In the model for side drop, compressive loads are transmitted from the basket support disks to the canister shell. The interface between the support disk and canister is modeled by using the ANSYS CONTAC52 element, which permits the support disk model nodes to interface with the canister elements. The interface between the canister shell and the inner radius of the transport cask inner shell is also modeled with CONTAC52 elements, which act as a compression-only element. The deformed shape of the transport cask inner shell is applied to the outer nodes of the CONTAC52 elements as boundary conditions. Contact elements are also modeled in the gap created by the slit located at the support rod hole. For all CONTAC52 elements the gap stiffness is set to 1.00E+06 lb/in. Because all contact interfaces are circular, additional rotational stiffness is added to the model by including weak beams between the support disk and the canister shell, and between the canister and cask inner shell.

The loads from the fuel assembly are modeled as a pressure loading at the inner surface of each support disk slot opening. The surface pressure loads are determined by performing a comparison analysis of all relevant PWR assemblies. For the PWR support disk the worst case loading is (PWR Class #1):

$$\text{Weight of single fuel assembly + fuel tube} = \frac{37608\text{lb}}{24\text{slots}} + \frac{3285\text{lb}}{24\text{slots}} \approx 1{,}705\,\text{lb}$$

$$\text{Pressure applied to web slot} = (1705\ \text{lb}/(9.272\ \text{in} \times 0.5\ \text{in}))/30 = 12.26\ \text{psi},$$

where, the slot size is 9.272 in., the thickness of the disk is 0.5 in, and the number of disks[1] is 30.

The weight of the tie-rods and split spacers is accounted for by multiplying the density of the support disk material by a factor of 1.373 as shown below.

$$\text{Ratio} = \frac{\text{Disk Weight + Rods and Spacers}}{\text{Disk Weight}} = \frac{186.4+69.4}{186.4} = 1.373$$

[1] No credit is taken for the top and bottom weldments when calculating the pressure load. Only the 30 support disks are used.

$$\text{Density} = 0.291 \times 1.373 = 0.3997 \text{ lb/in}^3$$

Inertial loads applied to the support disk include 20 *g* for normal and 60 *g* for accident conditions. The pressure load is also multiplied by the appropriate acceleration.

For the side drop, pressure loads are applied to the ligament based on the impact angle. The PWR fuel assembly basket with 24 slots exhibits one-eighth symmetry. A minimum perimeter radial thickness occurs between the corner of the fuel assembly slot in the basket and the outer radius at three locations: 18.22°, 26.28°, and 45° measured counterclockwise from the Y-axis (see Fig. 2.6.13.2-2). Therefore, to ensure that the bounding basket orientation is evaluated, drop orientations of 0°, 18.22°, 26.28°, and 45° are considered. To simulate end drop loading, pressure loads are set to zero and the acceleration is applied in the axial direction of the cask.

To evaluate oblique impacts, the stress components (i.e. S_x, S_y, S_{xy}) are calculated based on the stress results of the side and end drop cases. These stress combinations are accomplished with the use of an ANSYS macro. The macro extracts the component stresses based on the basket drop orientation for the side and end drop cases. Once the stress data is stored in an array, the macro cycles through the cask drop angles (0°, 23°, 30°, 40°, 45°, 50°, 60°, 70°, 75°, 80°, 85°, 88°, and 90°), as well as the basket drop orientation (0°, 18.22°, 26.28°, and 45°) and calculates the stresses. Finally, the macro then sorts the data to determine the worst case stresses and the drop orientations where the stress occurs.

To determine the most critical cross sections, a series of cross sections are considered. To aid in the identification of these sections, Figures 2.6.13.2-3 and 2.6.13.2-4 show the locations on a support disk. Table 2.6.13.2-1 lists the cross sections versus Point 1 and Point 2, which spans the cross section of the web in the plane of the support disk. Points 1 and 2 for each cross section are shown in Figures 2.6.13.2-3 and 2.6.13.2-4. For example, Section 3 from Table 2.6.13.2-1 refers to Points 5 and 6 shown in Figure 2.6.13.2-3 (just to the left of the center-line of the support disk). From the corresponding nodal coordinates given in Table 2.6.13.2-1, point 5 (x=-0.75, y=0.75) and point 6 (x=-0.75, y=-0.75), it is known that the section is taken across the vertical ligament.

The stress evaluation for the support disk is performed according to the ASME Code, Section III, Subsection NG [15]. According to this subsection, linearized stresses of cross sections of the

In the model for side drop, compressive loads are transmitted from the basket support disks to the canister shell. The interface between the support disk and canister is modeled by using the ANSYS CONTAC52 element, which permits the support disk model nodes to interface with the canister elements. The interface between the canister shell and the inner radius of the transport cask inner shell is also modeled with CONTAC52 elements, which act as a compression-only element. The deformed shape of the transport cask inner shell is applied to the outer nodes of the CONTAC52 elements as boundary conditions. Contact elements are also modeled in the gap created by the slit located at the support rod hole. For all CONTAC52 elements the gap stiffness is set to 1.00E+06 lb/in. Because all contact interfaces are circular, additional rotational stiffness is added to the model by including weak beams between the support disk and the canister shell and between the canister and cask inner shell.

The loads from the fuel assembly are modeled as a pressure loading at the inner surface of each support disk slot opening. The surface pressure loads are determined by performing a comparison analysis of all relevant PWR assemblies. For the PWR support disk the worst case loading is (PWR Class #1):

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where, the slot size is 9.272 in., the thickness of the disk is 0.5 in, and the number of disks[1] is 30.

The weight of the tie-rods and split spacers is accounted for by multiplying the density of the support disk material by a factor of 1.373 as shown below.

$$\text{Ratio} = \frac{\text{Disk Weight} + \text{Rods and Spacers}}{\text{Disk Weight}} = \frac{186.4 + 69.4}{186.4} = 1.373$$

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[1] No credit is taken for the top and bottom weldments when calculating the pressure load. Only the 30 support disks are used.

Density = 0.291 × 1.373 = 0.3997 lb/in^3

Inertial loads applied to the support disk include 20 g for normal and 60 g for accident conditions. The pressure load is also multiplied by the appropriate acceleration.

For the side drop, pressure loads are applied to the ligament based on the impact angle. The PWR fuel assembly basket with 24 slots exhibits one-eighth symmetry. A minimum perimeter radial thickness occurs between the corner of the fuel assembly slot in the basket and the outer radius at three locations: 18.22°, 26.28°, and 45° measured counterclockwise from the Y-axis (see Fig. 2.6.13.2-2). Therefore, to ensure that the bounding basket orientation is evaluated, drop orientations of 0°, 18.22°, 26.28°, and 45° are considered. To simulate end drop loading, pressure loads are set to zero and the acceleration is applied in the axial direction of the cask.

To evaluate oblique impacts, the stress components (i.e. S_x, S_y, S_{xy}) are calculated based on the stress results of the side and end drop cases. These stress combinations are accomplished with the use of an ANSYS macro. The macro extracts the component stresses based on the basket drop orientation for the side and end drop cases. Once the stress data is stored in an array, the macro cycles through the cask drop angles (0°, 23°, 30°, 40°, 45°, 50°, 60°, 70°, 75°, 80°, 85°, 88°, and 90°), as well as the basket drop orientation (0°, 18.22°, 26.28°, and 45°) and calculates the stresses. Finally, the macro then sorts the data to determine the worst case stresses and the drop orientations where the stress occurs.

To determine the most critical cross sections, a series of cross sections are considered. To aid in the identification of these sections, Figures 2.6.13.2-3 and 2.6.13.2-4 show the locations on a support disk. Table 2.6.13.2-1 lists the cross sections versus Point 1 and Point 2, which spans the cross section of the web in the plane of the support disk. Points 1 and 2 for each cross section are shown in Figures 2.6.13.2-3 and 2.6.13.2-4. For example, Section 3 from Table 2.6.13.2-1 refers to Points 5 and 6 shown in Figure 2.6.13.2-3 (just to the left of the center-line of the support disk). From the corresponding nodal coordinates given in Table 2.6.13.2-1, point 5 (x=-0.75, y=0.75) and point 6 (x=-0.75, y=-0.75), it is known that the section is taken across the vertical ligament.

The stress evaluation for the support disk is performed according to the ASME Code Section III Subsection NG [15]. According to this subsection, linearized stresses of cross sections of the

structure are to be compared against the allowable stresses. The allowable stresses for normal and accident conditions are taken from Subsection NG as shown below:

	Normal (Level A)	Accident (Level D)
P_m	1.0 Sm	0.7 Su
P_m+P_b	1.5 Sm	1.0 Su
P+Q	3.0 Sm	N/A

The following table summarizes the side, end, and off-angle stresses in the PWR support disk for normal conditions (1-Foot drop). The minimum margin of safety is +0.18.

Stress State	Thermal Case[1]	Section	Drop Angle[2]	Basket Angle[3]	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
P_m	B	120	90.0	45.0	9.6	-9.8	8.0	25.2	45.0	0.79
P_m+P_b	B	21	85.0	45.0	-46.8	-41.5	12.5	57.0	67.5	0.18
P+Q	B	21	88.0	45.0	-48.7	-45.2	15.6	62.7	135.0	1.15
P_m	A	120	90.0	45.0	9.1	-9.1	7.6	23.7	44.3	0.86
P_m+P_b	A	21	90.0	45.0	-42.8	-39.0	11.6	52.7	64.5	0.22
P+Q	A	4	85.0	26.3	-41.3	-43.6	14.9	57.4	125.9	1.19

[1] See Section 2.6.13.3 for definition of thermal cases.
[2] Cask drop angle, see figure shown on previous page.
[3] Basket angle (orientation), see Figure 2.6.13.2-2.

Figure 2.6.13.2-1 PWR Basket Model for Side-Drop

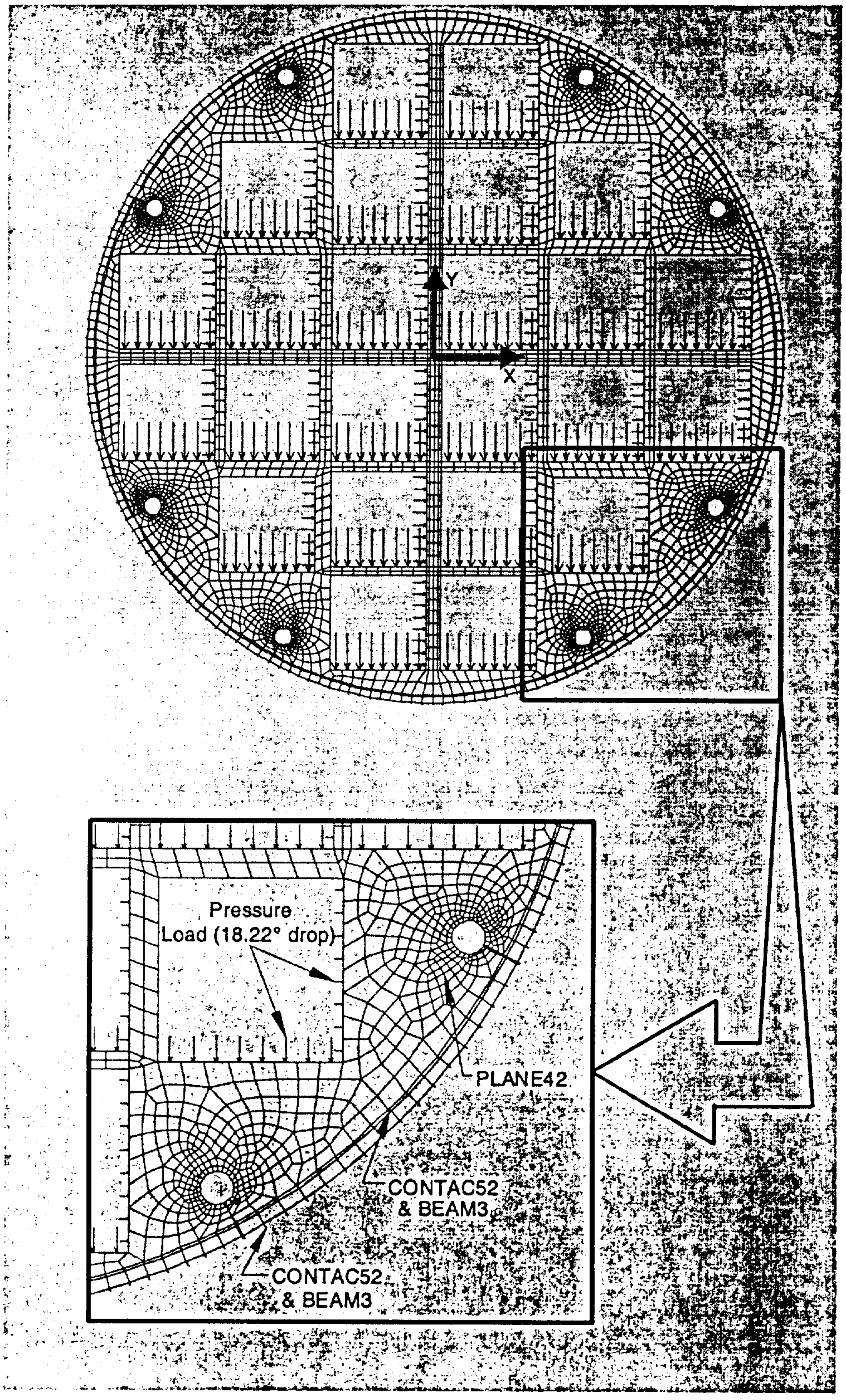


Figure 2.6.13.2-2 Side Drop Orientation

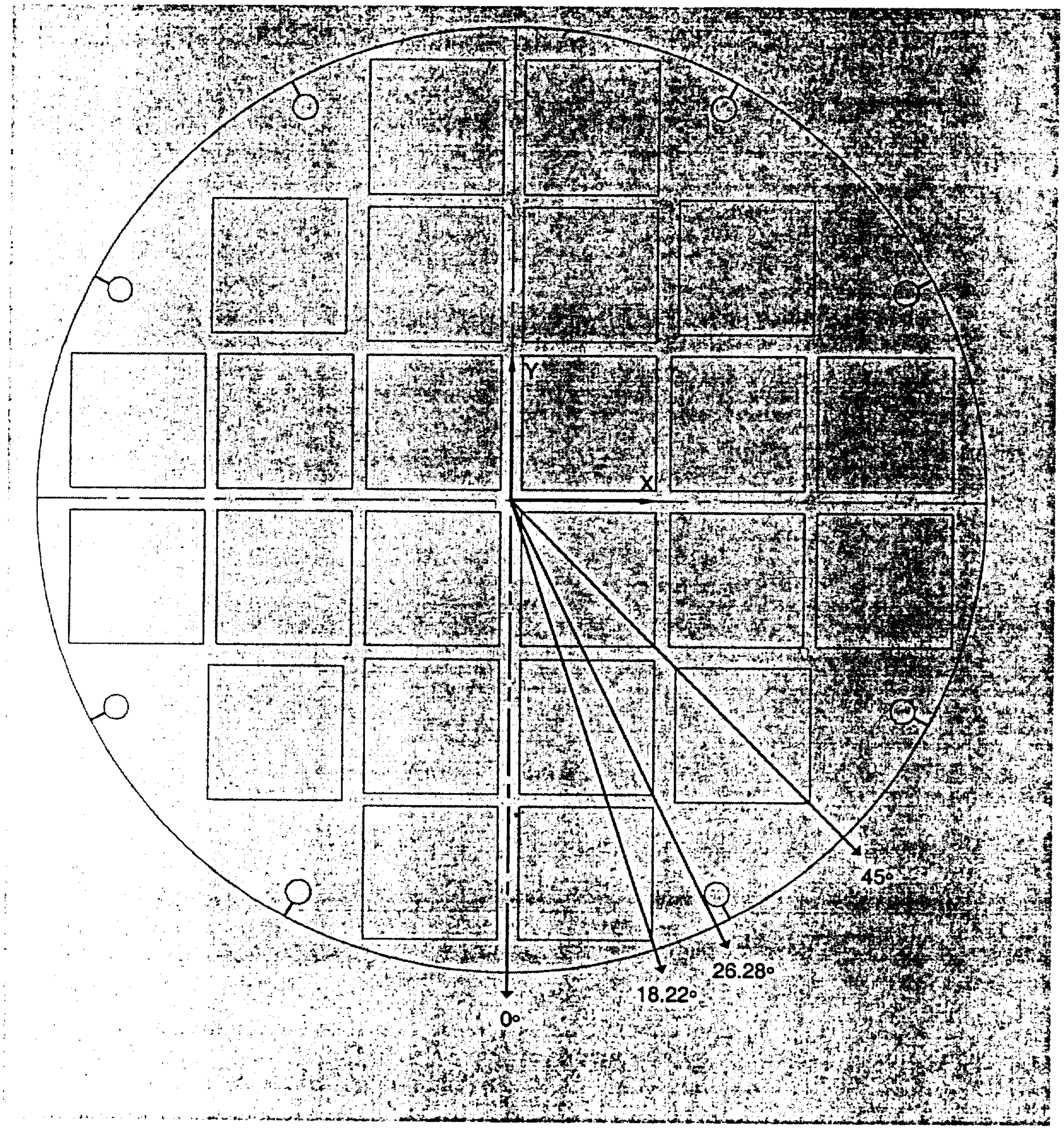


Figure 2.6.13.2-3 Location of the Section to Obtain Linearized Stresses (Left half of support disk)

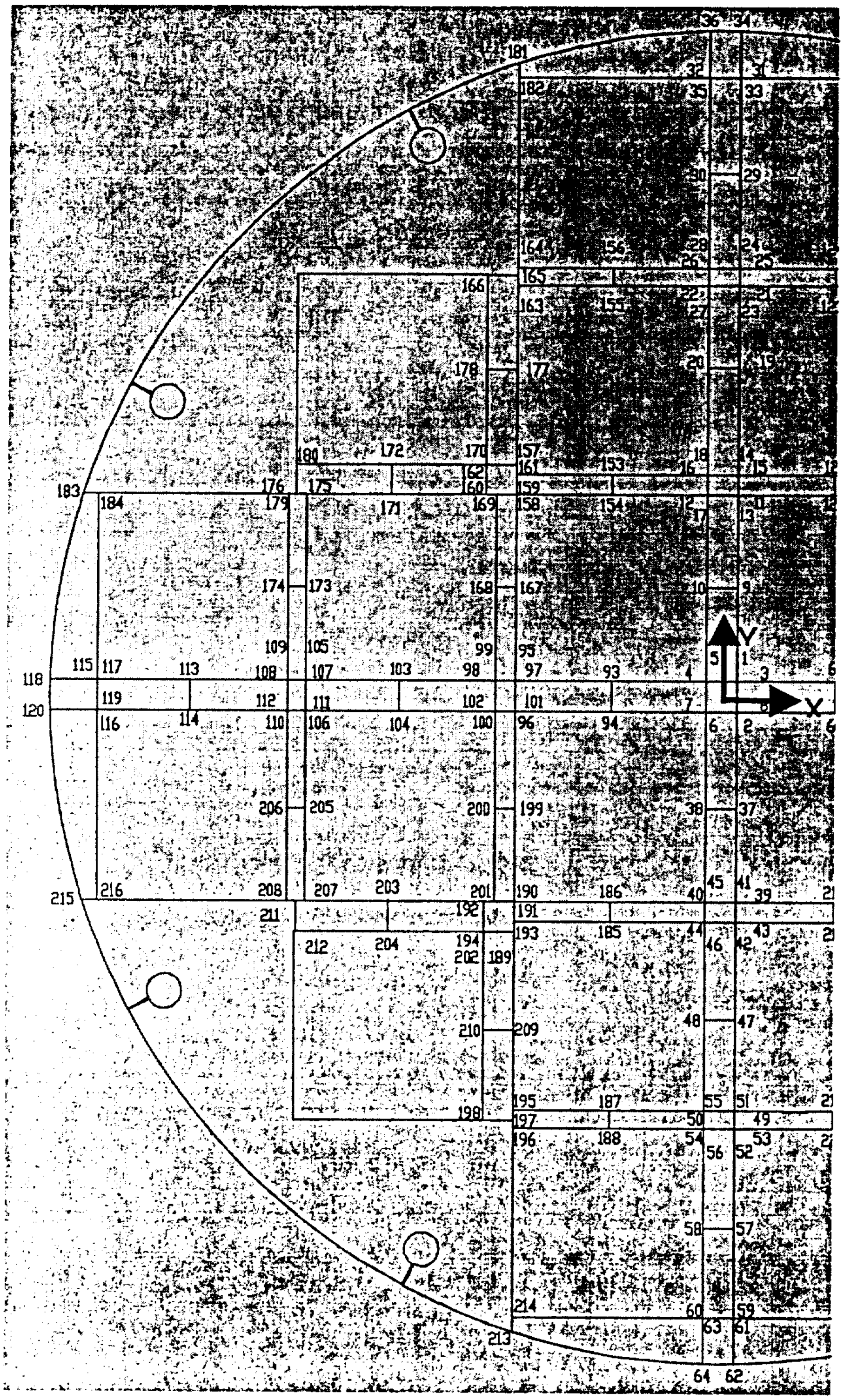


Figure 2.6.13.2-4 Location of the Section to Obtain Linearized Stresses (Right half of support disk)

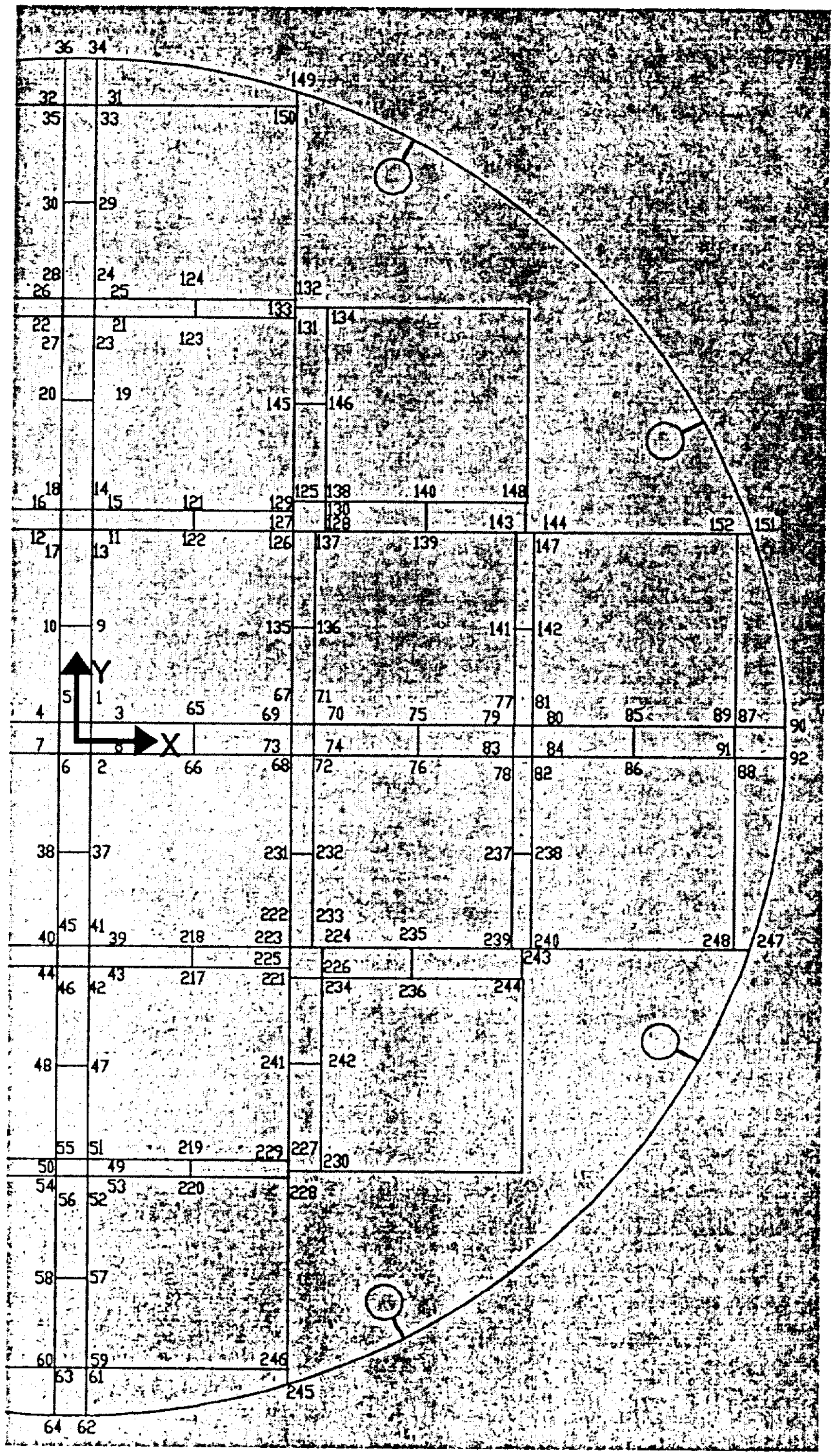


Table 2.6.13.2-1 Listing of Cross Sections for Stress Evaluation of Support Disk

Section & Line#	Point 1	Point 2	X 1	Y 1	X 2	Y 2
1	1	2	0.75	0.75	0.75	-0.75
2	3	4	0.75	0.75	-0.75	0.75
3	5	6	-0.75	0.75	-0.75	-0.75
4	7	8	-0.75	-0.75	0.75	-0.75
5	9	10	0.75	5.39	-0.75	5.39
6	11	12	0.75	10.02	-0.75	10.02
7	13	14	0.75	10.02	0.75	11.02
8	15	16	0.75	11.02	-0.75	11.02
9	17	18	-0.75	10.02	-0.75	11.02
10	19	20	0.75	15.66	-0.75	15.66
11	21	22	0.75	20.29	-0.75	20.29
12	23	24	0.75	20.29	0.75	21.17
13	25	26	0.75	21.17	-0.75	21.17
14	27	28	-0.75	20.29	-0.75	21.17
15	29	30	0.75	25.81	-0.75	25.81
16	31	32	0.75	30.44	-0.75	30.44
17	33	34	0.75	30.44	0.75	32.74
18	35	36	-0.75	30.44	-0.75	32.74
19	37	38	0.75	-5.39	-0.75	-5.39
20	39	40	0.75	-10.02	-0.75	-10.02
21	41	42	0.75	-10.02	0.75	-11.02
22	43	44	0.75	-11.02	-0.75	-11.02
23	45	46	-0.75	-10.02	-0.75	-11.02
24	47	48	0.75	-15.66	-0.75	-15.66
25	49	50	0.75	-20.29	-0.75	-20.29
26	51	52	0.75	-20.29	0.75	-21.17
27	53	54	0.75	-21.17	-0.75	-21.17
28	55	56	-0.75	-20.29	-0.75	-21.17
29	57	58	0.75	-25.81	-0.75	-25.81
30	59	60	0.75	-30.44	-0.75	-30.44
31	61	62	0.75	-30.44	0.75	-32.74
32	63	64	-0.75	-30.44	-0.75	-32.74
33	65	66	5.39	0.75	5.39	-0.75
34	67	68	10.02	0.75	10.02	-0.75
35	69	70	10.02	0.75	11.02	0.75
36	71	72	11.02	0.75	11.02	-0.75
37	73	74	10.02	-0.75	11.02	-0.75
38	75	76	15.66	0.75	15.66	-0.75
39	77	78	20.29	0.75	20.29	-0.75
40	79	80	20.29	0.75	21.17	0.75
41	81	82	21.17	0.75	21.17	-0.75

Table 2.6.13.2-1 Listing of Cross Sections for Stress Evaluation of Support Disk (Continued)

Section & Line#	Point 1	Point 2	X 1	Y 1	X 2	Y 2
42	83	84	20.29	-0.75	21.17	-0.75
43	85	86	25.81	0.75	25.81	-0.75
44	87	88	30.44	0.75	30.44	-0.75
45	89	90	30.44	0.75	32.74	0.75
46	91	92	30.44	-0.75	32.74	-0.75
47	93	94	-5.39	0.75	-5.39	-0.75
48	95	96	-10.02	0.75	-10.02	-0.75
49	97	98	-10.02	0.75	-11.02	0.75
50	99	100	-11.02	0.75	-11.02	-0.75
51	101	102	-10.02	-0.75	-11.02	-0.75
52	103	104	-15.66	0.75	-15.66	-0.75
53	105	106	-20.29	0.75	-20.29	-0.75
54	107	108	-20.29	0.75	-21.17	0.75
55	109	110	-21.17	0.75	-21.17	-0.75
56	111	112	-20.29	-0.75	-21.17	-0.75
57	113	114	-25.81	0.75	-25.81	-0.75
58	115	116	-30.44	0.75	-30.44	-0.75
59	117	118	-30.44	0.75	-32.74	0.75
60	119	120	-30.44	-0.75	-32.74	-0.75
61	121	122	5.39	11.02	5.39	10.02
62	123	124	5.39	20.29	5.39	21.17
63	125	126	10.02	11.02	10.02	10.02
64	127	128	10.02	10.02	11.02	10.02
65	129	130	10.02	11.52	11.52	11.52
66	131	132	10.02	20.29	10.02	21.17
67	133	134	10.02	20.29	11.52	20.29
68	135	136	10.02	5.39	11.02	5.39
69	137	138	11.52	10.02	11.52	11.52
70	139	140	16.16	10.02	16.16	11.52
71	141	142	20.29	5.39	21.17	5.39
72	143	144	20.29	10.02	21.17	10.02
73	145	146	10.02	16.16	11.52	16.16
74	147	148	20.29	10.02	20.29	11.52
75	149	150	10.02	31.18	10.02	30.44
76	151	152	31.18	10.02	30.44	10.02
77	153	154	-5.39	11.02	-5.39	10.02
78	155	156	-5.39	20.29	-5.39	21.17
79	157	158	-10.02	11.02	-10.02	10.02
80	159	160	-10.02	10.02	-11.02	10.02
81	161	162	-10.02	11.52	-11.52	11.52
82	163	164	-10.02	20.29	-10.02	21.17
83	165	166	-10.02	20.29	-11.52	20.29
84	167	168	-10.02	5.39	-11.02	5.39

Table 2.6.13.2-1 Listing of Cross Sections for Stress Evaluation of Support Disk (Continued)

Section & Line#	Point 1	Point 2	X 1	Y 1	X 2	Y 2
85	169	170	-11.52	10.02	-11.52	11.52
86	171	172	-16.16	10.02	-16.16	11.52
87	173	174	-20.29	5.39	-21.17	5.39
88	175	176	-20.29	10.02	-21.17	10.02
89	177	178	-10.02	16.16	-11.52	16.16
90	179	180	-20.29	10.02	-20.29	11.52
91	181	182	-10.02	31.18	-10.02	30.44
92	183	184	-31.18	10.02	-30.44	10.02
93	185	186	-5.39	-11.02	-5.39	-10.02
94	187	188	-5.39	-20.29	-5.39	-21.17
95	189	190	-10.02	-11.02	-10.02	-10.02
96	191	192	-10.02	-10.02	-11.02	-10.02
97	193	194	-10.02	-11.52	-11.52	-11.52
98	195	196	-10.02	-20.29	-10.02	-21.17
99	197	198	-10.02	-20.29	-11.52	-20.29
100	199	200	-10.02	-5.39	-11.02	-5.39
101	201	202	-11.52	-10.02	-11.52	-11.52
102	203	204	-16.16	-10.02	-16.16	-11.52
103	205	206	-20.29	-5.39	-21.17	-5.39
104	207	208	-20.29	-10.02	-21.17	-10.02
105	209	210	-10.02	-16.16	-11.52	-16.16
106	211	212	-20.29	-10.02	-20.29	-11.52
107	213	214	-10.02	-31.18	-10.02	-30.44
108	215	216	-31.18	-10.02	-30.44	-10.02
109	217	218	5.39	-11.02	5.39	-10.02
110	219	220	5.39	-20.29	5.39	-21.17
111	221	222	10.02	-11.02	10.02	-10.02
112	223	224	10.02	-10.02	11.02	-10.02
113	225	226	10.02	-11.52	11.52	-11.52
114	227	228	10.02	-20.29	10.02	-21.17
115	229	230	10.02	-20.29	11.52	-20.29
116	231	232	10.02	-5.39	11.02	-5.39
117	233	234	11.52	-10.02	11.52	-11.52
118	235	236	16.16	-10.02	16.16	-11.52
119	237	238	20.29	-5.39	21.17	-5.39
120	239	240	20.29	-10.02	21.17	-10.02
121	241	242	10.02	-16.16	11.52	-16.16
122	243	244	20.29	-10.02	20.29	-11.52
123	245	246	10.02	-31.18	10.02	-30.44
124	247	248	31.18	-10.02	30.44	-10.02

2.6.13.3 Thermal Conditions and Expansion Evaluation for PWR Support Disks

Three thermal conditions are considered when evaluating the PWR support disk evaluation.

Condition 1: 100°F ambient temperature with maximum decay heat load and maximum solar insolation.

Condition 2: -40°F ambient temperature with maximum decay heat load and no insolation.

Condition 3: -40°F ambient temperature, no decay heat load, and no solar insolation.

Temperatures of the support disk for each heat condition are as follows:

Heat Condition	T_{max} (°F)	T_{min} (°F)	ΔT (°F)
1	686	366	320
2	600	255	345
3	-40	-40	0

Two thermal cases (A and B) are considered in the analysis. As shown in the following table, Thermal case A bounds heat condition 1 (maximum temperature) and heat condition 2 (maximum temperature gradient) while thermal case B represents heat condition 3.

Thermal Case	Heat Condition	T_{max} (°F)	T_{min} (°F)	ΔT (°F)
A	1 & 2	686	341	345
B	3	-40	-40	0

The allowable stresses are calculated by using the temperature distribution based on the results of a steady-state conduction analysis performed by using temperature boundary conditions.

Temperatures are applied to the PWR support disk model to simulate worst-case temperature conditions. The maximum temperature is applied to the center of the support disk model and the minimum temperature is applied to the outer edge. A thermal conduction analysis (with all planar elements temporarily changed to ANSYS SHELL57 thermal elements) then determines the temperature distribution across the disk. The temperature data is then read back into the structural model so that material properties can be taken at temperature. For each basket angle, two analyses are prepared. The first run analyzes the support disk without thermal stresses and

the second run accounts for thermal stresses. Although thermal stress evaluations are not required for Level D conditions, combinations of impact and thermal stresses are calculated for both Level A and Level D as input to the buckling evaluations presented in Section 2.6.13.14.

The thermal stress at the outer radius of the basket is tension, whereas the interior thermal stress is compression. With the application of the primary loads, the area in contact with the shell is in compression, thus reducing the combined stresses. During the 1-ft drop impact, the support disk deflects so as to maximize the contact region with the canister. The result is tension stresses at the outer radius of the support disk and compression of the interior ligaments. For this reason, the primary + secondary stress intensity range evaluation is considered to envelope the evaluation for the thermal-stress-only condition.

2.6.13.4 Stress Evaluation of PWR Support Disks for 1-Foot End-Drop Load Condition

The support disks of the basket are located by eight tie rods with spacers. A structural analysis is performed by using ANSYS to evaluate the effect of a 1-ft end-drop impact that corresponds to the most severe out-of-plane loading. The finite element model described in Section 2.6.13.2 is used in conjunction with a 20 g deceleration.

The calculated values of maximum primary membrane and bending stresses for thermal cases A and B are provided in Tables 2.6.13.4-1 and 2.6.13.4-2. The membrane stresses for the 1-ft end drop conditions is effectively zero.

The maximum primary membrane plus bending stress intensity is 7.8 ksi (thermal case A), which results in a margin of safety of +7.44. The location of the top ten maximum primary membrane plus bending stresses, Thermal Case A, are presented in Figure 2.6.13.4-1.

Figure 2.6.13.4-1 Locations of Maximum P_m+P_b Stresses—1-Foot End Drop, Thermal Case A

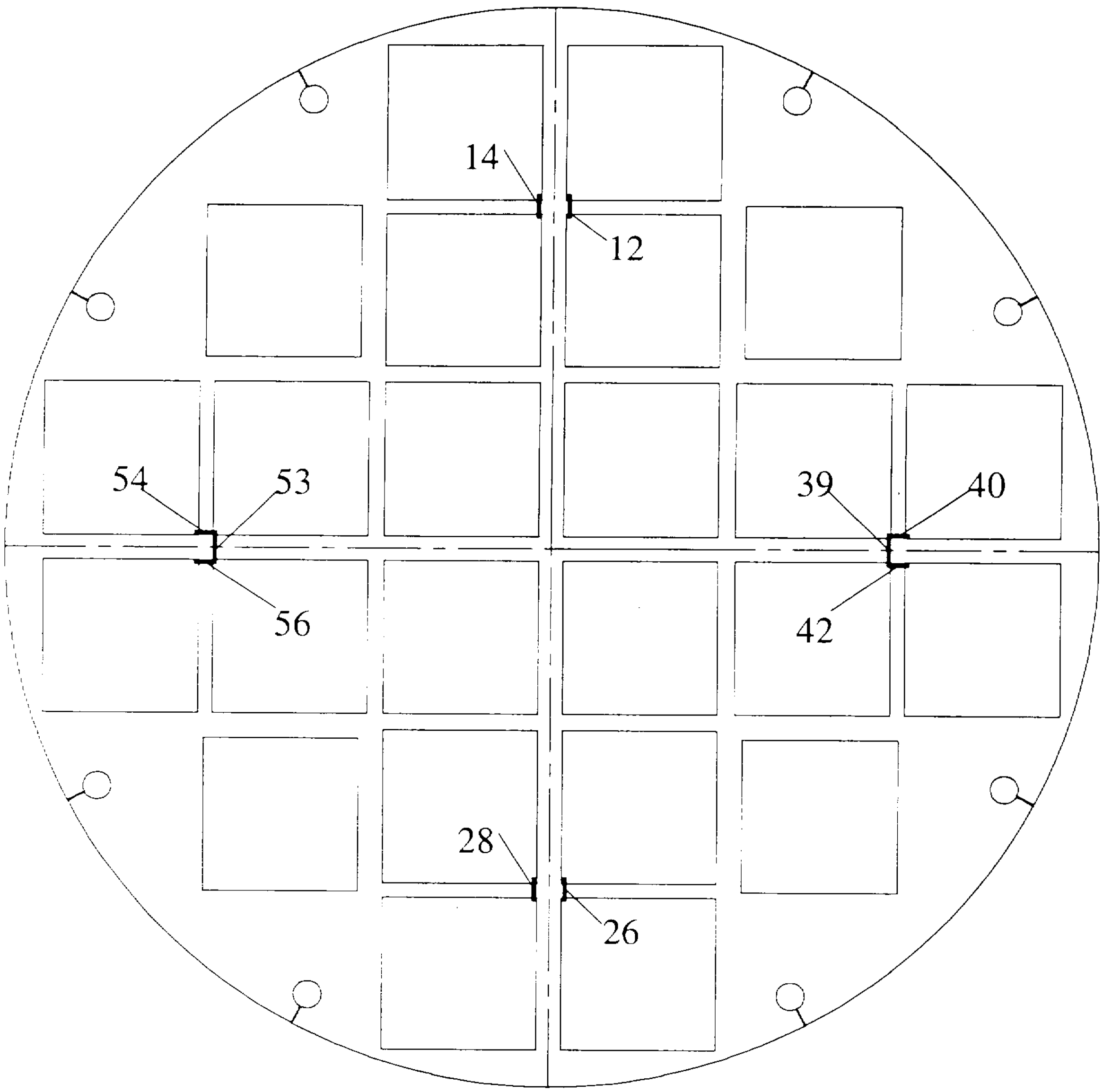


Table 2.6.13.4-1 $P_m + P_b$ Stresses for Support Disk—1-Foot End-Drop, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
40	2.0	-5.8	0.2	7.8	65.8	7.44
42	2.0	-5.8	-0.2	7.8	65.8	7.44
54	2.0	-5.8	-0.2	7.8	65.8	7.44
56	2.0	-5.8	0.2	7.8	65.8	7.44
12	-5.7	2.0	0.2	7.8	65.8	7.45
14	-5.7	2.0	-0.2	7.8	65.8	7.45
26	-5.7	2.0	-0.2	7.8	65.8	7.45
28	-5.7	2.0	0.2	7.8	65.8	7.45
39	2.6	-3.7	0.0	6.4	65.8	9.36
53	2.6	-3.7	0.0	6.4	65.8	9.36
11	-3.7	2.6	0.0	6.3	65.8	9.37
25	-3.7	2.6	0.0	6.3	65.8	9.37
67	1.7	5.1	2.3	6.2	66.4	9.63
83	1.7	5.1	-2.3	6.2	66.4	9.63
99	1.7	5.1	2.3	6.2	66.4	9.63
115	1.7	5.1	-2.3	6.2	66.4	9.63
74	5.0	1.6	2.3	6.2	66.4	9.73
106	5.0	1.6	2.3	6.2	66.4	9.73
90	5.0	1.6	-2.3	6.2	66.4	9.73
122	5.0	1.6	-2.3	6.2	66.4	9.73
55	2.2	-3.5	0.0	5.7	65.9	10.55
41	2.2	-3.5	0.0	5.7	65.9	10.55
27	-3.5	2.2	0.0	5.7	65.9	10.57
13	-3.5	2.2	0.0	5.7	65.9	10.57
82	3.4	3.2	-2.0	5.3	66.4	11.46
114	3.4	3.2	-2.0	5.3	66.4	11.46
98	3.4	3.2	2.0	5.3	66.4	11.46
66	3.4	3.2	2.0	5.3	66.4	11.46
72	3.2	3.4	2.0	5.3	66.4	11.52
104	3.2	3.4	2.0	5.3	66.4	11.52
120	3.2	3.4	-2.0	5.3	66.4	11.52
88	3.2	3.4	-2.0	5.3	66.4	11.52
5	0.0	-5.1	0.0	5.1	63.6	11.58
19	0.0	-5.1	0.0	5.1	63.6	11.58
33	-5.1	0.0	0.0	5.1	63.6	11.58
47	-5.1	0.0	0.0	5.1	63.6	11.58
2	-3.0	-4.9	0.0	4.9	63.0	11.91
4	-3.0	-4.9	0.0	4.9	63.0	11.91
3	-4.9	-3.0	0.0	4.9	63.0	11.92
1	-4.9	-3.0	0.0	4.9	63.0	11.92

Table 2.6.13.4-2 $P_m + P_b$ Stresses for Support Disk—1-Foot End-Drop, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
40	2.0	-5.8	0.2	7.8	67.5	7.67
42	2.0	-5.8	-0.2	7.8	67.5	7.67
54	2.0	-5.8	-0.2	7.8	67.5	7.67
56	2.0	-5.8	0.2	7.8	67.5	7.67
12	-5.8	2.0	0.2	7.8	67.5	7.68
14	-5.8	2.0	-0.2	7.8	67.5	7.68
26	-5.8	2.0	-0.2	7.8	67.5	7.68
28	-5.8	2.0	0.2	7.8	67.5	7.68
39	2.6	-3.7	0.0	6.3	67.5	9.69
53	2.6	-3.7	0.0	6.3	67.5	9.69
11	-3.7	2.6	0.0	6.3	67.5	9.70
25	-3.7	2.6	0.0	6.3	67.5	9.70
67	1.7	5.1	2.2	6.2	67.5	9.89
83	1.7	5.1	-2.2	6.2	67.5	9.89
99	1.7	5.1	2.2	6.2	67.5	9.89
115	1.7	5.1	-2.2	6.2	67.5	9.89
74	5.0	1.5	2.3	6.1	67.5	10.00
106	5.0	1.5	2.3	6.1	67.5	10.00
90	5.0	1.5	-2.3	6.1	67.5	10.00
122	5.0	1.5	-2.3	6.1	67.5	10.00
55	2.2	-3.5	0.0	5.7	67.5	10.86
41	2.2	-3.5	0.0	5.7	67.5	10.86
27	-3.5	2.2	0.0	5.7	67.5	10.89
13	-3.5	2.2	0.0	5.7	67.5	10.89
82	3.4	3.2	-2.0	5.3	67.5	11.76
114	3.4	3.2	-2.0	5.3	67.5	11.76
98	3.4	3.2	2.0	5.3	67.5	11.76
66	3.4	3.2	2.0	5.3	67.5	11.76
72	3.2	3.4	2.0	5.3	67.5	11.82
104	3.2	3.4	2.0	5.3	67.5	11.82
120	3.2	3.4	-2.0	5.3	67.5	11.82
88	3.2	3.4	-2.0	5.3	67.5	11.82
5	0.0	-5.2	0.0	5.2	67.5	11.95
19	0.0	-5.2	0.0	5.2	67.5	11.95
33	-5.2	0.0	0.0	5.2	67.5	11.96
47	-5.2	0.0	0.0	5.2	67.5	11.96
2	-3.1	-5.0	0.0	5.0	67.5	12.50
4	-3.1	-5.0	0.0	5.0	67.5	12.50
3	-5.0	-3.1	0.0	5.0	67.5	12.50
1	-5.0	-3.1	0.0	5.0	67.5	12.50

2.6.13.5 Stress Evaluation of PWR Support Disks for Combined Thermal and 1-Foot End Drop Conditions

The thermal expansion loading described in Section 2.6.13.3 are applied to the finite element model simultaneously with the 20 *g* end-drop loads described in Section 2.6.13.4 to produce a combined thermal expansion plus end-impact loading. The stress evaluation is performed according to the ASME Code, Section III, Subsection NG [15]. The stress intensity attains its maximum value at the surface of the extreme fiber.

Thermal case A is used for this evaluation. The top ten maximum sectional stress locations for the combined thermal and 1-ft end-drop condition are shown in Figure 2.6.13.5-1. The maximum stress intensity is 9.5 ksi and the $3S_m$ allowable limit at temperature for 17-4 PH [21] is 133.5 ksi, which results in a margin of safety of +13.07. Results of the combined thermal and 1-ft end-drop condition are presented in Table 2.6.13.5-1.

Figure 2.6.13.5-1 Locations of Maximum P+Q Stresses—1-Foot End Drop, Thermal Case A

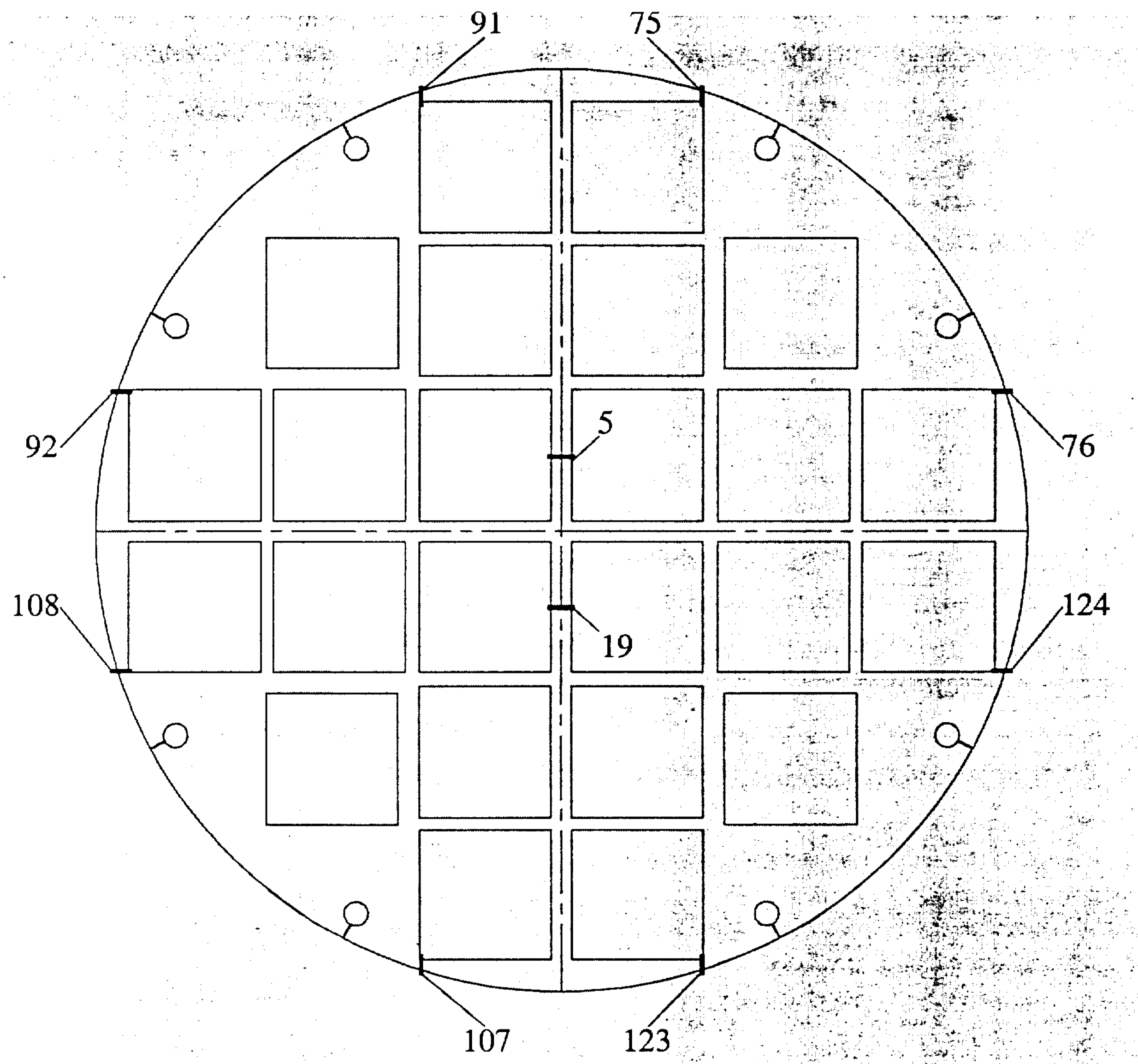


Table 2.6.13.5-1 $P_m + P_b + Q$ Stresses for Support Disk—1-Foot End-Drop, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
76	1.0	9.0	-2.0	9.5	133.5	13.07
92	1.0	9.0	2.0	9.5	133.5	13.07
108	1.0	9.0	-2.0	9.5	133.5	13.07
124	1.0	9.0	2.0	9.5	133.5	13.07
5	0.0	-8.9	0.0	8.9	127.3	13.23
19	0.0	-8.9	0.0	8.9	127.3	13.23
107	8.3	1.3	-3.0	9.4	133.5	13.25
91	8.3	1.3	3.0	9.4	133.5	13.25
123	8.3	1.3	3.0	9.4	133.5	13.25
75	8.3	1.3	-3.0	9.4	133.5	13.25
33	-8.9	0.0	0.0	8.9	127.3	13.26
47	-8.9	0.0	0.0	8.9	127.3	13.26
84	0.0	-9.1	-0.1	9.1	130.1	13.30
116	0.0	-9.1	-0.1	9.1	130.1	13.30
100	0.0	-9.1	0.1	9.1	130.1	13.30
68	0.0	-9.1	0.1	9.1	130.1	13.30
109	-9.1	0.0	-0.1	9.1	130.1	13.30
77	-9.1	0.0	-0.1	9.1	130.1	13.30
61	-9.1	0.0	0.1	9.1	130.1	13.30
93	-9.1	0.0	0.1	9.1	130.1	13.30
2	-4.9	-8.7	0.0	8.7	125.9	13.48
4	-4.9	-8.7	0.0	8.7	125.9	13.48
3	-8.7	-4.9	0.0	8.7	125.9	13.50
1	-8.7	-4.9	0.0	8.7	125.9	13.50
21	-8.3	-3.9	0.9	8.5	129.0	14.12
23	-8.3	-3.9	-0.9	8.5	129.0	14.12
9	-8.3	-3.9	0.9	8.5	129.0	14.12
7	-8.3	-3.9	-0.9	8.5	129.0	14.12
37	-3.9	-8.3	0.9	8.5	129.0	14.12
35	-3.9	-8.3	-0.9	8.5	129.0	14.12
49	-3.9	-8.3	0.9	8.5	129.0	14.12
51	-3.9	-8.3	-0.9	8.5	129.0	14.12
34	-5.5	-8.0	0.0	8.0	129.0	15.08
48	-5.5	-8.0	0.0	8.0	129.0	15.08
6	-8.0	-5.6	0.0	8.0	129.0	15.08
20	-8.0	-5.6	0.0	8.0	129.0	15.08
44	-1.7	-8.0	0.0	8.0	133.4	15.58
58	-1.7	-8.0	0.0	8.0	133.4	15.58
16	-8.0	-1.9	0.0	8.0	133.4	15.63
30	-8.0	-1.9	0.0	8.0	133.4	15.63

2.6.13.6 Stress Evaluation of PWR Support Disk for 1-Foot Side-Drop Load Conditions

To determine the structural adequacy of the PWR fuel basket support disk for the 1-ft side-drop impact load condition, a quasi-static impact load equal to the weight of the fuel and fuel tubes multiplied by a 20 *g* amplification factor is applied to the support disk structure. The inertial loading of the support disk is also included by means of the density input for the 17-4 PH stainless steel. The value of 20 *g* is conservative because the Universal Transport Cask impact limiter design deceleration for a 1-ft side-drop is 16.4 *g*. The fuel assembly load is transmitted in direct compression through the tube wall to the web structure of the support disk. A conservative number of disks is assumed to transmit the load to the canister shell (see Section 2.6.13.2). The maximum in-plane loading occurs in the side-drop, which requires a detailed structural evaluation. A finite element analysis is performed by using ANSYS and the finite element model described in Section 2.6.13.2.

2.6.13.6.1 Drop Orientations

For the side drop, pressure loads are applied to the ligament based on the impact angle. The PWR fuel assembly basket with 24 slots exhibits one-eighth symmetry. A minimum perimeter radial thickness occurs between the corner of the fuel assembly slot in the basket and the outer radius at four locations: 0°, 18.22°, 26.28°, and 45° measured counterclockwise from the Y-axis (see Fig. 2.6.13.6-1). Therefore, to ensure that the bounding basket orientation is evaluated, drop orientations of 0°, 18.22°, 26.28°, and 45° are considered. The material properties and stress allowables are taken at temperature for both thermal cases A and B.

2.6.13.6.2 Analysis Results for the 1-Foot Side-Drop

Finite element analyses are performed for the 1-ft side-drop load Conditions for the four different radial basket orientations (0°, 18.2°, 26.28°, and 45°) and for two thermal cases that would result in the use of different moduli of elasticity throughout the basket. Locations of maximum nodal SI stresses for the four orientations are shown in Figures 2.6.13.6-2 through 2.6.13.6-5.

For normal conditions of transport, the allowable stress limit for the support disk primary membrane stress (P_m) is S_m. For primary membrane + bending stress (P_m+P_b), the allowable stress is $1.5S_m$.

The cross sections with the 40 minimum margins of safety are presented in Tables 2.6.13.6-2 through 2.6.13.6-17. The tables are identified below:

Table Number	Basket Orientation (°)	Thermal Case	Stress Evaluation	Minimum Margin of Safety
2.6.13.6-2	0	A	P_m	+1.17
2.6.13.6-3	0	A	P_m+P_b	+0.53
2.6.13.6-4	0	B	P_m	+1.16
2.6.13.6-5	0	B	P_m+P_b	+0.50
2.6.13.6-6	18.22	A	P_m	+1.15
2.6.13.6-7	18.22	A	P_m+P_b	+0.27
2.6.13.6-8	18.22	B	P_m	+1.11
2.6.13.6-9	18.22	B	P_m+P_b	+0.31
2.6.13.6-10	26.28	A	P_m	+1.04
2.6.13.6-11	26.28	A	P_m+P_b	+0.40
2.6.13.6-12	26.28	B	P_m	+1.10
2.6.13.6-13	26.28	B	P_m+P_b	+0.41
2.6.13.6-14	45	A	P_m	+0.86
2.6.13.6-15	45	A	P_m+P_b	+0.22
2.6.13.6-16	45	B	P_m	+0.79
2.6.13.6-17	45	B	P_m+P_b	+0.19

The minimum margin of safety of +0.19 for the side-drop occurs in the 45°, Thermal Case B, no-thermal-stresses. This margin of safety is produced by a primary membrane plus bending stress of 56.9 ksi.

Figure 2.6.13.6-1 Support Disk Side-Drop Orientations

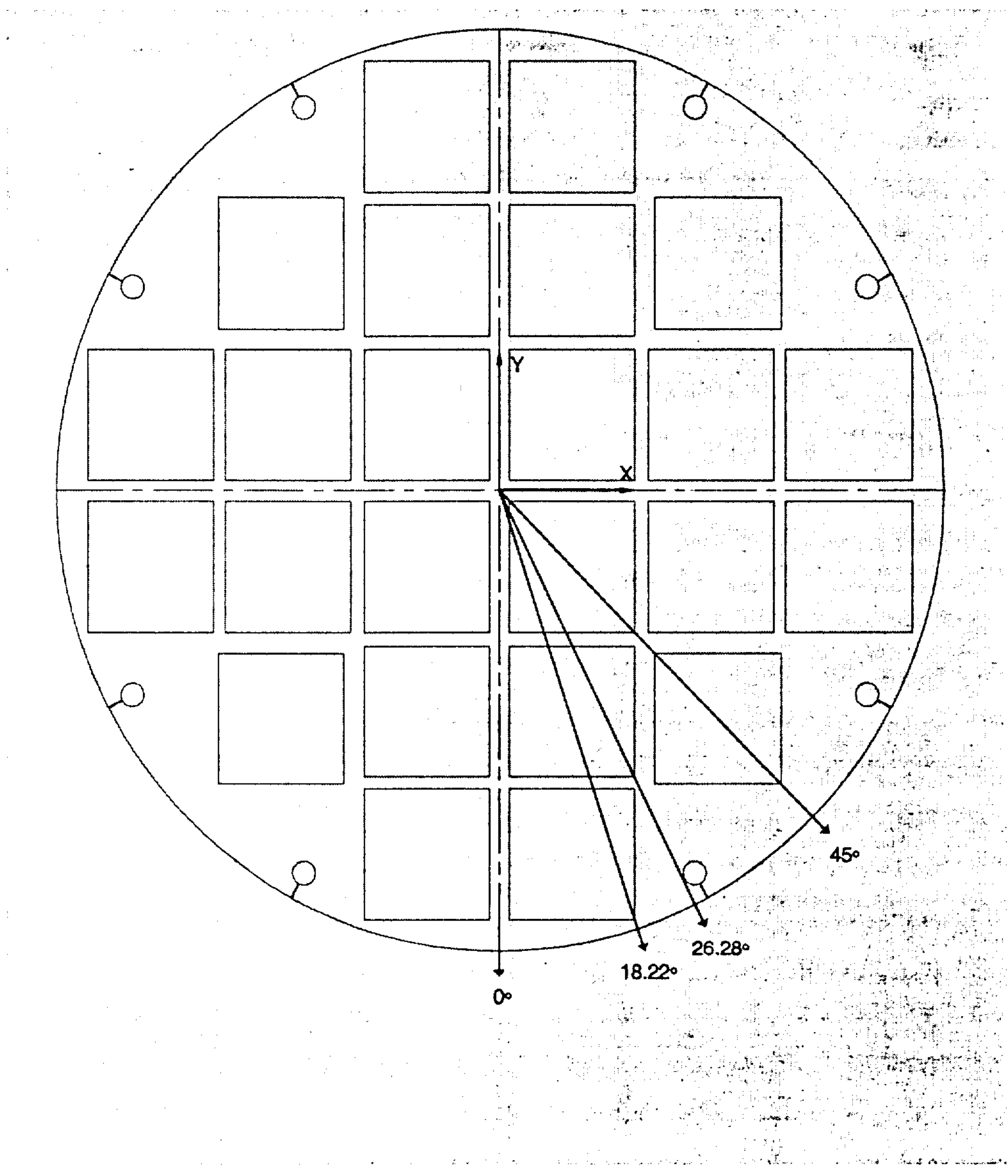


Figure 2.6.13.6-2 Locations of Maximum P_m+P_b Intensities—0° Side Drop Orientation, Thermal Case A

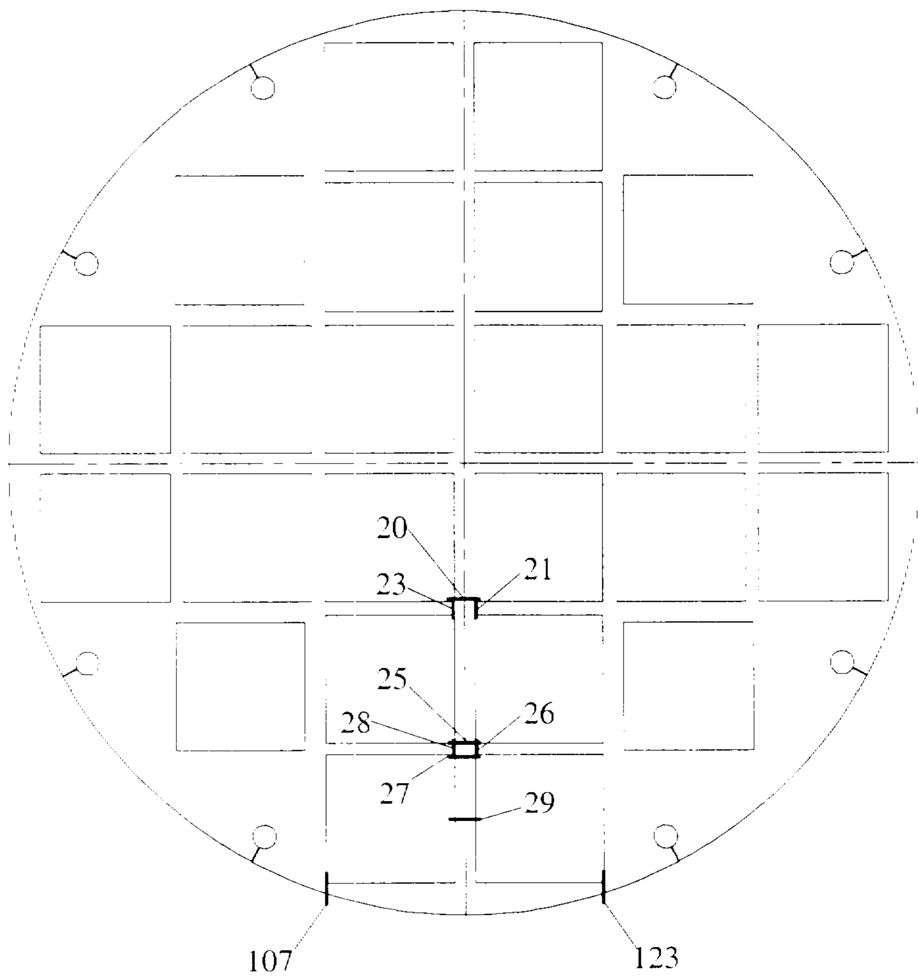


Figure 2.6.13.6-3 Locations of Maximum P_m+P_b Stresses—18.22° Side Drop Orientation, Thermal Case A

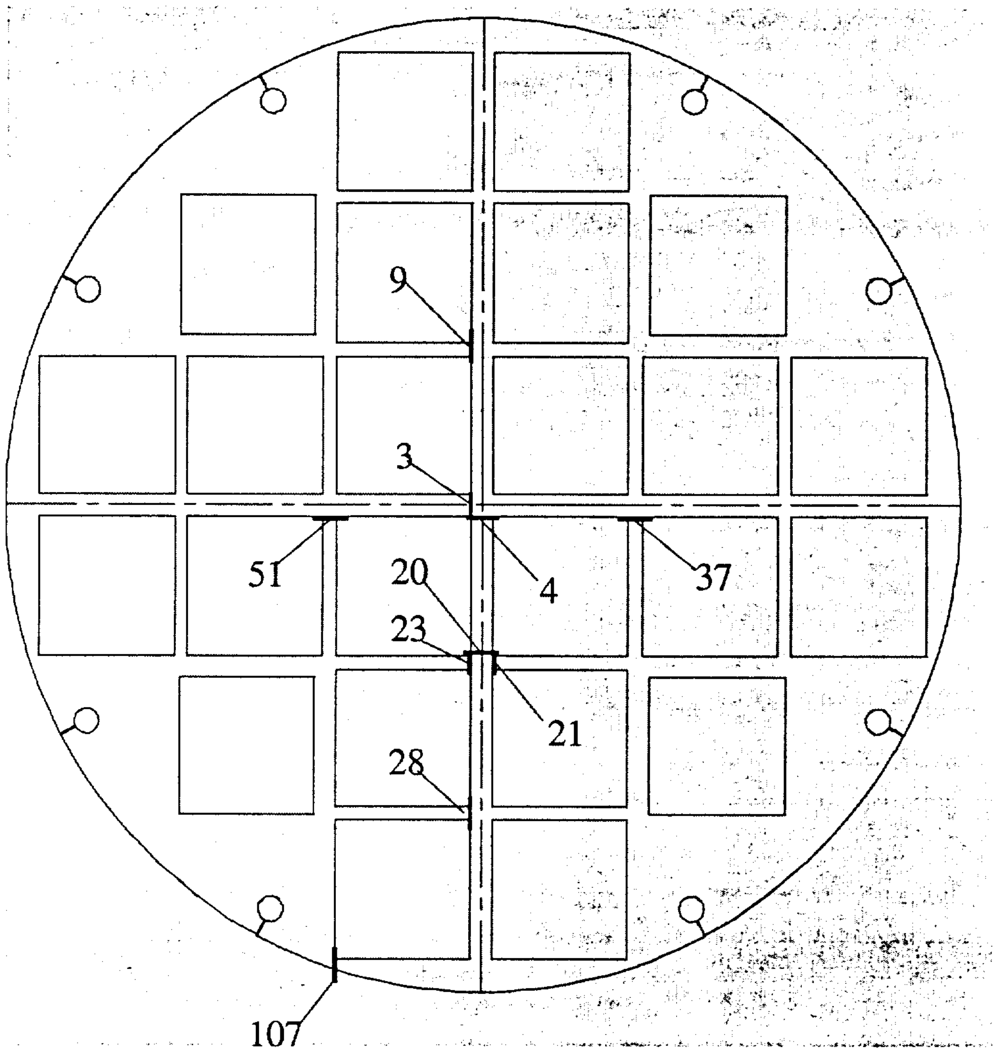


Figure 2.6.13.6-4 Locations of Maximum P_m+P_b Stresses—26.28° Side Drop Orientation, Thermal Case A

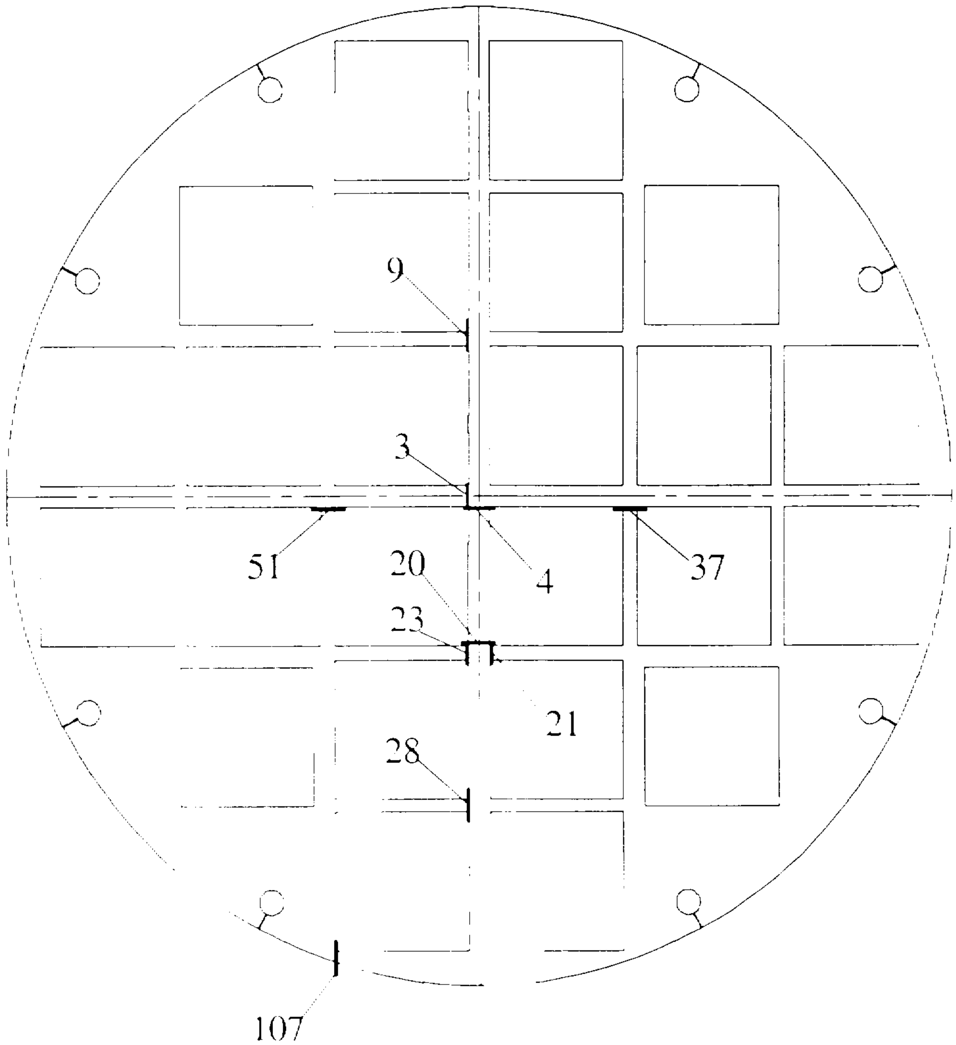
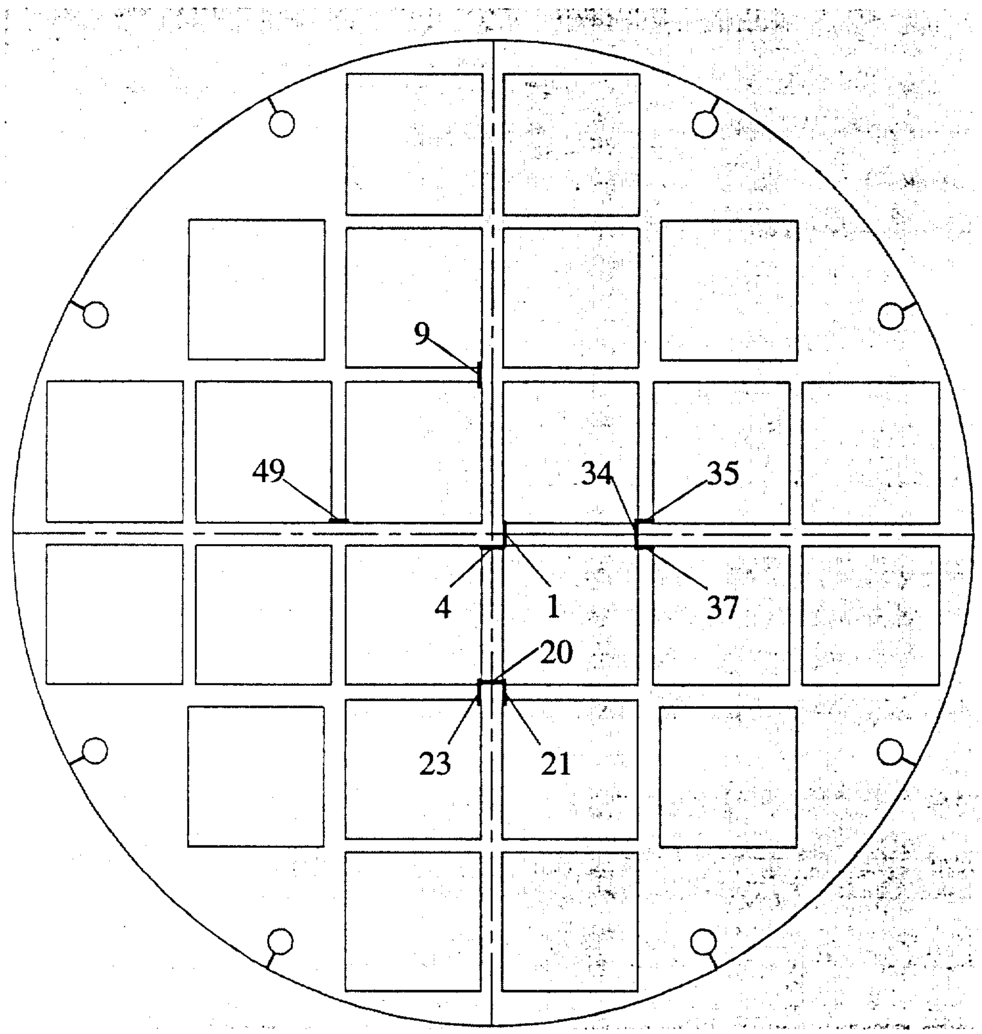


Figure 2.6.13.6-5 Locations of Maximum P_m+P_b Stresses—45° Side Drop Orientation, Thermal Case A



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FOR THE READER'S INFORMATION, TABLE 2.6.13.6-1 HAS BEEN DELETED

Table 2.6.13.6-2 P_m Stresses for Support Disk—1-Foot Side-Drop, 0° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
25	11.0	-9.2	0.0	20.2	43.9	1.17
107	-10.6	-13.2	8.1	20.1	44.5	1.21
123	-10.6	-13.2	-8.1	20.1	44.5	1.21
20	8.7	-7.3	0.0	16.0	43.0	1.70
29	0.0	-13.7	0.0	13.7	44.2	2.22
28	4.8	-6.9	3.2	13.4	43.9	2.28
26	4.8	-6.9	-3.2	13.4	43.9	2.28
27	-4.4	-12.5	0.0	12.5	43.9	2.51
2	6.1	-5.2	0.0	11.4	42.0	2.70
24	0.0	-11.4	0.0	11.4	43.5	2.81
22	-4.9	-10.4	0.0	10.4	43.1	3.16
21	2.8	-5.9	-2.6	10.1	43.0	3.25
23	2.8	-5.9	2.6	10.1	43.0	3.25
114	4.8	-5.3	-0.5	10.2	44.3	3.34
98	4.8	-5.3	0.5	10.2	44.3	3.34
30	-4.7	-9.6	0.0	9.6	44.5	3.63
19	0.0	-9.1	0.0	9.1	42.4	3.67
8	5.5	-3.1	0.0	8.6	43.1	3.99
4	-6.4	-7.9	0.0	7.9	42.0	4.30
31	-6.7	-6.2	1.7	8.2	44.5	4.45
32	-6.7	-6.2	-1.7	8.2	44.5	4.45
115	2.7	-5.2	-0.5	7.9	44.3	4.60
99	2.7	-5.2	0.5	7.9	44.3	4.60
112	2.7	-4.4	0.0	7.1	43.7	5.13
96	2.7	-4.4	0.0	7.1	43.7	5.13
95	2.5	-4.4	-0.2	6.9	43.7	5.32
111	2.5	-4.4	0.2	6.9	43.7	5.32
11	-6.9	-4.0	0.0	6.9	43.9	5.32
13	5.3	-1.3	0.0	6.6	43.9	5.64
6	-6.4	-5.9	0.0	6.4	43.0	5.74
5	0.0	-6.3	0.0	6.3	42.4	5.77
1	0.3	-4.5	-1.9	6.1	42.0	5.89
3	0.3	-4.5	1.9	6.1	42.0	5.89
110	6.2	-0.1	0.1	6.3	44.1	5.96
94	6.2	-0.1	-0.1	6.3	44.1	5.96
116	0.0	-6.1	0.0	6.1	43.4	6.16
100	0.0	-6.1	0.0	6.1	43.4	6.16
121	0.0	-5.9	-0.1	5.9	44.0	6.47
105	0.0	-5.9	0.1	5.9	44.0	6.47
7	-0.6	-3.2	-2.3	5.3	43.0	7.09

Table 2.6.13.6-3 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 0° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-23.6	-30.9	15.9	43.6	66.8	0.53
123	-23.6	-30.9	-15.9	43.6	66.8	0.53
25	11.0	-9.2	-1.1	20.3	65.8	2.24
26	15.5	-3.5	-2.4	19.6	65.8	2.36
28	15.5	-3.5	2.4	19.6	65.8	2.36
20	8.7	-7.3	-0.7	16.0	64.5	3.03
23	12.0	-2.9	1.7	15.2	64.5	3.23
21	12.0	-2.9	-1.7	15.2	64.5	3.23
27	-4.4	-12.5	-3.2	13.7	65.9	3.82
29	0.0	-13.7	0.0	13.7	66.3	3.83
114	7.1	-5.5	-0.3	12.6	66.4	4.29
98	7.1	-5.5	0.3	12.6	66.4	4.29
2	6.1	-5.2	-0.8	11.5	63.0	4.50
22	-4.9	-10.4	-3.0	11.7	64.6	4.52
30	-4.7	-9.6	4.2	12.0	66.7	4.54
1	8.9	-1.9	-1.0	11.1	63.0	4.70
3	8.9	-1.9	1.0	11.1	63.0	4.70
24	0.0	-11.4	0.0	11.4	65.2	4.72
14	-9.6	-4.7	3.1	11.1	65.8	4.91
12	-9.6	-4.7	-3.1	11.1	65.8	4.91
4	-6.4	-7.9	3.3	10.6	63.0	4.96
94	10.9	0.6	-0.1	10.9	66.1	5.07
110	10.9	0.6	0.1	10.9	66.1	5.07
9	-8.6	-5.9	3.1	10.6	64.5	5.07
7	-8.6	-5.9	-3.1	10.6	64.5	5.07
75	6.7	6.8	-3.6	10.4	66.8	5.44
91	6.7	6.8	3.6	10.4	66.8	5.44
31	-4.9	-7.9	3.3	10.0	66.7	5.65
32	-4.9	-7.9	-3.3	10.0	66.7	5.65
19	0.0	-9.1	0.0	9.1	63.6	6.01
8	5.5	-3.1	-0.9	8.8	64.6	6.35
6	-6.4	-5.9	-2.5	8.7	64.5	6.44
17	8.9	1.4	-0.7	9.0	66.7	6.45
18	8.9	1.4	0.7	9.0	66.7	6.45
115	2.2	-6.4	-0.6	8.7	66.4	6.63
99	2.2	-6.4	0.6	8.7	66.4	6.63
11	-6.9	-4.0	-2.4	8.3	65.8	6.96
37	-1.7	-7.8	-1.2	8.1	64.5	6.99
51	-1.7	-7.8	1.2	8.1	64.5	6.99
113	-2.6	-7.1	-1.4	7.5	65.6	7.79

Table 2.6.13.6-4 P_m Stresses for Support Disk—1-Foot Side-Drop, 0° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
25	11.3	-9.5	0.0	20.8	45.0	1.16
107	-10.3	-13.3	8.3	20.2	45.0	1.22
123	-10.3	-13.3	-8.3	20.2	45.0	1.22
20	9.0	-7.5	0.0	16.5	45.0	1.73
29	0.0	-14.1	0.0	14.1	45.0	2.18
28	4.9	-7.2	3.3	13.7	45.0	2.28
26	4.9	-7.2	-3.3	13.7	45.0	2.28
27	-4.6	-12.9	0.0	12.9	45.0	2.49
2	6.7	-5.4	0.0	12.0	45.0	2.74
24	0.0	-11.8	0.0	11.8	45.0	2.83
22	-5.2	-10.7	0.0	10.7	45.0	3.20
21	2.8	-6.1	-2.7	10.4	45.0	3.33
23	2.8	-6.1	2.7	10.4	45.0	3.33
114	4.9	-5.2	-0.6	10.2	45.0	3.43
98	4.9	-5.2	0.6	10.2	45.0	3.43
30	-4.6	-9.8	0.0	9.8	45.0	3.57
19	0.0	-9.4	0.0	9.4	45.0	3.79
8	5.8	-3.2	0.0	9.0	45.0	4.01
31	-6.7	-6.3	1.7	8.3	45.0	4.44
32	-6.7	-6.3	-1.7	8.3	45.0	4.44
4	-7.0	-8.2	0.0	8.2	45.0	4.48
115	2.6	-5.1	-0.5	7.7	45.0	4.85
99	2.6	-5.1	0.5	7.7	45.0	4.85
11	-7.2	-4.2	0.0	7.2	45.0	5.28
13	5.5	-1.3	0.0	6.8	45.0	5.57
111	2.5	-4.3	0.2	6.8	45.0	5.61
95	2.5	-4.3	-0.2	6.8	45.0	5.61
112	2.5	-4.3	0.0	6.8	45.0	5.63
96	2.5	-4.3	0.0	6.8	45.0	5.63
6	-6.7	-6.0	0.0	6.7	45.0	5.74
5	0.0	-6.4	0.0	6.4	45.0	5.98
110	6.3	-0.1	0.1	6.4	45.0	6.01
94	6.3	-0.1	-0.1	6.4	45.0	6.01
1	0.2	-4.6	-2.1	6.4	45.0	6.05
3	0.2	-4.6	2.1	6.4	45.0	6.05
116	0.0	-5.9	0.0	5.9	45.0	6.66
100	0.0	-5.9	0.0	5.9	45.0	6.66
121	0.0	-5.7	-0.1	5.7	45.0	6.84
105	0.0	-5.7	0.1	5.7	45.0	6.84
7	-0.6	-3.3	-2.4	5.5	45.0	7.12

Table 2.6.13.6-5 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 0° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-24.1	-31.9	16.5	44.9	67.5	0.50
123	-24.1	-31.9	-16.5	44.9	67.5	0.50
25	11.3	-9.5	-1.2	20.9	67.5	2.22
26	15.9	-3.6	-2.5	20.2	67.5	2.34
28	15.9	-3.6	2.5	20.2	67.5	2.34
20	9.0	-7.5	-0.8	16.6	67.5	3.07
23	12.4	-3.0	1.8	15.8	67.5	3.27
21	12.4	-3.0	-1.8	15.8	67.5	3.27
29	0.0	-14.1	0.0	14.1	67.5	3.78
27	-4.6	-12.9	-3.4	14.1	67.5	3.79
114	7.5	-5.2	-0.5	12.7	67.5	4.30
98	7.5	-5.2	0.5	12.7	67.5	4.30
30	-4.6	-9.8	4.3	12.3	67.5	4.50
22	-5.2	-10.7	-3.2	12.2	67.5	4.55
2	6.7	-5.4	-0.9	12.1	67.5	4.56
1	9.7	-1.9	-1.1	11.8	67.5	4.71
3	9.7	-1.9	1.1	11.8	67.5	4.71
24	0.0	-11.8	0.0	11.8	67.5	4.74
14	-9.9	-4.9	3.2	11.5	67.5	4.86
12	-9.9	-4.9	-3.2	11.5	67.5	4.86
4	-7.0	-8.2	3.5	11.1	67.5	5.06
9	-9.1	-6.1	3.2	11.1	67.5	5.07
7	-9.1	-6.1	-3.2	11.1	67.5	5.07
94	11.0	0.6	-0.1	11.0	67.5	5.14
110	11.0	0.6	0.1	11.0	67.5	5.14
75	7.1	7.2	-3.8	11.0	67.5	5.16
91	7.1	7.2	3.8	11.0	67.5	5.16
31	-4.7	-8.1	3.4	10.2	67.5	5.62
32	-4.7	-8.1	-3.4	10.2	67.5	5.62
18	9.4	1.5	0.8	9.4	67.5	6.15
17	9.4	1.5	-0.8	9.4	67.5	6.15
19	0.0	-9.4	0.0	9.4	67.5	6.19
8	5.8	-3.2	-0.9	9.2	67.5	6.36
6	-6.7	-6.0	-2.6	9.0	67.5	6.49
11	-7.2	-4.2	-2.4	8.5	67.5	6.91
115	2.0	-6.3	-0.6	8.4	67.5	7.00
99	2.0	-6.3	0.6	8.4	67.5	7.00
37	-1.6	-7.9	-1.2	8.1	67.5	7.31
51	-1.6	-7.9	1.2	8.1	67.5	7.31
113	-2.5	-7.0	-1.3	7.4	67.5	8.10

Table 2.6.13.6-6 P_m Stresses for Support Disk—1-Foot Side-Drop, 18.22° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
112	11.6	-7.8	3.0	20.3	43.7	1.15
35	11.4	-4.8	3.1	17.3	43.0	1.48
107	0.6	-6.7	7.3	16.4	44.5	1.72
37	-12.4	-10.1	3.3	14.8	43.0	1.92
120	6.7	-6.9	3.4	15.2	44.3	1.92
23	2.6	1.8	6.8	13.7	43.0	2.13
9	-1.0	-7.9	5.9	13.6	43.0	2.17
114	-3.8	2.8	6.0	13.6	44.3	2.25
51	11.8	1.8	3.9	13.2	43.0	2.27
28	-3.4	-2.9	6.6	13.3	43.9	2.30
21	-0.3	-11.3	3.0	12.5	43.0	2.44
49	-11.0	-1.2	3.7	12.3	43.0	2.50
116	0.0	-12.3	0.0	12.3	43.4	2.53
115	3.4	-7.8	2.5	12.2	44.3	2.62
64	-11.3	-6.4	1.9	11.9	43.7	2.67
20	5.6	-5.8	0.7	11.5	43.0	2.73
98	-3.9	-8.7	4.9	11.8	44.3	2.76
14	0.5	-1.2	5.6	11.3	43.9	2.88
31	-4.3	-10.9	1.8	11.3	44.5	2.92
63	0.6	-6.1	4.4	11.0	43.7	2.96
29	0.0	-11.0	0.7	11.0	44.2	3.00
95	2.0	-5.4	4.0	10.9	43.7	3.03
121	-0.4	-10.8	0.8	10.9	44.0	3.04
27	-8.1	-9.9	-1.5	10.8	43.9	3.08
113	-5.6	-10.1	1.4	10.5	43.8	3.17
25	2.9	-7.4	-0.1	10.4	43.9	3.24
66	-1.1	-4.3	4.9	10.3	44.3	3.29
26	-4.1	-9.5	2.0	10.2	43.9	3.32
123	-9.7	-0.7	-2.2	10.2	44.5	3.37
96	-7.9	-0.1	3.1	10.0	43.7	3.38
111	-0.4	-3.3	4.8	10.0	43.7	3.39
22	-4.1	-8.2	-2.6	9.4	43.1	3.57
2	4.3	-4.1	1.4	8.9	42.0	3.74
24	0.0	-9.1	0.6	9.1	43.5	3.77
119	0.0	-9.0	-0.2	9.0	44.1	3.91
36	0.2	-4.7	-3.6	8.8	43.1	3.92
80	8.2	0.7	2.3	8.9	43.7	3.92
82	0.8	4.7	3.9	8.7	44.3	4.09
40	2.9	-5.0	1.6	8.5	43.9	4.18
3	0.3	-4.6	3.1	7.9	42.0	4.33

Table 2.6.13.6-7 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 18.22° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-28.5	-37.9	18.7	52.4	66.8	0.27
23	36.6	21.3	8.0	40.0	64.5	0.61
4	-28.2	-34.0	4.3	36.3	63.0	0.74
3	-31.2	-30.3	4.0	34.8	63.0	0.81
9	-29.7	-24.4	8.0	35.4	64.5	0.82
37	-23.8	-29.1	8.2	35.0	64.5	0.84
28	-31.7	-17.3	7.6	35.0	65.8	0.88
20	32.7	18.8	1.1	32.8	64.5	0.97
51	25.2	23.9	7.3	31.9	64.5	1.02
21	-21.1	-26.4	5.9	30.2	64.5	1.14
49	-24.2	-21.6	6.8	29.8	64.5	1.17
2	-19.1	-28.3	0.9	28.4	63.0	1.22
34	-25.3	-25.7	3.4	28.9	64.5	1.23
6	-26.8	-25.2	2.4	28.5	64.5	1.26
48	27.7	22.6	2.0	28.4	64.5	1.27
111	-27.1	-19.1	4.0	28.8	65.5	1.28
30	-7.5	-27.5	5.7	29.0	66.7	1.30
98	-23.1	-16.5	8.2	28.6	66.4	1.32
95	-23.3	-21.1	5.8	28.1	65.5	1.33
22	-27.6	-16.6	-0.1	27.6	64.6	1.34
96	-23.8	-20.1	5.6	27.8	65.5	1.36
27	-26.8	-16.8	2.0	27.2	65.9	1.42
63	-22.5	-19.0	6.0	27.0	65.5	1.43
112	25.6	8.9	5.0	26.9	65.5	1.43
64	-22.2	-19.1	5.7	26.6	65.5	1.47
91	14.5	20.3	9.1	26.9	66.8	1.48
14	24.1	10.9	5.5	26.1	65.8	1.52
35	22.6	12.5	5.7	25.2	64.5	1.56
1	-19.4	-24.4	0.7	24.4	63.0	1.57
8	24.1	4.6	-1.3	24.2	64.6	1.67
115	-7.1	-24.6	-0.8	24.6	66.4	1.70
114	-23.3	-5.3	4.7	24.4	66.4	1.72
99	-19.8	-15.8	6.2	24.4	66.4	1.72
79	20.5	16.5	4.8	23.7	65.5	1.76
113	-16.0	-23.0	1.6	23.4	65.6	1.81
36	4.0	-18.2	-2.7	22.9	64.6	1.82
80	20.3	15.8	4.6	23.2	65.5	1.83
26	-17.5	-18.9	4.7	23.0	65.8	1.87
25	-16.9	-22.8	0.2	22.8	65.8	1.88
50	2.5	-17.7	-3.3	21.3	64.6	2.03

Table 2.6.13.6-8 P_m Stresses for Support Disk—1-Foot Side-Drop, 18.22° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
112	12.3	-8.2	3.0	21.3	45.0	1.11
35	12.1	-5.1	3.1	18.3	45.0	1.46
37	-13.2	-10.7	3.4	15.5	45.0	1.90
107	0.5	-6.3	7.0	15.5	45.0	1.91
120	6.3	-6.7	3.2	14.5	45.0	2.09
23	2.7	1.7	7.1	14.2	45.0	2.18
51	12.7	2.2	4.0	14.1	45.0	2.20
9	-1.1	-8.0	6.1	13.9	45.0	2.23
28	-3.3	-3.3	6.9	13.7	45.0	2.28
114	-3.7	2.2	6.2	13.7	45.0	2.29
49	-11.9	-1.1	3.8	13.1	45.0	2.42
115	3.8	-8.2	2.4	13.0	45.0	2.47
116	0.0	-12.9	0.0	12.9	45.0	2.48
21	-0.3	-11.4	3.1	12.8	45.0	2.52
64	-11.8	-6.8	1.8	12.4	45.0	2.64
31	-4.4	-11.4	1.8	11.8	45.0	2.81
20	5.8	-5.9	0.7	11.8	45.0	2.81
98	-3.9	-8.4	5.2	11.8	45.0	2.83
14	0.4	-1.2	5.7	11.6	45.0	2.88
121	-0.4	-11.4	0.8	11.5	45.0	2.93
63	0.6	-6.1	4.6	11.3	45.0	2.98
29	0.0	-11.2	0.7	11.2	45.0	3.01
113	-6.0	-10.7	1.4	11.1	45.0	3.07
95	2.2	-4.9	4.2	11.0	45.0	3.11
27	-8.0	-10.1	-1.5	10.8	45.0	3.15
96	-8.5	0.1	3.1	10.6	45.0	3.24
25	3.0	-7.6	-0.2	10.6	45.0	3.26
111	-0.4	-4.0	5.0	10.5	45.0	3.28
66	-1.1	-4.3	5.0	10.5	45.0	3.29
123	-9.8	-0.7	-2.2	10.3	45.0	3.36
26	-4.0	-9.3	2.2	10.1	45.0	3.46
22	-4.2	-8.3	-2.6	9.6	45.0	3.69
80	8.7	0.9	2.3	9.3	45.0	3.82
24	0.0	-9.2	0.6	9.3	45.0	3.85
36	0.2	-5.0	-3.8	9.2	45.0	3.88
2	4.5	-4.2	1.5	9.2	45.0	3.91
82	0.8	4.8	4.0	9.0	45.0	3.99
119	0.0	-8.7	-0.2	8.7	45.0	4.17
79	-0.6	4.0	3.5	8.4	45.0	4.36
30	-1.0	-7.4	2.6	8.3	45.0	4.39

Table 2.6.13.6-9 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 18.22° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-29.1	-37.1	18.2	51.7	67.5	0.31
23	37.8	22.0	8.2	41.3	67.5	0.63
4	-29.7	-35.6	4.5	38.0	67.5	0.78
9	-30.8	-25.1	8.2	36.7	67.5	0.84
3	-32.9	-31.8	4.2	36.5	67.5	0.85
28	-32.7	-18.2	7.9	36.2	67.5	0.87
37	-24.7	-29.7	8.5	36.0	67.5	0.87
20	33.8	19.3	1.1	33.9	67.5	0.99
51	26.3	24.8	7.7	33.3	67.5	1.03
21	-22.0	-27.1	6.1	31.1	67.5	1.17
49	-25.2	-21.9	7.1	30.8	67.5	1.19
30	-7.7	-29.0	5.9	30.5	67.5	1.21
111	-28.0	-20.0	4.3	29.9	67.5	1.26
34	-26.3	-26.3	3.6	29.9	67.5	1.26
2	-20.1	-29.7	0.9	29.8	67.5	1.26
48	29.0	23.3	2.2	29.8	67.5	1.27
6	-27.8	-25.9	2.4	29.4	67.5	1.29
98	-23.9	-16.5	8.4	29.3	67.5	1.30
95	28.5	11.2	2.4	28.8	67.5	1.34
22	-28.6	-17.3	-0.1	28.6	67.5	1.36
96	-24.5	-19.8	5.7	28.3	67.5	1.39
27	-27.8	-17.7	2.1	28.2	67.5	1.40
91	15.0	20.9	9.4	27.8	67.5	1.43
63	-23.1	-19.1	6.2	27.6	67.5	1.45
112	26.3	8.3	5.0	27.6	67.5	1.45
64	-22.8	-19.3	5.8	27.1	67.5	1.49
14	24.8	11.2	5.7	26.8	67.5	1.52
35	23.4	12.3	5.9	26.0	67.5	1.60
1	-20.5	-25.6	0.7	25.7	67.5	1.63
114	-23.9	-6.2	4.9	25.2	67.5	1.68
8	25.0	5.0	-1.4	25.1	67.5	1.69
115	-7.0	-25.0	-1.0	25.0	67.5	1.70
99	-20.5	-15.6	6.3	24.9	67.5	1.72
79	21.2	16.8	5.0	24.5	67.5	1.76
113	-16.4	-23.8	1.8	24.3	67.5	1.78
36	5.0	-18.4	-2.8	24.1	67.5	1.81
80	21.1	16.0	4.7	23.9	67.5	1.83
25	23.7	8.0	-0.5	23.7	67.5	1.85
26	-18.2	-19.2	4.8	23.6	67.5	1.86
50	3.4	-17.7	-3.6	22.3	67.5	2.03

Table 2.6.13.6-10 P_m Stresses for Support Disk—1-Foot Side-Drop, 26.28° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
120	9.4	-9.2	5.6	21.7	44.3	1.04
112	10.0	-7.2	4.4	19.3	43.7	1.26
114	-6.7	6.9	6.8	19.3	44.3	1.30
35	12.6	-3.5	4.5	18.5	43.0	1.33
37	-13.5	-9.2	5.0	16.8	43.0	1.57
21	-3.2	-14.8	4.3	16.2	43.0	1.66
23	1.4	6.2	7.7	16.1	43.0	1.67
9	-0.9	-9.9	6.5	15.8	43.0	1.72
51	13.7	2.9	5.1	15.7	43.0	1.74
49	-12.7	-0.8	4.7	15.2	43.0	1.83
28	-6.1	-1.6	6.8	14.4	43.9	2.06
96	-10.2	0.9	4.5	14.2	43.7	2.07
98	-6.7	-9.9	5.4	13.9	44.3	2.19
63	0.9	-7.6	5.0	13.2	43.7	2.31
64	-11.8	-5.3	2.8	12.9	43.7	2.40
95	0.2	-8.0	4.7	12.6	43.7	2.48
40	3.9	-7.2	2.7	12.4	43.9	2.54
66	-0.8	-5.7	5.7	12.4	44.3	2.58
119	0.0	-12.1	-0.3	12.1	44.1	2.65
14	1.2	-0.9	5.8	11.8	43.9	2.72
107	2.6	-4.4	4.9	12.0	44.5	2.72
26	-7.1	-9.8	2.8	11.5	43.9	2.81
111	-2.4	1.2	5.4	11.4	43.7	2.84
42	-5.6	-9.4	3.2	11.2	43.9	2.90
116	0.0	-11.1	0.0	11.1	43.4	2.91
31	-3.2	-11.0	1.6	11.3	44.5	2.92
80	9.8	1.2	3.1	10.8	43.7	3.06
27	-9.3	-8.6	-1.8	10.8	43.9	3.07
115	1.9	-6.5	3.4	10.9	44.3	3.08
72	-8.7	-7.6	2.4	10.6	44.3	3.16
104	-5.6	-0.1	4.5	10.6	44.3	3.18
79	0.0	6.4	4.0	10.2	43.7	3.28
22	-4.9	-7.1	-3.8	9.9	43.1	3.36
121	-0.5	-9.7	1.0	9.8	44.0	3.51
71	0.0	-9.7	-0.2	9.7	44.1	3.55
82	1.7	5.9	4.4	9.7	44.3	3.56
99	-9.3	-0.7	1.9	9.7	44.3	3.56
29	-0.1	-9.6	0.7	9.7	44.2	3.57
113	-5.8	-8.8	1.6	9.5	43.8	3.61
36	0.2	-3.5	-4.2	9.1	43.1	3.71

Table 2.6.13.6-11 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 26.28° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
23	40.4	29.3	9.9	46.2	64.5	0.40
4	-34.3	-41.3	4.5	43.5	63.0	0.45
37	-30.3	-37.2	10.0	44.3	64.5	0.46
3	-37.5	-36.8	4.3	41.4	63.0	0.52
107	-24.6	-31.3	14.6	42.9	66.8	0.56
21	-31.0	-33.9	8.6	41.2	64.5	0.57
9	-33.7	-29.3	9.2	41.0	64.5	0.57
51	31.1	31.8	9.2	40.6	64.5	0.59
20	-30.2	-38.1	1.4	38.3	64.5	0.68
28	-35.7	-17.1	7.8	38.6	65.8	0.71
49	-29.7	-27.0	8.2	36.7	64.5	0.76
34	-31.8	-33.4	3.3	36.0	64.5	0.79
95	-29.7	-27.5	7.6	36.2	65.5	0.81
96	-30.1	-26.3	7.4	35.9	65.5	0.83
2	33.5	27.0	2.2	34.2	63.0	0.84
48	33.8	29.6	2.3	34.8	64.5	0.85
111	-33.9	-19.5	3.8	34.8	65.5	0.88
35	29.0	21.3	7.6	33.6	64.5	0.92
6	-31.0	-30.7	2.4	33.3	64.5	0.94
22	-33.0	-14.1	-1.4	33.1	64.6	0.95
112	-9.6	-33.2	2.1	33.4	65.5	0.96
98	-27.7	-18.8	9.5	33.8	66.4	0.97
63	-26.7	-24.4	7.2	32.8	65.5	1.00
64	-26.8	-24.3	6.9	32.5	65.5	1.02
1	-27.8	-30.1	1.1	30.5	63.0	1.06
120	3.1	-27.1	3.9	31.2	66.4	1.13
27	-30.0	-15.8	1.7	30.2	65.9	1.18
79	24.9	21.9	6.1	29.7	65.5	1.20
30	-6.3	-28.8	5.5	30.0	66.7	1.22
114	-28.9	-2.1	4.8	29.7	66.4	1.23
7	24.5	22.0	5.5	28.8	64.5	1.24
80	24.9	21.3	5.9	29.3	65.5	1.24
8	28.0	5.0	-2.0	28.1	64.6	1.30
99	-23.9	-17.9	7.4	28.8	66.4	1.30
26	-23.8	-20.9	6.0	28.5	65.8	1.31
14	26.3	12.3	5.9	28.5	65.8	1.31
42	-14.3	-25.3	6.0	28.0	65.8	1.35
115	-10.1	-27.6	-0.5	27.7	66.4	1.40
91	13.9	21.0	9.1	27.3	66.8	1.45
36	0.5	-24.4	-3.5	25.9	64.6	1.50

Table 2.6.13.6-12 P_m Stresses for Support Disk—1-Foot Side-Drop, 26.28° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
120	9.5	-9.1	5.4	21.5	45.0	1.10
112	11.0	-7.6	4.4	20.6	45.0	1.19
114	-6.8	6.7	7.1	19.7	45.0	1.28
35	13.6	-3.8	4.5	19.7	45.0	1.29
37	-14.5	-9.9	5.0	17.8	45.0	1.54
51	14.5	3.4	5.2	16.6	45.0	1.72
23	1.6	6.3	7.9	16.4	45.0	1.74
21	-2.9	-14.7	4.6	16.3	45.0	1.77
9	-1.0	-10.0	6.7	16.1	45.0	1.79
49	-13.5	-0.7	4.8	16.0	45.0	1.81
28	-6.3	-1.6	7.0	14.7	45.0	2.05
96	-10.5	1.1	4.5	14.7	45.0	2.07
98	-7.0	-9.8	5.5	14.1	45.0	2.19
63	1.0	-7.6	5.2	13.6	45.0	2.32
64	-12.5	-5.7	2.8	13.5	45.0	2.34
66	-0.8	-5.8	5.8	12.7	45.0	2.54
95	0.6	-7.5	4.9	12.7	45.0	2.54
40	3.9	-7.2	2.5	12.2	45.0	2.68
14	1.2	-0.9	5.9	12.0	45.0	2.74
119	0.0	-12.0	-0.3	12.0	45.0	2.75
116	0.0	-11.9	0.0	11.9	45.0	2.78
31	-3.2	-11.5	1.6	11.8	45.0	2.82
26	-7.2	-9.7	3.1	11.8	45.0	2.83
111	-2.3	0.3	5.6	11.6	45.0	2.88
115	2.2	-7.0	3.5	11.6	45.0	2.89
80	10.2	1.5	3.0	11.2	45.0	3.02
107	2.5	-3.9	4.5	11.0	45.0	3.08
42	-5.6	-9.3	3.0	11.0	45.0	3.09
27	-9.2	-8.5	-1.8	10.7	45.0	3.20
79	-0.2	6.3	4.1	10.5	45.0	3.28
121	-0.5	-10.3	1.0	10.4	45.0	3.31
72	-8.7	-7.6	2.2	10.4	45.0	3.32
104	-5.6	0.0	4.4	10.3	45.0	3.35
113	-6.2	-9.5	1.7	10.2	45.0	3.40
99	-9.7	-0.4	1.9	10.0	45.0	3.48
82	1.7	6.0	4.5	10.0	45.0	3.50
22	-4.6	-7.0	-3.8	9.8	45.0	3.60
36	0.2	-3.9	-4.4	9.8	45.0	3.61
71	0.0	-9.6	-0.2	9.6	45.0	3.67
29	-0.1	-9.5	0.8	9.6	45.0	3.68

Table 2.6.13.6-13 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 26.28° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
23	41.9	30.1	10.2	47.7	67.5	0.41
37	-31.5	-38.2	10.4	45.8	67.5	0.47
4	-35.9	-43.1	4.6	45.4	67.5	0.49
3	-39.2	-38.5	4.4	43.2	67.5	0.56
21	-32.3	-34.7	8.9	42.4	67.5	0.59
9	-34.8	-30.1	9.4	42.2	67.5	0.60
51	32.1	32.6	9.5	41.9	67.5	0.61
107	-24.4	-29.9	13.9	41.3	67.5	0.63
28	-36.9	-17.7	8.0	39.8	67.5	0.70
20	-31.3	-38.8	1.3	39.0	67.5	0.73
49	-30.8	-27.3	8.5	37.8	67.5	0.79
34	-33.3	-34.2	3.6	37.4	67.5	0.81
95	-30.3	-27.3	7.7	36.6	67.5	0.84
111	-35.2	-20.9	4.1	36.3	67.5	0.86
48	35.0	30.4	2.6	36.1	67.5	0.87
96	-30.7	-25.9	7.5	36.1	67.5	0.87
2	35.1	28.7	2.2	35.8	67.5	0.89
35	30.1	21.4	7.9	34.8	67.5	0.94
98	-28.6	-19.0	9.8	34.7	67.5	0.94
6	-32.0	-31.4	2.4	34.1	67.5	0.98
22	-33.9	-14.9	-1.5	34.0	67.5	0.98
112	30.9	18.1	6.8	33.9	67.5	0.99
63	-27.6	-24.7	7.4	33.7	67.5	1.00
64	-27.6	-24.6	7.1	33.4	67.5	1.02
1	-29.5	-31.6	1.1	32.1	67.5	1.10
30	-6.6	-30.3	5.6	31.6	67.5	1.14
27	-31.1	-16.4	1.7	31.3	67.5	1.16
114	-30.2	-2.7	5.2	31.2	67.5	1.17
120	3.5	-26.2	3.7	30.6	67.5	1.21
79	25.7	22.1	6.3	30.4	67.5	1.22
7	25.7	22.8	5.7	30.1	67.5	1.24
26	-25.4	-21.5	6.3	30.0	67.5	1.25
80	25.6	21.4	6.1	29.9	67.5	1.26
99	-24.6	-18.0	7.6	29.6	67.5	1.28
14	26.9	12.6	6.0	29.1	67.5	1.32
8	28.8	5.5	-2.1	29.0	67.5	1.33
115	-10.4	-28.7	-0.6	28.7	67.5	1.35
91	14.2	21.4	9.3	27.8	67.5	1.43
36	1.7	-24.8	-3.7	27.5	67.5	1.46
42	-13.8	-24.3	5.8	26.9	67.5	1.51

Table 2.6.13.6-14 P_m Stresses for Support Disk—1-Foot Side-Drop, 45° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
120	9.1	-9.1	7.6	23.7	44.3	0.86
114	-9.0	9.1	7.6	23.7	44.3	0.87
35	12.7	-1.4	7.0	19.8	43.0	1.17
23	-1.4	12.7	7.0	19.8	43.0	1.17
37	-16.8	-7.7	6.0	19.8	43.0	1.17
21	-7.7	-16.8	6.0	19.8	43.0	1.18
49	-12.9	-0.6	6.4	17.7	43.0	1.44
9	-0.6	-12.9	6.4	17.6	43.0	1.44
112	7.1	-5.8	6.1	17.7	43.7	1.47
111	-5.8	7.0	6.1	17.7	43.7	1.47
96	-10.7	1.5	5.7	16.7	43.7	1.61
63	1.5	-10.6	5.7	16.7	43.7	1.61
51	12.0	3.1	5.4	14.5	43.0	1.96
7	3.1	12.0	5.4	14.5	43.0	1.96
28	-8.3	0.9	5.4	14.2	43.9	2.10
40	0.9	-8.3	5.4	14.2	43.9	2.10
98	-8.9	-10.3	4.6	14.3	44.3	2.11
72	-10.4	-8.8	4.5	14.1	44.3	2.14
66	-0.3	-6.7	6.2	13.9	44.3	2.18
104	-6.6	-0.1	6.1	13.9	44.3	2.19
64	-11.7	-3.2	4.5	13.6	43.7	2.21
95	-3.2	-11.6	4.5	13.6	43.7	2.21
42	-6.9	-9.4	4.2	12.5	43.9	2.51
26	-9.4	-6.9	4.2	12.5	43.9	2.51
80	9.8	1.1	4.1	12.0	43.7	2.63
79	1.1	9.8	4.1	12.0	43.7	2.64
119	-0.1	-12.1	-0.5	12.1	44.1	2.65
110	-12.1	-0.1	-0.5	12.1	44.1	2.65
94	-11.1	-0.1	-0.4	11.2	44.1	2.95
71	-0.1	-11.1	-0.4	11.1	44.1	2.96
46	-9.8	-1.0	2.0	10.3	44.5	3.33
36	-2.8	-4.1	-4.9	9.9	43.1	3.34
22	-4.1	-2.8	-4.9	9.9	43.1	3.34
74	-0.2	-9.5	2.0	10.1	44.3	3.37
99	-9.5	-0.3	2.0	10.1	44.3	3.38
14	2.5	0.6	4.8	9.8	43.9	3.47
54	0.5	2.5	4.8	9.8	43.9	3.49
31	-1.0	-9.4	1.9	9.8	44.5	3.53
122	-4.9	1.1	3.7	9.6	44.3	3.62
115	1.1	-4.7	3.8	9.5	44.3	3.65

Table 2.6.13.6-15 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 45° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
21	-42.8	-39.0	11.6	52.7	64.5	0.22
37	-39.0	-42.8	11.6	52.7	64.5	0.22
35	36.1	35.8	10.5	46.4	64.5	0.39
23	35.8	36.1	10.5	46.4	64.5	0.39
1	-41.9	-37.5	3.0	43.4	63.0	0.45
4	-37.5	-41.9	3.0	43.4	63.0	0.45
49	-34.1	-34.4	9.9	44.1	64.5	0.46
9	-34.4	-34.1	9.8	44.1	64.5	0.46
34	-42.0	-39.6	3.0	44.1	64.5	0.46
20	-39.6	-42.0	3.0	44.1	64.5	0.46
3	-40.8	-38.0	3.1	42.8	63.0	0.47
2	-38.0	-40.8	3.1	42.8	63.0	0.47
7	34.8	32.0	9.1	42.6	64.5	0.52
51	32.0	34.8	9.1	42.6	64.5	0.52
111	-41.3	-17.6	3.7	41.8	65.5	0.57
112	-17.6	-41.2	3.7	41.8	65.5	0.57
95	-32.2	-32.1	8.6	40.7	65.5	0.61
64	-32.1	-32.1	8.6	40.7	65.5	0.61
96	-32.4	-31.3	8.7	40.6	65.5	0.62
63	-31.3	-32.4	8.7	40.5	65.5	0.62
48	-36.6	-32.9	2.1	37.5	64.5	0.72
6	-32.9	-36.6	2.1	37.5	64.5	0.72
120	-0.3	-34.1	5.5	35.6	66.4	0.87
114	-34.0	-0.6	5.5	35.2	66.4	0.89
79	27.4	27.6	7.2	34.7	65.5	0.89
80	27.6	27.3	7.2	34.6	65.5	0.89
22	-33.6	-6.2	-3.5	34.0	64.6	0.90
36	-6.2	-33.6	-3.5	34.0	64.6	0.90
28	-32.9	-13.1	6.2	34.7	65.8	0.90
40	-13.0	-32.8	6.1	34.6	65.8	0.91
26	-31.1	-19.5	7.2	34.5	65.8	0.91
42	-19.5	-31.1	7.2	34.5	65.8	0.91
98	-27.1	-18.5	9.3	33.0	66.4	1.01
72	-18.6	-27.1	9.3	33.0	66.4	1.01
8	29.4	3.6	-3.4	29.8	64.6	1.17
50	3.5	29.3	-3.4	29.8	64.6	1.17
30	-9.2	-28.4	4.8	29.5	66.7	1.26
44	-28.2	-9.5	4.7	29.3	66.7	1.28
75	-16.2	-21.3	9.7	28.8	66.8	1.32
99	-23.4	-17.7	7.4	28.5	66.4	1.33

Table 2.6.13.6-16 P_m Stresses for Support Disk—1-Foot Side-Drop, 45° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
120	9.6	-9.8	8.0	25.2	45.0	0.79
114	-9.7	9.6	8.0	25.1	45.0	0.79
35	14.3	-1.4	7.1	21.2	45.0	1.12
23	-1.4	14.3	7.1	21.2	45.0	1.12
37	-17.7	-8.2	6.6	21.1	45.0	1.13
21	-8.2	-17.7	6.6	21.1	45.0	1.13
112	7.6	-6.2	6.5	18.9	45.0	1.38
111	-6.2	7.5	6.5	18.9	45.0	1.38
49	-13.1	-0.6	6.4	17.9	45.0	1.51
9	-0.6	-13.1	6.4	17.9	45.0	1.51
96	-10.8	1.7	6.0	17.4	45.0	1.59
63	1.7	-10.8	6.0	17.4	45.0	1.59
51	12.7	3.3	5.8	15.4	45.0	1.92
7	3.3	12.7	5.8	15.4	45.0	1.92
28	-8.9	1.6	5.2	14.9	45.0	2.03
40	1.7	-8.9	5.2	14.8	45.0	2.03
98	-9.6	-10.8	4.4	14.7	45.0	2.06
66	-0.1	-7.0	6.5	14.7	45.0	2.07
104	-7.0	0.0	6.4	14.6	45.0	2.08
72	-10.8	-9.4	4.4	14.6	45.0	2.09
64	-12.3	-3.3	4.6	14.3	45.0	2.16
95	-3.3	-12.3	4.6	14.2	45.0	2.16
42	-6.9	-10.1	4.5	13.3	45.0	2.38
26	-10.1	-6.9	4.6	13.3	45.0	2.38
119	-0.1	-13.0	-0.5	13.0	45.0	2.46
110	-13.0	-0.1	-0.5	13.0	45.0	2.46
80	9.9	1.1	4.2	12.2	45.0	2.68
79	1.1	9.9	4.2	12.2	45.0	2.69
94	-12.0	-0.1	-0.4	12.0	45.0	2.75
71	-0.1	-12.0	-0.4	12.0	45.0	2.75
36	-2.1	-3.7	-5.3	10.7	45.0	3.21
22	-3.7	-2.1	-5.3	10.7	45.0	3.22
74	-0.1	-9.7	2.1	10.5	45.0	3.30
99	-9.7	-0.2	2.1	10.5	45.0	3.30
122	-5.2	1.0	4.0	10.0	45.0	3.48
115	1.0	-5.0	4.0	10.0	45.0	3.51
14	2.7	0.6	4.8	9.8	45.0	3.61
54	0.6	2.7	4.7	9.7	45.0	3.63
116	-0.1	-9.6	0.0	9.6	45.0	3.70
109	-9.6	-0.1	0.0	9.6	45.0	3.70

Table 2.6.13.6-17 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 45° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
21	-46.6	-41.5	12.6	56.9	67.5	0.19
37	-41.5	-46.5	12.6	56.9	67.5	0.19
23	37.2	38.8	11.1	49.1	67.5	0.38
35	38.8	37.1	11.1	49.1	67.5	0.38
20	-42.8	-44.4	3.4	47.1	67.5	0.43
34	-44.4	-42.8	3.4	47.1	67.5	0.43
4	-39.5	-45.5	3.1	46.8	67.5	0.44
1	-45.5	-39.5	3.0	46.8	67.5	0.44
51	33.7	37.0	9.7	45.2	67.5	0.49
7	37.0	33.7	9.7	45.2	67.5	0.49
49	-35.0	-35.1	10.0	45.1	67.5	0.50
9	-35.1	-35.0	10.0	45.1	67.5	0.50
3	-42.5	-41.0	3.1	44.9	67.5	0.50
2	-41.0	-42.5	3.1	44.9	67.5	0.50
111	-44.0	-18.8	3.9	44.6	67.5	0.51
112	-18.7	-44.0	3.9	44.5	67.5	0.52
95	-33.2	-33.5	8.9	42.3	67.5	0.60
64	-33.5	-33.1	8.9	42.3	67.5	0.60
96	-33.5	-32.7	9.0	42.1	67.5	0.60
63	-32.7	-33.4	9.0	42.1	67.5	0.60
48	-37.6	-33.8	2.0	38.4	67.5	0.76
6	-33.8	-37.6	1.9	38.4	67.5	0.76
120	-0.3	-36.1	5.8	37.7	67.5	0.79
114	-36.1	-0.6	5.8	37.3	67.5	0.81
26	-33.4	-20.1	7.6	36.9	67.5	0.83
42	-20.1	-33.3	7.6	36.8	67.5	0.83
22	-34.9	-5.3	-4.1	35.5	67.5	0.90
36	-5.3	-34.9	-4.1	35.5	67.5	0.90
79	27.8	28.1	7.3	35.3	67.5	0.91
80	28.1	27.8	7.3	35.3	67.5	0.91
28	-33.1	-12.4	5.9	34.7	67.5	0.95
40	-12.4	-33.0	5.9	34.5	67.5	0.95
98	-27.5	-19.0	9.4	33.6	67.5	1.01
72	-19.0	-27.4	9.4	33.5	67.5	1.01
8	30.1	4.1	-3.6	30.6	67.5	1.21
75	-17.3	-22.6	10.3	30.6	67.5	1.21
50	4.0	30.1	-3.6	30.6	67.5	1.21
122	-29.2	-13.0	-0.5	29.2	67.5	1.31
30	-10.7	-28.1	4.5	29.2	67.5	1.31
99	-23.8	-18.2	7.6	29.1	67.5	1.32

2.6.13.7 Stress Evaluation of PWR Support Disk for Combined Thermal and 1-Foot Side-Drop Load Condition

The inertial loading for the 1-ft side-drop is combined with the thermal loading for Thermal Case A to produce the largest stress intensities. The allowable stress intensity 3 S_m, is evaluated at the section temperature.

The 40 sections with the smallest margins of safety are presented in Tables 2.6.13.7-1 through 2.6.13.7-4. The tables are identified here:

Table Number	Basket Orientation (°)	Thermal Case	Stress Evaluation	Minimum Margin of Safety
2.6.13.7-1	0	A	$P_m + P_b + Q$	+3.75
2.6.13.7-2	18.22	A	$P_m + P_b + Q$	+1.59
2.6.13.7-3	26.28	A	$P_m + P_b + Q$	+1.21
2.6.13.7-4	45	A	$P_m + P_b + Q$	+1.46

The minimum margin of safety is +1.21.

Table 2.6.13.7-1 $P_m + P_b + Q$ Stresses for Support Disk—1-Foot Side-Drop, 0°, Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
75	21.2	17.5	-8.5	28.1	133.5	3.75
91	21.2	17.5	8.5	28.1	133.5	3.75
107	-11.3	-21.2	9.3	26.7	133.5	3.99
123	-11.3	-21.2	-9.3	26.7	133.5	3.99
17	25.3	2.9	-2.0	25.4	133.4	4.24
18	25.3	2.9	2.0	25.4	133.4	4.24
26	12.7	-8.5	-1.3	21.3	131.6	5.17
28	12.7	-8.5	1.3	21.3	131.6	5.17
25	12.7	-8.5	-1.3	21.3	131.6	5.17
6	-16.8	-10.8	-5.4	20.0	129.0	5.46
7	-16.8	-10.8	-5.4	20.0	129.0	5.46
9	-16.8	-10.8	5.4	20.0	129.0	5.46
1	-13.0	-12.2	-4.9	17.5	125.9	6.19
3	-13.0	-12.2	4.9	17.5	125.9	6.19
4	-13.0	-12.2	4.9	17.5	125.9	6.19
29	0.0	-18.3	0.1	18.3	132.6	6.26
12	-14.8	-8.9	-5.0	17.6	131.6	6.48
14	-14.8	-8.9	5.0	17.6	131.6	6.48
11	-14.8	-8.9	-5.0	17.6	131.6	6.48
24	0.0	-16.1	0.1	16.1	130.4	7.09
23	-8.2	-13.4	4.2	15.7	129.0	7.22
21	-8.2	-13.4	-4.2	15.7	129.0	7.22
22	-8.2	-13.4	-4.2	15.7	129.2	7.23
27	-4.3	-14.4	-3.9	15.8	131.8	7.36
34	-7.4	-13.6	-3.5	15.2	129.0	7.46
35	-7.4	-13.6	-3.5	15.2	129.0	7.46
48	-7.4	-13.6	3.5	15.2	129.0	7.46
49	-7.4	-13.6	3.5	15.2	129.0	7.46
32	-7.4	-12.4	-5.1	15.6	133.4	7.54
30	-7.4	-12.4	5.1	15.6	133.4	7.54
31	-7.4	-12.4	5.1	15.6	133.4	7.54
16	-14.6	-10.2	-1.7	15.1	133.4	7.82
20	6.4	-7.9	0.0	14.3	129.0	8.00
19	0.0	-14.0	0.2	14.0	127.3	8.07
76	5.5	14.5	-1.3	14.7	133.5	8.08
92	5.5	14.5	1.3	14.7	133.5	8.08
13	12.5	-0.7	-3.0	14.4	131.8	8.12
2	7.4	-5.8	-1.2	13.4	125.9	8.38
46	1.4	13.6	0.9	13.6	133.4	8.80
60	1.4	13.6	-0.9	13.6	133.4	8.80

Table 2.6.13.7-2 $P_m + P_b + Q$ Stresses for Support Disk—1-Foot Side-Drop Orientation, 18.22°, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
3	-35.1	-36.6	12.8	48.7	125.9	1.59
4	-35.1	-36.6	12.8	48.7	125.9	1.59
6	-36.3	-29.0	11.5	44.7	129.0	1.89
9	-36.3	-29.0	11.5	44.7	129.0	1.89
34	-25.3	-33.1	10.1	40.0	129.0	2.23
37	-25.3	-33.1	10.1	40.0	129.0	2.23
48	-29.4	-29.7	10.2	39.6	129.0	2.25
49	-29.4	-29.7	10.2	39.6	129.0	2.25
91	26.4	28.5	11.8	39.3	133.5	2.40
21	-24.8	-31.2	9.1	37.6	129.0	2.43
20	-24.8	-31.2	9.1	37.6	129.0	2.43
2	29.2	17.4	8.9	34.0	125.9	2.71
23	-30.5	-18.9	7.7	34.4	129.0	2.75
22	-30.5	-18.9	7.7	34.4	129.2	2.76
1	-18.7	-27.9	7.2	31.8	125.9	2.96
107	-12.0	-27.8	10.4	32.9	133.5	3.06
96	-24.3	-22.0	7.3	30.5	131.0	3.29
95	-24.3	-22.0	7.3	30.5	131.0	3.29
11	-26.3	-16.2	7.9	30.6	131.6	3.30
14	-26.3	-16.2	7.9	30.6	131.6	3.30
28	-25.5	-18.5	7.7	30.5	131.6	3.32
27	-25.5	-18.5	7.7	30.5	131.8	3.32
111	-27.1	-19.5	5.3	29.8	131.0	3.39
13	26.9	7.9	6.8	29.1	131.8	3.52
51	23.4	18.1	6.8	28.0	129.0	3.60
8	26.9	3.6	5.1	28.0	129.2	3.61
30	-9.2	-24.8	7.8	28.0	133.4	3.76
31	-9.2	-24.8	7.8	28.0	133.4	3.76
112	-7.9	-26.6	4.2	27.5	131.0	3.77
26	-15.4	-22.6	6.1	26.1	131.6	4.05
25	-15.4	-22.6	6.1	26.1	131.6	4.05
79	-24.8	-11.3	3.9	25.8	131.0	4.07
80	21.3	17.6	6.0	25.7	131.0	4.11
115	-4.8	-25.1	0.8	25.2	132.8	4.28
39	-13.9	-21.2	6.3	24.8	131.6	4.30
42	-13.9	-21.2	6.3	24.8	131.6	4.30
64	-19.5	-17.6	6.0	24.6	131.0	4.32
63	-19.5	-17.6	6.0	24.6	131.0	4.32
16	-17.6	-22.2	4.5	25.0	133.4	4.33
18	-17.6	-22.2	4.5	25.0	133.4	4.33

Table 2.6.13.7-3 $P_m + P_b + Q$ Stresses for Support Disk—1-Foot Side-Drop, 26.28°, Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
3	-41.1	-43.0	15.0	57.0	125.9	1.21
4	-41.1	-43.0	15.0	57.0	125.9	1.21
6	-39.8	-33.9	12.9	50.1	129.0	1.57
9	-39.8	-33.9	12.9	50.1	129.0	1.57
34	-31.1	-40.5	12.2	48.8	129.0	1.64
37	-31.1	-40.5	12.2	48.8	129.0	1.64
20	-33.6	-39.0	12.0	48.6	129.0	1.66
21	-33.6	-39.0	12.0	48.6	129.0	1.66
48	-34.6	-35.0	11.9	46.7	129.0	1.76
49	-34.6	-35.0	11.9	46.7	129.0	1.76
2	34.6	23.4	10.9	41.3	125.9	2.05
1	-25.9	-33.1	9.4	39.6	125.9	2.18
23	31.9	24.7	9.8	38.8	129.0	2.32
95	-30.1	-28.4	9.3	38.7	131.0	2.39
96	-30.1	-28.4	9.3	38.7	131.0	2.39
22	-35.5	-15.9	7.6	38.1	129.2	2.39
91	25.7	28.8	11.7	39.0	133.5	2.43
112	-15.4	-34.9	5.9	36.6	131.0	2.58
51	28.7	25.1	8.8	35.8	129.0	2.60
42	-18.7	-29.6	8.5	34.2	131.6	2.85
39	-18.7	-29.6	8.5	34.2	131.6	2.85
111	-31.8	-17.4	5.6	33.7	131.0	2.88
28	-27.4	-18.5	8.0	32.1	131.6	3.10
27	-27.4	-18.5	8.0	32.1	131.8	3.10
8	30.2	3.5	5.3	31.2	129.2	3.14
80	25.3	22.8	7.4	31.6	131.0	3.15
79	25.3	22.8	7.4	31.6	131.0	3.15
107	28.3	16.9	-7.5	32.0	133.5	3.17
14	-26.5	-16.6	7.9	30.9	131.6	3.26
11	-26.5	-16.6	7.9	30.9	131.6	3.26
13	28.3	9.0	7.2	30.7	131.8	3.30
63	-23.0	-22.6	7.4	30.2	131.0	3.34
64	-23.0	-22.6	7.4	30.2	131.0	3.34
120	-0.6	-28.7	5.5	30.2	132.8	3.40
124	19.7	29.1	-0.1	29.1	133.5	3.59
31	-8.3	-25.8	7.8	28.8	133.4	3.64
30	-8.3	-25.8	7.8	28.8	133.4	3.64
26	-18.7	-22.9	6.7	27.8	131.6	3.73
25	-18.7	-22.9	6.7	27.8	131.6	3.73
35	22.7	14.9	6.4	26.3	129.0	3.91

Table 2.6.13.7-4 $P_m + P_b + Q$ Stresses for Support Disk—1-Foot Side-Drop, 45° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
1	-35.6	-40.3	13.0	51.1	125.9	1.46
2	-35.6	-40.3	13.0	51.1	125.9	1.46
6	-40.2	-37.4	13.5	52.4	129.0	1.46
9	-40.2	-37.4	13.5	52.4	129.0	1.46
48	-37.4	-40.2	13.5	52.4	129.0	1.46
49	-37.4	-40.2	13.5	52.4	129.0	1.46
3	-40.2	-35.6	13.0	51.1	125.9	1.46
4	-40.2	-35.6	13.0	51.1	125.9	1.46
34	-36.1	-36.5	12.1	48.4	129.0	1.67
37	-36.1	-36.5	12.1	48.4	129.0	1.67
20	-36.5	-36.1	12.1	48.4	129.0	1.67
21	-36.5	-36.1	12.1	48.4	129.0	1.67
63	-26.3	-28.3	8.8	36.1	131.0	2.63
64	-26.3	-28.3	8.8	36.1	131.0	2.63
95	-28.3	-26.2	8.8	36.1	131.0	2.63
96	-28.3	-26.2	8.8	36.1	131.0	2.63
111	-33.4	-16.4	5.9	35.2	131.0	2.72
112	-16.3	-33.3	5.9	35.1	131.0	2.73
79	26.5	26.5	8.2	34.7	131.0	2.78
80	26.5	26.5	8.2	34.7	131.0	2.78
35	-12.4	-31.7	6.2	33.5	129.0	2.85
23	-31.7	-12.4	6.2	33.5	129.0	2.85
36	-12.4	-31.7	6.2	33.5	129.2	2.85
22	-31.7	-12.4	6.2	33.5	129.2	2.85
91	22.8	25.3	10.2	34.3	133.5	2.90
8	29.8	1.6	4.6	30.5	129.2	3.23
50	1.6	29.8	4.6	30.5	129.2	3.23
44	-27.8	-10.5	8.4	31.2	133.4	3.28
46	-27.8	-10.5	8.4	31.2	133.4	3.28
30	-10.1	-27.6	8.2	30.9	133.4	3.32
31	-10.1	-27.6	8.2	30.9	133.4	3.32
7	20.5	24.4	7.0	29.7	129.0	3.34
51	24.4	20.4	7.0	29.7	129.0	3.35
26	-23.3	-20.6	7.3	29.4	131.6	3.48
25	-23.3	-20.6	7.3	29.4	131.6	3.48
42	-20.6	-23.3	7.3	29.3	131.6	3.49
39	-20.6	-23.3	7.3	29.3	131.6	3.49
14	26.0	9.6	6.8	28.4	131.6	3.64
13	26.0	9.6	6.8	28.4	131.8	3.64
54	9.5	25.9	6.8	28.3	131.6	3.65

2.6.13.8 Stress Evaluation of PWR Support Disk for 1-Foot Off-Angle Load Conditions

As previously discussed, the evaluation of off-angle impacts is accomplished by using the stress results from the side and end-drop evaluations. To evaluate oblique impacts, the stress components (i.e. S_x, S_y, S_{xy}) are combined from the side and end drop cases. The evaluatation considers various cask drop angles (ϕ = 0°, 23°, 30°, 45°, 60°, 70°, 75°, 80°, 85°, 88°, and 90°), as well as the basket drop orientation (0°, 18.22°, 26.28°, and 45°). Note that the end drop (ϕ = 0°) and side drop (ϕ = 90°) are included in the evaluation so that the results envelope all cask drop angles. The normal stresses (S_x and S_y) and the shear stress (S_{xy}) for an off-angle (ϕ) drop are calculated by the following equations,

$$S_{x(\phi)} = S_{x(end)} \text{Cos}\phi + S_{x(side)} \text{Sin}\phi \,,$$

$$S_{y(\phi)} = S_{y(end)} \text{Cos}\phi + S_{y(side)} \text{Sin}\phi \,,$$

$$S_{xy(\phi)} = S_{xy(end)} \text{Cos}\phi + S_{xy(side)} \text{Sin}\phi \,,$$

where,

$S_{x(side)}$, $S_{y(side)}$, and $S_{xy(side)}$ are the section stresses calculated by the ANSYS analysis for the side drop conditions. $S_{x(end)}$, $S_{y(end)}$, and $S_{xy(end)}$ are the sectional stresses calculated by the ANSYS analysis for the end drop. The principal stresses and the stress intensity are then determined based on the stress components. The orientations where the maximums occur for each loading condition are then determined. A summary of the evaluation is presented in Section 2.6.13.2.

2.6.13.9 Stress Evaluation of Support Disk for Combined Thermal and 1-Foot Off-Angle Conditions

The stress evaluation for the combined thermal and oblique condition is performed using the same methodology discussed in Section 2.6.13.8. The summary of the maximum P+Q stresses is also presented Section 2.6.13.2.

2.6.13.10 Stress Evaluation of Tie Rods and Spacers for 1-Foot End-Drop Load Condition

The PWR basket support disks are connected by eight tie rods with spacers to maintain spacing of the support disks and heat transfer disk. The tie rods and spacers are constructed from Type 304 stainless steel. The tie rods are threaded only at the upper end so that the top nut can provide rigidity of the basket assembly. The tie rods do not transmit any load other than their own weight. In a side-drop, the load resulting from the disks and the fuel is transmitted directly into the canister wall by the support disks. In an end-drop, the spacers transmit the load resulting from the weight of the support disks, aluminum heat transfer disks, one end weldment, and spacers to either the lid or bottom depending on the orientation of the drop. The weight of the fuel assemblies is transmitted directly into the canister lid or bottom, because the fuel tubes in the basket are open at both ends. In drop orientations other than on the end, the spacers experience only a portion of the weight of the support disks, heat transfer disks, one end weldment, and the spacers that act along the centerline axis of the cask. Thus, the end-drop is the critical loading condition.

During an end-drop, the weight of the support disks, end weldment, aluminum heat transfer disks, and spacers and end nuts is supported by the spacers on the 8 tie rods, thereby resulting in compressive stress over the cross-sectional area of the spacers. Taking the largest weight of all three PWR fuel classes, the total weight of the basket is 16,489 lb. Because the weights of the bottom end weldment (527 lb) and the fuel tubes (3,676 lb) are transmitted directly into the end of the canister, the remaining load acting over the area of the spacers is 12,286 lb. For the 1-ft end-drop, the deceleration is 20 g, which results in a total end-drop load of 245,720 lb. The area in compression is $\pi(3.0^2 - 1.75^2)/4 = 4.66\ in^2$. The compressive stress, is 245,720/(8 x 4.66) = 6,591 psi, and is considered to be a membrane stress.

Based on the ASME Code, Section III, Subsection NG, the allowable membrane stress is 1.0 S_m. Using a conservative material temperature for the outer edge of the support disk of 500°F, S_m = 17.5 ksi. The corresponding margin of safety is

$$MS = (17,500/6,591) - 1 = +1.66.$$

Therefore, structural adequacy of the tie rod/spacer assemblies is demonstrated.

2.6.13.11 Support Disk Shear Stresses for 1-Foot Drops

The ASME Code, Section III, Division 1, Subsection NG, criteria define the Level A allowable for shear stress to be 0.6 S_m. The extrapolated design stress intensity for 17-4 PH at a bounding temperature of 750°F is 41.9 ksi. The maximum stress intensity across any section (membrane stress) for the 1-ft side-drop is 31.4 ksi for the 45° drop orientation at Case 1. Similarly, for the end-drop, a maximum membrane stress across a section is 0 ksi for the 1-ft drop. Therefore, the maximum shear stress for any normal loading condition is 31.4/2 or 15.7 ksi.

Using the allowable stresses as stated previously, the minimum margin of safety for shear is

$$\begin{aligned} MS &= [2(0.6)S_m / SI] - 1 \\ &= [2(0.6)(41.9) / 31.4] - 1 \\ &= +0.60 \end{aligned}$$

Therefore, structural adequacy of the PWR fuel basket support disk design for the normal conditions of transport, 1-ft side and end-drops is demonstrated for shear stress criteria.

2.6.13.12 Bearing Stress - Basket Contact with Canister Shell

For the bearing stress (S_{br}) acting along the basket support disk-canister shell interface, an angular contact of 18° is considered on the basis of ANSYS gap element status (at a radius of 32.75 in). The load considered to be acting on the support disks is the total contents weight (55,810 lb), times the deceleration value of 20 g, divided among 30 support disks in the basket. The bearing area is considered to be the 0.5-in. thick disk over an 18° contact area.

$$S_{br} = (55{,}810)(20)/[(0.5)(30)(\pi)(65.5)/(360/18)] = 7{,}233 \text{ psi}$$

The allowable bearing stress is the yield stress, which is 89.8 ksi for SA-693, Type 630, 17-4 PH stainless steel at a temperature of 400°F. The margin of safety for the support disk (not the canister) is computed as

$$MS = 89.8/S_{br} - 1 = +11.41.$$

2.6.13.13 Basket Weldment Analysis for 1-Foot End-Drop

The responses of the top and bottom weldment plates of the fuel assembly to a 1-ft end-drop in conjunction with the thermal expansion stress are evaluated in this section. The top and bottom weldment plates are 1.25-in.-thick and 1.0-in.-thick plates of Type 304 stainless steel, respectively. The weldments support their own weight plus the weight of 24 PWR fuel assembly tubes. A finite element analysis is performed for both plates, because the support for each weldment is different as a result of the location of the welded ribs for each. Both models use the SHELL63 element, which permits out-of-plane loading. Figures 2.6.13.13-1 and 2.6.13.13-2 show the finite element models for the top and bottom weldments, respectively. The load from the fuel tube is represented as point forces applied to the nodes at the periphery of the fuel assembly slots. An average point force is applied. The application of the nodal loads at the slot periphery is accurate because the tube weight is transmitted to the edge of the slot, which provides support to the fuel tubes in the end-drop condition. The analysis using the applied nodal forces demonstrates that the weldment design satisfies the primary membrane (P_m) and the primary membrane plus bending (P_m+P_b) stress criteria. Thermal expansion stresses are also analyzed. The determination of the weldment temperatures is discussed in Chapter 3.0.

The margins of safety are calculated as

$$MS = [(P_m + P_b) / 1.5\ S_m] - 1$$

or

$$MS = [(P_m + P_b + Q) / 3\ S_m] - 1$$

The margins of safety evaluated for the weldments are shown in Table 2.6.13.13-1. The weldments are shown to satisfy the stress criteria in the ASME Code, Section III, Division I, Subsection NG.

Figure 2.6.13.13-1 Finite Element Model of the Top Weldment Plate

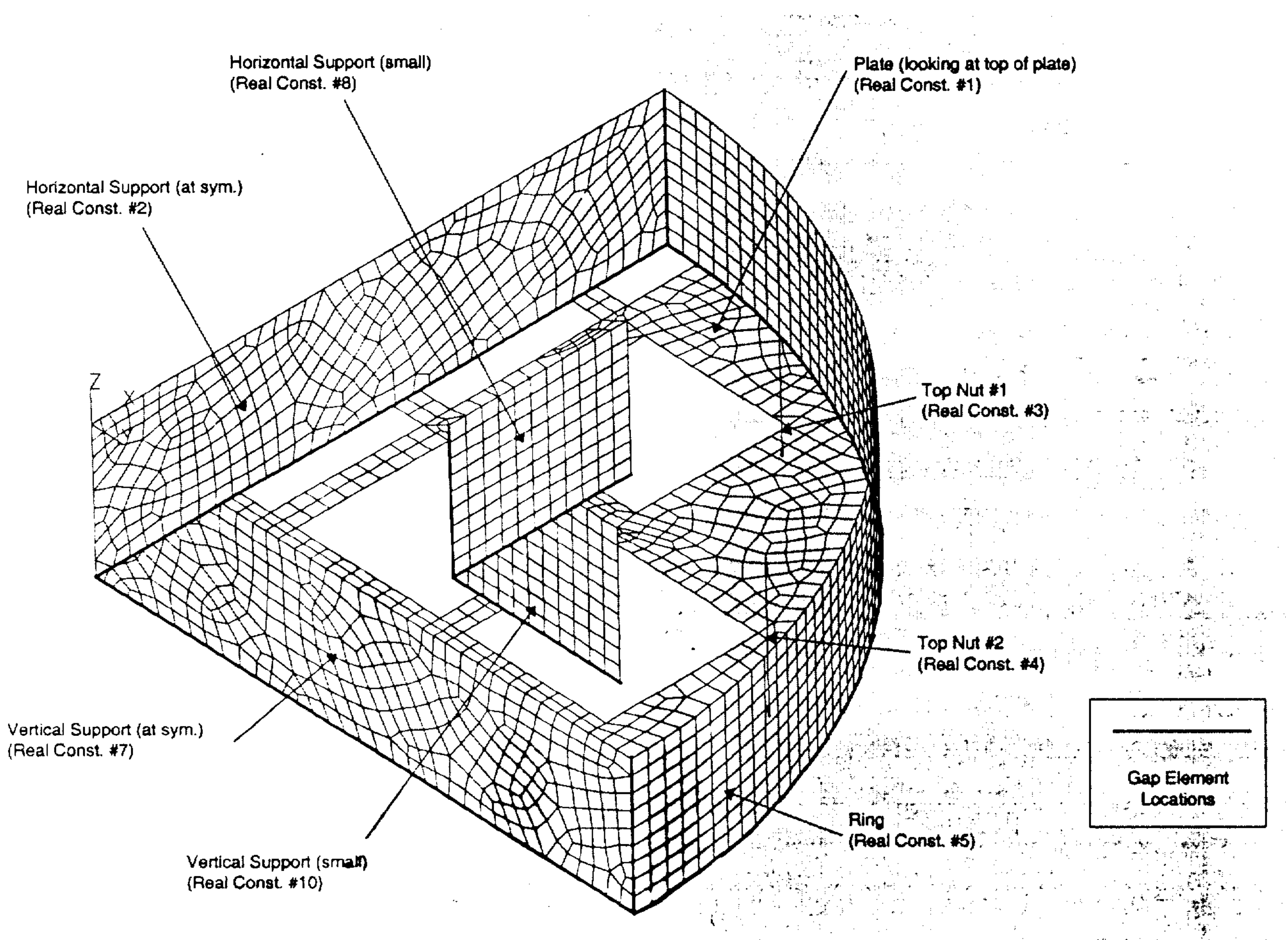


Figure 2.6.13.13-2 Finite Element Model of the Bottom Weldment Plate

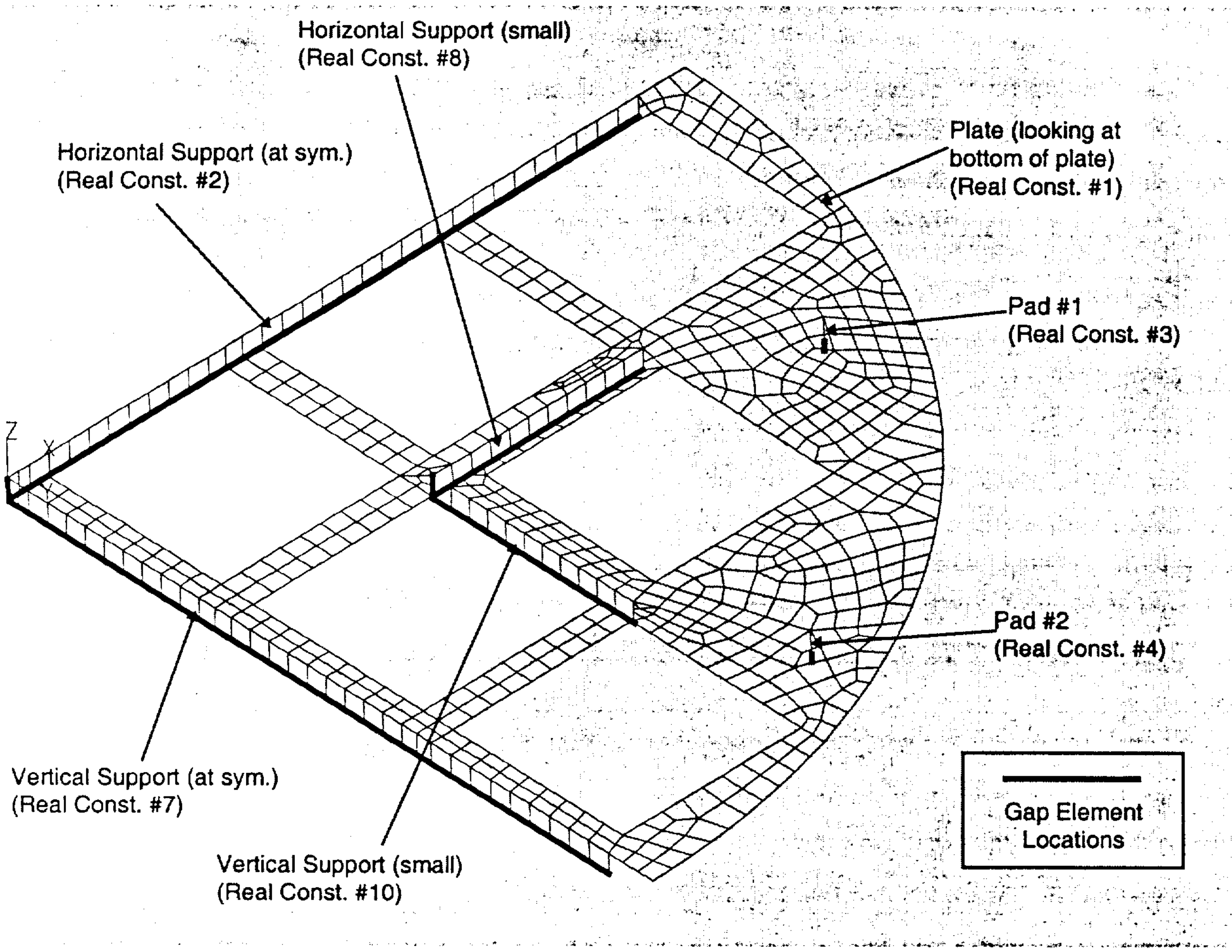


Table 2.6.13.13-1 Minimum Margins of Safety for the Top/Bottom Weldments for 1-Foot End-Drop

Component/Condition	P_m (ksi)	Allowable S_m (ksi)	MS
Top Weldment/1-ft End-Drop	5.86	17.38	+1.97
Bottom Weldment/1-ft End-Drop	6.13	17.56	+1.86
Component/Condition	$P_m + P_b$ (ksi)	Allowable $1.5S_m$ (ksi)	MS
Top Weldment/1-ft End-Drop	2.54	26.07	+9.26
Bottom Weldment/1-ft End-Drop	4.33	26.34	+5.08
Component/Condition	$P_m + P_b + Q$ (ksi)	Allowable $3S_m$ (ksi)	MS
Top Weldment/1-ft End-Drop + Thermal	35.41	52.14	+0.47
Bottom Weldment/1-ft End-Drop + Thermal	35.27	52.68	+0.49

2.6.13.14 Support Disk Buckling Evaluation

The PWR fuel basket support disks are subjected to compressive and inertial loads during impact conditions. Depending on the cask orientation for the impact, both in-plane and out-of-plane loads are applied to the support disk. The in-plane loads (basket side impact component) apply compressive forces and in-plane (strong axis) bending moments on the support disk and the out-of-plane inertial loads (basket end-impact component) produce out-of-plane (weak axis) bending moments on the support disk.

Buckling of the support disk is evaluated in accordance with the methods and acceptance criteria of NUREG/CR-6322. The support disk buckling evaluation for the hypothetical accident conditions is presented in Section 2.7.8.3.

2.6.13.14.1 Support Disk Buckling Evaluation Input Data

The support disk is constructed of SA-693, Type 630, 17-4 PH stainless steel plate. The properties are evaluated at the actual temperature of the locations where buckling evaluations are performed.

2.6.13.14.2 Detailed Support Disk Buckling Evaluation

Methodology

The buckling evaluation of the support disk web is based on the Interaction Equations 31 and 32 in NUREG/CR-6322. These two equations adopt the "Limit Analysis Design" approach for structural members subjected to stresses beyond the yield limit of the material, i.e., for members deformed elastically as a result of both axial load and bending moment. Other equations applicable to the calculations are listed later in this section.

The maximum forces and moments are determined for the end-drop condition and for four different radial orientations of the support disk for the side-drop condition based on the stress results of the finite element analysis (Sections 2.6.13.4 through 2.6.13.7). The forces and

moments for the cask off-angle drop conditions are determined from the end and side drop results based on the drop angle. The buckling evaluations account for both in-plane (about the strong axis of the web) and out-of-plane (about the weak axis of the web) buckling modes. Evaluation for strong axis buckling is performed only for the side drop condition since it is the governing case. Evaluation for weak axis buckling is performed for all end drops and off-angle drops (0°, 23°, 30°, 40°, 45°, 50°, 60°, 70°, 75°, 80°, 85°, and 88°).

Detailed buckling calculations are performed using ANSYS macros. The methodology and equations used in the calculations are those from NUREG/CR-6322. The load amplification factors used are 20 *g* for 1-ft end-drop, 1-ft side-drop, and off-angle drop conditions. The buckling evaluation is performed for each of the sections identified in Figures 2.6.13.2-3 and 2.6.13.2-4.

The buckling evaluation methodology/equations are summarized as follows:

Symbols and Units

- P = applied compressive axial load, kips
- M = moment, kips-in.
- P_a = allowable axial compressive load, kips
- P_{cr} = critical axial compression load, kips
- P_e = Euler buckling loads, kips
- P_y = plastic axial load, equal to profile area times specified minimum yield stress, kips (for normal operating condition)
- C_c = column slenderness ratio separating elastic and inelastic buckling
- C_m = coefficient applied to bending term in interaction equation
- M_m = critical moment that can be resisted by a plastically designed member in the absence of axial load, kip-in.
- M_p = plastic moment, kip-in.
- F_a = axial compressive stress permitted, ksi
- F_e = Euler stress for a prismatic member divided by factor of safety, ksi
- k = ratio of effective column length to actual unbraced length
- l = unbraced length of member, in.

r = radius of gyration, in.
S_y = yield stress allowable, ksi
A = area of the ligament, in^2
Z_x = plastic section modulus with respect to the major axis, in^3
Σ = allowable reduction factor, dimensionless.

From NUREG/CR-6322, the following equations are used to evaluate the support disk for normal conditions:

$$\frac{P}{P_{cr}} + \frac{C_m M}{M_m\left[1 - \frac{P}{P_e}\right]} \le 1.0$$

$$\frac{P}{P_y} + \frac{M}{1.18\,M_p} \le 1.0$$

where: $P_{cr} = 1.7 \times A \times F_a$

$$F_a = \frac{\left[1 - \frac{1}{2}\left(\frac{k\cdot l}{r\cdot C_c}\right)^2\right]\cdot S_y}{\frac{5}{3} + \frac{3}{8}\left(\frac{k\cdot l}{r\cdot C_c}\right) - \frac{1}{8}\left(\frac{k\cdot l}{r\cdot C_c}\right)^3} \quad \text{for} \quad \frac{k\cdot l}{r} < C_c = \sqrt{2\cdot\pi^2\frac{E}{S_y}}$$

$$P_e = 1.92 \times A \times F_e$$

$$F_e = \frac{\pi^2\cdot E}{1.92\left(\frac{k\cdot l}{r}\right)^2} \text{ (non-austenitic)}$$

$$F_e = \frac{\pi^2\cdot E}{1.3\left(\frac{k\cdot l^2}{r}\right)} \text{ (austenitic)}$$

$$P_y = S_y \times A$$

$C_m = 0.85$ for members with joint translation (sideways).

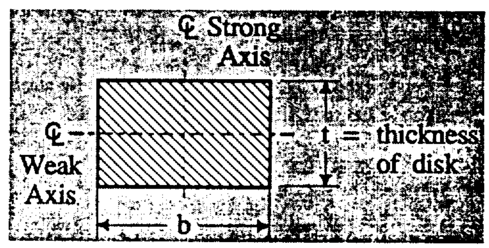
$M_p = S_y \times Z_x$

$$M_m = M_p \cdot \left(1.07 - \frac{\left(\frac{1}{r}\right) \cdot \sqrt{S_y}}{3160} \right) \le M_p$$

Buckling evaluation is performed at all sections defined in Figures 2.6.13.2-3 and 2.6.13.2-4. Using the cross-sectional stresses calculated at each of the section located in the web for each loading condition the corresponding compressive forces (P) and bending moment (M) are determined as follows,

$P = \sigma_m A,$

$M = \sigma_b S,$



where, σ_m is the membrane stress, σ_b is the strong axis bending stress or weak axis bending stress, A is the area (b × t), and S is the section modulus ($tb^2/6$ for strong axis bending and $bt^2/6$ for weak axis bending).

Support disk buckling evaluation results

The equations used in the buckling analysis are:

$$P_1 = P/P_{cr}, \quad M_1 = \frac{C_m M}{(1 - P/P_e) M_m}, \quad (P_1 + M_1 \le 1), \text{ (Eq. 31, NUREG/CR-6322)}$$

and $$P_2 = P/P_y, \quad M_2 = \frac{M_x}{1.18\, M_p}, \quad (P_1 + M_1 \le 1), \text{ (Eq. 32, NUREG/CR-6322)}$$

The margins of safety are calculated as:

$$MS1 = \frac{1}{P_1 + M_1} - 1 \quad \text{(based on Eq. 31, NUREG/CR-6322)}$$

and $$MS2 = \frac{1}{P_2 + M_2} - 1 \quad \text{(based on Eq. 32, NUREG/CR-6322)}$$

Table 2.6.13.14-1 summarizes the worst buckling margins of safety for each stress category and thermal case for normal conditions of transport. As the results demonstrate, the PWR support disks meet the requirements of NUREG/CR-6322.

Table 2.6.13.14-1 Minimum Margins of Safety from Buckling Evaluation of PWR Support Disk

Loading Condition	Stress State*	Thermal Case	Section Number	Drop Angle	Basket Angle	P (kip)	P_{cr} (kip)	M (in-kip)	M_p (in-kip)	M_m (in-kip)	MS1	MS2
Strong Axis Buckling												
Normal	P	A	21	90.00	45.00	3.8	39.3	2.9	10.9	10.7	1.97	2.18
	P+Q	A	4	90.00	26.28	7.8	59.6	6.2	23.6	23.6	1.80	1.88
	P	B	21	90.00	45.00	4.1	46.2	3.2	13.1	12.7	2.26	2.51
	P+Q	B	21	90.00	45.00	4.2	46.7	3.3	13.1	12.7	2.20	2.45
Weak Axis Buckling												
Normal	P	A	29	85.00	0.00	10.3	47.5	0.0	8.5	7.4	3.59	5.57
	P+Q	A	29	90.00	0.00	13.7	47.5	0.0	8.5	7.4	2.47	3.97
	P	B	29	85.00	0.00	10.6	53.4	0.0	9.8	8.5	4.02	6.40
	P+Q	B	29	85.00	0.00	10.6	53.4	0.0	9.8	8.5	3.98	6.33

* P = Primary Stress, P+Q = Primary + Secondary Stresses.

2.6.14 BWR Transportable Storage Canister Analysis - Normal Conditions of Transport

In this section, the Transportable Storage Canister Assembly containing BWR fuel is evaluated for the normal conditions of transport. The principal components of the canister assembly are the canister, fuel basket assembly, shield lid, and structural lid. The canister and the canister shell, bottom plate, and lids are shown in Figures 2.6.14-1 and 2.6.14-2.

Spacers are used to properly locate the canisters containing Class 4 and 5 BWR fuel in the cask cavity. The analysis of the spacers is presented in Section 2.6.16. The geometries and materials of construction of the canister, baskets, and spacers are described in Section 1.2.1.2.

Figure 2.6.14-1 BWR Transportable Storage Canister

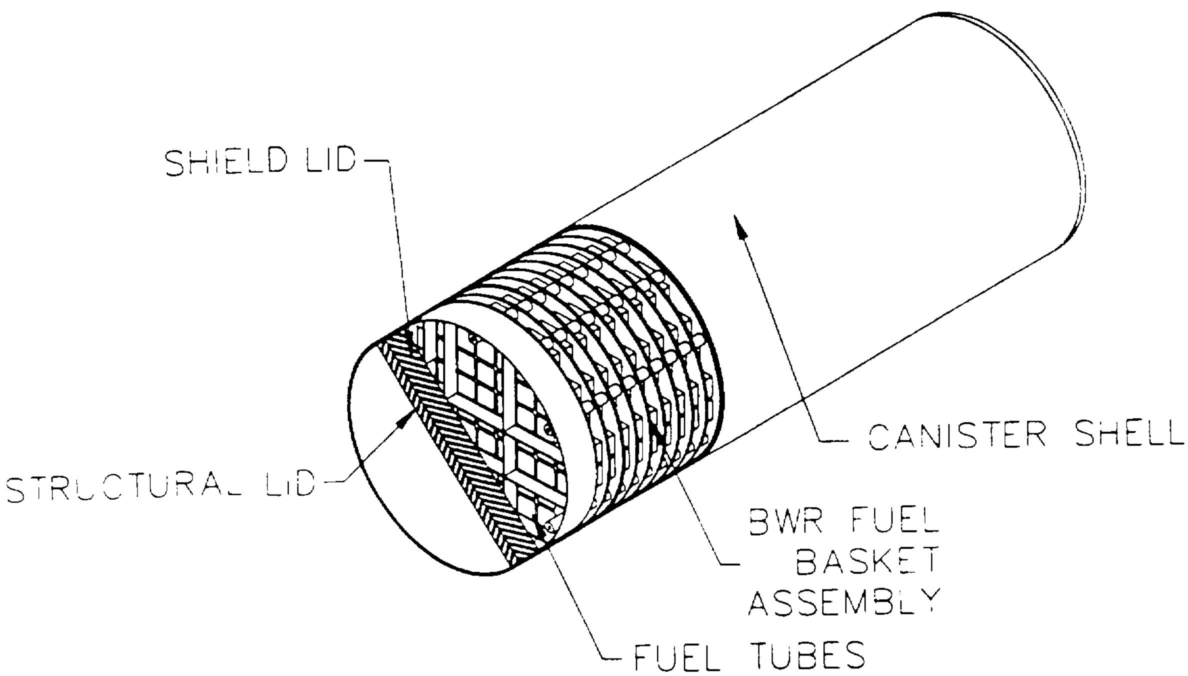
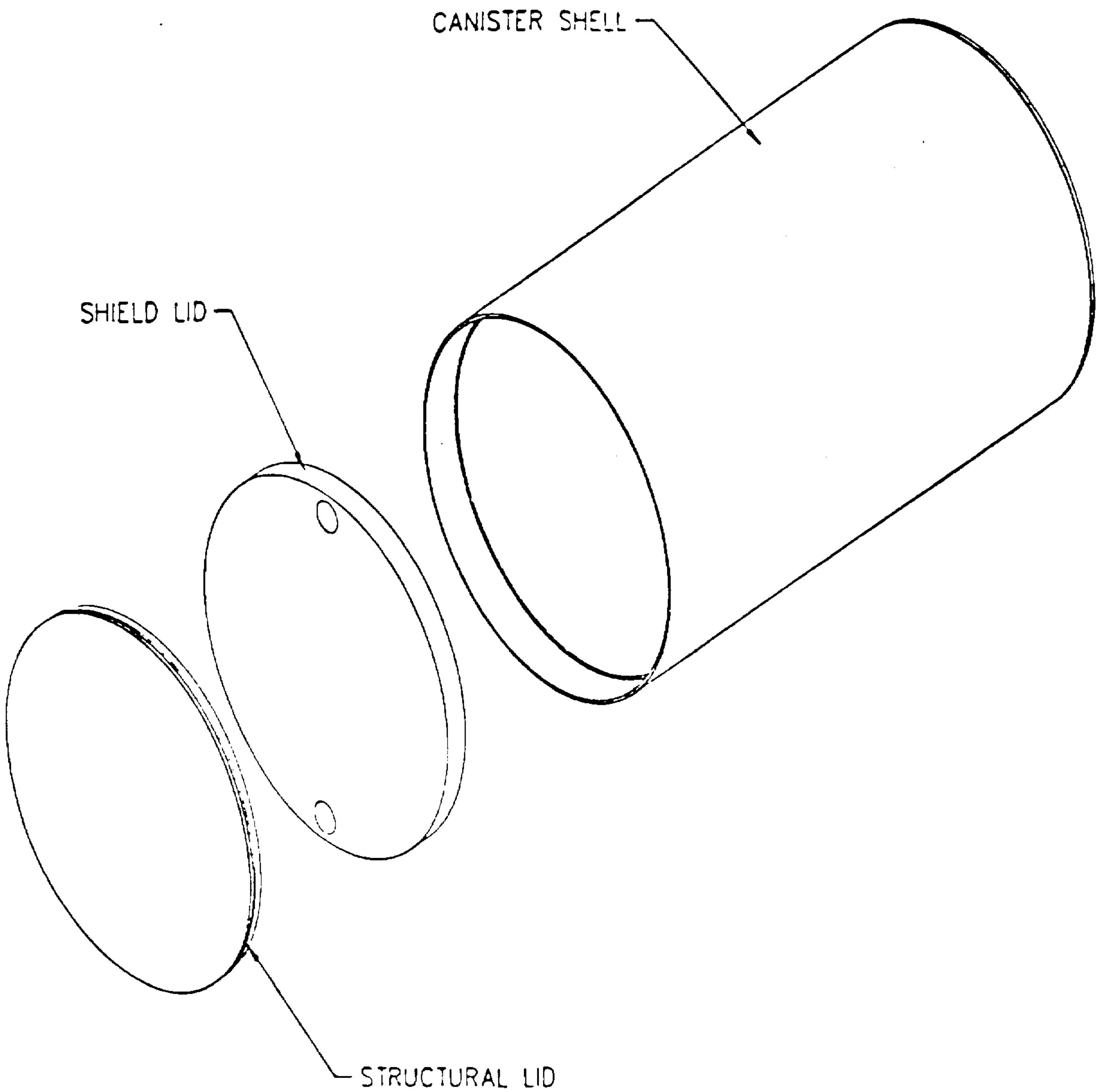


Figure 2.6.14-2 BWR Transportable Storage Canister Shell and Lids



2.6.14.1 Analysis Description

Two canisters of different lengths are designed to accommodate the two classes of BWR fuel. The overall lengths of the two BWR canisters are 185.75 in and 190.55 in. Other design parameters of the canisters are provided in Table 1.2-3. For this analysis, the largest load per disk configuration (BWR Class 4) is modeled with the longest canister of 191.95 in.

As is the case for the PWR canister, the structural design criteria for the BWR canister is the ASME Code, Section III, Subsection NB. Consistent with this criterion, the structural components of the canister are shown to satisfy the allowable stress limits presented in Tables 2.1.2-3 and 2.1.2-4 as applicable. The allowable stresses used in this analysis are based on a maximum material temperature of 380°F for all locations in the canister, unless otherwise indicated. These allowables are conservative for all sections because the maximum temperature in the canister shell central region is determined to be 372°F in the thermal analysis presented in Section 3.4.2. For the canister structural lid weld (Section 13, Figure 2.6.12.3-1), base metal properties are used to define the allowable stress limits since the weld filler rod tensile properties are greater than the base metal. Also, the allowable stress is multiplied by a stress reduction factor of 0.8 per ISG-4.

The ANSYS finite element computer program is used to analyze the canister for the 1-ft free-drop condition in the top and bottom end, side, and top and bottom corner-impact orientations. In addition, the effects of normal operating internal pressure and thermal stresses resulting from exposure of the cask to the hot (100°F ambient and solar insolance) and cold (-40°F ambient) normal conditions are evaluated. The worst-case stresses from these analyses are presented in Section 2.6.14.4.

2.6.14.2 Finite Element Model Description BWR Canister

To evaluate the BWR Transportable Storage Canister for normal conditions of transport, ANSYS is used to construct and analyze a finite element model of the canister and its contents. The contents modeled consist of the fuel basket support disks and weldments. The fuel assemblies, fuel tubes, tie-rods, and related hardware are not explicitly modeled but are accounted for by applying pressure loads to the support disk slots as appropriate.

The maximum unit load per length results in the largest bearing stresses. Stresses in the top and bottom of the canister are not affected by its length. Moreover, distortion in the shell is not affected by the 6-in differential of the longest canister and the shortest canister.

The finite element model of the BWR canister is similar to the model for the PWR canister. A detailed description of the PWR model is provided in Section 2.6.12.2. Table 2.6.14.2-1 lists the real constants assigned to specific components of the model. Table 2.6.14.2-2 lists the material properties used for the model.

Figure 2.6.14.2-1 is a plot of the entire canister finite element model. An isolated view of the canister shield and structural lids portion of the model is presented in Figure 2.6.14.2-2, and an enlarged view of the model in the structural lid and shield lid weld regions is shown in Figure 2.6.14.2-3. The canister bottom plate portion of the model is shown in Figure 2.6.14.2-4.

The loading for the normal operating condition is based on 1-ft drops in conjunction with the internal pressure loading (to the canister). Drop orientations considered are the top and bottom end, side, and top and bottom corner-drops. The transfer of loads due to the drop orientations and the resulting stresses are similar to the PWR canister case discussed in Section 2.6.12.2. The contents weight analyzed includes 38,920 lb for all fuel assemblies (56 fuel assemblies), the fuel tubes weight (4,034 lb), the disk spacer weight (1,060 lb), and the tie rods and nuts weights (586 + 116 lb). The actual bounding fuel assembly weight is 38,976 lb. The effect of the increased contents weight is discussed below.

For the side and corner-drops, the weights of the fuel assemblies (W_{tubes}), fuel tubes (W_{tubes}), tie rods (W_{rods}), nuts/washers (W_{nuts}), and spacers ($W_{spacers}$) are included in the model by applying a pressure load (F_{slot}) to the slot openings of the support/weldment disks. This pressure load is:

$$F_{slot} = \frac{W_{fuel} + W_{tubes} + W_{rods} + W_{nuts} + W_{spacers}}{N_{slots} \times w_{slot} \times N_{disks}} \times g$$

where,

N_{slots} = number of slot openings in each support/weldment disk;
w_{slot} = width of each slot opening in each support/weldment disk;
N_{disks} = number of support/weldment disks; and
g = the associated g-loading for the drop height of interest.

For basket orientations other than 0°, the components of this pressure load are applied to two faces of the slot opening. For corner-drops, the component resulting from accounting for the drop angle is used as the pressure load on the disk slot openings. For the BWR canister drop analyses, with 56 slot openings, a slot opening width of 6.278 inches, and a total of 35 support/weldment disks (33 support disks and 2 weldment disks), the base pressure load is:

$$F_{slot} = \frac{38{,}920 + 4{,}034 + 586 + 116 + 1{,}060}{56 \times 6.278 \times 35} \times g = 3.634 \times g$$

For the end drops, a uniform pressure representing the total weight of the fuel and fuel basket (54,351 lb) is applied to the canister shield lid (for top end-drop) or canister bottom plate (for bottom end-drop). For the corner-drops, the component of this uniform pressure resulting from accounting for the drop angle is applied to the appropriate elements.

Design changes were made to the BWR basket after the finite element analyses of the canister were performed. The effects of the design changes are evaluated as follows. The support disks were changed from thirty-three (33) 0.75-inch thick disks to forty (40) 0.625-inch thick disks. Reducing the thickness of the support disks makes them more similar to the PWR support disks (0.5-inch thick). Increasing the number of disks distributes the internal load more uniformly on the canister shell. Also, seventeen (17) aluminum heat transfer disks were added to the BWR basket design. The heat transfer disks do not provide structural support, but their addition along with the associated spacers does add weight that must be considered.

The increase in the number of support disks has a minimal effect on the stress results presented in this section since this change helps to distribute the load to the canister shell more evenly. In addition, the design changes and bounding fuel assembly weight results in a total fuel and fuel basket weight of 56,821 lb. This is an increase in weight of 2,471 lb (a 4.5% increase) over the total fuel and fuel basket weight (54,351 lb) used in the BWR canister analyses. Therefore, the stress intensities presented in the following tables for the BWR canister are conservatively ratioed up according to the following: Sections 3 through 8 (see Figure 2.6.14.3-1) are increased by 5% for the side and corner-drops to account for the additional contents weight on the canister shell. Sections 1 and 14 stress intensities are increased by 5% for the bottom end and bottom corner-drops to account for the additional load on the canister bottom end. Sections 12, 13, 15,

and 16 stress intensities are increased by 5% for the top end and top corner-drops to account for the additional load on the canister shield lid.

The operational conditions also contain loads developed from the temperature distribution in the canister. The temperature distributions used for the BWR canister analysis are obtained from the PWR thermal evaluation since this resulted in conservative values of the temperatures and temperature gradients in the canister. These are included in the canister model analyses. The thermal analyses are described in Section 3.4.

The BWR canister is analyzed for basket orientations of 0° and 45°. To accurately predict the canister response to impact, both orientations are run for these drop orientations: side, top corner, and bottom corner. Top- and bottom-end-drops are not required because the basket disks are not included in these runs (their presence is accounted for by using applied pressure loads to the inner surface of the top or bottom).

Figure 2.6.14.2-1 BWR Canister Assembly Finite Element Mesh (with 45° Basket orientation)

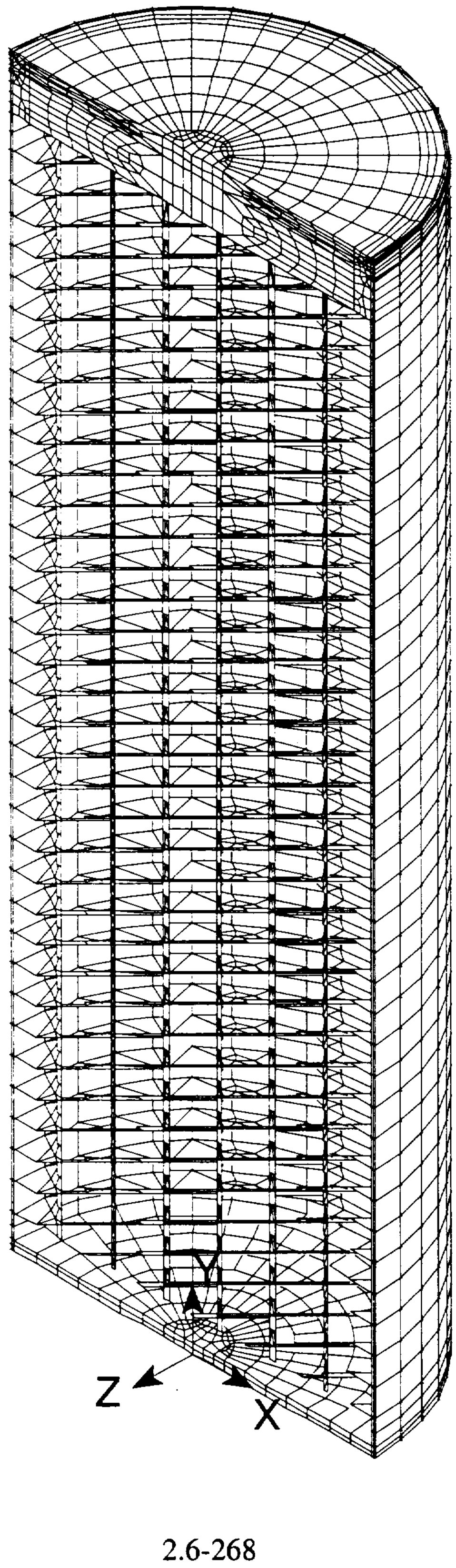


Figure 2.6.14.2-2 Canister Structural and Shield Lid Finite Element Mesh

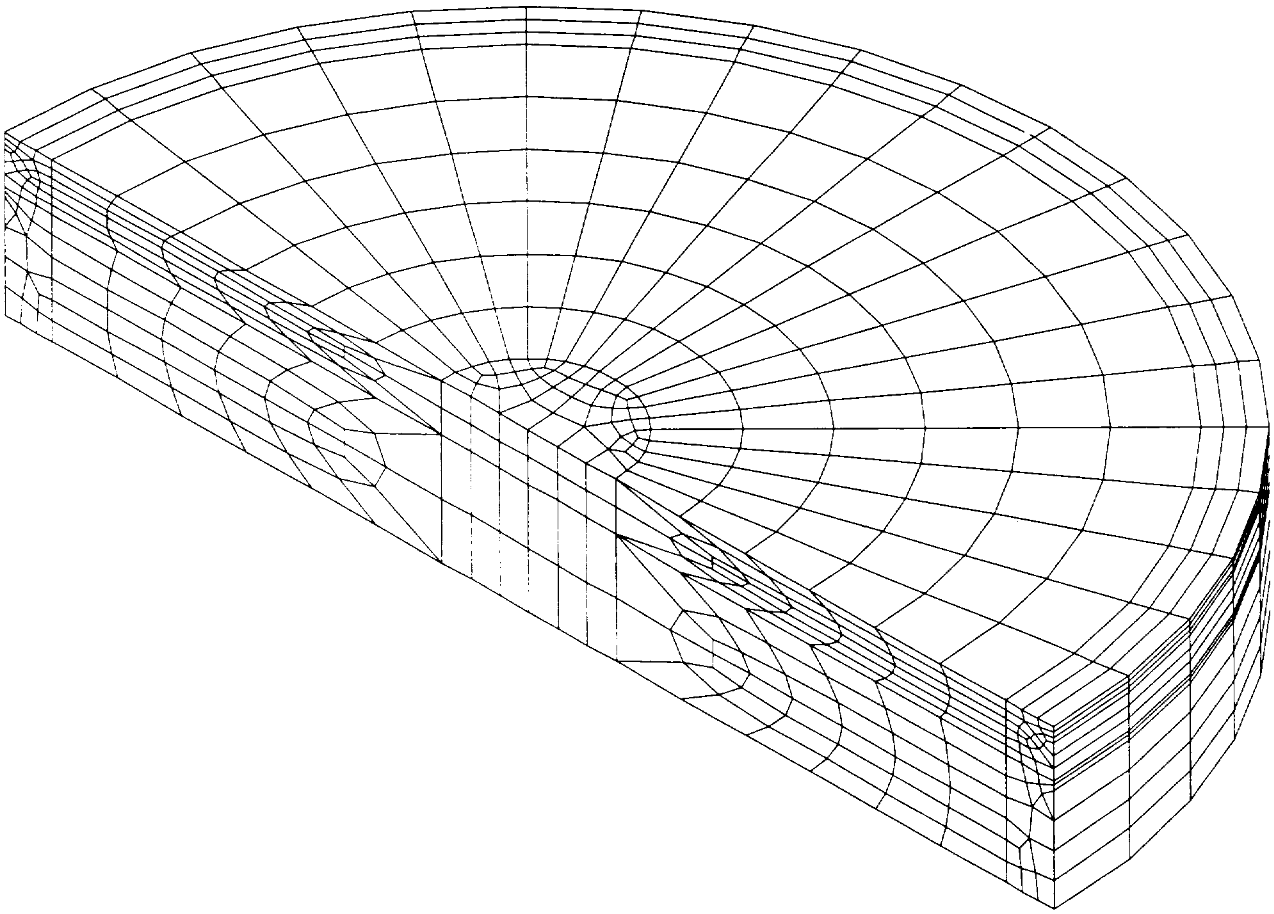


Figure 2.6.14.2-3 Structural and Shield Lid Weld Regions Finite Element Mesh

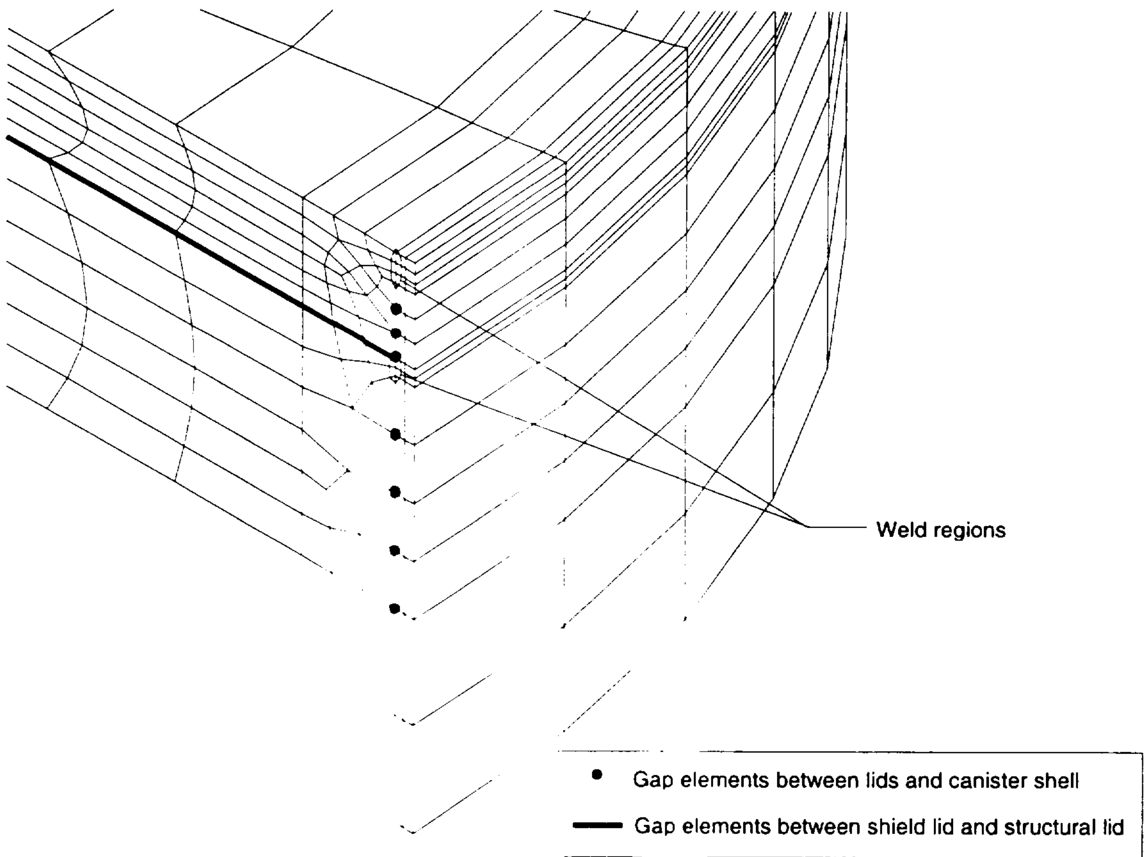


Figure 2.6.14.2-4 Canister Bottom Plate Finite Element Mesh

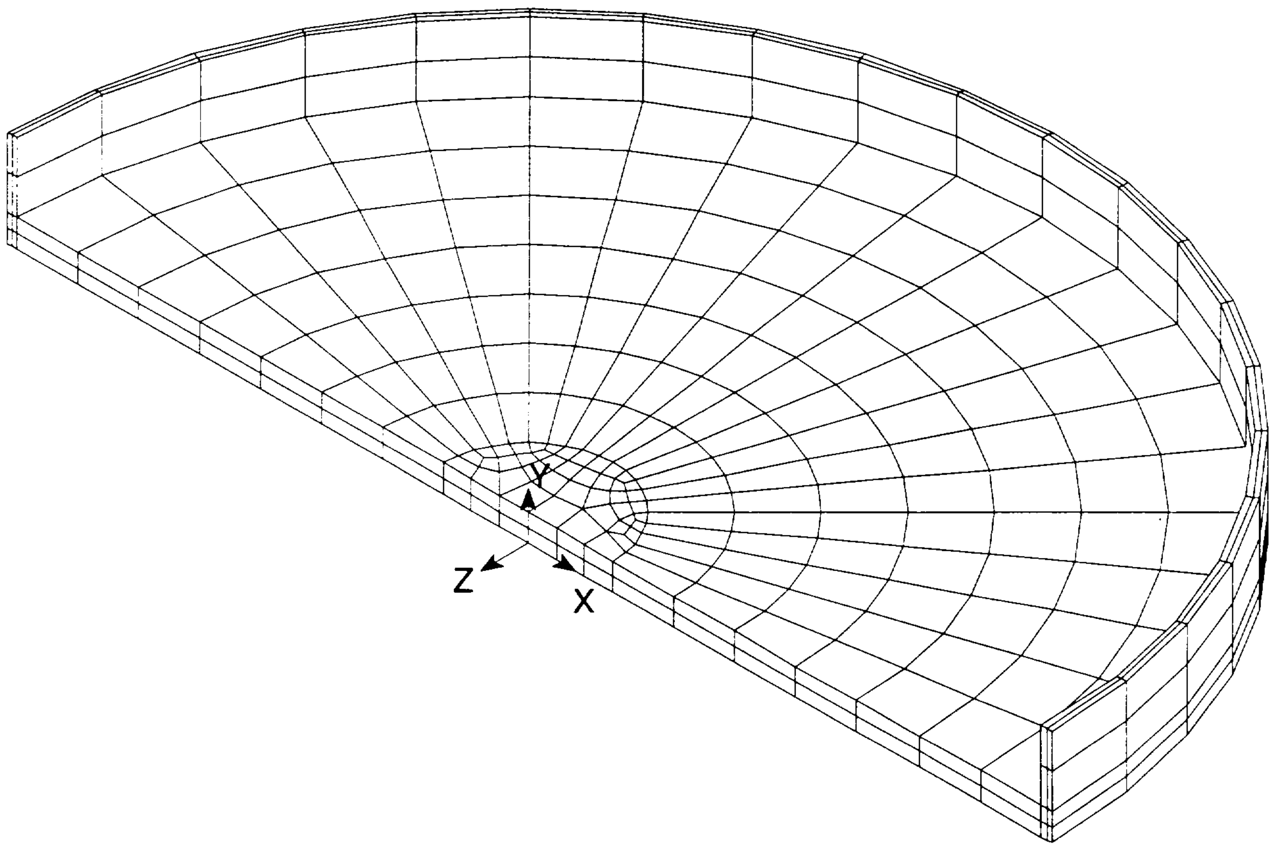


Table 2.6.14.2-1 Real Constant Sets Defined in Canister Model

Real Constant Set	Component
1	Canister Bottom Plate (SOLID45)
2-9	Canister Shell (SOLID45)
10-11	Shield Lid (SOLID45)
12-13	Structural Lid (SOLID45)
100	Axial Gaps from Canister Bottom Plate to Cask Shell (CONTAC52)
200	Radial Gaps from Canister Side to Cask Shell (CONTAC52)
300	Axial Gaps from Structural Lid Top to Cask Shell (CONTAC52)
400	Axial Gaps Between Structural and Shield Lid (COMBIN40)
500	Radial Gaps Between Shield Lid and Canister Inner Surface (CONTAC40)
600	Radial Gaps Between Shield Lid and Canister Inner Radius (CONTAC52)
700	Axial Gaps Between Shield Lid and Canister Wall to Simulate Backing Ring (COMBIN40)
800	Radial Gaps Between Basket and Canister Inner Surface (CONTAC52)
1000	Intermediate Basket Thickness Real Constant
1100	End Basket Thickness Real Constant
1200	Weak Spring Real Constant

Table 2.6.14.2-2 Material Sets Defined in Canister Model

Material Property Set	Component	Material
1	Canister Shell and Structural Lid	304L Stainless Steel; ASME SA240
2	Top and Bottom End Basket Disk	304 Stainless Steel; ASME SA240
3	Shield Lid	304 Stainless Steel; ASME SA240
4	Support disk	ASME SA-533, Type B Class 2 Carbon Steel

2.6.14.3 Thermal Expansion and Thermal Stress Evaluation of Canister for BWR Fuel

A thermal stress evaluation is performed by using ANSYS to determine the differential thermal expansion and the associated thermal stresses that result from a heat load of 16 kW. In assessing the thermal stresses, the following three extreme conditions are considered:

Condition	Ambient Temperature	Solar Insolance Applied to Cask Surface	16 kW Fuel Load
1	100°F	Yes	Yes
2	-40°F	No	Yes
3	-40°F	No	No

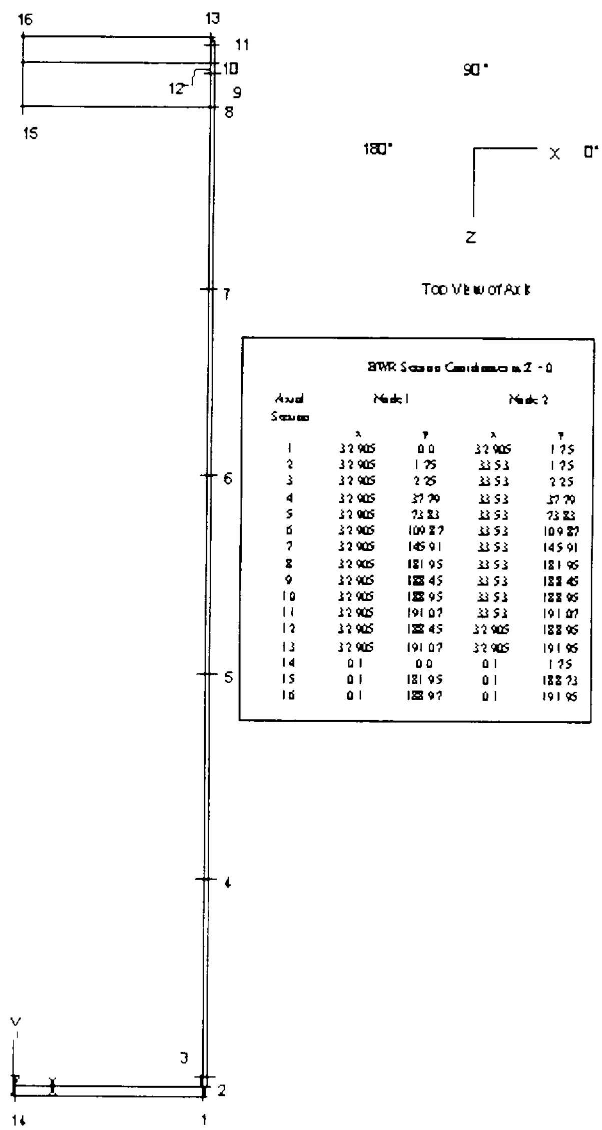
The temperatures employed in the thermal stress analysis are obtained by applying temperatures at 36 key locations on the canister shell and ends to the thermal equivalent model of the structural canister model as thermal boundary conditions. These temperatures are taken from the thermal evaluation described in Section 3.4. The temperature distribution of the PWR canister is conservatively used in the BWR canister analyses since this produces the peak temperatures and temperature gradients. The structural finite element model is described in Section 2.6.14.2 and 2.6.12.2. The equivalent thermal model is obtained by changing the structural element SOLID45, which has three global displacements for degrees of freedom, to a SOLID70, which has temperature degrees of freedom at the individual nodes.

The temperature-dependent thermal conductivity for the canister material is employed in the thermal conduction analysis. The temperatures generated in this analysis are used in the thermal stress analysis to evaluate the properties at temperature as well as the stresses resulting from thermal expansion. Using this method, two separate cases are evaluated: a hot case (100°F ambient with solar heat load and maximum decay heat) and a cold case (-40°F ambient and maximum decay heat). Condition 3 is not evaluated because the entire assembly would be at -40°F for the conditions described.

According to the ASME Code, Section III, Subsection NB, the allowable stress criteria are based on the evaluation of linearized stresses across critical cross sections through the canister wall. For the evaluation of the thermal stresses, the criteria for the stresses are based on peak stresses. The stress values taken from the analyses are the nodal stresses at the surface. The sections used in this evaluation are shown in Figure 2.6.14.3-1. The thermal stresses reported in Tables 2.6.14.3-1 and 2.6.14.3-2 correspond to the maximum stresses for any circumferential section for the locations shown in Figure 2.6.14.3-1.

For Conditions 1 or 2, the canister is hotter than the cask body and will undergo more thermal expansion than the cask body. To conservatively determine the minimum gap between the canister and the cask body results from thermal expansion, only expansion of the canister is considered as is the case in the analysis of the PWR canister. The canister is considered to be at 380°F (the maximum shell temperature for Condition 1 is 372°F) and the cask inner shell temperature is assumed to be 70°F. These conditions are conservatively bounded by the analysis presented in Section 2.6.12.3. Section 2.6.12.3 also provides a conservative evaluation of the axial thermal growth.

Figure 2.6.14.3-1 Identification of the Sections for Evaluating the Linearized Stresses in the Canister



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

Table 2.6.14.3-1 BWR Canister Linearized Q Stresses—Thermal Only (Hot 1)

Section Location	Angle of Peak Stress Location	Q Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	180	-0.5	0	2.3	-0.1	0	-0.2	2.8	47.9	16.29
2	9	0	-0.6	1.3	0	0	0.2	1.9	47.9	23.99
3	9	0	-0.6	1.2	0	0	0.2	1.8	47.9	25.87
4	0	0	-0.2	0.1	0	0	0	0.2	47.9	193.56
5	0	0	-0.5	0.3	0	0	0	0.8	47.9	59.35
6	0	0	-0.8	0.5	0	0.1	0	1.3	47.9	36.13
7	0	0	-0.5	0.1	0	0	0	0.6	47.9	76.09
8	90	1.1	1.6	0	0	0	0	1.6	47.9	28.39
9	162	0	-1.4	-0.4	-0.1	0	0.1	1.5	47.9	30.75
10	90	0.3	1.5	-0.1	-0.2	0	0.1	1.6	47.9	28.3
11	81	-0.4	-1	0.2	-0.1	-0.1	-0.1	1.3	47.9	36.48
12	162	-0.2	0.7	0	-0.1	0.1	-0.2	1	47.9	46.99
13	81	-0.3	0.4	-0.6	0	-0.1	0	1	38.32	37.32
14	0	-9	-1.1	-8.9	0.6	0.7	0.7	8.6	47.9	4.54
15	180	0.3	0	0	-0.8	0	2	4.2	47.9	10.33
16	180	-0.2	0	0.2	-0.6	0	-1.2	2.7	47.9	16.45

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

Table 2.6.14.3-2 BWR Canister Linearized Q Stresses—Thermal Only (Cold 2)

Section Location	Angle of Peak Stress Location	Q Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	180	-0.5	0	2.5	-0.1	0	-0.2	3.1	47.9	14.55
2	45	1.3	0.5	1.3	0	0	1	2.1	47.9	21.79
3	9	0	-0.6	1.4	0	0	0.2	1.9	47.9	23.64
4	0	0	-0.2	0.1	0	0	0	0.3	47.9	159.33
5	0	0	-0.6	0.4	0	-0.1	0	0.9	47.9	49.66
6	0	0	-1	0.5	0	0.1	0	1.5	47.9	30.31
7	0	0	-0.7	0.1	0	0	0	0.8	47.9	60.83
8	90	1.2	1.8	0	0	0	0	1.8	47.9	25.66
9	162	0.1	-1.4	-0.4	-0.1	0	0.1	1.5	47.9	30.23
10	90	0.4	1.7	-0.1	-0.2	0	0.1	1.8	47.9	24.97
11	81	-0.5	-1.1	0.2	-0.1	-0.1	-0.2	1.4	47.9	32.93
12	162	-0.2	0.7	0	-0.1	0.2	-0.2	1	47.9	44.7
13	81	-0.4	0.4	-0.7	0	-0.1	0	1.1	38.32*	33.84
14	0	-10.1	-1.3	-9.9	0.6	0.8	0.7	9.5	47.9	4.04
15	180	0.3	0	-0.1	-0.7	0	1.7	3.7	47.9	11.83
16	180	-0.2	0	0.2	-0.6	0	-1.1	2.4	47.9	18.7

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

2.6.14.4 Stress Evaluation of BWR Canister for 1-Foot End-Drop Load Condition

A structural analysis is performed using ANSYS to evaluate the effect of a 1-ft end-drop impact for both the bottom and top end orientations of the BWR canister. The ASME Code, Section III, Subsection NB requires that the stresses from operational loads be assessed on the basis of the primary loads. The primary loads for the 1-ft drop are due to the deceleration of the canister and its contents and the 25 psig pressure load internal to the canister. The applied deceleration is 20 *g* for both orientations. The inertial load of the canister is addressed by the deceleration factor applied to the canister density. The contents weight is represented by a pressure load on the inner end surface of the canister. Displacement constraints are applied to the plane of symmetry and the gap elements attached at the canister end to represent the top or bottom of the transport cask.

To determine the effect of the 25 psig pressure load, the top-end and bottom-end orientations with and without the pressure load are analyzed.

The locations of the linearized stresses are shown in Figure 2.6.14.3-1. The maximum stresses for P_m and $P_m + P_b$ are tabulated in Tables 2.6.14.4-2 through 2.6.14.4-7. Results from the end-drop analyses are presented for the cases that result in the minimum margins of safety. The critical sections for the pressure and the pressure plus the deceleration load, with reference to the section and the appropriate tables, are shown in Table 2.6.14.4-1. The margins of safety in these tables are calculated as:

MS = (allowable stress/SI) -1.

Table 2.6.14.4-1 BWR Canister Critical Sections for the 1-Foot End-Drop Condition

Condition	Stress	Critical Section	Table	Minimum Margin of Safety
Pressure (only)	P_m	2	2.6.14.4-2	+ 4.04
Pressure (only)	$P_m + P_b$	3	2.6.14.4-3	+ 1.28
Top End-Drop Inertia	P_m	3	2.6.14.4-4	+ 4.15
Top End-Drop Inertia	$P_m + P_b$	2	2.6.14.4-5	+ 1.65
Bottom End-Drop + Pressure	P_m	4	2.6.14.4-6	+ 4.18
Bottom End-Drop + Pressure	$P_m + P_b$	2	2.6.14.4-7	+ 6.13

Table 2.6.14.4-2 BWR Canister P_m Stresses - Internal Pressure

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-0.1	2	0.7	-0.4	0	0.1	2.2	16	6.12
2	0	0.9	-1.4	-2.2	-0.4	0	-0.2	3.2	16	4.04
3	0	0.6	-0.9	-2.6	-0.2	0	-0.2	3.2	16	3.94
4	180	0	0.7	1.3	0	0	-0.1	1.3	16	10.95
5	0	0	0.7	1.3	0	0	0.1	1.3	16	11.02
6	0	0	0.7	1.3	0	0	0.1	1.3	16	11.02
7	0	0	0.7	1.3	0	0	0.1	1.3	16	11.02
8	0	0	0.7	0.7	0	0	0.1	0.7	16	22.62
9	0	0	0.5	0.3	0.1	0	0	0.5	16	33.49
10	0	-0.3	0.3	0.2	-0.1	0	0	0.6	16	25.64
11	18	0.3	-0.1	0.2	0	0	-0.1	0.4	16	38.49
12	0	-0.1	-0.4	0	-0.1	0	0	0.5	16	34.2
13	180	0	0.3	0.2	0	0	0	0.3	12.8*	41.67
14	90	0.3	0	0.3	-0.1	0.1	0	0.4	16	35.12
15	180	0	0	0	0	0	0	0	16	1809.97
16	90	0	0	0	0	0	0	0	16	378.21

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

Table 2.6.14.4-3 BWR Canister $P_m + P_b$ Stresses - Internal Pressure

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	0.9	4.5	-0.5	-0.2	0	-0.1	5	24	3.77
2	0	0.8	-9.5	-4.6	-0.7	0	-0.4	10.5	24	1.28
3	0	0.7	-9.1	-5	-0.4	0	-0.4	9.8	24	1.44
4	0	0	0.7	1.3	0	0	0.1	1.4	24	16.64
5	0	0	0.7	1.3	0	0	0.1	1.4	24	16.74
6	0	0	0.7	1.3	0	0	0.1	1.3	24	16.77
7	180	0	0.7	1.3	0	0	-0.1	1.4	24	16.76
8	0	0	0.7	0.7	0	0	0.1	0.7	24	31.43
9	0	0.1	0.9	0.5	0.1	0	0	0.9	24	26.1
10	180	-0.1	1.4	0.6	0	0	-0.1	1.5	24	14.52
11	18	0.2	-0.9	-0.1	0.1	0	-0.1	1.1	24	20.14
12	135	-0.2	-0.8	-0.2	0.1	0.1	-0.1	0.7	24	34.23
13	0	-0.4	0	0	0.1	0	0	0.4	19.2*	47.00
14	90	8.1	0.1	8.1	-0.1	0.1	0	8.1	24	1.97
15	90	-0.6	0	-0.6	0	0	0	0.6	24	39.21
16	90	0.3	0	0.3	0	0	0	0.3	24	73.72

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

Table 2.6.14.4-4 BWR Canister P_m Stresses - 1-Foot Top End-Drop

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	0.1	-1.7	-0.6	0.3	0	-0.1	2	16	7.19
2	0	-0.7	1.2	2.1	0.4	0	0.2	2.9	16	4.46
3	0	-0.5	0.8	2.6	0.2	0	0.2	3.1	16	4.15
4	171	0	-0.8	0	0	0	0	0.8	16	18.84
5	36	0	-1	0	0	0	0	1	16	14.77
6	144	0	-1.2	0	0	0	0	1.2	16	12.07
7	171	0	-1.4	0	0	0	0	1.4	16	10.13
8	180	0	-1.3	0	0	0	0	1.4	16	10.52
9	135	-0.1	-1	-0.1	0	0	0.1	1	16	14.79
10	144	-0.1	-1	-0.1	0	0	0.1	0.9	16	16.12
11	135	-0.1	-0.9	-0.1	0	0	0.1	0.9	16	16.62
12*	144	0	-0.7	-0.1	0	0	0	0.8	16	19.77
13*	180	0	-0.8	-0.1	0	0	0	0.8	12.8**	15.00
14	90	-0.2	0	-0.2	0.1	-0.1	0	0.4	16	41.06
15*	144	0	-0.3	0	0	0	0	0.4	16	43.07
16*	0	0	-0.4	0	0	0	0	0.4	16	38.68

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

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

Table 2.6.14.4-5 BWR Canister $P_m + P_b$ Stresses - 1-Foot Top End-Drop

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-0.7	-4	0.6	0.1	0	0.1	4.6	24	4.2
2	0	-0.7	8.2	4.2	0.6	0	0.4	9	24	1.65
3	0	-0.6	7.9	4.6	0.4	0	0.4	8.5	24	1.81
4	180	0	-0.8	0	0	0	0	0.8	24	28.6
5	153	0	-1	0	0	0	0	1	24	22.64
6	162	0	-1.2	0	0	0	0	1.2	24	18.58
7	180	0	-1.4	0	0	0	0	1.4	24	15.68
8	180	0.1	-1.3	0	-0.1	0	0	1.4	24	15.81
9	135	-0.1	-1.2	-0.1	0	0	0.1	1.1	24	20.03
10	180	0	-1.1	-0.2	0	0	0	1.1	24	20.69
11	45	-0.1	-1	-0.1	0	0	-0.1	1	24	22.71
12*	180	0.1	-0.7	-0.1	-0.1	0	0	0.8	24	28.62
13*	180	0	-0.8	-0.1	0	0	0	0.8	19.2**	23.00
14	90	-7.3	-0.1	-7.3	0.1	-0.1	0	7.2	24	2.32
15*	81	0.1	-0.3	0.1	0	0	0	0.4	24	53.27
16*	0	0	-0.4	0	0	0	0	0.4	24	57.08

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

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

Table 2.6.14.4-6 BWR Canister P_m Stresses - 1-Foot Bottom End-Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1*	180	0	-0.7	-0.1	0.1	0	0	0.7	16	21.2
2	180	0.2	-1.9	-0.3	0.1	0	0	2.2	16	6.41
3	180	0.1	-2	-0.2	0.1	0	0	2.1	16	6.58
4	180	0	-1.8	1.3	0	0	-0.1	3.1	16	4.18
5	180	0	-1.6	1.3	0	0	-0.1	2.9	16	4.57
6	0	0	-1.3	1.3	0	0	0.1	2.7	16	5.01
7	180	0	-1.1	1.3	0	0	-0.1	2.5	16	5.52
8	180	0	-0.7	0.7	0	0	-0.1	1.4	16	10.31
9	72	-0.4	-0.5	-0.1	0	0.1	-0.1	0.4	16	36.29
10	180	0.4	-0.3	-0.2	-0.1	0	0	0.7	16	21.41
11	0	-0.5	0.1	-0.2	0	0	0	0.6	16	27.65
12	0	0.1	0.5	-0.1	0.1	0	0	0.5	16	28.25
13	180	0	-0.5	-0.3	0	0	0	0.4	12.8**	31.00
14*	0	0.1	-0.4	0.1	0	0	0	0.5	16	33.31
15	180	0	0	0	0	0	0	0.1	16	271.79
16	90	0	0	0	0	0	0	0	16	423.44

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

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

Table 2.6.14.4-7 BWR Canister $P_m + P_b$ Stresses - 1-Foot Bottom End-Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1*	180	0.1	-0.7	0	0.1	0	0	0.8	24	27.93
2	180	0.1	-3.2	-0.7	0.1	0	0.1	3.4	24	6.13
3	180	0.1	-3	-0.5	0.1	0	0	3.1	24	6.68
4	0	0	-1.8	1.3	0	0	0.1	3.1	24	6.74
5	0	0	-1.6	1.3	0	0	0.1	2.9	24	7.31
6	0	0	-1.3	1.3	0	0	0.1	2.7	24	7.97
7	0	0	-1.1	1.3	0	0	0.1	2.5	24	8.74
8	45	0.3	-0.9	0.3	0	0	0.3	1.5	24	14.93
9	72	-0.5	-1.1	-0.1	0	0.1	-0.1	1.1	24	21.24
10	90	-0.7	-1.6	0.1	0	0	0	1.8	24	12.59
11	0	-0.2	1.3	0.2	-0.1	0	0	1.5	24	14.87
12	90	0.1	0.8	0.5	0	-0.2	0	0.8	24	29.83
13	180	0.5	0	0	0.1	0	0	0.5	19.2**	37.4
14*	0	0.1	-0.4	0.1	0	0	0	0.5	24	47.50
15	90	0.8	0	0.8	0	0	0	0.8	24	28.02
16	90	-0.4	0	-0.4	0	0	0	0.4	24	59.45

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

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

2.6.14.5 Stress Evaluation of BWR Canister for Combined Thermal and 1-Foot End-Drop Load Condition

The stress evaluation of the BWR canister is performed by applying the thermal stress loads described in Section 2.6.14.3 in conjunction with the primary loads in Section 2.6.14.4 to produce a combined thermal stress plus end-impact loading. The evaluation is in accordance with the ASME Code, Section III, Subsection NB. The most critical sections are listed in Table 2.6.14.5-1. The stresses reported in this table correspond to the nodal stress at the surface. When 3 S_m is used as the stress criteria, the minimum margin of safety is +2.27. Tables 2.6.14.5-2 through 2.6.14.5-5 present the peak stresses for the hot and cold conditions for both the top and bottom end-drop cases for the loading conditions that result in the minimum margin of safety. The margins of safety are calculated as:

MS = (allowable stress/SI) -1.

Table 2.6.14.5-1 BWR Canister Critical Sections for the Combined 1-Foot End-Drop and Thermal Load Condition

Condition	**Stress**	**Critical Section**	**Table**	**Minimum Margin of Safety**
Top-End-Drop + Thermal (cold)	$P_m + P_b + Q$	14	2.6.14.5-2	+ 2.27
Top-End-Drop + Thermal (hot)	$P_m + P_b + Q$	14	2.6.14.5-3	+ 2.42
Bottom-End-Drop + Thermal (cold)	$P_m + P_b + Q$	14	2.6.14.5-4	+ 6.04
Bottom-End-Drop + Thermal (hot)	$P_m + P_b + Q$	14	2.6.14.5-5	+ 7.85

Table 2.6.14.5-2 BWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Top End-Drop, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	162	-0.8	-5.1	1.6	0	0	-0.9	7.1	47.9	5.78
2	171	-0.5	10	6.5	-0.5	-0.2	-1.1	10.7	47.9	3.5
3	171	-0.3	9.2	6.6	-0.3	-0.2	-1.1	9.7	47.9	3.94
4	0	0	-1.2	0	0	0	0	1.2	47.9	39.52
5	0	0	-1.9	0.2	0	-0.1	0	2.1	47.9	21.85
6	0	0	-2.6	0.4	0	0.1	0	3	47.9	14.95
7	0	0	-2.7	-0.1	0	0	0	2.7	47.9	16.85
8	9	-0.1	-3.3	0	0	0.1	0	3.3	47.9	13.41
9	162	0.1	-3.1	-0.7	-0.1	-0.1	0.3	3.3	47.9	13.55
10	0	-0.1	-2	-0.5	0.1	0	0	1.9	47.9	23.64
11	171	0	-3.2	-0.8	0	0	0.1	3.2	47.9	13.85
12*	0	0.3	-0.9	-0.1	0.2	0	0	1.4	47.9	33.21
13*	0	0.1	-1.1	-0.2	0.1	0	0	1.3	38.32**	28.48
14	0	-15.9	-1.3	-15.1	0.1	-0.8	0	14.7	47.9	2.27
15*	90	0.1	-0.3	0.1	0	0	0	0.4	47.9	112.07
16*	0	0.1	-0.5	0.1	0	0	0	0.6	47.9	84.16

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

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

Table 2.6.14.5-3 BWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Top End-Drop, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	9	-1	-5.1	1.8	0	0	0.5	6.9	47.9	5.9
2	171	-0.5	9.9	6.3	-0.5	-0.2	-1.1	10.7	47.9	3.49
3	171	-0.4	9.2	6.4	-0.3	-0.1	-1.1	9.7	47.9	3.92
4	0	0	-1.1	0	0	0	0	1.1	47.9	40.91
5	0	0	-1.8	0.2	0	-0.1	0	1.9	47.9	23.6
6	0	0	-2.4	0.3	0	0.1	0	2.8	47.9	16.39
7	0	0	-2.5	0	0	0	0	2.5	47.9	18.26
8	9	-0.1	-3.1	0	0	0.1	0	3.1	47.9	14.54
9	162	0.1	-3	-0.7	-0.1	-0.1	0.3	3.2	47.9	13.92
10	162	-0.3	-2.1	-0.6	-0.2	-0.1	0.1	1.8	47.9	25
11	171	0	-2.9	-0.7	0	0	0.1	3	47.9	15.12
12*	0	0.3	-0.9	-0.1	0.2	0	0	1.3	47.9	35.24
13*	0	0.1	-1	-0.1	0	0	0	1.2	38.32**	30.93
14	0	-15.1	-1.1	-14.4	0.1	-0.7	0	14	47.9	2.42
15*	90	0.1	-0.3	0.1	0	0	0	0.4	47.9	112.18
16*	0	0.1	-0.5	0.1	0	0	0	0.5	47.9	86.30

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

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

Table 2.6.14.5-4 BWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Bottom End-Drop, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1*	162	0.3	-2.1	1.3	0.2	0	-0.4	3.8	47.9	11.61
2	9	0	-3.5	1.1	-0.1	0.1	0.2	4.6	47.9	9.48
3	9	0	-3.5	1	0	0.1	0.1	4.5	47.9	9.69
4	0	0	-3.1	0	0	0	0	3.1	47.9	14.61
5	0	0	-3.1	0.3	0	-0.1	0	3.4	47.9	13.21
6	0	0	-3.2	0.5	0	0.1	0	3.7	47.9	12.02
7	0	0	-2.6	0	0	0	0	2.7	47.9	17.02
8	9	-0.1	-2.6	0	0	0.2	0	2.6	47.9	17.59
9	162	-0.2	-3.3	-1.3	0.1	0.1	0.4	3.3	47.9	13.64
10	0	0.4	-4	-1.5	0	0.1	-0.1	4.4	47.9	9.98
11	0	-0.5	2.8	0.7	-0.1	0.1	0.1	3.3	47.9	13.37
12	18	1.2	1.7	0.4	0.5	0.1	-0.1	1.6	47.9	28.13
13	0	-1.4	-2.1	-1	0.3	0	0	1.2	38.32**	30.93
14*	0	-10.8	-4.4	-10	0	0.2	0	6.7	47.9	6.15
15	72	1.7	0	1.4	0	0	0	1.7	47.9	27.57
16	81	-0.7	0	-0.6	0	0	0	0.7	47.9	67.25

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

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

Table 2.6.14.5-5 BWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Bottom End-Drop, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1*	162	0.3	-2	1.2	0.2	0	-0.4	3.5	47.9	12.69
2	9	0	-3.5	0.9	-0.1	0.1	0.1	4.4	47.9	9.89
3	9	0	-3.5	0.8	0	0.1	0.1	4.3	47.9	10.12
4	0	0	-3	0	0	0	0	3	47.9	15.16
5	0	0	-3	0.2	0	-0.1	0	3.2	47.9	13.91
6	0	0	-3	0.4	0	0.1	0	3.5	47.9	12.89
7	0	0	-2.5	0	0	0	0	2.5	47.9	17.93
8	9	-0.1	-2.4	0	0	0.2	0	2.4	47.9	18.79
9	162	-0.2	-3.2	-1.3	0.1	0.1	0.4	3.1	47.9	14.42
10	162	0.1	-3.8	-1.4	-0.1	0.1	0.5	4.1	47.9	10.79
11	9	-0.5	2.6	0.6	-0.1	0.1	0.2	3.2	47.9	14.15
12	162	0.7	1.9	0.2	-0.4	0	0.1	1.8	47.9	25.33
13	0	1	-0.2	0.2	-0.1	0	-0.1	1.2	38.32**	30.93
14*	0	-9.7	-3.9	-9	0	0.2	0	6.1	47.9	6.87
15	81	1.7	0	1.4	0	0	0	1.7	47.9	28.04
16	72	-0.8	-0.1	-0.6	0	0	0	0.7	47.9	67.46

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

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

2.6.14.6 Stress Evaluation of the BWR Canister for 1-Foot Side-Drop Load Condition

ANSYS is used to determine the stresses in the BWR canister resulting from a 1-ft side-drop. The finite element model of the BWR canister is similar to the model for the PWR canister. A detailed description of the PWR canister model is provided in Section 2.6.12.2.

The load resulting from the contents is applied to the basket by means of pressure acting in the plane of the disks. The weight is assumed to act over the effective width of 6.428 in. (for 33 support disks) in which each disk is 0.75 in. thick. This weight is distributed over the 33 support disks plus two end weldments. A deceleration factor of 20 *g* is applied to the weights to provide the loading for the basket assembly. In addition to the contents load, a 25 psig pressure is applied to the inner surface of the canister. The canister is analyzed for basket orientations of 0° and 45°. As discussed in Section 2.6.14.2, the actual design uses 40 support disks of 0.625 in. thickness. The impact of these differences are also discussed in Section 2.6.14.2.

The methodology used to evaluate the stresses for the side-drop are identical to that used for the PWR side-drop (Section 2.6.12.6). Sections 9, 10, and 11 at the 0° circumferential position (see Figure 2.6.12.3-1) are not included in the evaluation. These regions are characterized as a bearing stress since they result from the canister shell bearing against cask inner shell. Section 2.6.14.11 provides an assessment of the bearing stresses. Sections 9, 10, and 11 at all other angular locations are included in the evaluation. Also, Sections 12 and 13 at 0° are treated as local membrane stresses. According to the ASME Code, Section III, Subsection NB-3213.10, a stressed region may be considered local if the distance over which the membrane stress intensity exceeds 1.1 S_m does not extend more than 1.0 times the square root of RT in the meridional direction, where R is the minimum midsurface radius of curvature and T is the minimum thickness in the region considered. For Section 13, the minimum thickness is that of the canister shell (0.625 in.) and the midsurface radius of the shell is 33.2175 in. The resulting distance is 4.56 in. A section located 4.56 in. from Section 13 in the meridional direction results in a membrane stress intensity of 6.44 ksi, which is below S_m. This section conservatively encompasses Section 12 since it is located 1.56 in. from this section. The stresses at adjacent circumferential sections (i.e., at 9°) for Sections 12 and 13 are also included in the tables for comparison. The critical sections stresses are reported in Table 2.6.14.6-1 for the P_m and $P_m + P_b$ stresses.

Results are calculated for 1-ft side-drop with internal pressure for both the 0° and 45° basket orientations. Tables 2.6.14.6-2 and 2.6.14.6-3 present the worst-case margins of safety for the side-drop with the conditions noted. The minimum margin of safety occurs for primary membrane without pressure and with pressure for primary membrane plus primary bending. The minimum margin of safety for the BWR canister for the side-drop is +0.02, which occurs at Section 12 in Figure 2.6.14.3-1. The margins of safety are calculated as:

MS = (allowable stress/SI) -1.

Table 2.6.14.6-1 BWR Canister Critical Sections for the 1-Foot Side-Drop Load Condition

Condition	Stress	Critical Section	Table	Minimum Margin of Safety
Side-Drop	P_m	1	2.6.14.6-2	**+0.11**
Side-Drop + Pressure	$P_m + P_b$	12	2.6.14.6-3	+ 0.02

Table 2.6.14.6-2 BWR Canister P_m Stresses - 1-Foot Side-Drop

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-13.3	0.1	-4.2	-0.3	-0.1	-2	13.8	16	0.16
2	0	-8.5	-0.3	-4.6	-0.4	-0.3	-1.4	8.7	16	0.83
3**	0	-6.1	-0.3	-3.6	-0.3	-0.3	-1.3	6.75	16	1.37
4**	0	-2.3	-0.5	0.2	0	0	0.1	2.65	16	5.05
5**	0	-2.3	0.1	0.2	0	0	0.1	2.65	16	5.03
6**	0	-2.4	0.3	0.2	0	-0.1	0.1	2.88	16	4.56
7**	0	-2.4	0.3	0.1	0	-0.1	0.1	2.96	16	4.40
8**	0	-0.8	2.1	-1.1	-0.2	0.5	-0.1	3.56	16	3.50
9	9	-0.24	2.56	-1.99	0.05	1.35	-1.06	5.73	16	1.8
10	9	1.45	1.67	-2.09	-0.3	0.99	-0.65	4.6	16	2.48
11	9	4.17	1.8	-1.1	0.7	1.2	-1.7	6.75	16	1.37
12*	0	-24.3	-5.4	-6.6	-4.5	1.2	-1	21.6	24	0.11
12	9	-0.42	-0.18	-3.42	0.15	0.55	-1.9	4.97	16	2.22
13†	0-7.4	-11.61	-3.40	-4.00	0.05	1.10	-2.23	9.96	12.8***	0.29
14	0	-0.8	0	0.3	0	0	0	1.1	16	13.12
15	0	-0.3	0	0.1	0	0	0	0.4	16	35.05
16	0	-0.5	0	0.1	0	0	0	0.6	16	24.17

* Treated as a local membrane stress P_L. Allowable for normal conditions is $1.5\ S_m = 24$ ksi for P_L and P_L+P_B.

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

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

† Stress evaluated over weld compression region.

Table 2.6.14.6-3 BWR Canister $P_m + P_b$ Stresses - 1-Foot Side-Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-17.1	-0.9	-5.3	0.2	-0.1	-2	16.5	24	0.46
2	0	-8	0.8	-2.5	-0.6	-0.3	-1.7	9.4	24	1.55
3**	0	-5.8	0.9	-1.5	-0.4	-0.3	-1.5	7.7	24	2.12
4**	0	-2.4	1	3.3	0	0	0.4	6.1	24	2.93
5**	0	-2.4	1.6	3.6	0	-0.1	0.4	6.4	24	2.75
6**	0	-2.5	1.8	3.7	0	-0.1	0.4	6.6	24	2.64
7**	0	-2.5	1.7	3.7	0	-0.1	0.4	6.5	24	2.69
8**	0	-0.6	2.5	-2.4	-0.2	0.4	-0.2	5.2	24	3.61
9	9	1.1	6.4	-0.3	-0.08	1.6	0.1	7.44	24	2.22
10	0	-18.9	-2.1	-4.5	-5.3	1	-1.1	20.3	24	0.18
11	9	4.3	0.9	-1.4	0.8	1.3	2.7	8.4	24	1.86
12†	0	-28.6	-6.6	-8.2	-4.3	1.6	-0.7	24.5	25	0.02
13†*	0-7.8	-16.57	-6.23	-6.42	-0.09	1.68	-2	12.49	20***	0.60
14	0	-0.7	0	0.3	0	0	0	1.1	24	21.32
15	90	-0.7	0	-0.1	0	0	0	0.7	24	34.37
16	0	-0.6	0	0.1	0	0	0	0.7	24	34.67

† The peak temperature as calculated in Section 3.4 is 265°F in the region of Sections 12 and 13. The allowable stress is 1.5 (16.7 ksi) = 25.05 ksi based on this temperature.

* Stress evaluated over weld compression region.

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

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

2.6.14.7 Stress Evaluation of BWR Canister for Combined Thermal and 1-Foot Side-Drop Load Conditions

The BWR canister is evaluated by applying the thermal stress loads described in Section 2.6.14.3 in conjunction with the primary loads in Section 2.6.14.6 to produce a combined thermal stress plus 1-ft side-drop loading. The stress evaluation is performed according to the ASME Code, Section III, Subsection NB. The most critical sections are listed in Table 2.6.14.7-1. The stresses reported in this table correspond to the nodal stress at the surface. Results from the side-drop plus thermal load cases for the configurations that result in the minimum margins of safety are presented in Tables 2.6.14.7-2 and 2.6.14.7-3. The minimum margin of safety is +0.42 at Section 9 (see Figure 2.6.14.3-1) when 3 S_m is used as the stress criterion. The margins of safety are calculated as:

$$MS = (\text{allowable stress}/SI) - 1.$$

Table 2.6.14.7-1 BWR Canister Critical Sections for the Combined 1-Foot Side-Drop and Thermal Load Condition

Condition	**Stress**	**Critical Section**	**Table**	**Minimum Margin of Safety**
Side-Drop + Thermal (cold)	P + Q	9	2.6.14.7-2	+ 0.42
Side-Drop + Thermal (hot)	P + Q	9	2.6.14.7-3	+ 0.60

Table 2.6.14.7-2 BWR Canister $P_m + P_b + Q$ - 1-Foot Side-Drop, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-16.4	-1.3	-3	0.3	0	-1.7	15.4	47.9	2.12
2	0	-6.4	1.5	-0.4	0	-0.2	-1.6	8.3	47.9	4.77
3**	0	-4.6	1.6	0.2	-0.1	-0.1	-1.3	6.8	47.9	6.04
4**	0	-2.4	0.8	2.1	0	-0.1	0.3	4.7	47.9	9.19
5**	0	-2.1	-0.4	2.4	0	-0.3	0.4	4.8	47.9	8.98
6**	0	-1.9	-1.4	2.1	0	0.2	0.4	4.4	47.9	9.89
7**	0	-2.3	0.3	2.2	0	-0.1	0.3	4.8	47.9	8.98
8**	0	-0.3	2.2	-1.7	-0.2	0.6	-0.1	4.3	47.9	10.1
9	0	-26.6	6.7	-9	-2.1	1.7	0.1	33.7	47.9	0.42
10	0	-18.8	-2.8	-5	-4.5	0.9	-1.1	18.8	47.9	1.54
11	0	-26.3	3	-8.8	-0.3	1.8	-0.1	29.6	47.9	0.62
12	0	-26.3	-4.9	-7.9	-3.7	1.7	-0.7	23.4	47.9	1.05
13	0	-32.4	-9.9	-10.6	-1.2	1.9	-1.4	24.4	38.32*	0.57
14	0	-11.2	-3.3	-9.4	0	0	0	7.9	47.9	5.07
15	9	-0.7	0	-0.3	0	0	0	0.7	47.9	72.63
16	0	-0.6	0	0	0	0	0	0.7	47.9	69.59

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

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

Table 2.6.14.7-3 BWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Side-Drop, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-14.5	-0.3	-3	0.2	0	-1.5	14.3	47.9	2.35
2	0	-6	0.9	-0.6	-0.3	-0.1	-1.4	7.3	47.9	5.59
3**	0	-4.3	1	0	-0.3	-0.1	-1.2	5.9	47.9	7.12
4**	0	-2.3	0.2	1.5	0	0	0.3	4.1	47.9	10.68
5**	0	-2.1	-0.5	2.1	0	-0.2	0.4	4.4	47.9	9.89
6**	0	-2	-1.3	1.7	0	0.2	0.4	4.0	47.9	10.98
7**	0	-2.2	0.3	1.9	0	-0.1	0.3	4.3	47.9	10.14
8**	0	-0.3	2.2	-1.4	-0.1	0.5	-0.1	4.0	47.9	10.98
9	0	-23.4	6.3	-8.3	-1.9	1.5	0.3	30	47.9	0.6
10	0	-16.6	-2.2	-4.9	-3.9	0.8	-0.8	16.6	47.9	1.88
11	0	-22.8	2.8	-7.9	-0.2	1.5	0	25.9	47.9	0.85
12	0	-23.4	-4.2	-7.4	-3.2	1.5	-0.4	20.7	47.9	1.31
13	0	-28.2	-8.6	-9.7	-1	1.6	-1.1	21	38.32*	0.82
14	0	-9.7	-2.5	-8	0.1	-0.2	0	7.2	47.9	5.63
15	27	-0.6	0	-0.3	0	0	0	0.6	47.9	75.57
16	0	-0.6	0	0.1	0	0	0	0.7	47.9	65.48

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

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

2.6.14.8 Stress Evaluation of BWR Canister for 1-Foot Corner-Drop Load Condition

ANSYS is used to perform a structural analysis to evaluate the effect of a 1-ft end-drop impact for both the top and bottom corner orientations of the BWR canister. The ASME Code, Section III, Subsection NB requires that the stresses arising from operational loads be assessed on the basis of the primary loads. The primary loads for the 1-ft corner-drop result from the deceleration of the BWR canister and its contents and the 25-psig pressure load internal to the canister. The applied deceleration is 20 *g* for both orientations. The inertial load of the canister is addressed by the deceleration factor applied to the canister density. The contents weight is represented by a pressure load on the inner end surface of the canister and a pressure applied to the basket by means of pressure acting in the plane of the disks. Displacement constraints are applied to the plane of symmetry and the gap elements attached at the canister end to represent the top or bottom of the transport cask.

The locations of the linearized stresses are shown in Figure 2.6.14.3-1. The maximum stresses for P_m and $P_m + P_b$ are presented in Tables 2.6.14.8-2 through 2.6.14.8-5 for the conditions that result in the worst case stresses. The critical sections for the pressure and the pressure plus the deceleration load, with reference to the section and the appropriate tables, are shown in Table 2.6.14.8-1. The margins of safety in these tables are calculated as:

MS = (allowable stress/SI) - 1.

Table 2.6.14.8-1 BWR Canister Critical Sections for the 1-Foot Corner-Drop Load Condition

Condition	Stress	Critical Section	Table	Minimum Margin of Safety
Top Corner-Drop + Pressure	P_m	9	2.6.14.8-2	+ 0.18
Top Corner-Drop Inertia	$P_m + P_b$	9	2.6.14.8-3	+ 0.52
Bottom Corner-Drop + Pressure	P_m	11	2.6.14.8-4	+0.12
Bottom Corner-Drop +Inertia	$P_m + P_b$	11	2.6.14.8-5	+0.41

Table 2.6.14.8-2 BWR Canister P_m Stresses - 1-Foot Top Corner-Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-4.5	0.1	-1.2	0.3	-0.1	-0.6	4.8	16	2.32
2	0	-0.9	0.4	-0.9	0	-0.2	-0.3	1.7	16	8.54
3**	0	-0.6	0.4	-0.7	0	-0.2	-0.2	1.4	16	10.37
4**	0	-0.9	-0.3	1.4	0	0	0.2	2.4	16	5.66
5**	0	-0.9	-0.3	1.4	0	0	0.2	2.4	16	5.70
6**	0	-0.9	-0.5	1.4	0	0	0.2	2.4	16	5.68
7**	0	-0.9	-0.9	1.4	0	-0.1	0.2	2.4	16	5.65
8**	54	0.5	-1.1	0.2	-0.3	-0.2	0.3	2.0	16	7.04
9	0	-14.8	-1.8	-4	-1.6	0.5	-0.4	13.6	16	0.18
10	0	-10.2	-4	-3	-1.7	0.2	-0.7	8	16	1
11	0	-13.9	-6.1	-4.9	-0.6	0.4	-0.4	9.2	16	0.74
12**	0	-12.9	-5.7	-2.9	-2.7	0.2	-1	11.7	16	0.37
13**	0	-12.2	-7.3	-3.7	-0.7	0.2	-1	9.3	12.8*	0.38
14	0	-0.2	0	0.2	0	0	0	0.4	16	44.29
15**	0	-0.1	-0.3	0	0	0	0	0.4	16	38.74
16**	0	-0.2	-0.4	0.1	0	0	0	0.5	16	32.99

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

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

Table 2.6.14.8-3 BWR Canister $P_m + P_b$ Stresses - 1-Foot Top Corner Drop

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-9.2	-4.4	-2.2	-1.9	-0.1	-0.6	7.8	24	2.06
2	0	-8.9	4.9	-1.1	0.9	0.8	0.2	14	24	0.72
3**	0	-6.9	3.6	-0.6	0.5	0.7	-0.2	11.1	24	1.16
4**	0	-0.9	-0.7	0.5	0	0	0.1	1.5	24	15.00
5**	0	-0.9	-0.7	0.7	0	0	0.1	1.7	24	13.12
6**	0	-0.9	-0.9	0.7	0	0	0.1	1.8	24	12.33
7**	0	-0.9	-1.3	0.8	0	-0.1	0.1	2.2	24	9.91
8**	54	0.1	-1.4	0.1	-0.3	-0.3	0	1.8	24	12.27
9	0	-15.3	0.2	-4.7	-1.2	0.5	-0.2	15.8	24	0.52
10	0	-10.8	-5.2	-2.6	-3.1	0.1	-1	9.9	24	1.42
11	0	-15.5	-8.1	-5	-1.1	0.5	-0.7	10.8	24	1.23
12**	0	-13.9	-5.5	-3.3	-2.2	0.4	-0.8	12.1	24	0.98
13**	0	-14.2	-9.3	-4.8	-1.2	0.4	-0.9	10.4	19.2*	0.85
14	90	-6.9	-0.1	-6.4	0.1	-0.1	0	6.8	24	2.52
15**	90	0	-0.3	0.1	0	0	0	0.5	24	51.78
16**	0	-0.2	-0.3	0.1	0	0	0	0.5	24	51.61

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

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

Table 2.6.14.8-4 BWR Canister P_m Stresses - 1-Foot Bottom Corner-Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1**	0	-5.1	-0.8	-1.5	-0.1	0	-0.7	4.7	16	2.40
2	36	0	-2.4	-0.3	-0.1	0.1	-0.5	2.8	16	4.77
3**	36	0	-2.4	-0.3	0	0.1	-0.4	2.8	16	4.71
4**	0	-0.9	-2	1.3	0	0	0.2	3.6	16	3.44
5**	0	-0.9	-1.6	1.4	0	0	0.2	3.2	16	4.00
6**	180	0	-1.6	1.2	0	0	-0.1	2.9	16	4.52
7**	180	0	-1.3	1.2	0	0	-0.1	2.7	16	4.88
8**	63	0.5	-0.7	0.2	-0.2	-0.1	0.3	1.6	16	9.02
9	0	-13.4	0.4	-3.7	-1.3	0.8	-0.3	14.2	16	0.12
10	0	-7.3	-0.4	-2.1	-1.2	0.6	-0.6	7.6	16	1.09
11	0	-14.6	-0.9	-4.3	-0.2	1	-0.3	14	16	0.15
12	0	-10.7	-2.5	-2.4	-1.9	0.6	-0.8	9.7	16	0.65
13	0	-10.2	-2.7	-2.6	0	0.7	-1	8.4	12.8*	0.52
14**	0	-0.3	-0.4	0.2	0	0	0	0.6	16	27.64
15	0	-0.1	0	0.1	0	0	0	0.1	16	111.46
16	90	-0.2	0	0	0	0	0	0.3	16	61.79

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

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

Table 2.6.14.8-5 BWR Canister $P_m + P_b$ Stresses - 1-Foot Bottom Corner-Drop

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1**	0	-6.3	-0.8	-2	0.2	0	-0.8	6.0	24	3.00
2	27	-0.2	-4.2	-1.2	-0.1	-0.1	-0.6	4.3	24	4.57
3**	27	-0.2	-4	-1.1	-0.1	-0.1	-0.5	4.4	24	4.45
4**	0	-0.9	-2.4	0.8	0	0	0.1	3.5	24	5.86
5**	0	-0.9	-2	0.8	0	0	0.1	2.9	24	7.28
6**	0	-0.9	-1.7	0.9	0	0	0.1	2.6	24	8.23
7**	0	-0.9	-1.4	0.9	0	-0.1	0.1	2.4	24	9.00
8**	18	0.3	-1.1	-0.6	0.3	0.5	-0.2	1.9	24	11.63
9	0	-13.5	2.5	-4.4	-1	0.8	-0.1	16.2	24	0.48
10	0	-6.9	-0.7	-1.3	-2	0.5	-0.8	7.8	24	2.07
11	0	-14.2	2.6	-4	-0.1	0.9	0	17	24	0.41
12	0	-12.9	-3.3	-3.5	-1.6	0.7	-0.6	10.8	24	1.22
13	0	-16.1	-6.1	-5.3	-0.2	1	-0.8	11.6	19.2*	0.66
14**	0	-0.3	-0.3	0.1	0	0	0	0.5	24	47.00
15	45	1.3	0	1.5	0	0	0	1.5	24	15.49
16	9	-0.9	0	-0.7	0	0	0	0.9	24	26.14

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

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

2.6.14.9 Stress Evaluation of BWR Canister for Combined Thermal and 1-Foot Corner-Drop Load Conditions

The thermal stress loads described in Section 2.6.14.3 are applied in conjunction with the primary loads in Section 2.6.14.8 to produce a combined thermal stress plus corner impact loading. The stress evaluation is performed according to the ASME Code, Section III, Subsection NB. On the basis of results in Section 2.6.14.8, the most critical sections are listed in Table 2.6.14.9-1. The stresses reported in this table correspond to the nodal stress at the surface. The minimum margin of safety is +1.57 when 3 S_m is used as the stress criterion. Tables 2.6.14.9-2 through 2.6.14.9-5 present the results for top and bottom corner-drop with thermal results for the loading conditions that result in the minimum margins of safety. The margins of safety are calculated as:

MS = (allowable stress/SI) -1.

Table 2.6.14.9-1 BWR Canister Critical Sections for the Combined 1-Foot Corner-Drop and Thermal Load Condition

Condition	**Stress**	**Critical Section**	**Table No.**	**Minimum Margin of Safety**
Top Corner-Drop + Thermal (cold)	$P_m + P_b + Q$	2	2.6.14.9-2	+ 2.02
Top Corner-Drop + Thermal (hot)	$P_m + P_b + Q$	2	2.6.14.9-3	+ 2.05
Bottom Corner-Drop + Pressure + Thermal (cold), 45° Basket	$P_m + P_b + Q$	9	2.6.14.9-4	+1.54
Bottom Corner-Drop + Thermal (hot)	$P_m + P_b + Q$	11	2.6.14.9-5	+1.62

Table 2.6.14.9-2 BWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Top Corner-Drop, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-14.1	-4.7	-2	-2.5	0	-1.1	12.8	47.9	2.73
2	0	-14.3	1.3	-2.4	-0.1	1	-0.5	15.9	47.9	2.02
3**	0	-10.7	0.6	-1.4	-0.3	0.8	-0.7	12.4	47.9	2.86
4**	0	-0.9	-0.7	1.1	0	-0.1	0.1	2.1	47.9	21.81
5**	0	-0.8	-1.4	2.8	0	-0.2	0.4	4.4	47.9	9.89
6**	0	-0.6	-2.3	2.2	0	0.3	0.1	4.8	47.9	8.98
7**	180	0	-2.9	0	0	0	0	3.1	47.9	14.45
8**	171	-0.1	-3.6	-0.2	0	0.2	0	3.7	47.9	11.95
9	0	-12.6	0.1	-3.8	-1.1	0.5	-0.2	13	47.9	2.68
10	0	-10	-4.8	-2.4	-2.6	0.1	-1	9	47.9	4.35
11	0	-12	-7	-4	-1	0.4	-0.6	8.3	47.9	4.77
12**	0	-11.7	-4.2	-2.7	-2	0.4	-0.7	10.3	47.9	3.65
13**	0	-12	-7	-4	-1	0.4	-0.6	8.7	38.32*	3.40
14	0	-15.6	-1.2	-14.1	0.1	-0.8	0	14.4	47.9	2.34
15**	72	-0.1	-0.3	0.1	0	0	0	0.4	47.9	110.66
16**	0	-0.1	-0.4	0.1	0	0	0	0.6	47.9	80.29

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

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

Table 2.6.14.9-3 BWR Canister $P_m + P_b + Q$ - 1-Foot Top Corner-Drop, Thermal Heat

		$P_m + P_b + Q$ Stresses (ksi)								
Section Location	**Angle of Peak Stress Location**	**Sx**	**Sy**	**Sz**	**Sxy**	**Syz**	**Sxz**	**Stress Intensity (ksi)**	**Allowable Stress (ksi)**	**Margin of Safety**
1	0	-13.7	-4.6	-2.1	-2.4	0	-1.1	12.4	47.9	2.88
2	0	-13.9	1.6	-2.3	-0.2	0.9	-0.6	15.7	47.9	2.05
3**	0	-10.4	0.9	-1.3	-0.4	0.7	-0.7	12.2	47.9	2.93
4**	0	-0.8	-0.8	0.8	0	0	0.1	1.8	47.9	25.61
5**	0	-0.9	-1.5	2	0	-0.2	0.1	3.6	47.9	12.31
6**	0	-0.7	-2.1	1.8	0	0.2	0.2	4.2	47.9	10.40
7**	180	0	-3	0	0	0	0	3.2	47.9	13.97
8**	171	-0.1	-3.6	-0.2	0	0.2	0	3.7	47.9	11.95
9	0	-12.1	0.4	-3.5	-1	0.5	-0.2	12.7	47.9	2.78
10	0	-9.5	-4.5	-2.2	-2.5	0.1	-0.9	8.6	47.9	4.59
11	0	-11.4	-6.5	-3.7	-0.9	0.4	-0.6	8	47.9	5.03
12**	0	-11.1	-3.9	-2.6	-1.9	0.4	-0.7	9.9	47.9	3.84
13**	0	-11.4	-6.5	-3.7	-0.9	0.4	-0.6	8.4	38.32*	3.56
14	0	-14.8	-1.1	-13.5	0.1	-0.7	0	14.4	47.9	2.50
15**	90	0	-0.3	0.1	0	0	0	0.4	47.9	111.90
16**	0	-0.1	-0.4	0.1	0	0	0	0.5	47.9	82.69

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

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

Table 2.6.14.9-4 BWR Canister $P_m + P_b + Q$ Stresses - 1 Foot Bottom Corner-Drop, Internal Pressure, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1**	0	-2	0.1	1.7	0.2	0	-0.2	4.0	47.9	10.98
2	162	0.1	-4.5	0.8	0	0	-0.3	5.4	47.9	7.93
3**	162	0.1	-4.4	0.8	0	0	-0.3	5.6	47.9	7.55
4**	180	0	-3.7	1.3	0	0	-0.1	5.3	47.9	8.04
5**	0	-0.6	-1.4	3.9	0	-0.3	0.2	5.6	47.9	7.55
6**	0	-0.7	-2.4	3.4	0	0.2	0.1	6.2	47.9	6.73
7**	0	-1	-0.6	3.5	0	-0.1	0.3	4.7	47.9	9.19
8**	0	-0.6	0.6	2	-0.1	0.6	0.3	3.0	47.9	14.97
9	0	-15.6	2.7	-4.9	-1.2	1.1	-0.2	18.7	47.9	1.57
10	0	-10.4	-1.7	-2.1	-2.5	0.6	-1.1	10.6	47.9	3.54
11	0	-15.5	1.4	-5.1	-0.2	1	-0.1	17.1	47.9	1.81
12	0	-14.8	-3	-3.8	-2	1	-0.8	13.1	47.9	2.65
13	0	-19	-5.9	-6	-0.6	1.2	-0.9	14.4	38.32*	1.66
14**	0	-10.9	-4.4	-9.9	0	0.2	0	6.8	47.9	6.04
15	90	0.9	0	0.9	0	0	0	1	47.9	49.23
16	18	-0.6	0	-0.3	0	0	0	0.6	47.9	78.82

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.
** Stresses at these locations are increased by 5% to account for the heavier BWR fuel basket/fuel assemblies.

Table 2.6.14.9-5 BWR Canister $P_m + P_b + Q$ Stresses – 1-Foot Bottom Corner-Drop, Thermal Heat

		$P_m + P_b + Q$ Stresses (ksi)								
Section Location	Angle of Peak Stress Location	Sx	Sy	Sz	Sxy	Syz	Sxz	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
1**	162	0.4	-2.7	1.2	0.2	0.1	-0.3	4.2	47.9	10.40
2	162	0	-4.3	0.6	0	0	-0.3	5	47.9	8.57
3**	162	0	-4.3	0.6	0	0	-0.3	5.3	47.9	8.04
4**	180	0	-4.4	0	0	0	0	4.6	47.9	9.41
5**	180	0	-4	0	0	0	0	4.2	47.9	10.40
6**	0	-0.7	-2.9	1.8	0	0.2	0.2	5.0	47.9	8.58
7**	0	-0.9	-1.4	1.5	0	0	0.2	3.2	47.9	13.97
8**	171	-0.1	-2.4	-0.1	0	0.2	0	2.5	47.9	18.16
9	0	-15.4	2.3	-5.2	-1.2	1	-0.3	18	47.9	1.66
10	0	-9.6	-1.4	-2.1	-2.3	0.5	-1	9.9	47.9	3.85
11	0	-16.6	1.6	-5.4	-0.2	1.1	-0.1	18.3	47.9	1.62
12	0	-14.6	-3	-4	-1.8	1	-0.8	12.8	47.9	2.75
13	0	-20.2	-6.4	-6.6	-0.7	1.2	-1	15.1	38.32*	1.54
14**	0	-9.8	-3.9	-8.9	0	0.2	0	6.2	47.9	6.73
15	81	1.4	0	1.6	0	0	0	1.6	47.9	29.36
16	45	-1	-0.1	-0.6	0	0	0	0.9	47.9	52.33

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

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

2.6.14.10 Shear Stresses for 1-Foot Drops

The primary mechanism for shear loading in the canister drop analyses occurs for the bottom end-drop in the canister structural and shield lid welds. The maximum stress intensity for either sections 12 or 13 during any bottom end-drop is 1.8 ksi for the bottom end-drop with thermal heat (Table 2.6.14.5-5). The maximum shear is 1.8/2 = 0.9 ksi. The allowable shear is $0.6S_m$ per the ASME Code, Section III, Subsection NB-3227.2 for pure shear loading. The maximum canister shell temperature is 380°F and the margin of safety for pure shear is

$$MS = 0.6 \times 16.0 / 0.9 - 1 = 9.66$$

2.6.14.11 Canister Bearing Stresses for 1-Foot Side-Drop

The bearing stress evaluation presented in section 2.6.12.11 conservatively encompasses bounding values for both the BWR and PWR canisters.

2.6.14.12 Canister Buckling Evaluation for 1-Foot End-Drop

Code Case N-284-1 of the ASME Boiler and Pressure Vessel Code is used to analyze the BWR canister for the normal condition 1-ft end-drop (both top and bottom end-drops). 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 of Code Case N-284-1.

The canister buckling design criteria are described in Section 2.1.2.5.3.

A 20 g deceleration load was used for all the 1-ft drop canister analyses that are presented in Sections 2.6.14.4 through 2.6.14.9. The 20 g-load bounds all 1-ft deceleration loads for all other drop angles. The top- and bottom-end drops result in the largest potential for canister shell buckling and, therefore, are the two load cases presented here. The side drop load case is not considered a credible buckling mode of the canister shell and is, therefore, not presented here.

The BWR canister is evaluated for buckling in the same manner as the PWR canister (see Section 2.6.12.12). The analytical process used for the BWR canister is the same as that described in a step-by-step example presented in Section 2.7.12.3 (for the cask inner shell).

The stress results from the canister analyses are screened for the maximum values of the longitudinal compression, circumferential compression, or in-plane shear stresses for the 1-ft drop cases (top- and bottom-end drops) with and without pressure. For each loading case, the largest of each of the three stress components anywhere regardless of location within the BWR canister shell are combined. To these maximum stress components are added the maximum stresses from the hot and cold thermal cases (Tables 2.6.14.3-1 and 2.6.14.3-2). Combining the maximum stress components in this way produces a conservative, bounding-case buckling evaluation of the BWR canister, one which envelopes all 1-ft BWR canister drop cases including those presented in Tables 2.6.14.4-4 and 2.6.14.4-6.

The geometry parameters used in the BWR canister evaluation are presented in Table 2.6.14.12-1.

The maximum stress components used in the evaluation and the buckling interaction equation ratios for the BWR canister top- and bottom-end drop cases are provided in Table 2.6.14.12-2. The results of the buckling evaluation show that all interaction equation ratios are less than 1.0. Therefore, the buckling criteria of Code Case N-284-1 are satisfied, thus demonstrating that buckling of the BWR canister does not occur.

Table 2.6.14.12-1 Geometry Parameters for the BWR Canister

Parameter	**Value**
t = thickness (in)	0.625
ID = inside diameter (in)	65.81
R = radius (in) = (ID+t)/2	33.22
R/t	53.15
$(Rt)^{0.5}$	4.56
Overall Length (in)	190.55
Bottom Thickness (in)	1.75
Structural Lid Thickness (in)	3.0
L_ϕ = Length used in evaluation (in)*	185.8
$L_\theta = 2\pi R$ = circumference (in)	218.7
ν = Poisson's Ratio	0.275

* L_ϕ = Overall canister length - Bottom thickness - Structural lid thickness.

Table 2.6.14.12-2 Buckling Evaluation Results for the BWR Canister for 1-Foot End-Drop

Load Case	Load Condition	Longitudinal (Axial) Stress* S_ϕ (psi)	Circumferential (Hoop) Stress* S_θ (psi)	In-plane Shear Stress $S_{\phi\theta}$ (psi)	Elastic Buckling Interaction Equations				Plastic Buckling Interaction Equations			
					Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
A	1-Ft Top End-Drop	2100	200	400	0.0	.068	.043	0.0	.067	.043	.068	.043
B	1-Ft Bottom End-Drop	3100	500	300	.040	.099	.108	.040	.099	.108	.099	.108

Component stresses include thermal stresses.

* Compressive stresses.

2.6.15 BWR Basket Analysis—Normal Conditions of Transport

The Universal Transport Cask BWR basket is similar in design to the PWR basket. It is a right-cylinder structure fabricated with 56 square fuel tubes, a number of circular support disks, a number of heat transfer disks, six tie rods with split spacers, and two end weldment plates. The number of support disks and heat transfer disks varies depending upon the class of BWR fuel the basket is designed to contain. The basket components and their geometry are illustrated in Figure 2.6.15-1 and Figure 2.6.15-2. Figure 2.6.15-3 shows the details of the fuel tube with the encasing BORAL on two sides. The fuel tubes are open at each end; therefore, longitudinal fuel assembly loads are imparted to the canister shield lid or bottom plate, and not the fuel basket structure. The fuel basket contains the fuel and is laterally supported by the canister shell.

In the BWR basket, the fuel assemblies, together with the tubes, are laterally supported in the holes in the carbon steel support disks. The aluminum heat transfer disks located at the mid section of the cavity are used to fully optimize the passive heat rejection from the package and are self-supporting. The dimensional differences between the heat transfer disk and the support disk accommodate the different rate of thermal growth between aluminum and stainless steel, thereby preventing interference between the tube, support disk, and heat transfer disks.

The primary function of the spacers and the threaded top nut is the same as those in the PWR basket described in Section 2.6.13. As described in that section, the only component that requires a detailed finite element analysis is the support disk. The stainless steel fuel tubes are not considered to be structural components with respect to the disks other than consideration of their mass contribution to loading.

The basket support disk is designed to restrain 56 fuel assemblies, which would nominally fit into a 6.278 inch square slot. Since a populace of BWR fuel assemblies are not expected to fit into the 6.278 inch square, four oversized fuel assemblies slots are specified as 6.478 inch squares. This will reduce the thickness of the ligament at the outer most corner. However, the size of the web (.65 inch) is not changed. Therefore, the oversized slots will not affect the buckling calculations, since they pertain to the in-plane and out of plane buckling of the webs. In an inspection of the maximum stresses of the BWR basket, the ligament that contains the reduction due to the oversized slots, does not appear in the maximum stress summaries. The smallest ligament at the corner is still significantly controlled by the .8 inch ligament. Therefore,

the use of oversized holes is not considered to alter the model of the BWR basket which employs a slot size of 6.278 inches.

In this section, the BWR fuel basket is evaluated for the normal transport loads. As discussed in Section 2.6.13, the g-loads produced by the corner-drops are bounded by the g-loads produced by the end and side-drops. Therefore, only the end-drop and side-drop orientations are evaluated. The basket is evaluated for the hypothetical accident condition in Section 2.7.10.

Figure 2.6.15-1 BWR Fuel Assembly Basket

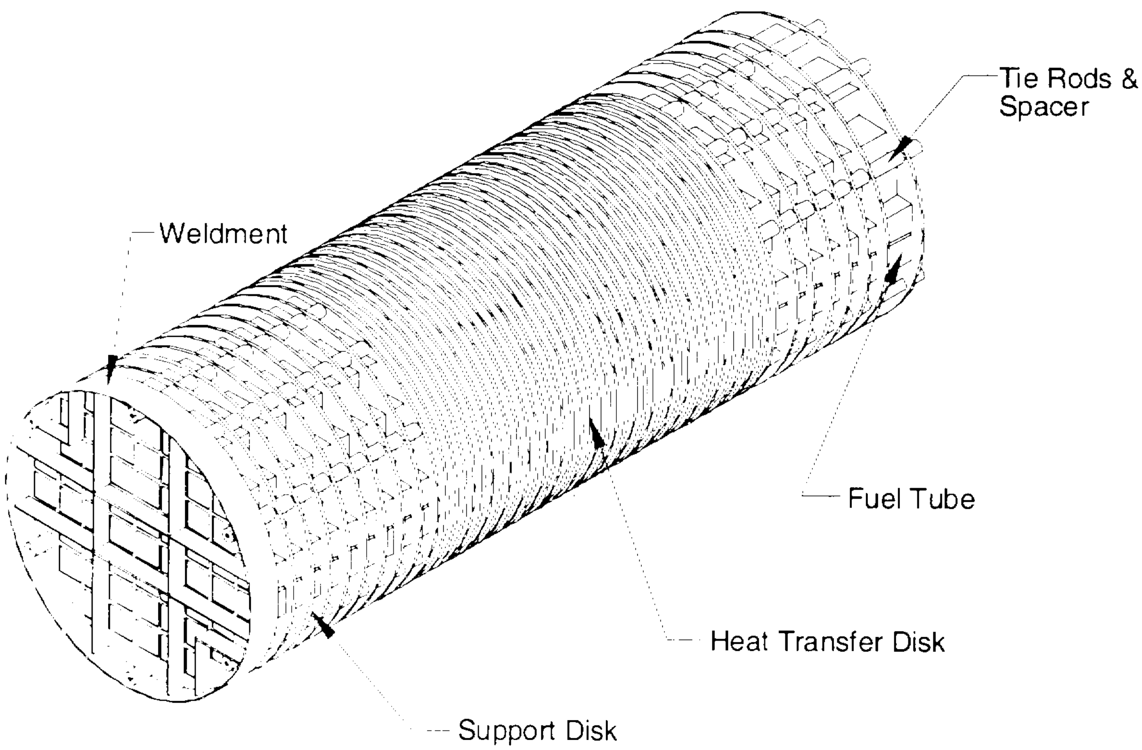
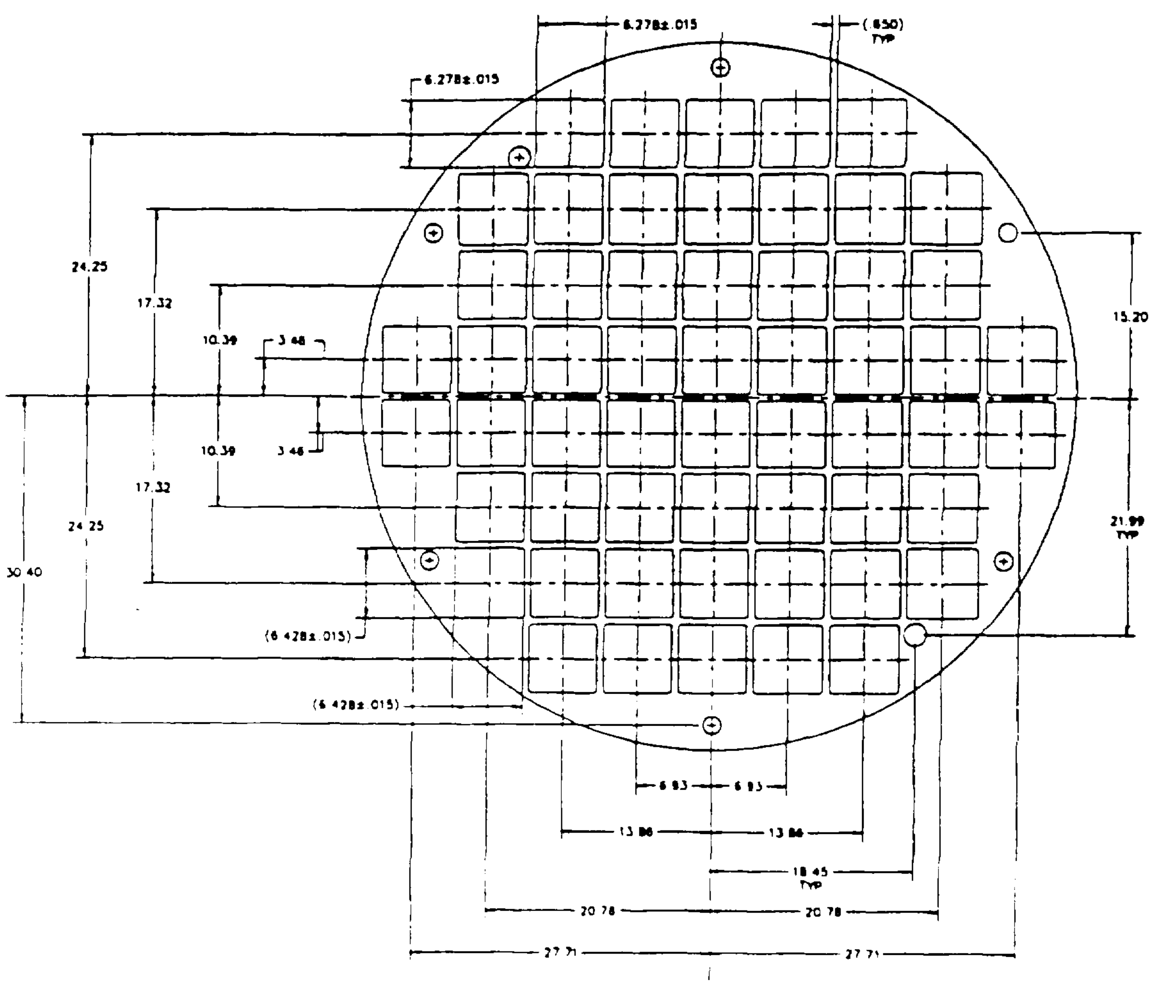


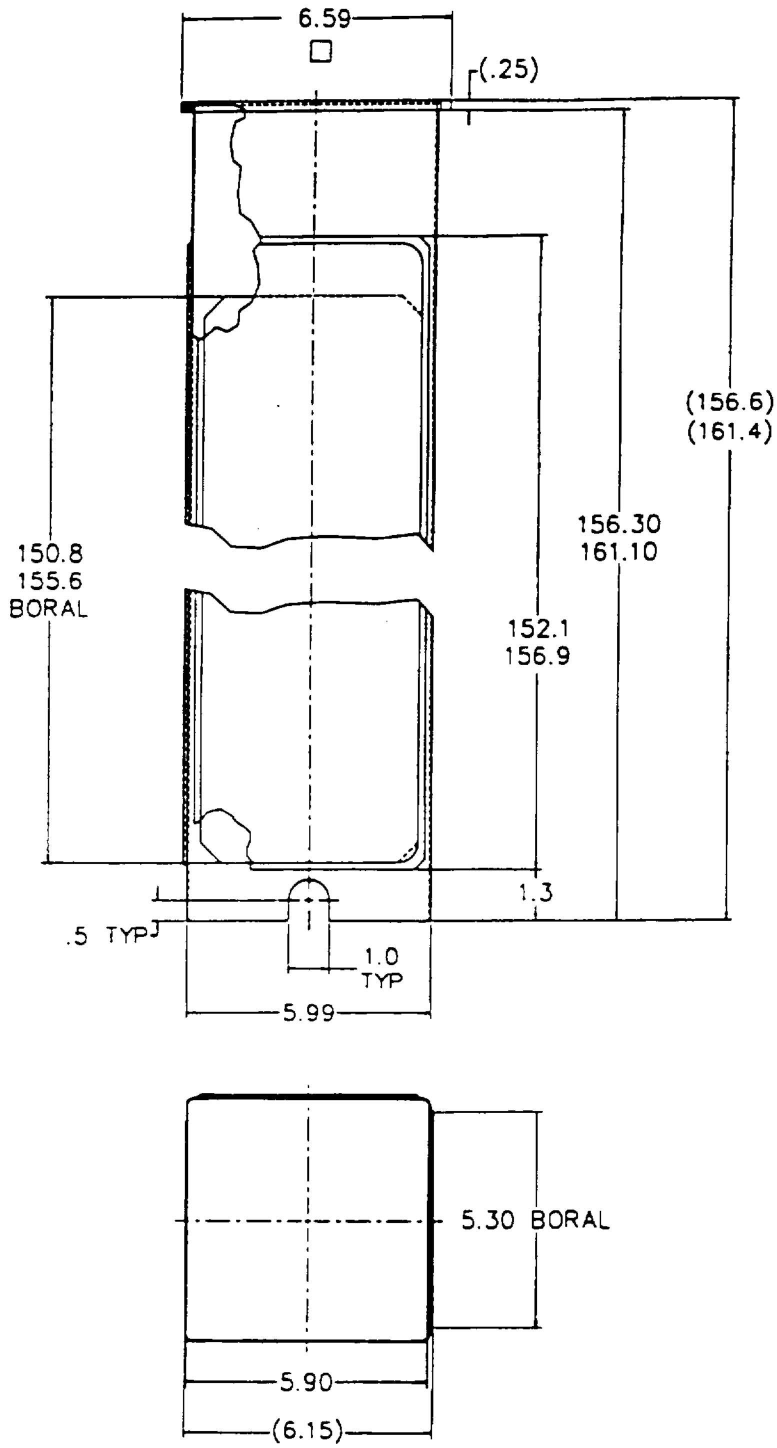
Figure 2.6.15-2 Support Disk Cross Section Configuration



Note:

Engineering drawings provide appropriate tolerances for dimensions shown.

Figure 2.6.15-3 BWR Fuel Tube Configuration



2.6.15.1 Analysis Description

The criticality and structural design criteria for the BWR basket are similar to those for the PWR basket discussed in Section 2.6.13.1. Consistent with the structural design criteria, the main structural component in the fuel basket—the stainless steel support disk—is shown to have (in any disk for any normal-condition load and position orientation) a maximum primary membrane stress intensity and primary membrane plus bending stress intensity that are less than the design stress intensity values S_m and $1.5S_m$, respectively. The value of S_m is defined at the temperatures for the component being analyzed.

In the side-drop, the loads of the fuel assemblies are transferred into the plane of the support disks, from which they are transmitted to the canister shell. In the vertical orientation, the fuel basket components are loaded by their own inertial weight and do not experience load from the guided but freestanding fuel assemblies. Various radial impact orientations of the support disk are evaluated. In addition to the load from inertial weight, the differential thermal expansion of the support disk is also evaluated.

2.6.15.2 Finite Element Model Description - BWR Basket

As is the case for the analysis of the PWR basket, two finite element models are generated to analyze the BWR fuel basket for the normal operating conditions: one for the end-drop, in which the loads are perpendicular to the plane of the disk, and one for the side-drop, in which the loads act in the plane of the disk. Both models accommodate thermal expansion effects by using the temperature distribution from the thermal analysis and the coefficient of thermal expansion.

A complete basket support disk is modeled for the side impact evaluation because planes of symmetry are not present when the impact can be at an arbitrary angle. The basket model for the side-drop is shown in Figure 2.6.15.2-1. Although the end-drop orientation exhibits a quarter symmetry, the model conversion is simplified by using the same nodal pattern as that for the side-drop model.

The finite element model for the side-drop evaluation of the BWR basket is similar to that used for the evaluation of the PWR basket. A detailed description of the model for the side-drop of the PWR basket is provided in Section 2.6.13.2. Figure 2.6.15.2-2 shows the ligaments and the

interface with the BWR canister shell and the cask inner shell. The loads from the fuel assembly are modeled as a pressure loading at the inner surface of each support disk slot opening. The surface pressure loads applied to the support disk slot opening to represent fuel assemblies are determined by performing a comparison analysis of all relevant BWR assemblies. A comparison is performed to determine the highest load per disk. The load is then divided by the fuel tube's width and the disk thickness to result in a worst case scenario pressure loading. The pressure loading applied to each slot opening is calculated as follows.

Load per disk = (Max. fuel assembly weight + max. fuel tube weight) / No. of loaded disk

Max. fuel assembly weight = 821.3 lbs (very conservative based on actual max fuel assembly weight of 696 lbs [GE BWR/2-3 & 4-6])

Max. fuel tube weight = 83

Number of loaded disks= 37

Load per disk = (821.3 lbs + 83 lbs)/37 disks = 24.4 lbs/disk

Therefore, the pressure loading applied to each slot opening is (24.4 lbs)(0.625)/ 6.278 = 6.2 psi). The loading is multiplied by a *g* load factor based on the drop condition being analyzed:

1. Normal condition - 20 *g*
2. Accident condition - 60 *g*

The PLANE42 element used in the model corresponds to plane stress and the thickness of the model is input as 0.625 in., which corresponds to the thickness of the support disk in the BWR basket.

Figure 2.6.15.2-1 ANSYS Model of BWR Basket for Side-Drop

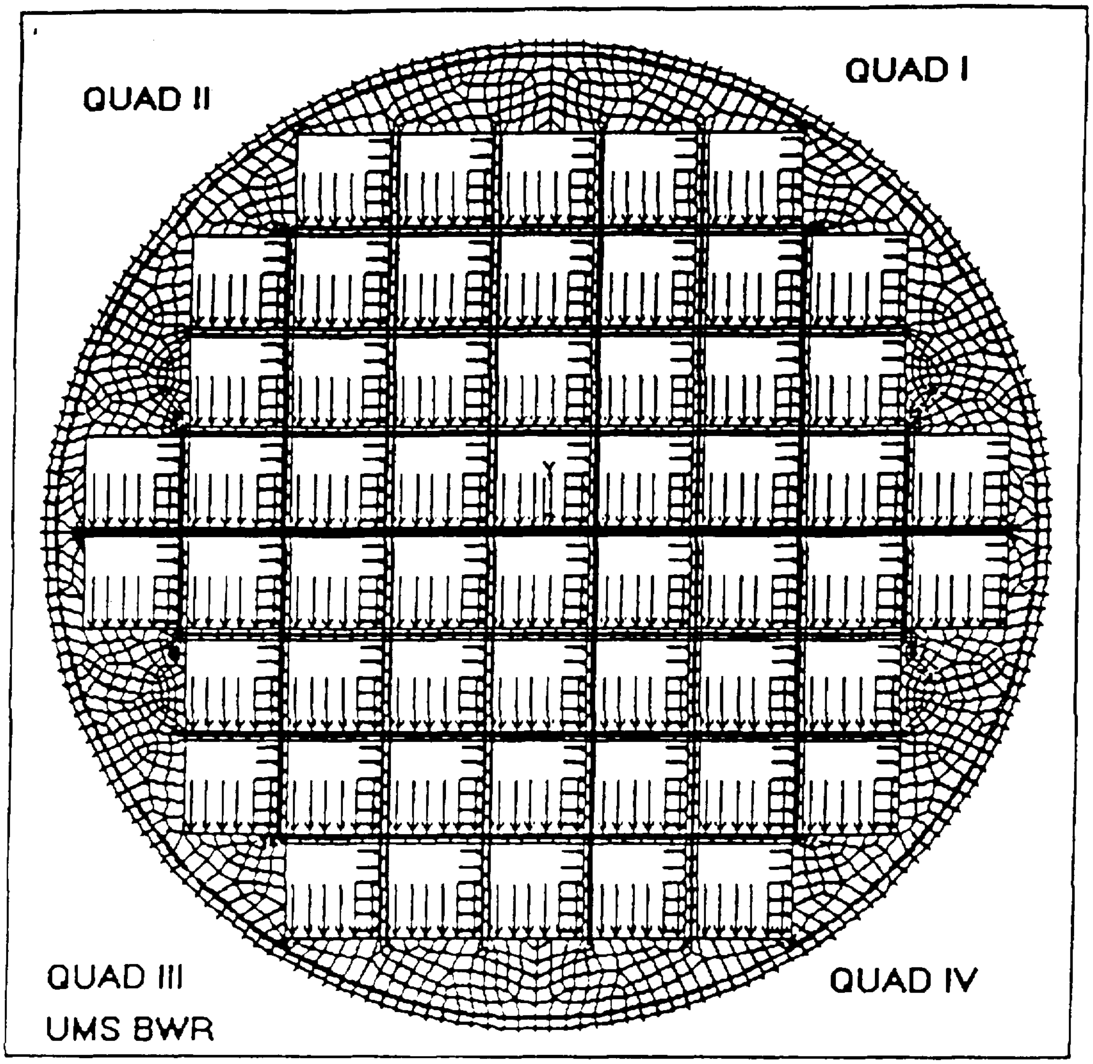
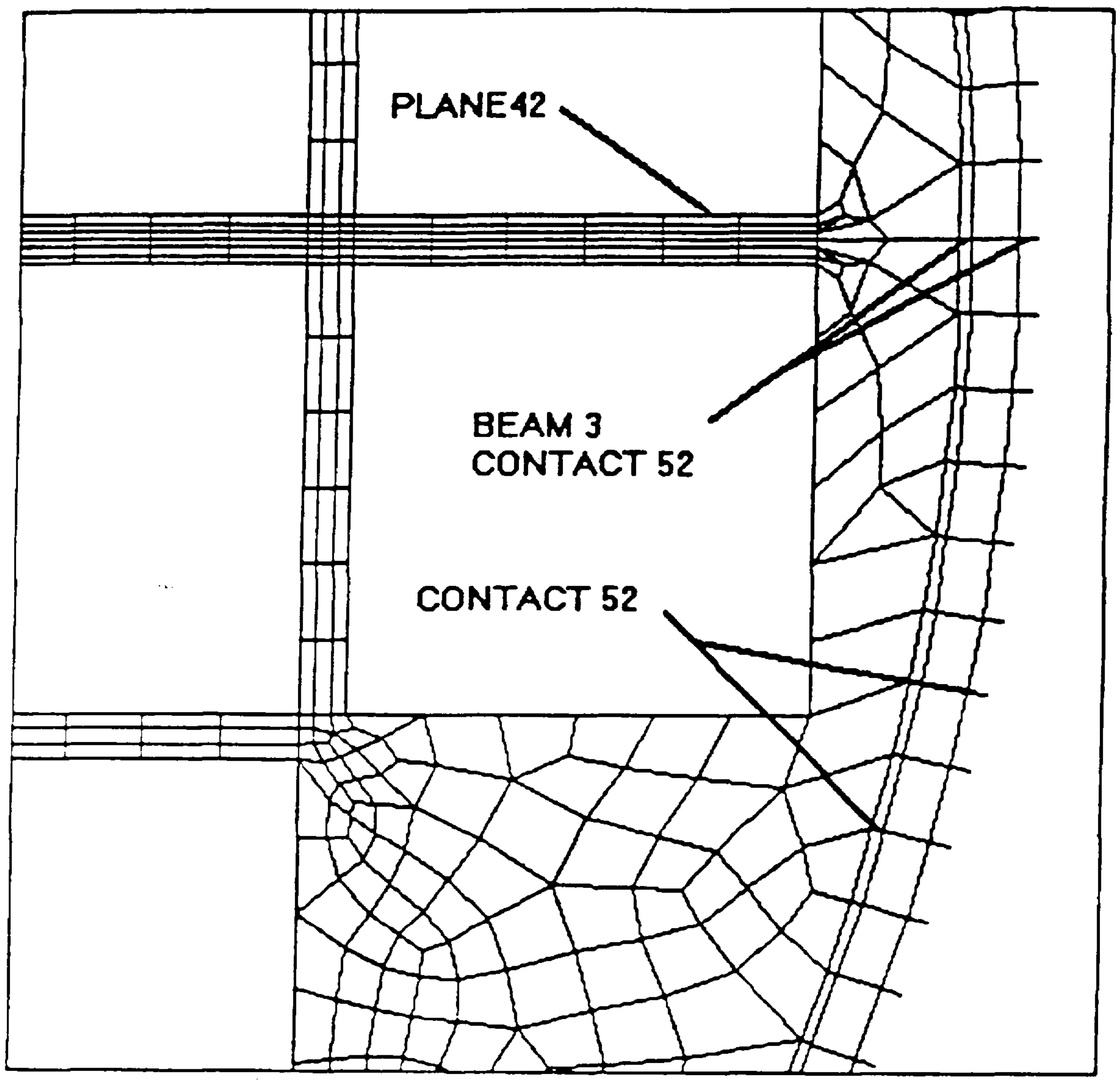


Figure 2.6.15.2-2 Close-up of the Ligaments and the Interface with the Canister Shell and the Cask Inner Shell



2.6.15.3 Thermal Condition and Expansion Evaluation of BWR Support-Disks

The three thermal conditions evaluated for the support disk analysis are as follows:

Thermal Condition	Ambient Temperature	Solar Insolance Applied to Cask Surface	16 kW Fuel Load
1	-40°F	No	No
2	-40°F	No	Yes
3	100°F	Yes	Yes

The table below reflects the maximum and minimum temperatures required for the support disk evaluation. These temperatures were obtained from the thermal analysis of the BWR configuration as contained in Section 3.4.2.

Case No.	T_{max}	T_{min}	Condition No.	α*	E*	Eα*
1	-40°F	-40°F	1	NC**	NC**	NC**
3	616°F	296°F	3	7.598E-6	27.34E3	.2077
5	524°F	349°F	2	7.433E-6	27.988E3	.2080

In the structural evaluation of the support disk, the table below shows the temperatures cases employed.

Case No.	T_{max}	T_{min}	Condition No.	α*	E*	Eα*
1	-40°F	-40°F	1	NC**	NC**	NC**
2	600°F	150°F	3	7.5425E-6	27.550E3	.2078
4	516°F	106°F	2	7.4465E-6	27.934E3	.2080

* Evaluated at average of T_{max} and T_{min} (α = thermal expansion coefficient, in/in/°F; E = modulus of elasticity, ksi)

** NC denotes Not Compared because of uniform temperature.

The thermal stress is dependent on the Eα as well as the overall temperature change along the basket radius. Consequently, Cases 2 and 4 are enveloping as compared to Cases 3 and 5, which are the results of the thermal analysis for the BWR configuration. In comparing Case 2 and 4,

the larger temperature change occurs for Case 2, and since the Eα's are approximately equal, the enveloping thermal stress would be developed in Case 4. To compute the margin of safety, the allowables are derived from Case 3 since it corresponds to the maximum temperatures which would result in the lowest stress allowables. Thermal condition 1 is also analyzed, since it generated the maximum modulus of elasticity, even though stresses arising a thermal gradient are zero.

2.6.15.4 Stress Evaluation of BWR Support Disks for 1-Foot End-Drop Load Condition

The BWR basket support disks are located by six tie rods with spacers. An ANSYS structural analysis evaluates the effect of a 1-ft-end-drop impact that corresponds to the most severe out of plane loading. The finite element model described in Section 2.6.15.2 (and Section 2.6.13.2) is used in conjunction with a 20 *g* deceleration. Because shell elements are employed for the analysis, the nodal stress for the midplane of the plate or the outer fiber stress can be reported at each node. Maximum nodal stresses for the midplane (which correspond to the primary membrane stress) and the outer fiber (which correspond to primary membrane plus bending) are shown in Figure 2.6.15.4-1.

The calculated values of maximum primary membrane and bending stresses are provided in Table 2.6.15.4-2. The membrane stresses for the 1-ft end drop condition is effectively zero.

The minimum margin of safety corresponding to a maximum primary membrane plus bending stress of 32.5 ksi is

$$MS\ (P_m+P_b) = (45.0/32.5) - 1 \qquad (1.5\ S_m \text{ at } 500°F = 45.00 \text{ ksi for SA533 carbon steel})$$

$$= +0.39.$$

Results of the 1-ft end-drop condition are presented in Tables 2.6.15.4-1 and 2.6.15.4-2.

Figure 2.6.15.4-1 Locations of Maximum Primary Nodal Stress Intensities for 1-Foot End-Drop

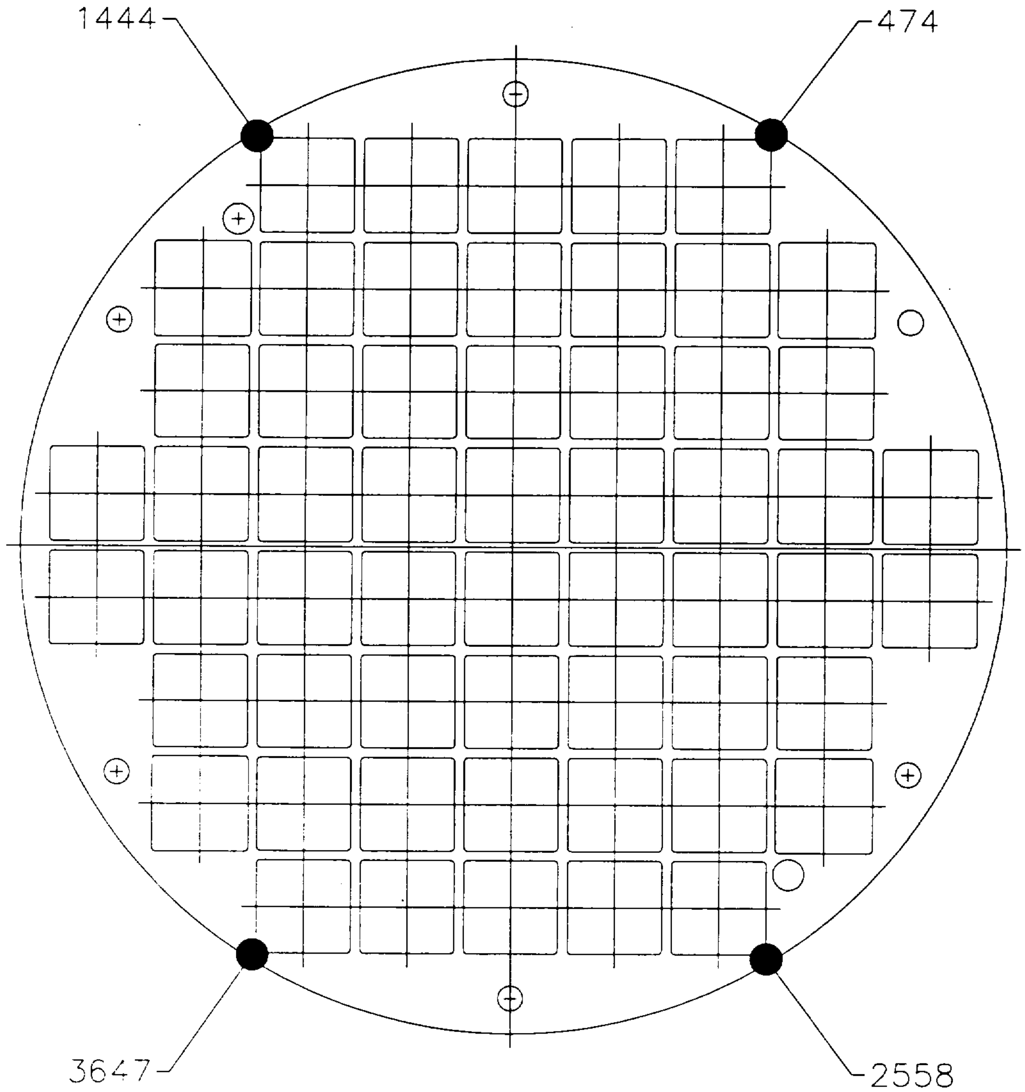


Table 2.6.15.4-1 $P_m + P_b$ Stresses for Support Disk 1-Foot End-Drop, Thermal Case 1

Node	Principal Stresses (ksi)			Stress Intensity (ksi)	Allowable Stress (ksi)*	Margin of Safety
	S1	S2	S3			
86	25.3	0.0	-1.0	26.3	45.0	0.71
474	32.2	2.1	0.0	32.2	45.0	0.40
1129	29.6	1.5	0.0	29.6	45.0	0.52
1444	32.2	2.1	0.0	32.2	45.0	0.40
1564	25.3	0.0	-1.0	26.3	45.0	0.71
2236	29.6	1.5	0.0	29.6	45.0	0.52
2558	32.2	2.1	0.0	32.2	45.0	0.40
2680	25.3	0.0	-1.0	26.3	45.0	0.71
3332	29.6	1.5	0.0	29.6	45.0	0.52
3647	32.2	2.1	0.0	32.2	45.0	0.40
3765	25.3	0.0	-1.0	26.3	45.0	0.71
4407	29.6	1.5	0.0	29.6	45.0	0.52

*1.5 S_m = 1.5 x 30.0 ksi at 500°F.

Table 2.6.15.4-2 $P_m + P_b$ Stresses for Support Disk 1-Foot End-Drop, Thermal Case 4

Node	Principal Stresses (psi)			Stress Intensity (psi)	Allowable Stress (psi)*	Margin of Safety
	S1	S2	S3			
86	25.6	0.0	-1.1	26.7	45.0	0.69
474	32.5	2.1	0.0	32.5	45.0	0.39
1129	29.9	1.5	0.0	29.9	45.0	0.51
1444	32.5	2.1	0.0	32.5	45.0	0.39
1564	25.6	0.0	-1.1	26.7	45.0	0.69
2236	29.9	1.5	0.0	29.9	45.0	0.51
2558	32.5	2.1	0.0	32.5	45.0	0.39
2680	25.6	0.0	-1.1	26.7	45.0	0.69
3332	29.9	1.5	0.0	29.9	45.0	0.51
3647	32.5	2.1	0.0	32.5	45.0	0.39
3765	25.6	.0	-1.1	26.7	45.0	0.69
4407	29.9	1.5	0.0	29.9	45.0	0.51

*1.5 S_m = 1.5 x 30.0 ksi at 500°F.

2.6.15.5 Stress Evaluation of BWR Support Disk for Combined Thermal and 1-Foot End Drop Load Conditions

The thermal expansion loads described in Section 2.6.15.3 (and 2.6.13.3) are applied to the finite element model simultaneously with the 20 *g* end-drop loads described in Section 2.6.15.4 to produce a combined thermal expansion plus end-impact loading. The stress evaluation is performed according to the ASME Code, Section III, Subsection NG. Because stress intensity is required at the surface only, the extreme fiber stress is required. Thermal Condition 4 is used for this evaluation. Maximum nodal stresses for the combined thermal and 1-ft end-drop condition are shown in Figure 2.6.15.5-1. The allowable stress intensity range is $3S_m$. The maximum stress intensity is 52.7 ksi and the $3S_m$ allowable limit at 500°F for SA533 Type B Class 2 carbon steel is 90 ksi, which results in a margin of safety of:

$$MS = (90/52.7) - 1 = +0.71.$$

Results from the combined thermal and 1-ft end-drop condition are presented in Table 2.6.15.5-1.

Figure 2.6.15.5-1 Locations of Maximum Primary and Secondary Nodal Stress Intensities for 1-Foot End-Drop

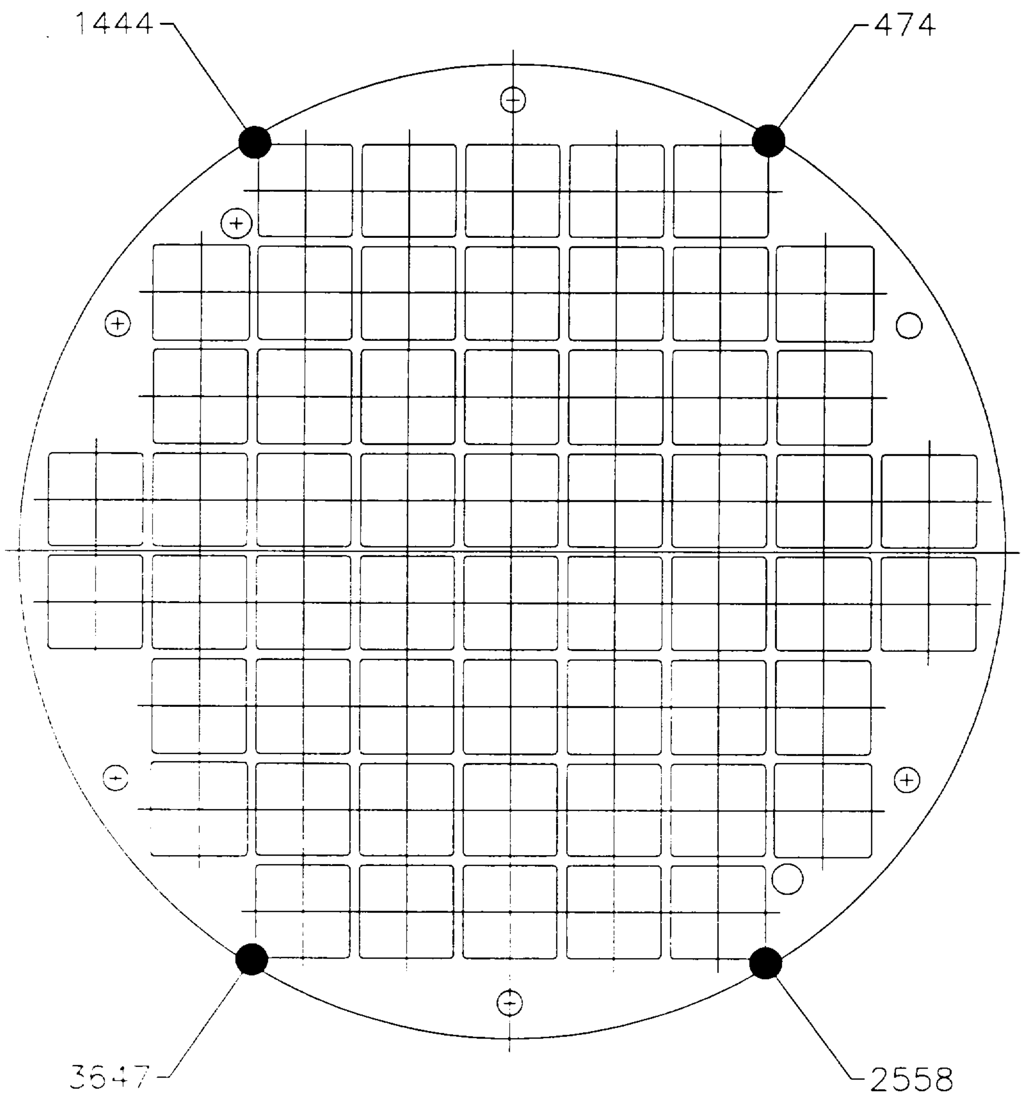


Table 2.6.15.5-1 $P_m + P_b + Q$ Stresses for Support Disk 1-Foot End-Drop, Thermal Case 4

Node	Principal Stresses (ksi)			Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
	S1	S2	S3			
474	52.7	7.2	0.0	52.7	90.0	0.71
481	35.0	0.0	-3.1	38.1	90.0	1.36
1129	40.3	3.6	0.0	40.3	90.0	1.23
1444	52.7	7.2	0.0	52.7	90.0	0.71
1451	35.0	0.0	-3.1	38.1	90.0	1.36
2236	40.3	3.6	0.0	40.3	90.0	1.23
2558	52.7	7.2	0.0	52.7	90.0	0.71
2565	35.0	0.0	-3.1	38.1	90.0	1.36
3332	40.3	3.6	0.0	40.3	90.0	1.23
3647	52.7	7.2	0.0	52.7	90.0	0.71
3654	35.0	0.0	-3.1	38.1	90.0	1.36
4407	40.3	3.6	0.0	40.3	90.0	1.23

*3.0 S_m = 3.0 x 30.0 ksi at 500°F.

2.6.15.6 Stress Evaluation of BWR Support Disk for 1-Foot Side-Drop Load Condition

To determine the structural adequacy of the BWR fuel basket support disk for the 1-ft side-drop load condition, a quasi-static impact load equal to the weight of the fuel and tubes multiplied by a 20 *g* amplification factor is applied to the support disk structure. The inertial loading of the support disk is also included by means of the density input for the SA533 Type B Class 2 carbon steel. The value of 20 *g* is conservative because the Universal Transport Cask impact limiter design deceleration for a 1-ft side-drop is 16.4 *g*. The fuel assembly load is transmitted in direct compression through the tube wall to the web structure of the support disk. A conservative number of disks is assumed to transmit the load to the canister shell (See Section 2.6.15.2). The maximum in-plane loading occurs in the side-drop, which requires a detailed structural evaluation. ANSYS and the finite element model described in Section 2.6.15.2 are used to perform a finite element analysis.

2.6.15.6.1 Drop Orientations

The BWR fuel basket exhibits one-quarter symmetry. A minimal radial thickness between the corner of the fuel assembly slot in the basket and the outer radius occurs at 31.82, 49.46, 77.92 and 90° measured counterclockwise from the +X axis. To ensure that the bounding basket orientation is evaluated, basket radial orientations of 0, 31.82, 49.46, 77.92, and 90° are considered. These orientations are identified in Figure 2.6.15.6-1. The material properties are evaluated at three thermal Cases 1, 2 and 4. Allowables are evaluated at Thermal Cases 1 and 3.

2.6.15.6.2 Definition of Cross Sections for Linearized Stresses

The stress evaluation for the support disk is performed according to the ASME Code, Section III, Subsection NG, which requires comparison of the linearized stresses of cross sections of the structure against the allowable stresses. Primary membrane stress intensity is compared with S_m and primary membrane plus bending stress intensity is compared with $1.5S_m$ for the material at temperature. A conservative temperature distribution is used to determine S_m at each of the cross sections. These temperatures are obtained through thermal conduction analysis by using Thermal Case 3, where the minimum temperature of the circumference and the maximum temperature is applied at the center of the basket.

To determine the most critical cross sections, a series of cross sections is considered. To aid in the identification of these sections, Figures 2.6.15.6-2 through 2.6.15.6-5 show the point locations on a support disk. Table 2.6.15.6-1 lists the cross section versus Point 1 and Point 2, which spans the cross section of the web in the plane of the support disk. Points 1 and 2 for each cross section are shown in the previously cited figures.

2.6.15.6.3 Analysis Results for 1-Foot Side-Drop

Finite element analyses are performed for the 1-ft side-drop load conditions for the five different radial basket orientations (0, 31.82, 49.46, 77.92 and 90°) and for two Thermal Cases that would result in the use of different moduli of elasticity throughout the basket. Figures 2.6.15.6-6 through 2.6.15.6-10 show the locations of maximum nodal stress intensities (SI) for the five basket orientations.

For the normal condition of transport, the allowable stress limit is S_m, for the support disk primary membrane stress (P_m) and $1.5S_m$ for primary membrane plus bending stress ($P_m + P_b$). The cross sections with the 20 minimum margins of safety are presented in Tables 2.6.15.6-2 through 2.6.15.6-21. A summary of the minimum margins of safety is presented below.

Table Number	Basket Orientation (Deg)	Thermal Case	Stress Evaluation	Minimum Margin of Safety
2.6.15.6-2	0	1	P_m	+0.45
2.6.15.6-3	0	1	$P_m + P_b$	+0.84
2.6.15.6-4	0	2	P_m	+0.47
2.6.15.6-5	0	2	$P_m + P_b$	+0.88
2.6.15.6-6	31.82	1	P_m	+0.54
2.6.15.6-7	31.82	1	$P_m + P_b$	+0.19
2.6.15.6-8	31.82	2	P_m	+0.60
2.6.15.6-9	31.82	2	$P_m + P_b$	+0.24
2.6.15.6-10	49.46	1	P_m	+0.35
2.6.15.6-11	49.46	1	$P_m + P_b$	+0.11
2.6.15.6-12	49.46	2	P_m	+0.43
2.6.15.6-13	49.46	2	$P_m + P_b$	+0.13
2.6.15.6-14	77.92	1	P_m	+0.29
2.6.15.6-15	77.92	1	$P_m + P_b$	+0.45
2.6.15.6-16	77.92	2	P_m	+0.32
2.6.15.6-17	77.92	2	$P_m + P_b$	+0.47
2.6.15.6-18	90	1	P_m	+0.09
2.6.15.6-19	90	1	$P_m + P_b$	+0.56
2.6.15.6-20	90	2	P_m	+0.12
2.6.15.6-21	90	2	$P_m + P_b$	+0.59

The margins of safety are calculated as

MS = (stress allowable/stress intensity) - 1.

The minimum margin of safety for the side-drop (+ 0.09) occurs for the 90° basket orientation at Thermal Case 2, no thermal stresses. This margin of safety is based on a primary membrane stress of 27.4 ksi.

Figure 2.6.15.6-1 Support Disk Side-Drop Orientations

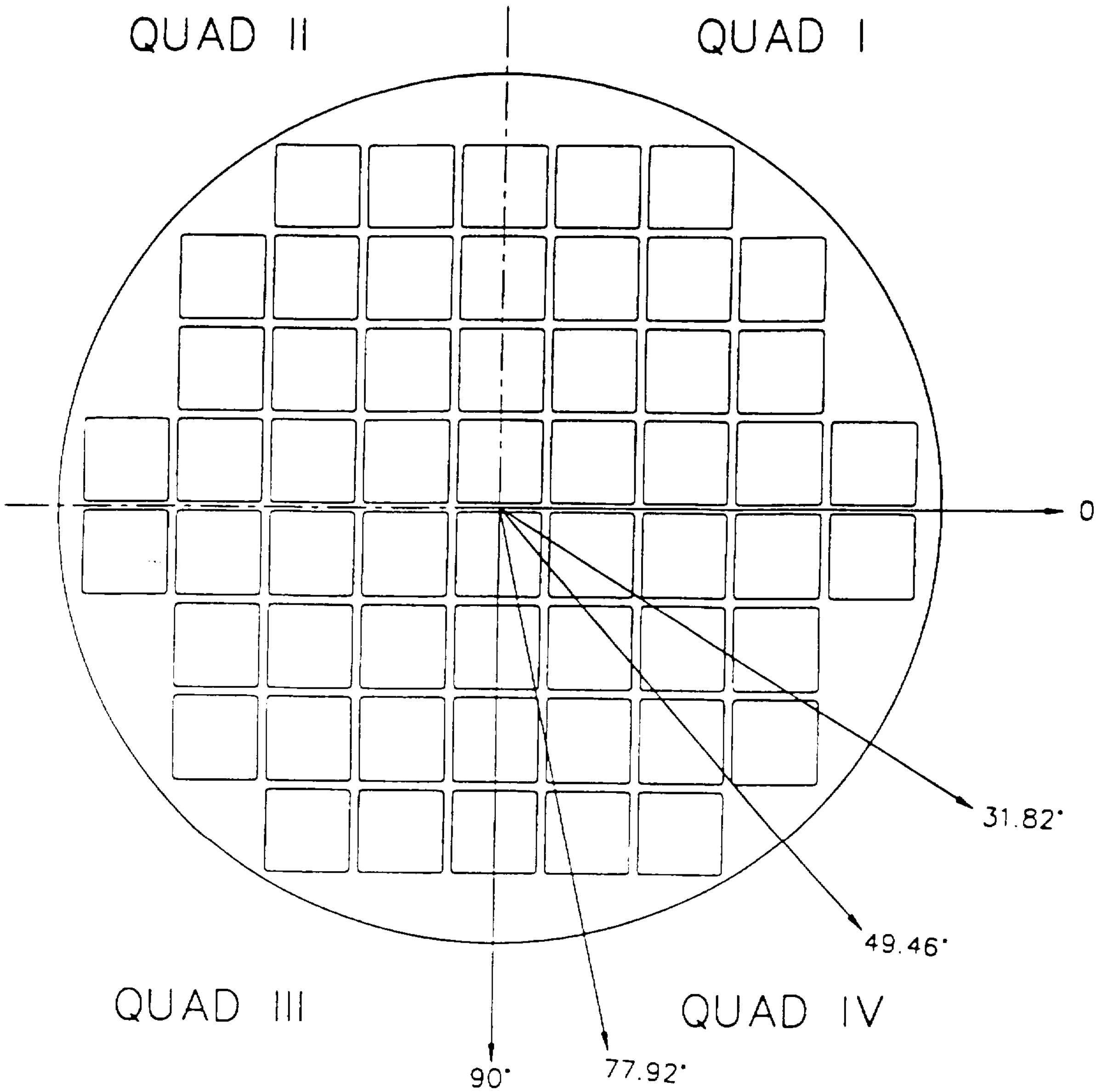
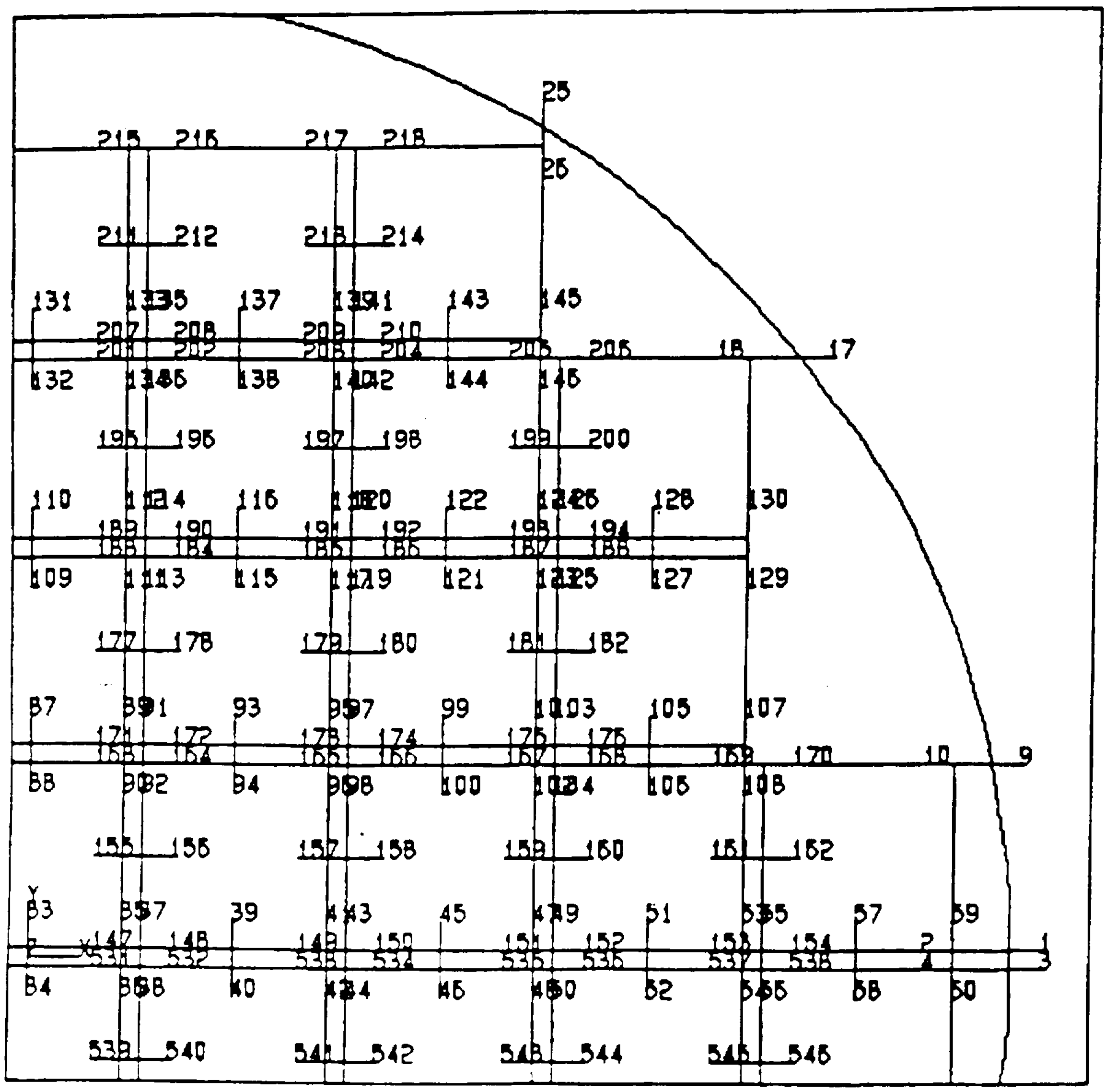


Figure 2.6.15.6-2 Locations of the Sections Used to Obtain Linearized Stresses for the Support Disk for the 1st Quadrant (X>0, Y>0)



QUAD I

Figure 2.6.15.6-3 Locations of the Sections Used to Obtain Linearized Stresses for the Support Disk for the 2nd Quadrant (X<0, Y<0)

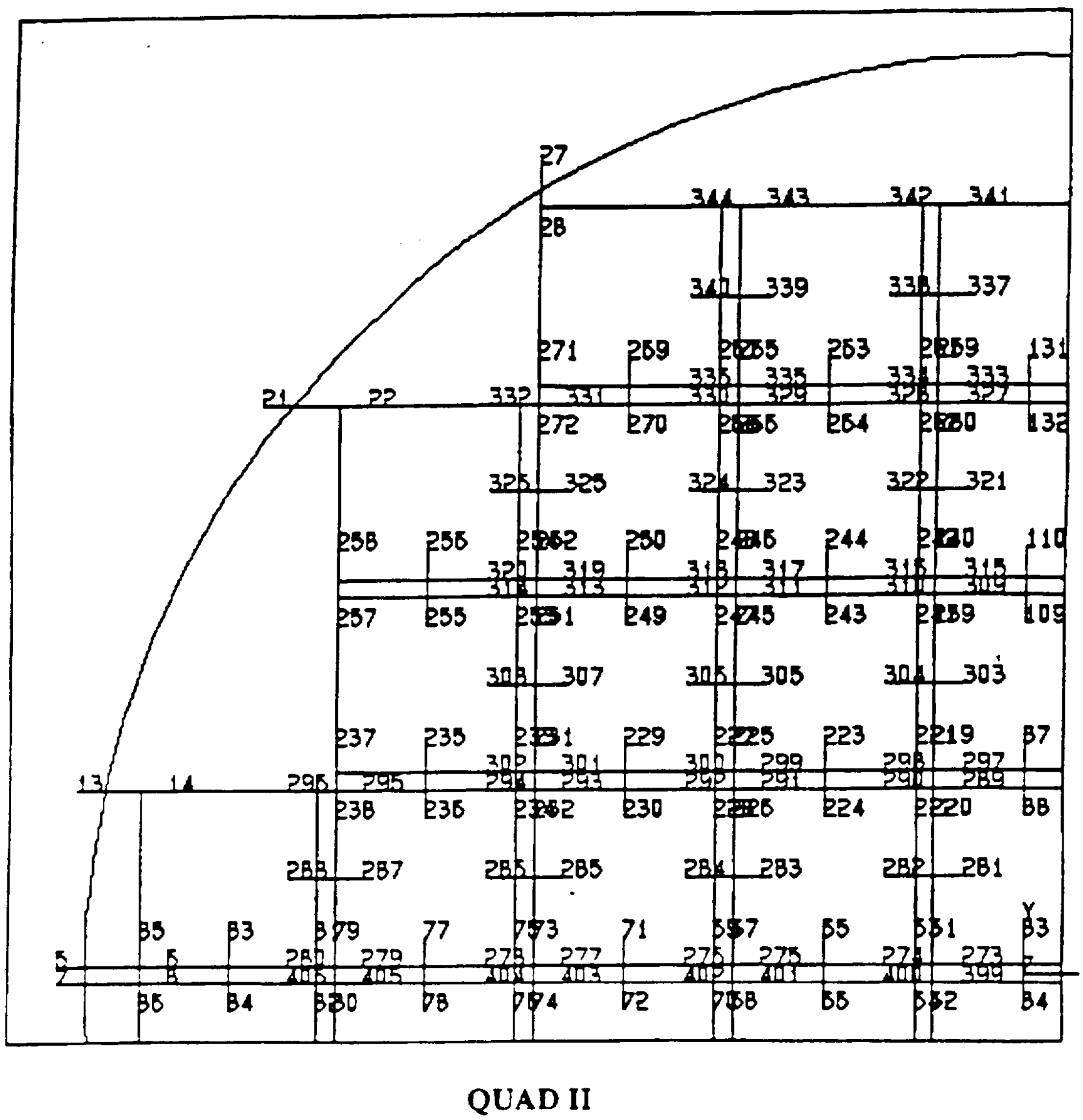
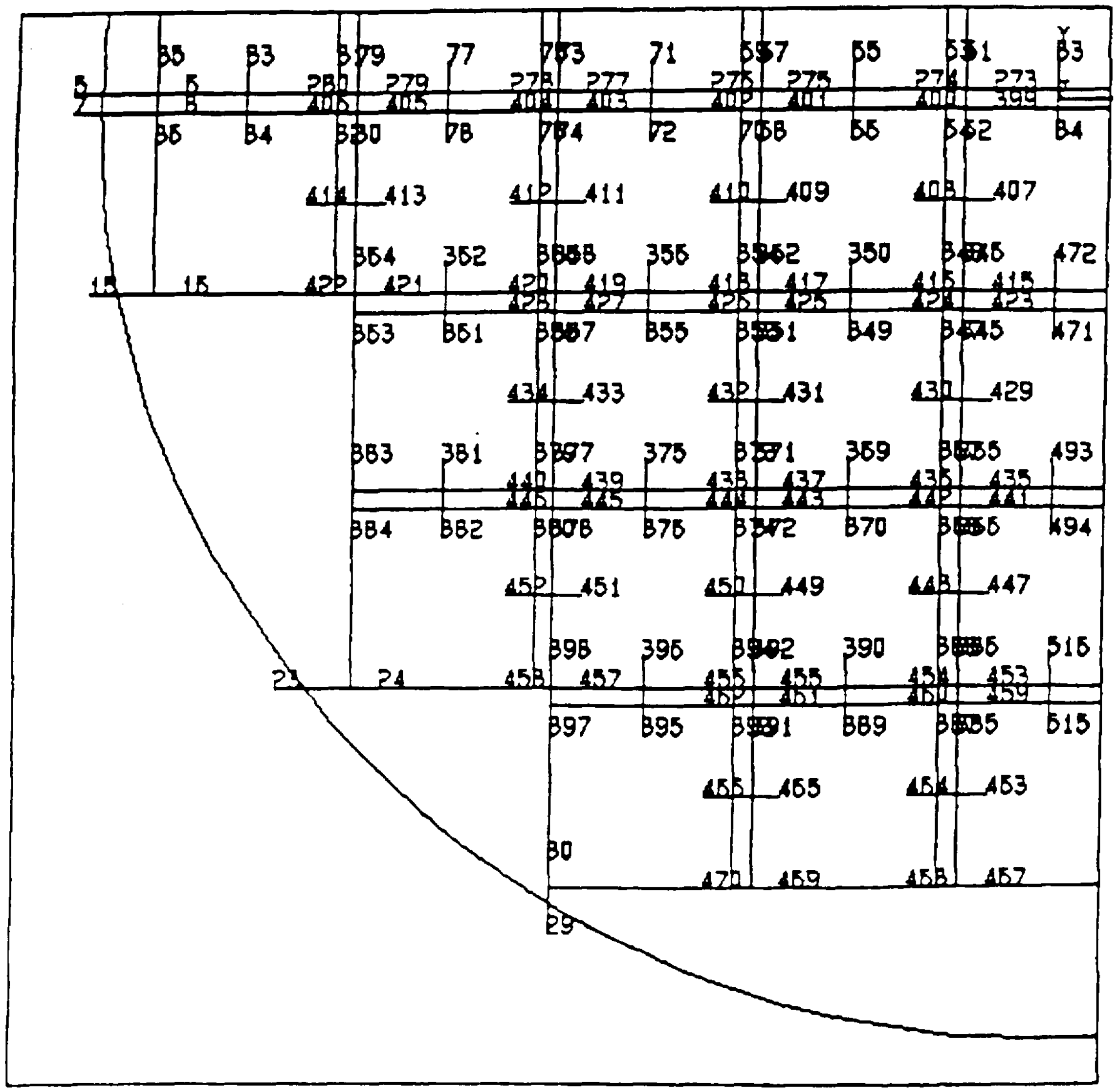
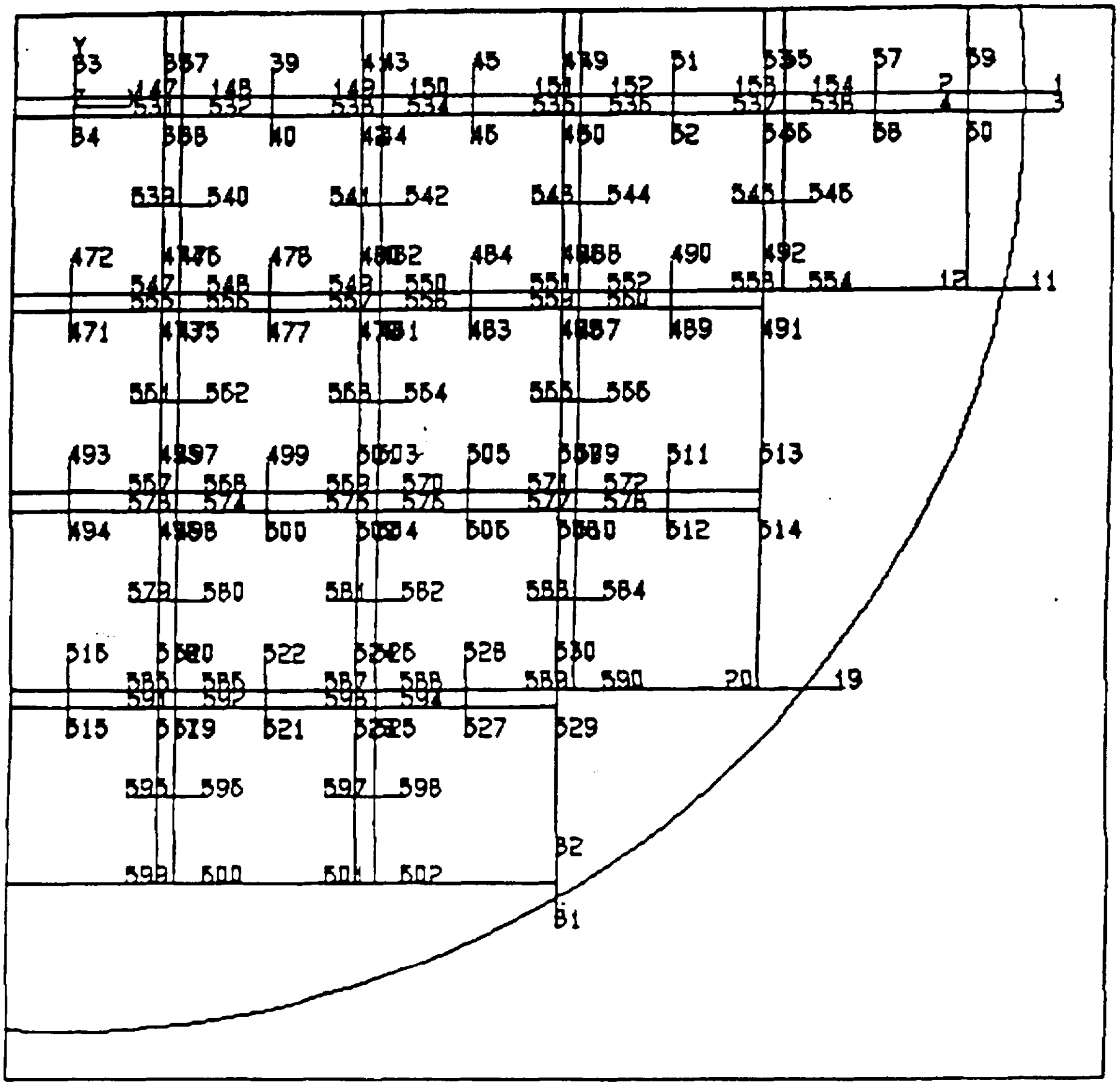


Figure 2.6.15.6-4 Locations of the Sections Used to Obtain Linearized Stresses for the Support Disk for the 3rd Quadrant (X<0, Y<0)



QUAD III

Figure 2.6.15.6-5	Locations of the Sections Used to Obtain Linearized Stresses for the Support Disk for the 4th Quadrant (X>0, Y<0)



QUAD IV

Figure 2.6.15.6-6 Locations of Maximum Linearized Stress Intensities - 0° Drop Orientation

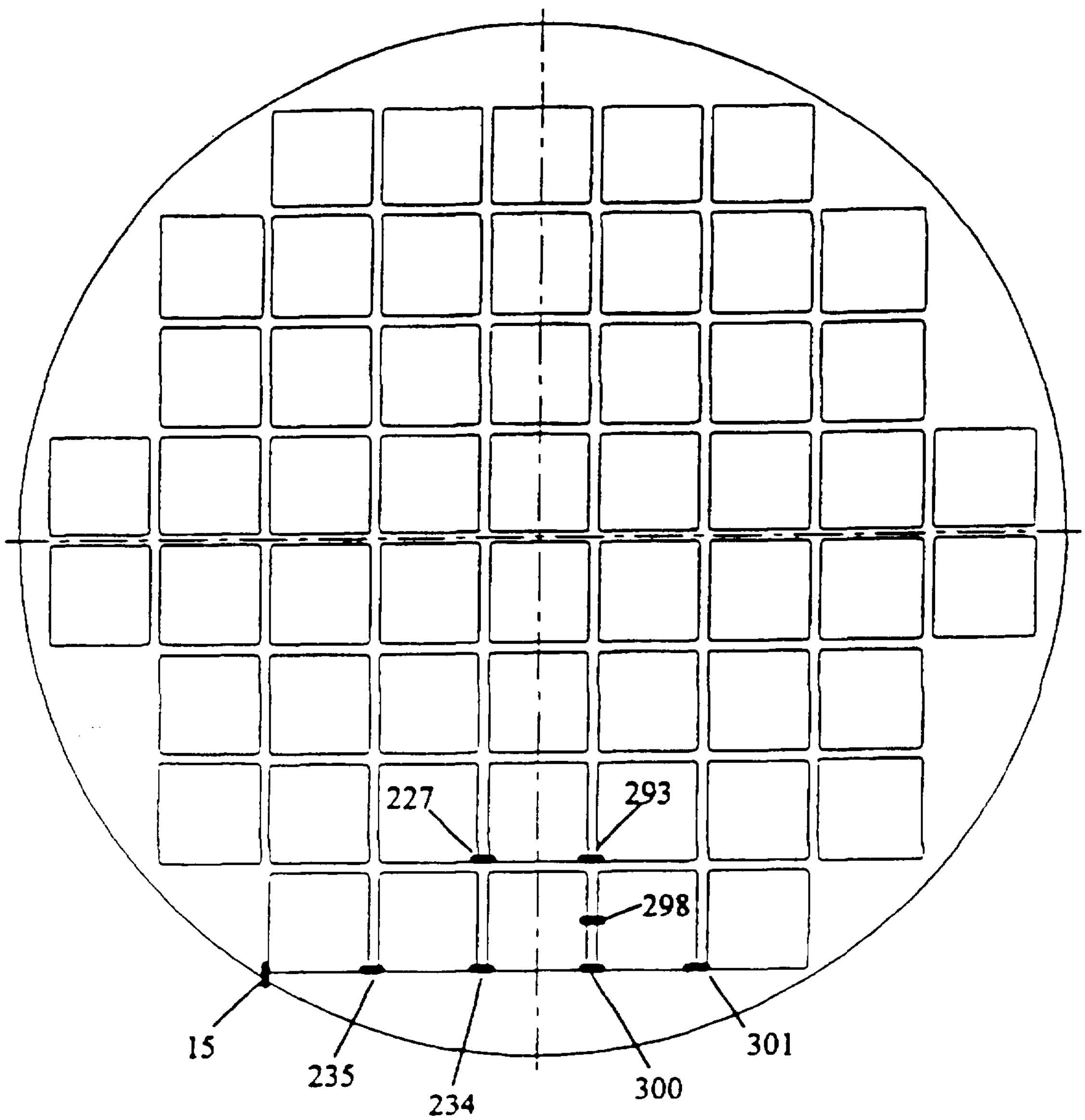


Figure 2.6.15.6-7 Locations of Maximum Linearized Stress Intensities - 31.82° Drop Orientation

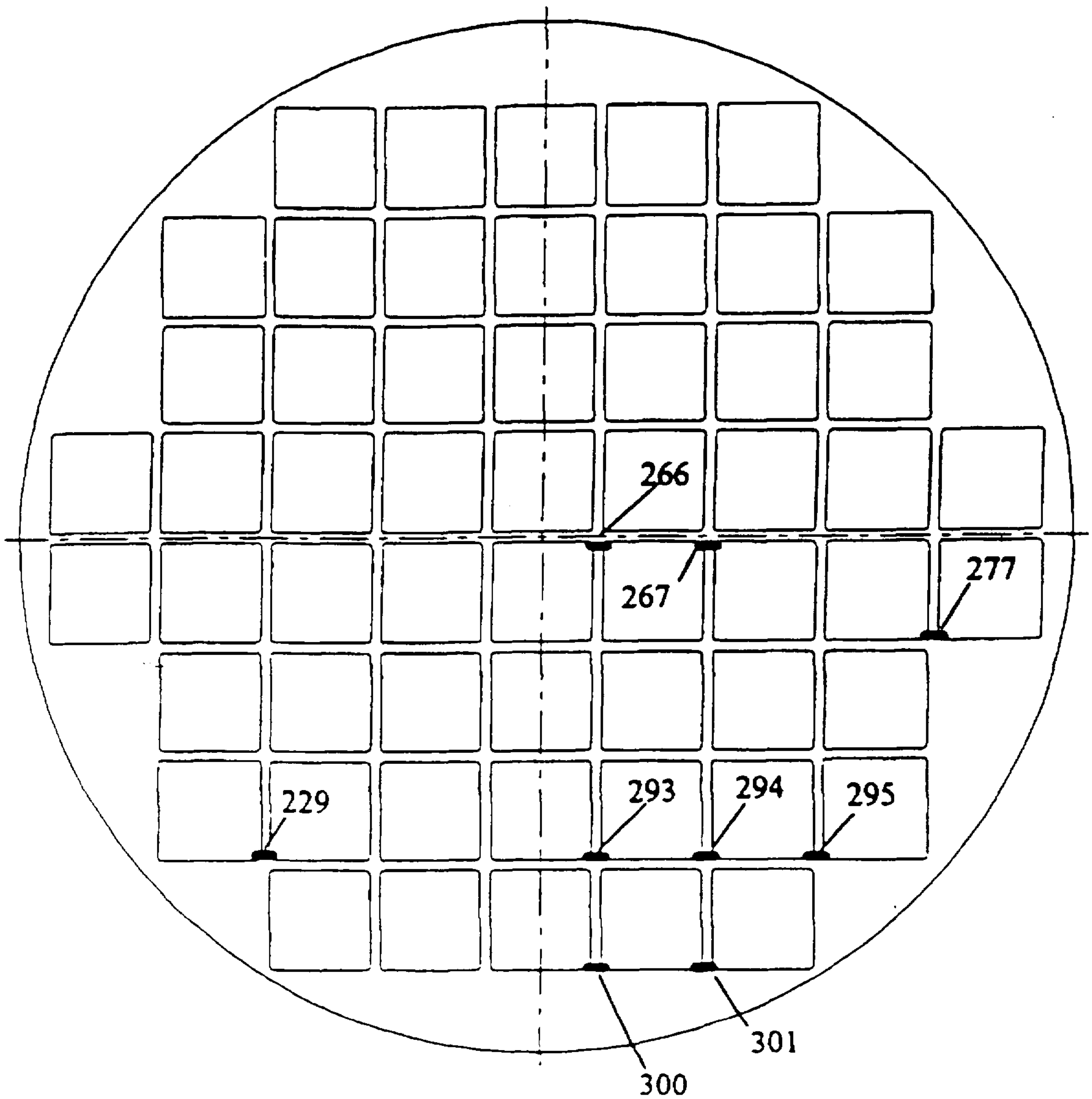


Figure 2.6.15.6-8 Locations of Maximum Linearized Stress Intensities - 49.46° Drop Orientation

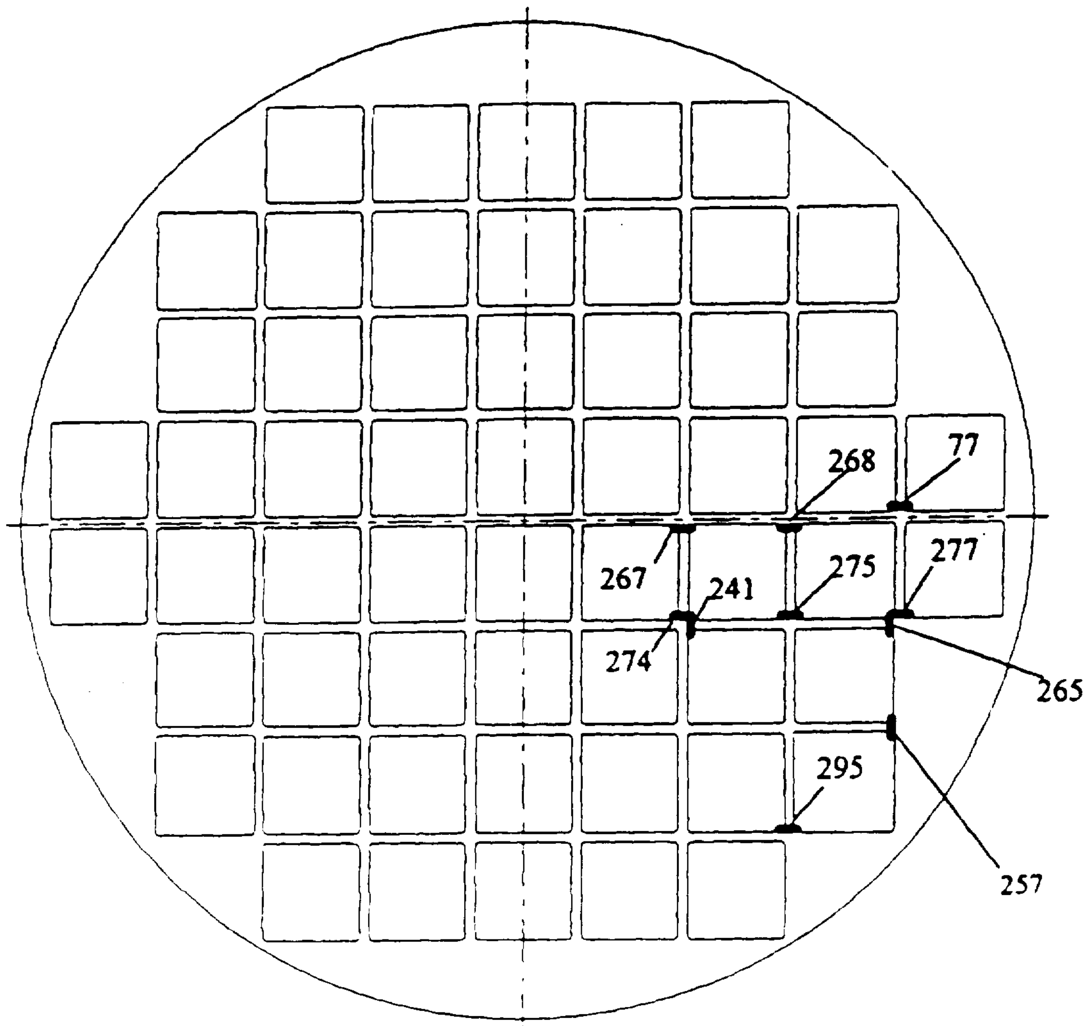


Figure 2.6.15.6-9 Locations of Maximum Linearized Stress Intensities - 77.92° Drop Orientation

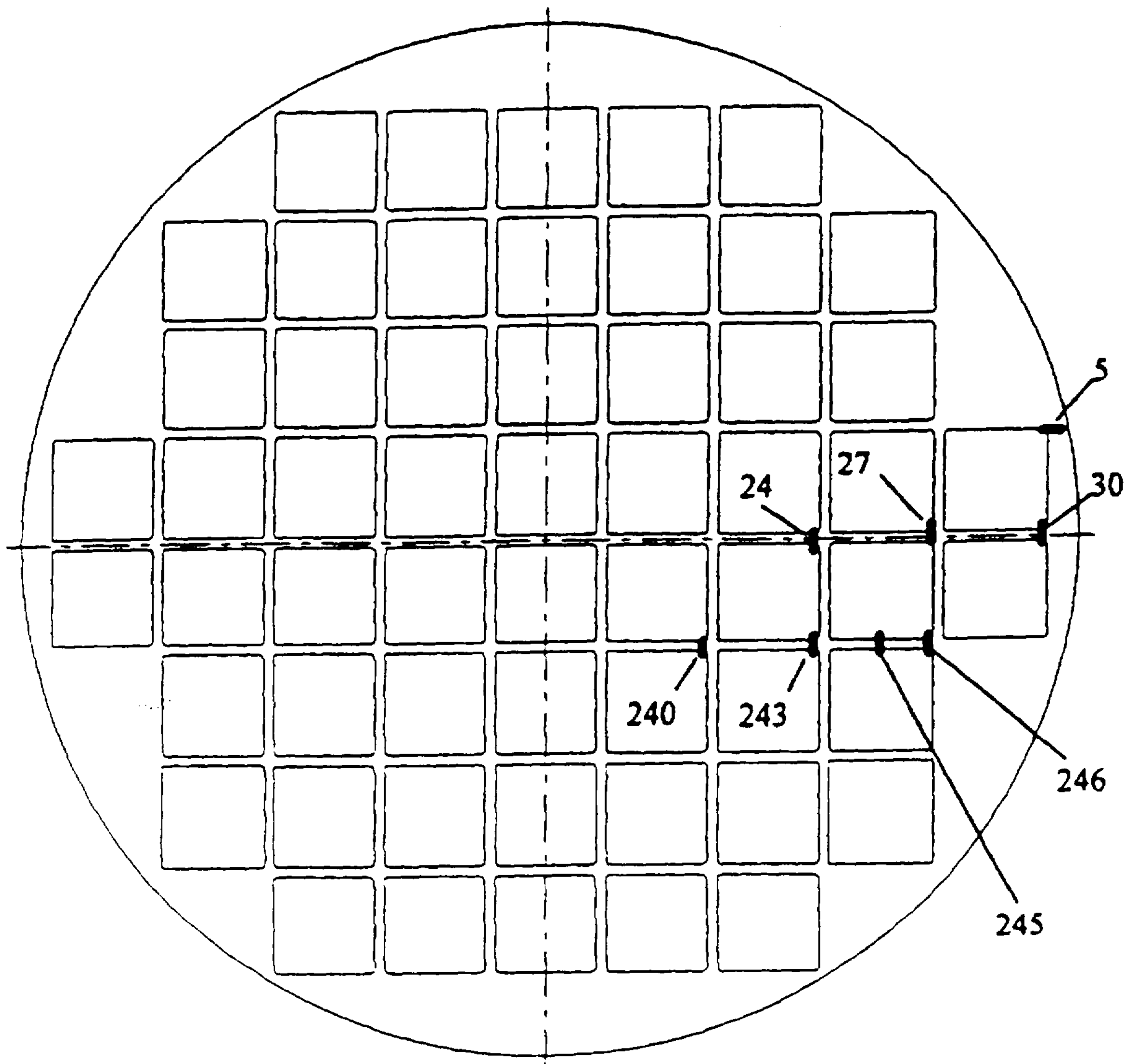


Figure 2.6.15.6-10 Locations of Maximum Linearized Stress Intensities - 90° Drop Orientation

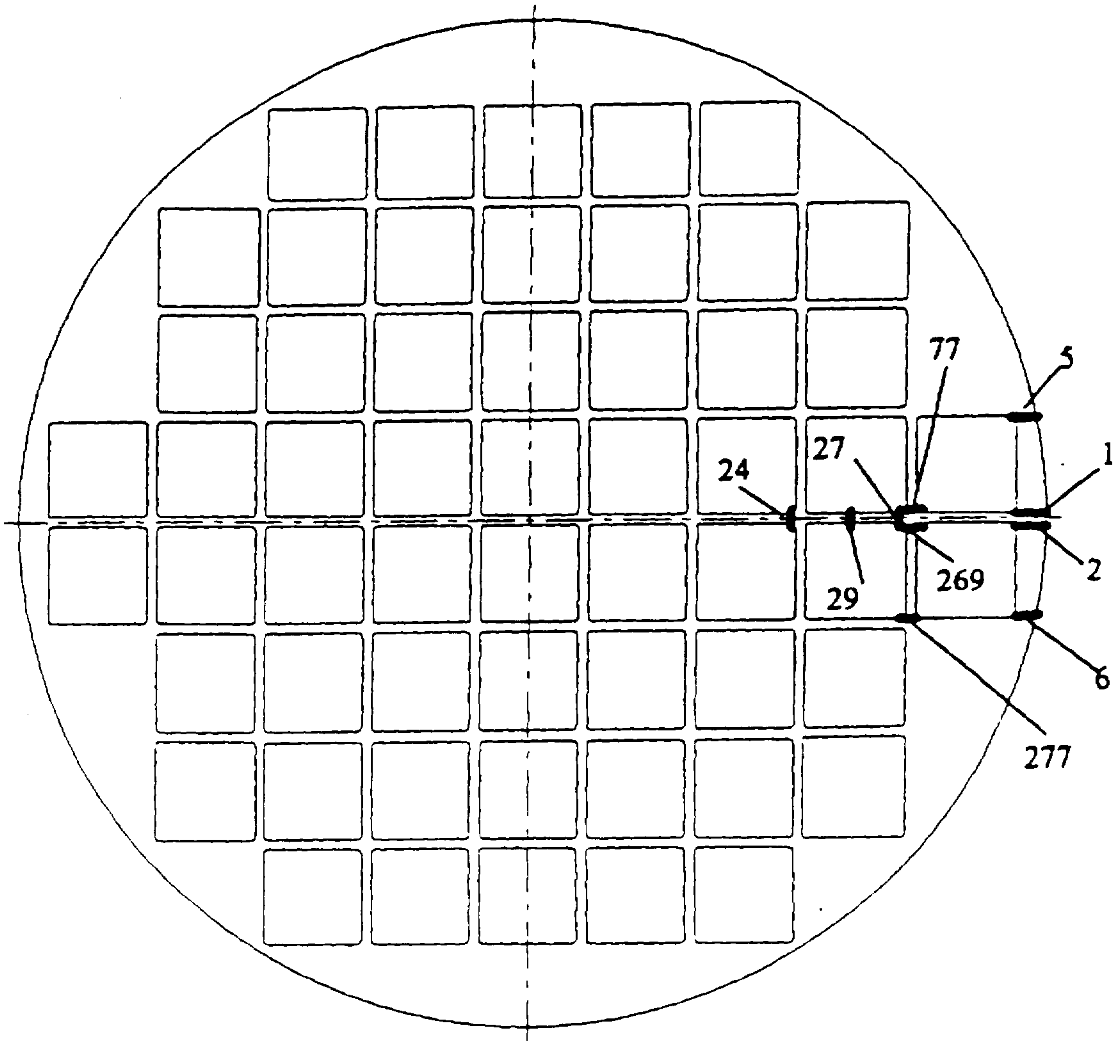


Table 2.6.15.6-1 Listing of Cross Sections for Stress Evaluation of Support Disk

Section & Line #	Point 1	Point 2	Node 1	Node 2	X 1	Y 1	X 2	Y 2
1	1	2	4724	4725	32.74	0.33	30.85	0.33
2	3	4	4726	4727	32.74	-0.33	30.85	-0.33
3	5	6	4728	4729	-32.74	0.33	-30.85	0.33
4	7	8	4730	4731	-32.74	-0.33	-30.85	-0.33
5	9	10	4732	4733	32.07	6.6	30.85	6.6
6	11	12	4734	4735	32.07	-6.6	30.85	-6.6
7	13	14	4736	4737	-32.07	6.6	-30.85	6.6
8	15	16	4738	4739	-32.07	-6.6	-30.85	-6.6
9	17	18	4740	4741	25.57	20.46	23.89	20.46
10	19	20	4742	4743	25.57	-20.46	23.89	-20.46
11	21	22	4744	4745	-25.57	20.46	-23.89	20.46
12	23	24	4746	4747	-25.57	-20.46	-23.89	-20.46
13	25	26	4748	4749	17	27.99	17	27.39
14	27	28	4750	4751	-17	27.99	-17	27.39
15	29	30	4752	4753	-17	-27.99	-17	-27.39
16	31	32	4754	4755	17	-27.99	17	-27.39
17	33	34	4756	4757	0	0.33	0	-0.33
18	35	36	4758	4759	3.14	0.33	3.14	-0.33
19	37	38	4760	4761	3.79	0.33	3.79	-0.33
20	39	40	4762	4763	6.93	0.33	6.93	-0.33
21	41	42	4764	4765	10.07	0.33	10.07	-0.33
22	43	44	4766	4767	10.72	0.33	10.72	-0.33
23	45	46	4768	4769	13.86	0.33	13.86	-0.33
24	47	48	4770	4771	17	0.33	17	-0.33
25	49	50	4772	4773	17.65	0.33	17.65	-0.33
26	51	52	4774	4775	20.78	0.33	20.78	-0.33
27	53	54	4776	4777	23.92	0.33	23.92	-0.33
28	55	56	4778	4779	24.57	0.33	24.57	-0.33
29	57	58	4780	4781	27.71	0.33	27.71	-0.33
30	59	60	4782	4783	30.85	0.33	30.85	-0.33
31	61	62	4784	4785	-3.14	0.33	-3.14	-0.33
32	63	64	4786	4787	-3.79	0.33	-3.79	-0.33
33	65	66	4788	4789	-6.93	0.33	-6.93	-0.33
34	67	68	4790	4791	-10.07	0.33	-10.07	-0.33
35	69	70	4792	4793	-10.72	0.33	-10.72	-0.33
36	71	72	4794	4795	-13.86	0.33	-13.86	-0.33
37	73	74	4796	4797	-17	0.33	-17	-0.33
38	75	76	4798	4799	-17.65	0.33	-17.65	-0.33
39	77	78	4800	4801	-20.78	0.33	-20.78	-0.33

Table 2.6.15.6-1 Listing of Cross Sections for Stress Evaluation of Support Disk (Continued)

Section & Line #	Point 1	Point 2	Node 1	Node 2	X 1	Y 1	X 2	Y 2
40	79	80	4802	4803	-23.92	0.33	-23.92	-0.33
41	81	82	4804	4805	-24.57	0.33	-24.57	-0.33
42	83	84	4806	4807	-27.71	0.33	-27.71	-0.33
43	85	86	4808	4809	-30.85	0.33	-30.85	-0.33
44	87	88	4810	4811	0	7.25	0	6.6
45	89	90	4812	4813	3.14	7.25	3.14	6.6
46	91	92	4814	4815	3.79	7.25	3.79	6.6
47	93	94	4816	4817	6.93	7.25	6.93	6.6
48	95	96	4818	4819	10.07	7.25	10.07	6.6
49	97	98	4820	4821	10.72	7.25	10.72	6.6
50	99	100	4822	4823	13.86	7.25	13.86	6.6
51	101	102	4824	4825	17	7.25	17	6.6
52	103	104	4826	4827	17.65	7.25	17.65	6.6
53	105	106	4828	4829	20.78	7.25	20.78	6.6
54	107	108	4830	4831	23.92	7.25	23.92	6.6
55	109	110	4832	4833	0	13.53	0	14.18
56	111	112	4834	4835	3.14	13.53	3.14	14.18
57	113	114	4836	4837	3.79	13.53	3.79	14.18
58	115	116	4838	4839	6.93	13.53	6.93	14.18
59	117	118	4840	4841	10.07	13.53	10.07	14.18
60	119	120	4842	4843	10.72	13.53	10.72	14.18
61	121	122	4844	4845	13.86	13.53	13.86	14.18
62	123	124	4846	4847	17	13.53	17	14.18
63	125	126	4848	4849	17.65	13.53	17.65	14.18
64	127	128	4850	4851	20.78	13.53	20.78	14.18
65	129	130	4852	4853	23.92	13.53	23.92	14.18
66	131	132	4854	4855	0	21.11	0	20.46
67	133	134	4856	4857	3.14	21.11	3.14	20.46
68	135	136	4858	4859	3.79	21.11	3.79	20.46
69	137	138	4860	4861	6.93	21.11	6.93	20.46
70	139	140	4862	4863	10.07	21.11	10.07	20.46
71	141	142	4864	4865	10.72	21.11	10.72	20.46
72	143	144	4866	4867	13.86	21.11	13.86	20.46
73	145	146	4868	4869	17	21.11	17	20.46
74	147	148	4870	4871	3.14	0.33	3.79	0.33
75	149	150	4872	4873	10.07	0.33	10.72	0.33
76	151	152	4874	4875	17	0.33	17.65	0.33
77	153	154	4876	4877	23.92	0.33	24.57	0.33

Table 2.6.15.6-1 Listing of Cross Sections for Stress Evaluation of Support Disk (Continued)

Section & Line #	Point 1	Point 2	Node 1	Node 2	X 1	Y 1	X 2	Y 2
78	155	156	4878	4879	3.14	3.46	3.79	3.46
79	157	158	4880	4881	10.07	3.46	10.72	3.46
80	159	160	4882	4883	17	3.46	17.65	3.46
81	161	162	4884	4885	23.92	3.46	24.57	3.46
82	163	164	4886	4887	3.14	6.6	3.79	6.6
83	165	166	4888	4889	10.07	6.6	10.72	6.6
84	167	168	4890	4891	17	6.6	17.65	6.6
85	169	170	4892	4893	23.92	6.6	24.57	6.6
86	171	172	4894	4895	3.14	7.25	3.79	7.25
87	173	174	4896	4897	10.07	7.25	10.72	7.25
88	175	176	4898	4899	17	7.25	17.65	7.25
89	177	178	4900	4901	3.14	10.39	3.79	10.39
90	179	180	4902	4903	10.07	10.39	10.72	10.39
91	181	182	4904	4905	17	10.39	17.65	10.39
92	183	184	4906	4907	3.14	13.53	3.79	13.53
93	185	186	4908	4909	10.07	13.53	10.72	13.53
94	187	188	4910	4911	17	13.53	17.65	13.53
95	189	190	4912	4913	3.14	14.18	3.79	14.18
96	191	192	4914	4915	10.07	14.18	10.72	14.18
97	193	194	4916	4917	17	14.18	17.65	14.18
98	195	196	4918	4919	3.14	17.32	3.79	17.32
99	197	198	4920	4921	10.07	17.32	10.72	17.32
100	199	200	4922	4923	17	17.32	17.65	17.32
101	201	202	4924	4925	3.14	20.46	3.79	20.46
102	203	204	4926	4927	10.07	20.46	10.72	20.46
103	205	206	4928	4929	17	20.46	17.65	20.46
104	207	208	4930	4931	3.14	21.11	3.79	21.11
105	209	210	4932	4933	10.07	21.11	10.72	21.11
106	211	212	4934	4935	3.14	24.25	3.79	24.25
107	213	214	4936	4937	10.07	24.25	10.72	24.25
108	215	216	4938	4939	3.14	27.39	3.79	27.39
109	217	218	4940	4941	10.07	27.39	10.72	27.39
110	219	220	4942	4943	-3.14	7.25	-3.14	6.6
111	221	222	4944	4945	-3.79	7.25	-3.79	6.6
112	223	224	4946	4947	-6.93	7.25	-6.93	6.6
113	225	226	4948	4949	-10.07	7.25	-10.07	6.6
114	227	228	4950	4951	-10.72	7.25	-10.72	6.6
115	229	230	4952	4953	-13.86	7.25	-13.86	6.6

Table 2.6.15.6-1 Listing of Cross Sections for Stress Evaluation of Support Disk (Continued)

Section & Line #	Point 1	Point 2	Node 1	Node 2	X 1	Y 1	X 2	Y 2
116	231	232	4954	4955	-17	7.25	-17	6.6
117	233	234	4956	4957	-17.65	7.25	-17.65	6.6
118	235	236	4958	4959	-20.78	7.25	-20.78	6.6
119	237	238	4960	4961	-23.92	7.25	-23.92	6.6
120	239	240	4962	4963	-3.14	13.53	-3.14	14.18
121	241	242	4964	4965	-3.79	13.53	-3.79	14.18
122	243	244	4966	4967	-6.93	13.53	-6.93	14.18
123	245	246	4968	4969	-10.07	13.53	-10.07	14.18
124	247	248	4970	4971	-10.72	13.53	-10.72	14.18
125	249	250	4972	4973	-13.86	13.53	-13.86	14.18
126	251	252	4974	4975	-17	13.53	-17	14.18
127	253	254	4976	4977	-17.65	13.53	-17.65	14.18
128	255	256	4978	4979	-20.78	13.53	-20.78	14.18
129	257	258	4980	4981	-23.92	13.53	-23.92	14.18
130	259	260	4982	4983	-3.14	21.11	-3.14	20.46
131	261	262	4984	4985	-3.79	21.11	-3.79	20.46
132	263	264	4986	4987	-6.93	21.11	-6.93	20.46
133	265	266	4988	4989	-10.07	21.11	-10.07	20.46
134	267	268	4990	4991	-10.72	21.11	-10.72	20.46
135	269	270	4992	4993	-13.86	21.11	-13.86	20.46
136	271	272	4994	4995	-17	21.11	-17	20.46
137	273	274	4996	4997	-3.14	0.33	-3.79	0.33
138	275	276	4998	4999	-10.07	0.33	-10.72	0.33
139	277	278	5000	5001	-17	0.33	-17.65	0.33
140	279	280	5002	5003	-23.92	0.33	-24.57	0.33
141	281	282	5004	5005	-3.14	3.46	-3.79	3.46
142	283	284	5006	5007	-10.07	3.46	-10.72	3.46
143	285	286	5008	5009	-17	3.46	-17.65	3.46
144	287	288	5010	5011	-23.92	3.46	-24.57	3.46
145	289	290	5012	5013	-3.14	6.6	-3.79	6.6
146	291	292	5014	5015	-10.07	6.6	-10.72	6.6
147	293	294	5016	5017	-17	6.6	-17.65	6.6
148	295	296	5018	5019	-23.92	6.6	-24.57	6.6
149	297	298	5020	5021	-3.14	7.25	-3.79	7.25
150	299	300	5022	5023	-10.07	7.25	-10.72	7.25
151	301	302	5024	5025	-17	7.25	-17.65	7.25
152	303	304	5026	5027	-3.14	10.39	-3.79	10.39
153	305	306	5028	5029	-10.07	10.39	-10.72	10.39

Table 2.6.15.6-1 Listing of Cross Sections for Stress Evaluation of Support Disk (Continued)

Section & Line #	Point 1	Point 2	Node 1	Node 2	X 1	Y 1	X 2	Y 2
154	307	308	5030	5031	-17	10.39	-17.65	10.39
155	309	310	5032	5033	-3.14	13.53	-3.79	13.53
156	311	312	5034	5035	-10.07	13.53	-10.72	13.53
157	313	314	5036	5037	-17	13.53	-17.65	13.53
158	315	316	5038	5039	-3.14	14.18	-3.79	14.18
159	317	318	5040	5041	-10.07	14.18	-10.72	14.18
160	319	320	5042	5043	-17	14.18	-17.65	14.18
161	321	322	5044	5045	-3.14	17.32	-3.79	17.32
162	323	324	5046	5047	-10.07	17.32	-10.72	17.32
163	325	326	5048	5049	-17	17.32	-17.65	17.32
164	327	328	5050	5051	-3.14	20.46	-3.79	20.46
165	329	330	5052	5053	-10.07	20.46	-10.72	20.46
166	331	332	5054	5055	-17	20.46	-17.65	20.46
167	333	334	5056	5057	-3.14	21.11	-3.79	21.11
168	335	336	5058	5059	-10.07	21.11	-10.72	21.11
169	337	338	5060	5061	-3.14	24.25	-3.79	24.25
170	339	340	5062	5063	-10.07	24.25	-10.72	24.25
171	341	342	5064	5065	-3.14	27.39	-3.79	27.39
172	343	344	5066	5067	-10.07	27.39	-10.72	27.39
173	345	346	5068	5069	-3.14	-7.25	-3.14	-6.6
174	347	348	5070	5071	-3.79	-7.25	-3.79	-6.6
175	349	350	5072	5073	-6.93	-7.25	-6.93	-6.6
176	351	352	5074	5075	-10.07	-7.25	-10.07	-6.6
177	353	354	5076	5077	-10.72	-7.25	-10.72	-6.6
178	355	356	5078	5079	-13.86	-7.25	-13.86	-6.6
179	357	358	5080	5081	-17	-7.25	-17	-6.6
180	359	360	5082	5083	-17.65	-7.25	-17.65	-6.6
181	361	362	5084	5085	-20.78	-7.25	-20.78	-6.6
182	363	364	5086	5087	-23.92	-7.25	-23.92	-6.6
183	365	366	5088	5089	-3.14	-13.53	-3.14	-14.18
184	367	368	5090	5091	-3.79	-13.53	-3.79	-14.18
185	369	370	5092	5093	-6.93	-13.53	-6.93	-14.18
186	371	372	5094	5095	-10.07	-13.53	-10.07	-14.18
187	373	374	5096	5097	-10.72	-13.53	-10.72	-14.18
188	375	376	5098	5099	-13.86	-13.53	-13.86	-14.18
189	377	378	5100	5101	-17	-13.53	-17	-14.18
190	379	380	5102	5103	-17.65	-13.53	-17.65	-14.18
191	381	382	5104	5105	-20.78	-13.53	-20.78	-14.18

Table 2.6.15.6-1 Listing of Cross Sections for Stress Evaluation of Support Disk (Continued)

Section & Line #	Point 1	Point 2	Node 1	Node 2	X 1	Y 1	X 2	Y 2
192	383	384	5106	5107	-23.92	-13.53	-23.92	-14.18
193	385	386	5108	5109	-3.14	-21.11	-3.14	-20.46
194	387	388	5110	5111	-3.79	-21.11	-3.79	-20.46
195	389	390	5112	5113	-6.93	-21.11	-6.93	-20.46
196	391	392	5114	5115	-10.07	-21.11	-10.07	-20.46
197	393	394	5116	5117	-10.72	-21.11	-10.72	-20.46
198	395	396	5118	5119	-13.86	-21.11	-13.86	-20.46
199	397	398	5120	5121	-17	-21.11	-17	-20.46
200	399	400	5122	5123	-3.14	-0.33	-3.79	-0.33
201	401	402	5124	5125	-10.07	-0.33	-10.72	-0.33
202	403	404	5126	5127	-17	-0.33	-17.65	-0.33
203	405	406	5128	5129	-23.92	-0.33	-24.57	-0.33
204	407	408	5130	5131	-3.14	-3.46	-3.79	-3.46
205	409	410	5132	5133	-10.07	-3.46	-10.72	-3.46
206	411	412	5134	5135	-17	-3.46	-17.65	-3.46
207	413	414	5136	5137	-23.92	-3.46	-24.57	-3.46
208	415	416	5138	5139	-3.14	-6.6	-3.79	-6.6
209	417	418	5140	5141	-10.07	-6.6	-10.72	-6.6
210	419	420	5142	5143	-17	-6.6	-17.65	-6.6
211	421	422	5144	5145	-23.92	-6.6	-24.57	-6.6
212	423	424	5146	5147	-3.14	-7.25	-3.79	-7.25
213	425	426	5148	5149	-10.07	-7.25	-10.72	-7.25
214	427	428	5150	5151	-17	-7.25	-17.65	-7.25
215	429	430	5152	5153	-3.14	-10.39	-3.79	-10.39
216	431	432	5154	5155	-10.07	-10.39	-10.72	-10.39
217	433	434	5156	5157	-17	-10.39	-17.65	-10.39
218	435	436	5158	5159	-3.14	-13.53	-3.79	-13.53
219	437	438	5160	5161	-10.07	-13.53	-10.72	-13.53
220	439	440	5162	5163	-17	-13.53	-17.65	-13.53
221	441	442	5164	5165	-3.14	-14.18	-3.79	-14.18
222	443	444	5166	5167	-10.07	-14.18	-10.72	-14.18
223	445	446	5168	5169	-17	-14.18	-17.65	-14.18
224	447	448	5170	5171	-3.14	-17.32	-3.79	-17.32
225	449	450	5172	5173	-10.07	-17.32	-10.72	-17.32
226	451	452	5174	5175	-17	-17.32	-17.65	-17.32
227	453	454	5176	5177	-3.14	-20.46	-3.79	-20.46
228	455	456	5178	5179	-10.07	-20.46	-10.72	-20.46
229	457	458	5180	5181	-17	-20.46	-17.65	-20.46

Table 2.6.15.6-1 Listing of Cross Sections for Stress Evaluation of Support Disk (Continued)

Section & Line #	Point 1	Point 2	Node 1	Node 2	X 1	Y 1	X 2	Y 2
230	459	460	5182	5183	-3.14	-21.11	-3.79	-21.11
231	461	462	5184	5185	-10.07	-21.11	-10.72	-21.11
232	463	464	5186	5187	-3.14	-24.25	-3.79	-24.25
233	465	466	5188	5189	-10.07	-24.25	-10.72	-24.25
234	467	468	5190	5191	-3.14	-27.39	-3.79	-27.39
235	469	470	5192	5193	-10.07	-27.39	-10.72	-27.39
236	471	472	5194	5195	0	-7.25	0	-6.6
237	473	474	5196	5197	3.14	-7.25	3.14	-6.6
238	475	476	5198	5199	3.79	-7.25	3.79	-6.6
239	477	478	5200	5201	6.93	-7.25	6.93	-6.6
240	479	480	5202	5203	10.07	-7.25	10.07	-6.6
241	481	482	5204	5205	10.72	-7.25	10.72	-6.6
242	483	484	5206	5207	13.86	-7.25	13.86	-6.6
243	485	486	5208	5209	17	-7.25	17	-6.6
244	487	488	5210	5211	17.65	-7.25	17.65	-6.6
245	489	490	5212	5213	20.78	-7.25	20.78	-6.6
246	491	492	5214	5215	23.92	-7.25	23.92	-6.6
247	493	494	5216	5217	0	-13.53	0	-14.18
248	495	496	5218	5219	3.14	-13.53	3.14	-14.18
249	497	498	5220	5221	3.79	-13.53	3.79	-14.18
250	499	500	5222	5223	6.93	-13.53	6.93	-14.18
251	501	502	5224	5225	10.07	-13.53	10.07	-14.18
252	503	504	5226	5227	10.72	-13.53	10.72	-14.18
253	505	506	5228	5229	13.86	-13.53	13.86	-14.18
254	507	508	5230	5231	17	-13.53	17	-14.18
255	509	510	5232	5233	17.65	-13.53	17.65	-14.18
256	511	512	5234	5235	20.78	-13.53	20.78	-14.18
257	513	514	5236	5237	23.92	-13.53	23.92	-14.18
258	515	516	5238	5239	0	-21.11	0	-20.46
259	517	518	5240	5241	3.14	-21.11	3.14	-20.46
260	519	520	5242	5243	3.79	-21.11	3.79	-20.46
261	521	522	5244	5245	6.93	-21.11	6.93	-20.46
262	523	524	5246	5247	10.07	-21.11	10.07	-20.46
263	525	526	5248	5249	10.72	-21.11	10.72	-20.46
264	527	528	5250	5251	13.86	-21.11	13.86	-20.46
265	529	530	5252	5253	17	-21.11	17	-20.46
266	531	532	5254	5255	3.14	-0.33	3.79	-0.33
267	533	534	5256	5257	10.07	-0.33	10.72	-0.33

Table 2.6.15.6-1 Listing of Cross Sections for Stress Evaluation of Support Disk (Continued)

Section & Line #	Point 1	Point 2	Node 1	Node 2	X 1	Y 1	X 2	Y 2
268	535	536	5258	5259	17	-0.33	17.65	-0.33
269	537	538	5260	5261	23.92	-0.33	24.57	-0.33
270	539	540	5262	5263	3.14	-3.46	3.79	-3.46
271	541	542	5264	5265	10.07	-3.46	10.72	-3.46
272	543	544	5266	5267	17	-3.46	17.65	-3.46
273	545	546	5268	5269	23.92	-3.46	24.57	-3.46
274	547	548	5270	5271	3.14	-6.6	3.79	-6.6
275	549	550	5272	5273	10.07	-6.6	10.72	-6.6
276	551	552	5274	5275	17	-6.6	17.65	-6.6
277	553	554	5276	5277	23.92	-6.6	24.57	-6.6
278	555	556	5278	5279	3.14	-7.25	3.79	-7.25
279	557	558	5280	5281	10.07	-7.25	10.72	-7.25
280	559	560	5282	5283	17	-7.25	17.65	-7.25
281	561	562	5284	5285	3.14	-10.39	3.79	-10.39
282	563	564	5286	5287	10.07	-10.39	10.72	-10.39
283	565	566	5288	5289	17	-10.39	17.65	-10.39
284	567	568	5290	5291	3.14	-13.53	3.79	-13.53
285	569	570	5292	5293	10.07	-13.53	10.72	-13.53
286	571	572	5294	5295	17	-13.53	17.65	-13.53
287	573	574	5296	5297	3.14	-14.18	3.79	-14.18
288	575	576	5298	5299	10.07	-14.18	10.72	-14.18
289	577	578	5300	5301	17	-14.18	17.65	-14.18
290	579	580	5302	5303	3.14	-17.32	3.79	-17.32
291	581	582	5304	5305	10.07	-17.32	10.72	-17.32
292	583	584	5306	5307	17	-17.32	17.65	-17.32
293	585	586	5308	5309	3.14	-20.46	3.79	-20.46
294	587	588	5310	5311	10.07	-20.46	10.72	-20.46
295	589	590	5312	5313	17	-20.46	17.65	-20.46
296	591	592	5314	5315	3.14	-21.11	3.79	-21.11
297	593	594	5316	5317	10.07	-21.11	10.72	-21.11
298	595	596	5318	5319	3.14	-24.25	3.79	-24.25
299	597	598	5320	5321	10.07	-24.25	10.72	-24.25
300	599	600	5322	5323	3.14	-27.39	3.79	-27.39
301	601	602	5324	5325	10.07	-27.39	10.72	-27.39

Table 2.6.15.6-2 P_m Stresses for Support Disk—1-Foot Side-Drop, 0° Orientation, Thermal Case 1

	P_m Stresses (ksi)					
Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
300	10.6	-10.0	-.9	20.7	30.0	.45
234	8.8	-9.8	1.8	18.9	30.0	.58
293	6.9	-11.4	.1	18.3	30.0	.64
227	6.5	-11.0	.0	17.5	30.0	.72
298	-.1	-16.8	.2	16.8	30.0	.78
232	-.1	-16.2	-.3	16.2	30.0	.85
290	-.1	-14.9	.1	14.9	30.0	1.02
284	4.7	-10.0	-.1	14.7	30.0	1.04
224	-.1	-14.3	-.1	14.3	30.0	1.09
218	4.5	-9.6	.3	14.1	30.0	1.13
294	6.1	-7.7	.0	13.9	30.0	1.16
260	4.6	-8.0	-2.0	13.3	30.0	1.25
296	-1.6	-13.3	-.4	13.3	30.0	1.26
194	4.5	-8.0	2.1	13.2	30.0	1.27
281	-.1	-13.1	.1	13.1	30.0	1.29
228	5.7	-7.2	.1	13.0	30.0	1.31
301	3.7	-7.6	-3.2	13.0	30.0	1.31
230	-1.3	-12.7	.7	12.8	30.0	1.35
235	2.9	-7.3	3.7	12.6	30.0	1.38
215	-.1	-12.6	-.1	12.6	30.0	1.38

Table 2.6.15.6-3 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 0° Orientation, Thermal Case 1

	$P_m + P_b$ Stresses (ksi)					
Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
234	8.2	-14.4	4.6	24.5	45.0	.84
300	10.5	-12.1	-3.7	23.8	45.0	.89
235	1.2	-18.4	5.7	22.6	45.0	.99
301	2.3	-17.3	-5.3	22.3	45.0	1.02
15	-13.0	-10.6	8.0	19.9	45.0	1.26
16	-12.5	-10.7	-7.9	19.6	45.0	1.30
231	-8.0	-17.8	3.5	18.9	45.0	1.38
293	8.3	-10.5	.4	18.8	45.0	1.40
297	-7.2	-17.3	-3.5	18.4	45.0	1.45
227	9.5	-8.7	-.3	18.2	45.0	1.48
230	-4.7	-16.9	3.6	17.9	45.0	1.51
298	-.2	-17.5	.1	17.5	45.0	1.57
232	-.3	-17.5	-.2	17.5	45.0	1.57
260	11.4	-5.4	-.9	16.8	45.0	1.67
194	12.5	-3.8	.9	16.5	45.0	1.73
296	-3.3	-15.4	-3.5	16.4	45.0	1.75
259	8.4	-7.2	.9	15.7	45.0	1.86
197	-7.0	-14.2	3.1	15.3	45.0	1.94
290	-.1	-15.0	.1	15.0	45.0	2.00
294	11.4	-3.5	-.2	14.9	45.0	2.01

Table 2.6.15.6-4 P_m Stresses for Support Disk—1-Foot Side-Drop, 0° Orientation, Thermal Case 2

	P_m Stresses (ksi)					
Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
300	10.5	-9.8	-.8	20.4	30.0	.47
234	8.5	-9.6	1.8	18.4	30.0	.63
293	6.8	-11.2	.1	18.1	30.0	.66
227	6.4	-10.8	.0	17.2	30.0	.74
298	-.1	-16.6	.1	16.6	30.0	.81
232	-.1	-15.9	-.3	15.9	30.0	.89
290	-.1	-14.7	.1	14.7	30.0	1.04
284	4.7	-9.8	-.1	14.5	30.0	1.07
224	-.1	-14.1	-.1	14.1	30.0	1.13
294	6.2	-7.8	.0	14.0	30.0	1.15
218	4.4	-9.4	.2	13.8	30.0	1.17
260	4.6	-7.9	-2.0	13.2	30.0	1.28
296	-1.6	-13.1	-.4	13.1	30.0	1.29
301	3.8	-7.6	-3.2	13.1	30.0	1.29
228	5.8	-7.3	.1	13.1	30.0	1.30
194	4.5	-7.9	2.0	13.1	30.0	1.30
281	-.1	-12.9	.1	12.9	30.0	1.33
235	3.1	-7.3	3.6	12.7	30.0	1.37
230	-1.2	-12.5	.7	12.6	30.0	1.39
215	-.1	-12.4	-.1	12.4	30.0	1.43

Table 2.6.15.6-5 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 0° Orientation, Thermal Case 2

	$P_m + P_b$ Stresses (ksi)					
Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
234	7.9	-14.2	4.5	23.9	45.0	.88
300	10.4	-11.9	-3.5	23.3	45.0	.93
235	1.4	-18.2	5.6	22.6	45.0	1.00
301	2.4	-17.2	-5.3	22.3	45.0	1.01
15	-13.0	-10.7	8.1	20.0	45.0	1.25
16	-12.6	-10.8	-8.0	19.7	45.0	1.29
231	-7.9	-17.7	3.5	18.8	45.0	1.40
293	8.1	-10.4	.3	18.5	45.0	1.43
297	-7.2	-17.2	-3.5	18.3	45.0	1.45
227	9.3	-8.6	-.3	17.9	45.0	1.52
230	-4.5	-16.6	3.5	17.6	45.0	1.56
298	-.2	-17.3	.1	17.3	45.0	1.61
232	-.3	-17.2	-.2	17.2	45.0	1.61
260	11.2	-5.3	-.9	16.6	45.0	1.70
194	12.3	-3.8	.9	16.2	45.0	1.78
296	-3.1	-15.1	-3.5	16.1	45.0	1.80
259	8.4	-7.1	.9	15.6	45.0	1.88
197	-6.9	-14.1	3.1	15.2	45.0	1.96
294	11.4	-3.6	-.2	15.0	45.0	2.00
290	-.1	-14.8	.1	14.8	45.0	2.04

Table 2.6.15.6-6 P_m Stresses for Support Disk—1-Foot Side-Drop, 31.82° Orientation, Thermal Case 1

	P_m Stresses (ksi)					
Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
295	3.6	-10.4	6.7	19.4	30.0	.54
277	9.6	-9.2	2.0	19.3	30.0	.56
229	-11.0	4.3	5.0	18.2	30.0	.65
301	6.0	-6.6	6.2	17.7	30.0	.69
300	.6	-5.5	7.7	16.6	30.0	.81
77	7.8	-8.1	.9	16.1	30.0	.87
235	-4.9	-2.6	7.5	15.2	30.0	.97
234	-3.7	-4.4	7.5	15.0	30.0	1.00
265	-4.6	5.6	5.0	14.3	30.0	1.10
257	-.2	-2.2	6.7	13.7	30.0	1.20
273	-.1	-13.3	-.5	13.3	30.0	1.25
299	-.1	-12.9	-.9	13.0	30.0	1.31
263	-7.1	-12.6	.2	12.6	30.0	1.38
294	-.1	-8.4	4.7	12.5	30.0	1.40
73	-.1	-6.1	5.0	11.7	30.0	1.57
291	.0	-11.3	-1.4	11.6	30.0	1.59
76	6.2	-4.2	2.6	11.6	30.0	1.59
103	-8.7	-.2	3.9	11.5	30.0	1.60
292	-.1	-11.3	-1.2	11.5	30.0	1.61
276	4.3	-5.6	2.8	11.3	30.0	1.65

Table 2.6.15.6-7 $P_m + P_b$ Stresses for Support Disks—1-Foot Side-Drop, 31.82° Orientation, Thermal Case 1

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
295	-6.9	-35.9	7.8	37.8	45.0	.19
294	-19.0	-34.8	6.2	37.0	45.0	.22
293	-22.7	-33.6	5.7	36.1	45.0	.25
267	-25.7	-31.9	5.9	35.4	45.0	.27
266	-25.7	-31.8	5.2	34.8	45.0	.29
288	-26.3	-31.0	5.2	34.4	45.0	.31
274	-23.3	-32.2	4.0	33.7	45.0	.34
251	-28.9	-27.0	5.3	33.4	45.0	.35
275	-20.4	-32.0	3.8	33.1	45.0	.36
227	-23.4	-30.3	5.2	33.0	45.0	.36
287	-26.0	-30.2	4.3	32.9	45.0	.37
260	-24.9	-28.7	5.0	32.1	45.0	.40
284	-23.3	-30.4	3.7	31.9	45.0	.41
248	-28.2	-26.8	4.3	31.9	45.0	.41
74	-22.8	-30.0	3.9	31.7	45.0	.42
200	-24.7	-28.8	4.4	31.6	45.0	.42
254	-27.2	-23.3	6.0	31.5	45.0	.43
301	2.1	-24.1	8.7	31.5	45.0	.43
268	-24.2	-25.7	6.3	31.3	45.0	.44
289	-24.1	-26.8	5.7	31.3	45.0	.44

Table 2.6.15.6-8 P_m Stresses for Support Disk—1-Foot Side-Drop, 31.82° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
277	9.3	-8.9	2.2	18.7	30.0	.60
295	3.5	-9.8	6.5	18.6	30.0	.61
229	-10.8	4.1	4.9	17.8	30.0	.69
301	6.1	-6.5	5.9	17.2	30.0	.74
300	1.4	-5.5	7.6	16.6	30.0	.81
77	7.6	-7.8	1.0	15.6	30.0	.93
235	-4.8	-2.8	7.5	15.1	30.0	.98
234	-3.3	-4.6	7.4	14.9	30.0	1.01
265	-4.3	5.5	4.7	13.6	30.0	1.20
257	-.3	-1.4	6.7	13.4	30.0	1.24
273	-.1	-12.9	-.5	12.9	30.0	1.33
299	-.1	-12.7	-.9	12.7	30.0	1.36
294	.1	-8.2	4.5	12.3	30.0	1.44
263	-6.6	-12.2	.1	12.2	30.0	1.46
103	-8.4	-.1	3.9	11.5	30.0	1.62
73	-.2	-6.0	4.9	11.3	30.0	1.65
291	.0	-11.0	-1.3	11.3	30.0	1.66
269	-8.9	-10.2	1.4	11.1	30.0	1.70
76	5.8	-3.9	2.5	10.9	30.0	1.76
292	-.1	-10.6	-1.1	10.8	30.0	1.78

Table 2.6.15.6-9 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 31.82° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
295	-6.6	-34.3	7.5	36.2	45.0	.24
294	-17.9	-33.5	5.9	35.5	45.0	.27
293	-21.6	-32.6	5.4	34.9	45.0	.29
267	-24.9	-30.9	5.7	34.3	45.0	.31
266	-24.4	-30.5	5.0	33.3	45.0	.35
288	-25.3	-29.6	5.0	32.9	45.0	.37
274	-22.4	-31.3	3.9	32.8	45.0	.37
275	-19.9	-31.3	3.8	32.5	45.0	.39
227	-22.5	-29.7	5.0	32.2	45.0	.40
251	-27.9	-25.8	5.2	32.1	45.0	.40
287	-25.2	-29.2	4.2	31.9	45.0	.41
248	-27.4	-25.9	4.3	31.0	45.0	.45
234	-8.1	-27.2	9.4	31.0	45.0	.45
284	-22.3	-29.5	3.6	31.0	45.0	.45
260	-23.5	-27.8	4.7	30.8	45.0	.46
268	-23.7	-25.1	6.1	30.6	45.0	.47
200	-23.8	-27.7	4.3	30.5	45.0	.48
74	-21.7	-28.8	3.7	30.4	45.0	.48
301	2.3	-23.2	8.3	30.4	45.0	.48
208	-22.8	-28.7	3.5	30.4	45.0	.48

Table 2.6.15.6-10 P_m Stresses for Support Disk—1-Foot Side-Drop, 49.46° Orientation, Thermal Case 1

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
277	9.4	-10.8	4.7	22.2	30.0	.35
265	-8.4	9.4	5.3	20.7	30.0	.45
77	9.1	-9.4	1.6	18.8	30.0	.59
257	-3.7	2.9	8.6	18.4	30.0	.63
295	.8	-7.4	7.4	16.9	30.0	.78
246	-7.5	.2	7.5	16.8	30.0	.79
229	-8.3	3.3	5.5	16.1	30.0	.87
54	-.2	-9.4	6.4	15.7	30.0	.91
273	-.1	-15.2	-1.1	15.3	30.0	.97
262	-8.6	5.7	2.3	15.0	30.0	1.00
269	-11.6	-12.1	3.0	14.8	30.0	1.03
264	-14.3	-.1	-1.0	14.4	30.0	1.09
103	-7.2	1.8	5.2	13.8	30.0	1.18
243	-7.0	3.7	4.3	13.7	30.0	1.19
85	-12.1	-9.7	2.3	13.5	30.0	1.22
73	1.2	-7.8	5.1	13.5	30.0	1.22
259	-7.0	5.6	2.1	13.2	30.0	1.27
65	-3.3	-4.1	6.3	12.7	30.0	1.37
211	-7.9	2.2	3.8	12.6	30.0	1.39
81	-.1	-12.4	-.7	12.5	30.0	1.41

Table 2.6.15.6-11 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 49.46° Orientation, Thermal Case 1

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
275	-30.2	-36.7	6.3	40.6	45.0	.11
268	-31.7	-32.7	7.2	39.4	45.0	.14
241	-33.4	-33.1	5.8	39.0	45.0	.15
274	-29.8	-35.1	6.0	39.0	45.0	.16
267	-30.3	-34.9	5.8	38.8	45.0	.16
295	-10.8	-36.1	8.4	38.6	45.0	.17
238	-32.7	-32.0	5.5	37.9	45.0	.19
246	-35.4	-11.8	7.9	37.7	45.0	.19
243	-36.6	-20.6	4.4	37.7	45.0	.19
276	-25.6	-34.8	5.7	37.6	45.0	.20
269	-26.3	-30.2	9.1	37.5	45.0	.20
24	-35.6	-28.0	4.3	37.5	45.0	.20
266	-29.1	-33.1	5.1	36.6	45.0	.23
208	-28.0	-32.8	5.4	36.3	45.0	.24
173	-30.4	-30.2	5.0	35.3	45.0	.28
254	-32.9	-21.8	5.6	35.3	45.0	.28
27	-30.6	-23.5	7.3	35.2	45.0	.28
294	-23.0	-30.8	7.2	35.1	45.0	.28
75	-28.2	-32.0	4.4	34.9	45.0	.29
240	-34.1	-22.2	3.1	34.8	45.0	.29

Table 2.6.15.6-12 P_m Stresses for Support Disk—1-Foot Side-Drop, 49.46° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
277	8.5	-10.0	5.0	21.0	30.0	.43
265	-7.8	9.0	5.1	19.6	30.0	.53
257	-3.7	3.2	8.2	17.8	30.0	.68
77	8.6	-8.7	1.6	17.6	30.0	.71
246	-7.8	1.4	7.3	17.2	30.0	.74
295	.9	-7.0	7.0	16.2	30.0	.86
229	-8.2	3.1	5.4	15.7	30.0	.91
54	-.2	-9.4	6.2	15.5	30.0	.93
243	-7.4	4.3	4.1	14.2	30.0	1.11
269	-11.1	-11.2	3.1	14.2	30.0	1.11
273	-.1	-14.1	-1.1	14.2	30.0	1.12
262	-8.0	5.3	2.3	14.0	30.0	1.14
103	-7.1	1.9	5.1	13.7	30.0	1.20
264	-13.4	-.1	-1.0	13.5	30.0	1.23
85	-11.8	-8.9	2.5	13.3	30.0	1.26
73	1.0	-7.6	4.9	13.1	30.0	1.29
245	-12.3	.0	-1.4	12.6	30.0	1.39
65	-3.4	-4.0	6.2	12.5	30.0	1.40
211	-7.8	2.0	3.8	12.5	30.0	1.41
259	-6.5	5.0	2.1	12.2	30.0	1.46

Table 2.6.15.6-13 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 49.46° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
275	-29.5	-36.1	6.4	40.0	45.0	.13
268	-31.1	-32.0	7.0	38.6	45.0	.17
241	-32.8	-32.4	5.8	38.4	45.0	.17
274	-28.9	-34.2	6.0	38.1	45.0	.18
267	-29.5	-34.0	5.6	37.8	45.0	.19
276	-25.5	-34.4	5.9	37.3	45.0	.21
269	-26.3	-29.9	8.9	37.1	45.0	.21
246	-35.0	-10.6	7.5	37.1	45.0	.21
238	-31.8	-31.1	5.5	37.0	45.0	.22
243	-35.9	-19.3	4.2	36.9	45.0	.22
24	-34.9	-27.4	4.2	36.8	45.0	.22
295	-10.1	-34.3	8.0	36.7	45.0	.23
208	-27.2	-32.1	5.4	35.6	45.0	.27
266	-27.7	-31.7	4.9	35.0	45.0	.28
27	-30.5	-23.4	7.1	34.9	45.0	.29
173	-29.7	-29.4	5.0	34.5	45.0	.30
244	-28.4	-30.3	5.0	34.4	45.0	.31
240	-33.4	-21.1	3.0	34.1	45.0	.32
75	-27.6	-31.1	4.3	34.0	45.0	.32
254	-31.7	-20.7	5.3	33.9	45.0	.33

Table 2.6.15.6-14 P_m Stresses for Support Disk—1-Foot Side-Drop, 77.92° Orientation, Thermal Case 1

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
246	-12.1	10.0	3.6	23.3	30.0	.29
243	-11.4	8.2	1.3	19.8	30.0	.52
245	-17.6	-.1	-.7	17.7	30.0	.70
27	-10.1	6.9	2.2	17.5	30.0	.71
240	-9.6	6.9	1.1	16.6	30.0	.81
85	-7.6	5.4	4.3	15.6	30.0	.93
242	-15.2	-.1	-.6	15.2	30.0	.97
269	-10.1	5.0	.1	15.1	30.0	.99
29	-14.6	-.1	-.7	14.6	30.0	1.05
244	-14.0	-5.2	.7	14.1	30.0	1.13
237	-7.9	6.0	1.1	14.1	30.0	1.13
24	-8.7	4.8	1.1	13.6	30.0	1.21
276	-7.1	3.1	4.0	12.9	30.0	1.33
239	-12.8	-.1	-.6	12.9	30.0	1.33
254	-8.5	4.1	1.0	12.8	30.0	1.35
26	-12.7	-.1	-1.0	12.7	30.0	1.35
256	-12.6	-.1	-.3	12.6	30.0	1.39
241	-12.1	-5.7	1.0	12.2	30.0	1.45
28	-11.9	-.9	-1.2	12.0	30.0	1.49
280	-8.5	2.8	-1.9	12.0	30.0	1.51

Table 2.6.15.6-15 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 77.92° Orientation, Thermal Case 1

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
5	-23.1	-30.6	2.0	31.1	45.0	.45
30	-27.1	-3.4	7.8	29.5	45.0	.53
27	-28.4	-5.8	3.3	28.9	45.0	.56
246	-23.3	4.2	3.7	28.4	45.0	.57
24	-26.5	-10.2	2.3	26.8	45.0	.68
22	-25.6	-16.7	3.4	26.8	45.0	.68
25	-25.8	-16.1	3.1	26.7	45.0	.69
6	-8.2	-25.8	1.2	25.9	45.0	.74
244	-23.3	-14.8	5.0	25.6	45.0	.76
77	11.1	24.4	4.2	25.6	45.0	.76
241	-22.6	-15.6	5.0	25.2	45.0	.79
75	-21.2	-18.7	5.1	25.1	45.0	.79
76	11.8	23.8	3.1	24.5	45.0	.84
19	-23.1	-16.0	3.0	24.2	45.0	.86
85	.5	23.5	3.3	24.0	45.0	.88
21	-23.4	-11.0	1.7	23.7	45.0	.90
74	-19.3	-18.0	4.6	23.3	45.0	.93
238	-20.3	-15.3	4.6	23.1	45.0	.95
84	11.6	21.9	3.3	22.8	45.0	.97
275	-18.3	-16.7	5.1	22.6	45.0	.99

Table 2.6.15.6-16 P_m Stresses for Support Disk—1-Foot Side-Drop, 77.92° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
246	-11.8	9.9	3.5	22.8	30.0	32
243	-11.2	8.0	1.3	19.3	30.0	.55
245	-17.2	-01	-06	17.2	30.0	.74
27	-9.8	6.8	2.2	17.2	30.0	.75
240	-9.4	6.6	1.0	16.1	30.0	.86
85	-7.8	5.4	4.1	15.5	30.0	.93
269	-10.0	5.0	.1	15.0	30.0	1.00
242	-14.8	-.1	-.6	14.9	30.0	1.02
29	-14.3	-.1	-.7	14.3	30.0	1.10
244	-13.7	-4.9	.7	13.7	30.0	1.18
237	-7.7	5.7	1.0	13.6	30.0	1.21
24	-805	4.7	1.0	13.3	30.0	1.26
254	-8.4	4.1	1.0	12.7	30.0	1.36
276	-6.9	3.1	3.8	12.6	30.0	1.38
239	-12.5	-.1	-.6	12.6	30.0	1.39
256	-12.5	-.1	-.3	12.5	30.0	1.40
26	-12.4	-.1	-1.0	12.4	30.0	1.41
5	-7.7	-3.7	5.7	12.0	30.0	1.50
241	-11.8	-5.4	1.0	11.9	30.0	1.51
257	-7.1	4.1	2.0	11.9	30.0	1.53

Table 2.6.15.6-17 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 77.92° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
5	-23.0	-29.9	2.2	30.5	45.0	.47
30	-26.2	-3.6	7.5	28.4	45.0	.58
27	-27.9	-5.6	3.3	28.4	45.0	.59
246	-22.9	4.1	3.7	27.9	45.0	.61
24	-25.8	-9.9	2.2	26.1	45.0	.72
22	-24.8	-16.1	3.3	25.9	45.0	.73
25	-25.1	-15.6	3.0	25.9	45.0	.74
6	-8.1	-25.6	1.2	25.7	45.0	.75
244	-22.8	-14.4	4.8	25.0	45.0	.80
77	10.9	23.8	4.1	25.0	45.0	.80
241	-22.0	-15.1	4.9	24.5	45.0	.84
75	-20.5	-17.9	4.9	24.3	45.0	.85
76	11.5	23.1	3.0	23.9	45.0	.89
85	.0	22.8	3.1	23.6	45.0	.91
19	-22.1	-15.1	2.9	23.1	45.0	.94
21	-22.6	-10.6	1.6	22.8	45.0	.97
238	-19.7	-14.7	4.4	22.3	45.0	1.02
74	-18.4	-17.0	4.4	22.2	45.0	1.03
243	-22.1	-1.8	1.2	22.2	45.0	1.03
84	11.1	21.2	3.1	22.1	45.0	1.04

Table 2.6.15.6-18 P_m Stresses for Support Disk—1-Foot Side-Drop, 90° Orientation, Thermal Case 1

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
27	-13.3	14.2	.0	27.4	30.0	.09
77	-8.3	13.5	3.1	22.7	30.0	.32
269	-8.3	13.5	-3.1	22.7	30.0	.32
85	-6.5	12.7	1.2	19.4	30.0	.55
277	-6.5	12.7	-1.2	19.4	30.0	.55
29	-19.3	-.1	.0	19.3	3.0	.55
24	-11.3	7.3	.0	18.5	30.0	.62
273	.1	17.4	.4	17.4	30.0	.73
81	.1	17.4	-.4	17.4	30.0	.73
28	-16.0	.9	.0	16.9	30.0	.77
26	-16.0	-.2	.0	16.6	30.0	.81
6	-11.0	-10.3	-5.9	16.5	30.0	.81
5	-11.0	-10.3	5.9	16.5	30.0	.81
21	-9.6	5.2	.0	14.8	30.0	1.03
23	-14.3	-.1	.0	14.3	30.0	1.09
246	-7.5	6.5	-.2	14.1	30.0	1.13
54	-7.5	6.5	.2	14.1	30.0	1.13
25	-13.5	-3.1	.0	13.5	30.0	1.23
18	-8.1	4.2	.0	12.3	30.0	1.44
20	-12.2	-.1	.0	12.2	30.0	1.45

Table 2.6.15.6-19 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 90° Orientation, Thermal Case 1

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
77	-6.3	22.0	3.0	28.9	45.0	.56
269	-6.3	22.0	-3.0	28.9	45.0	.56
27	-13.3	14.2	-.4	27.4	45.0	.64
6	-17.9	-18.4	-5.8	24.0	45.0	.88
5	-17.9	-18.4	5.8	24.0	45.0	.88
85	-5.4	16.4	2.4	22.3	45.0	1.02
277	-5.4	16.4	-2.4	22.3	45.0	1.02
2	-3.9	-19.4	-.1	19.4	45.0	1.32
1	-3.9	-19.4	.1	19.4	45.0	1.32
29	-19.3	-.1	.0	19.3	45.0	1.33
24	-11.3	7.3	-1.5	18.7	45.0	1.40
273	.2	18.6	.4	18.6	45.0	1.42
81	.2	18.6	-.4	18.6	45.0	1.42
28	-16.0	.9	3.5	18.3	45.0	1.45
26	-16.6	-.2	-.1	16.6	45.0	1.71
268	-5.7	10.4	-.9	16.2	45.0	1.78
76	-5.7	10.4	.9	16.2	45.0	1.78
54	-11.7	4.0	.9	15.8	45.0	1.85
246	-11.7	4.0	-.9	15.8	45.0	1.85
21	-9.6	5.2	-1.5	15.1	45.0	1.98

Table 2.6.15.6-20 P_m Stresses for Support Disk—1-Foot Side-Drop, 90° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
27	-12.9	13.8	.0	26.7	30.0	.12
77	-8.0	13.4	3.0	22.3	30.0	.35
269	-8.0	13.4	-3.0	22.3	30.0	.35
85	-6.6	12.6	1.2	19.3	30.0	.56
277	-6.6	12.6	-1.2	19.3	30.0	.56
29	-18.7	-.1	.0	18.7	30.0	.60
24	-10.9	7.0	.0	17.9	30.0	.67
273	.1	17.2	.3	17.2	30.0	.74
81	.1	17.2	-.3	17.2	30.0	.74
28	-15.5	1.2	.0	16.7	30.0	.80
5	-10.7	-10.4	5.7	16.2	30.0	.85
6	-10.7	-10.4	-5.7	16.2	30.0	.85
26	-16.1	-.2	.0	16.1	30.0	.86
21	-9.3	5.0	.0	14.3	30.0	1.10
246	-7.6	6.7	-.2	14.3	30.0	1.10
54	-7.6	6.7	.2	14.3	30.0	1.10
23	-13.9	-.1	.0	13.9	30.0	1.16
25	-13.1	-2.9	.0	13.1	30.0	1.29
20	-11.9	-.1	.0	11.9	30.0	1.53
18	-7.8	4.0	.0	11.8	30.0	1.54

Table 2.6.15.6-21 $P_m + P_b$ Stresses for Support Disk—1-Foot Side-Drop, 90° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
77	-6.2	21.5	2.9	28.2	45.0	.59
269	-6.2	21.5	-2.9	28.2	45.0	.59
27	-12.9	13.8	-.4	26.7	45.0	.69
6	-17.1	-17.7	-5.7	23.1	45.0	.95
5	-17.1	-17.7	5.7	23.1	45.0	.95
85	-5.5	15.9	2.3	21.9	45.0	1.05
277	-5.5	15.9	-2.3	21.9	45.0	1.05
2	-3.8	-19.0	-.1	19.0	45.0	1.37
1	-3.8	-19.0	.1	19.0	45.0	1.37
29	-18.7	-.1	.0	18.7	45.0	1.40
273	.2	18.5	.3	18.5	45.0	1.44
81	.2	18.5	-.3	18.5	45.0	1.44
24	-10.9	7.0	-1.4	18.2	45.0	1.48
28	-15.5	1.2	3.4	18.0	45.0	1.50
26	-16.1	-.2	-.1	16.1	45.0	1.79
246	-11.7	4.2	-.9	16.0	45.0	1.81
54	-11.7	4.2	.9	16.0	45.0	1.81
268	-5.5	10.1	-.8	15.7	45.0	1.87
76	-5.5	10.1	.8	15.7	45.0	1.87
21	-9.3	5.0	-1.4	14.6	45.0	2.08

2.6.15.7 Stress Evaluation of BWR Support Disk for Combined Thermal and 1-Foot Side-Drop Load Conditions

The loading for the 1-ft side-drop is combined with the thermal loading for Thermal Case 2 to produce the largest stress intensities. The allowable stress intensity, 3 $S_{m,}$ is evaluated at Thermal Case 3 (see Section 2.6.15.6.3). The corner-drop condition is bounded by the side and end-drops.

The 20 cross sections with the smallest margins of safety are presented in Tables 2.6.15.7-1 through 2.6.15.7-5. The margins of safety are calculated as

$$MS = (\text{stress allowable/stress intensity}) - 1.$$

The tables are identified here.

Table Number	Basket Orientation (Deg)	Thermal Case	Stress Evaluation	Minimum Margin of Safety
2.6.13.7-1	0	2	$P_m + P_b + Q$	+ 1.44
2.6.13.7-2	31.82	2	$P_m + P_b + Q$	+ 0.78
2.6.13.7-3	49.46	2	$P_m + P_b + Q$	+ 0.59
2.6.13.7-4	77.92	2	$P_m + P_b + Q$	+ 1.40
2.6.13.7-5	90	2	$P_m + P_b + Q$	+ 2.08

Table 2.6.15.7-1 $P_m + P_b + Q$ Stresses for Support Disk - 1-Foot Side-Drop, 0° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
14	25.5	18.4	14.5	36.9	90.0	1.44
13	24.3	17.6	-14.0	35.3	90.0	1.55
234	6.5	-14.4	5.1	23.3	90.0	2.86
232	-.2	-23.1	-.2	23.1	90.0	2.89
298	-.1	-23.1	.0	23.1	90.0	2.90
300	8.8	-11.9	-4.1	22.3	90.0	3.04
290	-.1	-21.0	.1	21.0	90.0	3.28
224	-.1	-20.6	-.2	20.6	90.0	3.37
281	-.1	-19.8	.1	19.8	90.0	3.55
145	-11.9	-14.9	6.0	19.6	90.0	3.60
111	-11.9	-14.9	6.0	19.6	90.0	3.60
215	-.1	-19.3	-.3	19.3	90.0	3.65
18	-9.3	-15.0	6.2	19.0	90.0	3.74
266	-9.3	-15.0	6.2	19.0	90.0	3.74
230	-4.1	-17.4	4.7	18.9	90.0	3.76
194	-4.1	-17.4	4.7	18.9	90.0	3.76
270	.0	-18.5	-.4	18.5	90.0	3.87
134	-15.2	-9.7	5.3	18.4	90.0	3.89
165	-15.2	-9.7	5.3	18.4	90.0	3.89
146	-12.9	-12.7	5.4	18.2	90.0	3.93

Table 2.6.15.7-2 $P_m + P_b + Q$ Stresses for Support Disk - 1-Foot Side-Drop, 31.82° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
18	-31.4	-37.3	15.9	50.5	90.0	.78
266	-31.4	-37.3	15.9	50.5	90.0	.78
21	-32.9	-35.4	16.0	50.3	90.0	.79
267	-32.9	-35.4	16.0	50.3	90.0	.79
238	-29.5	-36.1	13.4	46.6	90.0	.93
274	-29.5	-36.1	13.4	46.6	90.0	.93
268	-31.0	-31.6	15.0	46.3	90.0	.94
24	-31.0	-31.6	15.0	46.3	90.0	.94
137	-28.6	-33.4	14.1	45.2	90.0	.99
31	-28.6	-33.4	14.1	45.2	90.0	.99
138	-30.0	-29.1	13.7	43.3	90.0	1.08
34	-30.0	-29.1	13.7	43.3	90.0	1.08
200	-31.6	-28.0	13.0	43.0	90.0	1.09
32	-31.6	-28.0	13.0	43.0	90.0	1.09
260	-25.5	-34.1	12.1	42.6	90.0	1.11
293	-25.5	-34.1	12.1	42.6	90.0	1.11
275	-26.1	-34.0	11.9	42.6	90.0	1.11
241	-26.1	-34.0	11.9	42.6	90.0	1.11
288	-29.0	-30.8	12.1	42.0	90.0	1.14
251	-29.0	-30.8	12.1	42.0	90.0	1.14

Table 2.6.15.7-3 $P_m + P_b + Q$ Stresses for Support Disk - 1-Foot Side-Drop, 49.46° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
24	-38.6	-38.5	18.2	56.8	90.0	.59
268	-38.6	-38.5	18.2	56.8	90.0	.59
267	-37.6	-38.9	17.7	56.0	90.0	.61
21	-37.6	-38.9	17.7	56.0	90.0	.61
238	-37.1	-39.8	16.1	54.6	90.0	.65
274	-37.1	-39.8	16.1	54.6	90.0	.65
241	-37.1	-39.8	15.8	54.3	90.0	.66
275	-37.1	-39.8	15.8	54.3	90.0	.66
18	-34.8	-38.9	16.9	53.9	90.0	.67
266	-34.8	-38.9	16.9	53.9	90.0	.67
27	-35.5	-35.4	17.3	52.8	90.0	.71
269	-35.5	-35.4	17.3	52.8	90.0	.71
244	-34.4	-39.3	15.1	52.1	90.0	.73
276	-34.4	-39.3	15.1	52.1	90.0	.73
31	-32.8	-35.2	15.5	49.6	90.0	.82
137	-32.8	-35.2	15.5	49.6	90.0	.82
34	-33.4	-32.0	15.2	47.9	90.0	.88
138	-33.4	-32.0	15.2	47.9	90.0	.88
32	-34.5	-29.8	14.0	46.4	90.0	.94
200	-34.5	-29.8	14.0	46.4	90.0	.94

Table 2.6.15.7-4 $P_m + P_b + Q$ Stresses for Support Disk - 1-Foot Side-Drop, 77.92° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
31	-25.4	-25.2	12.2	37.5	90.0	1.40
137	-25.4	-25.2	12.2	37.5	90.0	1.40
24	-30.3	-18.4	11.5	37.3	90.0	1.42
268	-30.3	-18.4	11.5	37.3	90.0	1.42
138	-25.1	-23.2	11.8	35.9	90.0	1.51
34	-25.1	-23.2	11.8	35.9	90.0	1.51
27	-31.0	-11.6	10.4	35.6	90.0	1.53
269	-31.0	-11.6	10.4	35.6	90.0	1.53
25	-29.1	-17.3	10.8	35.5	90.0	1.54
76	-29.1	-17.3	10.8	35.5	90.0	1.54
244	-26.9	-22.7	10.5	35.5	90.0	1.54
276	-26.9	-22.7	10.5	35.5	90.0	1.54
74	-28.2	-18.9	10.8	35.3	90.0	1.55
19	-28.2	-18.9	10.8	35.3	90.0	1.55
2	-31.5	-5.7	10.5	35.2	90.0	1.55
30	-31.5	-5.7	10.5	35.2	90.0	1.55
75	-29.6	-15.6	10.6	35.2	90.0	1.56
22	-29.6	-15.6	10.6	35.2	90.0	1.56
37	-23.3	-24.0	11.5	35.1	90.0	1.56
139	-23.3	-24.0	11.5	35.1	90.0	1.56

Table 2.6.15.7-5 $P_m + P_b + Q$ Stresses for Support Disk - 1-Foot Side-Drop, 90° Orientation, Thermal Case 2

Section	Sx	Sy	Sxy	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
29	-29.2	.1	.0	29.2	90.0	2.08
27	-15.5	13.0	-1.2	28.7	90.0	2.14
77	-15.5	13.0	-1.2	28.7	90.0	2.14
269	-15.5	13.0	1.2	28.7	90.0	2.14
17	-28.1	-.4	-.1	28.1	90.0	2.20
26	-26.9	-.1	-.1	26.9	90.0	2.34
23	-25.5	.0	-.1	25.5	90.0	2.53
20	-24.3	.0	-.1	24.3	90.0	2.70
14	17.1	10.0	9.5	23.6	90.0	2.81
15	17.1	10.0	-9.5	23.6	90.0	2.81
3	1.2	23.6	.8	23.6	90.0	2.82
4	1.2	23.6	-.8	23.6	90.0	2.82
28	-18.9	2.2	5.1	23.4	90.0	2.84
16	14.5	9.4	8.1	20.5	90.0	3.40
13	14.5	9.4	-8.1	20.5	90.0	3.40
137	-13.7	-12.9	7.1	20.4	90.0	3.41
200	-13.7	-12.9	-7.1	20.4	90.0	3.41
31	-13.7	-12.9	7.1	20.4	90.0	3.41
33	-20.4	.1	.0	20.4	90.0	3.41
25	-17.2	-3.4	5.5	19.2	90.0	3.70

2.6.15.8 Stress Evaluation of BWR Support Disk for 1-Foot Corner-Drop Load Conditions

As is the case in the PWR basket support disks (see Section 2.6.13.8), the g-loads of the corner- and oblique-drop conditions are bounded by the g-load of the end- and side-drop conditions discussed in Section 2.6.15.6. Therefore, no separate evaluation of the 1-ft corner- and oblique-drop conditions is performed.

2.6.15.9 Stress Evaluation of BWR Support Disk for Combined Thermal and 1-Foot Corner-Drop Load Conditions

The combined thermal and 1-ft corner-drop and the combined thermal and 1-ft oblique-drop conditions are bounded by the results of combined thermal and 1-ft end- and side-drop conditions. Therefore, no separate evaluation of the combined thermal and 1-ft corner-drop condition and the combined thermal and 1-ft oblique-drop condition is performed.

2.6.15.10 Stress Evaluation of Tie Rods and Spacers for a 1-Foot End-Drop Load Condition

Tie rods and spacers are provided in the basket to maintain spacing of the support disks. Transmission of loads in different drop orientations of the BWR basket is similar to the transmission of loads in the PWR basket discussed in Section 2.6.13.10. As is the case in the PWR basket, in drop orientations other than on the end, the spacers only experience a portion of the weight of the support disks, heat transfer disks, one end weldment, and the spacers that act along the axis of the cask. Thus, the end-drop is the critical loading condition.

During an end-drop, the weight of the support disks, weldment, aluminum heat transfer disks, and spacers and end nuts is supported by the spacers on the 6 tie rods. Compressive stress over the cross-sectional area of the spacers results. With the largest weight of the two BWR fuel classes, the total weight of the basket is 18,199 lb. Because the weights of the bottom-end weldment (623 lb) and the fuel tubes (4,665 lb) are transmitted directly into the end of the canister, the remaining load acting over the area of the spacers is 12,911 lb. For the 1-ft end-drop the deceleration is 20 *g*, which results in a total end-drop load of 258,220 lb. The area in compression is $\pi(3.0^2 - 1.75^2)/4 = 4.66$ in^2. The compressive stress is 258,220/(6 x 4.66) = 9,235 psi and is considered to be a membrane stress.

The allowable membrane stress, on the basis of the ASME Code, Section III, Subsection NG [15], is 1.0 S_m. Using a conservative material temperature for the outer edge of the support disk of 500°F, S_m = 17.5 ksi. The corresponding margin of safety is

$$MS = (17{,}500/9{,}235) - 1 = +0.89.$$

Therefore, structural adequacy of the tie rod/spacer assemblies is demonstrated.

2.6.15.11 Support Disk Shear Stresses for 1-Foot Drops

ASME Code, Section III, Division 1, Subdivision NG [15], criteria define the Level A allowable for shear stress to be 0.6 S_m. The design stress intensity for SA 533 at a bounding temperature of 500°F (where maximum stresses occur) is 30 ksi. The maximum stress intensity across any section (membrane stress) for the 1-ft side-drop is 27.4 ksi for the 0° drop orientation at Thermal Condition 1. Similarly, for the end-drop, a maximum membrane stress across a section is reported at 0 ksi for the 1-ft drop. Therefore, the maximum shear stress for any normal loading condition is 27.4/2 or 13.7 ksi.

Using the allowable stresses as stated previously, the minimum margin of safety for shear is:

$$MS = [2(0.6)S_m / SI] - 1 = [2(0.6)(30) / 27.4] - 1 = +.0.31$$

Therefore, structural adequacy of the BWR fuel basket support disk design for the normal conditions of transport, 1-ft side and end-drops is demonstrated for shear stress criteria.

2.6.15.12 Bearing Stress - Basket Contact with Inner Shell

For the bearing stress (S_{br}) acting along the basket support disk–canister shell interface, an angular contact of 18° is considered on the basis of the ANSYS gap element status (at a radius of 32.75 in.). The load considered to be acting on the support disks is the total contents weight (57,044 lb) times the deceleration value of 20 g, divided among 40 support disks in the basket. The bearing area is considered to be the 0.625-in. thick disk over an 18° contact area.

$$S_{br} = (57{,}044)(20)/[(0.625)(40)(\pi)(65.5)/(360/18)] = 4{,}446 \text{ psi.}$$

The allowable bearing stress is the yield stress, which for SA533 Type B, Class 2 carbon steel at a temperature of 400°F, is 63.2 ksi. The margin of safety for the support disk (not the canister) is computed as

$$MS = (63.2/S_{br}) - 1 = +13.2.$$

2.6.15.13 Basket Weldment Analysis for 1-Foot End-Drop

The responses of the fuel assembly's top and bottom weldment plates to a 1-ft end-drop is evaluated in conjunction with the thermal expansion stress. The top and bottom weldment plates are 1.25-in thick and 1.0-in.-thick plates, respectively, of Type 304 stainless steel. The weldments support their own weight and the weight of 56 BWR fuel assembly tubes. A finite element analysis is performed for both plates, because the support for each weldment is different depending upon the location of the welded ribs for each. Both models use the SHELL63 element, which permits out-of-plane loading. Figures 2.6.15.13-1 and 2.6.15.13-2 show the finite element models for the top and bottom weldments, respectively. The load from the fuel tube is represented as point forces applied to the nodes at the periphery of the fuel assembly slots. An average point force is applied. The application of the nodal loads at the slot periphery is accurate because the tube weight is transmitted to the edge of the slot, which provides support to the fuel tubes in the end-drop condition

The analysis demonstrates that the weldment design satisfies the primary membrane (P_m) and the primary membrane plus bending (P_m+P_b) stress criteria. An analysis including the thermal expansion stresses is also performed.

The margins of safety are calculated as

$$MS = [(P_m + P_b) / 1.5\ S_m] - 1 \quad \text{or} \quad MS = [(P_m + P_b + Q) / 3\ S_m] - 1.$$

The margins of safety evaluated for the weldments are shown in Table 2.6.15.13-1. The weldments are shown to satisfy the stress criteria in the ASME Code, Section III Division I, Subsection NG [15].

Figure 2.6.15.13-1 Finite Element Model of the Top Weldment Plate

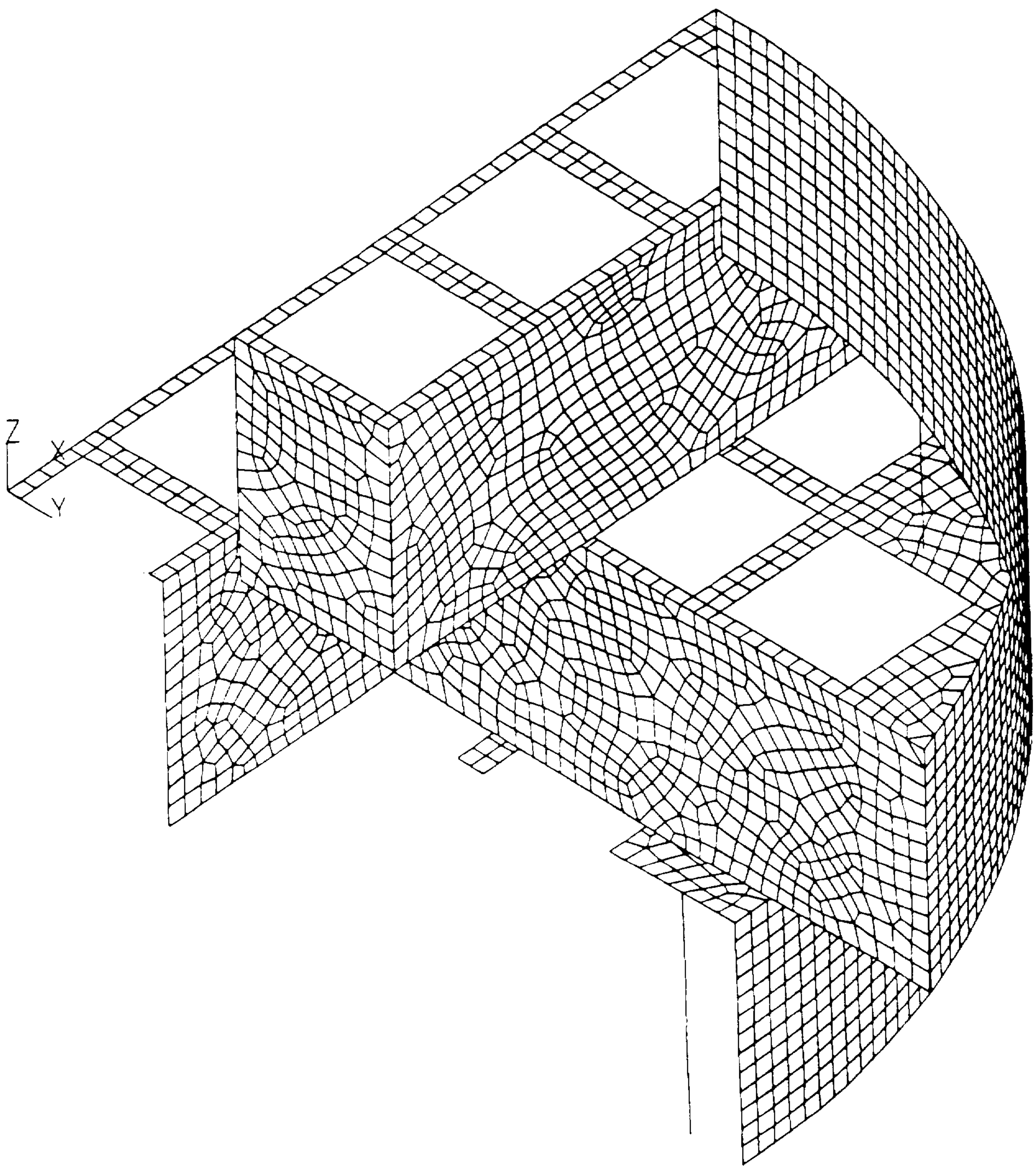


Figure 2.6.15.13-2 Finite Element Model of the Bottom Weldment Plate

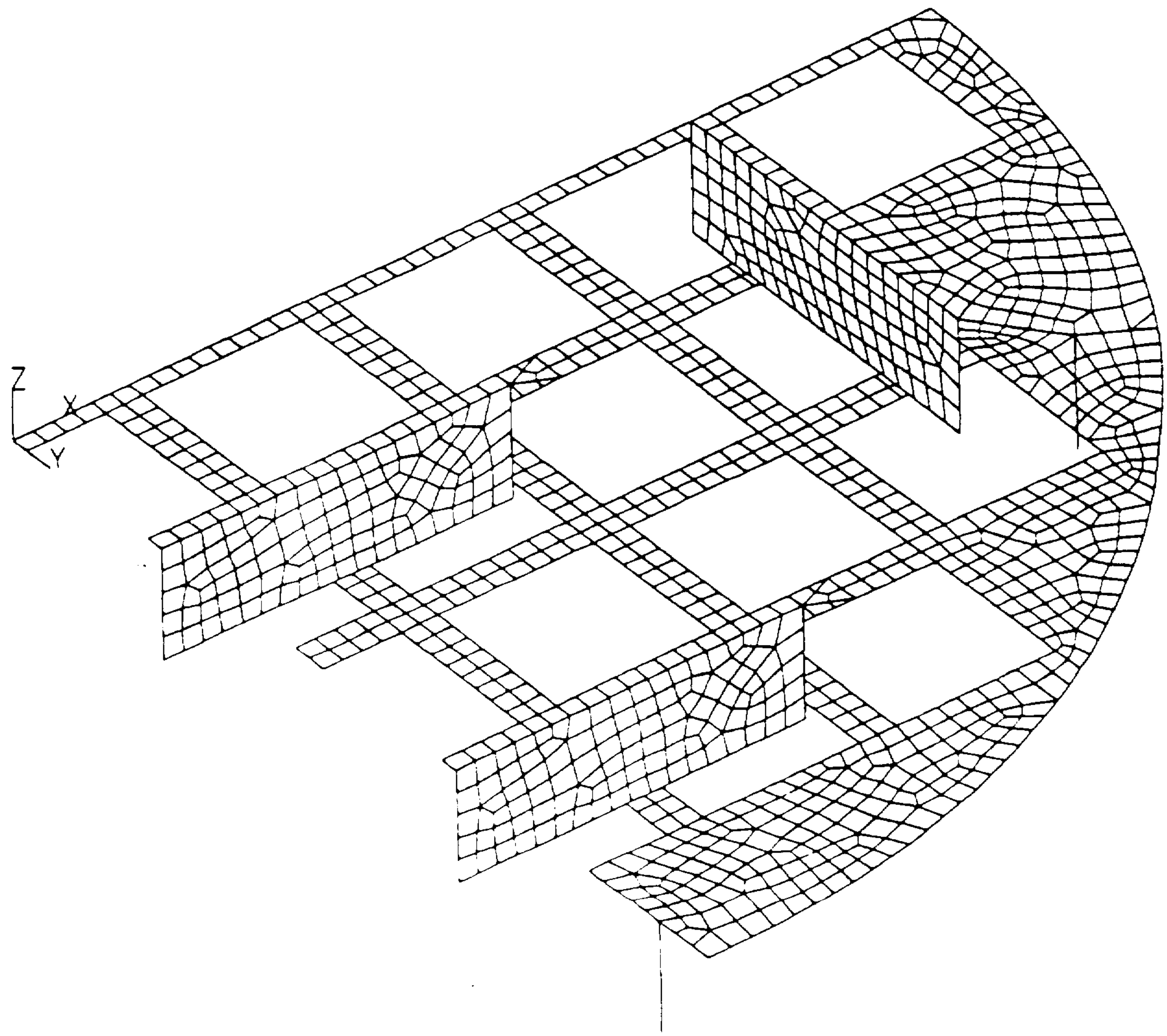


Table 2.6.15.13-1 Minimum Margins of Safety for the Top/Bottom Weldments for a 1-Foot End-Drop With and Without Thermal Stresses

Component/Condition	P_m (ksi)	Allowable S_m (ksi)	MS
Top Weldment/1-ft End-Drop	8.41	17.38	+1.07
Bottom Weldment/1-ft End-Drop	11.14	17.56	+0.58

Component/Condition	$P_m + P_b$ (ksi)	$1.5S_m$ (ksi)	MS
Top Weldment/1-ft End-Drop	16.50	26.07	+0.58
Bottom Weldment/1-ft End-Drop	18.98	26.34	+0.39

Component/Condition	$P_m + P_b + Q$ (ksi)	$3S_m$ (ksi)	MS
Top Weldment/1-ft End-Drop + Thermal	16.95	52.14	+2.08
Bottom Weldment/1-ft End-Drop + Thermal	27.26	52.68	+0.93

2.6.15.14 Support Disk Buckling Evaluation

The BWR fuel basket support disk is subjected to compressive or inertial loads during a 1-ft drop of the cask onto an unyielding surface. Depending on the cask orientation for the 1-ft drop impact, both in-plane and out-of-plane loads may be applied to the support disk. The in-plane loadings (basket side impact component) apply compressive forces on the support disk and the out-of-plane inertial loading (basket end impact component) produces bending moments in the support disk.

Buckling of the support disk is evaluated in accordance with the methods and acceptance criteria of NUREG/CR-6322. The support disk buckling evaluation for the hypothetical accident conditions is presented in Section 2.7.10.3. The characteristics of the support disk are as follows:

2.6.15.14.1 Support Disk Buckling Evaluation Input Data

Material:	SA-533, Type B, Class 2 carbon steel plate
Material yield strength for buckling:	S_y = 70.0 ksi at -40°F (Thermal Case 1) S_y = 59.3 ksi at 750°F (conservative) S_y = 60.5 ksi at 650°F (conservative)
Material modulus of elasticity for buckling:	E = 24.60 x 10^{-3} ksi at 750°F (conservative) E = 29.90 x 10^{-3} ksi at -40°F (Thermal Case 1)
Impact load amplification factor:	20 *g* for the 1-ft side or end-drop. E=25.56 x 10^{-3} ksi at 650°F (conservative)

Thermal Case 2 or 4 is bounding for Thermal Case 3.

2.6.15.14.2 Detailed Support Disk Buckling Evaluation

Conservative temperatures are used in the support disk buckling evaluation.

Methodology

The buckling evaluation of the support disk web is based on the interaction described by Equations 31 and 32 in NUREG/CR-6322 [16]. These two equations adapt the "Limit Analysis Design" approach for structural members for which stresses are beyond the yield limit of the material, i.e., for members deformed elastically as a result of both axial load and bending moment. Other equations applicable to the calculations are listed later in this section.

The maximum forces and moments are determined for the end-drop condition and for five different radial orientations of the support disk for the side-drop condition considering the thermal conditions as presented in Section 2.6.15.3. In this evaluation, thermal loading conditions (Loading Cases 1, 2 and 4) employ only the loads developed in the drop condition (no thermal stresses are considered), but the thermal cases are used to evaluate the material properties. Buckling evaluations are performed for both in-plane (about the strong axis of the web) and out-of-plane (about the weak axis of the web) forces and moments. In the in-plane buckling evaluation, the compressive forces and bending moments that occur for the 1-ft side-drop condition are considered. For the out-of-plane buckling evaluation, the compressive forces for the 1-ft side-drop condition are combined with the moment resulting from the inertial weight of the support disk in the 1-ft end-drop condition.

Detailed buckling calculations are performed in a spreadsheet format by using the methodology and equations from NUREG/CR-6322. The load amplification factors used are 20 *g* for both the 1-ft end-drop and the 1-ft side-drop conditions. The buckling evaluation is performed for each of the sections shown in Figures 2.6.15.6-2 through 2.6.15.6-5. The sections are listed in Table 2.6.15.6-1.

The buckling evaluation methodology/equations are summarized as follows:

Symbols and Units:

- P = applied loads, kips
- M = moment, kips-in.
- P_a = allowable axial compressive load, kips
- P_{cr} = critical axial compression load, kips
- P_e = Euler buckling loads, kips

P_y = plastic axial load, equal to profile area times specified minimum yield stress, kips (for normal operating condition)

C_c = column slenderness ratio separating elastic and inelastic buckling

C_m = coefficient applied to bending term in interaction equation

M_m = critical moment that can be resisted by a plastically designed member in the absence of axial load, kip-in.

M_p = plastic moment, kip-in.

F_a = axial compressive stress permitted, ksi

F_e = Euler stress for a prismatic member divided by factor of safety, ksi

k = ratio of effective column length to actual unbraced length

l = unbraced length of member, in.

r = radius of gyration, in.

S_y = yield stress allowable, ksi

A = area of the ligament, in^2

Z_x = plastic section modulus with respect to the major axis, in^3

Σ = allowable reduction factor, dimensionless.

$$\frac{P}{P_{cr}} + \frac{C_m M}{M_m \left[1 - \frac{P}{P_e}\right]} \le 1.0$$

$$\frac{P}{P_y} + \frac{M}{0.18\,M_p} \le 1.0$$

where, $P_{cr} = 1.7 \times A \times F_a$

$$F_a = \frac{\left[1 - \frac{1}{2}\left(\frac{k \cdot l}{r \cdot C_c}\right)^2\right] \cdot S_y}{\frac{5}{3} + \frac{3}{8}\left(\frac{k \cdot l}{r \cdot C_c}\right) - \frac{1}{8}\left(\frac{k \cdot l}{r \cdot C_c}\right)^3} \quad \text{for} \quad \frac{k \cdot l}{r} < C_c = \sqrt{2 \cdot \pi^2 \frac{E}{S_y}}$$

$P_e = 1.92 \times A \times F_e$

$$F_e = \frac{\pi^2 \cdot E}{1.92\left(\frac{k \cdot l}{r}\right)^2}$$

$$P_y = S_y \text{ x } A$$

$C_m = 0.85$ for members with joint translational (sideways)

$$M_p = S_y \text{ x } Z_x$$

$$M_m = M_p \cdot \left(1.07 - \frac{\left(\frac{l}{r}\right) \cdot \sqrt{S_y}}{3160}\right) \le M_p .$$

<u>Load Conditions</u>

The load conditions considered in the 1-ft drop normal condition buckling evaluation are as follows:

1. Primary loads, Thermal Case 1. (See Section 2.6.15.3)
2. Primary loads, Thermal Case 2. (See Section 2.6.15.3)
3. Primary plus secondary thermal loads, Thermal Case 4. (See Section 2.6.15.3)

For the buckling evaluation different values for the thicknesses are associated with the weak axis of the support disk web and with the strong axis of the web. The weak axis corresponds to the 0.625-in. support disk thickness and is associated with the load which would result in displacement perpendicular to the plane of the disk. The strong axis buckling would buckles the support disk web in the plane of the support disk.

Buckling of Support Disk Web Weak Axis

For weak-axis buckling the evaluation parameters are as follows (Section 17):

Parameter	Values	Parameter	Values
t	0.625 in.	S_y	60.5 ksi
b	0.66 in.	P_y	A x S_y = 24.956 ksi
A	0.4125 in^2	F_a	32.456
L	6.278 in.	C_c	91.32
I	$b\,t^3/12 = 0.0134\ in^4$	P_{cr}	22.76
r	=0.180	F_e	169.55
K	0.800	P_e	134.289
KL/r	27.837	M_p	3.899
Z	$bt^2/4 = 0.064$	M_m	3.838
E	25,560 ksi	C_m	0.85

Using the cross-sectional stresses calculated at each of the sections shown in Figures 2.6.15.6-2 through 2.6.15.6-5 for the 1-ft side-drop condition, the maximum corresponding compressive forces are combined with the maximum out-of-plane moment resulting from the 1-ft end-drop condition to obtain the conservative maximum interaction coefficients.

The terminology used in the buckling analysis is defined as follows:

$$P_1 = P/P_{cr} \qquad M_1 = \frac{C_m M}{(1 - P/P_e)M_m}$$

$$P_2 = P/P_y \qquad M_2 = \frac{M}{1.18\ M_p}$$

The X and Y directions refer to those webs that are parallel to the global X and Y directions, respectively, for the basket (X is the horizontal axis and Y is the vertical axis for the model shown in Figure 2.6.15.6-2). Section locations are identified in Figures 2.6.15.6-2 through 2.6.15.6-5 and Table 2.6.15.6-1.

The margins of safety are calculated as:

$$MS1 = \frac{1}{P_1 + M_1} - 1 \qquad \text{and} \qquad MS2 = \frac{1}{P_2 + M_2} - 1$$

For weak-axis buckling, the minimum margin of safety is +0.659 for the 90° radial basket orientation at Section 17 (thermal stresses are included).

The calculated minimum margins of safety for the drop orientations discussed in Section 2.6.15.6.1 are presented in Table 2.6.15.14-1. The location of the sections identified in the table are shown in Figures 2.6.15.6-2 through 2.6.15.6-5.

Buckling of Support Disk Web Strong Axis

For strong axis buckling the evaluation parameters are as follows:

Parameter	Value	Parameter	Value
t	0.65 in.	S_y	59.3 ksi
b	0.625 in.	P_y	A x S_y = 24.091 ksi
A	0.406 in^2	F_a	31.959
L	6.278 in.	C_c	90.491
I	$b\,t^3/12 = 0.0143\ in^4$	P_{cr}	22.071
r	=0.188	F_e	176.51
K	0.800	P_e	137.674
KL/r	26.766	M_p	3.915
Z	$bt^2/4 = 0.066$	M_m	3.87
E	24.600 ksi	C_m	0.85

Using the cross-sectional stresses evaluated for each of the sections shown in Figures 2.6.15.6-2 through 2.6.15.6-5, the maximum corresponding compressive forces in conjunction with the maximum in-plane moment produces the maximum interaction coefficients. Because the locations of the maximum force and the maximum moment may not coincide, the calculation of the interaction coefficient is conservative. The maximum magnitude of the moment is used, regardless of sign, to ensure the most severe condition.

The margins of safety are calculated by using Equations 31 and 32 from NUREG/CR-6322 as discussed earlier. For strong-axis buckling, the minimum margin of safety is + 1.552 for the 31.8° radial basket orientation at Section 295 (thermal stresses are included).

The calculated minimum margins of safety for the drop orientations discussed in Section 2.6.15.6.1 are presented in Table 2.6.15.14-2. The location of the sections identified in the table are shown in Figures 2.6.15.6-2 through 2.6.15.6-5.

Table 2.6.15.14-1 Minimum Margins of Safety from Buckling Evaluation of BWR Support Disks (Weak Axis)

Section No.	G-Load	Disk Drop Orientation	Heat Case	MS1	MS2
270	20	0	1	+2.56	+2.78
16	20	0	2	+1.68	+1.79
270	20	0	2 + thermal load	+1.22	+1.40
273	20	31.82	1	+1.93	+2.15
273	20	31.82	2	+1.57	+1.76
273	20	31.82	2 + thermal load	+1.22	+1.40
273	20	49.46	1	+1.74	+1.95
273	20	49.46	2	+1.75	+1.96
17	20	49.46	2 + thermal load	+1.18	+1.37
47	20	90	1	+3.09	+3.35
47	20	90	2	+2.56	+2.78
17	20	90	2 + thermal load	+0.66	+0.82
242	20	77.92	1	+2.22	+2.48
244	20	77.92	2	+2.66	+2.97
17	20	77.92	2 + thermal load	+0.77	+0.94

Table 2.6.15.14-2 Minimum Margins of Safety from Buckling Evaluation of BWR Support Disk (Strong Axis)

Section No.	G-Load	Disk Drop Orientation	Heat Case	MS1	MS2
298	20	0	1	+2.95	+3.303
298	20	0	2	+3.0	+3.36
298	20	0	2 + thermal load	+1.97	+2.25
295	20	31.82	1	+1.82	+1.99
295	20	31.82	2	+1.96	+2.14
295	20	31.82	2 + thermal load	+1.52	+1.69
243	20	49.46	1	+1.98	+2.13
243	20	49.46	2	+2.00	+2.16
246	20	49.46	2 + thermal load	+1.44	+1.60
244	20	77.92	1	+2.56	+2.85
244	20	77.92	2	+2.64	+2.93
244	20	77.92	2 + thermal load	+1.79	+2.03
53	20	90	1	+5.56	+6.15
53	20	90	2	+5.49	+6.08
53	20	90	2 + thermal load	+3.42	+3.82

2.6.16 Universal Transport Cask Cavity Spacers

This section documents the design analysis of the spacers used to position the Transportable Storage Canisters containing PWR or BWR fuel in the Universal Transport Cask cavity during transport of fuel. The spacers are freestanding components that are placed at the bottom of the cask cavity below the canister bottom, and are confined by the end of the canister and the bottom inner surface of the Universal Transport Cask. The spacers are designed to maintain the centers of gravity of the canisters at the required distance from the bottom inner surface of the cask.

The following requirements bound the spacer design:

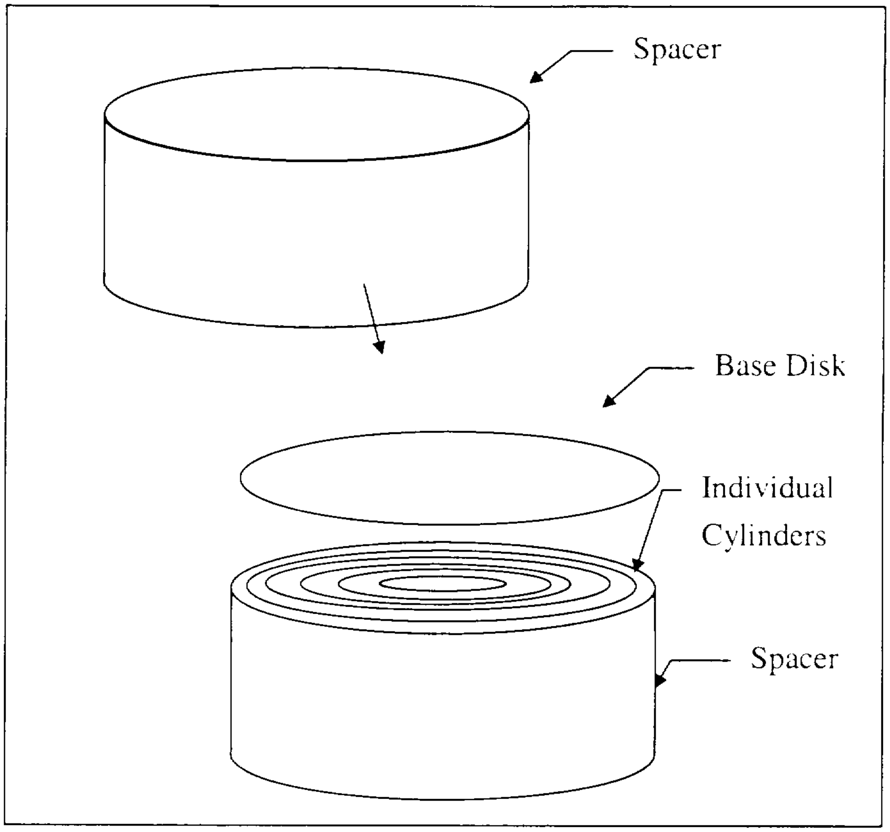
1. The spacers must meet the normal conditions of transport requirements detailed in 10 CFR 71.43(f) when subjected to the free drop (10 CFR 71.71).

2. The spacers must provide spacing of the canister so that the center of gravity of the cask and contents is maintained.

For impact loading conditions, the spacer is designed to meet the requirements of 10 CFR 71.43(f) for the 1-ft drop condition (10 CFR 71.71). 10 CFR 71.43(f) requires that no substantial reduction in the effectiveness of the package be experienced in normal conditions of transport. Classical analysis is used to demonstrate compliance with these requirements.

2.6.16.1 PWR Cask Cavity Spacers

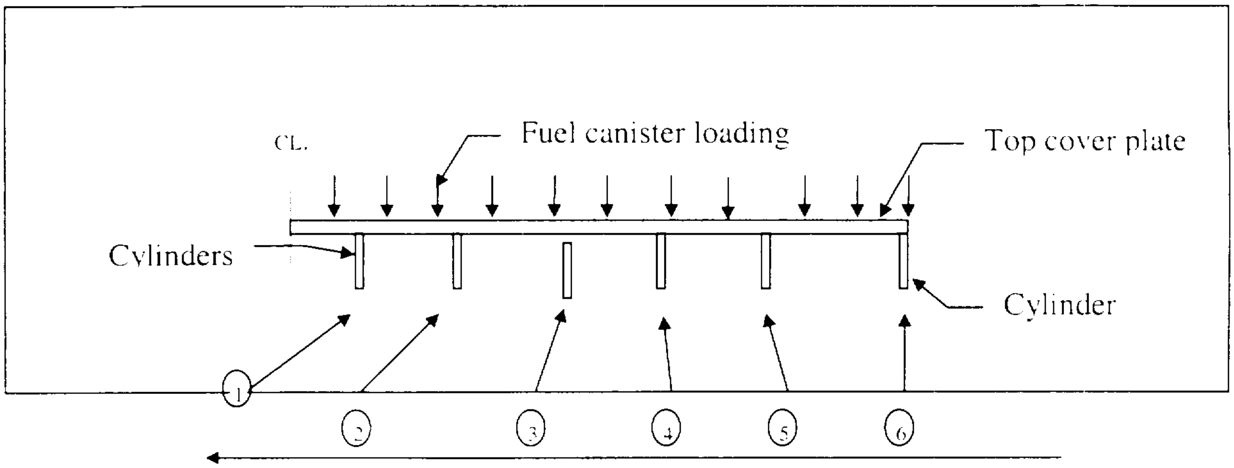
Each Transportable Storage Canister containing Class 1 or Class 2 PWR fuel is located by one spacer. Canisters containing Class 3 PWR fuel have no spacers. The PWR spacer is a weldment made of Type 304 stainless steel, ASTM A 240, 3/8-in. plate. The weldment consists of a base that is 67 in. in diameter with 6 raised cylinders of different diameters welded to it. The six different diameters are: 12, 24, 32, 50, 56, and 65 in. The lengths of the spacers used to locate the Class 1 and Class 2 fuel canisters vary. The Class 1 spacer is 18.25 in. long and the Class 2 spacer is 11.25 in. long. A sketch of the PWR spacer is provided below.



PWR Cask Cavity Spacers Accident Condition

For evaluation purposes, the PWR spacer can be viewed as separate cylinders. The cylinders are identified by numbers 1-6 with the inner most cylinder being number 1 and the outer most being 6 as shown in the following sketch.

The total load modeled is (73,000 lbs) x 60 g (conservative PWR canister weight).



The forces exerted on each cylinder were obtained from the finite element model:

$F_1 = 0.3561\ (10)^6$ lb
$F_2 = 0.6028\ (10)^6$ lb
$F_3 = 0.8372\ (10)^6$ lb
$F_4 = 1.024\ (10)^6$ lb
$F_5 = 0.8260\ (10)^6$ lb
$F_6 = 0.7346\ (10)^6$ lb

The membrane stress experienced by each member is as follows:

$\sigma_{membrane} = F/A$

$\sigma_1 = 0.3561\ (10)^6 \text{ lb} / 2\pi(5.625 + 0.1875)(0.375) \text{ in}^2 = 25,993$ psi
$\sigma_2 = 0.6028\ (10)^6 \text{ lb} / 2\pi(11.625 + 0.1875)(0.375) \text{ in}^2 = 21,660$ psi
$\sigma_3 = 0.8372\ (10)^6 \text{ lb} / 2\pi(15.625 + 0.1875)(0.375) \text{ in}^2 = 22,469$ psi
$\sigma_4 = 1.024\ (10)^6 \text{ lb} / 2\pi(24.625 + 0.1875)(0.375) \text{ in}^2 = 17,516$ psi
$\sigma_5 = 0.8260\ (10)^6 \text{ lb} / 2\pi(27.625 + 0.1875)(0.375) \text{ in}^2 = 12,605$ psi
$\sigma_6 = 0.7346\ (10)^6 \text{ lb} / 2\pi(32.125 + 0.1875)(0.375) \text{ in}^2 = 9,649$ psi

Based on the membrane stress the lowest margin of safety is:

Allowable stress at 300°F = $0.7S_u$ = 46,200 psi

MS = (46,200 psi/**25,993** psi) -1= **+ 0.78**

To evaluate buckling the critical stress was determined and compared to the actual:

$$\sigma_{critical} = E((0.605 - 10^{-7}m^2)/(m(1 + 0.004\phi))$$

where:

E = modulus of elasticity for 304 SS @ 300°F---27 10^6 psi
m = R/T = radius/thickness
ϕ= E/S_y for 304 SS = 27E6/20,000psi = 1,350 psi

$\sigma_{critical-1}$ = critical stress for each individual cylinder
$\sigma_{critical-1}$ = 27E6((0.605 - 10^{-7}(5.8125/0.375)^2)/((5.8125/0.375)(1 + 0.004(1350)) = 164,602 psi
$\sigma_{critical-2}$ = 27E6((0.605 - 10^{-7}(11.8125/0.375)^2)/((11.8125/0.375)(1 + 0.004(1350)) = **80,894** psi
$\sigma_{critical-3}$ = 27E6((0.605 - 10^{-7}(15.8125/0.375)^2)/((15.8125/0.375)(1 + 0.004(1350)) = 60,352 psi
$\sigma_{critical-4}$ = 27E6((0.605 - 10^{-7}(24.8125/0.375)^2)/((24.8125/0.375)(1 + 0.004(1350)) = 38,295 psi
$\sigma_{critical-5}$ = 27E6((0.605 - 10^{-7}(27.8125/0.375)^2)/((27.8125/0.375)(1 + 0.004(1350)) = 34,100 psi
$\sigma_{critical-6}$ = 27E6((0.605 - 10^{-7}(32.3125/0.375)^2)/((32.8125/0.375)(1 + 0.004(1350)) = 29,257 psi

The buckling evaluation produces a minimum margin of safety as follows:

MS = (38,295/**17,516**) - 1 = **+ 1.19**

The base disk of the canister spacer is evaluated to determine its ability to carry the loading of the canister. ANSYS Version 5.2 is used to construct a finite element model of the canister spacer. Plane 42 elements are used to represent the spacer. The model includes the bottom of the canister to minimize the bending experienced by the base disk. Link 1 elements are used to transmit the load from the canister bottom to the base disk.

A maximum stress intensity of **11,103** psi is calculated by ANSYS. Based on the maximum stress intensity a margin of safety is calculated as follows:

Allowable stress at 300°F = 0.7S_u= 46,200 psi.

$$MS = (46{,}200/11{,}103) - 1 = +3.2$$

PWR Cask Cavity Spacers Normal Condition

The normal condition cask cavity spacer evaluation was performed by ratioing stresses based on the linear accident condition analysis results.

The compressive buckling load is calculated as

$$S_{1\text{-ft}} = (S_{30\text{-ft}})(20\text{ g}/60\text{ g}) = (17{,}106)(20\text{ g}/60\text{ g}) = 5{,}702\text{ psi}$$

The critical buckling allowable stress calculated earlier is 38,295 psi.

The minimum margin of safety for critical buckling is:

$$MS = \left(\frac{38.29516}{5.70216}\right) - 1 = +5.71$$

The maximum stress intensity in the canister spacer was calculated to be:

$$(SI)_{1\text{-ft}} = (SI)_{30\text{-ft}}\left(\frac{20g}{60g}\right) = 11{,}000\left(\frac{20}{60}\right) = 3{,}667\text{ psi}$$

The allowable stress (S_m) for the PWR spacer at 300°F is 20,000 psi. This results in the following margin of safety:

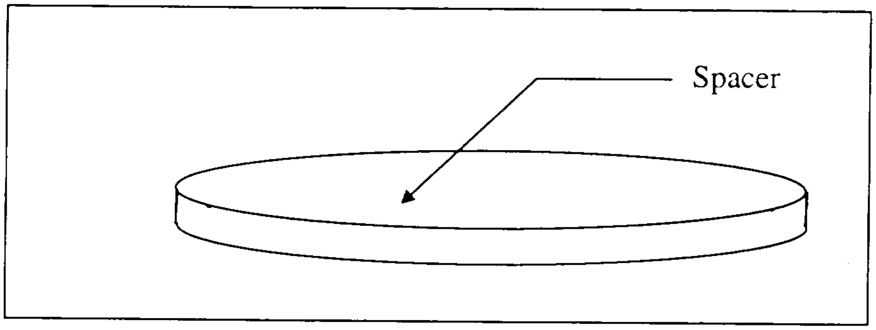
$$MS = \left(\frac{20{,}000\text{ psi}}{3{,}667\text{ psi}}\right) - 1 = +4.45$$

2.6.16.2 BWR Cask Cavity Spacers

Each canister containing Class 5 BWR fuel is located by one spacer. Canister containing Class 4 BWR fuel is located by 4 spacers. The lengths of the canisters containing Class 4 and Class 5 BWR fuel are 185.75 and 190.55 in., respectively. To maintain the centers of gravity of these canisters at the required distance from the bottom inner surface of the cask, spacers of 1.5 and 6

inches in length are designed to be placed at the bottom of the cask cavity below the canister bottom.

Each spacer used in the BWR cask consists of 1.5-in.-thick plate of ASTM B209 6061-T651 aluminum alloy. A sketch of the BWR spacer is provided below.



The aluminum alloy material is selected as the spacer material because it has the low weight, good thermal conductivity, and strength needed to meet the design requirements. This material is evaluated below for normal conditions of transport.

BWR Cask Cavity Spacers Accident Conditions

To apply a 1-ft end-drop load to the spacer, a total bounding load of 4,560,000 lbs (76,000 x 60 g) is applied.

The area of the spacer is taken to be 3,318 in². This results in a crushing pressure of

$$P_{cr} = (4{,}560{,}000 \text{ lb})/(3{,}318 \text{ in}^2) = 1{,}374 \text{ psi.}$$

The yield strength of 6061-T651 aluminum alloy at 300°F is 22,050 psi. Because the pressure load is less than the yield strength, the spacer will not permanently deform during the 1-ft drop. The margin of safety is

$$MS = (22{,}050/1{,}374) - 1 = +15.05$$

BWR Cask Cavity Spacers Normal Condition

The normal condition cask cavity evaluation was performed by rationing stresses based on the linear accident condition analysis results.

The compressive stress was calculated to be:

$$SI_{1\text{-ft}} = SI_{30\text{-ft}}\left(\frac{20g}{60g}\right) = 1{,}374\left(\frac{20g}{60g}\right) = 458 \text{ psi}$$

The allowable stress (S_m) for the BWR spacer at 300°F is 8,400 psi. This results in the following margin for safety:

$$MS = \left(\frac{8{,}400}{455}\right) - 1 = +17.46$$

2.7 Hypothetical Accident Conditions

The Universal Transport Cask meets the standards specified in 10 CFR 71.51 when subjected to the conditions and tests specified in 10 CFR 71.73 for hypothetical accidents. In accordance with 10 CFR 71.73, the cask is structurally evaluated for hypothetical accident scenarios of free drop, puncture, fire, crush, and water immersion. In the free-drop analyses, the cask impact orientation evaluated is that which inflicts the maximum damage to the cask. The most unfavorable ambient temperature condition during operation in the range from -40°F to 100°F is assumed. The following sections contain the evaluation of the cask for structural integrity under the hypothetical accident conditions.

2.7.1 Free Drop (30 ft) - Cask Body Analysis

The Universal Transport Cask is required by 10 CFR 71.73(c)(1) to demonstrate structural adequacy for a free drop through a distance of 30 feet (9 meters) onto a flat, unyielding, horizontal surface. The cask payload is oriented to strike the surface to inflict the maximum damage. In determining the orientation that produces the maximum damage, the cask is evaluated for impact orientations in which the cask strikes the impact surface on its top end, bottom end, side, top corner, bottom corner, top-end oblique, and bottom-end oblique. Evaluation of each drop orientation is accomplished by using finite element analysis techniques. A complete description of the 3-D model used to analyze the cask body is presented in Appendix 2.10.2. The results of each drop orientation listed above is presented in this section. The impact limiters and the impact limiter attachments are evaluated in Section 2.6.7.5 for all loading conditions and orientations.

The mass of the contents is considered when evaluating impact. The environmental temperature for the drop is between -40°F and 100°F. For the accident condition, stresses arising from thermal expansion are not considered for the stress reevaluation. However, for determination of properties, the temperatures are considered. Heat generation from the contents and solar insolance are also considered. An internal pressure of 150 psig is applied in the finite element models to produce the bounding critical stress condition in conjunction with the other loads previously discussed. Eighty (80.0) psig is used in the cask closure analysis. As shown in Table 2.7.3.1-4, a pressure of 80 psig conservatively exceeds the maximum calculated internal pressures. Closure lid bolt preload is considered and fabrication stresses are discussed.

The following method and assumptions are adopted in all the drop analyses:

1. The finite element method is utilized to do the impact analyses. The analyses are performed using the ANSYS computer program.

2. The analyses assume linear elastic behavior of the cask.

3. The cask contents are applied to the cask as a pressure load. The pressure simulates the actual contents by applying the pressure as a cosine distribution.

4. The finite element model of the cask includes, geometrically, only the components of the cask body to be structurally analyzed; however, the weight of radial neutron shield spacers (as appropriate), and impact limiters are modeled as non-geometrical point mass elements. The payload and spacer (as appropriate) are modeled as distributed loads to attain a total weight of 252,444 pounds. To bound the loads produced during a 30-ft drop, an acceleration of 60 *g* was used for all 30-ft drop orientations presented in this section. The actual predicted accelerations are less than 55 *g* (review impact limiter discussion presented in Section 2.7.1.6). Therefore, the weights presented for the cask body analysis are conservative and envelop the actual values presented in Section 2.2. Additionally, the stress results (worst case side and oblique drop stresses) were increased by a factor of 2.7% producing an effective cask weight of 259,260 lb (no credit taken for bounding acceleration).

5. To account for the lead slump during the drops, and for the differential thermal expansion between the cask stainless steel shells and lead shell, gap elements are used in the finite element model to simulate the multi-body contact between these components.

As discussed in Appendix 2.10.2, the loads and boundary conditions considered in the finite element analyses are: (1) Closure lid bolt preload, (2) internal pressure, (3) thermal, and (4) impact and inertial loads resulting from the impact event.

During fabrication of the Universal Transport Cask, thermal stresses can be introduced in the inner and outer shells as a result of pouring molten lead between them. However, any residual stresses in the containment vessel and the outer shell induced by shrinkage of the lead shielding after the lead pouring operation are relieved early in the life of the cask because of the low creep

strength of lead. Therefore, the effects of stresses resulting from the processes used in fabrication of the cask are considered to be negligible. Further discussion of fabrication stresses in provided in Section 2.6.11.

The following sections contain the evaluation of the cask for impact orientations in which the cask strikes the impact surface on its end (top and bottom), side, corner (top and bottom), and end oblique (top and bottom). The impact conditions in accordance with Regulatory Guide 7.8 and the categories of load to be considered for the hypothetical accident conditions are similar to those for the 1-foot free drops, under normal conditions of transport, discussed in Appendix 2.10.2. Therefore, the discussions in the following sections refer to Appendix 2.10.2 wherever applicable.

Three categories of load—closure lid bolt preload, internal pressure, and inertial body loads—are considered on the cask. The inertia loads imposed upon the cask by the impact limiter result from the mass of the entire assembly being acted upon by a design deceleration value of 60 *g* for the 30-ft end-drop case. The closure lid bolt preload, internal pressure load, and contents loads considered for the 30-ft end-drop condition are similar to those considered for 1-ft end-drop condition in Section 2.6.7.1, with the exception that thermal stresses are not considered for accident conditions. The material properties of the components are considered to be temperature dependent.

The allowable stress limit criteria is discussed in Section 2.1.2.3. These criteria are used to determine the allowable stresses for each cask component, conservatively using the maximum operating temperature within a given component to determine the allowable stress throughout that component (refer to Table 2.10.2.2-1). For cask body analyses presented in this section, the maximum heat conditions (thermal condition 1) is 100°F ambient temperature, maximum decay heat load, and maximum solar insolation.

2.7.1.1 30-Foot End Drop

In accordance with the requirements of 10 CFR 71.73(c)(1), the Universal Transport Cask is structurally evaluated for the 30-foot end-drop condition. In this hypothetical accident, the cask, with its payload, spacer (if appropriate), and the impact limiters, falls 30 feet onto a flat, unyielding, horizontal surface. The cask strikes the surface in a vertical position; consequently, an end impact on the bottom or top end of the cask occurs. The types of loading involved in an

end-drop accident are closure lid bolt preload, internal pressure, thermal, and inertial body load. Appendix 2.10.2 describes the application of each loading condition.

Figures 2.10.2.2-1 through 2.10.2.2-4 depict the sections used in the post-processing of the cask body results. Tables 2.7.1.1-1 through 2.7.1.1-4 present the results for the top-end drop. Tables 2.7.1.1-3 and 2.7.1.1-4 provide a summary of P_m and $P_m + P_b$ stresses for the top-end drop. Tables 2.7.1.1-5 through 2.7.1.1-8 tabulate the results for the bottom-end drop. Tables 2.7.1.1-7 and 2.7.1.1-8 provide a summary of P_m and $P_m + P_b$ stresses for the bottom end drop. For the top end, combined impact loading case, the calculated minimum margin of safety is 1.74 in the top forging (Table 2.7.1.1-3). The calculated minimum margin of safety is 0.87 (Table 2.7.1.1-4) for primary membrane plus bending. For the bottom end combined impact loading case, the minimum margin of safety is 0.53 (Table 2.7.1.1-7) in the ligaments. The minimum margin of safety for primary membrane plus bending stress intensity is 0.95 (Table 2.7.1.1-8) in the bottom forging.

Table 2.7.1.1-1 P_m Stresses—30-Foot Top End-Drop, Thermal Condition 1

		Cylindrical Stress Components (ksi)							Allowable Stress	
Section	Angle	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	SI (ksi)	(ksi)	MS
1	180	0.2	0.2	-0.1	0	0	0	0.3	48	142.58
2	180	0.2	0.3	-0.1	0	0	0	0.3	48	149.23
3	180	0.2	0.3	0.2	0	-0.1	0.4	0.9	48	53.64
4	180	-0.1	0.4	0.7	0.1	0	0.3	1	48	48.74
5	0	0	0.1	-0.2	0	0	-0.1	0.3	48	185.48
6	0	0	0.1	-0.1	0	0	0	0.2	48	216.79
7	180	0	-0.1	-0.4	0	0	0	0.4	48	112.23
8	180	-0.2	-0.5	-1.4	0.0	0.1	0.3	1.4	48	34.09
9	80	-1.3	-1	-1.9	-0.2	0.3	0.3	1.1	48	41.03
10	135	0.8	-0.3	-1.7	-0.2	0	1.6	4.1	45.9	10.14
11	120	-0.3	-1.4	-4	-0.3	0.2	1.1	4.4	45.9	9.41
12	90	0	0.3	0.8	-0.2	0	0	0.9	45.9	50.66
13	90	0.9	0.7	1.7	-0.3	-0.2	0.1	1.3	45.9	33.82
14	135	-0.5	0.2	0.9	-0.1	0	-0.3	1.4	47.3	31.98
15	80	0.9	0.5	0.8	-0.1	-0.2	0	0.7	47.3	70.41
16	0	-0.1	1.9	-0.2	-0.2	-0.1	0	2.1	47.3	21.52
17	0	-0.1	2.8	-0.7	-0.3	0	0	3.5	47.3	12.43
18	0	-0.1	3.4	-1.2	-0.4	0	0	4.7	47.3	9.11
19	0	-0.2	4.4	-1.7	-0.5	0	0	6.2	47.3	6.67
20	0	-0.2	6.4	-2.3	-0.7	0	0	8.8	47.3	4.38
21	0	-0.3	9.5	-3	-1	0	0	12.6	47.3	2.75
22	0	-0.5	12.4	-4.5	-1.2	0.1	0.2	17	47.3	1.79
23	120	-0.1	-0.3	-2.7	0	0.3	0.2	2.7	45.9	16.21
24	120	-0.1	0.5	-2.9	0	0.3	0	3.4	45.9	12.44
25	10	-0.1	-0.4	-3.3	0	0.1	0	3.1	45.9	13.58
26	10	-0.2	-1	-4	0.1	0.1	0	3.8	45.9	11.04
27	10	-0.2	-1.6	-4.6	0.1	0.1	0	4.4	45.9	9.35
28	10	-0.2	-3.3	-5.1	0.1	0	0	4.9	45.9	8.35
29	20	-0.3	-5.9	-5.4	0	0	0	5.6	45.9	7.19
30	20	-0.4	-9.6	-5.6	0	-0.2	0	9.2	45.9	3.97
31	60	-0.8	-10.3	-5.3	0	-0.9	0.4	9.7	45.9	3.75
32	0	-0.9	8.7	-5	-0.9	0.1	-0.8	14	48	2.44
33	0	3.4	5.3	-4.9	-0.2	0	-1.5	10.5	48	3.58
34	0	8.3	5.2	-8.3	0.1	0.3	2.7	17.5	48	1.74
35	180	-1.2	2	-5.7	0.4	-0.6	0.3	7.9	48	5.1
36	0	2	1	-6.6	0.1	0.7	0.3	8.7	48	4.53
37	180	-0.6	-0.2	-2.4	0	-0.5	0.9	2.8	48	16.08
38	0	-0.5	-0.2	-2.2	0	0.4	0.7	2.5	48	18.46
39	0	-0.2	-0.8	-5.5	0	0.5	0.3	5.4	48	7.9
40	0	-2.9	-2	-8.7	0	0.2	-1.6	7.1	48	5.73
41	180	-0.3	-0.2	-1.5	0	-0.1	0.5	1.5	48	31.56

Table 2.7.1.1-2 $P_m + P_b$ Stresses—30-Foot Top End-Drop, Thermal Condition 1

Section	Angle	Cylindrical Stress Components (ksi)						SI (ksi)	Allowable Stress (ksi)	MS
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	90	0.4	0.2	-0.1	0	0	0.1	0.5	72	145.34
2	120	0.5	0.4	0	0	0	0	0.5	72	130
3	180	-0.1	0.4	0.7	0.1	-0.1	0.6	1.5	72	47.1
4	180	-0.1	0.4	0.7	0.1	-0.1	0.6	1.4	72	49.31
5	0	0.1	0.6	-0.1	0	0	-0.1	0.7	65	90.88
6	135	0.7	0.3	-0.1	0	0	0	0.7	65	89.53
7	135	0.3	0.3	-0.2	0	0	0.3	0.7	65	88.4
8	135	0.2	-0.9	-2.9	-0.2	0.1	1.3	4.1	65	14.85
9	120	-3.4	-2.8	-5.5	-0.3	0.3	0.9	3.2	65	19.56
10	135	2.7	0.7	-0.5	-0.1	0	1.6	4.5	68.8	14.26
11	135	2.6	-0.1	-2.9	-0.2	0.1	1.5	6.3	68.8	9.99
12	120	-1.4	-0.3	0.2	-0.2	0.1	-0.2	1.7	68.8	40.17
13	120	-1.3	0	1.2	-0.2	-0.1	0.1	2.6	68.8	25.58
14	120	-1.2	-0.1	0.5	-0.1	0	-0.2	1.8	70.9	39.17
15	90	2.3	1.3	2.1	-0.3	-0.3	0.3	1.5	70.9	47.19
16	20	-0.1	2.1	-0.2	0	-0.1	0	2.3	70.9	29.86
17	20	-0.2	3.1	-0.6	0	-0.1	0	3.8	70.9	17.88
18	20	-0.2	4	-1	0	-0.1	0	5	70.9	13.23
19	0	0	4.9	-1.6	-0.5	0	0	6.6	70.9	9.82
20	20	-0.4	7.3	-2	0	0	0	9.3	70.9	6.66
21	0	-0.1	9.9	-3.1	-1	0	0.1	13.1	70.9	4.41
22	10	-0.8	11.1	-9.7	-0.1	0.3	0.1	20.8	70.9	2.41
23	120	-0.1	-0.3	-2.8	0	0.3	0.2	2.7	68.8	24.17
24	180	-0.3	0.9	-2.7	0.1	0	0	3.7	68.8	17.65
25	0	-0.3	0.3	-3.1	0	0.1	0	3.4	68.8	19.47
26	0	-0.3	-2	-4.3	0.2	0	0	4.1	68.8	15.8
27	0	-0.3	-2.8	-5	0.3	0	0	4.7	68.8	13.68
28	0	-0.5	-4.7	-5.7	0.5	0	0	5.3	68.8	12.07
29	0	-0.6	-7.4	-6.1	0.8	0	0	7	68.8	8.88
30	20	-0.1	-10.9	-6.5	0	-0.2	0	10.8	68.8	5.39
31	0	-1.4	-14.2	-16.6	1.3	0.1	0.4	15.3	68.8	3.5
32	0	-1.5	8.1	-7	-1	0.1	-0.7	15.3	62.7	3.11
33	0	-1.5	1.7	-12	-0.2	0	-0.9	13.8	62.7	3.55
34	0	-0.5	-4.9	-33.9	0.4	-0.2	-0.6	33.5	62.7	0.87
35	180	-1.3	1.9	-7.4	0.4	-0.6	0.1	9.4	62.7	5.69
36	180	-0.8	0	-10	0.1	-1.1	0.2	10.2	62.7	5.15
37	10	3.1	6.6	-1.5	0.1	0.1	1	8.3	63	6.57
38	180	3.5	-1.7	-2.6	-0.4	-0.6	0.7	6.6	63	8.58
39	0	7	0.7	-5.4	0.2	0.6	-0.4	12.6	63	4.02
40	0	-7.1	-5.7	-18	0.2	0.1	-0.4	12.3	63	4.12
41	180	0.5	-0.3	-2.5	-0.1	-0.1	0.6	3.2	72	21.51

Table 2.7.1.1-3 Critical P_m Stress Summary—30-Foot Top End-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	4	180	1	48	48.74
2	8	180	1.4	48	34.09
3	11	120	4.4	45.9	9.41
4	14	135	1.4	47.3	31.98
5	21	0	12.6	47.3	2.75
6	22	0	17	47.3	1.79
7	23	120	2.7	45.9	16.21
8	30	20	9.2	45.9	3.97
9	31	60	9.7	45.9	3.75
10	34	0	17.5	48	1.74
11	40	0	7.1	48	5.73
12	41	180	1.5	48	31.56

Table 2.7.1.1-4 Critical $P_m + P_b$ Stress Summary—30-Foot Top End Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	3	180	1.5	72	47.1
2	8	135	4.1	65	14.85
3	11	135	6.3	68.8	9.99
4	14	120	1.8	70.9	39.17
5	21	0	13.1	70.9	4.41
6	22	10	20.8	70.9	2.41
7	23	120	2.7	68.8	24.17
8	30	20	10.8	68.8	5.39
9	31	0	15.3	68.8	3.5
10	34	0	33.5	62.7	0.87
11	39	0	12.6	63	4.02
12	41	180	3.2	72	21.51

Table 2.7.1.1-5 P_m Stresses—30-Foot Bottom End-Drop, Thermal Condition 1

		Cylindrical Stress Components (ksi)						SI	Allowable Stress	Margin of
Section	Angle	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	(ksi)	(ksi)	Safety
1	70	-0.1	-5	-1.2	-0.6	1.9	0.4	5.9	48	7.1
2	180	-0.9	-2.7	0.1	0.1	0	-0.1	2.8	48	15.93
3	180	-0.2	-14.1	-3.2	-0.3	1.2	-0.1	14.1	48	2.4
4	180	-3.4	-9.9	-0.1	-0.5	1.5	-0.5	10.3	48	3.64
5	120	1.7	-2.7	1.7	1.6	2.4	-0.1	7.3	48	5.59
6	180	1.4	-2.2	1.9	1.6	0.7	-0.1	5.1	48	8.4
7	0	1.4	-5.8	0.5	1.9	0.1	-0.1	8.1	48	4.93
8	180	1.2	-7.8	-1.1	-4.5	0	0.4	12.8	48	2.76
9	180	6.4	-9.6	-0.9	2.5	0.8	1	17	48	1.82
10	180	10.7	-5.1	2.7	-12.7	-0.5	1.2	30.1	45.9	0.53
11	180	17.7	-4.5	4.4	-0.6	0.7	1.9	22.6	45.9	1.03
12	180	9.3	-2.1	4.5	6	1.7	0.9	17.1	45.9	1.69
13	180	19.5	5	9.6	-2.4	1	1.4	15.7	45.9	1.92
14	180	2.2	-9.7	0.6	5.2	1.8	0.3	16.2	47.3	1.92
15	180	10.6	-9.7	3.3	-2.6	0.7	0.8	21.1	47.3	1.24
16	0	-0.3	-5	11.4	-0.2	0	1.2	16.5	47.3	1.87
17	0	-0.2	-4.1	7.3	0	0	0.8	11.4	47.3	3.13
18	0	-0.2	-3.5	5.1	0	0	0.6	8.6	47.3	4.49
19	0	-0.1	-3	3.9	0	0	0.4	6.9	47.3	5.86
20	0	-0.1	-2.5	3.3	0	0	0.4	5.8	47.3	7.11
21	0	-0.1	-2	2.5	0	-0.1	0.3	4.5	47.3	9.45
22	0	0	-1.4	1.6	-0.1	-0.1	0.1	3.1	47.3	14.44
23	90	10.9	-5.8	-0.8	-1	0.1	0.3	10.3	45.9	3.46
24	0	-0.8	-6.8	-10.8	0	0	-1.1	10.3	45.9	3.46
25	0	-0.6	-6.6	-6.3	0	0	-0.7	6	45.9	6.6
26	0	-0.5	-6.2	-3.6	0	0	-0.5	5.8	45.9	6.96
27	0	-0.4	-5.6	-1.9	0	0	-0.3	5.3	45.9	7.62
28	0	-0.3	-5	-1.3	0	0	-0.2	4.7	45.9	8.74
29	0	-0.3	-4.3	-0.8	0	0	-0.1	4	45.9	10.35
30	0	-0.2	-3.6	0	0	0	0	3.5	45.9	12.05
31	0	-0.1	-2.9	1.7	0.1	0	0.2	4.6	45.9	9.06
32	0	-0.1	-1.1	1.8	0	-0.1	0.1	3	48	14.97
33	10	-0.4	-0.4	1.8	0.1	-0.1	0.4	2.5	48	18.54
34	0	0.2	-2.7	2.1	0	0	0.2	4.8	48	9.1
35	0	-0.1	-0.8	1.4	0.4	-0.1	0.1	2.3	48	19.73
36	80	1.1	-0.5	-0.3	0.1	-0.7	0.3	2.3	48	19.87
37	50	-0.2	-0.1	-0.2	0.2	-0.3	0	0.7	48	63.79
38	60	-0.2	0	-0.2	0.3	-0.4	0	1	48	48.01
39	0	-0.2	-1.9	-0.6	0.3	0	-0.1	1.8	48	25.46
40	80	0.7	1.9	0.1	-0.4	1.9	0	4.3	48	10.04
41	180	-1.2	-13.6	-0.3	-1.2	0.3	-0.2	13.5	48	2.55

Table 2.7.1.1-6 $P_m + P_b$ Stresses—30-Foot Bottom End-Drop, Thermal Condition 1

Section	Angle	Cylindrical Stress Components (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	180	0.6	-2.8	3.9	0.1	-0.2	-0.2	6.7	72	9.8
2	180	3.4	-1.8	4.7	-0.4	0	0.1	6.6	72	9.99
3	180	5.9	-9.8	-3.3	-0.6	1	0.4	15.9	72	3.53
4	180	-7	-18.8	-3.8	0	1.6	-0.6	15.5	72	3.65
5	0	3	-1.1	11.4	-1.4	0.3	0.7	13	65	3.99
6	120	8.9	-0.9	11.3	0	0	2.9	14.1	65	3.6
7	0	3	-10.6	-0.9	0.6	0.1	-0.3	13.6	65	3.77
8	180	4.8	-3.7	1	-9.7	-0.2	0.7	21.2	65	2.07
9	0	-3	-23.3	-7.3	-1	0.4	-0.4	20.5	65	2.17
10	180	15.6	2.8	6.8	-16.4	-0.6	1.2	35.4	68.8	0.95
11	180	13.8	-12	1.4	-7.4	0.9	1.8	30	68.8	1.29
12	180	7.9	-1.9	4	9.1	1.6	0.9	21	68.8	2.27
13	180	33.6	11.8	15.9	-7.1	1.2	2.2	26.7	68.8	1.58
14	0	-0.7	-19.7	-3.3	-2.5	0.9	-0.2	19.8	70.9	2.59
15	180	26.3	7.8	12.8	-6	0.9	1.4	22.3	70.9	2.18
16	20	0.8	-5.3	10.6	-0.1	0.2	4.1	17.4	70.9	3.07
17	0	-0.1	-4	7.8	0	0	0.8	11.9	70.9	4.96
18	20	0.4	-3.1	5.1	0	-0.1	2	9	70.9	6.86
19	20	0.3	-2.7	4	0	-0.1	1.6	7.2	70.9	8.8
20	20	0.3	-2.4	3.3	0	-0.1	1.3	6.1	70.9	10.56
21	20	0.2	-1.9	2.5	0	-0.1	0.9	4.7	70.9	14.04
22	0	0	-2	1.3	-0.2	-0.1	0.1	3.3	70.9	20.41
23	180	-1.7	-17.6	-14.1	0.2	0.8	1.9	16.4	68.8	3.2
24	0	-0.9	-7	-12.3	0	0	-1.2	11.6	68.8	4.91
25	0	-0.7	-7.1	-8.1	0	0	-0.8	7.6	68.8	8.05
26	0	-0.5	-6.7	-5.3	0	0	-0.6	6.3	68.8	9.98
27	0	-0.4	-6	-3.3	0	0	-0.4	5.7	68.8	11.03
28	0	-0.3	-5.4	-2.5	0	0	-0.3	5.1	68.8	12.4
29	0	-0.2	-4.6	-1.6	0	0	-0.2	4.3	68.8	14.83
30	0	-0.2	-3.3	0.5	0	0.1	0	3.8	68.8	16.92
31	0	-0.1	-3.3	1.7	0.1	0	0.2	5	68.8	12.67
32	0	-0.1	-1.1	2	0.1	-0.1	0.2	3.1	62.7	19.11
33	10	-1.1	-2	1.3	0.3	-0.1	0.5	3.5	62.7	16.98
34	0	-0.2	-4.3	1.6	0	0	0.2	5.9	62.7	9.55
35	0	0.1	-3.4	1.1	2	-0.3	0.1	5.4	62.7	10.61
36	80	0.9	-0.3	-1	0.2	-0.9	0.3	2.7	62.7	22.44
37	165	-1.8	-0.1	-2.6	-0.3	-0.1	0.2	2.6	63	23.07
38	20	-2.5	-0.1	-0.7	0.4	-0.1	0.7	2.7	63	22.05
39	0	4.6	-1.5	1.4	0.1	0.1	-0.3	6.1	63	9.34
40	10	1.8	8	3.2	-1.7	0.3	0.3	7	63	7.96
41	180	1.9	-18.1	-0.5	-2.7	0	0.1	20.8	72	2.46

Table 2.7.1.1-7 Critical P_m Stress Summary—30-Foot Bottom End-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	3	180	14.1	48	2.4
2	9	180	17.0	48	1.82
3	10	180	30.1	45.9	0.53
4	15	180	21.1	47.3	1.24
5	16	0	16.5	47.3	1.87
6	22	0	3.1	47.3	14.44
7	23	90	10.3	45.9	3.46
8	24	0	10.3	45.9	3.46
9	31	0	4.6	45.9	9.06
10	34	0	4.8	48	9.1
11	40	80	4.3	48	10.04
12	41	180	13.5	48	2.55

Table 2.7.1.1-8 Critical $P_m + P_b$ Stress Summary—30-Foot Bottom End-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	3	180	15.9	72	3.53
2	8	180	21.2	65	2.07
3	10	180	35.4	68.8	0.95
4	15	180	22.3	70.9	2.18
5	16	20	17.4	70.9	3.07
6	22	0	3.3	70.9	20.41
7	23	180	16.4	68.8	3.2
8	24	0	11.6	68.8	4.91
9	31	10	5.0	68.8	12.67
10	34	0	5.9	62.7	9.55
11	40	10	7.0	63	7.96
12	41	180	20.8	72	2.46

2.7.1.2 30-Foot Side Drop

In accordance with the requirements of 10 CFR 71.73(c)(1), the Universal Transport Cask is structurally evaluated for the hypothetical accident 30-foot side drop condition. In this event, the cask, with its payload, spacer (if appropriate), and impact limiters, falls 30 feet onto a flat, unyielding, horizontal surface. The package strikes the surface in a horizontal position; consequently, a side impact occurs. The types of loading involved in a side drop accident are closure lid bolt preload, internal pressure, and inertial body load.

As shown in Tables 2.7.1.2-1 through 2.7.1.2-4, the margins of safety are positive for the 30-ft side-drop accident. The minimum margin of safety for the primary membrane condition is 0.47 in component 4, bottom portion of the outer shell (Table 2.7.1.2-3). The minimum margin of safety for primary membrane plus bending is 0.04 in component 4, bottom section of the outer shell (Table 2.7.1.2-4).

Table 2.7.1.2-1 P_m Stresses—30-Foot Side-Drop, Thermal Condition 1

Section	Angle	Cylindrical Stress Components (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	180	-3.0	3.7	-0.1	0.2	0.0	0.1	6.8	48.0	6.08
2	135	-0.3	2.7	0.0	-3.2	-0.1	0.2	7.2	48.0	5.68
3	30	-5.3	-9.0	-0.5	0.4	0.7	-0.5	8.7	48.0	4.50
4	10	-12.1	-17.6	-0.5	0.2	0.4	-4.2	18.4	48 0	1.61
5	10	-8.3	-6.8	-0.1	0.6	0.0	-0.1	8.4	48 0	4.70
6	0	-10.2	-12.5	-0.1	0.2	0.1	0.2	12.4	48 0	2.86
7	0	-11.8	-18.1	7.2	0.3	-0.4	-1.3	25.5	48 0	0.88
8	0	-6.3	-24.4	0.6	1.1	-1.3	-3.8	27.0	48 0	0.78
9	0	-16.8	-28.6	1.5	1.2	-0.8	3.9	31.0	48 0	0.55
10	0	-14.1	-32.8	0.2	1.1	-1.0	-2.2	33.5	48 0	0.43
11	0	-20.4	-40.8	-0.6	1.4	-0.7	4.6	41.3	48 0	0.16
12	0	-27.6	-23.9	0.2	-0.8	-1.1	2.0	28.3	48 0	0.69
13	0	-17.2	-18.4	-0.6	-0.5	-1.2	2.8	18.5	48.0	1.60
14	0	-23.9	-32.5	-2.7	0.6	-0.8	-6.8	31.8	47.3	0.49
15	0	-13.6	-30.2	-0.3	1.4	-0.4	5.6	32.1	47.3	0.47
16	60	0.0	3.0	1.5	0.0	-10.3	-0.2	20.6	47.3	1.29
17	0	-0.3	5.4	21.1	-0.8	-0.8	0.2	21.6	47.3	1.19
18	0	-0.3	4.7	25.4	-0.9	-0.4	0.1	25.9	47.3	0.83
19	0	-0.3	4.5	27.0	-0.9	-0.1	0.0	27.4	47.3	0.72
20	0	-0.3	5.0	26.2	-0.8	0.3	-0.1	26.6	47.3	0.78
21	0	-0.3	6.0	22.4	-0.8	0.8	-0.2	22.8	47.3	1.07
22	60	0.0	5.3	1.8	-0.1	10.0	0.6	20.3	47.3	1.33
23	50	-0.2	-4.2	2.8	0.0	-10.7	0.3	22.6	45.9	1.03
24	50	-0.1	4.9	3.1	-0.1	-10.8	-0.2	21.7	45.9	1.12
25	0	-0.8	7.4	18.2	-0.8	-0.9	0.1	19.1	45.9	1.40
26	0	-0.8	7.4	23.3	-0.8	-0.5	0.1	24.2	45.9	0.89
27	0	-0.8	7.7	25.3	-0.9	0.0	0.0	26.2	45.9	0.75
28	0	-0.8	7.5	24.0	-0.8	0.4	0.0	25.0	45.9	0.84
29	0	-0.8	7.4	19.6	-0.8	0.8	-0.1	20.5	45.9	1.23
30	60	0.0	3.9	1.3	0.1	9.9	0.1	19.9	45.9	1.30
31	50	-0.2	4.2	3.3	-0.1	13.6	0.5	27.2	45.9	0.69
32	70	0.3	5.2	-0.6	0.3	10.4	1.0	21.7	48.0	1.22
33	80	-2.5	1.0	-0.7	-2.1	6.6	0.4	14.0	48.0	2.44
34	60	3.2	3.7	2.8	0.8	10.9	0.7	22.0	48.0	1.18
35	0	-3.5	-17.5	0.6	1.2	0.1	-3.0	19.8	48.0	1.42
36	180	2.7	18.3	-2.0	2.4	0.5	3.4	22.4	48.0	1.14
37	0	-9.7	-0.9	-0.1	0.0	0.0	-0.3	9.6	48.0	4.03
38	0	-10.7	-5.2	-0.3	0.1	0.0	-0.5	10.5	48.0	3.58
39	0	-11.4	-9.4	0.8	0.2	-0.2	-0.9	12.3	48.0	2.89
40	0	-9.8	-12.7	-4.3	0.5	-0.1	-0.4	8.5	48.0	4.63
41	0	-14.8	-9.0	-0.7	-0.4	0.1	0.4	14.2	48.0	2.39

Table 2.7.1.2-2 $P_m + P_b$ Stresses—30-Foot Side-Drop, Thermal Condition 1

		Cylindrical Stress Components (ksi)							Allowable Stress	Margin of
Section	Angle	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	SI (ksi)	(ksi)	Safety
1	180	-2.0	9.1	0.0	0.2	0.0	0.1	11.1	72.0	5.49
2	0	-10.5	-11.3	0.0	0.2	0.1	-0.2	11.3	72.0	5.37
3	0	-15.5	-18.7	-2.3	0.6	-0.1	-3.2	17.4	72.0	3.15
4	10	-16.8	-18.3	0.0	0.5	0.6	-4.6	20.0	72.0	2.60
5	0	-11.1	-12.9	-0.1	0.1	-0.1	-0.1	12.8	69.7	4.43
6	0	-11.8	-18.6	-0.1	0.3	0.1	0.2	18.4	69.7	2.79
7	0	-9.9	-19.8	17.6	0.1	-0.8	-0.9	37.5	69.7	0.86
8	0	1.1	-12.3	33.1	0.4	-1.5	-5.2	46.3	69.7	0.50
9	0	5.5	-5.0	58.8	1.0	-1.6	-0.6	64.2	69.7	0.09
10	0	-4.7	-27.6	4.9	1.4	-0.9	-6.6	35.4	68.8	0.94
11	0	2.6	-30.2	1.1	2.3	-1.1	1.3	42.0	68.8	0.64
12	0	-37.9	-27.0	2.0	-1.2	-1.1	0.0	40.1	68.8	0.72
13	0	-40.2	-27.3	9.4	-1.6	-1.5	2.6	50.0	68.8	0.38
14	0	-31.4	-22.9	36.6	-0.9	-1.0	-2.2	68.2	70.9	0.04
15	0	7.2	-7.1	58.0	0.7	-1.1	3.5	65.4	70.9	0.08
16	50	-0.1	10.2	5.0	-0.2	-13.8	-0.2	27.9	70.9	1.54
17	0	-0.2	26.6	29.9	-2.7	-0.3	0.2	30.4	70.9	1.33
18	0	-0.2	30.2	35.7	-3.1	-0.2	0.1	36.3	70.9	0.96
19	0	-0.4	-22.1	16.3	1.4	0.0	0.0	38.5	70.9	0.84
20	0	-0.2	29.7	36.5	-3.0	0.0	-0.1	37.0	70.9	0.92
21	0	-0.1	25.1	30.5	-2.5	0.1	-0.2	30.9	70.9	1.29
22	40	-0.2	6.8	3.2	-0.3	14.8	0.4	29.8	70.9	1.38
23	40	-0.3	-5.3	4.0	-0.1	-16.5	0.8	34.5	68.8	0.99
24	50	-0.3	12.7	4.9	-0.1	-14.2	-0.2	29.5	68.8	1.33
25	0	-0.6	28.0	26.3	-2.6	-0.4	0.1	29.3	68.8	1.35
26	0	-0.7	33.0	33.2	-3.1	-0.2	0.1	34.4	68.8	1.00
27	0	-0.6	35.4	36.0	-3.4	0.0	0.0	37.0	68.8	0.86
28	0	-0.6	34.4	34.4	-3.2	0.2	0.0	35.8	68.8	0.92
29	0	-0.6	31.0	28.8	-2.9	0.4	-0.1	32.2	68.8	1.13
30	50	-0.3	15.6	7.2	-0.2	12.5	0.0	26.4	68.8	1.61
31	40	-0.4	4.5	-0.7	-0.2	20.0	0.1	40.5	68.8	0.70
32	50	0.1	4.1	-5.4	0.1	14.6	0.1	30.6	62.7	1.05
33	60	-4.3	-2.4	-6.5	-6.2	11.1	0.5	25.7	62.7	1.44
34	50	-0.1	-2.3	-9.2	0.2	14.8	-1.1	30.5	62.7	1.06
35	40	-0.8	-11.4	0.5	0.2	11.2	0.1	25.4	62.7	1.47
36	0	-2.9	-21.5	1.7	2.1	0.4	1.7	24.0	62.7	1.61
37	0	-8.4	6.1	0.0	0.0	0.0	-0.2	14.5	63.0	3.35
38	0	-15.0	-0.6	-0.3	0.0	0.0	-0.5	14.7	63.0	3.29
39	0	-19.7	-5.8	3.2	-0.3	-0.2	2.8	23.5	63.0	1.68
40	0	9.1	-6.3	8.1	0.7	0.1	1.3	16.4	63.0	2.83
41	0	-15.2	-9.6	0.5	-0.3	0.0	0.1	15.6	72.0	3.61

Table 2.7.1.2-3 Critical P_m Stress Summary—30-Foot Side-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	4	10	18.4	48.0	1.61
2	9	0	31.0	48.0	0.55
3	13	0	18.5	48.0	1.60
4	15	0	32.1	47.3	0.47
5	19	0	27.4	47.3	0.72
6	22	60	20.3	47.3	1.33
7	23	50	22.6	45.9	1.03
8	27	0	26.2	45.9	0.75
9	31	50	27.2	45.9	0.69
10	36	180	22.4	48.0	1.14
11	39	0	12.3	48.0	2.89
12	41	0	14.2	48.0	2.39

Table 2.7.1.2-4 Critical $P_m + P_b$ Stress Summary—30-Foot Side-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	4	10	20.0	72.0	2.60
2	9	0	64.2	69.7	0.09
3	13	0	50.0	68.8	0.38
4	14	0	68.2	70.9	0.04
5	19	0	38.5	70.9	0.84
6	22	40	29.8	70.9	1.38
7	23	40	34.5	68.8	0.99
8	27	0	37.0	68.8	0.86
9	31	40	40.5	68.8	0.70
10	32	50	30.6	62.7	1.05
11	39	0	23.5	63.0	1.68
12	41	0	15.6	72.0	3.61

2.7.1.3 30-Foot Corner Drop

In accordance with the requirements of 10 CFR 71.73(c)(1), the Universal Transport Cask is structurally evaluated for the hypothetical accident 30-foot corner drop condition. In this event, the cask, payload, spacer (if appropriate), and impact limiters, falls 30 feet onto a flat, unyielding, horizontal surface. The cask strikes the surface on its top or bottom corner. The cask center of gravity is directly above the initial impact point for the corner drop condition. For the cask, an angle of 23° from vertical is calculated for the top corner drop orientation, and an angle of 23.5° from vertical is calculated for the bottom corner drop orientation.

The results of the stress evaluation are provided in Tables 2.7.1.3-1 through 2.7.1.3-4 for the top corner and Tables 2.7.1.3-5 through 2.7.1.3-8 for the bottom corner, respectively. For the top corner combined impact loading case, the minimum margin of safety for primary membrane stress intensity is 1.04 (Table 2.7.1.3-3) in the ligaments. The minimum margin of safety for primary membrane plus bending stress intensity is 0.96 in the top forging (Table 2.7.1.3-4).

For the bottom corner, combined impact loading case, the minimum margin of safety for membrane stress intensity is 0.78 in the ligaments (Table 2.7.1.3-7). The minimum margin of safety for membrane plus bending stress intensity is 0.94 (Table 2.7.1.3-8).

Table 2.7.1.3-1 P_m Stresses—30-Foot Top Corner-Drop, Thermal Condition 1

Section	Angle	Cylindrical Stress Components (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	180	-1	1.4	-0.1	0.1	0	0.1	2.4	48	18.83
2	120	0.2	0.4	0	-1.3	0	0	2.6	48	17.78
3	90	0.5	-0.2	0.2	-1.1	-1	0.4	3.1	48	14.32
4	0	-4.7	-6.4	0.2	0.2	0	-1.4	7	48	5.89
5	10	-2.9	-2.3	-0.1	0.2	0	-0.1	2.9	48	15.63
6	0	-3.6	-4.4	-0.1	0.1	0	0	4.3	48	10.24
7	0	-4.1	-6.5	2.4	0.1	-0.2	-0.5	9	48	4.36
8	0	-2.9	-9.3	-1.1	0.4	-0.5	-1.2	8.9	48	4.38
9	0	-7.3	-11	-1.1	0.4	-0.3	1.8	10.5	48	3.58
10	0	-5.3	-12.8	-11.3	0.5	-0.5	0.1	7.7	45.9	4.94
11	0	-8.3	-15.9	-17.1	0.5	-0.3	2.3	10.1	45.9	3.55
12	0	-10.1	-8.6	11.1	-0.3	-0.4	0.8	21.3	45.9	1.16
13	0	-6.2	-6.4	15.8	-0.2	-0.5	1	22.4	45.9	1.04
14	0	-9.1	-11.6	-0.4	0.2	-0.3	-2.6	12	47.3	2.94
15	0	-4.5	-10.6	0.6	0.5	-0.2	2	11.9	47.3	2.97
16	60	0	2.5	0.3	0	-3.9	-0.1	8.1	47.3	4.86
17	0	-0.2	4.4	6.7	-0.6	-0.3	0.1	7	47.3	5.77
18	0	-0.2	4.8	7.6	-0.7	-0.1	0	7.9	47.3	4.98
19	105	-0.1	3.4	-5.4	0.1	-0.1	0	8.8	47.3	4.38
20	105	-0.2	5.1	-5.3	0.1	0.8	0	10.5	47.3	3.49
21	80	-0.1	8.4	-3.5	0.1	2.8	0.1	13.1	47.3	2.61
22	60	-0.4	12.5	-2.4	0	5	0.3	18	47.3	1.63
23	50	-0.1	-1.3	-1.1	0	-3.8	0.2	7.6	45.9	5.04
24	50	-0.1	2	-1.4	0	-3.5	-0.1	7.9	45.9	4.83
25	80	-0.1	0.3	-4.5	0.1	-1.7	0	5.9	45.9	6.74
26	105	-0.2	-0.6	-6.3	0	-0.4	0	6.1	45.9	6.47
27	105	-0.2	-1	-6.8	0	0.3	0	6.6	45.9	5.98
28	90	-0.2	-2.2	-6.4	0.2	1.3	0	6.6	45.9	5.97
29	80	-0.3	-4.3	-5.5	0.1	2.4	0	7.1	45.9	5.46
30	60	-0.4	-7.5	-4.4	0	3.6	0.1	9.5	45.9	3.84
31	30	-0.9	-9.4	-6.4	-0.1	4.5	0.1	11.8	45.9	2.91
32	70	-0.6	8.8	-3	0.2	5.1	-0.5	15.7	48	2.05
33	0	5.1	1.9	-5.2	0	0.4	-2.2	11.2	48	3.3
34	0	5.8	-2	-12.6	0.6	0.9	1.9	18.9	48	1.54
35	180	-1.2	4.6	-5.4	0.8	-0.4	0.5	10.3	48	3.68
36	180	2.3	7.5	-6.1	0.8	-0.6	1.7	14.1	48	2.4
37	0	-4.2	-0.5	-2.1	0	0.3	0.8	4.1	48	10.81
38	10	-4.1	-2.2	-1.2	0.4	0.3	0.5	3.3	48	13.76
39	180	-2.4	-2.2	-5.7	-0.1	-0.4	0.2	3.7	48	12.09
40	180	-5.2	-3.3	-7.5	0.1	-0.1	-1.8	5.2	48	8.23
41	0	-5.2	-3.2	-1.1	-0.1	0.1	0.6	4.2	48	10.32

Table 2.7.1.3-2 $P_m + P_b$ Stresses—30-Foot Top Corner-Drop, Thermal Condition 1

		Cylindrical Stress Components (ksi)							Allowable Stress	Margin of
Section	Angle	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	SI (ksi)	(ksi)	Safety
1	180	-1.2	2.7	0	0.1	0	0	3.9	72	17.36
2	180	-0.6	2.9	0	0.1	0	0	3.6	72	19.11
3	0	-6.1	-6.9	-0.9	0.1	0.1	-1	6.2	72	10.62
4	0	-6.7	-6.9	-0.1	0.1	0	-1.5	7.4	72	8.77
5	0	-3.1	-3.3	-0.1	0	0	-0.1	3.2	65	19.46
6	0	-4.4	-6.1	-0.1	0.1	0	0	6	65	9.9
7	0	-4.4	-7.3	6.1	0	-0.3	-0.6	13.5	65	3.8
8	0	-0.7	-4.5	12.4	0.1	-0.6	-2.4	17.4	65	2.73
9	0	2.3	-1.3	22.1	0.3	-0.6	-0.2	23.5	65	1.76
10	0	-1.4	-10.8	-9.7	0.6	-0.4	-1.3	9.8	68.8	6
11	0	2.1	-11.3	-12.9	0.9	-0.5	1.1	15.3	68.8	3.49
12	0	-14.7	-10.1	10.1	-0.5	-0.4	0	24.8	68.8	1.77
13	0	-15.6	-10	12.5	-0.7	-0.6	1.1	28.3	68.8	1.43
14	0	-12.3	-8.6	13	-0.4	-0.4	-0.9	25.4	70.9	1.79
15	0	3.6	-2	21.7	0.3	-0.4	1.2	23.8	70.9	1.98
16	50	-0.1	5.3	1.4	-0.1	-5.1	-0.1	10.8	70.9	5.56
17	0	-0.1	12.3	10	-1.2	-0.1	0.1	12.6	70.9	4.63
18	0	-0.1	14.2	11.4	-1.5	0	0.1	14.6	70.9	3.85
19	0	-0.1	15.5	11.3	-1.6	0	0	15.9	70.9	3.46
20	0	-0.1	16.8	9.7	-1.7	0.1	0	17.2	70.9	3.12
21	0	-0.1	17.7	5.8	-1.8	0.2	0	18.1	70.9	2.91
22	50	-0.8	12.6	-8.1	-0.1	6.3	0.3	24.3	70.9	1.92
23	40	-0.2	-1.8	-1.1	0	-6.1	0.4	12.2	68.8	4.65
24	50	-0.2	5	-0.8	-0.1	-4.7	-0.1	11	68.8	5.24
25	0	-0.4	9.2	6.3	-0.8	-0.1	0	9.8	68.8	6.01
26	0	-0.5	10.1	7.8	-0.9	0	0	10.7	68.8	5.42
27	0	-0.5	10.1	7.8	-0.9	0	0	10.8	68.8	5.39
28	70	-0.3	-8.4	-7.4	0	1.5	0	9.2	68.8	6.51
29	70	-0.4	-9.7	-7	0	2.4	0	10.8	68.8	5.4
30	70	-0.6	-11.3	-5.4	0	3.2	0.1	12.1	68.8	4.67
31	40	-0.5	-6.2	2.8	-0.1	7.3	0.4	17.2	68.8	3
32	60	-1.2	8.4	-7.5	0	6	-0.6	20	62.7	2.13
33	180	-1.2	1.6	-13.2	0.4	0.1	-0.8	14.9	62.7	3.22
34	50	-0.4	-6.3	-31.2	0.1	5.3	-0.9	32	62.7	0.96
35	180	-1.3	4.6	-5.7	0.8	-0.6	0.8	10.6	62.7	4.93
36	180	-0.4	6.4	-8.2	1	-0.8	1.1	15	62.7	3.18
37	70	-2.3	-8.5	-1.8	1.1	0.2	1.1	7.8	63	7.05
38	70	4.7	-2.5	-1.1	1	0.1	0.6	7.5	63	7.39
39	180	5.5	0.2	-4.2	-0.4	-0.5	-0.2	9.8	63	5.4
40	0	-4.5	-6.5	-15.4	0.5	0.3	0.7	11.2	63	4.65
41	0	-6.4	-3.6	-0.1	-0.2	0	0.1	6.3	72	10.42

Table 2.7.1.3-3 Critical P_m Stress Summary—30-Foot Top Corner-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	4	0	7	48	5.89
2	9	0	10.5	48	3.58
3	13	0	22.4	45.9	1.04
4	14	0	12	47.3	2.94
5	21	80	13.1	47.3	2.61
6	22	60	18	47.3	1.63
7	23	50	7.6	45.9	5.04
8	30	60	9.5	45.9	3.84
9	31	30	11.8	45.9	2.91
10	34	0	18.9	48	1.54
11	40	180	5.2	48	8.23
12	41	0	4.2	48	10.32

Table 2.7.1.3-4 Critical $P_m + P_b$ Stress Summary—30-Foot Top Corner-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	4	0	7.4	72	8.77
2	9	0	23.5	65	1.76
3	13	0	28.3	68.8	1.43
4	14	0	25.4	70.9	1.79
5	21	0	18.1	70.9	2.91
6	22	50	24.3	70.9	1.92
7	23	40	12.2	68.8	4.65
8	30	70	12.1	68.8	4.67
9	31	40	17.2	68.8	3
10	34	50	32	62.7	0.96
11	40	0	11.2	63	4.65
12	41	0	6.3	72	10.42

Table 2.7.1.3-5 P_m Stresses—30-Foot Bottom Corner-Drop, Thermal Condition 1

		Cylindrical Stress Components (ksi)							Allowable Stress	Margin Of
Section	Angle	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	SI (ksi)	(ksi)	Safety
1	180	-2.2	1.6	-2.4	0.2	0	-0.3	4.1	48	10.59
2	180	-1.2	2.3	-1.5	0.2	0	0.2	3.9	48	11.2
3	0	-4	-9.8	-19.5	0	-1.7	-0.9	15.9	48	2.03
4	180	-2.6	2.5	-5.5	0.7	0.6	0.6	8.3	48	4.82
5	180	-1	1.8	-1.9	0.1	0.7	-1.5	5	48	8.52
6	180	-0.2	2.6	-1.4	0.2	0.2	0	4	48	11.1
7	80	0.8	-0.6	-3.6	-1.4	-1	2.1	6.9	48	5.92
8	80	3.9	-0.3	-2.9	-2.0	-2.4	3.3	11.2	48	3.3
9	70	4.6	-2.1	-4.7	-0.4	-2.5	-2.6	12	48	3.01
10	0	1.8	-9.3	-9.6	1	-0.3	11.3	25.4	45.9	0.81
11	0	8	-9.8	-15.5	1.6	-0.5	5.1	25.8	45.9	0.78
12	10	-2.9	-4.4	11	0.1	-1.7	-3.1	16.5	45.9	1.78
13	10	9.2	1.7	19.8	-0.2	-1.8	2	18.8	45.9	1.44
14	0	-7.7	-12.9	-14.7	0.6	-1.8	-7.7	17.3	47.3	1.74
15	0	1.3	-10.1	-13.9	0.9	-0.8	4.8	18.2	47.3	1.6
16	50	-0.2	11.4	-4	0	-5.1	-0.2	18.5	47.3	1.56
17	70	-0.1	6.8	-4.1	0.1	-3.4	0	12.8	47.3	2.68
18	90	-0.1	4.3	-5.4	0	-1.6	0	10.2	47.3	3.62
19	90	-0.1	3.2	-5.5	0	-0.6	0	8.8	47.3	4.37
20	90	-0.1	2.8	-4.9	0	0.5	0	7.8	47.3	5.09
21	90	-0.1	2.1	-3.8	0	1.5	0	6.6	47.3	6.19
22	70	0	2.5	-1	0	3.3	0.1	7.4	47.3	5.38
23	20	-0.9	-15.5	-9.4	0	-2.9	0.6	15.8	45.9	1.9
24	60	-0.4	-8.4	-5.4	0	-4.2	0	10.9	45.9	3.2
25	70	-0.3	-4.5	-5.6	0	-3.2	0	8	45.9	4.72
26	80	-0.2	-2.2	-6.2	0.1	-2.2	0	6.9	45.9	5.62
27	90	-0.2	-1	-6.7	0.2	-1.1	0	6.7	45.9	5.88
28	90	-0.2	-0.6	-6.4	0.1	-0.1	0	6.2	45.9	6.36
29	90	-0.2	-0.3	-5.5	0.1	0.8	0	5.6	45.9	7.22
30	60	-0.1	1.1	-2.6	0	2.7	0	6.5	45.9	6.02
31	40	-0.2	2.3	-1.6	-0.1	4.6	0.1	9.9	45.9	3.64
32	70	0.1	2.7	-0.8	0.1	3.5	0.3	7.8	48	5.12
33	80	-0.9	1.3	-0.3	-0.7	2.3	0.2	5.1	48	8.37
34	60	0.9	2.3	-1	0.2	3.6	0.2	8	48	5.03
35	0	-1.3	-4.9	-0.4	0.3	0.1	-0.9	5.2	48	8.3
36	180	1.3	6.8	-0.9	0.8	0.1	1.1	8.2	48	4.82
37	10	-3.1	-0.5	-0.1	0.5	0	0.1	3.1	48	14.53
38	0	-3.6	-1.8	-0.2	0	0	0	3.4	48	13.14
39	0	-3.8	-3.2	-0.3	0.1	-0.1	0.1	3.5	48	12.57
40	80	-1.3	-1.8	-3.4	-0.1	0	-1.4	3.6	48	12.49
41	0	-5.6	-2.9	-15	-0.3	-0.2	1.9	12.5	48	2.85

Table 2.7.1.3-6 $P_m + P_b$ Stresses—30-Foot Bottom Corner-Drop, Thermal Condition 1

		Cylindrical Stress Components (ksi)							Allowable Stress	Margin Of
Section	Angle	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	SI (ksi)	(ksi)	Safety
1	180	-2	3.9	-2.4	0.3	-0.2	-0.2	6.4	72	10.24
2	10	-8.4	-6.4	-0.6	0.2	-0.2	0.3	7.8	72	8.23
3	0	5.9	-7.4	-13.9	0.3	-1.5	0.8	20.2	72	2.57
4	0	-15.1	-13.3	-24.6	-0.3	-2.1	-3.1	13	72	4.53
5	180	-4.3	7	-1	1	0.5	-1.3	12	65	4.42
6	120	11.5	6.7	-0.8	-0.9	-0.1	0	12.5	65	4.2
7	80	3.8	-1.7	-7.1	-2.6	-1.9	1.3	12.9	65	4.04
8	0	4.5	-9.4	-11.2	1.3	-0.3	10.1	25.7	65	1.53
9	0	-3.6	-15.7	-21.8	1.4	-0.8	0.6	18.5	65	2.51
10	0	4.1	-6.9	-5.2	0.9	-0.2	12.3	26.4	68.8	1.61
11	0	14.1	-6.5	-12	1.6	-0.7	9.6	32.6	68.8	1.11
12	0	-8.9	-7	7.8	0.1	-1.5	-6.6	21.4	68.8	2.21
13	10	24.9	8.1	25.7	-0.6	-1.9	5.5	23	68.8	1.99
14	0	-7.6	-20.3	-40.6	1.1	-1.8	-7.7	36.7	70.9	0.94
15	0	-17.6	-26.9	-52.9	1	-0.4	3.8	36.3	70.9	0.96
16	40	-0.6	13.3	-4.8	-0.1	-6.2	-0.2	21.9	70.9	2.23
17	0	-0.1	16.4	4	-1.7	-0.2	0	16.9	70.9	3.21
18	0	-0.1	15.7	7.6	-1.6	-0.2	0	16.2	70.9	3.38
19	0	-0.1	14.9	9.5	-1.5	-0.1	0	15.4	70.9	3.61
20	0	-0.1	13.9	10.1	-1.4	0	-0.1	14.2	70.9	3.98
21	0	-0.1	11.3	8.9	-1.1	0	-0.1	11.6	70.9	5.09
22	40	-0.1	3.5	0.5	-0.1	5.1	0.1	10.6	70.9	5.67
23	0	-1.7	-19.3	-23.5	1.8	-0.7	0.7	22.2	68.8	2.1
24	20	-0.3	-11.1	-9.2	-0.1	-3.9	0	13.9	68.8	3.95
25	70	-0.4	-9.5	-7.4	0	-3	0	11.2	68.8	5.14
26	70	-0.3	-8.3	-7.9	0	-2.1	0	10	68.8	5.91
27	0	-0.6	9.7	6.1	-0.9	-0.1	0	10.4	68.8	5.61
28	0	-0.5	10.2	6.7	-0.9	0	0	10.9	68.8	5.33
29	0	-0.5	9.8	6.1	-0.9	0.1	0	10.4	68.8	5.59
30	50	-0.2	5.6	-0.4	-0.1	3.7	0	9.4	68.8	6.29
31	40	-0.2	2.7	-3.1	-0.1	7	0.1	15.2	68.8	3.54
32	50	0	2.6	-2.2	0	4.9	0.1	10.9	62.7	4.74
33	60	-1.9	0.1	-3	-2.1	3.7	0.4	9.2	62.7	5.84
34	60	-0.1	0.8	-5.9	0	4.7	-0.4	11.6	62.7	4.39
35	50	-0.6	-2.3	-1.9	0.1	4	1.1	8.5	62.7	6.41
36	180	2.7	7.2	-0.8	0.7	0.1	1.4	8.6	62.7	6.27
37	50	0.4	-1	-0.1	2	0.1	0.2	4.4	63	13.46
38	180	-5.5	-4.2	-0.2	0.1	0	0.1	5.2	63	11.02
39	80	4.5	1.1	-1.3	-0.1	0	-0.2	5.8	63	9.8
40	40	-1.7	-5.6	-8.4	-0.7	0.1	0.3	6.8	63	8.31
41	0	-0.4	-3	-22	0	0	3.5	22.7	72	2.17

Table 2.7.1.3-7 Critical P_m Stress Summary—30-Foot Bottom Corner-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	3	0	15.9	48	2.03
2	9	70	12.0	48	3.01
3	11	0	25.8	45.9	0.78
4	15	0	18.2	47.3	1.6
5	16	50	18.5	47.3	1.56
6	22	70	7.4	47.3	5.38
7	23	20	15.8	45.9	1.9
8	24	60	10.9	45.9	3.2
9	31	40	9.9	45.9	3.64
10	36	180	8.2	48	4.82
11	40	80	3.6	48	12.49
12	41	0	12.5	48	2.85

Table 2.7.1.3-8 Critical $P_m + P_b$ Stress Summary—30-Foot Bottom Corner-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	3	0	20.2	72	2.57
2	8	0	25.7	65	1.53
3	11	0	32.6	68.8	1.11
4	14	0	36.7	70.9	0.94
5	16	40	21.9	70.9	2.23
6	22	40	10.6	70.9	5.67
7	23	0	22.2	68.8	2.1
8	24	20	13.9	68.8	3.95
9	31	40	15.2	68.8	3.54
10	34	60	11.6	62.7	4.39
11	40	40	6.8	63	8.31
12	41	0	22.7	72	2.17

2.7.1.4 30-Foot Oblique Drop

In accordance with the requirements of 10 CFR 71.73, (c) (1) the Universal Transport Cask is structurally evaluated for the hypothetical accident 30-foot oblique drop condition. In this event, the cask, with its payload, spacer (if appropriate), and impact limiters, falls 30 feet onto a flat, unyielding, horizontal surface. The cask strikes the surface obliquely on its top or bottom corner. An oblique orientation angle of 75° from vertical is evaluated for the oblique drops.

In Section 2.6.7.5, an assessment is performed to determined the drop angle for which the maximum energy absorption is required for the secondary impact. Table 2.6.7.5-4 identifies the 75° drop to be the most severe angle. The larger energy absorption is associated with the most deformation of the impact limiter, which corresponds to the largest area of crush and the maximum impact limiter force exerted on the cask body. Maximizing the impact limiter force results in the largest deceleration of the cask body.

The results of the stress evaluation are provided in Tables 2.7.1.4-1 through 2.7.1.4-4 for the top oblique and 2.7.1.4-5 through 2.7.1.4-8 for the bottom oblique drop orientations. For the top oblique combined impact loading case, the minimum margin of safety for membrane stress intensity is 0.59 (Table 2.7.1.4-3) in the bottom portion of the outer shell. The minimum margin of safety for membrane plus bending stress intensity is 0.11 (Table 2.7.1.4-4) in the bottom forging.

For the bottom oblique, combined impact loading case, the minimum margin of safety for membrane stress intensity is 0.79 (Table 2.7.1.4-7) in the top portion of the inner shell. The minimum margin of safety for membrane plus bending stress intensity is 0.34 (Table 2.7.1.4-8) in the bottom section of the outer shell.

Table 2.7.1.4-1 P_m Stresses—30-Foot Top 75° Oblique-Drop, Thermal Condition 1

Section	Angle	Cylindrical Stress Components (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	180	-2.9	3.3	-0.1	0.1	0.0	0.1	6.2	48.0	6.79
2	0	-6.6	-3.6	0.0	0.2	0.1	-0.3	6.7	48.0	6.19
3	30	-4.9	-8.6	-0.8	0.4	0.7	-0.4	8.0	48.0	4.99
4	0	-11.4	-16.4	-0.2	0.5	-0.1	-3.8	17.5	48.0	1.75
5	10	-7.7	-6.2	-0.1	0.5	0.0	-0.1	7.8	48.0	5.15
6	0	-9.4	-11.6	-0.1	0.2	0.1	0.1	11.6	48.0	3.14
7	0	-10.9	-16.6	7.5	0.3	-0.4	-1.4	24.2	48.0	0.98
8	0	-6.2	-22.8	0.4	1.0	-1.3	-3.8	25.2	48.0	0.91
9	0	-17.0	-26.9	1.2	1.0	-0.8	4.5	29.3	48.0	0.64
10	0	-14.1	-31.5	-2.6	1.1	-1.0	-2.3	29.6	48.0	0.62
11	0	-21.6	-39.7	-0.9	1.3	-0.7	5.0	40.2	48.0	0.20
12	0	-26.5	-22.9	-2.6	-0.7	-0.9	2.0	24.4	48.0	0.96
13	0	-18.5	-18.6	-0.9	-0.5	-1.0	2.0	18.4	48.0	1.61
14	0	-22.4	-30.0	-2.1	0.6	-0.7	-6.1	29.7	47.3	0.59
15	0	-13.9	-28.4	-0.1	1.2	-0.3	4.6	29.8	47.3	0.59
16	60	0.1	2.0	0.6	0.0	-9.4	-0.2	19.0	47.3	1.49
17	0	-0.3	5.0	18.4	-0.8	-0.8	0.2	18.8	47.3	1.52
18	0	-0.3	4.8	22.0	-0.8	-0.3	0.1	22.5	47.3	1.10
19	0	-0.3	4.9	22.9	-0.9	0.0	0.0	23.4	47.3	1.02
20	0	-0.3	6.0	21.2	-0.9	0.4	-0.1	21.6	47.3	1.19
21	0	-0.3	7.6	16.0	-1.0	1.0	-0.2	16.5	47.3	1.86
22	60	-0.1	6.9	1.6	-0.1	10.7	0.6	22.0	47.3	1.15
23	50	0.0	-2.3	2.0	-0.1	-11.1	0.4	22.6	45.9	1.03
24	50	-0.1	6.2	2.3	-0.1	-10.2	-0.2	20.6	45.9	1.22
25	0	-0.7	7.8	16.3	-0.8	-0.8	0.1	17.2	45.9	1.68
26	0	-0.8	7.3	20.3	-0.8	-0.3	0.1	21.3	45.9	1.16
27	0	-0.8	7.3	21.4	-0.9	0.1	0.0	22.2	45.9	1.07
28	0	-0.8	6.8	19.3	-0.7	0.5	-0.1	20.2	45.9	1.27
29	0	-0.8	6.1	14.3	-0.6	0.9	-0.1	15.3	45.9	2.00
30	60	-0.1	1.7	0.0	0.1	9.9	0.1	19.7	45.9	1.33
31	40	-0.4	0.2	-0.7	-0.1	13.5	0.2	27.0	45.9	0.70
32	70	0.1	5.9	0.1	0.3	10.7	0.7	22.2	48.0	1.16
33	80	-1.4	1.5	-0.2	-2.1	6.6	0.0	13.9	48.0	2.46
34	50	3.5	0.4	0.2	0.9	10.7	0.9	21.6	48.0	1.23
35	10	-3.5	-16.8	-4.1	0.0	1.4	-2.9	16.1	48.0	1.98
36	180	3.0	16.9	-2.6	2.2	0.1	3.7	21.7	48.0	1.22
37	10	-9.0	-1.1	-0.5	1.5	0.1	0.3	8.9	48.0	4.37
38	10	-9.9	-5.0	-0.5	1.0	0.2	-0.2	9.4	48.0	4.08
39	10	-10.0	-9.1	0.0	0.4	0.0	-0.1	10.2	48.0	3.72
40	10	-9.9	-11.9	-6.1	0.3	-0.1	-0.3	5.9	48.0	7.20
41	0	-13.4	-8.3	-0.8	-0.3	0.1	0.4	12.6	48.0	2.80

Table 2.7.1.4-2 $P_m + P_b$ Stresses—30-Foot Top 75° Oblique-Drop, Thermal Condition 1

		Cylindrical Stress Components (ksi)							Allowable Stress	Margin of
Section	Angle	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	SI (ksi)	(ksi)	Safety
1	180	-2.2	7.7	0.0	0.2	0.0	0.1	10.0	72.0	6.23
2	0	-9.3	-10.1	0.0	0.1	0.1	-0.3	10.1	72.0	6.15
3	0	-14.7	-17.5	-2.1	0.5	0.1	-3.0	16.2	72.0	3.44
4	0	-15.9	-17.4	0.0	0.4	-0.1	-4.3	18.8	72.0	2.83
5	0	-9.7	-11.2	-0.1	0.1	-0.1	-0.1	11.1	69.7	5.28
6	0	-11.0	-16.8	-0.1	0.2	0.1	0.1	16.7	69.7	3.16
7	0	-9.7	-18.1	18.1	0.0	-0.7	-1.0	36.2	69.7	0.93
8	0	1.6	-10.4	33.9	0.3	-1.5	-4.9	45.1	69.7	0.55
9	0	5.6	-3.0	59.5	0.8	-1.5	-0.3	62.6	69.7	0.11
10	0	-5.3	-26.8	2.0	1.4	-0.9	-6.6	32.8	69.4	1.12
11	0	1.2	-29.2	10.0	2.2	-1.0	1.1	39.4	69.4	0.76
12	0	-35.3	-25.5	-1.1	-1.1	-0.9	0.3	34.4	69.4	1.02
13	0	-38.5	-26.2	6.5	-1.5	-1.3	2.3	45.5	69.4	0.53
14	0	-29.4	-21.9	31.9	-0.8	-0.9	-1.7	61.5	70.9	0.15
15	0	3.5	-8.4	50.8	0.6	-1.0	2.1	59.4	70.9	0.19
16	50	-0.1	8.8	3.8	-0.2	-12.7	-0.2	25.9	70.9	1.74
17	0	-0.2	24.6	26.6	-2.5	-0.3	0.1	27.1	70.9	1.62
18	0	-0.2	28.2	31.5	-2.9	-0.1	0.1	32.0	70.9	1.21
19	0	-0.2	29.1	32.7	-3.0	0.0	0.0	33.2	70.9	1.14
20	0	-0.2	27.9	30.3	-2.8	0.1	-0.1	30.8	70.9	1.30
21	0	-0.1	24.2	22.9	-2.4	0.3	-0.1	25.0	70.9	1.84
22	40	-0.4	7.7	-1.1	-0.3	15.1	0.4	31.5	70.9	1.25
23	40	-0.2	-4.0	0.7	-0.1	-16.5	1.0	33.4	68.8	1.06
24	40	-0.4	11.3	3.7	-0.4	-13.5	-0.2	27.9	68.8	1.46
25	0	-0.6	27.2	23.9	-2.5	-0.3	0.1	28.2	68.8	1.44
26	0	-0.6	31.1	29.6	-2.9	-0.1	0.1	32.2	68.8	1.13
27	0	-0.6	32.9	31.2	-3.2	0.1	0.0	34.1	68.8	1.02
28	0	-0.7	31.1	28.7	-2.9	0.3	0.0	32.4	68.8	1.13
29	0	-0.7	27.0	22.4	-2.5	0.5	-0.1	28.1	68.8	1.44
30	50	-0.3	12.1	4.4	-0.1	12.2	0.1	25.7	68.8	1.68
31	40	-0.5	1.7	-1.5	-0.2	19.4	0.2	39.0	68.8	0.76
32	50	-0.2	4.2	-6.4	0.1	14.6	-0.1	31.1	62.7	1.01
33	50	0.4	-1.4	-0.8	-6.0	11.0	-0.8	25.1	62.7	1.50
34	50	-0.2	-4.4	-14.1	0.1	14.2	-1.1	30.0	62.7	1.09
35	50	-0.9	-9.0	-0.5	0.4	10.9	0.4	23.4	62.7	1.68
36	180	5.6	17.7	-2.3	2.0	0.1	5.1	22.8	62.7	1.75
37	70	2.1	-7.8	-0.5	2.7	0.1	0.7	11.4	63.0	4.53
38	10	-12.8	-4.9	-0.5	1.6	0.2	-0.2	12.7	63.0	3.95
39	10	-14.7	-8.6	1.2	0.8	-0.2	2.9	17.0	63.0	2.70
40	10	-23.3	-17.0	-11.0	0.6	-0.3	-1.5	12.8	63.0	3.91
41	0	-14.0	-8.7	0.4	-0.3	0.1	0.1	14.5	72.0	3.97

Table 2.7.1.4-3 Critical P_m Stress Summary—30-Foot Top 75° Oblique-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	4	0	17.5	48.0	1.75
2	9	0	29.3	48.0	0.64
3	13	0	18.4	48.0	1.61
4	15	0	29.8	47.3	0.59
5	19	0	23.4	47.3	1.02
6	22	60	22.0	47.3	1.15
7	23	50	22.6	45.9	1.03
8	27	0	22.2	45.9	1.07
9	31	40	27.0	45.9	0.70
10	32	70	22.2	48.0	1.16
11	39	10	10.2	48.0	3.72
12	41	0	12.6	48.0	2.80

Table 2.7.1.4-4 Critical $P_m + P_b$ Stress Summary—30-Foot Top 75° Oblique-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	4	0	18.8	72.0	2.83
2	9	0	62.6	69.7	0.11
3	13	0	45.5	69.4	0.53
4	14	0	61.5	70.9	0.15
5	19	0	33.2	70.9	1.14
6	22	40	31.5	70.9	1.25
7	23	40	33.4	68.8	1.06
8	27	0	34.1	68.8	1.02
9	31	40	39.0	68.8	0.76
10	32	50	31.1	62.7	1.01
11	39	10	17.0	63.0	2.70
12	41	0	14.5	72.0	3.97

Table 2.7.1.4-5 P_m Stresses—30-Foot Bottom 75° Oblique-Drop, Thermal Condition 1

Section	Angle	Cylindrical Stress Components (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}			
1	180	-3.2	3.7	-0.2	0.2	0.0	0.0	7.0	48.0	5.87
2	135	-0.4	2.9	0.0	-3.2	-0.1	0.2	7.3	48.0	5.58
3	0	-8.6	-16.5	-18.6	0.3	-1.5	-2.5	11.8	48.0	3.06
4	10	-15.0	-19.8	-9.4	-0.6	-1.4	-4.8	13.9	48.0	2.46
5	10	-8.2	-6.0	-0.4	0.7	-0.1	-0.2	8.0	48.0	4.99
6	10	-9.8	-11.4	-0.3	0.2	-0.1	-0.1	11.2	48.0	3.29
7	10	-10.6	-18.1	2.3	-0.6	-0.8	-1.3	20.6	48.0	1.33
8	20	-9.8	-22.3	-4.5	-1.2	-3.5	-2.4	19.9	48.0	1.41
9	20	-12.6	-24.6	-6.1	0.3	-4.7	2.4	21.6	48.0	1.23
10	0	-13.7	-32.0	-4.9	1.6	-0.9	6.0	30.4	48.0	0.58
11	0	-14.9	-37.8	-3.5	2.2	-0.9	7.8	27.2	48.0	0.76
12	10	-23.4	-21.0	-4.9	0.0	-2.3	0.1	18.8	48.0	1.55
13	0	-11.9	-15.2	-3.5	0.0	-1.7	1.8	12.6	48.0	2.80
14	10	-21.4	-30.9	-13.0	0.3	-2.2	-8.2	23.4	47.3	1.02
15	10	-12.4	-28.6	-11.1	-0.2	-2.8	5.6	23.2	47.3	1.04
16	50	-0.1	6.3	1.4	-0.1	-11.4	-0.3	23.3	47.3	1.03
17	60	0.0	3.6	-0.2	0.0	-7.5	-0.1	15.6	47.3	2.03
18	0	-0.3	5.6	19.2	-0.9	-0.5	0.1	19.7	47.3	1.40
19	0	-0.3	5.1	21.9	-0.9	-0.2	0.0	22.4	47.3	1.11
20	0	-0.3	5.3	22.0	-0.8	0.2	-0.1	22.4	47.3	1.11
21	0	-0.3	5.8	19.0	-0.8	0.7	-0.2	19.4	47.3	1.44
22	60	0.0	4.5	0.9	-0.1	8.6	0.5	17.7	47.3	1.68
23	50	-0.4	-7.5	0.7	0.0	-11.1	0.3	23.6	45.9	0.94
24	50	-0.2	1.7	0.1	-0.1	-11.2	-0.2	22.5	45.9	1.04
25	60	-0.1	2.6	-1.0	0.0	-7.8	-0.1	16.0	45.9	1.86
26	0	-0.8	6.3	16.4	-0.7	-0.6	0.1	17.4	45.9	1.64
27	0	-0.8	6.9	19.5	-0.8	-0.2	0.0	20.4	45.9	1.25
28	0	-0.8	6.9	19.5	-0.8	0.2	0.0	20.4	45.9	1.25
29	0	-0.7	7.1	16.5	-0.7	0.6	-0.1	17.5	45.9	1.63
30	60	0.0	3.9	0.1	0.1	8.4	0.1	17.2	45.9	1.68
31	50	-0.1	4.9	2.5	-0.1	12.7	0.4	25.7	45.9	0.79
32	70	0.2	4.6	-1.1	0.3	8.9	0.9	18.8	48.0	1.55
33	80	-2.3	1.0	-0.8	-1.7	5.6	0.3	12.1	48.0	2.96
34	60	2.6	3.8	2.2	0.9	10.3	0.5	20.7	48.0	1.31
35	0	-3.1	-15.5	0.3	1.0	0.1	-2.7	17.4	48.0	1.77
36	180	2.5	16.0	-1.8	2.1	0.4	3.0	19.7	48.0	1.43
37	0	-8.7	-0.9	-0.1	0.0	0.0	-0.2	8.6	48.0	4.56
38	0	-9.7	-4.8	-0.3	0.1	0.0	-0.4	9.4	48.0	4.08
39	0	-10.4	-8.6	0.5	0.1	-0.2	-0.6	10.9	48.0	3.41
40	10	-8.7	-11.6	-4.6	0.2	-0.5	-0.5	7.1	48.0	5.77
41	0	-14.0	-7.0	-10.5	-0.6	-0.1	2.5	8.3	48.0	4.77

Table 2.7.1.4-6 $P_m + P_b$ Stresses—30-Foot Bottom 75° Oblique-Drop, Thermal Condition 1

		Cylindrical Stress Components (ksi)							Allowable Stress	Margin of
Section	Angle	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	SI (ksi)	(psi)	Safetu
1	180	1.1	9.0	-0.1	0.2	0.0	0.0	9.1	72.0	6.88
2	10	-11.9	-6.3	-0.3	1.0	-0.2	0.3	11.8	72.0	5.10
3	0	3.1	-10.1	-11.9	0.5	-1.2	0.8	15.7	72.0	3.58
4	10	-7.2	-15.5	-0.3	0.0	-1.3	-2.6	16.2	72.0	3.44
5	120	-7.7	-5.3	-0.2	-2.4	-0.1	-0.2	9.0	69.7	6.71
6	20	-10.0	-13.8	-0.3	-0.7	-0.1	-0.1	13.6	69.7	4.14
7	10	-13.2	-20.6	7.5	-1.3	-1.6	-2.9	29.1	69.7	1.40
8	10	-8.8	-16.3	19.7	-1.5	-2.8	-8.0	39.2	69.7	0.78
9	0	3.2	-8.1	40.6	1.1	-2.2	-2.2	49.1	69.7	0.42
10	0	-19.5	-36.2	-12.8	1.5	-1.1	8.3	29.3	69.4	1.37
11	0	4.4	-28.4	14.2	2.6	-1.2	7.2	46.7	69.4	0.49
12	10	-31.3	-23.7	-2.4	0.4	-2.1	-1.6	29.4	69.4	1.36
13	0	-33.3	-23.9	5.0	-0.7	-2.0	0.2	38.5	69.4	0.80
14	10	-25.8	-20.7	24.9	0.6	-2.4	-4.2	51.5	70.9	0.38
15	0	9.0	-5.2	47.3	0.8	-1.6	3.8	53.1	70.9	0.34
16	50	-0.2	11.3	1.6	-0.2	-14.5	-0.3	30.5	70.9	1.32
17	0	-0.2	25.4	21.1	-2.6	-0.5	0.1	26.1	70.9	1.72
18	0	-0.2	28.3	28.4	-2.9	-0.3	0.1	29.4	70.9	1.41
19	0	-0.2	29.3	31.6	-3.0	-0.2	0.0	32.1	70.9	1.21
20	0	-0.2	28.0	31.4	-2.9	-0.1	-0.1	31.9	70.9	1.22
21	0	-0.1	23.6	26.7	-2.4	0.1	-0.2	27.1	70.9	1.62
22	40	-0.2	6.1	2.7	-0.3	13.1	0.3	26.6	70.9	1.67
23	40	-0.4	-8.3	1.8	-0.1	-16.6	0.8	34.9	68.8	0.97
24	40	-0.4	6.3	-0.4	-0.3	-14.4	-0.1	29.6	68.8	1.33
25	0	-0.7	23.2	16.9	-2.2	-0.5	0.1	24.3	68.8	1.83
26	0	-0.7	29.0	25.1	-2.7	-0.3	0.1	30.2	68.8	1.28
27	0	-0.7	32.0	29.2	-3.1	-0.1	0.0	33.3	68.8	1.07
28	0	-0.7	31.6	29.0	-3.0	0.1	0.0	32.9	68.8	1.09
29	0	-0.6	29.0	25.1	-2.7	0.3	-0.1	30.1	68.8	1.29
30	0	-0.5	24.2	15.2	-2.3	0.6	-0.1	25.2	68.8	1.73
31	40	-0.4	5.4	-2.2	-0.2	19.0	0.1	38.7	68.8	0.78
32	50	0.2	3.7	-5.2	0.1	12.7	0.2	27.0	62.7	1.32
33	60	-4.4	-2.2	-6.8	-5.3	9.6	0.6	22.4	62.7	1.80
34	50	-0.1	-1.0	-7.7	0.2	14.0	-0.9	28.8	62.7	1.18
35	40	-0.7	-9.9	0.1	0.2	10.2	0.3	22.6	62.7	1.78
36	0	-2.4	-19.0	1.0	1.8	0.4	1.6	21.1	62.7	1.98
37	0	-8.4	4.4	-0.1	0.0	0.0	-0.1	12.8	63.0	3.91
38	0	-13.6	-1.0	-0.3	0.0	0.0	-0.4	13.2	63.0	3.76
39	0	-17.2	-5.3	2.5	-0.2	-0.2	2.6	20.3	63.0	2.10
40	0	6.8	-7.0	3.5	0.6	0.0	1.3	14.4	63.0	3.38
41	0	-19.7	-7.4	-3.3	-0.8	-0.3	1.0	16.5	72.0	3.35

Table 2.7.1.4-7 Critical P_m Stress Summary—30-Foot Bottom 75° Oblique-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	4	10	13.9	48.0	2.46
2	9	20	21.6	48.0	1.23
3	13	0	12.6	48.0	2.80
4	14	10	23.4	47.3	1.02
5	16	50	23.3	47.3	1.03
6	22	60	17.7	47.3	1.68
7	23	50	23.6	45.9	0.94
8	24	50	22.5	45.9	1.04
9	31	50	25.7	45.9	0.79
10	34	60	20.7	48.0	1.31
11	39	0	10.9	48.0	3.41
12	41	0	8.1	48.0	4.77

Table 2.7.1.4-8 Critical $P_m + P_b$ Stress Summary—30-Foot Bottom 75° Oblique-Drop, Thermal Condition 1

Component	Section	Angle	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	4	10	16.2	72.0	3.58
2	9	0	49.1	69.7	0.42
3	13	0	38.5	69.4	0.80
4	15	0	53.1	70.9	0.34
5	19	0	32.1	70.9	1.21
6	22	40	26.6	70.9	1.67
7	23	40	34.9	68.8	0.97
8	27	0	33.3	68.8	1.07
9	31	40	38.7	68.8	0.78
10	34	50	28.8	62.7	1.18
11	39	0	20.3	63.0	2.10
12	41	0	16.5	72.0	3.35

2.7.1.5 Lead Slump Resulting from a Cask Drop Accident

Following a drop accident, the shielding capability of the Universal Transport Cask may be reduced as a result of lead slump. The effect of the lead slump due to a bottom end-drop and a side-drop from a height of 30 feet on the dose rates is conservatively evaluated in Chapter 5.0 of this report. The dose rate as a result of the corner-drop is bounded by that for the bottom end-drop accident. The results of the evaluation are summarized in this section.

In the event of an end-drop, the lead gamma shielding could slump and fill the annular gap (if one exists) created by the cooling of the lead after fabrication. This accident could create a maximum gap of 3.05 in. at the top of the lead annulus. This gap is determined by considering the conservation of total lead volume:

$$\pi\left(r_{oa}^2 - r_i^2\right)H_a = \pi\left(r_{ob}^2 - r_i^2\right)H_b$$

where subscript "*a*" indicates quantities after slump, "*b*", before slump, *H* is the total lead height; r_i and r_o are the inner and outer lead radii, respectively. Using the transport cask geometry dimensions, the computed slump height is

$$H_b - H_a = 180.0 - 176.95 = 3.05 \text{ inches}$$

Note that the slumped lead is allowed to fill the gap between the before-drop lead outer radius and the outer shell inner radius. The parameters used in the calculation are shown in Table 2.7.1.5-1. Dose rate calculations on the basis of this 3.05-in. axial lead slump show that the peak 1 m total dose rate is 47 mrem/hr for the cask loaded with design basis PWR fuel assemblies and 64 mrem/hr for the cask loaded with design basis BWR fuel assemblies.

For a 30-ft side-drop accident, the lead may slump into the lower portion of the annulus between the inner and outer shells; thus, a reduction in the thickness of lead shielding may occur on the upper side of the cask as shown in Figure 2.7.1.5-1. An evaluation of the side-drop accident shows that the lead may sag at the opposite side by a maximum of 0.91 inch. The slump height is computed by equating the before- and after-drop cross sectional areas:

$$\frac{\pi}{2}\left(r_{oa}^2 - r_i^2\right) + 2\int_0^{\theta} \sin^2\theta \, d\theta - \frac{\pi}{2} r_i^2 = \pi\left(r_{ob}^2 - r_i^2\right)$$

θ is the angle subtended by the top of the slumped lead, as measured from the vertical, and the integral term gives the area of that part of the upper semi-circle bounded by the slumped lead. The integral is evaluated analytically and the Excel Solver utility is used to solve the resulting transcendental equation for θ. Given θ, the resulting slump height is 37.599 inches. Table 2.7.1.5-1 provides the parameters and results of the lead slump analysis. The radial slump is:

$$r_o - r_{oa} = 38.51 - 37.599 = 0.91\,\text{inch}$$

Dose rate calculations on the basis of this 0.91-in. radial lead slump show that the peak 1 meter total dose rate is 27 mrem/hr for the cask loaded with design basis PWR fuel assemblies and 21 mrem/hr for the cask loaded with design basis BWR fuel assemblies.

The above dose rates resulting from a lead slump condition are significantly below the hypothetical accident dose rate limit of 1,000 mrem/hr at 1 meter from the surface of the cask. Thus, the hypothetical accident dose rate limits of 10 CFR 71.51 are satisfied.

2.7.1.6 Impact Limiter Analysis - Hypothetical Accident Conditions

Removable upper and lower impact limiters are provided on the Universal Transport Cask to ensure that the design impact loads on the cask are not exceeded for any of the defined impact conditions. The defined conditions are that the cask falls 1 foot (normal conditions of transport) or 30 feet (hypothetical accident conditions) and lands (a) on its side, so that both impact limiters are impacted simultaneously; (b) flat on one impact limiter at either end; or (c) oblique on one impact limiter at either end.

Detailed analysis of the impact limiters for normal conditions of transport and hypothetical accident conditions is provided in Section 2.6.7.5. The analysis is based on the assumptions that the cask impacts on an unyielding surface and that the impact limiter remains in position on the cask during all impact events. A NAC International proprietary computer program, RBCUBED [33] is used to analyze the impact limiters for an impact event to determine the dynamics of the event, the forces generated during that event, and the depth of crush. Results of the analysis are provided in Section 2.6.7.5.

As demonstrated by the results, the deceleration g-loads predicted by the RBCUBED analysis for the 30-ft cask drop conditions are lower than the g-loads for which the Universal Transport Cask and the Transportable Storage Canister are designed.

Figure 2.7.1.5-1 Radial Lead Slump Model

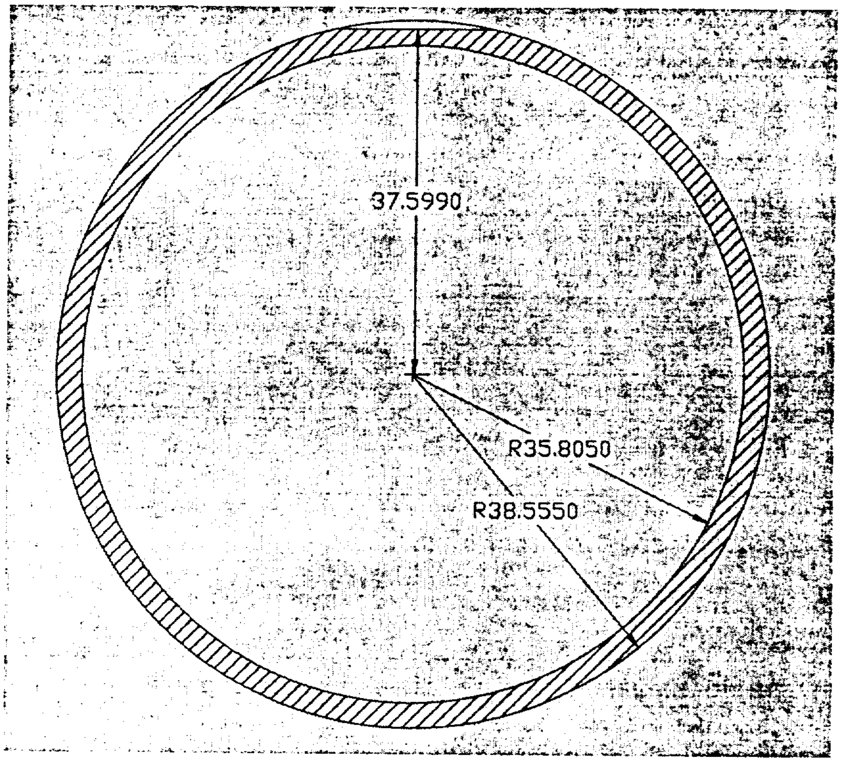


Table 2.7.1.5-1 Lead Slump Calculation Parameters

Parameter	Inch
Axial	
Inner Radius	35.805
Outer Lead Radius (pre)	38.510
Outer Lead Radius (post)	38.555
Lead Gap	0.045
Pre Shield Height	180.0
Shield Volume	1.1368E+05[1]
Post Shield Height	176.947
Axial Gap	3.053
Radial	
Pre Slump Area	6.32E+02[2]
Slump Angle (rad, deg)	0.2231
Slump Height	37.599
Slump Lower Area	3.21E+02[2]
Slump Upper Area	3.10E+02[2]
Total Slump Area	6.32E+02[2]
Difference	0.0
Radial Slump	0.911
Slump Width	17.061

1. Inches^3
2. Inches^2

2.7.1.7 Closure Analysis

Section 2.6.7.6 provides a general description of the analysis approaches employed to demonstrate the structural integrity of the Universal Transport Cask closure assembly for hypothetical accident conditions. The materials of construction and the geometry of the components of the closure assembly are also identified in Section 2.6.7.6.

The Universal Transport Cask closure lid and the bolts are required to satisfy two criteria: (1) calculated maximum stresses must be less than the allowable stress limit (the material yield strength is conservatively selected), and (2) lid deformation or rotation at the O-ring must be less than the elastic rebound of the O-rings. Analysis of the cask closure system in accordance with NUREG/CR-6007 is summarized below. Using consistently conservative assumptions, the analysis demonstrates that the cask closure assembly satisfies the performance and structural integrity requirements of 10 CFR 71.73(c)(1) for hypothetical accident conditions.

Accelerations for accident conditions are based on the impact limiter analysis for 30-ft drops. Therefore, a design acceleration of 60 *g* bounds the calculated values. The following calculations are a summary of the NUREG/CR-6007 evaluation based on a calculated preload of 111,680 lb/bolt as presented in Section 2.6.7.6. Maximum stresses result during the top-end corner drop (23.35° from axial plane of cask). Two load cases are considered for this evaluation. The first case includes the accident conditions except puncture, which tends to counter the moment produced by internal pressurization. The second case conservatively applies puncture without internal pressurization (when considering prying).

2.7.1.7.1 Closure Bolt Stress Evaluation

Case 1—Accident Conditions (no puncture)

The tensile bolt force per bolt, $F_{a/pt}$, due to preload and thermal is:

$$F_{a/pt} = P_L + P_{th} = 134{,}877 \text{ pounds}$$

where $P_L = 111{,}680$ pounds, preload

$P_{th} = 23{,}197$ pounds resulting from thermal expansion

The tensile force per bolt, $F_{a/al}$, from all other credible loads is:

$$F_{a/al} = P_o + P_i + P_{60} = 147{,}231 \text{ pounds}$$

where:

P_o = 667 lbs, load resulting from O-ring compression and operation

P_I = 6,549 lbs, load resulting from internal pressure of 80 psig

P_{60} = 140,015 lbs, load resulting from 60 g top-end corner impact.

Since $F_{a/al}$ is greater than $F_{a/pt}$, the total tensile bolt load, F_a, is equal to $F_{a/al}$:

$$F_a = 147{,}231 \text{ pounds}$$

The shear load is:

$$F_s = \left| P_i + P_{th} + P_{60} \right| = 38{,}008 \text{ lb}$$

where: P_I = 15,245 lb, load resulting from internal pressure (80 psi)

P_{th} = -57,647 lb, load resulting from temperature difference between the cask lid and upper forging, and

P_{60} = 4,394 lb, load resulting from 60 g top-end corner drop.

The bending moment is:

M_b = -675 inch-pounds, due to thermal load (other loads do not contribute due to cask lid design).

The resulting tensile stress in the bolt is

$$\sigma_a = \frac{1.2732\,F_a}{D^2} = 53{,}138 \text{ psi,}$$

where D = 1.878 in., minimum bolt diameter.

The shear stress is:

$$\tau = \frac{1.2732\,F_s}{D^2} = 13{,}718 \text{ psi}$$

where D = 1.878 in., minimum bolt diameter.

For normal conditions, Table 6.3 of NUREG/CR-6007 requires that the average tensile stress is the smaller of 0.7 S_u or S_y. For this case,

$$\sigma_{t(ave)} = \sigma_a = 53{,}138 \text{ psi} < 0.7\, S_u = 122{,}168 \text{ psi.}$$

Table 6.3 also requires that the average shear, which is comprised of the average direct shear (τ) is the smaller of 0.42 S_u or 0.6 S_y. This is expressed as

$$\sigma_{s(ave)} = \tau = 13{,}718 \text{ psi} < 0.42\, S_u = 73{,}301 \text{ psi.}$$

For the combined state of stress that includes tension plus shear, the computed average tensile stress divided by the allowable tensile stress plus the average shear stress divided by the allowable shear stress must be less than 1. This is expressed as

$$\left(\frac{53{,}138}{122{,}168}\right)^2 + \left(\frac{13{,}718}{73{,}301}\right)^2 = 0.22 < 1$$

Case 2—Accident conditions (with puncture)

This case applies the puncture load to the center of the cask lid. For conservatism, internal pressurization is ignored (for prying loads) to ensure that the closure bolts experience the maximum prying effect. Using the equations presented in NUREG/CR-6007, the puncture load is calculated to be

$$P_{pun} = -40{,}865 \text{ lbs}$$

and the associated prying load (including the effects of the thermal expansion of the lid) on the bolt is:

$$P_{pry} = 68{,}466 \text{ lb}$$

The tensile bolt force per bolt, F_{a_pt}, due to the preload and thermal expansion is:

$$F_{a/pt} = 134{,}877 \text{ lb}$$

The tensile bolt force per bolt, $F_{a/al}$, due to all other credible loads is:

$$F_{a/al} = P_o + P_i = 7{,}216 \text{ lb}$$

Therefore, since $F_{a/pt}$ is greater than $F_{a/al}$, the tensile bolt force, $F_{a/c}$ due to non-prying loads is equal to $F_{a/pt}$:

$$F_{a/c} = 134{,}877 \text{ lb}$$

Therefore, the maximum axial force becomes

$$F_a = F_{a/c} + P_{pry} = 203{,}343 \text{ lb}$$

The shear load is:

$$F_s = |P_i + P_{th}| = 42{,}402 \text{ lb}$$

The resulting tensile stress in the bolt is

$$\sigma_a = \frac{1.2732\,F_a}{D^2} = 73{,}390 \text{ psi},$$

where D = 1.878 in., minimum bolt diameter.

The shear stress is:

$$\tau = \frac{1.2732\,F_s}{D^2} = 15{,}304 \text{ psi}$$

where D = 1.878 in., minimum bolt diameter.

For normal conditions, Table 6.3 of NUREG/CR-6007 requires that the average tensile stress is the smaller of 0.7 S_u or S_y. For this case,

$$\sigma_{t(ave)} = \sigma_a = 73{,}390 \text{ psi} < 0.7\,S_u = 122{,}168 \text{ psi}.$$

Table 6.3 also requires that the average shear, which is comprised of the average direct shear (τ) is the smaller of 0.42 S_u or 0.6 S_y. This is expressed as

$$\sigma_{s(ave)} = \tau = 15{,}304 \text{ psi} < 0.42\,S_u = 73{,}301 \text{ psi}.$$

For the combined state of stress that includes tension plus shear, the square of the computed average tensile stress divided by the allowable tensile stress plus the square of the average shear stress divided by the allowable shear stress must be less than 1. This is expressed as:

$$\left(\frac{73{,}390}{122{,}168}\right)^2 + \left(\frac{15{,}304}{73{,}301}\right)^2 = 0.40 < 1$$

Lid Edge Deflection

To ensure that the closure lid bolts are not subjected to any force resulting from the contact of the cask lid and protecting lip of the cask top forging (flange), deflections of the lid edge and the flange during the 30-foot drop impact are examined. The side and top corner drops are considered bounding for the lid/flange interaction. The deflection and stress results for the lid edge and cask flange are obtained from the cask finite element analyses corresponding to these drop conditions (Sections 2.7.1.2 and 2.7.1.3).

The nominal radial gap that exists between the cask lid and flange is (78.36 – 78.20)/2 = 0.08 inch. To determine the amount of change in the nominal gap, the radial deflections at each node on the top outer radius of the lid and the adjacent flange node are obtained from the analyses for both the side and top-corner impacts. The change of radial gap due to the drop events is calculated as:

$$\text{Radial gap change} = UX_{flange} - UX_{lid}$$

Where:

UX_{flange} is radial deflection of the flange node.
UX_{lid} is the radial deflection of the lid.

Radial gap change is the amount of gap closure (or opening). It is positive when the gap is opening and negative when the gap is closing.

For the side drop the maximum gap closure is 0.0019 inch. For the top-corner drop, the maximum gap closure is 0.0005 inch. Since these gap closures are much less than the nominal radial gap of 0.08 inch, no contact results between the lid and cask flange. Therefore, the cask lid closure bolt will not be subjected to forces due to the deformation of the cask protective lip (flange) during the 30-foot drops.

The stresses at the cask protective lip (flange) are also evaluated for the 30-foot side and top-corner drops (Sections 2.7.1.2 and 2.7.1.3). The maximum stress at the cask flange (at Section location 36, Figure 2.10.2.2-4) is 22.4 ksi for primary membrane stresses and 24.0 ksi for the primary membrane plus bending stresses. The corresponding margins of safety are 1.14 and 1.61 for membrane and membrane plus bending, respectively.

2.7.1.7.2 Conclusion

Using consistently conservative assumptions, the Universal Transport Cask closure assembly is shown to satisfy the performance and structural integrity requirements of 10 CFR 71.73(c)(1) for hypothetical accident conditions.

2.7.2 Puncture

In accordance with the requirements of 10 CFR 71 for puncture (hypothetical accident condition) [1], the Universal Transport Cask is analyzed for structural adequacy. The puncture accident outlined in 10 CFR 71 Subpart F requires that the cask suffer no loss of containment as a result of a 40-inch free fall onto an upright 6-inch-diam mild steel bar (puncture pin), which is supported on an unyielding surface. The impact orientation of the cask is required to be such that maximum damage is inflicted upon the cask.

The maximum cask damage will result from direct impacts of the puncture pin on the following locations: (1) cask side—midpoint, (2) center of the cask lid, (3) center of the cask bottom, and (4) cask port covers. Because an impact at any other location is less severe, the Universal Transport Cask is analyzed for the puncture accident at these four locations. Results of the analyses demonstrate the structural and shielding adequacy of the Universal Transport Cask for a puncture pin impact. Therefore, the cask satisfies the structural and shielding requirements of 10 CFR 71 for the puncture event.

The cask is expected to experience both local and global effects from the puncture. The local effects will be limited to a surface close to and containing that of the bar impact. The global effects are those affecting the whole cask body, which can be assumed to behave as a cylinder subjected to a point force in the four conditions. The following conditions encompass the extreme initial conditions under which the drop takes place:

	Condition 1	Condition 2
Ambient temperature	100 °F	-40 °F
Insolation	Max.	Zero
Decay heat	Max.	Zero
Internal pressure	Max.	Zero
Fabrication stress	Yes	Yes

For this analysis, the cavity internal pressure is not relevant, and the fabrication stresses are negligible compared with the puncture effect. The following initial conditions are considered for each load case:

Condition 1: Puncture drop, thermal gradient resulting from maximum decay heat, maximum insolation, and ambient temperature 100°F.

Condition 2: Puncture drop, uniform temperature of -40°F. For the stress evaluation, only the most unfavorable load case, condition 1, will be considered.

2.7.2.1 Puncture - Cask Side Midpoint

In accordance with the requirements of 10 CFR 71 for puncture (hypothetical accident condition), the Universal Transport Cask is analyzed for structural adequacy, the cask is assumed to be in a horizontal position and dropped a distance of 40 inches onto a 6-inch-diam, mild steel bar oriented vertically on an unyielding surface.

To demonstrate the cask's resistance to puncture, a structural evaluation of the cask using a simplified model is performed.

2.7.2.1.1 Finite Element Model Description

The focus of the analysis is to accurately characterize the impact zone such that realistic stress results are obtained. For analysis purposes, global effects are assumed to be negligible.

Neglecting the contributions of the inner shell of the cask, and radial neutron shield shell to the stiffness of the cask, the finite element model consists of the 304 stainless steel outer shell and cask lid. Because of cask symmetry, only a 1/4 portion of the cask body is required for the analysis. Figure 2.7.2.1-1 shows the model and the boundary conditions.

The ANSYS program is used to analyze the cask. The ANSYS element type SOLID 45 is used for the three-dimensional modeling of solid structures.

The puncture effect is represented by a local pressure acting on a surface equal to that of the bar head. Strain rate and dynamic behavior of the bar material are considered.

The limiting bar impact force is that imposed by the dynamic yield stress (flow stress), S_{yD}, of the bar material, which is related to the static yield stress by of the following expression:

$$S_{yD} = S_y\left(1 + \frac{\varepsilon}{D}\right)^{1/p} = 47{,}000 \text{ psi}$$

where: S_y = static yield stress of bar material, SA-36, 36,000 psi

ε = strain rate of bar material during drop = 100 sec^{-1}

p = material constant for mild steel = 5

D = Material constant for mild steel = 40.

The impact force is

$$F = 47{,}000 \times \pi \times R^2 = 47{,}000 \times \pi \times 3^2 = 1.329 \times 10^6 \text{ lb}$$

where R = radius of bar.

The resultant impact deceleration, a, is

$$a = \frac{S_{yD}\,\pi R^2}{w} = \frac{(47{,}000)(\pi)(9)}{260{,}000} = 5.1\,g$$

where W = 260,000 lb, conservative weight of UMS cask with impact limiters.

To attain the design weight of the cask for the model, the density of the Type 304 material is increased as required; the weight density assigned to the model material is 1.5 lb/in^3. For the material mechanical properties, a uniform temperature, 280°F, is used.

2.7.2.1.2 Analysis results

The ANSYS postprocessing capabilities are used to obtain a contour plot of the stresses. This plot shows the negligible global effects of the puncture. The analysis of the results is then focused on the impact and neighboring surfaces. The sections chosen for evaluation are depicted in Figure 2.7.2.1-2, where the contour of the impact footprint is also shown.

Stresses are categorized according to the ASME Code, Section III, Subsection NB. Assuming the bar behaves as an integral attachment to the cask body, the bending stresses appear as a discontinuity effect and can be discarded because they are secondary in nature. Only the local membrane and shear stresses then remain for evaluation. The local membrane stresses are shown in Table 2.7.2.1-1. The results of the stress evaluation are shown in Table 2.7.2.1-2. The maximum stress intensity, S.I. = 56,750 psi in Section Y, coincides with the bar edge. The corresponding margin of safety is +0.18. A simplified evaluation can be performed for shear stresses by using the lateral surface of the outer shell corresponding to the punch cross section:

$$\tau = \frac{Q}{A} = \frac{P_p A_p}{2\pi Re} = 25{,}637 \text{ psi}$$

where:

P_p = Punch head pressure (dynamic flow stress) = 47,000 psi

A_p = Punch cross sectional area, in.^{2}

R = Punch bar radius = 3 in.

e = Outer shell thickness = 2.75 in.

The shear allowable is 0.5 S_u = (0.5)(67,000) = 33,500 psi > 25,637 psi. Therefore, puncture of the outer shell does not occur.

Figure 2.7.2.1-1 Cask Body Model for Puncture Analysis

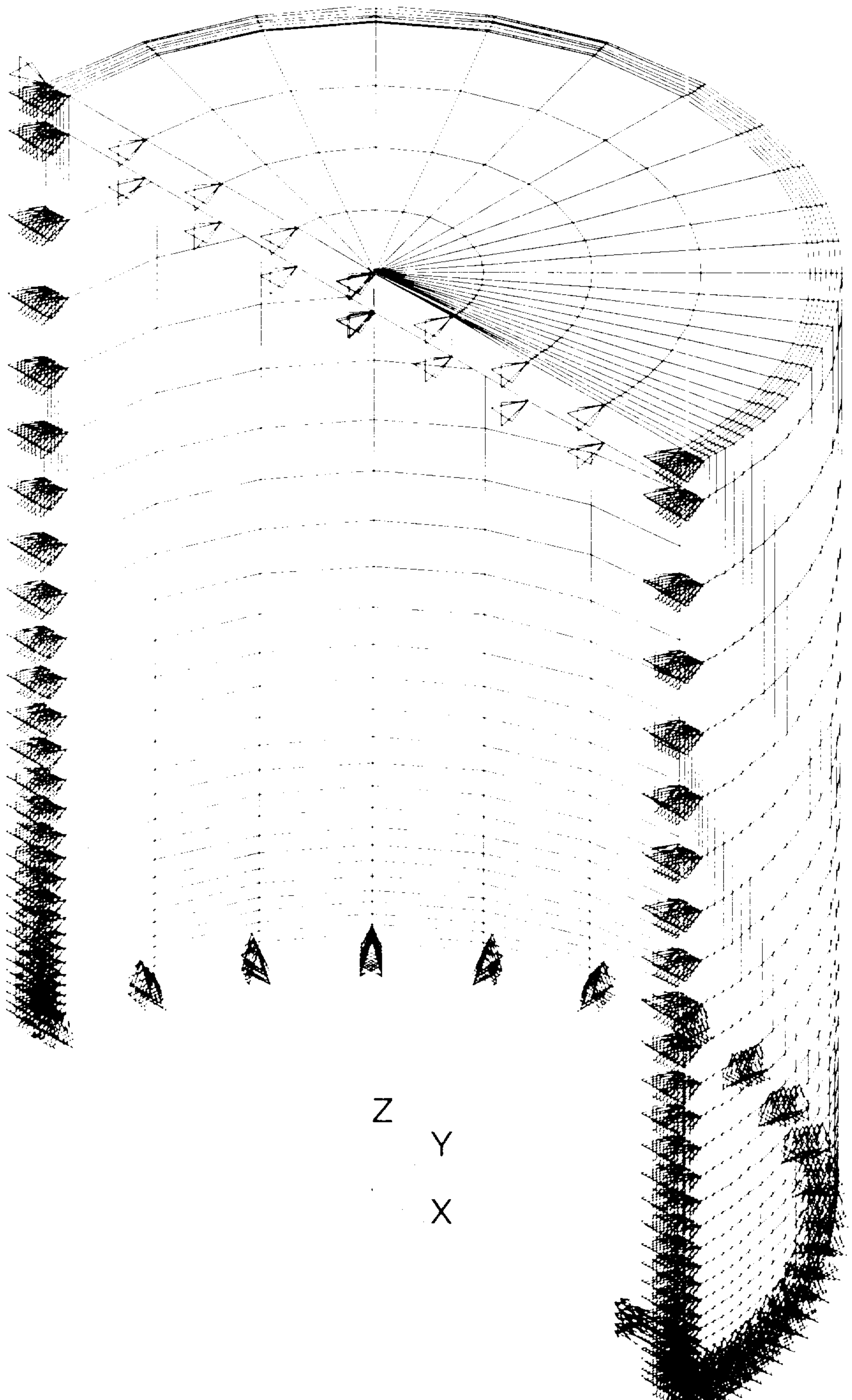


Figure 2.7.2.1-2 Location of Sections for Evaluation

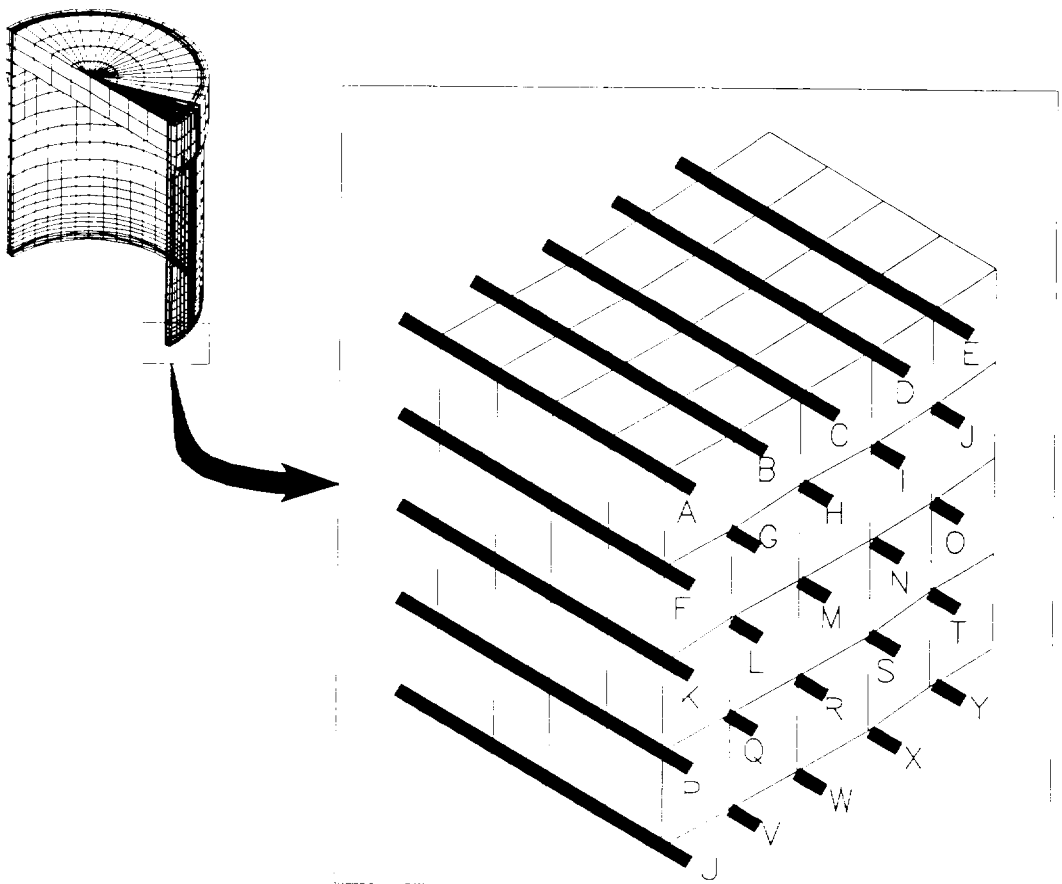


Table 2.7.2.1-1 Local Membrane Stresses - Puncture Cask Side

	Stress Components (psi)						Principal Stresses (psi)			
Section	**Sx**	**Sy**	**Sz**	**Sxy**	**Syz**	**Sxz**	**S1**	**S2**	**S3**	**SI (psi)**
A	4955	-19510	-28680	1859	-892	17870	12740	-19430	-36540	49280
B	2828	-21040	-28680	3568	-1832	16130	9836	-20620	-36110	45940
C	971	-22810	-28110	6410	-3056	12740	6609	-21420	-35130	41740
D	1856	-22640	-26390	7851	-3852	9921	6419	-20280	-33320	39730
E	1232	-23140	-25650	8229	-4513	7240	4828	-19850	-32530	37360
F	-27520	-29390	-34140	6915	-773	19390	-9938	-29430	-51680	41740
G	-13370	-28690	-30980	9511	-1649	17730	-467	-27830	-44740	44280
H	4487	-25460	-26480	11980	-2938	15330	13420	-22990	-37880	51300
I	1161	-27840	-27790	11700	-3826	10990	7709	-23990	-38180	45890
J	1750	-26910	-25720	11200	-4237	7497	6649	-22100	-35430	42080
K	-27160	-31170	-35620	7371	-427	14860	-14020	-31680	-48260	34240
L	-12150	-30460	-30400	9716	-982	14480	-1838	-29530	-41650	39810
M	-13600	-33170	-31460	15040	-2009	14060	-925	-30240	-47070	46140
N	4578	-29100	-25790	16540	-3159	11580	13710	-23900	-40120	53820
O	980	-31040	-26200	14520	-3608	6637	7317	-24300	-39280	46600
P	-27990	-31280	-35480	7726	-418	12320	-16340	-32040	-46380	30040
Q	-16300	-34280	-32360	10710	-727	10480	-7759	-32520	-42670	34910
R	-11360	-33100	-29470	15690	-1166	9473	-931	-29360	-43640	42710
S	-12320	-34820	-29450	19620	-1948	9157	696	-28900	-48390	49090
T	2234	-33590	-24660	18550	-2277	4059	10340	-24120	-42240	52580
U	-68160	-43370	-40950	12110	-416	12030	-33890	-41880	-76710	42810
V	-30310	-38470	-29790	13220	-639	8134	-17270	-31540	-49760	32490
W	-27370	-39160	-30440	16860	-822	7448	-13480	-31180	-52310	38830
X	-26380	-38730	-30350	22050	-1233	6705	-8657	-30360	-56440	47790
Y	3893	-34540	-23140	20700	-1349	2079	12970	-22990	-43780	56750

Table 2.7.2.1-2 Stress Evaluation - Puncture Cask Side

Section	Node I	Node J	Temperature (°F)	Allowable, S_u (psi)	SI (psi)	MS
A	197	866	280	67000	49280	0.36
B	222	891	280	67000	45940	0.46
C	247	916	280	67000	41740	0.61
D	272	941	280	67000	39730	0.69
E	297	966	280	67000	37360	0.79
F	196	867	280	67000	41740	0.61
G	221	892	280	67000	44280	0.51
H	246	917	280	67000	51300	0.31
I	271	942	280	67000	45890	0.46
J	296	967	280	67000	42080	0.59
K	195	868	280	67000	34240	0.96
L	220	893	280	67000	39810	0.68
M	245	918	280	67000	46140	0.45
N	270	943	280	67000	53820	0.24
O	295	968	280	67000	46600	0.44
P	194	869	280	67000	30040	1.23
Q	219	894	280	67000	34910	0.92
R	244	919	280	67000	42710	0.57
S	269	944	280	67000	49090	0.36
T	294	969	280	67000	52580	0.27
U	28	1	280	67000	42810	0.57
V	29	3	280	67000	32490	1.06
W	30	4	280	67000	38830	0.73
X	31	5	280	67000	47790	0.40
Y	32	6	280	67000	56750	0.18

2.7.2.2 Puncture - Lid Center

For this evaluation, the cask is assumed to be inverted lid downward when dropped through a distance of 40 inches onto the 6-inch-diam mild steel bar. Qualification of the lid center is accomplished by a finite element analysis and comparison with data derived from destructive testing.

The main closure of the Universal Transport Cask consists of a single bolted lid. The Type 304 stainless steel lid is secured to the top forging by 48 bolts, (2–8 UN-2A bolts fabricated from SB-637, grade N07718 nickel alloy steel) and is sealed by two EPDM O-rings (only one O-ring required for containment). For analysis purposes, metallic O-rings, which require a higher preload to resist the puncture load are assumed.

2.7.2.2.1 Lid Center Analysis

The ANSYS finite element program is used to determine the performance of the cask lid during the pin puncture. The pin puncture of the cask lid is assumed to occur at 275°F (maximum upper forging temperature is 256°F, Section 3.4.2) with no other loading except bolt preload.

To adequately analyze the cask lid, a two-dimensional axisymmetric model of the lid and top forging region was created. The geometry accounts for the bolt properties of the 48 closure bolts (2–8 UN). PLANE82 (eight noded quadrilateral element) and PLANE42 2D (four noded quadrilateral element) elements are used to model the lid and top forging. The lid is modeled by using material properties for the SA336 Type 304 stainless steel. The top forging is also appropriately modeled with this same material. BEAM4 elements are used to model the bolts and CONTACT52 elements we used model the contact surfaces between the lid and top forging. Beam properties are based on the critical cross section of the thread form including shank, threads, and head. The bolt is modeled with the properties of the nickel-based bolting alloy, SB-637, Grade N07718. Bolt properties are combined into one pseudo-bolt on the basis of a full 360 degree model. Shear correction factors are applied to the shank and thread regions to account for shear deflection of a cylindrical shape.

The configuration analyzed includes 48 bolts (2–8 UN) on a 73.86-inch diameter bolt circle. The bolt tensile area is 2.77 in^2. The sum net area is thus 132.96 in^2. The cross-sectional moment of inertia and total moment of inertia for all bolts is:

$$I_b = \frac{p\,D^4}{64} = 0.7854 \text{ in}^4,$$

$$I_{b_p} = 48 \times I_b = 37.699 \text{ in}^4.$$

The preload assumed for each bolt is 116,680 lb force, for an assumed total preload of 5,360,640 pounds force. The actual applied preload is 113,530 lb force . This analysis is conservative because the actual preload exerts a larger clamping force at the edge of the lid than the assumed preload. The shear deflection factor for a cylinder is taken to be 1.11. The stiffness of the head of the bolt is conservatively taken to be 10 times that of the bolt shank region.

Counter bore depth in the top forging region of the cask body is 6.5 inches to maintain full recess and protection of the lid and bolts. To negate prying action of the cask lid, a 0.125 inch undercut is added. This is simulated by absence of gap elements in the cross sectional area between the lid and top forging from the outer diameter of the lid to the centerline of the bolt. The ANSYS model and geometry of the lid is shown in Figure 2.7.2.2-1.

The puncture load is applied to a 6.0-inch diameter region which corresponds to a 6-inch diameter pin. The load is simulated with an evenly distributed pressure load equal to the dynamic flow stress of the pin, which is taken to be 47,000 psi (Section 2.7.2.1). Preload torque is included as an initial strain. The initial strain is determined by an iterative process involving application of strain and checking the resulting forces against the desired bolt preload (Section 2.10.2.1).

Stresses are linearized across critical sections to determine the membrane and bending stresses which are compared with allowable stress intensities.

2.7.2.2.2 Lid Center Analysis Results

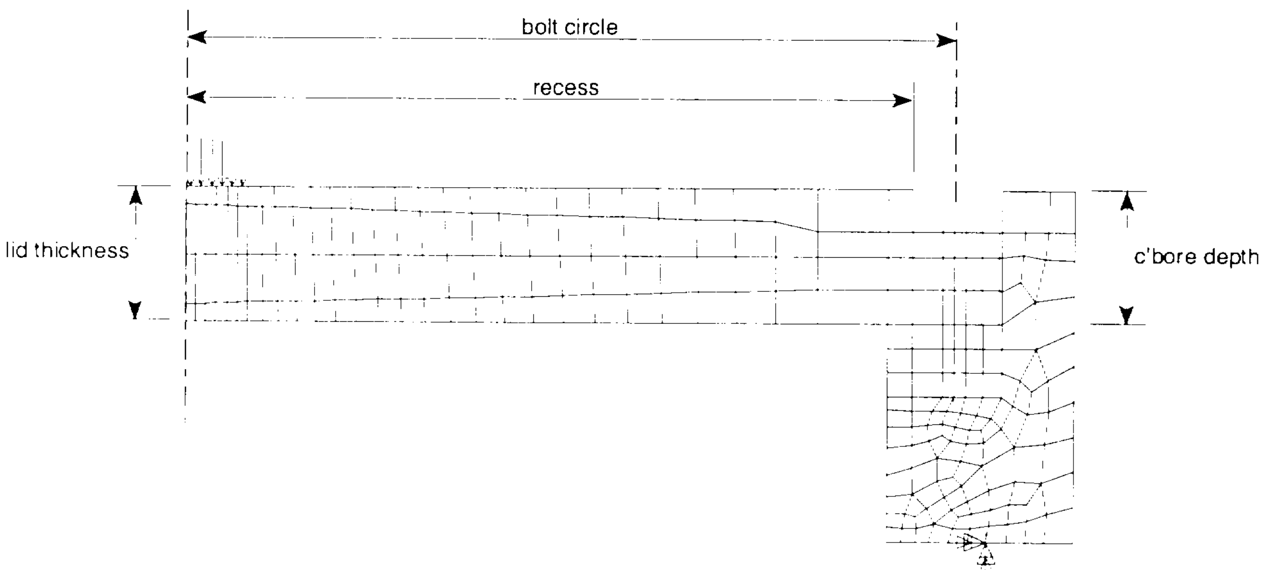
The maximum nodal stress is 59,193 psi. For conservatism, this stress is compared with stress allowables at 300°F. For Type 304 stainless steel, the allowable stress limit is 61,500 psi (3.6 S_m or S_u, whichever is less) for primary membrane and bending, where the value of S_m is 20,000 psi. The primary membrane stresses are limited to 48,000 psi (2.4 S_m or 0.7 S_u, whichever is less). Since nodal stresses are the sum total of all stresses, stating that the design meets this criteria is conservative. A table comparing some maximum stresses to allowable stresses and resulting margins of safety is presented as follows

P_m and P_m+P_b Stresses (psi) for Lid Pin Puncture

P_m	Allowable	MS	P_m+P_b	Allowable	MS
18,830	43,050	1.55	56,810	61,500	0.08
19,480	43,050	1.46	55,500	61,500	0.11
21,230	43,050	1.26	52,220	61,500	0.18

The minimum margin of safety (MS) is + .08, occurring at the centerline of the lid.

Fig. 2.7.2.2-1 ANSYS Model for Cask Lid



2.7.2.3 Puncture - Center of Cask Bottom

The cask is assumed to be vertical and upright when dropped through a distance of 40 inches onto a 6-inch diameter, mild steel bar oriented vertically on an unyielding surface. The structural evaluation of the cask bottom is performed by finite element analysis.

The cask bottom geometry is a 5-inch thick outer plate and a 4.25-inch thick inner plate enclosing a 1-inch thick layer of NS-4-FR neutron shield material. The plates are made from Type 304 stainless steel. The diameter of the layer of neutron shield material 71.61 inch.

A finite element evaluation of the bottom is performed using the ANSYS computer program and a two-dimensional axisymmetric model. During the impact, the puncture pin is considered to apply a pressure of 47,000 psi (assumed dynamic flow stress of mild steel calculated in Section 2.7.2.1.1) on the cask bottom at the centerline of the exterior surface in the inward normal direction. This is the critical load location on the bottom because the maximum bending stress and edge rotation take place here. The presence of an impact limiter is conservatively ignored. The bottom is evaluated at a temperature of 280°F.

2.7.2.3.1 Finite Element Model Description—Center of Cask Bottom

An axisymmetric ANSYS model is used to characterize the behavior of the cask for the puncture load acting at the center of the cask bottom. Figure 2.7.2.3-1 shows the model and boundary conditions.

The ANSYS model consists of PLANE42 elements. These elements are used for the two-dimensional modeling of solid structures.

The puncture effect is represented by a local pressure acting on a surface equal to that of the bar head. During impact, the puncture pin applies a pressure of 47,000 psi (assumed dynamic flow stress of mild steel) in the inward normal direction on the bottom over a 6-inch diameter region at a centerline of the exterior surfaces. The limiting bar impact force is that imposed by the dynamic yield stress (flow stress), S_{YD}, of the bar material, which is related to the static yield stress by the following expression:

$$S_{yD} = S_y\left(1+\frac{\varepsilon}{D}\right)^{1/p} = 47{,}000 \text{ psi}$$

where:
S_y = static yield stress of bar material, SA-36, 36,000 psi
ε = strain rate of bar material during drop = 100 sec^{-1}
p = material constant for mild steel = 5
D = material constant for mild steel = 40

The impact force is

$$F = 47{,}000 \times \pi \times R^2 = 47{,}000 \times \pi \times 3^2 = 1.329 \times 10^6 \text{ lb}$$

where R = radius of bar.

Using a design weight of 256,500 lbm, the impact deceleration is calculated to be 5.18 *g*. Use of this weight is considered to be conservative.

The effects of the cask contents and weight of the cask portion not represented in the model have been incorporated by specifying pressures on the internal surface of the bottom and on the ends of the shell stubs, respectively.

Internal Surface Pressure of the Bottom

$$P_i = \frac{P_c a}{A_c} = \frac{76{,}997 \times 5.18}{\pi \times 33.81^2} = 111 \text{ psi}$$

where:
P_c = analyzed contents weight, lb

a = impact deceleration, g

A_c = bottom area, in^2

Pressure Resulting from Lead Weight

$$P_2 = \frac{P_{Pb}\,a}{A_{Pb}} = \left(\frac{\rho \times h_{Pb} \times A_{Pb}}{A_{Pb}}\right) \times a = 0.41 \times 180 \times 5.18 = 383\,\frac{lbf}{in^2},$$

where: P_{Pb} = lead weight, 47,434 lbm

ρ_b = lead weight density, lbm/in^3

h_{Pb} = lead height, in

A_{Pb} = internal cavity lead surface, in^2

a = impact deceleration, *g*

Shell End Pressures

The shell end pressures depend upon the cask portion not represented in the model. The computed weight of the model is 28,187 lb then, the remaining weight, P_R, is therefore

$$P_R = 256{,}500 - P_c - P_b - 28{,}187 = 103{,}882 \text{ lbm}.$$

The pressure P_3 on the shells is

$$P_3 = \frac{P_R\,a}{A_s} = 483 \text{ psi} \approx 490 \text{ psi}$$

where A_s = 1,115 in^2, inner and outer shell area.

2.7.2.3.2 Analysis Results—Center of Cask Bottom

Stress is categorized in accordance with the ASME Code, Section III, Subsection NB. Maximum primary membrane and primary membrane plus bending stresses are obtained from the ANSYS

postprocessed results. Cask bottom stresses are provided in Table 2.7.2.3-1. The comparison of the maximum stress intensities and allowable stresses is provided in Table 2.7.2.3-2. In reference to Figure 2.7.2.3-2, the maximum stress intensity is SI_{max} = 49,960 psi in Section A and the corresponding margin of safety is 0.341.

A simplified evaluation can be carried out for shear stresses by using the lateral surface of the bottom shell corresponding to the punch cross section.

$$\tau = \frac{Q}{A} = \frac{P_p \times A_p}{2\pi Re} = 14{,}100 \text{ psi}$$

where:

P_p = punch head pressure = 47,000 psi

A_p = punch cross section

R = punch bar radius = 3 in.

e = bottom shell thickness = 5 in.

The shear limit is $0.5\ S_u = 0.5 \times 67{,}000 = 33{,}500$ psi > 14,100 psi.

Figure 2.7.2.3-1 Bottom Puncture Finite Element Model and Boundary Conditions

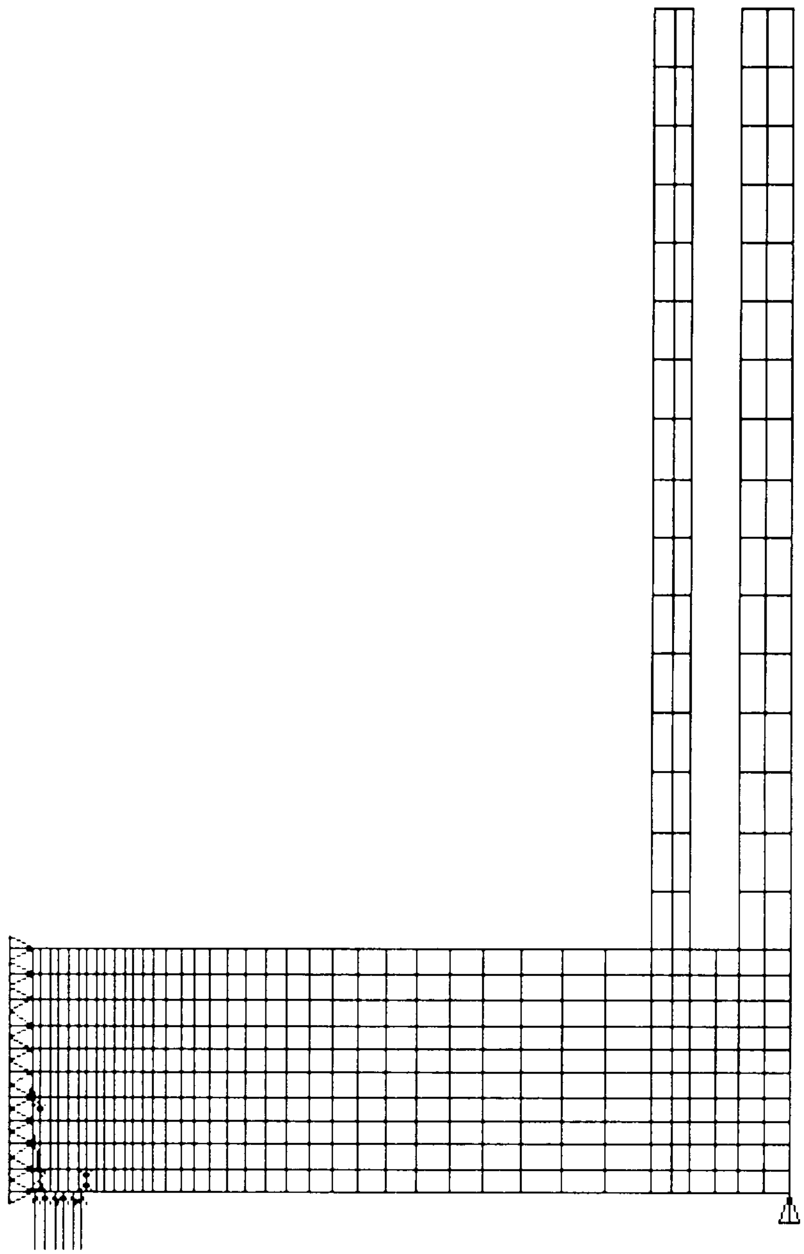


Figure 2.7.2.3-2 Location of Sections for Evaluation

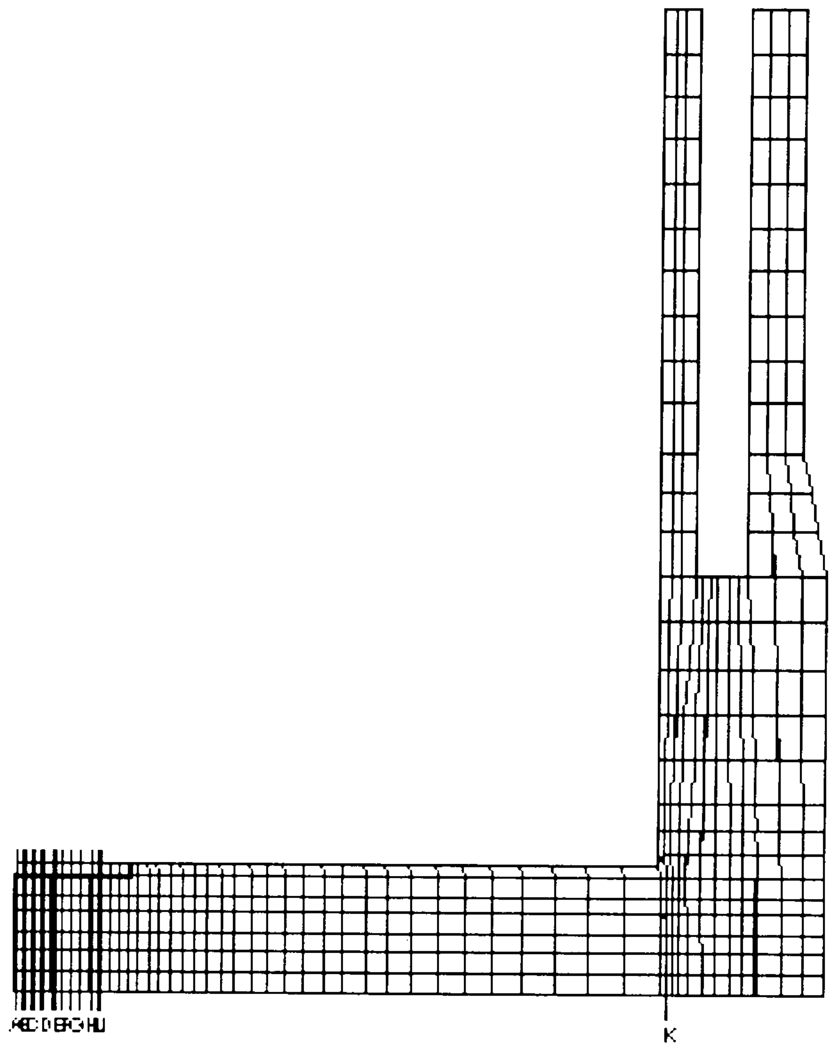


Table 2.7.2.3-1 Cask Bottom Puncture Stresses

Membrane			Stress Components (psi)				Principal Stresses (psi)			
Section	Node I	Node J	Sx	Sy	Sz	Sxy	S1	S2	S3	SI
A	204	167	-27260	-9534	-9534	0	-9534	-9534	-27260	17730
B	205	168	-27170	-9517	-9509	2242	-9237	-9509	-27450	18210
C	206	169	-26590	-9454	-9355	4333	-8420	-9355	-27630	19210
D	207	170	-25480	-9337	-9069	6380	-7120	-9069	-27700	20580
E	208	171	-23630	-9163	-8284	8472	-5257	-8284	-27540	22280
F	209	172	-20130	-8781	-7108	10600	-2437	-7108	-26480	24040
G	210	173	-12950	-8254	-5266	11510	1146	-5266	-22350	23490
H	211	174	-6428	-7619	-3889	10460	3454	-3889	-17500	20950
I	212	175	-3945	-7037	-3681	8823	3467	-3681	-14450	17920
J	213	176	-2470	-6551	-3597	7541	3302	-3597	-12320	15620
K	376	374	-712	-254	-1535	58	-247	-720	-1535	1289

Membrane + Bending (Node I)			Stress Components (psi)				Principal Stresses (psi)			
Section	Node I	Node J	Sx	Sy	Sz	Sxy	S1	S2	S3	SI
A	204	167	-44970	-60650	-60650	0	-44970	-60650	-60650	15680
B	205	168	-45530	-60010	-60490	2242	-45190	-60350	-60490	15300
C	206	169	-45440	-58300	-59290	4333	-44120	-59290	-59620	15500
D	207	170	-45230	-55590	-57500	6380	-42190	-57500	-58630	16440
E	208	171	-46870	-51920	-53870	8472	-40550	-53870	-58240	17680
F	209	172	-41590	-46670	-48180	10600	-33230	-48180	-55030	21790
G	210	173	-20910	-40570	-40800	11510	-15610	-40800	-45880	30270
H	211	174	-2206	-34380	-34500	10460	896	-34500	-37480	38370
I	212	175	-1370	-29070	-31850	8823	1201	-31640	-31850	33050
J	213	176	-265	-24830	-29480	7541	1866	-26960	-29480	31350
K	376	374	-58	2300	-1748	58	2302	-60	-1748	4050

Membrane + Bending (Node J)			Stress Components (psi)				Principal Stresses (psi)			
Section	Node I	Node J	Sx	Sy	Sz	Sxy	S1	S2	S3	SI
A	204	167	-8379	41580	41580	0	41580	41580	-8379	49960
B	205	168	-7812	40980	41470	2242	41470	41080	-7915	49390
C	206	169	-7490	39390	40570	4333	40570	39790	-7887	48460
D	207	170	-6913	36920	39360	6380	39360	37830	-7823	47180
E	208	171	-4674	33600	37300	8472	37300	35390	-6465	43770
F	209	172	-6046	29110	33960	10600	33960	32060	-8992	42950
G	210	173	-5233	24060	30260	11510	30260	28040	-9214	39480
H	211	174	-4594	19140	26720	10460	26720	23090	-8546	35270
I	212	175	-3920	14990	24490	8823	24490	18470	-7396	31880
J	213	176	-3326	11730	22290	7541	22290	14860	-6454	28740
K	376	374	-1853	-2808	-1322	58	-1322	-1850	-2812	1490

Table 2.7.2.3-2 Puncture Stress Evaluation Results

			Limits* (psi)	Stress Intensity (psi)			Evaluation		
Section	Node I	Node J	S (M)	S (I)	S (J)	S (M)	MS(I)	MS(J)	MS(M)
A	204	167	P_m	15680	49960	17730	3.273	0.341	1.645
B	205	168	P_m	15300	49390	18210	3.379	0.357	1.576
C	206	169	P_m	15500	48460	19210	3.323	0.383	1.441
D	207	170	P_m	16440	47180	20580	3.075	0.420	1.279
E	208	171	P_m	17680	43770	22280	2.790	0.531	1.105
F	209	172	P_m	21790	42950	24040	2.075	0.560	0.951
G	210	173	$P_m + P_b$	30270	39480	23490	1.213	0.697	0.997
H	211	174	$P_m + P_b$	38370	35270	20950	0.746	0.900	1.239
I	212	175	$P_m + P_b$	33050	31880	17920	1.027	1.102	1.617
J	213	176	$P_m + P_b$	31350	28740	15620	1.137	1.331	2.003
K	376	374	$P_m + P_b$	4050	1490	1289	15.543	43.966	35.384

*P_m = 46.900 psi (0.7 S_u)
$P_m + P_b$ = 67.000 psi (S_u)

2.7.2.4 Puncture - Port Cover

In accordance with the requirements of 10 CFR 71 for puncture (hypothetical accident condition), the port cover of the Universal Transport Cask is analyzed for structural adequacy. The cask is assumed to be in a horizontal position and dropped 40 inches onto a 6-inch diameter, mild steel bar, oriented vertically on an unyielding surface. The structural evaluation of the port cover is performed by classical elastic analysis methods.

2.7.2.4.1 Analysis description

This evaluation considers a port cover geometry typical of port covers on the UMS Cask. The primary difference between the port covers is location. For example, the vent cover, located in the bottom forging, is not easily accessible by the puncture probe. Therefore, a port cover located in the bottom plate is analyzed.

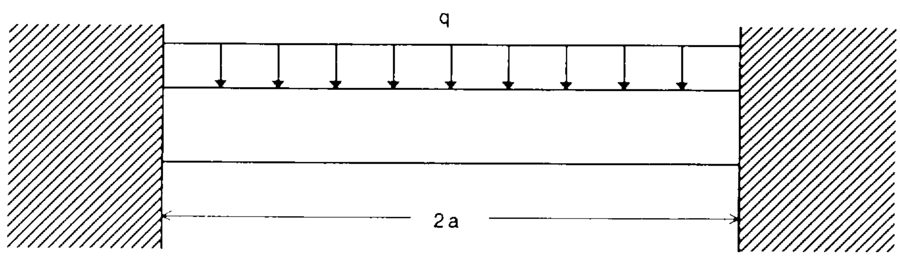
The cover centerline is located 9 inches axially from the cask end. In this region, the cask body is SA 336, Type 304 stainless steel. The port cover material is SA 240, Type 304 plate stainless steel. During the impact, the puncture pin is assumed to apply a pressure of 47,000 psi (assumed dynamic flow stress of mild steel) on the port cover and the bottom forging exterior surface of the cask in the inward normal direction. The port cover rotation at its mating surface with the cask body is restrained by the bolted flange configuration of the cover. The port cover is also restrained from rotation at its flange region resulting from the puncture pin pressure acting beyond the cask bottom forging.

2.7.2.4.2 Detailed Analysis

Local Impact Region—Port Cover

For the loading and displacement boundary conditions described, the deflection behavior of the port cover is assessed by applying formulas from Roark Table 24, Case 6 [28] for a uniformly loaded circular plate with fixed edges. The inward deflection of the port cover is

$$y = \frac{3 q a^4 (1 - v^2)}{16 E t^3} = 1.5 \times 10^{-4} \text{ in}$$



where:

q = 47,000 psi
a = 1 in
t = 1.25 in
E = 27×10^6 psi at 300°F
v = Poisson's ratio = 0.31.

Because a principal stress is a shear on the edges, a simplified evaluation can be carried out for shear stresses by using the lateral surface of the cover plate:

$$\text{(at edge) } S_{RZ} = \frac{q\,a}{2\,t} = 18{,}800 \text{ psi.}$$

Because the maximum port cover temperature is less than 300°F, the ultimate strength of the port cover (conservatively based on 300°F) is 66,000 psi. Therefore, the stress limit is 0.42 S_u = 27,720 psi, the minimum margin of safety is +0.36, and the clearance between the port cover and the valve exceeds 1.5×10^{-4} in.

2.7.2.5 Puncture Accident - Shielding Consequences

The puncture accident causes a localized reduction in the cask shielding. The resulting dose rates are bounded by the loss of neutron shield accident dose rates, which do not exceed the limits of 10 CFR 71.51.

2.7.3 Thermal

In accordance with the requirements of 10 CFR 71.73(c)(4), "Thermal, Hypothetical Accident Conditions," the Universal Transport Cask is analyzed for structural adequacy. The cask is assumed to be subjected to a fire, which produces a surrounding environment of 1,475°F for 30 minutes. The thermal evaluation of the hypothetical fire transient is presented in Section 3.5.

2.7.3.1 Summary of Pressures and Temperatures

The maximum thermal accident condition temperatures are summarized in Tables 2.7.3.1-1 and 2.7.3.1-2 for the various PWR and BWR cask components. A summary of pressures for the PWR and BWR canister configurations (both canister and cask pressures) are listed in tables 2.7.3.1-3 and 2.7.3.1-4. Cask closure bolts are qualified for a maximum pressure of 80 psig, which envelopes the maximum pressure developed during the fire.

The Universal Transport Cask inner and outer shells, lid, and lid bolts are demonstrated to be structurally adequate against loss of containment following a Thermal (fire) accident. Therefore, the cask satisfies 10 CFR 71 structural requirements for the fire accident scenario.

2.7.3.2 Differential Thermal Expansion Stress

Differential thermal expansion stresses and through-thickness thermal gradient stresses are induced in the Universal Transport Cask as a result of the Thermal (fire) accident event. All of these thermal stresses are classified as secondary, displacement-limited stresses according to the ASME Boiler and Pressure Vessel Code. Limits on secondary stresses do not apply for accident conditions; the secondary stresses, in themselves, do not compromise the integrity of the cask.

Table 2.7.3.1-1 Maximum Component Temperatures—Hypothetical Accident Conditions Fire Accident (PWR Cask)

Component	Temperature (°F)	Time (Hours)	Temperature Limit (°F)
Cask Lid Bolt[1]	306.10	5.8	—
Upper O-ring	286.45	13.0	375[3]
Cask Lid O-ring	304.45	5.5	375[3]
Cask Radial Outer Surface	1,376.49	0.5	—
Lead Gamma Shield	473.47	2.9	600
Maximum Fuel Rod Cladding[2]	918.75	—	1,058

Conditions: 30-min, 1475°F Fire, 20 kW decay heat

Notes:

1. Cask lid bolt is not explicitly modeled—maximum temperature taken to be maximum temperature of cask lid.
2. Estimated by adding maximum temperature gradient between cask inner shell and component of interest from normal condition results to peak temperature of cask inner shell during hypothetical accident analysis.
3. Accident temperature limit is 375°F for duration of 10 hours or less. [45]

Table 2.7.3.1-2 Maximum Component Temperatures—Hypothetical Accident Conditions Fire Accident (BWR Cask)

Component	Temperature (°F)	Time (Hours)	Temperature Limit (°F)
Cask Lid Bolt[1]	287	5.8	—
Upper O-ring	266	13.0	375[3]
Cask Lid O-ring	286	5.0	375[3]
Cask Radial Outer Surface	1,376	0.5	—
Lead Gamma Shield	457	2.9	600
Maximum Fuel Rod Cladding[2]	796	—	1,058

Conditions: 30-min, 1475°F Fire, 16 kW decay heat

Notes:

1. Cask lid bolt is not explicitly modeled—maximum temperature taken to be maximum temperature of cask lid.
2. Estimated by adding maximum temperature gradient between cask inner shell and component of interest from normal condition results to peak temperature of cask inner shell during hypothetical accident analysis.
3. Accident temperature limit is 375°F for duration of 10 hours or less.[45]

Table 2.7.3.1-3 Summary of Maximum Canister Pressures During Hypothetical Accident Conditions

Pressure Condition	Canister Internal Pressure (PWR)	Canister Internal Pressure (BWR)
Fire Accident and 100% Rod Failure	5.60 atm ≈ 82.0 psia ≈ 67.3psig	3.72 atm ≈ 54.66 psia ≈ 39.96 psig
Pressure used for Canister Analysis	70.84 psig	70.73 psig

Table 2.7.3.1-4 Summary of Maximum Cask Cavity Pressures During Hypothetical Accident Conditions

Pressure Condition	Cask Cavity Internal Pressure (PWR)	Cask Cavity Internal Pressure (BWR)
Fire Accident and 100% Rod Failure	5.07 atm ≈ 74.56 psia ≈ 59.86 psig	3.67 atm ≈ 53.90 psia ≈ 39.20 psig
Cask Lid Closure Analysis	80 psig	80 psig
Cask Body Finite Element Analysis	150 psig	150 psig

2.7.4 Crush

According to the IAEA Safety Series No. 6 Paragraph 627(c), and 10 CFR 71.73(c)(2), this test is not applicable to the Universal Transport Cask because the mass of the cask and contents is greater than 1,100 lb (500 kg) and the cask and contents have an overall density greater than 62.4 lb/ft^3 (1,000 kg/m^3).

2.7.5 Immersion - Fissile Material

According to the requirements of 10 CFR 71.73(c)(5), a package containing fissile material, where water inleakage has not been assumed for criticality analysis, must be subjected to water pressure equivalent to immersion under a head of water of at least 0.9 meters (3 feet) for 8 hours. This immersion is the fourth test in the hypothetical accident sequence of tests for the package. Paragraph No. 633 of IAEA Safety Series No. 6 specifies the same requirements for the international shipment of radioactive materials. A head of water of 0.9 m (3 ft) is equivalent to an external pressure of (3)(0.433) = 1.3 psig.

The analyses presented in Sections 2.7.6 evaluate the Universal Transport Cask for an external pressure of 290 psig. Since the containment boundary is predicted not to be structurally reduced following the hypothetical accident sequence, the external pressure analysis presented in Section 2.7.6 bounds this case.

2.7.6 Immersion - All Packages

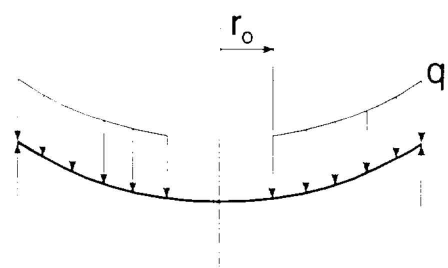
According to the requirements of 10 CFR 71.73(c)(6), a package must be subjected to water pressure equivalent to immersion under a head of water of at least 15 meters (50 ft) for 8 hours. Paragraph 630 of IAEA Safety Series No. 6 requires that a package be immersed under a head of water of at least 200 meters (656 ft) for not less than one hour. A head of water of 200 meters (656 ft) is equivalent to an external pressure of (656)(0.433) = 284 psig. In addition, 10 CFR 71.61 requires that a package's undamaged containment system be capable of withstanding an external water pressure of 290 psi for not less than one hour without collapse, buckling, or inleakage of water.

The structural adequacy of the cask body when subjected to an external pressure of 290 psi is demonstrated using classical closed-form solutions of stresses for simplified geometries. Specifically, the formulas for the stresses in these calculations are obtained from Roark [28]. The stresses generated by the 290 psi external pressure are calculated at the following locations:

1) Cask Outer Shell (away from ends)
2) Cask Bottom Forging (at center)
3) Cask Lid (at center)
4) Cask Bottom Plate (at center)
5) Port Cover Plate (at center).

The locations of the stresses evaluated (in the numbered list above) are shown in Figure 2.7.6-1 with the exception of the port cover plate (Item 6).

The bending stresses at the center of the circular plates (Items 3 through 6 in the above list) are evaluated using the formulas in Roark [28], Table 24, Case 10 for simply-supported plates with uniform thickness under a uniformly distributed pressure. The formulas are as follows:



For $r_o = 0$, the bending moment at the center of the plate is

$$M_c = \frac{qa^2(3+v)}{16}$$

where

M_c = bending moment (in-lb/in)
q = pressure load (lb/in²)
a = outer radius (in.)
v = Poisson's ratio.

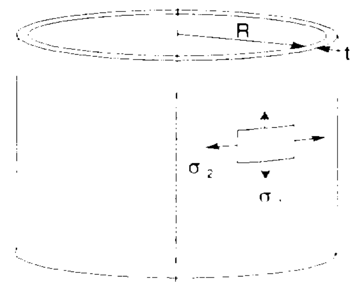
The bending stress at the center of the plate is then calculated as,

$$\sigma_b = \frac{6M_c}{t^2}$$

where σ_b = bending stress at center (lb/in^2)
M_c = bending moment (in-lb/in)
t = thickness of the plate (in.).

The primary membrane stresses (Items 1 through 2) in a cylindrical shell with uniform external pressure consist of axial and hoop (circumferential) stresses. Theses stresses are evaluated using formulas in Roark [28], Table 28, Case 1c for cylindrical thin-walled shells with capped ends under external pressure loading. The formulas are as follows:

$$\sigma_1 = \frac{qR}{2t} \quad \text{and} \quad \sigma_2 = \frac{qR}{t}$$



where σ_1 = axial stress (lb/in^2)
σ_2 = hoop stress (lb/in^2)
q = external pressure (lb/in^2)
R = mean radius (in.)
t = thickness of the shell (in.).

From these equations the stresses in the cask body at the locations described above are calculated in the ensuing sections. In addition, a comparison to the allowable stress is made for each stress calculated. Because this is considered to be an accident condition, the calculated stresses are compared to stress allowables as follows (refer to Section 2.1.2):

P_m < the lesser of $2.4S_m$ and $0.7S_u$
$P_m + P_b$ < the lesser of $3.6S_m$ and S_u

The stress allowables for this evaluation are conservatively taken at 400°F since the maximum temperature of the cask is 368°F.

The cask inner shell and port coverplate are constructed of SA240, Type 304 stainless steel. The cask outer shell and bottom are constructed of A240, Type 304 stainless steel. At a temperature

of 400°F, SA240, Type 304 stainless steel has an ultimate strength, S_u, of 64.4 ksi and a design stress intensity, S_m, of 18.7 ksi. Therefore, the stress allowables are:

Primary Membrane:	44.88 ksi ($2.4S_m$)
Primary Membrane + Bending:	64.4 ksi (S_u).

The cask bottom forging, top forging, and lid are constructed of SA336, Type 304 stainless steel. At a temperature of 400°F, SA336, Type 304 stainless steel has an ultimate strength, S_u, of 60.0 ksi and a design stress intensity, S_m, of 18.7 ksi. Therefore, the stress allowables are:

Primary Membrane:	42.0 ksi ($0.7S_u$)
Primary Membrane + Bending:	60.0 ksi (S_u).

2.7.6.1 Membrane Stresses in Cask Outer Shell (away from ends)

The membrane stresses in the cask outer shell are calculated as follows:

$$\sigma_1 = \frac{(-290 \text{ psi})(39.93 \text{ in.})}{2(2.75 \text{ in.})} = -2{,}105 \text{ psi}$$

$$MS = \frac{44{,}880 \text{ psi}}{2{,}105 \text{ psi}} - 1 = +20.32$$

$$\sigma_2 = \frac{(-290 \text{ psi})(34.93 \text{ in.})}{2.75 \text{ in.}} = -4{,}211 \text{ psi}$$

$$MS = \frac{44{,}880 \text{ psi}}{4{,}211 \text{ psi}} - 1 = +9.65$$

2.7.6.2 Bending Stress in the Bottom Forging (at center)

At a temperature of 400°F, SA336, Type 304 stainless steel has a Poison's ratio, ν, = 0.31. The bending stress in the bottom forging at the center is calculated as follows:

$$M_c = \frac{(-290\,lb/in^2)(34.805\,in.)^2(3+0.31)}{16} = -72{,}676\,in-lb/in$$

$$\sigma_b = \frac{6(-72{,}676\,in-lb/in)}{(4.25\,in.)^2} = -24{,}142\ psi$$

$$MS = \frac{60{,}000\ psi}{24{,}142\ psi} - 1 = +1.48$$

2.7.6.3 Bending Stress in the Cask Lid (at center)

At a temperature of 400°F, SA336, Type 304 stainless steel has a Poisson's ratio, ν, = 0.31. The bending stress in the cask lid at the center is calculated as follows (note the outer radius is taken to be half of the bolt circle):

$$M_c = \frac{(-290\,lb/in^2)(36.93\,in.)^2(3+0.31)}{16} = -81{,}821\,in-lb/in$$

$$\sigma_b = \frac{6(-81{,}821\,in-lb/in)}{(6.50\,in.)^2} = -11{,}620\ psi$$

$$MS = \frac{60{,}000\ psi}{11{,}620\ psi} - 1 = +4.16$$

2.7.6.4 Bending Stress in the Cask Bottom (at center)

At a temperature of 400°F, A240, Type 304 stainless steel has a Poisson's ratio, ν, = 0.31. The bending stress in the cask lid at the center is calculated as follows:

$$M_c = \frac{(-290\,lb/in^2)(41.305\,in.)^2(3+0.31)}{16} = -102{,}356\,in-lb/in$$

$$\sigma_b = \frac{6(-102{,}356\,\text{in} - \text{lb}/\text{in})}{(5.00\,\text{in.})^2} = -24{,}565\ \text{psi}$$

$$MS = \frac{64{,}400\ \text{psi}}{24{,}565\ \text{psi}} - 1 = +1.62$$

2.7.6.5 Bending Stress in the Port Cover Plate (at center)

At a temperature of 400°F, SA240, Type 304 stainless steel has a Poisson's ratio, $\nu = 0.31$. The bending stress in the cask lid at the center is calculated as follows (note that the outer radius is taken to be half of the bolt circle):

$$M_c = \frac{(-290\,\text{lb}/\text{in}^2)(2.0625\,\text{in.})^2(3+0.31)}{16} = -255\,\text{in} - \text{lb}/\text{in}$$

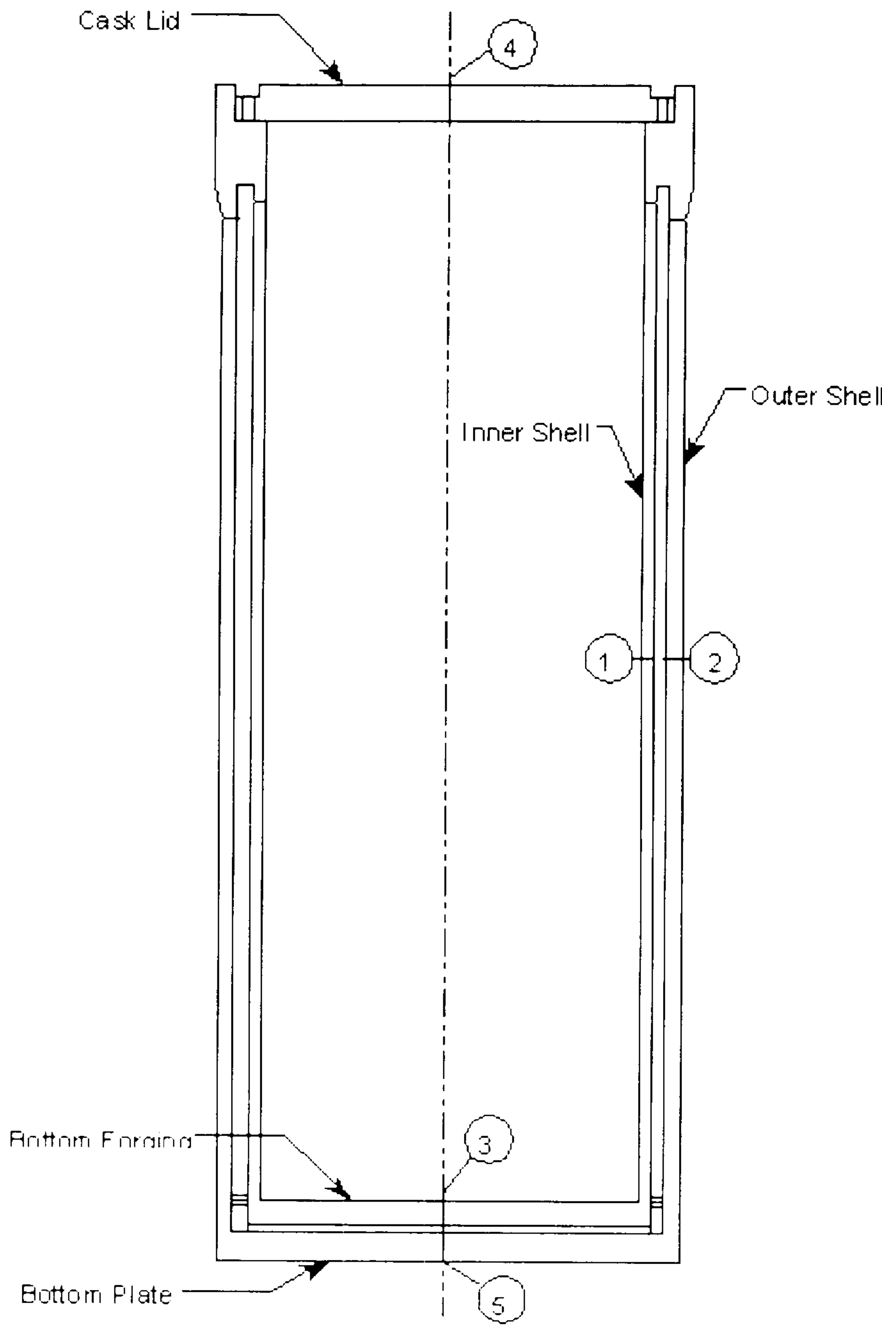
$$\sigma_s = \frac{6(-255\,\text{in} - \text{lb}/\text{in})}{(1.25\,\text{in.})^2} = -979\ \text{psi}$$

$$MS = \frac{64{,}400\ \text{psi}}{979\ \text{psi}} - 1 = +64.78$$

The minimum margin of safety calculated in this evaluation is +1.48 (for the bottom forging). Because the cask body maintains positive margins of safety when exposed to the 290 psi external pressure, structural adequacy is demonstrated.

Therefore, the Universal Transport Cask satisfies all of the immersion requirements for a package that is used for the domestic and international shipment of radioactive materials.

Figure 2.7.6-1 Cross-Section of Cask Body



2.7.7 PWR Transportable Storage Canister Analysis – Accident Conditions

This section presents the evaluation of the PWR Transportable Storage Canister for the hypothetical accident conditions. The evaluation of the canister for normal conditions of transport is presented in Section 2.6.12.

The principal components of the canister are the canister shell, including the bottom plate, fuel basket, shield lid, and structural lid. The geometry and materials of construction of the canister, baskets, and spacers are described in Section 1.2.1.2. The general arrangement of the canister, shown with the fuel basket, is shown in Figure 2.6.12-1. The individual components of the canister are shown in Figure 2.6.12-2.

A drop accident stress evaluation is performed for the 30-ft side-drop, top and bottom-end drops, and for the top and bottom-corner drop conditions by applying a 60 g deceleration load. The loads developed in the basket are transferred through the canister wall into the inner shell (for the side-drop and oblique drops), and any axial component is transferred into the ends of the cask cavity. The axial loads are maximized for the end-drops and corner-drop conditions. The lateral loads are maximized in the side-drop since an enveloping acceleration is employed in the analysis. Regardless of the angle of the drop, the canister wall is uniformly supported along its length by the transport cask inner shell, and the load path is not affected by drop orientations close to the side-drop orientation. The oblique orientation will not provide enveloping loading above the side-drop conditions. Therefore, oblique orientations other than the corner drops are not considered.

In addition, the evaluations are performed with and without the 25 psig internal pressure. For the side, top-corner, and bottom-corner drop orientations, basket orientations of 0° and 45° are evaluated. The angles describe the orientation of the basket elements with respect to the symmetry plane of the model. A value of 0° orients the ligaments in the basket elements parallel and perpendicular to the symmetry plane. A value of 45° orients the basket ligaments at +/- 45° from the symmetry plane. In the evaluations, the maximum temperatures present during the normal condition evaluation with 100°F ambient; solar insolation, and maximum decay heat are considered.

2.7.7.1 Analysis Description

The Transportable Storage Canister is a right-circular shell fabricated from rolled 5/8-in. thick, Type 304L stainless steel plate. The canister is closed on its bottom end with a Type 304L stainless steel circular plate that is 1.75-in. thick. The canister is closed at the top end with a 7-in. thick, Type 304 stainless steel shield lid, which is seal welded to the canister shell. The shield lid is covered by a 3-in. thick, Type 304L, stainless steel structural lid welded to the canister shell at its top inside edge. The loaded canister is lifted by using six swivel hoist rings threaded into the top of the structural lid. The canister is the defined confinement boundary for spent fuel contents during long term storage, but no credit is taken for containment in transport. The Universal Transport Cask containment boundary is defined in Section 1.1.

The structural design criteria for the canister are contained in the ASME Code, Section III, Subsection NB, "Class 1 Components." Consistent with this criteria, the structural components of the canister (shell, bottom plate, and structural lid) are shown to satisfy the allowable stress intensity limits presented in Table 2.1.2-3.

For the canister structural lid weld (Section 13, Figure 2.6.12.3-1), base metal properties are used to define the allowable stress limits since the weld filler rod tensile properties are greater than the base metal. Also, the allowable stress is multiplied by a stress reduction factor of 0.8 per ISG-4.

The ANSYS finite element program is used to evaluate the canister for the 30-ft drop conditions in the top and bottom end, top and bottom corner, and side impact orientations. The ANSYS finite element model is the same as that used for the evaluation of the 1-ft drop impacts evaluated for normal conditions of transport. The model is described in Section 2.6.12.2.

2.7.7.2 Analysis Results - PWR Canister

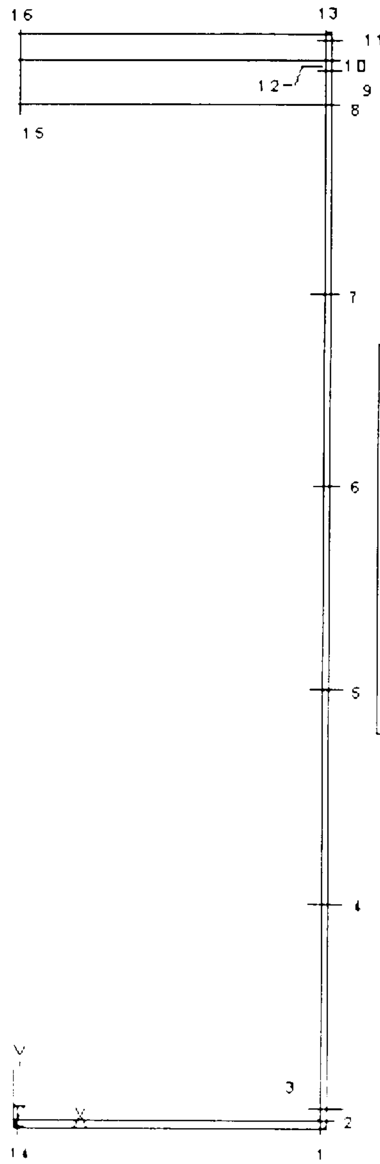
The results of the analysis for the 30-ft side, top and bottom corner, and top and bottom end-drops are presented in Tables 2.7.7.2-1 through 2.7.7.2-10. Only the load cases that result in the worst case margins are presented for each of the drop orientations considered. For the side-drop, the worst configuration is without pressure and the basket oriented at 45°. For the bottom drop, the worst case occurs with the canister internal pressure. For the top-end drop, the most severe condition occurs without pressure. For the bottom corner and top-corner drops, the worst case stresses occur without pressure and the basket oriented at 0°.

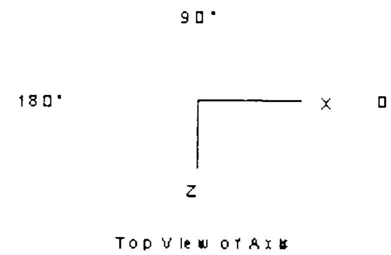
The section stresses presented in the tables are identified by a section number. The minimum margin at each section is presented by denoting the circumferential angle where the minimum margin of safety occurs. A cross section of the canister showing the section numbers is presented in Figure 2.7.7.2-1. Stresses are evaluated at 9° increments around the circumference for each of the locations shown in Figure 2.7.7.2-1. The minimum margin is denoted by an angular location at each section. The canister minimum margins of safety for the evaluated drop conditions are summarized in Table 2.7.7.2-11.

The methodology used to evaluate the stresses for the side-drop are identical to that used for the normal conditions 1-ft side drop for the PWR canister (Section 2.6.12.6). Sections 9, 10, and 11 at the 0° circumferential position (see Figure 2.6.12.3-1) are not included in the evaluation. These regions are characterized as a bearing stress since they result from the canister shell bearing against cask inner shell. An evaluation of these bearing stresses is not required for accident conditions. Results for Sections 9, 10, and 11 at angular locations other than 0° are included in the evaluation.

The allowable stresses presented in the tables 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. These allowables are evaluated at 380°F, unless otherwise indicated. Review of the thermal analyses shows that the maximum temperature of the canister is 399°F (Section 3.4.2), which occurs in the center portion of the canister wall (Sections 5 and 6 described in Figure 2.7.7.2-1). The impact of this temperature increase is addressed by evaluating the margins presented at Sections 5 and 6 where the peak temperature occurs. The minimum margin for all the accident cases considered at Sections 5 or 6 is 4.41, which occurs for the 30-ft bottom-corner drop plus internal pressure. The allowable S_m for Type 304L stainless steel is reduced from 16.0 ksi to 15.8 ksi at 400°F. The margin of safety for this case would be reduced to 4.34. Therefore, the increased peak temperature in the center of the canister will have a negligible impact on the presented minimum margins of safety.

Figure 2.7.7.2-1 Identification of the Sections for Evaluating the Linearized Stresses in the PWR Canister





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

Table 2.7.7.2-1 PWR Canister P_m Stresses - 30-Foot Side-Drop - 45° Basket Orientation

Section Location	Angle of peak stress location	P_m Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-20.6	0.4	-12.6	-0.2	-0.3	-1.6	21.3	38.4	0.8
2	0	-15.4	0.4	-12.8	-1.2	-0.9	-0.7	16.3	38.4	1.36
3	0	-4.2	-0.1	-8.9	-0.4	-1.2	-0.9	9.3	38.4	3.11
4	108	-0.2	-2.2	0	2.1	-0.7	0.1	4.8	38.4	7.01
5	9	-2.1	2.1	0.3	0	0	0.4	4.2	38.4	8.03
6	9	-2.1	2.6	0.2	0	-0.1	0.4	4.7	38.4	7.1
7	9	-2.3	2.4	1	0	-0.3	0.5	4.9	38.4	6.9
8	72	0	-0.8	0	-4.5	-1.5	-0.1	9.5	38.4	3.03
9	9	-24.1	6.1	-10.0	-2.9	3.4	1.1	31.5	38.4	0.22
10	9	25	2.7	-13.5	-5.3	2.1	0.8	29.9	38.4	0.28
11	9	-17.7	1.0	-9.5	0.9	2.3	0	19.3	38.4	1.0
12	0	-39.7	-8.1	-17.6	-7.1	1.8	0.8	35	38.4	0.09
13	0	-30.9	-9.5	-12.8	0.2	1.4	-1.5	22	30.72*	0.40
14	0	-2.9	0	1	0	0	-0.1	3.8	38.4	8.98
15	0	-1	0	0.4	-0.1	0	0	1.3	38.4	27.49
16	0	-1.6	0	0.4	0	0	0	2	38.4	18.25

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

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-2 PWR Canister $P_m + P_b$ Stresses - 30-Foot Side-Drop 45° Basket Orientation

Section Location	Angle of peak stress location	$P_m + P_b$ Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-23.9	-0.1	-14.1	0.8	0.1	-1.6	24.1	57.5	1.39
2	0	-17.1	1.1	-10.9	-1.7	-0.9	-1.3	18.8	57.5	2.06
3	45	-3.5	-17.8	-3.6	1.6	1.3	-4.2	18.9	57.5	2.05
4	9	-2.3	0.9	3.6	0.1	0.4	0.9	6.3	57.5	8.19
5	9	-2	2.8	2.4	0	0	0.7	4.9	57.5	10.71
6	9	-2	3.3	2.4	0	-0.1	0.7	5.4	57.5	9.62
7	9	-2.3	3	3	0	-0.3	0.8	5.8	57.5	8.88
8	72	0.1	-0.8	0	-5.5	-1.9	-0.1	11.7	57.5	3.91
9	9	-21.8	15.8	-7.9	-2.7	3.9	3.0	39.2	57.5	0.47
10	9	-26.9	0	-11.9	-7.4	1.6	0.5	30.9	57.5	0.86
11	9	-42.1	13	-15.3	0.2	2.4	1.6	55.3	57.5	0.04
12	0	-49	-11.5	-21.2	-7.1	2.5	1.1	40.6	57.5	0.42
13	0	-49.1	-19.1	-21.7	-0.3	2.1	-0.8	31.2	46.0*	0.47
14	0	-2.9	0	1	0	0	-0.1	3.8	57.5	13.95
15	0	-1.9	0	-0.6	-0.1	0	0	1.9	57.5	29.9
16	0	-1.2	0	0.9	0	0	0	2	57.5	27.23

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

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-3 PWR Canister P_m Stresses - 30-Foot Bottom End-Drop Internal Pressure

Section Location	Angle of peak stress location	P_m Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	180	0	-2.6	-0.4	0.2	0.1	0	2.6	38.4	13.85
2	180	0.7	-6.3	-1.1	0.3	0.1	0.1	7.1	38.4	4.43
3	180	0.1	-6.9	-1.2	0	0.1	0.1	7	38.4	4.49
4	180	0	-6.3	1.3	0	0	-0.1	7.7	38.4	4.01
5	180	0	-5.8	1.3	0	0	-0.1	7.1	38.4	4.41
6	180	0	-5.2	1.3	0	0	-0.1	6.5	38.4	4.88
7	180	0	-4.6	1.3	0	0	-0.1	6	38.4	5.44
8	81	0.7	-3.1	0.1	0	-0.1	0.1	3.8	38.4	9.03
9	72	-1.7	-1.9	-0.7	-0.1	0.4	-0.4	1.6	38.4	22.94
10	180	1.7	-1.3	-1	-0.3	0	0.2	3.1	38.4	11.5
11	0	-2	0.5	-0.9	0	0	0.1	2.5	38.4	14.17
12	0	0.7	1.8	-0.4	0.2	0.1	-0.1	2.2	38.4	16.18
13	180	0	-2	-1.2	0	0	0.1	2	30.72*	14.36
14	0	0.1	-1.1	0.1	0	0	0	1.2	38.4	30.57
15	171	0.2	-0.1	0.2	0	0	0	0.2	38.4	186.72
16	90	-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.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-4 PWR Canister $P_m + P_b$ Stresses - 30-Foot Bottom End-Drop - Internal Pressure

Section Location	Angle of peak stress location	$P_m + P_b$ Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	180	0.4	-2.9	-0.2	0.3	0.1	0	3.4	57.5	16.11
2	180	0.4	-9.5	-2.1	0.1	0.1	0.2	9.9	57.5	4.84
3	180	0.1	-8.9	-1.8	-0.1	0.1	0.1	9	57.5	5.39
4	180	0	-6.3	1.3	0	0	-0.1	7.7	57.5	6.49
5	0	0	-5.8	1.3	0	0	0.1	7.1	57.5	7.1
6	180	0	-5.2	1.3	0	0	-0.1	6.5	57.5	7.8
7	180	0	-4.6	1.3	0	0	-0.1	6	57.5	8.64
8	90	0.6	-3.4	0.3	0	-0.2	0	4.1	57.5	13.03
9	90	-2.4	-3.9	-0.4	0	0.7	0	3.7	57.5	14.53
10	90	-2.9	-6.6	0.6	0	0.2	0	7.3	57.5	6.91
11	0	-1.1	5.6	0.9	-0.4	0	0.1	6.8	57.5	7.52
12	0	2.6	3.6	0.7	0.7	0	-0.1	3.3	57.5	16.27
13	180	2.3	0.1	0.1	0.4	0.1	0.2	2.4	46.0*	18.17
14	0	0.1	-1.2	0.1	0	0	0	1.3	57.5	43.49
15	81	3.6	0	3.6	0	0	0	3.6	57.5	14.82
16	81	-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.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-5 PWR Canister P_m Stresses - 30-Foot Top End-Drop

Section Location	Angle of peak stress location	P_m Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-0.4	-5.9	-2.2	0.8	0	-0.1	5.8	38.4	5.65
2	0	-3.8	3.7	5.5	0.9	-0.1	0.6	9.5	38.4	3.03
3	0	-0.8	0.1	7.6	-0.7	0.1	0.6	8.9	38.4	3.31
4	135	0	-2.2	0	0	0	0	2.2	38.4	16.27
5	153	0	-2.8	0	0	0	0	2.8	38.4	12.75
6	153	0	-3.4	0	0	0	0	3.4	38.4	10.43
7	180	0	-3.9	0	0	0	0	3.9	38.4	8.77
8	180	0.1	-3.7	0.1	-0.1	0	0	3.8	38.4	9.07
9	180	0.1	-2.8	-0.5	-0.1	0	0	2.8	38.4	12.49
10	144	-0.2	-2.7	-0.3	0	0	0.2	2.6	38.4	13.53
11	135	-0.2	-2.6	-0.2	0	0	0.2	2.6	38.4	13.74
12	36	-0.1	-2.1	-0.2	0.1	-0.1	-0.1	2.1	38.4	17.05
13	180	0	-2.2	-0.3	0	0	0	2.2	30.72*	12.96
14	90	-0.7	0	-0.7	0.2	-0.4	0	1.1	38.4	35.05
15	153	0	-1	0	0	0	0	1.1	38.4	35.42
16	0	0	-1.1	0	0	0	0	1.2	38.4	31.89

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

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-6 PWR Canister $P_m + P_b$ Stresses - 30-Foot Top End-Drop

Section Location	Angle of peak stress location	$P_m + P_b$ Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-4.3	-14.2	0.2	0.1	-0.1	0.2	14.4	57.5	2.99
2	0	-1.9	27.1	13	2	-0.1	1.1	29.4	57.5	0.96
3	0	-1.6	32.5	16.9	-0.1	0	1.4	34.2	57.5	0.68
4	162	0	-2.3	0	0	0	0	2.3	57.5	24.44
5	153	0	-2.8	0	0	0	0	2.8	57.5	19.63
6	171	0	-3.4	0	0	0	0	3.4	57.5	16.14
7	180	0	-3.9	0	0	0	0	3.9	57.5	13.64
8	180	0.3	-3.6	0.1	-0.2	0	0	3.9	57.5	13.71
9	135	-0.3	-3.2	-0.3	0	0	0.3	3.2	57.5	17.13
10	180	0	-3.1	-0.6	0	0	0	3.1	57.5	17.78
11	135	-0.3	-3	-0.3	0	0	0.2	2.9	57.5	18.74
12	180	0.1	-2	-0.2	-0.2	0	0	2.2	57.5	25.09
13	180	-0.1	-2.3	-0.4	-0.1	0	0	2.2	46.0*	19.91
14	90	-20.4	-0.3	-20.4	0.2	-0.4	0	20.2	57.5	1.85
15	81	0.3	-1	0.3	0	0	0	1.3	57.5	44.4
16	0	0.1	-1.1	0.1	0	0	0	1.2	57.5	47.14

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

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-7 PWR Canister P_m Stresses - 30-Foot Bottom Corner-Drop

Section Location	Angle of peak stress location	P_m Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-15	-3.3	-6.1	-0.5	-0.1	-1.9	12.1	38.4	2.16
2	18	2.2	-8.7	-1.1	0.3	-0.8	-1.9	11.9	38.4	2.23
3	27	-0.2	-9.3	-2.7	0.6	-0.1	-1.1	9.6	38.4	2.99
4	0	-0.4	-6.9	0.3	0	0.1	0.4	7.4	38.4	4.19
5	180	0	-6.8	-0.2	0	0	0	6.8	38.4	4.68
6	180	0	-6.5	-0.2	0	0	0	6.5	38.4	4.92
7	180	0	-5.8	-0.2	0	0	0	5.8	38.4	5.62
8	54	0.1	-3.5	0.1	-0.8	-0.7	0	4.1	38.4	8.26
9	0	-30.6	1	-10.7	-3	1.9	-0.1	32.5	38.4	0.18
10	0	-14	-0.7	-6.2	-2.7	1.4	-0.9	14.8	38.4	1.59
11	0	-36.8	-1.4	-12.2	-0.4	2	-0.3	35.8	38.4	0.07
12	0	-23.2	-5.3	-7.5	-3.8	1.3	-1.2	20.1	38.4	0.9
13	0	-23.6	-7.4	-7.7	0.3	1.4	-2.1	17.8	30.72*	0.73
14	0	-1.1	-1	0.4	0	0	0	1.5	38.4	24.48
15	0	-0.2	0	0.3	0	0	0	0.5	38.4	81.71
16	0	-0.9	0	0	0	0	0	0.9	38.4	43.06

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

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-8 PWR Canister $P_m + P_b$ Stresses - 30-Foot Bottom Corner-Drop

Section Location	Angle of peak stress location	$P_m + P_b$ Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-16.3	-2	-6.2	0.8	0.1	-2	14.8	57.5	2.89
2	18	0.4	-18.8	-3.5	-0.1	-0.1	-2	20	57.5	1.87
3	27	-0.8	-18	-4.6	0.1	-1.1	-2.1	18.2	57.5	2.15
4	0	-0.4	-6.1	2.8	0	0.1	0.7	9	57.5	5.37
5	0	-0.4	-4.8	2.6	0	0	0.6	7.5	57.5	6.64
6	0	-0.5	-3.9	2.6	0	0	0.5	6.6	57.5	7.76
7	0	-0.4	-3.2	2.6	0	0	0.6	5.9	57.5	8.81
8	18	0.4	-2.7	-1.3	1	1.8	-0.7	5	57.5	10.54
9	0	-30.5	7.2	-11.3	-2.5	1.8	0.4	38.2	57.5	0.51
10	0	-14.3	-0.9	-4.2	-4.2	1	-1.4	16.3	57.5	2.53
11	0	-32.9	8	-10.2	-0.2	2	0.5	41.2	57.5	0.4
12	0	-30.2	-7.8	-10.2	-3.7	1.7	-0.8	24.5	57.5	1.35
13	0	-38	-15	-14.3	-0.1	1.9	-1.5	25.5	46.0*	0.80
14	0	-1	-1	0.5	0	0	0	1.5	57.5	37.12
15	81	3.9	0	4.3	0	0	0	4.3	57.5	12.39
16	0	-2.7	0	-1.9	0	0	0	2.7	57.5	20.31

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

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-9 PWR Canister P_m Stresses - 30-Foot Top Corner-Drop

Section Location	Angle of peak stress location	P_m Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	9	-2.1	-7	-4.8	0.7	-1.1	-1	5.9	38.4	5.53
2	0	-38	-1.4	-10.4	-5.2	0.7	-0.2	38.1	38.4	0.01
3	0	-12.1	-2.5	-2.6	-5.3	0.5	-0.3	14.5	38.4	1.65
4	180	0	-2.7	-0.2	0	0	0	2.7	38.4	13.07
5	180	0	-3.5	-0.2	0	0	0	3.5	38.4	9.89
6	180	0	-3.9	-0.2	0	0	0	3.9	38.4	8.82
7	72	0.1	-3.5	0	-0.9	-0.3	0	4.1	38.4	8.39
8	45	0.1	-3.9	0.1	-1.1	-1.2	0.1	5.2	38.4	6.31
9	0	-31.3	-4.8	-10.8	-3.4	0.9	-0.1	27.5	38.4	0.39
10	0	-21.1	-9.8	-8.9	-4	0.2	-0.7	14.2	38.4	1.7
11	0	-30.8	-14.9	-12.3	-1.5	0.7	-0.7	18.9	38.4	1.03
12	0	-27.7	-13.5	-9.2	-5.6	0.4	-1.1	20.7	38.4	0.85
13	0	-26.9	-17.7	-9.7	-1.6	0.4	-1.9	17.9	30.72*	0.72
14	90	-1.4	0	-0.3	0.1	-0.3	0	1.7	38.4	21.81
15	0	-0.4	-1	0.1	0	0	0	1.1	38.4	33.99
16	0	-0.6	-1.1	0.2	0	0	0	1.3	38.4	29.2

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

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-10 PWR Canister $P_m + P_b$ Stresses - 30-Foot Top Corner-Drop

		$P_m + P_b$ Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-28.1	-15.6	-10.7	-7.5	-0.1	-1.1	21.2	57.5	1.71
2	0	-37.9	17.6	-5.7	-2.1	1.6	0.5	55.8	57.5	0.03
3	180	-1.4	29.4	15.6	0.1	0	-1.3	30.9	57.5	0.86
4	27	0.3	-1.7	-2.1	0	-0.1	-1.4	3.7	57.5	14.66
5	0	-0.4	-0.9	2.6	0	0	0.6	3.6	57.5	15.02
6	0	-0.4	-1.6	2.6	0	-0.1	0.6	4.3	57.5	12.39
7	0	-0.4	-2.5	2.8	0	-0.1	0.7	5.4	57.5	9.58
8	45	0.4	-3.8	0.4	-1.3	-1.6	0.2	6	57.5	8.53
9	0	-31.6	0.8	-11.8	-2.4	0.9	0.4	32.8	57.5	0.75
10	0	-23.1	-12.1	-8	-6.7	0	-1.3	18.7	57.5	2.08
11	0	-34	-18.9	-12.5	-2.5	0.9	-1.3	22.1	57.5	1.6
12	0	-30.1	-13	-9.8	-4.6	0.9	-0.8	21.9	57.5	1.63
13	0	-31.3	-21.6	-12.2	-2.7	0.7	-1.8	20.2	46.0*	1.28
14	72	-19.1	-0.3	-17.3	0.1	-0.3	0	18.8	57.5	2.06
15	72	-0.2	-0.9	0.4	0	0	0	1.3	57.5	43.02
16	0	-0.6	-1	0.3	0	0	0	1.3	57.5	43.39

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

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 399°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-11 Summary of Minimum Margins of Safety for PWR Canister - 30-Foot Drops

Drop Orientation	Loading Condition	Stress Evaluated	Min. Margin of Safety	Section No.*
Side	30-ft impact (45 degree basket)	P_m	0.09	12
Side	30-ft impact (45 degree basket)	$P_m + P_b$	0.04	11
Bottom end	30-ft impact + pressure (25 psi)	P_m	4.01	4
Bottom end	30-ft impact + pressure (25 psi)	$P_m + P_b$	4.84	2
Top end	30-ft impact	P_m	3.03	2
Top end	30-ft impact	$P_m + P_b$	0.68	3
Bottom Corner	30-ft impact	P_m	0.07	11
Bottom Corner	30-ft impact	$P_m + P_b$	0.4	11
Top Corner	30-ft impact	P_m	0.01	2
Top Corner	30-ft impact	$P_m + P_b$	0.03	2

* See Figure 2.7.7.2-1 for section locations.

2.7.7.3 Canister Buckling Evaluation for 30-Foot End Drop

Code Case N-284-1 [12] of the ASME Boiler and Pressure Vessel Code is used to analyze the PWR canister for the accident condition 30-foot end drop (both top and bottom end drops). 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 of Code Case N-284-1. The canister buckling design criteria are described Section 2.1.2.5.3.

The PWR canister for the 30-foot end drop is evaluated for buckling in the same manner as the PWR canister for the 1-foot end drop (see Section 2.6.12.12). The analytical process used for the PWR canister is the same as that described in a step-by-step example presented in Section 2.7.12.3 (for the cask inner shell).

A 60 g deceleration load was used for all the 30-ft drop canister analyses that are presented in Sections 2.7.7.2. The 60 g-load bounds all 30-ft deceleration loads for all other drop angles. The top- and bottom-end drops result in the largest potential for canister shell buckling and, therefore, are the two load cases presented here. The side drop load case is not considered a credible buckling mode of the canister shell and is, therefore, not presented here.

The stress results from the dynamic shell analyses (ANSYS) are screened for the maximum values of the longitudinal compression, circumferential compression, or in-plane shear stresses for the 30-ft drop cases (top- and bottom-end drops) with and without pressure. For each loading case, the largest of each of the three stress components anywhere regardless of location within the PWR canister shell are combined. Combining the maximum stress components in this way produces a conservative, bounding-case buckling evaluation of the PWR canister, one which envelopes all 30-ft PWR canister drop cases including those presented in Tables 2.7.7.2-3 and 2.7.7.2-5.

The geometry parameters used in the PWR canister evaluation are the same as those presented in Table 2.6.12.12-1.

The maximum stress components used in the evaluation and the resulting buckling interaction equation ratios are provided in Table 2.7.7.3-1. 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, thus demonstrating that buckling of the PWR canister does not occur.

Table 2.7.7.3-1 Buckling Evaluation Results for the PWR Canister for 30-Foot End Drop

Load Condition	Longitudinal (Axial) Stress* S_ϕ (psi)	Circumferential (Hoop) Stress* S_θ (psi)	In-plane Shear Stress $S_{\phi\theta}$ (psi)	Elastic Buckling Interaction Equations				Plastic Buckling Interaction Equations			
				Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1-Ft Top End Drop	3900	100	700	.012	.084	.015	.012	.084	.015	.084	.015
1-Ft Bottom End Drop	7400	1500	100	.142	.159	.219	.142	.159	.219	.159	.219

Component stresses include thermal stresses.

* Compressive stresses.

2.7.8 PWR Basket Analysis - Accident Conditions

The PWR fuel basket in the Transportable Storage Canister is designed to contain up to 24 PWR fuel assemblies. The basket structure has a right-circular cylinder configuration and consists of 24 square tubes supported by circular support disks and a circular top and bottom plate that are retained by eight axial tie rods. The number of support disks provided in the basket varies, depending upon the class (Class 1, 2, or 3) of PWR fuel the basket is designed to contain.

The support disks and top and bottom plates are separated and supported by split spacers at the tie rods. The configuration of the basket is shown in Figure 2.6.13-1. Design of the basket and its components is discussed in detail in Chapter 1.0.

The PWR fuel basket is evaluated for hypothetical accident loads in this section (evaluation of the basket for loads under normal conditions of transport is presented in Section 2.6.13). Both stress analyses and buckling evaluations are performed and documented in the subsequent sections. The structural analysis of the basket components is in accordance with the ASME Code, Section III, Division 1, Subsection NG [15]. In addition, the stainless steel/BORAL composite fuel tube is evaluated for a postulated impact load.

The fuel tubes are not structural components and are not considered in the basket evaluation. The tie rods and spacers locate and structurally assemble the circular support disks, heat transfer disks, and top and bottom plates to form an integral assembly. The spacers carry the weight of the support disks, heat transfer disks, and endplate and their own weight in the 30-ft end-drop accident loading condition. The end-drop loading condition of the spacers is a classical, closed-form analysis, and the spacers are evaluated independently of the finite element basket model. Two finite element models of a single disk are used to perform the support disk structural evaluation. Figure 2.6.13.2-1 shows the PWR support disk model for the side drop evaluation. For further details of the basket, refer to Section 2.6.13.

2.7.8.1 Stress Evaluation of Support Disk

To determine the structural adequacy of the support disks, 30-ft-drop accident impact loads are evaluated for the worst-case radial orientations of the basket (0°, 18.22°, 26.28°, and 45°). The cask orientations considered are side-drop, end-drop, and oblique drops (0°, 10°, 20°, 23°, 30°, 40°, 50°, 60°, 70°, 75°, 80°, and 88°).

A load equal to the weight of the fuel assembly and fuel tubes multiplied by a 60 *g* amplification factor is applied to the support disk structure to simulate the 30-ft side-drop accident condition. The 60 *g* amplification factor is the design value that envelopes the calculated deceleration values in Section 2.6.7.5 for a 30-ft side-drop accident condition. The fuel assembly loads are transmitted in direct compression through the tube wall to the web structure of each support disk. These loads are transmitted to the canister and to the inner shell of the cask by the support disks, top weldment, and bottom weldment. The support disk configuration is analyzed for four worst-case radial orientations—0°, 18.22°, 26.28°, and 45°—to bound the possible maximum stress cases. The 18.22° orientation is located at the thinnest radial section of the disk perimeter.

For the end-drop condition, the support disk is loaded by the inertia of its own weight multiplied by the 60 *g* end-drop amplification factor.

Two limiting boundary conditions (thermal Case A and B) are considered in the evaluation (See Section 2.6.13.3 for case definition). Note that temperatures in the model are used only to determine material allowables for stress evaluation. However, thermal stresses are considered in the buckling evaluation (Section 2.7.8.3).

The stress evaluation for the support disk is performed according to the ASME Code, Section III, Subsection NG. According to this subsection, linearized stresses of cross sections of the structure are to be compared against the allowable stresses. The allowable stresses for Normal and Accident conditions are taken from Subsection NG as shown below.

	Accident (Level D)
P_m	$0.7\ S_u$
P_m+P_b	$1.0\ S_u$

The allowable limit is $0.7\ S_u$ or $2.4\ S_m$, whichever is less. For the support disk, $2.4\ S_m \geq 0.7\ S_u$; therefore, $0.7\ S_u$ is limiting.

2.7.8.1.1 Finite Element Model Description

Finite element analyses are performed for the basket support disk for hypothetical accident conditions: the 30-ft side-drop impact condition (60 *g*) and 30-ft end-drop impact condition (60 *g*). The 30-ft oblique impact conditions are evaluated based on the stress results from the end impact and side impact analyses. Two finite element models are used for the basket side impact and end impact evaluations, respectively. These models are the same models used in the evaluation for normal transport conditions. The models are described in Section 2.6.13.2.

2.7.8.1.2 PWR Support Disk Impact Loading Conditions

The lateral impact load applied to the support disk for a side-drop accident includes the inertial weights of the canister, fuel assemblies, stainless steel tubes, and weight of the support disk itself. A detailed description of the loadings is provided in Section 2.6.13.2. The heat transfer disks are considered to be self-supporting. A 60 *g* load factor is used to amplify the weight of the basket components for the 30-ft side-drop condition.

2.7.8.1.3 PWR Support Disk Side-Drop Analysis Results

Finite element stress analyses for the 60 *g* side impact load cases are performed for four different radial basket orientations—0°, 18.22°, 26.28°, and 45°. The analyzed section locations are defined in Section 2.6.13.2 and in Figures 2.6.13.2-3 through 2.6.13.2-4.

The calculated stresses for the sections with the 40 lowest margins of safety are presented in Tables 2.7.8.1-2 through 2.7.8.1-17. The minimum margin of safety is +0.28 for primary membrane plus primary bending stress at Section 107 for Thermal Case B side-drop with the basket orientation equal to 18.22° (Table 2.7.8.1-9). The minimum margins of safety for all side-drop analysis results are summarized in Table 2.7.8.1-1.

2.7.8.1.4 PWR Support Disk End-Drop Analysis Results

Finite element stress analyses of the PWR basket support disk are performed for a 60 *g* end impact (30-ft end-drop) for Thermal Case A and B. The primary membrane stresses in the disk for the end drop conditions are essentially zero. The maximum primary membrane plus bending stresses in the support disk for the 30-ft end-drop accident condition are summarized in

Table 2.7.8.1-18. The calculated stresses for the sections with the 40 lowest margins of safety are presented in Tables 2.7.8.1-19 and 2.7.8.1-20.

2.7.8.1.5 PWR Support Disk Oblique Drop Analysis Results

To evaluate oblique impacts, the stress components (i.e., S_x, S_y, S_{xy}) are combined from the side and end drop cases. These stress combinations are accomplished using the same methodology as described in Section 2.6.13.8 for the normal conditions of transport evaluation. The evaluation considers various cask drop angles (φ = 0°, 23°, 30°, 45°, 60°, 70°, 75°, 80°, 85°, and 88°, and 90°), as well as the basket drop orientation (0°, 18.22°, 26.28°, and 45°). The end drop (φ = 0°) and the side drop (φ = 90°) conditions are included in the evaluation so that the results envelope all cask drop angles.

The maximum stresses in the support disk for the 30-ft oblique accident condition are summarized in Table 2.7.8.1-21.

Table 2.7.8.1-1 Summary of Stress Evaluation of Support Disk—30-Foot Side-Drop

Table Number	Basket Orientation (deg)	Thermal Case	Stress Evaluation	Minimum Margin of Safety
2.7.8.1-2	0	A	P_m	+0.86
2.7.8.1-3	0	A	$P_m + P_b$	+0.49
2.7.8.1-4	0	B	P_m	+0.87
2.7.8.1-5	0	B	$P_m + P_b$	+0.47
2.7.8.1-6	18.22	A	P_m	+1.24
2.7.8.1-7	18.22	A	$P_m + P_b$	+0.30
2.7.8.1-8	18.22	B	P_m	+1.27
2.7.8.1-9	18.22	B	$P_m + P_b$	+0.28
2.7.8.1-10	26.28	A	P_m	+1.37
2.7.8.1-11	26.28	A	$P_m + P_b$	+0.31
2.7.8.1-12	26.28	B	P_m	+1.43
2.7.8.1-13	26.28	B	$P_m + P_b$	+0.30
2.7.8.1-14	45	A	P_m	+1.76
2.7.8.1-15	45	A	$P_m + P_b$	+0.43
2.7.8.1-16	45	B	P_m	+1.76
2.7.8.1-17	45	B	$P_m + P_b$	+0.43

Table 2.7.8.1-2 Pm Stresses for Support Disk—30-Foot Side-Drop, 0° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-35.5	-27.7	18.3	50.3	93.5	0.86
123	-35.5	-27.7	-18.3	50.3	93.5	0.86
25	20.7	-22.2	0.0	42.8	92.2	1.15
20	18.4	-17.4	0.0	35.7	90.4	1.53
29	0.0	-32.4	0.0	32.4	92.8	1.86
112	13.6	-15.7	0.6	29.4	91.7	2.12
96	13.6	-15.7	-0.6	29.4	91.7	2.12
27	-8.5	-29.1	0.0	29.1	92.2	2.17
28	8.9	-16.6	6.3	28.4	92.2	2.24
26	8.9	-16.6	-6.3	28.4	92.2	2.24
114	8.9	-19.4	1.6	28.4	93.0	2.27
98	8.9	-19.4	-1.6	28.4	93.0	2.27
115	8.7	-18.4	-1.5	27.3	93.0	2.41
99	8.7	-18.4	1.5	27.3	93.0	2.41
24	0.0	-26.7	0.0	26.7	91.3	2.41
21	8.1	-13.7	-5.2	24.1	90.4	2.75
23	8.1	-13.7	5.2	24.1	90.4	2.75
30	-21.3	-24.8	0.0	24.8	93.4	2.77
22	-7.2	-23.9	0.0	23.9	90.5	2.79
2	10.4	-12.5	0.0	22.9	88.1	2.84
95	6.8	-16.2	-2.7	23.6	91.7	2.89
111	6.8	-16.2	2.7	23.6	91.7	2.89
116	0.0	-22.6	0.0	22.7	91.1	3.02
100	0.0	-22.6	0.0	22.7	91.1	3.02
19	0.0	-21.1	0.0	21.1	89.1	3.23
121	0.1	-21.5	-0.2	21.5	92.5	3.29
105	0.1	-21.5	0.2	21.5	92.5	3.29
31	-18.1	-14.8	4.4	21.2	93.4	3.40
32	-18.1	-14.8	-4.4	21.2	93.4	3.40
113	-4.9	-19.8	-0.4	19.8	91.9	3.65
97	-4.9	-19.8	0.4	19.8	91.9	3.65
4	-10.9	-18.2	0.0	18.2	88.1	3.86
8	11.1	-7.1	0.0	18.2	90.5	3.96
37	-5.6	-17.6	-1.1	17.7	90.4	4.10
51	-5.6	-17.6	1.1	17.7	90.4	4.10
101	6.9	-9.9	2.0	17.2	91.9	4.33
117	6.9	-9.9	-2.0	17.2	91.9	4.33
49	4.2	-12.4	1.0	16.7	90.4	4.40
35	4.2	-12.4	-1.0	16.7	90.4	4.40
68	0.0	-15.7	0.0	15.7	91.1	4.82

Table 2.7.8.1-3 $P_m + P_b$ Stresses for Support Disk—30-Foot Side-Drop, 0° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-57.7	-58.0	31.8	89.6	133.5	0.49
123	-57.7	-58.0	-31.8	89.6	133.5	0.49
25	20.7	-22.2	-1.6	43.0	131.6	2.06
26	28.6	-9.7	-4.1	39.2	131.6	2.36
28	28.6	-9.7	4.1	39.2	131.6	2.36
20	18.4	-17.4	-1.4	35.8	129.1	2.60
23	25.1	-7.6	3.3	33.4	129.1	2.87
21	25.1	-7.6	-3.3	33.4	129.1	2.87
30	-21.3	-24.8	10.2	33.4	133.4	3.00
29	0.0	-32.4	0.0	32.4	132.6	3.09
27	-8.5	-29.1	-7.3	31.4	131.8	3.20
112	9.2	-21.7	0.1	30.9	131.0	3.24
96	9.2	-21.7	-0.1	30.9	131.0	3.24
115	10.6	-20.6	-1.3	31.3	132.8	3.25
99	10.6	-20.6	1.3	31.3	132.8	3.25
31	-23.7	-21.7	8.0	30.8	133.4	3.33
32	-23.7	-21.7	-8.0	30.8	133.4	3.33
111	13.4	-16.5	0.8	29.9	131.0	3.38
95	13.4	-16.5	-0.8	29.9	131.0	3.38
98	5.2	-23.1	-3.7	29.2	132.8	3.55
114	5.2	-23.1	3.7	29.2	132.8	3.55
24	0.0	-26.7	0.0	26.7	130.4	3.88
22	-7.2	-23.9	-6.4	26.0	129.3	3.97
37	-9.2	-23.6	-5.2	25.3	129.1	4.10
51	-9.2	-23.6	5.2	25.3	129.1	4.10
110	25.1	1.8	0.1	25.1	132.3	4.28
94	25.1	1.8	-0.1	25.1	132.3	4.28
117	24.4	0.5	1.8	24.5	131.3	4.35
101	24.4	0.5	-1.8	24.5	131.3	4.35
14	-20.9	-10.6	7.1	24.6	131.6	4.36
12	-20.9	-10.6	-7.1	24.6	131.6	4.36
100	-0.2	-24.1	0.0	24.1	130.1	4.41
116	-0.2	-24.1	0.0	24.1	130.1	4.41
2	10.4	-12.5	-0.8	23.0	125.9	4.47
113	-9.9	-22.1	-4.6	23.6	131.3	4.56
97	-9.9	-22.1	4.6	23.6	131.3	4.56
9	-18.3	-13.3	6.9	23.1	129.1	4.59
7	-18.3	-13.3	-6.9	23.1	129.1	4.59
4	-10.9	-18.2	6.7	22.1	125.9	4.69
121	-0.3	-23.2	-0.4	23.2	132.1	4.69

Table 2.7.8.1-4 P_m Stresses for Support Disk—30-Foot Side-Drop, 0° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-35.2	-28.2	18.6	50.6	94.5	0.87
123	-35.2	-28.2	-18.6	50.6	94.5	0.87
25	21.3	-22.6	0.0	43.9	94.5	1.15
20	18.9	-17.7	0.0	36.6	94.5	1.58
29	0.0	-33.0	0.0	33.0	94.5	1.86
27	-8.7	-29.7	0.0	29.7	94.5	2.19
28	9.2	-16.9	6.4	29.1	94.5	2.25
26	9.2	-16.9	-6.4	29.1	94.5	2.25
112	13.3	-15.6	0.5	28.9	94.5	2.27
96	13.3	-15.6	-0.5	28.9	94.5	2.27
114	9.2	-19.2	1.4	28.5	94.5	2.32
98	9.2	-19.2	-1.4	28.5	94.5	2.32
24	0.0	-27.3	0.0	27.3	94.5	2.46
115	8.7	-18.2	-1.5	27.1	94.5	2.49
99	8.7	-18.2	1.5	27.1	94.5	2.49
30	-21.4	-25.2	0.0	25.2	94.5	2.75
23	8.1	-14.0	5.4	24.5	94.5	2.85
21	8.1	-14.0	-5.4	24.5	94.5	2.85
22	-7.8	-24.4	0.0	24.4	94.5	2.87
2	11.2	-12.7	0.0	23.9	94.5	2.95
95	6.8	-16.0	-2.5	23.4	94.5	3.04
111	6.8	-16.0	2.5	23.4	94.5	3.04
116	0.0	-22.4	0.0	22.4	94.5	3.22
100	0.0	-22.4	0.0	22.4	94.5	3.22
19	0.0	-21.5	0.0	21.5	94.5	3.39
31	-18.2	-15.0	4.5	21.4	94.5	3.42
32	-18.2	-15.0	-4.5	21.4	94.5	3.42
121	0.1	-21.2	-0.2	21.3	94.5	3.43
105	0.1	-21.2	0.2	21.3	94.5	3.43
113	-4.7	-19.5	-0.4	19.6	94.5	3.83
97	-4.7	-19.5	0.4	19.6	94.5	3.83
8	11.6	-7.3	0.0	18.8	94.5	4.02
4	-11.7	-18.6	0.0	18.6	94.5	4.09
37	-5.2	-17.4	-1.1	17.5	94.5	4.40
51	-5.2	-17.4	1.1	17.5	94.5	4.40
101	6.9	-9.8	2.0	17.1	94.5	4.51
117	6.9	-9.8	-2.0	17.1	94.5	4.51
49	3.8	-12.4	1.1	16.3	94.5	4.79
35	3.8	-12.4	-1.1	16.3	94.5	4.79
11	-15.8	-9.1	0.0	15.8	94.5	4.98

Table 2.7.8.1-5 $P_m + P_b$ Stresses for Support Disk—30-Foot Side-Drop, 0° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-58.4	-59.7	32.7	91.7	135.0	0.47
123	-58.4	-59.7	-32.7	91.7	135.0	0.47
25	21.3	-22.6	-1.7	44.0	135.0	2.07
26	29.5	-9.9	-4.2	40.3	135.0	2.35
28	29.5	-9.9	4.2	40.3	135.0	2.35
20	18.9	-17.7	-1.5	36.7	135.0	2.68
23	25.8	-7.7	3.4	34.2	135.0	2.95
21	25.8	-7.7	-3.4	34.2	135.0	2.95
30	-21.4	-25.2	10.4	33.8	135.0	2.99
29	0.0	-33.0	0.0	33.0	135.0	3.09
27	-8.7	-29.7	-7.4	32.0	135.0	3.22
31	-23.8	-22.1	8.2	31.1	135.0	3.34
32	-23.8	-22.1	-8.2	31.1	135.0	3.34
115	10.4	-20.5	-1.3	31.0	135.0	3.36
99	10.4	-20.5	1.3	31.0	135.0	3.36
96	8.7	-21.8	0.0	30.4	135.0	3.43
112	8.7	-21.8	0.0	30.4	135.0	3.43
98	6.0	-22.7	-3.4	29.5	135.0	3.57
114	6.0	-22.7	3.4	29.5	135.0	3.57
95	12.9	-16.6	-0.7	29.5	135.0	3.58
111	12.9	-16.6	0.7	29.5	135.0	3.58
24	0.0	-27.3	0.0	27.3	135.0	3.95
22	-7.8	-24.4	-6.5	26.7	135.0	4.06
110	25.4	1.8	0.1	25.4	135.0	4.31
94	25.4	1.8	-0.1	25.4	135.0	4.31
37	-9.0	-23.8	-5.2	25.4	135.0	4.31
51	-9.0	-23.8	5.2	25.4	135.0	4.31
14	-21.5	-10.8	7.3	25.2	135.0	4.36
12	-21.5	-10.8	-7.3	25.2	135.0	4.36
117	24.2	0.6	1.8	24.4	135.0	4.54
101	24.2	0.6	-1.8	24.4	135.0	4.54
2	11.2	-12.7	-1.0	24.0	135.0	4.62
100	-0.2	-23.9	0.0	23.9	135.0	4.64
116	-0.2	-23.9	0.0	23.9	135.0	4.64
9	-19.0	-13.7	7.1	23.9	135.0	4.65
7	-19.0	-13.7	-7.1	23.9	135.0	4.65
113	-9.8	-22.1	-4.6	23.6	135.0	4.73
97	-9.8	-22.1	4.6	23.6	135.0	4.73
121	-0.3	-23.0	-0.4	23.1	135.0	4.86
105	-0.3	-23.0	0.4	23.1	135.0	4.86

Table 2.7.8.1-6 P_m Stresses for Support Disk—30-Foot Side-Drop, 18.22° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-15.5	-30.6	17.0	41.7	93.5	1.24
120	14.8	-19.3	10.4	39.9	93.0	1.33
112	15.1	-15.6	8.0	34.6	91.7	1.65
21	-3.9	-30.9	3.8	31.4	90.4	1.88
123	-27.2	-11.2	-10.4	32.3	93.5	1.89
35	16.2	-8.3	7.7	29.0	90.4	2.12
9	-2.5	-20.1	11.4	28.8	90.4	2.14
98	-5.7	-28.6	4.5	29.4	93.0	2.16
95	0.7	-26.3	4.1	28.2	91.7	2.25
29	-0.1	-28.2	0.5	28.2	92.8	2.29
37	-20.6	-18.3	7.4	26.9	90.4	2.36
25	8.2	-19.0	1.4	27.4	92.2	2.36
20	10.9	-14.6	3.1	26.3	90.4	2.44
27	-17.1	-25.2	-3.6	26.6	92.2	2.47
23	3.9	6.4	12.8	25.8	90.4	2.51
26	-8.4	-26.1	-0.4	26.1	92.2	2.53
51	11.7	-7.9	8.0	25.3	90.4	2.57
119	-0.1	-25.0	-0.6	25.0	92.6	2.70
22	-11.1	-20.4	-6.2	23.5	90.5	2.85
40	8.6	-12.3	5.8	23.9	92.2	2.86
24	-0.1	-23.0	0.8	23.0	91.3	2.97
114	-7.7	5.9	9.4	23.2	93.0	3.02
116	-0.1	-22.6	0.0	22.6	91.1	3.03
42	-14.7	-19.4	5.2	22.8	92.2	3.05
63	0.2	-14.5	8.1	21.8	91.7	3.20
30	-15.0	-21.3	2.1	21.9	93.4	3.26
28	-4.5	-5.0	10.6	21.2	92.2	3.34
64	-19.0	-10.2	4.8	21.1	91.7	3.35
115	3.1	-15.5	5.2	21.3	93.0	3.36
121	-0.7	-20.7	1.4	20.8	92.5	3.45
14	1.5	-2.7	10.1	20.6	92.2	3.47
49	-12.9	-9.2	8.5	19.7	90.4	3.58
72	-16.8	-12.7	5.1	20.2	93.0	3.60
31	-12.6	-18.0	4.2	20.3	93.4	3.60
2	7.6	-10.3	8.0	18.8	88.1	3.68
19	-0.1	-17.7	2.4	18.3	89.1	3.88
113	-9.0	-18.5	1.8	18.8	91.9	3.88
104	-11.3	-3.9	8.6	18.7	93.0	3.96
8	10.0	-5.4	-4.6	17.9	90.5	4.06
66	-2.0	-8.5	8.5	18.3	93.0	4.09

Table 2.7.8.1-7 $P_m + P_b$ Stresses for Support Disk—30-Foot Side-Drop, 18.22° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-50.3	-76.3	36.9	102.4	133.5	0.30
4	-55.2	-67.0	9.1	71.9	125.9	0.75
23	64.8	40.7	15.9	72.7	129.1	0.78
37	-46.9	-61.0	15.6	71.1	129.1	0.82
5	-61.3	-59.5	8.4	68.8	125.9	0.83
9	-55.9	-50.3	16.8	70.1	129.1	0.84
20	-36.8	-65.4	2.7	65.6	129.1	0.97
49	-42.2	-55.1	12.9	63.1	129.1	1.05
96	-36.4	-56.4	11.4	61.6	131.0	1.13
21	-35.8	-54.6	12.2	60.6	129.1	1.15
2	-37.6	-57.0	2.4	57.3	125.9	1.20
6	-50.4	-53.1	6.5	58.4	129.1	1.21
112	-14.5	-58.6	6.2	59.2	131.0	1.21
95	-33.0	-54.0	10.8	58.5	131.0	1.24
34	-48.9	-54.2	5.3	57.5	129.1	1.25
120	4.5	-51.5	8.6	58.6	132.8	1.27
51	-17.0	-54.4	6.1	55.4	129.1	1.33
64	-42.5	-42.0	11.7	54.0	131.0	1.43
63	-42.2	-41.5	12.0	53.8	131.0	1.44
42	-29.9	-46.1	11.9	52.4	131.6	1.51
48	-43.9	-50.3	2.1	50.9	129.1	1.53
28	-46.5	-25.7	11.7	51.8	131.6	1.54
35	43.1	33.3	11.5	50.7	129.1	1.55
111	44.2	32.7	11.0	50.9	131.0	1.58
1	-38.8	-48.5	1.9	48.8	125.9	1.58
22	26.8	-16.0	-12.6	49.6	129.3	1.60
50	-11.0	-47.0	-3.1	47.3	129.3	1.73
115	-13.1	-46.7	0.1	46.7	132.8	1.84
25	-17.2	-46.1	1.9	46.3	131.6	1.85
104	-26.7	-36.2	13.0	45.3	132.8	1.93
14	41.3	16.9	10.0	44.9	131.6	1.93
8	43.7	0.3	2.7	43.9	129.3	1.95
98	-25.2	-36.2	12.6	44.4	132.8	1.99
99	-22.2	-38.9	11.1	44.4	132.8	1.99
36	4.7	-42.4	-4.2	42.8	129.3	2.02
80	-17.4	-42.6	3.9	43.2	131.0	2.03
30	-20.7	-38.7	10.7	43.6	133.4	2.06
123	-33.9	-19.8	-14.4	42.9	133.5	2.11
72	-25.6	-33.1	12.3	42.2	132.8	2.15
39	-30.9	-39.1	4.4	41.0	131.6	2.21

Table 2.7.8.1-8 P_m Stresses for Support Disk—30-Foot Side-Drop, 18.22° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
120	15.5	-20.0	10.9	41.6	94.5	1.27
107	-13.9	-30.6	17.3	41.5	94.5	1.28
112	15.7	-16.1	8.5	36.1	94.5	1.62
21	-4.7	-32.8	4.5	33.5	94.5	1.82
123	-26.7	-10.5	-10.0	31.5	94.5	2.00
35	18.1	-8.4	8.0	31.0	94.5	2.05
9	-2.5	-21.3	12.0	30.5	94.5	2.10
98	-6.3	-28.6	5.0	29.7	94.5	2.19
95	0.6	-26.6	4.8	28.8	94.5	2.28
37	-21.7	-19.0	8.2	28.6	94.5	2.30
29	-0.1	-28.5	0.5	28.5	94.5	2.31
23	3.9	8.0	13.7	27.6	94.5	2.42
25	8.0	-19.3	1.3	27.4	94.5	2.45
51	14.1	-6.7	8.8	27.3	94.5	2.46
27	-17.7	-25.5	-3.8	27.0	94.5	2.50
26	-9.0	-26.6	0.0	26.6	94.5	2.55
20	10.9	-14.8	3.4	26.6	94.5	2.56
119	-0.1	-25.9	-0.6	25.9	94.5	2.64
40	9.1	-13.0	5.8	25.0	94.5	2.78
114	-8.3	6.7	9.9	24.7	94.5	2.82
22	-11.6	-20.7	-6.7	24.3	94.5	2.89
42	-14.5	-20.1	5.7	23.7	94.5	2.99
116	-0.1	-23.4	0.0	23.4	94.5	3.04
24	-0.1	-23.3	0.8	23.3	94.5	3.06
63	0.6	-15.1	8.5	23.1	94.5	3.09
28	-5.1	-5.0	11.1	22.2	94.5	3.26
30	-14.7	-21.5	2.3	22.2	94.5	3.26
115	3.1	-15.9	5.5	22.0	94.5	3.30
64	-19.6	-10.5	5.1	21.9	94.5	3.32
14	1.6	-2.9	10.5	21.4	94.5	3.41
121	-0.7	-21.3	1.5	21.4	94.5	3.42
49	-14.7	-8.9	8.9	21.2	94.5	3.46
72	-17.2	-13.5	5.2	20.8	94.5	3.54
31	-12.3	-18.6	4.3	20.8	94.5	3.55
104	-11.7	-3.6	9.0	19.7	94.5	3.80
2	8.3	-10.4	8.1	19.6	94.5	3.81
113	-9.6	-19.0	2.0	19.4	94.5	3.86
66	-2.0	-9.0	8.9	19.1	94.5	3.94
8	10.4	-5.4	-4.9	18.7	94.5	4.06
19	-0.1	-18.0	2.7	18.7	94.5	4.07

Table 2.7.8.1-9 $P_m + P_b$ Stresses for Support Disk—30-Foot Side-Drop, 18.22° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-51.1	-78.9	38.2	105.6	135.0	0.28
4	-60.5	-73.7	9.7	78.8	135.0	0.71
23	69.3	45.0	17.2	78.2	135.0	0.73
37	-50.2	-65.8	16.9	76.6	135.0	0.76
5	-66.9	-65.4	9.0	75.1	135.0	0.80
9	-59.2	-53.4	17.7	74.3	135.0	0.82
20	-41.1	-70.2	3.0	70.5	135.0	0.92
49	-45.9	-57.3	13.8	66.6	135.0	1.03
21	-40.4	-59.0	13.5	66.1	135.0	1.04
96	-40.1	-58.5	12.3	64.7	135.0	1.09
112	-16.1	-62.3	5.5	62.9	135.0	1.15
95	-36.9	-56.5	11.7	61.9	135.0	1.18
6	-53.6	-56.4	6.7	61.9	135.0	1.18
34	-52.1	-58.4	5.7	61.8	135.0	1.19
2	-41.4	-61.2	2.3	61.5	135.0	1.20
120	4.4	-54.1	9.0	61.2	135.0	1.21
51	-16.8	-57.3	6.0	58.2	135.0	1.32
64	-44.4	-43.9	12.3	56.4	135.0	1.39
63	-44.0	-43.5	12.5	56.3	135.0	1.40
42	-30.7	-49.1	12.5	55.4	135.0	1.44
28	-49.5	-26.9	12.3	54.9	135.0	1.46
35	46.6	35.4	12.3	54.5	135.0	1.48
111	46.7	35.5	11.8	54.1	135.0	1.50
48	-48.1	-52.9	2.2	53.8	135.0	1.51
22	-52.9	-25.4	-0.1	52.9	135.0	1.55
1	-42.9	-52.4	1.7	52.7	135.0	1.56
50	-10.1	-49.6	-3.8	49.9	135.0	1.70
115	-13.9	-48.8	0.0	48.8	135.0	1.76
25	-19.3	-47.9	1.9	48.0	135.0	1.81
14	43.3	17.8	10.4	47.0	135.0	1.87
8	46.7	0.7	-3.0	46.9	135.0	1.88
98	-28.0	-37.1	13.4	46.7	135.0	1.89
104	-27.5	-37.1	13.4	46.6	135.0	1.90
99	-24.5	-39.5	11.6	45.9	135.0	1.94
30	-21.1	-40.7	11.0	45.6	135.0	1.96
36	-4.1	-44.5	-4.9	45.1	135.0	1.99
80	-17.5	-43.9	3.8	44.4	135.0	2.04
72	-26.3	-34.3	12.7	43.6	135.0	2.10
39	-31.3	-41.5	4.5	43.2	135.0	2.13
27	-40.4	-26.8	4.8	41.9	135.0	2.22

Table 2.7.8.1-10 P_m Stresses for Support Disk—30-Foot Side-Drop, 26.28° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-12.2	-29.5	16.6	39.5	93.5	1.37
120	13.2	-17.2	10.8	37.3	93.0	1.49
21	-6.9	-31.5	4.1	32.1	90.4	1.81
112	12.3	-14.0	8.4	31.2	91.7	1.94
9	-3.7	-20.9	11.8	29.1	90.4	2.10
123	-25.4	-9.8	-9.5	29.9	93.5	2.13
98	-6.1	-27.3	5.1	28.5	93.0	2.26
35	14.4	-6.4	9.1	27.6	90.4	2.27
37	-23.2	-16.4	6.8	27.4	90.4	2.30
95	-1.4	-26.4	4.6	27.2	91.7	2.37
23	1.8	7.9	12.9	26.4	90.4	2.42
29	-0.2	-26.8	0.5	26.8	92.8	2.46
27	-17.5	-24.0	-3.8	25.8	92.2	2.58
26	-9.6	-25.7	0.0	25.7	92.2	2.59
25	7.4	-18.0	1.5	25.6	92.2	2.60
114	-9.0	7.0	9.5	24.8	93.0	2.75
51	12.1	-6.4	7.5	23.8	90.4	2.79
20	8.8	-13.8	3.4	23.7	90.4	2.82
22	-12.7	-19.4	-6.5	23.4	90.5	2.87
49	-15.5	-8.5	9.7	22.3	90.4	3.05
72	-19.4	-11.9	5.7	22.5	93.0	3.14
119	-0.1	-22.4	-0.6	22.4	92.6	3.14
64	-20.3	-8.4	5.1	22.2	91.7	3.14
24	-0.2	-21.8	0.8	21.8	91.3	3.18
40	4.3	-11.4	7.6	21.8	92.2	3.23
28	-5.1	-4.1	10.7	21.4	92.2	3.30
42	-15.8	-17.3	4.7	21.3	92.2	3.33
63	-1.2	-13.8	8.1	20.6	91.7	3.46
14	1.8	-2.0	10.1	20.6	92.2	3.48
30	-13.0	-20.0	2.5	20.8	93.4	3.50
116	-0.1	-20.2	0.0	20.2	91.1	3.52
31	-11.7	-18.0	4.0	20.0	93.4	3.68
111	-4.9	4.0	8.5	19.1	91.7	3.80
104	-11.2	-4.0	8.9	19.3	93.0	3.82
115	2.3	-13.8	5.3	19.3	93.0	3.83
121	-0.7	-18.6	1.4	18.7	92.5	3.94
66	-2.6	9.3	8.7	18.6	93.0	4.01
2	5.7	9.6	3.9	17.2	88.1	4.13
19	-0.2	-16.8	2.5	17.3	89.1	4.14
80	7.3	-6.2	5.6	17.5	91.7	4.25

Table 2.7.8.1-11 $P_m + P_b$ Stresses for Support Disk—30-Foot Side-Drop, 26.28° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-48.4	-76.3	36.9	101.8	133.5	0.31
9	-59.7	-52.8	17.5	74.1	129.1	0.74
4	-58.1	-65.5	8.6	71.2	125.9	0.77
3	-65.6	-59.0	8.1	71.0	125.9	0.77
23	63.1	42.6	16.1	71.9	129.1	0.80
37	-49.8	-58.0	15.4	69.9	129.1	0.85
49	-47.1	-59.3	14.7	69.1	129.1	0.87
20	-40.0	-66.3	3.3	66.7	129.1	0.94
2	-42.7	-62.1	3.6	62.7	125.9	1.01
21	-39.9	-55.8	13.1	63.2	129.1	1.04
96	-39.7	-56.9	12.2	63.2	131.0	1.07
6	-53.9	-55.7	6.5	61.3	129.1	1.10
95	-37.0	-54.8	11.7	60.6	131.0	1.16
112	-18.3	-59.1	5.7	59.9	131.0	1.19
34	-53.7	-52.5	4.9	58.1	129.1	1.22
63	-45.6	-42.8	12.3	56.6	131.0	1.32
48	-49.1	-54.0	3.2	55.6	129.1	1.32
64	-45.6	-42.7	12.1	56.3	131.0	1.33
1	-44.5	-52.8	3.3	54.0	125.9	1.33
35	43.8	40.8	12.8	55.2	129.1	1.34
120	1.7	-50.9	8.7	55.4	132.8	1.40
51	-16.8	-51.8	5.2	52.6	129.1	1.46
28	-47.9	-25.3	11.6	52.8	131.6	1.49
111	-51.0	-27.8	5.8	52.3	131.0	1.50
22	-50.9	-23.2	0.0	50.9	129.3	1.54
42	-31.2	-43.0	11.1	49.7	131.6	1.65
36	-9.6	-45.6	3.3	45.9	129.3	1.81
50	-11.5	-45.4	4.1	45.8	129.3	1.82
40	-14.4	-44.8	7.5	46.6	131.6	1.83
8	45.3	1.2	3.2	45.5	129.3	1.84
25	-19.3	-45.9	2.0	46.1	131.6	1.86
14	42.3	18.2	10.3	46.1	131.6	1.86
104	-26.9	-37.1	13.2	46.2	132.8	1.87
72	-28.9	-34.9	13.3	45.6	132.8	1.91
98	-27.7	-35.7	13.1	45.4	132.8	1.92
80	-17.8	-43.4	5.6	43.9	131.0	1.98
115	-13.7	-44.4	0.2	44.4	132.8	1.99
99	-24.2	-37.9	11.3	44.3	132.8	2.00
30	-19.7	-39.6	10.5	44.1	133.4	2.02
44	-39.1	-16.8	7.7	41.5	133.4	2.21

Table 2.7.8.1-12 P_m Stresses for Support Disk—30-Foot Side-Drop, 26.28° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
120	13.8	-17.8	11.4	38.9	94.5	1.43
107	-10.5	-28.7	16.7	38.6	94.5	1.45
21	-7.8	-33.5	4.7	34.3	94.5	1.75
112	12.7	-14.5	9.0	32.6	94.5	1.90
9	-3.5	-22.8	12.5	31.5	94.5	2.00
35	16.0	-6.5	9.7	29.7	94.5	2.18
37	-24.6	-17.1	7.6	29.3	94.5	2.22
123	-24.7	-9.1	-9.0	28.9	94.5	2.27
98	-6.9	-27.3	5.6	28.8	94.5	2.28
23	1.6	9.6	13.7	28.4	94.5	2.32
95	-1.6	-26.8	5.2	27.8	94.5	2.40
29	-0.2	-27.0	0.6	27.1	94.5	2.49
114	-9.6	7.8	9.9	26.4	94.5	2.58
27	-18.1	-24.2	-3.9	26.1	94.5	2.62
26	-10.2	-26.0	0.3	26.1	94.5	2.63
51	14.4	-5.3	8.3	25.7	94.5	2.68
25	7.1	-18.2	1.4	25.4	94.5	2.72
49	-17.6	-8.2	10.4	24.3	94.5	2.89
22	-13.2	-19.6	-7.1	24.2	94.5	2.90
20	8.7	-14.0	3.7	23.8	94.5	2.97
119	-0.1	-23.1	-0.6	23.1	94.5	3.08
72	-19.4	-12.5	6.1	23.0	94.5	3.11
40	4.5	-12.0	7.9	22.9	94.5	3.13
64	-20.6	-8.6	5.6	22.8	94.5	3.14
63	-0.5	-15.2	8.6	22.6	94.5	3.18
28	-5.8	-4.1	11.2	22.4	94.5	3.21
42	-15.9	-17.9	5.1	22.1	94.5	3.27
24	-0.2	-22.0	0.8	22.0	94.5	3.29
14	2.0	-2.1	10.5	21.3	94.5	3.43
116	-0.1	-21.0	0.0	21.0	94.5	3.51
30	-12.6	-20.1	2.7	20.9	94.5	3.51
111	-5.5	4.7	9.0	20.7	94.5	3.57
31	-11.4	-18.6	4.1	20.5	94.5	3.62
104	-11.6	-3.7	9.3	20.3	94.5	3.66
115	2.3	-14.2	5.6	19.9	94.5	3.75
66	-2.5	-9.7	9.0	19.4	94.5	3.88
121	-0.8	-19.2	1.4	19.3	94.5	3.89
80	8.8	-5.7	6.1	18.9	94.5	3.99
8	9.3	-5.0	-5.4	17.9	94.5	4.27
2	6.2	-9.7	4.1	17.9	94.5	4.28

Table 2.7.8.1-13 $P_m + P_b$ Stresses for Support Disk—30-Foot Side-Drop, 26.28° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-49.0	-77.8	37.9	103.9	135.0	0.30
9	-63.4	-57.0	18.7	79.2	135.0	0.71
4	-63.9	-72.0	9.2	77.9	135.0	0.73
3	-72.0	-64.9	8.6	77.7	135.0	0.74
23	67.5	46.9	17.4	77.4	135.0	0.75
37	-53.8	-62.9	16.7	75.6	135.0	0.79
49	-51.5	-62.7	15.9	74.0	135.0	0.83
20	-44.5	-71.2	3.6	71.7	135.0	0.88
21	-44.6	-60.4	14.4	68.9	135.0	0.96
2	-47.6	-67.7	5.8	68.4	135.0	0.97
96	-43.5	-59.2	13.1	66.6	135.0	1.03
6	-57.4	-60.3	6.8	65.8	135.0	1.05
95	-40.9	-57.5	12.6	64.2	135.0	1.10
112	-20.1	-63.0	6.1	63.8	135.0	1.12
34	-57.8	-56.9	5.3	62.6	135.0	1.16
35	47.8	44.4	13.8	60.0	135.0	1.25
63	-47.5	-45.9	13.0	59.8	135.0	1.26
64	-47.8	-45.9	12.8	59.7	135.0	1.26
48	-54.0	-57.5	3.5	59.7	135.0	1.26
1	-49.7	-57.9	3.4	59.2	135.0	1.28
120	1.5	-53.5	9.1	58.0	135.0	1.33
51	45.7	44.1	11.4	56.3	135.0	1.40
111	-54.7	-29.3	6.1	56.1	135.0	1.41
28	-50.8	-26.5	12.2	55.9	135.0	1.42
22	-54.8	-23.6	-0.5	54.8	135.0	1.46
42	-32.5	-45.9	11.7	52.7	135.0	1.56
36	-9.8	-48.9	-3.9	49.3	135.0	1.74
40	-15.3	-47.3	7.9	49.1	135.0	1.75
8	48.7	1.0	-3.6	49.0	135.0	1.75
50	-11.1	-48.0	-4.8	48.6	135.0	1.77
14	44.2	19.0	10.7	48.1	135.0	1.81
72	-29.8	-37.2	14.0	48.0	135.0	1.82
104	-27.9	-38.3	13.7	47.8	135.0	1.83
98	-30.4	-36.6	13.9	47.7	135.0	1.83
25	-21.5	-47.5	2.0	47.6	135.0	1.83
115	-14.6	-46.5	0.2	46.5	135.0	1.90
80	-18.3	-45.9	8.7	46.3	135.0	1.91
30	-19.9	-41.7	10.8	46.1	135.0	1.93
99	-26.5	-38.5	11.9	45.8	135.0	1.95
79	34.7	36.0	8.4	43.8	135.0	2.08

Table 2.7.8.1-14 P_m Stresses for Support Disk—30-Foot Side-Drop, 45° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-2.5	-21.4	14.1	33.8	93.5	1.76
37	-29.1	-12.0	4.8	30.3	90.4	1.98
21	-12.0	-29.1	4.8	30.3	90.4	1.98
9	-5.9	-22.3	12.3	29.5	90.4	2.06
49	-22.2	-5.9	12.3	29.5	90.4	2.06
76	-26.6	-10.4	7.2	29.4	93.5	2.18
114	-12.0	9.5	9.9	29.2	93.0	2.18
120	9.4	-12.0	9.9	29.2	93.0	2.19
35	9.3	-2.5	12.3	27.3	90.4	2.31
23	-2.5	9.3	12.3	27.3	90.4	2.31
72	-22.5	-7.6	7.0	25.3	93.0	2.68
98	-7.7	-22.4	6.9	25.2	93.0	2.69
64	-22.8	-5.0	5.8	24.5	91.7	2.75
95	-5.0	-22.8	5.7	24.5	91.7	2.75
111	-9.8	7.8	8.4	24.3	91.7	2.77
112	7.8	-9.7	8.4	24.3	91.7	2.77
42	-22.8	-12.2	1.6	23.0	92.2	3.00
26	-12.3	-22.8	1.6	23.0	92.2	3.01
41	-19.5	-17.5	-4.0	22.6	92.2	3.07
27	-17.5	-19.4	-4.0	22.6	92.2	3.08
40	-1.8	-6.9	10.9	22.4	92.2	3.12
28	-6.9	-1.8	10.9	22.3	92.2	3.13
36	-15.7	-14.6	-6.7	21.8	90.5	3.15
22	-14.5	-15.7	-6.6	21.8	90.5	3.16
123	-19.5	-5.2	-6.3	21.9	93.5	3.27
43	-21.7	-0.3	0.8	21.7	92.8	3.28
124	-5.8	-18.7	-7.1	21.8	93.5	3.29
29	-0.3	-21.6	0.8	21.6	92.8	3.29
54	-0.1	2.5	9.8	19.8	92.2	3.65
14	2.5	0.0	9.8	19.8	92.2	3.66
46	-18.8	-8.9	3.7	20.0	93.4	3.66
63	-3.7	-13.1	8.4	19.2	91.7	3.78
96	-13.1	-3.7	8.3	19.1	91.7	3.80
7	-1.7	13.3	5.6	18.7	90.4	3.83
51	13.2	-1.8	5.5	18.6	90.4	3.85
31	-8.8	-18.1	3.5	19.2	93.4	3.86
39	-14.4	4.3	1.5	18.9	92.2	3.87
25	4.2	-14.4	1.5	18.8	92.2	3.90
66	-4.0	-10.1	8.8	18.6	93.0	3.99
104	-10.1	-3.8	8.7	18.5	93.0	4.03

Table 2.7.8.1-15 $P_m \pm P_b$ Stresses for Support Disk—30-Foot Side-Drop, 45° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-42.9	-69.4	34.5	93.1	133.5	0.43
49	-57.5	-66.6	18.7	81.3	129.1	0.59
9	-66.5	-57.5	18.7	81.2	129.1	0.59
2	-54.0	-73.3	6.8	75.4	125.9	0.67
3	-73.2	-53.9	6.7	75.3	125.9	0.67
1	-57.2	-62.3	7.0	67.1	125.9	0.88
4	-62.2	-57.1	6.9	67.0	125.9	0.88
35	43.8	57.6	15.3	67.5	129.1	0.91
23	57.4	43.7	15.3	67.3	129.1	0.92
48	-60.7	-60.2	6.1	66.6	129.1	0.94
6	-60.2	-60.8	6.1	66.6	129.1	0.94
37	-54.7	-47.1	14.0	65.4	129.1	0.97
21	-47.2	-54.7	14.0	65.4	129.1	0.97
34	-63.2	-45.4	3.8	64.0	129.1	1.02
20	-45.4	-63.1	3.8	63.9	129.1	1.02
63	-52.3	-45.9	13.1	62.6	131.0	1.09
96	-45.8	-52.3	13.1	62.5	131.0	1.10
64	-51.9	-44.8	12.8	61.7	131.0	1.13
95	-44.7	-51.8	12.8	61.6	131.0	1.13
76	-59.9	-53.9	4.6	62.4	133.5	1.14
111	-54.8	-22.9	5.9	55.9	131.0	1.35
40	-24.4	-51.9	11.5	56.1	131.6	1.35
112	-22.8	-54.7	5.9	55.8	131.0	1.35
28	-51.8	-24.4	11.5	56.0	131.6	1.35
36	-20.8	-52.9	-0.6	52.9	129.3	1.44
22	-52.9	-20.7	-0.6	52.9	129.3	1.45
50	3.3	48.2	-4.3	48.6	129.3	1.66
8	48.2	3.2	-4.4	48.6	129.3	1.66
7	37.3	40.7	9.1	48.2	129.1	1.68
51	40.5	37.1	9.1	48.1	129.1	1.69
72	-33.1	-35.3	14.4	48.6	132.8	1.73
98	-35.1	-33.1	14.4	48.6	132.8	1.73
14	43.3	21.0	10.7	47.6	131.6	1.76
54	20.9	43.3	10.7	47.6	131.6	1.76
79	37.2	38.6	9.2	47.1	131.0	1.78
80	38.6	37.2	9.2	47.1	131.0	1.78
44	-43.4	-16.5	10.1	46.7	133.4	1.85
30	-16.1	-43.2	10.1	46.6	133.4	1.86
39	-43.8	-26.6	2.2	44.1	131.6	1.99
25	-26.6	-43.8	2.2	44.0	131.6	1.99

Table 2.7.8.1-16 P_m Stresses for Support Disk—30-Foot Side-Drop, 45° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-0.8	-20.4	14.0	34.2	94.5	1.76
37	-30.9	-12.7	5.4	32.4	94.5	1.91
21	-12.8	-30.9	5.5	32.4	94.5	1.92
9	-5.6	-24.6	13.1	32.3	94.5	1.92
49	-24.6	-5.6	13.1	32.3	94.5	1.93
114	-12.6	10.2	10.5	30.9	94.5	2.06
120	10.1	-12.6	10.4	30.8	94.5	2.07
35	10.8	-2.6	13.1	29.5	94.5	2.20
23	-2.6	10.8	13.1	29.4	94.5	2.21
76	-25.1	-9.3	6.7	27.6	94.5	2.43
111	-10.4	8.3	9.0	25.9	94.5	2.65
112	8.3	-10.3	8.9	25.9	94.5	2.65
72	-22.4	-8.3	7.5	25.7	94.5	2.68
98	-8.4	-22.4	7.5	25.6	94.5	2.69
64	-23.0	-5.2	6.4	25.1	94.5	2.77
95	-5.2	-23.0	6.4	25.1	94.5	2.77
42	-23.1	-12.9	2.0	23.5	94.5	3.03
26	-12.9	-23.1	2.0	23.4	94.5	3.03
40	-1.9	-7.6	11.4	23.4	94.5	3.03
28	-7.6	-1.8	11.4	23.4	94.5	3.03
41	-19.7	-18.1	-4.1	23.1	94.5	3.10
27	-18.1	-19.6	-4.1	23.0	94.5	3.10
36	-15.9	-15.0	-7.2	22.7	94.5	3.17
22	-15.0	-15.9	-7.2	22.6	94.5	3.18
43	-21.9	-0.3	0.9	21.9	94.5	3.31
29	-0.3	-21.8	0.9	21.9	94.5	3.32
63	-2.8	-14.8	8.9	21.5	94.5	3.40
96	-14.8	-2.8	8.9	21.4	94.5	3.41
123	-18.8	-4.5	-5.9	20.9	94.5	3.53
124	-5.0	-17.8	-6.8	20.7	94.5	3.56
46	-19.5	-8.5	3.8	20.7	94.5	3.57
54	-0.1	2.8	10.2	20.5	94.5	3.60
14	2.8	0.0	10.2	20.5	94.5	3.60
7	-0.5	15.7	6.2	20.4	94.5	3.63
51	15.6	-0.6	6.2	20.4	94.5	3.64
31	-8.5	-18.8	3.6	19.9	94.5	3.76
80	12.3	-2.6	6.5	19.7	94.5	3.80
79	-2.6	12.3	6.4	19.7	94.5	3.80
66	-3.9	-10.5	9.1	19.5	94.5	3.86
104	-10.5	-3.7	9.0	19.3	94.5	3.89

Table 2.7.8.1-17 $P_m + P_b$ Stresses for Support Disk—30-Foot Side-Drop, 45° Orientation, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
107	-43.5	-70.4	35.1	94.6	135.0	0.43
49	-62.4	-70.6	20.1	87.0	135.0	0.55
9	-70.5	-62.4	20.1	87.0	135.0	0.55
2	-59.6	-80.2	7.1	82.4	135.0	0.64
3	-80.1	-59.5	7.1	82.3	135.0	0.64
1	-63.1	-68.3	7.4	73.5	135.0	0.84
4	-68.3	-63.0	7.3	73.4	135.0	0.84
35	48.0	61.9	16.6	72.9	135.0	0.85
23	61.8	47.9	16.5	72.8	135.0	0.86
6	-64.2	-66.1	6.5	71.8	135.0	0.88
48	-66.1	-64.2	6.5	71.7	135.0	0.88
37	-59.0	-51.8	15.3	71.1	135.0	0.90
21	-51.9	-59.0	15.3	71.1	135.0	0.90
34	-67.8	-49.8	4.1	68.7	135.0	0.96
20	-49.8	-67.7	4.1	68.6	135.0	0.97
63	-54.4	-49.6	14.0	66.2	135.0	1.04
96	-49.6	-54.4	13.9	66.1	135.0	1.04
64	-54.3	-48.7	13.7	65.5	135.0	1.06
95	-48.6	-54.2	13.7	65.4	135.0	1.06
76	-59.6	-55.7	3.6	61.8	135.0	1.18
111	-58.5	-24.5	6.2	59.6	135.0	1.26
112	-24.5	-58.4	6.2	59.5	135.0	1.27
40	-25.8	-54.9	12.1	59.3	135.0	1.28
28	-54.9	-25.7	12.1	59.3	135.0	1.28
36	-21.3	-56.8	-1.0	56.8	135.0	1.38
22	-56.8	-21.3	-1.0	56.8	135.0	1.38
7	42.3	45.4	10.6	54.6	135.0	1.47
51	45.3	42.2	10.6	54.4	135.0	1.48
50	2.7	52.0	-4.9	52.5	135.0	1.57
8	52.0	2.7	-4.9	52.5	135.0	1.57
80	42.4	41.1	10.3	52.1	135.0	1.59
79	41.1	42.4	10.3	52.1	135.0	1.59
72	-34.0	-38.1	15.2	51.3	135.0	1.63
98	-37.9	-34.0	15.2	51.3	135.0	1.63
14	45.3	21.9	11.1	49.8	135.0	1.71
54	21.8	45.3	11.1	49.7	135.0	1.72
44	-45.6	-16.6	10.4	49.0	135.0	1.76
30	-16.2	-45.5	10.4	48.8	135.0	1.76
120	2.4	45.3	7.8	46.7	135.0	1.89
114	45.1	2.7	7.8	46.5	135.0	1.90

Table 2.7.8.1-18 Summary of Stress Evaluation of Support Disk—30-Ft End-Drop

Table Number	g-Load	Thermal Case	Stress Evaluation	Minimum Margin of Safety
2.7.8.1-19	60	A	P_m+P_b	+4.63
2.7.8.1-20	60	B	P_m+P_b	+4.78

Table 2.7.8.1-19 P_m+P_b Stresses for Support Disk—30-Ft End-Drop, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
40	6.1	-17.3	0.7	23.4	131.6	4.63
42	6.1	-17.3	-0.7	23.4	131.6	4.63
54	6.1	-17.3	-0.7	23.4	131.6	4.63
56	6.1	-17.3	0.7	23.4	131.6	4.63
12	-17.2	6.1	0.7	23.4	131.6	4.64
14	-17.2	6.1	-0.7	23.4	131.6	4.64
26	-17.2	6.1	-0.7	23.4	131.6	4.64
28	-17.2	6.1	0.7	23.4	131.6	4.64
39	7.9	-11.2	0.0	19.1	131.6	5.91
53	7.9	-11.2	0.0	19.1	131.6	5.91
11	-11.2	7.9	0.0	19.0	131.6	5.91
25	-11.2	7.9	0.0	19.0	131.6	5.91
67	5.1	15.4	6.8	18.7	132.8	6.09
83	5.1	15.4	-6.8	18.7	132.8	6.09
99	5.1	15.4	6.8	18.7	132.8	6.09
115	5.1	15.4	-6.8	18.7	132.8	6.09
74	15.1	4.7	6.9	18.6	132.8	6.15
106	15.1	4.7	6.9	18.6	132.8	6.15
90	15.1	4.7	-6.9	18.6	132.8	6.15
122	15.1	4.7	-6.9	18.6	132.8	6.15
55	6.7	-10.4	0.0	17.1	131.8	6.70
41	6.7	-10.4	0.0	17.1	131.8	6.70
27	-10.4	6.7	0.0	17.1	131.8	6.71
13	-10.4	6.7	0.0	17.1	131.8	6.71
82	10.2	9.6	-6.1	16.0	132.8	7.31
114	10.2	9.6	-6.1	16.0	132.8	7.31
98	10.2	9.6	6.1	16.0	132.8	7.31
66	10.2	9.6	6.1	16.0	132.8	7.31
72	9.6	10.2	6.0	15.9	132.8	7.34
104	9.6	10.2	6.0	15.9	132.8	7.34
120	9.6	10.2	-6.0	15.9	132.8	7.34
88	9.6	10.2	-6.0	15.9	132.8	7.34
5	0.0	-15.2	0.0	15.2	127.3	7.39
19	0.0	-15.2	0.0	15.2	127.3	7.39
33	-15.2	0.0	0.0	15.2	127.3	7.39
47	-15.2	0.0	0.0	15.2	127.3	7.39
2	-9.1	-14.6	0.0	14.6	125.9	7.61
4	-9.1	-14.6	0.0	14.6	125.9	7.61
3	-14.6	-9.1	0.0	14.6	125.9	7.61
1	-14.6	-9.1	0.0	14.6	125.9	7.61

Table 2.7.8.1-20 P_m+P_b Stresses for Support Disk—30-Foot End-Drop, Thermal Case B

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
40	6.0	-17.3	0.7	23.4	135.0	4.78
42	6.0	-17.3	-0.7	23.4	135.0	4.78
54	6.0	-17.3	-0.7	23.4	135.0	4.78
56	6.0	-17.3	0.7	23.4	135.0	4.78
12	-17.3	6.0	0.7	23.3	135.0	4.79
14	-17.3	6.0	-0.7	23.3	135.0	4.79
26	-17.3	6.0	-0.7	23.3	135.0	4.79
28	-17.3	6.0	0.7	23.3	135.0	4.79
39	7.7	-11.2	0.0	18.9	135.0	6.13
53	7.7	-11.2	0.0	18.9	135.0	6.13
11	-11.2	7.7	0.0	18.9	135.0	6.14
25	-11.2	7.7	0.0	18.9	135.0	6.14
67	5.0	15.3	6.7	18.6	135.0	6.26
83	5.0	15.3	-6.7	18.6	135.0	6.26
99	5.0	15.3	6.7	18.6	135.0	6.26
115	5.0	15.3	-6.7	18.6	135.0	6.26
74	15.0	4.6	6.8	18.4	135.0	6.33
106	15.0	4.6	6.8	18.4	135.0	6.33
90	15.0	4.6	-6.8	18.4	135.0	6.33
122	15.0	4.6	-6.8	18.4	135.0	6.33
55	6.7	-10.4	0.0	17.1	135.0	6.91
41	6.7	-10.4	0.0	17.1	135.0	6.91
27	-10.4	6.6	0.0	17.0	135.0	6.93
13	-10.4	6.6	0.0	17.0	135.0	6.93
82	10.2	9.5	-6.0	15.9	135.0	7.51
114	10.2	9.5	-6.0	15.9	135.0	7.51
98	10.2	9.5	6.0	15.9	135.0	7.51
66	10.2	9.5	6.0	15.9	135.0	7.51
72	9.5	10.2	6.0	15.8	135.0	7.54
104	9.5	10.2	6.0	15.8	135.0	7.54
120	9.5	10.2	-6.0	15.8	135.0	7.54
88	9.5	10.2	-6.0	15.8	135.0	7.54
19	0.0	-15.6	0.0	15.6	135.0	7.64
33	-15.6	0.0	0.0	15.6	135.0	7.64
5	0.0	-15.6	0.0	15.6	135.0	7.64
47	-15.6	0.0	0.0	15.6	135.0	7.64
1	-15.0	-9.4	0.0	15.0	135.0	8.00
2	-9.4	-15.0	0.0	15.0	135.0	8.00
3	-15.0	-9.4	0.0	15.0	135.0	8.00
4	-9.4	-15.0	0.0	15.0	135.0	8.00

Table 2.7.8.1-21 Summary of Stress Evaluation of Support Disk—30-Ft Off-Angle Drop

Thermal Case	Section Number	Drop Angle	Basket Angle	P (kip)	P_{cr} (kip)	M (in-kip)	M_p (in-kip)	M_m (in-kip)	MS1	MS2
A	19	45.0	0.0	11.2	56.5	2.0	8.0	7.1	1.14	1.59
B	29	70.0	0.0	23.3	67.2	0.5	9.8	8.5	1.46	1.97

2.7.8.2 Stress Evaluation of Tie Rods and Spacers

The structural adequacy of the tie rods and spacers in the PWR basket is evaluated following a free drop of the Universal Transport Cask of 30 feet onto a flat, unyielding surface. The design deceleration for the cask for the hypothetical accident 30-ft end-drop is 60 *g*.

The structural capacity of the spacers supporting the basket is evaluated by hand calculations using classical analysis. In accordance with Section III, Subsection NG of the ASME Code [19], accident loading resulting from the 30-ft drop of the fuel basket is compared to the stress limit of 0.7 S_u.

The tie rods serve basket assembly purposes and are not part of the load path for the condition evaluated. The tie rods are loaded during fabrication by a 190 ft-lb preload. Under drop conditions, the preload is reduced. The tie rod design is, therefore, acceptable by inspection, and no detailed evaluation of the rods is required.

During the end drop, the spacers are loaded with the weight of support disks, the aluminum heat transfer disks, one end plate, and their own weight. The load is resisted by the effective area of eight spacers. The compressive stresses are calculated on the effective area of the spacer.

The material allowable stress is conservatively selected at a bounding temperature of 500°F. The temperature near the outer edge of the support disks is below 500°F.

2.7.8.2.1 Design Criteria

Stress limits	=	0.7 S_u (accident condition) (more limiting than 2.4 S_m)
Loading criteria (g)	=	60 *g* (accident condition)
Evaluation temperature	=	500°F

Basket Parameters

Fuel basket weight	=	16,489 lb
Bottom weldment weight	=	527 lb
Fuel tube weight (24 tubes)	=	3,676 lb
Rod diameter	=	1.625 in.
Spacer OD	=	3.0 in.

Materials [21]

Tie rod	=	SA 479 Type 304 Stainless Steel
Spacer	=	SA 479 Type 304 Stainless Steel

Material Allowables

Type 304 stainless steel [21]	=	S_m = 17,500 psi (500°F)
	=	S_u = 63,500 psi (500°F)

2.7.8.2.2 30-Foot End-Drop Condition - Results

The deceleration assumed for the PWR basket in the 30-ft end-drop is 60 *g*. The spacers are loaded with the weight of the support disks, the aluminum heat transfer disks, one end plate and their own weight. These loads are calculated as follows:

Total weight of basket	=	16,489 lb
Less weight of bottom weldment	=	-527 lb
Less weight of fuel tubes	=	-3,676 lb
1 g-load on spacers	=	12,286 lb
Applied g level	=	60 *g*

Therefore,

Accident condition

load on spacers = 12,186 × 60 = 737,160 lb

The effective area of one spacer at each of eight locations supporting the weight of the support disks is equal to the net area of the spacer and is calculated as

$$A = \frac{3.14 \times (3.0^2 - 1.75^2)}{4} = 4.66 \text{ in}^2.$$

The average compressive stress, S_c, in the spacer is

$$S_c = \frac{737{,}160}{8 \times 4.66} = 19{,}774 \text{ psi.}$$

The allowable stress for SA479, Type 304 SS under accident conditions is 0.7 S_u:

$$S_u = 63{,}500 \text{ psi}$$

$$0.7\ S_u = 0.7 \times 63{,}500 = 44{,}450 \text{ psi.}$$

The margin of safety, which is defined as $\frac{0.7S_u}{S_c} - 1$, is calculated as

$$MS = \frac{44{,}450}{19{,}774} - 1 = +1.24$$

Therefore, the spacers are structurally adequate for a 60 g end impact under accident conditions.

2.7.8.3 Buckling Evaluation of Support Disk

During the impact following a 30-ft side drop of the Universal Transport Cask onto an unyielding surface, the support disk is subjected to compressive loading and bending moments in the plane of the disk. For cask impact orientations other than on the side, loads acting perpendicular to the plane of the support disk (out-of-plane) may also be applied. The compressive in-plane loadings in conjunction with the bending moments resulting from in-plane or out-of-plane loadings require that buckling of the support disk be a design consideration.

Buckling of the support disk is evaluated in accordance with the methods and acceptance criteria of NUREG/CR-6322 [16]. The support disk is constructed of SA-693, Type 630, 17-4 PH stainless steel plate. The properties are evaluated at the actual temperature of the linearized cross sections where buckling evaluations are performed.

2.7.8.3.1 Support Disk Buckling Analysis

The buckling evaluation of the support disk web is based on the Interaction Equations 31 and 32 in NUREG/CR-6322. These two equations adopt the "Limit Analysis Design" approach for structural members subjected to stresses beyond the yield limit of the material, i.e., for members deformed elastically as a result of both axial load and bending moment. Other equations applicable to the calculations are listed later in this section.

The maximum forces and moments are determined for the end-drop condition and for four different radial orientations of the support disk for the side-drop condition based on the finite element analysis results. The forces and moments for the cask oblique drop conditions are determined from the end and side drop results based on the drop angle. The buckling evaluations account for both in-plane (about the strong axis of the web) and out-of-plane (about the weak axis of the web) buckling modes. Evaluation for strong axis buckling is performed only for the side drop condition since it is the governing case. Evaluation for weak axis buckling is performed for all end drops and oblique drops (0°, 23°, 30°, 40°, 45°, 50°, 60°, 70°, 75°, 80°, 85°, and 88°).

Detailed buckling calculations are performed using ANSYS macros. The methodology and equations used in the calculations are those from NUREG/CR-6322. The load amplification factors used are 60 g for 30-ft end-drop, 30-ft side-drop, and 30-ft oblique drop conditions. The buckling evaluation is performed for each of the sections identified Figures 2.6.13.2-3 and 2.6.13.2-4.

The buckling evaluation methodology/equations are summarized as:

Symbols and Units

P = applied axial compressive load, kips

M = moment, kips-in.

P_a = allowable axial compressive load, kips

P_{cr} = critical axial compression load, kips

P_e = Euler buckling loads, kips

P_y = plastic axial load, equal to profile area times specified minimum yield stress, kips (for normal operating condition)

C_c = column slenderness ratio separating elastic and inelastic buckling

C_m = coefficient applied to bending term in interaction equation

M_m = critical moment that can be resisted by a plastically designed member in the absence of axial load, kip-in.

M_p = plastic moment, kip-in.

F_a = axial compressive stress permitted, ksi

F_e = Euler stress for a prismatic member divided by factor of safety, ksi

k = ratio of effective column length to actual unbraced length

l = unbraced length of member, in.

r = radius of gyration, in.

S_y = yield stress allowable, ksi

A = area of the ligament, in^2

Z_x = plastic section modulus with respect to the major axis, in^3

Σ = allowable reduction factor, dimensionless

From NUREG/CR-6322, the following equations are used to evaluate the support disk:

$$\frac{P}{P_{cr}} + \frac{C_m M}{M_m \left[1 - \frac{P}{P_e}\right]} \leq 1.0$$

$$\frac{P}{P_y} + \frac{M}{1.18\, M_p} \leq 1.0$$

where:

P_{cr} = $1.7 \times A \times F_a$

$$F_a = \frac{P_a}{A} \text{ for } P_a = P_y \left[\frac{1 - \frac{\lambda^2}{4}}{1.11 + 0.5\lambda + 0.17\lambda^2 - 0.28\lambda^3} \right] \text{ and } \lambda = \frac{1}{\pi}\left(\frac{kl}{r}\right)\sqrt{\frac{S_y}{E}}$$

$$P_e = 1.92 \times A \times F_e$$

$$F_e = \frac{\pi^2 \cdot E}{1.92\left(\frac{k \cdot l}{r}\right)^2} \text{ (non-austenitic)}$$

$$F_e = \frac{\pi^2 \cdot E}{1.3\left(\frac{k \cdot l^2}{r}\right)} \text{ (austenitic)}$$

$$P_y = S_y \times A$$

C_m = 0.85 for members with joint translation (sideways).

$$M_p = S_y \times Z_x$$

$$M_m = M_p \cdot \left(1.07 - \frac{\left(\frac{l}{r}\right) \cdot \sqrt{S_y}}{3160}\right) \le M_p$$

Load Conditions

A buckling evaluation is performed at all sections defined in Figures 2.6.13.2-3 and 2.6.13.2-4. Using the same method described in Section 2.6.13.14, the corresponding force (P) and the bending moment (M) are determined and applied to Equations 31 and 32 of NUREG/CR-6322.

Using the cross-sectional stresses calculated at each of the sections located in the web for each loading condition, the maximum corresponding compressive forces are combined with the maximum out-of-plane moment resulting from the 20 *g* and 60 *g* end-drop conditions to obtain the conservative maximum interaction coefficients. The equations used in the buckling analysis are:

$$P_1 = P/P_{cr} \quad M_1 = \frac{C_m M}{(1 - P/P_e) M_m} \quad (P_1 + M_1 \leq 1) \quad \text{(Eq. 31, NUREG/CR-6322)}$$

and

$$P_2 = P/P_y \; M_2 = \frac{M}{1.18\, M_p} \quad (P_1 + M_1 \leq 1) \quad \text{(Eq. 32, NUREG/CR-6322)}$$

The margins of safety are calculated as:

$$MS1 = \frac{1}{P_1 + M_1} - 1 \qquad \text{(based on Eq. 31, NUREG/CR-6322)}$$

and

$$MS2 = \frac{1}{P_2 + M_2} - 1$$ (based on Eq. 32, NUREG/CR-6322)

The following table summarizes the minimum buckling margins of safety for each stress category and thermal case for the accident conditions.

Loading Condition	Stress State*	Thermal Case	Section Number	Drop Angle	Basket Angle	P (kip)	P_{cr} (kip)	M (in-kip)	M_p' (in-kip)	M_m' (in-kip)	MS1	MS2
Strong Axis Buckling												
Accident	P	A	2	90.00	45.00	5.6	81.8	12.3	23.6	23.6	0.94	0.88
	P+Q	A	2	90.00	45.00	9.2	81.8	11.0	23.6	23.6	0.95	0.85
	P	B	107	90.00	0.00	13.0	40.8	1.1	7.2	6.7	1.13	1.18
	P+Q	B	107	90.00	0.00	13.0	40.8	1.1	7.2	6.7	1.12	1.17
Weak Axis Buckling												
Accident	P	A	107	80.00	0.00	12.9	29.6	0.0	4.2	3.7	1.22	1.56
	P+Q	A	29	85.00	0.00	27.2	59.6	0.0	8.5	7.4	1.17	1.48
	P	B	107	80.00	0.00	12.8	33.2	0.0	4.9	4.2	1.51	1.96
	P+Q	B	107	80.00	0.00	12.8	33.2	0.0	4.9	4.2	1.51	1.96

* P = Primary Stress, P+Q = Primary + Secondary Stresses

As the results demonstrate, the PWR support disks meet the requirements of NUREG/CR-6322.

2.7.8.4 Fuel Tube Analysis

The fuel tube provides a foundation and sealed cavity to mount BORAL poison plates within the fuel basket structure. The fuel tube does not serve a structural function relative to the support of the fuel assembly. The fuel tube design is presented in Figure 2.6.13-3. To ensure that the fuel tube remains functional when the cask is subjected to design load conditions, a structural evaluation of the tube is performed for both the end and side-impact load conditions.

2.7.8.4.1 Fuel Tube End Impact Analysis

During the postulated cask end impact, fuel assemblies are supported by the cask bottom for the bottom-end drop and the lid for the top-end drop. The fuel tubes do not carry fuel assembly load. Therefore, evaluation of the fuel tube for the end-impact load is performed by considering the weight of the fuel tube subjected to the cask deceleration carried by the minimum tube cross section. The minimum tube cross section is located at the contact point of the tube with the bottom weldment. From the dimensions of the tube shown in Figure 2.6.13-3, the minimum cross-sectional area is

$$\text{Area} = (\text{thickness})(\text{mean perimeter})\ (0.048)$$
$$= [(8.8+0.048)4] = 1.69\ \text{in}^2.$$

The total bearing load on the tube and BORAL during the cask bottom-end impact is 9,180 lb, (60 $g \times 153$ lb). The maximum compressive and bearing stress in the fuel tube is 5,432 psi (9180/1.69). Limiting the compressive stress level in the tube to the material yield strength ensures that the tube remains in position when the cask is subjected to the postulated end-drop. Type 304 stainless steel yield strength is 19,400 psi at a conservatively high temperature of 500°F for the axial location on the fuel tube that has the minimum cross-section area. Using this criterion to evaluate the tube for the end-drop load, a margin of safety of +2.57 is achieved.

2.7.8.4.2 Fuel Tube Side-Impact Analysis

During the cask side-impact load configuration, the fuel tube is supported by the fuel basket's stainless steel support disks. The fuel basket support disks support the full length of the fuel tube, and are spaced at 4.42 in. apart (which is about one half of the fuel tube width of

8.8 in.). Considering the fuel tube subjected to the 60 g [1] side-impact deceleration and the 30 support locations provided by the basket support disks, the fuel tube shear stress is

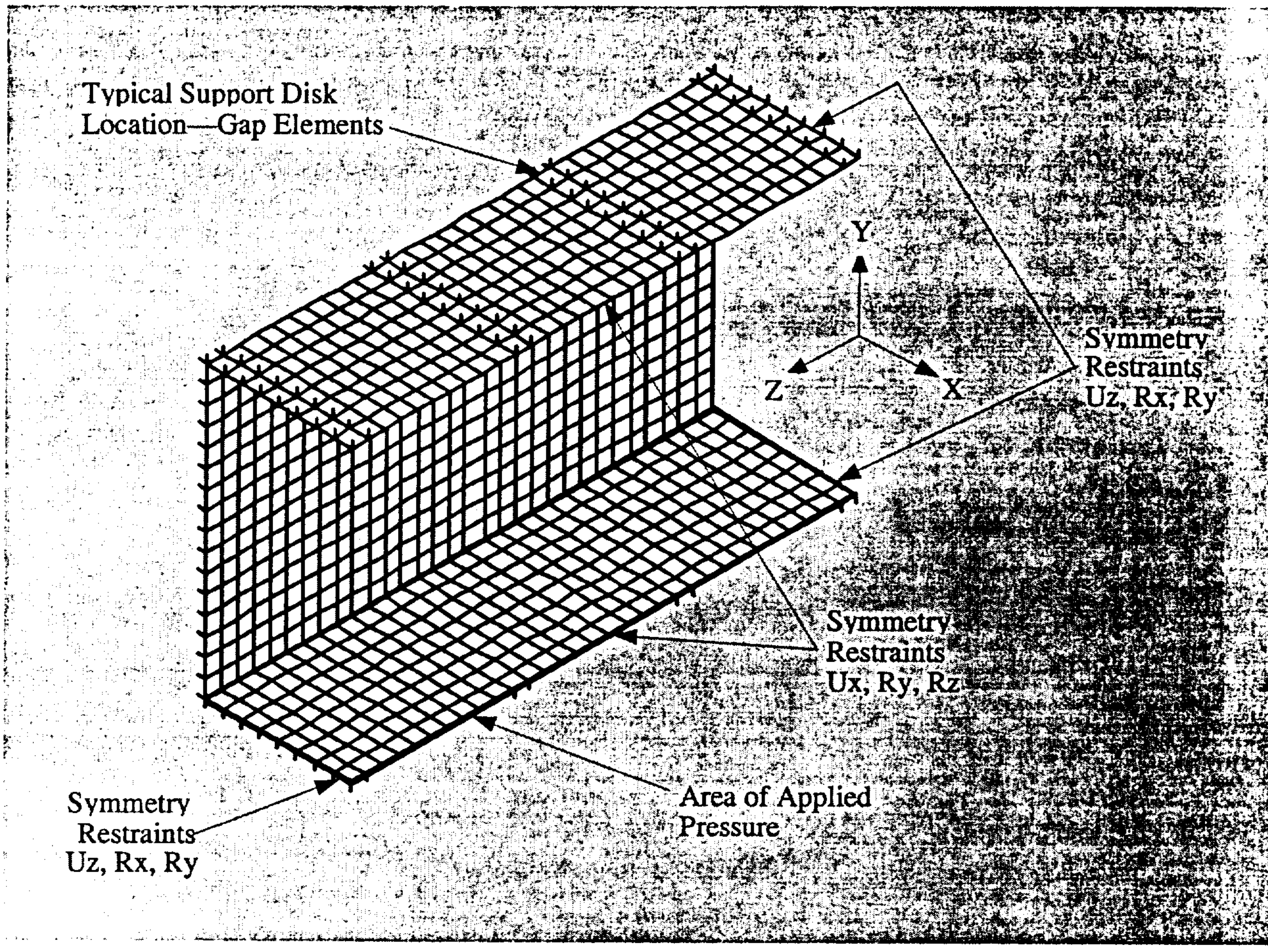
Impact shear load	= (60)(1,602)/30 = 3,204 lb
Shear area of tube	= (0.048)(8.8)(2) = 0.845 in^2
Shear stress of tube	= 3,204/0.845 = 3,792 psi.

The yield strength of Type 304 stainless steel at 750°F is 17,300 psi. Using an allowable shear stress equivalent to half the yield strength of the tube wall material, 8,650 psi, results in a large positive margin of safety. The conservative evaluation of the tube loading resulting from its own mass during the side-impact configuration indicates that the tube structure will maintain position and will function.

The load transfer of a fuel assembly to the fuel basket support disk when the cask is subjected to a side impact will be through direct bearing and compression of the distributed load of the fuel assembly through the fuel tube to the support disk web. The analysis considers the fuel assembly load as a distributed pressure on the inside tube surface.

The load transfer of the weight of the fuel assembly to the fuel basket support disk in the side impact is through direct bearing and compression of the distributed load of the fuel assembly through the fuel tube to the support disk web. Two load conditions are considered in the fuel tube evaluation. The first considers the fuel assembly load as a distributed pressure on the inside surface of the fuel tube. The second postulates that the fuel assembly grid is located at the center of the span between the support disks and produces a localized distributed load over the effective area of the grid.

Two different ANSYS finite element models of the tube are developed for these two load conditions since the fuel tube structural performance for either load is nonlinear. As shown in the following, the first model represents a fuel tube section with a length of three spans, i.e., the model is supported at four locations by support disks. The model conservatively considers the fuel tube wall thickness of 0.048 inch as the only material subjected to a distributed pressure load representative of the fuel assembly deceleration of 60g. Fuel assembly stiffness is not considered in the development of the imposed pressure load on the fuel tube.



The tube is modeled with the ANSYS plastic, quadrilateral shell element (SHELL43). The support disks are represented by gap elements (CONTAC52). The outer nodes of the gap elements are fully restrained in all three translational directions. Edge restraints were applied to the model to represent symmetry boundary conditions. The effective load on the fuel tube due to the 60g deceleration of the fuel assembly is applied as a pressure to the inside area of the fuel tube.

The finite element analysis results show that the maximum stress in the tube is 23.8 ksi, which is local to the sections of the tube resting on the support disks. At 750°F, the ultimate strength for Type 304 stainless steel is 63.1 ksi. The margin of safety is:

$$MS = \frac{63.1}{23.8} - 1 = +1.65$$

The analysis shows that the maximum total strain is 0.026 inch/inch. Defining the acceptable elastic-plastic response of the stainless steel as one half of the material failure strain of 0.40 in./in. at 750°F [24], the resulting margin of safety is:

$$MS = \frac{0.40/2}{0.026} - 1 = +\text{large}$$

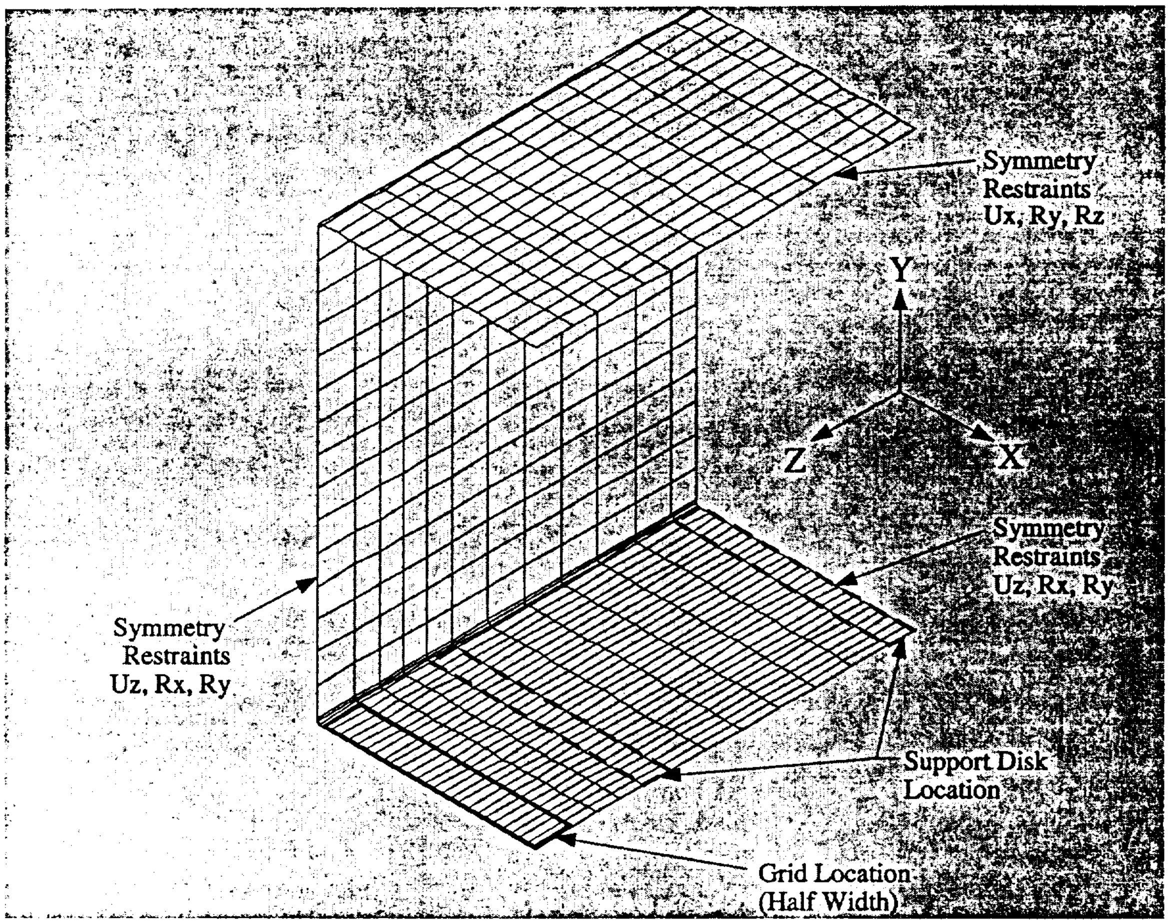
Similarly, the margin of safety for elastic-plastic stress becomes:

$$MS = \frac{63.1 - 17.3}{23.8 - 17.3} - 1 = 6.05$$

where the yield strength of Type 304 stainless steel is 17.3 ksi at 750°F.

The second finite element model is used to evaluate the load condition with the fuel assembly grid located at the center of the span between two support disks. The fuel tube is subjected to a localized distributed load over the effective area of the grid. As shown in the following, the model is a quarter-symmetry periodic section of the fuel tube. As in the finite element model used for the distributed pressure case, this model conservatively considers a fuel tube wall thickness of 0.048 inch. The BORAL plate (0.075 inch) and stainless steel cover plate (0.018 inch) are conservatively not included in the model. The tube wall is modeled with ANSYS SHELL43 elements. The support disks are modeled with CONTAC52 elements.

Based on the Lawrence Livermore evaluation of the fuel rods for a side impact (UCID-21246) [43], the fuel rods and fuel assemblies maintain their structural integrity during the side impact resulting from a cask tip-over accident and the displacement of the fuel tube is limited. The maximum displacement of the fuel tube section between the support disks will not exceed the "thickness" of the grid spacer, which is the distance between the outer surface of the grid and the outer surface of the fuel rod array. When the displacement of the fuel tube reaches the "thickness" of the grid spacer, the fuel rods will be in contact with the inner surface of the fuel tube and the weight of the fuel rods will be transferred through the tube wall to the support disks. Therefore, a bounding load condition for this model is simulated by applying a constant displacement of 0.08 inch in the negative Y direction to the nodes corresponding to the grid location in the model. Note that 0.08 inch displacement bounds all PWR fuel assemblies. It is assumed that the fuel assembly grid spacer is rigid and therefore a constant displacement is conservatively applied.



The finite element analysis results show that the maximum stress in the tube is 38.4 ksi which is local to the corner of the tube at the grid spacer location of the model close to the side wall of the tube. At 750°F the ultimate strength for Type 304 stainless steel is 63.1 ksi. The margin of safety is:

$$MS = \frac{63.1}{38.4} - 1 = +0.64$$

The analysis shows that the maximum total strain is 0.11 inch/inch. Defining the acceptable elastic-plastic response of the stainless steel as one half of the material failure strain of 0.40 in./in. at 750°F [24], the resulting margin of safety is:

$$MS = \frac{0.40/2}{0.11} - 1 = 0.82$$

Similarly, the margin of safety for elastic-plastic stress becomes:

$$MS = \frac{63.1 - 17.3}{38.4 - 17.3} - 1 = 1.17$$

where the yield strength of Type 304 stainless steel is 17.3 ksi at 750°F.

Both the maximum total strain and the elastic-plastic stress analyses indicate that the tube position within the support basket is maintained.

Assurance that the BORAL remains attached to the fuel tube is evaluated by considering that loads produced by the BORAL plate and stainless steel attachment plate (assuming a 60g load) are carried by the attachment plate weld. Total load and resultant stress on the weld are calculated as:

$F_{b/ss} = (g)(\rho)(t)(w)(l)$ .... Load exerted by BORAL/Stainless Steel Attachment Plate

where:

- g = acceleration (g)
- ρ = density of material (lb/in^3) (The density of aluminum (0.098 lb/in^3) is conservatively used for the BORAL.
- t = thickness of material (in.)
- w = width of material (in.)
- l = length of material section (in.)

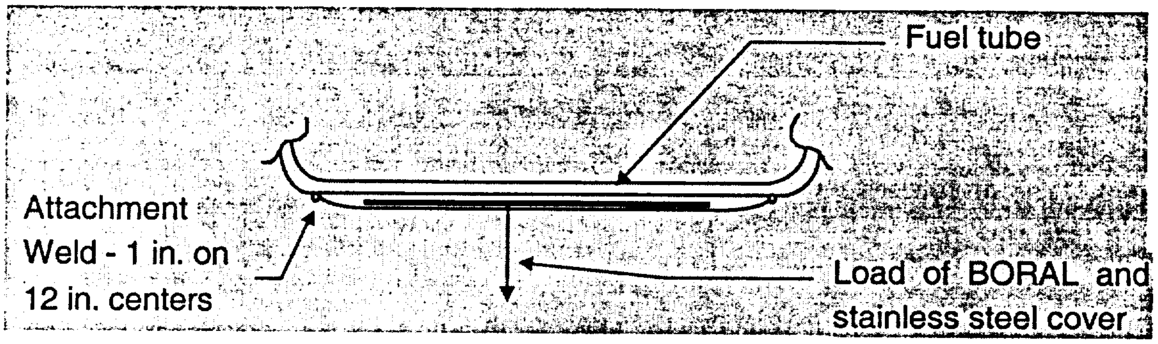
The forces on the weld due to a 12-inch section of BORAL (F_b) and a 12-inch section of stainless steel plate (F_{ss}) are:

$$F_b = (60g)(0.098\ \text{lb/in}^3)(0.075\ \text{in.})(8.2\ \text{in.})(12\ \text{in.}) = 43.4\ \text{lbs}$$

$$F_{ss} = (60g)(0.291\ \text{lb/in}^3)(0.018\ \text{in.})(8.7\ \text{in.})(12\ \text{in.}) = 32.8\ \text{lbs}$$

The total load (F_t) on a 1-inch attachment weld for a 12-inch section is:

F_t = 43.4 lbs + 32.8 lbs = 76.2 lbs



The resulting weld stress is: $\sigma = P/A = (76.2 \text{ lb}/2) / (1 \text{ in.}) (0.018 \text{ in.}) = 2{,}117 \text{ psi}$

Since the weld material is Type 304 stainless steel, the margin of safety (at 750°F) is:

$$MS = \frac{17{,}300}{2{,}117} - 1 = +7.2$$

Therefore, the BORAL remains enclosed on each outer surface of the fuel tube wall.

2.7.8.5 Basket Weldment Analysis for 30-Foot End Drop

The responses of the top and the bottom weldment plates of the fuel basket assembly to a 60 *g* accident condition deceleration load are examined. Two finite element models representing the PWR basket top and bottom weldments are constructed for structural evaluation. The structural evaluations are performed at normal condition temperatures; therefore, prior to the structural evaluation portion of the analyses, the steady-state temperature distribution in the top and bottom weldment models is determined by applying fixed temperatures to the outer circular edge and to the node at the intersection of the symmetry planes and then solving for the intermediate temperatures. These fixed temperatures are obtained from the normal conditions thermal analysis with -40°F ambient temperature and maximum heat generation. The material allowable stresses are based on the maximum temperature of the weldments determined for normal conditions with 100°F ambient temperature and maximum heat generation.

During the temperature solution portion of the analyses, ANSYS three-dimensional thermal shell elements (SHELL57) are used to construct the finite element models. During the structural evaluation portion of the analyses, ANSYS three-dimensional, six-degrees-of-freedom, elastic shell elements (SHELL63) in the weldment plate and structural support plate regions are used to construct the finite element models. BEAM4 elements are used to model the top nut/pads. Contact between the structural support plates and the structural support ring (where applicable) are modeled using CONTACT52 elements. The finite element models represent one-quarter sections of the weldments.

The top and bottom weldments are 1.0-in. and 1.25 in. thick, respectively, and are fabricated from SA-240, Type 304 stainless steel. The top weldment supports its own weight and 24 fuel tubes (without the fuel assemblies) during a top-end drop. Eleven structural support places, eight tie-rod top nuts, and a circumferential ring support the top weldment and its loads during a top-end drop. These structural components are modeled as zero-translation restraints in the direction of the end drop. The finite element models of the top and bottom weldments are presented in Figures 2.6.13.13-1 and 2.6.13.13-2, respectively.

2.7.8.5.1 Results of Basket Weldment Analyses (30-Foot End-Drop)

The maximum stress intensities (SI), for primary membrane plus primary bending ($P_m + P_b$), for the 30-ft end-drop analysis and the corresponding minimum margins of safety are:

Component/Condition	$P_m + P_b$ (ksi)	S_u (ksi)	MS
Top Weldment/30-ft Drop	7.62	62.56	+7.21
Bottom Weldment/30-ft Drop	12.99	63.22	+3.87

Because a large radial temperature gradient occurs through the weldments, the maximum stress intensities presented in the preceding table do not occur at the maximum temperature of the models. Therefore, comparing these stress intensities with stress allowables based upon the maximum temperature is conservative. Therefore, the stress evaluation is performed on a nodal basis. That is, using ANSYS, the maximum stress at each node in each model is compared with the maximum allowable stress at the temperature of the node being evaluated.

For hypothetical accident conditions, the following criteria are used in evaluating the top and bottom weldments nodal stress intensities:

$$P_m + P_b < 3.6S_m \text{ or } S_u\text{, whichever is less.}$$

(Note: For Type 304 stainless steel in these temperature ranges, S_u is smaller than $3.6S_m$.)

The margin of safety (MS) is calculated as

$$MS = \frac{\text{Allowable Stress}}{\text{Nodal Stress Intensity}} - 1.$$

2.7.8.5.2 Top Weldment Structural Rib Buckling Evaluation

The structural ribs on the top weldment are subjected to axial loads during a top-end drop. End constraints on the ribs during a top-end drop are fixed at the end welded to the top weldment, and free at the other end. Because no closed solutions are readily available for evaluating a plate for buckling loads with end constraints matching those of the top weldment ribs, a closed-form solution for the buckling of a column is used to analyze a 1-in. section of one of the ribs.

For a column under axial loading with one end fixed and the other end free, the critical load (P_{cr}) is determined by

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

where:
I = moment of inertia,
E = modulus of elasticity,
L = length of the column, and
K = effective length factor (K = 2 for a column with one end fixed and the other free).

Evaluating a 1-in. section of one of the ribs at the maximum weldment temperature of 515°F gives

$$P_{cr} = \frac{\pi^2 (25.7 \times 10^6) \frac{1}{12} (1.0)(1.0)^3}{(2 \times 8.15)^2} = 8.0 \text{ x } 10^4 \text{ lb}$$

For the 30-ft top-end drop, the sum of the forces on the nodes representing the ribs is a maximum of 1,422 lb.

Thus, the margin of safety for buckling of one of the structural ribs of the top weldment during a 30-ft top-end drop is:

$$MS = \frac{8.0 \text{ x } 10^4}{1,422} - 1 = + \text{Large}$$

2.7.8.5.3 Conclusions

As shown in this section, both the top and bottom weldments maintain positive margins of safety when subjected to the 30-ft end-drop conditions. As shown in the top weldment structural rib buckling calculation, the actual maximum load (P) on one of the structural ribs of the top weldment during a 30-ft drop is much less than the predicted buckling load (P_{cr}). Therefore, the top and bottom weldments are structurally adequate.

2.7.9 BWR Transportable Storage Canister Analysis – Accident Conditions

Evaluation of the BWR Transportable Storage Canister for the hypothetical accident conditions is presented in this section. The evaluation of the canister for normal conditions of transport is presented in Section 2.6.14.

The principal components of the canister assembly are the canister shell, bottom plate, fuel basket, shield lid, and structural lid. The geometry and materials of construction of the canister, baskets, and spacers are described in Section 1.2.1.2. The general arrangement of the canister depicted with the fuel basket is shown in Figure 2.6.14-1. The individual components of the canister are depicted in Figure 2.6.14-2.

A drop accident stress evaluation is performed for the 30-ft side-drop condition, top and bottom end-drops, and for the top and bottom corner-drop conditions by applying a 60 *g* deceleration load. The loads developed in the basket are transferred through the canister wall into the inner shell (for the side drops and oblique drops), and any axial component is transferred into the ends of the cask cavity. The axial loads are maximized for the end-drops and corner-drop conditions. The lateral loads are maximized in the side-drop since an enveloping acceleration is employed in the analysis. Regardless of the angle of the drop, the canister wall is uniformly supported along its length by the transport cask inner shell, and the load path is not affected by drop orientations close to the side-drop orientation. The oblique orientation will not provide enveloping loading above the side-drop conditions. Therefore, oblique orientations other than the corner drops are not considered.

In addition, the evaluations are performed with and without the 25 psig internal pressure. Also, for the side, top corner, and bottom corner-drop orientations, basket orientations of 0° and 45° are evaluated. The angles describe the orientation of the basket elements with respect to the symmetry plane of the model. A value of 0° orients the ligaments in the basket elements parallel and perpendicular to the symmetry plane while a value of 45° orients the basket ligaments at +/-45° from the symmetry plane. The evaluations consider the maximum temperatures present during the normal conditions evaluated with 100°F ambient; solar insolation, and maximum decay heat.

2.7.9.1 Analysis Description

The structural design criteria for the canister are contained the ASME Code, Section III, Subsection NB. Consistent with these criteria, the structural components of the canister (shell, bottom plate, and structural lid) are shown to satisfy the allowable stress intensity limits presented in Table 2.1.2-3. For the canister structural lid weld (Section 13, Figure 2.6.12.3-1), base metal properties are used to define the allowable stress limits since the weld filler rod tensile properties are greater than the base metal. Also, the allowable stress is multiplied by a stress reduction factor of 0.8 per ISG-4.

The ANSYS finite element program is used to evaluate the canister for the 30-ft drop conditions in the top and bottom-end, top and bottom-corner, and side-impact orientations. The ANSYS finite element model is the same as that used for the evaluation of the 1-ft drop impacts evaluated for normal conditions of transport. The model is described in Section 2.6.14.2.

2.7.9.2 Analysis Results - BWR Canister

The detailed results of the analysis for the 30-ft side, top and bottom corner, and top and bottom-end drops are presented in Tables 2.7.9.2-1 through 2.7.9.2-10. Only the load cases that result in the worst case margins are presented for each of the drop orientations considered. For the side drop, the worst case configuration is without pressure and the basket oriented at 0°. For the bottom-drop, the worst case occurs with internal pressure. For the top-end drop, the most severe condition occurs without pressure. For the bottom-corner drops, the worst case stresses occur without pressure and the basket oriented at 0°. For the top-corner drops, the worst case occurs with pressure for primary membrane and without pressure for membrane plus bending.

A drop accident stress evaluation is performed for the 30-ft side-drop, top and bottom-end drops, and for the top and bottom-corner drop conditions by applying a 60 *g* deceleration load. The loads developed in the basket are transferred through the canister wall into the inner shell (for the side-drop and oblique drops), and any axial component is transferred into the ends of the cask cavity. The axial loads are maximized for the end-drops and corner-drop conditions. The lateral loads are maximized in the side-drop since an enveloping acceleration is employed in the analysis. Regardless of the angle of the drop, the canister wall is uniformly supported along its length by the transport cask inner shell, and the load path is not affected by drop orientations close to the side-drop orientation. The oblique orientation will not provide enveloping loading above the side-drop conditions. Therefore, oblique orientations other than the corner drops are not considered.

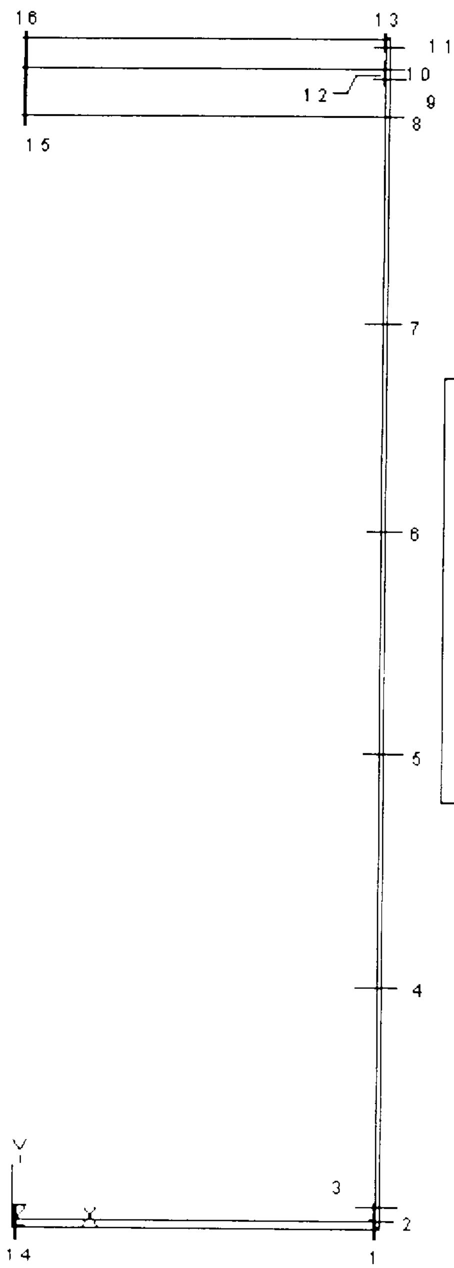
The section stresses presented in the tables are identified by a section number. The minimum margin of safety at each section is presented by denoting the circumferential angle where the minimum margin of safety occurs. A cross-section of the canister showing the section numbers is presented in Figure 2.7.9.2-1. Stresses are evaluated at 9° increments around the circumference for each of the locations shown in Figure 2.7.9.2-1. The canister minimum margins of safety for the governing drop conditions are summarized in Table 2.7.9.2-11.

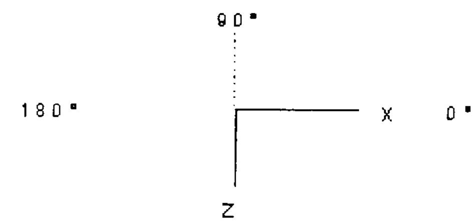
The methodology used to evaluate the stresses for the side drop is identical to that used for the normal conditions 1-ft side drop for the BWR canister (Section 2.6.14.6). Sections 9, 10, and 11 at the 0° circumferential position (see Figure 2.6.12.3-1) are not included in the evaluation. These regions are characterized as a bearing stress since they result from the canister shell bearing against cask inner shell. An evaluation of these bearing stresses is not required for accident conditions. Results for Sections 9, 10, and 11 at angular locations other than 0° are included in the evaluation.

Design changes were made to the BWR basket after the initial analyses were performed. The effects of the design changes on the BWR canister are discussed in Section 2.6.14.2. The same procedure used to scale the BWR canister stress intensities in Section 2.6.14.2 is used for the accident conditions in the following evaluation.

The allowable stresses presented in the tables are for Type 304L stainless steel. The shield lid is constructed of Type 304 stainless steel, which possesses higher allowable stresses, resulting in a conservative evaluation. These allowables are evaluated at 380°F, unless otherwise indicated. Review of the thermal analyses shows that the maximum temperature of the canister is 372°F (Section 3.4), so the presented margins of safety are conservative.

Figure 2.7.9.2-1 Identification of Sections for Evaluating Linearized Stresses in BWR Canister





Top View of Axis

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

Table 2.7.9.2-1 BWR Canister P_m Stresses - 30-Foot Side Drop

		P_m Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	0	-18.3	0.4	-10.7	-0.2	-0.2	-1.7	19.1	38.4	1.01
2	0	-10.4	0.2	-10.2	-0.6	-0.5	-1	11.6	38.4	2.31
3*	0	-7.4	-0.1	-8.7	-0.4	-0.5	-0.9	9.8	38.4	2.92
4*	90	0	0.3	0	2.1	0	0	4.4	38.4	7.73
5*	180	0	-4.5	-0.6	0	-0.1	0	4.7	38.4	7.17
6*	180	0	-4.6	-0.6	0	0	0	4.8	38.4	7.00
7*	0	-1.6	2.4	0.1	0	-0.2	0.2	4.3	38.4	7.93
8*	0	-0.6	6.2	-2.7	-0.1	1	-0.1	9.6	38.4	3.00
9	9	-22.7	5.7	-9.6	-2.7	3.3	1.0	29.7	38.4	0.29
10	0	-24.4	2.5	-13	-5.1	2	0.8	29	38.4	0.32
11	9	-16.3	1.0	-8.9	0.9	2.3	-0.07	18.0	38.4	1.13
12	0	-38.7	-7.9	-16.8	-6.9	1.8	0.7	34.1	38.4	0.13
13	0	-30.2	-9.3	-12.2	0.2	1.4	-1.6	21.6	30.72**	0.42
14	0	-2.4	0	0.8	0	0	-0.1	3.3	38.4	10.66
15	0	-1	0	0.4	-0.1	0	0	1.3	38.4	28.08
16	0	-1.5	0	0.4	0	0	0	1.8	38.4	19.9

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

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

Table 2.7.9.2-2 BWR Canister $P_m + P_b$ Stresses - 30-Foot Side Drop

Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		$P_m + P_b$ Stresses (ksi)								
1	0	-22.6	-0.1	-12.3	0.6	0	-1.7	22.8	57.5	1.52
2	0	-12.2	0.7	-8.6	-1.1	-0.5	-1.5	13.6	57.5	3.23
3*	0	-8.8	0.6	-6.9	-0.8	-0.5	-1.3	10.8	57.5	4.32
4*	0	-1.6	1	3	0	0.1	0.5	4.9	57.5	10.73
5*	0	-1.7	2.6	2.8	0	0	0.2	4.7	57.5	11.23
6*	0	-1.7	3.1	2.8	0	-0.1	0	5.0	57.5	10.5
7*	0	-1.6	3.1	2.5	0	-0.2	0.3	5.1	57.5	10.27
8*	0	-0.3	6.1	-4.9	-0.1	1	-0.3	11.8	57.5	3.87
9	9	-20.5	14.9	-7.5	-2.5	3.6	2.8	37.0	57.5	0.55
10	0	-26.2	-0.1	-11.4	-7.2	1.5	0.4	30	57.5	0.92
11	0	-41.2	12.5	-14.7	0.1	2.4	1.5	54	57.5	0.06
12	0	-47.8	-11.3	-20.4	-6.8	2.4	1.1	39.5	57.5	0.46
13	0	-48	-18.7	-20.9	-0.3	2.1	-0.8	30.7	46.0	0.50
14	0	-2.5	0	0.8	0	0	-0.1	3.3	57.5	16.41
15	0	-0.3	0	1.5	-0.1	0	0	1.8	57.5	31.74
16	0	-1.2	0	0.9	0	0	0	2	57.5	27.39

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

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

Table 2.7.9.2-3 BWR Canister P_m Stresses - 30-Foot Bottom-End Drop, Internal Pressure

Section Location	Angle of peak stress location	P_m Stresses (ksi) Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1*	180	-0.1	-2.8	-0.4	0.2	0.1	0	2.8	38.4	12.57
2	180	0.6	-6.5	-1.2	0.3	0.1	0.1	7.1	38.4	4.39
3	180	0.4	-6.7	-1.1	0.2	0.1	0.1	7.1	38.4	4.37
4	180	0	-6.6	1.3	0	0	-0.1	7.9	38.4	3.85
5	180	0	-6	1.3	0	0	-0.1	7.3	38.4	4.27
6	180	0	-5.3	1.3	0	0	-0.1	6.6	38.4	4.77
7	180	0	-4.7	1.3	0	0	-0.1	6	38.4	5.37
8	54	0.5	-3.1	0.3	0	0	0.3	3.8	38.4	9.03
9	72	-1.7	-1.9	-0.7	-0.1	0.4	-0.4	1.6	38.4	22.94
10	180	1.7	-1.3	-1	-0.3	0	0.2	3.1	38.4	11.5
11	0	-2	0.5	-0.9	0	0	0.1	2.5	38.4	14.17
12	0	0.7	1.8	-0.4	0.2	0.1	-0.1	2.2	38.4	16.18
13	180	0	-2	-1.2	0	0	0.1	2	30.72**	14.36
14*	0	0.1	-1.1	0.1	0	0	0	1.3	38.4	29.44
15	180	0.2	-0.1	0.2	0	0	0	0.2	38.4	186.72
16	90	-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.

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

Table 2.7.9.2-4 BWR Canister $P_m + P_b$ Stresses - 30-Foot Bottom-End Drop, Internal Pressure

		$P_m + P_b$ Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1*	180	0.3	-3.2	-0.3	0.3	0.1	0	3.7	57.5	14.54
2	180	0.3	-9.4	-2.1	0.2	0.1	0.2	9.7	57.5	4.95
3	180	0.2	-9	-1.8	0.1	0.1	0.1	9.2	57.5	5.28
4	180	0	-6.6	1.3	0	0	-0.1	7.9	57.5	6.25
5	0	0	-6	1.3	0	0	0.1	7.3	57.5	6.89
6	180	0	-5.3	1.3	0	0	-0.1	6.7	57.5	7.64
7	180	0	-4.7	1.3	0	0	-0.1	6	57.5	8.54
8	45	0.5	-3.4	0.5	0.1	-0.1	0.2	4.1	57.5	13.03
9	90	-2.4	-3.9	-0.4	0	0.7	0	3.7	57.5	14.53
10	90	-2.9	-6.6	0.6	0	0.2	0	7.3	57.5	6.91
11	0	-1.1	5.6	0.9	-0.4	0	0.1	6.8	57.5	7.52
12	0	2.6	3.6	0.7	0.7	0	-0.1	3.3	57.5	16.27
13	180	2.3	0.1	0.1	0.4	0.1	0.2	2.4	46.0*	18.17
14*	0	0.1	-1.1	0.1	0	0	0	1.4	57.5	37.33
15	90	3.6	0	3.6	0	0	0	3.6	57.5	14.82
16	81	-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.

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

Table 2.7.9.2-5 BWR Canister P_m Stresses - 30-Foot Top-End Drop

		P_m Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	0	0.3	-5.2	-1.8	1	-0.1	-0.2	5.8	38.4	5.56
2	0	-2.1	3.5	6.4	1.1	-0.1	0.6	8.8	38.4	3.37
3	0	-1.5	2.3	7.7	0.5	0	0.7	9.3	38.4	3.12
4	135	0	-2.4	0	0	0	0	2.4	38.4	14.87
5	153	0	-3	0	0	0	0	3	38.4	11.62
6	153	0	-3.7	0	0	0	0	3.7	38.4	9.45
7	171	0	-4.3	0	0	0	0	4.3	38.4	7.91
8	180	0.1	-4	0.1	-0.1	0	0	4.2	38.4	8.23
9	180	0.1	-3	-0.5	-0.1	0	0	3	38.4	11.67
10	144	-0.2	-2.9	-0.4	-0.1	0	0.2	2.8	38.4	12.75
11	135	-0.3	-2.8	-0.3	0	0	0.2	2.7	38.4	13.19
12*	36	-0.1	-2.2	-0.2	0.1	-0.1	-0.1	2.3	38.4	15.69
13*	180	0	-2.3	-0.3	0	0	0	2.4	30.72**	11.80
14	90	-0.7	0	-0.7	0.2	-0.4	0	1.1	38.4	32.64
15*	0	0	-1	0	0	0	0	1.1	38.4	33.91
16*	0	0	-1.1	0	0	0	0	1.3	38.4	28.55

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

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

Table 2.7.9.2-6 BWR Canister $P_m + P_b$ Stresses - 30-Foot Top-End Drop

		$P_m + P_b$ Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1	0	-2.1	-11.9	1.9	0.4	-0.1	0.2	13.8	57.5	3.16
2	0	-2.2	24.6	12.6	1.8	-0.1	1.1	27.1	57.5	1.12
3	0	-1.7	23.7	13.8	1.2	-0.1	1.2	25.6	57.5	1.25
4	180	0	-2.4	0	0	0	0	2.4	57.5	22.68
5	153	0	-3	0	0	0	0	3	57.5	17.92
6	162	0	-3.7	0	0	0	0	3.7	57.5	14.68
7	180	0	-4.3	0	0	0	0	4.3	57.5	12.35
8	180	0.3	-4	0.1	-0.2	-0.1	0	4.3	57.5	12.47
9	135	-0.4	-3.5	-0.4	0	0	0.3	3.4	57.5	15.88
10	180	0	-3.3	-0.7	-0.1	0	0.1	3.3	57.5	16.37
11	135	-0.3	-3.1	-0.3	0	0	0.3	3	57.5	18.14
12*	180	0.2	-2.1	-0.3	-0.2	0	0	2.4	57.5	22.81
13*	180	-0.1	-2.5	-0.4	-0.1	0	0	2.4	46.0**	18.17
14	81	-21.9	-0.3	-21.9	0.2	-0.4	0	21.6	57.5	1.66
15*	72	0.3	-1	0.3	0	0	0	1.3	57.5	42.61
16*	0	0.1	-1.1	0.1	0	0	0	1.2	57.5	45.55

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

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

Table 2.7.9.2-7 BWR Canister P_m Stresses - 30-Foot Bottom-Corner Drop

		P_m Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allowable Stress (ksi)	Margin of Safety
1*	0	-13.6	-3.2	-5	-0.5	0	-2	11.4	38.4	2.37
2	36	-0.2	-8	-1.3	-0.2	0.3	-1.7	9	38.4	3.25
3*	36	-0.3	-8.2	-1.4	-0.1	0.2	-1.5	9.5	38.4	3.04
4*	0	-2.6	-7.9	0.2	0	0	0.1	8.5	38.4	3.52
5*	180	0	-7	-0.2	0	0	0	7.4	38.4	4.19
6*	180	0	-6.7	-0.2	0	0	0	7.0	38.4	4.49
7*	180	0	-6	-0.2	0	0	0	6.3	38.4	5.10
8*	72	0.1	-3.5	0.1	-0.8	-0.4	0	4.2	38.4	8.14
9	0	-29.5	0.8	-10.1	-2.9	1.8	-0.2	31.1	38.4	0.23
10	0	-13.5	-0.8	-5.8	-2.6	1.4	-1	14.2	38.4	1.7
11	0	-35.9	-1.5	-11.6	-0.4	2	-0.3	34.8	38.4	0.1
12	0	-22.4	-5.2	-6.9	-3.7	1.2	-1.3	19.5	38.4	0.97
13	0	-23	-7.2	-7.3	0.3	1.4	-2.2	17.5	30.72**	0.76
14*	0	-0.9	-1	0.4	0	0	0	1.5	38.4	24.60
15	0	-0.1	0	0.3	0	0	0	0.4	38.4	88.61
16	0	-0.8	0	0	0	0	0	0.8	38.4	47.41

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

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

Table 2.7.9.2-8 BWR Canister P_m + P_b Stresses - 30-Foot Bottom-Corner Drop

		P_m + P_b Stresses (ksi)								
Section Location	**Angle of peak stress location**	**Sx**	**Sy**	**Sz**	**Sxy**	**Syz**	**Sxz**	**SI (ksi)**	**Allowable Stress (ksi)**	**Margin of Safety**
1*	0	-16.3	-2.3	-5.5	0.6	0.1	-2	15.1	57.5	2.81
2	27	-0.6	-12.5	-3.5	-0.2	-0.3	-1.8	12.7	57.5	3.53
3*	36	-0.8	-11.6	-2.1	-0.1	0.2	-1.8	12.6	57.5	3.56
4*	0	-2.7	-7.3	2.3	0	0	0.3	10.2	57.5	4.63
5*	0	-2.7	-6	2.3	0	0	0.3	8.7	57.5	5.61
6*	0	-2.6	-5	2.3	0	-0.1	0.3	7.8	57.5	6.37
7*	0	-2.6	-4.3	2.3	0	-0.1	0.3	6.9	57.5	7.33
8*	18	0.5	-3	-1.4	0.9	1.5	-0.6	5.1	57.5	10.27
9	0	-29.4	6.5	-10.8	-2.5	1.8	0.3	36.5	57.5	0.58
10	0	-13.8	-1	-3.8	-4.1	1	-1.4	15.8	57.5	2.65
11	0	-32.1	7.6	-9.8	-0.2	1.9	0.4	39.9	57.5	0.44
12	0	-29.1	-7.5	-9.5	-3.6	1.7	-0.9	23.7	57.5	1.43
13	0	-37	-14.6	-13.7	-0.1	1.9	-1.5	25	46.0**	0.84
14*	0	-0.9	-1	0.4	0	0	0	1.6	57.5	34.94
15	81	3.9	0	4.4	0	0	0	4.4	57.5	12.18
16	18	-2.7	0	-2	0	0	0	2.6	57.5	20.89

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

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

Table 2.7.9.2-9 BWR Canister P_m Stresses - 30-Foot Top-Corner Drop, Internal Pressure

		P_m Stresses (ksi)								
Section Location	**Angle of peak stress location**	**Sx**	**Sy**	**Sz**	**Sxy**	**Syz**	**Sxz**	**SI (ksi)**	**Allowable Stress (ksi)**	**Margin of Safety**
1	9	-0.1	-3.3	-2.8	1.3	-0.9	-1.1	4.9	38.4	6.83
2	0	-20.2	-1.9	-5.8	-1.7	0.4	-1	18.8	38.4	1.04
3*	0	-14.7	-2	-3.8	-1.7	0.4	-1	14.0	38.4	1.74
4*	0	-2.6	-1.8	1.5	0	0	0.3	4.3	38.4	7.93
5*	180	0	-3.2	1.1	0	0	-0.1	4.5	38.4	7.53
6*	180	0	-3.6	1.1	0	0	-0.1	4.9	38.4	6.84
7*	0	-2.5	-3.9	1.3	0	-0.2	0.3	5.6	38.4	5.86
8*	54	0.5	-4	0.3	-1.1	-0.8	0.3	5.8	38.4	5.62
9	0	-30.7	-4.7	-10.3	-3.3	1	-0.2	27	38.4	0.42
10	0	-20.8	-9.6	-8.4	-3.9	0.2	-0.8	14.1	38.4	1.72
11	0	-30.4	-14.7	-11.8	-1.5	0.7	-0.7	19	38.4	1.02
12*	0	-27.1	-13.2	-8.7	-5.5	0.4	-1.2	21.6	38.4	0.78
13*	0	-26.6	-17.3	-9.3	-1.6	0.4	-1.9	18.9	30.72**	0.63
14	90	-1.1	0	-0.1	0.1	-0.2	0	1.3	38.4	28.89
15*	0	-0.4	-1	0.1	0	0	0	1.2	38.4	31.88
16*	0	-0.6	-1.1	0.2	0	0	0	1.3	38.4	27.58

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

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

Table 2.7.9.2-10 BWR Canister $P_m + P_b$ Stresses - 30-Foot Top-Corner Drop

		$P_m + P_b$ Stresses (ksi)								
Section Location	**Angle of peak stress location**	**Sx**	**Sy**	**Sz**	**Sxy**	**Syz**	**Sxz**	**SI (ksi)**	**Allowable Stress (ksi)**	**Margin of Safety**
1	0	-20.3	-11.3	-5.7	-3.8	-0.1	-1.6	16.3	57.5	2.53
2	0	-18	18.3	1.3	1.3	0.9	-0.1	36.4	57.5	0.58
3*	0	-13.4	14.1	1.6	0.4	0.8	-0.3	29.0	57.5	0.98
4*	0	-2.8	-1.8	2.2	0	0	0.3	5.4	57.5	9.65
5*	0	-2.5	-1.8	2.2	0	-0.1	0.4	5.0	57.5	10.50
6*	0	-2.1	-2.3	2.9	0	-0.1	1	5.7	57.5	9.09
7*	0	-2.7	-3.9	2.3	0	-0.2	0.3	6.5	57.5	7.85
8*	54	0.3	-4.2	0.3	-1	-1	0	5.6	57.5	9.27
9	0	-31	0.3	-11.3	-2.3	0.9	0.3	31.7	57.5	0.81
10	0	-22.5	-11.9	-7.5	-6.5	0	-1.3	18.5	57.5	2.11
11	0	-33.4	-18.6	-12	-2.4	0.9	-1.4	22.1	57.5	1.6
12*	0	-29.2	-12.7	-9.2	-4.5	0.8	-0.9	22.7	57.5	1.53
13*	0	-30.9	-21.3	-11.7	-2.7	0.7	-1.8	21.2	46.0**	1.17
14	90	-20.6	-0.3	-19	0.2	-0.3	0	20.3	57.5	1.83
15*	72	-0.2	-0.9	0.4	0	0	0	1.4	57.5	41.24
16*	0	-0.5	-1	0.2	0	0	0	1.3	57.5	41.87

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

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

Table 2.7.9.2-11 Summary of Minimum Margins of Safety for BWR Canister - 30-Foot Drops

Drop Orientation	Loading Condition	Stress Evaluated	Minimum Margin of Safety	Section Number*
Side	30-ft impact	P_m	0.13	12
Side	30-ft impact	$P_m + P_b$	0.06	11
Bottom end	30-ft impact + pressure (25 psi)	P_m	3.85	4
Bottom end	30-ft impact + pressure (25 psi)	$P_m + P_b$	4.95	2
Top end	30-ft impact	P_m	3.12	2
Top end	30-ft impact	$P_m + P_b$	1.12	2
Bottom Corner	30-ft impact	P_m	0.10	11
Bottom Corner	30-ft impact	$P_m + P_b$	0.44	11
Top Corner	30-ft impact; internal pressure	P_m	0.42	9
Top Corner	30-ft impact	$P_m + P_b$	0.58	2

* See Figure 2.7.9.2-1 for section locations.

2.7.9.3 Canister Buckling Evaluation for 30-Foot End Drop

Code Case N-284-1 [12] of the ASME Boiler and Pressure Vessel Code is used to analyze the BWR canister for the accident condition 30-foot end-drop (both top- and bottom-end drops). 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 of Code Case N-284-1. The canister buckling design criteria are described in Section 2.1.2.5.3.

The BWR canister for the 30-foot end-drop is evaluated for buckling in the same manner as the PWR canister for the 1-foot end-drop (see Section 2.6.12.12). The analytical process used for the BWR canister is the same as that described in a step-by-step example presented in Section 2.7.12.3 (for the cask inner shell).

A 60 g deceleration load was used for all the 30-ft drop canister analyses that are presented in Sections 2.7.9.2. The 60 g-load bounds all 30-ft deceleration loads for all other drop angles. The top- and bottom-end drops result in the largest potential for canister shell buckling and, therefore, are the two load cases presented here. The side drop load case is not considered a credible buckling mode of the canister shell and is, therefore, not presented here.

The stress results from the dynamic shell analyses (ANSYS) are screened for the maximum values of the longitudinal compression, circumferential compression, or in-plane shear stresses for the 30-ft drop cases (top- and bottom-end drops) with and without pressure. For each loading case, the largest of each of the three stress components anywhere regardless of location within the BWR canister shell are combined. Combining the maximum stress components in this way produces a conservative, bounding-case buckling evaluation of the BWR canister, one which envelopes all 30-ft BWR canister drop cases including those presented in Tables 2.7.9.2-3 and 2.7.9.2-5.

The geometry parameters used in the BWR canister evaluation are the same as those presented in Table 2.6.14.12-1.

The maximum stress components used in the evaluation and the resulting buckling interaction equation ratios are provided in Table 2.7.9.3-1. 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, thus demonstrating that buckling of the BWR canister does not occur.

Table 2.7.9.3-1 Buckling Evaluation Results for the BWR Canister for 30-Foot End Drop

Load Condition	Longitudinal (Axial) Stress* S_o (psi)	Circumferential (Hoop) Stress* S_θ (psi)	In-plane Shear Stress $S_{o\theta}$ (psi)	Elastic Buckling Interaction Equations				Plastic Buckling Interaction Equations			
				Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
30-Ft Top End Drop	4300	100	700	.021	.093	.015	.021	.092	.014	.093	.015
30-Ft Bottom End Drop	7100	1300	300	.122	.152	.188	.122	.152	.188	.152	.188

Component stresses include thermal stresses.

* Compressive stresses.

2.7.10 BWR Basket Analysis - Accident Conditions

The BWR fuel basket in the Transportable Storage Canister is designed to contain up to 56 BWR fuel assemblies. The basket structure has a right-circular cylinder configuration and consists of 56 square tubes supported by circular support disks and a circular top and bottom plate that are retained by six axial tie rods. The number of support disks provided in the basket varies, depending upon the class (Class 4 or 5) of BWR fuel the basket is designed to contain. The support disks and top and bottom plates are separated and supported by split spacers at the tie rods. The configuration of the basket is shown in Figure 2.6.15-1. Design of the basket and its components is discussed in detail in Chapter 1.0.

In this section, the BWR fuel basket is evaluated for hypothetical accident loads (evaluation of the basket for normal conditions of transport loads is presented in Section 2.6.15). Both stress analyses and buckling evaluations are performed and documented. The structural analysis of the basket components is in accordance with ASME Code, Section III, Division 1, Subsection NG. In addition, the stainless steel/BORAL composite fuel tube is evaluated for a postulated impact load.

The fuel tubes are not structural components and are not considered in the basket evaluation. The tie rods and spacers locate and structurally assemble the circular support disks, heat transfer disks, and top and bottom plates to form an integral assembly. The spacers carry the weight of the support disks, heat transfer disks, and endplate and their own weight in the 30-ft end-drop accident loading condition. The end-drop loading condition of the spacers is a classical, closed-form analysis and the spacers are evaluated independently of the finite element basket model. A finite element model of a single disk is used to evaluate the support disk structural evaluation. Figure 2.6.15-2 shows the support disk cross-section. For further details of the basket refer to Section 2.6.15.

The basket support disk is designed to restrain 56 fuel assemblies, which would nominally fit into a 6.278-inch square slot. Since a populace of BWR fuel assemblies are not expected to fit into the 6.278-inch square, four oversized fuel assemblies slots are specified as 6.478-inch squares. This will reduce the thickness of the ligament at the outer most corner. However, the size of the web (.65 inch) is not changed. Therefore the oversized slots will not affect the buckling calculations, since they pertain to the in-plane and out of plane buckling of the webs. In an inspection of the maximum stresses of the BWR basket, the ligament, which contains the

reduction due to the oversized slots, does not appear in the maximum stress summaries. The smallest ligament at the corner is still significantly controlled by the .8-inch ligament. Therefore, the use of oversized holes is not considered to alter the model of the BWR basket which employs a slot size of 6.278 inches.

2.7.10.1 Stress Evaluation of Support Disk

To determine the structural adequacy of the support disks, 30-ft-drop accident side impact loads are evaluated for the worst-case radial orientations of the basket. End-drop impact is also considered.

A load equal to the weight of the fuel and tubes multiplied by a 60 *g* amplification factor is applied to the support disk structure to simulate the 30-ft side-drop accident condition. The 60 *g* amplification factor is the design value that envelopes the calculated deceleration values for a 30-ft side-drop accident condition. The fuel assembly loads are transmitted in direct compression through the tube wall to the web structure of each support disk. These loads are transmitted to the canister and to the inner shell by a conservative number of disks, the top weldment, and the bottom weldment. The support disk configuration is analyzed for five worst-case radial orientations (0, 31.82, 49.46, 77.92, and 90°) to bound the possible maximum stress cases. The 31.82, 49.46, and 77.92° orientations are located at the thinnest radial section of the disk perimeter.

For the end-drop condition, the support disk is loaded by the inertia of its own weight multiplied by the 55 *g* end-drop amplification factor. Thermal Case 4 is the limiting boundary condition (See Section 2.6.15.3 for case definition).

To calculate the stresses in a support disk, the ANSYS computer code is used to perform a finite element analysis. In accordance with the ASME Code, Section III, Subsection NG, the maximum primary membrane stress intensity calculated in the support disk is compared with the allowable stress limit, 0.7 S_u or 2.4 S_m, whichever is less. The material strength is taken at the maximum support disk temperature. For the support disk, 2.4 S_m > 0.7 S_u; therefore, 0.7 S_u is limiting.

Temperature boundary conditions are presented in Section 2.6.13.3.

2.7.10.1.1 Finite Element Model Description

Finite element analyses are performed for the basket support disk for two hypothetical accident conditions: the 30-ft side-drop impact condition (60 *g*) and the 30-ft end-drop impact condition (55 *g*). The *g*-loads produced by 30-ft corner-drops and 30-ft oblique drops are bounded by the *g*-loads produced by 30-ft end-drop and side-drop conditions. Therefore, no separate evaluation of 30-ft corner-drop or 30-ft oblique-drop is performed.

The method of analysis of the side-drop impact condition is similar to that used in PWR support disk evaluation (Section 2.7.8.1.1).

An amplification factor of 60 *g* simulates the 30-ft side-drop impact. The thickness option of the planar elements is used to simulate the volume necessary to determine the inertial effects. The fuel weight is simulated as a distributed load over the length of the ligament. The fuel is accelerated by the amplification factor and normalized into horizontal and vertical components on the basis of the orientation angle of the support disk. The amplification factor is oriented in the direction of the drop. A steady-state thermal conduction model is analyzed with temperature boundary conditions from the thermal analyses for the worst thermal case (Thermal Case 2). The resulting nodal temperature distribution is then used as input for the structural model.

The ANSYS finite element model of the support disk for the end-drop impact analysis is generated by changing the PLANE42 elements of the side-drop model to SHELL63 elements. The shell elements are used in the end-drop analyses because they can determine out-of-plane stresses as a result of their extra degrees of freedom. The canister elements and nodes, beam elements, and contact elements in the side-drop model are deleted for the end-drop model.

2.7.10.1.2 Impact Loading Conditions

The lateral impact load applied on the support disk for a side-drop accident, includes the inertial weights of the canister, fuel assemblies, and stainless steel tubes and the weight of the support disk itself. A detailed description of the loadings is provided in Section 2.6.15.2. The heat transfer disks are considered to be self-supporting. A 60 *g*-load factor is used to amplify the weight of the basket components for the 30-ft side-drop condition.

2.7.10.1.3 Side-Drop Analysis Results

Finite element stress analyses are performed for the 60g side impact load cases for five different radial basket orientations—0, 31.82, 49.46, 77.92, and 90°. The analysis section locations are defined in Section 2.6.15.6 and in Figures 2.6.15.6-2 through 2.6.15.6-5. The stress evaluations are performed in accordance with the ASME Code, Section III, Division 1, Subsection NG. The calculated stresses for the sections with the lowest margins of safety are presented in Tables 2.7.10.1-2 through 2.7.10.1-21. The minimum margin of safety is +0.12 for primary membrane stress at Section 27 for the Thermal Case 1 side-drop with the basket orientation equal to 90° (Table 2.7.10.1-18). The minimum margin of safety for all side-drop analysis results are summarized in Table 2.7.10.1-1.

2.7.10.1.4 End-Drop Analysis Results

Finite element stress analyses of the BWR basket support disk are performed for a 55 *g* end impact (30-ft end-drop) on the cask and canister for Thermal Case 1 and for Thermal Case 4. Three layers of stresses are obtained from the shell elements used to model the support disk: primary membrane plus bending stress at the top layer, primary membrane stress at the middle layer, and primary membrane plus bending stress at the bottom layer. The maximum stresses in the support disk for the 30-ft end-drop accident condition are summarized in Table 2.7.10.1-22.

The margin of safety is

$$MS = (Allowable/Stress) - 1.$$

For conservatism, the allowable stresses are interpolated to the maximum disk temperature for the hot thermal condition. From these results, Thermal Case 4 with no thermal stresses has the lowest margin of safety, +0.01, principally as a result of bending loads, using an allowable stress intensity of 90 ksi.

The allowable stresses are taken at a temperature of 500°F, which is conservative, given the fact that the maximum stresses occur at the outer edges of the disk where the temperatures are lower.

Table 2.7.10.1-1 Summary of Stress Evaluation of Support Disk - 30-Foot Side-Drop

Table Number	Basket Orientation (deg)	Thermal Case	Stress Evaluation	Minimum Margin of Safety
2.7.10.1-2	0	1	P_m	+ 0.49
2.7.10.1-3	0	1	$P_m + P_b$	+ 0.61
2.7.10.1-4	0	2	P_m	+ 0.47
2.7.10.1-5	0	2	$P_m + P_b$	+ 0.60
2.7.10.1-6	31.82	1	P_m	+ 0.75
2.7.10.1-7	31.82	1	$P_m + P_b$	+ 0.16
2.7.10.1-8	31.82	2	P_m	+ 0.72
2.7.10.1-9	31.82	2	$P_m + P_b$	+ 0.15
2.7.10.1-10	49.46	1	P_m	+ 0.82
2.7.10.1-11	49.46	1	$P_m + P_b$	+ 0.36
2.7.10.1-12	49.46	2	P_m	+ 0.60
2.7.10.1-13	49.46	2	$P_m + P_b$	+ 0.32
2.7.10.1-14	77.92	1	P_m	+ 0.46
2.7.10.1-15	77.92	1	$P_m + P_b$	+ 0.35
2.7.10.1-16	77.92	2	P_m	+ 0.46
2.7.10.1-17	77.92	2	$P_m + P_b$	+ 0.35
2.7.10.1-18	90	1	P_m	+ 0.12
2.7.10.1-19	90	1	$P_m + P_b$	+ 0.59
2.7.10.1-20	90	2	P_m	+ 0.13
2.7.10.1-21	90	2	$P_m + P_b$	+ 0.59

Table 2.7.10.1-2 P_m Stresses for Support Disk 30-Foot Side-Drop, 0° Orientation, Thermal Case 1

Section	Stress (ksi)			Stress	Stress	Margin of
	Sx	Sy	Sxy	Intensity (ksi)	Allowable (ksi)	Safety
293	14.9	-27.4	-0.3	42.4	63.0	0.49
294	17.8	-23.7	-0.8	41.6	63.0	0.52
298	-0.3	-40.3	0.0	40.3	63.0	0.56
227	13.5	-25.7	0.0	39.2	63.0	0.61
232	-0.2	-37.6	-0.5	37.6	63.0	0.68
299	-0.2	-36.7	0.7	36.8	63.0	0.71
290	-0.2	-35.6	0.1	35.6	63.0	0.77
300	10.7	-24.9	0.2	35.6	63.0	0.77
228	14.5	-20.8	0.7	35.3	63.0	0.79
284	10.8	-23.8	-0.1	34.6	63.0	0.82
224	-0.2	-33.2	-0.2	33.2	63.0	0.90
301	9.1	-22.4	-4.0	32.6	63.0	0.93
218	9.8	-22.2	0.4	32.0	63.0	0.97
233	-0.1	-31.9	-0.8	31.9	63.0	0.98
285	12.0	-19.8	-0.6	31.8	63.0	0.98
296	-1.5	-31.6	0.2	31.6	63.0	0.99
259	12.0	-18.6	3.6	31.4	63.0	1.01
291	-0.2	-31.0	0.6	31.0	63.0	1.03
281	-0.2	-31.0	0.1	31.0	63.0	1.03
263	11.7	-16.6	-5.9	30.8	63.0	1.05

Table 2.7.10.1-3 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 0° Orientation, Thermal Case 1

Section	Stress (ksi)			Stress Intensity (ksi)	Stress Allowable (ksi)	Margin of Safety
	Sx	Sy	Sxy			
16	-31.2	-35.4	-22.4	55.8	90.0	0.61
15	-29.3	-32.8	19.6	50.7	90.0	0.77
301	7.1	-36.7	-10.8	48.8	90.0	0.84
293	14.0	-29.0	-1.5	43.1	90.0	1.09
297	-14.2	-39.9	-8.5	42.5	90.0	1.12
294	8.5	-33.3	-0.4	41.8	90.0	1.15
298	-0.3	-40.6	0.0	40.6	90.0	1.22
234	3.9	-31.3	9.8	40.3	90.0	1.23
227	18.1	-22.1	-1.2	40.3	90.0	1.24
232	-0.4	-39.7	-0.4	39.7	90.0	1.27
299	-0.5	-39.6	0.7	39.6	90.0	1.28
263	35.0	-3.6	-4.1	39.4	90.0	1.28
235	-2.8	-35.6	10.6	39.2	90.0	1.30
231	-11.8	-36.8	7.1	38.6	90.0	1.33
300	10.8	-24.9	7.3	38.6	90.0	1.33
259	20.7	-16.8	1.3	37.6	90.0	1.39
230	-5.5	-36.0	7.1	37.5	90.0	1.40
262	15.2	-21.9	2.4	37.4	90.0	1.41
260	22.7	-14.1	-1.8	37.0	90.0	1.44
288	-14.2	-33.6	-7.8	36.3	90.0	1.48

Table 2.7.10.1-4 P_m Stresses for Support Disk 30-Foot Side-Drop, 0° Orientation, Thermal Case 2

Section	Stress (ksi)			Stress	Stress	Margin of
	Sx	Sy	Sxy	Intensity (ksi)	Allowable (ksi)	Safety
293	15.2	-27.6	-0.3	42.8	63.0	0.47
294	18.0	-23.7	-0.8	41.7	63.0	0.51
298	-0.3	-40.6	0.0	40.6	63.0	0.55
227	13.8	-25.9	0.0	39.6	63.0	0.59
232	-0.2	-37.9	-0.5	37.9	63.0	0.66
299	-0.2	-36.8	0.8	36.8	63.0	0.71
300	11.7	-25.0	0.1	36.7	63.0	0.72
290	-0.2	-35.8	0.1	35.8	63.0	0.76
228	14.5	-20.9	0.7	35.7	63.0	0.76
284	10.8	-23.9	-0.1	34.9	63.0	0.81
224	-0.2	-33.5	-0.2	33.5	63.0	0.88
301	9.1	-22.5	-4.4	33.4	63.0	0.88
218	9.8	-22.4	0.4	32.3	63.0	0.95
233	-0.1	-32.1	-0.8	32.2	63.0	0.96
296	12.0	-31.9	0.1	31.9	63.0	0.98
285	-1.5	-19.8	-0.6	31.8	63.0	0.98
259	12.0	-18.7	3.6	31.7	63.0	0.99
281	-0.2	-31.2	0.1	31.2	63.0	1.02
263	-0.2	-16.9	-0.6	31.1	63.0	1.02
291	11.7	-31.0	0.6	31.0	63.0	1.03

Table 2.7.10.1-5 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 0° Orientation, Thermal Case 2

Section	Stress (ksi)			Stress Intensity (ksi)	Stress Allowable (ksi)	Margin of Safety
	Sx	Sy	Sxy			
16	-32.0	-35.3	-22.6	56.3	90.0	0.60
15	-30.0	-33.0	19.9	51.5	90.0	0.75
301	7.7	-37.7	-11.1	50.5	90.0	0.78
293	14.1	-29.3	-1.4	43.5	90.0	1.07
297	-14.7	-40.7	-8.7	43.3	90.0	1.08
294	27.8	-13.9	-1.2	41.8	90.0	1.15
234	4.8	-31.6	9.9	41.4	90.0	1.18
298	-0.3	-40.9	0.0	40.9	90.0	1.20
235	-2.0	-36.5	10.9	40.8	90.0	1.21
227	18.4	-22.2	-1.2	40.8	90.0	1.21
232	-0.4	-40.0	-0.4	40.0	90.0	1.25
299	-0.6	-39.9	0.7	39.9	90.0	1.25
263	35.6	-3.4	-4.1	39.8	90.0	1.26
231	-12.4	-37.6	7.3	39.5	90.0	1.28
300	11.5	-25.3	-7.0	39.4	90.0	1.39
259	20.9	-17.0	1.4	38.1	90.0	1.37
230	-5.7	-36.3	7.2	37.9	90.0	1.37
260	23.3	-14.0	-1.9	37.5	90.0	1.40
262	15.0	-22.1	2.5	37.4	90.0	1.41
288	-14.4	-33.8	-7.8	36.6	90.0	1.46

Table 2.7.10.1-6 P_m Stresses for Support Disk 30-Foot Side-Drop, 31.82° Orientation, Thermal Case 1

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
246	-17.9	10.0	11.3	35.9	63.0	.75
234	6.4	-18.4	12.2	34.9	63.0	.81
300	10.3	-18.8	9.2	34.4	63.0	.83
235	-2.4	-13.7	15.0	32.0	63.0	.97
298	-.3	-31.8	-1.4	31.8	63.0	.98
293	4.7	-21.0	7.0	29.3	63.0	1.15
243	-16.4	9.4	6.3	28.7	63.0	1.20
299	-.2	-28.5	-.8	28.5	63.0	1.21
229	-18.6	3.8	8.8	28.5	63.0	1.21
232	-.2	-27.8	-2.0	28.0	63.0	1.25
290	-.2	-27.6	-2.0	27.8	63.0	1.27
245	-27.3	-.2	-2.1	27.5	63.0	1.29
227	5.0	-18.3	6.8	27.0	63.0	1.33
277	7.8	-10.2	9.6	26.3	63.0	1.39
301	7.3	-16.4	5.7	26.3	63.0	1.40
294	3.6	-18.3	7.2	26.3	63.0	1.40
54	.0	-14.9	10.3	25.4	63.0	1.48
295	2.8	-14.0	9.3	25.0	63.0	1.52
263	-8.3	-24.8	-1.4	24.9	63.0	1.53
257	-6.4	5.5	10.9	24.9	63.0	1.53

Table 2.7.10.1-7 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 31.82° Orientation, Thermal Case 1

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
274	-46.2	-73.0	12.5	77.9	90.0	.16
208	-47.6	-72.5	11.7	77.2	90.0	.17
266	-55.9	-67.6	12.6	75.6	90.0	.19
200	-56.6	-67.2	12.0	75.0	90.0	.20
275	-43.7	-67.2	12.3	72.4	90.0	.24
209	-48.7	-65.5	10.6	70.6	90.0	.27
267	-54.2	-61.6	12.1	70.5	90.0	.28
74	-46.3	-66.0	9.2	69.6	90.0	.29
137	-48.2	-65.8	9.1	69.6	90.0	.29
82	-45.2	-63.6	10.8	68.6	90.0	.31
173	-51.5	-62.3	9.8	68.1	90.0	.32
238	-50.7	-61.8	10.5	68.1	90.0	.32
145	-46.6	-62.8	10.2	67.7	90.0	.33
201	-52.8	-59.9	9.4	66.4	90.0	.36
18	-61.7	-55.1	7.0	66.2	90.0	.36
32	-62.0	-55.6	6.1	65.7	90.0	.37
234	-1.2	-54.9	18.4	65.1	90.0	.38
176	-52.4	-58.3	9.2	65.1	90.0	.38
21	-60.7	-50.8	7.1	64.4	90.0	.40
241	-49.1	-57.0	10.4	64.2	90.0	.40

Table 2.7.10.1-8 P_m Stresses for Support Disk 30-Foot Side-Drop, 31.82° Orientation, Thermal Case 2

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
246	-17.9	10.2	11.8	36.7	63.0	.72
300	11.4	-18.7	9.7	35.8	63.0	.76
234	6.1	-18.4	12.8	35.5	63.0	.78
235	-3.0	-13.7	15.4	32.6	63.0	.93
298	-.3	-31.9	-1.5	32.0	63.0	.97
229	-19.3	4.0	9.1	29.5	63.0	1.13
293	4.8	-21.1	7.1	29.5	63.0	1.14
243	-16.5	10.0	6.2	29.2	63.0	1.15
299	-.2	-28.9	-.8	28.9	63.0	1.18
277	8.7	-11.3	10.2	28.4	63.0	1.22
290	-.2	-27.7	-2.1	27.8	63.0	1.26
232	-.2	-27.6	-2.1	27.8	63.0	1.27
301	8.7	-16.4	5.9	27.8	63.0	1.27
245	-27.5	-.2	-2.2	27.7	63.0	1.28
294	3.9	-18.5	7.4	26.9	63.0	1.34
227	4.8	-18.2	6.9	26.8	63.0	1.35
257	-6.3	6.2	11.6	26.4	63.0	1.38
54	-.1	-15.5	10.7	26.3	63.0	1.39
263	-8.5	-25.3	-1.6	25.4	63.0	1.48
295	2.5	-13.8	9.6	25.2	63.0	1.50

Table 2.7.10.1-9 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 31.82° Orientation, Thermal Case 2

	Stresses (ksi)			Stress	Stress	Margin of
Section	Sx	Sy	Sxy	Intensity (ksi)	Allow(ksi)	Safety
274	-46.7	-73.6	12.6	78.6	90.0	.15
208	-48.2	-72.9	11.7	77.5	90.0	.16
266	-55.0	-67.7	12.5	75.3	89.8	.19
200	-56.2	-66.9	12.0	74.7	89.8	.20
275	-44.5	-68.5	12.5	73.9	90.0	.22
267	-54.5	-62.9	12.2	71.6	90.0	.26
209	-49.5	-66.3	10.7	71.5	90.0	.26
74	-45.8	-65.3	9.1	68.9	89.8	.30
238	-51.3	-62.3	10.5	68.7	90.0	.31
82	-45.3	-63.7	10.7	68.6	90.0	.31
173	-52.1	-62.7	9.8	68.6	90.0	.31
137	-47.2	-64.7	8.7	68.3	89.8	.31
145	-46.6	-62.5	10.0	67.3	90.0	.34
201	-53.2	-60.5	9.5	67.1	90.0	.34
234	-1.7	-56.5	19.0	66.6	90.0	.35
176	-53.3	-59.1	9.4	66.0	90.0	.36
276	-43.5	-58.9	12.1	65.5	90.0	.37
235	-11.8	-59.1	18.4	65.4	90.0	.38
241	-49.9	-58.2	10.5	65.3	90.0	.38
18	-60.5	-55.1	6.8	65.1	89.8	.38

Table 2.7.10.1-10 P_m Stresses for Support Disk 30-Foot Side-Drop, 49.46° Orientation, Thermal Case 1

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
246	-19.3	8.0	10.6	34.5	63.0	.82
27	-18.1	7.0	8.4	30.2	63.0	1.09
85	-25.6	2.5	5.3	30.0	63.0	1.10
300	10.0	-13.7	8.9	29.7	63.0	1.12
234	3.6	-13.6	11.8	29.2	63.0	1.15
245	-28.3	-.2	-1.8	28.4	63.0	1.22
269	-28.3	-.9	.3	28.3	63.0	1.23
243	-17.9	8.1	5.5	28.2	63.0	1.23
235	-4.5	-9.9	13.1	26.8	63.0	1.35
29	-26.8	-.2	-.6	26.8	63.0	1.35
103	-11.2	7.8	9.2	26.4	63.0	1.39
65	-13.1	-5.4	12.1	25.4	63.0	1.48
229	-16.1	3.5	8.0	25.3	63.0	1.49
257	-10.6	4.7	9.6	24.6	63.0	1.56
242	-23.8	-.2	-1.9	24.0	63.0	1.63
28	-21.5	-5.6	-6.7	23.9	63.0	1.63
298	-.3	-23.9	-1.3	23.9	63.0	1.63
5	-17.6	-7.3	9.9	23.5	63.0	1.68
265	-9.1	11.0	5.7	23.2	63.0	1.72
26	-22.9	-.3	-2.1	23.1	63.0	1.72

Table 2.7.10.1-11 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 49.46° Orientation, Thermal Case 1

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
74	-46.5	-60.1	11.0	66.2	90.0	.36
137	-47.3	-59.1	10.5	65.2	90.0	.38
27	-62.1	-16.6	11.7	64.9	90.0	.39
274	-42.1	-59.5	10.5	64.4	90.0	.40
208	-43.3	-59.3	10.0	64.1	90.0	.40
24	-62.0	-30.5	7.7	63.8	90.0	.41
21	-60.7	-38.6	7.0	62.7	90.0	.44
18	-60.3	-43.0	6.7	62.6	90.0	.44
75	-45.4	-55.1	10.7	62.0	90.0	.45
266	-51.7	-52.1	10.1	62.0	90.0	.45
200	-51.1	-51.9	9.3	60.9	90.0	.48
32	-58.6	-43.6	5.6	60.4	90.0	.49
138	-47.3	-52.6	9.7	60.1	90.0	.50
209	-43.6	-53.6	9.2	59.0	90.0	.52
82	-44.8	-53.4	9.0	59.0	90.0	.52
275	-40.3	-53.4	10.1	58.9	90.0	.53
173	-47.8	-51.9	8.7	58.8	90.0	.53
238	-47.3	-51.2	9.2	58.6	90.0	.54
267	-50.9	-45.8	9.5	58.2	90.0	.55
246	-54.7	-6.6	11.9	57.5	90.0	.57

Table 2.7.10.1-12 P_m Stresses for Support Disk 30-Foot Side-Drop, 49.46° Orientation, Thermal Case 2

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
246	-21.1	11.3	11.1	39.3	63.0	.60
243	-19.6	10.5	5.7	32.1	63.0	.96
245	-31.2	-.2	-1.9	31.3	63.0	1.01
300	10.0	-13.5	9.4	30.1	63.0	1.09
85	-25.2	2.1	6.2	30.0	63.0	1.10
234	3.1	-13.4	12.2	29.4	63.0	1.14
27	-17.1	5.5	8.4	28.2	63.0	1.24
269	-27.3	-1.3	1.4	27.4	63.0	1.30
235	-4.8	-9.9	13.4	27.2	63.0	1.31
103	-11.5	8.1	9.4	27.2	63.0	1.32
242	-26.2	-.2	-2.0	26.4	63.0	1.39
257	-11.1	5.8	9.9	26.0	63.0	1.42
229	-16.4	3.6	8.2	25.9	63.0	1.44
65	-12.9	-5.5	12.4	25.8	63.0	1.44
29	-25.0	-.2	-.9	25.1	63.0	1.51
244	-24.7	-14.0	.6	24.7	63.0	1.55
240	-15.8	5.3	5.9	24.2	63.0	1.61
256	-23.6	-.2	-1.4	23.7	63.0	1.66
298	-.3	-23.5	-1.4	23.6	63.0	1.67
265	-8.9	11.3	5.8	23.3	63.0	1.71

Table 2.7.10.1-13 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 49.46° Orientation, Thermal Case 2

	Stresses (ksi)			Stress	Stress	Margin of
Section	Sx	Sy	Sxy	Intensity (ksi)	Allow(ksi)	Safety
274	-44.8	-62.5	11.5	68.1	90.0	.32
27	-64.6	-21.4	11.7	67.5	90.0	.33
208	-45.6	-61.8	10.8	67.2	90.0	.34
74	-47.7	-60.6	11.0	66.9	89.8	.34
24	-64.3	-34.1	7.6	66.1	90.0	.36
137	-47.8	-59.2	10.2	65.2	89.8	.38
21	-62.5	-41.6	7.0	64.6	90.0	.39
275	-43.4	-57.6	11.4	63.9	90.0	.41
75	-47.3	-56.9	10.7	63.8	90.0	.41
266	-52.4	-54.1	10.3	63.6	89.8	.41
18	-60.7	-44.8	6.6	63.1	89.8	.42
200	-52.1	-53.5	9.6	62.5	89.8	.44
209	-45.8	-56.4	10.0	62.4	90.0	.44
238	-50.6	-53.9	10.0	62.4	90.0	.44
173	-50.6	-54.2	9.5	62.0	90.0	.45
32	-59.4	-45.0	5.6	61.3	89.9	.47
267	-53.0	-49.4	10.1	61.4	90.0	.47
138	-48.7	-53.9	9.6	61.3	90.0	.47
246	-58.6	-5.3	11.9	61.1	90.0	.47
82	-45.2	-55.2	9.2	60.7	90.0	.48

Table 2.7.10.1-14 P_m Stresses for Support Disk 30-Foot Side-Drop, 77.92° Orientation, Thermal Case 1

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
27	-26.3	14.3	7.4	43.1	63.0	.46
246	-25.2	12.9	9.6	42.5	63.0	.48
85	-30.5	10.5	4.1	41.8	63.0	.51
269	-31.4	9.1	-1.3	40.5	63.0	.55
29	-37.9	-.1	-.4	37.9	63.0	.66
243	-23.6	12.2	4.8	37.1	63.0	.70
245	-36.1	-.3	-1.6	36.1	63.0	.74
5	-24.4	-18.4	12.3	34.1	63.0	.85
24	-22.7	9.6	3.9	33.2	63.0	.90
26	-33.0	-.3	-1.9	33.1	63.0	.90
265	-16.6	13.5	6.8	33.1	63.0	.90
28	-30.7	-2.3	-6.0	31.9	63.0	.97
256	-31.8	-.2	-1.0	31.8	63.0	.98
240	-19.7	11.2	2.8	31.4	63.0	1.00
242	-31.0	-.2	-1.8	31.1	63.0	1.03
254	-21.2	7.9	4.7	30.6	63.0	1.06
23	-28.5	-.2	-2.3	28.7	63.0	1.19
244	-28.3	-7.8	.5	28.3	63.0	1.22
65	-16.7	-4.7	12.8	28.3	63.0	1.23
262	-15.2	12.4	1.2	27.7	63.0	1.27

Table 2.7.10.1-15 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 77.92° Orientation, Thermal Case 1

	Stresses (ksi)			Stress	Stress	Margin of
Section	Sx	Sy	Sxy	Intensity (ksi)	Allow(ksi)	Safety
27	-64.6	-5.4	11.1	66.6	90.0	.35
24	-64.8	-22.4	7.7	66.2	90.0	.36
22	-61.1	-37.9	8.4	63.8	90.0	.41
65	-54.7	-12.7	17.7	61.1	90.0	.47
246	-54.6	1.6	11.6	60.9	90.0	.48
75	-49.8	-42.0	12.0	58.5	90.0	.54
241	-53.8	-35.9	10.2	58.4	90.0	.54
54	-54.3	-14.1	13.6	58.4	90.0	.54
9	-45.1	-37.3	16.3	58.0	90.0	.55
19	-54.9	-36.3	7.3	57.4	90.0	.57
243	-56.2	-14.3	5.8	57.0	90.0	.58
21	-55.7	-25.2	4.4	56.3	90.0	.60
25	-53.8	-33.8	6.2	55.6	90.0	.62
5	-43.9	-45.8	10.6	55.5	90.0	.62
51	-52.9	-29.0	7.5	55.0	90.0	.64
74	-45.3	-40.7	10.9	54.1	90.0	.66
238	-48.2	-35.1	9.3	53.0	90.0	.70
31	-49.9	-35.1	6.4	52.3	90.0	.72
268	-50.1	-22.4	7.4	51.9	90.0	.73
244	-48.3	-31.9	8.3	51.8	90.0	.74

Table 2.7.10.1-16 P_m Stresses for Support Disk 30-Foot Side-Drop, 77.92° Orientation, Thermal Case 2

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
246	-25.2	13.4	9.7	43.2	63.0	.46
27	-25.9	14.1	7.4	42.6	63.0	.48
85	-30.7	10.6	4.1	42.1	63.0	.50
269	-31.2	9.2	-1.1	40.4	63.0	.56
243	-23.7	12.8	4.5	37.6	63.0	.67
29	-37.4	-.1	-.4	37.4	63.0	.69
245	-36.2	-.3	-1.6	36.3	63.0	.74
5	-24.4	-18.6	12.3	34.1	63.0	.85
24	-22.4	9.7	3.7	32.9	63.0	.91
26	-32.5	-.3	-1.9	32.6	63.0	.93
265	-16.1	13.8	6.5	32.6	63.0	.93
256	-32.1	-.2	-1.0	32.1	63.0	.96
240	-19.8	11.2	2.9	31.5	63.0	1.00
28	-30.3	-2.0	-6.0	31.5	63.0	1.00
242	-31.1	-.2	-1.8	31.2	63.0	1.02
254	-21.4	8.5	4.3	31.2	63.0	1.02
65	-16.9	-4.8	12.9	28.5	63.0	1.21
244	-28.5	-7.6	.7	28.5	63.0	1.21
23	-28.1	-.2	-2.3	28.3	63.0	1.22
253	-27.9	-.2	-1.4	28.0	63.0	1.25

Table 2.7.10.1-17 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 77.92° Orientation, Thermal Case 2

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
27	-64.7	-6.0	11.1	66.7	90.0	.35
24	-63.6	-22.0	7.4	64.9	90.0	.39
22	-59.8	-37.1	8.2	62.4	90.0	.44
65	-55.2	-12.8	17.8	61.7	90.0	.46
246	-55.1	1.8	11.6	61.5	90.0	.46
54	-54.7	-14.2	13.7	58.9	90.0	.53
9	-45.5	-37.6	16.4	58.5	90.0	.54
241	-53.0	-35.5	10.1	57.6	90.0	.56
75	-48.8	-41.1	11.7	57.3	90.0	.57
243	-55.4	-13.4	5.4	56.1	90.0	.60
19	-53.5	-35.0	7.2	56.0	89.9	.61
5	-43.9	-46.2	10.6	55.7	90.0	.62
25	-53.9	-33.1	6.2	55.6	90.0	.62
21	-54.8	-24.8	4.5	55.5	90.0	.62
51	-52.1	-28.4	7.2	54.2	90.0	.66
74	-44.1	-39.2	10.6	52.6	89.8	.71
244	-49.0	-31.7	8.5	52.5	90.0	.71
238	-47.7	-34.6	9.3	52.5	90.0	.71
103	6.4	49.1	9.9	51.3	90.0	.76
76	25.2	49.4	6.8	51.2	90.0	.76

Table 2.7.10.1-18 P_m Stresses for Support Disk 30-Foot Side-Drop, 90° Orientation, Thermal Case 1

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
27	-31.0	25.4	.0	56.4	63.0	.12
77	-19.0	28.8	4.5	48.7	63.0	.29
269	-19.0	28.8	-4.5	48.7	63.0	.29
85	-20.9	26.6	.2	47.4	63.0	.33
277	-20.9	26.6	-.2	47.4	63.0	.33
54	-24.8	19.4	.3	44.2	63.0	.43
246	-24.8	19.4	-.3	44.2	63.0	.43
29	-43.6	-.2	.0	43.6	63.0	.44
28	-35.8	6.7	.0	42.5	63.0	.48
24	-26.8	13.6	.0	40.3	63.0	.56
26	-38.4	-.4	.0	38.4	63.0	.64
6	-19.1	-30.4	-11.3	37.4	63.0	.68
5	-19.1	-30.4	11.3	37.4	63.0	.68
273	.3	37.0	.4	37.0	63.0	.70
81	.3	37.0	-.4	37.0	63.0	.70
51	-22.8	12.1	.2	34.9	63.0	.80
243	-22.8	12.1	-.2	34.9	63.0	.80
53	-33.8	-.3	-.3	33.8	63.0	.86
245	-33.8	-.3	.3	33.8	63.0	.86
23	-33.6	-.2	.0	33.6	63.0	.88

Table 2.7.10.1-19 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 90° Orientation, Thermal Case 1

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
77	-15.9	40.4	3.8	56.8	90.0	.59
269	-15.9	40.4	-3.8	56.8	90.0	.59
27	-31.0	25.4	-2.3	56.6	90.0	.59
246	-33.6	15.4	-2.5	49.2	90.0	.83
54	-33.6	15.4	2.5	49.2	90.0	.83
85	-20.3	28.6	-.8	48.9	90.0	.84
277	-20.3	28.6	.8	48.9	90.0	.84
28	-35.8	6.7	7.2	44.8	90.0	1.01
5	-25.6	-35.0	13.0	44.1	90.0	1.04
6	-25.6	-35.0	-13.0	44.1	90.0	1.04
29	-43.6	-.2	.2	43.6	90.0	1.06
273	.7	41.2	.4	41.2	90.0	1.19
81	.7	41.2	-.4	41.2	90.0	1.19
24	-26.8	13.6	-4.0	41.1	90.0	1.19
257	-35.3	-1.0	-10.8	40.5	90.0	1.22
65	-35.3	-1.0	10.8	40.5	90.0	1.22
26	-38.4	-.4	-.2	38.4	90.0	1.34
10	-29.6	-19.7	-10.6	36.3	90.0	1.48
9	-29.6	-19.7	10.6	36.3	90.0	1.48
63	-33.6	-11.3	6.7	35.5	90.0	1.54

Table 2.7.10.1-20 P_m Stresses for Support Disk 30-Foot Side-Drop, 90° Orientation, Thermal Case 2

Section	Stresses (ksi) Sx	Sy	Sxy	Stress Intensity (ksi)	Stress Allow(ksi)	Margin of Safety
27	-30.6	25.4	.0	56.0	63.0	.13
77	-18.8	28.8	4.5	48.4	63.0	.30
269	-18.8	28.8	-4.5	48.4	63.0	.30
85	-20.8	26.5	.2	47.3	63.0	.33
277	-20.8	26.5	-.2	47.3	63.0	.33
54	-24.7	19.4	.3	44.1	63.0	.43
246	-24.7	19.4	-.3	44.1	63.0	.43
29	-43.1	-.2	.0	43.1	63.0	.46
28	-35.4	6.7	.0	42.1	63.0	.50
24	-26.4	13.5	.0	39.9	63.0	.58
26	-37.9	-.4	.0	37.9	63.0	.66
6	-19.0	-30.5	-11.3	37.4	63.0	.69
5	-19.0	-30.5	11.3	37.4	63.0	.69
273	.3	36.9	.4	36.9	63.0	.71
81	.3	36.9	-.4	36.9	63.0	.71
51	-22.8	12.1	.2	34.8	63.0	.81
243	-22.8	12.1	-.2	34.8	63.0	.81
53	-33.7	-.3	-.3	33.7	63.0	.87
245	-33.7	-.3	.3	33.7	63.0	.87
23	-33.1	-.2	.0	33.1	63.0	.90

Table 2.7.10.1-21 $P_m + P_b$ Stresses for Support Disk 30-Foot Side-Drop, 90° Orientation, Thermal Case 2

Section	Stress (ksi)			Stress	Stress	Margin of
	Sx	Sy	Sxy	Intensity (ksi)	Allow (ksi)	Safety
77	-15.7	40.2	3.9	56.4	90.0	.59
269	-15.7	40.2	-3.9	56.4	90.0	.59
27	-30.6	25.4	-2.2	56.1	90.0	.60
246	-33.5	15.4	-2.4	49.1	90.0	.83
54	-33.5	15.4	2.4	49.1	90.0	.83
85	-20.2	28.6	-0.8	48.8	90.0	.84
277	-20.2	28.6	0.8	48.8	90.0	.84
28	-35.4	6.7	7.1	44.4	90.0	1.03
5	-25.3	-34.9	13.0	44.0	90.0	1.05
6	-25.3	-34.9	-13.0	44.0	90.0	1.05
29	-43.1	-0.2	0.2	43.1	90.0	1.09
273	0.7	41.1	0.3	41.1	90.0	1.19
81	0.7	41.1	-0.3	41.1	90.0	1.19
24	-26.4	13.5	-3.9	40.7	90.0	1.21
257	-35.3	-1.0	-10.8	40.6	90.0	1.22
65	-35.3	-1.0	10.8	40.6	90.0	1.22
26	-37.9	-0.4	-0.2	38.0	90.0	1.37
10	-29.8	-19.8	-10.6	36.5	90.0	1.47
9	-29.8	-19.8	10.6	36.5	90.0	1.47
63	-33.5	-11.3	6.7	35.4	90.0	1.54

Table 2.7.10.1-22 Summary of Stress Evaluations of Support Disk - 30-Foot End-Drop

Table Number	g Load	Thermal Case	Stress Evaluation	Minimum Margin of Safety
2.7.10.1-23	55	1	$P_m + P_b$	+.02
2.7.10.1-24	55	4	$P_m + P_b$	+.01

Table 2.7.10.1-23 $P_m + P_b$ Stresses for Support Disk 30-Foot End-Drop, Thermal Case 1

Node	Principal Stresses (ksi)			Stress Intensity (ksi)	Allowable Stress (ksi)*	Margin of Safety
	S1	S2	S3			
86	69.7	0.0	-2.9	72.6	90.0	0.24
474	88.4	5,.3	0.0	88.4	90.0	0.02
1129	81.4	4.0	0.0	81.4	90.0	0.11
1444	88.4	5.8	0.0	88.4	90.0	0.02
1564	69.7	0.0	-2.9	72.6	90.0	0.24
2236	81.4	4.0	0.0	81.4	90.0	0.11
2558	88.4	5.8	0.0	88.4	90.0	0.02
2680	69.7	0.0	-2.9	72.6	90.0	0.24
3332	81.4	4.0	0.0	81.4	90.0	0.11
3647	88.4	5.8	0.0	88.4	90.0	0.02
3765	69.7	0.0	-2.9	72.6	90.0	0.24
4407	81.4	4.0	0.0	81.4	90.0	0.11

*3.0 S_m = 3.0 x 30.0 ksi at 500°F.

Table 2.7.10.1-24 $P_m + P_b$ Stresses for Support Disk 30-Foot End-Drop, Thermal Case [redacted]

Node	Principal Stresses (ksi)			Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
	S1	S2	S3			
86	70.4	0.0	-2.9	73.3	90.0	0.23
474	89.3	5.9	0.0	89.3	90.0	0.01
1129	82.3	4.0	0.0	82.3	90.0	0.09
1444	89.3	5.9	0.0	89.3	90.0	0.01
1564	70.4	0.0	-2.9	73.3	90.0	0.23
2236	82.3	4.0	0.0	82.3	90.0	0.09
2558	89.3	5.9	0.0	89.3	90.0	0.01
2680	70.4	0.0	-2.9	73.3	90.0	0.23
3332	82.3	4.0	0.0	82.3	90.0	0.09
3647	89.3	5.9	0.0	89.3	90.0	0.01
3765	70.4	0.0	-2.9	73.3	90.0	0.23
4407	82.3	4.0	0.0	82.3	90.0	0.09

*3.0 S_m = 3.0 x 30.0 ksi at 500°F.

2.7.10.2 Stress Evaluation of Tie Rods and Spacers

The tie rods and spacers in the BWR basket are evaluated for structural adequacy following a free drop of the Universal Transport Cask 30 feet onto a flat, unyielding surface. The design deceleration for the cask for the hypothetical accident 30-ft end-drop is 60 *g*.

The structural capacity of the spacers supporting the basket is evaluated by hand calculations using classical analysis. Accident loading resulting from the 30-ft drop of the fuel basket is compared with stress limit of 0.7 S_u in accordance with Section III, Subsection NG of the ASME Code [19].

The tie rods serve basket assembly purposes and are not part of the load path for the condition evaluated. The tie rods are loaded during fabrication by a 190 ft-lb preload. Under drop conditions, the preload will be reduced. The tie rod design is, therefore, acceptable by inspection, and no detailed evaluation of the rods is required.

During the end-drop, the spacers are loaded with the weight of the support disks, the aluminum heat transfer disks, one end plate, and the weight of the spacers. The load is resisted by the effective area of six spacers. The compressive stresses are calculated on the effective area of the spacer.

The material allowable stress is conservatively selected at a bounding temperature of 500°F. The temperature near the outer edge of the support disks (at the tie rods) is below 500°F.

2.7.10.2.1 Design Criteria

Stress limits	=	0.7 S_u (accident condition, more limiting than 2.4 S_m)
Loading criteria (g)	=	60 *g* (accident condition)
Evaluation temperature	=	500°F

Basket Parameters

Fuel basket weight	=	18,199 lb
Bottom weldment weight	=	623 lb

Fuel tube weight (56 tubes)	=	4,665 lb
Rod diameter	=	1.625 in.
Spacer outer diameter	=	3.0 in.

Materials [21]

Tie rod	=	SA 479 Type 304 Stainless Steel
Spacer	=	SA 479 Type 304 Stainless Steel

Material Allowables

Type 304 stainless steel: S_m = 17,500 psi (500°F)

S_u = 63,500 psi (500°F).

2.7.10.2.2 30-Foot End-Drop Condition—Results

The deceleration assumed for the BWR basket in the 30-ft end-drop is 60 g. The spacers are loaded with the weight of the support disks, the aluminum heat transfer disks, one end plate, and the weight of the spacers. These loads are calculated as follows:

Total weight of basket	=	18,199 lb
Less weight of bottom weldment	=	-623 lb
Less weight of fuel tubes	=	-4,665 lb
1-g-load on spacers	=	12,911 lb
Applied g level	=	60 g

Therefore, Accident condition load on spacers = 12,911 x 60 = 774,660 lb

As a result of the end-drop, all spacers are compressed, thus distributing the load through the entire wall of the split spacer. The split spacer at each of six locations supporting the weight of the support disks is equal to the net area of the spacer and is calculated as

$$A = (3.14 \times (3.0^2 - 1.75^2))/(4) = 4.66 \text{ in}^2.$$

The average compressive stress, S_c, in the spacer is

S_c = (774,600)/(6 x 4.66) = 27,706 psi.

The allowable stress for SA479 Type 304 SS under accident conditions of transport is 0.7 S_u:

S_u = 63,500 psi

0.7 S_u = 0.7 x 63,500 = 44,450 psi.

The margin of safety, which is defined as $\frac{0.7S_u}{S_c} - 1$, is

(44,450 / 27,706) - 1 = + 0.60.

Therefore, the spacers are structurally adequate for a 60 *g* end impact under accident conditions.

2.7.10.3 Buckling Evaluation of Support Disk

During the impact following a 30-ft side-drop of the Universal Transport Cask onto an unyielding surface, the support disk is subjected to compressive loading in the plane of the disk. For cask impact orientations other than on the side, loads acting perpendicular to the plane of the support disk (out of plane) may also be applied. The compressive in-plane loadings in conjunction with the bending moments resulting from the out-of-plane loadings require that buckling of the support disk be a design consideration. The acceptance criteria are contained in NUREG/CR-6322.

2.7.10.3.1 Method of Support Disk Buckling Analysis

The support disk buckling evaluation is based on the acceptance criteria of NUREG/CR-6322, which requires that both normal conditions of transport and hypothetical accident conditions be addressed.

The BWR fuel basket support disk material is SA 533, TYPE B, Class 2 with the following characteristics:

The yield strength	S_y = 59.3 ksi at 750°F	(Conservative)
	S_y = 70.0 ksi at -40°F	(Thermal Case 1)
	S_y = 60.5 ksi at 650°F	(Conservative)
The modulus of elasticity	E = 24.60 $(10)^3$ ksi at 750°F	(Conservative)
	E = 29.90 $(10)^3$ ksi at -40°F	(Thermal Case 1)
	E = 25.56E $(10)^3$ ksi at 650°F	(Conservative)

The dynamic amplification factor g = 60 g for the 30-ft side-drop
= 55 g for the 30-ft end-drop

Thermal Case 2 or 4 is bounding for Thermal Case 3. Conservative temperatures are used in the analysis.

2.7.10.3.2 Detailed Support Disk Buckling Analysis

Four thermal conditions are defined in Section 2.7.10.1.1. For these thermal conditions, the maximum forces and moments are determined for the side-drop condition for different radial orientations of the support disk. The buckling evaluation of the support disk web is based on Interaction Equations 31 and 32 in NUREG/CR-6322. These two equations adopt the "Limit Analysis Design" approach for structural members that experience stresses beyond the yield limit of the material, i.e., for members deformed inelastically as a result of both axial load and bending moment. Other equations applicable to the calculations are listed in this section.

Buckling stresses are calculated for both the strong and the weak axes of the support disk webs. In a side-drop condition, the bending moments are in-plane and are about the strong axis. For the weak axis buckling evaluation, the compressive forces from the side-drop are combined with the moments resulting from the end-drop.

Detailed calculations for the accident condition buckling evaluation are performed in a spreadsheet format by using the equations from NUREG/CR-6322. The load amplification factors are 60 g for the side-drop and 55 g for the end-drop. The calculational methodology is the same as the one discussed in Section 2.7.8.3.2 for the PWR support disk buckling analysis.

The loading conditions and the terminology used in the buckling evaluation are also the same as those discussed in Section 2.7.8.3.2.

For the buckling evaluation parameters, different values are associated with the weak and strong axes of the support disk web. The weak axis corresponds to the 0.625-in. support disk thickness and is associated with the moments that would buckle the webs with an out-of-plane motion. Moments that would buckle the support disk web in the plane of the support disk are associated with the strong axis of the web.

Weak-Axis Buckling

For the weak-axis buckling evaluation, the parameters are as follows for (Section 17):

Parameter	Value	Parameter	Value
t	0.625 in.	λ	0.431
b	0.66 in.	P_y	A x S_y = 24,956 ksi
A	0.413 in^2	F_a	43.22
L	6.278 in.	C_c	91.32
I	$b\,t^3/12 = 0.0134\ in^4$	P_{cr}	30.31
r	0.18	F_e	250.42
K	0.800	P_e	198.33
KL/r	27.83	M_p	3.83
Z	$bt^2/4 = 0.0614$	M_m	3.83
E	25,560 ksi	C_m	0.85
S_y	60.5 ksi		

Using the cross-sectional stresses calculated at each of the sections shown in Figures 2.6.15.6-2 through 2.6.15.6-5 for the 30-ft side-drop condition, the maximum corresponding compressive forces are combined with the maximum out-of-plane moment resulting from the 30-ft end-drop condition to obtain the conservative maximum interaction coefficients.

For weak axis buckling, the minimum margin of safety is +0.002 for the 90° radial basket orientation at Section 17 (thermal stresses are included).

The calculated minimum margins of safety for the drop orientations discussed in Section 2.6.13.6.1 are presented in Table 2.7.10.3-1. The location of the sections identified in the table are shown in Figures 2.6.13.14-2 through 2.6.13.14-5.

Strong-Axis Buckling

For the strong-axis buckling evaluation, the parameters are as follows for (Section 274):

Parameter	Value	Parameter	Value
t	0.65 in.	λ	0.418
b	0.625 in.	P_y	A x S_y = 24.091
A	0.406 in^2	F_a	42.687
L	6.278 in.	C_c	90.491
I	$b\,t^3/12 = 0.014\ in^4$	P_{cr}	29.481
r	0.188	F_e	260.68
K	0.800	P_e	203.334
KL/r	26.766	M_p	3.91
Z	$bt^2/4 = 0.066$	M_m	3.87
E	24,600 ksi	C_m	0.85
S_y	59.3 ksi		

Using the cross-sectional stresses evaluated for each of the sections shown in Figures 2.6.15.6-2 through 2.6.15.6-5, the maximum corresponding compressive forces in conjunction with the maximum in-plane moment produces the maximum interaction coefficients. Because the location of the maximum force and the maximum moment may not coincide, the calculation of the interaction coefficient is conservative. The maximum magnitude of the moment is used, regardless of sign, to ensure the most severe condition.

For strong-axis buckling, the minimum margin of safety is +0.33 for the 31.8° radial basket orientation at Section 274 (thermal stresses are included).

The calculated minimum margins of safety for the drop orientations discussed in Section 2.6.13.6.1 are presented in Table 2.7.10.3-2. The location of the sections identified in the table are shown in Figures 2.6.15.6-2 through 2.6.15.6-5.

Table 2.7.10.3-1 Minimum Margins of Safety from Buckling Evaluation of BWR Support Disks (Weak Axis)

Section No.	G-Load*	Disk Drop Orientation	Heat Case	MS1	MS2
270	60	0	1	+0.334	+0.294
270	60	0	2	0.165	0.130
270	60	0	2 + thermal load	0.041	0.001
270	60	31.82	1	0.461	0.431
270	60	31.82	2	0.282	0.253
270	60	31.82	2 + thermal load	0.139	0.102
270	60	49.46	1	0.589	0.571
239	60	49.46	2	0.353	0.312
17	60	49.46	2 + thermal load	0.158	0.111
239	60	77.92	1	0.448	0.396
239	60	77.92	2	0.258	0.213
17	60	77.92	2 + thermal load	0.120	0.062
47	60	90	1	0.461	0.410
13	60	90	2	0.11	0.023
17	60	90	2 + thermal load	0.06	0.002

* Includes out-of-plane moment due to 30-ft end-drop impact of 55 *g*.

Table 2.7.10.3-2 Minimum Margins of Safety from Buckling Evaluation of BWR Support Disk (Strong Axis)

Section No.	G-Load	Disk Drop Orientation	Heat Case	MS1	MS2
298	60	0	1	+1.24	+0.833
298	60	0	2	1.22	0.818
298	60	0	2 + thermal load	0.847	0.511
274	60	31.82	1	0.600	0.552
274	60	31.82	2	0.587	0.539
274	60	31.82	2 + thermal load	0.391	0.339
274	60	49.46	1	0.990	0.993
246	60	49.46	2	0.877	0.753
246	60	49.46	2 + thermal load	0.605	0.490
243	60	77.92	1	0.914	0.763
246	60	77.92	2	0.927	0.760
246	60	77.92	2 + thermal load	0.722	0.569
53	60	90	1	1.63	1.160
81	60	90	2	1.268	0.889
53	60	90	2 + thermal load	1.320	0.913

2.7.10.4 Fuel Tube Analysis

The fuel tube provides a foundation and sealed cavity to mount BORAL poison plates within the fuel basket structure and does not provide a structural function relative to the support of the fuel assembly. The fuel tube design is presented in Figure 2.6.15-3. To ensure that the fuel tube remains functional when the cask is subjected to design load conditions, a structural evaluation of the tube is performed for both the end- and side-impact load conditions.

2.7.10.4.1 Fuel Tube End-Impact Analysis

During the postulated cask end impact, fuel assemblies are supported by the cask bottom for the bottom-end-drop and the lid for the top-end-drop. Fuel assembly load is not carried by the fuel tubes. Therefore, the fuel tube for the end-impact load is evaluated by considering the weight of the fuel tube subjected to the cask deceleration carried by the minimum tube cross section. The minimum tube cross section is located at the contact point of the tube with the bottom weldment. The BWR fuel tube bearing analysis is bounded by the PWR analysis based on weight (See Section 2.7.8.4.1 for details).

2.7.10.4.2 Fuel Tube Side-Impact Analysis

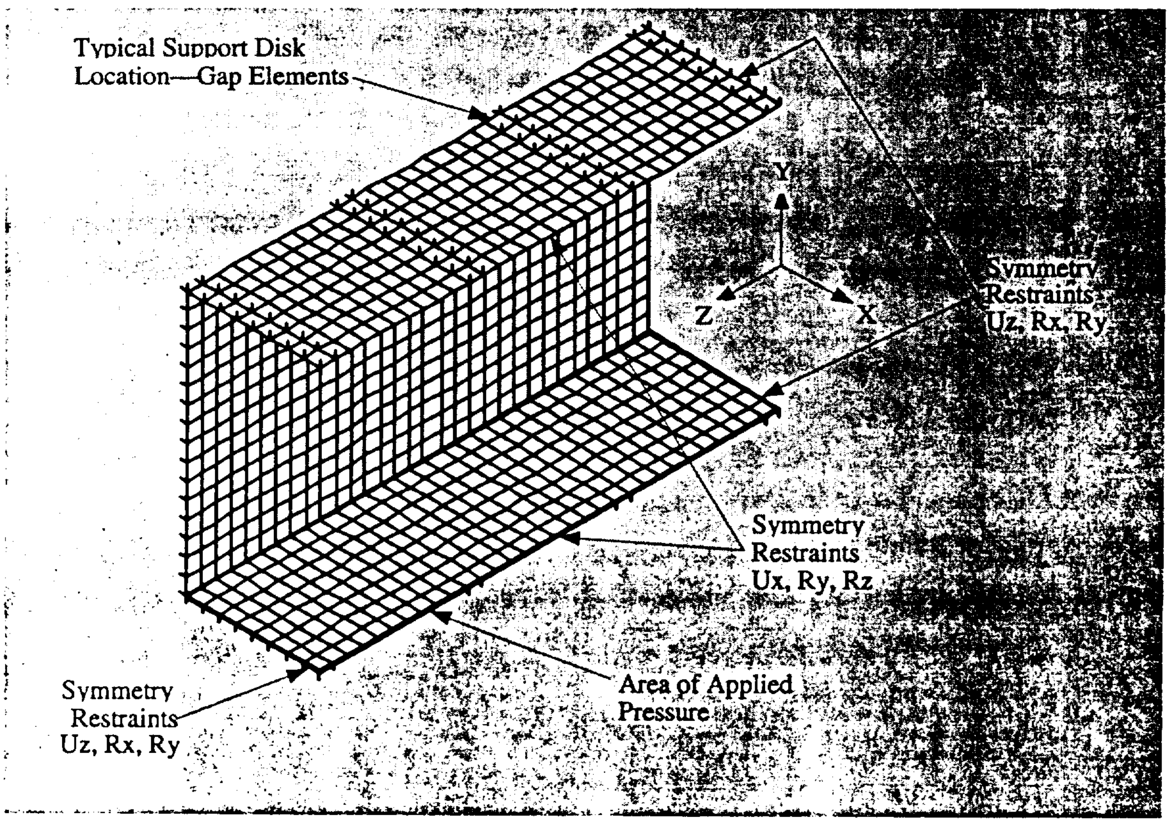
During the cask side-impact load configuration, the fuel tube is supported by the fuel basket 40 stainless steel support disks. The fuel basket support disks are spaced at 3.205 in. (which is slightly more than one half of the fuel tube width of 5.90 in.) and support the full length of the fuel tube. Considering the fuel tube subjected to the 60 g side impact deceleration and the 40 support locations provided by the basket support disks, the fuel tube shear stress is

Impact shear load	= (60)(700)/40 = 1,050 lb
Shear area of tube	= (0.048)(5.90)(2) = 0.566 in^2
Shear stress of tube	= 1,050/0.566 = 1,855 psi.

A temperature of 750°F is conservatively used to determine the allowable stresses. The yield strength of Type 304 stainless steel at 750°F is 17,300 psi. Using 8,650 psi, an allowable shear stress equivalent to half the yield strength of the tube wall material, results in a large positive margin of safety. The conservative evaluation of the tube loading resulting from its own mass during the side-impact configuration indicates that the tube structure will maintain position and will function.

The load transfer of the fuel assembly to the weight of the fuel basket support disk in the side impact is through direct bearing and compression of the distributed load of the fuel assembly through the fuel tube to the support disk web. Two load conditions are considered in the fuel tube evaluation. The first considers the fuel assembly load as a distributed pressure on the inside surface of the fuel tube. The second postulates that the fuel assembly grid is located at the center of the span between the support disks and produces a localized distributed load over the effective area of the grid.

Two different ANSYS finite element models of the tube are developed for these two load conditions since the fuel assembly structural performance for either load is nonlinear. As shown in the following, the first model represents a fuel tube section with a length of three spans, i.e.



the model is supported at four locations by support disks. The model conservatively considers the fuel tube wall thickness of 0.048 inch as the only material subjected to a distributed pressure load representative of the fuel assembly deceleration of 60g. Fuel assembly stiffness is not considered in the development of the imposed pressure load on the fuel tube.

The fuel tube is modeled with the ANSYS plastic, quadrilateral shell element (SHELL43). The support disks are represented as rigid gap elements (CONTAC52). The outer nodes of the gap

elements are fully restrained in all three translational directions. Edge restraints were applied to the model to represent symmetry boundary conditions. The effective load on the fuel tube due to the 60g deceleration of the assembly is applied as a pressure to the inside area of the fuel tube.

The finite element analysis results show that the maximum stress in the tube is 19.5 ksi, which is local to the sections of the tube resting on the support disks. At 750°F the ultimate strength for Type 304 stainless steel is 63.1 ksi. The margin of safety is:

$$MS = \frac{63.1}{19.5} - 1 = +2.24$$

The analysis shows that the maximum total strain is 0.0078 inch/inch. Defining the acceptable elastic-plastic response of the stainless steel as one half of the material failure strain of 0.40 in./in. at 750°F [24], the resulting margin of safety is:

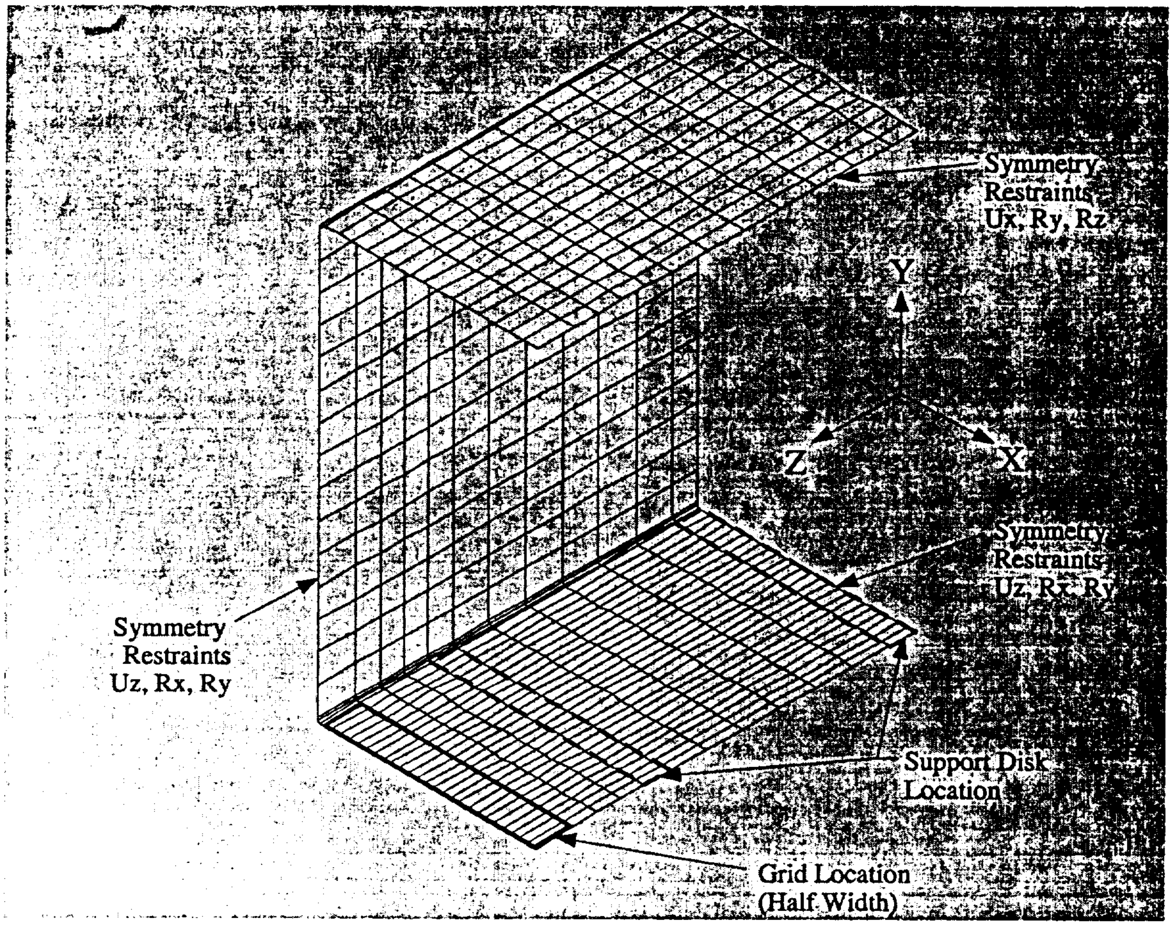
$$MS = \frac{0.40/2}{0.0078} - 1 = +Large$$

Similarly, the margin of safety for elastic-plastic stress becomes

$$MS = \frac{63.1 - 17.3}{19.5 - 17.3} - 1 = +Large$$

where the yield strength of Type 304 stainless steel is 17.3 ksi at 750°F.

The second finite element model is used to evaluate the load condition with the fuel assembly grid located at the center of the span between two support disks. The fuel tube is subjected to a localized distributed load over the effective area of the grid. As shown in the following, the model is a quarter-symmetry periodic section of the fuel tube. As in the finite element model used for the distributed pressure case, this model conservatively considers a fuel tube wall thickness of 0.048 inch. The BORAL plate (0.135 inch) and stainless steel cover plate (0.018 inch) are conservatively not included in the model. The tube wall is modeled with ANSYS SHELL43 elements. The support disks are modeled with CONTAC52 elements. A uniform pressure corresponding to the fuel assembly weight with the 60g load is applied to the elements at the grid location of the model. The displacement in the Y direction for the nodes at the grid location of the model are coupled to represent the structural rigidity of the spacer grid.



The finite element analysis results show that the maximum stress in the tube is 38.1 ksi. At 750°F the ultimate strength for Type 304 stainless steel is 63.1 ksi. The margin of safety is:

$$MS = \frac{63.1}{38.1} - 1 = +0.66$$

The analysis shows that the maximum total strain is 0.10 inch/inch. Defining the acceptable elastic-plastic response of the stainless steel as one half of the material failure strain of 0.40 in./in. at 750°F [24], the resulting margin of safety is:

$$MS = \frac{0.40/2}{0.10} - 1 = +1.0$$

Similarly, the margin of safety for elastic-plastic stress becomes:

$$MS = \frac{63.1 - 17.3}{38.1 - 17.3} - 1 = +1.2$$

where the yield strength of Type 304 stainless steel is 17.3 ksi at 750°F.

Both the maximum total strain and the elastic-plastic stress analyses indicate that the tube position within the support basket is maintained.

Assurance that the BORAL remains attached to the fuel tube is evaluated by considering that loads produced by the BORAL plate and stainless steel attachment plate, assuming a 60g load, are carried by the attachment plate weld. Total load and resultant stress on the weld are calculated as:

$F_{b/ss} = (g)(\rho)(t)(w)(l)$ Load exerted by BORAL/Stainless Steel Attachment Plate

where;

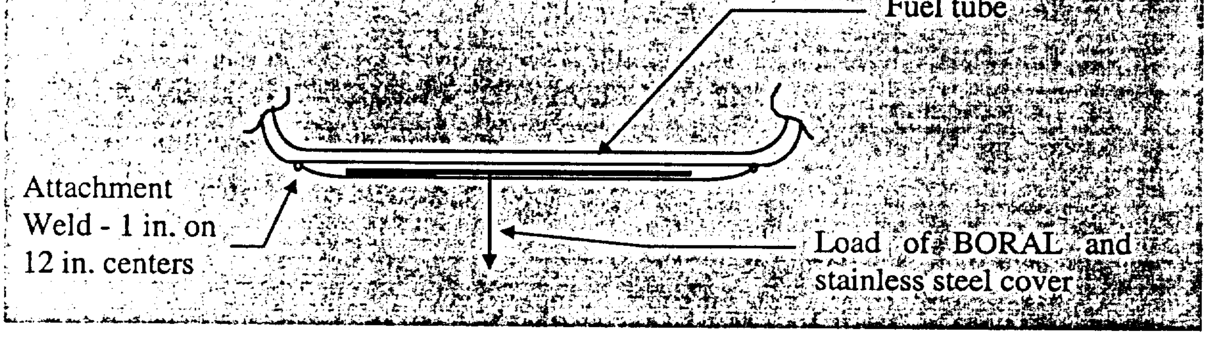
- g = acceleration (g)
- ρ = density of material (lb/in^3) (The density of aluminum (0.098 lb/in^3) is conservatively used for the BORAL.
- t = thickness of material (in.)
- w = width of material (in.)
- l = length of material section (in.)

The forces on the weld due to a 12-inch section of BORAL (F_b) and a 12-inch section of stainless steel plate (F_{ss}) are:

F_b = (60g)(0.098 lb/in^3)(0.135 in)(5.45 in)(12 in) = 51.9 lbs.

F_{ss} = (60g)(0.291 lb/in^3)(0.018 in)(5.79 in)(12 in) = 21.8 lbs.

The total load (F_t) on a 1-inch attachment for a 12-inch section is F_t = 73.7 lbs (51.9 + 21.8) lbs



The resulting weld stress is: $\sigma = P/A = (73.7 \text{ lbs}/2) / (1 \text{ in}) (0.018 \text{ in}) = 2,074$ psi

Since the weld material is Type 304 stainless steel, the margin of safety (at 750°F) is:

$$MS = \frac{17,300}{2,047} - 1 = +7.5$$

Therefore, the BORAL remains enclosed on each outer surface of the fuel tube wall.

2.7.10.5 Basket Weldment Analysis for 30-Foot End-Drop

The responses of the top and bottom weldment plates of the fuel basket assembly to a 60 *g* accident condition deceleration load are examined. Two finite element models representing the BWR basket top and bottom weldments are constructed for structural evaluation. The structural evaluations are performed at normal condition temperatures; therefore, prior to the structural evaluation portion of the analyses, the steady-state temperature distribution in the top and bottom weldment models is determined by applying fixed temperatures to the outer circular edge and to the node at the intersection of the symmetry planes. These fixed temperatures are obtained from the normal condition thermal analysis with -40°F ambient temperature and maximum heat generation. The material allowable stresses are based on the maximum temperature of the weldments determined for normal conditions with 100°F ambient temperature and maximum heat generation.

During the temperature solution portion of the analyses, the finite element models are constructed by using ANSYS three-dimensional thermal shell elements (SHELL57). During the structural evaluation portion of the analyses, the finite element models are constructed by using ANSYS three-dimensional, six-degrees-of-freedom, elastic shell elements (SHELL63) in the weldment plate and structural support region. The top nuts/pads are modeled by using BEAM 4 elements. Contact between the structural supports plates and between the structural support ring were modeled by using CONTACT 52 elements. The finite element models represent one-quarter sections of the weldments.

The top and bottom weldments are 1.0 in. thick and are fabricated from SA-240, Type 304 stainless steel. The top weldment supports its own weight and 56 fuel tubes (without the fuel assemblies) during a top-end-drop. Eight structural plates, eight tie-rod top nuts, and a

circumferential ring support the top weldment and its loads during a top-end-drop. These structural components are modeled as zero-translation restraints in the direction of the end-drop. The finite element models of the top and bottom weldments are presented in Figures 2.6.15.13-1 and 2.6.15.13-2, respectively.

2.7.10.5.1 Results of Basket Weldment Analyses (30-Foot End-Drop)

The maximum stress intensities (SI) for primary membrane plus primary bending ($P_m + P_b$) for the 30-ft end-drop analysis are 49.27 ksi for the top weldment and 56.67 ksi for the bottom weldment as tabulated below. The corresponding minimum margins of safety are +0.26 and +0.12 as shown below:

Component/Condition	$P_m + P_b$ (ksi)	Allowable S_u (ksi)	MS
Top Weldment/30-ft Drop	49.49	62.56	+0.26
Bottom Weldment/30-ft Drop	56.93	63.22	+0.11

Because a large radial temperature gradient occurs through the weldments, the maximum stress intensities presented in the preceding table do not occur at the maximum temperature of the models, and comparing these stress intensities with stress allowables on the basis of the maximum temperature is overly conservative. Therefore, the stress evaluation is performed on a nodal basis. That is, using ANSYS, the maximum stress at each node in each model is compared with the maximum allowable stress at the temperature of the node being evaluated.

For hypothetical accident conditions, the following criteria are used to evaluate the nodal stress intensities for the top and bottom weldment:

$$P_m + P_b < 3.6\ S_m \text{ or } S_u\text{, whichever is less.}$$

(Note that for Type 304 stainless steel in these temperature ranges, S_u is smaller than 3.6 S_m.)

The margin of safety is

$$MS = \frac{\text{Allowable Stress}}{\text{Nodal Stress Intensity}} - 1.$$

2.7.10.5.2 Top Weldment Structural Rib Buckling Evaluation

The structural ribs on the top weldment are subjected to axial loads during a top-end-drop. End constraints on the ribs during a top-end-drop are fixed at the end welded to the top weldment and free at the other end. Because no closed solutions are readily available for evaluating a plate for buckling loads with end constraints matching those of the top weldment ribs, a closed-form solution for the buckling of a column is used to analyze a 1-in. section of one of the ribs.

For a column under axial loading with one end of the structural rib fixed and the other end free, the critical load (P_{cr}) is determined by

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

where:
- I = moment of inertia
- E = modulus of elasticity
- L = length of the column
- K = effective length factor (K = 2 for a column, one end fixed; other end free).

Evaluating a 1-in. section of one of the ribs at the maximum weldment temperature of 515°F yields

$$P_{cr} = \frac{\pi\left(25.7\times10^6 \text{ lbf / in}^2\right)\frac{1}{12}(1.0 \text{ in})(0.5 \text{ in})^3}{(2\times10.25 \text{ in})^2} = 6{,}288 \text{ lb.}$$

For the 30-ft top-end-drop, the sum of the forces on the nodes representing the ribs is a maximum of 26,945 lb. Thus, the maximum load (P) on a 1-in. section of one of the structural ribs is 1,152 lb.

Thus, the margin of safety for buckling of one of the structural ribs of the top weldment during a 30-ft top-end-drop is

$$MS = \frac{6{,}288 \text{ lb}}{1{,}152 \text{ lb}} - 1 = \boxed{+4.45}$$

2.7.10.5.3 Conclusions

As shown in this section, both the top and bottom weldments maintain positive margins of safety when subjected to the 30-ft end-drop conditions. As shown in the top weldment structural rib buckling calculation, the actual maximum load (P) on one of the structural ribs of the top weldment during a 30-ft drop is much less than the predicted buckling load (P_{cr}). Therefore, the top and bottom weldments are structurally adequate.

2.7.11 Summary of Damage to Cask Due to Hypothetical Accident Conditions

The analysis results reported in Sections 2.7.1 and 2.7.2 (30-ft drop, and puncture accidents) are summarized in Tables 2.7.11-1 and 2.7.11-2, respectively. The results shown in Tables 2.7.11-1 and 2.7.11-2 demonstrate that the damage incurred by the Universal Transport Cask during the hypothetical accident is minimal and does not diminish the cask's ability to maintain the containment boundary. A 30-ft drop or a 40-in. pin puncture accident may damage the neutron shield and result in a reduction in the cask's neutron shielding ability. However, the gamma shielding remains intact to provide sufficient shielding and to satisfy the accident shielding criteria. The peak dose rates resulting from a maximum slump of 3.05 in. that could occur in the gamma shielding following a 30-ft end-drop are well below the regulatory limits (The shielding consequences of the drop accidents are discussed in Section 2.7.1.5 and Chapter 5.0).

As discussed in Section 2.7.3, stresses in the cask during the fire accident are classified as secondary by the ASME Code, Section III, Subsection NB. For accident conditions, there are no set limits on secondary stresses. Review of the applicable regulations presented for crush in Section 2.7.4 shows that crush need not be considered for the Universal Transport Cask. The conformance of the cask to immersion requirements is discussed in Sections 2.7.5 and 2.7.6. An evaluation of individual cask components for a sustained external pressure of 290 psi shows that the cask meets worst case immersion requirements.

In a 30-ft hypothetical corner-drop accident, the upper impact limiter may crush to a maximum depth of 31.1 in. As shown in Section 2.7.1.6, this has no structural consequences.

Based on the analyses of Section 2.7.1 through 2.7.6, the Universal Transport Cask fulfills the structural and shielding requirements of 10 CFR 71 for all of the hypothetical accident conditions.

Table 2.7.11-1 Summary of Maximum Calculated Stresses in Cask—30-Foot Free Drop

30-Foot Drop	Conditions* 1 (100°F -40°F)	2	3	4	5	Maximum Calculated Stress Type	Value (ksi)	Allowable Stress (ksi)	Margin of Safety
Containment** (on end)	✓	✓	✓	✓	✓	P_m	17.5	48.0	1.74
	✓	✓	✓	✓	✓	$P_m + P_b$	33.5	62.7	0.87
Noncontainment*** (on end)	✓	✓	✓	✓	✓	P_m	23.4	45.9	0.96
	✓	✓	✓	✓	✓	$P_m + P_b$	22.9	70.9	2.10
Containment** (on side)	✓	✓	✓	✓	✓	P_m	31.0	48.0	0.55
	✓	✓	✓	✓	✓	$P_m + P_b$	62.4	65.0	0.04
Noncontainment*** (on side)	✓	✓	✓	✓	✓	P_m	32.1	47.3	0.47
	✓	✓	✓	✓	✓	$P_m + P_b$	68.2	70.9	0.04
Containment** (on corner)	✓	✓	✓	✓	✓	P_m	18.9	48.0	1.54
	✓	✓	✓	✓	✓	$P_m + P_b$	32.0	62.7	0.96
Noncontainment*** (on corner)	✓	✓	✓	✓	✓	P_m	25.8	45.9	0.78
	✓	✓	✓	✓	✓	$P_m + P_b$	36.7	70.9	0.94
Containment** (oblique)	✓	✓	✓	✓	✓	P_m	28.5	48.0	0.68
	✓	✓	✓	✓	✓	$P_m + P_b$	62.6	69.7	0.11
Noncontainment*** (oblique)	✓	✓	✓	✓	✓	P_m	29.8	47.3	0.59
	✓	✓	✓	✓	✓	$P_m + P_b$	61.5	70.9	0.15

*Conditions:
1. Ambient Temperature
2. Insolance
3. Decay Heat
4. Internal Pressure
5. Weight of Contents.

** The containment structure includes cask lid, top forging, inner shell, and bottom forging.

*** The noncontainment structure includes the outer shell and the bottom plate.

Table 2.7.11-2 Summary of Maximum Calculated Stresses in Cask— Puncture

40-In. Free Drop	Conditions* 1		2	3	4	5	Maximum Calculated Stress Type	Maximum Calculated Stress Value (ksi)	Allowable Stress (ksi)	Margin of Safety
	100°F	-40°F								
Containment** (lid)	✓		✓	✓	✓	✓	$P_m + P_b$	56.81	61.5	0.08
Noncontainment*** (on mid-length)	✓		✓	✓		✓	$P_m + P_b$	56.75	66.9	0.18
Noncontainment** (on bottom center)	✓		✓	✓			$P_m + P_b$	49.96	66.9	0.34

* Conditions: 1. Ambient Temperature
2. Insolance
3. Decay Heat
4. Internal Pressure
5. Weight of Contents.

** The containment structure includes cask lid, top forging, inner shell, and bottom inner forging.

*** The noncontainment structure includes the outer shell and the bottom plate.

2.7.12 Cask Inner Shell Buckling Analysis

Code Case N-284-1 (Metal Containment Shell Buckling Design Methods) [12] of the ASME Boiler and Pressure Vessel Code is used to analyze the Universal Transport Cask inner shell for structural stability. Structural stability ensures that the inner shell does not buckle during cask fabrication, normal conditions of transport, or hypothetical accident conditions. Fabrication stresses are evaluated in Section 2.6.11 and are shown to be very low, so that that including them in the buckling evaluation would not significantly affect the margins of safety demonstrated in this section. The buckling evaluation requirements of Regulatory Guide 7.6, Paragraph C.5, are shown to be satisfied by the results of the buckling interaction equation calculations from Code Case N-284-1.

The cask inner shell buckling design criteria, are described in Section 2.1.2.5.3.

2.7.12.1 Analysis Methodology

The structural stability of the Universal Transport Cask inner shell is analyzed in accordance with the ASME Code Case N-284-1. The data considered for the buckling evaluation includes shell geometry parameters, shell fabrication tolerances, shell material properties, theoretical elastic buckling stress values for the shell, and membrane stress components in the shell. 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 upon the applied loading. Only these three stress components are considered in the buckling analysis.

For each dynamic loading case, the stress results from the ANSYS dynamic shell analyses (Sections 2.6.7.1 through 2.6.7.4 for 1-ft cask drops and Sections 2.7.1.1 through 2.7.1.4 for 30-ft cask drops) are screened for the maximum values of the longitudinal compression, circumferential compression, or in-plane shear stresses for the individual drop load cases, regardless of where in the shell they individually occur. This was performed for all cask drop orientations.

The ANSYS analyses for both the 1-ft and 30-ft drops were performed with an internal pressure of 150 psig. The internal pressure tends to stiffen the inner shell. To compensate for this, and to bound the worst case situation, the axial and hoop stresses corresponding to this internal pressure

were combined with (added to) the compressive axial and hoop stresses from the ANSYS analyses to give maximum stress values.

Also, the ANSYS stress components used in the buckling evaluations for the normal 1-ft drop load cases conservatively include thermal peak stresses and bending stresses from thermal and drop loadings. Combining the maximum stress components in this way produces a conservative, bounding-case buckling evaluation of the inner shell. The maximum ANSYS plus internal pressure stress components used in the buckling evaluations are presented in Table 2.7.12-1.

2.7.12.2 Analysis Results

As discussed above, the worst-case combination of stress components within a given drop orientation from the ANSYS analyses, regardless of location within the shell cylinder, and including temperature and pressure effects, are determined and used for input as stress components in the buckling evaluations. These conservatively determined stress components, therefore, envelope the specific load case tables presented in Sections 2.6.7.1 through 2.6.7.4 for 1-ft cask drops and Sections 2.7.1.1 through 2.7.1.4 for 30-ft cask drops.

The results of the buckling analysis of the cask inner shell are summarized in Table 2.7.12-1. All interaction equations ratios are less than 1.0. Therefore, the buckling criteria of Code Case N-284-1 are satisfied, thus demonstrating that buckling of the Universal Transport Cask inner shell does not occur.

2.7.12.3 Detailed Code Case N-284-1 Buckling Evaluation

A step-by-step analysis procedure presented below as an example of implementing the procedure recommended in Code Case N-284-1. This same procedure was followed to determine the results presented in Table 2.7.12-1.

In the buckling evaluation, the symbols ϕ, θ, or $\phi\theta$ correspond to the longitudinal (axial) direction or stress component, circumferential (hoop) direction or stress component, and in-plane shear stress component, respectively, as used in Code Case N-284-1.

In the evaluation, the formulas for cylindrical shells (unstiffened) are used. Each of the 14 load cases presented in Table 2.7.12-1 is evaluated in the manner detailed below for Load Case "N",

the hypothetical accident condition of a 30-ft bottom oblique (75°) drop; the results are listed in the table. The manner of conservatively screening for the highest stress components and the compensation for internal pressure is described above in Section 2.7.12.1.

The geometry parameters used for the cask inner shell evaluation are presented in Table 2.7.12-2.

In the example that follows, a factor of safety (FS) of 1.34 is used in accordance with the Code Case.

<u>Step 1. Determine Stresses</u>: For the 30-ft bottom oblique (75°) drop (load case "N" shown in Table 2.7.12-1), the maximum individual axial, hoop, and shear stresses regardless of location in the cask inner shell from the ANSYS analysis are:

Axial Stress (ANSYS) S_ϕ = 11,840 psi (Compression)
Hoop Stress (ANSYS) S_θ = 16,880 psi (Compression)
Shear Stress (ANSYS) $S_{\phi\theta}$ = 12,440 psi.

To these values are added the effects of an internal pressure, IP = 150 psig. The tensile load due to internal pressure. Acting on the area of the cask lid with an area A_L = 3,590 in^2, the internal pressure creates a force, F = 538,521 lb. Cross sectional area of the inner shell A_S = 216 in^2. Therefore, the axial stress in the inner shell due to the internal pressure is

Axial Stress (IP) = F/A_S = 2,498 psi

The hoop stress due to internal pressure

Hoop Stress (IP) = $IP(D_i)/2t$ = 2,535 psi

where D_i = internal diameter = 67.61 in.
t = shell thickness = 2.0 in.

Combining the axial and hoop stresses from ANSYS analysis and due to the effects of internal pressure, with no compensation necessary for the shear stress, gives the stress state used for the buckling evaluation example:

S_ϕ = 14,338 psi (axial compression)
S_θ = 19,415 psi (hoop compression)
$S_{\phi\theta}$ = 12,440 psi (shear).

Step 2. Determine Capacity Reduction Factors: (Code Case N-284-1, Paragraph-1500)
The reduction in capacity due to imperfections and nonlinearity in geometry and boundary conditions is provided through the use of Capacity Reduction Factors. Capacity Reduction Factors, based on the parameters in Table 2.7.11-2 are as follows:

$\alpha_{\phi L}$ = 0.231
$\alpha_{\theta L}$ = 0.8
$\alpha_{\phi\theta L}$ = 0.8.

To directly use the Capacity Reduction Factors, the tolerance requirements of Article NE-4220 of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NE must be satisfied. Article NE-4221.1 and Article NE-4221.2 set forth the "maximum difference in cross-sectional diameters" and "maximum deviation from true theoretical form for external pressure."

The requirements of Articles NE-4221.1 and NE-4221.2 are satisfied, as long as the maximum tolerances and configuration constraints are met during manufacturing:

Max ID = 67.67 in.
Min ID = 67.57 in.
Max ID - Min ID = 0.10 in.
Allowable deviation (per Subsection NE) = Nominal ID/100 = 0.677 in.
0.10 in. < 0.677 in.

Allowable deviation (per Subsection NB*) shall not exceed the smaller of

$(D + 50)/200 = (67.61 + 50)/200 = 0.588$ in., and

Nominal ID/100 = 0.677 in.

0.10 in. < 0.588 in.

*(Evaluation of the tolerance requirements of Subsection NB is included in the evaluation because the Universal Transport Cask is being constructed to the requirements of Subsection NB.)

Therefore, direct use of the Capacity Reduction Factors is allowed.

<u>Step 3. Determine Plasticity Reduction Factors</u>: (Code Case N-284-1, Paragraph-1600)

When the elastic buckling stresses exceed the proportional limit for the fabricated material, Plasticity Reduction Factors are used to account for the non-linear material properties. Plasticity Reduction Factors are determined as follows:

a. Axial Compression

$\Delta = S_\phi(FS)/S_y = (14{,}338)(1.34)/(2.07\times10^4) = 0.928$

For $0.55 < \Delta \leq 1.6$,

$\eta_\phi = 0.45/\Delta + 0.18 = (0.45/0.928) + 0.18 = 0.665$

b. Hoop Compression

$\Delta = S_\theta(FS)/S_y = (19{,}415)(1.34)/(2.07\times10^4) = 1.257$

For $0.67 < \Delta \leq 4.2$,

$\eta_\theta = 2.53/(1 + 2.29\Delta) = 2.53/(1 + 2.29 \times 1.257) = 0.652$

c. Shear

$\Delta = S_{\phi\theta}(FS)/S_y = (12{,}440)(1.34)/(2.07\times10^4) = 0.805$

For $0.48 < \Delta \leq 1.7$,

$\eta_{\phi\theta} = 0.43/\Delta + 0.1 = (0.43/0.805) + 0.1 = 0.634$

Step 4. Determine Theoretical Uniaxial Buckling Values: (Code Case N-284-1, Paragraph-1712) Elastic Buckling Coefficients are first calculated followed by the calculation of the theoretical buckling values as shown below:

$M_\phi = L_\phi/(Rt)^{.5} = 180/(34.81 \times 2.0)^{.5} = 21.57$

$Et/R = [26.5(10)^6 \times 2.0] / 34.81 = 1.5228(10)^6$ psi

a. Axial Compression

For $M_\phi \geq 1.73$, $C_\phi = 0.605$

$S_{\phi eL} = C_\phi (Et/R) = 921{,}276$ psi

b(1). External Pressure - No End Pressure

$1.65(Rt) = 28.71$

For $3.0 \leq M_\phi < 1.65(RT)$,

$C_{\phi r} = 0.92/(M_\phi - 1.17) = 0.0451$

$S_{\theta eL} = S_{reL} = C_{\phi r} (Et/R) = 68{,}659$ psi

b(2). External Pressure - End Pressure Included

For $3.5 \leq M_\phi < 1.65(Rt)$,

$C_{\phi h} = 0.92/(M_\phi - 0.636) = 0.0439$

$S_{heL} = C_{\phi h} (Et/R) = 66{,}908$ psi

c. Shear

$8.69(Rt) = 151.23$

For $26 < M_\phi < 8.69(Rt)$,

$C_{\phi\theta} = 0.746/(M_\phi)^{.5} = 0.161$

$S_{\phi\theta eL} = C_{\phi\theta} (Et/R) = 244{,}571$ psi

Step 5. Evaluate Elastic Buckling: (Code Case N-284-1, Paragraph-1713.1)
First, the elastic buckling allowable stresses for specific loading cases are calculated. This is followed by determining the individual elastic interaction ratios, Q1 through Q4.

Elastic buckling allowable stresses are

$S_{xa} = a_{\phi L}S_{\phi eL}/FS =$ 159,050 psi — Axial Compression alone

$S_{ha} = a_{\theta L}S_{heL}/FS =$ 39,945 psi — Hydrostatic External Pressure

$S_{ra} = a_{\theta L}S_{reL}/FS =$ 40,991 psi — Radial External Pressure

$S_{ta} = a_{\phi\theta}S_{\phi\theta eL}/FS =$ 146,012 psi — In-plane Shear alone.

a. Axial Compression plus Hoop Compression (for $K < 0.5$)

$K = S_\phi/S_\theta = 0.74 > 0.5$ Therefore, go to (b) below.

b. Axial Compression plus Hoop Compression (for $K \geq 0.5$)

No interaction check is required if $S_\phi / S_{ha} < 0.5$

$S_\phi / S_{ha} = 14{,}338/39{,}945 = 0.359$

Therefore, no interaction check is required and

$Q1 = 0.0$

c. Axial Compression plus Shear

$(S_\phi/S_{xa}) + (S_{\phi\theta}/S_{\tau a})^2 \leq 1.0$

$(14{,}338/159{,}050) + (12{,}440/146{,}012)^2 = 0.097$

Therefore, $Q2 = 0.082 < 1.0$

d. Hoop Compression plus Shear

$(S_\theta/S_{ra}) + (S_{\phi\theta}/S_{\tau a})^2 \leq 1.0$

$(19,415/39,945) + (12,440/146,012)2 = 0.481$

Therefore, $Q3 = 0.419 < 1.0$

e. Axial Compression plus Hoop Compression plus Shear

$K_s = 1 - (S_{\phi\theta}/S_{\tau a})^2 = 0.993$

Substituting K into Equation (b):

$(S_\phi - .5*K_sS_{ha})/(K_sS_{xa} - .5*K_sS_{ha}) + (S_\theta/K_sS_{ha})^2 \leq 1.0$
However, since Q1 = 0.0 from Equation (b), then
also Q4 = 0.0

Step 6. Evaluate Inelastic Buckling: (Code Case N-284-1, Paragraph-1713.2)
First, the inelastic buckling allowable stresses for specific loading cases are calculated. This is followed by determining the individual elastic interaction ratios, Q5 through Q8.

Inelastic buckling allowable stresses are

$S_{xc} = \eta_\phi S_{xa} =$ 105.739 psi Axial compression alone

$S_{rc} = \eta_\theta S_{ra} =$ 26,741 psi Radial external pressure

$S_{\tau c} = \eta_{\phi\theta} S_{\tau a} =$ 92,567 psi In-plane shear alone.

a. Axial Compression or Hoop Compression

Axial Compression: $S_\phi/S_{xc} \le 1.0$

14,338/105,739 = 0.136

Therefore, Q5 = 0.136 < 1.0

Hoop Compression: $S_\theta/S_{rc} \le 1.0$

19,415/26,741 = 0.726

Therefore, Q6 = 0.726 < 1.0

b. Axial Compression plus Shear

$S_\phi/S_{xc} + (S_{\phi\theta}/S_{\tau c})^2 \le 1.0$

$14{,}338/105{,}739 + (12{,}440/92{,}567)^2 = 0.154$

Therefore, Q7 = 0.154 < 1.0

c. Hoop Compression plus Shear

$S_\theta/S_{rc} + (S_{\phi\theta}/S_{\tau c})^2 \le 1.0$

$19{,}415/26{,}741 + (12{,}440/92{,}567)^2 = 0.744$

Therefore, Q8 = 0.744 < 1.0

Table 2.7.12-1 Buckling Evaluation Load Cases and Results for the Universal Transport Cask

Load Case	Load Condition	Longitudinal (Axial) Stress* S_ϕ (psi)	Circumferential (Hoop) Stress* S_θ (psi)	In-plane Shear Stress $S_{\phi\theta}$ (psi)	Elastic Buckling Interaction Equations				Plastic Buckling Interaction Equations			
					Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
A	1-Ft Top End	16,808	8,135	1,410	.129	.158	.296	.129	.345	.328	.345	.328
B	1-Ft Bottom End	16,478	7,325	1,370	.108	.155	.267	.108	.334	.276	.334	.276
C	1-Ft Side	9,418	8,235	4,230	.052	.089	.300	.052	.131	.334	.131	.335
D	1-Ft Top Corner	16,708	6,915	2,470	.102	.157	.252	.103	.342	.252	.342	.252
E	1-Ft Bottom Corner	8,478	15,165	2,050	.552	.080	.552	.269	.109	.951	.109	.951
F	1-Ft Top Oblique (75°)	12,668	7,165	430	.064	.119	.261	.064	.217	.267	.217	.267
G	1-Ft Bottom Oblique (75°)	9,668	8,585	3,760	.063	.091	.313	.063	.137	.358	.137	.358
H	30-Ft Top End	8,528	12,865	1,120	.021	.054	.314	.021	.054	.361	.054	.361
I	30-Ft Bottom End	9,648	13,565	990	.041	.061	.331	.041	.067	.394	.067	.394
J	30-Ft Side	12,308	17,125	13240	.129	.086	.426	.132	.104	.584	.127	.607
K	30-Ft Top Corner	11,858	12,555	4,940	.040	.076	.307	.041	.097	.346	.098	.348
L	30-Ft Bottom Corner	14,698	18,605	4,550	.179	.093	.455	.180	.142	.674	.143	.675
M	30-Ft Top Oblique (75°)	12,008	14,115	13,140	.068	.084	.352	.070	.099	.421	.122	.443
N	30-Ft Bottom Oblique (75°)	14,338	19,415	12,440	.196	.097	.481	.200	.136	.726	.154	.744

* Compressive stresses.

Table 2.7.12-2 Geometry Parameters for the Universal Transport Cask

Parameter	**Value**
t = thickness (in)	2.0
ID = inside diameter (in)	67.61
R = radius (in) = (ID+t)/2	34.81
R/t	17.40
L_ϕ = Length (in)	180.00
$(Rt)^{0.5}$	8.34
$L_\theta = 2\pi R$ = circumference (in)	218.7
$M_\phi = L_\phi/(Rt)^{0.5}$	21.57
$M_\theta = L_\theta/(Rt)^{0.5}$	26.21
ν = Poisson's ratio	0.275

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