3.5.4.8 Impact Limiter Rib Study

A thermal analysis has been performed to evaluate the effect of including the rib properties (the ribs are located within the impact limiter). The analysis results presented in configuration 1 do not include any effects due to the ribs. The analysis presented here includes the ribs, by increasing the thickness of the impact limiter inside shell by an amount equal to the volume of the ribs.

This comparative study includes the following two configurations:

- **Configuration 1** – Impact limiter with no rib structure
- **Configuration 2** – Impact limiter inner liner shell thicknesses revised to include the total mass of all ribs

The Model AOS-025A, AOS-050A, AOS-100A, and AOS-100B transport packages are used in this study. Loadings for Normal conditions of transport use Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation. Loadings for Hypothetical Accident conditions of transport consider the 30-minute fire with a 7.5-hour cool-down transient, Load Cases 111 and 112, respectively.

The results show that for all models analyzed, under Normal conditions of transport using additional thickness in the impact limiter shell, the maximum component temperatures are consistently lower. Under Hypothetical Accident conditions of transport, the maximum component temperatures are also consistently lower, with a few exceptions. Conditions in which inclusion of ribs increased the temperature, experienced an increase of no more than 6°F. The results provided in condition 1 are compared with results defined by this analysis.

Table 3-120 lists the Configuration 1 and Configuration 2 thicknesses used in the analysis, by model, for the inside plate and cylindrical/conical rings.

Table 3-120. Configuration 1 and Configuration 2 Inside Plate and Cylindrical/ Conical Ring Thicknesses – All Models

Component	AOS-025A		AOS-050A		AOS-100A AOS-100B	
	Configuration 1 (.in)	Revised, Configuration 2 (.in)	Configuration 1 (.in)	Revised, Configuration 2 (.in)	Configuration 1 (.in)	Revised, Configuration 2 (.in)
Inside Plate	0.048	0.071	0.090	0.136	0.188	0.293
Cylindrical/ Conical Rings	0.027	0.044	0.050	0.081	0.105	0.172

3.5.4.8.1 Impact Limiter Rib Study Results – Model AOS-025A

This paragraph provides the study results for the Model AOS-025A transport package, with the inclusion of the impact limiter ribs. Under Normal and Hypothetical Accident conditions of transport, the maximum component temperatures are 3°F lower than what is reported in Configuration 1.

Normal conditions of transport – Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for Load Case 102 in Table 3-121.

Hypothetical Accident conditions of transport – Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for the 30-minute fire transient in Table 3-122. Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for the 7.5-hour cool-down transient in Table 3-123.

Table 3-121. Maximum Component Temperatures, Normal Conditions of Transport – Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Model AOS-025A

	Configuration 1			Configuration 2		
		Maximum Temperature			Maximum Temperature	
Component	Node	°C	°F	Node	°C	°F
Cask Outer Shell	662	1.2417E+02	2.5550E+02	684	1.2350E+02	2.5430E+02
Bottom Plate	3148	1.2367E+02	2.5460E+02	3145	1.2294E+02	2.5330E+02
Cask Lid	3233	1.2394E+02	2.5510E+02	3233	1.2328E+02	2.5390E+02
Cask Cavity Shell	4227	1.2506E+02	2.5710E+02	4227	1.2433E+02	2.5580E+02
Cask Lid Plug	5001	1.2556E+02	2.5800E+02	5001	1.2483E+02	2.5670E+02
Tungsten Alloy	6424	1.2433E+02	2.5580E+02	6376	1.2361E+02	2.5450E+02
Bottom Cavity	4227	1.2506E+02	2.5710E+02	4227	1.2433E+02	2.5580E+02
Side Cavity	4537	1.2472E+02	2.5650E+02	4467	1.2400E+02	2.5520E+02
Top Cavity	5001	1.2556E+02	2.5800E+02	5001	1.2483E+02	2.5670E+02
Cask Lid Seal Area	4995	1.2400E+02	2.5520E+02	4995	1.2333E+02	2.5400E+02
Cask Vent Port	2537	1.2394E+02	2.5510E+02	2537	1.2322E+02	2.5380E+02
Cask Drain Port	583	1.2372E+02	2.5470E+02	583	1.2306E+02	2.5350E+02
Test Port	3419	1.2394E+02	2.5510E+02	3419	1.2322E+02	2.5380E+02

Table 3-122. Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Model AOS-025A

Component	Configuration 1			Configuration 2		
	Node	Maximum Temperature		Node	Maximum Temperature	
		°C	°F		°C	°F
Cask Outer Shell	1712	1.4539E+02	2.9370E+02	1712	1.4378E+02	2.9080E+02
Bottom Plate	3120	1.3156E+02	2.6880E+02	3120	1.3078E+02	2.6740E+02
Cask Lid	3233	1.2828E+02	2.6290E+02	3233	1.2750E+02	2.6150E+02
Cask Cavity Shell	4417	1.3411E+02	2.7340E+02	4417	1.3333E+02	2.7200E+02
Cask Lid Plug	5011	1.3044E+02	2.6680E+02	5012	1.2967E+02	2.6540E+02
Tungsten Alloy	6696	1.3344E+02	2.7220E+02	6685	1.3267E+02	2.7080E+02
Bottom Cavity	4227	1.3333E+02	2.7200E+02	4227	1.3256E+02	2.7060E+02
Side Cavity	4417	1.3411E+02	2.7340E+02	4417	1.3333E+02	2.7200E+02
Top Cavity	5011	1.3044E+02	2.6680E+02	5012	1.2967E+02	2.6540E+02
Cask Lid Seal Area	4995	1.2817E+02	2.6270E+02	4995	1.2733E+02	2.6120E+02
Cask Vent Port	2537	1.2861E+02	2.6350E+02	2537	1.2783E+02	2.6210E+02
Cask Drain Port	583	1.3311E+02	2.7160E+02	583	1.3239E+02	2.7030E+02
Test Port	3419	1.2789E+02	2.6220E+02	3419	1.2711E+02	2.6080E+02

Table 3-123. Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 112, 7.5-Hour Cool-Down Transient, Model AOS-025A

Component	Configuration 1			Configuration 2		
	Node	Maximum Temperature		Node	Maximum Temperature	
		°C	°F		°C	°F
Cask Outer Shell	1712	1.3839E+02	2.8110E+02	1712	1.3717E+02	2.7890E+02
Bottom Plate	3001	1.3711E+02	2.7880E+02	3001	1.3694E+02	2.7850E+02
Cask Lid	3233	1.3439E+02	2.7390E+02	3233	1.3444E+02	2.7400E+02
Cask Cavity Shell	4227	1.3583E+02	2.7650E+02	4227	1.3578E+02	2.7640E+02
Cask Lid Plug	5001	1.3594E+02	2.7670E+02	5001	1.3600E+02	2.7680E+02
Tungsten Alloy	6001	1.3533E+02	2.7560E+02	6001	1.3528E+02	2.7550E+02
Bottom Cavity	4227	1.3583E+02	2.7650E+02	4227	1.3578E+02	2.7640E+02
Side Cavity	4372	1.3522E+02	2.7540E+02	4372	1.3522E+02	2.7540E+02
Top Cavity	5001	1.3594E+02	2.7670E+02	5001	1.3600E+02	2.7680E+02
Cask Lid Seal Area	4995	1.3444E+02	2.7400E+02	4995	1.3450E+02	2.7410E+02
Cask Vent Port	2537	1.3433E+02	2.7380E+02	2537	1.3439E+02	2.7390E+02
Cask Drain Port	583	1.3544E+02	2.7580E+02	583	1.3522E+02	2.7540E+02
Test Port	3419	1.3433E+02	2.7380E+02	3419	1.3439E+02	2.7390E+02

3.5.4.8.2 Impact Limiter Rib Study Results – Model AOS-050A

This paragraph provides the study results for the Model AOS-050A transport package, with the inclusion of the impact limiter ribs.

Normal conditions of transport – The maximum component temperatures were 7°F lower than what is reported in Configuration 1. Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for Load Case 102 in Table 3-124.

Hypothetical Accident conditions of transport – Configuration 2 maximum component temperatures are higher than or equal to the Configuration 1 values during the 7.5-hour cool-down period. At the region exposed to the environment, the cask outer shell temperature is 6°F higher. Other maximum component temperature differences are 3°F higher than the values presented for Configuration 1. Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for the 30-minute fire transient in Table 3-125. Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for the 7.5-hour cool-down transient in Table 3-126.

Table 3-124. Maximum Component Temperatures, Normal Conditions of Transport – Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Model AOS-050A

Component	Configuration 1			Configuration 2		
	Node	Maximum Temperature		Node	Maximum Temperature	
		°C	°F		°C	°F
Cask Outer Shell	606	1.4161E+02	2.8690E+02	606	1.3794E+02	2.8030E+02
Bottom Plate	3120	1.4128E+02	2.8630E+02	3002	1.3756E+02	2.7960E+02
Cask Lid	3233	1.4111E+02	2.8600E+02	3233	1.3728E+02	2.7910E+02
Cask Cavity Shell	4227	1.4650E+02	2.9570E+02	4227	1.4283E+02	2.8910E+02
Cask Lid Plug	5001	1.4800E+02	2.9840E+02	5001	1.4428E+02	2.9170E+02
Tungsten Alloy	6247	1.4244E+02	2.8840E+02	6247	1.3878E+02	2.8180E+02
Bottom Cavity	4227	1.4650E+02	2.9570E+02	4227	1.4283E+02	2.8910E+02
Side Cavity	4372	1.4439E+02	2.9190E+02	4372	1.4072E+02	2.8530E+02
Top Cavity	5001	1.4800E+02	2.9840E+02	5001	1.4428E+02	2.9170E+02
Cask Lid Seal Area	4995	1.4094E+02	2.8570E+02	4995	1.3711E+02	2.7880E+02
Cask Vent Port	2537	1.4022E+02	2.8440E+02	2537	1.3633E+02	2.7740E+02
Cask Drain Port	583	1.4089E+02	2.8560E+02	583	1.3717E+02	2.7890E+02
Test Port	3419	1.4089E+02	2.8560E+02	3419	1.3700E+02	2.7860E+02

Table 3-125. Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Model AOS-050A

Component	Configuration 1			Configuration 2		
	Node	Maximum Temperature		Node	Maximum Temperature	
		°C	°F		°C	°F
Cask Outer Shell	1888	4.1394E+02	7.7710E+02	1888	4.1683E+02	7.8230E+02
Bottom Plate	3120	1.7489E+02	3.4680E+02	3120	1.7256E+02	3.4260E+02
Cask Lid	3233	1.6972E+02	3.3750E+02	3233	1.6700E+02	3.3260E+02
Cask Cavity Shell	4536	2.4056E+02	4.6500E+02	4536	2.4100E+02	4.6580E+02
Cask Lid Plug	5012	1.9583E+02	3.8450E+02	5012	1.9450E+02	3.8210E+02
Tungsten Alloy	6949	2.5039E+02	4.8270E+02	6949	2.5111E+02	4.8400E+02
Bottom Cavity	4236	2.0144E+02	3.9460E+02	4236	2.0044E+02	3.9280E+02
Side Cavity	4532	2.4033E+02	4.6460E+02	4532	2.4072E+02	4.6530E+02
Top Cavity	5012	1.9583E+02	3.8450E+02	5012	1.9450E+02	3.8210E+02
Cask Lid Seal Area	4995	1.6933E+02	3.3680E+02	4995	1.6678E+02	3.3220E+02
Cask Vent Port	2537	1.9650E+02	3.8570E+02	2537	1.9617E+02	3.8510E+02
Cask Drain Port	583	1.9539E+02	3.8370E+02	583	1.9506E+02	3.8310E+02
Test Port	3419	1.6528E+02	3.2950E+02	3419	1.6233E+02	3.2420E+02

Table 3-126. Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 112, 7.5-Hour Cool-Down Transient, Model AOS-050A

Component	Configuration 1			Configuration 2		
	Node	Maximum Temperature		Node	Maximum Temperature	
		°C	°F		°C	°F
Cask Outer Shell	1887	3.7294E+02	7.0330E+02	1887	3.7606E+02	7.0890E+02
Bottom Plate	3001	2.2383E+02	4.3490E+02	3001	2.2406E+02	4.3530E+02
Cask Lid	3329	2.2289E+02	4.3320E+02	3248	2.2289E+02	4.3320E+02
Cask Cavity Shell	4532	2.5939E+02	4.9890E+02	4532	2.6083E+02	5.0150E+02
Cask Lid Plug	5001	2.2972E+02	4.4550E+02	5001	2.2989E+02	4.4580E+02
Tungsten Alloy	6938	2.6200E+02	5.0360E+02	6938	2.6350E+02	5.0630E+02
Bottom Cavity	4236	2.3072E+02	4.4730E+02	4236	2.3128E+02	4.4830E+02
Side Cavity	4532	2.5939E+02	4.9890E+02	4532	2.6083E+02	5.0150E+02
Top Cavity	5001	2.2972E+02	4.4550E+02	5001	2.2989E+02	4.4580E+02
Cask Lid Seal Area	4995	2.2344E+02	4.3420E+02	4995	2.2350E+02	4.3430E+02
Cask Vent Port	2537	2.2494E+02	4.3690E+02	2537	2.2528E+02	4.3750E+02
Cask Drain Port	583	2.2689E+02	4.4040E+02	583	2.2722E+02	4.4100E+02
Test Port	3419	2.2272E+02	4.3290E+02	3419	2.2272E+02	4.3290E+02

3.5.4.8.3 Impact Limiter Rib Study Results – Model AOS-100A

This paragraph provides the study results for the Model AOS-100A transport package, with the inclusion of the impact limiter ribs. In this study, the Model AOS-100A is in a horizontal position. Under Normal and Hypothetical Accident conditions of transport, Configuration 2 maximum component temperatures are 5°F lower than what is reported for Configuration 1. The exception is at the cask vent port and cask drain port, where the maximum temperatures are 2°F higher with the inclusion of the ribs.

Normal conditions of transport – Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for Load Case 102 in Table 3-127.

Hypothetical Accident conditions of transport – Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for the 30-minute fire transient in Table 3-128. Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for the 7.5-hour cool-down transient in Table 3-129.

Table 3-127. Maximum Component Temperatures, Normal Conditions of Transport – Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Model AOS-100A

	Configuration 1			Configuration 2		
		Maximum Temperature			Maximum Temperature	
Component	Node	°C	°F	Node	°C	°F
Cask Outer Shell	648	1.3744E+02	2.7940E+02	654	1.3489E+02	2.7480E+02
Bottom Plate	3103	1.3650E+02	2.7770E+02	3103	1.3361E+02	2.7250E+02
Cask Lid	3233	1.3711E+02	2.7880E+02	3233	1.3422E+02	2.7360E+02
Cask Cavity Shell	4227	1.4678E+02	2.9620E+02	4227	1.4411E+02	2.9140E+02
Cask Lid Plug	5001	1.5017E+02	3.0230E+02	5001	1.4750E+02	2.9750E+02
Tungsten Alloy	7552	1.3911E+02	2.8240E+02	6384	1.3644E+02	2.7760E+02
Bottom Cavity	4227	1.4678E+02	2.9620E+02	4227	1.4411E+02	2.9140E+02
Side Cavity	4372	1.4283E+02	2.8910E+02	4372	1.4017E+02	2.8430E+02
Top Cavity	5001	1.5017E+02	3.0230E+02	5001	1.4750E+02	2.9750E+02
Cask Lid Seal Area	4995	1.3667E+02	2.7800E+02	4995	1.3383E+02	2.7290E+02
Cask Vent Port	2537	1.3494E+02	2.7490E+02	2537	1.3206E+02	2.6970E+02
Cask Drain Port	583	1.3494E+02	2.7490E+02	583	1.3206E+02	2.6970E+02
Test Port	3419	1.3656E+02	2.7780E+02	3419	1.3367E+02	2.7260E+02

Table 3-128. Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Model AOS-100A

Component	Configuration 1			Configuration 2		
	Node	Maximum Temperature		Node	Maximum Temperature	
		°C	°F		°C	°F
Cask Outer Shell	1888	4.5794E+02	8.5630E+02	1888	4.5656E+02	8.5380E+02
Bottom Plate	3120	1.3972E+02	2.8350E+02	3120	1.3694E+02	2.7850E+02
Cask Lid	3233	1.3889E+02	2.8200E+02	3233	1.3606E+02	2.7690E+02
Cask Cavity Shell	4531	1.7017E+02	3.3830E+02	4531	1.6772E+02	3.3390E+02
Cask Lid Plug	5012	1.5039E+02	3.0270E+02	5012	1.4778E+02	2.9800E+02
Tungsten Alloy	6949	1.8244E+02	3.6040E+02	6938	1.8000E+02	3.5600E+02
Bottom Cavity	4236	1.5161E+02	3.0490E+02	4236	1.4906E+02	3.0030E+02
Side Cavity	4527	1.6944E+02	3.3700E+02	4527	1.6700E+02	3.3260E+02
Top Cavity	5012	1.5039E+02	3.0270E+02	5012	1.4778E+02	2.9800E+02
Cask Lid Seal Area	4995	1.3850E+02	2.8130E+02	4995	1.3572E+02	2.7630E+02
Cask Vent Port	2537	1.8711E+02	3.6880E+02	2537	1.8811E+02	3.7060E+02
Cask Drain Port	583	1.8389E+02	3.6300E+02	583	1.8467E+02	3.6440E+02
Test Port	3419	1.3733E+02	2.7920E+02	3419	1.3450E+02	2.7410E+02

Table 3-129. Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 112, 7.5-Hour Cool-Down Transient, Model AOS-100A

Component	Configuration 1			Configuration 2		
	Node	Maximum Temperature		Node	Maximum Temperature	
		°C	°F		°C	°F
Cask Outer Shell	1888	4.2156E+02	7.9080E+02	1888	4.2011E+02	7.8820E+02
Bottom Plate	3120	1.9622E+02	3.8520E+02	3103	1.9417E+02	3.8150E+02
Cask Lid	3233	1.9756E+02	3.8760E+02	3233	1.9561E+02	3.8410E+02
Cask Cavity Shell	4532	2.3867E+02	4.6160E+02	4532	2.3756E+02	4.5960E+02
Cask Lid Plug	5001	2.1067E+02	4.1120E+02	5001	2.0906E+02	4.0830E+02
Tungsten Alloy	6949	2.3817E+02	4.6070E+02	6938	2.3694E+02	4.5850E+02
Bottom Cavity	4236	2.0928E+02	4.0870E+02	4236	2.0806E+02	4.0650E+02
Side Cavity	4532	2.3867E+02	4.6160E+02	4532	2.3756E+02	4.5960E+02
Top Cavity	5001	2.1067E+02	4.1120E+02	5001	2.0906E+02	4.0830E+02
Cask Lid Seal Area	4995	1.9811E+02	3.8860E+02	4995	1.9628E+02	3.8530E+02
Cask Vent Port	2537	1.9989E+02	3.9180E+02	2537	1.9894E+02	3.9010E+02
Cask Drain Port	583	2.0100E+02	3.9380E+02	583	1.9944E+02	3.9100E+02
Test Port	3419	1.9717E+02	3.8690E+02	3419	1.9517E+02	3.8330E+02

3.5.4.8.4 Impact Limiter Rib Study Results – Model AOS-100B

This paragraph provides the study results for the Model AOS-100B transport package, with the inclusion of the impact limiter ribs. In this study, the Model AOS-100B is in a horizontal position. Under Normal and Hypothetical Accident conditions of transport, Configuration 2 maximum component temperatures are 5°F lower than what is reported for Configuration 1. The exception is at the cask vent port and cask drain port, where the maximum temperatures are 2°F higher with the inclusion of the ribs.

Normal conditions of transport – Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for Load Case 102 in Table 3-130.

Hypothetical Accident conditions of transport – Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for the 30-minute fire transient in Table 3-131. Comparative results between Configuration 1 and Configuration 2 maximum component temperatures are provided for the 7.5-hour cool-down transient in Table 3-132.

Table 3-130. Maximum Component Temperatures, Normal Conditions of Transport – Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Model AOS-100B

	Configuration 1			Configuration 2		
		Maximum Temperature			Maximum Temperature	
Component	Node	°C	°F	Node	°C	°F
Cask Outer Shell	644	1.3744E+02	2.7940E+02	650	1.3489E+02	2.7480E+02
Bottom Plate	3120	1.3656E+02	2.7780E+02	3120	1.3367E+02	2.7260E+02
Cask Lid	3233	1.3711E+02	2.7880E+02	3233	1.3422E+02	2.7360E+02
Cask Cavity Shell	4227	1.4694E+02	2.9650E+02	4227	1.4428E+02	2.9170E+02
Cask Lid Plug	5001	1.5033E+02	3.0260E+02	5001	1.4761E+02	2.9770E+02
Carbon Steel	6384	1.3939E+02	2.8290E+02	6408	1.3683E+02	2.7830E+02
Bottom Cavity	4227	1.4694E+02	2.9650E+02	4227	1.4428E+02	2.9170E+02
Side Cavity	4372	1.4306E+02	2.8950E+02	4472	1.4050E+02	2.8490E+02
Top Cavity	5001	1.5033E+02	3.0260E+02	5001	1.4761E+02	2.9770E+02
Cask Lid Seal Area	4995	1.3667E+02	2.7800E+02	4995	1.3383E+02	2.7290E+02
Cask Vent Port	2537	1.3494E+02	2.7490E+02	2537	1.3206E+02	2.6970E+02
Cask Drain Port	583	1.3494E+02	2.7490E+02	583	1.3206E+02	2.6970E+02
Test Port	3419	1.3656E+02	2.7780E+02	3419	1.3367E+02	2.7260E+02

Table 3-131. Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Model AOS-100B

Component	Configuration 1			Configuration 2		
		Maximum Temperature			Maximum Temperature	
	Node	°C	°F	Node	°C	°F
Cask Outer Shell	1888	4.5789E+02	8.5620E+02	1888	4.5650E+02	8.5370E+02
Bottom Plate	3120	1.3872E+02	2.8170E+02	3120	1.3594E+02	2.7670E+02
Cask Lid	3360	1.3850E+02	2.8130E+02	3360	1.3572E+02	2.7630E+02
Cask Cavity Shell	4536	1.6428E+02	3.2770E+02	4531	1.6178E+02	3.2320E+02
Cask Lid Plug	5001	1.4983E+02	3.0170E+02	5001	1.4717E+02	2.9690E+02
Carbon Steel	6949	1.8072E+02	3.5730E+02	6949	1.7828E+02	3.5290E+02
Bottom Cavity	4236	1.4844E+02	2.9920E+02	4236	1.4589E+02	2.9460E+02
Side Cavity	4527	1.6383E+02	3.2690E+02	4527	1.6139E+02	3.2250E+02
Top Cavity	5001	1.4983E+02	3.0170E+02	5001	1.4717E+02	2.9690E+02
Cask Lid Seal Area	4995	1.3833E+02	2.8100E+02	4995	1.3556E+02	2.7600E+02
Cask Vent Port	2537	1.8706E+02	3.6870E+02	2537	1.8806E+02	3.7050E+02
Cask Drain Port	583	1.8389E+02	3.6300E+02	583	1.8461E+02	3.6430E+02
Test Port	3419	1.3722E+02	2.7900E+02	3419	1.3439E+02	2.7390E+02

Table 3-132. Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 112, 7.5-Hour Cool-Down Transient, Model AOS-100B

Component	Configuration 1			Configuration 2		
		Maximum Temperature			Maximum Temperature	
	Node	°C	°F	Node	°C	°F
Cask Outer Shell	1888	4.2150E+02	7.9070E+02	1877	4.2006E+02	7.8810E+02
Bottom Plate	3120	1.9367E+02	3.8060E+02	3120	1.9161E+02	3.7690E+02
Cask Lid	3233	1.9472E+02	3.8250E+02	3233	1.9272E+02	3.7890E+02
Cask Cavity Shell	4527	2.3367E+02	4.5260E+02	4532	2.3250E+02	4.5050E+02
Cask Lid Plug	5001	2.0794E+02	4.0630E+02	5001	2.0628E+02	4.0330E+02
Carbon Steel	6949	2.3383E+02	4.5290E+02	6949	2.3256E+02	4.5060E+02
Bottom Cavity	4227	2.0628E+02	4.0330E+02	4227	2.0483E+02	4.0070E+02
Side Cavity	4527	2.3367E+02	4.5260E+02	4532	2.3250E+02	4.5050E+02
Top Cavity	5001	2.0794E+02	4.0630E+02	5001	2.0628E+02	4.0330E+02
Cask Lid Seal Area	4995	1.9533E+02	3.8360E+02	4995	1.9344E+02	3.8020E+02
Cask Vent Port	2537	1.9794E+02	3.8830E+02	2537	1.9861E+02	3.8950E+02
Cask Drain Port	583	1.9811E+02	3.8860E+02	583	1.9656E+02	3.8580E+02
Test Port	3419	1.9439E+02	3.8190E+02	3419	1.9239E+02	3.7830E+02

3.5.4.9 Sensitivity Study – Foam Properties

3.5.4.9.1 Density

An analysis has been performed to determine the effect of varying the foam density property. The analysis consisted of an initial steady state, followed with a 30-minute fire environment at 1,475°F solution. Three (3) solutions were made, with different foam density values:

- Nominal
- 115% of the nominal
- 85% of the nominal

Table 3-133 lists the results for these three (3) foam density values. The Model AOS-100A transport package was used for this analysis, with a geometry containing the deformation due to a 30-ft. Head-On Drop. In this study, the Model AOS-100A cask is in a horizontal position.

Table 3-133. Foam Density Properties – Nominal, 115% Nominal, and 85% Nominal, Model AOS-100A

Solution	Description	Impact Limiter	Density		Conductivity	
			pcf	pci	Btu/hr-ft^2-°F/in	Btu/hr-in-°F
1	Nominal	Lower	12	0.00694	0.241	0.00167
		Upper	14.6	0.00845	0.277	0.00192
2	115% Nominal	Lower	13.8	0.00799	0.266	0.00185
		Upper	16.79	0.00972	0.307	0.00213
3	85% Nominal	Lower	10.2	0.00590	0.216	0.00150
		Upper	12.41	0.00718	0.246	0.00171

Results show maximum cask component temperatures are all within 1°F of nominal density results. The maximum component temperatures within the impact limiter are lower by 1°F when the higher density value (115% nominal) is used. In contrast, the maximum component temperatures within the impact limiter are higher by 1°F when the lower density value (85% nominal) is used. Comparative results between the three (3) solutions are provided in Table 3-134.

Table 3-134. Comparison of Maximum Component Temperatures with Varying Foam Densities – Model AOS-100A

Component	Node	Nominal Maximum Temperature (°F)	Node	115% Nominal Maximum Temperature (°F)	Node	85% Nominal Maximum Temperature (°F)
Cask Outer Shell	1888	8.5630E+02	1888	8.5600E+02	1877	8.5650E+02
Bottom Plate	3120	2.8350E+02	3120	2.8300E+02	3120	2.8390E+02
Cask Lid	3233	2.8200E+02	3233	2.8140E+02	3233	2.8250E+02
Cask Cavity Shell	4531	3.3830E+02	4536	3.3790E+02	4536	3.3880E+02
Cask Lid Plug	5012	3.0270E+02	5012	3.0220E+02	5012	3.0320E+02
Tungsten Alloy	6949	3.6040E+02	6938	3.5990E+02	6938	3.6080E+02
Bottom Cavity	4236	3.0490E+02	4236	3.0440E+02	4236	3.0540E+02
Side Cavity	4527	3.3700E+02	4527	3.3660E+02	4532	3.3750E+02
Top Cavity	5012	3.0270E+02	5012	3.0220E+02	5012	3.0320E+02
Cask Lid Seal Area	4995	2.8130E+02	4995	2.8080E+02	4995	2.8190E+02
Cask Vent Port	2537	3.6880E+02	2537	3.6810E+02	2537	3.6950E+02
Cask Drain Port	583	3.6300E+02	583	3.6230E+02	583	3.6370E+02
Test Port	3419	2.7920E+02	3419	2.7870E+02	3419	2.7980E+02
Impact Limiter, Foam	8673	1.4720E+03	8673	1.4710E+03	8673	1.4720E+03

3.5.4.9.2 Specific Heat

An analysis has been performed to determine the effect of varying the specific heat property of the foam material. The analysis consisted of an initial steady state, followed with a 30-minute fire environment at 1,475°F solution. Three (3) solutions were made, with different foam specific heat values:

- Nominal
- 120% of the nominal
- 80% of the nominal

Table 3-135 lists the results for these three (3) foam specific heat values. The Model AOS-100A transport package was used for this analysis, with a geometry containing the deformation due to a 30-ft. Head-On Drop.

Table 3-135. Nominal, 115% Nominal, and 80% Nominal Foam Specific Heat Properties – Model AOS-100A

Solution	Description	Specific Heat Btu/lb-°F
1	Nominal, Cp	0.00167
2	120% Nominal, Cp	0.00185
3	80% Nominal, Cp	0.00150

Results show that the maximum cask component temperatures are all within 1°F of nominal results. The maximum component temperatures are slightly lower when a higher specific heat value is used. In contrast, the maximum component temperatures are slightly higher when a lower specific heat value is used. Comparative results between the three (3) solutions are provided in Table 3-136.

Table 3-136. Comparison of Maximum Component Temperatures with Varying Specific Heat Values – Model AOS-100A

Component	Node	Nominal Maximum Temperature (°F)	Node	120% Nominal Maximum Temperature (°F)	Node	80% Nominal Maximum Temperature (°F)
Cask Outer Shell	1888	8.5630E+02	1877	8.5620E+02	1888	8.5630E+02
Bottom Plate	3120	2.8350E+02	3120	2.8350E+02	3120	2.8350E+02
Cask Lid	3233	2.8200E+02	3233	2.8190E+02	3233	2.8200E+02
Cask Cavity Shell	4531	3.3830E+02	4531	3.3830E+02	4531	3.3830E+02
Cask Lid Plug	5012	3.0270E+02	5012	3.0260E+02	5012	3.0270E+02
Tungsten Alloy	6949	3.6040E+02	6949	3.6040E+02	6938	3.6040E+02
Bottom Cavity	4236	3.0490E+02	4236	3.0490E+02	4236	3.0490E+02
Side Cavity	4527	3.3700E+02	4527	3.3700E+02	4532	3.3710E+02
Top Cavity	5012	3.0270E+02	5012	3.0260E+02	5012	3.0270E+02
Cask Lid Seal Area	4995	2.8130E+02	4995	2.8130E+02	4995	2.8140E+02
Cask Vent Port	2537	3.6880E+02	2537	3.6860E+02	2537	3.6910E+02
Cask Drain Port	583	3.6300E+02	583	3.6280E+02	583	3.6320E+02
Test Port	3419	2.7920E+02	3419	2.7920E+02	3419	2.7920E+02
Impact Limiter, Foam	8673	1.4720E+03	8673	1.4710E+03	8673	1.4720E+03

3.5.5 LIBRA File Input Showing Material Property Assignation

```
TI Load Case_111 - 100F Ambient, Max Decay Heat, max Insolation
*
mc 12 31 32 33 34
cnd  1      0.0,     0.0,      0.0
cnd  2      8.1185, 0.0,      0.0
cnd  3      13.688, 0.0,      0.0
cnd  103    13.70,  0.0,      0.0
cnd  4      18.10,  0.0,      0.0
cnd  104    18.10,  0.0,      0.0
cnd  5      19.88,  0.0,      0.0
cnd  6      0.0,    3.22,     0.0
cnd  106    0.0,    3.226,    0.0
cnd  7      4.6058, 3.226,    0.0
cnd  8      6.6528, 3.226,    0.0
cnd  9      8.188,  3.226,    0.0
cnd  109    8.25,   3.22,     0.0
cnd  1009   8.25,   3.226,    0.0
cnd  10     13.688, 3.22,     0.0
cnd  110    13.688, 3.226,    0.0
cnd  1010   13.70,  3.22,     0.0
cnd  11     18.10,  3.22,     0.0
cnd  111    18.10,  3.22,     0.0
cnd  12     19.6,   3.22,     0.0
cnd  13     23.1,   3.22,     0.0
cnd  14     0.0,    10.446,   0.0
cnd  114    0.0,    10.456,   0.0
cnd  15     5.36,   10.446,   0.0
cnd  115    5.36,   10.456,   0.0
cnd  16     6.725,   10.446,  0.0
cnd  116    6.725,   10.456,  0.0
cnd  17     8.188,  10.446,   0.0
cnd  117    8.25,   10.456,   0.0
cnd  18     13.1936,9.661,    0.0
cnd  19     13.688, 9.5815,   0.0
cnd  20     5.36,   12.024,   0.0
cnd  21     6.725,   11.70,   0.0
cnd  121    6.730,   11.763, 0.0
cnd  22     8.25,   11.70,    0.0
cnd  122    8.25,   11.763,   0.0
cnd  23     13.20,  11.70,    0.0
cnd  123    13.075, 11.763,   0.0
cnd  1023   13.20,  11.71,    0.0
cnd  24     13.688, 11.70,    0.0
cnd  124    13.70,  11.71,    0.0
cnd  25     18.10,  11.71,    0.0
cnd  125    18.10,  11.71,    0.0
cnd  26     23.10,  11.71,    0.0
cnd  27     0.0,    13.20,    0.0
cnd  28     5.36,   13.20,    0.0
cnd  29     6.725,   13.20,   0.0
cnd  129    6.730,   13.20,  0.0
```

```
cnd  30    8.25,    13.20,   0.0
cnd  31    13.075, 13.2262, 0.0
cnd  51    0.0,     46.20,   0.0
cnd  52    5.344,   46.20,   0.0
cnd  152   5.36,    46.20,   0.0
cnd  53    6.725,    46.20,   0.0
cnd  153   6.730,    46.20,  0.0
cnd  54    8.25,    46.20,   0.0
cnd  55    10.18, 46.20,   0.0
cnd  56    13.075,   46.20, 0.0
cnd  57    0.0,     47.70,   0.0
cnd  58    5.344,   47.70,   0.0
cnd  158   5.36,    47.70,   0.0
cnd  59    6.725,    47.70,   0.0
cnd  159   6.730,    47.637, 0.0
cnd  60    8.25,    47.637,  0.0
cnd  160   8.25,    47.70,   0.0
cnd  61    9.125,   47.637,  0.0
cnd  161   9.125,   47.70,   0.0
cnd  62    13.075, 47.637,  0.0
cnd  162   13.20,   47.69,   0.0
cnd  1062  13.20,   47.70,   0.0
cnd  63    13.688, 47.70,   0.0
cnd  163   13.70,   47.69,   0.0
cnd  64    18.10,   47.69,   0.0
cnd  164   18.10,   47.69,   0.0
cnd  65    23.10,   47.69,   0.0
cnd  66    0.0,     48.327,  0.0
cnd  67    5.344,   48.327,  0.0
cnd  167   5.36,    48.317,  0.0
cnd  68    6.725,    48.317,  0.0
cnd  168   6.725,    48.327,  0.0
cnd  69    8.25,    48.317,  0.0
cnd  169   8.25,    48.327,  0.0
cnd  70    9.125,   48.317,  0.0
cnd  170   9.075,   48.327,  0.0
cnd  71    13.0361,49.16566,0.0
cnd  72    13.688, 49.3071, 0.0
cnd  73    0.0,     48.944,  0.0
cnd  173   0.0,     48.954,  0.0
cnd  74    5.344,   48.944,  0.0
cnd  174   5.344,   48.954,  0.0
cnd  75    6.96914, 48.944, 0.0
cnd  76    8.188,   48.954,  0.0
cnd  176   8.25,    48.944,  0.0
cnd  78    9.075,   48.944,  0.0
cnd  178   9.125,   48.944,  0.0
cnd  79    13.688, 50.9243, 0.0
cnd  80    0.0,     56.174,  0.0
cnd  180   0.0,     56.18,   0.0
cnd  81    5.0417, 56.174,  0.0
cnd  82    8.188,   56.174,  0.0
cnd  182   8.25,    56.18,   0.0
cnd  83    9.075,   56.18,   0.0
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cnd  183    9.125,  56.174,  0.0
cnd  1083   9.125,  56.18,   0.0
cnd  84     13.688, 56.174,  0.0
cnd  184    13.688, 56.18,   0.0
cnd  1084   13.70,  56.18,   0.0
cnd  85     18.10,  56.18,   0.0
cnd  185    18.10,  56.18,   0.0
cnd  86     19.60,  56.18,   0.0
cnd  87     23.1,   56.18,   0.0
cnd  88     0.0,    56.862,  0.0
cnd  188    0.0,    56.893,  0.0
cnd  89     8.25,   56.862,  0.0
cnd  189    8.25,   56.893,  0.0
cnd  90     9.075,  56.862,  0.0
cnd  190    9.125,  56.893,  0.0
cnd  92     13.688, 57.5657, 0.0
cnd  93     0.0,    59.40,   0.0
cnd  94     8.496,  59.40,   0.0
cnd  95     10.384, 59.40,   0.0
cnd  96     13.688, 59.40,   0.0
cnd  196    13.70,  59.40,   0.0
cnd  97     18.10,  59.40,   0.0
cnd  197    18.10,  59.40,   0.0
cnd  98     19.88,  59.40,   0.0
cnd  401    5.36,   42.2,    0.0
cnd  402    6.725,   42.2,    0.0
cnd  403    5.36,   43.2,    0.0
cnd  404    6.725,    43.2,    0.0
* impact limiter
cnd 201      0.0,     -.02,      0.0
cnd 202      0.0,     -14.19,    0.0
cnd 203      13.70,   -.02,      0.0
cnd 204     13.35,    -14.19,    0.0
cnd 205     13.35,    -22.39,    0.0
cnd 2050    14.101,   -22.251,   0.0
cnd 206      18.10,   -.02,      0.0
cnd 207     20.0442,  -7.4535,   0.0
cnd 2080    21.856,   -20.333,   0.0
cnd 209      19.92,   -.02,      0.0
cnd 210     22.2703,  -5.2050,   0.0
cnd 211     28.66,    -17.896,   0.0
cnd 2110    31.125,   -16.825,   0.0
cnd 212     26.1625,  -3.0625,   0.0
cnd 213     33.198,    -15.66,    0.0
cnd 214     23.3,      3.18,     0.0
cnd 215     30.,     .8180,    0.0
cnd 216     33.198,    -.38,      0.0
cnd 217     23.3,      11.71,    0.0
cnd 218     30.,    11.71,    0.0
cnd 219     33.198,     11.71,    0.0
cnd 220     23.3,      16.71,    0.0
cnd 221     30.,    16.71,    0.0
cnd 222     33.198,     16.71,    0.0
cnd 223     23.3,      42.69,    0.0
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cnd 224     31.6,    42.69,    0.0
cnd 225     33.198,     42.69,    0.0
cnd 226     23.3,      47.69,    0.0
cnd 227     31.6,    47.69,    0.0
cnd 228     33.198,     47.69,    0.0
cnd 229     23.3,      56.22,    0.0
cnd 230     31.6,      64., 0.0
cnd 231     33.198,     65.14,    0.0
cnd 234     19.92,     59.42,    0.0
cnd 237     18.10,     59.42,    0.0
cnd 240     13.70,     59.42,    0.0
cnd 241     16.35,     72.06,    0.0
cnd 243     0.0,       59.42,    0.0
cnd 244     0.0,       72.06,    0.0
cnd 301     0.0,   -12.7,     0.0
cnd 302     13.35, -12.7,    0.0
cnd 303     14.85, -12.7,    0.0
cnd 304     14.85, -14.19,   0.0
cnd 305     13.35, -20.9,    0.0
cnd 306     14.85, -20.9,    0.0
cnd 307     14.85, -22.103,   0.0
cnd 308     27.9,  -16.3,    0.0
cnd 309     31.9,  -14,    0.0
cnd 310     31.9,  0.2,      0.0
cnd 311     31.9,  11.71,    0.0
cnd 312     23.3,  15.21,    0.0
cnd 313     30.,   15.21,    0.0
cnd 314     31.9,  15.21,    0.0
cnd 315     33.198, 15.21,    0.0
cnd 316     31.9,  16.71,    0.0
cnd 320     0.0,     70.5,  0.0
cnd 321     16.3,  70.5,  0.0
cnd 323     25.28,  72.06,  0.0
cnd 324     23.7,  70.5,  0.0
cnd 325     23.3,   44.2,  0.0
cnd 326     31.6,   44.2,  0.0
cnd 327     33.198,  44.2,  0.0
*                                         node/element range
*  part 1 Outside Stainless Steel shell    101 - 3000   - 101/1
*  part 2 Top?? plates                    3001 - 4000   - 102/2
*  part 3 cavity Inside shell             4001 - 5000   - 103/3
*  part 4 Inside plug                     5001 - 6000   - 104/4
*  part 5 Tungsten alloy cylinder         6001 - 8000   - 105/5
*  impact limiter foam                    8001 - 17275 - 106/6
* part 1 Outside ss shell, prop/mat=101/1
G10
  10,8,  101,101,   34,101,,1  Identify the NM for the Element that creates.
  103,4,11,1010        See G10 record, attached.

-1
G10
  4,8,     -1,-1,    34,101,,1
  104,5,12,111
-1
```

```
G9
  8,8,8,  -1,-1,     31,34,101,,1
  5,13,12
-1
G10
  10,17,     -1,-1,  34,101,,1
  1010,11,25,124
-1
G10
  11,17,     -1,-1,  34,101,,1
  111,13,26,125
-1
G10
  2,73,   -1,-1,     34,101,,1
  1023,124,163,162
-1
G10
  10,73,  -1,-1,     34,101,,1
  124,25,64,163
-1
G10
  11,73,   -1,-1,    34,101,,1
  125,26,65,164
-1
G10
  10,22,  -1,-1,   34,101,,1
  163,64,85,1084
-1
G10
  11,22,  -1,-1,   34,101,,1
  164,65,87,185
-1
G10
  10,8,   -1,-1,   34,101,,1
  1084,85,97,196
-1
G10
  4,8,  -1,-1,     34,101,,1
  185,86,98,197
-1
G9
  8,8,8,   -1,-1,  31,34,101,,1
  87,98,86
-1
* part 2
* bottom cover plate , prop/mat 102/2
G10
  17,8,  3001,3001,    34,102,,1
  1,2,109,6
-1
G10
  12,8,  -1,-1,    34,102,,1
  2,3,10,109
-1
```

```
* lid cover plate
G10
  19,5,  -1,-1,    34,102,,1
  188,189,94,93
-1
G10
  5,5,  -1,-1,    34,102,,1
  189,190,95,94
-1
G10
  8,4,  -1,-1,    34,102,,1
  1083,184,92,190
-1
G10
  8,5,  -1,-1,    34,102,,1
  190,92,96,95
-1
* part 3 cavity inside shell, prop/mat 103/3
G10
   12,13,   4001,4001,   34,103,,1
   1009,110,19,117
-1
G10
   10,8,   -1,-1,     34,103,,1
   114,115,28,27
-1
G10
   5,5,   -1,-1,    34,103,,1
   115,116,21,20
-1
G10
   4,5,    -1,-1,    34,103,,1
   116,117,22,21
-1
G10
   11,5,   -1,-1,    34,103,,1
   117,18,23,22
-1
G10
   2,5,   -1,-1,     34,103,,1
   18,19,24,23
-1
G10
   5,4,   -1,-1,     34,103,,1
   20,21,29,28
-1
G10
   5,59,   -1,-1,     34,103,,1
   28,29,402,401
-1
G10
   5,3,   -1,-1,     34,103,,1
   401,402,404,403
-1
```

```
G10
   5,7,    -1,-1,      34,103,,1
   403,404,53,152
-1
G10
   5,4,    -1,-1,      34,103,,1
   152,53,59,158
-1
G10
   5,5,    -1,-1,    34,103,,1
   158,59,68,167
-1
G10
   4,5,    -1,-1,      34,103,,1
   59,160,69,68
-1
G10
   5,5,    -1,-1,      34,103,,1
   160,161,70,69
-1
G10
   7,5,    -1,-1,      34,103,,1
   161,1062,71,70
-1
G10
   2,5,    -1,-1,      34,103,,1
   1062,63,72,71
-1
G10
   8,5,    -1,-1,      34,103,,1
   70,72,79,178
-1
G10
   8,14,    -1,-1,     34,103,,1
   178,79,84,183
-1
* part 4 - plug cylinder shell, prop/mat-104/4
*
G10
   12,4,    5001,5001,  34,104,,1
   51,52,58,57
-1
G10
   12,5,      -1,-1,     34,104,,1
   57,58,67,66
-1
G10
   12,5,     -1,-1,      34,104,,1
   66,67,74,73
-1
G10
   5,5,     -1,-1,       34,104,,1
   67,168,75,74
-1
```

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G10
   4,5,     -1,-1,      34,104,,1
   168,169,176,75
-1
G10
   5,5,    -1,-1,       34,104,,1
   169,170,78,176
-1
G10
   5,14,      -1,-1,    34,104,,1
   176,78,83,182
-1
G10
   19,4,     -1,-1,     34,104,,1
   180,182,89,88
-1
G10
   5,4,    -1,-1,       34,104,,1
   182,83,90,89
-1
* part 5 Tungsten alloy, prop/mat=105/5
* Tungsten alloy at bottom
G10
   10,13,   6001,6001,  34,105,,1
   106,7,15,14
-1
G10
   5,13,    -1,-1,      34,105,,1
   7,8,16,15
-1
G10
   4,13,    -1,-1,      34,105,,1
   8,9,17,16
-1
* side tungsten alloy
G10
  4,4,   -1,-1,         34,105,,1
  121,122,30,129
-1
G10
  11,4,   -1,-1,        34,105,,1
  122,123,31,30
-1
G10
  4,67,   -1,-1,        34,105,,1
  129,30,54,153
-1
G10
  11,67,    -1,-1,      34,105,,1
  30,31,56,54
-1
G10
  4,4,    -1,-1,        34,105,,1
  153,54,60,159
```

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-1
G10
  5,4,   -1,-1,        34,105,,1
  54,55,61,60
-1
G10
  7,4,   -1,-1,        34,105,,1
  55,56,62,61
-1
*  Tungsten alloy in plug
G10
  12,14,  -1,-1,    34,105,,1
  173,174,81,80
-1
G10
  8,14,  -1,-1,    34,105,,1
  174,76,82,81
-1
*
* impact limiter
* bottom section
G10
   28,8,  8001,8001,     34,106,,1
   301,302,203,201
-1
G10
   28,16,  -1,-1,     34,106,,1
   202,204,302,301
-1
G10
   16,16,    -1,-1,       34,106,,1
   205,307,306,305
   5,2050
-1
G10
   16,6,    -1,-1,       34,106,,1
   305,306,304,204
-1
G10
   16,16,    -1,-1,       34,106,,1
   204,304,303,302
-1
g8
    16,8,10,8   -1,-1,   31,34,106,,1
   302,303,206,203
-1
G8
   11,7,11,16  -1,-1,     31,34,106,,1
   304,308,210,303
-1
G9
   8,8,8      -1,-1,     31,34,106,,1
   206,303,207
-1
```

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G10
   4,8         -1,-1,      34,106,,1
   207,210,209,206
-1
G9
   6,11,11       -1,-1,      31,34,106,,1
   304,306,308
-1
G10
   11,16         -1,-1,      34,106,,1
   307,211,308,306
   5,2080
-1
G9
   8,8,8       -1,-1,      31,34,106,,1
   214,209,212
-1
G9
   8,8,8       -1,-1,      31,34,106,,1
   209,210,212
-1
G9
   8,8,8       -1,-1,      31,34,106,,1
   212,215,214
-1
G10
   8,16,       -1,-1,       34,106,,1
   211,213,309,308
   5,2110
-1
G10
   8,7,       -1,-1,        34,106,,1
   308,309,212,210
-1
G10
   8,16,     -1,-1,         34,106,,1
   213,216,310,309
-1
G10
   8,7,       -1,-1,     34,106,,1
   309,310,215,212
-1
G10
   17,16     -1,-1,         34,106,,1
   216,219,311,310
-1
G10
   17,7     -1,-1,         34,106,,1
   310,311,218,215
-1
G10
   17,8     -1,-1,         34,106,,1
   215,218,217,214
-1
```

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G10
   8,16    -1,-1,        34,106,,1
   219,315,314,311
-1
G10
   8,7    -1,-1,        34,106,,1
   311,314,313,218
-1
G10
   8,8    -1,-1,        34,106,,1
   218,313,312,217
-1
G10
   16,16    -1,-1,        34,106,,1
   315,222,316,314
-1
G10
   16,7    -1,-1,        34,106,,1
   314,316,221,313
-1
G10
   16,8    -1,-1,        34,106,,1
   313,221,220,312
-1
* top section
G10
   30,16,  15001,15001,     34,1060,,1
   320,321,241,244
-1
G10
   30,8,  -1,-1,     34,1060,,1
   243,240,321,320
-1
G10
   10,16,    -1,-1,        34,1060,,1
   321,324,323,241
-1
G10
   10,8,    -1,-1,        34,1060,,1
   240,237,324,321
-1
G9
   4,8,8,   -1,-1,      31,34,1060,,1
   237,234,324
-1
G10
   8,16        -1,-1,             34,1060,,1
   324,230,231,323
-1
G10
   8,8         -1,-1,             34,1060,,1
   234,229,230,324
-1
G10
```

```
   22,16    -1,-1,                34,1060,,1
   230,227,228,231
-1
G10
   22,8    -1,-1,                34,1060,,1
   227,230,229,226
-1
G10
   8,16    -1,-1,                34,1060,,1
   227,326,327,228
-1
G10
   8,8    -1,-1,                34,1060,,1
   326,227,226,325
-1
G10
   16,16    -1,-1,                34,1060,,1
   326,224,225,327
-1
G10
   8,16    -1,-1,                34,1060,,1
   223,224,326,325
-1
scale   0.606061,,101,17275
*  interface surface 1D elements, type 33
*  el,#,type,prop,n1,n2,total,incr1,incr2
*  tungsten alloy gaps pr=151 pressure contact,152=steel wool
*  bottom 0.0 gaps
el   20001,33,151,   3120,6001,   10,1,1
el   20011,33,151,   3130,6132,   4,1,1
el   20015,33,151,   3134,6197,   3,1,1
el   20018,33,151,   6121,4157,   10,1,1
el   20028,33,151,   6192,4238,   4,1,1
el   20032,33,151,   6245,4263,   2,1,1
el   20034,33,151,   6247,4145
* gap steel wool
el   20035,33,152,   6199,4001,   13,4,12
* side tungsten alloy - 0.013" gaps
el   20048,33,153,   4261,6248
el   20049,33,153,   4356,6252,   3,5,4
el   20052,33,153,   4376,6312,   58,5,4
el   20110,33,153,   4671,6544,   2,5,4
el   20112,33,153,   4686,6552,   6,5,4
el   20118,33,153,   4721,7317,   3,5,4
*  gap - steel wool
el   20121,33,156,   6274,606,    4,11,2
el   20125,33,156,   6597,614,    66,11,2
el   20191,33,156,   7362,746,    3,7,2
*  gap - steel wool, top and bottom
el   20194,33,154,   4261,6248
el   20195,33,154,   4279,6249,   3,1,1
el   20198,33,154,   4327,6265,   10,1,1
el   20208,33,154,   7325,4731
el   20209,33,154,   7326,4758,   3,1,1
```

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el   20212,33,154,   7345,4778,   4,1,1
el   20216,33,154,   7371,4803,   6,1,1
* top tungsten alloy - 0.0 gap
el   20222,33,155,   5157,7377,   12,1,1
el   20234,33,155,   5190,7546,   4,1,1
el   20238,33,155,   5211,7550,   3,1,1
el   20241,33,155,   7533,5309,   12,1,1
el   20253,33,155,   7650,5321,   6,1,1
el   20259,33,155,   7656,5304
* gap steel wool
el   20260,33,157    7552,5213
el   20261,33,157,   7560,5244,   13,8,5
* contact-Outside shell and bottom plate, low press cont.
***weld at el 20401
el   20401,33,109,   3148,101
el   20402,33,161,   3160,111    7,12,10
* contact-bottom cavity shell and Outside shell, low press cont.
***weld at el 20409
el   20409,33,1090,   4012,171
el   20410,33,161,   4024,259,    12,12,10
el   20422,33,161,   4340,379,    4,2,10
el   20426,33,160,   4346,409             ; lip
el   20427,33,160,   4336,606             ; lip
* contact-bottom cavity shell and bottom plate, low press cont.
el   20428,33,162,   3136,4001
el   20429,33,162,   3222,4002,   11,1,1
* contact-lid and Outside shell at top .017"
el   20440,33,163,   3360,2495
el   20441,33,163,   3368,2757,   3,8,10
el   20444,33,163,   3400,2787,   4,8,10
*
el   20448,33,160,   750,4808,    2,1,30    ; lip
* contact-cavity and Outside shells gap=.017"
el   20450,33,163,   4838,751
el   20451,33,163,   4840,2295,   4,2,10
el   20455,33,163,   4862,2335,   4,8,10
el   20459,33,163,   4902,2375,   12,8,10
***weld at el 20471
el   20471,33,1090,  4998,2495
* contact lid and cavity top 0.0 gap
el   20472,33,164,   4991,3353,   8,1,1
* contact cavity wall and plug - lower vertical I/F .020"
el   20480,33,165,   5012,4707
el   20481,33,165,   5024,4717,   3,12,5
el   20484,33,165,   5072,4737,   4,12,5
* contact cavity wall and plug - horizontal plane 0.0 gap
el   20488,33,166,   4752,5169,   5,1,1
el   20493,33,166,   4774,5195,   3,1,1
el   20496,33,166,   4798,5215,   4,1,1
* contact cavity wall and plug - upper vertical I/F .040"
el   20500,33,167    5218,4801
el   20501,33,167,   5223,4855,   4,5,8
el   20505,33,167,   5248,4895,   13,5,8
* contact lid and plug - .029"@top,
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el   20518,33,167,   5308,3353
el   20519,33,167,   5394,3361,   2,5,8
el   20521,33,167,   5404,3332
el   20522,33,168,   5366,3233,   19,1,1
el   20541,33,168,   5401,3329,   4,1,1
* gap between cask and impact limiter
* lower segment 0.0 gp
el   20825,33,170,   3001,8197,  17,1,1
el   20842,33,170,   3138,8214,  11,1,1
el   20853,33,170,   101,8224
el   20854,33,170,   102,9289
el   20855,33,170,   103,9288
el   20856,33,170,   104,9287
el   20857,33,170,   105,9286
el   20858,33,170,   106,9285
el   20859,33,170,   107,9284
el   20860,33,170,   108,9283
el   20861,33,170,   109,9282
el   20862,33,170,   110,9281
el   20863,33,170,   181,9281
el   20864,33,170,   182,9569,   3,1,1
* pr171=0.131" air gap
el   20867,33,171,   215,9812
el   20868,33,171,   218,9805
el   20869,33,171,   222,9799
el   20870,33,171,   227,9794
el   20871,33,171,   233,9790
el   20872,33,171,   240,9787
el   20873,33,171,   248,9785
el   20874,33,171,   440,10772,   16,11,1
el   20890,33,171,   1503,11029,  7,11,1
el   20897,33,171,   1580,11521,  3,11,5
* upper segment
el   20900,33,171,   2174,17148, 3,11,40
el   20904,33,171,   2207,16884, 7,11,1
el   20911,33,171,   2515,16678, 21,11,1
el   20932,33,171,   2746,16115
el   20933,33,171,   2861,16114
el   20934,33,171,   2864,16113
el   20935,33,171,   2868,16112
el   20936,33,171,   2873,16111
el   20937,33,171,   2879,16110
el   20938,33,171,   2886,16109
* 0.0 gap
el   20939,33,170,   3309,15481,   19,1,1
el   20958,33,170,   3349,15500,   4,1,1
el   20962,33,170,   3418,15504,   7,1,1
el   20969,33,170,   2817,15510
el   20970,33,170,   2818,15882,   9,1,1
el   20979,33,170,   2856,15978
el   20980,33,170,   2857,15977
el   20981,33,170,   2858,15976
* 304SS impact limiter shell
* bottom
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```
el    21001,33,107,     8225,8226,27,1,1
el    21028,33,107,     8929,8945,5,16,16
el    21033,33,107,     8673,8689,15,16,16
el    21048,33,107,     8673,8674,15,1,1
el    21063,33,107,     9609,9610,10,1,1
el    21073,33,107,     9893,9894,7,1,1
el    21080,33,107,     10077,10078,7,1,1
el    21087,33,107,     10261,10262,16,1,1
el    21103,33,107,     10788,10789,7,1,1
el    21110,33,107,     11036,11037,15,1,1
el    21125,33,107,     11051,11067,15,16,16
el    21140,33,107,     11307,11323,6,16,16
el    21146,33,107,     11419,11435,7,16,16
el    21153,33,108,     8197,8198,27,1,1
el    21180,33,108,     9281,9282,9,1,1
el    21189,33,107,     9568,9569,3,1,1
el    21190,33,107,     9820,9812
el    21191,33,107,     9812,9805
el    21192,33,107,     9805,9799
el    21193,33,107,     9799,9794
el    21194,33,107,     9794,9790
el    21195,33,107,     9790,9787
el    21196,33,107,     9787,9785
el    21197,33,107,     10771,10772,16,1,1
el    21213,33,107,     11028,11029,7,1,1
el    21220,33,107,     11516,11517,15,1,1
* top
el    21301,33,107,     15451,15452,29,1,1
el    21330,33,107,     15480,15872
el    21331,33,107,     15872,15873,8,1,1
el    21339,33,107,     15880,16101
el    21340,33,107,     16101,16102,6,1,1
el    21346,33,107,     16107,16503
el    21347,33,107,     16503,16504,20,1,1
el    21367,33,107,     16523,16821
el    21368,33,107,     16821,16822,6,1,1
el    21374,33,107,     16827,17133
el    21375,33,107,     17133,17134,14,1,1
el    21389,33,107,     17148,17149,6,1,1
el    21395,33,107,     17154,16907
el    21396,33,107,     16907,16923,15,16,16
el    21411,33,107,     17148,17156,15,8,8
el    21426,33,107,     16884,16885,6,1,1
el    21432,33,107,     16890,16678
el    21433,33,107,     16678,16679,20,1,1
el    21453,33,107,     16698,16115
el    21454,33,108,     15481,15482,29,1,1
el    21483,33,108,     15881,15882,9,1,1
el    21492,33,108,     15976,15977,3,1,1
el    21495,33,107,     16108,16109,7,1,1
*
*  Outside surface convective elements - 32's
* surface 1
el    22001,32,110,     8225,8226,27,1,1
```

```
* surface 2
el   22028,32,111,   8929,8945,5,16,16
el   22033,32,111,   8673,8689,15,16,16
* surface 3
el   22048,32,112,   8673,8674,15,1,1
el   22063,32,112,   9609,9610,10,1,1
el   22073,32,112,   9893,9894,7,1,1
* surface 4
el   22080,32,113,   10077,10078,7,1,1
el   22087,32,113,   10261,10262,16,1,1
el   22106,32,113,   10788,10789,7,1,1
el   22113,32,113,   11036,11037,15,1,1
* surface 5
el   22128,32,114,   11051,11067,15,16,16
el   22143,32,114,   11307,11323,6,16,16
el   22149,32,114,   11419,11435,7,16,16
* surface 6 side
el   22156,32,115,   1602,1613,52,11,11
* surface 7
el   22208,32,116,   16907,16923,15,16,16
el   22223,32,116,   17148,17149,7,1,1
* surface 8
el   22230,32,117,   17132,17133,15,1,1
el   22245,32,117,   16820,16821,7,1,1
el   22252,32,117,   16502,16503,21,1,1
* surface 9
el   22273,32,118,   16100,16101,7,1,1
* surface 10
* none
* surface 11
el   22280,32,120,   15451,15452,29,1,1
el   22309,32,120,   15871,15872,9,1,1
* cavity decay heat boundary elements
el   23001,32,121,   4227,4228,9,1,1
el   23010,32,121,   4236,4372
el   23011,32,121,   4372,4377,57,5,5
el   23069,32,121,   4657,4667
el   23070,32,121,   4667,4672
el   23071,32,121,   4672,4682
el   23072,32,121,   4682,4687,5,5,5
el   23077,32,121,   5001,5002,11,1,1
me 0.001
* Element Properties - axisymmetric
* stif34 - pr,pr#,mat#,thk,q,h,t(bath)
pr  101,1,0.0,0.0,0.0,0.0          ; 304ss Outside shell.  NM 101, thermal
                                                Properties located in 1.
                                                See PR record, attached.
pr  102,2,0.0,0.0,0.0,0.0          ; 304ss bottom plate and lid
pr  103,3,0.0,0.0,0.0,0.0          ; 304ss cavity shell
pr  104,4,0.0,0.0,0.0,0.0          ; 304ss plug shell
pr  105,5,0.0,0.0,0.0,0.0          ; tungsten alloy
pr  106,6,0.0,0.0,0.0,0.0          ; foam-16 pcf lower IL
pr  1060,66,0.0,0.0,0.0,0.0          ; foam-22 pcf upper IL
*  stif33 input - pr,pr#pr,mat#,area,q,conv flag, h
```

```
pr  107,7,.105,0.0,0,0,             ; impact limiter 12 gage shell
pr  108,7,.188,0.0,0,0,             ; impact limiter .188" base plate
pr  109,8,.625, 0.0,0,0,            ; 5/8" weld
pr  1090,8,.50,0.0,0,0,             ; 1/2" weld
pr  1,-201,-202,.29              ; 304ss  PR record for 1, points to Properties
                                    records, 201 and 202. Minus (-) in
                                    front identified that the properties
                                    are a function of Temperature.
pr  2,-201,-202,.29               ; 304ss
pr  3,-201,-202,.29               ; 304ss
pr  4,-201,-202,.29               ; 304ss
pr  5,-203,-204,.654              ; tungsten alloy
pr  6,.00206,.353,.00926          ; foam - 16 lb/ft3
pr  66,.00260,.353,.0127          ; foam - 22 lb/ft3
pr  7,-201,-202,.29               ; a304 ss impact limiter shell
pr  8,-201,-202,.29               ; a304 weld material
*  stif33 input - elpr,matpr,area,heat flux,conv flag, h
pr  151,11,0.32,   0.0,1,0.0231   ; 0.0 y gap tungsten alloy-304 I/F
pr  152,12,0.36,   0.0,,           ;  x gap with stl wool tungsten alloy I/F
pr  153,18,0.30,   0.0,,           ; 0.013" x gap tungsten alloy I/F
pr  154,11,0.31,   0.0,1,0.0231    ; 0.0 y gap, shimmed,  I/F
pr  155,11,0.29,   0.0,1,0.0231    ; 0.0 y gap tungsten alloy-304 I/F
pr  156,12,0.30,   0.0,,           ;  x gap with stl wool tungsten alloy I/F
pr  157,12,0.34,   0.0,,           ; top tungsten alloy w/ stl wool
pr  160,11,.15,    0.0,1,0.0231    ;  lip cavity to Outside shells
pr  161,11,0.31,   0.0,1,0.0231    ; 0.0 x gap 304 to 304 I/F's
pr  162,11,0.30,   0.0,1,0.0231    ; 0.0 y gap 304 to 304 I/F's
pr  163,13,0.25,   0.0,,           ; 0.017" x gap lid??Outside
pr  164,11,0.39,  0.0,1,0.0231     ; 0.0 y gap lid to cavity surface @ bolt
pr  165,14,0.18,  0.0,,          ; 0.020" x-gap plug-cavity wall lower vertical
pr  166,11,0.21,  0.0,1,0.0231     ; 0.0 y gap horz plane cavity-plug
pr  167,15,0.26,  0.0,,          ; 0.040" x gap plug-cavity wall upper vertical
pr  168,16,0.25,  0.0,,            ; 0.029" y gap conv?  plug-lid
pr  170,11,0.31,  0.0,1,0.0231     ; 0.0 y gap cask-over pack i/f
pr  171,17,0.32,  0.0,,            ; cask-over pack 0.121" x gap
* Thermal material properties - prop#,kx,c,m,e,ky,kz
pr  11,0.0,0.0,0.0,,,             ; convect.i/p see pr
151,161,162,164,166,169,170
pr  12,.068,.24,.029              ; stl wool -
k=.1*k(304),c=c(air),den=.1*d(304)
pr  13,-216,-220,-221             ; enclosed air pr 163 s=.012"
pr  14,-217,-220,-221             ; enclosed air pr 165 s=.016"
pr  15,-218,-220,-221             ; enclosed air pr 153,and 167 s=.050"
pr  16,-219,-220,-221             ; enclosed air pr 168 s=.031"
pr  17,-222,-220,-221             ; air gap 0.2" at over pack i/f
pr  18,-223,-220,-221             ; air gap 0.013" at side tungsten alloy i/f
pr  201,  .6851,  4.544e-4,-4.126e-8  ; poly.coef.304ss cond.  Polynomial
pr  202,  .1120,  3.504e-5,-1.080e-8  ; poly.coef.304ss.sp.ht. Coefficients.
```

REFER TO THE CONDUCTIVITY AND SPECIFIC HEAT EQUATIONS PROVIDED IN CHAPTER 3, Paragraph 3.2.1.1, FOR A COMPARISON OF THE COEFFICIENTS SHOWN ABOVE, AND THOSE PRESENTED IN THE EQUATIONS.

```
pr  203,  3.673,    4.028e-4,-4.167e-7     ; tung.cond-test data
```

```
pr  204,  3.631e-2, 8.017e-6,-1.807e-9     ; tung.sp.ht.-test data
pr  205,  1.836e-3, 4.690e-5,-3.378e-8, 2.374e-11  ; h surf.1, e=.52
pr  206,  1.836e-3, 4.690e-5,-3.378e-8, 2.374e-11  ; h surf.2, e=.52
pr  207,  1.836e-3, 4.690e-5,-3.378e-8, 2.374e-11  ; h surf.3, e=.52
pr  208,  1.836e-3, 4.690e-5,-3.378e-8, 2.374e-11  ; h surf.4, e=.52
pr  209,  1.836e-3, 4.690e-5,-3.378e-8, 2.374e-11  ; h surf.5, e=.52
pr  210, -2.141e-4, 4.196e-5,-4.190e-8, 2.022e-11  ; h surf.6, e=.20
pr  211,  1.836e-3, 4.690e-5,-3.378e-8, 2.374e-11  ; h surf.7, e=.52
pr  212,  1.836e-3, 4.690e-5,-3.378e-8, 2.374e-11  ; h surf.8, e=.52
pr  213,  1.836e-3, 4.690e-5,-3.378e-8, 2.374e-11  ; h surf.9, e=.52
pr  215,  1.836e-3, 4.690e-5,-3.378e-8, 2.374e-11  ; h surf.11, e=.52
pr  216,  1.131e-3, 2.072e-6, 5.018e-10  ; k enclosed air pr 163-.017"
pr  217,  1.137e-3, 2.063e-6, 6.642e-10  ; k enclosed air pr 165-.020"
pr  218,  1.177e-3, 2.005e-6, 1.747e-9   ; k enclosed air pr 167-.040"
pr  219,  1.164e-3, 2.037e-6, 1.152e-9   ; k enclosed air pr 168-.029"
pr  220,  2.402e-1,-1.401e-6, 3.995e-8, -1.570e-11 ; Cp enclosed air
pr  221,  4.684e-5,-7.150e-8, 5.869e-11,-1.834e-14 ; density enclosed air
pr  222,  1.359e-3, 1.743e-6, 6.675e-9 ; k enclosed air impact limiter
pr171-.131"
pr  223,  1.113e-3, 2.097e-6, 1.447e-11; k enclosed air tungsten alloy
pr153-.013"
*  32's pr,pr#,h,thk,Temp,q,e
*  solar heat
pr  110,-205,     0.0,100,  0.4267,0.0  ; conv. surf.1 - 200c/cm2
pr  111,-206,     0.0,100,  0.8533,0.0  ; conv. surf.2 - 400c/cm2
pr  112,-207,     0.0,100,  0.8533,0.0  ; conv. surf.3 - 400c/cm2
pr  113,-208,     0.0,100,  0.8533,0.0  ; conv. surf.4 - 400c/cm2
pr  114,-209,     0.0,100,  0.4267,0.0  ; conv. surf.5 - 200c/cm2
pr  115,-210,     0.0,100,  0.8533,0.0  ; conv. surf.6 - 400c/cm2
pr  116,-211,     0.0,100,  0.4267,0.0  ; conv. surf.7 - 200c/cm2
pr  117,-212,     0.0,100,  0.8533,0.0  ; conv. surf.8 - 400c/cm2
pr  118,-213,     0.0,100,  0.8533,0.0  ; conv. surf.9 - 400c/cm2
pr  120,-215,     0.0,100,  0.4267,0.0  ; conv. surf.11- 200c/cm2
pr  121,0.0,      0.0,70,   2.875     ; decay heat - 400 W
sc   20,1,1,10,0,    1,0,0.1,1.0,70, 1.0,1,,       ; SS with decay heat
end
```

Generate 2D Region by Isoparametric Mapping (G10)

G10 generates regions of 3- or 4-node elements and nodes by mapping with quadratic, isoparametric functions. Both flat and curved surfaces can be generated, with curved surfaces and curved boundaries mapped by parabolic functions. Mesh density is controlled by the location of mid-side nodes. By placing the mid-side node closer to a corner, the mesh density is increased in the corner region. This generator is flagged by a record containing only the descriptor G10 .

The coordinates of the control points (corners and mid-sides of the generated region) may entered directly, or by defining them on CND records and specifying the CND node ID numbers.

Control Data Record for Generator 10

ITEM	DESCRIPTION	SYMBOL
1	Number of nodes along side 1	N1
2	Number of nodes along side 2	N2
3	Number of first node (1)	NND1
4	Number of first element (2)	NEL1
5	Element type (3)	NET
6	Associated property set	MAT
7	Flag for local coordinates (4)	LCS
8	Flag for control points (5)	ICTLPT

Notes
-----

1) If NND1=-1, node numbering continued from highest node number. The highest node and element numbers are listed on file MAX_NODE.
2) If NEL1=-1, element numbering continued from the highest element number. If NEL1=0, no elements are generated.
3) If NET, MAT, LCS and ICTLPT are omitted, values from last call to G10 used.
4) If control nodes are entered in local coordinates, set LCS=1
5) If the corners and mid-sides of the generated region are defined on Control Point Records, set ICTLPT=1. Otherwise set ICLTPT=0.

First Corner Node Data Record

If ICLTPT=0:

ITEM	DESCRIPTION	SYMBOL
1	X-coordinate of first node	X1
2	Y-coordinate of first node	Y1
3	Z-coordinate of first node	Z1
4	X-coordinate of second node	X2
5	Y-coordinate of second node	Y2
6	Z-coordinate of second node	Z2

If ICLTPT=1:

ITEM	DESCRIPTION	SYMBOL
1	ID number of first corner point	NCP(1)
2	ID number of second corner point	NCP(2)
3	ID number of third corner point	NCP(3)
4	ID number of forth corner point	NCP(4)

Second Corner Node Data Record

This record is omitted if the corners and mid-sides of the generated region are specified by defining the points with ID numbers.

ITEM	DESCRIPTION	SYMBOL
1	X-coordinate of third node	X3
2	Y-coordinate of third node	Y3
3	Z-coordinate of third node	Z3
4	X-coordinate of forth node	X4
5	Y-coordinate of forth node	Y4
6	Z-coordinate of forth node	Z4

Mid-Side Node Data Record

This data record defines a mid-side node, and is required for each mid-side node. Mid-side nodes are only required for curved boundaries.

If ICLTPT=0:

ITEM	DESCRIPTION	SYMBOL
1	Number of mid side node (1)	NND
2	X-coordinate of mid-side node	X
3	Y-coordinate of mid-side node	Y
4	Z-coordinate of mid-side node	Z

If ICLTPT=1:

ITEM	DESCRIPTION	SYMBOL
1	Number of mid side node (1)	NND
2	ID number of mid-side point	NCP

Notes

1) The four corner nodes are numbered 1-4. The mid-side nodes are numbered 5-8 as follows:

Corner Node Nos.	Mid-Side Node No.
1,2	5
2,3	6
3,4	7
4,1	8

Termination Record for Mid-Side Nodes

This data record terminates mid-side data. The record contains only -1, and is required even if no mid-side nodes are entered.

ITEM	DESCRIPTION	SYMBOL
	-1	

Element Property Set Record (PR)

All element data is entered on Element Property records. This section defines the format of Element·Property records, the specific data entries are defined in the Element Property Manual for the various element types.

The connection between elements and property records is the element property number. This number is entered on the element definition record (or specified to the model generator) and defines the first property record required by the element.

ITEM	DESCRIPTION	SYMBOL
	Descriptor (PR)	
1	Property set number (1)	NM
2	First field of property set	PR_1
3	Second field of property set	PR_2
...	...	...
8	Eighth field of property set	PR_8

Notes:

1) Maximum value, NM=99999

Thermal Material Properties (THE_PROP)

This record defines constant thermal properties, or pointers to temperature-dependent property sets. For temperature-dependent properties, enter the negative of number the temperature-dependent property set in place of the constant value. Data for temperature-dependent property sets is defined below.

ITEM	DESCRIPTION	SYMBOL
	Descriptor (PR)	
	Property set number (1)	NM
1	X-conductivity / temp-depend property set (1)	Kx
2	Specific heat / temp-depend property set (1)	C
3	Lb-mass density / temp-depend property set (1)	m
4	Emissivity	e
5	Thermal conductivity in global y-direction (2)	Ky
6	Thermal conductivity in global z-direction (3)	Kz
7	Coordinate system for conduction properties (4)	MCS

Notes
-----
1) For temperature-dependent properties, set value to NEGATIVE of temperature-dependent property set number.

2) Default Ky=Kx

3) Default Kz=Kx

4) For orthotropic conduction, MCS is the number of the coordinate system that defines the directions of Kx, Ky and Kz. For MCS=0 in 2D problems, Kx and Ky are oriented in the local x and y directions. For 3D problems, with MCS=0, Kx, Ky and Kz are oriented in the global x, y, and z directions.

Temperature-Dependent Thermal Properties

Temperature dependent properties are represented by a polynomial function of temperature:

f(t) = a0 + a1*t + a2*t^2 + a3*t^3 + ...

The coefficients a0, a1, a2, ..., are entered on this property set record. From 1 to 8 coefficients may be entered. Trailing null coefficients may be omitted, but intermediate null coefficients must be entered.

Temperature-dependent properties may be specified for the following element properties:

STIF31: K,C,H,m
STIF32: H
STIF33: K,C,m
STIF34: K,C,H,m
STIF35: K,C,m
STIF36: K,C,H,m
STIF37: K,C,m
STIF38: K,C,m
STIF39: K,C,m

where, K:conduction, C:capacitence, m:lb-mass, H:convection

The initial temperature specified on the Solution Control record is required to determine initial property values. Temperature-dependent materials are assumed to be isotropic.

ITEM	DESCRIPTION	SYMBOL
	Descriptor (PR)	
	Property set number (1)	NM
1	First coefficient	a0
2	Second coefficient	a1
...		...
	Eighth coefficient	a7

3.5.6 Justification for Use of Uniformly Distributed Decay Heat throughout Cask Cavity

Typically, the content is placed into the cask cavity, within a basket or rack device. This device provides shoring to the content, to ensure that its loading arrangement is maintained during transportation. Selection of the type of material for fabrication of this device is based upon the temperature environment within the cask cavity. A cavity temperature of less than 204.44°C (400°F) allows for the use of aluminum. For temperatures of 204.44°C (400°F) or greater, the choice is stainless steel material, although this material could be used in either case.

The cavity temperature within all AOS Transport System models is less than 148.89°C (300°F), under Normal conditions of transport; therefore, the use of either material in the fabrication of the shoring devices is acceptable.

In the AOS cask analyses, the decay heat is assumed to be uniformly distributed throughout the cask cavity surfaces. The effect of this assumption is examined here, by comparing cask stress and temperatures corresponding to three (3) assumed distributions of decay heat over the cask cavity surfaces, provided below:

- **Case 1** – Decay heat is uniformly distributed over the cask cavity cylindrical surface, top surface, and bottom surface (as in the AOS analyses).
- **Case 2** – Decay heat is distributed over the cask cavity cylindrical surface, top surface, and bottom surface, such that the cylindrical surface receives twice the heat intensity as the top and bottom surfaces.
- **Case 3** – Decay heat is distributed over only the cask cavity cylindrical surface, with the top and bottom surfaces receiving no heat.

Cask temperatures and thermal stress are determined for each of the assumed distributions. The maximum component temperatures are presented in Table 3-137 through Table 3-139, and cask temperature distributions are illustrated in Figure 3-178 through Figure 3-180. P_m and P_b stress at the critical cask cross-sections are presented in Table 3-140 through Table 3-142, and plots of maximum principal stress in the cask dog-leg region are illustrated in Figure 3-181 through Figure 3-183.

A comparison of Table 3-137 through Table 3-139 shows little variation in maximum temperature for the three (3) heat distributions. Figure 3-178 through Figure 3-180 show that Case 1, uniformly distributed decay heat, provides maximum temperature in the seal region. From Table 3-137 through Table 3-139, the maximum temperature difference is less than 6°F.

A comparison of Table 3-140 through Table 3-142 shows little variation in stress due to heat distribution. Maximum thermal bending stress occurs at Location 4, and the maximum stress difference due to heat distribution is 0.5 ksi. Figure 3-181 through Figure 3-183 also show only a small stress difference in the cask dog-leg region due to the heat distribution.

In the AOS cask analyses, thermal stress due to maximum decay heat represents only a small portion of total stress in all load combinations. As a result, the small stress change in the three (3) cases shows that a change in assumed decay heat distribution would have negligible effect upon overall stress evaluations. In addition, maximum change in the corresponding temperatures for the three (3) cases is less than 6°F, with the uniform decay heat distribution producing maximum temperature within the seal region.

Table 3-137. Case 1, Maximum Component Temperatures[a]

Component	Node_1	Node_2	Node	Max_Temp
---------	------	------	----	--------
Cask Outer Shell	101	2894	606	1.8090E+02
Bottom Plate	3001	3232	3120	1.8160E+02
Cask Lid	3233	3424	3233	1.8210E+02
Cask Cavity Shell	4001	4998	4227	1.9420E+02
Cask Lid Plug	5001	5404	5001	1.9820E+02
Shielding Material	6001	7656	7377	1.8620E+02
Impact Limiter, Foam	8001	10791	9501	1.8160E+02

Table 3-138. Case 2, Maximum Component Temperatures[b]

Component	Node_1	Node_2	Node	Max_Temp
---------	------	------	----	--------
Cask Outer Shell	101	2894	620	1.7830E+02
Bottom Plate	3001	3232	3120	1.7850E+02
Cask Lid	3233	3424	3233	1.7680E+02
Cask Cavity Shell	4001	4998	4482	1.8920E+02
Cask Lid Plug	5001	5404	5012	1.8000E+02
Shielding Material	6001	7656	6392	1.8120E+02
Impact Limiter, Foam	8001	10791	8197	1.7810E+02

Table 3-139. Case 3, Maximum Component Temperatures[c]

Component	Node_1	Node_2	Node	Max_Temp
---------	------	------	----	--------
Cask Outer Shell	101	2894	634	1.8120E+02
Bottom Plate	3001	3232	3120	1.8060E+02
Cask Lid	3233	3424	3233	1.8000E+02
Cask Cavity Shell	4001	4998	4497	1.9310E+02
Cask Lid Plug	5001	5404	5012	1.8350E+02
Shielding Material	6001	7656	6432	1.8450E+02
Impact Limiter, Foam	8001	10791	8197	1.8030E+02

a. ***Case 1*** *– Decay heat uniformly distributed over the cask cavity cylindrical surface, top surface, and bottom surface (as in the AOS analyses).*
b. ***Case 2*** *– Decay heat distributed over the cask cavity cylindrical surface, top surface, and bottom surface, such that the cylindrical surface receives twice the heat intensity as the top and bottom surfaces.*
c. ***Case 3*** *– Decay heat distributed over only cask cavity cylindrical surface, with the top and bottom surfaces receiving no heat.*

Table 3-140. Case 1, Stress (psi/MPa)

Location	Sigma_1	Sigma_2	Sigma_3	Pm	Pb
1	1.0456E+02	-1.8983E+02	-2.8034E+01	2.9439E+02	4.2926E+02
	7.2091E-01	-1.3088E+00	-1.9329E-01	2.0297E+00	2.9597E+00
2	1.3149E+02	-2.9406E+02	-8.4539E+01	4.2555E+02	8.7203E+02
	9.0661E-01	-2.0275E+00	-5.8288E-01	2.9341E+00	6.0124E+00
3	1.0021E+02	-1.8730E+02	-2.2414E+01	2.8752E+02	4.2741E+02
	6.9094E-01	-1.2914E+00	-1.5454E-01	1.9823E+00	2.9469E+00
4	6.3127E+02	-2.1814E+03	-4.4076E+02	2.8126E+03	5.5355E+03
	4.3524E+00	-1.5040E+01	-3.0390E+00	1.9392E+01	3.8166E+01
5	6.2466E+02	-2.4329E+03	-9.8919E+02	3.0575E+03	4.8291E+03
	4.3069E+00	-1.6774E+01	-6.8202E+00	2.1081E+01	3.3295E+01
6	9.6377E+01	-1.2090E+03	-1.3048E+03	1.3054E+03	1.5833E+03
	6.6450E-01	-8.3357E+00	-8.9960E+00	9.0002E+00	1.0916E+01
7	-1.9217E+01	-4.1327E+02	2.4598E+01	3.9406E+02	4.2739E+02
	-1.3249E-01	-2.8494E+00	1.6960E-01	2.7169E+00	2.9468E+00
8	-1.9485E+01	-4.1288E+02	-1.5849E-01	3.9339E+02	4.2023E+02
	-1.3434E-01	-2.8467E+00	-1.0927E-03	2.7123E+00	2.8974E+00
9	-1.9384E+01	-4.1271E+02	-1.5390E+00	3.9333E+02	4.1618E+02
	-1.3364E-01	-2.8456E+00	-1.0611E-02	2.7119E+00	2.8695E+00
10	-7.2193E+01	-5.3770E+02	6.2101E+01	4.6550E+02	9.5760E+02
	-4.9775E-01	-3.7073E+00	4.2817E-01	3.2095E+00	6.6024E+00
11	-1.2200E+02	-6.7410E+02	-3.2254E+02	5.5211E+02	1.2549E+02
	-8.4114E-01	-4.6478E+00	-2.2238E+00	3.8066E+00	8.6522E-01
12	2.5799E+00	-8.1753E+02	-8.1351E+02	8.2011E+02	1.7232E+02
	1.7788E-02	-5.6367E+00	-5.6090E+00	5.6545E+00	1.1881E+00
13	-8.6733E+01	-1.2094E+03	-1.2100E+02	1.1227E+03	8.1844E+02
	-5.9800E-01	-8.3386E+00	-8.3430E-01	7.7406E+00	5.6430E+00
14	-6.9338E+01	-1.0534E+03	5.7286E+01	9.8411E+02	6.6719E+02
	-4.7807E-01	-7.2632E+00	3.9497E-01	6.7852E+00	4.6001E+00
15	2.1678E+02	-2.8099E+02	-3.4633E+01	4.9777E+02	8.3966E+02
	1.4946E+00	-1.9374E+00	-2.3879E-01	3.4320E+00	5.7893E+00
16	6.5964E+01	-1.3093E+02	-3.3301E+01	1.9689E+02	3.3071E+02
	4.5480E-01	-9.0271E-01	-2.2960E-01	1.3575E+00	2.2802E+00

17	3.0783E+01	-9.2873E+01	-1.1470E+01	1.2366E+02	2.1759E+02
	2.1224E-01	-6.4034E-01	-7.9082E-02	8.5258E-01	1.5002E+00
18	4.5328E+01	-9.9979E+01	5.5228E+02	1.4531E+02	6.1413E+01
	3.1252E-01	-6.8933E-01	3.8078E+00	1.0019E+00	4.2343E-01
19	-1.8918E+01	-2.1523E+02	6.9267E+02	1.9631E+02	2.1305E+02
	-1.3043E-01	-1.4840E+00	4.7758E+00	1.3535E+00	1.4689E+00
20	-3.7965E+01	-5.4220E+02	1.6813E+02	5.0423E+02	2.4979E+02
	-2.6176E-01	-3.7383E+00	1.1592E+00	3.4765E+00	1.7222E+00
21	3.1481E+00	-8.6388E+01	-8.2724E+01	8.9536E+01	1.2184E+02
	2.1705E-02	-5.9563E-01	-5.7036E-01	6.1733E-01	8.4008E-01
22	-2.8719E+01	-1.4109E+02	-1.3557E+02	1.1237E+02	1.3962E+02
	-1.9801E-01	-9.7277E-01	-9.3474E-01	7.7476E-01	9.6264E-01

Table 3-141. Case 2, Stress (psi/MPa)

Location	Sigma_1	Sigma_2	Sigma_3	Pm	Pb
1	1.0626E+02	-1.8898E+02	-1.7071E+01	2.9524E+02	4.2317E+02
	7.3263E-01	-1.3029E+00	-1.1770E-01	2.0356E+00	2.9176E+00
2	1.3586E+02	-3.0081E+02	-9.1768E+01	4.3667E+02	8.9696E+02
	9.3669E-01	-2.0740E+00	-6.3272E-01	3.0107E+00	6.1843E+00
3	1.0306E+02	-1.8881E+02	-1.6976E+01	2.9187E+02	4.2935E+02
	7.1056E-01	-1.3018E+00	-1.1704E-01	2.0124E+00	2.9603E+00
4	6.8554E+02	-2.0418E+03	-4.0530E+02	2.7273E+03	5.3361E+03
	4.7267E+00	-1.4077E+01	-2.7944E+00	1.8804E+01	3.6791E+01
5	7.1795E+02	-2.3302E+03	-7.5061E+02	3.0481E+03	4.8219E+03
	4.9501E+00	-1.6066E+01	-5.1752E+00	2.1016E+01	3.3246E+01
6	1.0763E+02	-1.1763E+03	-9.7713E+02	1.2839E+03	1.6656E+03
	7.4210E-01	-8.1103E+00	-6.7371E+00	8.8524E+00	1.1484E+01
7	-2.0446E+01	-4.0750E+02	2.8551E+01	3.8706E+02	4.7858E+02
	-1.4097E-01	-2.8096E+00	1.9685E-01	2.6687E+00	3.2997E+00
8	-2.0978E+01	-4.0600E+02	-4.8058E-01	3.8502E+02	4.5443E+02
	-1.4464E-01	-2.7992E+00	-3.3135E-03	2.6546E+00	3.1332E+00
9	-2.0912E+01	-4.0664E+02	9.9173E+00	3.8573E+02	4.6822E+02
	-1.4418E-01	-2.8037E+00	6.8378E-02	2.6595E+00	3.2283E+00
10	-5.2623E+01	-4.2684E+02	-1.1668E+02	3.7421E+02	5.2219E+02
	-3.6282E-01	-2.9429E+00	-8.0447E-01	2.5801E+00	3.6003E+00
11	-4.6965E+01	-4.3616E+02	-2.8320E+02	3.8919E+02	1.9263E+01
	-3.2381E-01	-3.0072E+00	-1.9526E+00	2.6834E+00	1.3281E-01
12	1.4280E+00	-4.9718E+02	-4.9572E+02	4.9861E+02	7.6981E+00
	9.8457E-03	-3.4279E+00	-3.4179E+00	3.4378E+00	5.3076E-02
13	-6.2872E+01	-1.0239E+03	-1.9446E+02	9.6098E+02	8.5804E+02
	-4.3349E-01	-7.0592E+00	-1.3407E+00	6.6258E+00	5.9160E+00
14	-3.7412E+01	-8.9557E+02	-3.3335E+01	8.5816E+02	6.0010E+02
	-2.5795E-01	-6.1747E+00	-2.2984E-01	5.9168E+00	4.1376E+00
15	2.1957E+02	-2.7300E+02	-2.5945E+01	4.9258E+02	8.3463E+02
	1.5139E+00	-1.8823E+00	-1.7889E-01	3.3962E+00	5.7545E+00
16	6.4300E+01	-1.2668E+02	-3.6108E+01	1.9097E+02	3.1495E+02
	4.4333E-01	-8.7340E-01	-2.4895E-01	1.3167E+00	2.1715E+00

17	2.8317E+01	-8.6767E+01	1.9932E+00	1.1508E+02	2.0063E+02
	1.9524E-01	-5.9824E-01	1.3742E-02	7.9347E-01	1.3833E+00
18	7.6299E+00	-4.6973E+01	1.0789E+02	5.4603E+01	6.5954E+01
	5.2606E-02	-3.2387E-01	7.4391E-01	3.7647E-01	4.5473E-01
19	1.4607E+01	-8.9408E+01	8.3077E+01	1.0401E+02	1.6972E+02
	1.0071E-01	-6.1645E-01	5.7280E-01	7.1716E-01	1.1702E+00
20	2.8480E+00	-1.0012E+02	-6.3027E+01	1.0297E+02	1.9318E+02
	1.9636E-02	-6.9030E-01	-4.3456E-01	7.0994E-01	1.3319E+00
21	5.8399E+00	-7.5225E+01	-6.8959E+01	8.1065E+01	1.2310E+02
	4.0265E-02	-5.1866E-01	-4.7546E-01	5.5892E-01	8.4872E-01
22	-2.2860E+01	-5.5165E+01	-4.5433E+01	3.2305E+01	5.0119E+01
	-1.5761E-01	-3.8035E-01	-3.1325E-01	2.2273E-01	3.4556E-01

Table 3-142. Case 3, Stress (psi/MPa)

Location	Sigma_1	Sigma_2	Sigma_3	Pm	Pb
1	1.1332E+02	-2.0167E+02	-1.7830E+01	3.1499E+02	4.5244E+02
	7.8130E-01	-1.3904E+00	-1.2294E-01	2.1717E+00	3.1195E+00
2	1.4456E+02	-3.1945E+02	-9.9536E+01	4.6401E+02	9.5345E+02
	9.9670E-01	-2.2025E+00	-6.8628E-01	3.1992E+00	6.5738E+00
3	1.0883E+02	-1.9587E+02	-1.1934E+01	3.0470E+02	4.4224E+02
	7.5036E-01	-1.3504E+00	-8.2283E-02	2.1008E+00	3.0492E+00
4	6.9648E+02	-2.1058E+03	-4.1724E+02	2.8022E+03	5.4835E+03
	4.8021E+00	-1.4519E+01	-2.8768E+00	1.9321E+01	3.7807E+01
5	7.3302E+02	-2.4089E+03	-7.8913E+02	3.1419E+03	4.9727E+03
	5.0540E+00	-1.6609E+01	-5.4409E+00	2.1663E+01	3.4285E+01
6	1.1040E+02	-1.2142E+03	-1.0213E+03	1.3246E+03	1.7067E+03
	7.6121E-01	-8.3716E+00	-7.0419E+00	9.1328E+00	1.1767E+01
7	-2.1151E+01	-4.2187E+02	3.0050E+01	4.0072E+02	5.1802E+02
	-1.4583E-01	-2.9087E+00	2.0719E-01	2.7629E+00	3.5716E+00
8	-2.2697E+01	-4.1929E+02	-8.1965E-01	3.9660E+02	4.9239E+02
	-1.5649E-01	-2.8909E+00	-5.6513E-03	2.7344E+00	3.3949E+00
9	-2.0069E+01	-4.2351E+02	2.3821E+01	4.0344E+02	5.2751E+02
	-1.3837E-01	-2.9200E+00	1.6424E-01	2.7816E+00	3.6370E+00
10	1.0335E+02	-4.4853E+02	-3.3947E+02	5.5188E+02	1.1988E+00
	7.1255E-01	-3.0925E+00	-2.3405E+00	3.8050E+00	8.2654E-03
11	1.0720E+02	-2.2665E+02	-2.4470E+02	3.3385E+02	1.8718E+02
	7.3910E-01	-1.5627E+00	-1.6871E+00	2.3018E+00	1.2906E+00
12	1.2235E+01	-1.3838E+02	-1.2779E+02	1.5061E+02	2.1751E+02
	8.4356E-02	-9.5409E-01	-8.8110E-01	1.0384E+00	1.4996E+00
13	3.8109E+00	-8.7929E+02	-2.9444E+02	8.8310E+02	9.4655E+02
	2.6275E-02	-6.0625E+00	-2.0301E+00	6.0887E+00	6.5262E+00
14	1.4413E+01	-7.5512E+02	-1.5131E+02	7.6954E+02	5.5921E+02
	9.9376E-02	-5.2064E+00	-1.0432E+00	5.3058E+00	3.8556E+00
15	2.3622E+02	-2.9365E+02	-2.7933E+01	5.2987E+02	8.9787E+02
	1.6287E+00	-2.0246E+00	-1.9259E-01	3.6533E+00	6.1906E+00
16	6.9144E+01	-1.3625E+02	-3.8755E+01	2.0539E+02	3.3867E+02
	4.7673E-01	-9.3939E-01	-2.6721E-01	1.4161E+00	2.3350E+00

17	3.0430E+01	-9.3259E+01	2.3069E+00	1.2369E+02	2.1560E+02
	2.0981E-01	-6.4300E-01	1.5906E-02	8.5281E-01	1.4865E+00
18	8.1408E+00	-5.0305E+01	1.1570E+02	5.8446E+01	7.0571E+01
	5.6129E-02	-3.4684E-01	7.9773E-01	4.0297E-01	4.8657E-01
19	1.5492E+01	-9.5652E+01	8.9411E+01	1.1114E+02	1.8136E+02
	1.0681E-01	-6.5950E-01	6.1647E-01	7.6631E-01	1.2505E+00
20	2.8083E+00	-1.0699E+02	-6.7307E+01	1.0980E+02	2.0545E+02
	1.9362E-02	-7.3769E-01	-4.6406E-01	7.5706E-01	1.4165E+00
21	1.1268E+01	-6.6794E+01	-5.5199E+01	7.8062E+01	1.3120E+02
	7.7691E-02	-4.6053E-01	-3.8058E-01	5.3822E-01	9.0459E-01
22	-2.4790E+01	-5.9183E+01	-4.8922E+01	3.4393E+01	5.6968E+01
	-1.7092E-01	-4.0805E-01	-3.3730E-01	2.3713E-01	3.9278E-01

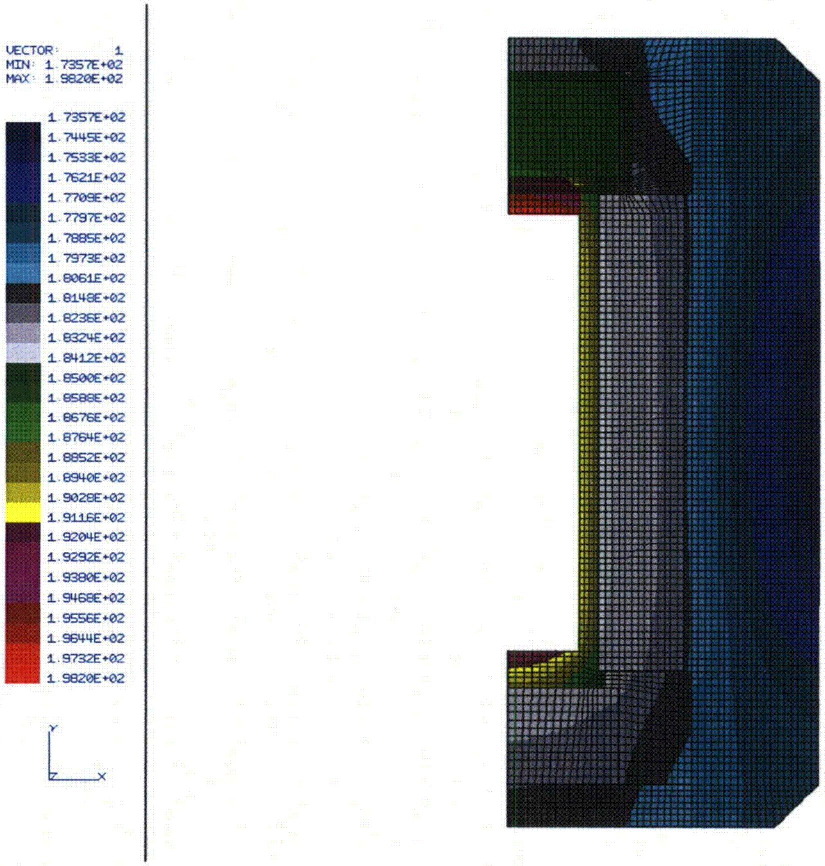

Figure 3-178. Case 1 – Temperature

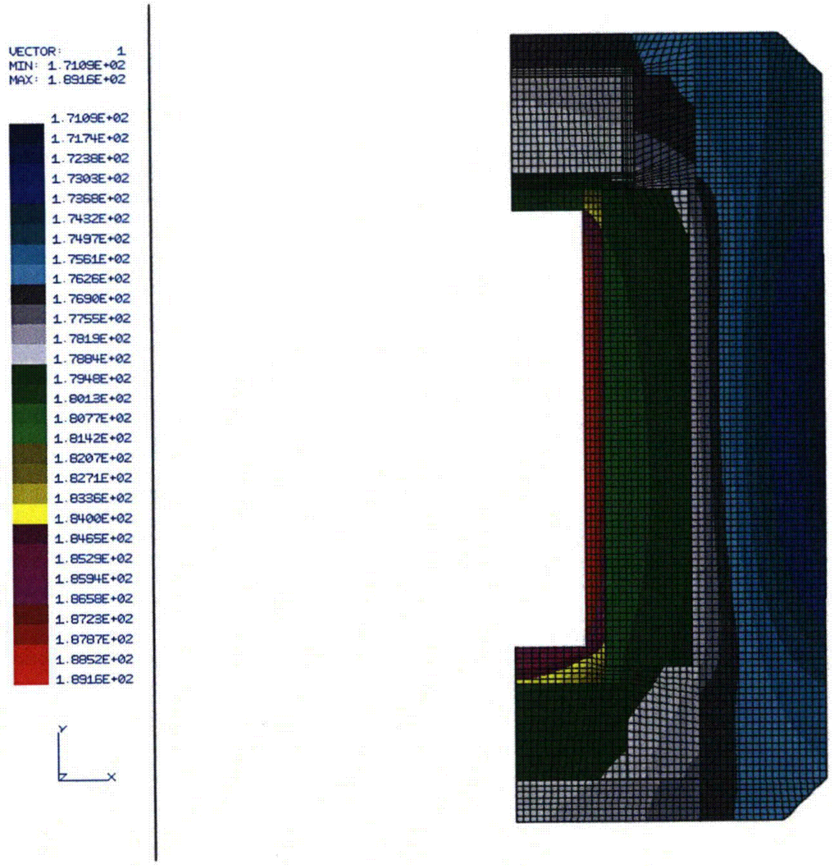

Figure 3-179. Case 2 – Temperature

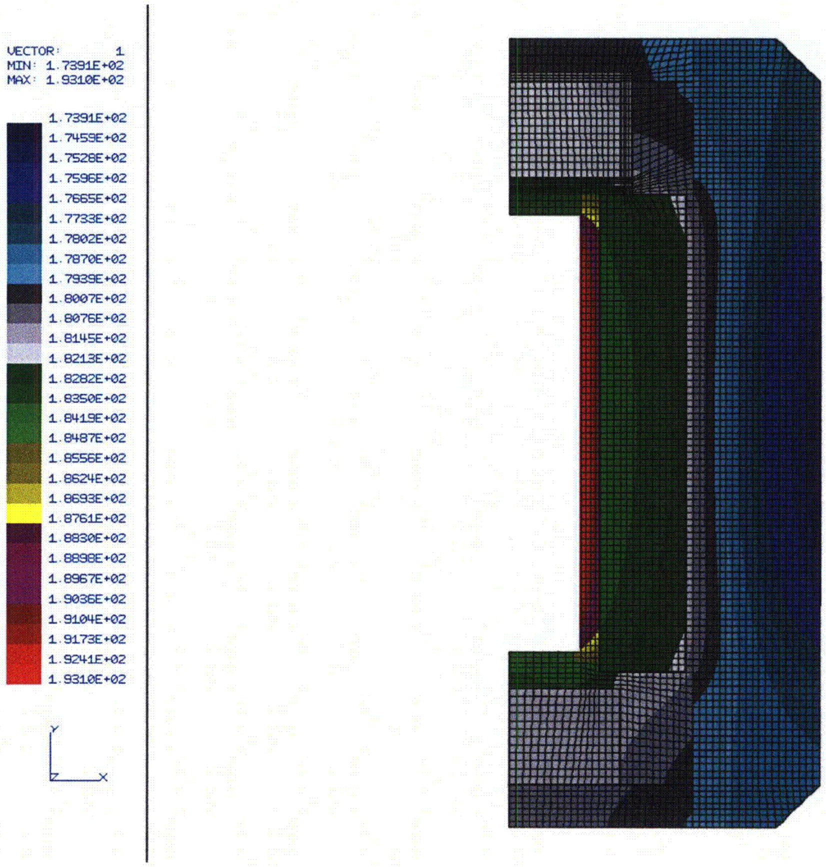

Figure 3-180. Case 3 – Temperature

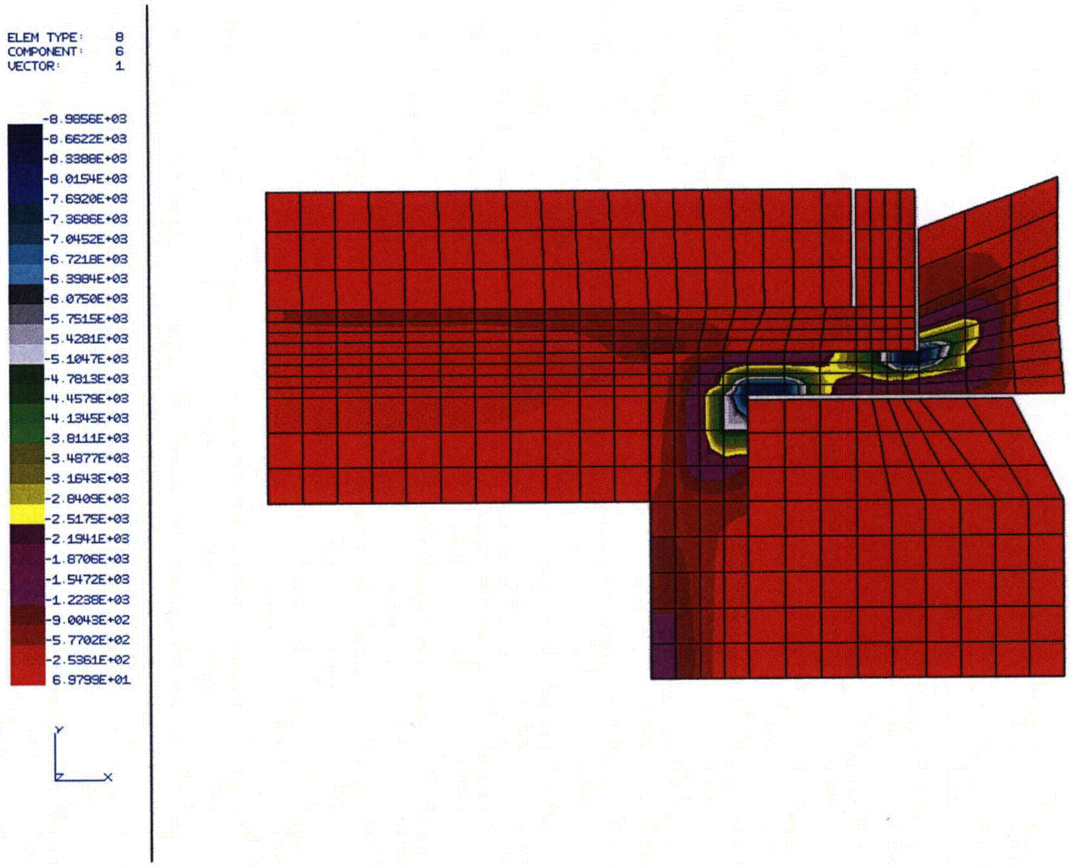

Figure 3-181. Case 1 – Maximum Principal Stress at Cask Lid Corner

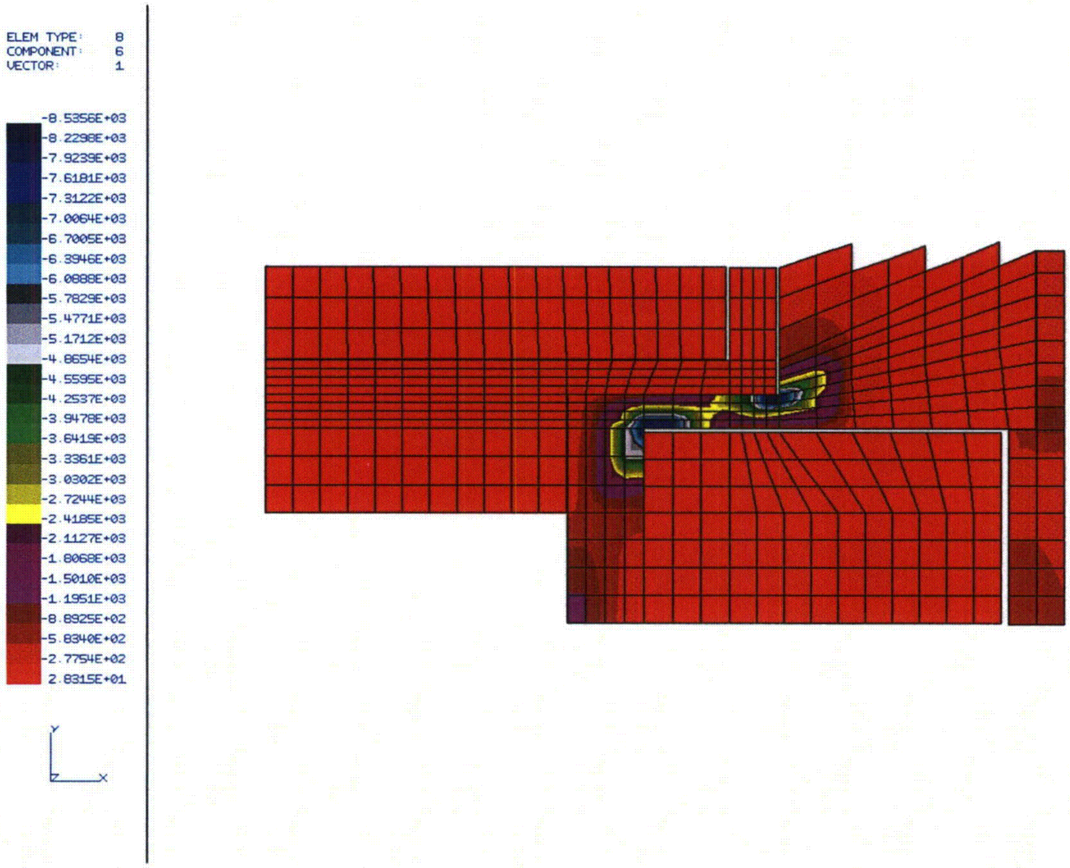

Figure 3-182. Case 2 – Maximum Principal Stress at Cask Lid Corner

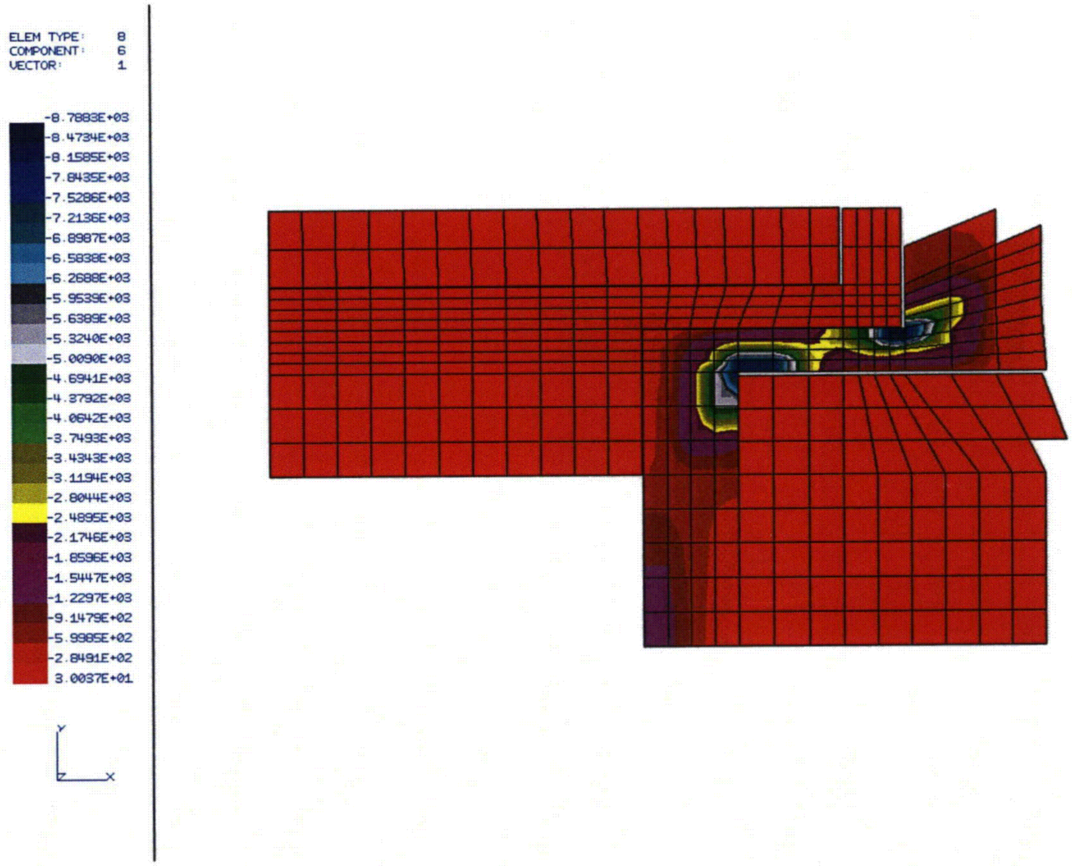

Figure 3-183. Case 3 – Maximum Principal Stress at Cask Lid Corner

3.5.7 Thermal Tests

The thermal test described here provides a comparison between the normal cask and thermal test cask configurations.

A thermal test is performed to evaluate the analytical model used, to demonstrate compliance with the thermal regulatory environments. The test results are compared with the results of the analytical model subjected to the same environment as the test.

3.5.7.1 Test Setup Discussion

Test setup consists of concentrically placing an electrical heat source within the cask cavity. Temperature-sensing devices are strategically placed:

- At various locations within the cask cavity
- On exterior surfaces of the cask
- Within the environment surrounding the cask

The heat source is turned on to a value equal to or greater than the decay heat value of the radioactive source proposed for the cask. (A 7-kW source is used in this test.) Temperature data is recorded at a minimum interval of one (1) minute during the transient event, until the cask reaches a steady state and remains significantly unchanged for approximately one (1) hour. This completes the "heating cycle." Thereafter, the heat source is turned off, to allow the cask to cool down. The "cool-down cycle" is also recorded, as in the previous cycle. Refer to Figure 3-184 for a typical thermal test setup.

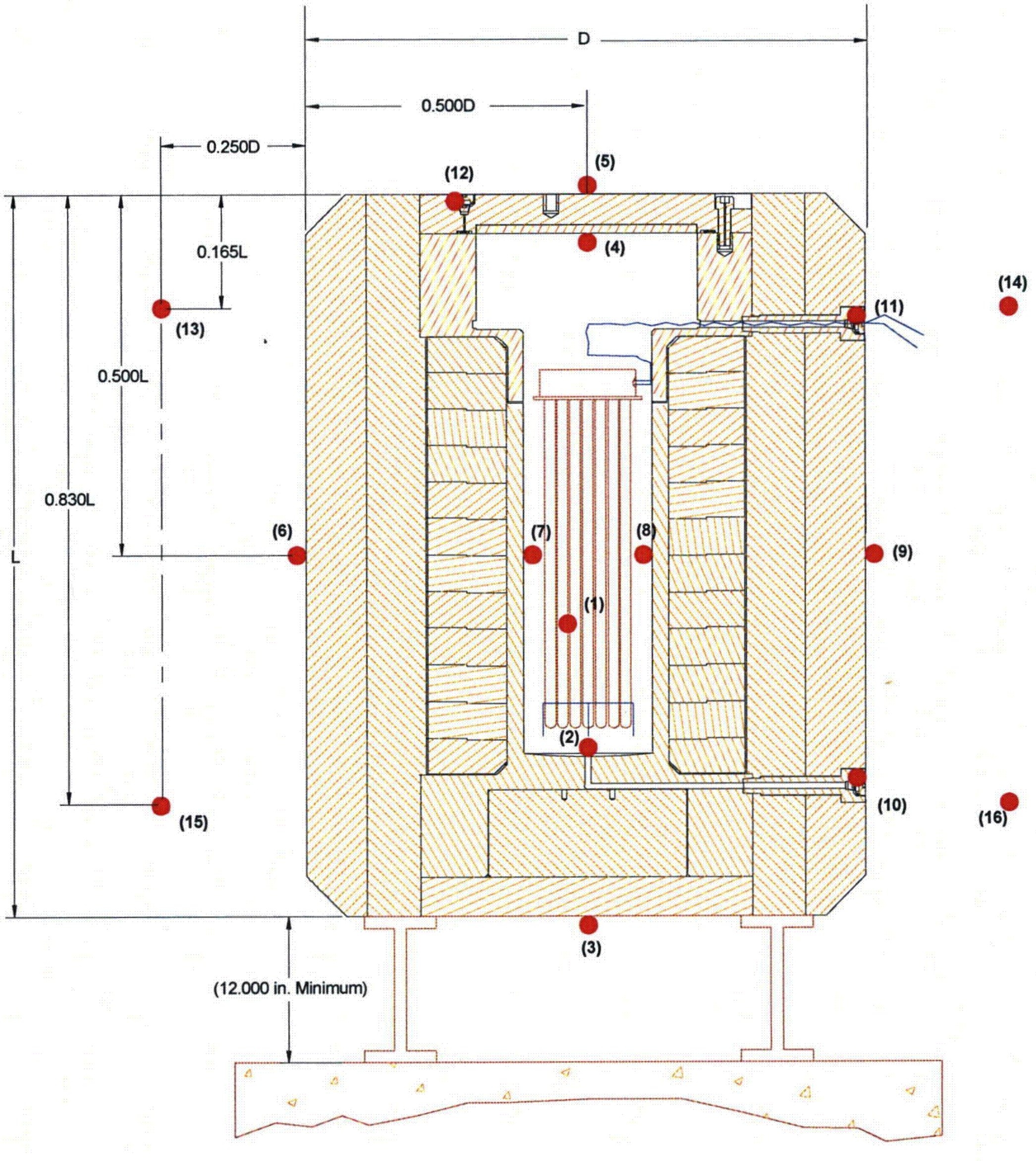

Figure 3-184. Typical Thermal Test Setup

Notes: *The numbered red dots in Figure 3-184 represent thermocouple locations.*

The cask lid plug component is removed, to allow the heater power wire to exit the cask body.

3.5.7.2 Test Cask Analytical Model

The physical cask test item consists of five components:

- Cask outer shell
- Cask cavity shell
- Cask lid
- Bottom plate
- Shielding (located on bottom and side of the cask)

The test cask is larger than the Model AOS-100A cask by a factor of 1.65, and all components are constructed of the same materials as the Model AOS-100A components, also increased by a factor of 1.65. The cask outer shell is made with two parts that are tied together by a shrinkfit procedure. The analytical model matches all component physical dimensions of the test cask. The cask outline height is 59.4 inches, with a diameter of 46.2 inches.

The material used to make the test cask is type 304 stainless steel (SS304). The material used for the shielding is tungsten alloy. Material properties used in this analysis are described in Subsection 3.2.1, "Material Properties." Temperature varying properties are used in this analysis.

The thermal test is conducted with the test cask in a vertical position. Gaps between the cask and the tungsten alloy vertical walls are packed with stainless steel wool, and their locations are shown in Figure 3-185. Packed steel wool conductive and density thermal properties are assumed to be approximately 10% that of SS304 material, and its specific heat is approximated to be that of air.

K = 0.068 Btu/hr-in-°F

Cp = 0.24 Btu/lb-°F

Density = 0.029 lb/in^3

Two (2) gaps are included in the analysis model. A gap of 0.13 inches is located between the upper region of the side tungsten alloy shielding and cask cavity shell. A weld in the cask cavity shell requires a gap to be present. A second gap, 0.012 inches, is located between the cask outer shell and the cask lid/cask cavity shell. The gap is defined by the fabrication drawing. Gap locations are shown in Figure 3-185.

All other interface surfaces are assumed to have no gap. Heat transfer between components is by contact resistance. For the shrinkfit interface, a low-contact resistance is used, which reflects a much higher interface pressure. Contact resistance surfaces are shown in Figure 3-185.

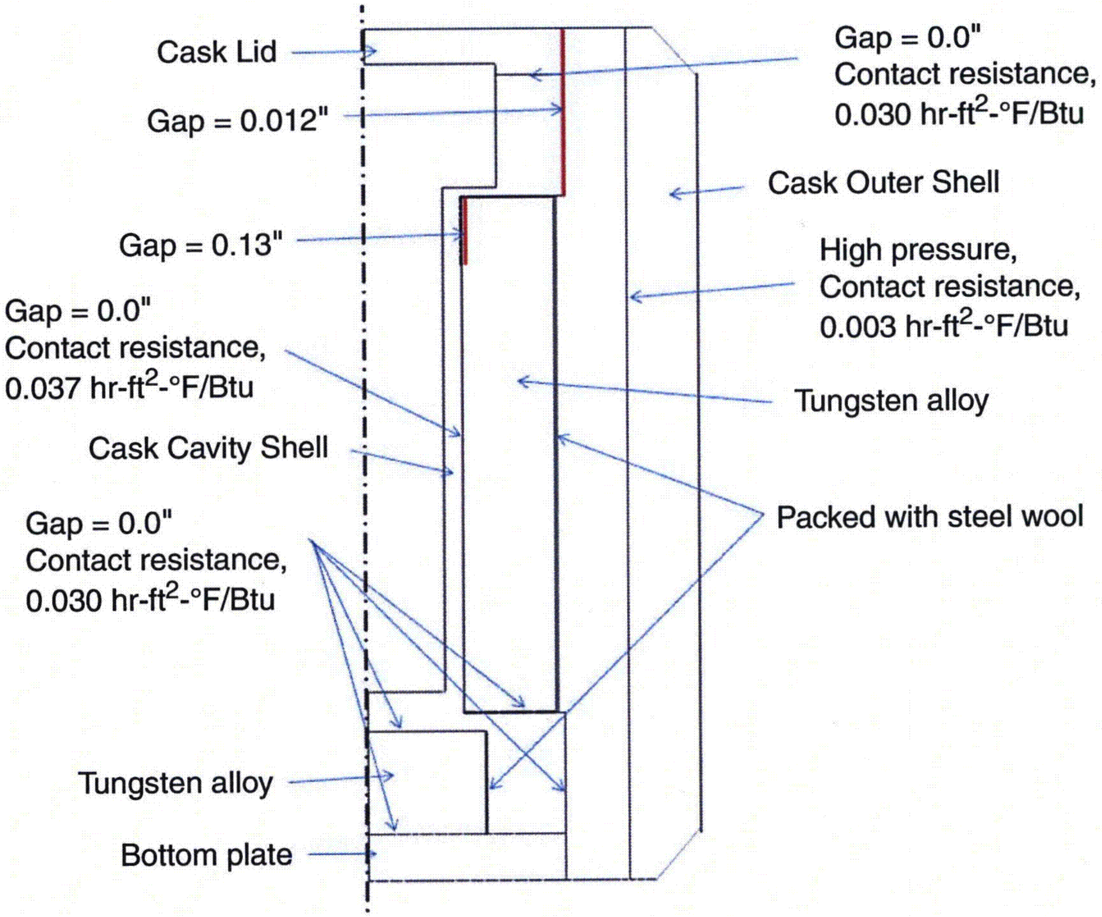

Figure 3-185. Test Cask Modeling Features

3.5.7.3 Test Procedure

The 7-kW heat source is placed in the cask cavity, and the resulting temperatures are recorded until the system reaches steady state. The test is conducted inside a 3m L × 3m W × 3m D (10 ft. L × 10 ft. W × 10 ft. D) pit, to maintain the ambient temperature as constant as possible during the entire test. The instrumented cask sits upon a fiber steel wool insulation pad, on top of a 46-cm (18-in.)-high carbon steel pedestal located inside the pit. Figure 3-186 illustrates the instrumented cask inside the pit. Temperature data is recorded once per minute with a data acquisition system permitting easy analysis and plotting of the results, until the temperature remains significantly unchanged. The heat source is then turned off and data is recorded once per minute, until the system temperature returns close to the initial ambient condition.

Figure 3-186. Instrument Cask Inside Pit

3.5.7.4 Acceptance Criteria

Thermal test results are provided in Figure 3-187 through Figure 3-190. Figure 3-187 and Figure 3-188 illustrate the heat cycle test results. Figure 3-189 and Figure 3-190 illustrate the cooling cycle test results.

A verification analysis was performed. An axisymmetric (2D) model of the test article is analyzed with a 7-kW heat source, illustrated in Figure 3-191. Figure 3-192 illustrates its heat cycle boundary conditions, and Figure 3-193 illustrates its cooling cycle boundary conditions.

The eight (8) thermocouples located on the test cask – TC 3, 4, 5, 6, 7, 10, 11, and 12 – are used for comparing test results with analysis. (Refer to Figure 3-184.) Thermocouple temperature comparison results are provided in Figure 3-194 through Figure 3-201.

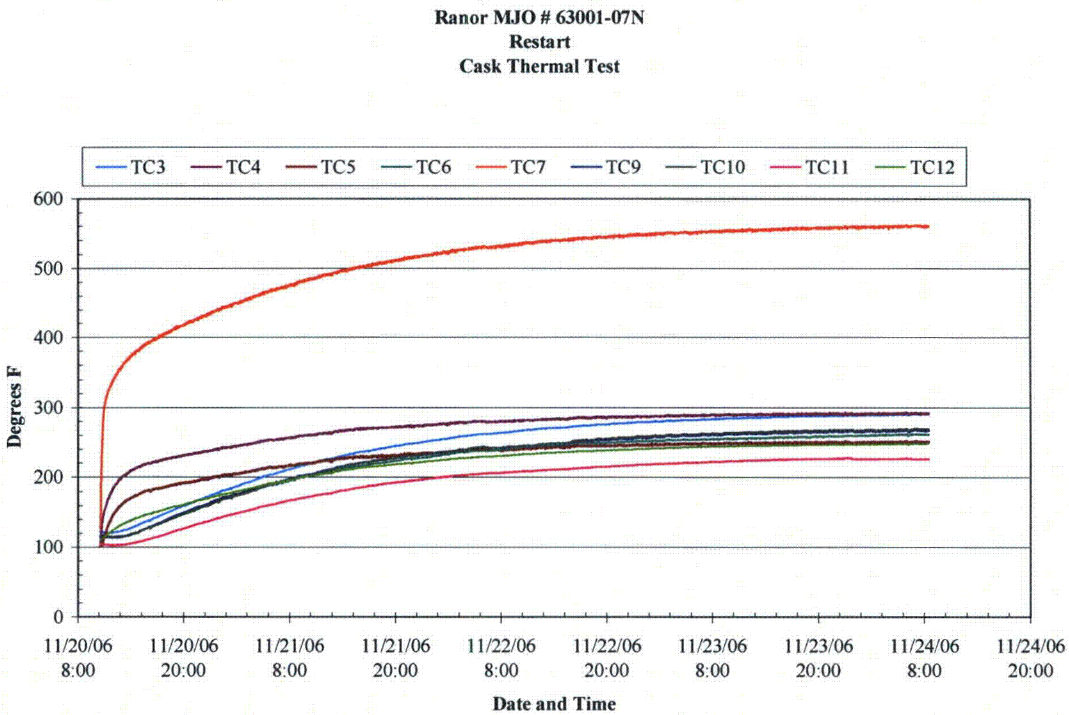

Figure 3-187. Temperature versus Time – Heat Cycle for Thermocouples 3 through 12

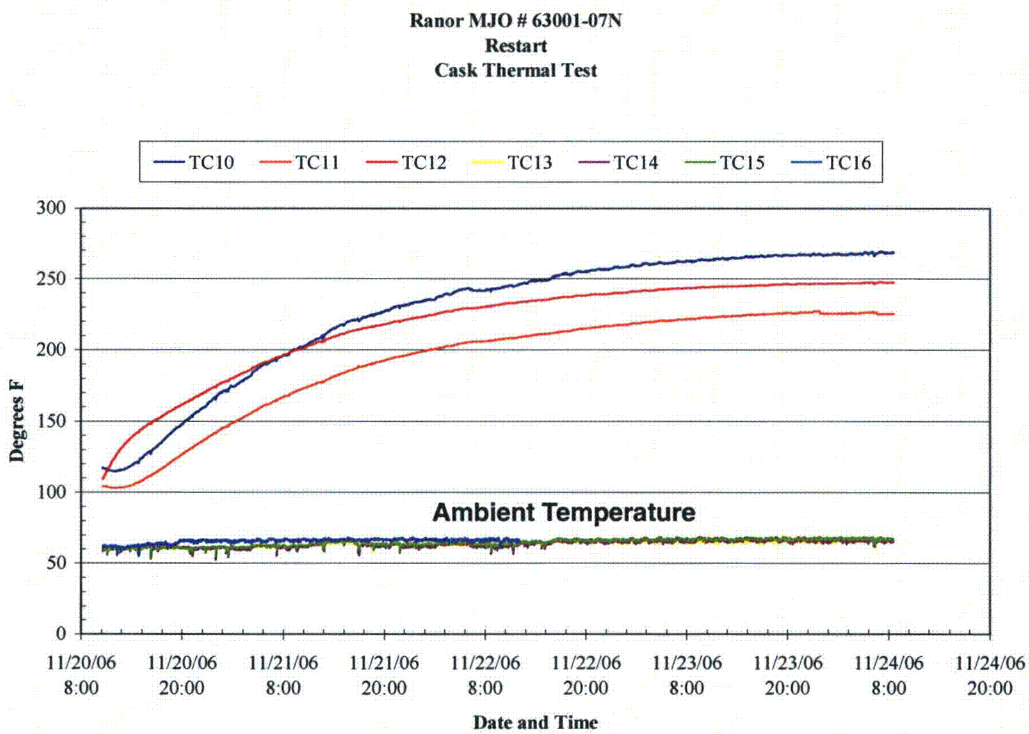

Figure 3-188. Temperature versus Time – Heat Cycle for Thermocouples 10 through 16

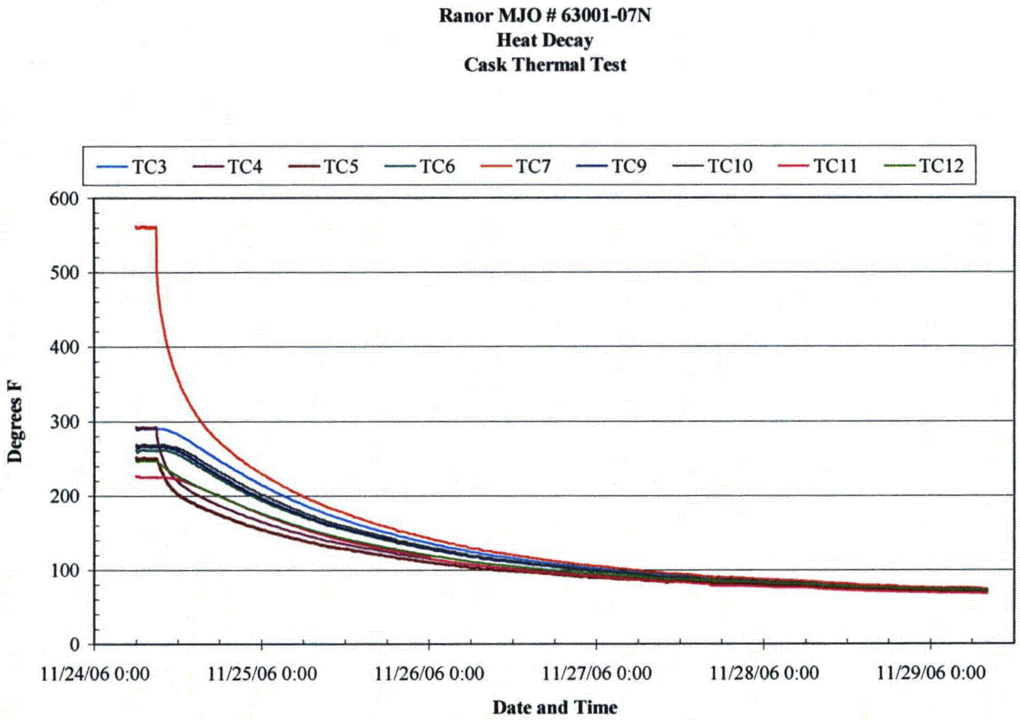

Figure 3-189. Temperature versus Time – Cooling Cycle for Thermocouples 3 through 12

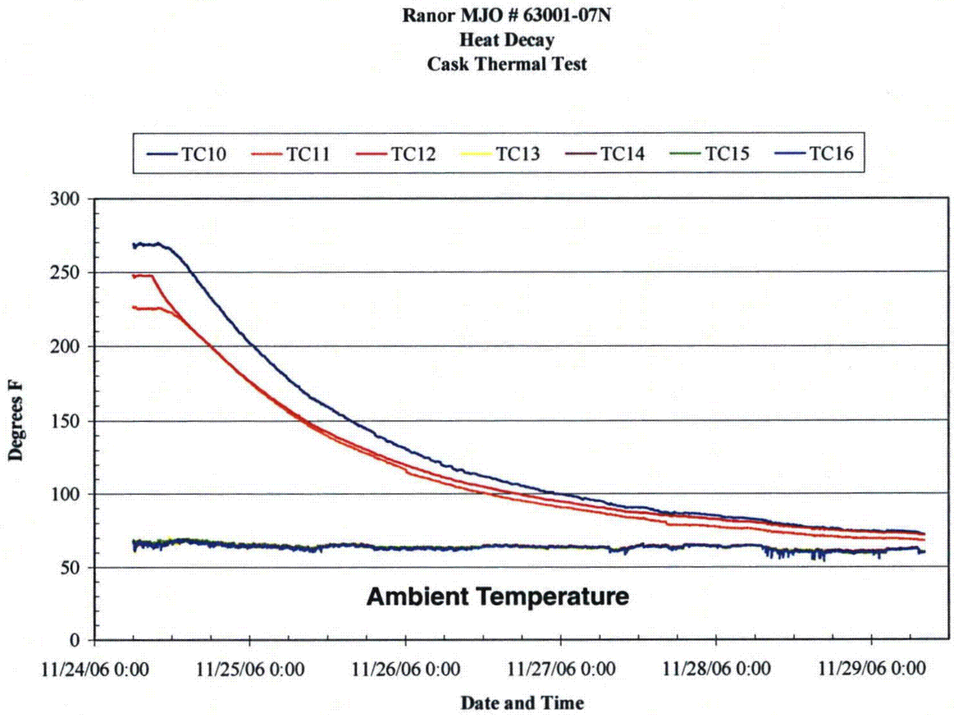

Figure 3-190. Temperature versus Time – Cooling Cycle for Thermocouples 10 through 16

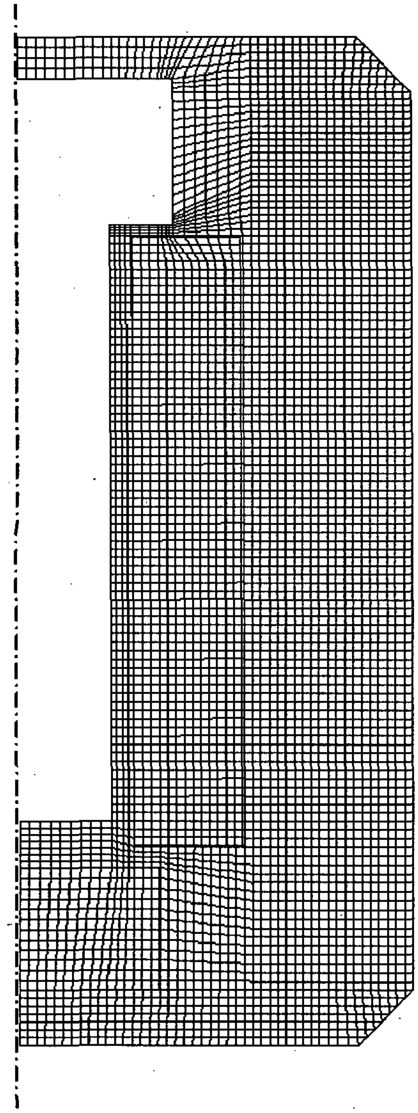

Figure 3-191. Verification Analysis – Axisymmetric (2D) Model of Test Cask

Boundary Conditions during Test Heat Up

A constant heat load of 7,000W (23,891 BTU/hr) is applied during the heat up phase. The applied heat flux for each surface is:

Surface	Heat flux (BTU/hr-in^2)
1	9.0
2	4.5
3	37.8
4	1.3
5	11.0
6	7.5

The outer convective surface has properties that are assumed to be constant during the heat up portion of the test:

Surface	Convective Property (BTU/hr-in^2-F)
1	0.0025
2	0.0060
3	0.0100
4	0.0135
5	0.0130
6	0.0130
7	0.0345

Ambient temperature is 17.78°C (64°F).
Initial cask temperatures are set to 45.56°C (114°F).

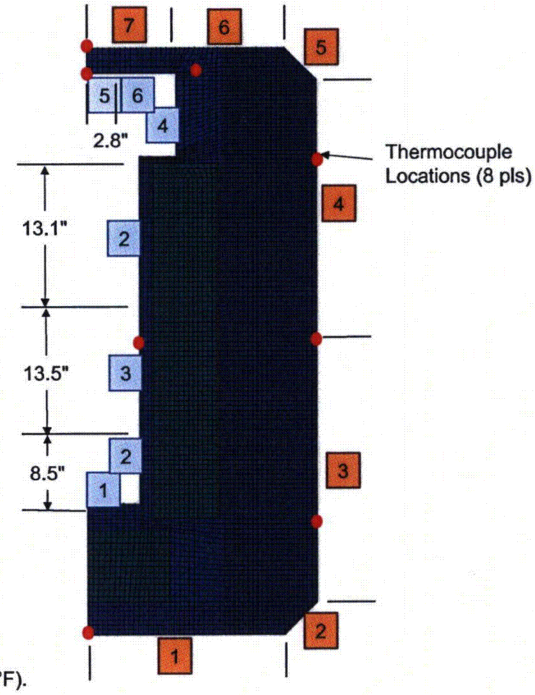

Figure 3-192. Verification Analysis – Heat Cycle Boundary Conditions

Boundary Conditions during Test Cool Down

The heat load of 7,000W (23,891 BTU/hr) is removed during the cool down phase.

The outer convective surface has properties that are assumed to be constant during the cool down portion of the test:

Surface	Convective Property (BTU/hr-in^2-F)
1	0.0025
2	0.0060
3	0.0100
4	0.0100
5	0.0100
6	0.0100
7	0.0200

Ambient temperature is 17.78°C (64°F).

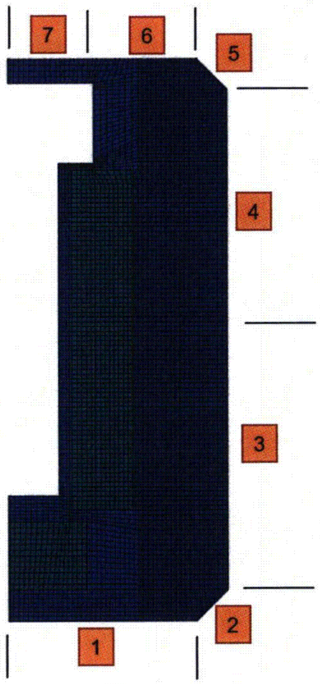

Figure 3-193. Verification Analysis – Cooling Cycle Boundary Conditions

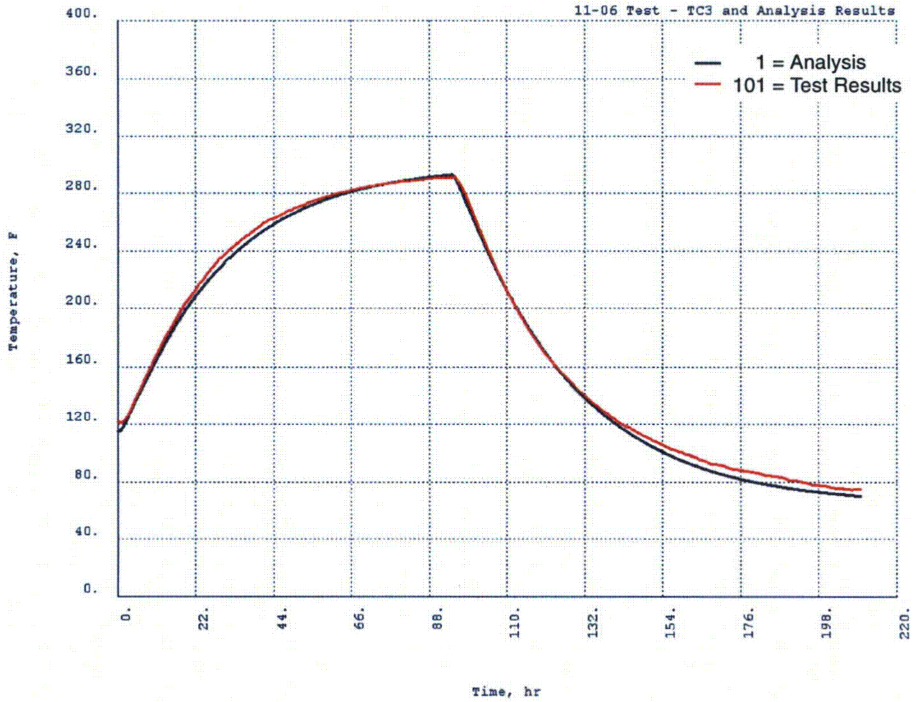

Figure 3-194. Comparison Test Data versus Analytical Results – Center, Cask Bottom

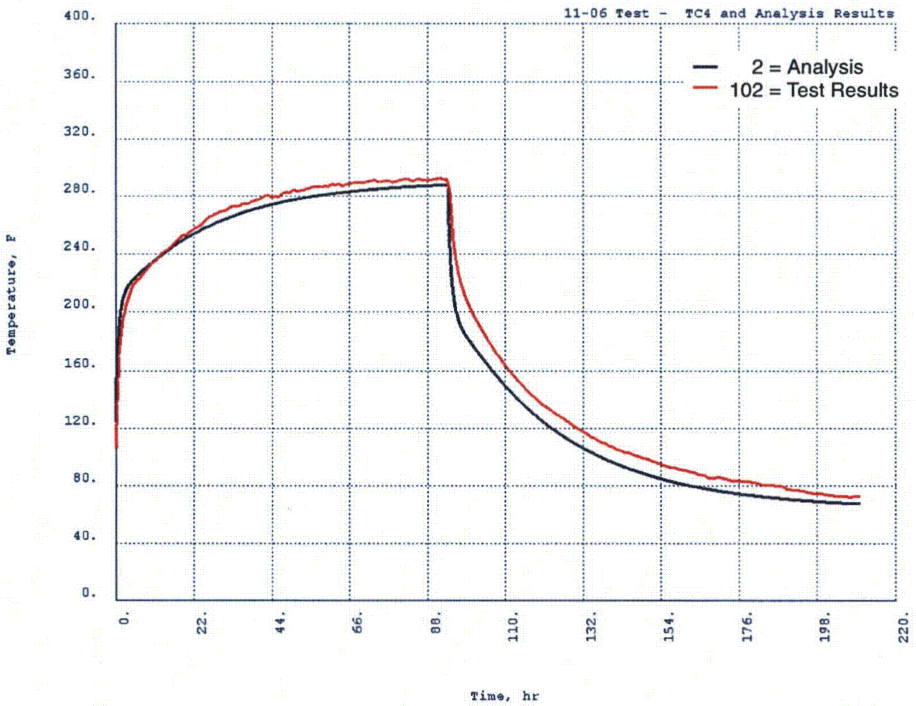

Figure 3-195. Comparison Test Data versus Analytical Results – Center, Inside Cask Lid Surface

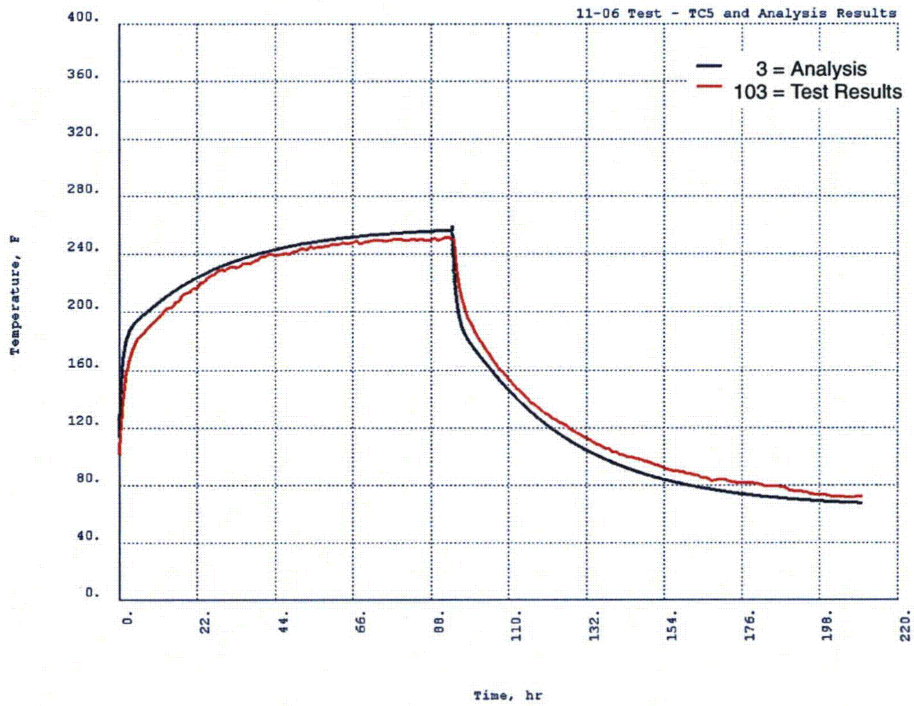

Figure 3-196. Comparison Test Data versus Analytical Results – Center, Outside Cask Lid Surface

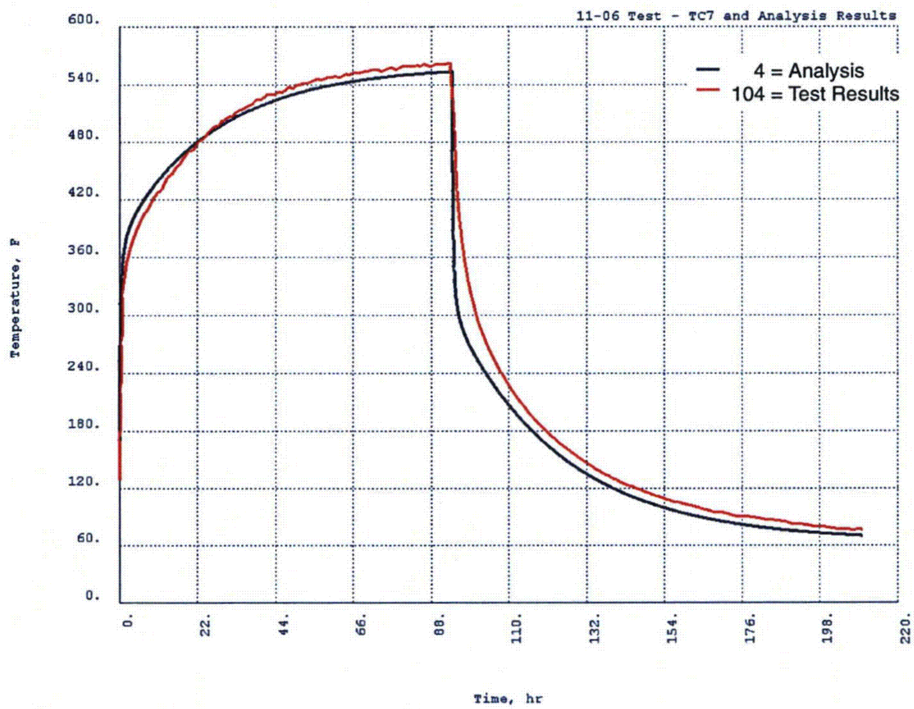

Figure 3-197. Comparison Test Data versus Analytical Results – Middle, Cask Cavity Wall

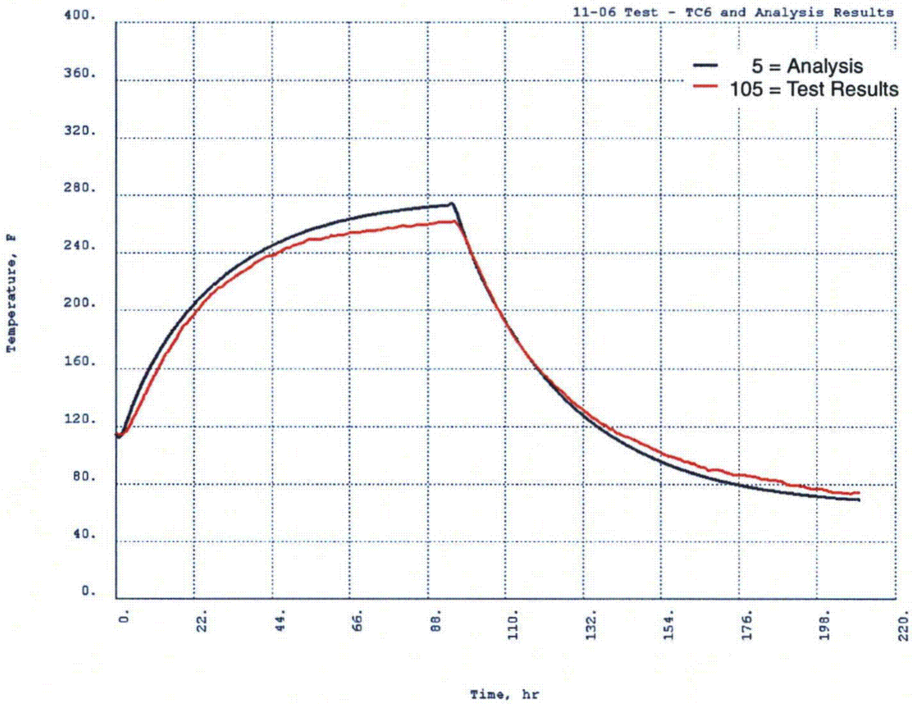

Figure 3-198. Comparison Test Data versus Analytical Results – Middle, Outside Wall

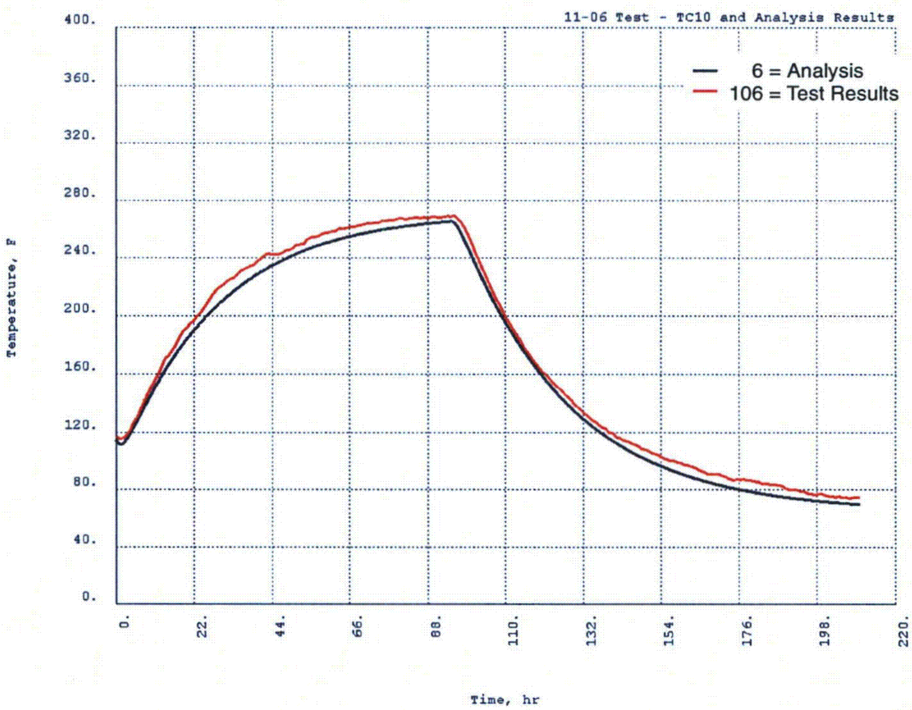

Figure 3-199. Comparison Test Data versus Analytical Results – Cask Drain Port Area

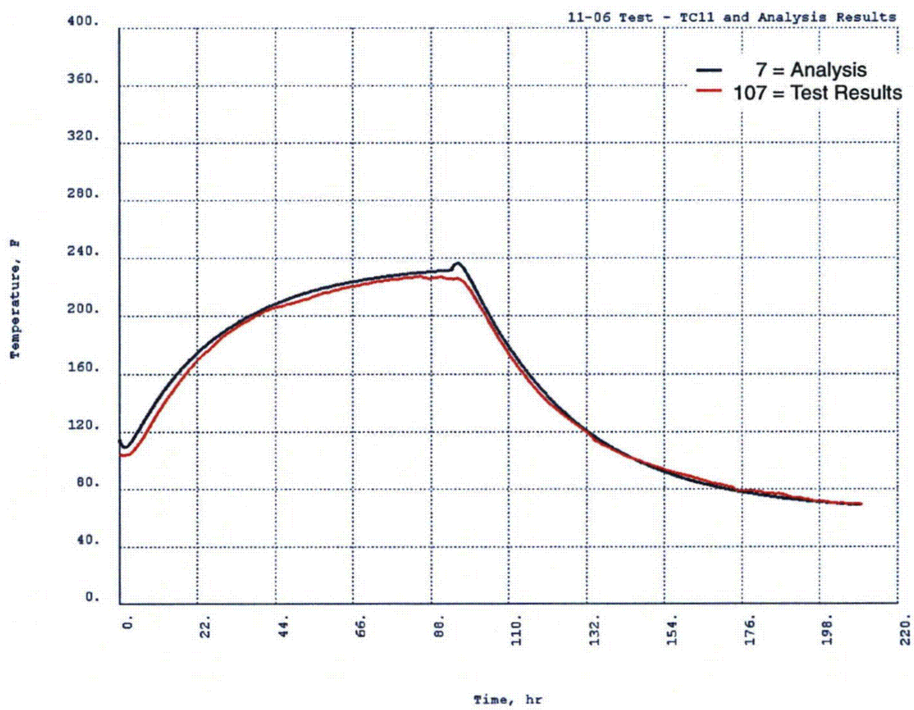

Figure 3-200. Comparison Test Data versus Analytical Results – Cask Vent Port Area

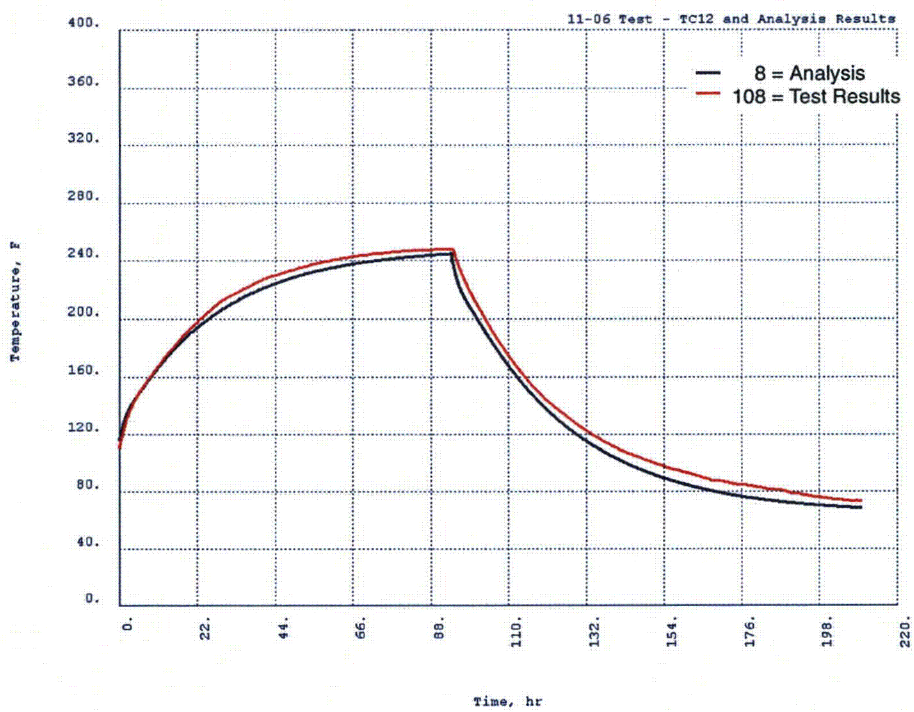

Figure 3-201. Comparison Test Data versus Analytical Results – Test Port Area

3.5.8 Heat Test Report – AOS-165A Prototype

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NTS

Report No. TR63001-07N
Revision 0

Total number of pages =418

Testing performed by:
National Technical Systems
533 Main Street
Acton, MA 01720

Testing performed for:
RANOR, Inc.
1 Bella Drive
Westminster, MA 01473

TEST REPORT
for
THERMAL CONDUCTIVITY TESTING
on
AOS-165 CASK ASSEMBLY

Purchase Order No. 108533

Prepared by: Charles R. Pilotte **Date:** 12DEC06
Charles R. Pilotte, Program Manager
NTS Products Group

Reviewed and Approved by: **Date:** 12 December 2006
Independent Reviewer
NTS Products Group

Reviewed and Approved by: **Date:** 12/12/06
Quality Management Representative
NTS Products Group

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TABLE OF CONTENTS

SECTION **PAGE NOS**

NTS

ABSTRACT

The report contained herein provides details on the testing that was performed on the AOS-165 cask assembly. The intent of the program was to gather test data on the behavior of the cask pertaining to heat load loss versus time. The internal surfaces and external surfaces of the cask had type J thermocouples spot welded at designated locations and interfaced with a data acquisition system. In addition, a heater externally controlled by a DC power supply was inserted within the cask to provide for a constant 7,000 watt load ± 70. Voltage and current going to the heater was recorded at the same interval as the thermocouple data. The interval of recording was set to once every minute. The heater wattage was calculated by the data logger multiplying the applied volts DC by the current being drawn.

Starting at room temperature conditions a constant 7,000 watt heat load was applied and the cask allowed sufficient time to stabilize in regards to the temperature gradient. Once stabilization was achieved, the heat load was removed and the temperatures of the cask allowed to decay back to ambient temperatures. Heat stabilization runs had to be performed twice as a result of the data logger not running during the first heat decay run attempt.

All data acquired is presented within this report, both in tabular format and charts of temperature versus time

NTS

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NTS

1.0 INTRODUCTION AND SCOPE

The purpose of this test report is to present the methodology that was utilized in performance of heat transfer testing of the AOS-165 Cask Assembly as described in Section 3.0 of this report. The objective of the testing was to obtain transient and steady state temperature data with a known heat input for verifying conformance to thermal requirements and modeling of the cask.

The cask body detailed within Section 3.0 was made available at the fabricator's facility for the purpose of performing the thermal testing.

The fabricator RANOR Inc. provided the floor space and crane facilities to support the testing effort. National Technical System (NTS) personnel were allowed access to the fabricator's facility to survey the site and for performance of the thermal testing. The facility made available 480VAC, 3 phase power for interfacing with NTS power controls. Section 4.0 of this report describes in detail the procedure that was used during the test. NTS was responsible for providing the following activities.

- 16 type J thermocouples including mounting.
- Variable regulated power source for operation of heater.
- Data acquisition system for recording thermocouples and power characteristics to the heater.

All work conducted was accordance with NTS Corporate Quality Policy Manual Revision 4 dated 21 March, 2006. This program fulfills the requirements of 10CFR50, Appendix B, and 10CFR, Part 21.

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2.0 APPLICABLE REFERENCE DOCUMENTS

2.1 NTS Corporate Quality Policy Manual Revision 4, dated 21 March, 2006.

2.2 NTS Quotation No. A-0606-1991-1 dated 29 June, 2006.

2.3 RANOR Inc. purchase order 108533 dated 23 August, 2006.

2.4 GE Nuclear Specification Number 2249423 Rev 0, "AOS Cask Thermal Acceptance Test"

2.5 NTS Test Procedure TP63001-07N Revision 0 reviewed and approved by RANOR on 3 November, 2006.

2.6 NTS Standard Operating Procedure SOP NOR-CAL 19, Revision 0, "Calibration Verification Procedure for Thermocouples using Dry Well Temperature Calibrators"

3.0 ITEM DESCRIPTION

The test item is an"AOS-165 Cask Assembly". The cask tested under this program was manufactured by RANOR, Inc located in Westminster, MA. The original set-up was intended to be as shown in Figure 1. The actual configuration used is shown in Figure 2.

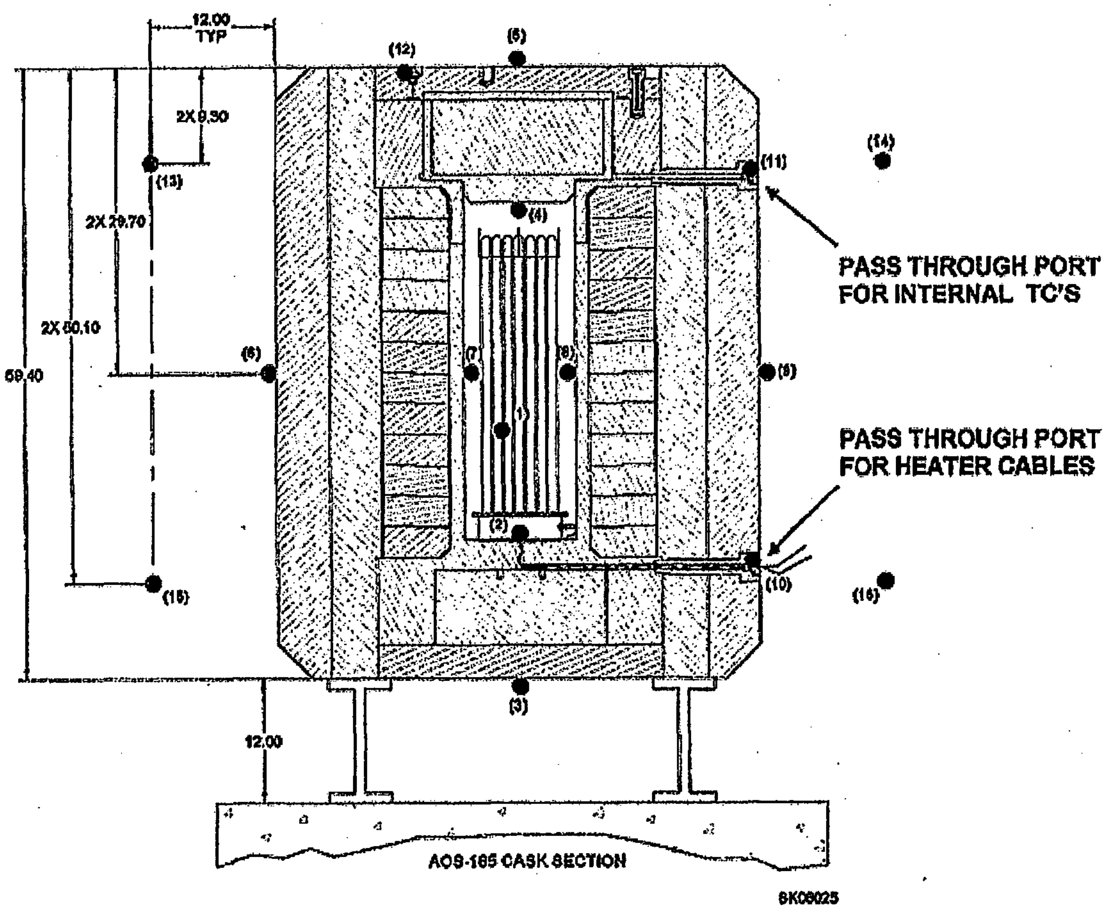


Figure 1

Test Report No. TR63001-07N
Revision 0
Section 3.0
Page 1 of 2

3.0 ITEM DESCRIPTION (continued)

In performing the set-up the hole at the bottom of the cask was too small to allow for routing of power cables to the heater. As a result per request by GE Nuclear personnel on site the installation of the heater was in its normal orientation and the power cables brought out through the upper side wall hole. Also, the clearance between the top plug insert and the cask was insufficient to allow for cables so per decision by GE Nuclear personnel the plug insert was not used.

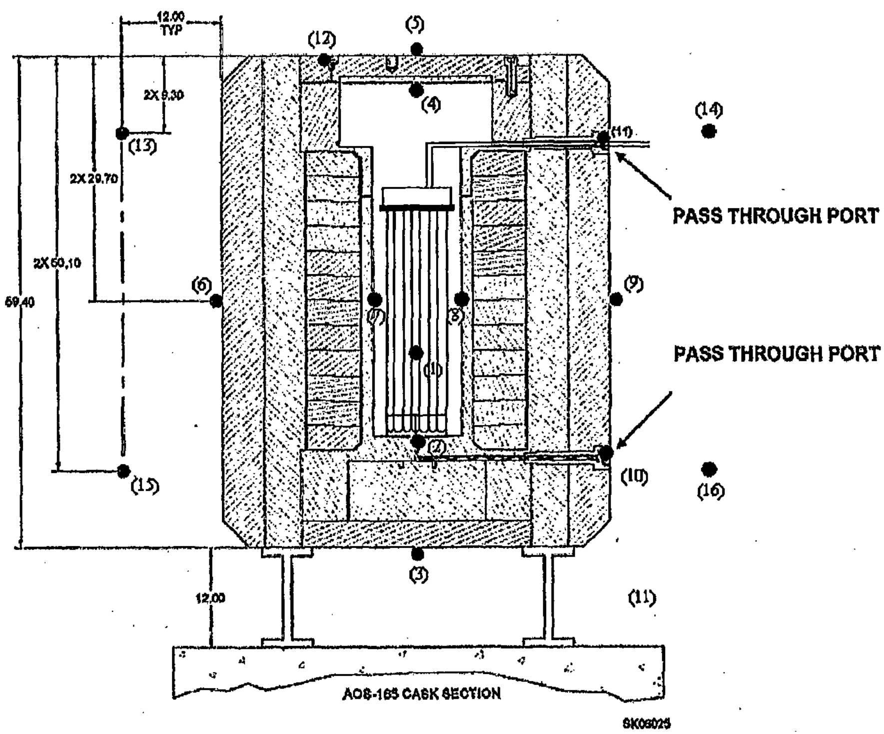
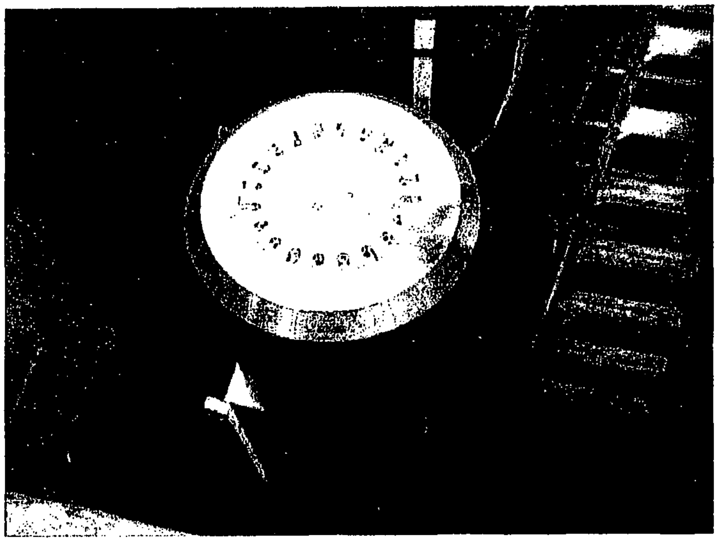


Figure 2

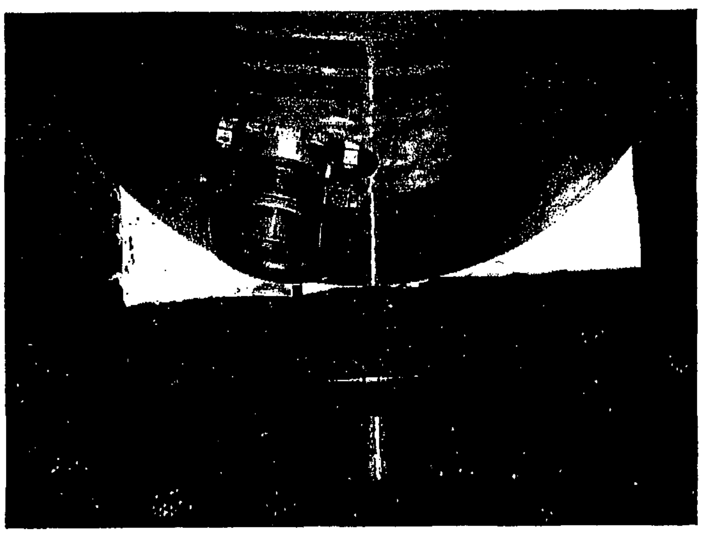
Test Report No. TR63001-07N
Revision 0
Section 3.0
Page 2 of 2

4.0 TEST SET-UP AND SEQUENCE

4.1 Photographs



Cask located down onto pit area

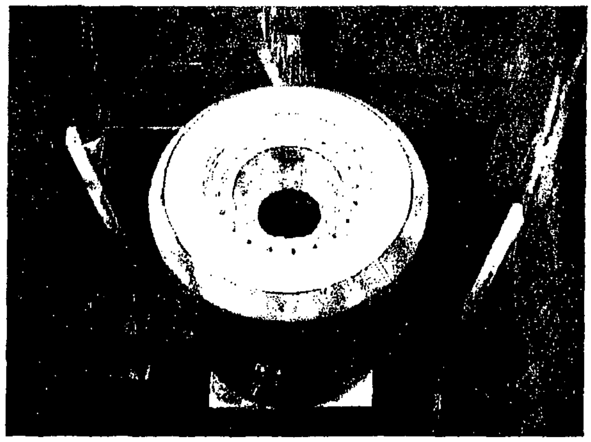


Cask sitting on fiber wool insulation

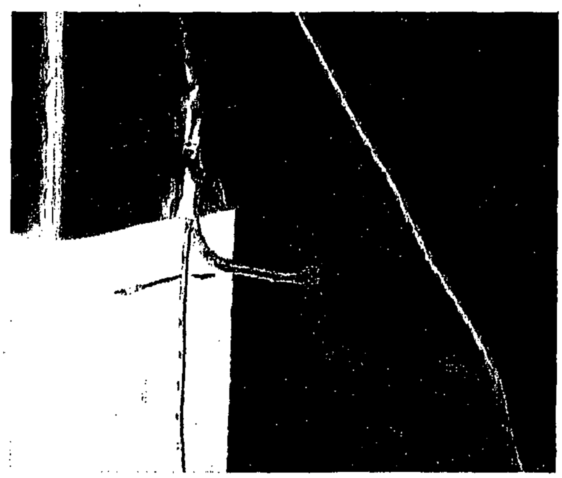
Test Report No. TR63001-07N
Revision 0
Section 4.0
Page No. 1 of 9

4.0 **TEST SET-UP AND SEQUENCE** (continued)

4.1 **Photographs**



Wooden stands placed on either side of cask for locating ambient thermocouples 13, 14, 15 & 16

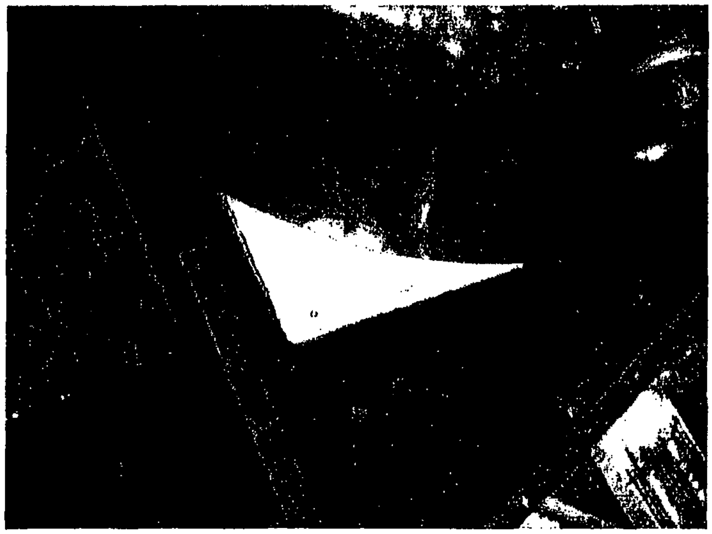


Close-up mounting of ambient thermocouples. Tip placed 12 inches from cask wall.

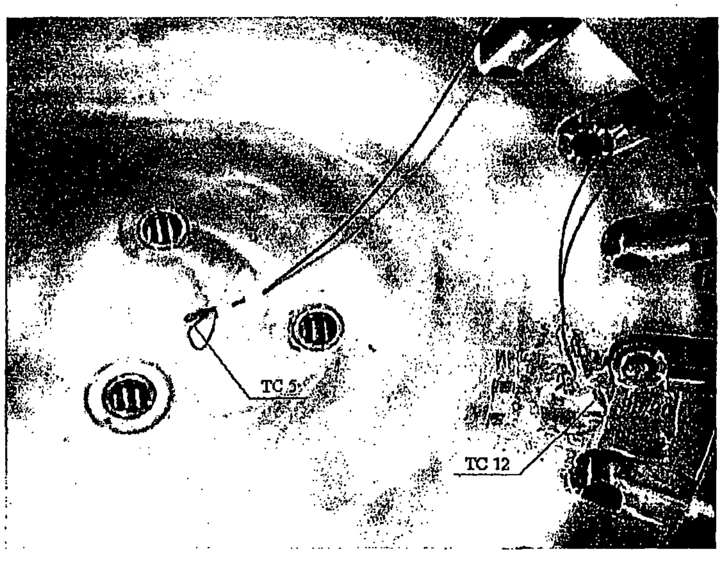
Test Report No. TR63001-07N
Revision 0
Section 4.0
Page No. 2 of 9

4.0 TEST SET-UP AND SEQUENCE (continued)

4.1 Photographs



Insulation pads between bottom of cask and I Beam support stands

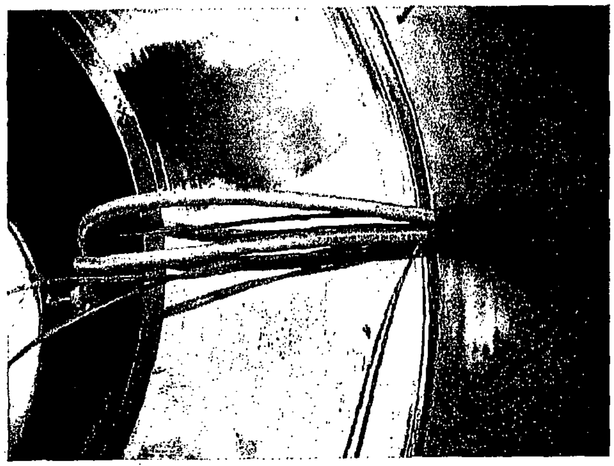


Thermocouples TC 5 and TC 12 on top of cask cover. TC 4 located on underside of cover and centered.

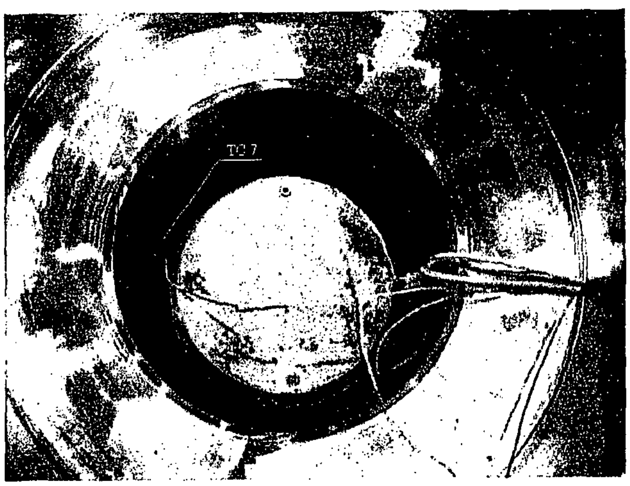
Test Report No. TR63001-07N
Revision 0
Section 4.0
Page No. 3 of 9

4.0 TEST SET-UP AND SEQUENCE (continued)

4.1 Photographs



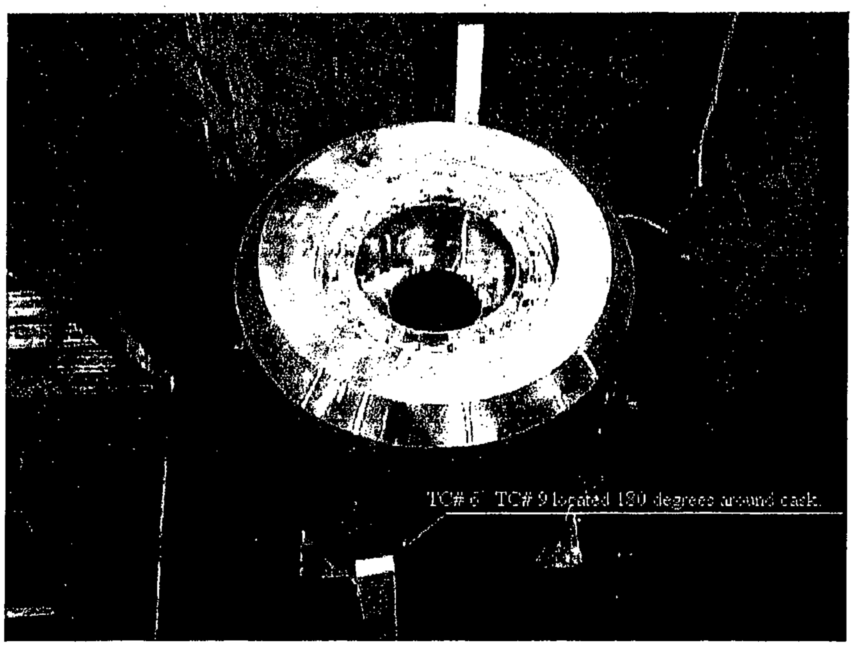
Wire feed through at top end of cask



Heater placed down inside of cask well. TC# 7 located 29.75 inches down from top of cask. TC#8 located 180 degrees around cask.

4.0 TEST SET-UP AND SEQUENCE (continued)

4.1 Photographs



TC# 7 location 29.75 inches down from top of cask.

4.2 Thermocouples

A total of 16 type J thermocouples were used made from "Special Limits of Error" type J thermocouple wire. The wire has double insulation glass fiber coating and is 24 solid AWG. Each thermocouple had a lead length of approximately 30 feet. One end of each wire was beaded (welded) and each TC wire was calibrated at NTS prior to installation. Placement of the thermocouples was per Figure 2.

4.0 TEST SET-UP AND SEQUENCE (continued)

4.3 Cask Placement and Thermocouple Installation

The cask was set in a pit at the RANOR Inc. facility. The pit provided for some protection against direct ambient air drafts.

All thermocouples measuring the cask were welded onto the cask. The location for thermocouples # 11 and 12 located at the entry of the top and bottom pass through ports had the ports stuffed with steel wool. This was done to provide a better medium for heat transfer within the through hole.

All thermocouple wires were terminated to a data acquisition system that acquired the data at 1 minute intervals throughout the duration of testing.

4.4 Heat Load

A heater capable of outputting a heat load of 7,000 watts was supplied by GE Nuclear, and located at the fabrication facility; and was placed internal to the cask. The heater was placed within the cask cavity to allow for the power lines to be fed out of the top through hole. The bottom through hole had a 90 degree bend which preventing the power cables from being snaked through. NTS provided a regulated DC voltage source such that the wattage being dissipated from the load remained at ± 70 watts from the desired value. The desired value was given as 7,000 watts.

4.0 TEST SET-UP AND SEQUENCE (continued)

4.4 Heat Load

The voltage supplied and current drawn by the heater was recorded at the same time and intervals as the thermocouple data. Watts was calculated as the product of volts times current via a math function within the data logger.

4.5 Load Testing

4.5.1 1st Heat Rise Test

Testing began at 20:08 on 13 November, 2006. A constant heat load of 7,000 ± 70 watts was applied to the cask until thermal stability was reached. Thermal stability was considered reached on 18 November, 2006 at 08:07 at which time the heat load was shut off to start the heat decay measurement.

On 20 November, 2006 when downloading data it was discovered that the data logger had been stopped on 18 November, 2006 at 08:07 and not restarted. This caused the heat decay test data to be lost. Notice of Deviation 001 was issued. A copy is provided within Appendix G of this report. As a result the heat load had to be reapplied to allow for the unit to restabilize.

The tabulated data gathered for this run is contained within **Appendix A pages A-2 through A-111.** Charts produced are contained within **Appendix D pages D-2 through D-20.** Thermocouple TC# 8 was showing erratic behavior and was verified to have a fractured junction when inspected upon completion of the test.

ATS

4.0 TEST SET-UP AND SEQUENCE (continued)

4.5 Load Testing

4.5.2 2nd Heat Rise Test

Retesting for heat rise began at 10:33 on 20 November, 2006. A constant heat load of 7,000 ± 70 watts was applied to the cask until thermal stability was reached. Thermal stability was considered reached on 24 November, 2006 at 08:32 at which time the heat load was shut off to start the heat decay measurement.

The tabulated data gathered for this run is contained within **Appendix B pages B-2 through B-99.** Charts produced are contained within **Appendix E pages E-2 through E-20.**

The following table depicts the final values achieved for each data channel for the two heat rise stabilization runs.

	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8
1st Heat Run	1203.7 F	914.2 F	284.6 F	295.9 F	253.7 F	261.6 F	559.0 F	Lost data
2nd Heat Run	1199.1 F	902.1 F	290.6 F	291.7 F	250.7 F	260.9 F	559.7 F	Lost data

	TC9	TC10	TC11	TC12	TC13	TC14	TC15	TC16
1st Heat Run	264.6 F	261.4 F	232.2 F	252.2 F	61.8 F	59.2 F	62.8 F	59.1 F
2nd Heat Run	267.2 F	268.6 F	225.5 F	247.5 F	65.4 F	65.7 F	67.3 F	65.7 F

	Amps	Volts	Watts					
1st Heat Run	30.24	230.00	6955.20					
2nd Heat Run	30.23	230.20	6961.97					

4.0 TEST SET-UP AND SEQUENCE (continued)

4.6 Heat Decay Test

Heat Decay testing began at the moment the heaters were shut off which was on 24 November, 2006 at 08:32. Measurements continued until 08:10 on 29 November, 2006 at which time NTS was instructed by GE personnel to end the testing.

The tabulated data gathered for this run is contained within **Appendix C pages C-2 through C-128.** Charts produced are contained within **Appendix F pages F-2 through F-20.**

The following table depicts the final values achieved for each data channel for the two heat rise stabilization runs.

	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8
Start 08:32 11/24/06	1199.1 F	902.1 F	290.6 F	291.7 F	250.7 F	260.9 F	559.7 F	Lost data
End 08:10 11/29/06	74.9 F	74.3 F	72.9 F	70.8 F	70.0 F	72.1 F	73.8 F	Lost data

	TC9	TC10	TC11	TC12	TC13	TC14	TC15	TC16
Start 08:32 11/24/06	267.2 F	268.6 F	225.5 F	247.5 F	65.4 F	65.7 F	67.3 F	65.7 F
End 08:10 11/29/06	72.0 F	71.9 F	68.0 F	71.7 F	60.6 F	60.4 F	60.2 F	59.8 F

	Amps	Volts	Watts					
Start 08:32 11/24/06	30.23	230.20	6961.97					
End 08:10 11/29/06	0.00	0.00	0.00					

5.0 TEST EQUIPMENT

All test equipment used for this program was checked prior to testing to assure that it was in calibration and that the parameters being measured were appropriate for the range on the measuring instrument.

Calibration is performed and checked on a routine basis in accordance with standards traceable to the National Institute of Standards and Technology (NIST). Calibration of equipment is performed in accordance with the NTS quality program.

A list of test equipment used and verification of the suitability of the measuring instrument is included on the following pages.

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[illegible]/06/06 National Technical Systems - Equipment List NTS Job No: 63001
RANOR, INC

Shortcut#	Old Invent #	Description/Manufacturer	Model #/Serial #	Range/Accuracy	Frq/Due Dt	Calibration Status
AC0083	ML559	CURRENT SHUNT GENERAL ELECTRIC	50-140-034 100A/100M		000012 11/10/07	CAL
AC0093	ML574	DIGITAL MULTIMETER FLUKE	8840A 4382012	0 TO 1000 VDC SEE MFGR ftS SPEC	000006 2/28/07	CAL
AC0490	ZR320	DECADE RESISTOR IET	HARS-X-7-0.01 B2-892808212	.01 TO 10 KOHM +/-1%	000000 NCR	NCR
AC0495	ZR321	DECADE RESISTOR IET	HARS-X-7-0.01 B3-892808112	.01 TO 10 KOHMS,7 DECADES +/-(.01%+2mOHMS)	000000 NCR	NCR
AC1901	AC1901	30 CHANNEL RECORDER YOKOGAWA	DX230-2 954513	0-20V,RTD:PT100 0.1%RDG+2	000012 1/20/07	CAL
AC2029	AC2029	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	000000	CAL
AC2030	AC2030	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2031	AC2031	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2032	AC2032	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2034	AC2034	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2035	AC2035	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2036	AC2036	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2037	AC2036	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2038	AC2038	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2039	AC2039	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2040	AC2040	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL

Calibration Abbreviations
UWCE - use with calibrated equipment
CBU - calibrate before use
NQM - not used for quantitative measurement
CAL - calibrated
NCR - no calibration required

12/06/06 National Technical Systems - Equipment List NTS Job No: 63001
RANOR, INC

Shortcut#	Old Invent #	Description/Manufacturer	Model #/Serial #	Range/Accuracy	Frq/Due Dt	Calibration Status
AC2041	AC2041	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2042	AC2042	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2044	AC2044	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2045	AC2045	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL
AC2047	AC2047	TYPE J THERMOCOUPLE WIRE 30 ft NTS	TYPE J	0 TO 1300 F +/- 2 F	11/10/07	CAL

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CAL - calibrated
NCR - no calibration required