3.0 THERMAL EVALUATION

The objective of the thermal evaluation is to determine the temperature distribution in the transport package which occurs during normal and hypothetical accident conditions of the performance requirements of 10CFR71 and to establish temperature effects on the package components and their performance, as these effects relate to safety and compliance with the regulations.

The Model 2000 Transport Package has been fully analyzed and certified for use by Nuclear Regulatory Commission for up to 600 watts contents thermal loading [3.1]. In addition, the analytical model for the Transport Package has also been verified by the actual thermal testing at ambient condition for both 600 watts and 2000 watts contents thermal loading, which is presented in Reference [3.2]. This Chapter presents the thermal analyses of the Model 2000 Transport Package with a contents thermal loading of 2000 watts, specifically, Subsections 3.4 and 3.5 for normal and accident transport conditions, and those of the Multifunctional rack loaded with Cs^{137} capsules, presented in Subsection 3.7. The results of these analyses show that the package with the proposed content performs within all regulatory limits.

Also, additional analyses demonstrated that the location of the sources within the cask cavity is not critical in meeting the regulatory requirements. See Subsection 3.7.4.

3.1 DISCUSSION

The Model 2000 package is designed with a thermally passive system. The cask is enclosed by an overpack structure which acts as a fire shield. The overpack structure is designed to reduce heat flow from the fire environment into the cask structure by the use of enclosed air spaces. The overpack structure is composed of two concentric cylinders approximately 83 in. long with an OD of 48.5 in. and an ID of 40.5 in. The cylinders are separated radially by eight equally spaced tubes and horizontally by two tube sections to provide closed air spaces. a 24-inch tube diameter toroidal shell is attached to both ends of the external cylinder with a circular plate enclosing the inner regions of the torus. The internal cylinder is also closed at each end by a circular plate. All materials are 0.5-in.-thick Type 304 stainless steel except for the spacer tubes. The vertical tubes are 3 in. OD, 0.25 in. thick while the horizontal tube sections are 7.25 in. OD, 0.375 in. thick. Attached at both ends of the overpack inner surface there are aluminum honeycomb pads. The cask is placed within the overpack at assembly. Air gap of 1.0 in. radially and 1.5 in. at the top separates the cask from the overpack inner surfaces. It is postulated that the air spaces within the overpack structure will not be affected in the 30-foot free drop accident condition, which was verified by the test discussed in Subsection 2.7.5 of the Reference [3.1].

3.1.1 Thermal Design Criteria

Thermal design criteria are specified for regions throughout the cask, cask cavity and the outside overpack wall. The seal material is limited to a temperature range of -65°F to 400°F, and this serves as the thermal criteria for the region associated with the seal area. The maximum allowable internal pressure is dictated to be 30 psia, which corresponds to air of 100% humidity heated to 600°F at constant volume.

3.1.2 Design Bases Conditions

Temperature distributions in the Model 2000 cask are evaluated for the contents thermal loading of 2000 watts for the following thermal conditions:

1. 100°F ambient with maximum decay heat and maximum solar load
2. 100°F ambient with maximum decay heat
3. Fire transient, t = 0 to 5.0 hours
4. -20°F ambient with maximum decay heat
5. -20°F ambient
6. -40°F ambient with maximum decay heat
7. -40°F ambient

All conditions are analyzed using the finite element program LIBRA with the exception of conditions 5 and 7, where uniform temperature fields of -20°F and -40°F are assigned. A description of the LIBRA finite element program heat transfer module is presented in Subsection 3.7.1. Subsection 3.7.1 also includes the qualification and verification program performed by GE to support modeling techniques and assumptions taken throughout the thermal evaluation. For condition 3, fire transient; the analysis is initiated at the steady-state condition 1 in which the maximum solar load is applied. A maximum decay heat of 2000 watts is distributed onto the cavity surface of the cask.

3.1.3 Results of Design Basis Thermal Analyses

The maximum temperatures determined by the analyses and the regulatory and/or component thermal criteria are given in Table 3.1. The comparison of these component temperatures between 600 watts contents heat [3.2] vs. 2000 watts contents heat is presented in Table 3.2.

Table 3.1. Summary of Temperatures

Package Component	Thermal Condition Temperatures (°F)							Component Criteria (°F)
	1	2	3(1)	4	5	6	7	
Cask Cavity Surface	341	308	415	233	-20	199	-40	T < 600
Lead Shield	338	305	413	231	-20	221	-40	T < 620
Cask Seal Area	315	278	381	201	20	188	-40	-65 < T < 400
Cask Test Port	312	275	379	198	20	185	-40	-65 < T < 500
Cask Drain Port	301	272	424	196	20	184	-40	-65 < T < 500
Cask Vent Port	320	283	384	207	20	194	-40	-65 < T < 500
Cask Outer Surface	322	287	407	208	-20	195	-40	N/A
Overpack Inner Surface	262	219	821	124	-20	108	-40	N/A
Overpack Outer Surface	197	146	1340	34	-20	15	-40	T < 180 for #2

(1) Values given are maximum temperatures obtained for each component throughout the 5 hours transient.

Table 3.2. Comparison Between 600W vs. 2000W Contents Heat

Thermal Conditions	Thermal Condition Temperatures (°F)									
	1		2		3		4		6	
Decay Heat (Watts)	**2000**	**600**	**2000**	**600**	**2000**	**600**	**2000**	**600**	**2000**	**600**
Cask Cavity Surface	341	220	308	161	415	294	233	41	199	21
Lead Shield	338	220	305	161	413	237	231	40	221	20
Cask Seal Area	315	215	278	153	381	276	201	33	188	13
Cask Test Port	312	214	275	152	379	284	198	32	185	12
Cask Drain Port	301	204	272	151	424	350	196	30	184	10
Cask Vent Port	320	217	283	155	384	244	207	35	194	15
Cask Outer Surface	322	218	287	159	407	401	208	39	195	19
Overpack Inner Surface	262	199	219	131	821	774	124	15	108	-5
Overpack Outer Surface	197	173	146	112	1340	1153	34	-8	15	-29

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

The transport package model consists of four materials whose thermal properties are listed in Subsections 3.2.1 to 3.2.4. The curve fit functions which give the variation of the properties with temperature are also given. These property functions are used in the transient analysis to update the material properties as the temperature changes.

3.2.1 Lead

Temp (°F)	Thermophysical Properties		
	k (Btu/hr-ft-°F) [3.3]	Cp(Btu/lb.-°F) [3.4]	ρ(lb./in.^{3}) [3.5]
68.0	—	0.0305	0.4097
80.3	20.3	—	
158.0	—	0.0310	
170.3	20.1		
248.0	—	0.0316	
260.3	19.5		
338.0	—	0.0320	
428.0	—	0.0325	
440.3	18.8		
500.0	—	0.0329	
608.0	—	0.0334	
620.3	18.0	—	

Conductivity, k (Btu/hr-in.-°F)

$k(T) = 1.7263 - 3.6418 \times 10^{-4}\ T$ 68.0°F < T < 620.3°F

Specific Heat, Cp (Btu/lb.-°F)

$Cp(T) = 3.0177 \times 10^{-2} + 5.3924 \times 10^{-6}\ T$ 68.0°F<T<620.3°F

Density, ρ (lb./in.^{3})

$\rho(T) = 0.41$ 68.0°F < T < 620.3°F

3.2.2 Stainless Steel (304 Type)

Thermophysical Properties[3.6]		
Temp (°F)	**k(Btu/hr-ft-°F)**	**α(ft^2/hr)**
70	8.6	0.151
100	8.7	0.152
200	9.3	0.156
300	9.8	0.160
400	10.4	0.165
500	10.9	0.170
600	11.3	0.174
700	11.8	0.179
800	12.2	0.184
900	12.7	0.189
1,000	13.2	0.194
1,100	13.6	0.198
1,200	14.0	0.203
1,300	14.5	0.208
1,400	14.9	0.212
1,500	15.3	0.216

Conductivity, k (Btu/hr-in.-°F)

$k(T) = 7.0287 \times 10^{-1} + 3.8987 \times 10^{-4}\ T$ $\qquad 70°F < T < 1500°F$

Thermal Diffusivity, α (in.^{2}/hr)

$\alpha(T) = 21.110 + 6.7346 \times 10^{-3}\ T$ $\qquad 70°F < T < 1500°F$

Density, ρ (lb./in.^{3})

$\rho(T) = 0.29$ $\qquad 70°F < T < 1000°F$

Specific Heat, Cp (Btu/lb.-°F)

$Cp(T) = k(T)/\alpha(T)(\rho) = k(T)/(6.1219 + 1.953 \times 10^{-3}\ T)$ $\qquad 70°F < T < 1000°F$

3.2.3 Air

Temp (°F)	Thermophysical Properties[3.6]					
	ρ (lb./ft^3)	Cp (Btu/lb.-°F)	$\mu \times 10^{-5}$ (lb./ft-sec)	k(Btu/hr-ft-°F)	Pr	$g\beta\rho^2/\mu^2$
32	0.081	0.200	1.165	0.0140	0.76	3.16×10^6
100	0.071	0.240	1.285	0.0154	0.72	1.76
200	0.060	0.241	1.440	0.0174	0.72	0.850
300	0.052	0.243	1.610	0.0193	0.71	0.444
400	0.046	0.245	1.750	0.0212	0.689	0.258
500	0.0412	0.247	1.890	0.0231	0.683	0.159
600	0.0373	0.250	2.000	0.0250	0.685	0.106
700	0.0341	0.253	2.140	0.0268	0.690	70.4×10^3
800	0.0314	0.256	2.250	0.0286	0.697	49.8
900	0.0291	0.259	2.360	0.0303	0.705	36.0
1,000	0.0271	0.262	2.470	0.0319	0.713	26.5
1,500	0.0202	0.276	3.000	0.0400	0.739	7.45
2,000	0.0161	0.286	3.450	0.0471	0.753	2.84

Conductivity, k (Btu/hr-in.-°F)

$$k(T) = 1.1138 \times 10^{-3} + 1.6988 \times 10^{-6}\, T - 1.4993 \times 10^{-10}\, T^2 \qquad 32°F < T < 2000°F$$

Prandtl Number, Pr

$$Pr(T) = 0.72 \qquad 32°F < T < 200°F$$

$$Pr(T) = 0.603 + 1.3017 \times 10^{-3}\, T - 4.450 \times 10^{-6}\, T^2 + 4.3333 \times 10^{-9}\, T^3 \qquad 200°F < T < 500°F$$

$$Pr(T) = 0.7793 - 4.6950 \times 10^{-4}\, T + 7.474 \times 10^{-7}\, T^2 - 4.2962 \times 10^{-10}\, T^3 + 8.5365 \times 10^{-19}\, T^4 \qquad 500°F < T < 2000°F$$

Parameter, $g\beta\rho^2/\mu^2$ (1/°F-in.^{3})

$$g\beta\rho^2/\mu^2 (T) = 2.4306 \times 10^3 - 21.484\ T + 8.8318 \times 10^{-2}\ T^2 - 1.4682 \times 10^{-4}\ T^3$$

0°F < T < 200°F

$$g\beta\rho^2/\mu^2 (T) = 1.6610 \times 10^3 - 9.2850\ T + 2.1356 \times 10^{-2}\ T^2 - 2.268 \times 10^{-5}\ T^3 + 9.1329 \times 10^{-9}\ T^4$$

200°F < T < 800°F

$$g\beta\rho^2/\mu^2 (T) = 1.8475 \times 10^2 - 3.2975 \times 10^{-1}\ T + 2.0129 \times 10^{-4}\ T^2 - 4.1096 \times 10^{-8}\ T^3$$

800°F < T < 2000°F

Specific Heat, Cp (Btu/lb.-°F)

$$Cp(T) = 0.2386 + 8.8082 \times 10^{-6}\ T + 2.1375 \times 10^{-8}\ T^2 - 6.9784 \times 10^{-12}\ T^3$$

100°F < T < 2000°F

Density, p(lb./in.^{3})

$$\rho(T) = 5.787 \times 10^{-4}/(11.6125 + 2.527 \times 10^{-2}\ T) \qquad 32°F < T < 2000°F$$

3.2.4 Helium

	Thermophysical Properties[3.6]				
Temp (°F)	ρ (lb./ft^3)	Cp (Btu/lb.-°F)	k (Btu/hr-ft-°F)	Pr	$g\beta\rho^2/\mu^2$ (1/°F-ft^3)
0	0.012	1.24	0.078	0.670	77800
200	0.0085	1.24	0.097	0.686	15600
400	0.0064	1.24	0.115	0.700	4840
600	0.0052	1.24	0.129	0.715	2010
800	0.0044	1.24	0.138	0.730	932

Thermal Conductivity (Btu/hr-in-°F)

$$k(T) = 0.00675 + 7.042E^{-6}T \qquad 0°F < T < 800°F$$

Prandtl Number, Pr

$$Pr(T) = 0.67040 + 0.00007\ T \qquad 0°F < T < 800°F$$

Parameter, $g\beta\rho^2/\mu^2$ (1/°F-in^3)

$$g\beta\rho^2/\mu^2 = 45.0 - 3.2\times10^{-1}\,T + 9.4\text{x}10^{-4}\,T^2 - 1.2\times10^{-6}\,T^3 + 5.7\text{x}10^{-10}\,T^4$$

0°F < T < 800°F

Specific heat, Cp (Btu/lb.-°F)

Cp = 1.242 0°F < T < 800°F

Density, p (lb./in^3)

p(T) = 1/1728 (0.0119/(1+0.002168T)) 0°F < T < 800°F

3.3 TECHNICAL SPECIFICATIONS OF COMPONENTS

The component material within the transport package, that is considered to be temperature sensitive, are the elastomeric materials used in the cask seal and cask port plug O-rings. These materials, basically enhanced ethylene propylene rubbers, have been tested by GE and by the manufacture, respectively, to demonstrate their capacity to perform at the rated temperature. The seal test showed that it maintain leak-tightness under low (-40°F), normal (70°F), and high (400°F) temperature environments. The seal test procedure and results are discussed in detail in Section 4.4 of Reference [3.1].

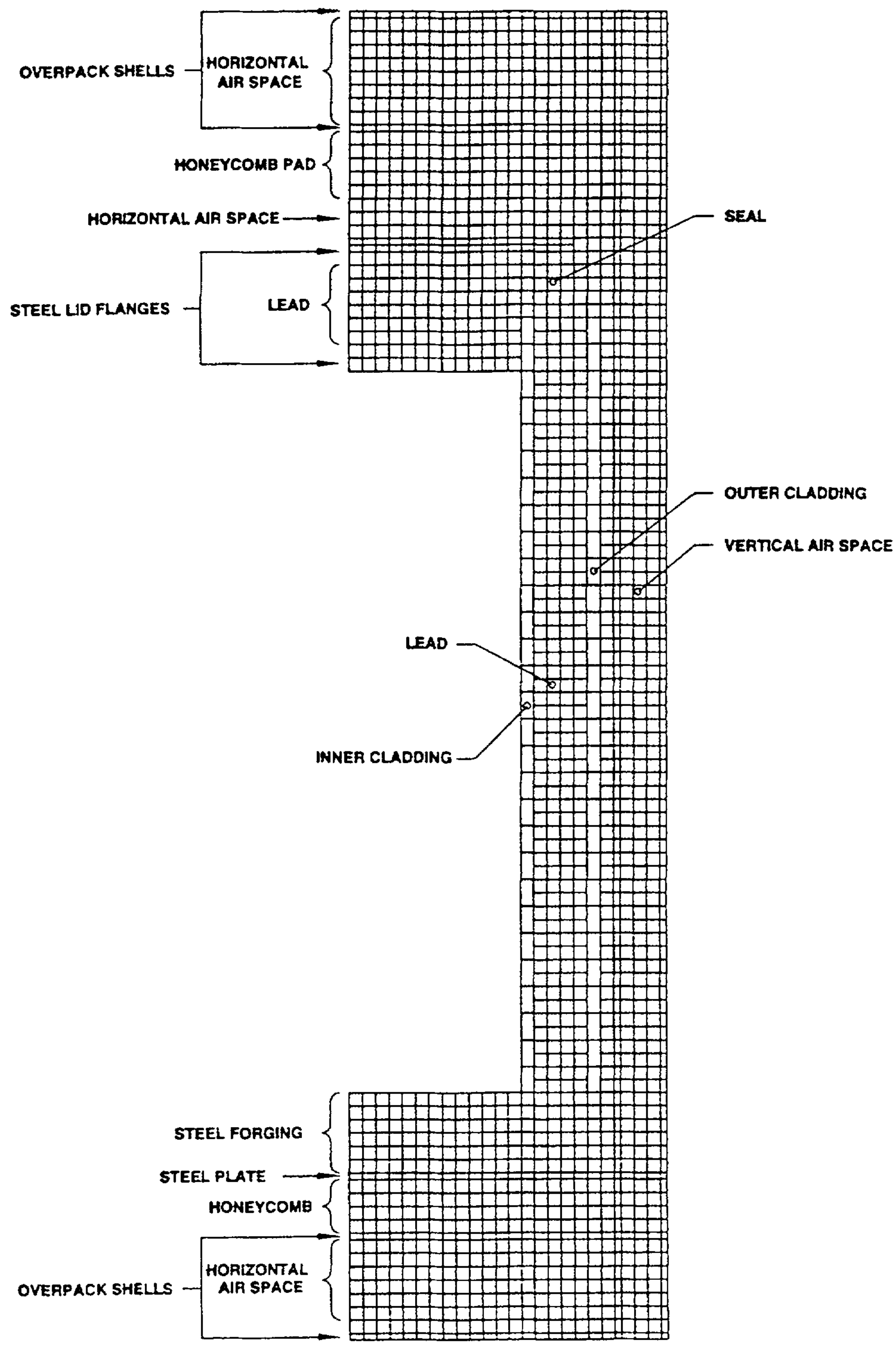
Other package materials are stainless steel, lead and aluminum. The melting points of these materials are 2,600°F, 620°F and 900°F, respectively. The temperatures resulting from normal and accident thermal conditions fall within these temperatures.

3.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

This Section presents the thermal analyses of the Model 2000 Transport Package for the normal conditions of transport. The thermal conditions considered are those specified in 10CFR71 [3.9] as summarized in Subsection 3.1.2. The Model 2000 Transport Package is mounted on the truck in its normal position (vertical orientation) and is subjected to natural convection and radiation heat transfer on the Package surface.

It is noted here that the thermal analysis presented in this Section, and Section 3.5 for the accident conditions, specifically evaluates the thermal characteristics of the Model 2000 Transport Package without emphasis on the specific temperature distribution of the shipping rack. Rather, heat loads are applied to the interior of the package based on relative interior surface areas. Subsection 3.7.3 provides a detailed thermal analysis of the heat sources and the shipping rack.

The finite element model of the Model 2000 Transport Package used for the thermal analyses consists of 2,201 nodes and 2,172 elements, as shown in Figure 3.1. The model represents the lead cask and the overpack structure. Because an axisymmetric solution is used, only a cross section of the package need be modeled. The model includes two-node conductive elements, four- and eight-node quadrilateral elements, and two-node boundary elements. Each element is characterized by one of a total of 41 different element property sets. These many property sets allow a detailed representation of the four materials (steel, lead, aluminum and air) within the model. Several material property sets represent the same material (e.g., steel, material property sets 1, 2, 4, 5, 29, 30, etc.) but at different temperatures. This is because of their location within the model. Air is also represented by various property sets to account not only for temperature variation but also for different heat transfer modes. The mode of heat transfer across an air space varies if the air space is enclosed or open and also if it is horizontally or vertically oriented.



Number of Elements: 3,579   Number of Nodes: 5,324

Figure 3.1. Finite Element Thermal Model

3.4.1 Analytical Model

The model closely represents the actual transport package with the exception of the overpack toroid shells. Figure 3.2 shows the finite element model overlaid on the transport package drawing. The toroidal shells are not included in the model because they will collapse during the free-drop event, and their omission in the evaluation of normal condition is conservative.

The bulk of the cask is lead. The cask cavity and surface are lined with a 304 stainless steel cladding, 1.0 inch in thickness. This cladding is modeled with one-element thickness, eight-node quadrilateral elements. An air gap exists between the cask lead and the outer cladding. This air gap forms due to shrinkage of the lead relative to the stainless steel during the manufacturing process. The air gap is modeled by two-node conduction elements with conduction and radiation properties. The cask sits inside the overpack on a 4-inch-thick aluminum honeycomb material pad. A plate, 0.5 in. thick, separates the bottom of the cask from the honeycomb pad. The plate is represented by one element while the honeycomb pad is represented by four elements in thickness.

Between the vertical cask surface and the inner overpack shell is an air space. This vertical air space is modeled by four-node conduction elements, one element in thickness. Air space followed by 6-inch honeycomb material pad exists between the top cask surface and the overpack inner top plate. This region is represented with four-node conduction elements with four- and six-element thickness for the horizontal air space and the honeycomb pad. The overpack consists of two concentric 0.5-inch-thick, 304 stainless steel cylindrical shells separated by an air space. Eight equally spaced 3-in. OD tubes vertically separate these shells, and two 7.25-in. OD tubes horizontally separate them at both ends. The overpack is modeled by a one-element thickness on the steel and a three-element thickness on the vertical air space. The top and bottom horizontal air spaces are represented by a seven-element thickness. The presence of these tubes in the air spaces is neglected in the model because of their small total volume as compared to the total air space volume.

The decay heat of the cask contents is introduced in the model by boundary elements along the cask cavity wall. The maximum heat load for this transport package is designed to be 2000 watts. In the model it is assumed that approximately 81% of the load is distributed radially while a corresponding 10% and 9% are applied axially to the cask cavity bottom and top, respectively. This assumption is based on the ratios of the top, bottom, and vertical areas to the total cavity area. Also, boundary elements manifest the convective and radiative interfaces between the overpack outer surface and the regulatory environments, as well as the solar heat flux.

The adequacy of the analytical model to predict the thermal behavior of the Model 2000 Package is verified by a test conducted at 600 and 2000 watts of decay heat, refer to Subsection 3.7.2. The test data show excellent correlation with the analytical results.

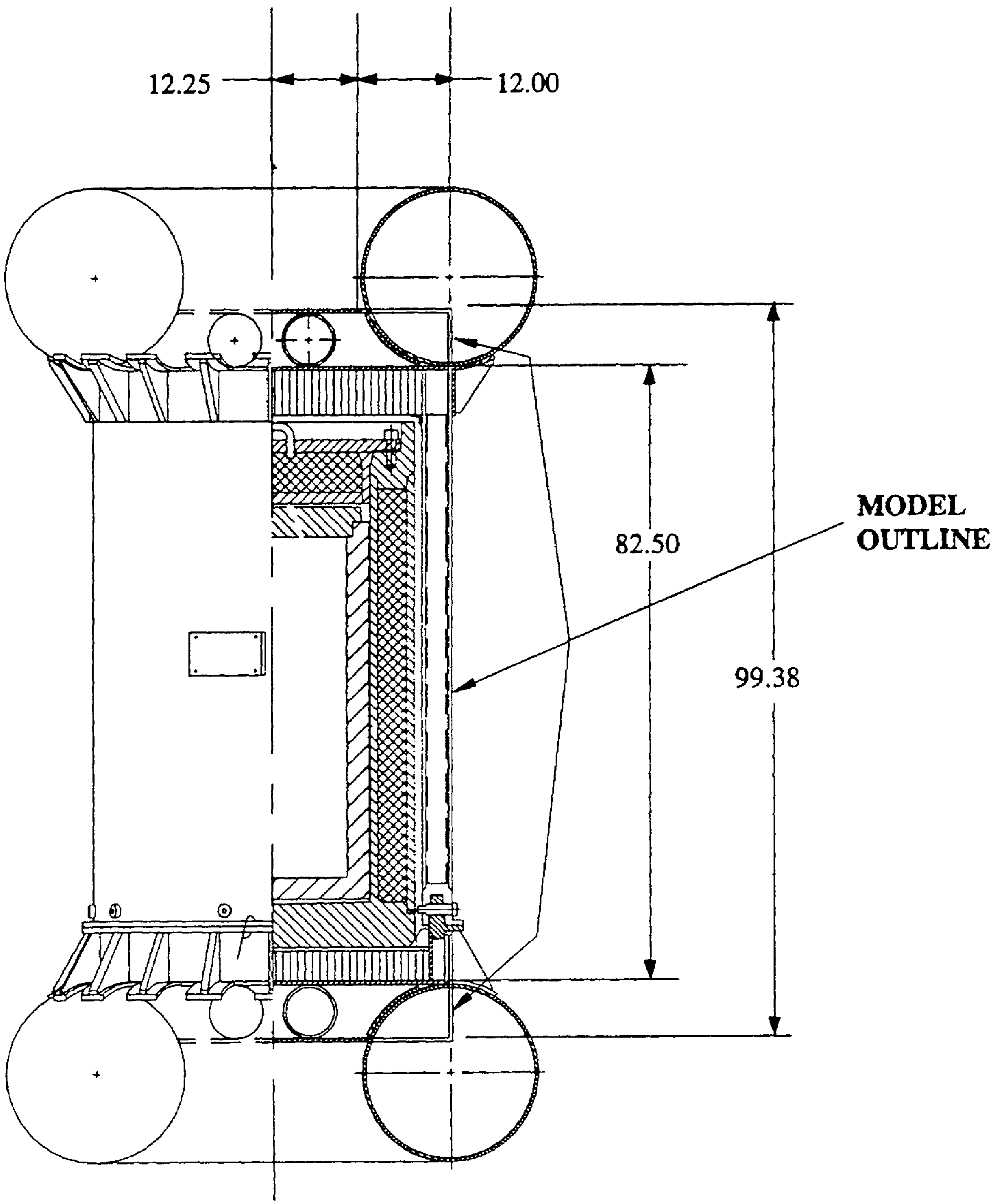


Figure 3.2. Thermal Finite Element Model, Overlaid on Transport Overpack

3.4.1.1 Heat Flux Property Sets. Element property sets 10 through 12 apply to convective boundary elements located in the cask cavity of the model. The only data these sets contain are the prescribed heat flux in Btu/hr-in. The maximum heat load for this transport package is 2000 watts. As discussed in Subsection 3.4.1, this load is applied as a uniform surface heat flux to the entire cavity surface area. It was determined that the radial heat flux represents 81% of the total load; therefore, its value is calculated as follows:

$$q''_{(11)} = \frac{q}{A} = \frac{2.0\ \text{kW}(3{,}414\ \text{Btu/hr}-\text{kW})\ (0.81)}{2\pi(13.25\ \text{in.})\ (54.5\ \text{in.})}$$

$$= 1.23\ \text{Btu/hr-in.}^2$$

Similarly:

$q''_{(10)} = 1.24$ Btu/hr-in.^{2} and (Bottom of Cavity)

$q''_{(12)} = 1.13$ Btu/hr-in.^{2} (Top of Cavity)

3.4.1.2 Enclosed Air Space Property Sets. Five-element property sets represent the enclosed air spaces. Property set 24 is the vertical air space between the cask surface and the inner shell of the overpack structure. Property set 25 applies to the horizontal air space between the cask lid top surface and the upper honeycomb pad surface. Property sets 31, 32 and 33 represent the horizontal, vertical and horizontal air spaces, respectively, between the inner and outer shell of the overpack structure.

For convective heat transfer in an enclosed vertical air space, Gebhart[3.10] gives the following:

$$Nu = 0.18 \cdot \sqrt[4]{Gr}(H/s)^{-\frac{1}{9}} \qquad 2 \cdot 10^4 < Gr < 2 \cdot 10^5$$

$$Nu = 0.065 \cdot \sqrt[3]{Gr}(H/s)^{-\frac{1}{9}} \qquad 2 \cdot 10^5 < Gr < 11 \cdot 10^6$$

where: Nu = Nusselt Number
Gr = Grashof Number based on s
s = distance across enclosed space
H = height of enclosed space

For Gr less than 2,000 the process is simple conduction, i.e., Nu = 1.0. The Grashof Number is defined here as

$$Gr = \frac{\rho^2 g \beta s^3 \Delta T}{\mu^2}$$

where: ρ = density, lb./ft^3
g = acceleration of gravity (32.1 ft/sec^2)
β = coefficient of the thermal expansion (°F)
ΔT = temperature difference across enclosure (°F)
μ = viscosity (lb./ft-sec)

The relationship between Nu and Gr given above applies strictly to an air and helium space enclosed between plates

The convective heat transfer in an enclosed horizontal space depends on the temperature of the upper and lower plates. If the upper plate temperature is higher than the lower plate, the process is simple conduction; therefore

$$Nu = 1.0$$

If vice versa, lower plate warmer, then

$$Nu = 1.0 \qquad Gr < 2 \cdot 10^4$$
$$Nu = 0.195 \sqrt[4]{Gr} \qquad 2 \cdot 10^4 < Gr < 4 \cdot 10^5$$
$$Nu = 0.068 \sqrt[4]{Gr} \qquad 4 \cdot 10^5 < Gr$$

These relations are given in Gebhart [3.12]. Properties are evaluated at the average of the two surface temperatures.

Once Nu is known, convective heat transfer coefficient, h_c, can be found by the following expression for both vertical and horizontal air spaces:

$$h_c = \frac{Nu \cdot k}{s}$$

where: k = thermal conductivity of air (Btu/hr-in.-°F)
s = as before, distance across the space (in.)

For radiative heat transfer,

$$h_r = F\sigma\,(T_1^{\,2} + T_2^{\,2})\cdot(T_1 + T_2)$$

where:

T_1, T_2 = temperatures on either side of the space (°R)

σ = 1.1944×10^{11} (Btu/hr-in.^{2}-°R^4)

F = gray body shape factor

The gray body shape factor, F, is defined as:

$$F = \frac{1}{\left(\dfrac{1}{e_1} - 1\right) + \dfrac{A_1}{A_2}\left(\dfrac{1}{e_2} - 1\right) + \dfrac{1}{F_{12}}}$$

where:

A_1 = area of smaller surface

A_2 = area of larger surface

e_1, e_2 = emissivities

F_{12} = shape factor

The shape factor, F_{12}, is purely a function of the geometry of the system. When body A_1 is completely enclosed by body A_2 and A_1 cannot see itself, $F_{12} = 1.0$ [3.13].

As an example, for oxidized 304 SS, $e_1 = e_2 = 0.52$ [3.14] and assuming $A_1 = A_2$,

$$F_{12} = 0.351$$

for all five enclosed air space material sets.

The finite element model represents these air spaces with conductive elements. The conversions from h to k are as follows:

$$k = h \cdot s$$

As before, s is the distance across the air space.

In general, the effective conductivity across the air space, k_e, is due to conduction plus radiation. However, a convective mode may arise depending upon the Gr and/or the plates' temperatures as discussed before. Therefore, the makeup of k_e may be as follows:

$$k_e = k + h_r \cdot s, \text{ or}$$

$$k_e = (h_c + h_r) \cdot s$$

In the perpendicular direction, along the space, the effective conductivity, k_e, is assumed to be pure conduction.

$$k_e = k$$

The vertical air space between the inner and outer shells of the overpack structure, material set 32, contains eight evenly spaced tubes. These tubes are used as energy absorbing devices and spacers. The effect of these tubes as heat transfer mechanisms is neglected. This is based on the low value 0.03 of the ratio of total tube area to total air area.

3.4.1.3 Boundary Property Sets. There are three material property sets, numbers 39 through 41, surrounding the model. These sets link the model with the external environment. Each set contains the film coefficient, ambient temperature and solar heat flux value.

Property set 40 covers the vertical outside wall of the model, while sets 39 and 41 are along the bottom and top horizontal surfaces, respectively. For convection from a large diameter cylinder [3.15]

$$Nu = 0.59\ \sqrt[4]{Ra} \qquad 10^4 < Ra < 10^8$$

$$Nu = 0.13\ \sqrt[3]{Ra} \qquad 10^8 < Ra$$

where the Rayleigh number, Ra, is defined as

$$Ra = Gr \cdot Pr$$

and the Gr is based upon L dimensions instead of s in the enclosed space condition in Section 3.4.1.2. The fluid properties are determined at the average temperature between the wall (T_0) and film (T_f) temperatures.

For horizontal surfaces, the following relations apply [3.16]:

If the surface warmer than the surrounding medium is facing upward or the cooler surface is facing downward, then:

$$Nu = 0.54\ (GrPr)^{1/4} \qquad 10^5 < Gr \leq 2 \cdot 10^7$$

$$Nu = 0.14\ (GrPr)^{1/3} \qquad 2 \cdot 10^7 < Gr \leq 3 \cdot 10^{10}$$

However, for the warmer side facing downward and the cooler side facing upward,

$$Nu = 0.27\ (GrPr)^{1/4} \qquad 3 \cdot 10^5 < Gr < 3 \cdot 10^{10}$$

Here, also, the fluid properties are determined at the average temperature, $0.5(T_o + T_f)$; and the L dimension is replaced by 0.9 D, where D is the diameter of the disk.

After Nu is determined, the convective heat transfer coefficient is calculated using the equation below. In this equation, s represents the cylinder length L for material set 40 and 0.9 D for the other sets.

$$h_c = \frac{Nu \cdot k}{s}$$

In addition to convection, the cask surface interacts radiatively with its surroundings. The radiative heat transfer coefficient, h_r, is calculated using the equations given in Paragraph 3.4.1.2. Regulatory environments place the transport package in an outside environment. Therefore, in evaluating the equation for the gray body shape factor, it was assumed that:

(1) A_1 is negligible compared with A_2, and

(2) $F_{12} = 1$.

The film coefficient, h (Btu/hr-in.^{2}-°F) is

$$h = h_c + h_r$$

The overpack structure of the transport package is basically cylindrical but does contain a toroidal shell at both ends. These shells substantially mitigate the effects of the thermal environment. However, their effects are local in relation to the cask structure because of the transport package geometry. The distance from the cask structure to the outside environment is shorter in the radial direction than through the toroidal shell. Therefore, the cask structure would not be affected by the surroundings of the toroidal shells. For this reason, the model does not account for their effects. These areas are treated in the model as an extension of the top and bottom horizontal plates and the vertical cylindrical wall. The only credit taken for their presence is during the solar load calculations. The solar input over the toroid shell area is calculated based on fraction of curve and horizontal surfaces to the total surface of the model.

3.4.1.4 Solar Heat Load. The solar load is represented in the model by the quantity "q", rate of heat transfer per unit area. The value of q is calculated as follows:

For flat surface transported horizontally:

Solar Load Value = 2,950 Btu per ft^2 per 12 hours [3.17]

$$q_f = \frac{2{,}950 \text{ Btu}}{(144 \text{ in}^2)\ 12 \text{ hr}} = 1.707 \frac{\text{Btu}}{\text{hr} - \text{in}^2}$$

For curved surface:

Solar Load Value = 1,475 Btu per ft^2 per 12 hours [3.17]

$$q_c = \frac{1475 \text{ Btu}}{(144 \text{ in}^2)\ 12 \text{ hr}} = 0.853 \frac{\text{Btu}}{\text{hr} - \text{in}^2}$$

Refer to Figure 3.2 for dimensions used in this analysis.

Overpack outside shell, material set 40:

$$q_{(40)} = q_c \cdot \frac{\text{actual overpack cylinderical shell height}}{\text{model overpack cylinderical shell height}}$$

$$= 0.854 \cdot \frac{82.5}{99.38} = 0.709 \text{ Btu/hr - in.}^2$$

Overpack top surface, material set 41:

$$q_{(41)} = q_f \frac{\text{flat surface area} = \text{A}}{\text{total model area} = \text{C}} + q_c \frac{\text{curved surface area} = \text{B}}{\text{total model area} = \text{C}}$$

$A = \pi(12.25)^2 = 471.43 \text{ in}^2$; $B = \pi(24.25^2 - 12.25^2) = 1376.02 \text{ in}^2$; $C = A + B = 1847.45 \text{ in}^2$

$$= 1.707 \cdot \frac{471.43}{1847.45} + 0.854 \frac{1376.02}{1847.45}$$

$$= 1.074 \text{ Btu/hr - in}^2$$

3.4.1.5 Fire Effect. Fire effect is introduced to the model by a thermal radiation environment of 1,475°F for 30 minutes with an emissivity coefficient of 0.9 and a transport package surface absorption coefficient of 0.8.[3.18] After the fire, the cask is cooled naturally for a total period of 3 hours in ambient air at 100°F.

During the fire the gray body shape factor, F, is given by:

$$F = \frac{1}{\frac{1}{e_1} + \frac{1}{e_2} - 1} = \frac{1}{\frac{1}{.8} + \frac{1}{.9} - 1}$$

$$= 0.7347$$

and the radiation coefficient is calculated by the equation given in Paragraph 3.4.1.2.

3.4.1.6 Overpack Outer Shell Elements Property Set. The overpack outer shell is represented in the model by three material property sets, sets 34 through 38. The model does not account for any effect given by the toroidal shells because they are smashed during the 30-foot free-drop event. The free-drop event precedes the fire event.

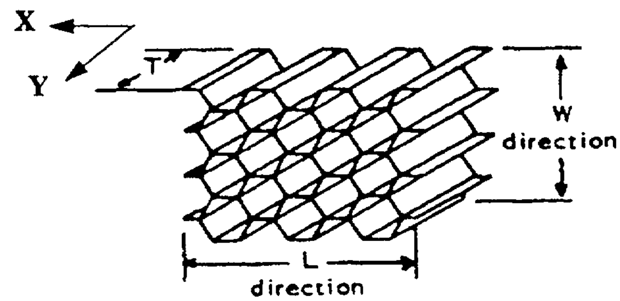
3.4.1.7 Aluminum-Air Conglomerate Property Sets (Honeycomb Material). Property sets 26 and 28 represent the honeycomb pad installed at the bottom and top of the cask structure. The material is made of corrugated aluminum foil 0.002 in. gauge with a cell width of 0.125 in. The density of the material is listed by the manufacturer as 8.1 pcf nominal. Based on these data, the thermal properties were calculated as follows:

Pad Volume, Vp

$$Vp = \pi R^2 H$$

where: R = pad radius, 20 in. Mat's 26 and 28

H = pad height, 4 in. Mat 26 and 6 in. Mat 28



For property set 26

$$Vp = \pi(20.0)^2(4) = 5{,}026.55 \text{ in.}^3$$

its weight,

$$Wt = Vp \cdot \rho = 5{,}026.55(8.1)/1{,}728 = 23.56 \text{ lb.}$$

Next, the air and aluminum volume fractions are determined by solving the following equations,

$$W_t = \rho_{Al} \cdot V_{Al} + \rho_{Air} V_{Air}$$

$$V_P = V_{Al} + V_{Air}$$

$$V_{Al} = 241.64 \text{ in.}^3 \text{ and } V_{Air} = 4{,}784.91 \text{ in.}^3$$

Therefore, $$\frac{V_{Al}}{V_P} = 0.048 \text{ and } \frac{V_{Air}}{V_P} = 0.952$$

$$k_x = \frac{V_{Al}}{V_P} \cdot k_{Al} + \frac{V_{Air}}{V_P} \cdot k_{Air}$$

$$= 0.048 \cdot k_{Al} + 0.952 \cdot k_{Air}$$

$$k_y = \frac{b_1}{L} \cdot k_{Al} + \frac{b_2}{L} \cdot k_{Air}$$

$$= 0.0679 \cdot k_{Al} + 0.9321 \cdot k_{Air}$$

where b_1 = Aluminum foil thickness = 0.002 in.
b_2 = Air space thickness = 0.125 in.
L = Honeycomb pad thickness = 4.0 in. Mat 26 or 6.0 in. Mat 28

The k_y value calculated by this formula was verified against test data published by Hexcel Corporation Bulletin TSB120, "Mechanical Properties of Hexcel Honeycomb Materials." The Bulletin data is presented in term of thermal resistance, R (reciprocal of conductivity) and several honeycomb core thickness and densities at a mean temperature of 75°F. The honeycomb density used in the Model 2000 Package is 8.1 lb/ft^3, and the thickness of the bottom pad, material property 26, is 4.0 in. Based on these values the R given is 0.04 HR-ft-°F/BTU. Using the formula for k_y at the same condition, the calculated R is 0.0445 HR-ft-°F/BTU. A comparison of these two values shows an excellent correlation.

$$C_P = \frac{V_{Al}}{V_P} \cdot C_{P_{Al}} + \frac{V_{Air}}{V_P} \cdot C_{P_{Air}}$$

$$= 0.048 \cdot C_{P_{Al}} + 0.952 \cdot C_{P_{Air}}$$

$$\rho = 0.048 \cdot \rho_{Al} + 0.952 \cdot \rho_{Air}$$

3.4.2 Maximum Temperatures

Under the normal conditions of transport, the maximum temperature distribution in the Model 2000 occurs when the ambient temperature is 100°, there is maximum decay heat, and the maximum solar load is applied. Figure 3.3 presents the finite element model with monitored area and corresponding node numbers. Figures 3.4 through 3.7 present temperature values at several locations on the thermal model under normal conditions. Some of the elements within the thermal model on these figures have been erased for clarity. These values also included those values which are maximum. Figures 3.8 through 3.11 show the temperature contour plot for the normal conditions of transport.

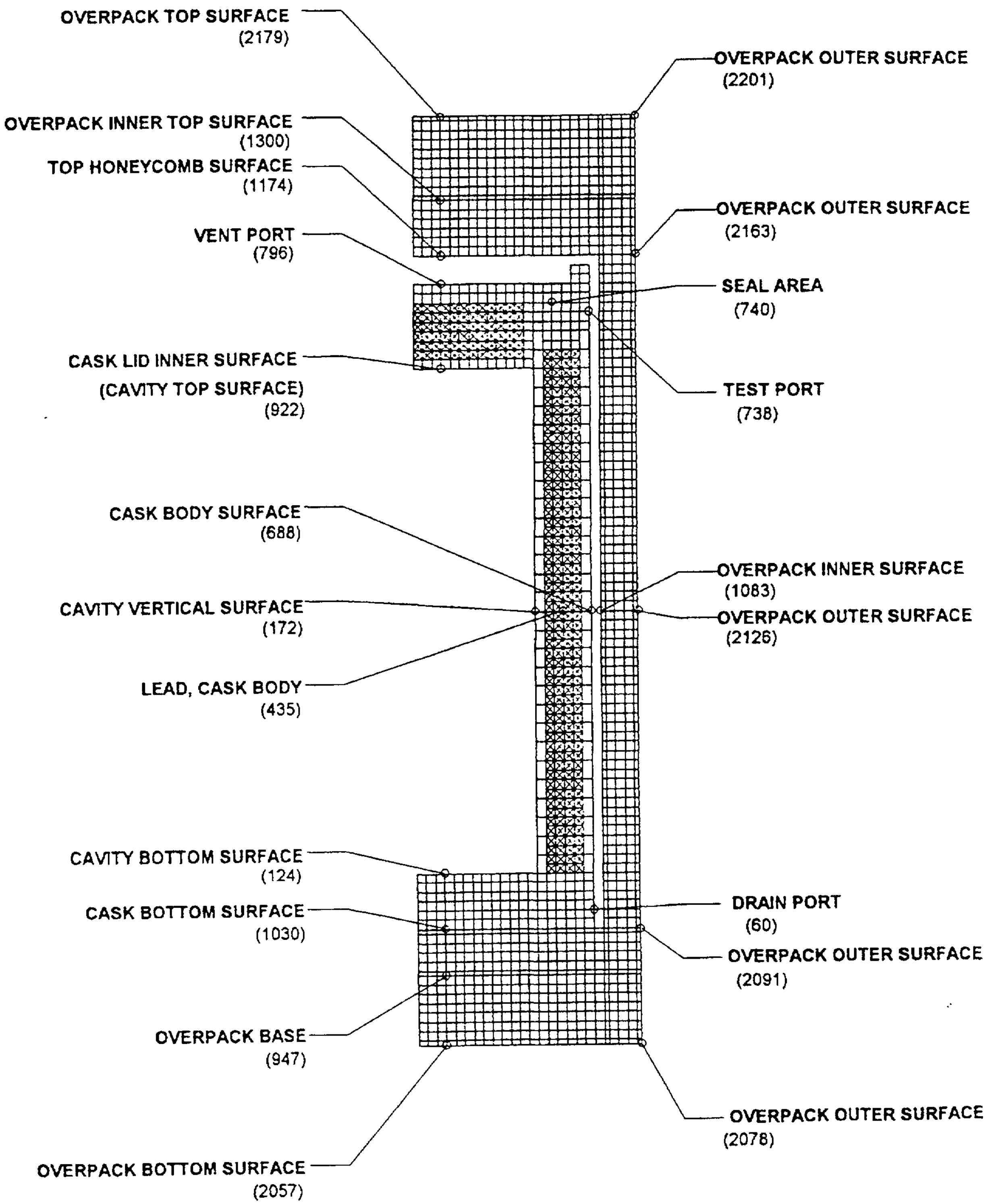


Figure 3.3. Key Plot of Temperature Locations

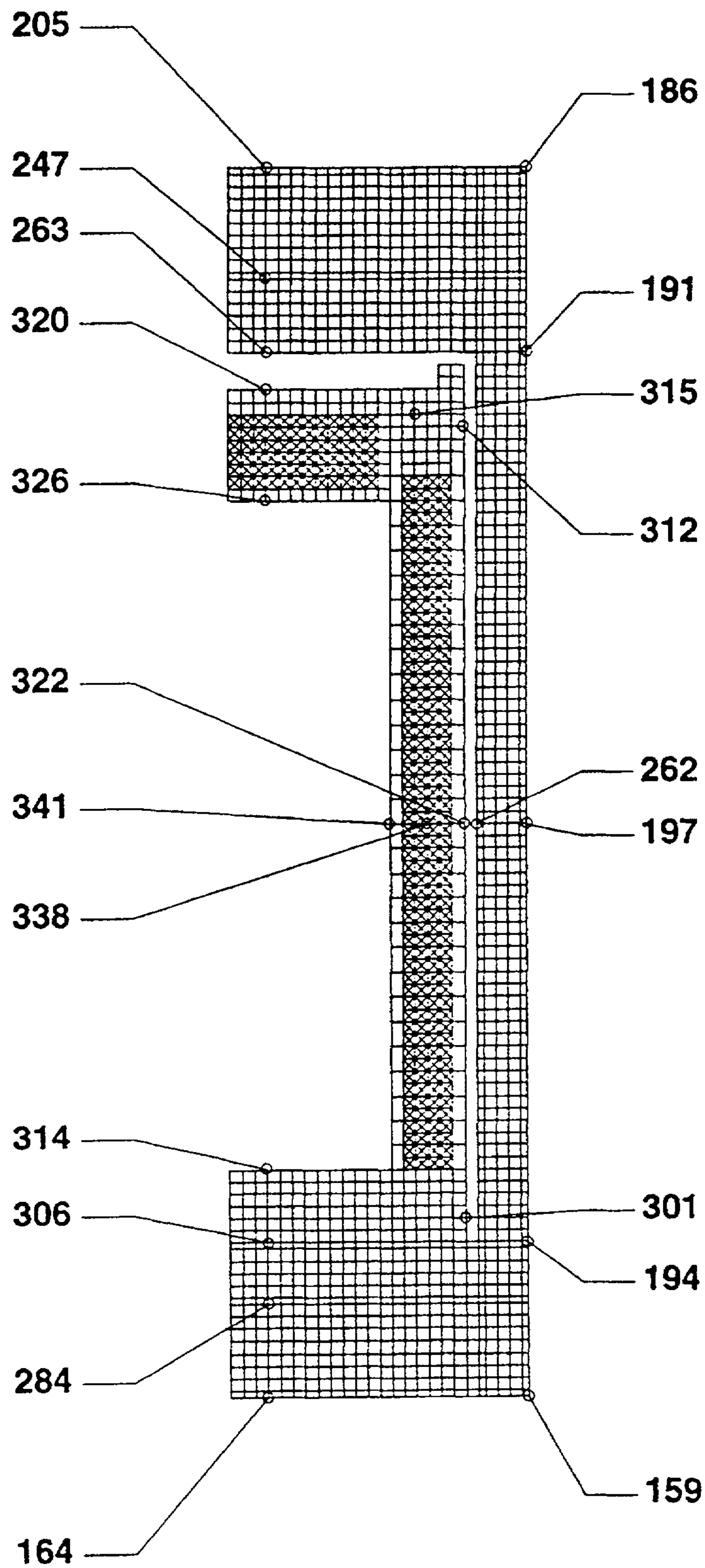


Figure 3.4. Model 2000 Transport Package, Steady-State Analysis 100°F Ambient Temperature, Maximum Decay Heat and Minimum Insolation

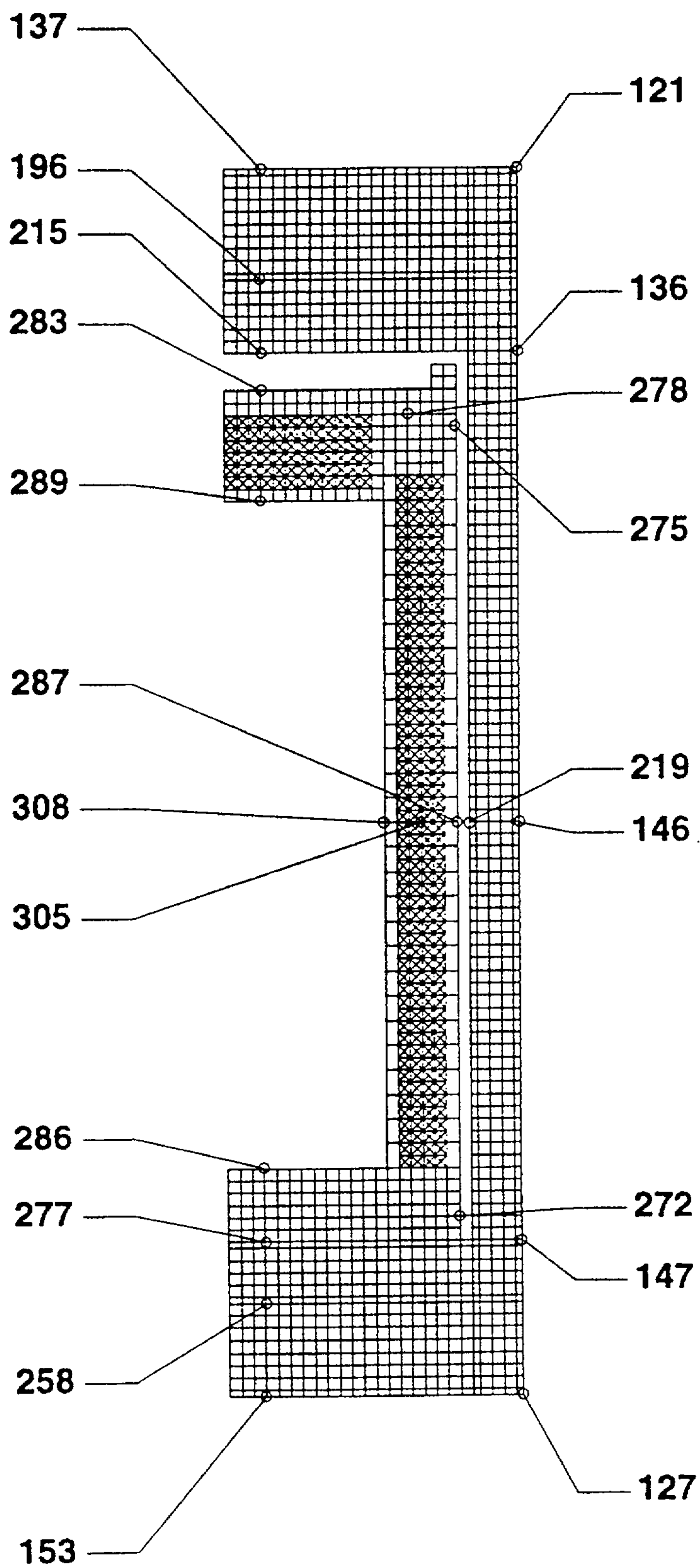


Figure 3.5. Model 2000 Transport Package, Steady-State Analysis 100°F Ambient Temperature and Maximum Decay Heat

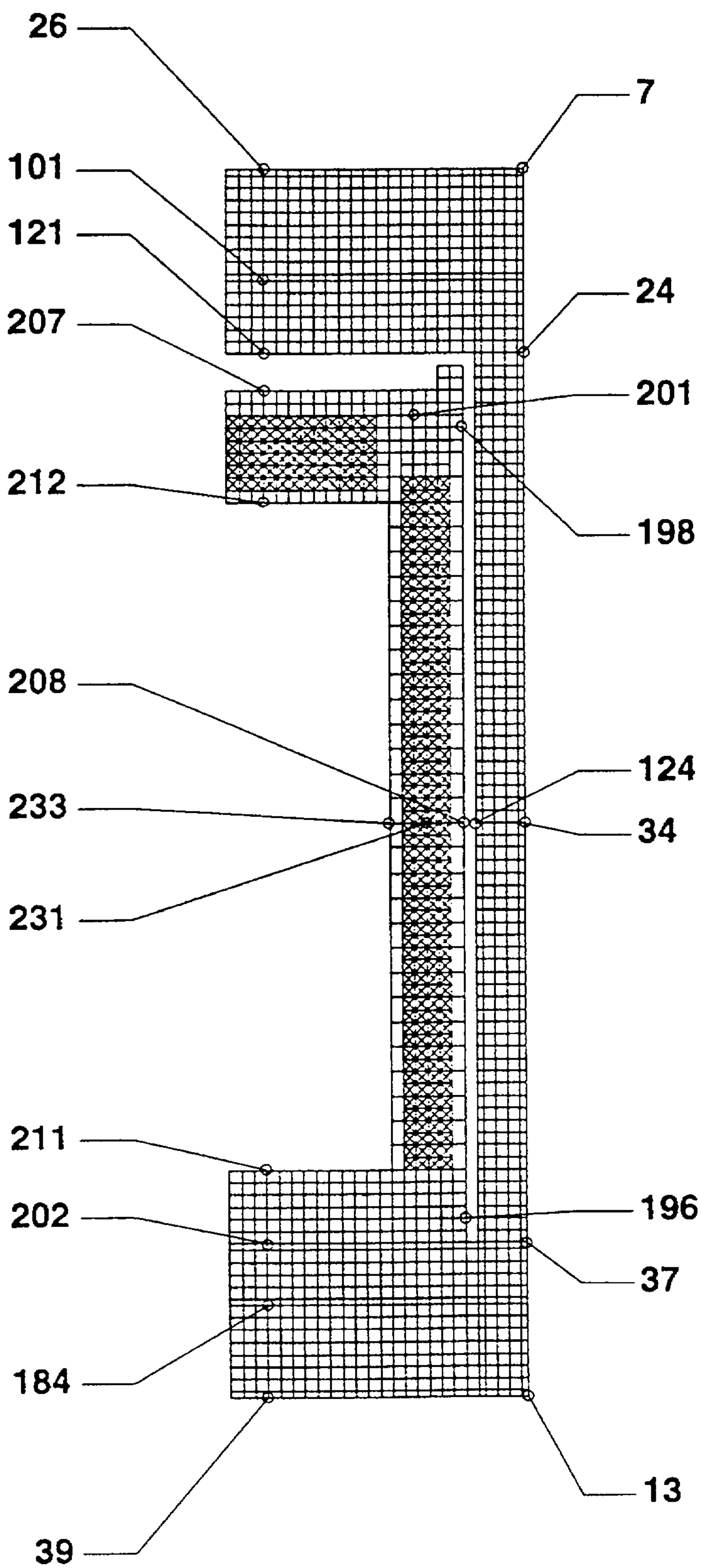


Figure 3.6. Model 2000 Transport Package, Steady-State Analysis -20°F Ambient Temperature and Maximum Decay Heat

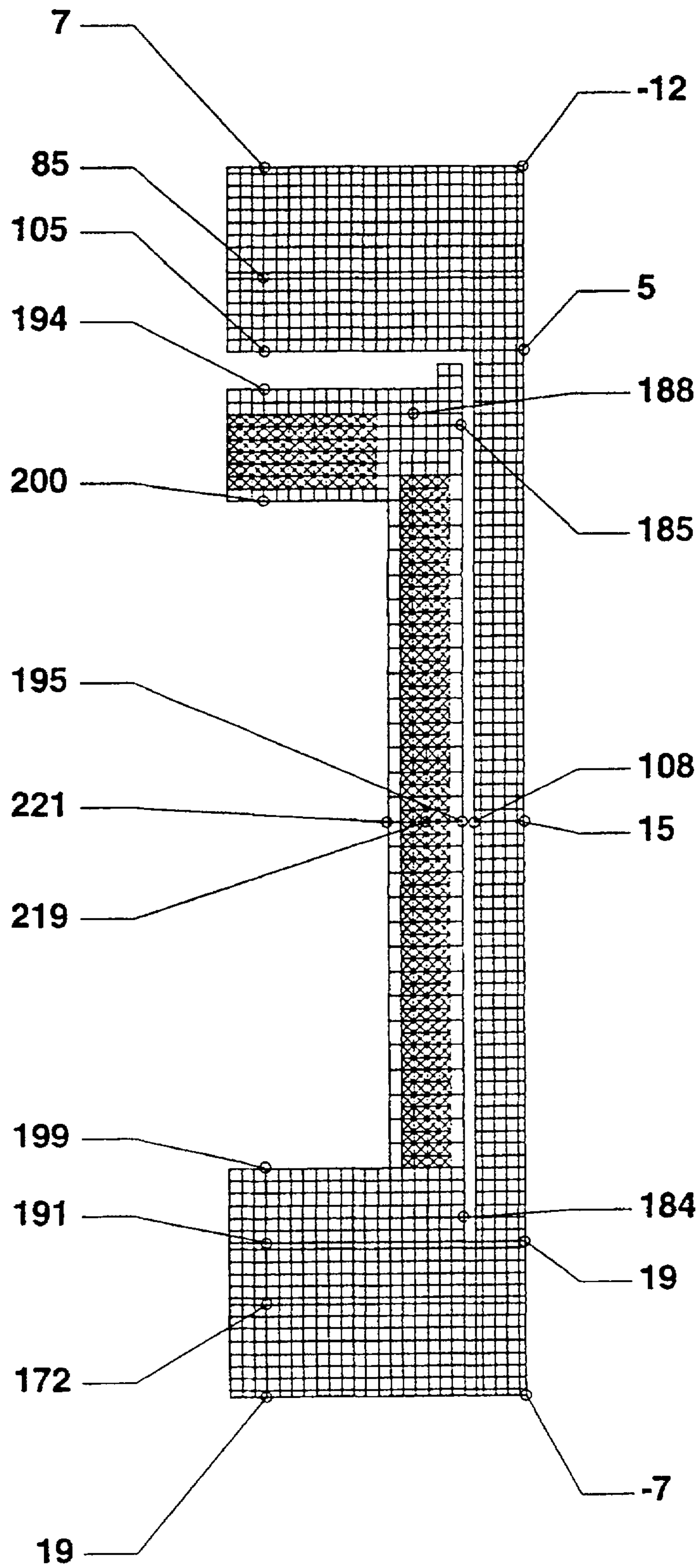


Figure 3.7. Model 2000 Transport Package, Steady-State Analysis -40°F Ambient Temperature and Maximum Decay Heat

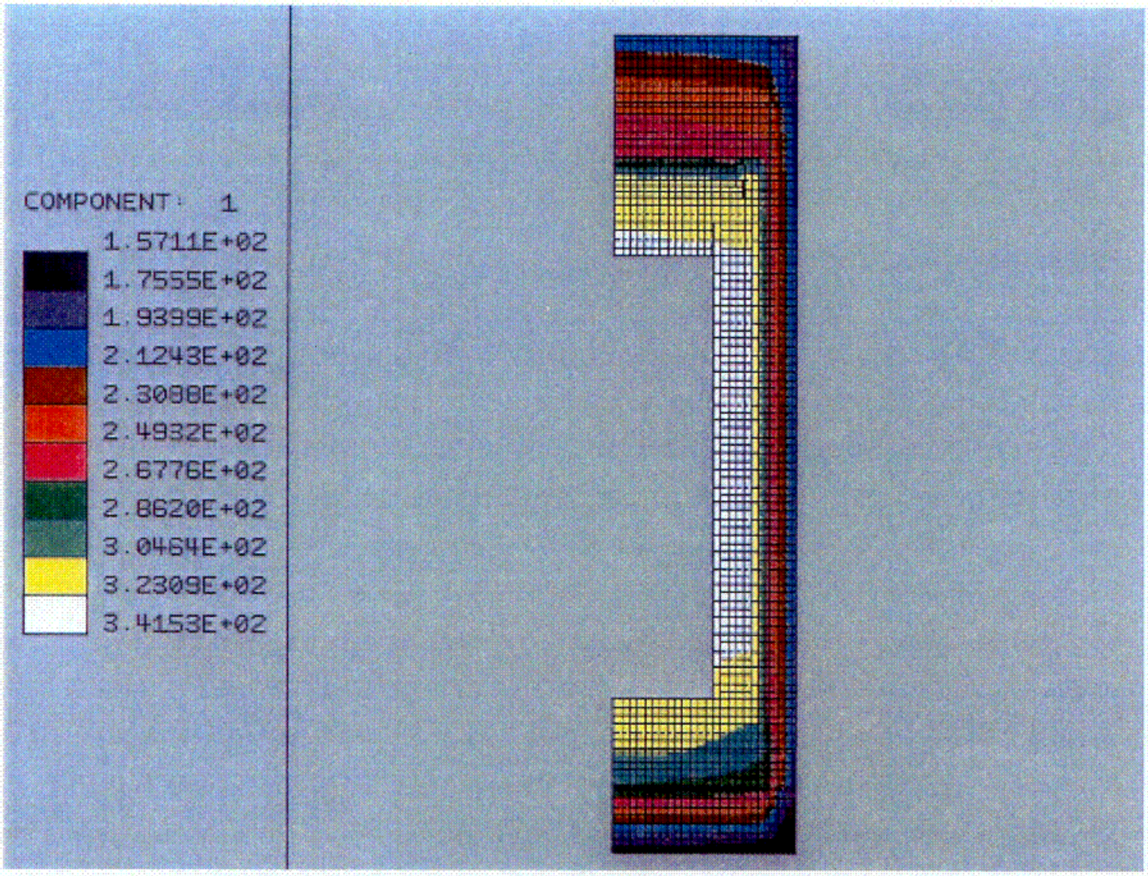


Figure 3.8. Model 2000 Cask – Contour Plot Steady-State Condition – 100°F Ambient Temperature, Maximum Decay Heat Plus Minimum Insolation

C01

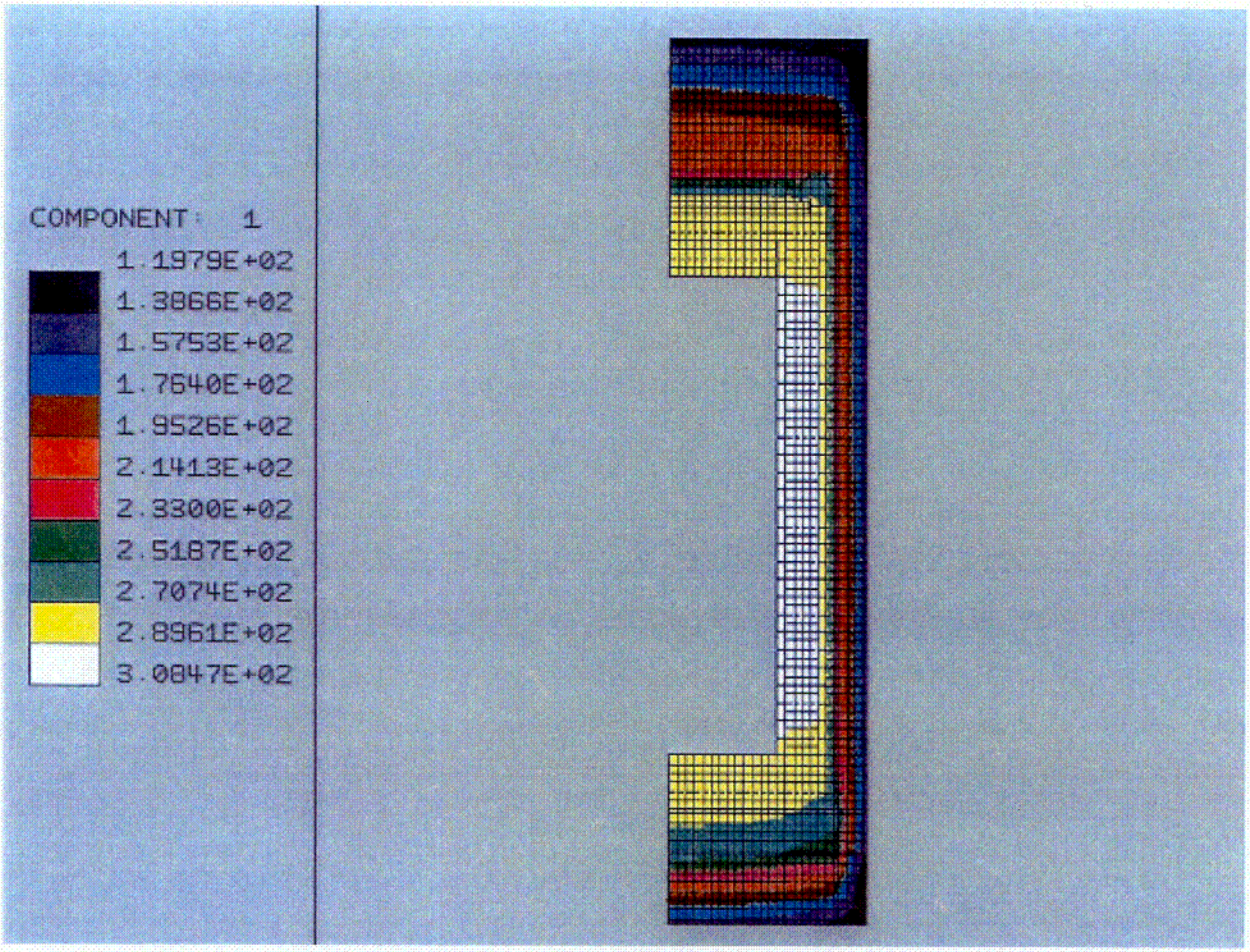


Figure 3.9. Model 2000 Transport Package – Contour Plot Steady-State Condition – 100°F Ambient Temperature, Maximum Decay Heat

C02

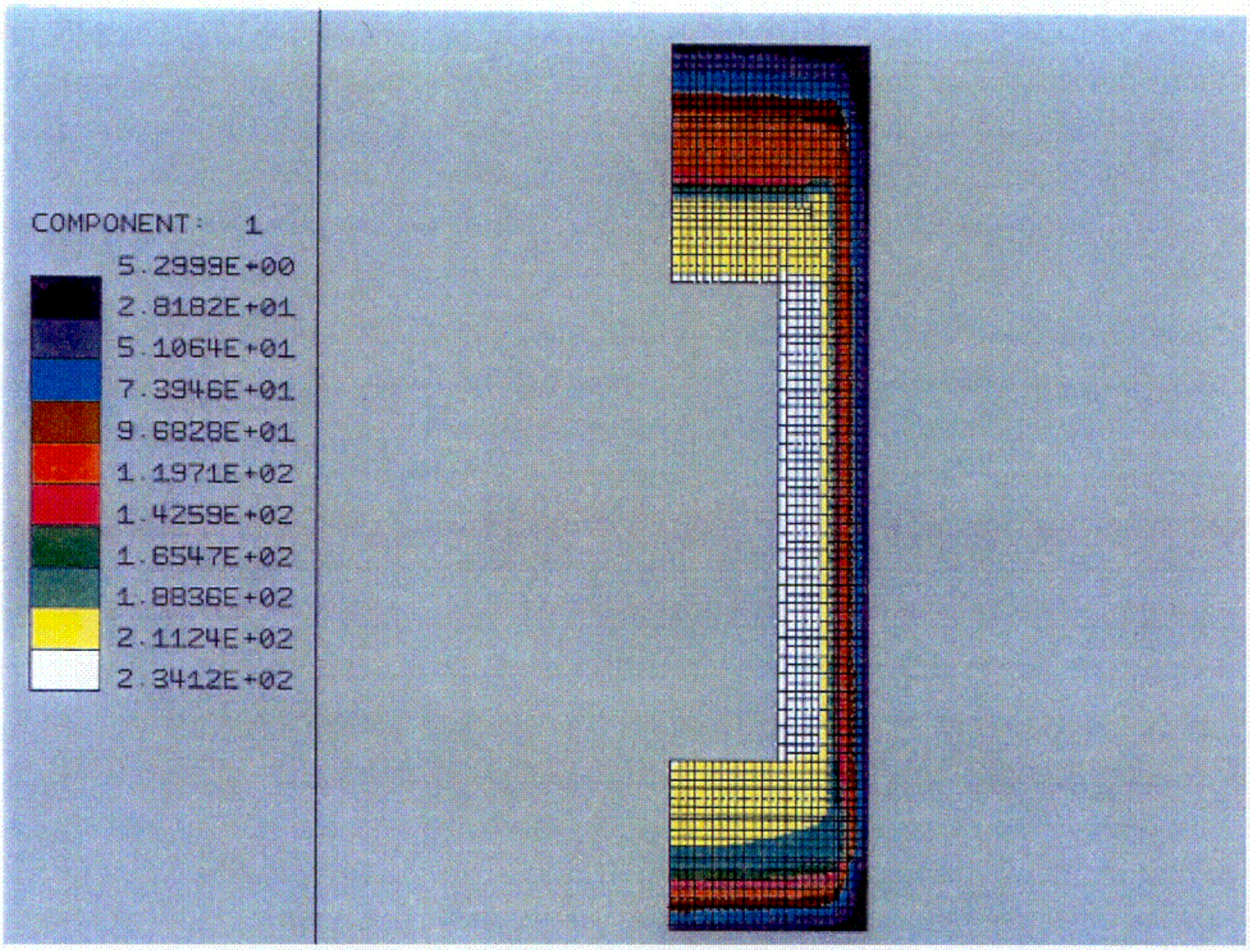


Figure 3.10. Model 2000 Transport Package – Contour Plot Steady-State Condition: -20°F Ambient Temperature, Maximum Decay Heat

C03

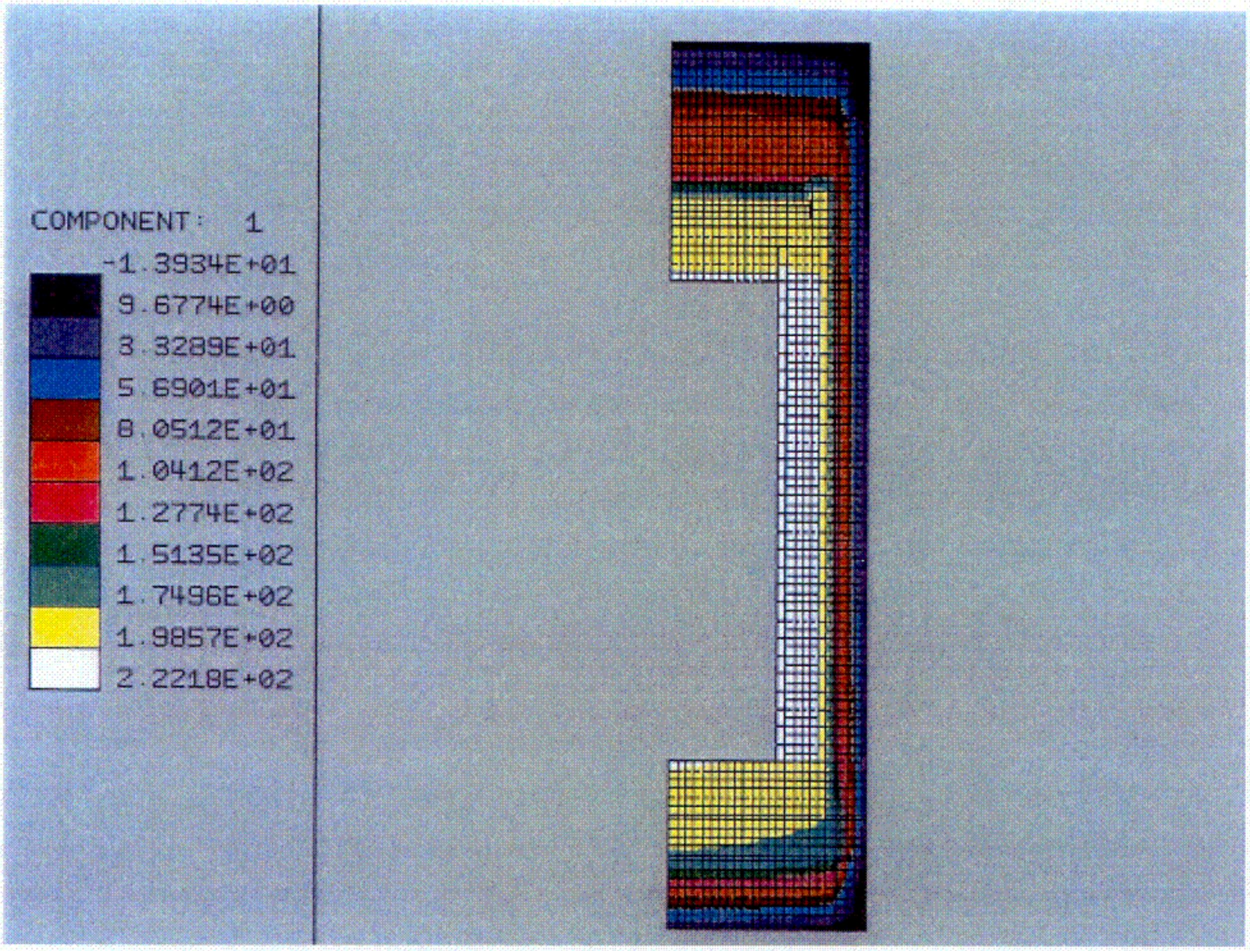


Figure 3.11. Model 2000 Transport Package – Contour Plot Steady-State Condition: -40°F Ambient Temperature, Maximum Decay Heat

C04

3.4.3 Minimum Temperatures

The minimum temperature distribution is a result of an ambient temperature of -40°F. It is assumed that there is no heating effect from decay heat or solar radiation; therefore, the transport package is assigned a minimum temperature of -40°F throughout.

3.4.4 Maximum Internal Pressures

The design internal pressure is 30 psia. This value corresponds to atmospheric air heated up to 600°F at constant volume. The temperature within the cask cavity during the fire transient is less than 600°F and, therefore, the maximum internal pressure is below 30 psia.

3.4.5 Maximum Thermal Stresses

The highest thermal stresses in the Model 2000 arise from an ambient temperature of 100°F, the maximum decay heat of 2000 watts and the maximum solar load. Figures 3.12 through 3.15 give the thermal stress intensity values (P_m + P_b, ksi) throughout the cask for normal conditions of transport.

The lead-pouring operations will not produce a significant residual stress on the cask structure. The fabrication procedure calls for the cask body without the upper flange to be uniformly heated to a temperature range of 575 to 650°F. This temperature is maintained throughout the entire lead-pouring process. Lead is then poured through the open end to the bottom of the annulus between the cladding shells. After the lead pouring is completed, the cask body is gradually cooled down from the bottom up.

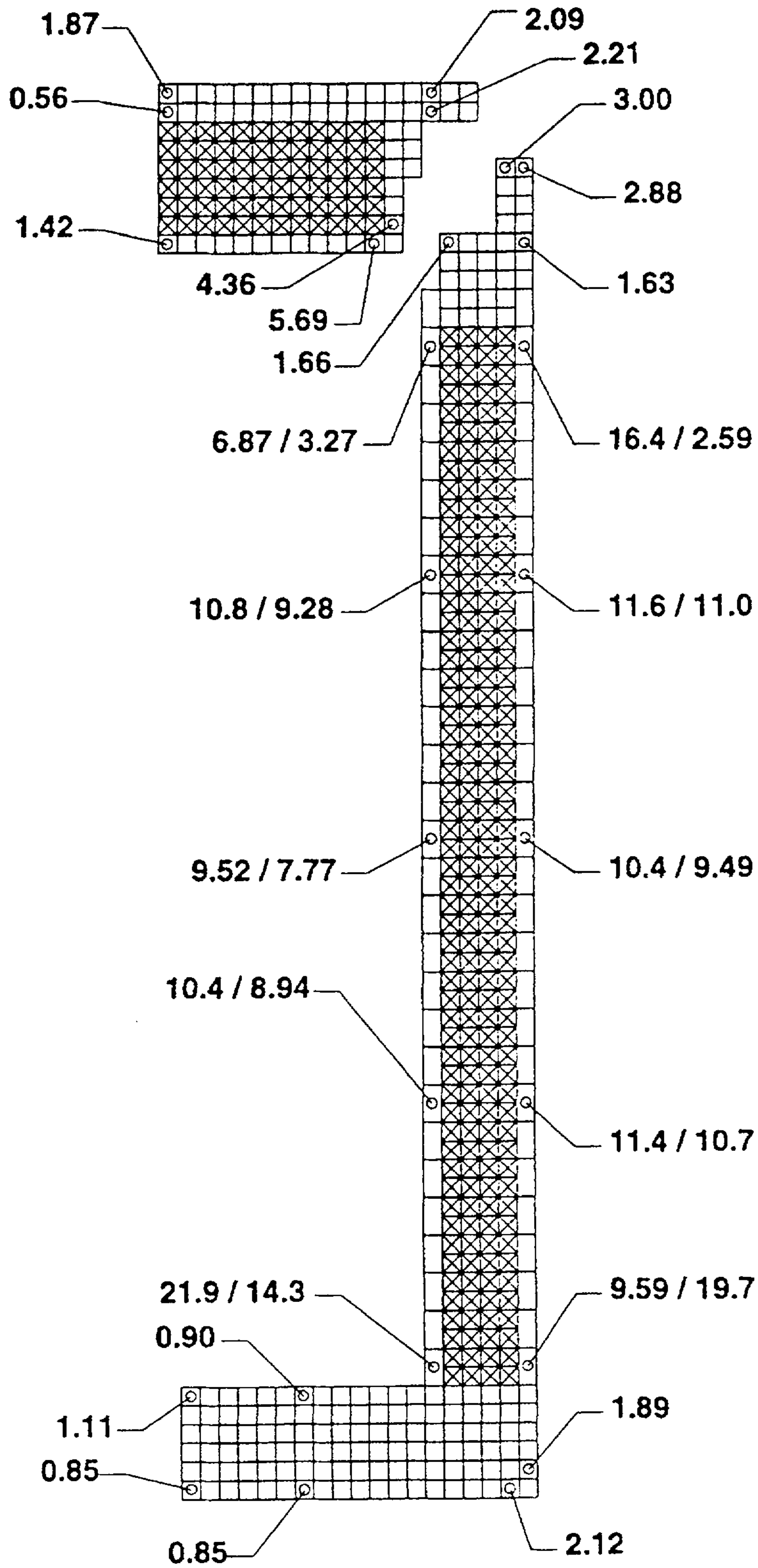


Figure 3.12. Model 2000 Cask – Thermal Stress Analysis (Q, ksi) Steady-State Condition; 100°F Ambient Temperature, Maximum Decay Heat Plus Maximum Insolation

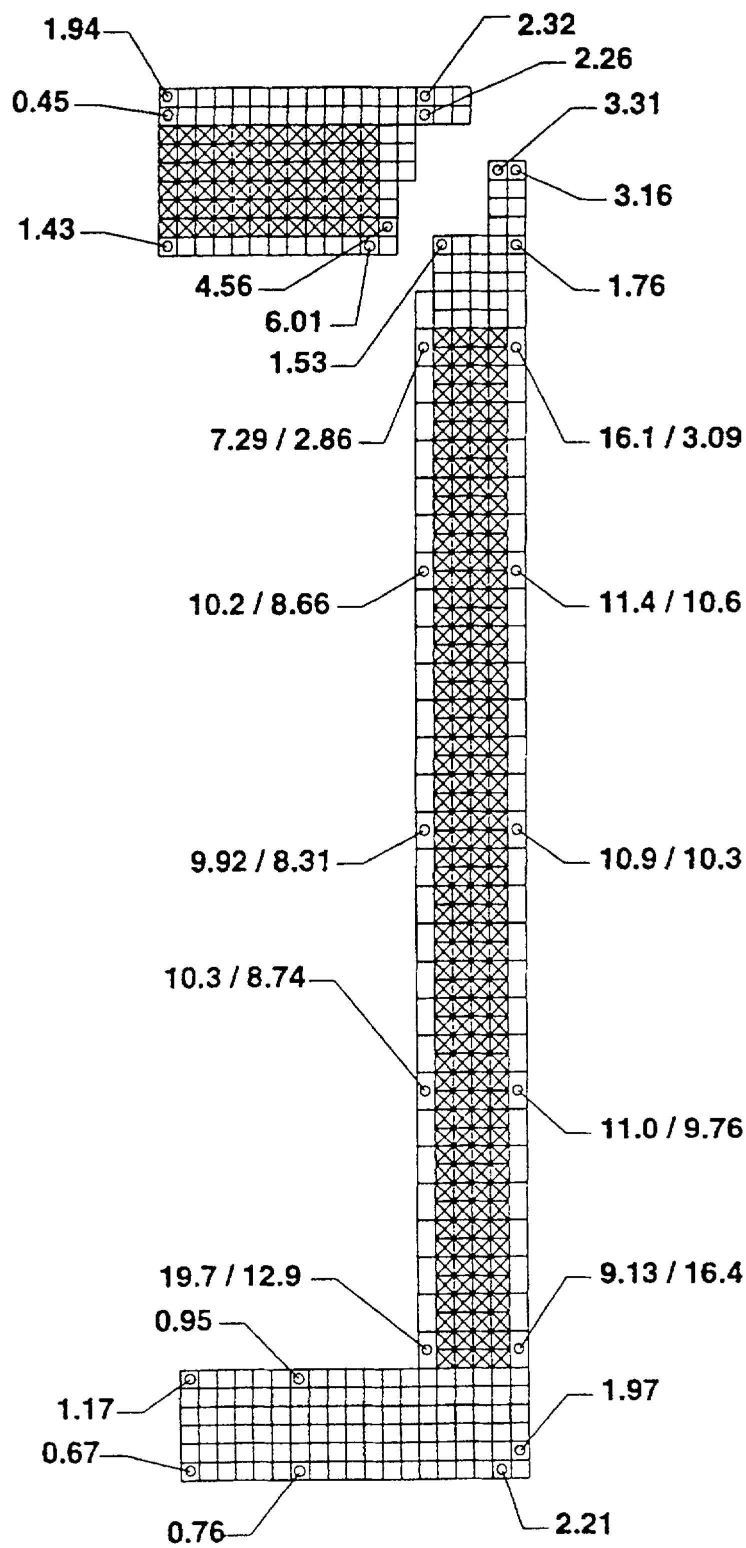


Figure 3.13. Model 2000 Cask – Thermal Stress Analysis (Q, ksi) Steady-State Condition; 100°F Ambient Temperature and Maximum Decay Heat

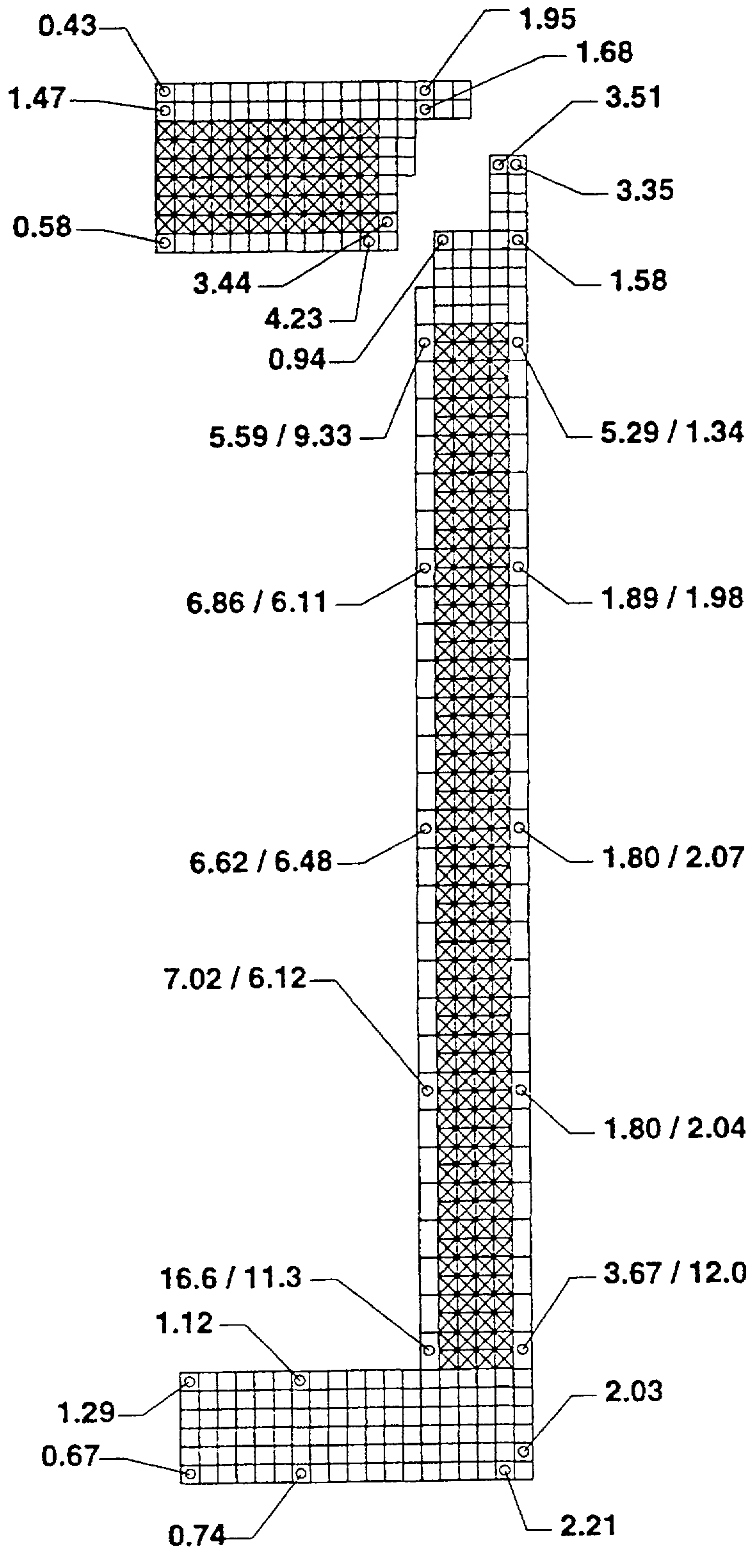


Figure 3.14. Model 2000 Cask – Thermal Stress Analysis (Q, ksi) Steady-State Condition; -20°F Ambient Temperature and Maximum Decay Heat

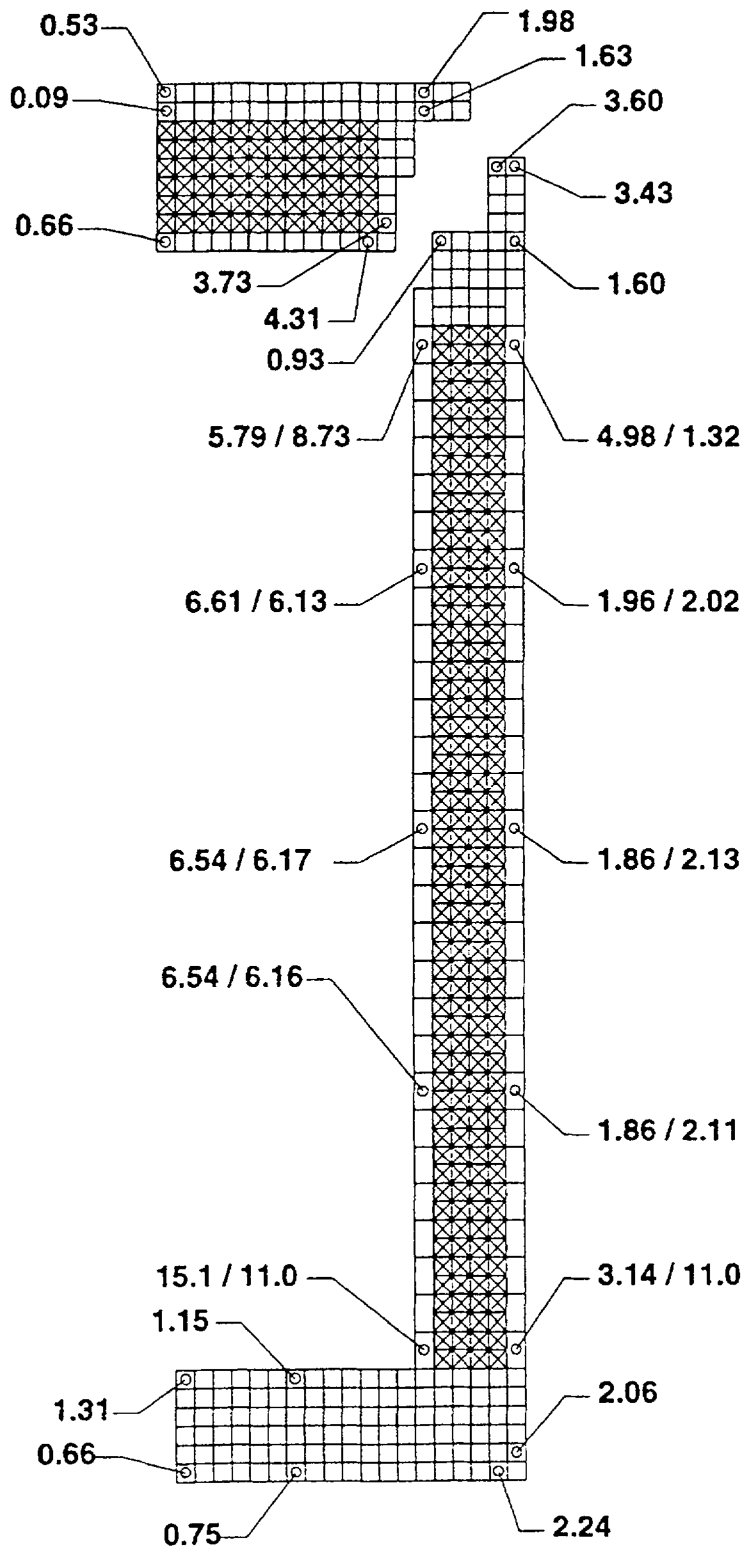


Figure 3.15. Model 2000 Cask – Thermal Stress Analysis (Q, ksi) Steady-State Condition; -40°F Ambient Temperature and Maximum Decay Heat

3.5 HYPOTHETICAL ACCIDENT THERMAL EVALUATION

After a free drop through 30 feet and a free drop through four feet onto a cylindrical punch, the package should be exposed to a fire transient. This thermal test consists of exposure of the whole package for not less than 30 minutes to a radiation environment of 800°C (1,475°F) with an emissivity coefficient of at least 0.9. The surface absorptivity of the package is taken as 0.8, and a convective heat input based on still ambient air at 800°C (1,475°F) is applied. The transient is then continued until maximum temperature values within the cask are obtained.[3.17]

The thermal performance of the package during the fire transient is evaluated using the finite element program LIBRA. In this evaluation, the properties were updated every time step by the user-originated subroutine CPHFIR.F. This subroutine contains expressions relating element properties to temperature. Thermal properties as well as density and heat capacitance are updated periodically. The time step for the 0 - 1.0 hour range is set at 1.2 minute, while the time step for 1.0 - 5.0 hours is set at 6.0 minutes. The maximum temperature was peaked near 5th hour for most of the components. The LIBRA program allows the user to select the time marching scheme. In this analysis, the backward difference scheme is selected for mathematical stability of the finite element model.

3.5.1 Analytical Model

The analytical model used to evaluate the hypothetical accident condition is identical to that described in Subsection 3.4.1. The model accounts for damage during the accidental condition by not including the toroidal shells.

3.5.2 Package Conditions and Environment

During the drop events the toroidal shell of the overpack structure will collapse, absorbing the kinetic energy of the event. Therefore, the thermal models described in Subsection 3.3.1 does not include the toroidal shells.

3.5.3 Package Temperatures

Temperature values at several locations within the model are given in Figures 3.16 through 3.21 for time steps for 0 to 3.0 hours during the fire transient. In addition, the contour plots at these times are presented from 3.22 through 3.27. Figure 3.28 present the temperature vs. time plot for 0.0 to 5.0 hours.

3.5.4 Maximum Internal Pressures

The maximum allowable cask cavity temperature is 600°F, which corresponds to when the cask cavity is filled with 100% humidity air at 30 psia. The temperature within the cask cavity remains below 600°F during the fire transient; therefore, the maximum internal pressure is below 30 psia.

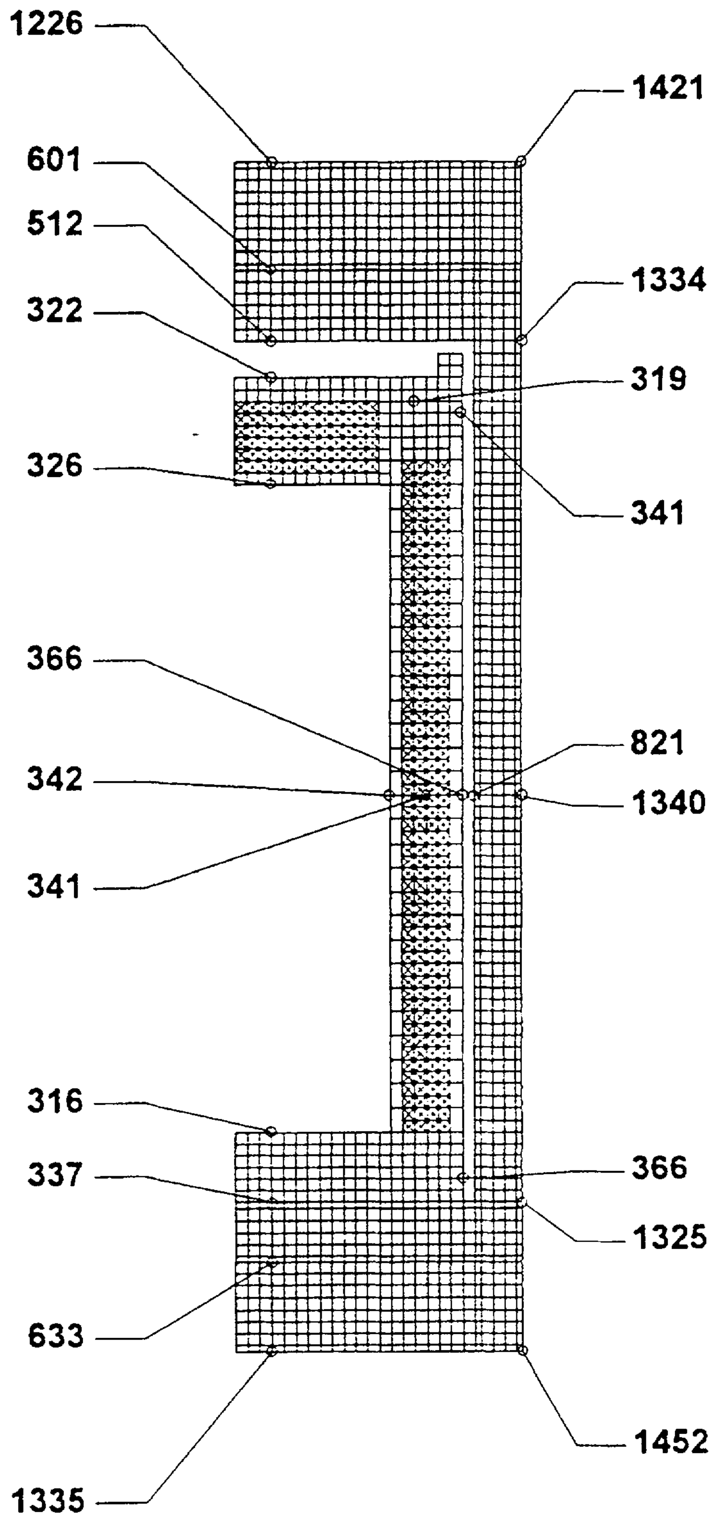


Figure 3.16. Model 2000 Transport Package, Transient Analysis – Fire 100°F Ambient Temperature, Maximum Decay Heat and Maximum Insolation
Time: 0.5 Hr

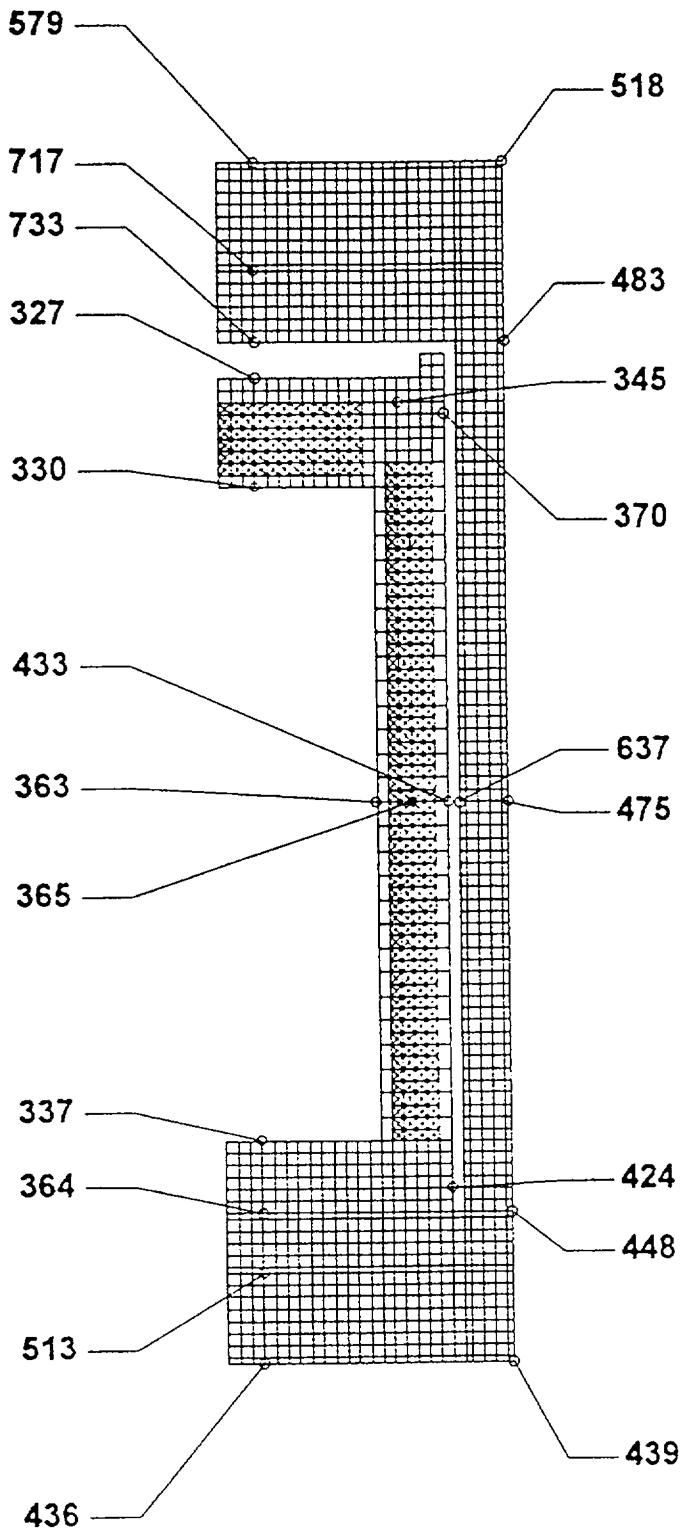


Figure 3.17. Model 2000 Transport Package, Transient Analysis – Fire 100°F Ambient Temperature, Maximum Decay Heat and Maximum Insolation Time: 1.0 Hr

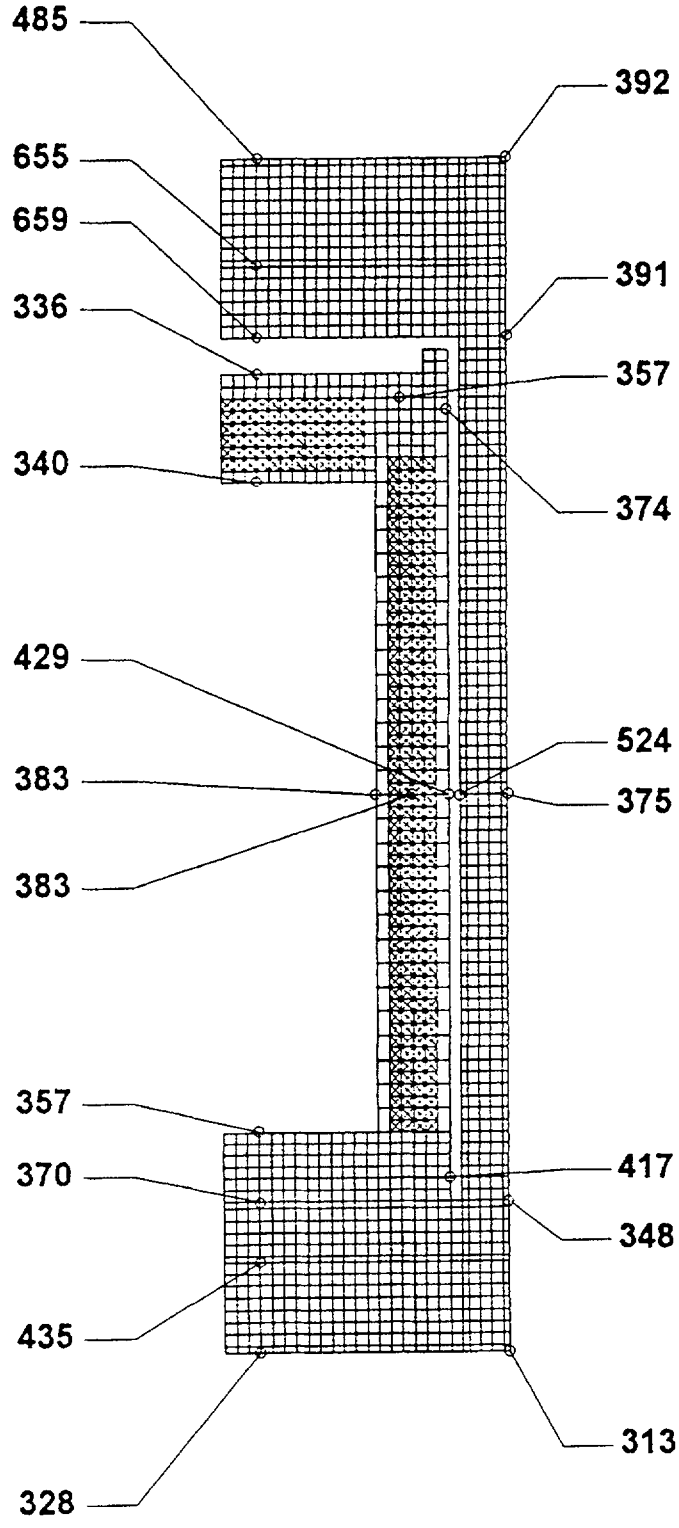


Figure 3.18. Model 2000 Transport Package, Transient Analysis – Fire 100°F Ambient Temperature, Maximum Decay Heat and Minimum Insolation Time: 1.5 Hr

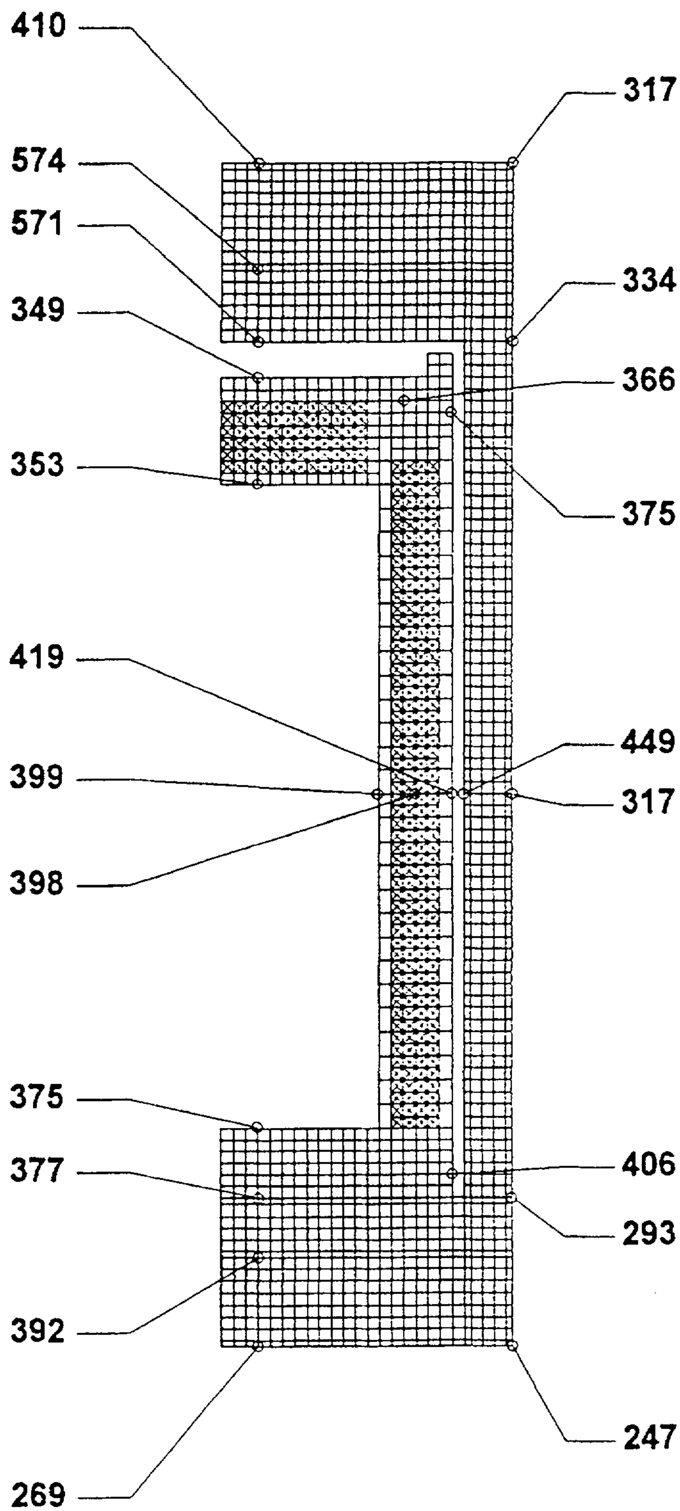


Figure 3.19. Model 2000 Transport Package, Transient Analysis – Fire 100°F Ambient Temperature, Maximum Decay Heat and Maximum Insolation Time: 2.0 Hr

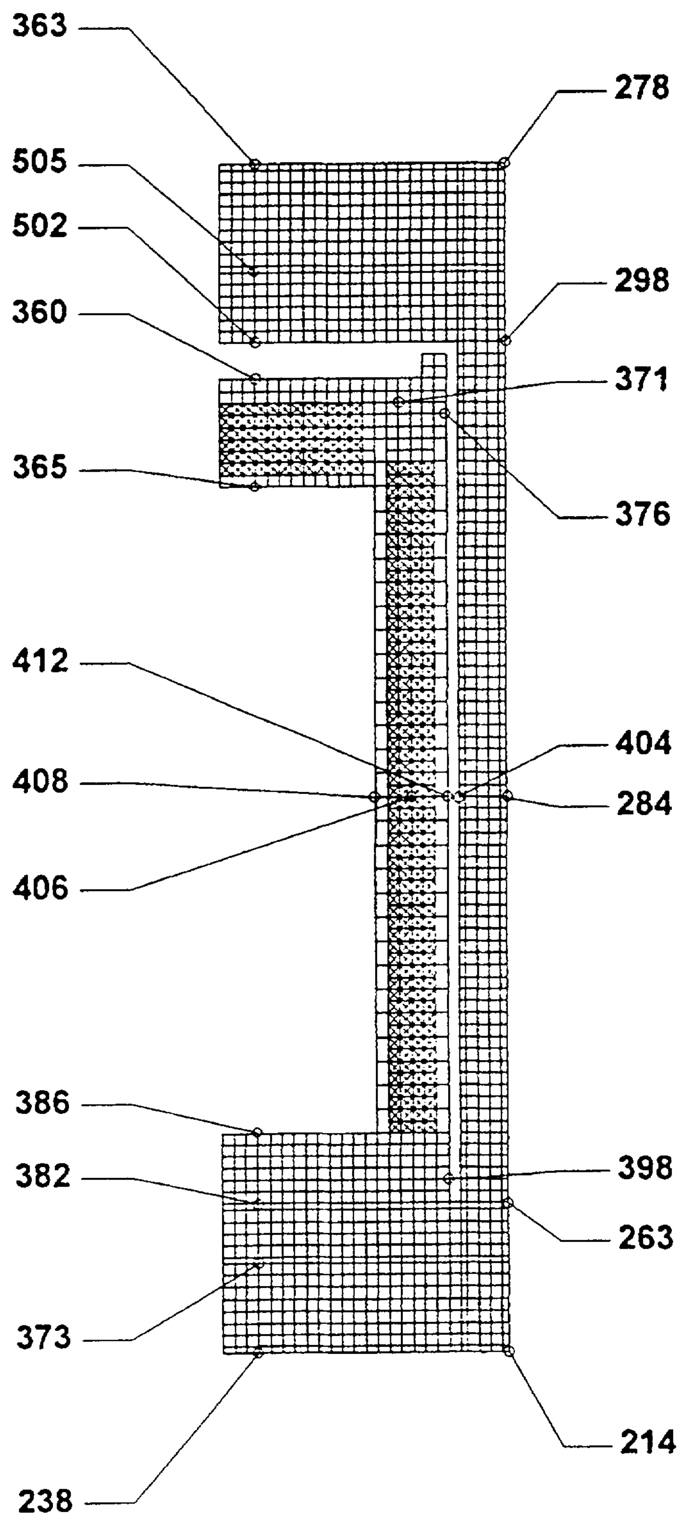


Figure 3.20. Model 2000 Transport Package, Transient Analysis – Fire 100°F Ambient Temperature Plus Maximum Decay Heat and Maximum Insolation Time: 2.5 Hr

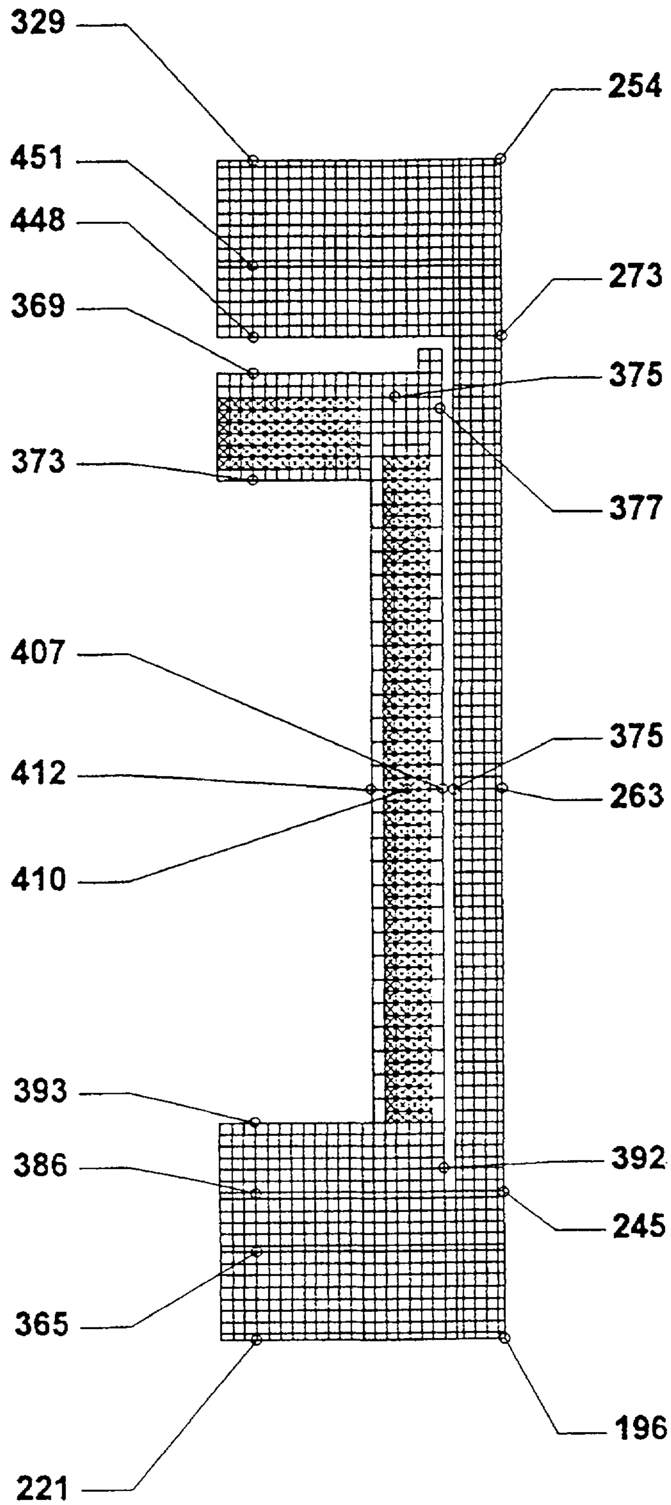


Figure 3.21. Model 2000 Transport Package, Transient Analysis – Fire 100°F Ambient Temperature Plus Maximum Decay Heat and Maximum Insolation
Time: 3.0 Hr

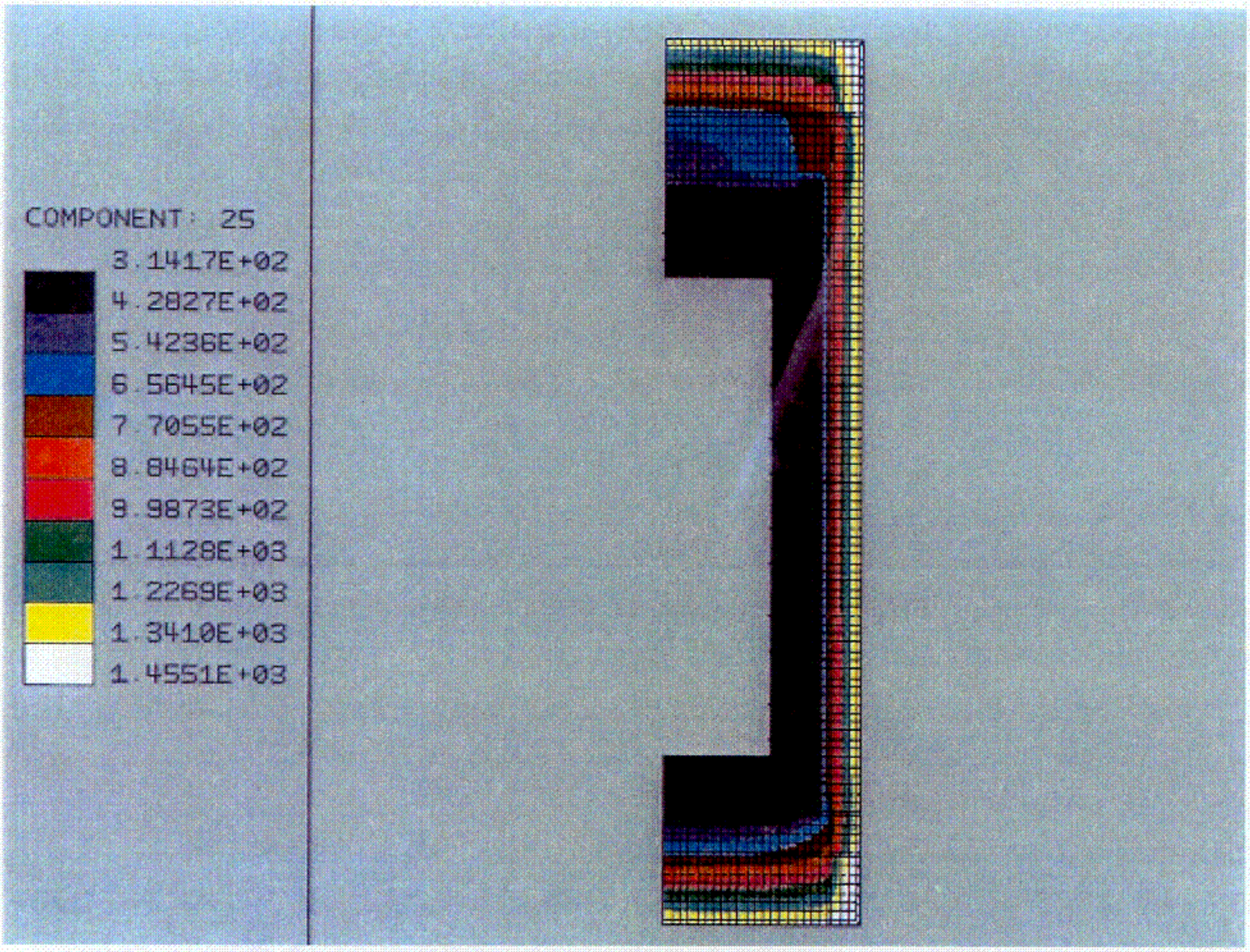


Figure 3.22. Model 2000 Transport Package – Contour Plot Transient Analysis: Fire Plus 100°F Ambient Temperature Maximum Decay Heat and Maximum Insolation Time: 0.5 Hour

C05

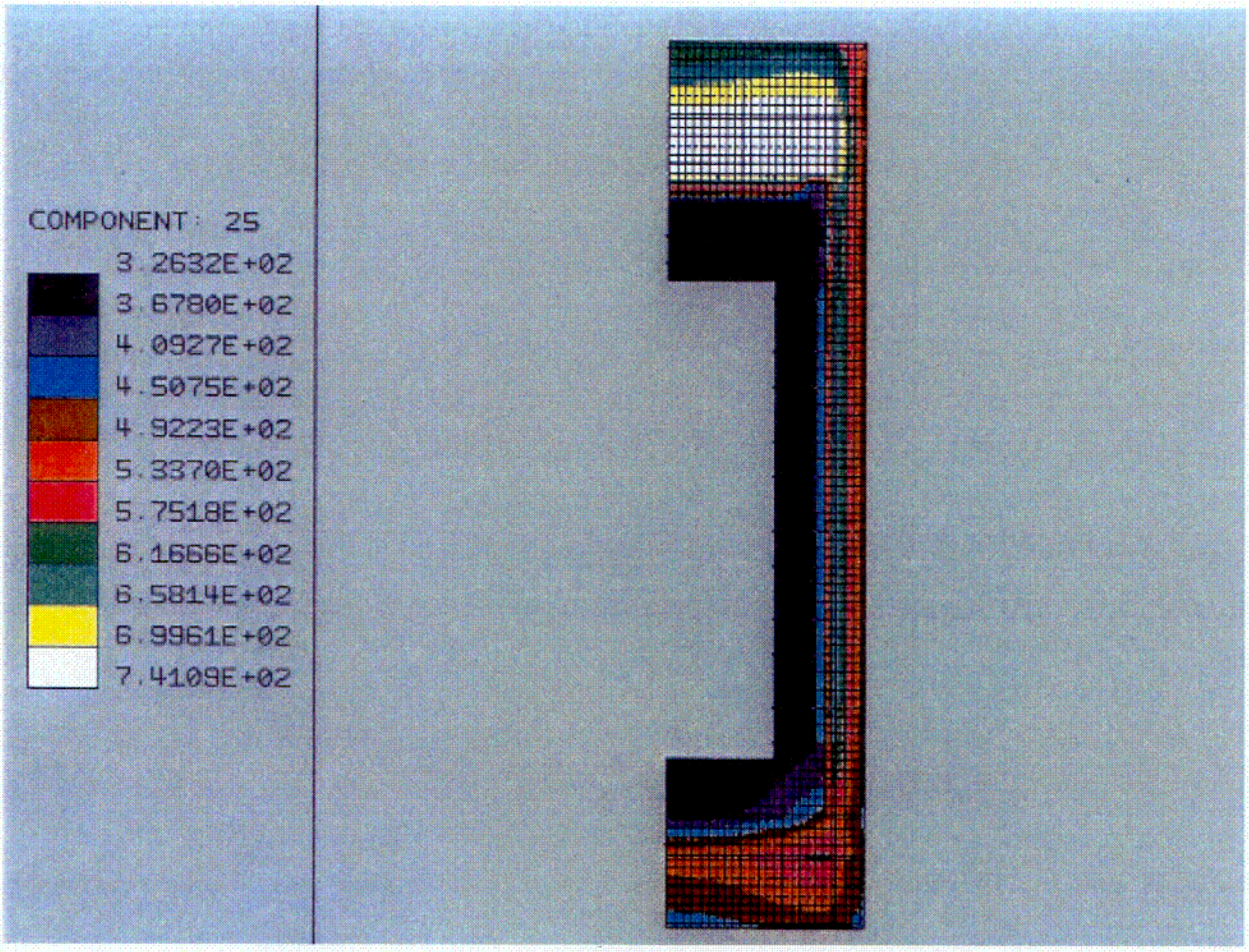


Figure 3.23. Model 2000 Transport Package – Contour Plot Transient Analysis: Fire Plus 100°F Ambient Temperature Maximum Decay Heat and Maximum Insolation Time: 1.0 Hour

C06

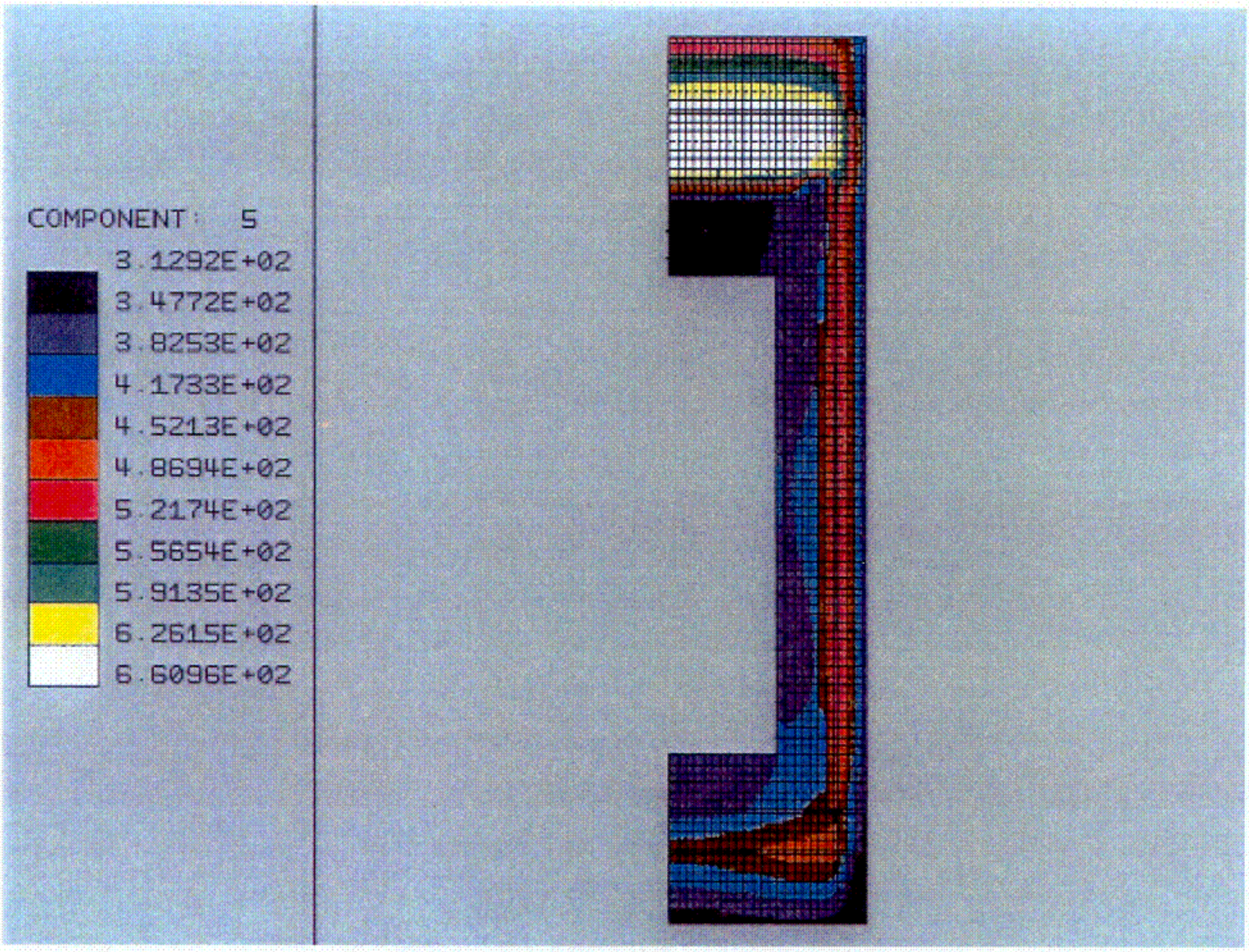


Figure 3.24. Model 2000 Transport Package – Contour Plot Transient Analysis: Fire Plus 100°F Ambient Temperature Maximum Decay Heat and Maximum Insolation Time: 1.5 Hour

C07

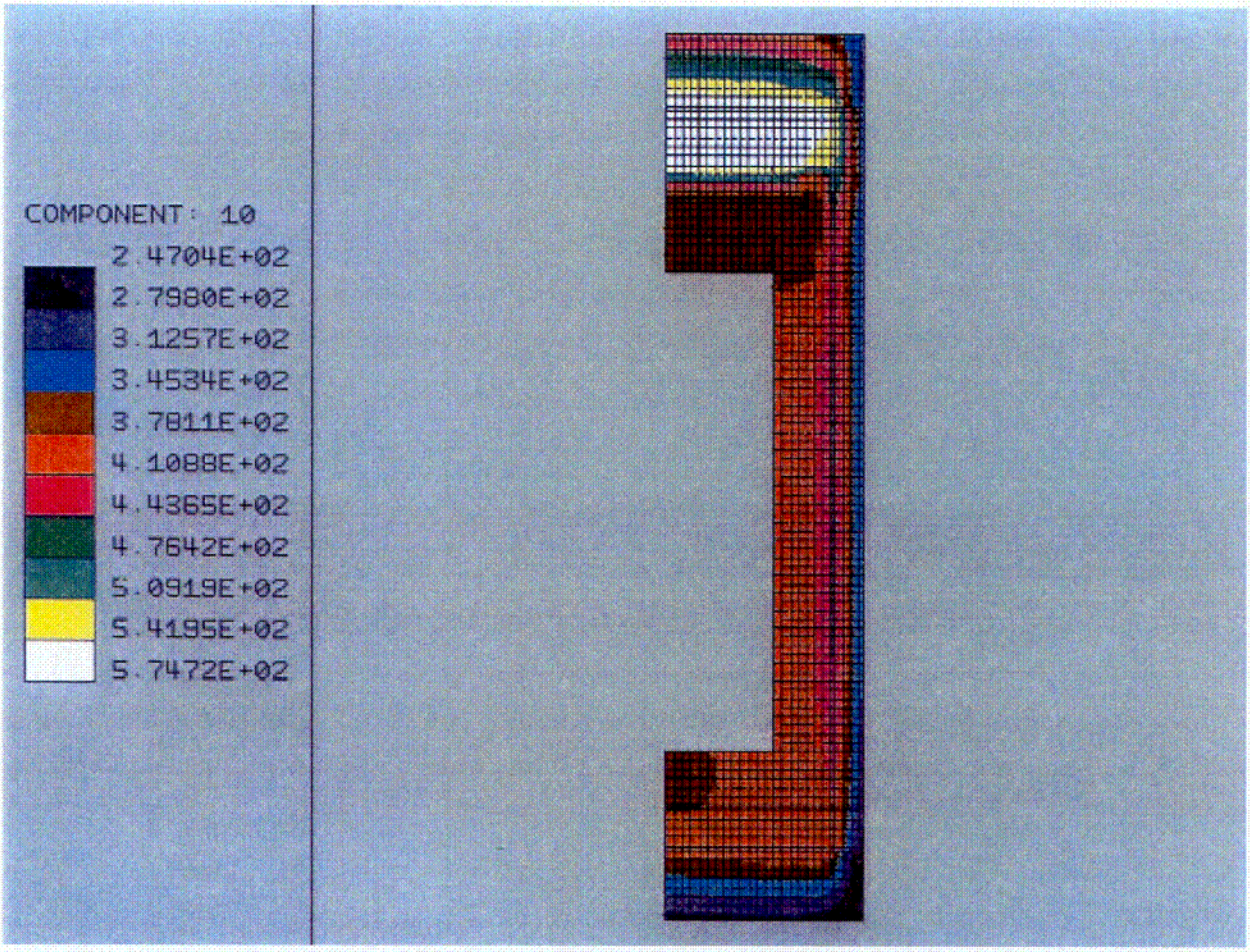


**Figure 3.25. Model 2000 Transport Package – Contour Plot
Transient Analysis: Fire Plus 100°F Ambient Temperature
Maximum Decay Heat and Maximum Insolation
Time: 2.0 Hour**

C08

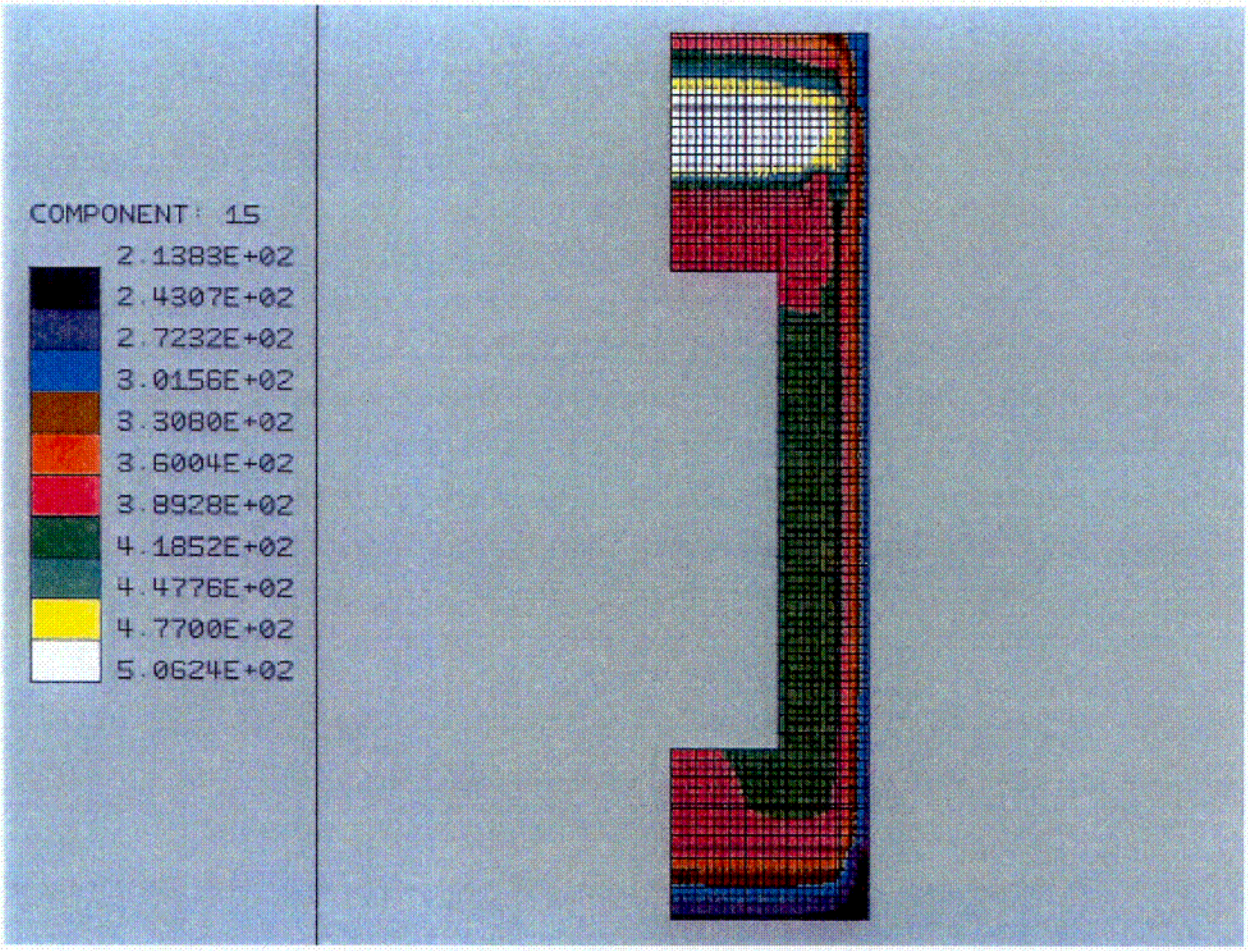


Figure 3.26. Model 2000 Transport Package – Contour Plot Transient Analysis: Fire Plus 100°F Ambient Temperature Maximum Decay Heat and Maximum Insolation Time: 2.5 Hour

C09

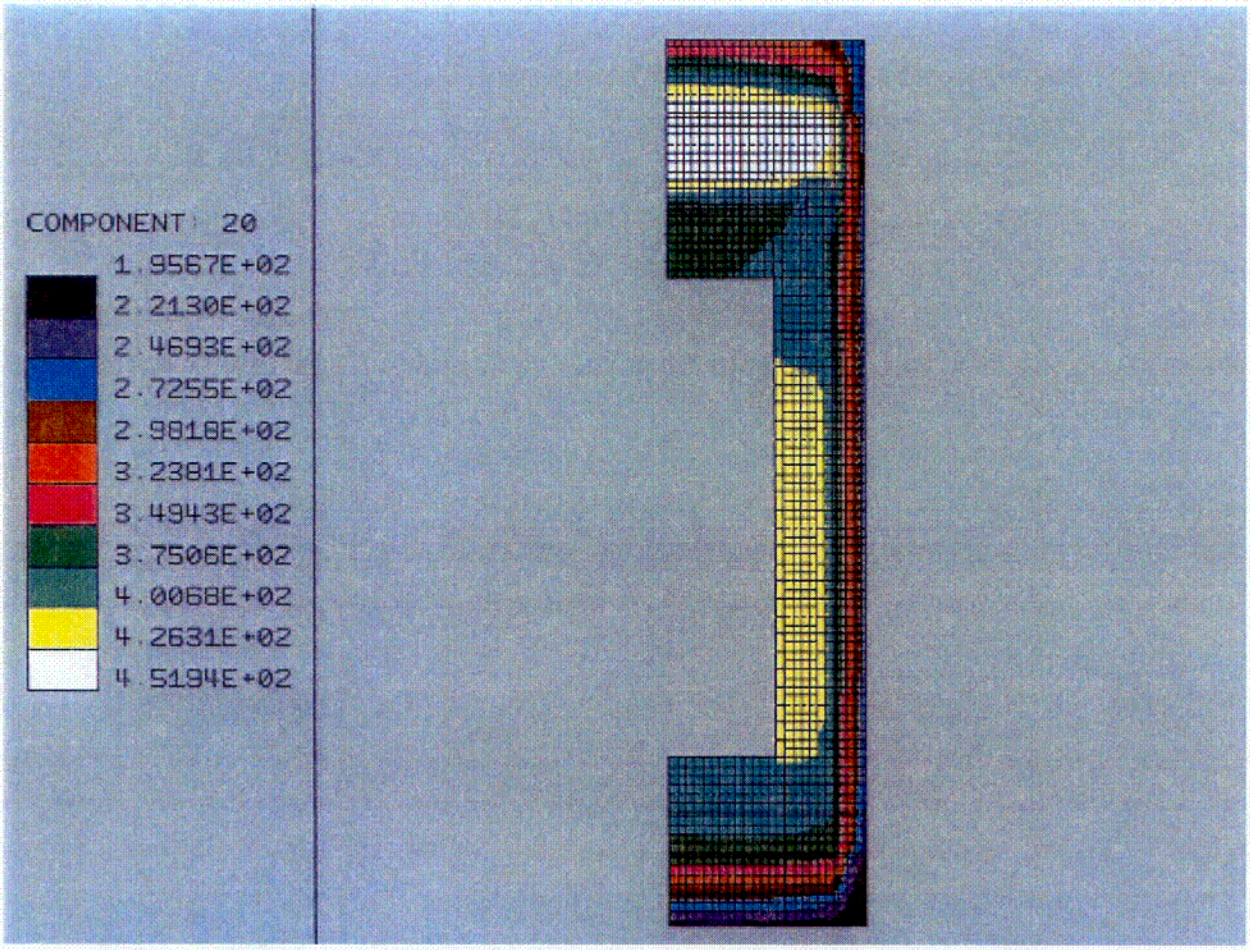
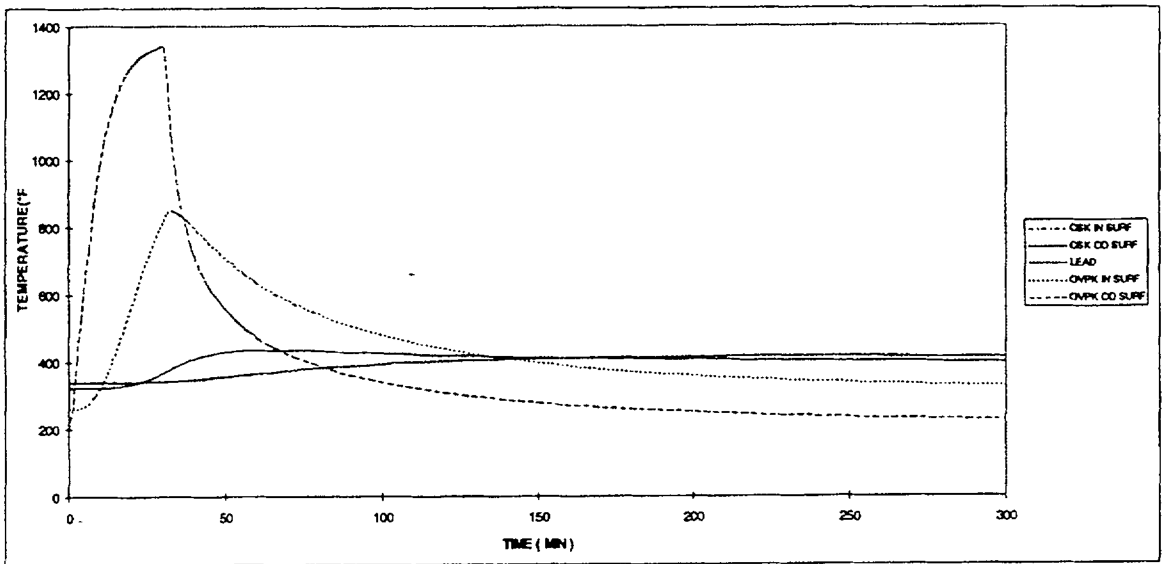


**Figure 3.27. Model 2000 Transport Package – Contour Plot
Transient Analysis: Fire Plus 100°F Ambient Temperature
Maximum Decay Heat and Maximum Insolation
Time: 3.0 Hour**

C10



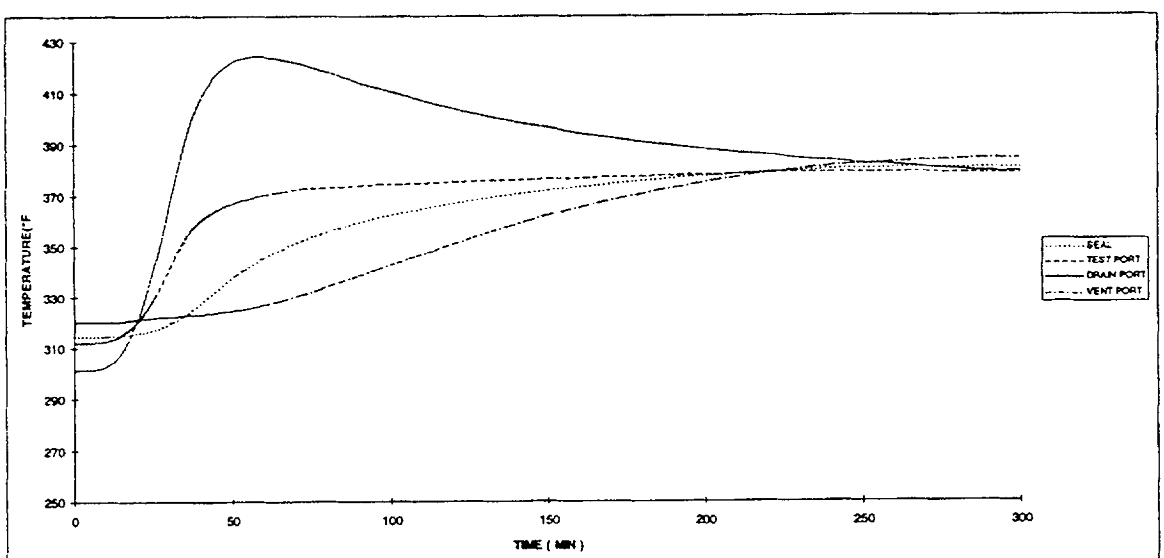


Figure 3.28. Temperature vs. Time, Accident Condition

3.5.5 Maximum Thermal Stresses

Thermal stresses in the Model 2000 are evaluated at 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 hours during the fire transient. Stress intensity values ($Q = P_m + P_b$, ksi) at several locations within the model are given in Figures 3.29 through 3.34. These stress values are included for information only. They are not included in Section 2.0, since there are no regulatory limits on secondary stresses for accident conditions according to U.S. NRC Regulatory Guide 7.6.

3.5.6 Evaluation of Package Performance for the Hypothetical Accident

The temperature values obtained within the model during the fire transient are presented in Subsection 3.5.3. The temperatures evaluated are below the thermal design criteria of the material for each component. The highest lead temperature noted is 413°F. This temperature is way below the melting point of lead. The peak temperature of the cask seal is 381°F and for the O-rings (Drain Port) is 424°F. Both of these peak temperatures are below their corresponding materials performing temperature criteria of 400°F and 500°F respectively.

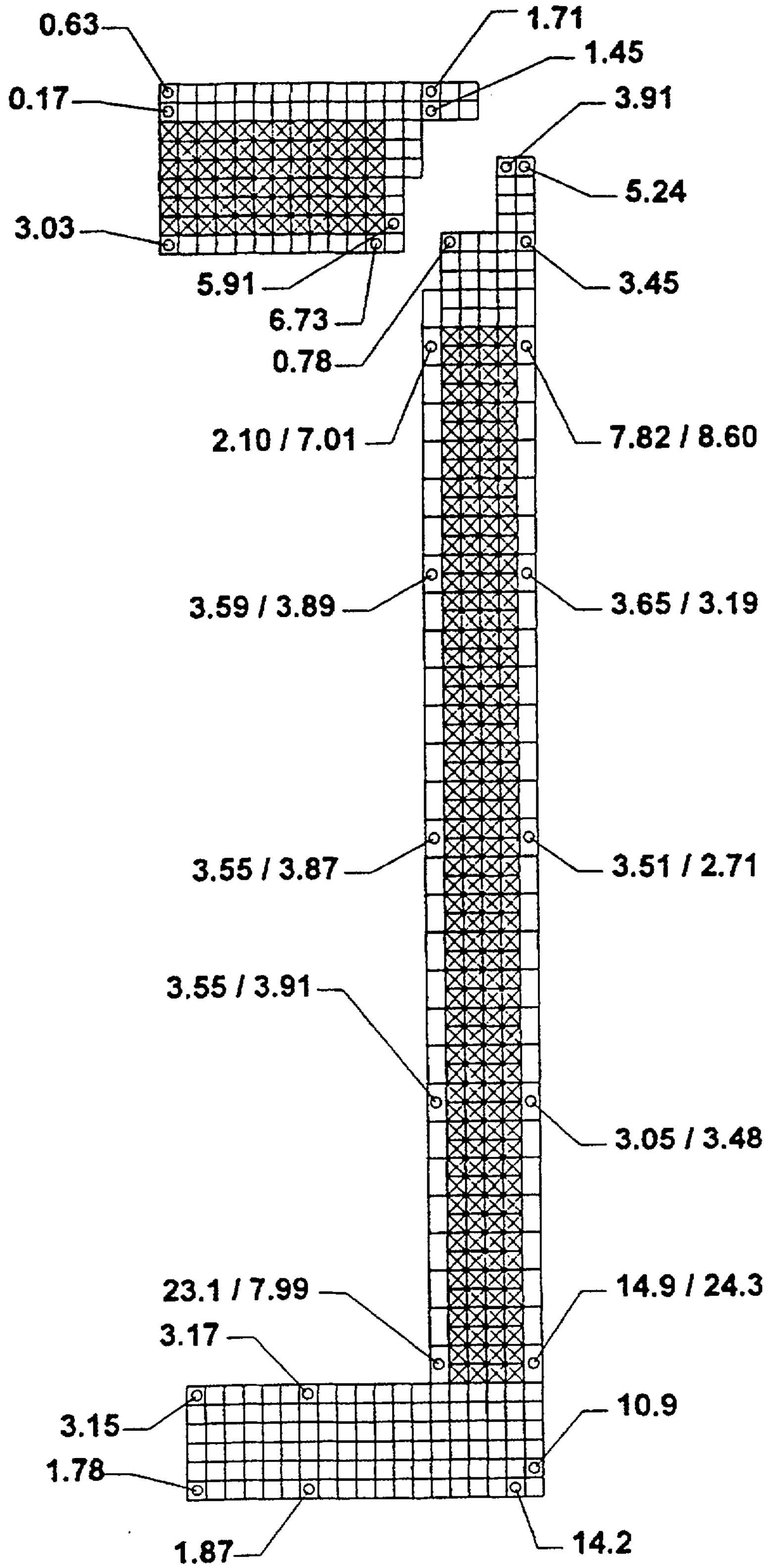


Figure 3.29. Model 2000 Cask – Thermal Stress Analysis (Q, ksi)
Fire Transient Condition (t = 0.5 Hour)

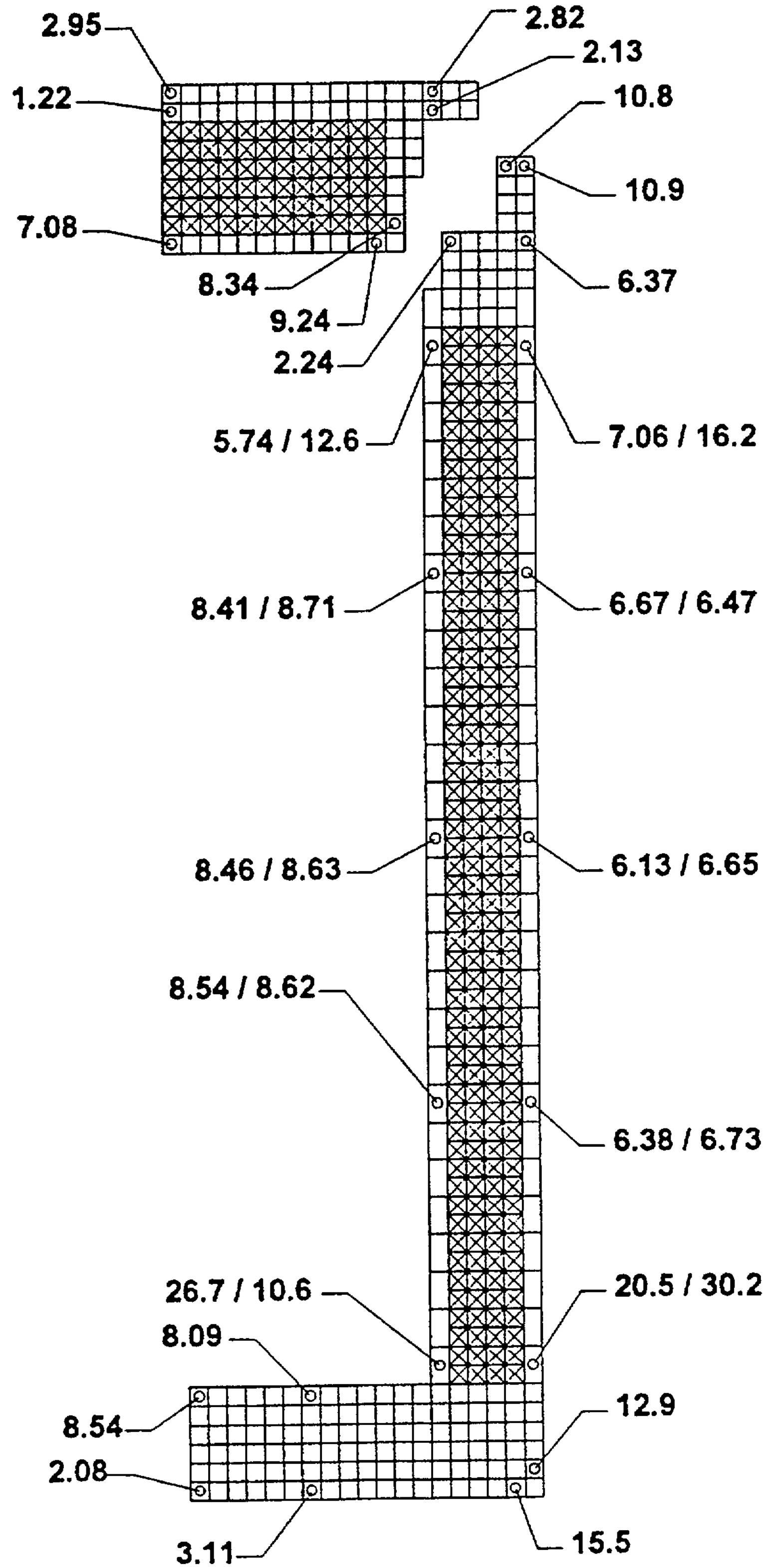


Figure 3.30. Model 2000 Cask – Thermal Stress Analysis (Q, ksi) Transient Condition (t = 1.0 Hour)

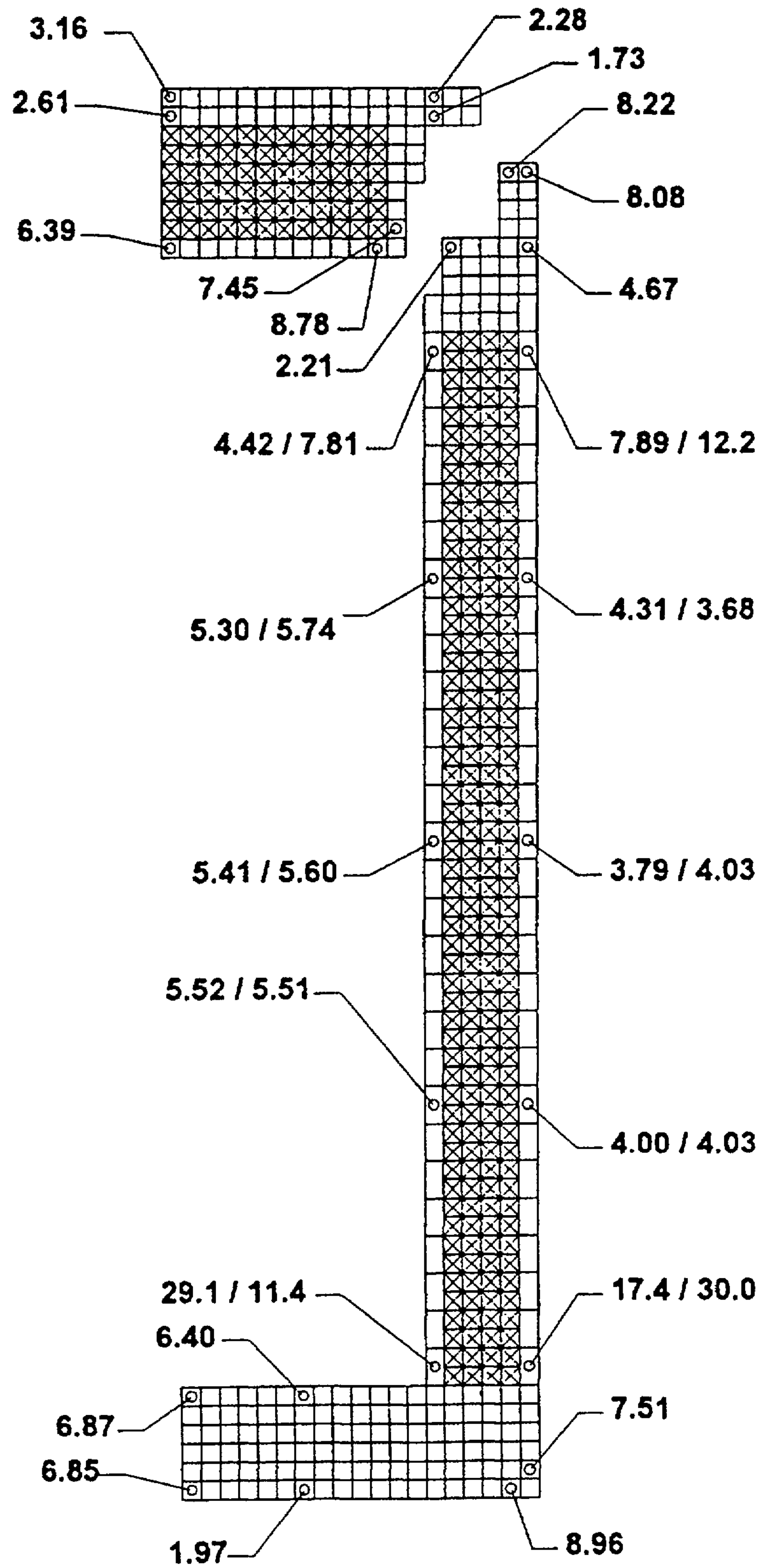


Figure 3.31. Model 2000 Cask – Thermal Stress Analysis (Q, ksi) Transient Condition (t = 1.5 Hours)

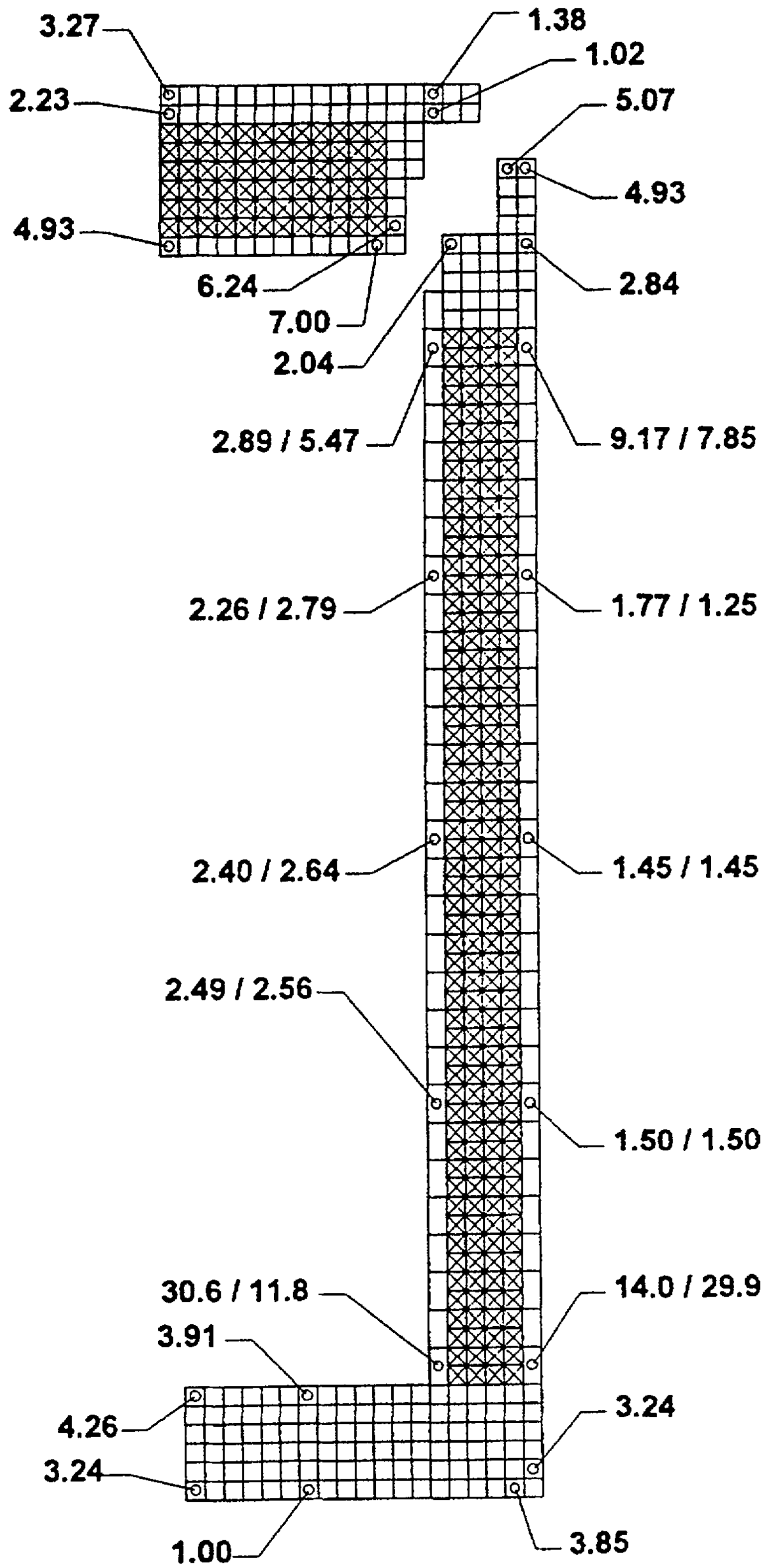


Figure 3.32. Model 2000 Cask – Thermal Stress Analysis (Q, ksi)
Transient Condition (t = 2.0 Hours)

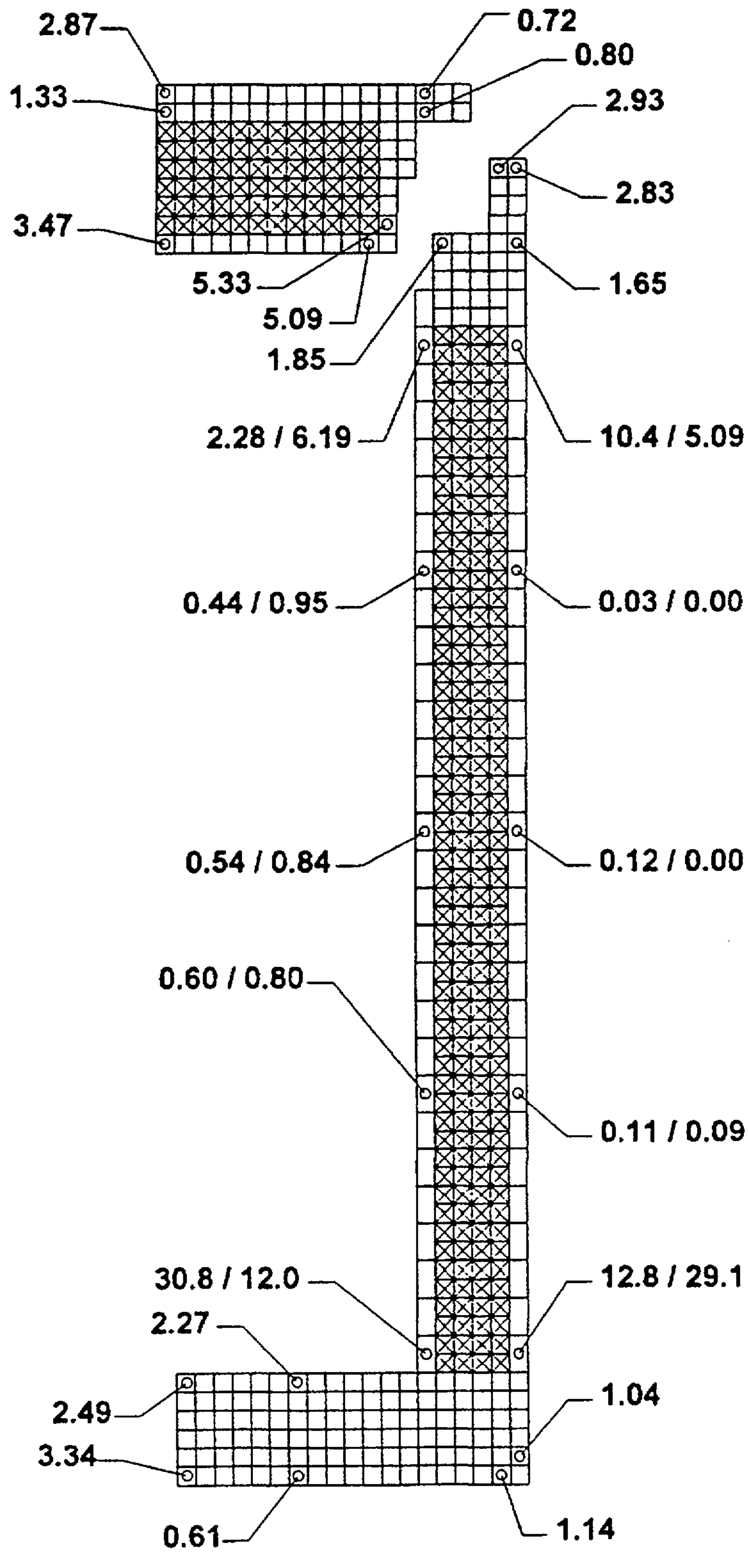


Figure 3.33. Model 2000 Cask – Thermal Stress Analysis (Q, ksi) Transient Condition (t = 2.5 Hours)

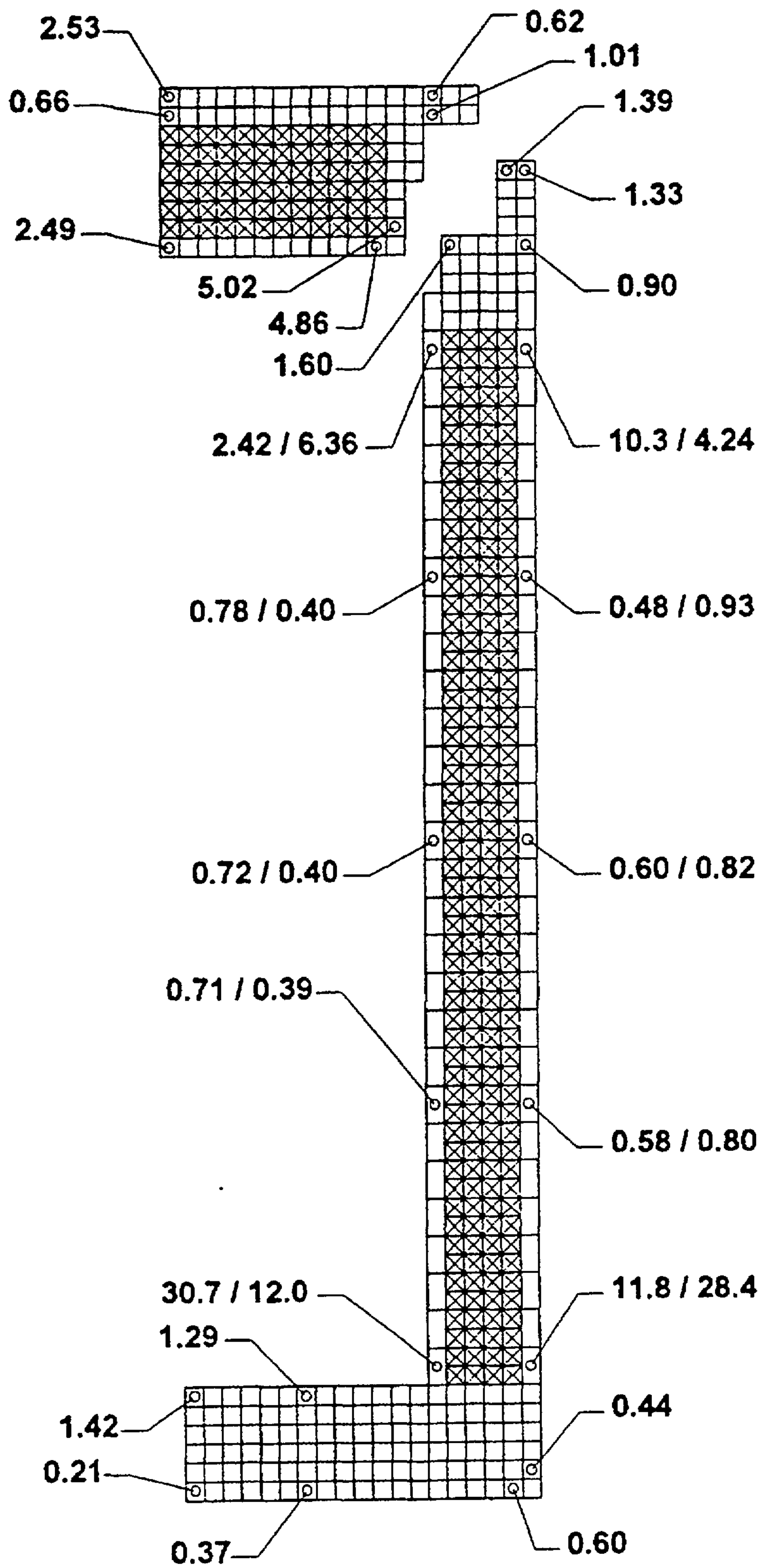


Figure 3.34. Model 2000 Cask – Thermal Stress Analysis (Q, ksi) Transient Condition (t = 3.0 Hours)

3.6 REFERENCES

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3.9. USNRC Rules and Regulation, 10CFR71, "Packaging and Transportation of Radioactive Material", November, 1992.

3.10. Gebhart, B., Heat Transfer, McGraw-Hill Book Company, New York, 2nd Ed., 1971, p. 377.

3.11. Ibid, p.355.

3.12. Ibid, p. 376.

3.13. Kreith, F., Principles of Heat Transfer, International Textbook Company, Pennsylvania, 2nd Ed., 1969, Table 5-2.

3.14. Heat Transfer Data Book, D. A. Kaminski, Ed.; General Electric Company, New

3.15. Gebhart, B., Heat Transfer, McGraw-Hill Book Company, New York, 2nd Ed., 1971, p. 371.

3.16. Kreith, F., Principles of Heat Transfer, International Textbook Company, 3.7.14. Pennsylvania, 2nd Ed., 1969, p. 340.

3.17. USNRC, Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Cask", May 1977.

3.18. Morris & Wendel, "HFIR System RELAP5 Input Model", Oak Ridge National Laboratory, ORNL/TM- 11647, January, 1993.

3.7 APPENDIX

3.7.1 LIBRA Finite Element Program Heat Transfer Module

3.7.1.1 Description of the LIBRA Heat Transfer Program. The LIBRA heat transfer program performs steady-state and transient analyses of two- and three-dimensional structures. The LIBRA heat transfer code is compatible with the structural code in that essentially the same model can be used for both structural and thermal analyses, and temperature fields determined in thermal analyses can be saved and applied in subsequent structural analyses.

For transient thermal problems the user can control the integration scheme by specifying the integration parameter. A zero value of this parameter gives an explicit integration scheme, while values between zero and one give implicit schemes. Usually, a value of one for the integration parameter was used, and this value corresponds to a backward difference integration technique.

The LIBRA user can specify property changes at user-directed intervals in transient problems. At such times, the LIBRA code passes control to a user-written subroutine which, allows the introduction of temperature-dependent properties. This program feature was widely used in the analysis of the transport package.

3.7.1.2 Qualification and Verification of LIBRA Program. To assess the accuracy of the LIBRA computer program, a qualification and verification program was conducted. The program included verification against exact solution type of problems and benchmarking in the thermal area. A thermal test was performed on a GE Model 1500 transport package to verify transient and steady-state analyses at various power levels. In all cases, verification against exact solutions and benchmarking, the agreement between theory or testing and analysis results were excellent.

3.7.1.3 Heat Transfer Problems With Exact Solution. Six example problems were solved analytically and by application of the LIBRA heat transfer program. The problems solved include plane and axisymmetric geometry and involve convective, radiative, and fixed temperature boundary conditions. In all problems solved, both steady-state and transient problems, agreement between the analytical solutions and the LIBRA program was within one percent. Table 3.3 summarizes these problems and the comparison of results.

Table 3.3. Summary of Exact-Solution Heat Transfer Problems and Their Results

Problem Type	Problem Statement	Theory	LIBRA	References
Transient Conduction	Concrete wall at initial temperature (T_i) suddenly exposed on one side to hot gas at (T_g)	x/L T(°F) 0 508.8 0.167 538.2 0.333 625.3 0.500 766.3 0.667 954.7 0.833 1180.7 1.0 1431.8	T(°F) 507 535 622 763 952 1180 1430	F. Kreith, Principles of Heat Transfer, 2nd. ed., International Textbook Co., Scranton, 1965. Example 4-4.
Steady-state Conduction	Concrete slab has its two surfaces maintained at T_1 and T_2. Obtain heat transfer rate.	120 Btu/hr-ft^2	120 Btu/hr-ft^2	Gebhart, B., Heat Transfer, 2nd ed., McGraw-Hill Book Co., New York, 1971. Example 2-1.
Internal Heat Generation, Steady-state	A uniformly heat-generating plate of thickness t, subjected to a temperature T_1 on inside and T_2 on the other side.	x/L T(°F) 0 141 0.125 330 0.250 471 0.375 562 0.500 605 0.625 599 0.750 544 0.875 440 1.0 288	T(°F) 142 331 471 562 605 599 544 440 287	J.K. Garrett, "THTD Design Review Report," General Electric Co., San Jose, 1980. Test case 1.
Conduction with Radiation and Convection Boundary Conditions	A plate has a heat flux on one side and the other side radiates to two sinks.	Surface Temperature 659.7°F	Surface Temperature 659.7°F	J.K. Garrett, "THTD Design Review Report," General Electric Co., San Jose, 1980. Test case 2.
Axisymmetric Transient Conduction	An infinitely long rod of radius R having a uniform initial temperature $T_{\sim}$ is plunged suddenly into a bath at T_∞.	r/R T(°F) 0 86.6 0.1 87.0 0.2 87.6 0.3 88.5 0.4 89.7 0.5 91.2 0.6 92.8 0.7 94.6 0.8 96.5 0.9 98.3 1.0 100.0	T(°F) 86.6 87.0 87.6 88.5 89.7 91.2 92.9 94.7 96.5 98.3 100.0	V.S. Arpaci, Conduction Heat Transfer, Addison Wesley, Reading, Mass, 1966. Example 5-7.
Axisymmetric Transient Conduction with Convective Boundary Conditions	A rod having a uniform initial temperature T_i is quenched in an oil bath at T_∞.	r/R T(°F) 0 490.0 0.1 489.0 0.2 485.7 0.3 480.2 0.4 472.6 0.5 462.9 0.6 451.3 0.7 437.8 0.8 422.5 0.9 405.6 1.0 387.2	T(°F) 490 488 485 479 472 462 450 437 421 404 386	V.S. Arpaci, Conduction Heat Transfer, Addison Wesley, Reading, Mass, 1966. Example 5-13.

3.7.1.4 Thermal Benchmarking Test on GE Model 1500 Transport Package. A thermal test was performed on a GE Model 1500 transport package[3.19]. Radioactive contents heat load was simulated by electric heaters. Thermocouples were placed at strategic locations inside the cask cavity, on the outer cask surface, on the inside overpack surfaces, and exterior to the overpack structure. Temperatures were periodically recorded as the heater power was varied from 0 to 3 kW. Steady-state temperatures were recorded for various heater powers from 1 kW to 3 kW.

A finite element model of the package was developed and it was applied to a thermal analysis using the LIBRA Heat Transfer Program. A comparison of heat test (HT) and LIBRA results are given in Table 3.4

Table 3.4. Comparison of Thermal Test on Model 1500 and LIBRA Results

	p = 1.1 kW		p = 2 kW		p = 3 kW	
Location	**HT**	**LIBRA**	**HT**	**LIBRA**	**HT**	**LIBRA**
Cavity	264°F	248°F	395°F	372°F	527°F	474°F
Cask Surface	166°F	179°F	243°F	256°F	319°F	308°F
Inner Jacket	101°F	99°F	139°F	138°F	168°F	158°F
Outer Jacket	80°F	82°F	98°F	107°F	102°F	111°F

3.7.2 Thermal Test on GE Model 2000 Transport Package [3.2]

A thermal test has been conducted on a GE Model 2000 Transport Package. The objective of the test is to verify the thermal analytical model by comparing the analytical results to those of the physical testing [3.2]. The testing is done at ambient conditions with 600 and 2000 watts heat input in the cask cavity to simulate the maximum decay heat. The test also demonstrates the capability of the Model 2000 to safely dissipate 600 and 2000 watts of decay heat.

The thermal test is performed by placing an electric heat source concentrically within the cask cavity. Thirteen temperature sensing devices are placed within the cask cavity, on the external surfaces of the cask, and on the overpack surfaces. In the radial direction, temperatures measured include the cask cavity air, internal cask wall, external cask wall, overpack inside surface, and the overpack external surface. In the axial direction, the temperatures measured include the cask cavity floor, the bottom cask surface, below the lower honeycomb pad, at the bottom of the overpack, at the top of the cask cavity (under the lid), at the gasket lower surface, at the top of the lid, and at the top of the overpack. Three additional transducers record the external ambient temperature. The temperature data are recorded at 30 minute intervals during the transient until a steady state condition is reached (temperatures remain significantly unchanged for a one our period).

The LIBRA finite element model used for this evaluation is the same model used in the original application except that the contents (fuel, basket, and liner) are not included. Heat loading of 600 and 2000 watts is uniformly distributed in the cask internal walls. Temperatures at various points of the cask are calculated and continuously monitored during the over forty-hour simulation.

Differences between the test and the model temperatures are 3% in the cask cavity, 1% at the cask outer wall, 5% at the overpack inner wall, and 1% at the overpack outer wall. Test data and the LIBRA predictions of cavity wall temperature versus time for the 2000 watt case are plotted in Figure 3.35: excellent correlation between test and analysis results is displayed. The physical test verifies the adequacy and accuracy of the LIBRA finite element thermal analysis model of the Model 2000 Package.

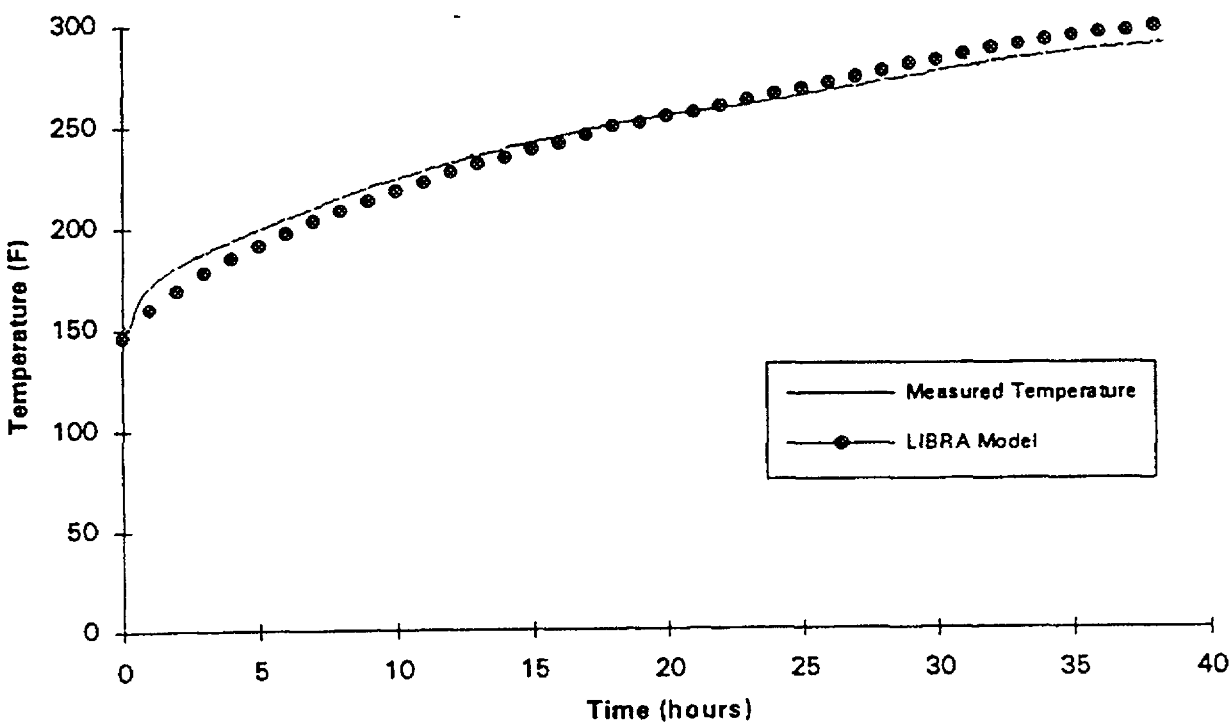


Figure 3.35. Cavity Wall Temperature – Thermal Test vs. LIBRA Model Model 2000 Transport Package With 2000 Watts Heat

3.7.3 Thermal Evaluation of Shipping Racks

While the main chapters of this report is concentrated on investigating the thermal behavior of the Model 2000 Transport Package without the shipping rack being modeled specifically, this Subsection addresses the thermal characteristics of the shipping rack and the heating elements (up to 2000 watts decay heat).

The thermal analyses assume that the cask cavity is dry and has one atmosphere of helium, which is the normal shipping mode. These analyses demonstrate that the Model 2000 Transport Package with the contents provides suitable heat dissipation to maintain the temperature distribution of the Package within the limits established in the Package's Safety Analysis Report [3.1]. All thermal conditions are analyzed using the finite element computer code LIBRA under normal and accident conditions with the exception of the cold environment (-20°F and -40°F). In these cases, it is assumed that a uniform temperature field exists throughout the Package.

3.7.3.1 Thermal Design Criteria. The design pressure of the Model 2000 Cask is 30 psia. The maximum heating element surface temperature is 800°F for content or material. The temperature limits of the various components in the Model 2000 Package established in the Model 2000 Package SAR, Reference [3.1] and USNRC Rules and Regulation, 10CFR71, Reference [3.9] are

For the cask seal area	≤ 400°F
Within the lead regions	≤ 600°F
Cask cavity	≤ 600°F
Exterior Package surface	≤ 180°F (for no solar and exclusive use)

3.7.3.2 Design Bases Conditions. Temperature distributions in the Model 2000 Transport Package with the source materials including the shipping rack are evaluated for the following thermal environments:

1. Normal Operating Condition

    a) 100°F ambient temperature with maximum decay heat with insolation
    b) 100°F ambient temperature with maximum decay heat w/o solar
    c) -20°F ambient temperature with maximum decay heat w/o solar

2. Thermal Fire Accident

    a) 30 minutes after start of fire
    b) Post fire steady-state

3.7.3.3 Results of Design Basis Thermal Analyses. The analytical results obtained from evaluating the design basis conditions for the source materials carried by the Multifunctional shipping rack in the Model 2000 Package are summarized in Table 3.5. In additions, the temperature results from the Model 2000 Package analysis (Table 3.1 in Subsection 3.1.3) are tabulated in Table 3.6 for comparison. They are based on the use of the thermal analysis modules of the LIBRA Code. As expected, the differences between these models is minimal, since the only relevant effect is due to different heat input distributions.

Table 3.5. Summary of Temperatures

Package Component	Thermal Condition Temperatures (°F)				Component Criteria (°F)
	1.a	1.b	1.c	2.b(1)	
Source material (Cs^{137})	537	531	522	558	800
(1) Values given are maximum temperatures obtained during the fire transient and cooling down period.					

Table 3.6. Comparison Between Two Different Models

Package Component	Thermal Condition Temperatures (°F)							
	1.a		1.b		1.c		2b	
	A	B	A	B	A	B	A	B
Cask Cavity Surface	350	341	318	308	243	233	421	415
Lead Shield	348	338	315	305	241	231	419	413
Cask Seal Area	310	315	273	278	196	201	370	381
Cask Test Port	308	312	272	275	194	198	373	379
Cask Drain Port	296	301	267	272	192	196	420	424
Cask Vent Port	312	320	275	283	199	207	361	384
Cask Outer Surface	330	322	296	287	217	208	441	407
Overpack Inner Surface	266	262	224	219	129	124	853	821
Overpack Outer Surface	199	197	148	146	35	34	1341	1340

Note: Column A: Package model with source materials specifically modeled
Column B: Package model as presented in Sections 3.4 and 3.5.

3.7.3.4 Thermal Evaluation of Normal Conditions of Transport. This Subsection presents the thermal analysis of the source materials positioned in the Multifunctional rack in the Model 2000 Transport Package. Since thermal analysis of Model 2000 Transport Package has been already discussed in Section 3.4, only those parts of the analysis relevant to the source material are discussed in this section.

3.7.3.4.1 Thermal Analytical Model. The cask cavity is gas-filled (helium) which serves as a medium for heat transfer by conduction and natural convection from the heating elements to the cask cavity wall In addition, heat generated from the source materials is also radiated directly to the cask cavity wall, and also conducted and radiated to the carrying rack which in turn is radiated and conducted to the cask cavity wall.

To establish the temperature of the source materials carried in the shipping rack, the heating elements are added to the Model 2000 Package model. Figure 3.36 shows the combined finite element model. The shipping rack is not modeled for simplicity of the analysis. The omission of the rack will provide the upper bounds of the temperature of the radioactive elements. In the finite element model, heat transfer from the heating elements to the cask cavity wall is by all three heat transfer modes, conduction and convection through helium and direct radiation, of which the radiation heat transfer is the dominant mode.

The source material is modeled with 2 node axisymmetric convection elements where 2000 watts of heat are uniformly distributed. For axisymmetric elements, LIBRA requires the heat input to the model to be in the form of heat flux, i.e., total heat divided by the elements area. The heat in each fuel element is assumed to be uniformly distributed throughout the element body. Element property sets, 47 and 48 represent these heating elements, where the heat flux generated in the elements are calculated as follows:

$$q_{(47,48)} = \frac{\text{Heat input}}{\text{Model Area}} = \frac{2.0\ \text{kW}\,(3{,}414\ \text{Btu/hr} - \text{kW})}{2\pi(9.0\ \text{in.})\ 2(21.\ \text{in.})}$$

$$= 2.87\ \text{Btu/hr-in.}^2$$

The helium space are modeled with 4 node quadrilateral elements that conduction, convection and radiation heat transfer modes are allowed. The properties of the helium spaces are calculated by CHGPRP routines as discussed in Paragraph 3.4.1.2. While the source materials are arranged in an array of discrete cylindrical tubes, its representation of the finite element model is an axisymmetric model. To account for the area differences, the material property of the helium are adjusted by the ratio of the actual total source material surface area to the model area, as an example, for the effective thermal conductivity of the helium,

$$k_{eff} = k \cdot \frac{\text{Actual Area}}{\text{Model Area}} = k \cdot \frac{(6)2\pi(1.0)(21)}{2\pi(9)(21)} = 0.67 \cdot k$$

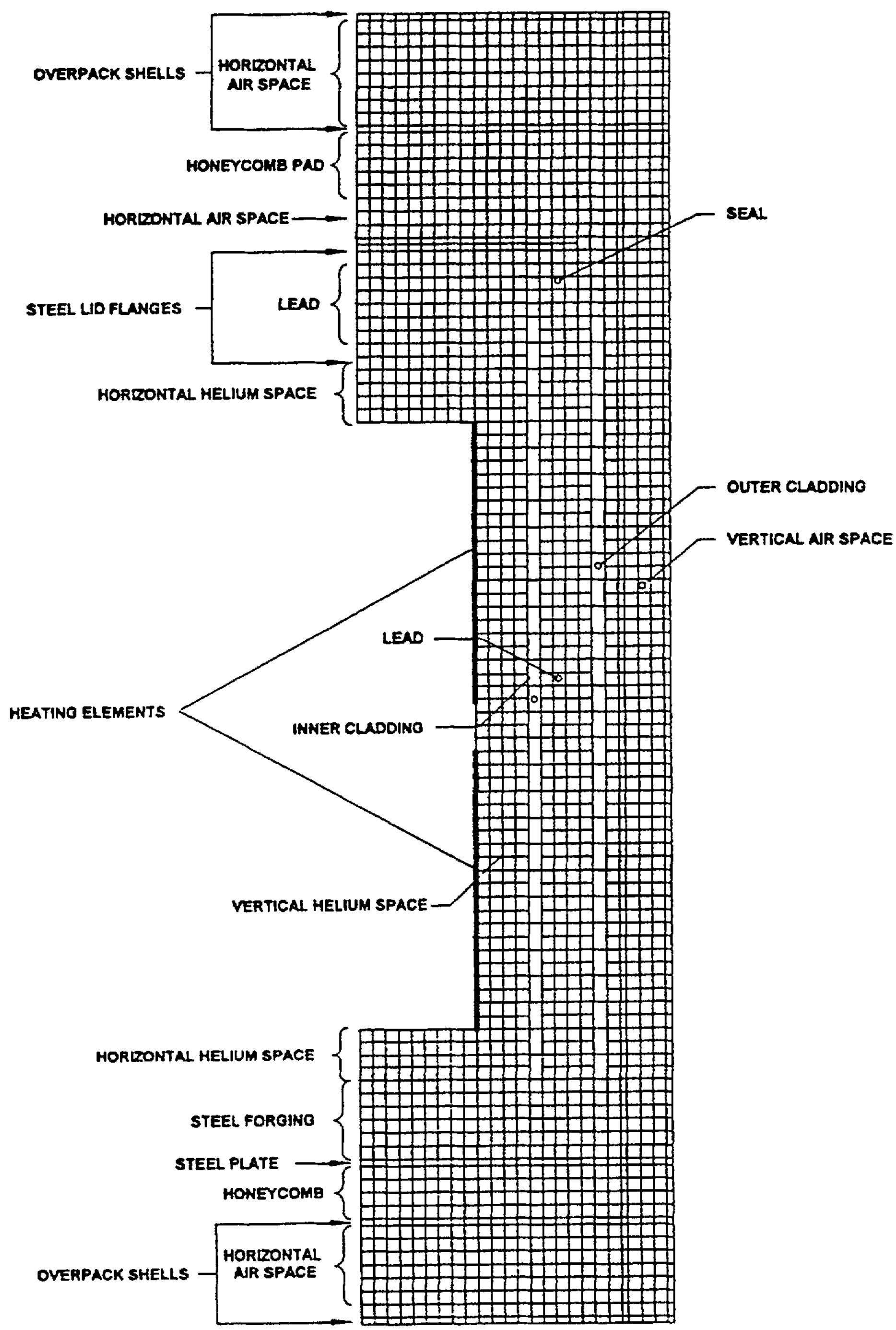
where k_{eff} = effective thermal conductivity of helium

k = thermal conductivity of helium

Actual Area = (no. of sources)(2π)(radius of source)(length of source)
= (6)(2π)(1.0)(21)

Model Area = (2π)(radius of model)(length of model)
= (2π)(9)(21)

The same finite element model is used for both normal conditions and accident conditions following the procedures as discussed in Sections 3.4 and 3.5.



Number of Elements:

Number of Nodes:

Figure 3.36. Finite Element Model

3.7.3.4.2 Maximum Temperatures. Under the normal conditions of transport, the maximum temperature distribution in the radioactive material occurs when the ambient temperature is 100°, with maximum decay heat and the maximum solar load. Figures 3.37 through 3.39 present temperature contour plots for the steady state conditions of transport.

3.7.3.4.3 Maximum Internal Pressures. The cask cavity is initially filled with dry helium to 15 psia at ambient temperature (70°F). Under the normal conditions of transport, the maximum temperature of the helium inside the cavity occurs near the fuel element. Using the average helium temperature of 440°F, the maximum internal pressure is calculated.

Using the ideal gas law, the temperature and pressure relationship is, for a constant volume,

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

where P_1 and T_1 = Pressure and Temperature at initial state, respectively
P_2 and T_2 = Pressure and Temperature at steady state, respectively

Therefore the maximum internal pressure during normal transportation is calculated as

$$P2 = (15\ \text{psia})\frac{(440+460)}{(70+460)} = 25.5\ \text{psia}$$

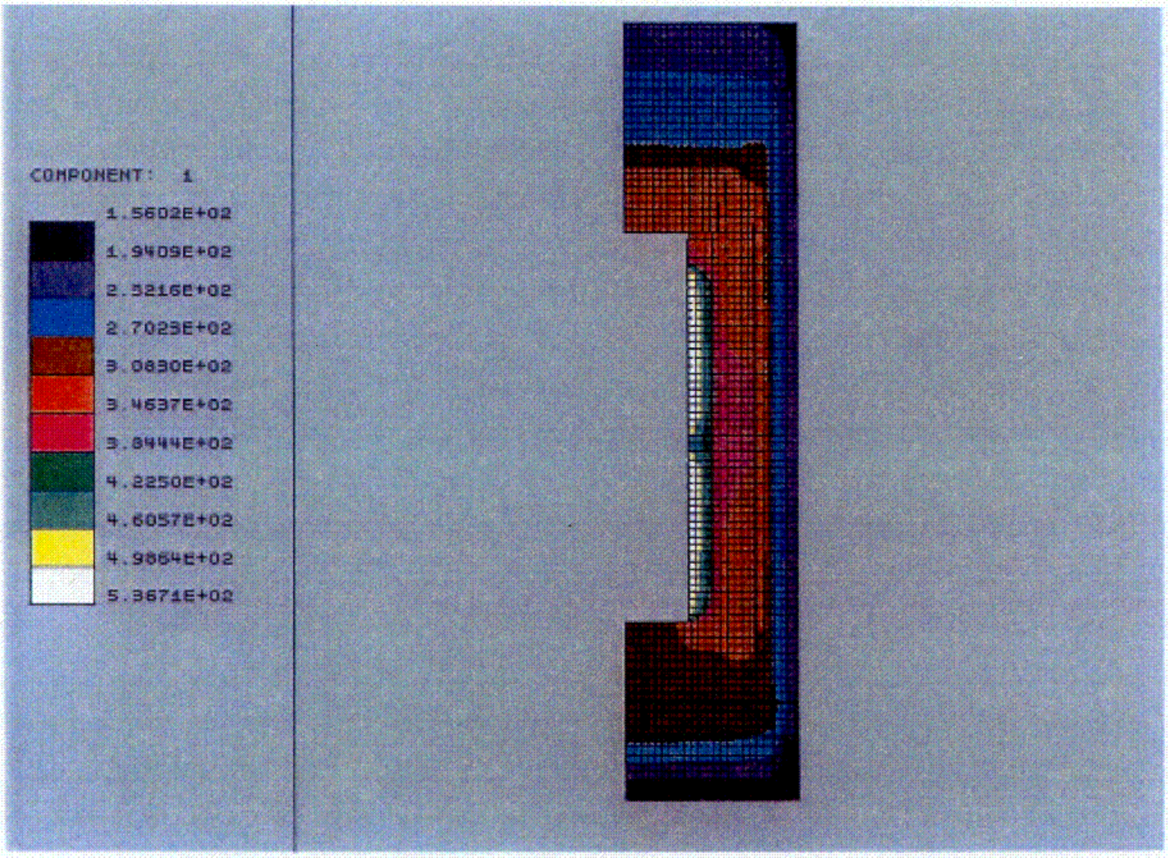


Figure 3.37. Model 2000 Transport Package – Contour Plot Steady State Condition – 100°F Ambient Temperature, Maximum Insolation, and Maximum Decay Heat, Source Material Model

C11

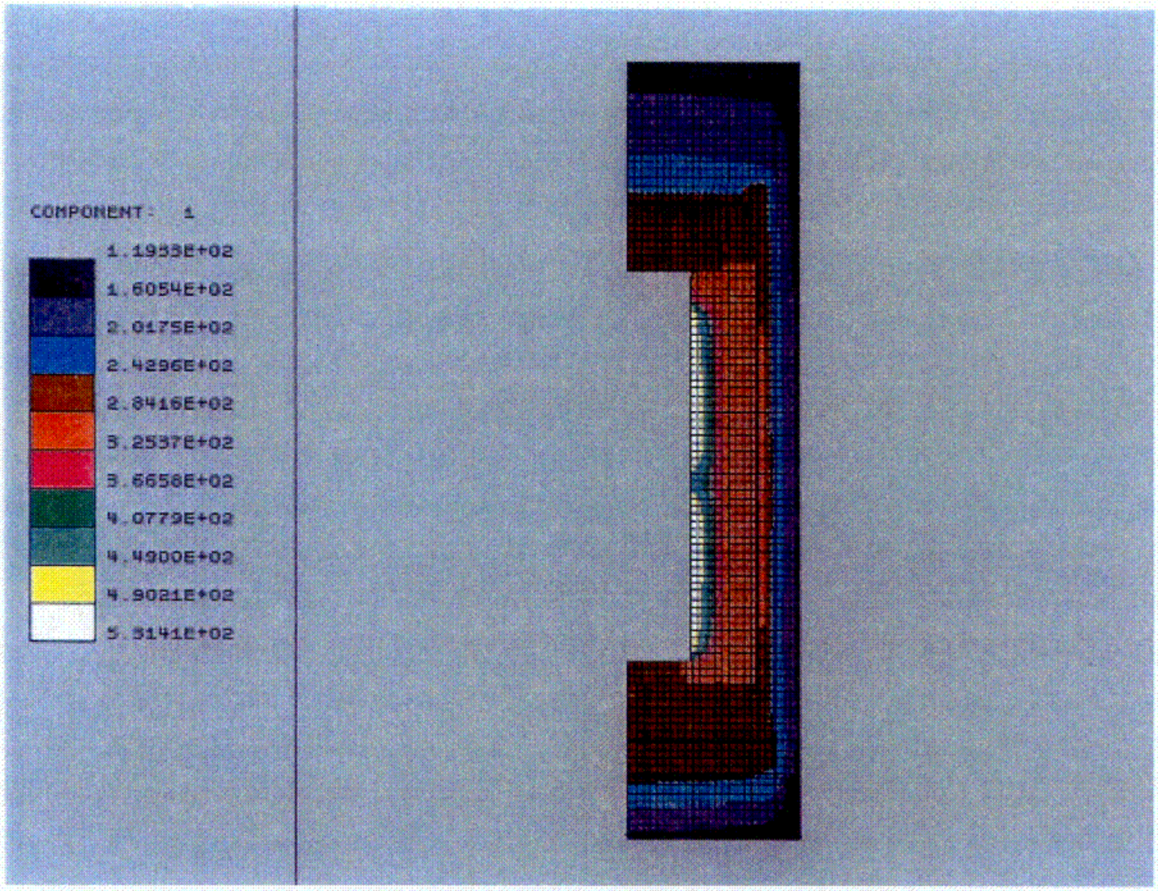


Figure 3.38. Model 2000 Transport Package – Contour Plot Steady State Condition – 100°F Ambient Temperature, and Maximum Decay Heat, Source Material Model

C12

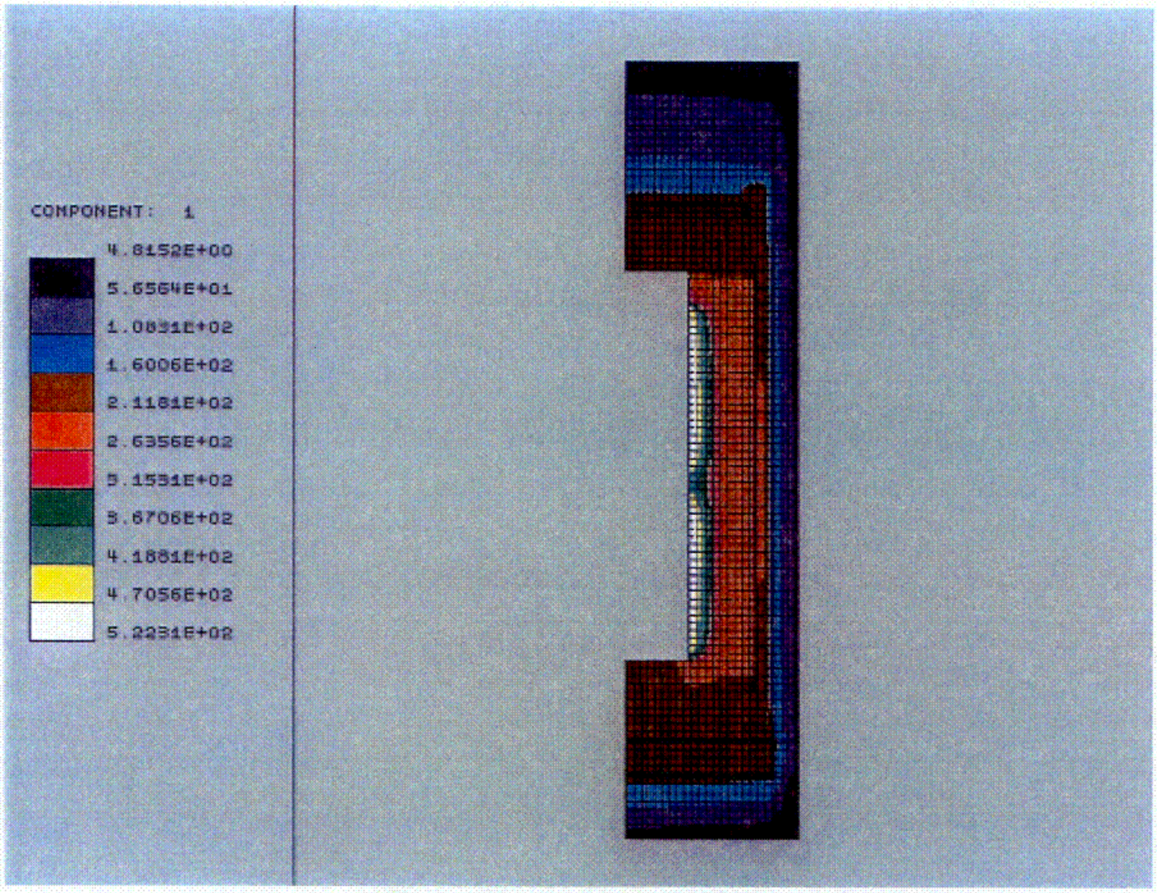


Figure 3.39. Model 2000 Transport Package – Contour Plot Steady State Condition – -20°F Ambient Temperature, and Maximum Decay Heat, Source Material Model

C13

3.7.3.5 Hypothetical Accident Thermal Evaluation.

3.7.3.5.1 Analytical Model. The analytical model used to evaluate the hypothetical accident condition is identical to that described in Paragraph 3.7.3.4 The model accounts for damage during the accidental condition by not including the toroidal shells.

3.7.3.5.2 Maximum Temperatures. The maximum temperature of the source material is found to be 550°F at the end of the cooling period. The temperature contour plots at the end of fire (time =0.5 hr) and at the end of the cooling period (t = 3 hr) in Figure 3.40 and 3.41 respectively.

3.7.3.5.3 Maximum Internal Pressures. The maximum internal pressure is reached at the maximum cavity temperature, which occurs around thirteen hours after the fire. The average helium temperature of 490°F is used to calculate the maximum internal pressure using the same methodology as discussed in Subsection 3.5.3.

The maximum internal pressure is calculated as

$$P = (15\ psia) \cdot \frac{490 + 460}{70 + 460} = 26.9\ psia$$

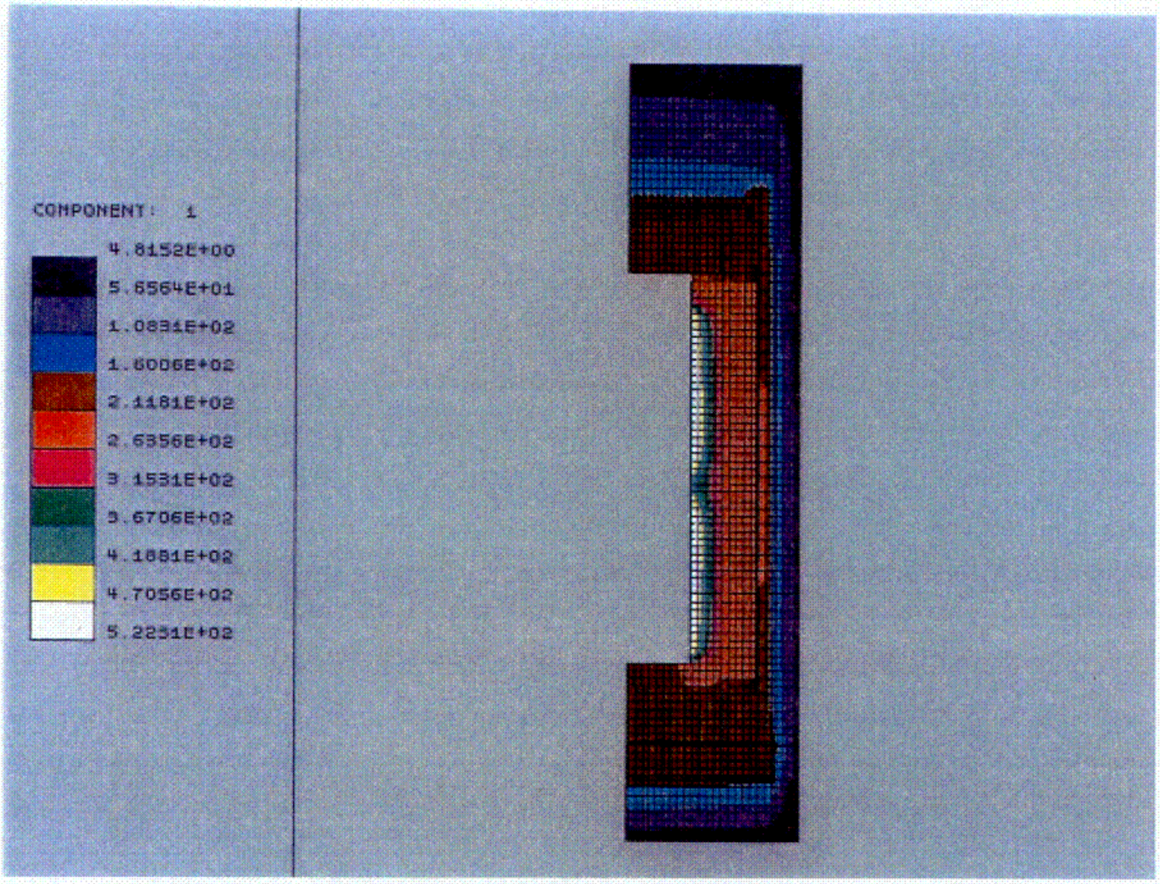


Figure 3.40. Model 2000 Transport Package – Contour Plot Transient Analysis: Fire Plus 100°F Ambient Temperature, and Maximum Decay Heat Time: 0.5 Hour Source Material Moel

C14

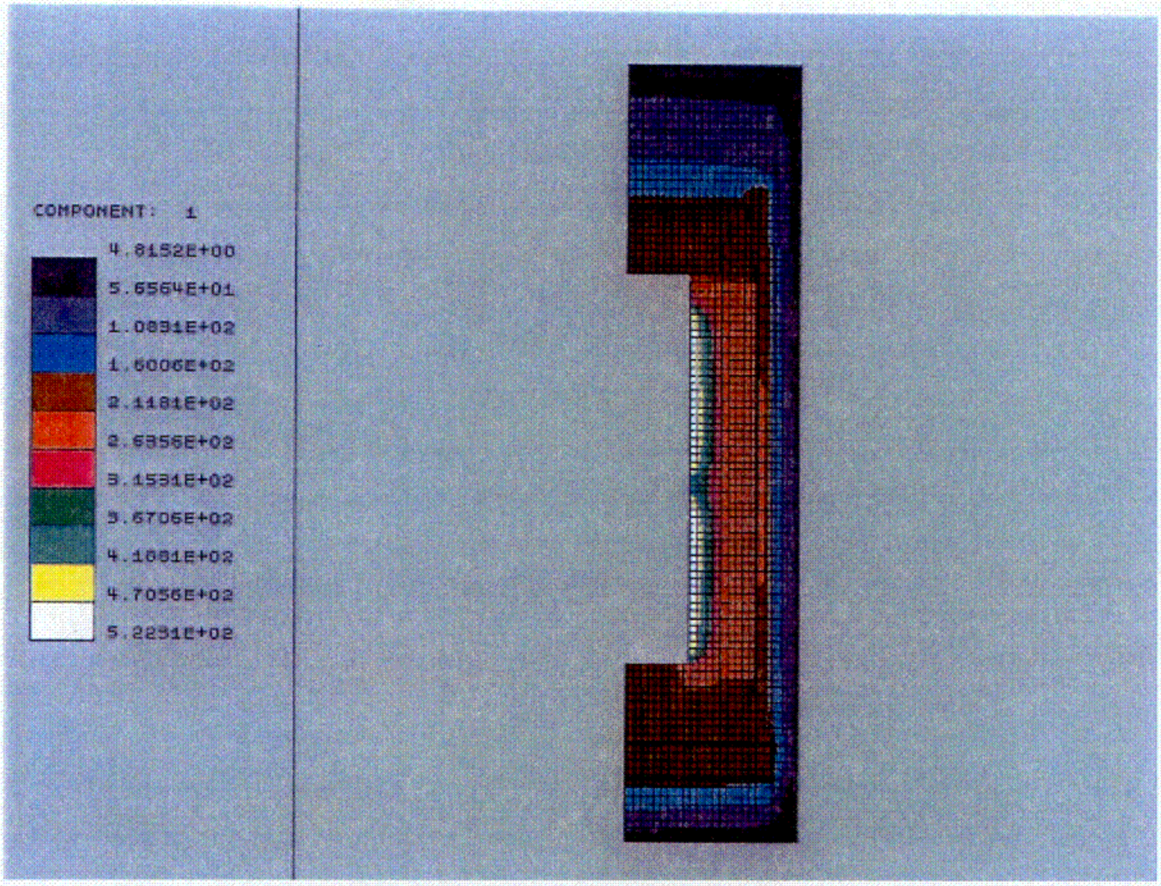


Figure 3.41. Model 2000 Transport Package – Contour Plot Transient Analysis: Fire Plus 100°F Ambient Temperature, and Maximum Decay Heat Time: 3.0 Hour Source Material Model

C15

3.7.3.6 Multifunctional Rack Thermal Stress Analysis. The thermal stresses are of the secondary stresses as defined in NRC Regulation Guide 7.8, Reference [3.17]. In order to evaluate the thermal stresses developed in the Multifunctional rack, a hill 3-D finite element model is needed for the Multifunctional shipping rack, since the arrangement of source material and the support pipes are non-axisymmetric. Therefore a separate 3-D finite element model is constructed for thermal stress analysis.

See Chapter 2 for details of the model constructions and descriptions.

This Subsection describes the thermal stress modeling and calculation of thermal stresses for the following conditions: The thermal condition at -20°F without decay heat is not included since there is no thermal stresses at a uniform temperature throughout the rack. The operating condition of 100°F with maximum decay heat without insolation is not included, since this condition is encompassed by the condition (a) below for thermal stresses calculations.

Normal Operating Condition

a) 100°F ambient temperature with maximum decay heat with insolation
b) -20°F ambient temperature with maximum decay heat

3.7.3.6.1 Analytical Model. The Multifunctional rack consists of several SS304 horizontal circular plates welded together to a SS304 central cylindrical tubing to form a multi-tier structure. These plates are further secured by eighteen SS304 tubes in between each one of them. Various types of source materials in a form of cylindrical tubing are seated through the holes provided in the circular plates. Currently, the full rack consists of two racks, upper one and lower one.

Since both racks are similar in structure, only one rack is modeled. Furthermore, due to symmetry, only one half the real structure is modeled. The circular plates and the center cylinder are modeled with 4 node quadrilateral elements, while the plate support pipes are modeled with two node linear beam elements. See Figures 3.42 and 3.43 for the finite element model for thermal stress analysis. These are identical to the structural models presented in Chapter 2.

Because the Transport Package (overpack and cask) thermal analysis model is a 2-D axisymmetric model and the rack structure model (or rack thermal stress model) is a 3-D shell model, a three step process is used as follows for the calculations of the thermal stresses in the rack.

The source materials temperatures are found from the thermal analysis using the full model including Model 2000 Transport Package. The boundary temperatures, namely, the source materials temperatures, are then input into the rack model, and LIBRA calculates the temperature distribution throughout the rack. These temperature distributions are then used as input to determine the thermal stresses in the rack model.

As described in Paragraph 3.7.3.4.1, the temperature gradient within Me source material is fictitiously high - as much as 200°F, while in reality almost no temperature gradient is expected. This approach of using the source material temperatures as the boundary conditions for the thermal stress calculations is extremely conservative, since a fictitiously high thermal gradient is fixed in the rack finite element model by these boundary temperatures. Using a high and conservative temperature gradient will cause conservative thermal stresses.

3.7.3.6.2 Thermal Stresses. Some elements of high stresses (for thermal and also other structural loading conditions as discussed in Chapter 3) are shown in Figure 3.44 and Figure 3.45. The thermal stresses due to the temperature gradient throughout the Multifunctional rack are tabulated in Table 3.7. Further discussion of the stresses is presented in Chapter 2.

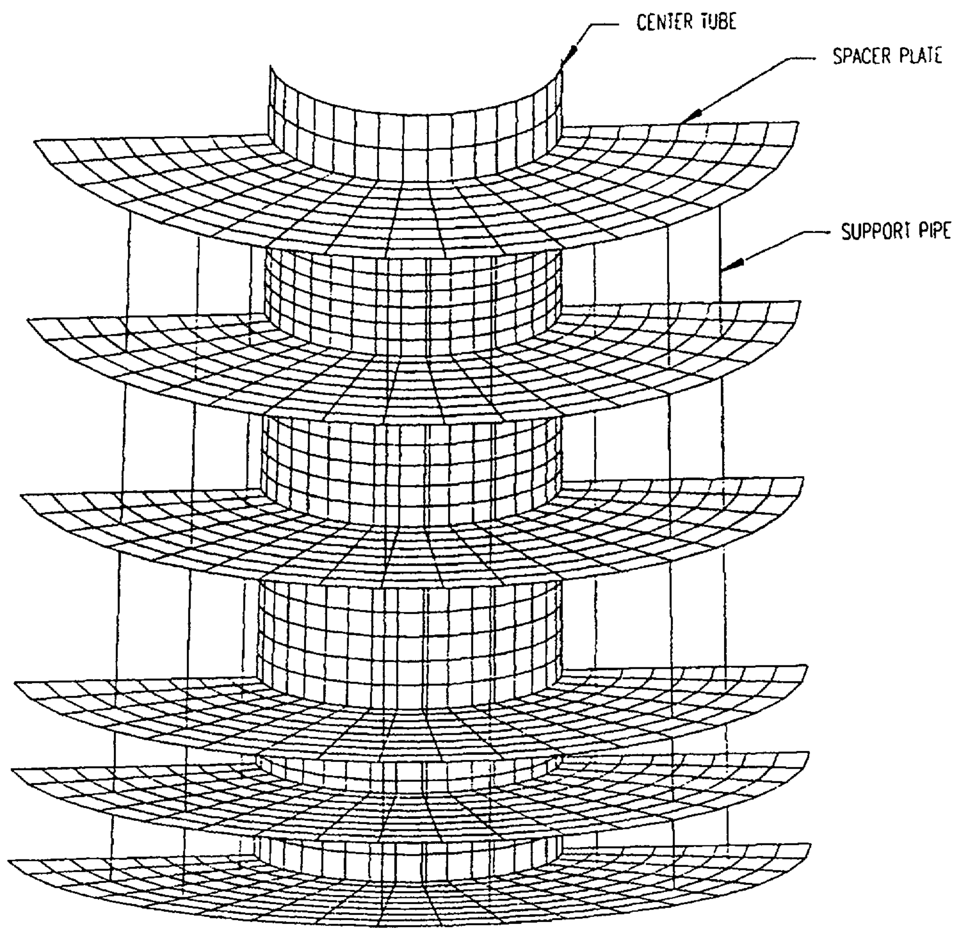


Figure 3.42. Multifunctional Rack Finite Element Model, Normal Configuration

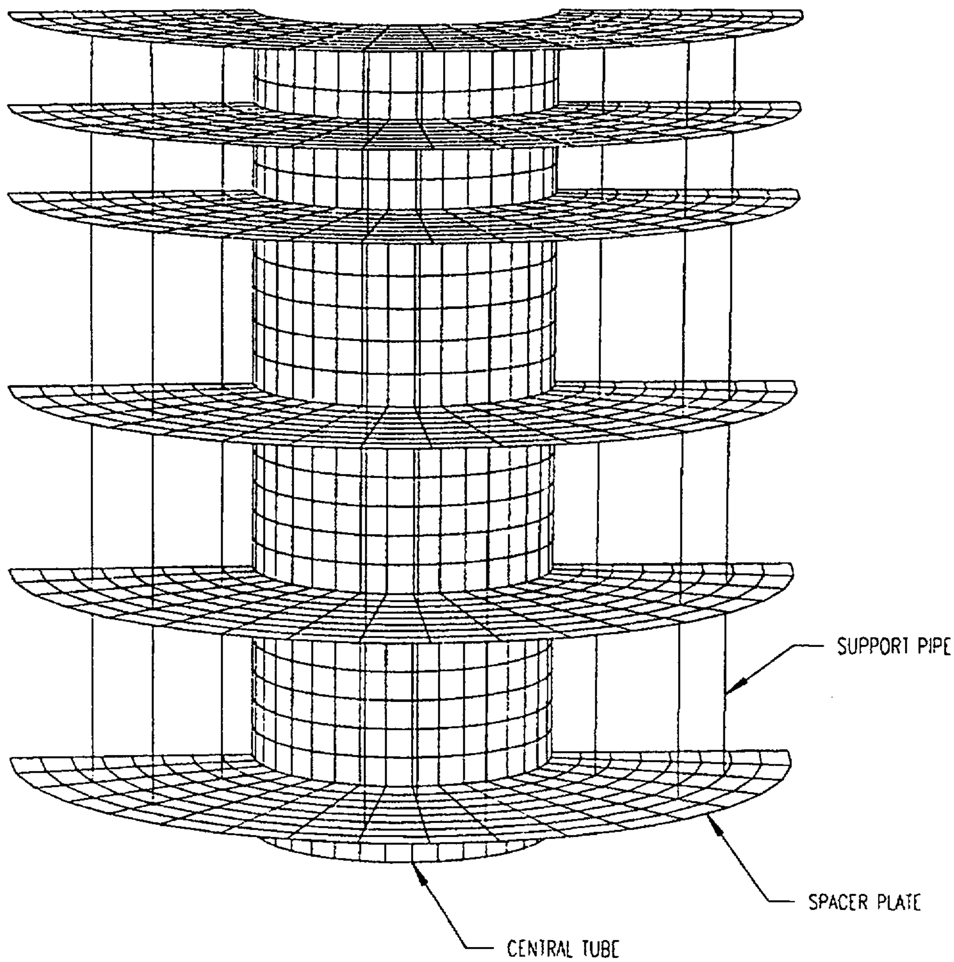


Figure 3.43. Multifunctional Rack Finite Element Model, Inverted Configuration

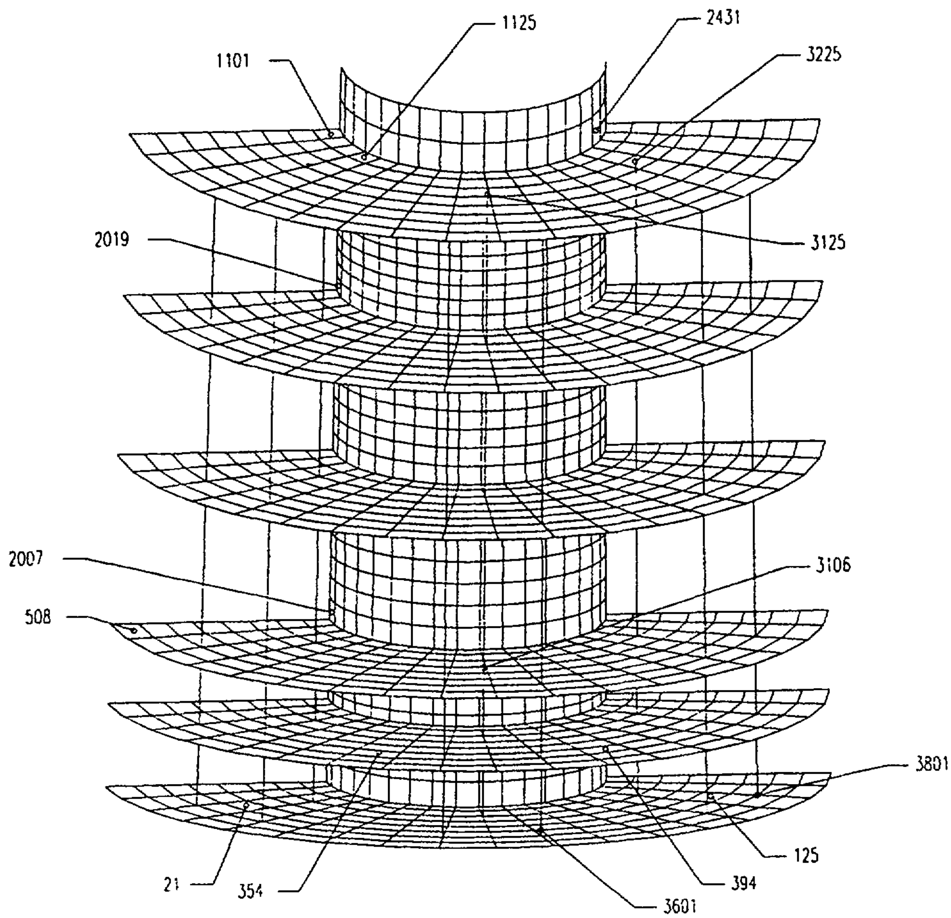


Figure 3.44. Elements of High Stresses

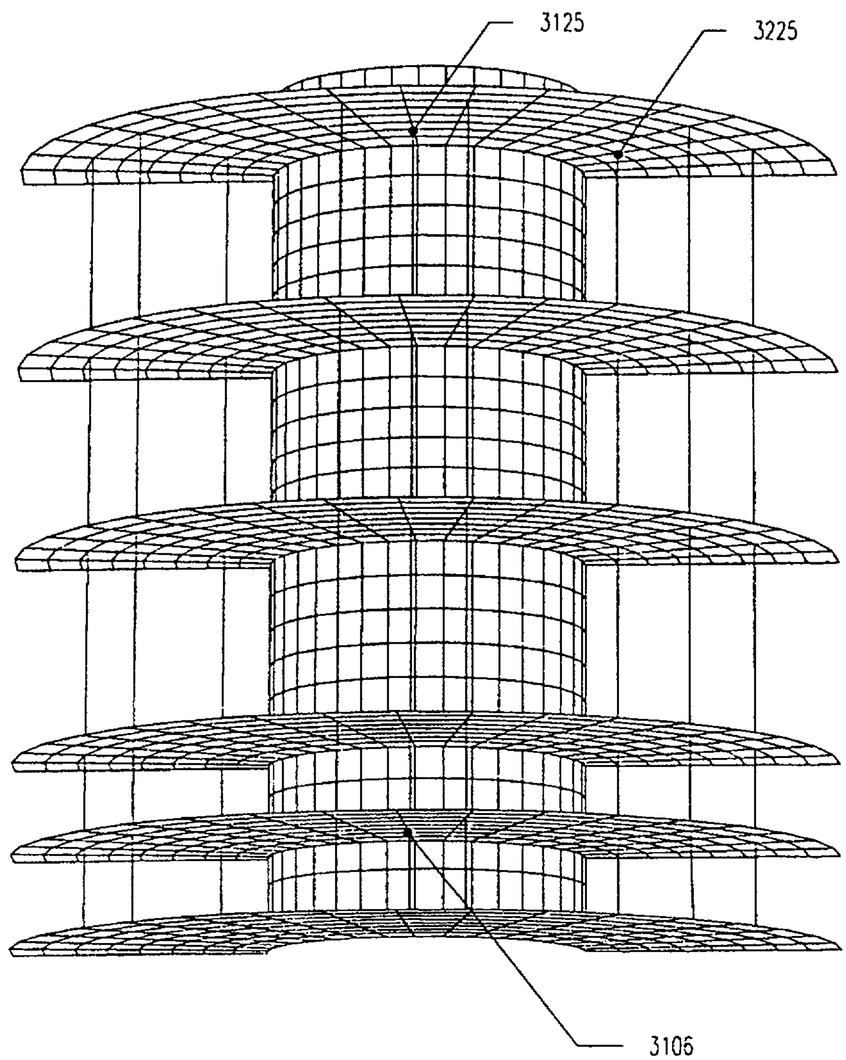


Figure 3.45. Elements of High Stresses, Beam Elements

Table 3.7. Thermal Stresses

Thermal Stresses								
Ambient Temperature								
	(-20 Degrees F)				(100 Degrees F)			
Element	**Sig1**	**Sig2**	**Sig3**	**Q**	**Sig1**	**Sig2**	**Sig3**	**Q**
Rack Flange								
21	0.338	0.013	0.239	0.325	0.250	0.006	0.178	0.245
125	0.336	0.015	0.240	0.321	0.249	0.007	0.179	0.242
354	0.256	-0.766	0.511	1.277	0.188	-0.557	0.373	0.930
394	0.163	-0.673	0.557	1.229	0.122	-0.491	0.407	0.898
508	1.471	0.051	0.710	1.420	1.070	0.036	0.517	1.034
1101	0.815	0.714	0.186	0.629	0.626	0.566	0.159	0.497
1125	0.874	0.582	0.348	0.526	0.676	0.485	0.271	0.405
Cylinder								
2007	4.866	-1.456	3.161	6.322	3.539	-1.064	2.302	4.603
2019	2.867	2.557	1.949	0.918	2.027	1.809	1.376	0.651
2431	0.508	0.229	0.333	0.279	0.507	0.313	0.338	0.194
Supports								
3106	0.089	9.148	0.088	9.059	0.059	6.624	0.059	6.565
3125	0.336	0.888	0.336	0.552	0.233	0.714	0.233	0.481
3225	0.336	0.612	0.814	0.478	0.233	0.473	0.649	0.416
3601	0.118	1.913	0.422	1.795	0.088	1.405	0.311	1.317
3801	0.118	0.753	1.824	1.706	0.088	0.554	1.340	1.251

3.7.4 Effect of Source Locations within the Cask Cavity

Additional analyses are performed to support the decay heat distribution used in the preceding evaluation (Condition 0) and to assure their results represent the limiting temperatures for the key components of the Package. The additional analyses considered three different scenarios; (1) the 2000 watts of decay heat is applied to the top area of the cask cavity, 90% radially for a length of 21 inches and 10% to the lid area; (2) same as the previously condition but applied to the bottom surface of the cavity; and (3) 100% is applied to the wall of the cask cavity. These scenarios represent the content or materials conglomerated at each end of the cavity and uniformly distributed along the cavity wall. All analyses are for 2000 watts of decay heat, full solar, and 100°F ambient temperature.

Table 3.8 presents the maximum temperature determined by these analyses and the regulatory and/or component thermal criteria. The results of these analyses (Figures 3.46 through 3.48) show that even under these extreme scenario conditions the key component temperatures are within their temperature criteria. It can therefore be concluded that the location of these sources within the cask cavity is not critical in meeting the regulatory requirements.

Table 3.8. Summary of Temperatures

Package (Key) Component	Thermal Condition Temperatures (°F)				Component Criteria (°F)
	0	1(1)	2(1)	3(1)	
Cask Cavity Surface	341	389	385	350	T<600
Lead Shield	338	383	370	347	T< 620
Cask Seal Area	315	361	272	312	-65 < T < 400
Cask Test Port	312	358	271	310	-65 < T < 500
Cask Drain Port	301	258	347	298	-65 < T < 500
Cask Vent Port	320	367	273	313	-65 < T < 500
Cask Outer Surface	322	361	353	329	N/A
Overpack Inner Surface	262	285	351	266	N/A
Overpack Outer Surface	197	205	208	198	N/A
(1) Values given are maximum temperatures obtained for each component.					

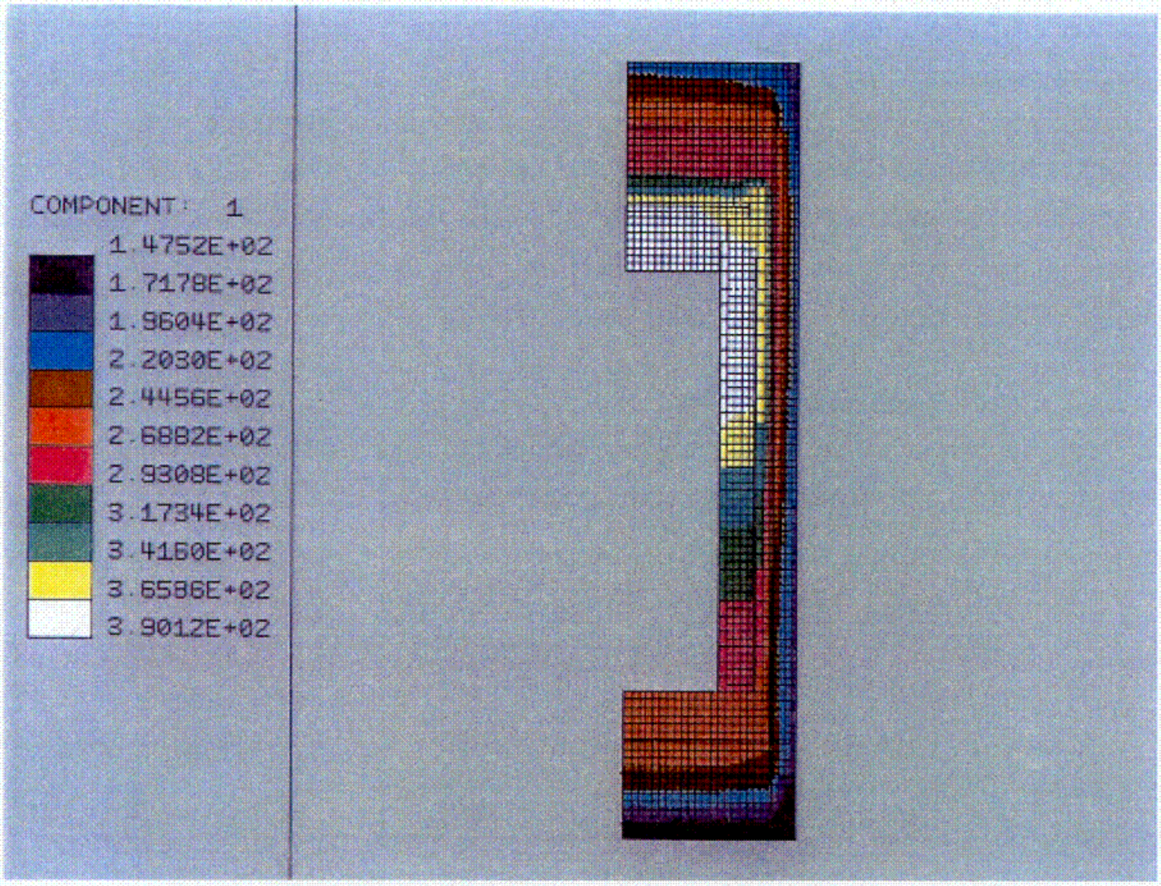


Figure 3.46. Model 2000 Transport Package – Contour Plot Steady State Condition – 100°F Ambient Temperature, Maximum Insolation, and Maximum Decay Heat Applied, 90% Top 21 Inches Cavity Wall and 10% at Lid

C16

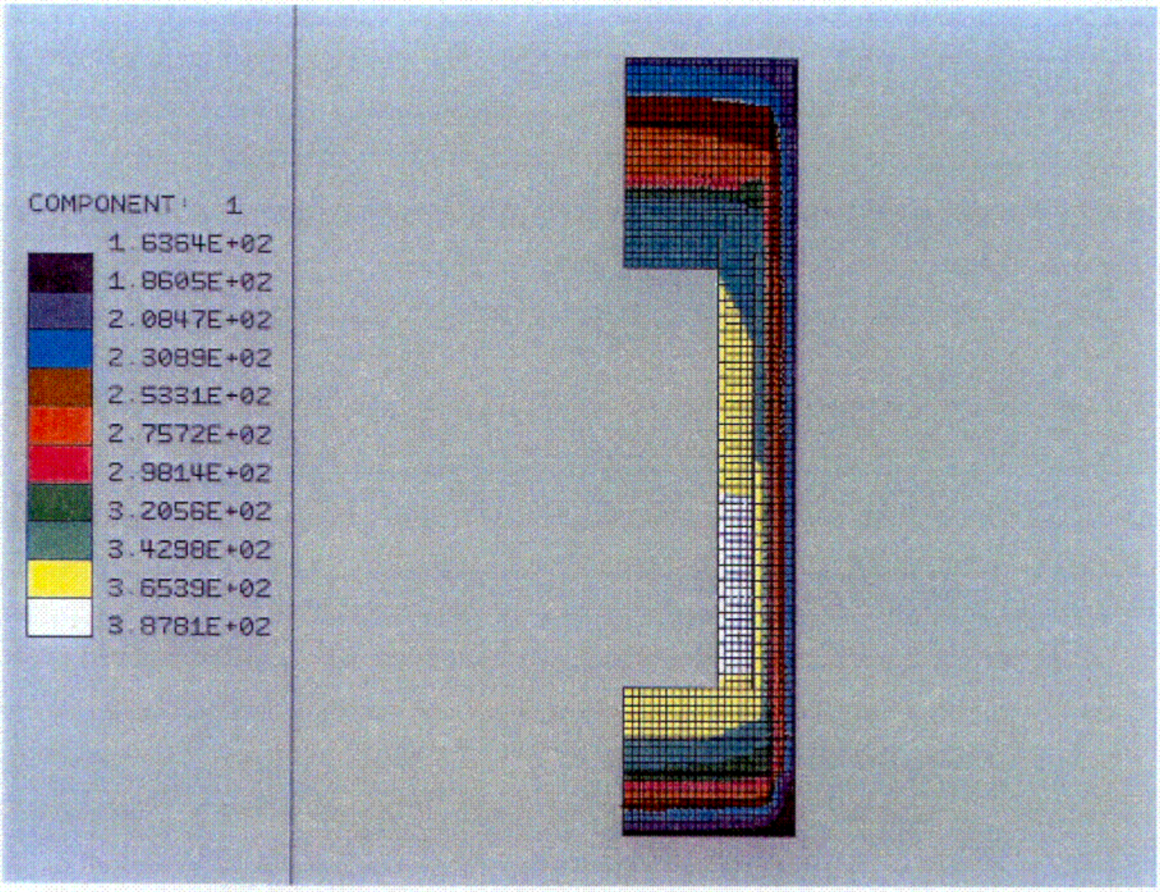


Figure 3.47. Model 2000 Transport Package – Contour Plot Steady State Condition – 100°F Ambient Temperature, Maximum Insolation, and Maximum Decay Heat Applied, 80% Bottom 21 Inches Cavity Wall and 10% at Each End

C17

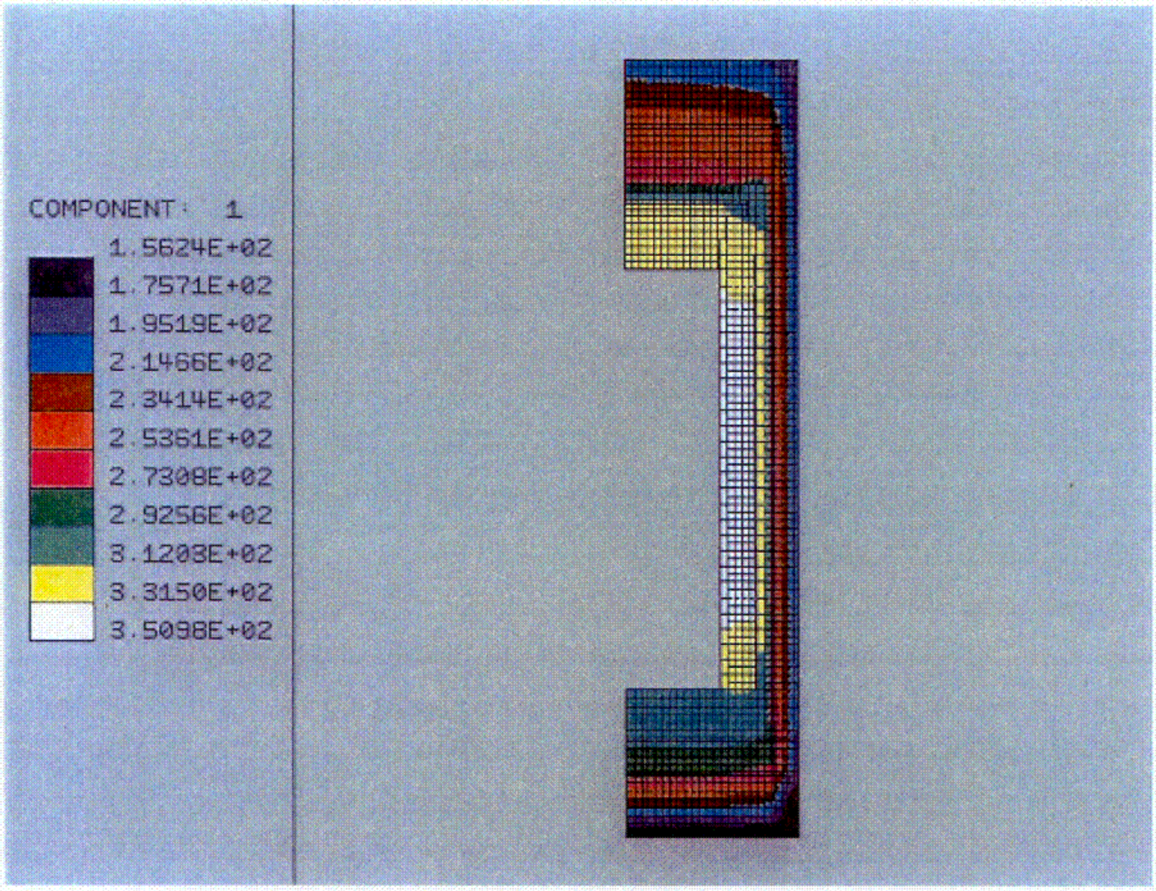


Figure 3.48. Model 2000 Transport Package – Contour Plot Steady State Condition – 100°F Ambient Temperature, Maximum Insolation, and Maximum Decay Heat Applied, 100% Cavity Wall

C18

4.0 CONTAINMENT

The containment evaluation of the Model 2000 Transport Package is provided in Chapter 4.0 of the Package Safety Analyses Report (SAR), NEDO-31581, April 1988. It was demonstrated that the Package remains leak tight under all normal and specified hypothetical accident conditions. The 2000 watts decay heat upgrade has no physical effect on the cask containment boundary. The maximum temperature at the seal region is below 400°F and those of penetrations or port areas are below 500°F. The internal pressure in the cask cavity may increase to 26.9 psia due to rise in the temperature. The Model 2000 cask is loaded dry or underwater. If loaded underwater the cavity must be vacuum dry to remove any residual moisture. Regardless of the way the cask is loaded, after it is loaded a leak test is performed. To perform the leak test He is introduced in the cavity to a pressure of 15 psig. At the conclusion of the test, the pressure is released. Therefore it can be assumed that He remains inside the cavity. The average He temperature inside the cask cavity is 490°F according with the evaluation presented in Chapter 3.0. The seal elastomeric material is prototype tested, to an acceptance procedure, at 400°F. The pressure of 26.9 psia is less than the design pressure of 30 psia. Therefore, the Model 2000 design pressure is a conservative design basis for the shipment of content or materials, excluding irradiated fuels, with 2000 watts of decay heat.

5.0 SHIELDING EVALUATION

This chapter contains the discussion, assumptions, input, results, and tools used for demonstrating the shielding adequacy of the Model 2000 shipping container when used for several typical isotopic sources. The radionuclides analyzed are Cesium-137, Cobalt-60, Hafnium-181, Iridium-192, Strontium/Yttrium-90, and Zirconium/Niobium-95. The activity of each isotope used for the evaluation is equivalent to a decay heat of 2,000 watts.

The evaluation for Cs-137 was done using a source size which is typical of actual sources to be transported in the cask. No additional liner was included for the Cs-137 evaluation, i.e., the source was modeled as a two cylinders at the inner wall of the cavity of the shipping cask. One-half of the total activity was in each source, which were stacked vertically in the cask cavity. The top source was shielded on the bottom by a one inch thick steel end plug and 2.375 inches of steel plate (from the Multifunctional Rack). The lower source was also shielded on the bottom by a one inch end plug and an additional 1.375 inches of steel plate.

The Co-60 source was modeled as a typical rod source in the center of the cask, and it was additionally shielded by a seven inch thick wall steel cylinder with a tungsten plug in the bottom.

The Zr/Nb-95 source was also modeled as a cylindrical source at the inner wall of the cask, with additional tungsten shielding in the bottom of the container.

All other sources were modeled as point sources at the inner wall of the cask.

The materials used for the source volumes, where applicable, were approximated by one of the limited available materials in the code library.

The evaluations demonstrate with ample conservatism that the dose rates from a 2,000-watt load of isotopes in the Model 2000 shipping container are within the regulatory limits for exclusive-use shipment.

The ISOSHLD computer code used for these calculations is a kernel integration code used for general purpose isotope shielding analyses. It is available from the RSIC COMPUTER CODE COLLECTION and was contributed by Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington.

5.1 DISCUSSION AND RESULTS

The Model 2000 Transport Package is designed for transporting irradiated fuel, sealed sources, hardware, and waste. In view of the above, there is no single specific source term. Considering the varied use of the cask (e.g., hot cell waste, irradiated SNM, irradiated reactor hardware), it is extremely difficult to generate one appropriate source term. The purpose of the shielding is to maintain external dose rates from the loaded container within DOT transportation limits. Calculations have been made to demonstrate that the normal and accident condition dose rates with various, worst case radionuclide loads will not exceed the regulatory limits.

Several theoretical analyses of the Model 2000 Transport Package shielding capabilities were performed for various isotopic contents. Hypothetical shielding models were set up for activities of Cobalt-60, Cesium-137, Zirconium/Niobium-95, Iridium-192, Hafnium-181, and Strontium-90 equivalent to 2,000 watts of decay heat. The gamma dose rate calculations were made with a Radiation Shielding Information Center (RSIC)-provided computer code, ISOSHLD. ISOSHLD is a point kernel, general purpose shielding analysis code.

The 2000 Series Cask uses poured lead and stainless steel as the primary shielding media. The stainless steel structural shells of the overpack and distances to the outer surfaces of the overpack serve to further attenuate the radiation from the contents. An optional, lead-filled liner may be inserted in the cask cavity to provide additional shielding; the liner was not included in any of the analyses. The Co-60 analysis used seven inches of additional steel shielding at the side of the cask. Tungsten shielding is added to the bottom of the sources as required to reduce the dose rates from the bottom of the container.

The nominal thicknesses of shielding materials and distances, as determined from the fabrication drawings, were used in the shielding analysis. The same source geometry was used in the normal and accident cases, taking credit for self-shielding by the source material, where appropriate.

The summary of the calculated and estimated dose rates from a Cs-137 source load is given in Table 5.1.1. The other analyses are summarized in Table 5.1.2.

Table 5.1.1. Summary of Maximum Dose Rates (Mr/Hr) from a 422,000 Curie Cs-137 Source in the Multifunctional Rack

	Package Surface			1 Meter from Surface of Package			2 Meters from Side of Vehicle (Exclusive Use)	Cab of Vehicle
	Side	Top	Bottom*	Side	Top	Bottom*		
Normal Conditions								
Gamma	0.7	6E-5	75				0.2	0.02
Neutron								
Total	0.7	6E-5	75				0.2	0.02
49 CFR Part 173,441 Limit	200	200	200	–	–	–	10	2
Hypothetical Accident Conditions								
Gamma				0.4	2E-5	25		
Neutron								
Total				0.4	2E-5	25		
10 CFR Part 71 Limit	–	–	–	1000	1000	1000		

* At bottom surface of transport trailer.

Table 5.1.2. Summary of Calculated Radial Dose Rates (Mr/Hr) from Other Isotopes

Isotope	Curies	Source Material and Density	Radial Dose Rates			Shipping Configuration
			Location	Calculated	Limit	
Co-60	130,000	9/16-in. dia. Nickel, 8.9 g/cc	Surface	47.4	200	Barrel Rack, 7.0" min. wall thickness and Material basket with 1.25" min. W thickness
			1 meter*	17.2	1000	
			2 meters	6.3	10	
Ir-92	348,000	N/A, point source	Surface	0.08	200	Multifunctional Rack
			1 meter*	0.006	1000	
			2 meters	0.002	10	
Zr/Nb-95	409,000	3/8-in. dia. Zirconium, 6.4 g/cc	Surface	0.3	200	Multifunctional Rack
			1 meter*	0.03	1000	
			2 meters	0.01	10	
Hf-181	456,000	N/A, point source	Surface	0.06	200	Multifunctional Rack
			1 meter*	0.003	1000	
			2 meters	0.0008	10	
Sr/Y-90	596,000	N/A, point source	Surface	0	200	Multifunctional Rack
			1 meter*	0	1000	
			2 meters	0	10	

* Hypothetical accident condition (no distortion of source model).

5.2 SOURCE SPECIFICATIONS

The activity in the volume sources is uniformly distributed throughout the cylinder. The Co-60 normal condition source is located at the center of the cask. The rest of the sources are located at the wall of the cask. The hypothetical accident condition sources are the same as the normal condition sources, except for the Co-60 source, which is located closer to the inner wall of the cask. The evaluation in Chapter 2 demonstrates the lack of damage to or degradation of the cask shielding and structures.

5.2.1 Gamma Sources

The isotope activities used for the source models are the activities equivalent to 2,000 watts of decay heat. The tabular list of the gamma photon source and the average energy of each group is shown in Table 5.2.1.

The total photons from an isotope are sorted into the energy groups by a computer routine. Details of these processes can be found in the code descriptions (Reference 1).

5.2.2 Neutron Source

Not applicable for the sources analyzed.

Table 5.2.1. Isotopic Gamma Sources

Isotope	Group Production Rates (photons/sec)	Group Average Energy (MeV)
Cs-137	1.33E+16	0.662
Co-60	4.81E+15	1.173
	4.81E+15	1.332
Ir-192	3.74E+15	0.296
	3.82E+15	0.308
	1.07E+16	0.317
	8.55E+13	0.416
	6.19E+15	0.468
	5.88E+14	0.589
	1.06E+15	0.604
	6.88E+14	0.612
	3.89E+13	0.885
Hf-181	7.04E+15	0.133
	1.01E+15	0.136
	2.90E+15	0.346
	7.09E+13	0.476
	1.40E+16	0.482
	2.41E+13	0.616
Zr/Nb-95	2.07E+15	0.724
	2.6225E+15	0.757
	1.04E+16	0.766
Sr/Y-90	N/A	N/A

5.3 MODEL SPECIFICATION

5.3.1 Description of the Radial and Axial Shielding Configuration

A cutaway sketch of the package showing the normal condition source and dose rate points is presented in Figure 5.1.

The simplified geometry used for the computer analysis (i.e., cylindrical and point sources shielded by an iron slab and a lead slab) is shown in Figure 5.2. Iron is used in place of the stainless steel shells because it is one of the standard materials available in the ISOSHLD library, and there is no significant difference in attenuation properties.

No reductions in the nominal shield thickness were made for localized penetrations or variations, such as drain lines or bolt holes. The justification for this decision is that an actual radioactive load in the container would be generally distributed and, therefore, only a small fraction of the source radiation would penetrate directly through shield depletions. Practically, any maximum dose rate from streaming or localized source concentration will be detected during the mandatory radiation surveys on loaded containers before shipment. The dose rates must comply with the appropriate transport limits.

The difference between the normal condition evaluation and the accident condition evaluation for the Co-60 source was the location of the source. In the normal case evaluation, the distance from the centerline of the cylindrical source to the side dose points was equivalent to placing the source at the center of the cask cavity. In the accident condition, the distance was equivalent to locating the source and steel liner at the inner wall of the cask cavity. The shapes and distances of the other sources remained unchanged.

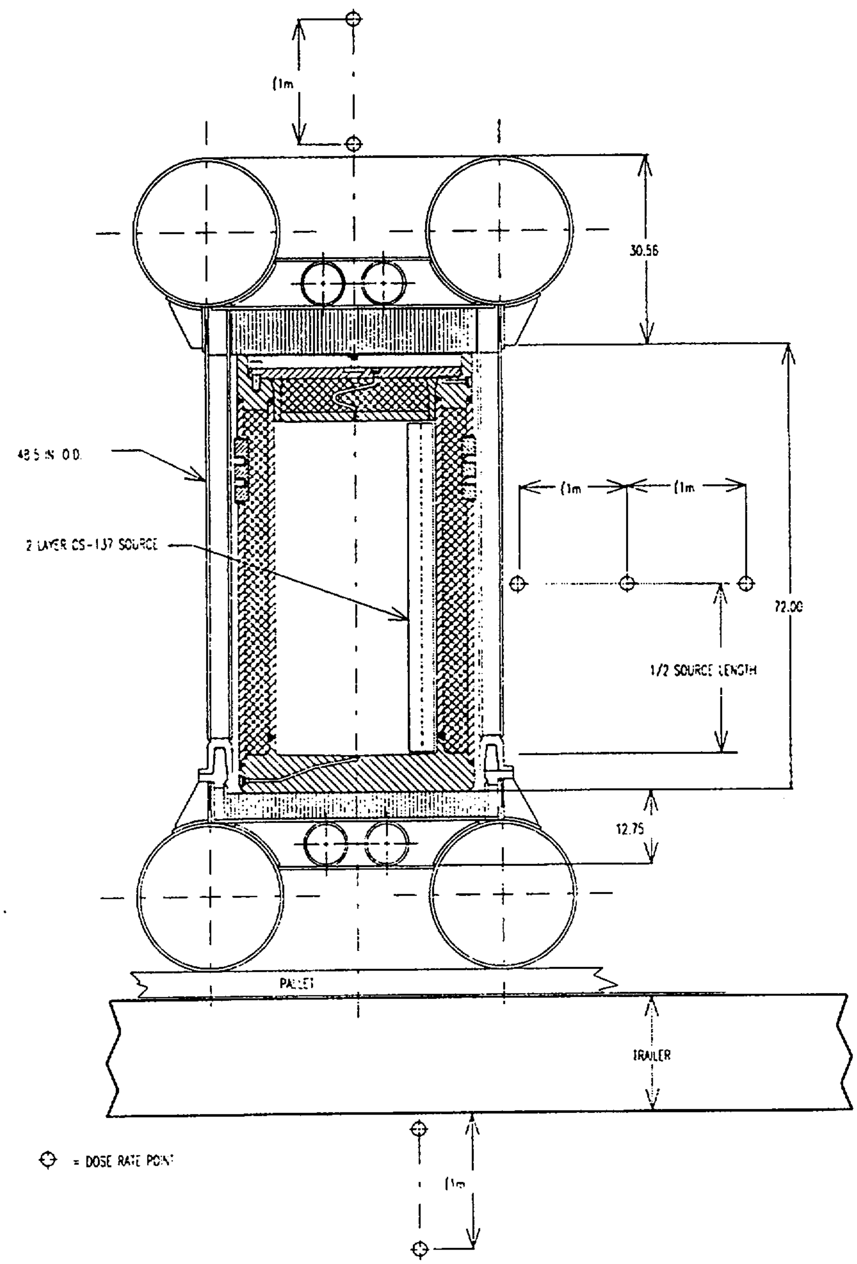


Figure 5.1. Normal Condition Shield Analysis Geometry

NOTE: Top and bottom variables in brackets [ ]

(For Cs-137, Top source)

Variable	Side	Top	Bottom
	Dimension, inches		
T(1)	2.5	16	16
T(2)	0.004	0.004	0.004
T(3)	3.0	4.31	11.13
T(4)	4.0	5.37	0.0
SLTH	16	1.21	2.5
Y	0.0	NA	NA
X (Contact)	13.5	76.11	86.14
X(1 meter)	52.87	115.48	125.51
X (2 meters)	92.24	154.06	164.88

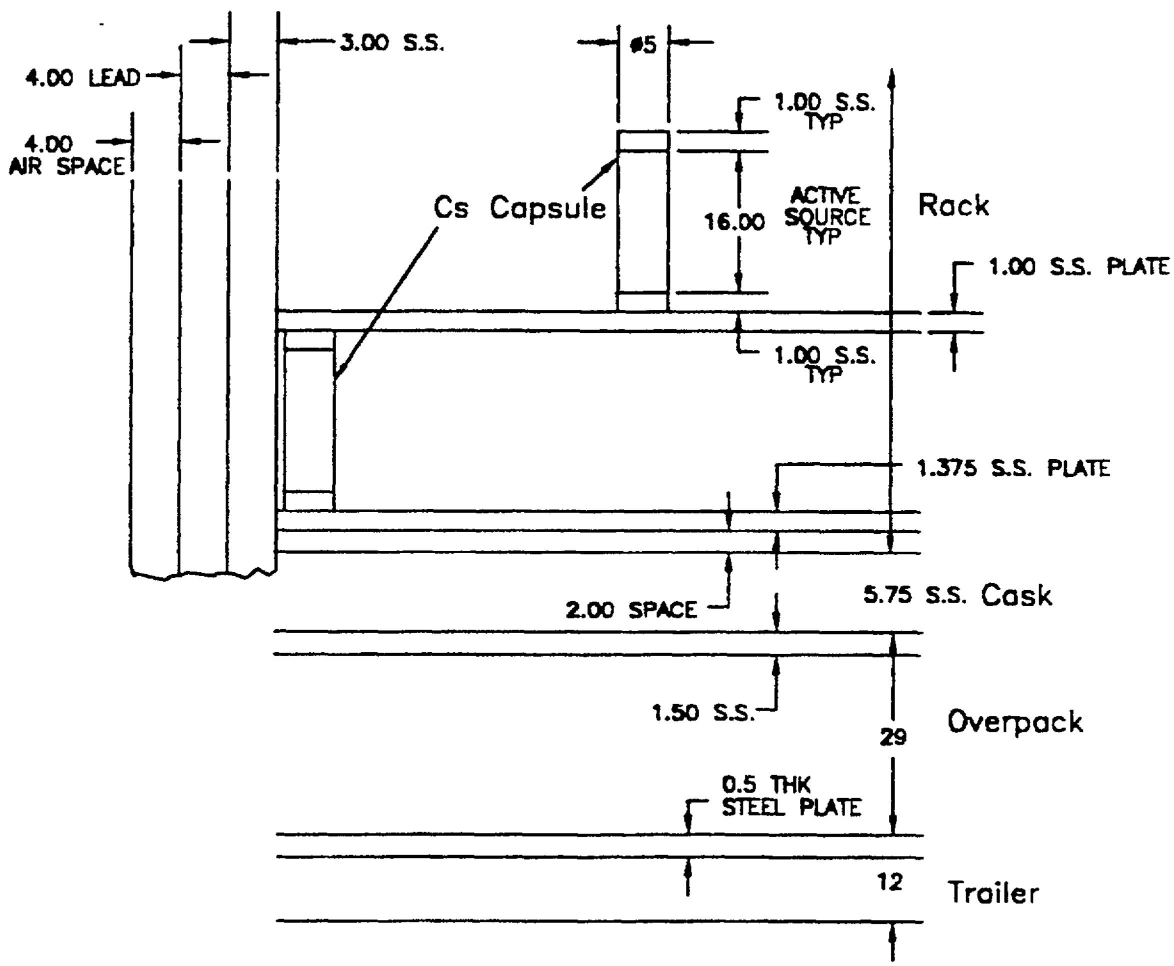


Figure 5.2. Cs-137 Capsule Model Geometry

5.3.2 Shield Regional Densities

The shipping container material densities used for the shielding analyses were:

Air inside the liner cavity	1.293×10^{-3} g/cc
Lead in the liner and cask	11.34 g/cc
Iron in the liner, cask and overpack	7.8 g/cc.

The source materials were approximated by available materials in the ISOSHLD library as follows:

Isotope	Material	Density, g/cc
Cs-137	Tin	3.97
Co-60	Nickel	8.9
Hf-181	N/A	N/A
Ir-192	N/A	N/A
Sr-90	N/A	N/A
Zr/Nb-95	Zirconium	6.4

5.4 SHIELDING EVALUATION

5.4.1 Fuel Source

Not analyzed for this evaluation.

5.4.2 Activation Product Sources

The method for estimating the dose rates at the surface, one meter, two meters, and 21 feet (cab of vehicle) from the surface of the Model 2000 transport container is outlined as follows.

1. The cask and overpack geometry for the analysis consisted of a cylindrical or point source at the side wall of the cask shielded by a 4.0-in. slab of lead plus a 3.0-in. slab of iron at the side, a 5.37-in. slab of lead plus a 4.31-in. slab of iron at the top, and a 7.75-in. slab of iron at the bottom. The input to ISOSHLD to express the relative geometry of a cylindrical source, slab shields, and the dose point requires the vertical distance from the end of the source to the detector, differential thicknesses to define the point source elements, the thickness of the shields, the distance from the detector to the center or end of the cylinder, and the dimensions of the cylinder.

The input values for the normal conditions are:

		Cs-137 Case*	Top Case	Bottom Case	Side Case
Source radius	=	6.35 cm			
Source length	=	40.64 cm			
Air thickness	=	0.01 cm			
Iron thickness	=	–	10.95 cm	19.69** cm	7.62 cm
Lead thickness	=	–	13.64 cm	0.0 cm	10.16 cm
Buildup shield	=	–	Lead	Iron	Lead
Number of source division angles	=	–	30	30	30 × 30
Source length or radius divisions	=	–	1.35 cm	1.35 cm	0.212 cm
Distance to surface	=	–	193.3 cm	218.8 cm	34.29 cm
Distance to one meter	=	–	293.3 cm	318.8 cm	134.29 cm
Distance to two meters	=	–	393.3 cm	418.8 cm	234.29 cm

*Two Cs-137 sources, top layer dimensions given.
** Not including the end plugs and rack plates.

The RIBD-ISOSHLD computer program was selected for the shielding analysis because it is a public domain code (i.e., it is distributed by the RSIC for unrestricted use), and reasonable accuracy is possible with the standard isotope, attenuation, and buildup libraries included in the code. The results from the ISOSHLD evaluation could be reasonably duplicated by standard hand calculations, barring human error.

The gamma flux-to-dose rate conversion factors as a function of energy are given below.

Group Average Energy (MeV)	Flux-To-Dose Rate Conversion Factor (R/hr per MeV/cm^2-sec)
1.500E–02	8.230E–05
2.500E–02	1.730E–05
3.500E–02	6.349E–06
4.500E–02	3.280E–06
5.500E–02	2.289E–06
6.500E–02	1.891E–06
7.500E–02	1.714E–06
8.500E–02	1.618E–06
9.500E–02	1.603E–06
1.500E–01	1.728E–06
2.500E–01	1.960E–06
3.500E–01	2.060E–06
4.750E–01	2.039E–06
6.500E–01	2.080E–06
8.250E–01	2.000E–06
1.000E+00	1.930E–06
1.225E+00	1.841E–06
1.475E+00	1.761E–06
1.700E+00	1.710E–06
1.900E+00	1.660E–06
2.100E+00	1.600E–06
2.300E+00	1.540E–06
2.500E+00	1.520E–06
2.700E+00	1.480E–06
3.000E+00	1.430E–06

Dose rates from a shipment of radionuclides are determined by many variables. Some of the variables are: physical form and configuration, thicknesses of container shields, irradiation time, operating power (neutron flux), decay time, composition of hardware (or target material), and so forth. For this reason, defining a maximum source load for the container is conditional. Two significant limits which are practical for assuring public safety are the criticality mass limit for SNM and the maximum heat load to prevent structural failure. The normal condition quantity limits and dose rate limits are defined by the transportation regulations, and compliance with these limits is demonstrated for each particular load. Accident condition dose rates are a function of geometry changes in the load and/or shielding. Major changes are prevented by the structural integrity of the container. Typically, the controlling dose rate limit is the two-meter limit of 10 mRem/hr. Barring loss of shielding, the accident case geometry does not result in the limiting dose rate of 1,000 mR/hr at one meter from the surface of the container.

2. For this evaluation the activation product source was chosen as a volume of material which contains a uniform dispersion of the isotope of interest. Activated hardware can have many shapes and sizes. For the normal condition shielding analysis of activation products it was assumed that the source isotope is a point source or contained in a cylinder with a volume which is capable of containing the individual isotopic activities equivalent to 2,000 watts of decay heat. The dimensions of the cylindrical volume used for the Cs-137 evaluation are 5-in. diameter by 16 in. long. The Cs-137 source is divided into two stacked sources.

   The accident case geometry for irradiated hardware is a the same as the normal condition source with the source moved as close as possible to the inner wall of the cask. The isotopes for which limits were calculated are: Cobalt-60, Cesium-137, Zirconium-95/Niobium-95, Hafnium-181, Iridium-192, and Strontium-90/Yttrium-90.

5.4.3 Bounding Limits

The maximum cask loadings which result from the above discussed dose rate calculations are summarized in Table 5.4.1. The activity limits are for the geometry and material cases analyzed only and are the curie loads which are equivalent to 2,000 watts of decay heat. With the shielding conditions described, no dose rate limits will be exceeded by these source loads.

The method used to calculate decay heat values for any particular isotope or parent/daughter chain of isotopes is to convert the energy emitted per disintegration, in MeV, to watts per curie using standard conversion factors. The activity, in curies, which is equivalent to 2000 watts of decay heat can then be determined from this specific decay heat. The values used in the conversion are:

1 watt-second = 1E7 ergs
1 erg = 6.2416E5 MeV
1 curie = 3.7E10 disintegrations/second

These equivalencies yield a conversion factor of 1 watt/curie = 168.7 MeV/disintegration.

The decay heat in MeV/disintegration for a particular isotope is determined from the "beta-decay energy" given in the fourteenth edition of the GE Chart of the Nuclides[1] and the average and end-point beta energies given in the Radioactive Decay Data Tables[2]. The "beta-decay energy" is the sum of the beta particle end-point (maximum) energy and the gamma photon energies. The desired decay energy of an isotope for the purpose of determining the total decay heat is the average beta energy, which is roughly one third of the maximum beta energy, plus the gamma energies. Therefore the average energy per disintegration is calculated by subtracting the maximum beta energy from the "beta-decay energy" and then adding the average beta energy to arrive at an average decay energy in MeV/disintegration. This average decay energy is then converted to the specific decay heat, in watts/curie using the above conversion factor. The number of curies in a 2000 watt decay heat isotope source is calculated by dividing 2000 watts by the specific decay heat.

For example, Co-60 has a beta-decay heat value of 2.824 MeV/disintegration, the maximum beta energy is 0.3189 MeV, and the average beta energy is 0.09579 MeV. Then the average decay energy of Co-60 is 2.602 MeV/disintegration. This energy converts to a specific decay heat of 0.0154 watts/curie (or 64.8 curies/watt). The activity of Co-60 required to produce 2000 watts of decay heat is approximately 130,000 curies.

---

[1] Nuclides and Isotopes, Fourteenth Edition, Revised 1989 by F. William Walker, Josef R. Parrington, and Frank Feiner, General Electric Company, Nuclear Energy Operations, 175 Curtner Avenue, M/C 397, San Jose, California, 95125.

[2] David C. Kocher, Radioactive Decay Data Tables, 1981, DOE/TIC-11026.

For isotopes which decay to radioactive daughter isotopes, the ratio of the activities of the parent and daughter is assumed to be the theoretical equilibrium ratio. Specific decay heats for each isotope are calculated by the method described above. A unit activity of a decay chain is composed of the relative activities of the parent and daughter. If the equilibrium ratio between the parent and daughter is one, i.e., they both have equal activities, then two curies of the chain contains one curie each of the parent and daughter. In this case the specific heat of the mixture is one half of the sum of the specific heats of the individual isotopes. For example, Sr-90 decays to Y-90, and at equilibrium they have equal activities. The specific heat of Sr-90 is calculated to be 1.16E-3 watts/curie and the specific heat of Y-90 is calculated to be 5.55E-3 watts/curie. Then the specific heat of the Sr-90/Y-90 chain is 3.35E-3 watts per curie of the mixture, and likewise the activity of this mixture which is equivalent to 2000 watts is approximately 600,000 curies of Sr-90 plus Y-90, or 300,000 curies of each isotope. The presentation of the activity equivalence to 2000 watts can be misinterpreted if it is not clear whether the activity refers only to the parent isotope or to the combined activity of the parent plus the daughter. For consistency, Table 5.4.1 shall list the curies equivalent to 2000 watts of decay heat as the sum of the parent plus the daughter activities at equilibrium.

Table 5.4.1. Curie Limits for Model 2000 (Dose Rate and Decay Heat Bases)

Source Type	Isotope	Activity Limits, Curies Equivalent to 2.000 Watts
Activation Product	Co-60	1.30E5
Fission Product	Cs-137	4.22E5
Activation Product	Zr/Nb-95	4.09E5
Activation Product	Hf-181	4.56E5
Fission Product	Sr/Y-90	5.96E5
Activation Product	Ir-192	3.48E5

5.5 REFERENCES

1. ISOSHLD, Kernel Integration Code - General Purpose Isotope Shielding Analysis, CCC-79.

5.6 APPENDIX

RSIC CODE PACKAGE CCC-79

1. NAME AND TITLE OF CODE

ISOSHLD: Kernel Integration Code - General Purpose Isotope Shielding Analysis.

Two versions are packaged: ISOSHLD I and II. RIBD is used in both versions as a subroutine to calculate fission product inventories. The CCC-3 1/BREMRAD code package can be used to calculate the bremsstrahlung spectrum mesh, but must be requested separately. -

2. CONTRIBUTOR

Battelle Memorial Institute, Pacific Northwest Laboratories, Richland, Washington.

3. CODING LANGUAGE AND COMPUTER

(A) ISOSHLD III: FORTRAN IV; UNIVAC 1108 (Update 12/73)
(B) ISOSHLD II: FORTRAN IV; IBM 360.
(C) ISOSHLD II: FORTRAN IV; UNIVAC 1108

4. NATURE OF PROBLEM SOLVED

ISOSHLD calculates the decay gamma-ray and bremsstrahlung dose at the exterior of a shielded radiation source. The source may be one of a number of common geometric shapes. If the radiation source originated as one or a group of fission products produced under known irradiation conditions, then the strength of the source is also calculated. The code calculates shield region mass attenuation coefficients, buildup factors, and other basic data necessary to solve the specific problem.

5. METHOD OF SOLUTION

ISOSHLD performs kernel integration for common geometric shapes. The "standard" point attenuation kernel (buildup factor × exponential attenuation ÷ geometry factor) is numerically integrated over the source volume for 25 source energy groups. Buildup is considered characteristic of the last shield region (or a different specified region) but dependent on the total number of mean free paths from source to dose point, and is obtained by interpolation on effective atomic number from a table of point isotopic buildup factor data. Mixed mass attenuation coefficients are obtained from a library of basic data using code input material density specifications. The source strength may be specified 1) as the emissions from a selection of fission products irradiated under specific conditions, 2) the curies of particular fission and/or activation products, or 3) a number of photons per second of energy E specified by input. An exponential source distribution may be specified for those source geometries which are applicable. If the source originates in a combination of fission products and their daughters, these are calculated by a fission product inventory procedure which runs through transmutation (decay chain) calculations for each fission product and daughter. The latest modification (ISOSHLD -

ISOSHLD II) adds the capability for calculating shielded dose rates from bremsstrahlung sources. This addition consists of routines for calculating the bremsstrahlung source spectra from the beta decay properties of the isotope(s) of interest. Bremsstrahlung photons per group for 25 energy groups (9 groups below 0.1 MeV have been added) are obtained by interpolation from tables of resolved spectra. This spectral mesh, for internal and external bremsstrahlung, is tabulated as a function of the following parameters: beta-emitting and stopping nuclides with atomic numbers of 10, 30, 50, 70, and 90; ratios of photon energy to beta end point energy for 25 intervals from 0.00375 to 1.0; beta and point energies at the intervals 0.1, 0.2, 0.5, 1, 2, and 4 MeV. Buildup factors for photon energies less than 0.1 MeV are interpolated from a table which contains data for 5 values of initial photon energy in the range 0.01 to 0.2 MeV, seven values of shield thickness in the range 1 to 20 mfp, and 6 atomic numbers in the range 13 to 92.

The entire shielding problem is solved for most types of isotope shielding applications without reference to shielding handbooks for basic data.

6. RESTRICTIONS OR LIMITATIONS

These limits apply: 5 source cooling times, 500 radioactive isotopes, 5 shield regions including source region, 25 energy groups, 20 materials in each shield region, choice of 11 source geometries.

7. TYPICAL RUNNING TIME

Dose from cylindrical volume source - 20 integration increments in each direction, fission product inventory calculations with 5 decay times, 25 energy groups, 4 shield layers, 5 materials homogenized into each shield layer and the source volume – 6 minutes UNIVAC 1107. (Most other source geometries require less computation time.)

8. COMPUTER HARDWARE REQUIREMENTS

The codes were originally designed for the 65k UNIVAC 1107. They have been modified by RSIC to run on the IBM 7090 (I) and the 360 (II).

9. COMPUTER SOFTWARE REQUIREMENTS

The codes were originally designed for the UNIVAC 1107 EXEC II Monitor System.

ISOSHLD I is available as an overlay job on the IBM FORTRAN IV IBJOB Monitor within the IBSYS Operating System. The ALTIO package is used.

ISOSHLD II is available for the IBM 360 computer and has been run on the Model 50 on the Level H compiler.

A library of data is packaged for each version.

10. REFERENCES

R. L. Engle, J. Greenborg, and M. M. Hendrickson, "ISOSHLD - A Computer Code for General Purpose Isotope shielding Analysis", BNWL-236 (June 1966).

R. O. Gumprecht, "RIBD-Radioisotope Buildup and Decay", Unpublished data.

H. H. Van Tuyl, "BREMRAD - A Computer Code for External and Internal Bremsstrahlung Calculations, HW-83784 (September 1964) (Packaged in CCC-31 only).

G. L. Simmons, J. J. Regimbal, J. Greenborg, E. L. Kelly, Jr., and H. H. Van Tuyl, "ISOSHLD-II: Code Revision to Include Calculations of Dose Rate from Shielded Bremsstrahlung Sources", BNWL-236SUP1 (March 1967).

11. CONTENTS OF CODE PACKAGE

The package contains the following items:

a. the referenced documents, with exception noted, and

b. for each code version a reel of magnetic tape has been written which contains the BCD source card decks, the binary card decks, a BCD library of data, BCD input for a sample problem, and a BCD output listing for the problem.

12. HOW TO OBTAIN PACKAGE

Inquiries or requests for the code package should be mailed to

CODES COORDINATOR
Radiation shielding Information Center
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37830

or telephoned to

Area code 615; 483-8611, extension 3-6944, or to
FTS xx-615-483-6944.

Persons requesting the package should send a reel of magnetic tape to the above address, specifying the version desired.

13. DATE OF ABSTRACT

January 1968.

```
$$ ASIS,ROUT(1U),TAB(:,8,16,79)
$:IDENT:V151,BMM,VVV18,X4455
$:OPTION:FORTRAN
$:SELECT:ISHLD01
$:LIMITS:100,44K,,30K
S:REMOTE:06,1U
$:DATA:I*
  MODE = 2
SIDE OF 2000, 422 KCi Cs137 16x5 CYL TWO LAYERS, NOLINER, SURFACE
 $INPUT NEXT = 1, IGEOM = 9, T(1) = 6.35, T(2) = 0.01, T(3) = 7.62,
 T(4) = 10.16, SLTH = 40.64, X = 34.29, Y = 0.0, NTHETA = 30,
 NPSI = 30, DELR = 0.212,
 NSHLD = 4, JBUF = 4, ISPEC = 1, WEIGHT(335) = 4.22E05 $
 TIN    12 3.970E 00
 AIR    3        1.293E-03
 IRON  9                 7.800E 00
 LEAD  14                         1.134E 01               1
SIDE OF 2000, 422 KCi Cs137 16x5 CYL TWO LAYERS, NOLINER, 1 METER
 $INPUT NEXT = 4, X = 134.29 $
SIDE OF 2000, 422 KCi Cs137 16x5 CYL TWO LAYERS, NOLINER, 2 METERS
 $INPUT NEXT = 4, X = 234.29 $
SIDE OF 2000, 422 KCi Cs137 16x5 CYL TWO LAYERS, NOLINER, 21 FEET, CAB
 $INPUT NEXT = 4, X = 640.1 $
DUMMY TITLE CARD
 $INPUT NEXT = 6 $
$:ENDJOB
```

```
$$ ASIS,ROUT(1U),TAB(:,8,16,79)
$:IDENT:V151,BMM,VVV18,X4455
$:OPTION:FORTRAN
$: SELECT:ISHLD01
$:LIMITS: 100,44K,,30K
$:REMOTE:06,1U
$:DATA:I*
  MODE = 3
TRLR BOTTOM, CASE 1, 211 KCi Cs137 16x5 CYL TOP LAYER, SURFACE
 $INPUT NEXT = 3, IGEOM = 9, SLTH = 6.35, NTHETA = 30., X = 218.76,
 T(1) = 40.64, T(2) = 0.01, T(3) = 28.26, DELR = 1.35,
 NSHLD = 3, JBUF = 3, ISPEC = 1,
 SOURCE(1,1) = 6.645E15, SOURCE(2,1) = 0.662 $
 TIN    12 3.970E 00
 AIR    3        1.293E-03
 IRON  9                 7.800E 00                     1
TRLR BOTTOM, CASE 1, 211 KCi Cs137 16x5 CYL TOP LAYER, 1 METER
 $INPUT NEXT = 4, X = 318.76 $
TRLR BOTTOM, CASE 1, 211 KCi Cs137 16x5 CYL TOP LAYER, 2 METERS
 $INPUT NEXT = 4, X = 418.76 $
TRLR BOTTOM, CASE 2, 211 KCi Cs137 16x5 CYL BOTTOM LAYER, SURFACE
 $INPUT NEXT = 4, T(3) = 25.72, X = 170.50 $
TRLR BOTTOM, CASE 2, 211 KCi Cs137 16x5 CYL BOTTOM LAYER, 1 METER
 $INPUT NEXT = 4, X = 270.50 $
TRLR BOTTOM, CASE 2, 211 KCi Cs137 16x5 CYL BOTTOM LAYER, 2 METERS
 $INPUT NEXT = 4, X = 370.50 $
DUMMY TITLE CARD
 $INPUT NEXT = 6 $
$:ENDJOB
```

```
$$ ASIS,ROUT(1U),TAB(:,8,16,79)
$:IDENT:V151,BMM,VVV18,X4455
$:OPTION:FORTRAN
$:SELECT:ISHLD01
$:LIMITS:100,44K,,30K
$:REMOTE:06,1U
$:DATA:I*
  MODE = 2
TOP OF 2000, CASE 1, 211 KCi Cs137 16x5 CYL TOP LAYER, SURFACE
 $INPUT NEXT = 1, IGEOM = 9, SLTH = 6.35, NTHETA = 30., X = 193.31,
 T(1) = 40.64, T(2) = 0.01, T(3) = 10.95, T(4) = 13.64. DELR = 1.35,
 NSHLD = 4, JBUF = 4, ISPEC = 1, WEIGHT(335) = 2.11E05 $
 TIN    12 3.970E 00
 AIR    3          1.293E-03
 IRON  9                    7.800E 00
 LEAD  14                             1.134E 01                1
TOP OF 2000, CASE 1, 211 KCi Cs137 16x5 CYL TOP LAYER, 1 METER
 $INPUT NEXT = 4, X = 293.31 $
TOP OF 2000, CASE 1, 211 KCi Cs137 16x5 CYL TOP LAYER, 2 METERS
 $INPUT NEXT = 4, X = 393.31 $
TOP OF 2000, CASE 2, 211 KCi Cs137 16x5 CYL BOTTOM LAYER, SURFACE
 $INPUT NEXT = 4, T(3) = 13.49, X = 236.49 $
TOP OF 2000, CASE 2, 211 KCi Cs137 16x5 CYL BOTTOM LAYER, 1 METER
 $INPUT NEXT = 4, X = 336.49 $
TOP OF 2000, CASE 2, 211 KCi Cs137 16x5 CYL BOTTOM LAYER, 2 METERS
 $INPUT NEXT = 4, X = 436.49 $
DUMMY TITLE CARD
 $INPUT NEXT = 6 $
$:ENDJOB
```

ISOSHLD-III

ISOTOPE SELECTION DATA

ISOTOPES CONSIDERED ARE

VALUES SPECIFY CURIES

CS2 137
0.211E 06

SHIELD COMPOSITION GR/CC	1	2	3	4	5
SN	3.970E 00	0.	0.	0.	0.
AIR	0.	1.293E-03	0.	0.	0.
IRON	0.	0.	7.800E 00	0.	0.
LEAD	0.	0.	0.	1.134E 01	0.

MASS ABSORPTION COEFFICIENTS (LAST REGION IS AIR)

3.463E 02	4.425E-03	3.445E 02	8.201E 02	4.424E-03	0.
5.427E 01	6.543E-04	9.576E 01	5.415E 02	6.542E-04	0.
3.473E 01	.504E-04	4.434E 01	1.928E 02	3.504E-04	0.
3.242E 01	2.715E-04	2.055E 01	9.202E 01	2.715E-04	0.
2.432E 01	2.405E-04	1.135E 01	5.262E 01	2.405E-04	0.
1.829E 01	2.247E-04	7.574E 00	3.489E 01	2.247E-04	0.
1.299E 01	2.137E-04	5.405E 00	2.419E 01	2.137E-04	0.
9.524E 00	2.049E-04	3.918E 00	2.507E 01	2.049E-04	0.
7.206E 00	1.985E-04	3.111E 00	2.853E 01	1.985E-04	0.
2.541E 00	1.725E-04	1.591E 00	1.564E 01	1.725E-04	0.
8.734E-01	1.474E-04	1.069E 00	6.339E 00	1.474E-04	0.
5.161E-01	1.312E-04	7.784E-01	3.476E 00	1.312E-04	0.
3.712E-01	1.183E-04	6.825E-01	2.013E 00	1.183E-04	0.
2.858E-01	1.118E-04	5.616E-01	1.452E 00	1.118E-04	0.
2.461E-01	8.986E-05	4.969E-01	9.923E-01	8.986E-05	0.
2.184E-01	8.211E-05	4.586E-01	8.233E-01	8.210E-05	0.
1.945E-01	7.409E-05	4.001E-01	7.008E-01	7.408E-05	0.
1.767E-01	6.659E-05	3.666E-01	6.056E-01	6.658E-05	0.
1.648E-01	6.181E-05	3.479E-01	5.534E-01	6.180E-05	0.
1.608E-01	5.818E-05	3.237E-01	5.250E-01	5.818E-05	0.
1.548E-01	5.495E-05	3.136E-01	5.024E-01	5.495E-05	0.
1.509E-01	5.263E-05	2.972E-01	4.854E-01	5.262E-05	0.
1 449E-01	5.004E-05	2.948E-01	4.751E-01	5.004E-05	0.
1.449E-01	4.784E-05	2.855E-01	4.683E-01	4.784E-05	0.
1.429E-01	4.383E-05	2.769E-01	4.661E-01	4.383E-05	0.

GAMMA ATTENUATION CALCULATION SIDE OF 2000, 422 KCI CS137 16X5 CYL TWO LAYERS, NOLINER, SURFACE

SOURCE END OF CYL. SHIELDS SLAB DIST TO DETECTOR 3.429E 01 CM. VOL. =3.295E 04 CC

LENGTH = 6.350E 00 CM RADIUS = 4.064E 01 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 30 DELR = 0.2120E 00

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS 6.350E 00 1.000E-02 7.620E 00 1.016E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	1.327E 16	6.500E-01	3.158E 02	6.570E-04
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	1.327E 16		3.158E 02	6.570E-04

GAMMA ATTENUATION CALCULATION SIDE OF 2000, 422 KCI CS137 16X5 CYL TWO LAYERS, NOLINER, 1 METER

SOURCE SHIELDS DIST TO DETECTOR 1.343E 02 CM.
END OF CYL. SLAB VOL. = 3.295E 04 CC

LENGTH = 6.350E 00 CM RADIUS = 4.064E 01 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 30 DELR =0.2120E 00

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS 6.350E 00 1.000E-02 7.620E 00 1.016E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	1.327E 16	6.500E-01	1.874E 02	3.898E-04
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	1.327E 16		1.874E 02	3.898E-04

GAMMA ATTENUATION CALCULATION   SIDE OF 2000, 422 KCI CS137 16X5 CYL TWO LAYERS, NOLINER, 2 METERS

SOURCE   SHIELDS   DIST TO DETECTOR 2.343E 02 CM.
END OF CYL.   SLAB   VOL. =3.295E 04 CC

LENGTH = 6.350E 00 CM   RADIUS = 4.064E 01 CM

INTEGRATION SPECS NTHETA = 31   NPSI = 30   DELR = 0.2120E 00

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS   6.350E 00   1.000E-02   7.620E 00   1.016E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	1.327E 16	6.500E-01	7.897E 01	1.643E-04
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	1.327E 16		7.897E 01	1.643E-04

GAMMA ATTENUATION CALCULATION SIDE OF 2000, 422 KCI CS137 16X5 CYL TWO LAYERS, NOLINER. 21 FEET, CAB

SOURCE SHIELDS DIST TO DETECTOR 6.401E 02 CM.
END OF CYL. SLAB VOL. = 3.295E 04 CC

LENGTH = 6.350E 00 CM RADIUS = 4.064E 01 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 30 DELR = 0.2120E 00

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS 6.350E 00 1.000E-02 7.620E 00 1.016E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	1.327E 16	6.500E-01	1.116E 01	2.321E-05
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	1.327E 16		1.116E 01	2.321E-05

SHIELD COMPOSITION GR/CC	1	2	3	4	5
SN	3.970E 00	0.	0.	0.	0.
AIR	0.	1.293E-03	0.	0.	0.
IRON	0.	0.	7.800E 00	0.	0.

MASS ABSORPTION COEFFICIENTS (LAST REGION IS AIR)

2.831E-01	1.103E-04	5.572E-01	1.018E-04	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.

GAMMA ATTENUATION CALCULATION TRLR BOTTOM, CASE 1, 211 KCI CS137 16X5 CYL TOP LAYER, SURFACE

SOURCE SHIELDS DIST TO DETECTOR 2.188E 02 CM.
END OF CYL. SLAB VOL. = 5.148E 03 CC

LENGTH = 4.064E 01 CM RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 0 DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 3 WITH EFFECTIVE ATOMIC NUMBER OF 26.0 USED

SHIELD THICKNESS 4.064E 01 1.000E-02 2.826E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	6.645E 15	6.620E-01	4.785E 03	9.926E-03
TOTAL	6.645E 15		4.785E 03	9.926E-03

GAMMA ATTENUATION CALCULATION TRLR BOTTOM, CASE 1, 211 KCI CS137 16X5 CYL TOP LAYER, 1 METER

SOURCE SHIELDS DIST TO DETECTOR 3.188E 02 CM.
END OF CYL. SLAB VOL. = 5.148E 03 CC

LENGTH = 4.064E 01 CM RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 0 DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 3 WITH EFFECTIVE ATOMIC NUMBER OF 26.0 USED

SHIELD THICKNESS 4.064E 01 1.000E-02 2.826E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	6.645E 15	6.620E-01	1.968E 03	4.083E-03
TOTAL	6.645E 15		1.968E 03	4.083E-03

GAMMA ATTENUATION CALCULATION TRLR BOTTOM, CASE 1, 211 KCI CS137 16X5 CYL TOP LAYER, 2 METERS

SOURCE SHIELDS DIST TO DETECTOR 4.188E 02 CM.
END OF CYL. SLAB VOL. = 5.148E 03 CC

LENGTH = 4.064E 01 CM RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 0 DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 3 WITH EFFECTIVE ATOMIC NUMBER OF 26.0 USED

SHIELD THICKNESS 4.064E 01 1.000E-02 2.826E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	6.645E 15	6.620E-01	1.059E 03	2.196E-03
TOTAL	6.645E 15		1.059E 03	2.196E-03

GAMMA ATTENUATION CALCULATION TRLR BOTTOM, CASE 2, 211 KCI CS137 16X5 CYL BOTTOM LAYER, SURFACE

SOURCE SHIELDS DIST TO DETECTOR 1.705E 02 CM.
END OF CYL. SLAB VOL. = 5.148E 03 CC

LENGTH = 4.064E 01 CM RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 0 DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 3 WITH EFFECTIVE ATOMIC NUMBER OF 26.0 USED

SHIELD THICKNESS 4.064E 01 1.000E-02 2.572E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	6.645E 15	6.620E-01	3.123E 04	6.478E-02
TOTAL	6.645E 15		3.123E 04	6.478E-02

GAMMA ATTENUATION CALCULATION   TRLR BOTTOM, CASE 2, 211 KCI CS137 16X5 CYL BOTTOM LAYER, 1 METER

SOURCE   SHIELDS   DIST TO DETECTOR 2.705E 02 CM.
END OF CYL.   SLAB   VOL. = 5.148E 03 CC

LENGTH = 4.064E 01 CM   RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31   NPSI = 0   DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 3 WITH EFFECTIVE ATOMIC NUMBER OF 26.0 USED

SHIELD THICKNESS   4.064E 01   1.000E-02   2.572E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	6.645E 15	6.620E-01	1.013E 04	2.101E-02
TOTAL	6.645E 15		1.013E 04	2.101E-02

GAMMA ATTENUATION CALCULATION TRLR BOTTOM, CASE 2, 211 KCI CS 137 16X5 CYL BOTTOM LAYER, 2 METERS

SOURCE SHIELDS DIST TO DETECTOR 3.705E 02 CM.
END OF CYL. SLAB VOL. = 5.148E 03 CC

LENGTH = 4.064E 01 CM RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 0 DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 3 WITH EFFECTIVE ATOMIC NUMBER OF 26.0 USED

SHIELD THICKNESS 4.064E 01 1.000E-02 2.572E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	6.645E 15	6.620E-01	4.904E 03	1.017E-02
TOTAL	6.645E 15		4.904E 03	1.017E-02

ISOTOPE SELECTION DATA

ISOTOPES CONSIDERED ARE

VALUES SPECIFY CURIES

CS2 137
0.211E 06

SHIELD COMPOSITION GR/CC	1	2	3	4	5
SN	3.970E 00	0.	0.	0.	0.
AIR	0.	1.293E-03	0.	0.	0.
IRON	0.	0.	7.800E 00	0.	0.
LEAD	0.	0.	0.	1.134E 01	0.

MASS ABSORPTION COEFFICIENTS (LAST REGION IS AIR)

3.463E 02	4.425E-03	3.445E 02	8.201E 02	4.424E-03	0.
5.427E 01	6.543E-04	9.576E 01	5.415E 02	6.542E-04	0.
3.473E 01	.504E 04	4.434E 01	1.928E 02	3.504E-04	0.
3.242E 01	2.715E-04	2.055E 01	9.202E 01	2.715E-04	0.
2.432E 01	2.405E-04	1.135E 01	5.262E 01	2.405E-04	0.
1.829E 01	2.247E-04	7.574E 00	3.489E 01	2.247E-04	0.
1.299E 01	2.137E-04	5.405E 00	2.419E 01	2.137E-04	0.
9.524E 00	2.049E-04	3.918E 00	2.507E 01	2.049E-04	0.
7.206E 00	1.985E-04	3.111E 00	2.853E 01	1.985E-04	0.
2.541E 00	1.725E-04	1.591E 00	1.564E 01	1.725E-04	0.
8.734E-01	1.474E-04	1.069E 00	6.339E 00	1.474E-04	0.
5.161E-01	1.312E-04	7.784E-01	3.476E 00	1.312E-04	0.
3.712E-01	1.183E-04	6.825E-01	2.013E 00	1.183E 04	0.
2.858E-01	1.118E-04	5.616E-01	1.452E 00	1.118E-04	0.
2.461E-01	8.986E-05	4.969E-01	9.923E-01	8.986E-05	0.
2.184E-01	8.211E-05	4.586E-01	8.233E-01	8.210E-05	0.
1.945E-01	7.409E-05	4.001E-01	7.008E-01	7.408E-05	0.
1.767E-01	6.659E-05	3.666E-01	6.056E-01	6.658E-05	0.
1.648E-01	6.181E-05	3.479E-01	5.534E-01	6.180E-05	0.
1.608E-01	5.818E-05	3.237E-01	5.250E-01	5.818E-05	0.
1.548E-01	5.495E-05	3.136E-01	5.024E-01	5.495E-05	0.
1.509E-01	5.263E-05	2.972E-01	4.854E-01	5.262E-05	0.
1.449E-01	5.004E-05	2.948E-01	4.751E-01	5.004E-05	0.
1.449E-01	4.784E-05	2.855E-01	4.683E-01	4.784E-05	0.
1.429E-01	4.383E-05	2.769E-01	4.661E-01	4.383E-05	0.

GAMMA ATTENUATION CALCULATION   TOP OF 2000, CASE 1, 211 KCl CS137 16X5 CYL TOP LAYER, SURFACE

SOURCE   SHIELDS   DIST TO DETECTOR 1.933E 02 CM.
END OF CYL.   SLAB   VOL. =5.148E 03 CC

LENGTH = 4.064E 01 CM   RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31   NPSI = 0   DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS   4.064E 01   1.000E-02   1.095E 01   1.364E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	6.636E 15	6.500E-01	2.338E-02	4.863E-08
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	6.636E 15		2.338E-02	4.863E-08

GAMMA ATTENUATION CALCULATION TOP OF 2000. CASE 1, 211 KCI CS 137 16X5 CYL TOP LAYER, 1 METER

SOURCE SHIELDS DIST TO DETECTOR 2.933E 02 CM.
END OF CYL. SLAB VOL. =5.148E 03 CC

LENGTH = 4.064E 01 CM RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 0 DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS 4.064E 01 1.000E-02 1.095E 01 1.364E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	6.636E 15	6.500E-01	8.613E-03	1.791E-08
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	6.636E 15		8.613E-03	1.791E-08

GAMMA ATTENUATION CALCULATION TOP OF 2000, CASE 1, 211 KCI CS137 16X5 CYL TOP LAYER, 2 METERS

SOURCE SHIELDS DIST TO DETECTOR 3.933E 02 CM.
END OF CYL. SLAB VOL. =5.148E 03 CC

LENGTH = 4.064E 01 CM RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 0 DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS 4.064E 01 1.000E-02 1.095E 01 1.364E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	6.636E 15	6.500E-01	4.394E-03	9.139E-09
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	6.636E 15		4.394E-03	9.139E-09

GAMMA ATTENUATION CALCULATION TOP OF 2000, CASE 2, 211 KCI CS137 16X5 CYL BOTTOM LAYER, SURFACE

SOURCE SHIELDS DIST TO DETECTOR 2.365E 02 CM.
END OF CYL. SLAB VOL. =5.148E 03 CC

LENGTH = 4.064E 01 CM RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 0 DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS 4.064E 01 1.000E-02 1.349E 01 1.364E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	6.636E 15	6.500E-01	3.590E-03	7.467E-09
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	6.636E 15		3.590E-03	7.467E-09

GAMMA ATTENUATION CALCULATION   TOP OF 2000, CASE 2, 211 KCI CS137 16X5 CYL BOTTOM LAYER, 1 METER

SOURCE   SHIELDS   DIST TO DETECTOR 3.365E 02 CM.
END OF CYL.   SLAB   VOL. =5.148E 03 CC

LENGTH = 4.064E 01 CM   RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31   NPSI = 0   DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS   4.064E 01   1.000E-02   1.349E 01   1.364E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	6.636E 15	6.500E-01	1.572E-03	3.269E-09
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	6.636E 15		1.572E-03	3.269E-09

GAMMA ATTENUATION CALCULATION TOP OF 2000, CASE 2, 211 KCI CS137 16X5 CYL BOTTOM LAYER, 2 METERS

SOURCE SHIELDS DIST TO DETECTOR 4.365 E 02 CM.
END OF CYL. SLAB VOL. =5.148E 03 CC

LENGTH = 4.064E 01 CM RADIUS = 6.350E 00 CM

INTEGRATION SPECS NTHETA = 31 NPSI = 0 DELR = 0.1350E 01

TAYLOR BUILDUP DATA FOR SHIELD 4 WITH EFFECTIVE ATOMIC NUMBER OF 82.0 USED

SHIELD THICKNESS 4.064E 01 1.000E-02 1.349E 01 1.364E 01

GROUP	GROUP PRODUCTION RATE PHOTONS	GROUP AVERAGE ENERGY MEV	ENERGY FLUX AT DOSE RATE MEV/CMS/SEC	DOSE RATE AT DOSE POINT ROENTGENS/HOUR
1	0.	1.500E-02	0.	0.
2	0.	2.500E-02	0.	0.
3	0.	3.500E-02	0.	0.
4	0.	4.500E-02	0.	0.
5	0.	5.500E-02	0.	0.
6	0.	6.500E-02	0.	0.
7	0.	7.500E-02	0.	0.
8	0.	8.500E-02	0.	0.
9	0.	9.500E-02	0.	0.
10	0.	1.500E-01	0.	0.
11	0.	2.500E-01	0.	0.
12	0.	3.500E-01	0.	0.
13	0.	4.750E-01	0.	0.
14	6.636E 15	6.500E-01	8.711E-04	1.812E-09
15	0.	8.250E-01	0.	0.
16	0.	1.000E 00	0.	0.
17	0.	1.225E 00	0.	0.
18	0.	1.475E 00	0.	0.
19	0.	1.700E 00	0.	0.
20	0.	1.900E 00	0.	0.
21	0.	2.100E 00	0.	0.
22	0.	2.300E 00	0.	0.
23	0.	2.500E 00	0.	0.
24	0.	2.700E 00	0.	0.
25	0.	3.000E 00	0.	0.
TOTAL	6.636E 15		8.711E-04	1.812E-09

6.0 CRITICALITY EVALUATION

The criticality evaluation for the Model 2000 Transport Package is provided in Chapter 6 of the Package Safety Analysis Report (SAR), NEDO-31581, April 1988, and supplemented by the HFIR Fuel Basket and Liner SAR, NEDO-32229, July 1993. The evaluation presented in these SAR's identifies, describes, discusses, and analyzes the principle criticality engineering physics design of the packaging and components important to safety and necessary to comply with the requirements of 10CFR Part 71 for the transport of fissile materials. Since the 2000 watts of decay heat is only applicable to non-fissile materials, an additional criticality evaluation is not necessary.

7.0 OPERATING PROCEDURES

The operating procedures for the Model 2000 Transport Package are provided in Chapter 7 of the Package Safety Analysis Report (SAR), NEDO-31581, April 1988. The procedures in the SAR include those for loading, unloading, and preparation of the empty container for transport. These procedures are also applicable to the 2000 watts decay heat upgrade and the use of the Multifunctional and Barrel racks which are the subject of this Safety Analysis Report.

Separate operating procedures will be developed to provide detail information of the use of these racks. These procedures are not considered part of this SAR since they shall meet applicable operating conditions and constraints established in Chapter 7, Model 2000 SAR (NEDO-31581).

Part of the Operating Procedure is a Pre-shipment Engineering Evaluation to ensure that the packaging with its proposed contents satisfies the applicable requirements of the package's license or certificate. This evaluation includes, but is not limited to, the review of:

- Proposed contents' isotopic composition, quantities, and decay heat;
- Proposed contents' form, weight, and geometry;
- Shielding requirements;
- Structural requirements;
- Thermal requirements.
- Shipping hardware (liners, racks, dividers, baskets, shoring device, etc.)

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The acceptance tests and maintenance programs for the Model 2000 Transport Package presented in Chapter 8 of Package Safety Analysis Report (SAR), NEDO-31581, April 1988 is include here. The programs are also applicable to the 2000 watts of decay heat upgrade presented in this Safety Analysis Report.

The non-destructive examinations required during fabrication of the Multifunctional and Barrel racks are shown in Appendix 1.4. Routine inspection (prior to each loading) of the racks consists of visual examination for physical damages of all surfaces and bail components. Periodic or once a year inspection includes visual examination of the racks, penetrant inspection of welds, and replacement of all non-safety related components as applicable.

8.1 ACCEPTANCE TEST

The inspection and acceptance tests are specified in the fabrication specifications and engineering drawings for the Model 2000 Transport Packaging and are governed by GE Quality Assurance Program QAP-1. QAP-1 has been approved by the NRC (Docket Number 71-0170).

8.1.1 Visual Inspection

Visual examinations of all welds and dimensions are conducted during fabrication. In addition, all welds within the cask containment boundary are liquid penetration tested (root and final passes); also, the welds forming the toroidal shell are 100% radiographed. These inspections are performed to insure no cracks, incomplete fusion or lack of penetration exist. Parts that do not meet the established criteria are repaired or replaced in accordance with written procedures. Nondestructive examination (NDE) procedures and acceptance standards are based on the ASME Code, Section III, Subsection NG. The above criteria applied to the fabrication of packaging serial number (S/N) 2001. All future fabrication will meet the requirements of the ASME code, Section III as follows:

Cask assembly including ears:

- Materials per NB-2000, Certification NCA-3800
- Fabrication per NB-4000
- NDE per NB-5000
- Pressure testing per NB-6000

The following components of the cask assembly will be excluded of the above requirements:

- Shielding lead and its installation
- Elastomers
- Seals and test port components
- Electro-polishing
- Miscellaneous equipment like name plate and its screws, honeycomb, and thread inserts.

Overpack assembly per Subsection NF.

8.1.2 Structural and Pressure

The inner and outer cylinder welds of the cask are leak tested with a helium Mass Spectrometer Leak Detector (MSLD) by surrounding the cask with He and evacuating the plenum or by pressurizing the lead region of the cask and sniff all cask body welds. These test methods have a minimum sensitivity level of 10^{-6} atm cm^3/s. If any helium is detected above the minimum sensitivity, the failed weld area will be located, repaired, and reinspected.

In addition to the above test, the cask cavity is hydrostatically tested, to ensure that it is tight, per the requirements of NB6200, Subsection NG, Section III of the ASME Code. The test pressure is 45 psia.

8.1.3 Leak Tests

The assembled cask is leak tested by pressurizing the cavity to 15 psig with helium. Leak testing of the vent and drain plugs as well as the lid seal is performed using a MSLD with a sensitivity of _ 1×10^{-9} atm cc/sec. The lid seal is tested by connecting the test probe to a test port between the two seal rings of the seal and determining the leak rate. A leak-tightness criterion of 10^{-7} atm cm^3/s or less based on dry air at 25°C and for a pressure differential of 1 atm is used. If the leak-tightness criterion is not met, a new seal will be tested.

8.1.4 Component Tests

8.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices. Component tests of valves, rupture discs and/or fluid transport devices are not applicable, since these parts do not exist in the Model 2000 packaging design.

8.1.4.2 Seal Testing. The procedure for testing the seals is based on ANSI 14.5-1977, "Standard for Leakage Tests on Packages for Shipment of Radioactive Materials". The seal material is tested under normal, high and low temperature environments. The temperatures are 70°F, 400°F and -40°F, respectively. The seal material is mounted in a test flange and leak tested with a MSLD. Seal material exceeding the allowable leak rate is rejected. The test seal/flange joint used for the tests is scaled by matching the force per inch on the seal, and the flange stiffness so they are the same as for the actual joint. Results of the initial seal qualification tests are presented in Section 4.4.1.

8.1.4.3 Honeycomb Testing. The honeycomb energy absorber is tested in accordance with military specification MIL-STD-401B, Sandwich Constructions and Core Materials, General Test Methods.

The test procedure determines the compressive properties of the honeycomb material in the direction normal to the plane of facings. The test produces a load deformation curve, and from this curve the compressive stress at proportional limit load is computed. If the honeycomb material does not meet the required crush strength, the material will be rejected.

8.1.5 Test for Shielding Integrity

The lead shielding is inspected for integrity by placing a cobalt source inside the cask and surveying the outside of the cask with a gamma detection instrument. The cask outside surface is divided by radial lines 12° apart and by equally spaced circumferential lines along the vertical axis. Dose rate readings are taken over each of the 420 rectangular regions (~4 in. square); see Figure 8.1.5.1. If an area of void is detected, radiographic film is placed over this area to determine the size and location of the void. The criterion used to evaluate the effect of the void is that the dose rate may not exceed one and one-half times the mean dose rate. Any void area that does not meet the criteria will be repoured with lead.

8.1.6 Thermal Acceptance Tests

A thermal test is performed on the first unit built of the Model 2000 packaging to determine the thermal performance of the system versus what is predicted by the analysis. Corrective measures will be taken to prevent the temperature of the seal area from exceeding 400°F and/or the temperature of the lead body from exceeding 600°F.

8.1.6.1 Discussion of Test Setup. A 600-watt heat source is concentrically installed within the cask cavity. Thermocouples are strategically placed within the cavity and the external portions of the cask and overpack surfaces as schematically shown in Figure 8.1.6.1.

8.1.6.2 Test Procedure. The test is conducted with a 600-W heat source in a controlled ambient environment to simulate normal conditions of transport. The temperature data are recorded every 30 minutes with a data acquisition system, permitting easy analysis and plotting of the results. Data are recorded until temperature remains significantly unchanged for a one-hour period.

8.1.6.3 Acceptance Criteria. The results of the thermal test are evaluated against the predicted thermal performances. If the evaluation shows a discrepancy, the analytical thermal model is corrected based on the test results, and a new thermal analysis will be conducted. If the new analysis results indicate deficiency in the thermal characteristics of the packaging, thermal barrier coating could be applied to the inner surface of the overpack structure as a corrective measure.

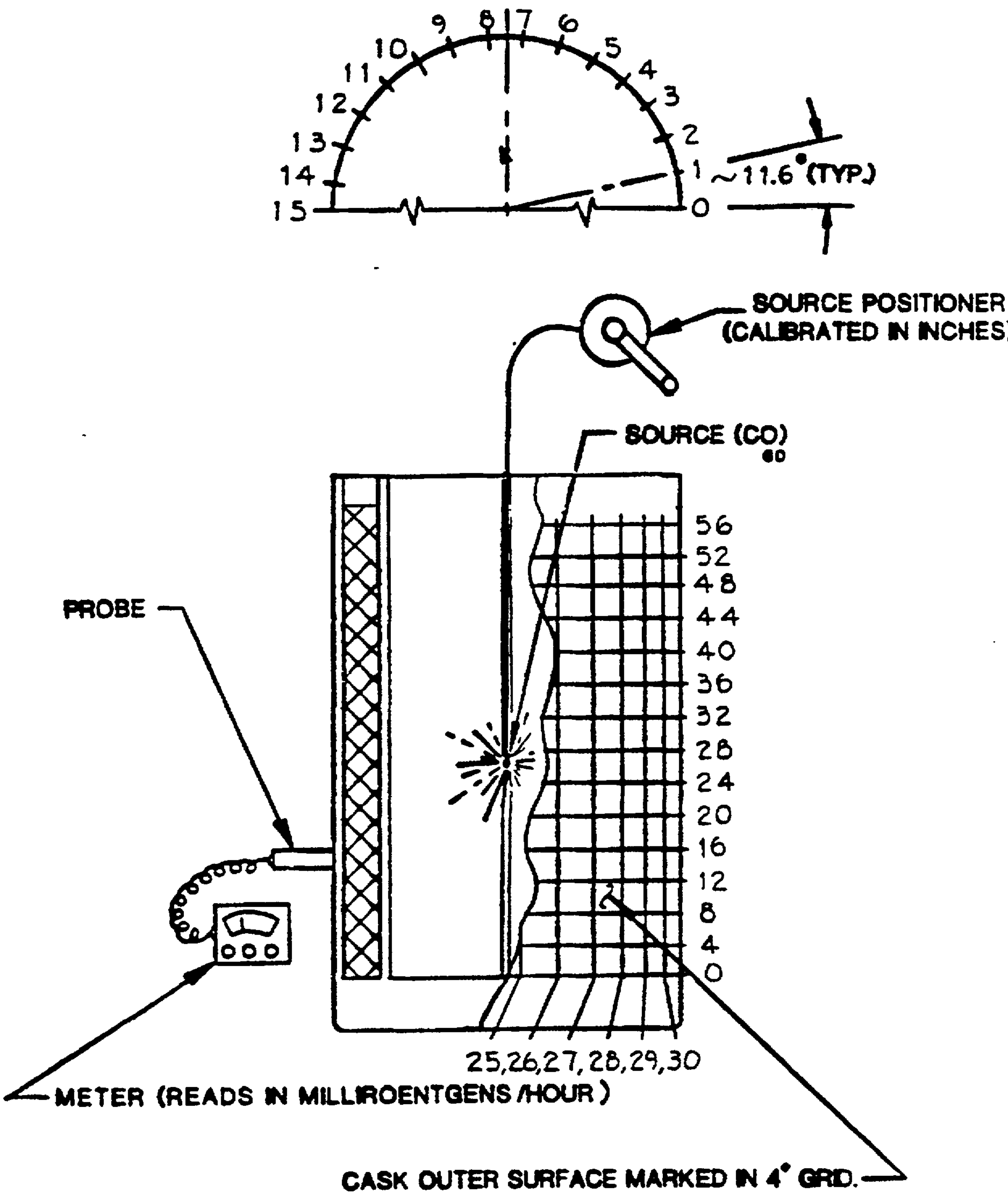


Figure 8.1. Cask Shielding Inspection Points

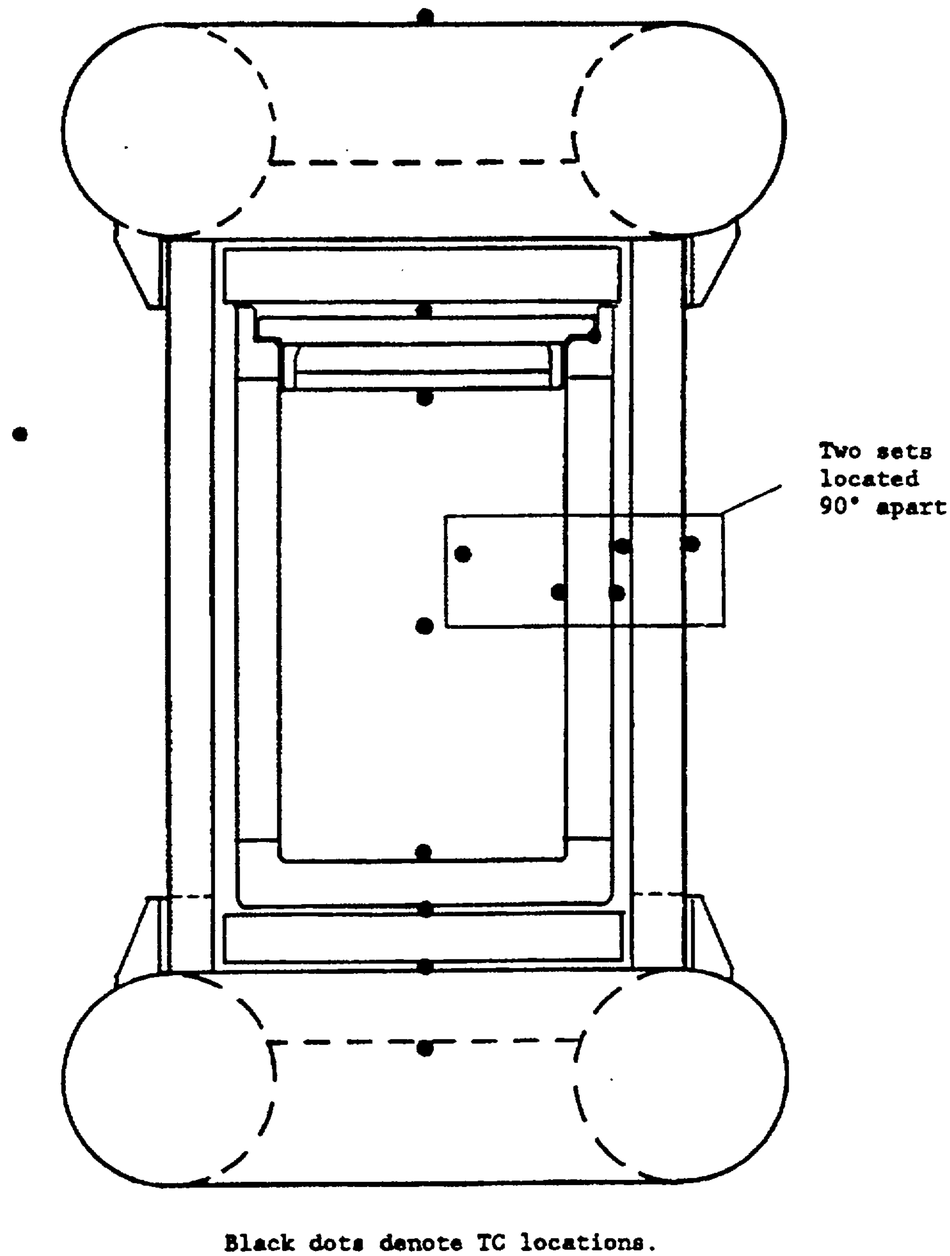


Figure 8.2. Thermocouple Locations

8.2 MAINTENANCE PROGRAM

The cask maintenance program is covered in Radiological Products and Services (RP&S) Standard Operating Procedures (SOP) Chapter XVII, Cask/Fireshield Maintenance.

Routine inspections are performed prior to each assembly and prior to each shipment. These inspections include visual and dimensional checks of the cask and components and pressurization of the cask cavity. This pressurization is part of the leak check procedure. Additional, more detailed, inspections are also performed every 12 usages.

8.2.1 Structural and Pressure Tests

8.2.1.1 Routine Inspection. Prior to each loading and assembly operation, the cask and lid are inspected for physical damage, especially the bolt holes. vent ports and sealing surfaces. The lid bolts, port plugs and O-rings, and lid gasket are all inspected visually and for proper dimensions and identification. As part of the leak check, the cask cavity is pressurized to 15 psig with helium.

8.2.1.2 Periodic Inspections. After every 12 usages, the following inspections are made. Any maintenance work required is identified on a maintenance checksheet.

a. Overpack

This is inspected for:

1) Signs of excessive heat or fire.

2) Punctures, holes, or other surface failures.

3) Crushed sides or ends indicating a drop or severe impact.

4) Defects resulting from normal or abnormal wear.

5) Compression or damage to the honeycomb absorber material.

6) Cracks or other damage to welds.

7) Proper identification and damage to the bolts.

b. Cask

The cask is inspected for:

1) Wear, corrosion or damage to the vent and drain port plugs, caps, and O-rings.

2) Damage to sealing surfaces on the cask and lid.

3) Damage or cracks to welds on the cask and lid.

4) Proper identification or damage to the lid and ear bolts.

8.2.2 Leak Tests

a. Routine

Leakage testing of the cask closure seal and vent and drain plugs is performed with a thermal conductivity sensing instrument. The test is performed by pressurizing the cask cavity to 15 psig with He then "sniffing" with the instrument which senses differences in the thermal conductivity of the sampled gas if helium is present. The instrument will be calibrated to a sensitivity of 1×10^{-5} atm cm^3/sec (helium). If leakage _ 1×10^{-3} atm cm^3/sec is detected, the offending components will be repaired or replaced and then retested for leakage.

b. Periodic

After every 12 usages, the cask closure seal and vent and drain plugs will be leak checked with a helium Mass Spectrometer Leak Detector (MSLD). This instrument has a sensitivity of $<1 \times 10^{-9}$ atm cm^3/sec (helium). This test is performed by pressurizing the cask cavity to 15 psig and then testing for leaks. If any leaks _ 1×10^{-7} atm cm^3/sec are detected, the offending component will be repaired or replaced and then retested.

8.2.3 Subsystems Maintenance

There are no auxiliary cooling systems or other subsystems requiring maintenance.

8.2.4 Valves, Rupture Disks, and Gaskets on Containment Vessel

The cask closure seal will be used until visual and/or leak test inspections identify the seal as defective. The O-rings on the three penetration caps will be replaced when visual or leak test inspections identify them as defective, or during the periodic inspection, whichever comes first.

8.2.5 Shielding

The shielding material is lead. The initial tests for voids during fabrication and the required radiological surveys following each loading assure shielding integrity.

If the results of surveys exceed the regulatory requirements, the contents are reduced and/or the lead liner is installed.

8.2.6 Thermal

Thermal testing is performed following fabrication. As the construction of the cask is lead and steel, no thermal degradation will occur.