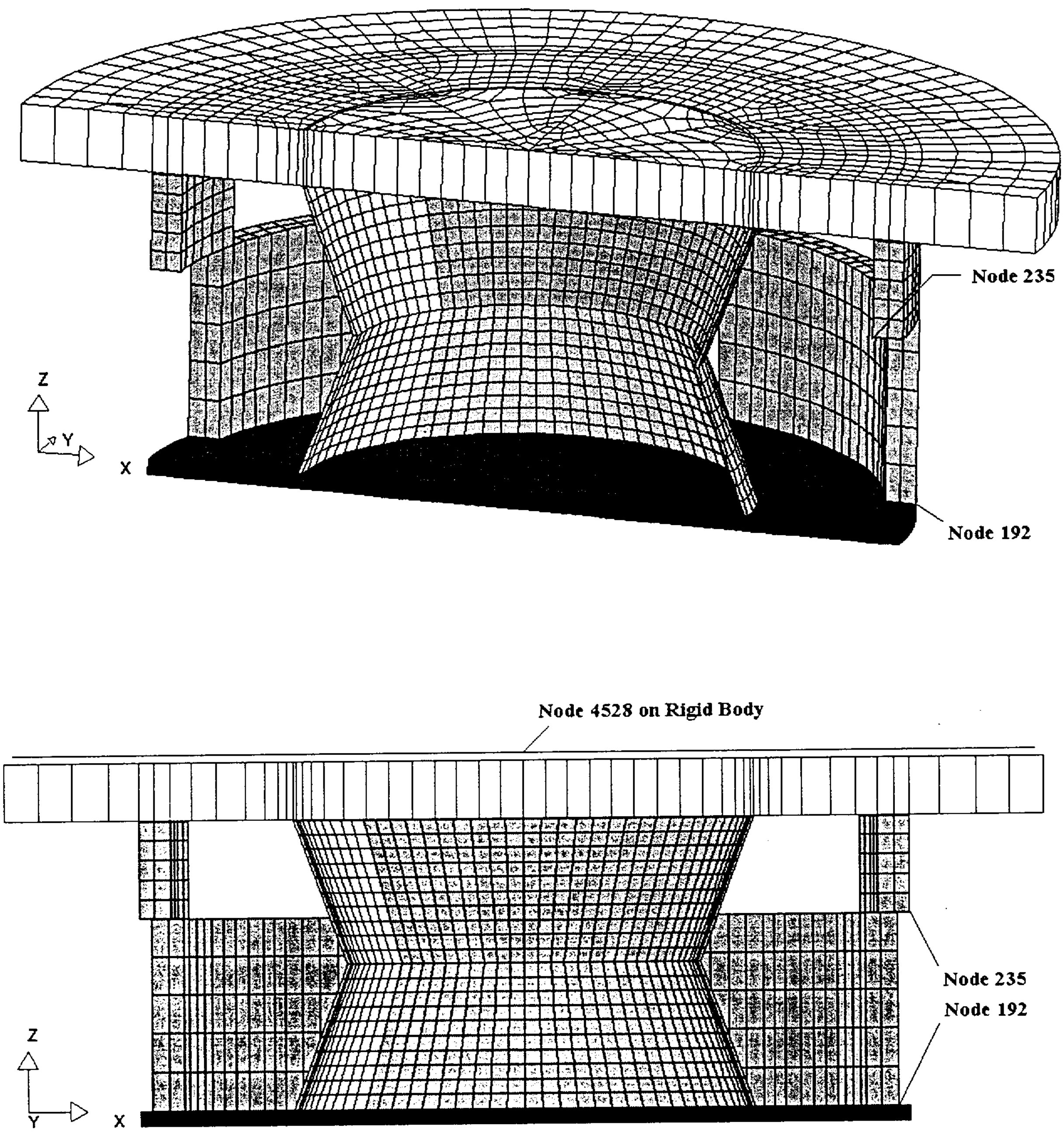


Figure 11.2.4.4-3 Strain Rate Dependent Stress-Strain Curves for the Advanced Concrete Cask Base Weldment Structural Steel

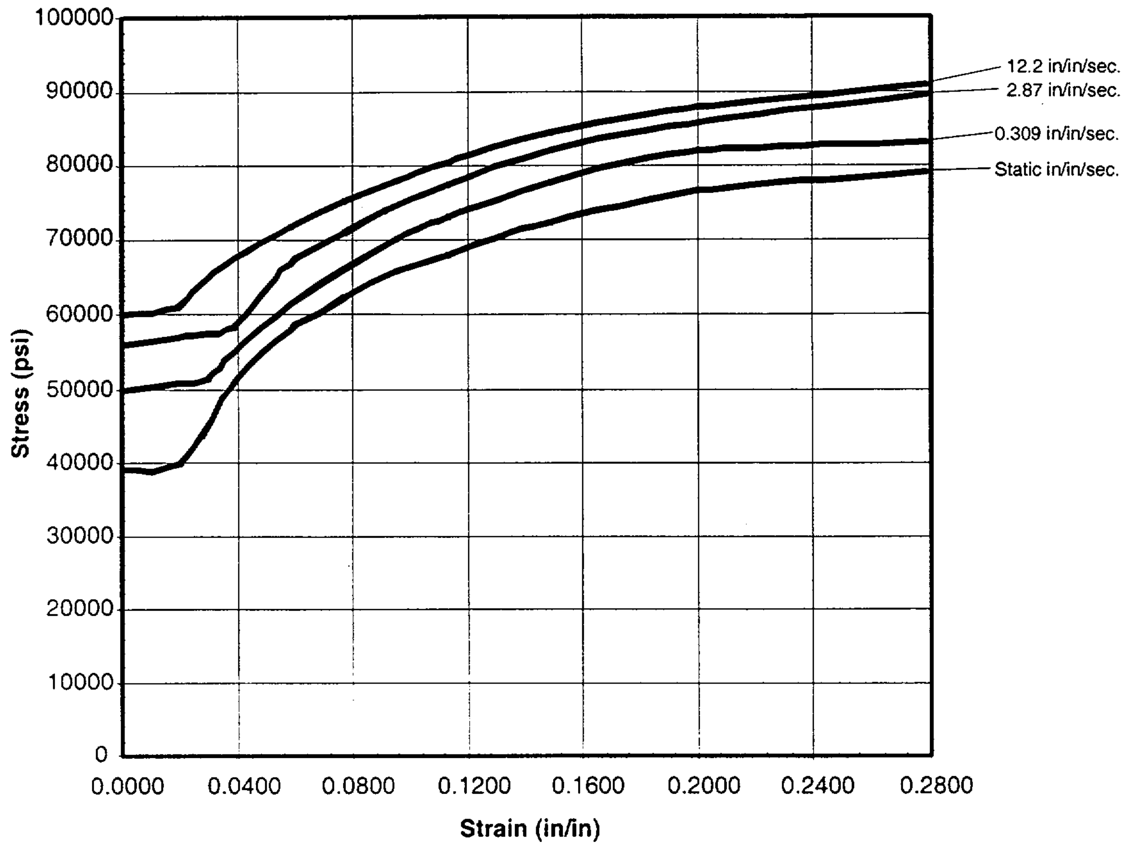


Figure 11.2.4.4-4 Acceleration Time-History of the Canister Bottom During the Advanced Concrete Cask 24-inch Drop Accident with Static Strain Properties

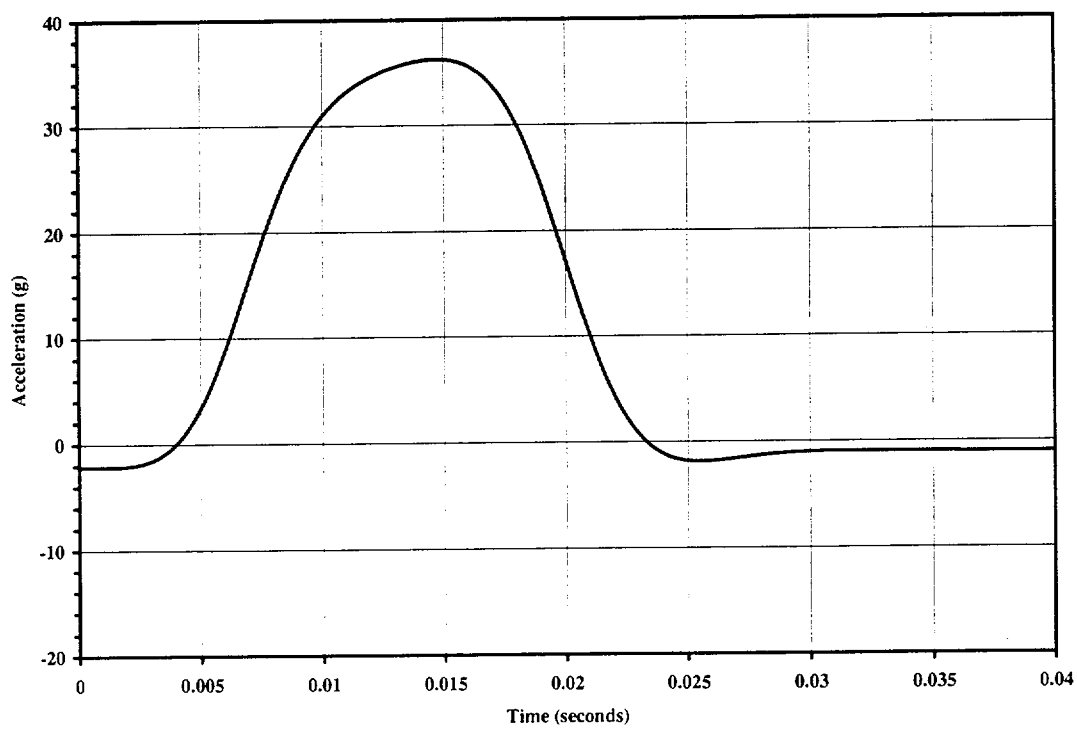


Figure 11.2.4.4-5 Acceleration Time-History of the Advanced Canister Bottom in the 24-inch Drop Accident with Strain Rate Dependent Properties

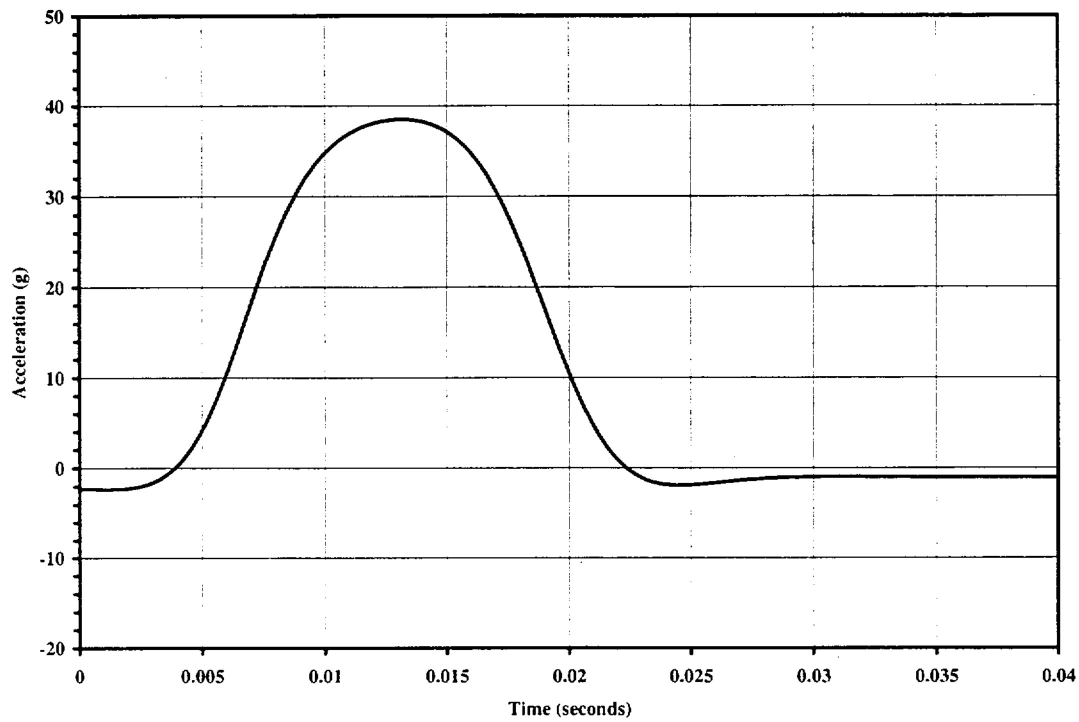


Figure 11.2.4.4-6 Response Spectra for Half-Sine Impulse

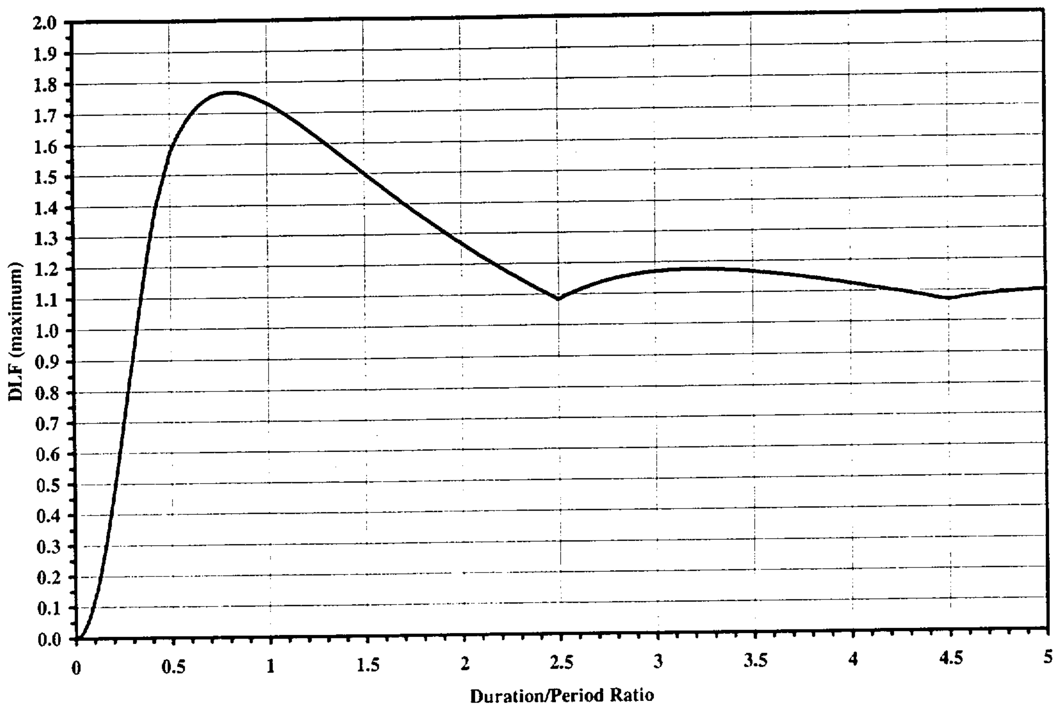


Figure 11.2.4.4-7 Advanced Canister Finite Element Model for 60g Bottom End Impact

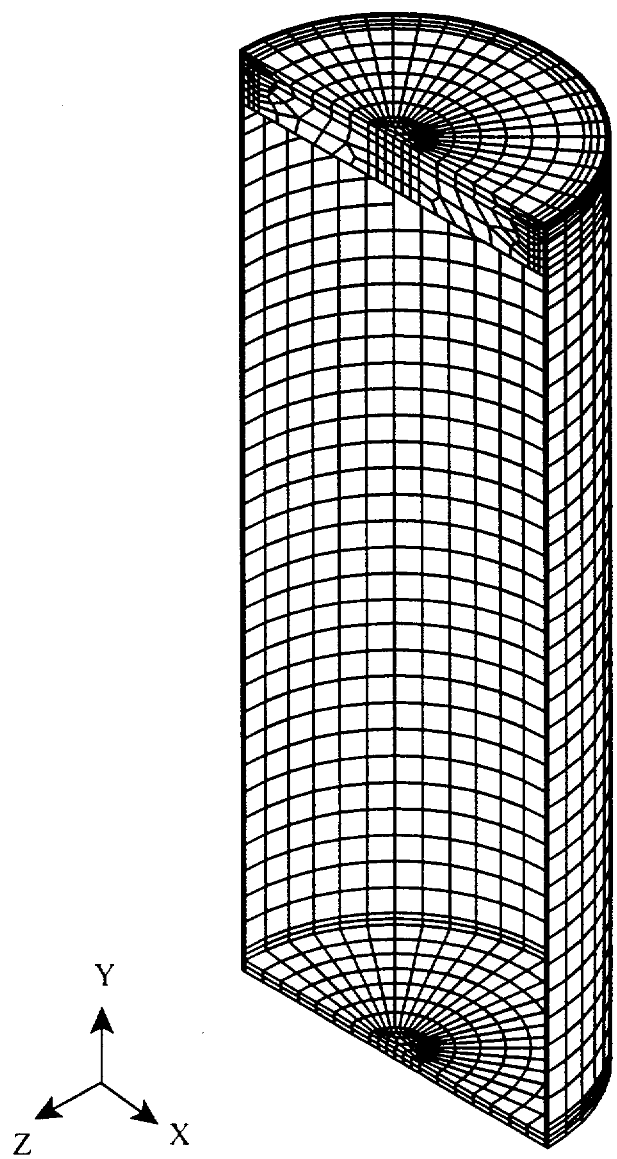
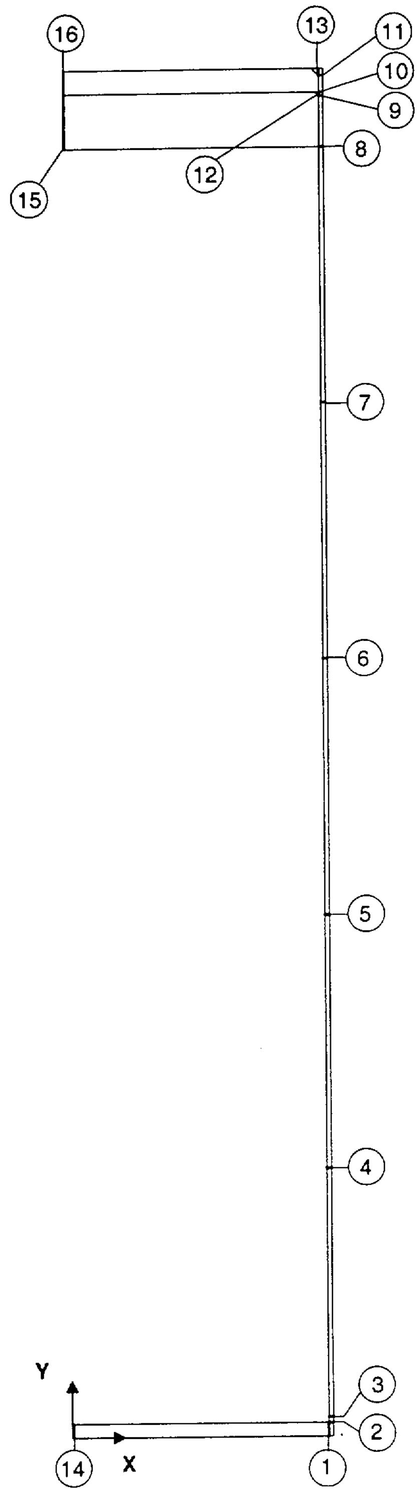
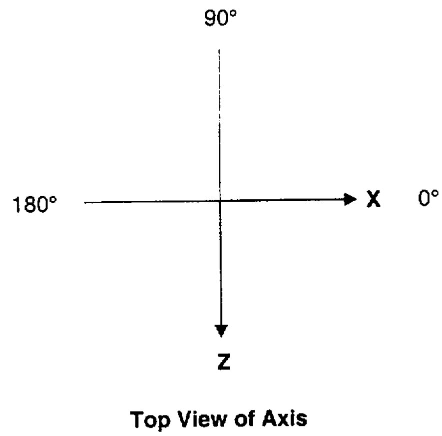


Figure 11.2.4.4-8 Identification of the Advanced Canister Section for the Evaluation of Canister Stresses Due to a 60g Bottom End Impact





Section Coordinates at Z=0 and X>0

Axial Section	Node 1 X	Node 1 Y	Node 2 X	Node 2 Y
1	32.905	0.0	32.905	2.00
2	32.905	2.00	33.53	2.00
3	32.905	3.13	33.53	3.13
4	32.905	34.21	33.53	34.21
5	32.905	66.42	33.53	66.42
6	32.905	98.63	33.53	98.63
7	32.905	130.84	33.53	130.84
8	32.905	163.05	33.53	163.05
9	32.905	171.80	33.53	171.80
10	32.905	172.30	33.53	172.30
11	32.905	174.17	33.53	174.17
12	32.905	171.80	32.905	172.30
13	32.905	174.17	32.905	175.30
14	0.1	0.0	0.1	2.00
15	0.1	165.30	0.1	172.30
16	0.1	172.30	0.1	175.30

Table 11.2.4.4-1 Advanced Canister P_m Stresses During a 60g Bottom Impact (with 40 psig Internal Pressure)

Section Location	Angle (deg)	P_m Stress (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	60	-0.3	-2.8	-0.1	-0.2	0.3	-0.2	2.85	40.08	13.1
2	0	0.8	-5.8	-0.9	-0.3	0.0	-0.1	6.62	40.08	5.1
3	180	-0.2	-6.5	-0.9	-0.2	0.0	0.1	6.36	40.08	5.3
4	180	0.0	-6.0	2.1	0.0	0.0	-0.1	8.07	37.90	3.7
5	0	0.0	-5.4	2.1	0.0	0.0	0.1	7.51	35.32	3.7
6	0	0.0	-4.8	2.1	0.0	0.0	0.1	6.95	35.03	4.0
7	180	0.0	-4.3	2.1	0.0	0.0	-0.1	6.38	36.96	4.8
8	0	0.1	-3.6	2.0	0.0	0.0	0.1	5.53	39.18	6.1
9	15	-0.6	-1.9	-1.5	-0.4	0.1	-0.3	1.58	39.78	24.2
10	0	1.5	-1.1	-0.8	0.4	0.0	-0.1	2.78	39.80	13.3
11	180	-1.6	0.6	-0.6	0.0	0.0	0.0	2.23	39.96	16.9
12	0	0.6	1.6	-0.3	0.3	0.1	-0.1	1.95	39.78	19.4
13	0	0.1	-1.7	-0.9	-0.2	0.0	-0.1	1.90	*31.98	16.8
14	0	0.1	-1.3	0.1	0.0	0.0	0.0	1.39	39.58	27.5
15	0	0.2	0.0	0.2	0.0	0.0	0.0	0.26	39.04	149.2
16	0	-0.2	0.0	-0.2	0.0	0.0	0.0	0.22	39.56	178.8

* Allowable stress includes a stress reduction factor for the weld: 0.8 × allowable stress.

Table 11.2.4.4-2 Advanced Canister $P_m + P_b$ Stresses During a 60g Bottom Impact (40 psig Internal Pressure)

Section Location	Angle (deg)	$P_m + P_b$ Stress (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	180	0.6	-2.6	-0.1	0.3	0.0	0.0	3.33	60.12	17.1
2	180	0.5	-8.9	-1.9	0.3	0.0	0.1	9.37	60.12	5.4
3	0	0.0	-8.1	-1.3	0.2	0.0	-0.1	8.07	60.12	6.5
4	0	0.0	-6.0	2.1	0.0	0.0	0.1	8.10	56.85	6.0
5	0	0.0	-5.4	2.1	0.0	0.0	0.1	7.53	52.98	6.0
6	0	0.0	-4.8	2.1	0.0	0.0	0.1	6.97	52.54	6.5
7	180	0.0	-4.3	2.1	0.0	0.0	-0.1	6.40	55.44	7.7
8	0	0.2	-4.9	1.6	0.1	0.0	0.1	6.52	58.78	8.0
9	98	-2.2	-4.0	-0.4	0.1	0.6	0.2	3.82	59.67	14.6
10	83	-2.3	-5.7	0.8	0.0	0.1	-0.4	6.49	59.71	8.2
11	180	-1.2	4.6	0.7	0.1	0.0	-0.1	5.85	59.94	9.3
12	0	2.2	3.0	0.6	0.9	0.0	-0.1	2.93	59.68	19.4
13	0	1.7	-0.6	-0.3	-0.4	0.1	-0.1	2.43	*47.96	18.7
14	180	0.1	-1.3	0.1	0.0	0.0	0.0	1.39	59.38	41.7
15	180	3.0	0.0	3.0	0.0	0.0	0.0	2.97	58.56	18.7
16	0	-1.6	0.0	-1.6	0.0	0.0	0.0	1.53	59.34	37.8

* Allowable stress includes a stress reduction factor for the weld: 0.8 × allowable stress.

11.2.4.5 Corrective Actions

Although the concrete cask remains functional following this event and no immediate recovery actions are required, the canister should be moved to a new concrete cask as soon as one is available. The damaged cask should be inspected for stability, and repaired as required prior to continued use.

11.2.4.6 Radiological Impact

There are no radiological consequences for this accident.

11.2.5 Explosion

The analysis of a design basis flood presented in Section 11.2.9 shows that the flood exerts a pressure of 22 psig on the canister, and that the Universal Storage System experiences no adverse effects due to this pressure. The pressure of 22 psig is considered to bound any pressure due to an explosion occurring in the vicinity of the ISFSI. Since the Standard and Advanced configurations have the same canister surface area for the canisters of the same Class, this analysis is applicable to both the Standard and Advanced configurations of the Universal Storage System.

11.2.5.1 Cause of Explosion

An explosion affecting the Universal Storage System may be caused by industrial accidents or the presence of explosive substances in the vicinity of the ISFSI. However, no flammable or explosive substances are stored or used at the storage facility. In addition, site administrative controls exclude explosive substances in the vicinity of the ISFSI. Therefore, an explosion affecting the site is extremely unlikely. This accident is evaluated in order to provide a bounding pressure that could be used in the event that the potential of an explosion must be considered at a given site.

11.2.5.2 Analysis of Explosion

Pressure due to an explosion event is bounded by the pressure effects of a flood having a depth of 50 feet. The Transportable Storage Canister shell is evaluated in Section 11.2.9 for the effects of the flood having a depth of 50 feet, and the results are summarized in Tables 11.2.9-1 and 11.2.9-2.

There is no adverse consequence to the canister as a result of the 22 psig pressure exerted by a design basis flood. This pressure conservatively bounds an explosion event.

11.2.5.3 Corrective Actions

In the unlikely event of a nearby explosion, inspection of the concrete casks is required to ensure that the air inlets and outlets are free of debris, and to ensure that the monitoring system and screens are intact. No further recovery or corrective actions are required for this accident.

11.2.5.4 Radiological Impact

There are no radiological consequences for this accident.

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11.2.6 Fire Accident

This section evaluates the effects of a bounding condition hypothetical fire accident, although a fire accident is a very unlikely occurrence in the lifetime of the Universal Storage System. The Universal Storage System includes the Standard and Advanced configurations of the Transportable Storage Canisters (canister) and Vertical Concrete Casks (concrete cask). The design basis heat load of the Advanced configuration is higher than for the Standard configuration. The evaluation demonstrates that for the hypothetical thermal accident (fire) condition the cask meets its storage performance requirements.

11.2.6.1 Cause of Fire

A fire may be caused by flammable material or by a transport vehicle. While it is possible that a transport vehicle could cause a fire while transferring a loaded storage cask at the ISFSI, this fire will be confined to the vehicle and will be rapidly extinguished by the persons performing the transfer operations or by the site fire crew. The maximum permissible quantity of fuel in the combined fuel tanks of the transport vehicle and prime mover is the only means by which fuel (maximum 50 gallons) would be next to a cask, and potentially at, or above, the elevation of the surface on which the cask is supported.

The fuel carried by other on-site vehicles or by other equipment used for ISFSI operations and maintenance, such as air compressors or electrical generators, is considered not to be within the proximity of a loaded cask on the ISFSI pad. Site-specific analysis of fire hazards will evaluate the specific equipment used at the ISFSI and determine any additional controls required.

11.2.6.2 Detection of Fire

A fire in the vicinity of the Universal Storage System will be detected by observation of the fire or smoke.

11.2.6.3 Analysis of the Fire Event

The vertical concrete cask with its internal contents, initially at the steady state normal storage condition, is subject to a hypothetical fire accident. The fire is due to the ignition of a flammable fluid, and operationally, the volume of flammable fluid that is permitted to be on the ISFSI pad (at, or above, the elevation of the surface on which a cask is supported and within approximately two feet of an individual cask) is limited to 50 gallons. The lowest burning rate (change of depth per unit time of flammable fluid for a pool of fluid) reported in the Edition of the Fire Protection Handbook [37] is 5 inches/hour for kerosene. The flammable liquid is assumed to cover a 15-foot square area, corresponding to the center-to-center distance of the concrete casks, less the footprint of the concrete cask, which is a 128-inch diameter circle. The depth (D) of the 50 gallons of flammable liquid is calculated as:

$$D = \frac{50\,(\text{gallons})\,\text{x}\,231\,(\text{in}^3/(\text{gallon})}{15\,\text{x}\,15\,\text{x}\,144\,(\text{in}^2) - 3.14\,\text{x}\,128^2/4\,(\text{in}^2)}$$

D = 0.6 inches

With a burning rate of 5 inches/hour, the fire would continue for 7.2 minutes. The fire accident evaluation in this section conservatively considers an 8-minute fire. The temperature of the fire is taken to be 1475°F, which is specified for the fire accident condition in 10 CFR 71.73c(3).

The fire event is an accident condition and is initiated with the concrete cask in a normal operating steady state condition.

11.2.6.3.1 Analysis of the Fire Event for the Standard Configuration

To determine the maximum temperatures of the Standard concrete cask components, the two-dimensional axisymmetric finite element model described in Section 4.4.1.1.1 is used to perform a transient analysis. However, the effective properties for the canister content for specific heat, density and thermal conductivity for the PWR are used, to conservatively maximize the thermal diffusivity, which results in higher temperatures for the canister contents during the fire accident condition.

The initial condition of the fire accident transient analysis is based on the steady state analysis results for the normal condition of storage, which corresponds to an ambient temperature of 76°F in conjunction with solar insolation (as specified in Section 4.4.1.1.1). The fire condition is implemented by constraining the nodes at the inlet to be 1475°F for 8 minutes (see Figure 11.2.6-1). One of the nodes at the edge of the inlet is attached to an element in the concrete region. This temperature boundary condition is applied as a stepped boundary condition. During the 8-minute fire, solar insolation is also applied to the outer surface of the concrete cask. At the end of the 8 minutes, the temperature of the nodes at the inlet is reset to the ambient temperature of 76°F.

The cool down phase is continued for an additional 10.7 hours to observe the maximum canister shell temperature and the average temperature of the canister contents.

The maximum temperatures of the fuel cladding and basket are obtained by adding the maximum temperature change due to the fire transient to the maximum component temperature for the normal operational condition. The maximum component temperature are presented in Table 11.2.6-1, which shows that the component temperatures are below the allowable temperatures. The limited duration of the fire and the large thermal capacitance of the concrete cask restricted the temperatures above 244°F to a region less than 3 inches above the top surface of the air inlets. The maximum bulk concrete temperature is 138°F during and after the fire accident. This corresponds to an increase of less than 3°F compared to the bulk concrete temperature for normal condition of storage. These results confirm that the operation of the concrete cask is not adversely affected during and after the fire accident condition.

11.2.6.3.2 Analysis of the Fire Event for the Advanced Configuration

To determine the maximum temperatures of the Advanced concrete cask components, the two-dimensional axisymmetric computational fluid dynamics model for the PWR configuration described in Section 4.4.1.2.1 is used to perform a transient analysis.

The initial condition of the fire accident transient analysis is based on the steady state analysis results for the normal condition of storage, which corresponds to an ambient temperature of 76°F in conjunction with solar insolation (as specified in Section 4.4.1.2.1). The fire condition is implemented by applying a temperature boundary condition of 1475°F for 8 minutes at the air inlet (see Figure 11.2.6-2). This temperature boundary condition is applied as a stepped boundary condition. During the 8-minute fire, solar insolation is also applied to the outer surface of the concrete cask. At the end of the 8 minutes, the temperature boundary condition at the inlet is reset to the ambient temperature of 76°F. The cool down phase is continued for an additional 17.5 minutes to observe the maximum canister shell temperature and the average temperature of the canister contents.

The maximum temperatures of the fuel cladding and basket are obtained by adding the maximum temperature change due to the fire transient to the maximum component temperature for the normal operational condition. The maximum component temperatures are presented in Table 11.2.6-2, which shows that the component temperatures are below the allowable temperatures. The limited duration of the fire and the large thermal capacitance of the concrete cask restricted the temperatures above 260°F to a region less than 1 inch above the top surface of the air inlets. The maximum bulk (volume average) concrete temperature is 139°F during and after the fire accident. This corresponds to an increase of less than 1°F compared to the bulk concrete temperature for normal condition of storage. These results confirm that the operation of the concrete cask is not adversely affected during and after the fire accident condition.

11.2.6.4 Corrective Actions

Immediately upon detection of the fire, appropriate actions should be taken by site personnel to extinguish the fire. The concrete cask should then be inspected for general deterioration of the concrete, loss of shielding (spalling of concrete), exposed reinforcing bar, and surface discoloration that could affect heat rejection. This inspection will be the basis for the determination of any repair activities necessary to return the concrete cask to its design basis configuration.

11.2.6.5 Radiological Impact

There are no significant radiological consequences for this accident. There may be local spalling of concrete during the fire event, which could lead to some minor reduction in shielding effectiveness. The principal effect would be local increases in radiation dose rate on the cask surface.

Figure 11.2.6-1 Temperature Boundary Condition Applied to the Nodes of the Standard Concrete Cask Inlet for the Fire Event

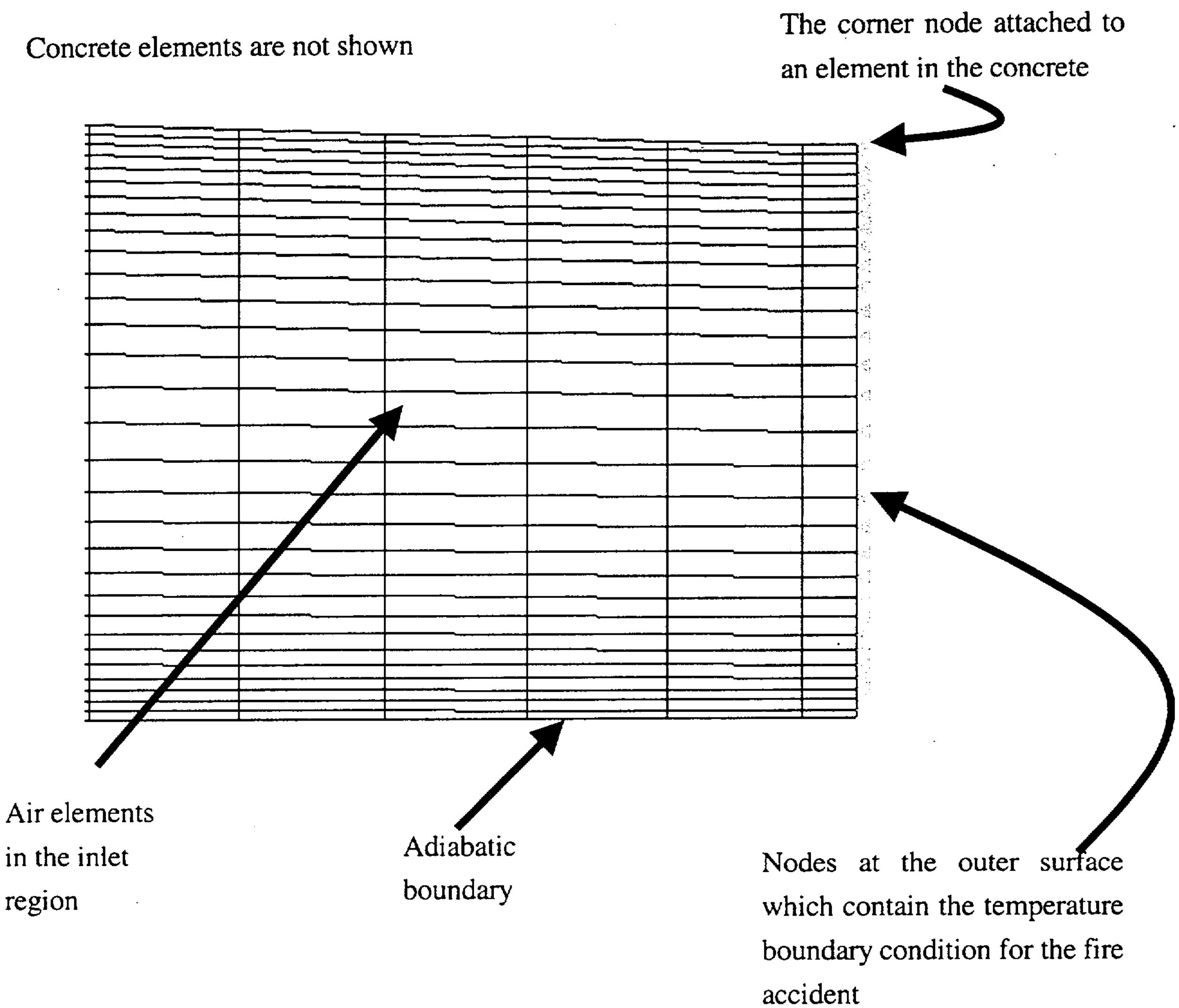

Figure 11.2.6-2 Temperature Boundary Condition Applied to the Nodes of the Advanced Concrete Cask Inlet for the Fire Event

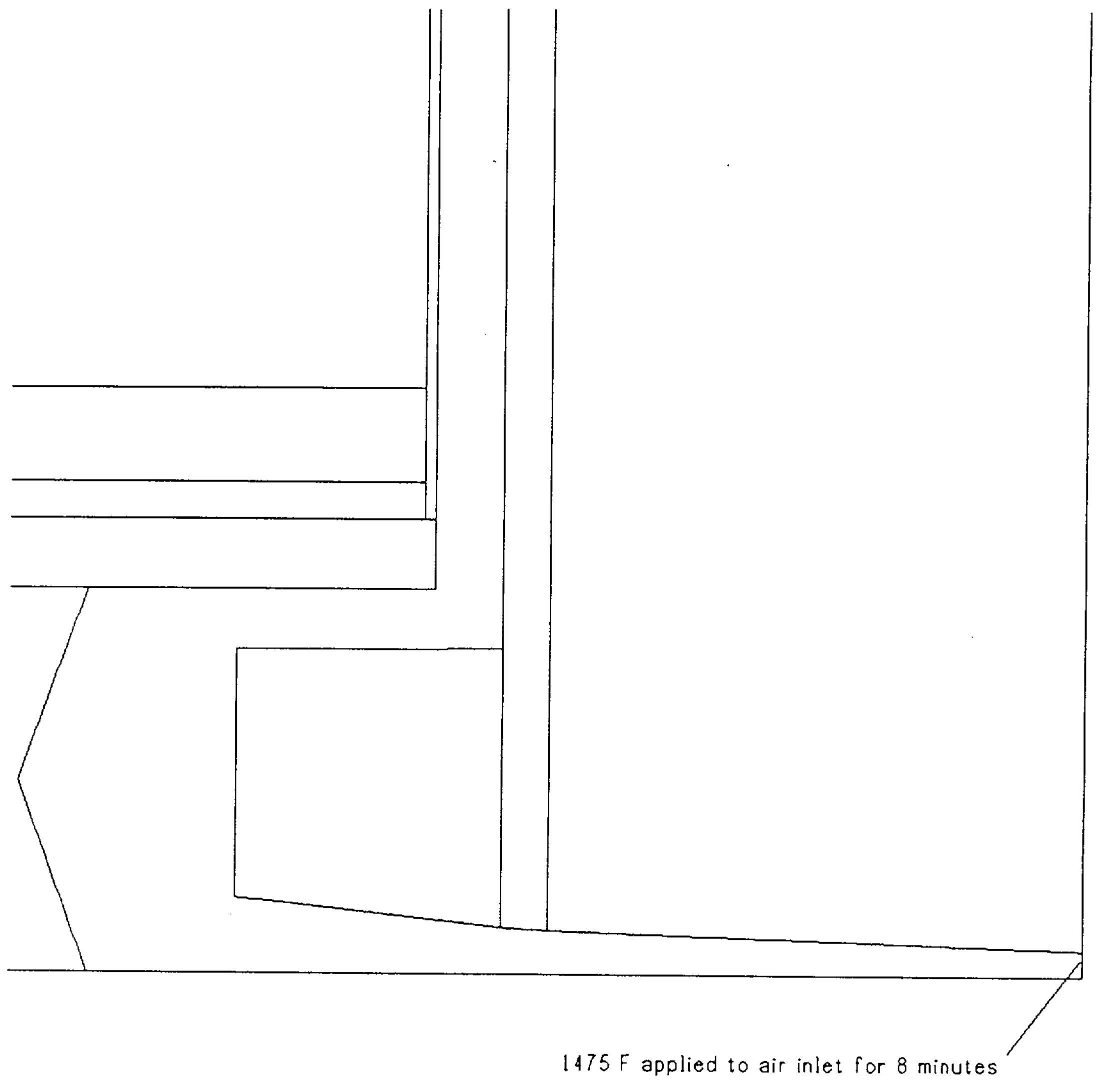

Table 11.2.6-1 Maximum Standard Configuration Component Temperatures During and After the Fire Event

Component	PWR Maximum temperature (°F)	PWR Allowable temperature (°F)	BWR Maximum temperature (°F)	BWR Allowable temperature (°F)
Fuel clad	710	1,058	691	1,058
Support disk	655	800	664	700
Heat transfer disk	652	700	662	700
Canister shell	459	800	416	800
Concrete[1]	244	350	244	350

1. Temperatures of 244°F, and greater, are within 3 inches of the inlet, which does not affect the operation of the concrete cask.

Table 11.2.6-2 Maximum Advanced Configuration Component Temperatures During and After the Fire Event

Component	PWR Maximum Temperature (°F)	PWR Allowable Temperature (°F)
Fuel clad	729	1,058
Basket	715	850
Canister shell	390	800
Concrete[1]	267	350

1. Temperatures of 267°F, and greater, are within 1 inch of the inlet, which does not affect the operation of the concrete cask.

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11.2.7 Maximum Anticipated Heat Load (133°F Ambient Temperature)

This section evaluates the Universal Storage System response to storage operation at an ambient temperature of 133°F. The Universal Storage System includes the Standard and Advanced configurations of the Transportable Storage Canisters (canister) and Vertical Concrete Casks (concrete cask). The design basis heat load of the Advanced configuration is higher than for the Standard configuration. The condition is analyzed in accordance with the requirements of ANSI/ANS 57.9 [1] to evaluate a credible worst-case thermal loading. A steady state condition is considered in the thermal evaluation of the system for this accident condition.

11.2.7.1 Cause of Maximum Anticipated Heat Load

This condition results from a weather event that causes the concrete cask to be subject to a 133°F ambient temperature with full insolation.

11.2.7.2 Detection of Maximum Anticipated Heat Load

Detection of the high ambient temperature condition will be by the daily measurement of ambient temperature and concrete cask outlet air temperature.

11.2.7.3 Analysis of Maximum Anticipated Heat Load

The analysis of the maximum anticipated heat load is performed using the same methods and thermal models described in Section 11.1.1 for the severe ambient temperature (106°F and -40°F) event.

11.2.7.3.1 Analysis of Maximum Anticipated Heat Load for the Standard Configuration

Thermal evaluations are performed for the Standard concrete cask and the canister with its contents for this accident condition using the thermal models described in Section 11.1.1. The principal Standard PWR and BWR configuration component temperatures for this ambient condition are:

Standard Component	Maximum Component Temperature (°F) at 133°F Ambient		Allowable Component Temperature (°F)	
	PWR	BWR	PWR	BWR
Fuel Cladding	715	1,058	702	1,058
Support Disks	664	800	677	700
Heat Transfer Disks	661	700	675	700
Canister Shell	408	800	432	800
Concrete	262	350	266	350

This evaluation shows that the Standard configuration component temperatures are within the allowable temperatures for the extreme ambient temperature conditions.

Thermal stress evaluations for the Standard concrete cask are performed using the method and model presented in Section 3.4.4.2. The concrete temperature results obtained from the thermal analysis for this accident condition are applied to the structural model for stress calculation. The maximum stress, 7,160 psi in the reinforcing steel, occurs in the circumferential direction. The margin of safety is 54,000 psi/7,160 psi -1 = +6.5. The maximum compressive stress, 655 psi, in the concrete occurs in the vertical direction. The maximum circumferential compressive stress in the concrete is 94 psi. The margin of safety is [0.7(4,000 psi)/655 psi] -1 = +3.3. These stresses are used in the loading combination for the concrete cask shown in Section 3.4.4.2.

11.2.7.3.2 Analysis of Maximum Anticipated Heat Load for the Advanced Configuration

Thermal evaluations are performed for the Advanced configuration using the same methods and thermal models described in Section 11.1.1 for the off-normal conditions of severe ambient temperatures (106°F and -40°F), thermal evaluations are performed for the concrete cask and the canister with its contents for this accident condition (133°F ambient temperature). The maximum component temperatures of the PWR Advanced configuration for the maximum anticipated heat load event during storage are:

Advanced Component	Maximum Component Temperature (°F) at 133°F Ambient	Allowable Component Temperature (°F)
Fuel Cladding	757	1,058
Basket Plates	745	850
Canister Shell	426	800
Concrete	276	350

This evaluation shows that the Advanced configuration component temperatures are within the allowable temperatures for the extreme ambient temperature conditions.

Thermal stress evaluations for the Advanced concrete cask are performed using the method and model presented in Section 3.4.4.4. From the thermal analysis evaluation the maximum stress occurs in the circumferential direction. The maximum stress in the reinforcing steel is 8,164 psi. The margin of safety is 54,000 psi/8164 psi-1 = +5.6. The maximum compressive stress, 775 psi, in the concrete occurs in the vertical direction. The maximum circumferential compressive stress in the concrete is 134 psi. The margin of safety is [0.7(4,000 psi)/775 psi] –1 = +2.6. These stresses are used in the loading combination for the concrete cask shown in Section 3.4.4.4

11.2.7.4 Corrective Actions

The high ambient temperature condition is a natural phenomenon, and no recovery or corrective actions are required.

11.2.7.5 Radiological Impact

There are no dose implications due to this event.

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11.2.8 Earthquake Event

This section provides an evaluation of the response of the vertical concrete cask to an earthquake imparting a horizontal acceleration of 0.26 g at the top surface of the concrete pad. This evaluation shows that the loaded or empty vertical concrete cask does not tip over or slide in the earthquake event. The vertical acceleration is defined as 2/3 of the horizontal acceleration in accordance with ASCE 4-86 [36].

11.2.8.1 Cause of the Earthquake Event

Earthquakes are natural phenomena to which the storage system might be subjected at any U.S. site. Earthquakes are detected by the ground motion and by seismic instrumentation on and off site.

11.2.8.2 Earthquake Event Analysis

In the event of earthquake, there exists a base shear force or overturning force due to the horizontal acceleration ground motion and a restoring force due to the vertical acceleration ground motion. This ground motion tends to rotate the concrete cask about the bottom corner at the point of rotation (at the chamfer). The horizontal moment arm extends from the center of gravity (C.G.) toward the outer radius of the concrete cask. The vertical moment arm reaches from the C.G. to the bottom of the cask. When the overturning moment is greater than or equal to the restoring moment, the cask will tip over. To maximize this overturning moment, the dimensions for the Class 3 PWR configuration, which has the highest C.G., are used in this evaluation. Based on the requirements presented in NUREG-0800 [22], the static analysis method is considered applicable if the natural frequency of the structure is greater than 33 cycles per second (Hz).

The combined effect of shear and flexure is computed as:

$$\frac{1}{f^2} = \frac{1}{f_f^{\,2}} + \frac{1}{f_s^{\,2}} = \frac{1}{348.6} + \frac{1}{150.7} \quad [19]$$

or

$$f = 105.2 \text{ Hz} > 33 \text{ Hz}$$

where:

f_f = frequency for the first free-free mode based on flexure deformation only (Hz),
f_s = frequency for the first free-free mode based on shear deformation only (Hz).

The frequency f_f is computed as:

$$F_f = \frac{\lambda^2}{2\pi L^2}\sqrt{\frac{EI}{M}} = \frac{4.730^2}{2\pi(226)^2}\sqrt{\frac{(3.38\times10^6)\times(1.4832\times10^7)}{2.005}} \quad [19]$$

$f_f = 348.6$ Hz

where:

$\lambda = 4.730$,

L = 226 in, length of concrete cask,

$E = 3.38 \times 10^6$ psi, modulus of elasticity for concrete at 200°F,

$$I = \text{moment of inertia} = \frac{\pi(D_o^4 - D_i^4)}{64} = \frac{\pi\left[(136\text{ in})^4 - (79.5\text{ in})^4\right]}{64} = 1.4832\times10^7\text{ in}^4,$$

$$\rho = \frac{140}{1728\times386.4} = 2.096\times10^{-4}\text{ lbm/in}^3\text{, mass density,}$$

$$M = \pi(68^2 - 39.75^2)\times(2.096\times10^{-4}) = 2.005\text{ lbm/in}$$

The frequency accounting for the shear deformation is:

$$f_s = \frac{\lambda_s}{2\pi L}\sqrt{\frac{KG}{\mu}} = \frac{3.141593}{2(3.141595)(226)}\sqrt{\left(\frac{(0.6947)(1.40\times10^6)}{2.096\times10^{-4}}\right)} \quad [19]$$

$f_s =$ 150.7 Hz

where:

$\lambda_s = \pi$,

L = 226 in, length of concrete cask,

$$K = \frac{6(1+\nu)(1+m^2)^2}{(7+6\nu)(1+m^2)+(20+12\nu)m^2}\text{, shear coefficient,}$$

$= 0.6947,$

$\mu = \dfrac{140}{1728 \times 386.4} = 2.096 \times 10^{-4}$ lbm/in^3, mass density of the material,

$G = \dfrac{0.5E}{(1+\nu)} = \dfrac{0.5(3.38 \times 10^6)}{(1+0.2)} = 1.408 \times 10^6$ psi, modulus of rigidity,

and,

$m = R_i/R_o = 39.75/68 = 0.5846,$

$\nu = 0.2$, Poisson's ratio for concrete.

Since the fundamental mode frequency is greater than 33 Hz, static analysis is appropriate.

11.2.8.2.1 Tip-Over Evaluation of the Vertical Concrete Cask

To maintain the concrete cask in equilibrium, the restoring moment, M_R must be greater than, or equal to, the overturning moment, M_o (i.e. $M_R \geq M_o$). Based on this premise, the following derivation shows that 0.26g acceleration of the design basis earthquake at the surface of the concrete pad is well below the acceleration required to tip-over the cask.

The combination of horizontal and vertical acceleration components is based on the 100-40-40 approach of ASCE 4-86 [36], which considers that when the maximum response from one component occurs, the response from the other two components are 40% of the maximum. The vertical component of acceleration is obtained by scaling the corresponding ordinates of the horizontal components by two-thirds.

Let:

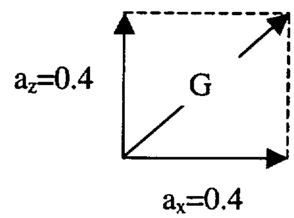
$a_x = a_z = a$ = horizontal acceleration components
$a_y = (2/3)\ a$ = vertical acceleration component
G_h = Vector sum of two horizontal acceleration components
G_v = Vertical acceleration component

There are two cases that have to be analyzed:

Case 1) The vertical acceleration, a_y, is at its peak: ($a_y = 2/3a$, $a_x = .4a$, $a_z = .4a$)

$$G_h = \sqrt{a_x^2 + a_z^2}$$

$$G_h = \sqrt{(0.4 \times a)^2 + (0.4 \times a)^2} = 0.566 \times a$$

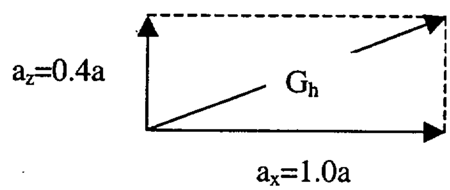


$$G_v = 1.0 \times a_y = 1.0 \times \left(a \times \frac{2}{3} \right) = 0.667 \times a$$

Case 2) One horizonal acceleration, a_x, is at its peak: (a_y=.4 x 2/3a, a_x = a, a_z = .4a)

$$G_h = \sqrt{a_x^2 + a_z^2}$$

$$G_h = \sqrt{(1.0 \times a)^2 + (0.4 \times a)^2} = 1.077 \times a$$



$$G_v = 0.4 \times a_y = 0.4 \times \left(a \times \frac{2}{3} \right) = 0.267 \times a$$

In order for the cask to resist overturning, the restoring moment, M_R, about the point of rotation, must be greater than the overturning moment, M_o, that:

$$M_R \geq M_o \text{, or}$$

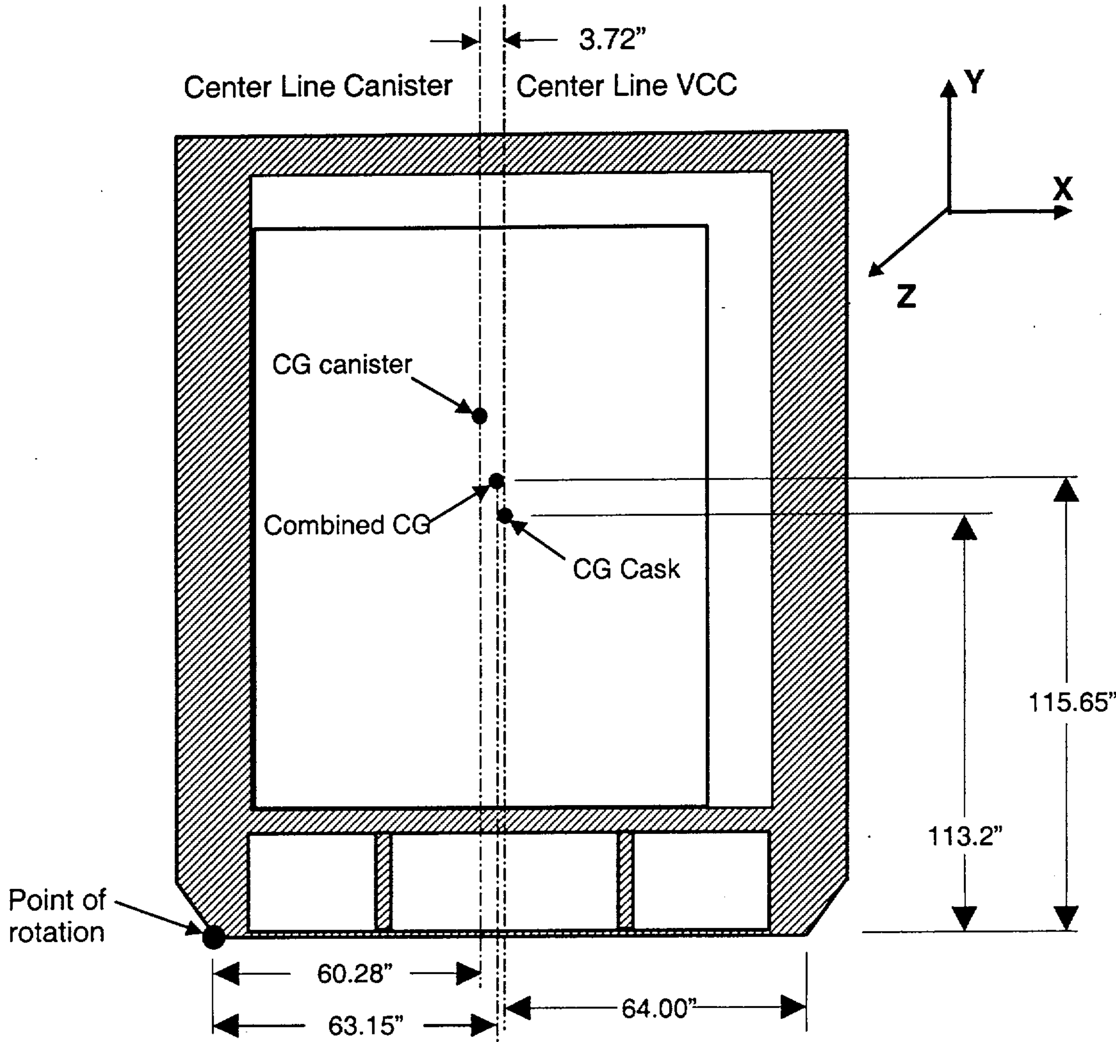
$$F_r \times b \geq F_o \times d \Rightarrow (W \times 1 - W \times G_v) \times b \geq (W \times G_h) \times d$$

where:

- d = vertical distance measured from the base of the concrete cask to the center of gravity
- b = horizontal distance measured from the point of rotation to the C.G.
- W = the weight of the concrete cask
- F_o = overturning force
- F_r = restoring force

Tip-over Evaluation of the Standard Vertical Concrete Cask

This section provides the tip-over evaluation of the Standard vertical concrete cask, which has a lower weight than the Advanced vertical concrete cask due to the increased weight of the canister and different pedestal design of the Advanced concrete cask.



substituting for G_h and G_v gives:

Case 1

$$(1-0.667a)\frac{b}{d} \geq 0.566 \times a$$

$$a \leq \frac{b/d}{0.566 + 0.667\, b/d}$$

Case 2

$$(1-0.267a)\frac{b}{d} \geq 1.077a$$

$$a \leq \frac{b/d}{1.077 + 0.267(b/d)}$$

Because the canister is not attached to the concrete cask, the combined center of gravity for the concrete cask, with the canister in its maximum off-center position, must be calculated. The point of rotation is established at the outside lower edge of the concrete cask.

The inside diameter of the concrete cask is 74.5 inches and the outside diameter of the canister is 67.06 inches; therefore, the maximum eccentricity between the two is:

$$e = \frac{74.50\,\text{in} - 67.06\,\text{in}}{2} = 3.72\text{ in.}$$

The horizontal displacement, x, of the combined C.G. due to eccentric placement of the canister is

$$x = \frac{70{,}783(3.72)}{308{,}432} = 0.85\,\text{in}$$

Therefore,

$$b = 64 - 0.85 = 63.15\text{ in.}$$

The C.G. of the loaded Class 3 vertical concrete cask is:

$$d = 115.65\text{ in.}$$

1) $$a \le \frac{63.15/115.65}{0.566 + 0.667 \times 63.15/115.65}$$

$a \le 0.59g$

2) $$a \le \frac{63.15/115.65}{1.077 + 0.267 \times 63.15/115.65}$$

$a \le 0.45g$

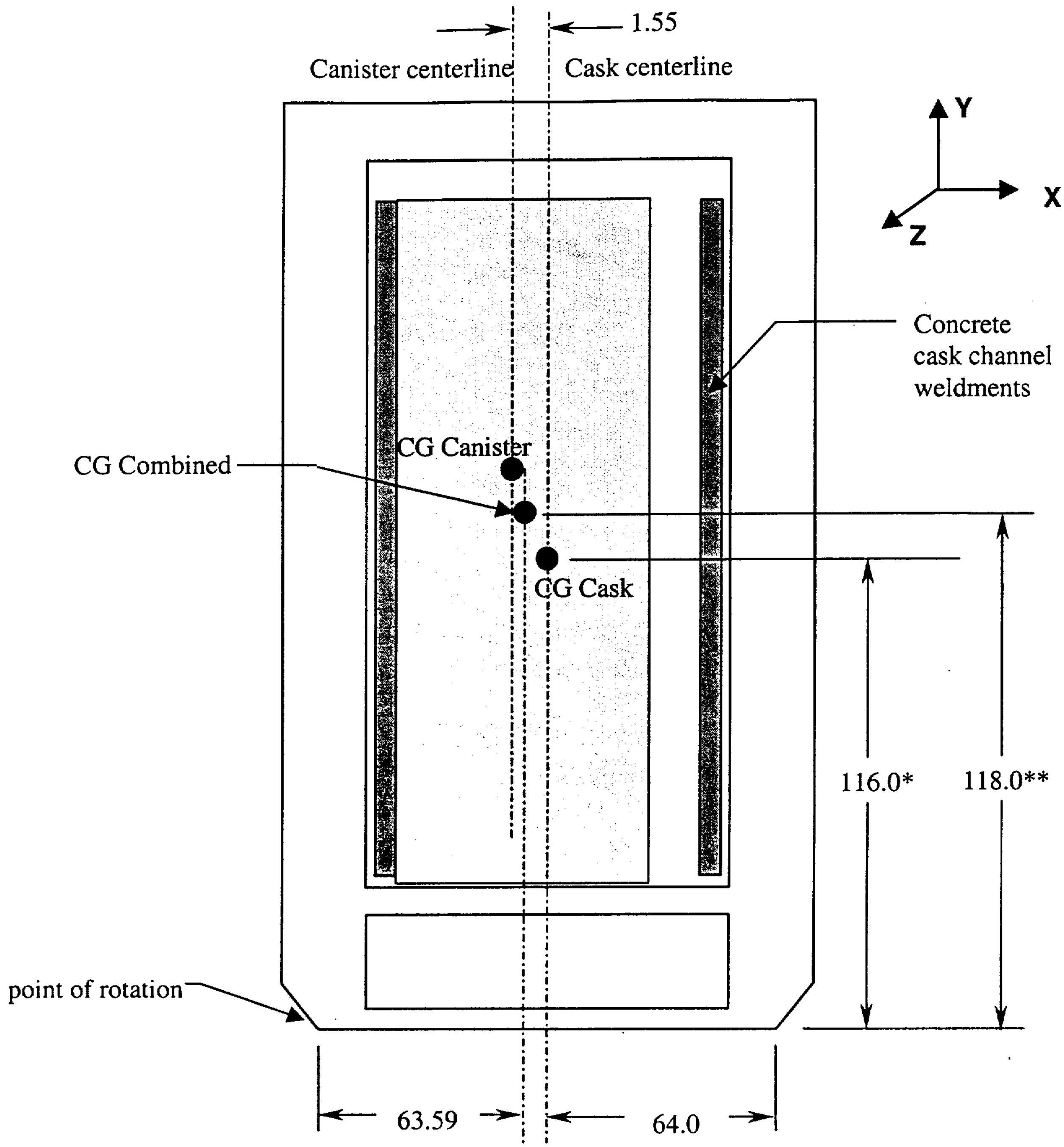
Therefore, the minimum ground acceleration that may cause a tip-over of a loaded concrete cask is 0.45g. Since the 0.26g design basis earthquake ground acceleration for the Standard UMS system is less than 0.45g, the storage cask will not tip over.

The factor of safety is 0.45 / 0.26 = 1.73, which is greater than the required factor of safety of 1.1 in accordance with ANSI/ANS-57.9.

Since an empty Standard concrete cask has a lower C.G. as compared to a loaded concrete cask, the tip-over evaluation for the empty concrete cask is bounded by that for the loaded concrete cask.

Tip-over Evaluation of the Advanced Vertical Concrete Cask

This section provides the tip-over evaluation of the Advanced vertical concrete cask which has a higher weight than the Standard vertical concrete cask due to the increased weight of the canister and different liner design of the Standard concrete cask.



*bounds the highest C.G. for empty casks

**bounds the highest C.G. for loaded casks

Because the canister is not attached to the pedestal, the combined center of gravity for the loaded Advanced concrete cask is calculated with the canister in its maximum off-center position.

The concrete cask channel weldments limit the eccentricity (e) between the canister and the concrete cask centerlines to:

$$e = \frac{74.50 - 67.06 - 2(2.17)}{2} = 1.55 \text{ in.}$$

The combined CG displacement is:

$$x = \frac{95{,}000(1.55)}{332{,}000} = 0.44$$

Therefore,

$$b \quad = 64.00 - 0.44 = 63.56 \text{ in.}$$

The vertical CG of the loaded concrete cask is:

$$d \quad = 118.0 \text{ in.}$$

For Case 2

$$a \le \frac{63.56/118.0}{1.077 + 0.267\left(63.56/118.0\right)} = 0.44$$

The factor of safety is 0.44/0.26 = 1.69, which is greater than the required factor of safety of 1.1 in accordance with ANSI/ANS-57.9.

11.2.8.2.2 Sliding Evaluation of the Vertical Concrete Cask

To keep the cask from sliding on the concrete pad, the force holding the cask (F_s) has to be greater than or equal to the force trying to move the cask.

Based on the equation for static friction:

$$F_s = \mu N \ge G_h W$$
$$\mu\left(1 - G_v\right)W \ge G_h W$$

where:

μ = coefficient of friction

N = the normal force

W = the weight of the concrete cask

G_v = vertical acceleration component

G_h = resultant of horizontal acceleration component

Substituting G_h and G_v for the two cases:

Case 1) $\mu(1 - 0.667a) \geq 0.566\,a$

$$\mu \geq \frac{0.566a}{1 - 0.667a}$$

Case 2) $\mu(1 - 0.267a) \geq 1.077\,a$

$$\mu \geq \frac{1.077a}{1 - 0.267a}$$

For a = 0.26g

Case 1) $\mu \geq 0.18$

Case 2) $\mu \geq 0.30$

The analysis shows that the minimum coefficient of friction, μ, required to prevent sliding of the concrete cask is 0.30. The coefficient of friction between the steel bottom plate of the concrete cask and the concrete surface of the storage pad, 0.35 [21], is greater than the coefficient of friction required to prevent sliding of the concrete cask. Therefore, the concrete cask will not slide under design-basis earthquake conditions. The factor of safety is 0.35 / 0.30 =1.17 which is greater than the required factor of safety of 1.1 in accordance with ANSI/ANS-57.9.

11.2.8.2.3 Stress Generated in the Vertical Concrete Cask During an Earthquake Event

To demonstrate the ability of the concrete cask to withstand earthquake loading conditions, the fully loaded cask is conservatively evaluated for seismic loads of 0.5g in the horizontal direction and 0.5g in the vertical direction. These accelerations reflect a more rigorous seismic loading and, therefore, bound the design basis earthquake event. No credit is taken for the steel inner liner of the concrete cask. The maximum compressive stress at the outer and inner surfaces of the concrete shell are conservatively calculated by assuming the vertical concrete cask to be a cantilever beam with its bottom end fixed.

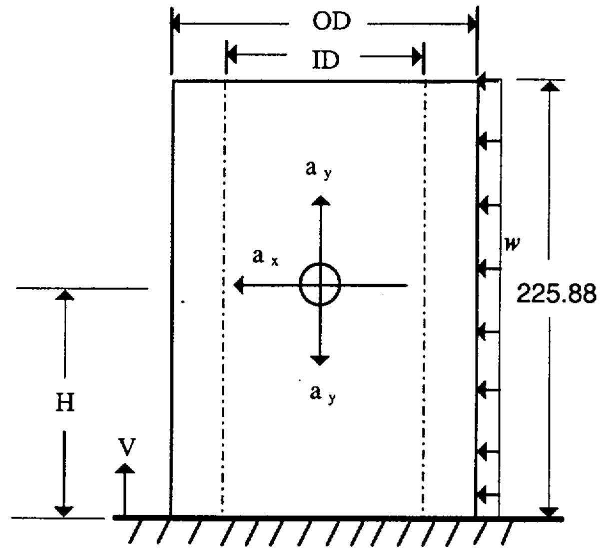
Stress Generated in the Standard Concrete Cask

The maximum compressive stresses in the Standard concrete cask are:

$$\sigma_{v\,outer} = (M / S_{outer}) + ((1+a_y)(W_{scc}) / A) = -72 - 44 = -116 \text{ psi},$$

$$\sigma_{v\,inner} = (M / S_{inner}) + ((1+a_y)(W_{scc}) / A) = -42 - 44 = -86 \text{ psi},$$

where:



- $a =$ 0.50 g, horizontal direction,
- a_y = 0.50 g, vertical direction,
- H = 115.4 in., fully loaded C.G.,
- W_{scc} = 279,000 lbf, concrete cask weight (includes canister and basket weight used in seismic evaluation),
- OD = 136 in., concrete exterior diameter,
- ID = 79.50 in., concrete interior diameter,
- $A = \pi\,(OD^2 - ID^{2)} / 4 = 9{,}562.8 \text{ in.}^2$,
- $I = \pi\,(OD^4 - ID^{4)} / 64 = 14.83 \times 10^6 \text{ in.}^4$,
- $S_{outer} = 2I/OD = 218{,}088.2 \text{ in.}^3$,
- $S_{inner} = 2I/ID = 373{,}035.0 \text{ in.}^3$,
- $w = a_x W_{vcc} / 225.88 = 618$ lbf / in.
- $M = w\,(225.88)^2 / 2 = 1.58 \times 10^7$ in.-lbf , the maximum bending moment at the support.

The calculated compressive stresses are used in the load combinations for the Standard concrete cask as shown in Table 3.4.4.2-1.

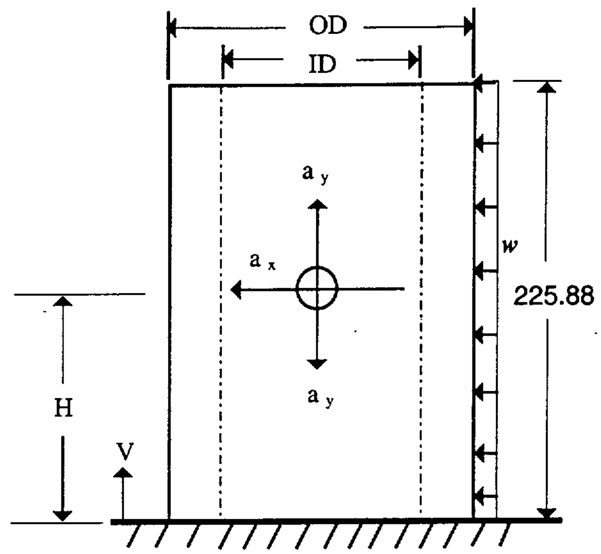
Stress Generated in the Advanced Concrete Cask

The maximum compressive stresses in the Advanced concrete cask are:

$$\sigma_{v\,outer} = \frac{M}{S_{outer}} + \frac{(1 + a_y)W_{ACC}}{A} = \frac{1.87 \times 10^7}{218{,}088.2} + \frac{(1.5)332{,}000}{9{,}562.8} = 138 \text{ psi}$$

$$\sigma_{v\,inner} = \frac{M}{S_{inner}} + \frac{(1 + a_y)W_{ACC}}{A} = \frac{1.87 \times 10^7}{373{,}035.0} + \frac{(1.5)332{,}000}{9{,}562.8} = 102 \text{ psi}$$

where:



a	= 0.50 g, horizontal direction,
a_y	= 0.50 g, vertical direction,
W_{acc}	= 332,000 lbf, concrete cask weight (includes canister and basket weight used in seismic evaluation),
OD	= 136 in., concrete exterior diameter,
ID	= 79.50 in., concrete interior diameter,
A	$= \pi (OD^2 - ID^{2)} / 4 = 9{,}562.8$ in.^{2},
I	$= \pi (OD^4 - ID^{4)} / 64 = 14.83 \times 10^6$ in.^{4},
S_{outer}	$= 2I/OD = 218{,}088.2$ in.^{3},
S_{inner}	$= 2I/ID = 373{,}035.0$ in.^{3},
w	$= a_x W_{acc} / 225.88 = 735$ lbf / in.
M	$= w\ (225.88)^2 / 2 = 1.87 \times 10^7$ in.-lbf , the maximum bending moment at the support.

The calculated compressive stresses are used in the load combinations for the vertical concrete cask as shown in Table 3.4.4.4-1.

11.2.8.3 Corrective Actions

Inspection of the vertical concrete casks is required following an earthquake event. The positions of the concrete casks should be verified to ensure they maintain the 15-foot center-to-center spacing established in Section 8.1.3. The temperature monitoring system should be checked for operation.

11.2.8.4 Radiological Impact

There are no radiological consequences for this accident.

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11.2.9 Flood

This evaluation considers design basis flood conditions of a 50-foot depth of water having a velocity of 15 feet per second. This flood depth would fully submerge the Universal Storage System. Analysis demonstrates that the Vertical Concrete Cask does not slide or overturn during the design-basis flood. The hydrostatic pressure exerted by the 50-foot depth of water does not produce significant stress in the canister. The Universal Storage System is therefore not adversely impacted by the design basis flood.

Small floods may lead to a blockage of concrete cask air inlets. Full blockage of air inlets is evaluated in Section 11.2.13.

11.2.9.1 Cause of Flood

The probability of a flood event at a given ISFSI site is unlikely because geographical features, and environmental factors specific to that site are considered in the site approval and acceptance process. Some possible sources of a flood are: (1) overflow from a river or stream due to unusually heavy rain, snow-melt runoff, a dam or major water supply line break caused by a seismic event (earthquake); (2) high tides produced by a hurricane; and (3) a tsunami (tidal wave) caused by an underwater earthquake or volcanic eruption.

11.2.9.2 Analysis of Flood

The concrete cask is considered to be resting on a flat level concrete pad when subjected to a flood velocity pressure distributed uniformly over the projected area of the concrete cask. Because of the concrete cask geometry and rigidity, it is analyzed as a rigid body. Assuming full submersion of the concrete cask and steady-state flow conditions, the drag force, F_D, is calculated using classical fluid mechanics for turbulent flow conditions. A safety factor of 1.1 for stability against overturning and sliding is applied to ensure that the analyses bound design basis conditions. The coefficient of friction between carbon steel and concrete used in this analysis is 0.35 [23].

Analysis shows that the concrete cask configured for storing the Class 3 PWR spent fuel in either the Standard or Advanced configuration, because of its center of gravity, weight, and geometry has the least resistance to flood velocity pressure. Conservatively, the analysis is performed for a canister containing no fuel. The evaluation of the Standard configuration is provided in Section 11.2.9.2.1. The evaluation of the Advanced configuration is provided in Section 11.2.9.2.2.

11.2.9.2.1 Analysis of Flood Condition for the Standard Configuration

The buoyancy force, F_b, is calculated from the weight of water (62.4 lbs/ft^3) displaced by the fully submerged concrete cask holding the Standard Class 3 canister. The displacement volume of the concrete cask containing the canister is 1,724 ft^3. The displacement volume is the volume occupied by the cask and the transport canister less the free space in the central annular cavity of the concrete cask.

$$F_b = \text{Vol} \times 62.4 \text{ lbs/ft}^3$$
$$= 107{,}557 \text{ lbs.}$$

Assuming the steady-state flow conditions for a rigid cylinder, the total drag force of the water on the concrete cask is given by the formula:

$$F_D = (C_D)(\rho)(V^2)\left(\frac{A}{2}\right) \qquad [24]$$
$$= 32{,}810 \text{ lbs.}$$

where:

C_D = Drag coefficient, which is dependent upon the Reynolds Number (Re). For flow velocities greater than 6 ft/sec, the value of C_D approaches 0.7 [24].

ρ = mass density of water = 1.94 slugs/ft^3

D = Concrete cask outside diameter (136.0 in. / 12 = 11.33 ft)

V = velocity of water flow (15 ft/sec)

A = projected area of the cask normal to water flow (diameter 11.33 ft × overall height 18.95 ft = 214.7 ft^2)

The drag force required to overturn the concrete cask is determined by summing the moments of the drag force and the submerged weight (weight of the cask less the buoyant force) about a point on the bottom edge of the cask. This method assumes a pinned connection, i.e., the cask will rotate about the point on the edge rather than slide. When these moments are in equilibrium, the cask is at the point of overturning.

$$F_D \times \left(\frac{h}{2}\right) = \left(W_{cask} - F_b\right) \times r$$

$F_D = 98{,}960$ lbs

where:

h	=	concrete cask overall height (18.95 ft)
W_{CASK}	=	concrete cask weight = 272,912 lbs (Loaded concrete cask - fuel = 308,432 lbs- 35,520 lbs)
F_b	=	buoyant force = 107,557 lbs
r	=	concrete cask radius (5.67 ft)

Solving the drag force equation for the velocity, V, that is required to overturn the concrete cask:

$$V = \sqrt{\frac{2F_D}{C_D \rho A}}$$

$= 24.8$ ft/sec. (including safety factor of 1.1)

To prevent sliding, the minimum coefficient of friction (with a safety factor of 1.1) between the carbon steel bottom plate of the concrete cask and the concrete surface upon which it rests is,

$$\mu_{min} = \frac{(1.1)F_{D15}}{F_y} = \frac{(1.1)32{,}810 \text{ lb}}{(272{,}912 - 107{,}557) \text{ lb}} = 0.22$$

where:

F_y = the submerged weight of the concrete cask.

The analysis shows that the minimum coefficient of friction, μ, required to prevent sliding of the concrete cask is 0.22. The coefficient of friction between the steel bottom plate of the concrete cask and the concrete surface of the storage pad (0.35) is greater than the minimum coefficient of friction required to prevent sliding of the concrete cask. Therefore, the concrete cask does not slide under design-basis flood conditions.

The water velocity required to overturn the concrete cask is greater than the design-basis velocity of 15 ft/sec. Therefore, the concrete cask is not overturned under design basis flood conditions.

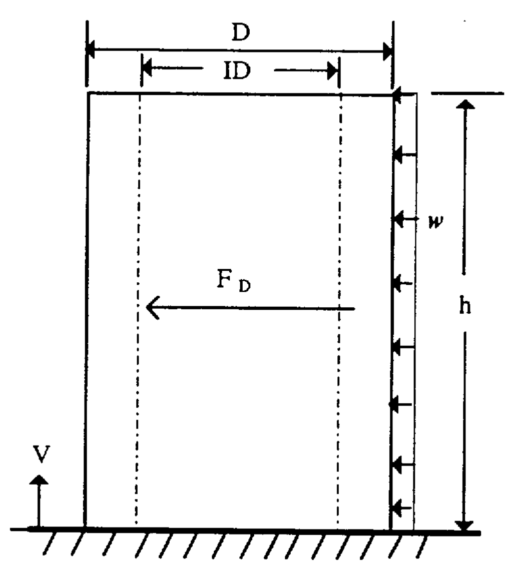
The flood depth of 50 feet exerts a hydrostatic pressure on the canister and the concrete cask. The water exerts a pressure of 22 psi (50 x 62.4/144) on the canister, which results in stresses in the canister shell. Canister internal pressure is conservatively taken as 0 psi. The canister structural analysis for the increased external pressure due to flood conditions is performed using an ANSYS finite element model as described in Section 3.4.4.1.

The resulting maximum canister stresses for flood loads are summarized in Tables 11.2.9-1 and 11.2.9-2 for primary membrane and primary membrane plus bending stresses, respectively.

The sectional stresses shown in Tables 11.2.9-1 and 11.2.9-2 at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.1-4. Consequently, there is no adverse consequence to the canister as a result of the hydrostatic pressure due to the flood condition.

The concrete cask is a thick monolithic structure and is not affected by the hydrostatic pressure due to design basis flood. Nonetheless, the stresses in the concrete due to the drag force (F_D) are conservatively calculated as shown below. The concrete cask is considered to be fixed at its base.

$F_D = 32{,}810$ lbs
$D = 136.0$ in. (concrete exterior diameter)
$ID = 79.5$ in. (concrete interior diameter)
$h = 225.88$ in. (cask overall height)
$A = \pi (D^2 - ID^{2)} / 4 = 9{,}563 \text{ in.}^2$
(Cross-sectional area)
$I = \pi (D^4 - ID^{4)} / 64 = 14.83\times10^6 \text{ in.}^4$
(Moment of Inertia)
$S = 2I/D = 218{,}088 \text{ in.}^3$
(Section Modulus for outer surface)
$w = F_D/h = 145.3$ lbf / in.
$M = w(h)^2 / 2 = 3.7\times10^6$ in.-lbs
(Bending Moment at the base)



Maximum stresses at the base surface:

$\sigma_v = M / S_{outer} = 16.9$ psi (tension or compression)

The compressive stresses are included in load combination No. 7 in Table 3.4.4.2–1. As shown in Table 3.4.4.2–1, the maximum combined stresses for the load combination due to dead, live, thermal and flood loading, are less than the allowable stress.

11.2.9.2.2 Analysis of Flood Condition for the Advanced Configuration

The buoyancy force, F_b, is calculated from the weight of water (62.4 lbs/ft^3) displaced by the fully submerged concrete cask. The displacement volume of the concrete cask containing the canister is 1,735 ft^3. The displacement volume is the volume occupied by the cask and the transport canister less the free space in the central annular cavity of the concrete cask.

$$F_b = \text{Vol} \times 62.4 \text{ lbs/ft}^3 \approx 110{,}000 \text{ lbs.}$$

Assuming the steady-state flow conditions for a rigid cylinder, the total drag force of the water on the concrete cask is given by the formula:

$$F_D = (C_D)(\rho)(V^2)\left(\frac{A}{2}\right) \qquad [24]$$

$$= 32{,}605 \text{ lbs.}$$

where:

C_D = Drag coefficient, which is dependent upon the Reynolds Number (Re). For flow velocities greater than 6 ft/sec, the value of C_D approaches 0.7 [24].

ρ = mass density of water = 1.94 slugs/ft^3

D = Concrete cask outside diameter (136.0 in. / 12 = 11.34 ft)

V = velocity of water flow (15 ft/sec)

A = projected area of the cask normal to water flow (diameter 11.34 ft × overall height 18.82 ft = 213.42 ft^2)

The drag force required to overturn the concrete cask is determined by summing the moments of the drag force and the submerged weight (weight of the cask less the buoyant force) about a point on the bottom edge of the cask. This method assumes a pinned connection, i.e., the cask will rotate about the point on the edge rather than slide. When these moments are in equilibrium, the cask is at the point of overturning. The bounding configuration is an empty concrete cask.

$$F_D \times \left(\frac{h}{2}\right) = \left(W_{cask} - F_b\right) \times r$$

$F_D = 62{,}365$ lbs

where:

h	=	concrete cask overall height (18.82 ft)
W_{CASK}	=	concrete cask weight = 220,000 lbs (This is conservative (220,000 < 227,000), since a larger weight would reduce the coefficient of friction to prevent sliding).
F_b	=	buoyant force = 110,000 lbs
r	=	concrete cask radius (5.34 ft)

Solving the drag force equation for the velocity, V, that is required to overturn the concrete cask:

$$V = \sqrt{\frac{2F_D}{(1.1)C_D\rho A}}$$

= 19.8 ft/sec. (including safety factor of 1.1)

To prevent sliding, the minimum coefficient of friction (with a safety factor of 1.1) between the carbon steel bottom plate of the concrete cask and the concrete surface upon which it rests is,

$$\mu_{min} = \frac{(1.1)F_{D15}}{F_y} = \frac{(1.1)32{,}605}{(220{,}000 - 110{,}000)} = 0.33$$

where:

F_y = 110,000 lbs the submerged weight of the concrete cask.

The analysis shows that the minimum coefficient of friction, μ, required to prevent sliding of the concrete cask is 0.33. The coefficient of friction between the steel bottom plate of the concrete cask and the concrete surface of the storage pad (0.35) is greater than the minimum coefficient of friction required to prevent sliding of the concrete cask. Therefore, the concrete cask does not slide under design-basis flood conditions.

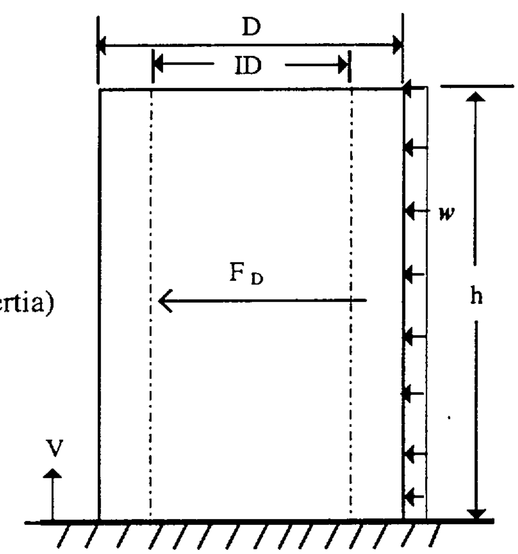
The water velocity required to overturn the concrete cask is greater than the design-basis velocity of 15 ft/sec. Therefore, the concrete cask is not overturned under design basis flood conditions.

The flood depth of 50 feet exerts a hydrostatic pressure on the canister and the concrete cask. The water exerts a pressure of 22 psi (50 x 62.4/144) on the canister, which results in stresses in the canister shell. Canister internal pressure is conservatively taken as 0 psi. The canister structural analysis for the increased external pressure due to flood conditions is performed using an ANSYS finite element model as described in Section 3.4.4.3.

The resulting maximum canister stresses for flood loads are summarized in Tables 11.2.9-3 and 11.2.9-4 for primary membrane and primary membrane plus bending stresses, respectively. The sectional stresses shown in these tables at 16 axial locations are obtained for each angular division of the model (a total of 19 angular locations for each axial location). The locations of the stress sections are shown in Figure 3.4.4.3-4. Consequently, there is no adverse consequence to the canister as a result of the hydrostatic pressure due to the flood condition.

The concrete cask is a thick monolithic structure and is not affected by the hydrostatic pressure due to design basis flood. Nonetheless, the stresses in the concrete due to the drag force (F_D) are conservatively calculated as shown below. The concrete cask is considered to be fixed at its base.

F_D = 32,810 lbs
D = 136.0 in. (concrete exterior diameter)
ID = 79.5 in. (concrete interior diameter)
h = 227.38 in. (cask overall height)
A $= \pi (D^2 - ID^{2)} / 4 = 9{,}563$ in.^{2} (Cross-sectional area)
I $= \pi (D^4 - ID^{4)} / 64 = 14.83\times10^6$ in.^{4} (Moment of Inertia)
S $= 2I/D = 218{,}088$ in.^{3}
(Section Modulus for outer surface)
w $= F_D/h = 144.3$ lbf / in.
M $= w(h)^2 / 2 = 3.73\times10^6$ in.-lbs
(Bending Moment at the base)



Maximum stresses at the base surface:

$\sigma_{v\,outer} = M / S_{outer} = 17.1$ psi (tension or compression)
$\sigma_{v\,inner} = M / S_{inner} = 10.0$ psi (tension or compression)

The compressive stresses are included in load combination No. 7 in Table 3.4.4.4–1. As shown in Table 3.4.4.4–1, the maximum combined stresses for the load combination due to dead, live, thermal and flood loading, are less than the allowable stress.

11.2.9.3 Corrective Actions

Inspection of the concrete casks is required following a flood. While the cask does not tip over or slide, a potential exists for collection of debris or accumulation of silt at the base of the cask, which could clog or obstruct the air inlets. Operation of the temperature monitoring system should be verified, as flood conditions may have impaired its operation.

11.2.9.4 Radiological Impact

There are no dose consequences associated with the design basis flood event.

Table 11.2.9-1 Standard Canister Increased External Pressure (22 psi) with No Internal Pressure (0 psi) Primary Membrane (P_m) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Allowable Stress[2]	Margin of Safety
1	0	-0.2	-2.2	-0.9	0.3	0	-0.1	2.09	40.08	18.16
2	0	-1.5	1.4	1.8	0.3	0	0.2	3.28	40.08	11.21
3	0	0.2	-0.6	2.7	-0.6	0.1	0.2	3.69	40.08	9.87
4	0	0	-0.6	-1.2	0	0	-0.1	1.18	39.76	32.70
5	0	0	-0.6	-1.2	0	0	-0.1	1.17	36.98	30.63
6	0	0	-0.6	-1.2	0	0	-0.1	1.17	36.52	30.24
7	0	0	-0.6	-1.2	0	0	-0.1	1.17	38.55	31.98
8	0	0	-0.5	-1.1	0	0	-0.1	1.09	40.08	35.67
9	0	-0.3	-0.2	-0.3	-0.1	0	0	0.27	40.08	149.28
10	0	0.3	-0.1	-0.1	-0.1	0	0	0.47	40.08	85.08
11	180	-0.3	0.1	-0.1	0	0	0	0.41	40.08	96.61
12	180	0.1	-0.2	-0.2	0	0	0	0.31	40.08	129.85
13	180	0	-0.3	-0.2	0.1	0	0	0.38	40.08	103.92
14	80	-0.3	0	-0.3	-0.3	0.2	0	0.73	40.08	53.64
15	70	0	0	0	0	0	0	0.02	40.08	Large
16	70	0	0	0	0	0	0	0.02	40.08	Large

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.
2. ASME Service Level D is used for material allowable stress.

Table 11.2.9-2 Standard Canister Increased External Pressure (22 psi) with No Internal Pressure (0 psi) Primary Membrane + Primary Bending ($P_m + P_b$) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Allowable Stress[2]	Margin of Safety
1	0	-1.7	-5.2	-0.2	0.0	0.0	0.1	5.00	60.12	11.02
2	0	-0.7	9.9	4.5	0.7	0.0	0.4	10.79	60.12	4.57
3	0	1.0	-14.0	-1.0	-0.8	0.1	-0.1	15.07	60.12	2.99
4	0	0.0	-0.6	-1.2	0.0	0	-0.1	1.19	59.64	48.99
5	0	0.0	-0.6	-1.2	0	0	-0.1	1.19	55.47	45.69
6	0	0.0	-0.6	-1.2	0	0	-0.1	1.19	54.79	45.12
7	0	0.0	-0.6	-1.2	0	0	-0.1	1.19	57.83	47.68
8	0	0	-0.8	-1.2	0	0.0	-0.1	1.16	60.12	50.87
9	180	-0.2	0.2	-0.2	0.2	0.0	0.0	0.52	60.12	114.79
10	20	0.1	-0.3	-0.2	-0.2	0.1	-0.1	0.57	60.12	103.78
11	180	-0.2	0.8	0.1	0.1	0.0	0	1.00	60.12	59.31
12	0	0.6	0.1	0.0	0.1	0.0	0.0	0.56	60.12	105.50
13	180	0.4	-0.2	0.0	0.1	0	0.0	0.57	60.12	104.73
14	180	-7.1	-0.1	-7.2	-0.2	0.2	0	7.12	60.12	7.45
15	0	0.6	0	0.5	0	0	0	0.55	60.12	108.23
16	0	-0.3	0	-0.3	0	0	0	0.26	60.12	231.93

1. See Figure 3.4.4.1-4 for definition of locations and angles of stress sections.
2. ASME Service Level D is used for material allowable stress.

Table 11.2.9-3 Advanced Canister Increased External Pressure (22 psi) with No Internal Pressure (0 psi) Primary Membrane (P_m) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Allowable Stress[2]	Margin of Safety
1	0	-0.04	-0.35	-0.15	-0.01	0.00	-0.01	0.31	38.90	124.48
2	180	-0.10	-0.31	-0.15	0.02	0.00	0.01	0.21	38.89	184.19
3	180	0.02	-0.60	-0.30	0.08	0.00	0.02	0.63	38.82	60.62
4	180	-0.02	-0.60	-1.18	0.00	0.00	0.08	1.17	36.88	30.52
5	0	-0.02	-0.60	-1.18	0.00	0.00	-0.08	1.17	35.11	29.01
6	0	-0.02	-0.60	-1.18	0.00	0.00	-0.08	1.17	35.03	28.94
7	0	-0.02	-0.60	-1.18	0.00	0.00	-0.08	1.17	36.96	30.59
8	180	-0.01	-0.57	-1.14	0.00	0.00	0.07	1.14	39.18	33.37
9	0	-0.26	-0.16	-0.31	-0.14	0.01	-0.01	0.30	39.78	131.60
10	180	0.34	-0.07	-0.10	0.02	0.00	0.03	0.44	39.80	89.45
11	0	-0.30	0.14	-0.11	-0.03	0.00	0.01	0.45	39.96	87.80
12	180	0.10	-0.09	-0.18	0.00	0.01	0.02	0.28	39.78	141.07
13	0	0.01	-0.33	-0.17	-0.05	0.01	-0.01	0.36	39.97	110.03
14	180	-0.05	0.00	-0.05	0.00	0.00	0.00	0.05	36.82	735.40
15	180	0.02	-0.01	0.02	0.00	0.00	0.00	0.03	39.04	1300.33
16	0	-0.05	-0.02	-0.05	0.00	0.00	0.00	0.03	39.56	1317.67

1. See Figure 3.4.4.3-4 for definition of locations and angles of stress sections.
2. ASME Service Level D is used for material allowable stress.

Table 11.2.9-4 Advanced Canister Increased External Pressure (22 psi) with No Internal Pressure (0 psi) Primary Membrane + Primary Bending ($P_m + P_b$) Stresses (ksi)

Section No.[1]	Angle (degrees)	SX	SY	SZ	SXY	SYZ	SXZ	Stress Intensity	Allowable Stress[2]	Margin of Safety
1	0	-0.08	-0.64	-0.25	-0.05	0.00	-0.01	0.58	58.35	99.60
2	180	-0.10	-0.86	-0.32	0.07	0.00	0.02	0.76	58.34	75.76
3	0	0.08	-1.40	-0.52	-0.09	0.01	-0.04	1.50	58.24	37.83
4	0	-0.01	-0.60	-1.19	0.00	0.00	-0.08	1.19	55.31	45.48
5	0	-0.01	-0.60	-1.19	0.00	0.00	-0.08	1.19	52.66	43.25
6	0	-0.01	-0.60	-1.19	0.00	0.00	-0.08	1.19	52.54	43.15
7	0	-0.01	-0.60	-1.19	0.00	0.00	-0.08	1.19	55.44	45.59
8	0	0.01	-0.48	-1.12	0.01	0.00	-0.07	1.15	58.78	50.11
9	0	-0.21	0.30	-0.15	-0.19	0.01	0.00	0.63	59.67	93.71
10	180	0.16	-0.45	-0.26	0.13	0.01	0.02	0.66	59.71	89.47
11	0	-0.23	0.87	0.13	-0.03	0.00	0.02	1.10	59.94	53.49
12	0	0.56	0.29	0.07	0.10	0.01	-0.03	0.52	59.68	113.77
13	0	0.30	-0.14	-0.05	-0.07	0.01	-0.02	0.47	59.95	126.55
14	180	-0.05	0.00	-0.05	0.00	0.00	0.00	0.05	55.23	1103.60
15	0	0.50	0.01	0.50	0.00	0.00	0.00	0.50	58.56	116.12
16	0	-0.28	-0.03	-0.28	0.00	0.00	0.00	0.26	59.34	227.23

1. See Figure 3.4.4.3-4 for definition of locations and angles of stress sections.
2. ASME Service Level D is used for material allowable stress.

11.2.10 Lightning Strike

This section evaluates the impact of a lightning strike on the Standard or Advanced Vertical Concrete Cask. The evaluation shows that the cask does not experience adverse effects due to a lightning strike.

11.2.10.1 Cause of Lightning Strike

A lightning strike is a random weather-related event. Because the Vertical Concrete Cask is located on an unsheltered pad, the cask may be subject to a lightning strike. The probability of a lightning strike is primarily dependent on the geographical location of the ISFSI site, as some geographical regions experience a higher frequency of storms containing lightning than others.

11.2.10.2 Detection of Lightning Strike

A lightning strike on a concrete cask may be visually detected at the time of the strike, or by visible surface discoloration at the point of entry or exit of the current flow. Most reactor sites in locations experiencing a frequency of lightning bearing storms have lightning detection systems as an aid to ensuring stability of site electric power.

11.2.10.3 Analysis of the Lightning Strike Event

The analysis of the lightning strike event assumes that the lightning strikes the upper-most metal surface and proceeds through the concrete cask liner to the ground. Therefore, the current path is from the lightning strike point on the outer radius of the top flange of the storage cask, down through the carbon steel inner shell and the bottom plate to the ground. The electrical current flow path results in current-induced Joule heating along that path. This path is the same for both the Standard and Advanced configurations of the concrete cask. Consequently, this analysis applies to either configuration.

The integrated maximum current for a lightning strike is a peak current of 250 kiloamps over a period of 260 microseconds, and a continuing current of up to 2 kiloamps for 2 seconds in the case of severe lightning discharges [25].

From Joule's Law, the amount of thermal energy developed by the combined currents is given by the following expression [26]:

$$
\begin{aligned}
Q &= 0.0009478R\left[I_1^2(dt_1) + I_2^2(dt_2)\right] \\
&= (22.98 \times 10^3)\ R\ \text{Btu}
\end{aligned}
\qquad \text{[Equation 11.2.10.1]}
$$

where:

Q = thermal energy (BTU)
I_1 = peak current (amps)
I_2 = continuing current (amps)
dt_1 = duration of peak current (seconds)
dt_2 = duration of continuing current (seconds)
R = resistance (ohms)

The maximum lightning discharge is assumed to attach to the smallest current-carrying component, that is, the top flange connected to the cask lid.

The propagation of the lightning through the carbon steel cask liner, which is both permeable and conductive, is considered to be a transient. For static conditions, the current is distributed throughout the shell. In a transient condition the current will be near the surface of the conductor. Similar to a concentrated surface heat flux incident upon a small surface area, a concentrated current in a confined area of the steel shell will result in higher temperatures than if the current were spread over the entire area, which leads to a conservative result. This conservative assumption is used by constraining the current flow area to a 90 degree sector of the circular cross section of the steel liner as opposed to the entire cross section. The depth of the current penetration (δ in meters) is estimated [27] as:

$$\delta = \frac{1}{\sqrt{\pi \mu f \sigma}}$$

where:

μ = permeability of the conductor = $100\mu_0$ ($\mu_0 = 4\pi \times 10^{-7}$ Henries/m)
σ = electrical conductivity (seimens/meter) = $1/\rho$
= 1/resistivity = $1/9.78 \times 10^{-8}$ (ohm-m)
f = frequency of the field (Hz)

The pulse is represented conservatively as a half sine form, so that the equivalent $f = 1/2\tau$, where τ is the referenced pulse duration. Two skin depths, corresponding to different pulse duration, are computed. The larger effective frequency will result in a smaller effective area to conduct the current. The effective resistance is computed as:

$$R = \frac{\rho\, l}{a}$$

where:

R	= resistance (ohms)
ρ	= resistivity = 9.78×10^{-8} (ohm-m)
l	= length of conductor path
a	= area of conductor (m^2)

Using the current level of the pulse and the duration in conjunction with the carbon steel liner, the resulting energy into the shell is computed using Equation 11.2.10.1.

This thermal energy dissipation is conservatively assumed to occur in the localized volume of the carbon steel involved in the current flow path through the flange to the inner liner. Assuming no heat loss or thermal diffusion beyond the current flow boundary, the maximum temperature increase in the flange due to this thermal energy dissipation is calculated [28] as:

$$\Delta T = \frac{Q}{mc}$$

where:

ΔT	= temperature change (°F)
Q	= thermal energy (BTU)
C	= 0.113 Btu/lbs °F
m	= mass (lbm)

The ΔT_1 for the peak current (250KA, 260 μsec) is found to be 4.7°F.

The ΔT_2 for the continuous current (2 kA, 2 sec) is found to be negligible (0.0006°F).

The ΔT_1 corresponds to the increase in the maximum temperature of the steel within the current path. For the concrete to experience an increase in temperature, the heat must disperse from the steel surface throughout the steel. Using the total thickness of the steel, over the 90 degree section, the increase in temperature would be proportional to the volume of steel in this sector resulting in a temperature rise of less than 1°F.

Therefore the increase in concrete temperature attributed to Joulean heating is not significant.

11.2.10.4 Corrective Actions

The casks should be visually inspected for any damage following the lightning event and actions taken as appropriate.

11.2.10.5 Radiological Impact

There are no dose implications due to the lightning event.

11.2.11 Tornado and Tornado Driven Missiles

This section evaluates the strength and stability of the Standard and Advanced Vertical Concrete Casks for a maximum tornado wind loading and for the impacts of tornado generated missiles. The design basis tornado characteristics are selected in accordance with Regulatory Guide 1.76 [29].

The evaluation demonstrates that the concrete cask remains stable in tornado wind loading in conjunction with impact from a high energy tornado missile. The performance of the cask is not significantly affected by the tornado event.

11.2.11.1 Cause of Tornado and Tornado Driven Missiles

A tornado is a random weather event. Probability of its occurrence is dependent upon the time of the year and geographical areas. Wind loading and tornado driven missiles have the potential for causing damage from pressure differential loading and from impact loading.

11.2.11.2 Detection of Tornado and Tornado Driven Missiles

A tornado event is expected to be visually observed. Advance warning of a tornado and of tornado sightings may be received from the National Weather Service, local radio and television stations, local law enforcement personnel, and site personnel.

11.2.11.3 Analysis of Tornado and Tornado Driven Missiles

Classical techniques are used to evaluate the loading conditions. Cask stability analysis for the maximum tornado wind loading is based on NUREG-0800 [30], Section 3.3.1, "Wind Loadings," and Section 3.3.2, "Tornado Loadings." Loads due to tornado-generated missiles are based on NUREG-0800, Section 3.5.1.4, "Missiles Generated by Natural Phenomena."

The concrete cask stability in a maximum tornado wind is evaluated based on the design wind pressure calculated in accordance with ANSI/ASCE 7-93 [31] and using classical free body stability analysis methods.

Local damage to the concrete shell is assessed using a formula developed for the National Defense Research Committee (NDRC) [32]. This formula is selected as the basis for predicting depth of missile penetration and minimum concrete thickness requirements to prevent scabbing of the concrete. Penetration depths calculated using this formula have been shown to provide reasonable correlation with test results (EPRI Report NP-440) [33].

The local shear strength of the concrete shell is evaluated on the basis of ACI 349-85 [34], Section 11.11.2.1, discounting the reinforcing and the steel internal shell. The concrete shell shear capacity is also evaluated for missile loading using ACI 349-85, Section 11.7.

The cask configuration used in this analysis combines the height of the tallest (Class 3 PWR) cask with the weight and center of gravity of the lightest (Class 1 PWR) cask. This configuration bounds all other configurations for cask stability. The cask properties considered in this evaluation are:

H = Cask Height = 225.88 in (Class 3 PWR)
D_o = Cask Outside Diameter = 136.0 in
D_i = Inside Diameter of concrete shell = 79.5 in
W_{SCC} = Weight of Standard cask with Standard canister, basket and fuel = 292,401 lbs
W_{ACC} = Weight of Advanced cask with Advanced canister, basket and fuel = 300,000 lbs. (This is conservative (300,000 < 311,900), since a larger weight would increase stability).
A_c = Cross section area of concrete shell = 9,563 in^2
I_c = Moment of inertia of concrete shell = 14.83×10^6 in^4
f_c' = Compressive strength of concrete shell = 4,000 psi

Tornado Wind Loading (Concrete Cask)

The tornado wind velocity is transformed into an effective pressure applied to the cask using procedures delineated in ANSI/ASCE 7-93 Building Code Requirements for Minimum Design Loads in Buildings and Other Structures. The maximum pressure, q, is determined from the maximum tornado wind velocity as follows:

$$q = (0.00256)\ V^2 \text{ psf}$$

where:

V = Maximum tornado wind speed = 360 mph

The velocity pressure exposure coefficient for local terrain effects K, Importance Factor I, and the Gust Factor G, may be taken as unity (1) for evaluating the effects of tornado wind velocity pressure. Then:

$q = (0.00256)(360)^2 = 331.8$ psf

Considering that the cask is small with respect to the tornado radius, the velocity pressure is assumed uniform over the projected area of the cask. Because the cask is vented, the tornado-induced pressure drop is equalized from inside to outside and has no effect on the cask structure.

The total wind loading on the projected area of the cask, F_w is then computed as:

$$F_w = q \times G \times C_f \times A_p$$
$$= 36{,}100 \text{ lbs}$$

where:

q	=	Effective velocity pressure (psf) = 331.8 psf.
C_f	=	Force Coefficient = 0.51 (ASCE 7-93, Table 12 with D $q^{1/2}$ = 206.4 for a moderately smooth surface, h/D = 18.8 ft /11.3 ft = 1.7)
A_f	=	Projected area of cask = (225.88 in × 136.0 in)/144 = 213.3 ft^2
G	=	Constant = 1.0

The wind overturning moment, M_w, is computed as:

$$M_w = F_w \times H/2 = 36{,}100 \text{ lbs} \times 225.88 \text{ in}/12 \times 1/2 \cong 340{,}000 \text{ ft-lbs}$$

where H is the cask height.

The stability moment, M_s, of the cask (with the canister, basket and no fuel load) about an edge of the base, is:

$$M_s = W_{cask} \times D_o/2$$

where:

D_o	=	Cask base plate diameter = 128.0 in
W_{cask}	=	Weight of the cask with canister
	≅	292,401 lbs (Class 1 PWR, Standard Configuration), or
	≅	300,000 lbs (Class 1 PWR, Advanced Configuration)
M_s	=	292,401 lbs × 128.0 in /12 × 1/2 = 1.56×10^6 ft-lbs

ASCE 7-93 requires that the overturning moment due to wind load shall not exceed two-thirds of the dead load stabilizing moment unless the structure is anchored. Therefore, the Margin of Safety against overturning of the Standard concrete cask is:

$$MS = \frac{M_S}{M_W} - 1 = \frac{(0.67)1.56 \times 10^6}{3.40 \times 10^5} - 1 = +2.07\,.$$

A coefficient of friction of 0.12 (36,100/292,000) between the cask base and the concrete pad on which it rests will inhibit sliding.

Against a coefficient of friction of steel on concrete of approximately 0.35 [23], the Margin of Safety against sliding of the Standard concrete cask is:

$$MS = \frac{0.35}{0.12} - 1 = +1.92\,.$$

The Margin of Safety, against overturning of the Advanced concrete cask is:

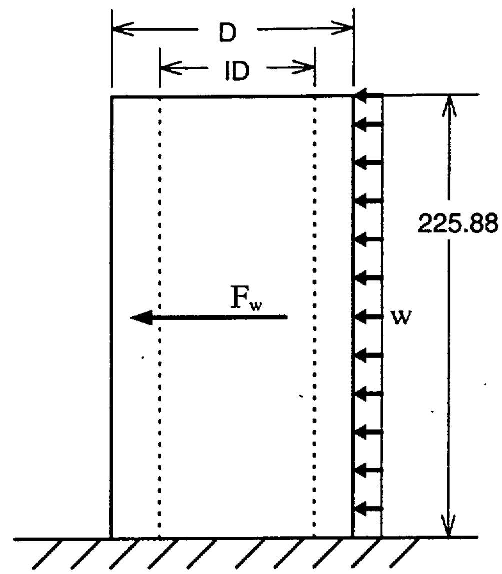
$$MS = \frac{M_S}{M_W} - 1 = \frac{(0.67)1.6 \times 10^6}{3.40 \times 10^5} - 1 = +2.1\,.$$

A coefficient of friction of 0.12 (36,100/300,000) between the cask base and the concrete pad on which it rests will inhibit sliding.

Against a coefficient of friction of steel on concrete of approximately 0.35 [23], the Margin of Safety against sliding of the Advanced concrete cask is:

$$MS = \frac{0.35}{0.12} - 1 = +1.92\,.$$

The stresses in the concrete due to the tornado wind load are conservatively calculated as follows. The concrete cask is considered to be fixed at its base.



F_W = 36,100 lbs

D = 136.0 in. (concrete outside diameter)

ID = 79.5 in. (concrete inside diameter)

H = 225.8 in. /12 = 18.82 ft

A = $\pi (D^2 - ID^{2)} / 4 = 9{,}563 \text{ in}^2$

I = $\pi (D^4 - ID^{4)} / 64 = 14.83 \times 10^6 \text{ in}^4$

(Moment of Inertia)

$$M = \frac{F_w \times H}{2} \cong 340{,}000 \text{ lbs-ft}$$

Maximum stresses:

$$\sigma_{outer} = \frac{M_{max} c_{outer}}{I} = 18.7 \text{ psi} \quad \text{(tension or compression)}$$

$$\sigma_{inner} = \frac{M_{max} c_{inner}}{I} = 10.9 \text{ psi} \quad \text{(tension or compression)}$$

where:

$c_{outer} = 136.0/2 = 68.0$ in.

$c_{inner} = 79.5/2 = 39.8$ in.

For the Standard configuration, the compressive stresses are included in the load combination No. 3 in Table 3.4.4.2-1, since they are governing stresses for the load combination. As shown in Tables 3.4.4.2-1 and 3.4.4.2-2, the maximum combined stresses for the load combination of dead, live, thermal and tornado wind are less than the allowable stress. For the Advanced configuration, stresses are reported in Tables 3.4.4.4-1 and 3.4.4.4-2.

Tornado Missile Loading (Standard Concrete Cask)

The Standard Vertical Concrete Cask is designed to withstand the effects of impacts associated with postulated tornado generated missiles identified in NUREG-0800, Section 3.5.1.4.III.4, Spectrum I missiles. These missiles consist of: 1) a massive high kinetic energy missile (4,000 lbs automobile, with a frontal area of 20 square feet that deforms on impact); 2) a 280 lbs, 8-inch-diameter armor piercing artillery shell; and 3) a small 1-inch diameter solid steel sphere. All of these missiles are assumed to impact in a manner that produces the maximum damage at a velocity of 126 mph (35% of the maximum tornado wind speed of 360 mph). The cask is evaluated for impact effects associated with each of the above missiles.

The principal dimensions and moment arms used in this evaluation are shown in Figure 11.2.11-1.

The concrete cask has no openings except for the four outlets at the top and four inlets at the bottom. The upper openings are configured such that a 1-inch diameter solid steel missile cannot directly enter the concrete cask interior. Additionally, the canister is protected by the canister structural and shield lids. The canister is protected from small missiles entering the lower inlets by a steel pedestal (bottom plate). Therefore, a detailed analysis of the impact of a 1-inch diameter steel missile is not required.

Concrete Shell Local Damage Prediction (Penetration Missile)

Local damage to the cask body is assessed by using the National Defense Research Committee (NDRC) formula [32]. This formula is selected as the basis for predicting depth of penetration and minimum concrete thickness requirements to prevent scabbing. Penetration depths calculated by using this formula have been shown to provide reasonable correlation with test results [33].

Concrete shell penetration depths are calculated as follows:

$x/2d \leq 2.0$

where:

d = Missile diameter = 8 in

x = Missile penetration depth = $[4KNWd^{-0.8}(V/1000)^{1.8}]^{0.5}$

where:

K = Coefficient depending on concrete strength

$= 180/(f_c')^{1/2} = 180/(4000)^{1/2} = 2.846$

N = 1.14 Shape factor for sharp nosed missiles

W = Missile weight = 280 lbs

V = Missile velocity = 126 mph = 185 ft/sec

$x = [(4)(2.846)(1.14)(280)(8^{-0.8})(185/1000)^{1.8}]^{0.5}$

$= 5.75$ inches

$x/2d = 5.75/(2)(8) = 0.359 < 2.0$

The minimum concrete shell thickness required to prevent scabbing is three times the predicted penetration depth of 5.75 inches based on the NDRC formula, or 17.25 inches. The concrete cask wall thickness includes 28.25 inches of concrete, which is more than the thickness required to prevent damage due to the penetration missile. This analysis conservatively neglects the 2.5-inch steel shell at the inside face of the concrete shell.

Closure Plate Local Damage Prediction (Penetration Missile)

The concrete cask is closed with a 1.5-inch thick steel plate bolted in place. The following missile penetration analysis shows that the 1.5-inch steel closure plate is adequate to withstand the impact of the 280-lbs armor piercing missile, impacting at 126 mph.

The perforation thickness of the closure steel plate is calculated by the Ballistic Research Laboratories Formula with K = 1, formula number 2-7, in Section 2.2 of Topical Report BC-TOP-9A, Revision 2 [35].

$$T = [0.5 m_m V^2]^{2/3}/672d = 0.523 \text{ inch}$$

where:

T = Perforation thickness
m_m = Missile mass = W/g = 280 lbs/32.174 ft/sec^2 = 8.70 slugs
g = Acceleration of gravity = 32.174 ft/sec^2

BC-TOP-9A recommends that the plate thickness be 25% greater than the calculated perforation thickness, T, to prevent perforation. Therefore, the recommended plate thickness is:

$$T = 1.25 \times 0.523 \text{ in.} = 0.654 \text{ in.}$$

The closure plate is 1.5 inches thick; therefore the plate is adequate to withstand the local impingement damage due to the specified armor piercing missile.

Overall Damage Prediction for a Tornado Missile Impact (High Energy Missile)

The concrete cask is a free-standing structure. Therefore, the principal consideration in overall damage response is the potential of upsetting or overturning the cask as a result of the impact of a high energy missile. Based on the following analysis, it is concluded that the cask can sustain an impact from the defined massive high kinetic energy missile and does not overturn.

From the principle of conservation of momentum, the impulse of the force from the missile impact on the cask must equal the change in angular momentum of the cask. Also, the impulse force due to the impact of the missile must equal the change in linear momentum of the missile. These relationships may be expressed as follows:

Change in momentum of the missile, during the deformation phase

$$\int_{t_1}^{t_2} (F)(dt) = m_m(v_2 - v_1)$$

where:

F	=	Impact impulse force on missile
m_m	=	Mass of missile = 4000 lbs/g = 124 slugs/12 = 10.4 (lbs sec^2 /in)
t_1	=	Time at missile impact
t_2	=	Time at conclusion of deformation phase
v_1	=	Velocity of missile at impact = 126 mph = 185 ft/sec
v_2	=	Velocity of missile at time t_2

The change in angular momentum of the cask, about the bottom outside edge/rim, opposite the side of impact is:

$$\int_{t_1}^{t_2} M_c(dt) = \int_{t_1}^{t_2} (H)(F)(dt) = I_m(\omega_1 - \omega_2)$$

Substituting,

$$\int (F)(dt) = m_m(v_2 - v_1) = \frac{I_m(\omega_1 - \omega_2)}{H}$$

where:

M_c = Moment of the impact force on the cask

I_m = Concrete cask mass moment of inertia, about point of rotation on the bottom rim

ω_1 = Angular velocity at time t_1

ω_2 = Angular velocity at time t_2

For the Standard configuration:

m_c = Mass of concrete cask = W_c/g = 292,401/32.174
= 9,076 slugs/12 = 756.3 lbs sec^2 /in)

I_{mx} = Mass moment of inertia of concrete cask about x axis through its center of gravity
$\cong$ 1/12(m_c)($3r^2 + H^2$) (Conservatively assuming a solid cylinder.)
$\cong$ (1/12)(756.3) [(3)(68.0)^2 + (225.88)^2] = 4.09×10^6 lbs-sec^2-in

$I_m \quad = I_{mx} + (m_c)(d_{CG})^2 = 4.09\times10^6 + (756.3)(121.05)^2 = 15.9\times10^6$ lbs-sec^2-in.

d_{CG} = The distance between the cask CG and a rotation point on base rim = 121.05 in.

For the Advanced configuration:

m_c = Mass of concrete cask = $W_c/g = 300{,}000/32.174$

= 9,324 slugs/12 = 777 lbs sec^2 /in)

I_{mx} = Mass moment of inertia of concrete cask about x axis through its center of gravity

$\cong 1/12(m_c)(3r^2 + H^2)$ (Conservatively assuming a solid cylinder.)

$\cong (1/12)(777)\,[(3)(68.0)^2 + (225.88)^2] = 4.2 \times 10^6$ lbs-sec^2-in

$I_m \quad = I_{mx} + (m_c)(d_{CG})^2 = 4.2\times10^6 + (777)(134.2)^2 = 18.2\times10^6$ lbs-sec^2-in.

d_{CG} = The distance between the cask CG and a rotation point on base rim = 134.2 in.

Based on conservation of momentum, the impulse of the impact force on the missile is equated to the impulse of the force on the cask.

$$m_m(v_2 - v_1) = I_m(\omega_1 - \omega_2)/H$$

at time t_1, v_1 = 185 ft/sec and ω_1 = 0 rad/sec

at time t_2, v_2 = 0 ft/sec

During the restitution phase, the final velocity of the missile depends upon the coefficient of restitution of the missile, the geometry of the missile and target, the angle of incidence, and on the amount of energy dissipated in deforming the missile and target. On the basis of tests conducted by EPRI, the final velocity of the missile, v_f, following the impact is assumed to be zero. Assuming conservatively that all of the missile energy is transferred to the cask, and equating the impulse of the impact force on the missile to the impulse of the force on the cask,

$$(10.4)(v_2 - 185 \text{ ft/sec} \times 12 \text{ in/ ft}) = 15.9\times10^6 \text{ lbs-sec}^2\text{-in } (0 - \omega_2)/225.88$$

ω_2 = 0.328 rad/sec (when $v_2 = 0$) for the Standard configuration

ω_2 = 0.287 rad/sec (when $v_2 = 0$) for the Advanced configuration

Back solving for v_2

$v_2 = 261.6 \times \omega_2 = (261.6)(0.328) = 85.8$ in/sec for the Standard configuration

$v_2 = 261.6 \times \omega_2 = (261.6)(0.287) = 75.1$ in/sec for the Advanced configuration where the distance from the point of missile impact to the point of cask rotation is $\sqrt{132.0^2 + 225.88^2} = 261.6$ in. (See Figure 11.2.11-1). The line of missile impact is conservatively assumed normal to this line.

Equating the impulse of the force on the missile during restitution to the impulse of the force on the Standard cask yields:

$$-[m_m(v_f - v_2] = I_m\,(\omega_f - \omega_2)/H$$

$$-[10.4(0 - 85.8)] = 15.9\times10^6 \text{ lbs-sec}^2\text{-in } (\omega_f - 0.328)/225.88$$

$$\omega_f = 0.341 \text{ rad/sec}$$

where:

$$v_f = 0$$
$$v_2 = 85.8 \text{ in/sec}$$
$$\omega_2 = 0.328 \text{ rad/sec}$$

Thus, the final energy of the Standard cask following the impact , E_k, is:

$$E_k = (I_m)(\omega_f)^2/(2) = (15.9\times10^6)(0.341)^2/(2) = 9.24\times10^5 \text{ in-lb}_f$$

Similarly, for the Advanced cask:

$$-[m_m(v_f - v_2] = I_m\,(\omega_f - \omega_2)/H$$

$$-[10.4(0 - 75.1)] = 18.2\times10^6 \text{ lbs-sec}^2\text{-in } (\omega_f - 0.287)/261.6$$

$$\omega_f = 0.298 \text{ rad/sec}$$

where:

$$v_f = 0$$
$$v_2 = 75.1 \text{ in/sec}$$
$$\omega_2 = 0.287 \text{ rad/sec}$$

The final energy of the Advanced cask following the impact , E_k, is:

$$E_k = (I_m)(\omega_f)^2/(2) = (18.2\times10^6)(0.297)^2/(2) = 8.08\times10^5 \text{ in-lb}_f$$

The change in potential energy, E_p, of the cask due to rotating it until its center of gravity is above the point of rotation (the condition where the cask will begin to tip-over and the height of the center of gravity has increased by the distance, h_{PE}, see Figure 11.2.11-1) is:

$$E_p = (W_{cask})(h_{PE})$$
$$E_p = 292{,}401 \text{ lbs} \times 17.6 \text{ in. (Standard configuration)}$$
$$E_p = 5.15 \times 10^6 \text{ in-lb}_f \text{ (Standard configuration)}$$
$$E_p = 300{,}000 \text{ lbs} \times 16.18 \text{ in. (Advanced configuration)}$$
$$E_p = 5.05 \times 10^6 \text{ in-lb}_f \text{ (Advanced configuration)}$$

The massive high kinetic energy tornado generated missile imparts less kinetic energy than the change in potential energy of the cask at the tip-over point. Therefore, cask overturning from missile impact is not postulated to occur. The Margin of Safety against overturning of the Standard configuration is:

$$MS = \frac{5.15 \times 10^6}{9.24 \times 10^5} - 1 = +4.6$$

Similarly, the Margin of Safety against overturning of the Advanced configuration is:

$$MS = \frac{5.05 \times 10^6}{8.0 \times 10^5} - 1 = +5.31$$

Combined Tornado Wind and Missile Loading (High Energy Missile)

The Standard cask rotation due to the heavy missile impact is calculated as (See Figure 11.2.11-1 for dimensions):

$$h_{KE} = E_k / W_c = 9.24 \times 10^5 \text{ in-lb}_f / 292{,}000 \text{ lbs} = 3.16 \text{ in}$$

Then, for the Standard configuration:

$$\cos\beta = (h_{CG} + h_{KE}) / d_{CG}$$
$$\cos\beta = (107.39 + 3.16) / 121.05 = 0.8843$$
$$\beta = 27.8 \text{ deg}$$
$$\cos\alpha = 107.39 / 121.05 = 0.8591$$
$$\alpha = 30.8 \text{ deg}$$
$$e = d_{CG} \sin\beta$$
$$e = 121.05 \sin 27.8 = 58.3 \text{ in}$$

Therefore, cask rotation after impact $= \alpha - \beta = 30.8 - 27.8 = 3.0$ deg

The available gravity restoration moment after missile impact:

$$= (W_c)(e)$$
$$= 292{,}000 \text{ lbs} \times 58.3 \text{ in}/12$$
$$= 1.42\times10^6 \text{ ft-lbs} >> \text{Tornado Wind Moment} = 3.40\times10^5 \text{ ft-lbs}$$

Therefore, the combined effects of tornado wind loading and the high energy missile impact loading will not overturn the cask. Considering that the overturning moment should not exceed two-thirds of the restoring stability moment, the margin of safety, MS, is:

$$MS = \frac{0.67(1.42\times10^6)}{3.40\times10^5} - 1 = +1.80$$

Similarly, for the Advanced configuration, the cask rotation due to the heavy missile impact is calculated as (See Figure 11.2.11-1 for dimensions):

$$h_{KE} = E_k / W_c = 8.08\times10^5 \text{ in-lb}_f/300{,}000 \text{ lbs} \cong 3.0 \text{ in}$$

$$\cos\beta = (h_{CG} + h_{KE}) / d_{CG}$$
$$\cos\beta = (118.0 + 3.0) / 134.2 = 0.9016$$
$$\beta = 26 \text{ deg}$$
$$\cos\alpha = 118.0 / 134.2 = 0.8793$$
$$\alpha = 28 \text{ deg}$$
$$e = d_{CG} \sin\beta$$
$$e = 134.2 \sin 26 = 58.8 \text{ in}$$

Therefore, cask rotation after impact $= \alpha - \beta = 28 - 26 = 2.0$ deg

The available gravity restoration moment after missile impact:

$$= (W_c)(e)$$
$$= 300{,}000 \text{ lbs} \times 58.8 \text{ in}/12$$
$$= 1.47 \times 10^6 \text{ ft-lbs} >> \text{Tornado Wind Moment} = 3.40\times10^5 \text{ ft-lbs}$$

Therefore, the combined effects of tornado wind loading and the high energy missile impact loading will not overturn the cask. Considering that the overturning moment should not exceed two-thirds of the restoring stability moment, the margin of safety, MS, is:

$$MS = \frac{0.67(1.47\times10^6)}{3.40\times10^5} - 1 = +1.90$$

Local Shear Strength Capacity of Concrete Shell (High Energy Missile)

This section evaluates the shear strength of the concrete at the top edge of the concrete shell due to a high energy missile impact based on ACI 349-85 [59], Chapter 11, Section 11.11.2.1, on concrete punching shear strength.

The force developed by the massive high kinetic energy missile having a frontal area of 20 square feet, is evaluated using the methodology presented in Topical Report, BC-TOP-9A.

$$F = 0.625(v)(W_M)$$
$$F = 0.625(185\text{ ft/sec})(4{,}000\text{ lbs}) = 462.5\text{ kips}$$
$$F_u = LF\times F = 1.1\times 462.5 = 508.8\text{ kips}$$

Based on a rectangular missile contact area, having proportions of 2 (horizontal) to 1 (vertical) and the top of the area flush with the top of the concrete cask, the required missile contact area based on the concrete punching shear strength (neglecting reinforcing) is calculated as follows.

$$V_c = (2+4/\beta_c)\,(f_c')^{1/2} b_o\, d, \text{ where } \beta_c = 2/1 = 2$$
$$V_c = 4\,(f_c')^{1/2} b_o\, d$$
$$d = 28.25\text{ in} - 3.25\text{ in} = 25\text{ in}$$
$$(f_c')^{1/2} = 63.24\text{ psi, where } f_c' = 4{,}000\text{ psi}$$
b_o = perimeter of punching shear area at d/2 from missile contact area
$$b_o = (2b + 25) + 2(b + 12.5) = 4b + 50$$
$$V_u = \Phi(V_c + V_s), \text{ where } V_s = 0, \text{ assuming no steel shear}$$
$$V_u = \Phi V_c = \Phi\, 4\,(f_c')^{1/2} b_o\, d = (0.85)(4)(63.24)(4b + 50)(25) = 21{,}501\, b + 268{,}770.$$

Setting, V_u equal to F_u and solving for b

$$508.8\times10^3 = 21{,}501\, b + 268{,}770$$
$$b = 11.12\text{ inches (say 1.0 ft)}$$

The implied missile impact area required $= 2b \times b = 2 \times 1 \times 1 = 2.0$ sq ft < 20.0 sq ft

Thus, the concrete shell alone, based on the concrete conical punching strength and discounting the steel reinforcement and shell, has sufficient capacity to react to the high energy missile impact force.

The effects of tornado winds and missiles are considered both separately and combined in accordance with NUREG-800, Section 3.3.2 II.3.d [30]. For the case of tornado wind plus missile loading, the stability of the cask is assessed and found to be acceptable. Equating the kinetic energy of the cask following missile impact to the potential energy yields a maximum postulated rotation of the cask, as a result of the impact, of 3.0 degrees. Applying the total tornado wind load to the cask in this configuration results in an available restoring moment considerably greater than the tornado wind overturning moment. Therefore, overturning of the cask under the combined effects of tornado winds, plus tornado-generated missiles, does not occur.

Tornado Effects on the Canister

The postulated tornado wind loading and missile impacts are not capable of overturning the cask, or penetrating the boundary established by the concrete cask. Consequently, there is no effect on the canister. Stresses resulting from the tornado-induced decreased external pressure are bounded by the stresses due to the accident internal pressure discussed in Section 11.2.1.

11.2.11.4 Corrective Actions

A tornado is not expected to result in the need to take any corrective action other than an inspection of the ISFSI. This inspection would be directed at ensuring that inlets and outlets had not become blocked by wind-blown debris and at checking for obvious (concrete) surface damage.

11.2.11.5 Radiological Impact

Damage to the vertical concrete cask after a design basis accident does not result in a radiation exposure at the controlled area boundary in excess of 5 rem to the whole body or any organ. The penetrating missile impact is estimated to reduce the concrete shielding thickness, locally at the point of impact, by approximately 6 inches. Localized cask surface dose rates for the removal of 6 inches of concrete are estimated to be less than 250 mrem/hr for the PWR and BWR configurations.

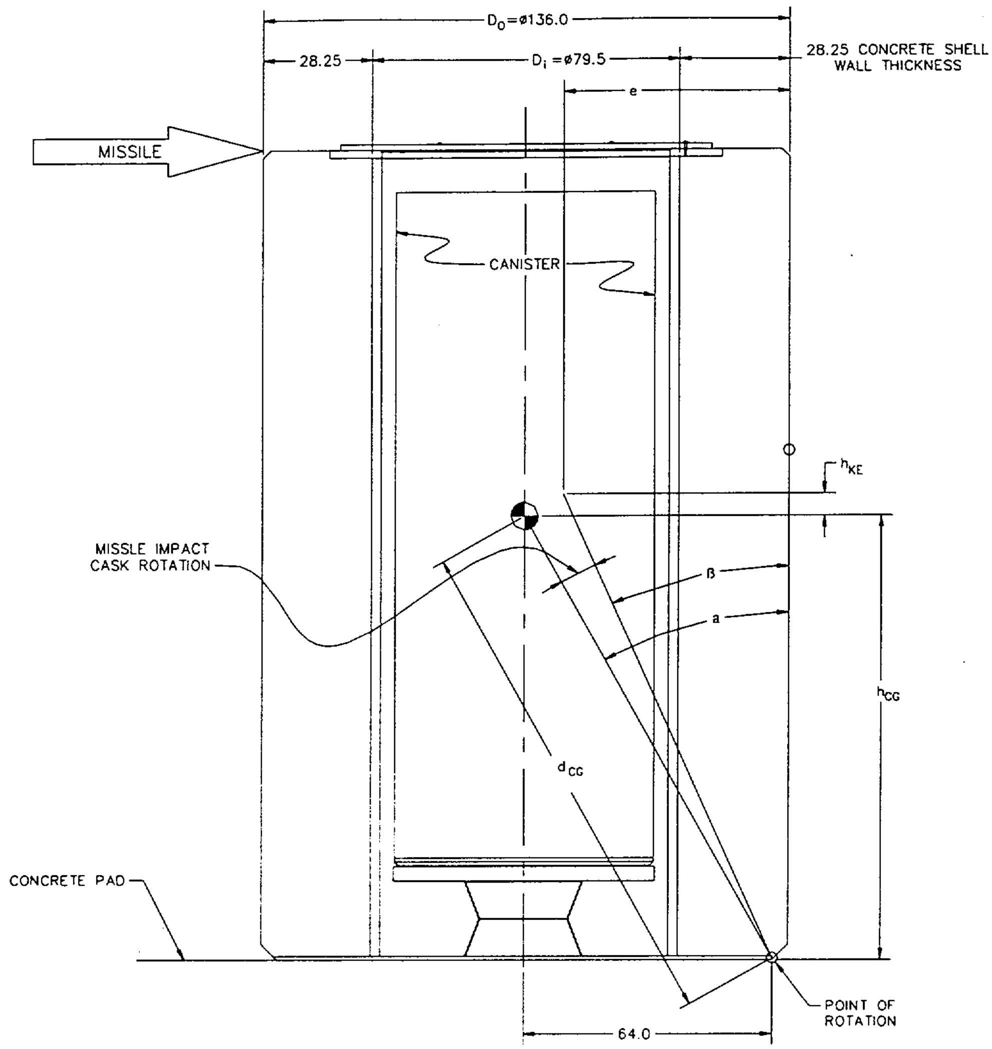


Figure 11.2.11-1 Principal Dimensions and Moment Arms Used in Tornado Evaluation

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