Table 2.6.12.6-2 PWR Canister: P_m Stresses - 1 Foot Side Drop

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-14.7	-0.2	-5.2	-0.4	-0.1	-2	14.9	16	0.07
2	0	-13	-0.8	-6.4	-0.8	-0.4	-1.2	12.5	16	0.28
3	0	-3.8	-0.6	-3.3	-0.3	-0.6	-1.3	4.5	16	2.55
4	81	0	-0.2	0	0.8	0.1	0	1.5	16	9.39
5	9	-0.7	0.9	0.2	0	0	0.2	1.6	16	9.23
6	9	-0.7	1	0.2	0	0	0.2	1.7	16	8.19
7	9	-0.8	1.1	0.3	0	-0.1	0.2	2	16	7.18
8	0	-0.7	2.5	-1.1	-0.1	0.5	-0.1	3.7	16	3.34
9	9	-0.4	2.6	-2.1	0.05	1.3	-1.0	5.8	16	1.76
10	9	1.5	1.7	-2.1	-0.3	1.0	-0.6	4.6	16	2.48
11	9	3.7	1.8	-1.2	0.7	1.2	-1.6	6.4	16	1.5
12***	0	-24.4	-5.4	-6.7	-4.5	1.2	-1	21.7	24***	0.11
12	9	-0.5	-0.1	-3.5	0.1	0.6	-1.9	4.9	16	2.27
13*	0-7.5	-11.66	-3.42	-4.02	0.05	1.1	-2.33	9.99	12.8**	0.28
14	0	-0.9	-0.1	0.3	0	0	0	1.2	16	11.92
15	0	-0.3	0	0.1	0	0	0	0.4	16	35.79
16	0	-0.5	0.1	0.2	0	0	0	0.7	16	22.61

* Stress evaluated over weld compression region

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

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

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 408°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 2.6.12.1.

Table 2.6.12.6-3 PWR 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)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-23	-0.9	-7.6	0.6	0	-2	22.5	24	0.07
2	18	0.5	-12.7	-3.1	-0.2	0.2	-1.5	13.7	24	0.74
3	27	-0.6	-12.5	-4.6	0.1	-0.6	-2.3	13	24	0.85
4	9	-0.8	1.9	3.9	0	0.1	0.7	4.8	24	3.95
5	9	-0.6	2.3	3.7	0	0	0.7	4.5	24	4.3
6	9	-0.6	2.4	3.7	0	-0.1	0.7	4.5	24	4.33
7	9	-0.7	2.4	3.7	0	-0.1	0.7	4.7	24	4.12
8	0	-0.4	2.7	-2.4	-0.2	0.4	-0.2	5.1	24	3.66
9	9	1.2	6.3	-0.4	-0.1	1.5	0.1	7.4	24	2.24
10	0	-18.9	-2	-4.5	-5.3	1	-1.1	20.3	24	0.18
11	9	4.0	0.9	-1.4	0.8	1.3	2.7	8.2	24	1.93
12*	0	-28.6	-6.6	-8.2	-4.3	1.5	-0.7	24.5	25	0.02
13**	0-7.9	-16.65	-6.26	-6.48	-0.11	1.66	-1.98	12.49	20***	0.60
14	90	-0.8	0	0.4	0	0	0	1.2	24	18.27
15	90	-0.6	0	-0.2	0	0	0	0.6	24	39.77
16	0	-0.4	0	0.3	0	0	0	0.7	24	33.98

* The peak temperature as calculated in Section 3.4 is 265°F in the region of Sections 12 and 13. There the allowable stress for Type 304L stainless steel is 1.5 (16.7) = 25.05 ksi.

** The peak temperature as calculated in Section 3.4 is 265°F in the region of Sections 12 and 13. There the allowable stress for 304L stainless steel is 1.5 (16.7) = 25.05 ksi. Stress evaluated over weld compressing region.

*** Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

2.6.12.7 Stress Evaluation of PWR Canister for Combined Thermal and 1-Foot Side Drop Load Condition

The thermal stress loads described in Section 2.6.12.3 are applied in conjunction with the primary loads in Section 2.6.12.6 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 2.6.12.7-1. Results from the side-drop plus thermal load cases for the configurations that result in the minimum margins are presented in Tables 2.6.12.7-2 and 2.6.12.7-3. The stresses reported in this table correspond to the nodal stress at the surface. The minimum margin is +0.41 at Section 9 (see Table 2.6.12.7-1) when 3 S_m is used as the stress criteria. The margins of safety are calculated as:

MS = (allowable stress/SI) -1.

Table 2.6.12.7-1 PWR Canister Critical Sections for Combined 1-Foot Side Drop and Thermal Load Condition

Condition	Stress	Critical Section	Table	Minimum Margin of Safety
Side Drop + Thermal (cold)	$P_m + P_b + Q$	9	2.6.12.7-2	+ 0.41
Side Drop + Thermal (hot)	$P_m + P_b + Q$	9	2.6.12.7-3	+ 0.59

Table 2.6.12.7-2 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Side Drop, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-15.3	-0.4	-4	-0.1	0.1	-1.7	15.1	47.9	2.17
2	0	-11.7	-0.2	-2.2	-1.2	-0.4	-1.7	12.1	47.9	2.97
3	27	0.7	5.2	1.3	1.2	1.6	1.2	6.4	47.9	6.46
4	0	-0.4	1.1	2.9	0	-0.1	0.6	3.5	47.9	12.73
5	45	-1.2	1.5	-1.2	-0.4	-0.4	-1.3	4.2	47.9	10.41
6	45	-1	1.2	-1.1	0.3	0.3	-1.2	3.5	47.9	12.51
7	0	-0.4	1.1	2.6	0	0	0.5	3.1	47.9	14.33
8	0	0	2.7	-1.5	-0.1	0.6	-0.1	4.3	47.9	10.04
9	0	-26.6	6.9	-9.1	-2.1	1.7	0.2	34	47.9	0.41
10	0	-18.8	-2.6	-5	-4.5	0.9	-1.1	18.9	47.9	1.54
11	0	-26.3	3.3	-8.7	-0.3	1.8	-0.1	29.9	47.9	0.6
12	0	-26.4	-4.8	-7.9	-3.7	1.7	-0.6	23.5	47.9	1.04
13	0	-32.5	-9.8	-10.6	-1.2	2	-1.4	24.5	38.32*	0.56
14	180	-9.3	-2.5	-7.6	0.1	1.2	-0.1	7	47.9	5.8
15	0	-0.7	0	-0.1	0	0	0	0.7	47.9	69.76
16	0	-0.6	0.1	0.1	0	0	0	0.7	47.9	63.87

* Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

Table 2.6.12.7-3 PWR 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)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-13.4	-0.3	-3.8	-0.1	0.1	-1.4	13.2	47.9	2.62
2	0	-9.8	0	-2	-1	-0.3	-1.4	10.2	47.9	3.7
3	27	0.6	4.6	1.1	1	1.3	1	5.5	47.9	7.65
4	0	-0.4	0.8	2.4	0	-0.1	0.5	3	47.9	15.13
5	45	-1	1.2	-1.1	-0.4	-0.4	-1.2	3.6	47.9	12.17
6	45	-0.9	1.1	-0.9	0.3	0.3	-1	3.1	47.9	14.39
7	0	-0.4	1	2.1	0	0	0.4	2.7	47.9	16.98
8	0	0	2.6	-1.2	-0.1	0.5	-0.1	4	47.9	11.05
9	0	-23.3	6.4	-8.2	-1.8	1.4	0.3	30.1	47.9	0.59
10	0	-16.5	-2.1	-4.8	-3.9	0.8	-0.8	16.6	47.9	1.88
11	0	-22.8	3.2	-7.8	-0.2	1.5	0	26.1	47.9	0.83
12	0	-23.3	-4.1	-7.4	-3.2	1.5	-0.4	20.8	47.9	1.31
13	0	-28.2	-8.5	-9.6	-1	1.6	-1.1	21.1	38.32*	0.82
14	180	-8.8	-1.6	-7.1	0.1	0.8	-0.1	7.4	47.9	5.51
15	0	-0.6	0	0.1	0	0	0	0.7	47.9	69.62
16	0	-0.7	0	-0.1	0	0	0	0.8	47.9	61.85

* Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

2.6.12.8 Stress Evaluation of PWR Canister for 1-Foot Corner Drop Load Condition

A structural analysis performed by using ANSYS to evaluate the effect of a 1-ft end-drop impact for both the top-and bottom-corner orientations of the PWR canister. The ASME Code, Section III, Subsection NB, requires that 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 canister and its contents and the 25-psig pressure load internal to the canister. The applied deceleration is 20 *g* for both orientations (Note—the actual deceleration is 5.6 *g*; therefore, the results presented in this section are conservative). 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 2.6.12.3-1. The maximum stresses for P_m and $P_m + P_b$ are tabulated in Tables 2.6.12.8-2 through 2.6.12.8-5 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 2.6.12.8-1. The margins of safety in these tables are calculated as:

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

Table 2.6.12.8-1 PWR Canister Critical Sections for the 1-Foot Corner Drop Load Condition

Condition	Stress	Critical Section	Table	Margin of Safety*
Top Corner Drop + Pressure	P_m	9	2.6.12.8-2	+ 0.08
Top Corner Drop Inertia	$P_m + P_b$	2	2.6.12.8-3	+ 0.02
Bottom Corner Drop + Pressure	P_m	9	2.6.12.8-4	+0.02
Bottom Corner Drop + Inertia	$P_m + P_b$	11	2.6.12.8-5	+0.26

* Note: These margins of safety are based on stresses calculated for corner drops with a 20 g deceleration load. The actual deceleration load is 5.6 g; therefore, these margins of safety are conservative.

Table 2.6.12.8-2 PWR Canister P_m Stresses 1-Foot Top Corner Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-5.9	0.3	-1.7	0.2	-0.1	-0.8	6.4	16	1.5
2	0	-1.6	0.3	-1.5	-0.1	-0.3	-0.4	2.4	16	5.75
3	0	-0.5	0.5	-0.9	0.2	-0.3	-0.3	1.7	16	8.18
4	0	-1.2	-0.1	1.5	0	0	0	2.7	16	4.89
5	0	-1.2	-0.2	1.4	0	0	0	2.6	16	5.14
6	0	-1.2	-0.4	1.4	0	0	0	2.6	16	5.12
7	0	-1.2	-0.8	1.5	0	-0.1	0	2.7	16	4.91
8	45	0.4	-0.8	0.3	-0.4	-0.4	0.4	1.9	16	7.39
9	0	-16.1	-2	-4.4	-1.8	0.5	-0.4	14.7	16	0.08
10	0	-11.1	-4.3	-3.3	-1.9	0.2	-0.8	8.6	16	0.86
11	0	-15.1	-6.6	-5.4	-0.7	0.4	-0.4	9.9	16	0.61
12	0	-14.1	-6.2	-3.3	-2.9	0.2	-1	12	16	0.33
13	0	-13.2	-8	-4	-0.8	0.2	-1	9.5	12.8*	0.35
14	0	-0.2	0	0.2	0	0	0	0.4	16	37.89
15	171	-0.1	-0.3	0	0	0	0	0.4	16	40.38
16	0	-0.2	-0.4	0.1	0	0	0	0.5	16	34.04

* Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

Table 2.6.12.8-3 PWR Canister $P_m + P_b$ Stresses - 1-Foot Top Corner Drop

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-15.3	-6.5	-4.5	-3.9	-0.2	-1	12.4	24	0.93
2	0	-19.4	3.9	-4.4	-0.7	1.2	-0.1	23.5	24	0.02
3	180	-0.5	9.9	5.3	0	0	-0.4	10.4	24	1.3
4	0	-1.4	0	2.5	0	0	0.1	4	24	5.04
5	0	-1.4	-0.1	2.4	0	0	0.1	3.8	24	5.37
6	0	-1.4	-0.4	2.4	0	0	0.1	3.8	24	5.35
7	0	-1.4	-0.7	2.5	0	-0.1	0.1	3.9	24	5.09
8	36	0.1	-1.4	0.1	-0.4	-0.7	0.1	2.2	24	9.92
9	0	-16.9	0.2	-5.4	-1.3	0.5	-0.2	17.3	24	0.38
10	0	-11.9	-5.7	-2.9	-3.4	0.1	-1.1	10.9	24	1.21
11	0	-17	-8.9	-5.6	-1.2	0.5	-0.7	11.8	24	1.03
12	0	-15.4	-6.1	-3.7	-2.4	0.4	-0.9	12.6	24	0.91
13	0	-15.7	-10.2	-5.4	-1.4	0.4	-1	10.8	19.2*	0.78
14	90	-6.4	-0.1	-5.9	0.1	-0.1	0	6.3	24	2.78
15	81	0	-0.3	0.1	0	0	0	0.4	24	54.38
16	0	-0.2	-0.3	0.1	0	0	0	0.4	24	53.04

* Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

Table 2.6.12.8-4 PWR Canister P_m Stresses - 1-Foot Bottom Corner Drop

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-7	-1.9	-2.4	-0.3	0	-1	6	16	1.67
2	18	0.6	-3.3	-0.6	0.1	-0.1	-0.5	4	16	2.95
3	18	0	-3.1	-0.9	0.1	-0.2	-0.4	3.3	16	3.84
4	0	-1.2	-2.3	0.2	0	0	-0.1	2.8	16	4.75
5	180	0	-2.2	-0.1	0	0	0	2.3	16	6.07
6	180	0	-2.2	-0.1	0	0	0	2.2	16	6.36
7	180	0	-1.9	-0.1	0	0	0	1.9	16	7.27
8	45	0.1	-1.1	0	-0.3	-0.3	0	1.5	16	10.29
9	0	-15	0.2	-4.5	-1.4	0.9	-0.3	15.6	16	0.02
10	0	-7.5	-0.4	-2.5	-1.4	0.7	-0.7	7.9	16	1.03
11**	0	-17.6	-1.1	-5.1	-0.2	1.1	-0.3	16.8	24	0.43**
11	9	2.9	1.3	-0.5	0.3	0.6	-1.0	4.1	16	2.90
12	0	-11.7	-2.7	-2.8	-2	0.6	-0.8	10.5	16	0.53
13	0	-11.8	-3.4	-3.1	0.1	0.8	-1.2	9.6	12.8*	0.33
14	0	-0.4	-0.3	0.2	0	0	0	0.5	16	28.96
15	0	-0.1	0	0.1	0	0	0	0.2	16	104.27
16	0	-0.3	0	0	0	0	0	0.3	16	50.45

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

** Stresses treated as local membrane stress. Allowable for normal conditons is 1.5 S_m = 24 ksi for P_L and $P_L + P_B$.

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 408°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 2.6.12.1.

Table 2.6.12.8-5 PWR Canister $P_m + P_b$ Stresses - 1-Foot Bottom Corner Drop

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-7.5	-0.8	-2.5	0.3	0.1	-1	7	24	2.44
2	18	-0.2	-6.9	-1.4	-0.1	0	-0.5	6.9	24	2.46
3	18	-0.3	-6.1	-1.3	0.2	0	-0.5	6	24	3.02
4	0	-1.4	-1.9	2.5	0	0	0.1	4.4	24	4.39
5	0	-1.3	-1.4	2.4	0	0	0.1	3.9	24	5.21
6	0	-1.3	-1.1	2.4	0	0	0.1	3.7	24	5.4
7	0	-1.4	-0.8	2.4	0	0	0.1	3.8	24	5.27
8	18	0.3	-1.1	-0.9	0.3	0.4	-0.4	2	24	11.1
9	0	-15.2	2.9	-5	-1.2	0.9	-0.1	18.3	24	0.31
10	0	-7.9	-0.8	-1.5	-2.3	0.5	-0.9	8.9	24	1.7
11	0	-15.9	2.9	-4.4	-0.1	1	0	18.9	24	0.26
12	0	-14.6	-3.7	-3.9	-1.8	0.8	-0.7	12.2	24	0.96
13	0	-18	-6.8	-5.9	-0.2	1.1	-0.9	13	19.2*	0.48
14	0	-0.4	-0.3	0.2	0	0	0	0.5	24	43.89
15	72	1.3	0	1.4	0	0	0	1.4	24	15.9
16	18	-0.9	0	-0.6	0	0	0	0.9	24	25.01

* Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

2.6.12.9 Stress Evaluation of PWR Canister for Combined Thermal and 1-Foot Corner Drop Load Conditions

The thermal stress loads described in Section 2.6.12.3 are applied in conjunction with the primary loads in Section 2.6.12.8 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 the results in Section 2.6.12.8, the most critical sections are identified in Table 2.6.12.9-1. The stresses reported in this table correspond to the nodal stress at the surface. The minimum margin of safety is +1.14 when 3 S_m is used as the stress criterion. Tables 2.6.12.9-2 through 2.6.12.9-5 tabulate the results for top and bottom corner-drop with thermal results for the conditions that result in the minimum margins of safety. The stress intensity criterion of 3.0 S_m is satisfied. The margins of safety are calculated as:

MS = (allowable stress/SI)-1.

Table 2.6.12.9-1 PWR Canister Critical Sections for the Combined 1-Foot Corner Drop and Thermal Load Condition

Condition	Stress	Critical Section	Table	Minimum Margin of Safety
Top Corner Drop + Thermal (cold)	$P_m + P_b + Q$	2	2.6.12.9-2	+ 1.14
Top Corner Drop + Thermal (hot)	$P_m + P_b + Q$	2	2.6.12.9-3	+ 1.24
Bottom Corner Drop + Pressure + Thermal (cold)	$P_m + P_b + Q$	9	2.6.12.9-4	+1.96
Bottom Corner Drop + Pressure + Thermal (hot)	$P_m + P_b + Q$	9	2.6.12.9-5	+1.37

Table 2.6.12.9-2 PWR 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)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-19.5	-7.1	-4.4	-3.7	-0.2	-1	16.3	47.9	1.95
2	0	-19.9	2.3	-3.3	-0.6	1.2	-0.3	22.4	47.9	1.14
3	126	0.4	-10.3	0.3	0.7	0.1	-0.5	11.2	47.9	3.3
4	0	-1.4	-0.6	2.4	0	-0.1	0	3.7	47.9	11.79
5	0	-0.8	-2.9	1.7	0	-0.4	-0.2	4.8	47.9	9.08
6	0	-1.1	-1.9	2.1	0	0.2	-0.2	4.1	47.9	10.72
7	0	-1.3	-0.7	2.3	0	0	0	3.5	47.9	12.54
8	171	-0.2	-3.6	-0.4	0	0.2	0	3.5	47.9	12.78
9	0	-12.6	0.1	-3.8	-1.1	0.5	-0.2	12.9	47.9	2.71
10	0	-10	-4.8	-2.4	-2.5	0.1	-1	9	47.9	4.35
11	0	-11.8	-6.9	-3.9	-0.9	0.4	-0.6	8.2	47.9	4.85
12	0	-11.8	-4.2	-2.8	-1.9	0.4	-0.7	9.8	47.9	3.87
13	0	-11.8	-6.9	-3.9	-0.9	0.4	-0.6	8.2	**38.32***	**3.67**
14	0	-15.3	-1.8	-14.4	0	-1	0	13.6	47.9	2.52
15	81	-0.1	-0.3	0.1	0	0	0	0.4	47.9	116.04
16	0	-0.1	-0.4	0.1	0	0	0	0.6	47.9	82.56

* Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

Table 2.6.12.9-3 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Top Corner Drop, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-18.3	-6.7	-4.4	-3.4	-0.2	-0.9	14.9	47.9	2.22
2	0	-18.7	2.5	-3.1	-0.7	1	-0.3	21.4	47.9	1.24
3	126	0.4	-10.2	0.2	0.7	0.1	-0.4	11	47.9	3.35
4	0	-1.1	-0.5	2	0	-0.1	0.1	3.1	47.9	14.7
5	0	-0.5	-2.4	1.7	0	-0.3	0.1	4.2	47.9	10.38
6	0	-0.6	-1.5	2.1	0	0.2	0.3	3.7	47.9	12.08
7	180	0	-2.9	0	0	0	0	2.9	47.9	15.69
8	171	-0.1	-3.6	-0.4	0	0.2	0	3.5	47.9	12.78
9	0	-12.8	0.4	-3.8	-1.1	0.5	-0.2	13.5	47.9	2.56
10	0	-10.2	-4.8	-2.4	-2.6	0.1	-1	9.1	47.9	4.27
11	0	-12	-6.9	-4	-1	0.4	-0.6	8.4	47.9	4.73
12	0	-11.9	-4.1	-2.8	-2.1	0.4	-0.7	10	47.9	3.81
13	0	-12	-6.9	-4	-1	0.4	-0.6	8.4	38.32*	3.56
14	0	-14.5	-1.6	-13.6	0.1	-0.9	0	13	47.9	2.69
15	90	-0.1	-0.3	0.1	0	0	0	0.4	47.9	116.24
16	0	-0.1	-0.4	0.1	0	0	0	0.6	47.9	84.45

* Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

Table 2.6.12.9-4 PWR 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)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-6.3	-0.9	-1.9	0.1	0	-0.8	5.6	47.9	7.53
2	27	-0.2	-5	-1.4	-0.2	-0.1	-0.8	5.2	47.9	8.15
3	27	-0.2	-5.1	-1.3	0	-0.3	-0.6	5.2	47.9	8.20
4	0	-1	-1.5	2.8	0	0	-0.2	4.3	47.9	10.03
5	0	-1	-1.1	2.8	0	0	0.2	3.9	47.9	11.33
6	0	-0.9	-0.8	2.8	0	0	0.2	3.8	47.9	11.75
7	0	-0.9	-0.6	2.8	-0.2	0	0.2	3.7	47.9	11.81
8	0	-0.6	0.2	1.2	-1.1	0.4	0.1	2	47.9	22.65
9	0	-14.3	2.2	-4.5	-1.1	0.9	-0.2	16.7	47.9	1.86
10	0	-9	-1.5	-1.7	-2.2	0.5	-1	9.2	47.9	4.23
11	0	-14.2	1.1	-4.5	-0.2	1.9	-0.1	15.4	47.9	2.11
12	0	-13.6	-2.9	-3.5	-1.8	9	-0.7	11.9	47.9	3.02
13	0	-17.3	-5.6	-5.5	-0.5	1	-0.8	12.9	38.32*	1.97
14	0	-0.3	-0.4	0.2	0	0	0	0.6	47.9	85.16
15	81	0.7	0	0.9	0	0	0	0.9	47.9	51.95
16	45	-0.6	-0.1	-0.4	0	0	0	0.6	47.9	82.75

* Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

Table 2.6.12.9-5 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Bottom Corner Drop, Internal Pressure, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-2.1	0	1.3	0	0.1	-0.1	3.5	47.9	12.79
2	162	0.1	-5.1	0.3	0.1	0	-0.1	5.4	47.9	7.87
3	162	0.1	-4.9	0.4	0	-0.1	-0.1	5.3	47.9	8.12
4	180	0	-3.7	1.2	0	0	-0.1	4.9	47.9	8.76
5	180	0	-3.8	1.5	0	-0.2	0	5.3	47.9	8.06
6	0	-0.5	-1.6	3.5	0	0.1	0.2	5.1	47.9	8.34
7	0	-0.9	-0.6	3.2	0	-0.1	0.3	4.1	47.9	10.82
8	0	-0.6	0.8	2	-0.1	0.6	0.3	2.9	47.9	15.7
9	0	-17	2.9	-5.3	-1.3	1.2	-0.3	20.2	47.9	1.37
10	0	-11.5	-1.9	-2.4	-2.7	0.6	-1.2	11.6	47.9	3.13
11	0	-16.7	1.4	-5.5	-0.2	1.1	-0.2	18.4	47.9	1.61
12	0	-16	-3.2	-4	-2.2	1	-0.9	14.3	47.9	2.36
13	0	-20.5	-6.3	-6.5	-0.7	1.3	-1	15.6	38.3*	1.46
14	0	-10	-4.9	-9.7	0	0.1	0	5.1	47.9	8.33
15	90	0.8	0	1	0	0	0	1	47.9	47.69
16	27	-0.6	-0.1	-0.3	0	0	0	0.6	47.9	79.93

* Allowable stress includes a stress reduction factor for 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 408°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 2.6.12.1.

2.6.12.10 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 the bottom end-drop is 1.8 ksi for the bottom end-drop with thermal heat (Table 2.6.12.5-5). The maximum shear is 1.8/2 = 0.9 ksi. The allowable shear is 0.6 S_m per the ASME Code, Section III, Subsection NB-3227.2 for pure shear loading. The maximum canister shell temperature is 399°F and the margin of safety for pure shear is

$$MS = 0.6 \times 15.8 / 0.9 - 1 = 9.53$$

2.6.12.11 Canister Bearing Stresses for 1-Foot Side Drop

The average bearing stress on the canister wall is computed for the side-drop using the smallest length of canister and the maximum mass for either the PWR or BWR canisters. This results in a conservatively bounding value of the average bearing stress. The maximum canister plus contents mass is for the BWR Class 5 with a weight of 75,896 lb. For contact of the canister wall with the inner shell over an 18° arc (conservative), the projected bearing width is 10.54 in. The length of the shortest canister is 175.25 in. (PWR Class 1). The average bearing stress is

$$\text{Bearing Stress} = 75{,}896 \text{ lb} \times 20g/(175.25 \text{ in.} \times 10.54 \text{ in.}) = 822 \text{ psi}$$

Based on a yield strength of 17.5 ksi at 400°F, the margin of safety is

$$MS = (17.5 / 0.822) - 1 = +\text{Large}$$

Next, the bearing stress evaluation is presented in the regions under the shield lid and structural lid welds for the normal conditions side-drop (see Sections 9, 10, and 11 in Figure 2.6.12.3-1). Three separate regions are considered for the bearing evaluation; (1) the area beneath the structural lid weld from 0° to 9°, (2) area between the structural lid weld and shield lid weld from 0° to 9°, and (3) area below shield lid weld between 0° and 9°.

In order to calculate the bearing stresses in these regions, forces from the gap elements between the canister shell and the cask inner shell in these regions are examined. The forces from the gap elements act normal to the surface of the shell (i.e., radially), but are conservatively summed for each of the three regions described above. The following enveloping force summations are obtained from the PWR and BWR analysis results for each of the regions. The governing load case is also noted.

Region 1:	-45,373 lb	PWR Side Drop with no Internal Pressure
Region 2:	-43,935 lb	PWR Side Drop With Internal Pressure
Region 3:	-78,640 lb	BWR Side Drop with Internal Pressure

Gaps at both 0° and 9° are closed. Gaps at angular locations greater than 9° remain open in the regions of interest. The projected width conservatively based on 9° contact is 5.27 for the three regions. Region 1 has a length equal to the weld thickness (0.88 in.), Region 2 has a length of (3 - 0.88) 2.12 in., and Region 3 has a length of 0.5 in. equal to length of the shield lid weld. The corresponding bearing stresses for each region are

Region 1: $45{,}373/(5.27 \times 0.88) = 9{,}784$ psi

Region 2: $43{,}935/(5.27 \times 2.12) = 3{,}932$ psi

Region 3: $78{,}640/(5.27 \times 0.5) = 29{,}844$ psi

The peak temperature in the canister shell in the region of the lids is 266°F for the PWR canister (see Section 3.4). The yield strength is 19,950 psi based on this temperature for 304L stainless steel. The margins of safety for each region are presented below.

Region 1: $19.950 / 9.784 - 1 = 1.04$

Region 2: 19.950 / 3.918 - 1 = 4.09

Region 3 is allowed 1.5 S_y since the width of application of the load is less than the distance to the free edge (0.5 < 3.0) and

Region 3: 1.5 x 19.950 / 29.844 - 1 = 0.0026

2.6.12.12 Canister Buckling Evaluation for 1-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 normal condition 1-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 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 on the applied loading. Only these three stress components are considered in the buckling analysis.

A 20 g deceleration load was used for all the 1-ft drop canister analyses that are presented in Sections 2.6.12.4 through 2.6.12.9. 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 stress results from the canister analysis 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 PWR canister shell are combined. To these maximum stress components are added the maximum

stresses from the hot and cold thermal cases (Tables 2.6.12.3-1 and 2.6.12.3-2). Combining the maximum stress components in this way produces a conservative, bounding-case buckling evaluation of the PWR canister, one which envelopes all 1-ft PWR canister drop cases including those presented in Tables 2.6.12.4-4 and 2.6.12.4-6.

Consistent with the Code Case, the following are used:

- 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.
- The formulas in the Code Case for cylindrical shells (unstiffened) are used.
- The factor of safety is 2.0 for Normal Conditions.

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).

The geometry parameters used in the PWR canister evaluation are presented in Table 2.6.12.12-1.

The maximum stress components used in the evaluation and the buckling interaction ratios for the top- and bottom-end drop cases are provided in Table 2.6.12.12-2. The results of the buckling analysis 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 2.6.12.12-1 Geometry Parameters for the PWR 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)	191.95
Bottom Thickness (in)	1.75
Structural Lid Thickness (in)	3.0
L_ϕ = Length used in evaluation (in)*	187.2
$L_\theta = 2\pi R$ = circumference (in)	208.7
ν = Poisson's Ratio	0.275

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

Table 2.6.12.12-2 Buckling Evaluation Results for the PWR Canister for 1-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	2400	300	400	.009	.077	.066	.009	.077	.065	.077	.066
1-Ft Bottom End Drop	3600	600	300	.063	.115	.131	.064	.115	.131	.115	.131

Component stresses include thermal stresses.

* Compressive stresses

2.6.13 PWR Basket Analysis - Normal Conditions of Transport

The Universal Transport Cask PWR basket is a right-cylinder structure fabricated with 24 square fuel tubes, a number of circular support disks, a number of heat transfer disks, eight tie rods with spacers, and two end weldment plates. The number of support disks and heat transfer disks varies depending upon the class of PWR fuel the basket is designed to contain. The basket components and their geometry are illustrated in Figure 2.6.13-1 and Figure 2.6.13-2. Figure 2.6.13-3 shows the details of the fuel tube with the encasing BORAL. The fuel tubes are open at each end; therefore, longitudinal fuel assembly loads are imparted to the canister shield lid or the bottom plate, and not the fuel basket structure. The fuel basket contains the fuel and is laterally supported by the canister shell.

The fuel assemblies together with the tubes are laterally supported in the holes in the stainless steel support disks. The aluminum heat transfer disks are located throughout the cavity to fully optimize the passive heat rejection from the package. They serve no structural function other than supporting their own weight. 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 to locate and structurally assemble the support disks, heat transfer disks, and top and bottom weldment plates into an integral assembly. The spacers carry the inertial weight of the support disks, heat transfer disks, one end plate, and their own inertial weight for a normal transport condition 1-ft end-drop. The end-drop loading of the split spacers and tie rods represents a classical, closed-form structural analysis. The support disk requires a detailed finite element analysis for side-drop, end-drop, and oblique drops. The stainless steel fuel tubes are not considered to be a structural component with respect to the disks other than consideration of their mass contribution to loading.

The PWR fuel basket is evaluated for the normal transport loads in this section. End-drop, side-drop, oblique drop orientations are evaluated. The basket is evaluated for the hypothetical accident condition in Section 2.7.8.

Figure 2.6.13-1 PWR Fuel Assembly Basket

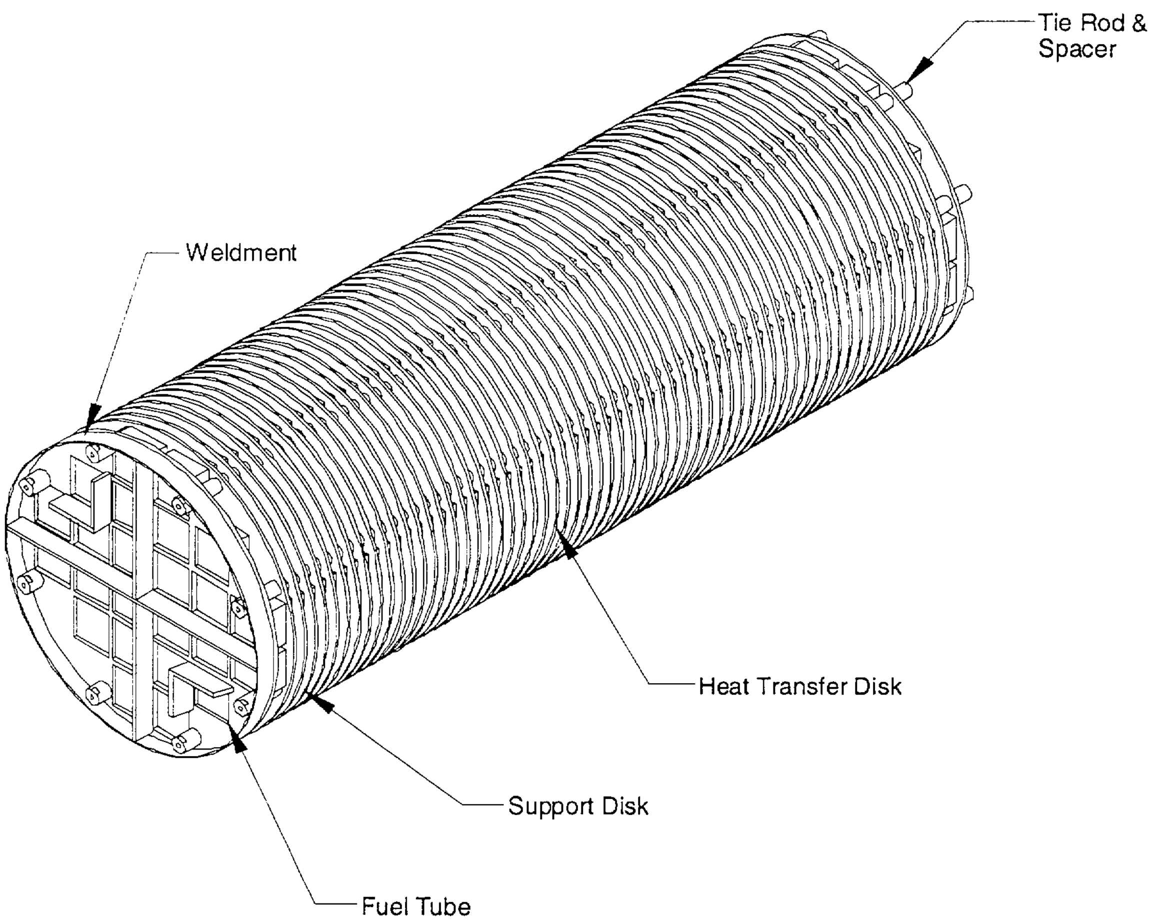


Figure 2.6.13-2 Support Disk Cross-Section Configuration

FIGURE WITHHELD UNDER 10 CFR 2.390

Note:

Engineering drawings provide appropriate tolerances for dimensions shown.

Figure 2.6.13-3 PWR Fuel Tube Configuration

FIGURE WITHHELD UNDER 10 CFR 2.390

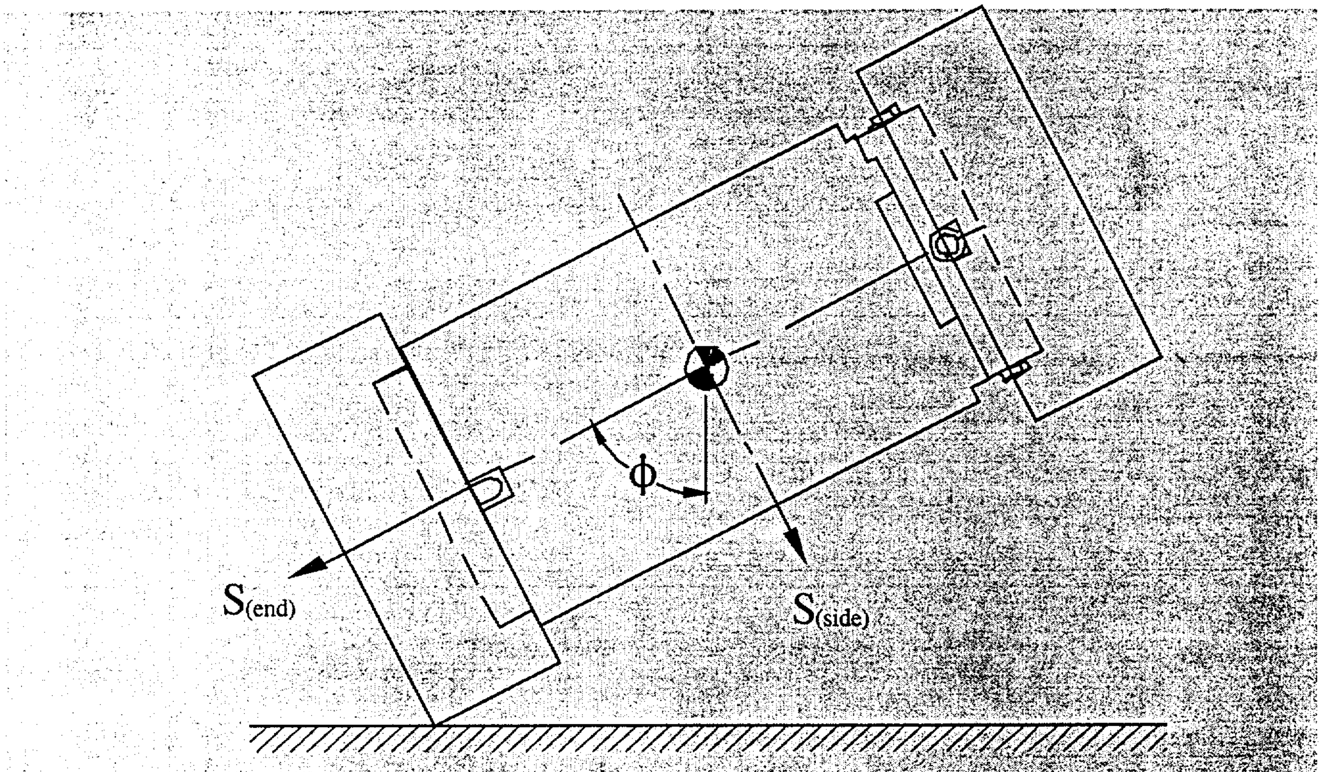
2.6.13.1 Analysis Description

On the basis of criticality control requirements, the PWR fuel basket design criteria require the maintenance of fuel support and control of spacing of the fuel assemblies for all load conditions. The structural design criteria for the structural components in the fuel basket is the ASME Code, Section III, Division 1, Subsection NG [15]. Consistent with this criterion, for any normal condition load and position orientation, the main structural component in the fuel basket, the stainless steel support disk, is shown to have a maximum primary membrane stress intensity and a primary membrane plus bending stress intensity in any disk. These are less than the design stress intensity value 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. For the end-drop, the fuel basket components are loaded by their own inertial weight and do not experience load from the guided but freestanding fuel assemblies. Various cask drop angles and 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.

2.6.13.2 Finite Element Model Description - PWR Basket

Two finite element models are generated to analyze the PWR 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. Off-angle (ϕ) drop results are calculated based on the component stresses from the end and side drop evaluation.



Oblique Drop

The finite element model for the side-drop is a two-dimensional model that includes the cross section of the canister shell. A complete basket support disk is modeled for the side impact evaluation (see Figure 2.6.13.2-1). ANSYS PLANE42 elements are used to model the support disk and canister. The PLANE42 is a two-dimensional element with four nodes. The PLANE42 elements correspond to plane stress and the thickness of the model for the disk is input as 0.5 in., which corresponds to the thickness of the support disk. For the canister shell, a thickness of 4 inches is used to approximate the center to center distance of support disks. For the end-drop, the PLANE42 elements are replaced with the SHELL63 elements and elements for canister shell are deleted. The nodal-element relationship is the same, with the exception of the change in the stiffness-displacement degree of freedoms. The shell elements accommodate the out-of-plane bending, which is present in the end-drop condition. The only loading in the out-of-plane direction is the inertial weight of the support disk.

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.

Density = $0.291 \times 1.373 = 0.3997$ 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

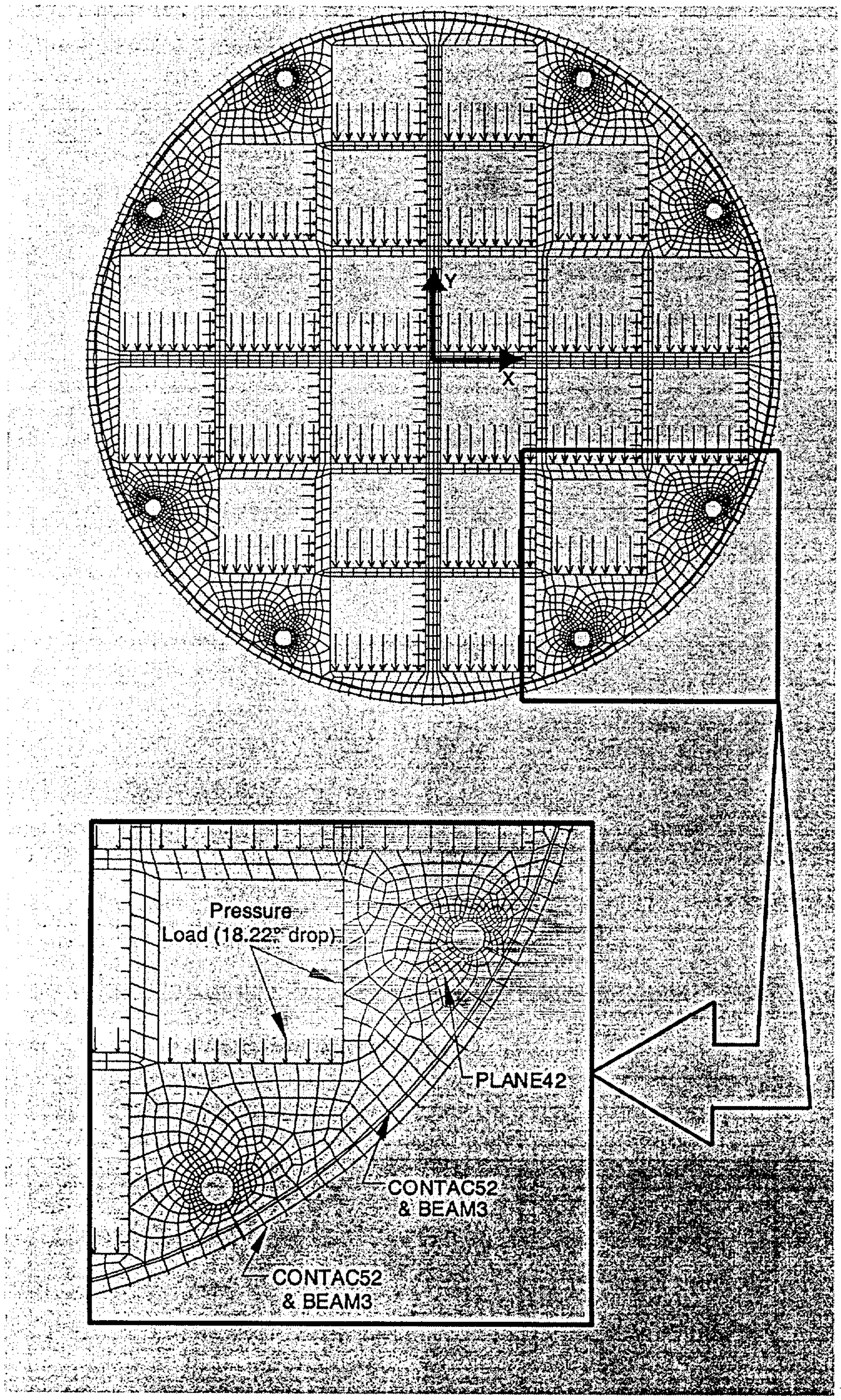


Figure 2.6.13.2-2 Side Drop Orientation

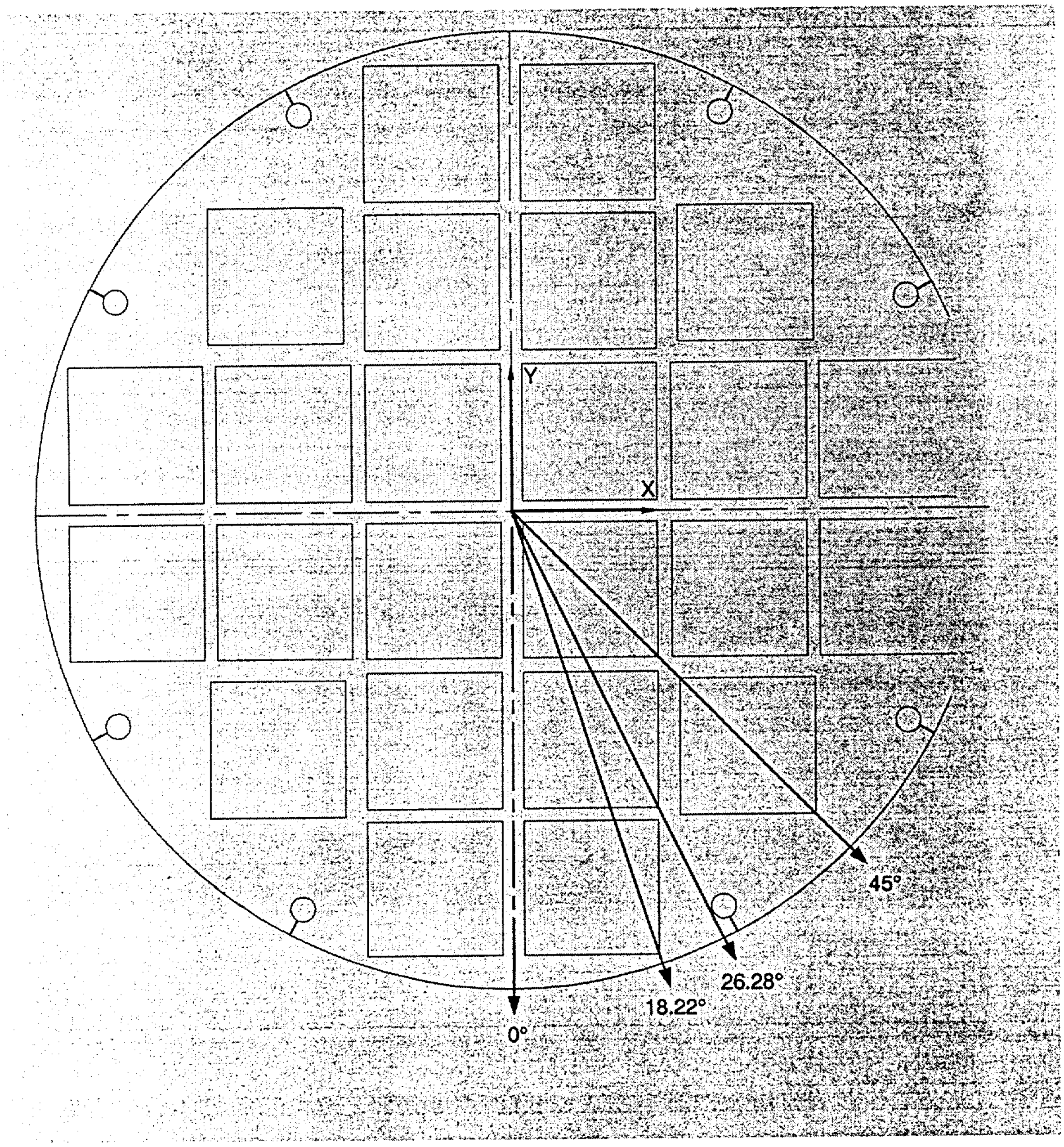


Figure 2.6.13.2-3 Location of the Section to Obtain Linearized Stresses (Left half of support disk)

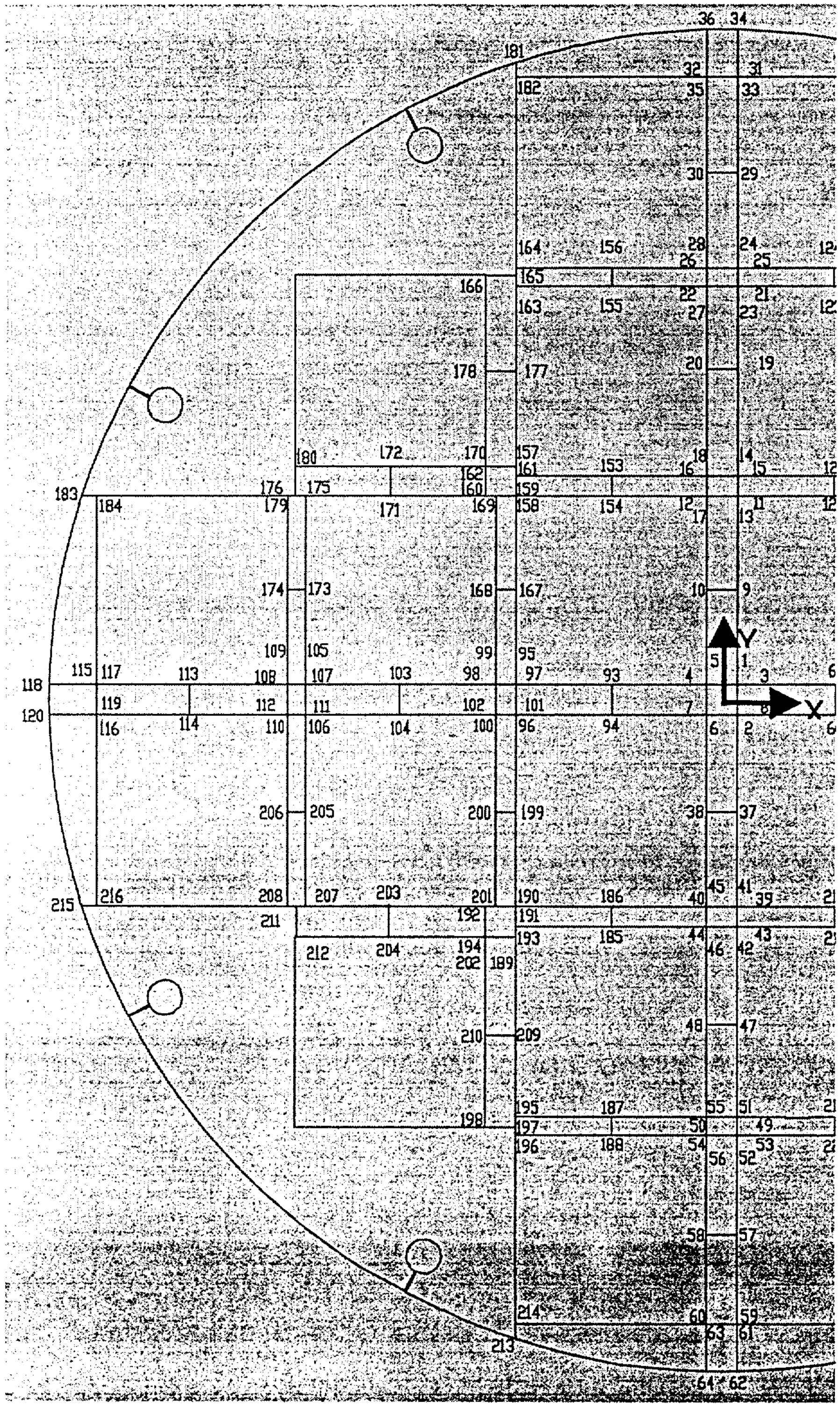


Figure 2.6.13.2-4 Location of the Section to Obtain Linearized Stresses (Right half of support disk)

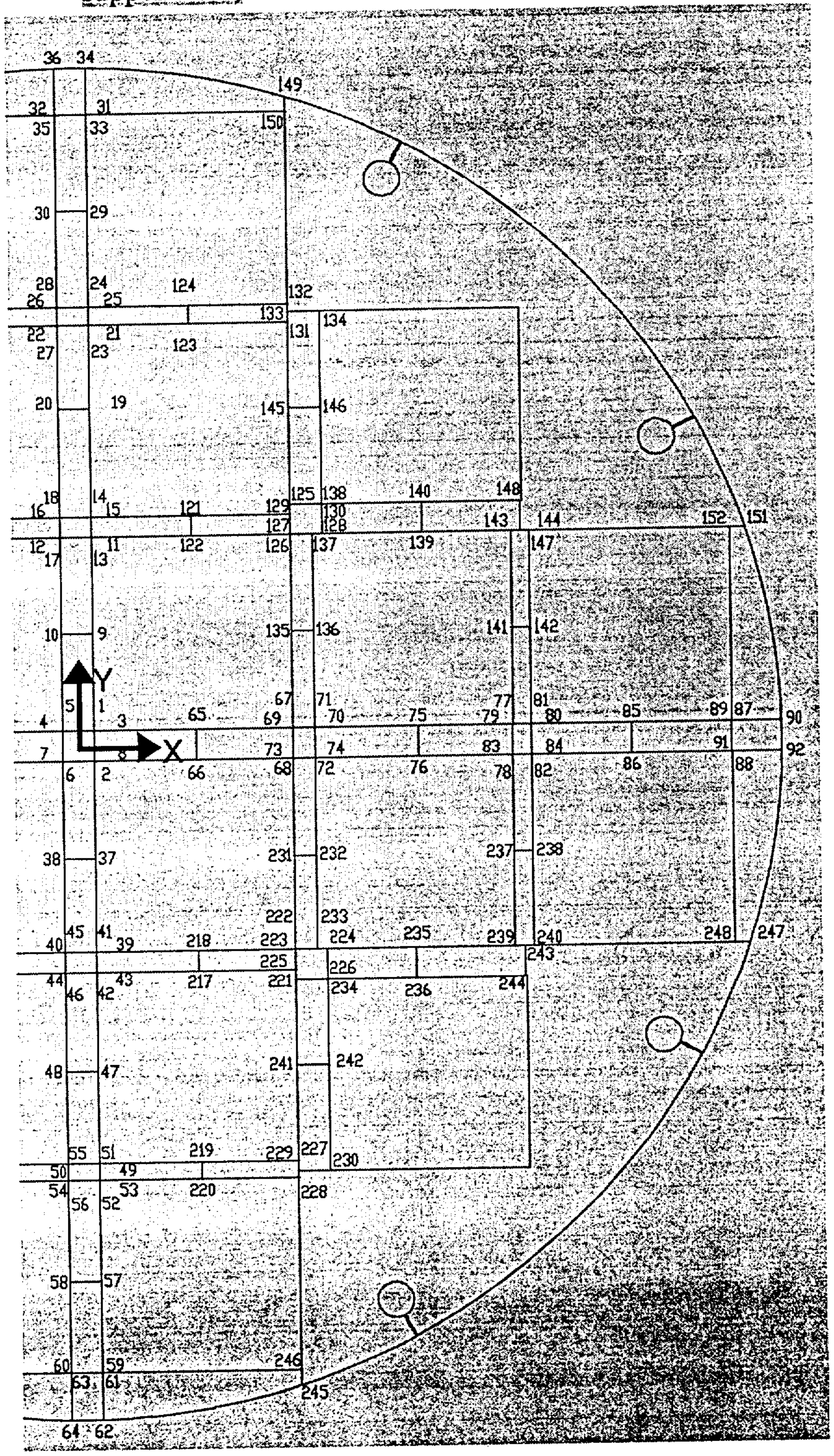


Table 2.6.13.2-1 Listing of Cross-Sections for Stress Evaluation of Support Disk

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

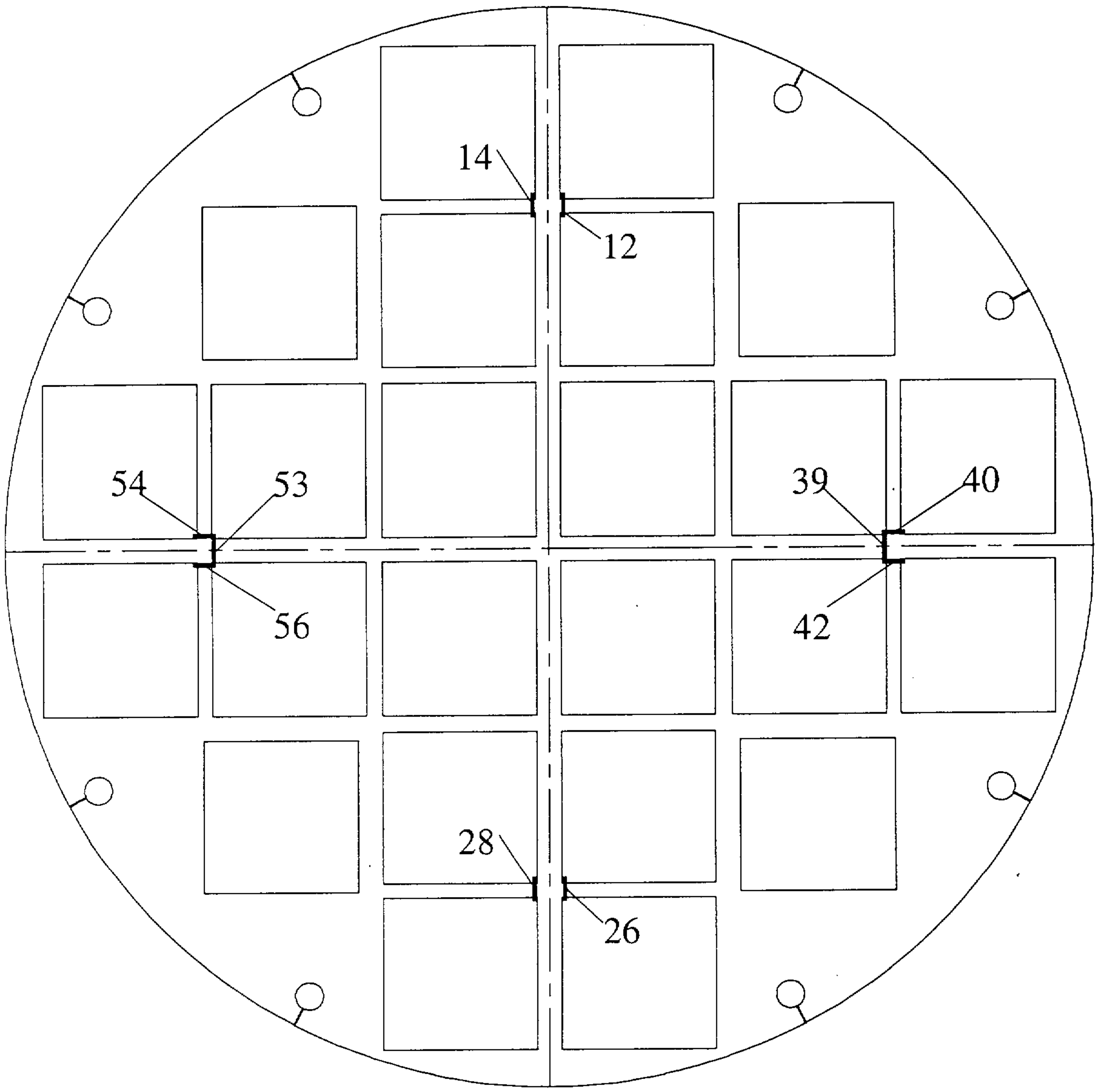


Table 2.6.13.4-1 $P_m + P_b$ Stresses for Support Disk—1-Foot End-Drop, Thermal Case A

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

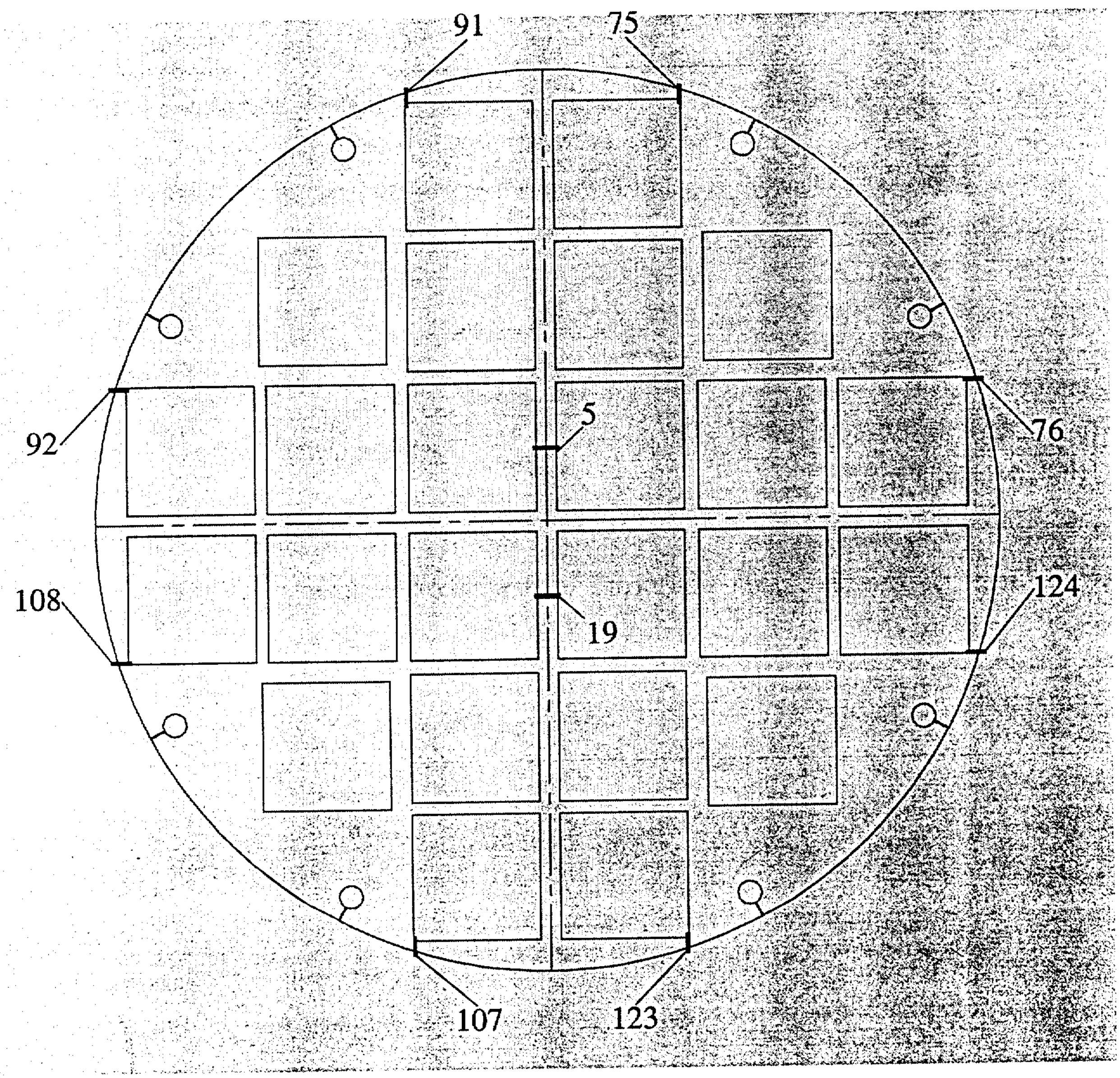


Table 2.6.13.5-1 $P_m + P_b + Q$ Stresses for Support Disk—1-Foot End-Drop, Thermal Case A

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

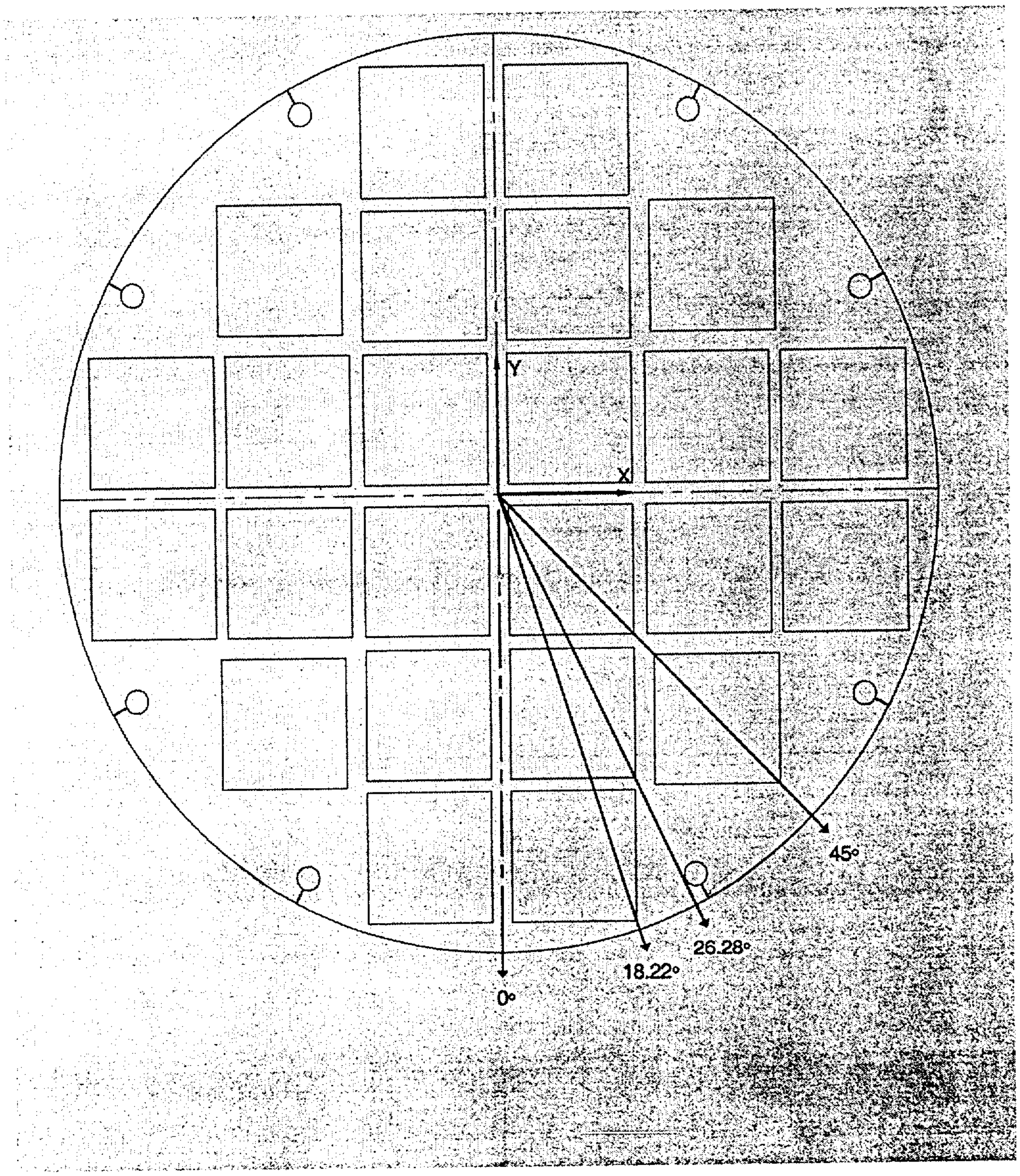


Figure 2.6.13.6-2 Locations of Maximum P_m+P_b Intensities—0° Side Drop Orientation, Thermal Case A

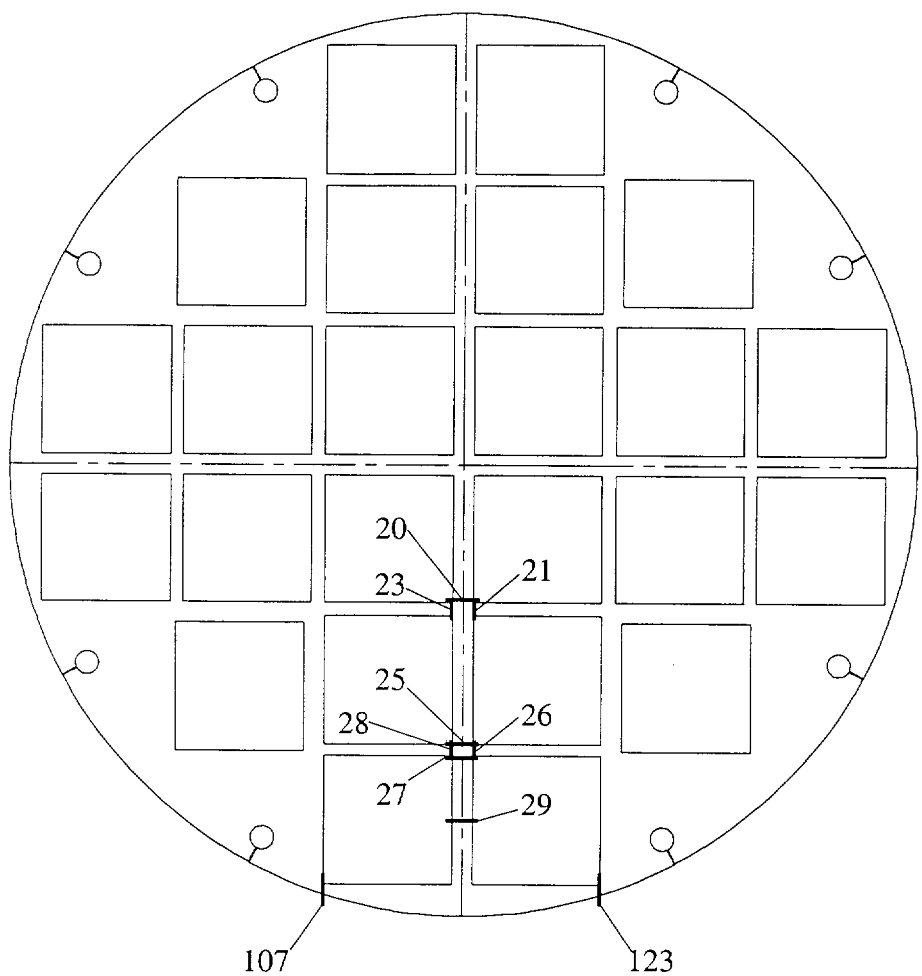


Figure 2.6.13.6-3 Locations of Maximum P_m+P_b Stresses—18.22° Side Drop Orientation, Thermal Case A

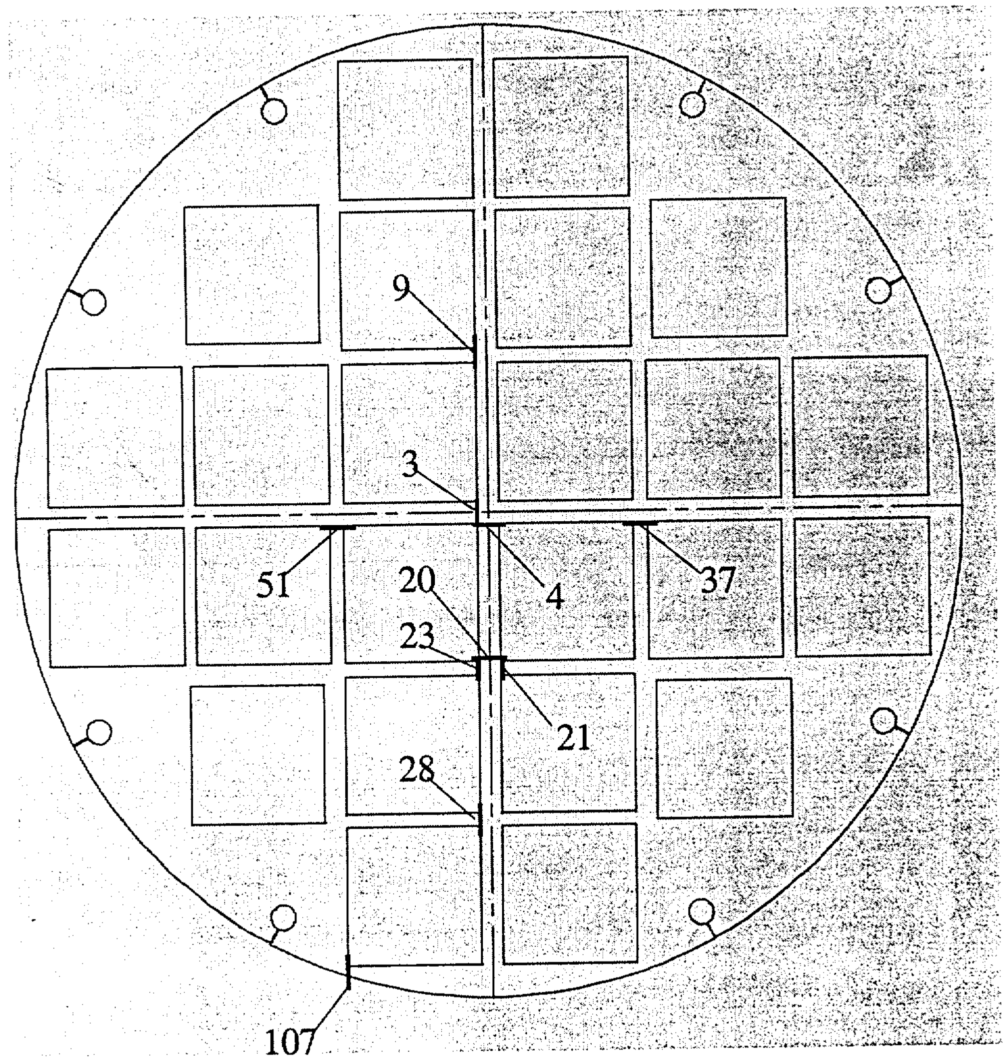


Figure 2.6.13.6-4 Locations of Maximum P_m+P_b Stresses—26.28° Side Drop Orientation, Thermal Case A

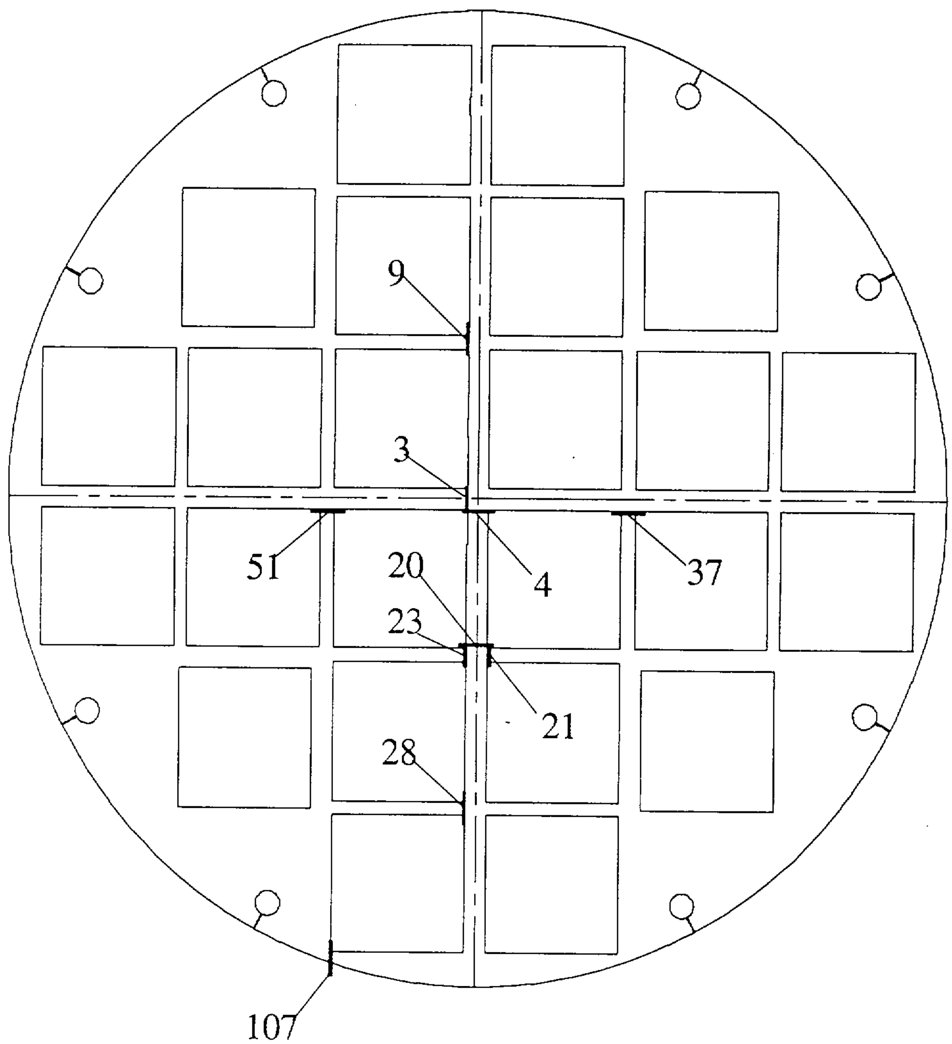
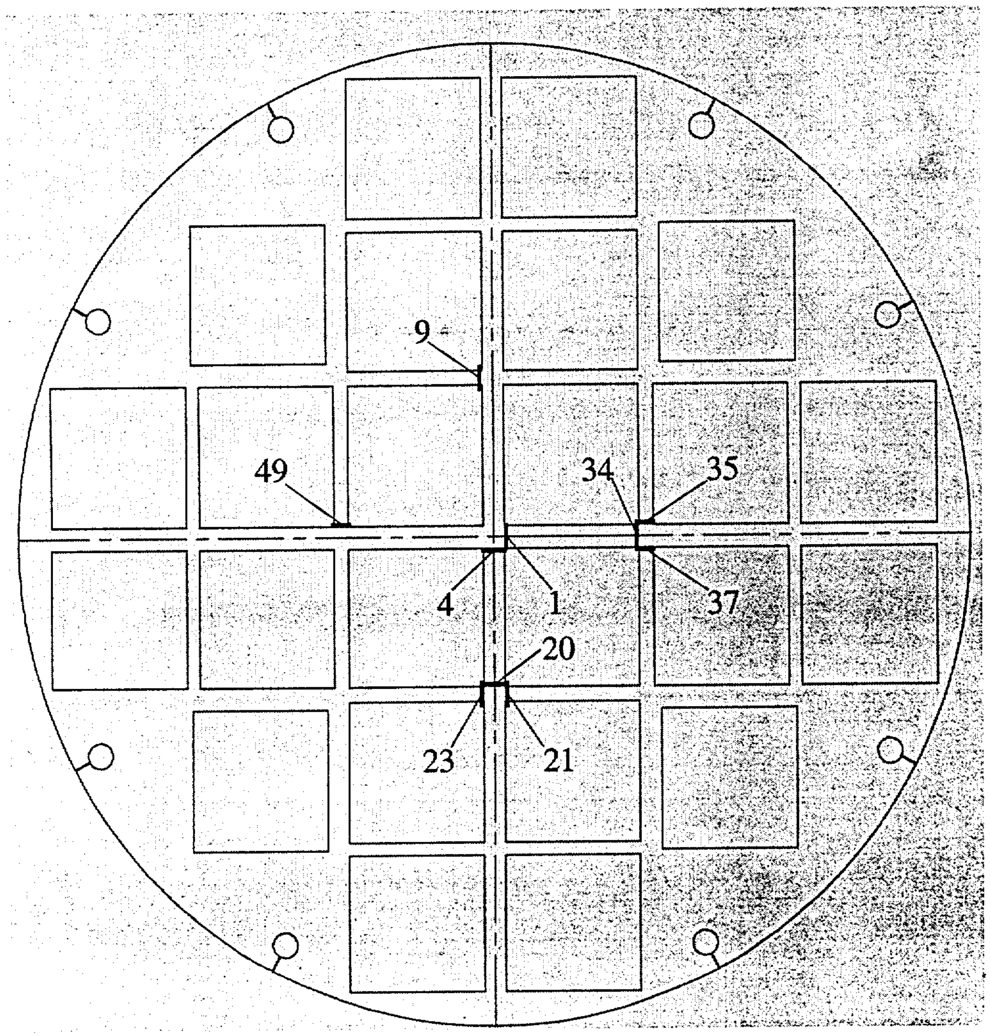


Figure 2.6.13.6-5 Locations of Maximum P_m+P_b Stresses—45° Side Drop Orientation, Thermal Case A



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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, 18.22° Orientation, 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 evaluation 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

$$MS = [2(0.6)S_m / SI] - 1$$
$$= [2(0.6)(41.9) / 31.4] - 1$$
$$= +0.60$$

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

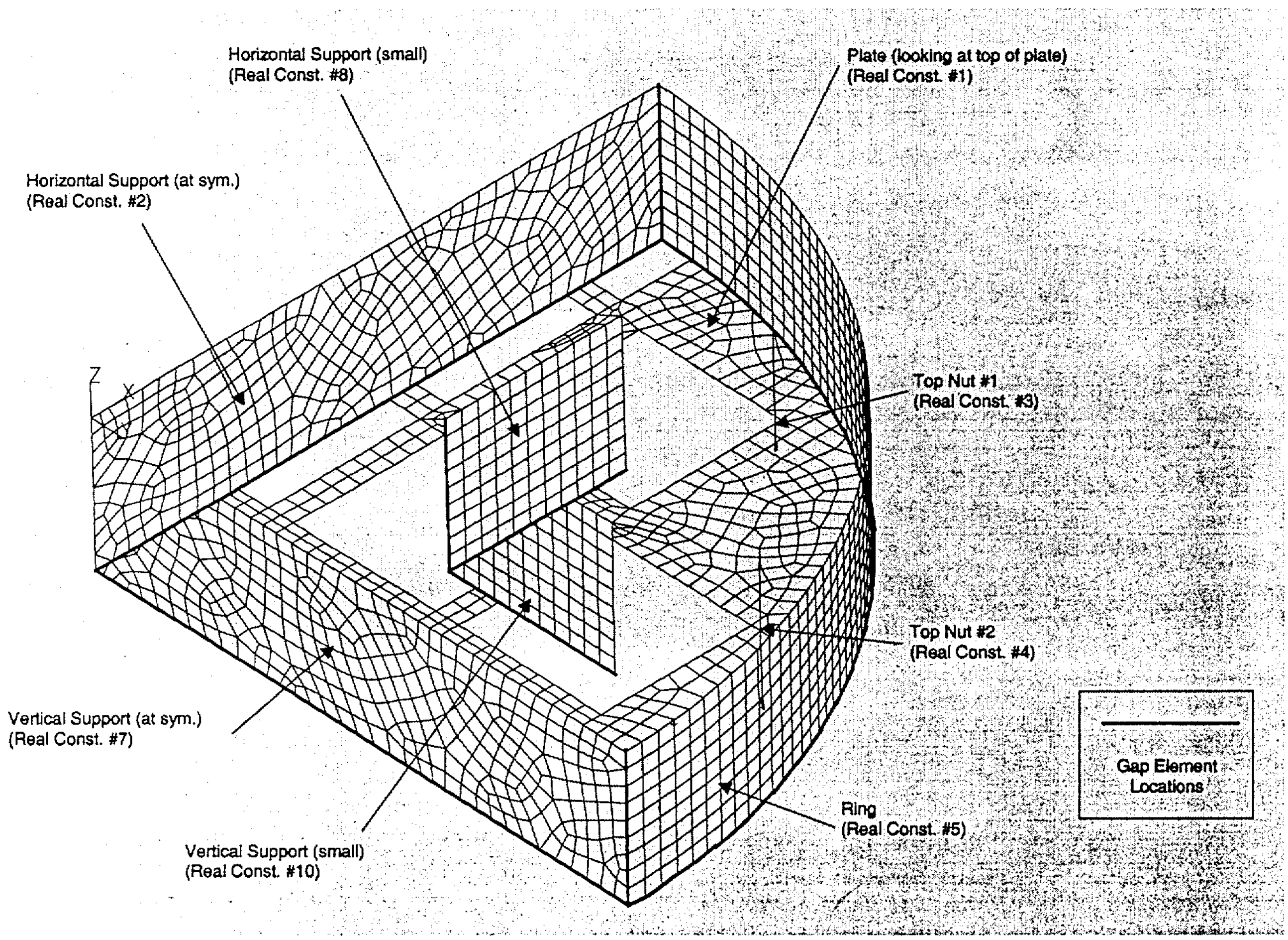


Figure 2.6.13.13-2 Finite Element Model of the Bottom Weldment Plate

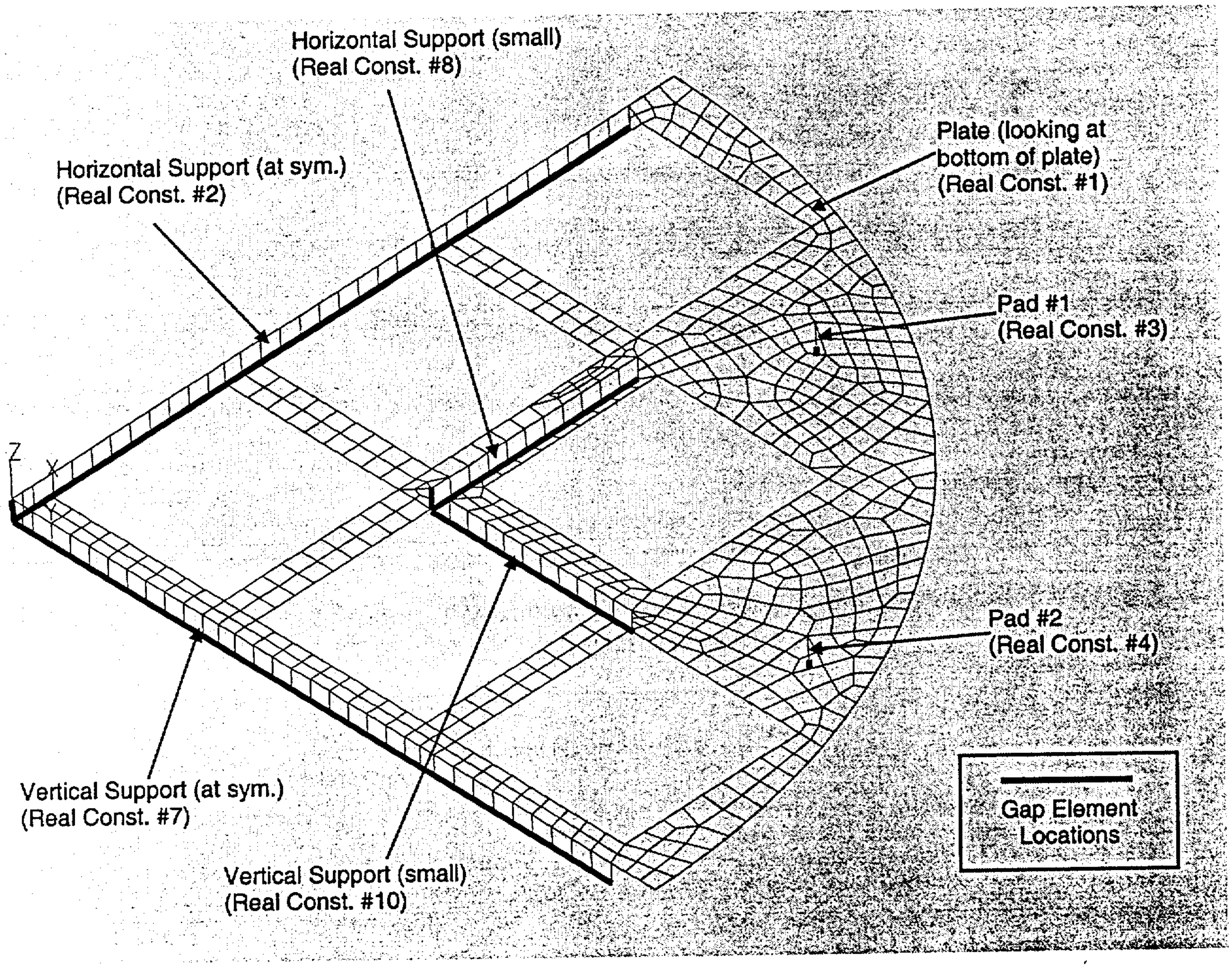


Table 2.6.13.13-1 Minimum Margins of Safety for the Top/Bottom Weldments for 1-Foot End-Drop

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:

<u>Symbols and Units</u>

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

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

$P_e = 1.92 \times A \times F_e$

$$F_e = \frac{\pi^2 \cdot E}{1.92\left(\frac{k \cdot 1}{r}\right)^2} \text{ (non-austenitic)}$$

$$F_e = \frac{\pi^2 \cdot E}{1.3\left(\frac{k \cdot 1^2}{r}\right)} \text{ (austenitic)}$$

$P_y = S_y \times A$

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

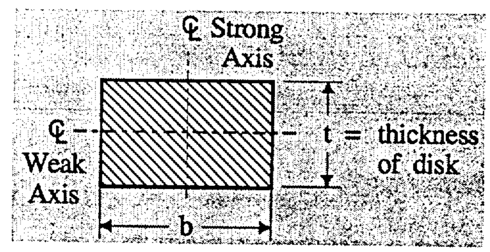
$$M_p = S_y \times Z_x$$

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

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:

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

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

The margins of safety are calculated as:

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

and $$MS2 = \frac{1}{P_2 + M_2} - 1$$ (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	46.7	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

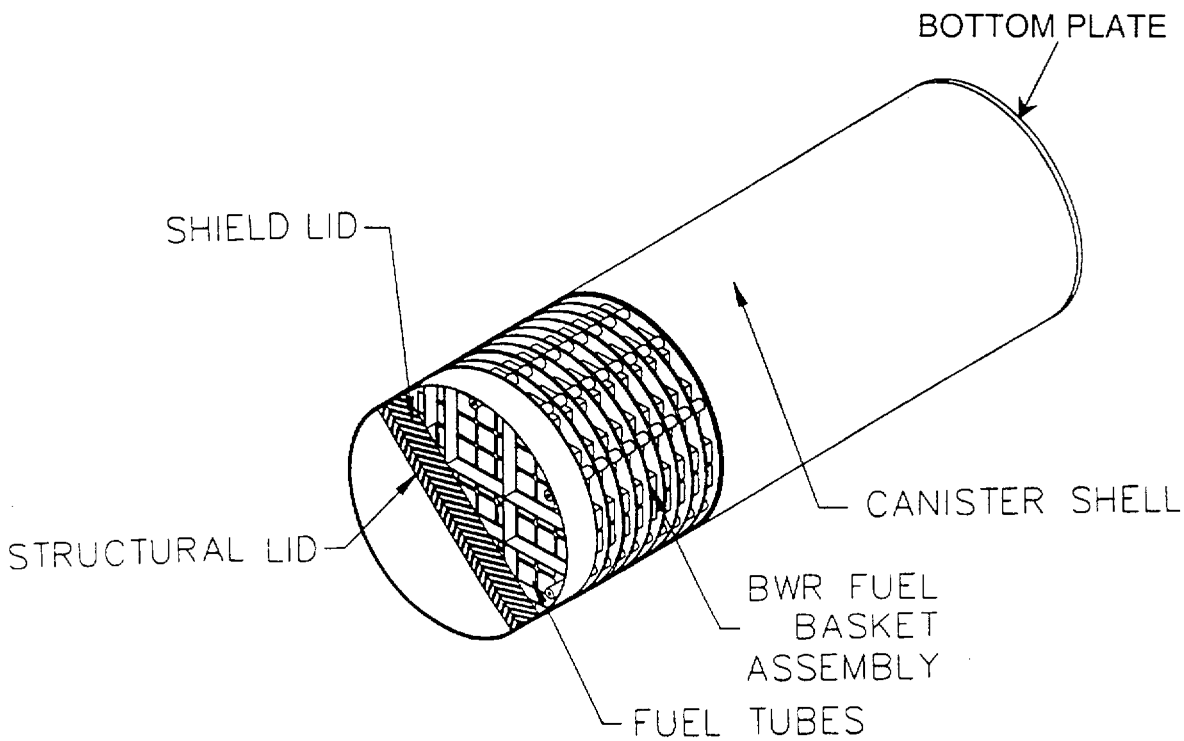
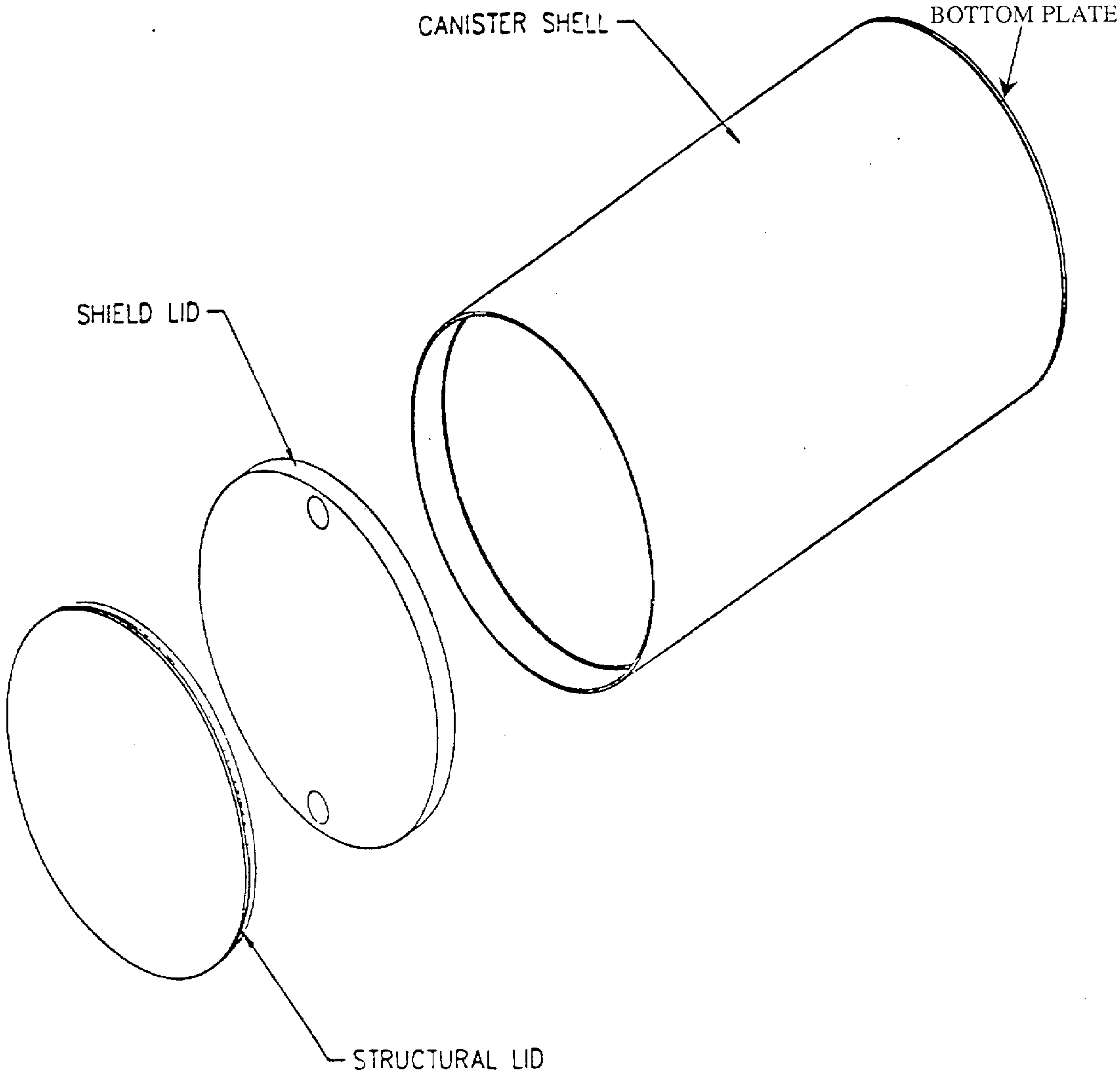


Figure 2.6.14-2 BWR Transportable Storage Canister Shell and Lids



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 363°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.

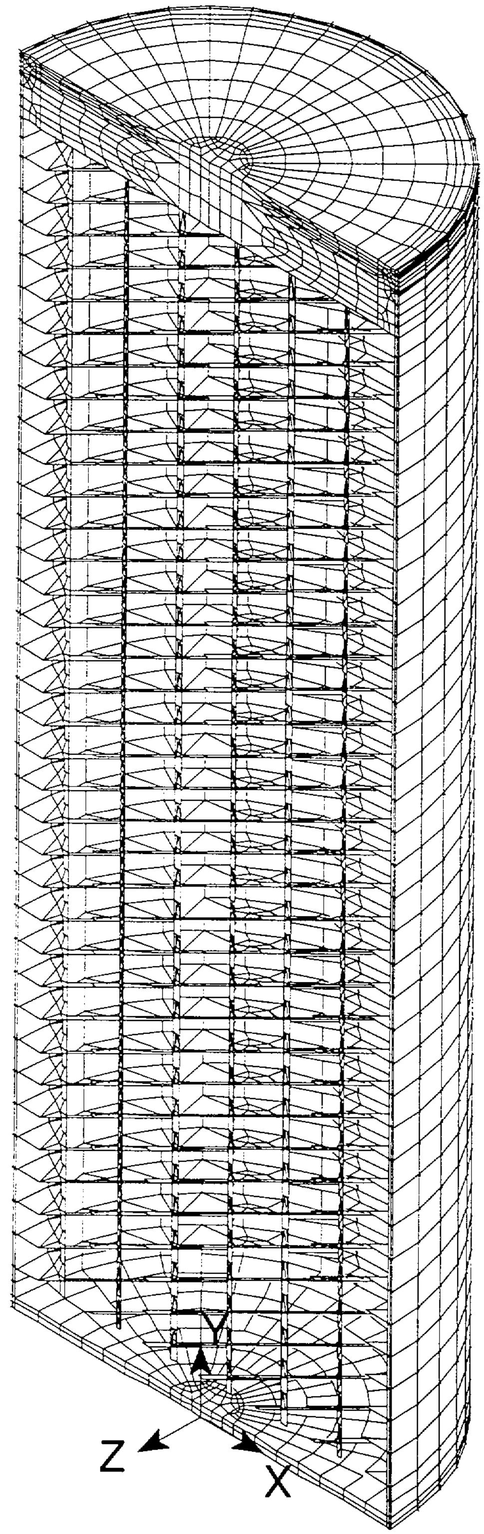
The increase in the number of support disks has a minimal effect on the stress results presented in this section since this change helps to distribute the load to the canister shell more evenly. In addition, the design changes and bounding fuel assembly weight results in a total fuel and fuel basket 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)



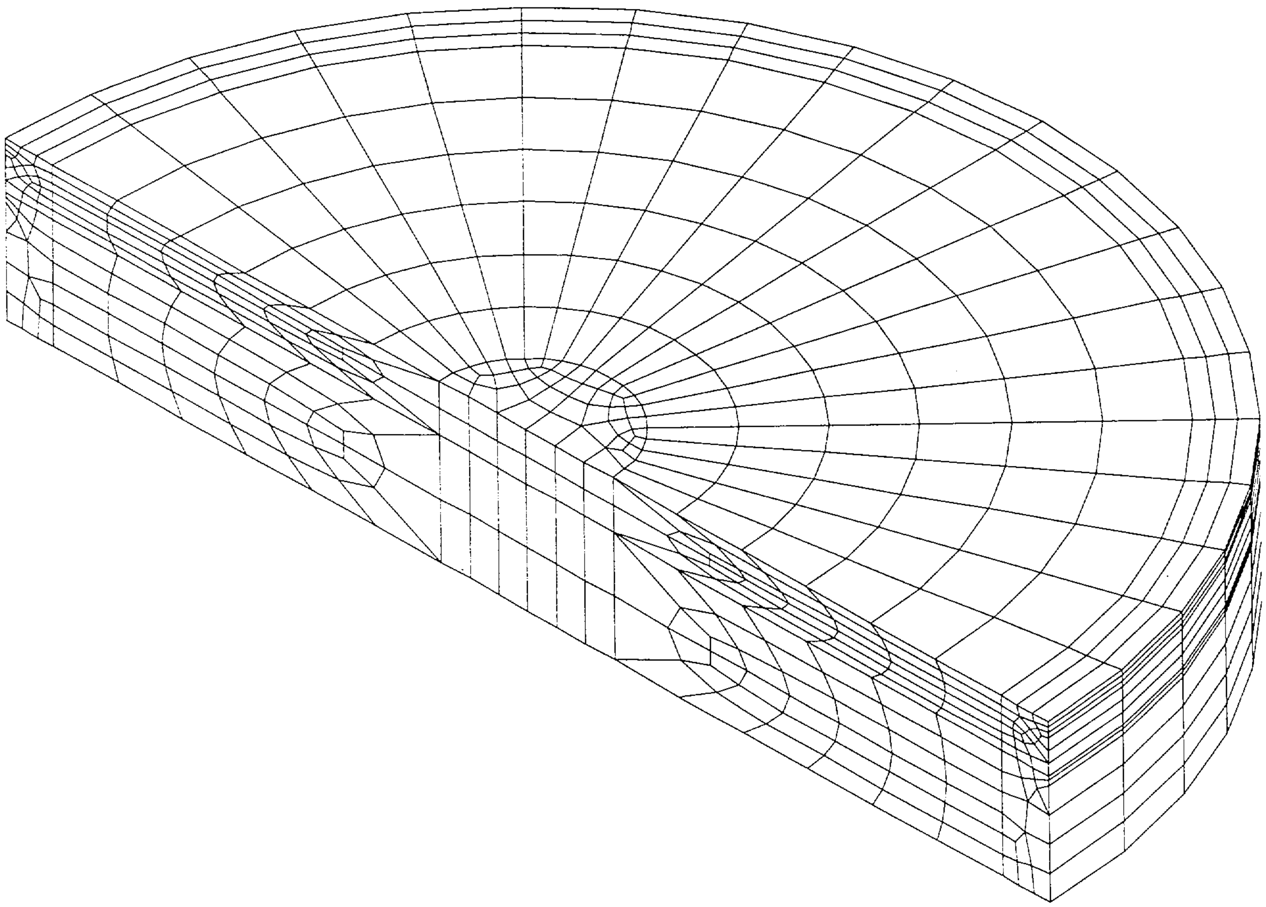


Figure 2.6.14.2-2 Canister Structural and Shield Lid Finite Element Mesh

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

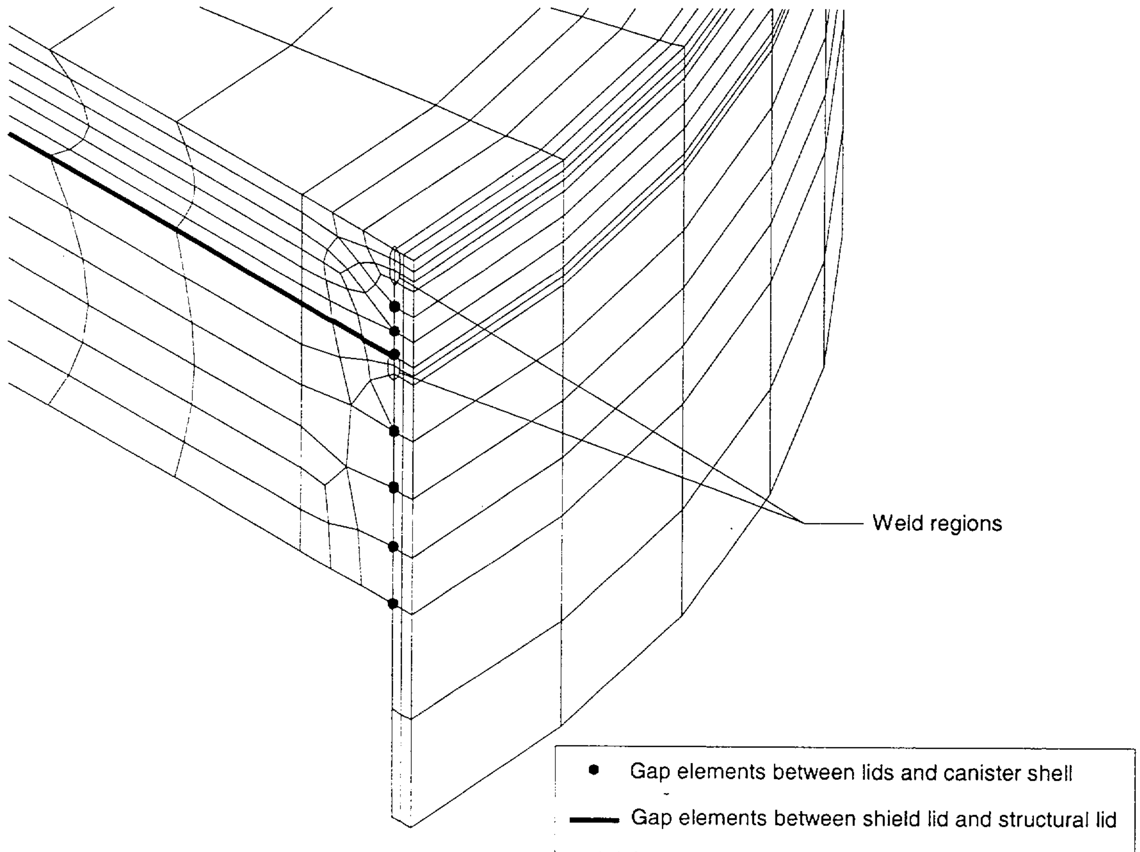


Figure 2.6.14.2-4 Canister Bottom Plate Finite Element Mesh

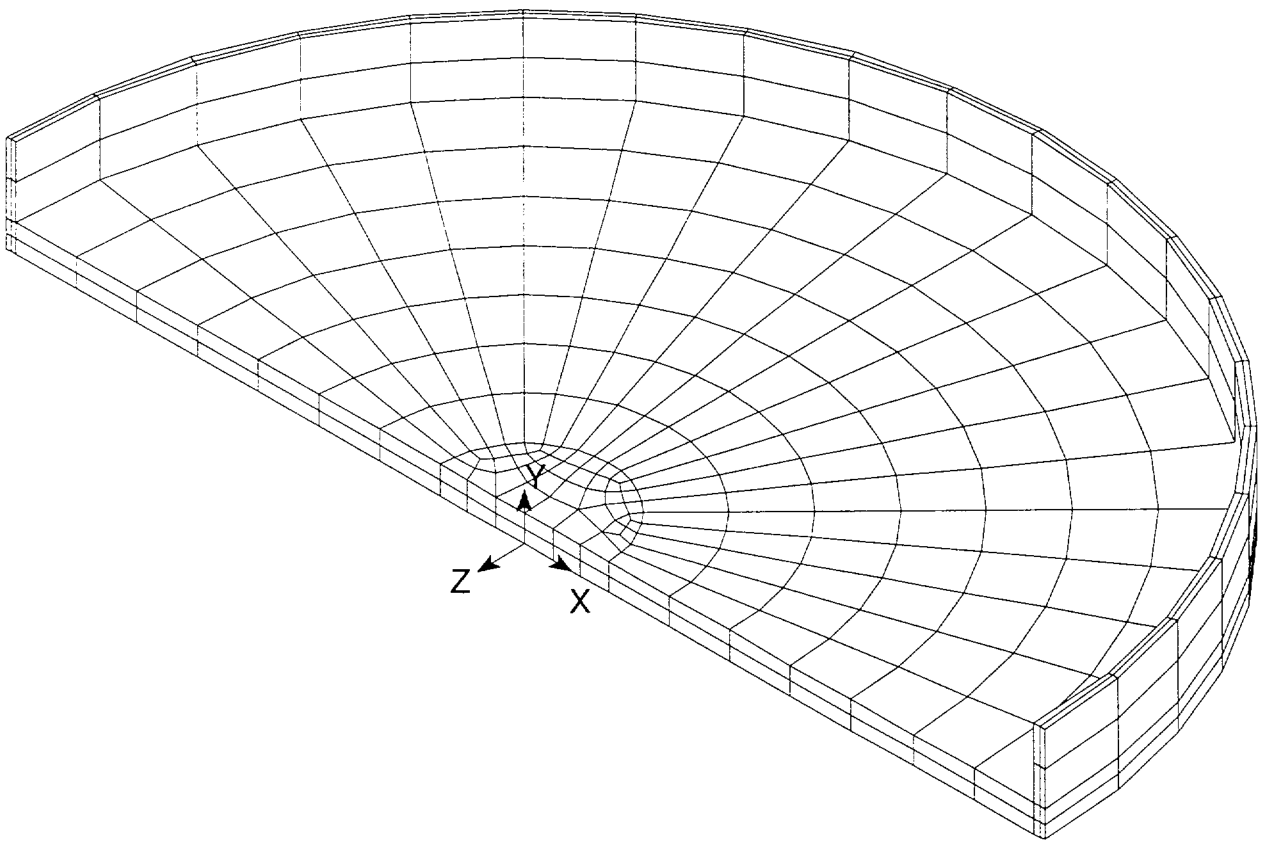


Table 2.6.14.2-1 Real Constant Sets Defined in Canister Model

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 Spacer 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

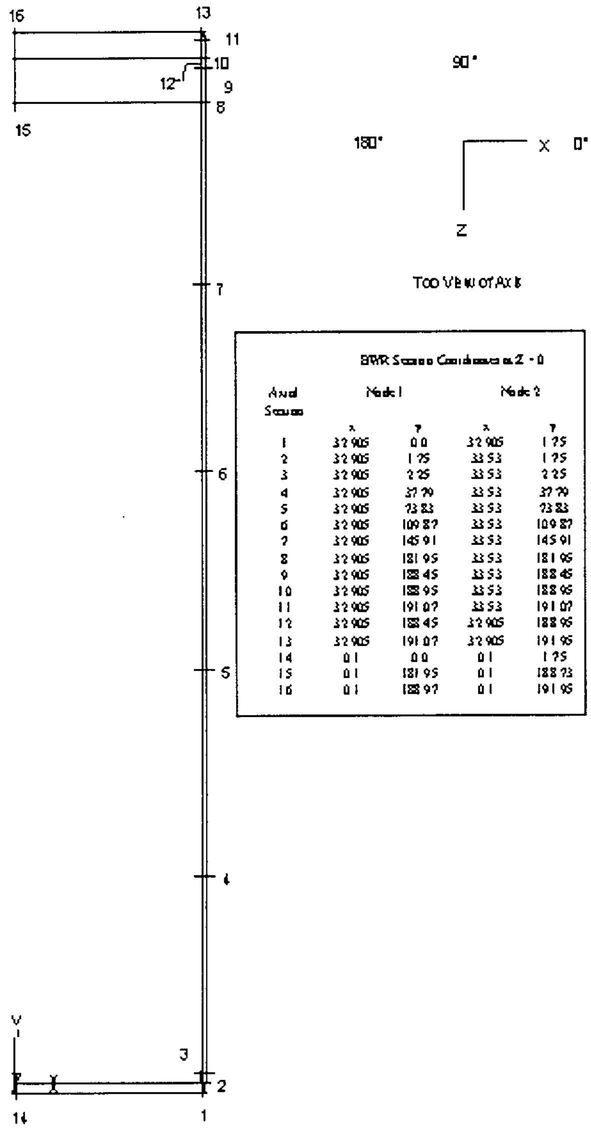
The temperatures employed in the thermal stress analysis are obtained by applying temperatures at 36 key locations on the canister shell and ends to the thermal equivalent model of the structural canister model as thermal boundary conditions. These temperatures are taken from the thermal evaluation described 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		Node 2	
	x	y	x	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 . 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 = (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 408°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 Q1	Q2	Q3	Q4	Plastic Buckling Interaction Equations 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

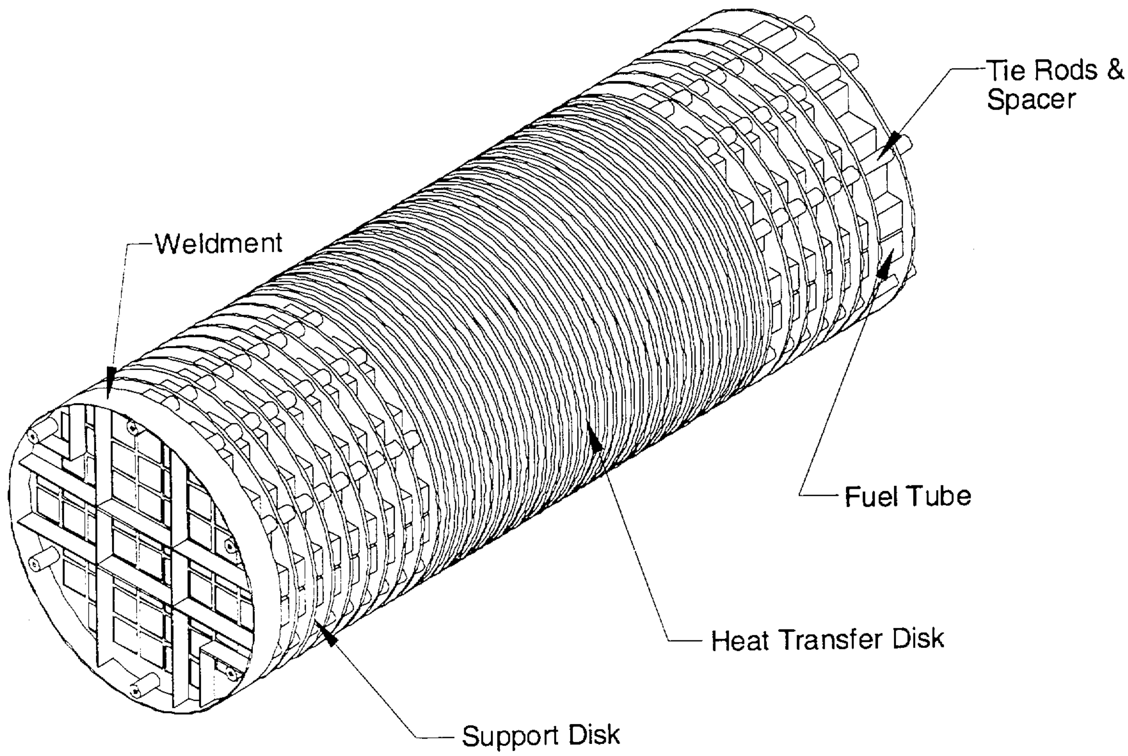


Figure 2.6.15-2 Support Disk Cross-Section Configuration

FIGURE WITHHELD UNDER 10 CFR 2.390

Note:

Engineering drawings provide appropriate tolerances for dimensions shown.

Figure 2.6.15-3 BWR Fuel Tube Configuration

FIGURE WITHHELD UNDER 10 CFR 2.390

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 carbon 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

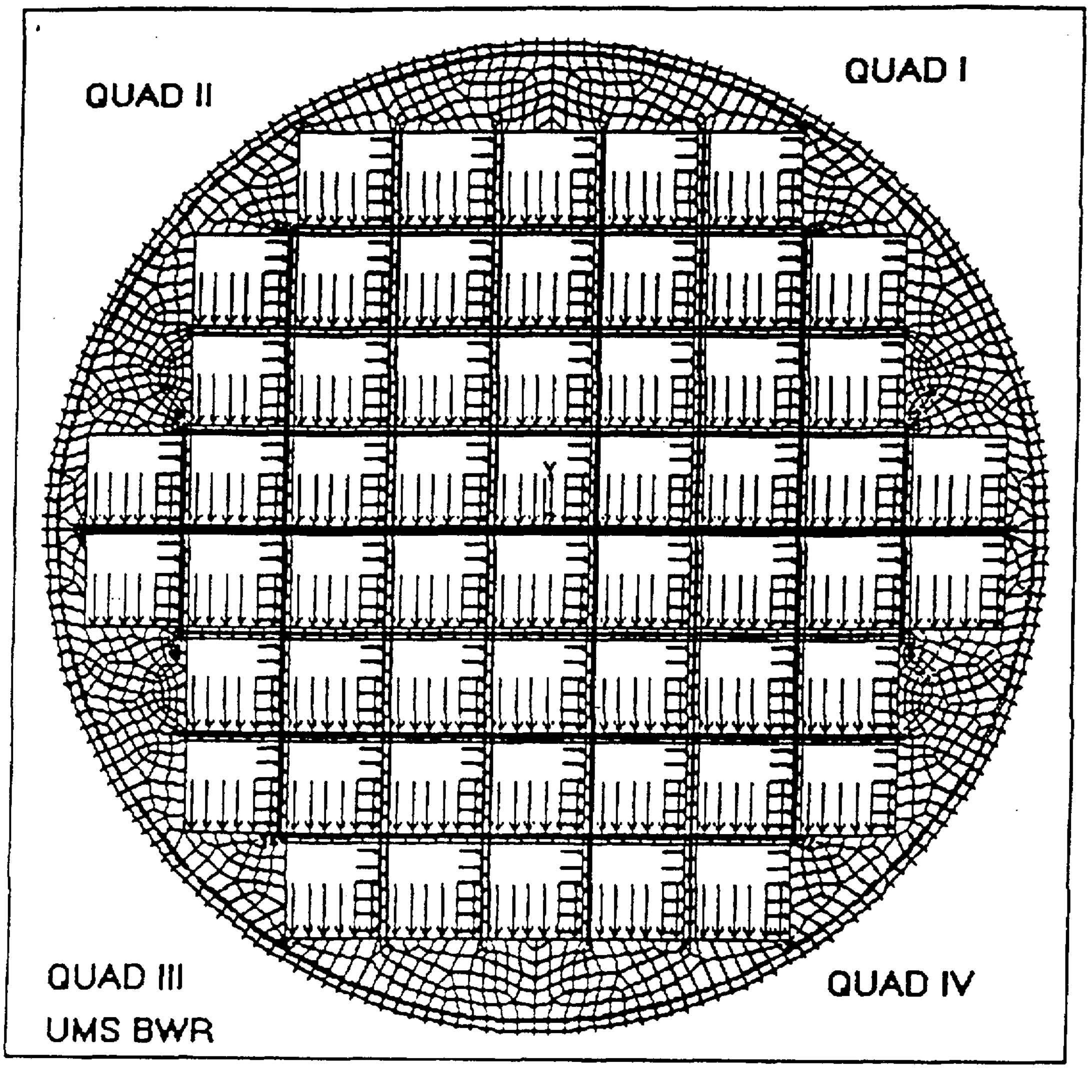
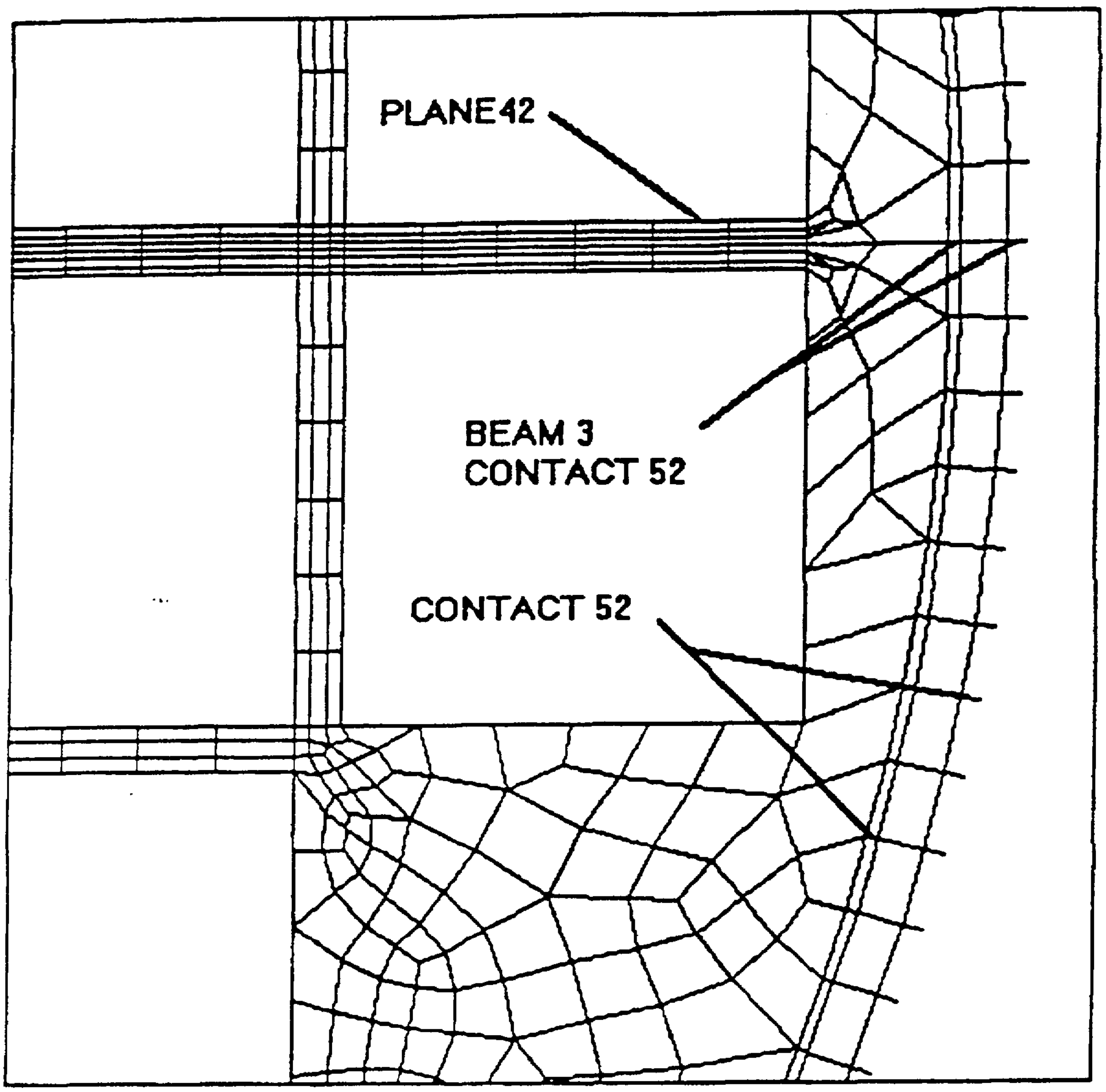


Figure 2.6.15.2-2 Close-up of the Ligaments and the Interface with the Canister Shell and the Cask Inner Shell



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 from 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 positioned 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 are 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

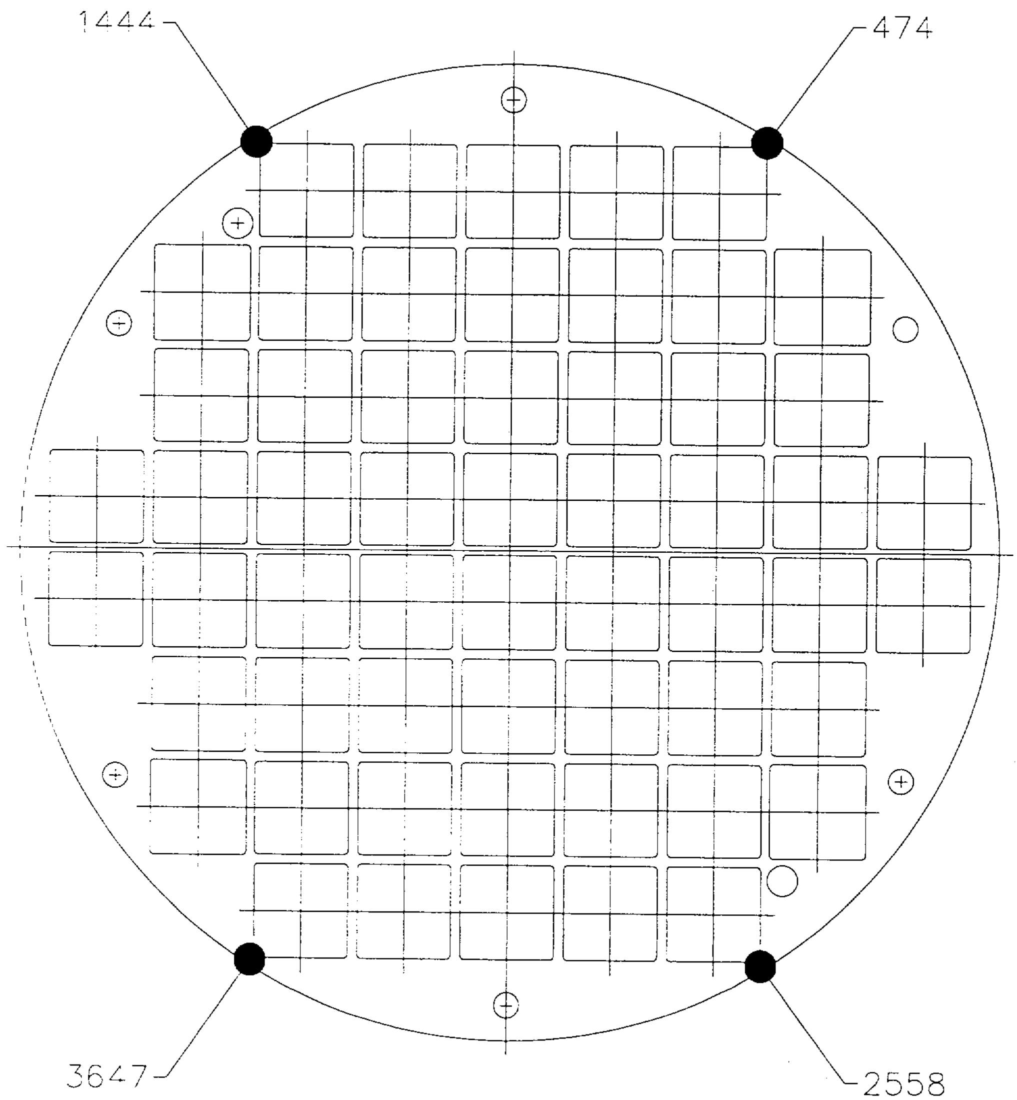


Table 2.6.15.4-1 $P_m + P_b$ Stresses for Support Disk 1-Foot End-Drop, Thermal Case 1

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

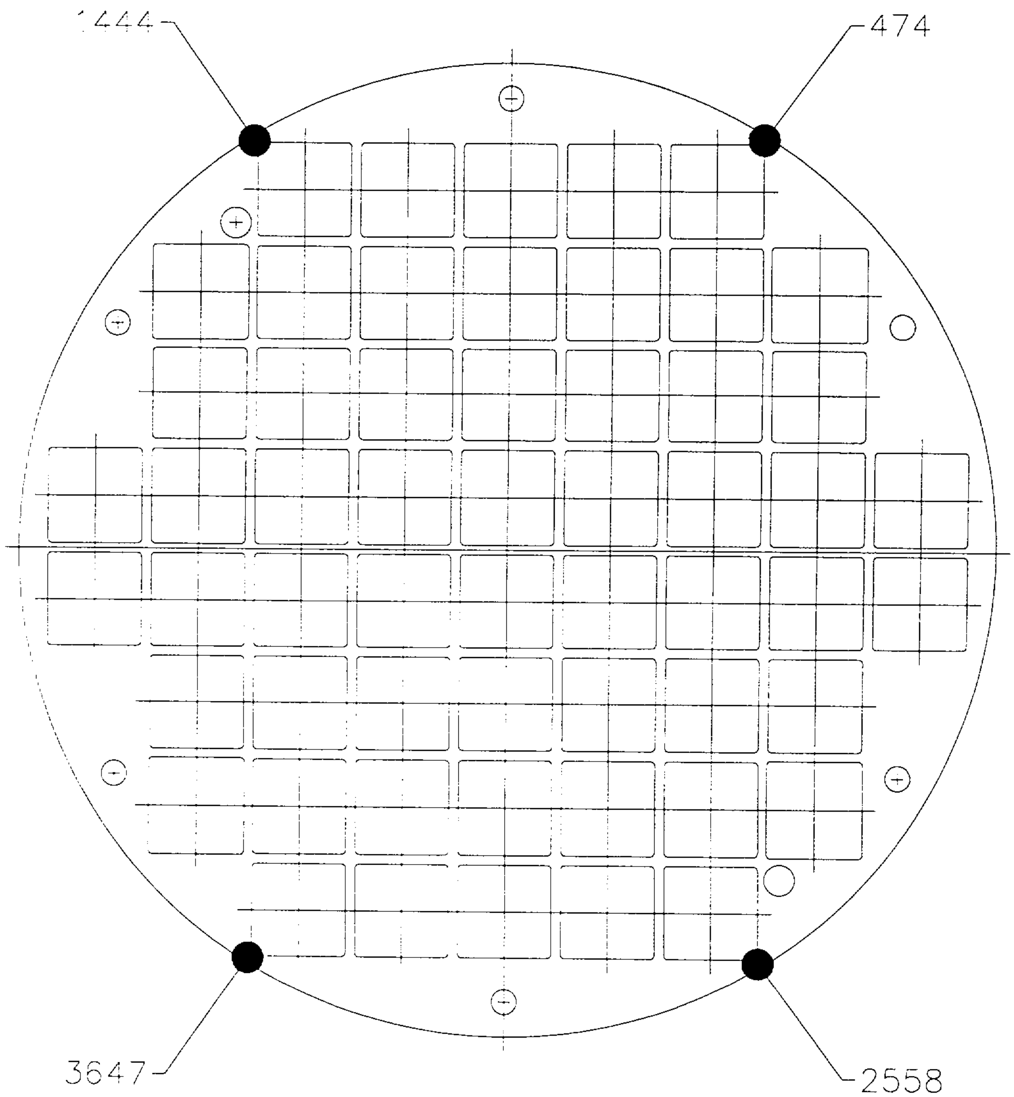


Table 2.6.15.5-1 $P_m + P_b + Q$ Stresses for Support Disk 1-Foot End-Drop, Thermal Case 4

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

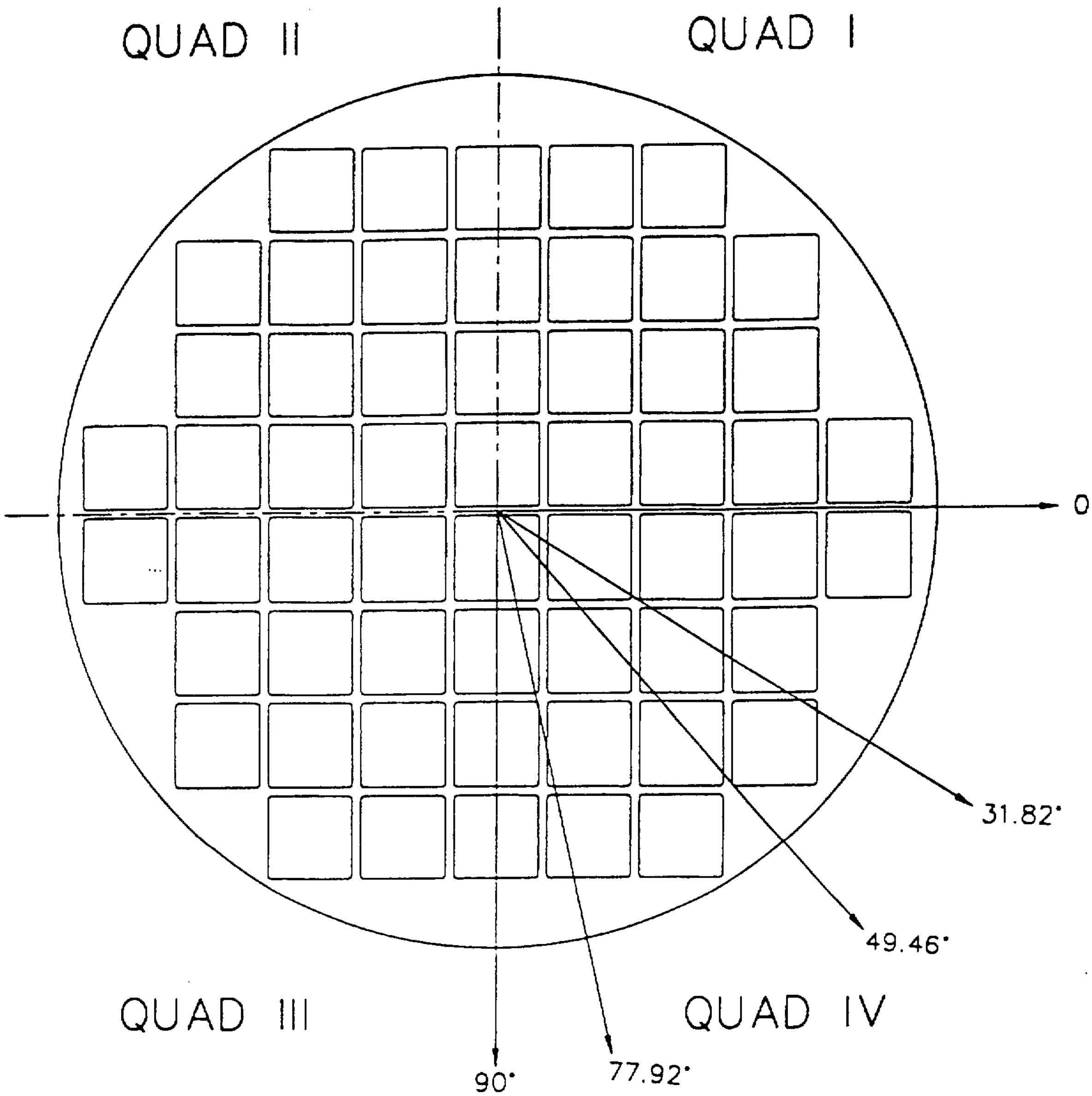
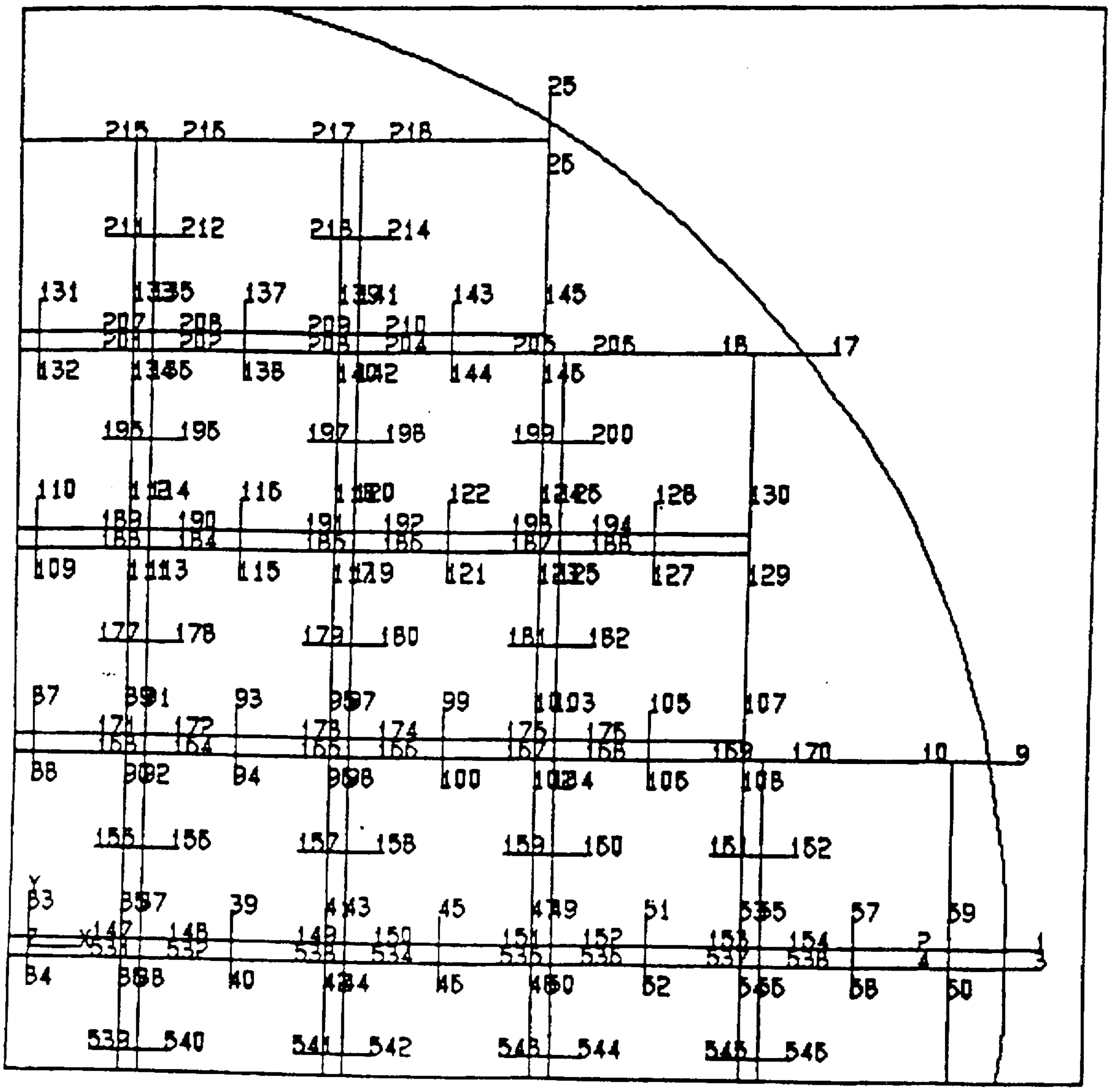
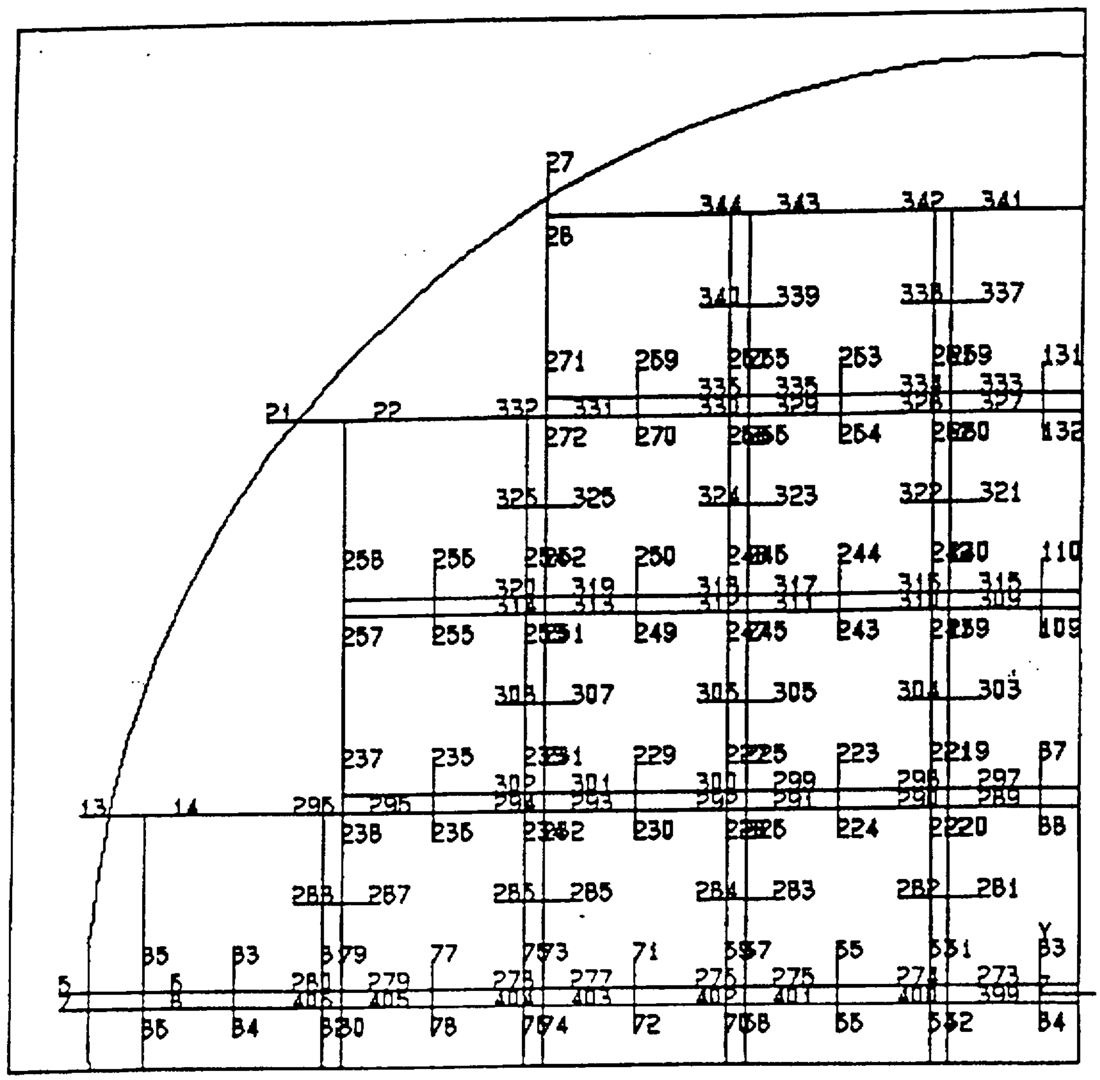


Figure 2.6.15.6-2 Locations of the Sections Used to Obtain Linearized Stresses for the Support Disk for the 1st Quadrant (X>0, Y>0)



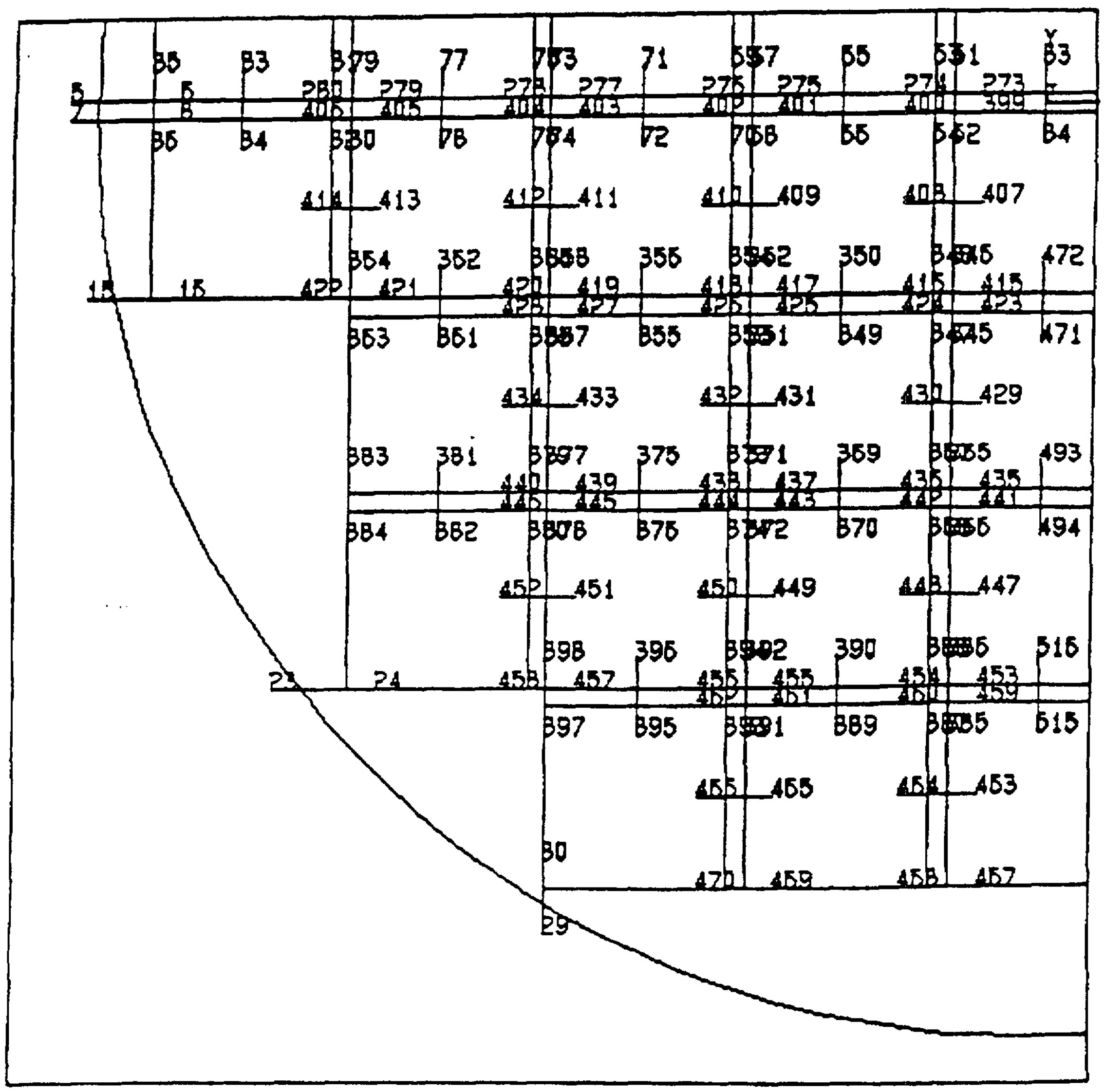
QUAD I

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)



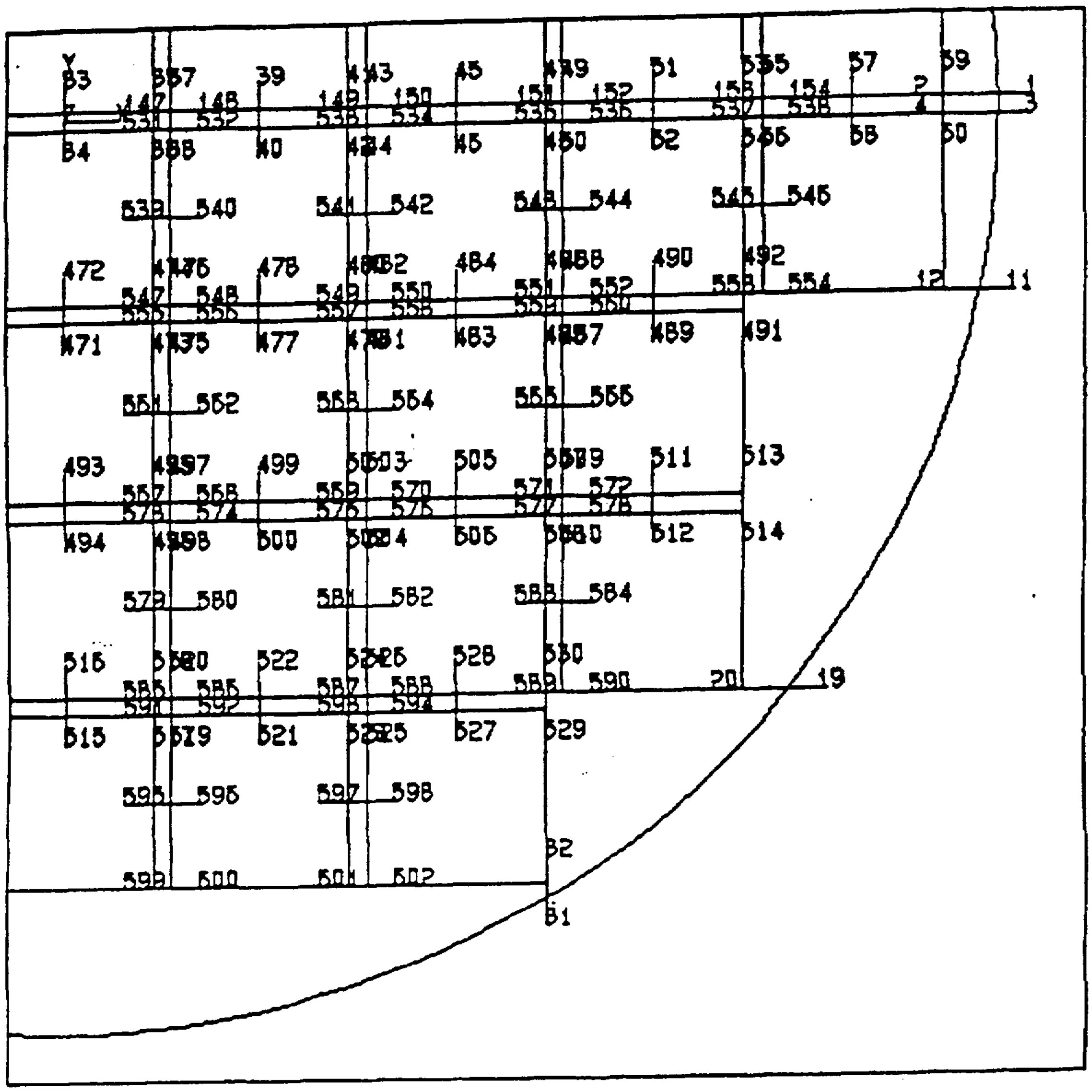
QUAD II

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

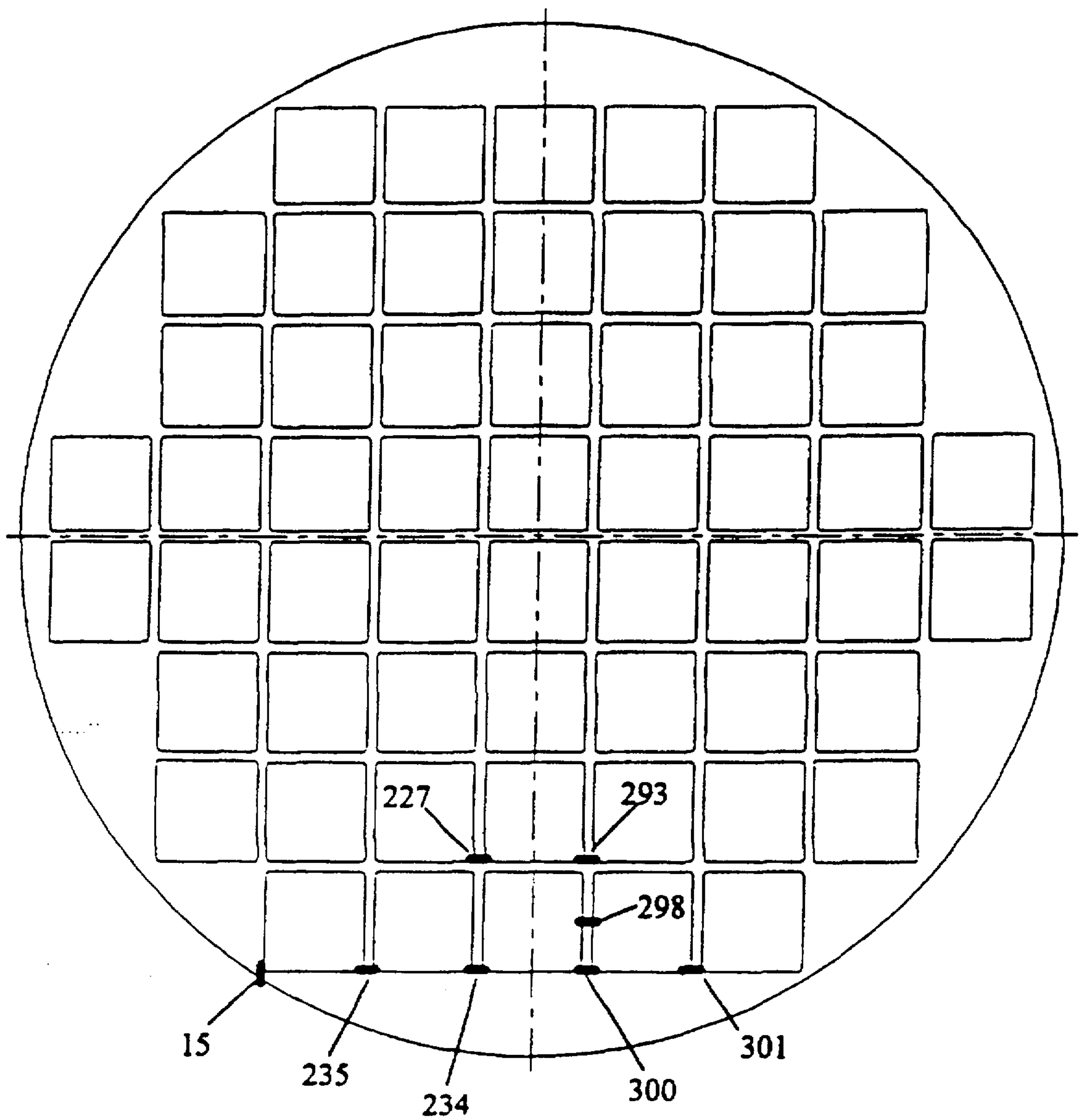


Figure 2.6.15.6-7 Locations of Maximum Linearized Stress Intensities - 31.82° Drop Orientation

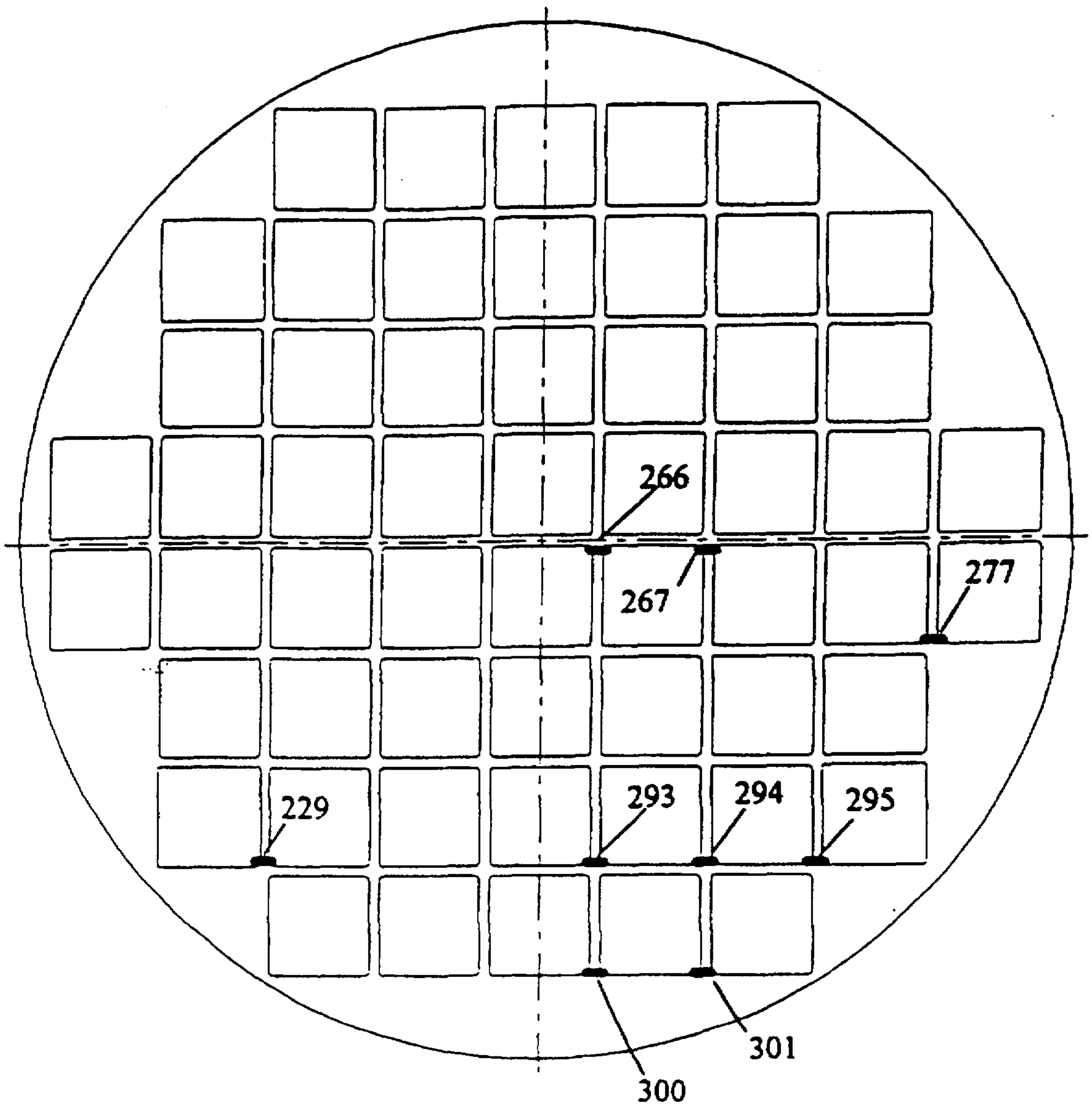


Figure 2.6.15.6-8 Locations of Maximum Linearized Stress Intensities - 49.46° Drop Orientation

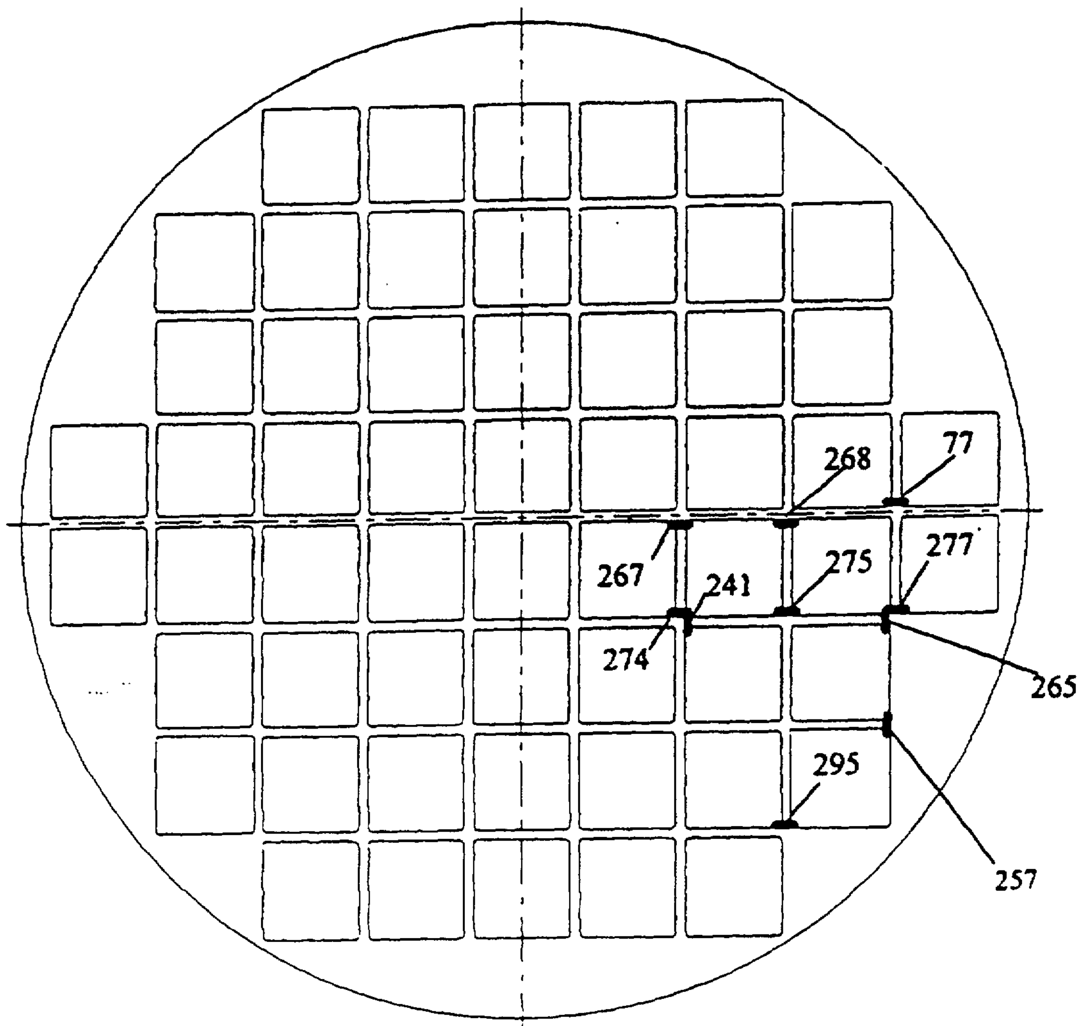


Figure 2.6.15.6-9 Locations of Maximum Linearized Stress Intensities - 77.92° Drop Orientation

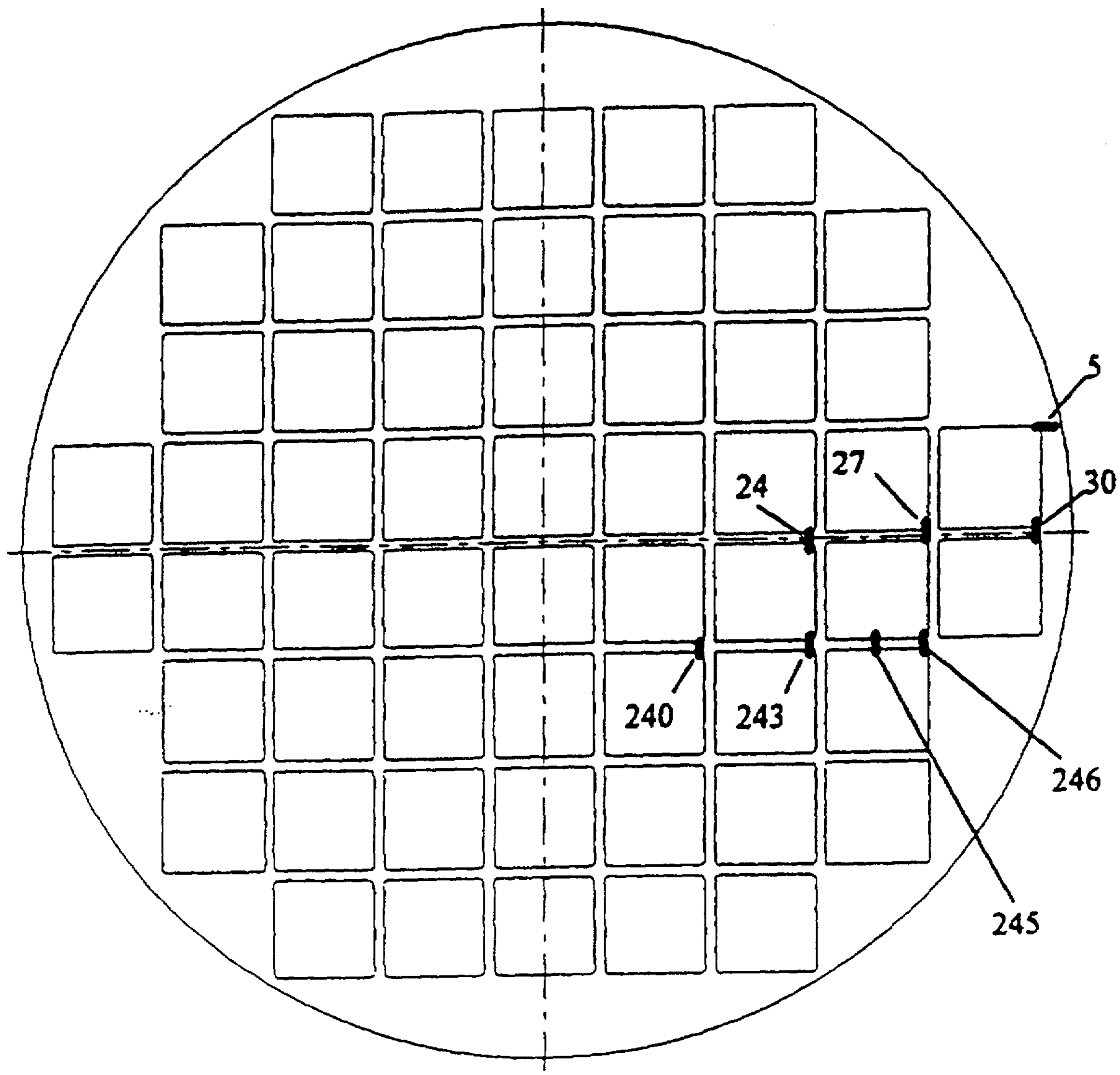


Figure 2.6.15.6-10 Locations of Maximum Linearized Stress Intensities - 90° Drop Orientation

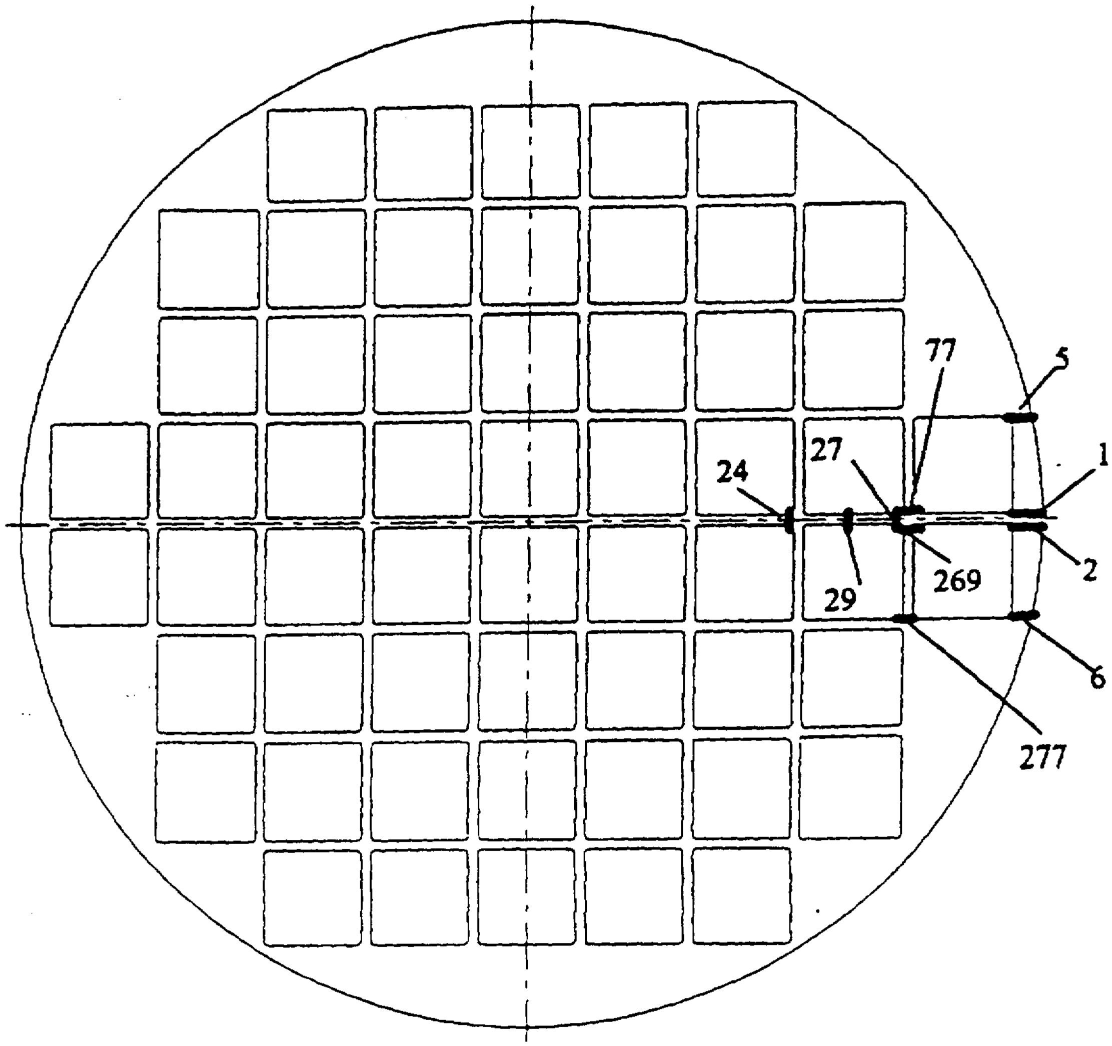


Table 2.6.15.6-1 Listing of Cross-Sections for Stress Evaluation of Support Disk

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 = (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 $258{,}220/(6 \times 4.66) = 9{,}235$ 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

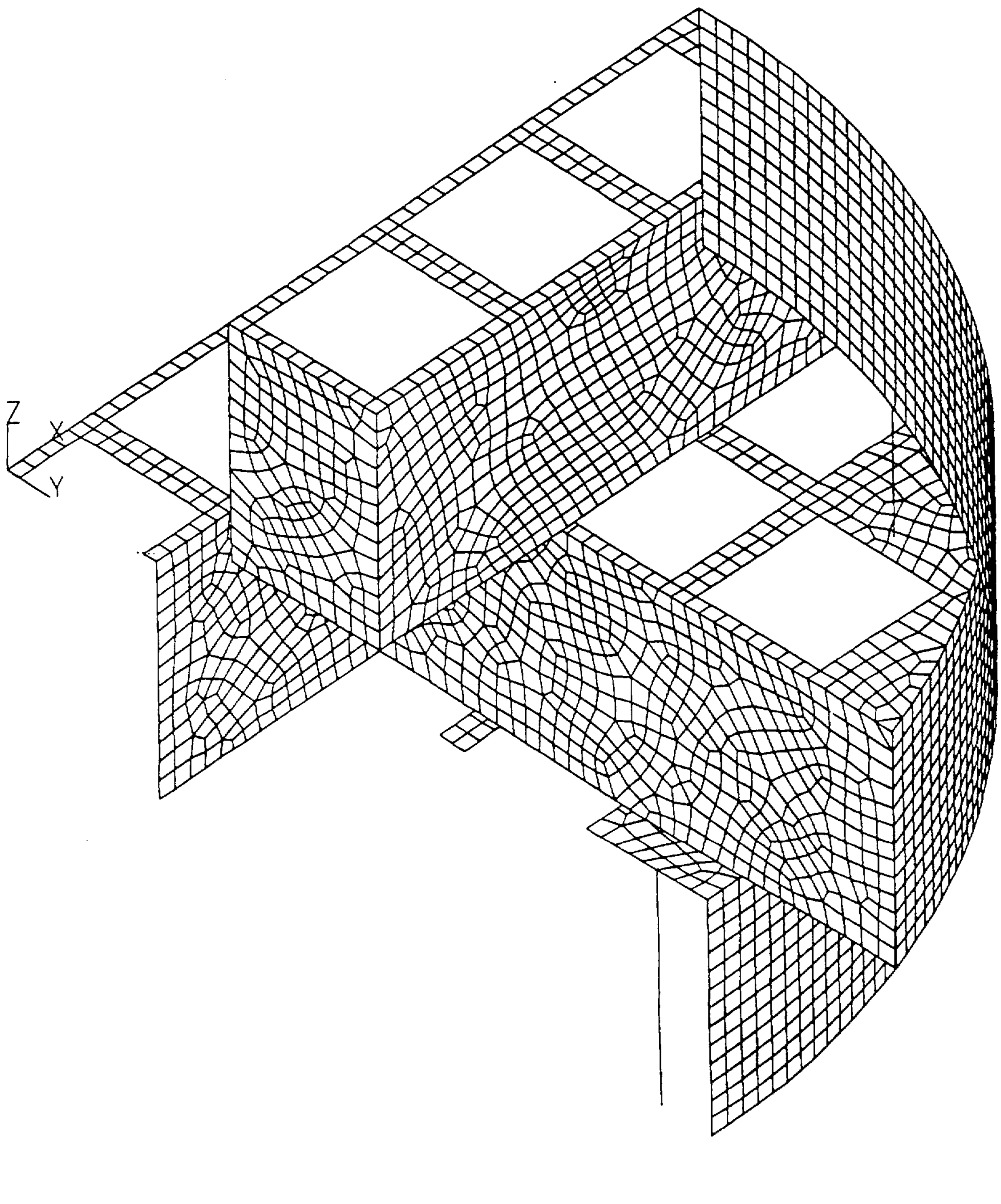


Figure 2.6.15.13-2 Finite Element Model of the Bottom Weldment Plate

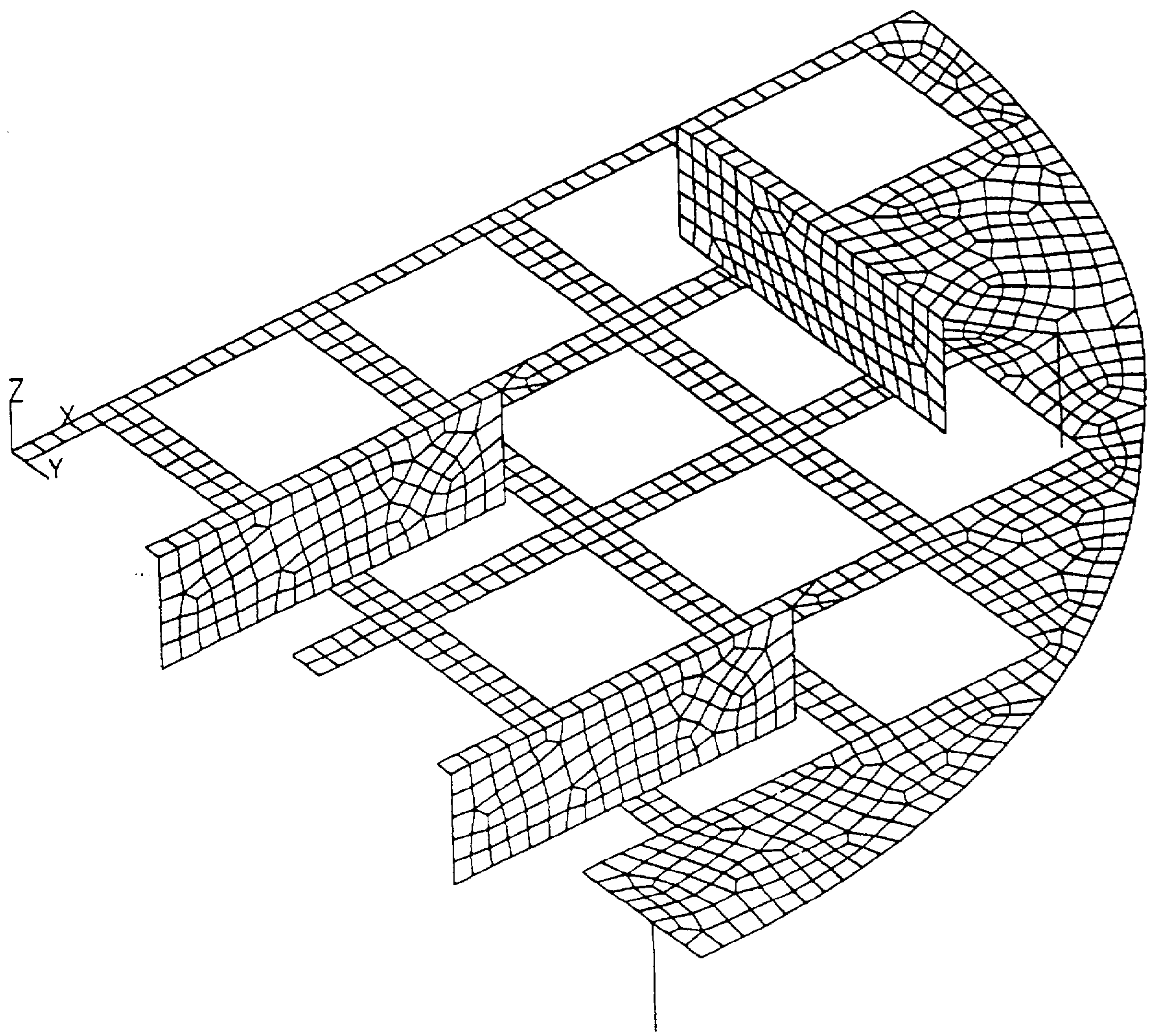


Table 2.6.15.13-1 Minimum Margins of Safety for the Top/Bottom Weldments for a 1-Foot End-Drop With and Without Thermal Stresses

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.

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

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

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

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

$P_e = 1.92 \text{ x } A \text{ x } F_e$

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

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

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

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

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

Load Conditions

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:

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

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

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:

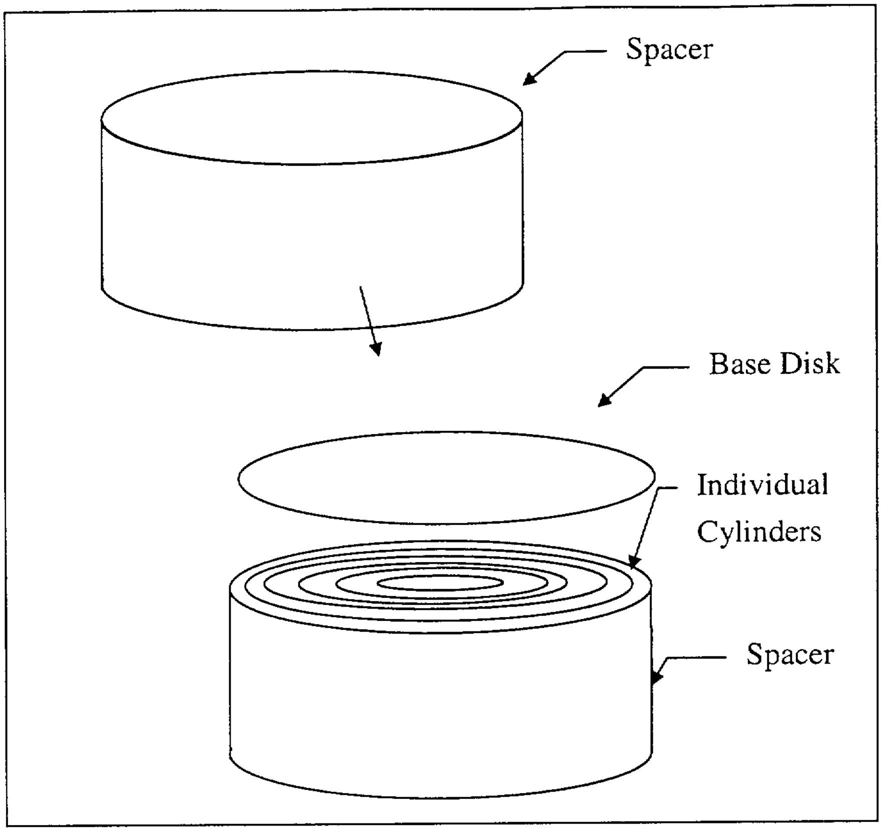
1. The spacers must meet the normal conditions of transport requirements detailed in 10 CFR 71.43(f) when subjected to the free drop (10 CFR 71.71).

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

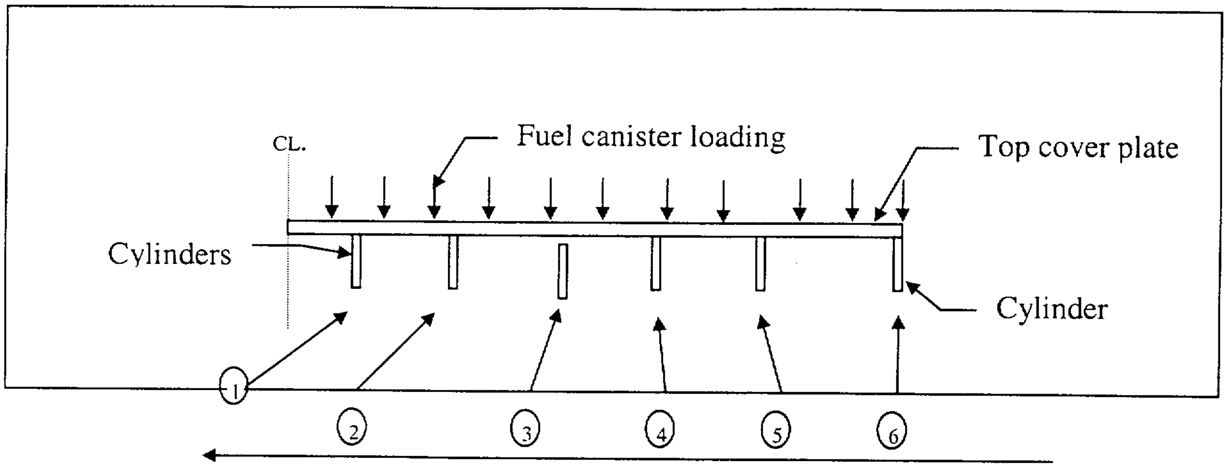
Each Transportable Storage Canister containing Class 1 or Class 2 PWR fuel is located by one spacer. Canisters containing Class 3 PWR fuel have no spacers. The PWR spacer is a weldment made of Type 304 stainless steel, ASTM A 240, 3/8-in. plate. The weldment consists of a base that is 67 in. in diameter 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:

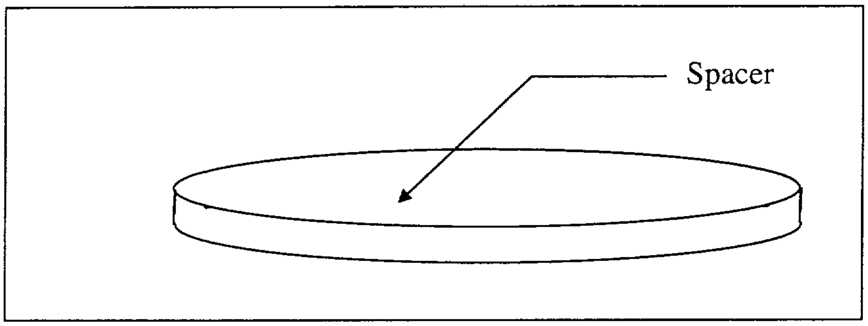
$$MS = \left(\frac{20{,}000\text{ psi}}{3{,}667\text{ psi}}\right) - 1 = +4.45$$

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 in^2. 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:

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